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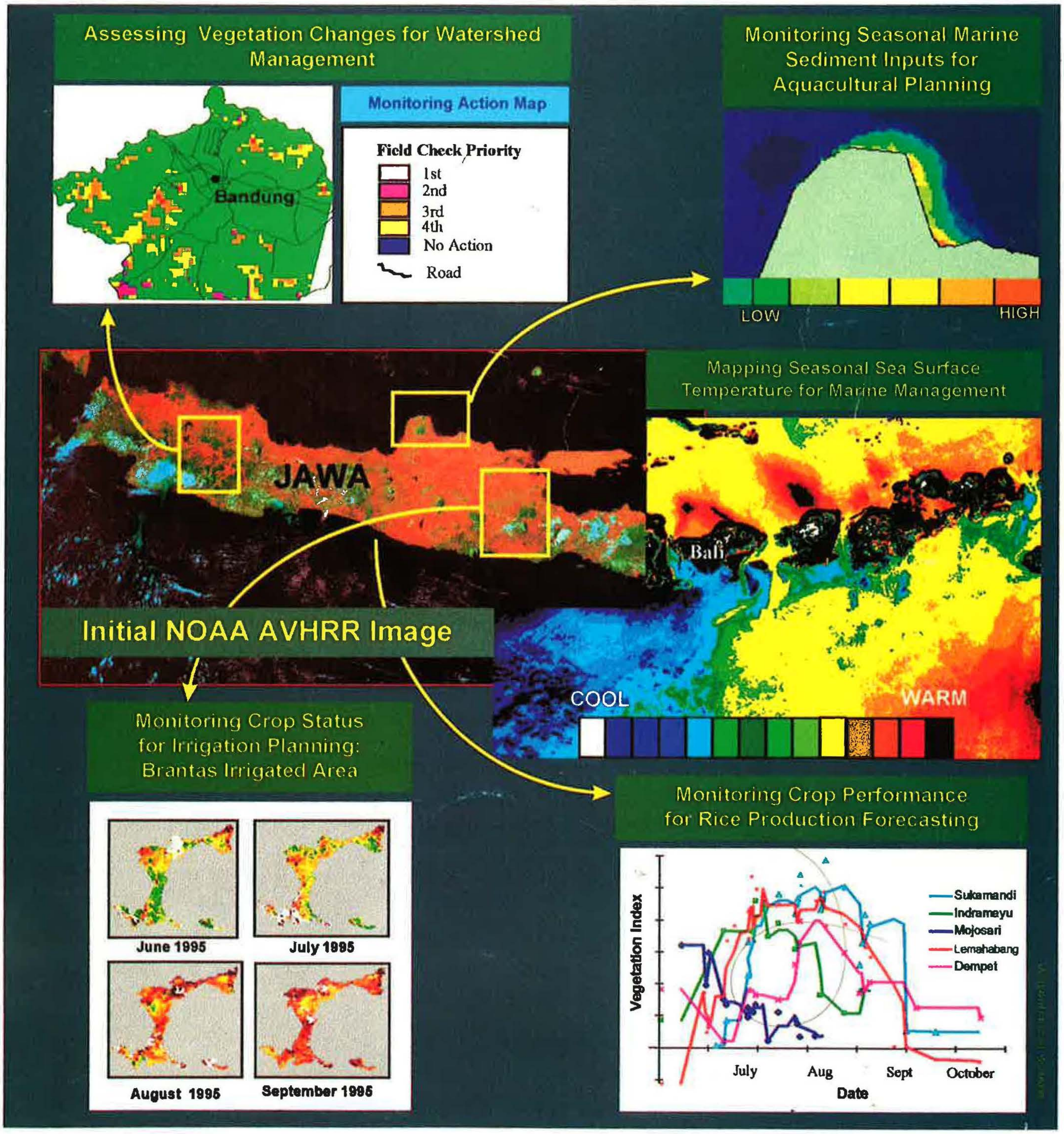
PROCEEDINGS OF WORKSHOP ON

DIRECT RECEPTION OF SATELLITE DATA FOR INTEGRATED AND SUSTAINABLE ENVIRONMENTAL MONITORING IN INDONESIA



April 16, 1996

BPP Teknologi, Jakarta - Indonesia

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Editors:
Simon Trigg & Izzat Farahidy

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Editorial Remarks

Since April 1995, the Indonesian-UK Environmental Monitoring Project has demonstrated and developed real-time and economic techniques for improving accessibility to environmental information. This one year project has shown how local institutions can directly access free satellite data and extract up-to-date and useful information for use in time-sensitive decision making.

In June 1995, the Project installed two PC-based satellite receivers in Jakarta, one at BMG and one at BPPT. Each station collects free images of Indonesia on a daily basis from the US NOAA (National Oceanic and Atmospheric Administration) series of meteorological satellites. Application groups have assessed direct reception for marine, land use and crop yield, watershed and meteorological motoring applications. This Workshop on Direct Reception of Satellite Data for Integrated and Sustainable Environmental Monitoring in Indonesia marks the fruition of a concerted team effort.

There are twelve papers published in the proceedings, demonstrating the diverse applicability of direct satellite data reception to routine monitoring. The papers cover a broad range of topics including the monitoring of marine surface temperature and sediment inputs at the coastal zone, techniques for rice production forecasting and assessing land cover changes, irrigation planning, and forest fire monitoring. Each study focuses on delivery of needed and useful environmental information.

We would like to express our deep appreciation to the authors from BPPT and other participating agencies (BMG, Ministry of Forestry) who have spent time and effort writing the papers. We would also like to thank to the editorial team at NRI and the Open University, UK, for their much appreciated assistance in comprehensively reviewing the papers. We also thank the TISDA-Public Relations division for helping the Organising Committee with all of the logistical arrangements.

We hope that the workshop and proceedings will stimulate discussion, and we look forward to hearing your comments and suggestions on the future applicability of direct satellite reception in the context of Indonesian environmental information needs.

Jakarta, April 1996

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REMARKS FROM THE DIRECTOR OF TECHNOLOGY FOR NATURAL RESOURCES INVENTORY, BPP TEKNOLOGI

This Workshop on DIRECT RECEPTION OF SATELLITE DATA FOR INTEGRATED AND SUSTAINABLE ENVIRONMENTAL MONITORING IN INDONESIA marks the conclusion of the 10-month study on the assessment and application of NOAA low-resolution satellite data for environmental monitoring tasks in Indonesia. Within the Indonesia - United Kingdom Environmental Monitoring Project, the Indonesian scientists and their UK counterparts have worked in a high spirit of cooperation to produce various prototypes, applicable to the Indonesian environmental conditions. I am very happy to learn the various positive outcomes of this study, including the enhanced technical and management capabilities of the Indonesian experts in handling the NOAA Satellite Ground Stations and in designing integrated field works, both on land and in the sea with the BPPT's Baruna Jaya Research Vessel. Results presented in this Proceedings mark the success of the joint efforts showcased by both parties.

This is the Directorate of TISDA-BPPT's first opportunity to link a joint scientific cooperation with the NRI of the United Kingdom. We are very pleased to have this opportunity. Also within this project, some members of the Indonesian scientific groups will continue their acquintances with their UK counterparts, as part of the advanced degree programs in several UK Universities.

This Indonesia - United Kingdom Environmental Monitoring Project has successfully established operational NOAA receiving stations at BPPT and BMG vicinity. This project has also produced NOAA application prototypes for rice yield predictions, forest fire monitoring, watershed management, marine biota productivity, weather forecasting and climate predictions. We would like to invite Indonesian experts from various government and private institutions to optimally utilize these facilities and expertise for the benefit of the Indonesian overall National development program.

On behalf of the Government of Indonesia's Agency for the Assessment and Application of Technology (BPP Teknologi), may I express our gratitude and acknowledgement to the Government of the United Kingdom, particularly to the Overseas Development Agency and the Natural Resources Institute, for the overall support on the implementation of this Project. I would also like to congratulate the Indonesian Team of experts for the job well done.

I hope that this Proceeding will benefit to its readers.

Dr.Ir.Indroyono Soesilo MSc
Director of Technology for
Natural Resources Inventory

THE NEED FOR AN INTEGRATED ENVIRONMENTAL MONITORING SYSTEM IN INDONESIA

By

Indroyono Soesilo

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A large archipelagic country of Indonesia, with 17508 islands, requires a good and solid environmental monitoring system to support the country's sustainable development efforts. One of the possible Indonesia's monitoring instrument is the integrated wide area monitoring system which covers monitoring satellites, telecommunication satellites, geopositioning satellites, airborne surveillance system, weather radar, environmental data centers, and the ocean monitoring system. All of these systems are being integrated and being put in operational status in a newly established National/regional coordination center.

The embryo of the Indonesia's integrated environmental monitoring system is presently start emerging through the implementation of various national level regional land, marine and coastal data centers ins the provincial planning offices are underway within LREP and MREP projects. One high-resolution remote sensing satellite ground station and six low-resolution satellite ground stations are in operational status. Four of those ground stations are being established through cooperation with the ODA and NRI of the United Kingdom.

Since 1976, the country's domestic telecommunication satellite services is being provided by the Palapa Series satellites, while the DGPS positioning satellite services, ARGOS services and the Direct Broadcasting Satellites (DBS) services should be operational in Indonesia during 1996-1997 period.

Various assessments are also underway for Indonesia's airborne monitoring capabilities. The assessments cover: LADS, CASI, Airborne Imaging Radar, Airborne Laser and Airborne Video. Through the National Aerial Photographic Surveys Program and the Marine Digital Mapping Program, among others, the assessment efforts are in progress.

The Indonesia's environmental monitoring system capabilities are being established through BPPT-NRI-ODA Environmental Monitoring Project. Other environmental monitoring programs, include: National Environmental Resources Information Center (NERIC), the Sea Watch Program, the Oil Spill Contingency Planning Program and the COREMAP Program.

Besides the technological matters, the success of an integrated monitoring system in Indonesia also depends on the coordination and management approaches.

OVERVIEW OF THE INDONESIA-UK ENVIRONMENTAL MONITORING PROJECT

By

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ABSTRACT

The objective of the Indonesia-UK Environment Monitoring Project is to demonstrate that integrated and sustainable environment monitoring in Indonesia is both practical and cost effective. The structure and rationale of the project and the technical approach are presented in relation to the needs for environmental information in Indonesia.
Supported by the UK government's Overseas Development Administration, a joint environmental monitoring program between the Indonesian Agency for Assessment and Application of Technology (BPPT) and the UK Natural Resources Institute, has been working for a year to demonstrate some of the many advantages of using 'free' meteorological satellite data, together with other sources of information, to monitor daily, weekly, monthly and annual changes in the environment of the whole archipelago.

Since June 1995, daily NOAA[1] satellite imagery of Indonesia have been collected on a PC-based receiving station at BPPT's main building in Jakarta. and used in real time for demonstrating and delivering useful environmental information to Indonesian decision makers, resource managers and researchers. Applications include i) the assessment and management of marine resources, ii) mapping land use and crop yield variations, iii) monitoring catchment degradation and water resources and iv) assessing meteorological variation. Making use of techniques developed elsewhere, application groups have explored priority information needs in each application area, devised and implemented preliminary field surveys to evaluate the utility of NOAA data for meeting defined needs, and modified NOAA processing routines and interpretation methods to deliver the information required. Progress and current outputs of the application working groups are summarised and potential next steps discussed. Details of activities and results from the application working groups are described in technical papers following in the proceedings.

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[1] Polar orbiting meteorological satellites belonging to the National Oceanic and Atmospheric Administration of the United States of America, designed and launched for their National Weather Service, and freely available for use by other meteorological or environmental services.

INTRODUCTION

The overall purpose of the Indonesia - UK Environmental Monitoring Project is to help develop more integrated and sustainable environment monitoring methods in Indonesia towards improved management of natural resources. The project objective is to enable more appropriate and cost effective environmental monitoring by GORI institutions by demonstrating and evaluating applications of real-time local reception of free data from environmental satellites, ensuring their relevance and sustainability in the institutional context of Indonesian agencies.

The Project consists of technical support and institutional strengthening over a twelve-month (Phase I) period and is supported through the programme administered by the South East Asia Development Division (SEADD, Bangkok) of the UK Overseas Development Administration (ODA) and by counterpart contributions. The Project is based in Jakarta at Badan Penerapan dan Pengkajian Teknologi (BPPT) - the Indonesian Agency for the Assessment and Application of Technology. In addition Badan Meteorologi dan Geofisika (BMG) - the Indonesian Agency for Meteorology and Geophysics - is a joint collaborative partner to the project. BPPT is a unique institution, charged by the President with a mandate to assess new technologies for their relevance to Indonesian needs and, where appropriate, to assist GORI institutions to adopt and adapt them.

The project phase I is designed to assist BPPT in a comparative evaluation of direct satellite data reception technology and its relevance and sustainability in the context of Indonesian agencies' needs. To this end, the project has provided a long term technical officer in-country and has installed two ground stations (at BPPT and BMG respectively) in Jakarta for direct reception of satellite data. Staff from BPPT and other institutions have been trained to use and evaluate these systems for environmental monitoring purposes.

PROJECT BACKGROUND AND OVERVIEW

The Indonesia - UK Environmental Monitoring Project arose when the Indonesia-UK Tropical Forest Management Project (ODA-ITFMP) in Central Kalimantan were beginning to make use of real time NOAA satellite data for forest fire detection. BPPT expressed interest in a collaborative project supported by the British Government which would supply both the technology for local data reception and also the technical assistance support to evaluate its possible contribution for multi-purpose environmental monitoring in Indonesia. The Directorate of Technology for Natural Resources Inventory at BPPT, headed by Dr. Indroyono Soesilo, identified an important niche for remote sensing imagery characterised by low spatial resolution and high temporal resolution as a highly cost effective alternative to very expensive imagery (with high spatial resolution but low temporal resolution) commonly used by the remote sensing community.

Indonesia is increasingly aligning its environmental policies with the conclusions of the Rio Summit and the provisions of AGENDA 21. More specifically, government policy now reflects world concerns about the environment, and agencies need to develop monitoring and management techniques that are cost effective. Comprehensive monitoring of the environment is difficult, costly and often difficult to justify in terms of direct benefits. This is especially so over the Indonesia archipelago, which comprises over 13,000 islands, has a total land area almost 2 million km² and an exclusive economic zone approaching 8 million km². Frequency of observation over such a large region is also important, as environmentally significant events may occur over a time scale of hours to years. Routine monitoring using ground-based methods alone is clearly impractical.

Indonesia is developing very rapidly and both public and private sectors are investing heavily in development projects of many kinds, particularly in the peri-urban areas of Java but also in the coastal lowlands of the largely undeveloped outer islands of the archipelago. Forest concessions are being actively exploited, resettlement schemes continue, and tree crop estates are being created in many accessible areas. The present rapid economic growth threatens the long term sustainable use of Indonesia's natural resources, particularly its forestry, agricultural lands, marine resources and their biodiversity. To help ensure best resource utilisation, **managers** need timely spatial data and are keenly aware of remote sensing's **potential** role and value, but they lack easy access to imagery and have limited technology appropriate for cost effective and timely monitoring of large areas.

Agencies responsible for ensuring that this rapid development is sustainable, and does not take place at the expense of the environment or reduce biodiversity, are also hampered in their conservation efforts because they lack the means to monitor large areas in real time and at an economic cost. They often have great difficulty monitoring, measuring and controlling the extent of environmental degradation. **The range of activities pursued during this project provides a unique opportunity to assist BPPT in developing a framework within which, other more detailed data sets from many line agencies may be integrated to form a sustainable, nationwide environmental monitoring system.**

As the national weather bureau, BMG is the line agency most immediately concerned with data from meteorological satellites, but in BPPT Indonesia has a unique institution for evaluating technology in support of national line agencies. Thus while a duplicate system is installed at BMG, the main thrust of the project has been to enable BPPT to evaluate the technology and its usefulness across the whole spectrum of agencies concerned with the management and sustainable use of Indonesia's many, varied and valuable, renewable natural resources.

Why Use Remote Sensing ?

As suggested above, there are particular advantages in utilising remote sensing satellite data for environment monitoring and, indeed, Indonesian agencies are no strangers to remote sensing data and capabilities. There are a number of data reception and processing facilities in Indonesia and a wide variety of projects developing applications and capabilities in the region.

All of these activities recognise the advantages of the regular, wide-area repeat coverage provided by satellites. There is no other cost effective means of obtaining high spatial density sampling simultaneously at every point over large or inaccessible regions. Sensors on these satellites scan the Earth below at different spatial resolutions (for example, 1 km for NOAA AVHRR, 10 m for SPOT Panchromatic) to provide observations in different spectral channels which can be used to derive much information on [e.g.] weather events, surface temperatures, vegetation conditions, land cover types, water quality, geology........ as well as to provide an up to date map or "snap shot" of the environment.

This project is particularly focused on utilisation of low resolution data from the NOAA series of meteorological satellites currently in orbit. Although widely used for weather forecasting, their potential for other operational environment monitoring purposes is often overlooked. The particular advantages of the instruments onboard these satellites (i.e. AVHRR) is that they provide a] very large area coverage of useful environment monitoring information, with b] a high temporal resolution (some 3 or 4 passes daily) and c] the data is available free, via direct broadcast to a ground station.

Although the technical capability of using satellites for environmental monitoring is well known, use of data for time sensitive monitoring and decision making has been limited for practical reasons. In particular, where data are collected in centralised facilities there can be long delays between data acquisition and its availability to end users. Using funds from ODA, NRI has in recent years headed a consortium that developed low cost hardware and software for the real-time reception of satellite data, with uptake and use through the local application of remote sensing techniques [LARST] for real time resource management.

High resolution optical satellites (SPOT, LANDSAT) offer excellent spatial resolution (up to 10 m), but costs for acquiring the basic data and processing it into useful information can be high for routine monitoring. The typical revisit period of about 20 days for high resolution satellites mean short-duration events are often missed, and, due to tropical conditions in Indonesia, the chances of cloud free views at an acceptable acquisition frequency are low. The active ERS-1 SAR microwave sensor 'guarantees' a complete inventory at the period of its 35 days repeat cycle, as they can effectively 'see' the land through the cloud. The high spatial resolution of SAR (30m when processed to remove speckle) is also appropriate for detailed studies. However, the 35 - day repeat cycle is a limitation as, for example, the rice crop can only be observed three times during its (typically) 110 day growing cycle. Other factors include the commercial costs for each ERS-1 scene acquired and the relative difficulty of interpreting ERS-1 compared to optical satellite data..

NOAA AVHRR data are, however, freely available on a daily basis. The near polar orbit of NOAA and low resolution (1.1 km pixel at best) of the AVHRR sensor allows a broad (3000 km) swath of the Earth's surface to be observed by each overpass. This means that the AVHRR instrument onboard each NOAA satellite takes images of the entire earth's surface every 12 hours. With three satellites operational (NOAA 10, 12 and 14), there are 6 opportunities a day to obtain thermal information using AVHRR channel 3, 4 and 5. The daily NOAA 14 afternoon overpass is especially well suited to vegetation monitoring, and the visible and near infra-red channels allow calculation of vegetation indices appropriate for monitoring vegetation development. The short revisit period, useful and appropriate channels, large area coverage, and free (no commercial costs) availability of AVHRR data together make it **a highly practical and previously much underutilised tool for routine low resolution monitoring over the whole of Indonesia.** The project has therefore installed two ground stations at BPPT and BMG in Jakarta for direct reception and use of satellite data. A more detailed account of the technical capabilities of the ground stations, NOAA satellites and AVHRR data is given in the paper by Trigg (1996) in these proceedings.

PROJECT STRUCTURE

The Project is based in Jakarta at Badan Penerapan dan Pengkajian Teknologi (BPPT) and the Badan Meteorologi dan Geofisika (BMG) is a joint collaborative partner to the project. Links with other bodies such as universities, line agencies and the private sector have been developed during the project through user demands, workshops, open days and general publicity.

The project has provided technical equipment for the ground stations as well as the services of one cooperation officer for twelve months and short term expert consultancies. The project is also providing scholarships for MSc training in the UK and support for attendance Indonesian counterparts at international conferences. BPPT and BMG are providing in-country physical resources (office accommodation, field work facilities, research vessels, etc.) and counterpart personnel.

Four applications working groups (or sub-projects) have been selected by BPPT with the aim of applying the technology and testing the value of remote sensing for the assessment and management of natural resources and environment. The four groups reflect applications with perceived demand from GORI institutions, line agencies, universities and private sector organisations for this type of environmental information. The working groups concern:

- Marine resources and the coastal zone
- Mapping land use and crop yield variations
- Monitoring watershed degradation and water resources
- Meteorological variation

As part of the review of Phase I, this Workshop has been convened so that decision makers and related parties that may be able to derive practical benefits from the methods being developed can participate in evaluating the results to date. The working groups will present the results of their analysis work and conclusions on the usefulness of real-time NOAA satellite data reception. The presentations will compare the accuracy, cost and convenience of remotely sensed information with conventional sources of data collection by ground survey, and will draw conclusions on their respective strengths and weaknesses. Potential users have attended previous receptions and meetings to assess the capabilities and their relevance to particular end-user or line agency demands.

The period after the Workshop is to be used to modify and refine the technical papers, and to pursue in depth the specific needs of line agencies and other potential users as developed during the project to date and articulated during the Workshop. Proposals for further hardware and software development will be prioritised, and arrangements to ensure that the technology is locally sustainable will be finalised and tested. Table 1 summarises the specific Project activities and outputs:

	Activities	Outputs
1	Installation of NOAA equipment and collection of images Demonstration of data collection and software applications	Use of cost-effective and sustainable technology to exploit free data from low resolution meteorological satellites demonstrated
2	Training counterparts to collect images Implement surveys for calibration and validation Customise software for selected applications and products	Counterpart multidisciplinary teams' ability to use and evaluate the technology strengthened
3	Compare conventional ground truthing sources from cal/val surveys with RS information within GIS Evaluation of roles for imagery at different spatial and temporal resolutions	Comparative advantages of low spatial resolution imagery assessed
4	Assist counterparts to prepare technical presentations for peer group/client workshops Prioritise proposal to satisfy RS/GIS and product needs with clients	Clients and their specific RS/GIS application requirements defined
5	Test local hardware and software support Secure reliable suppliers of crucial components	Sources identified for cost-effective hardware and software support maximising the Indonesian component

Table 1: Summary of the specific Project activities and outputs

PROJECT STATUS

The project commenced in May 1995 and the NOAA ground stations became operational in June 1995. Project start up meetings were held in Jakarta in early June to coincide with the BPPT hosted conference on "Remote Sensing and GIS for Environmental Resources Management - the Indonesian European Experience". Discussions were held with BPPT and BMG on the project objectives, project schedule and financing. Separate working group meetings were convened to draft an initial plan of work. Internet access to NOAA orbital parameters was achieved, and BPPT is now self-sufficient in updating these. Since then, operational data collection procedures and a significant time series of NOAA data has been established. Full details of these capabilities are described in Trigg (1996) in these proceedings. A number of workshops have been held to guide the activities of the application working groups.

Application Group Workshops

A series of Application Group Workshops specific to each of the selected application areas was held during August. These were convened to introduce the project to 25 invited potential users working within Indonesian ministries, agencies, academic institutions and industry within the four application areas. The specific objectives were to (a) introduce potential users to the project and the possibilities of local satellite reception for improved natural resource management and (b) learning these user's information requirements, and areas of interest, to assist in focusing on demand-driven project research and development objectives. Each workshop covered a project overview and an application specific presentation about the utility of local reception in that application area by BPPT application group representatives followed by open discussion and questions from participants. Demonstration of the NOAA station was accompanied by the provision of a demonstration disk to each delegate. The disk packs showed users that low cost and simple techniques can be used to quickly deliver up-to-date satellite information and that satellite data can be accessed using straightforward and cost effective tools.

The workshops provoked much interest, resulting in three requests for further collaboration with local institutions, a formal letter of collaboration between BPPT and a local watershed management company, and several requests for NOAA data. Discussion with potential users at the workshops were used to focusing research and development objectives for the remainder of the project.

The NOAA station and software were demonstrated to more than 50 other potential users during BPPT's annual 'Open House' during August and a full colour project brochure was also produced and supplied to workshop participants. The brochure aims to encourage collaboration with local institutions and illustrates the potential of direct satellite reception and outlined proposed research and development areas.

APPLICATION WORKING GROUPS

Four applications working groups have been selected by BPPT with the aim of applying the technology and testing the value of remote sensing for the assessment and management of natural resources and environment. The broad results of these working groups are summarised below. The accompanying technical papers in these proceedings provide detailed results.

Marine Resources / Coastal Zone Working Group

Indonesian waters cover a wide area with the national exclusive economic zone approaching 8 million km^2. Consistent, regular temperature monitoring over such an extensive area can only be performed using data from suitable Earth-orbiting satellites. Regular observation of local sea surface temperature (SST) patterns allows water circulation phenomena to be detected and the evolution of such features tracked throughout the season. These features are of direct importance to Indonesian fisheries since the associated upwelling brings nutrient rich water from deep in the water column up to the surface where increased light levels allows the phytoplankton to photosynthesise more efficiently. The potential for near-surface primary production is thus increased by such upwelling events, which in turn enhances associated fish stocks. The work to date using corroborative results from a long term Indonesian surface based monitoring study carried out between 1991 and 1995 shows that seasonal patterns of upwelling and circulation can be monitored effectively using locally captured NOAA AVHRR data. Data obtained from remote monitoring studies have been compared to fish catch statistics and additional oceanographic data collected during two research cruises.

The marine resources group covered three key aspects of using NOAA satellite data to monitor the coastal zone. Firstly the need to ensure a reliable, calibrated sea surface temperature (SST) algorithm. Secondly, the application of time series SST monitoring in relation to fisheries management and, lastly, an investigation of the potential of NOAA to provide information on coastal sediment phenomena. The area of Indian Ocean to the South of East Java and to the South of Bali was chosen as the first research cruise-area. This is because a) it is a known area of cold water upwelling, and local fish abundance is considered to be spatially related to the upwelling events and b) fish catch data may be available from a local port in Surabaya.

A reliable procedure for estimating sea surface temperature (SST) from satellite imagery is an essential component for regularly monitoring the oceanic conditions around Indonesia. The accuracy of remotely sensed SST estimates over Javanese waters has been examined by using a match-up dataset consisting of *in-situ* (research cruise) data and NOAA AVHRR satellite imagery collected at the BPPT ground station. This study compares the accuracies of a number of published SST algorithms and indicates how further algorithms maybe derived. The analysis suggests that the currently utilised CSIRO algorithm (see paper by Nani Hendiarti *et al*, this issue) gave an error of ±0.8 °C (root mean square deviation) with night time AVHRR data. Certain algorithms tested appeared to improve upon this and results show that regular maps of SST for the whole of Indonesia can be produced to an accuracy of better than ±0.8 °C. Further analysis indicates that the night time observations are more representative of the bulk SST due to the diurnal thermocline being built-up during daylight hours, but which is completely broken down at night. The methodology for accurately and remotely estimating the oceanic SST for the whole of Indonesia has now been developed and implemented at the BPPT receiving station. This situation significantly lessens the need for expensive and time-consuming *in situ* sampling campaigns. The SST data are suitable for use in a wide variety of oceanographic applications, such as investigations into water circulation patterns and upwelling phenomena. The accompanying paper (Nani Hendiarti *et al.*, this issue) explains these applications in further detail, this paper will describe how the remotely sensed estimates of SST were derived and validated.

Sediment discharged into the coastal zone is known to adversely affect the marine environment. For Indonesia, economic implications have included a marked decline in the productivity of shrimp aquaculture in recent years. Monitoring water quality is important to efforts at reducing sedimentation and in planning. The capability of low spatial resolution (1 km^2) NOAA AVHRR data to detect and monitor the seasonal distribution of water-borne sediment was demonstrated for parts of the northern coastal zone of the Island of Java, Indonesia. Simple qualitative methods of atmospheric correction and image enhancement (radiance subtraction and density-slicing) were applied to highlight areas of sediment reflectance. Suspected sediment plumes were detected during different seasons along the coast line of northern Java. The AVHRR observations were partially validated using high resolution data of the same geographical area. The results agree with the hypothesis that high sediment intrusions occur from the rivers during the wet season, with lower intrusion during the dry season. Further work is needed to investigate the possibility of remotely obtaining quantitative information on sediment concentration.

Land Use and Crop Yield (LUCY) Working Group

The agricultural sector is given a high priority in Phase II of Indonesia's Long Term Development Plan, one objective of which is to maintain self-sufficiency despite population growth. The availability of information on rice growing conditions to producers, distributors and government is essential in the context of food security. At present, agricultural statistics are collected manually from the farm level and assimilated up to the national level. As a result, annual yield statistics become available long after the season has ended, and may contain errors due to the many iterations of combining the statistics.

This group is thus largely focused on the use of NOAA data to assess broad variations in land cover and vegetation status as a means of providing additional inputs to crop yield assessment and assisting general environment monitoring or early warning with regard to agricultural areas. The Semarang area of east Java and the Krawang- Subang-Purwarkarta areas of west Java were selected as demonstration areas. East and west-Java sites were chosen due to the split in growing season between the two areas; the east being roughly one month in advance of the west. The west-Java site has the advantage that rice crop yield statistics are available from the Ministry of Agriculture. The group has evaluated preliminary techniques for providing an early, qualitative assessment of the Indonesian rice harvest. The techniques use freely available NOAA data combined with more detailed high resolution satellite, map and field data. The group has been collaborating with the SARI team at BPPT.

The work (see Mubekti et.al, this issue) details the basic theory and the project's progress towards extracting useful information on rice development from NOAA AVHRR data (collected at BPPT) for qualitative and timely pre-harvest assessments. A description of the typical rice development cycle is given, followed by the principles of using NOAA for monitoring rice development. Details are given on how NOAA can be used to monitor crop greenness, and its approximate temperature, at regular intervals throughout the growing season. The implications for crop yield forecasting have been considered as two case studies; the Krangkeng area of Java (where NOAA Vegetation Index and land surface temperature indicators are compared with field information to check the idealised model) and, secondly, five additional rice production areas in Java where differences in crop calendars and vegetation greenness between sites have been assessed. Where possible, field data has been used to verify NOAA interpretation.

The results are most encouraging, with a good correspondence between NOAA and field observations. This correspondence suggests that inexpensive NOAA data, integrated with more detailed field and satellite studies, could provide the basis for a national (pre-harvest) production forecasting system. This demonstration shows great potential for development into a national pre-harvest rice production forecasting system suited to support the national effort of self-sufficiency. A further paper (Rahmadi *et al.*, this issue) details implications for irrigation assessment. For the future, this component also needs to be considered in conjunction with BMG Operations due to the importance of agro-meteorological parameters on crop yield.

Watershed Management Working Group

In Indonesia, as elsewhere, watershed management is tending towards holistic monitoring and control of entire river catchments as single units, from the upper watershed, with its springs and generally forested cover, to the delta in the sea and its important fishery resorts. The integrated management is complex. It includes management of water distribution and quality as well as the land use for the whole watershed. A key element in such management is the timely and cost effective monitoring of events.

The ability to monitor vegetation loss over land areas susceptible to degradation is of great potential use to watershed management. Such information can assist in prioritising land use planning, rehabilitation and regulation activities to preserve and protect critical areas. This in turn can help to reduce soil erosion and associated sedimentation problems, improving water conservation and reduce the possibility of flooding. Two watersheds were selected: The Brantas watershed in eastern Java and the Chimanuk watershed in Central Java. The former is actively managed by the company Jasa Tirta whilst the latter is not currently managed as a watershed unit, but is the site of a planned reservoir. The two sites were chosen due to the contrasts in existing management.

Jasa Tirta is a private company responsible for the integrated management of the entire Brantas watershed in eastern Java. Management is undertaken as a first pilot project in Indonesia, which, if successful, will be implemented for the whole country. So far it is already regarded as a successful example. Management includes the control of water quality and distribution from numerous reservoirs to agricultural irrigation schemes, industrial and domestic users within the catchment. Several meetings were held with Jasa Tirta's managerial and technical staff in order to find out which aspect of the management could benefit from the use of low resolution satellite data. The rapid identification of land use changes is important to operational watershed management. It can highlight land degradation problem areas that require special attention. Three main areas were identified: rainfall estimations, irrigation planning and land use changes.

The work has demonstrated a prototype technique for inexpensively monitoring land use changes occurring within remote or critical watershed areas. The magnitude of AVHRR-derived vegetation changes was cross-referenced with critical land status as a basis for prioritising management action. The main study area has been in the upper Citarum watershed of West Java. Vegetation status was monitored between June and October using vegetation indices (NDVI) derived from satellite data (AVHRR) collected in 1995 using the BPPT NOAA ground receiver. A Monitoring Action map was produced by combined analysis of the vegetation status and critical land status maps. It prioritises appropriate monitoring and monitoring actions dependent on the magnitude of vegetation changes with respect to critical land status. Incorporation of further knowledge on the area (from local or satellite sources) such as seasonal trends is seen as an essential further step to increase the robustness of the technique.

During the dry season, water is very precious. When the demand for irrigation water starts overtaking its availability, the water manager has to make difficult choices. The group have also worked on how the use of NOAA-AVHRR data can contribute to the prioritisation of water delivery, as well as monitor the state and evolution of the crops. Case studies show how crop status and water availability indicators were obtained for the Brantas and Northern Citarum irrigation areas of Java for the 1995 growing season. These indicators could be used to help watershed managers assess the performance of the annual irrigation plan and prioritise water flow to balance the opposing demands of water conservation and irrigation demand.

BMG Operational Meteorology Group

Routine NOAA image capture at BMG is ongoing and much of the application work has concerned the integration of other meteorological satellite data sets such as GMS and TOVS. Research and development priorities towards better understanding and characterising meteorological variation have been identified as:

- Tiros Operational Vertical Sounder (TOVS)
  Access to the (NOAA provided) TOVS is to be evaluated as soon as possible for assessing the extension of radio sonde coverage for input in weather forecasting activities.

- Media System
  The existing TV weather presentation, although prepared on PC and recorded onto video tape at BMG, is to be upgraded to optimal standards for best understanding and use by viewers. BMG are to be provided with a NRI media system which will greatly improve the presentation. BMG also intend to incorporate Geostationary Meteorological Satellite (GMS) imagery into the presentation

- Environment
  BMG have a role to monitor and exchange data on fires with other ASEAN countries. Information on Indonesian fires can be obtained from NOAA data and could be fed directly to the ASEAN specialised Meteorological Centre, Singapore. In October 1995, fire detection software was installed at BMG to allow vegetation fires burning in Sumatra and Kalimantan to be identified on the NOAA imagery. BPPT regularly delivered such fire maps to the Minister of Environment. NOAA imagery showing vegetation fires in Sumatra has also been supplied to the Forest Fire Control and Prevention Component of the EC-Forest Sector Support Programme. This imagery is used to train counterpart staff in NOAA fire detection techniques in advance of the project procuring its own NOAA system.

- Sea Surface Temperature
  BMG have interest in SST for long range weather forecasting (seasonal oceanic temperature in Indonesia has been strongly related to the Pacific El Nino/Southern Oscillation phenomenon]. NOAA derived SST information could be augmented by the provision of weekly reports to help validate / calibrate the CSIRO archive and recently acquired NOAA SST imagery.

CONCLUSION

The project has demonstrated the practicality of delivering up-to-date information, derived from AVHRR data, to Indonesian decision makers in support of environmental decision making. From June 1995, NOAA data of Indonesia was routinely collected, and provided the basic data for research in marine, land use and crop yield, watershed and meteorological application areas. Local reception of NOAA data has reduced the need to rely on other suppliers for data and enabled the project to schedule (with complete reliability) the simultaneous collection of related field and NOAA data. The synchronous data sets allow meaningful calibration of NOAA data for operational monitoring purposes.

The initial objectives of the project have been achieved, and in some cases substantially exceeded. The work described in the accompanying technical papers demonstrate that NOAA AVHRR data contains much useful information in itself, but can be made even more useful when combined with more detailed satellite and field survey within a Geographic Information System. Regularly acquired, free NOAA data can greatly improve the temporal context and interpretability of high resolution surveys.

It is clear that by extending the scope of these kind of activities within an organised institutional framework to help meet the time sensitive information needs of a wider range of resource mangers and decision makers, BPPT is well on the way to developing an integrated national environment monitoring system. Since the cost of collecting this information is small in comparison to the high value of the resources and environment being managed, such a system can be relatively easily sustained from technical and financial points of view. Institutional sustainability is not so easy to ensure without the active involvement of critical parties.

It is recommended that efforts are continued along the lines prototyped here towards achieving integrated and sustainable environment monitoring in Indonesia. Operational monitoring must make best use of different environment monitoring tools according to their particular advantages and costs. As rates of change grow ever more rapid, the importance of real time monitoring and rapid response management can only increase. Development of a sustainable system is possible but will require additional investment to support an expanded second phase.

ACKNOWLEDGMENTS

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LOCAL RECEPTION OF NOAA AVHRR DATA AT BPPT FOR INTEGRATED AND SUSTAINABLE ENVIRONMENTAL MONITORING

By

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ABSTRACT

This paper shows how BPPT staff used a low cost, PC-based receiving station to reliably collect real time AVHRR data and transform it into timely environmental information. Details of the AVHRR sensor are given and its suitability for providing Indonesia-wide, low cost, repetitive monitoring are described. The AVHRR receiving station is then described, along with the project experience with installing systems and establishing routine AVHRR collection at BPPT and BMG.

The paper gives details of how free NOAA AVHRR images of both the marine and terrestrial study areas were collected with complete reliability for duration of the project. The activities established a substantial information resource upon which to base the application demonstrations in the following papers.

Procedures used to extract environmental parameters from the raw AVHRR data are then described. The hierarchy of flexible processing tools used to deliver information according to the monitoring need are explained. The GIS tools used to integrate AVHRR images with more detailed data sets to produce thematic information prioducts are described.

The paper shows how both AVHRR data reception and use were achieved at low cost within the same organisation by non-reception experts. The experience has shown that when information *users* control their own satellite *reception*, they can tailor image and field data collection to meet their own very specific environmental monitoring needs. The techniques are found to be highly suited to integrated and sustainable environmental monitoring from the local to national scale.

INTRODUCTION

The advent of low cost yet powerful Personal Computers has resulted in their proliferation across the globe. The majority of offices now have at least one PC, and many professionals are familiar with using them. Satellite receiving technology has advanced significantly in parallel with these developments. Low cost receiving units are now available which can collect freely available AVHRR satellite data directly onto PC. Many Geographic Information Systems (GIS) now also operate on PC. These provide accessible and powerful tools which can be used to increase the interpretability of AVHRR data by integrating it with more detailed information from other sources. The opportunity now exists for providing natural resource managers with integrated satellite reception and analysis tools for use in time sensitive environmental monitoring.

This paper gives details of how this potential was demonstrated at BPPT using such low cost receiving and integrated processing and analysis tools. The next section describes the AVHRR instrument and its suitability for integrated and sustainable environmental monitoring in Indonesia.

THE NOAA AVHRR

The Advanced Very High Resolution Radiometer (AVHRR) is highly suited to the task of providing regular observations over the whole of Indonesia, adding excellent temporal sampling to the detail obtained from less frequent high resolution surveys.

The AVHRR is flown on the U.S. National Oceanic and Atmospheric Administration (NOAA) polar orbiting series of satellites which were originally developed for meteorological applications and have been flown operationally since the end of the seventies. The satellite follows a near-polar orbit, covering the full globe at least twice a day. Each satellite orbits the Earth approximately every 102 minutes. The orbits are shifted a certain distance every day (relative to the surface), resulting in the same target being observed from different angles on consecutive days.

The AVHRR is a scanning radiometer measuring reflected and emitted radiation in five channels. It covers the visible, near infrared, middle infrared and thermal infrared portions of the electomagnetic spectrum, making it sensitive to diverse environmental parameters. The term "very high resolution" refers to the high radiometric resolution (10 bit, 1024 levels). Its spatial resolution is 1.1 km at nadir is significantly coarser than for the high resolution satellite sensors.

Table 1 gives specifications of the AVHRR sensor, whilst this section describes the main aspects which make it appropriate for routinely monitoring Indonesia.

1. *Free coverage and ease of access to resource managers*

AVHRR data are transmitted continuously. The data are free (no commercial cost) with unlimited access to any user with a receiving station. This means that once the receiving station has been purchased, recurrent costs for routine monitoring are extremely low, being only for archiving and printing consumables. As already discussed, low cost AVHRR receiving stations are now available to collect the data directly onto PC.

2. *Large area systematic, synoptic coverage*

A 2700 km swath of the earth's surface is covered during each satellite overpass. This means that almost the whole of Indonesia, can be covered by collecting just two consecutive orbits of the same satellite, spaced 102 minutes apart in time. The whole of Java can be covered by just one AVHRR image, compared tens of high resolution images needed to cover the same area. The large area coverage is achieved by the AVHRR sampling at a coarse (1.1km) spatial resolution, which is markedly less detailed than for Landsat and SPOT. Although coarse, the data still provide systematic measurements over extensive areas, and are not subject to the human biases involved with field observation. The simplification of land units arising from the coarse resolution can be highly appropriate for national monitoring.

3. *Frequent coverage*

Due to the low resolution scanning of a broad swath width, each AVHRR covers the entire globe every twelve hours. With two operational satellites, there are therefore four opportunities per day to collect imagery of Indonesia. This is a significant improvement on the repeat periods of high resolution satellites (35 days for ERS-1, and 26 days for Landsat). Experience of this project with monitoring the Javanese rice crop between June and October 1996 (see Mubekti et al., this issue) showed that AVHRR acquired daily during this period provided many more observations of the rice development stages than would have been possible using ERS-1. The high temporal sampling frequency was sufficient to allow temporal discrimination of flooded, vegetative, reproductive, ripening and bare soil stages. During the wet season, however, cloud-free conditions are rare, and ERS-1 may have a better chance of providing repeated coverage due to its ability to penetrate the clouds.

4. *Variety of environmental information can be extracted*

The five AVHRR channels, covering visible to thermal infra-red wavelengths have been found to be sensitive to numerous surface characteristics, including vegetation greenness, aspects of vegetation moisture, sea and land surface temperature, vegetation fires, volcanic and industrial heat sources, and cloud characteristics.

5. *Historical data freely available*

Two important sources of historical AVHRR-derived data are available which can be used to place present-day AVHRR images and products in their historical context (Malingreau and Belward, 1992). Global Area Coverage (GAC) data are reduced spatial resolution data recorded on-board the NOAA satellite. The global GAC archive dates back to June 1981, and allows long-term trends to be assessed over large geographical areas. Global Vegetation Index Imagery (GAC) are freely available from the Internet and provide a weekly synthesis of global Normalised Difference Vegetation Index (NDVI - see Box 2) until the present. These two sources of historical AVHRR-derived data are extremely useful for placing newly acquired AVHRR imagery in a 'normal' context. Mubekti et. al., (this issue) discusses the implications of this in the context of rice production forecasting.

TABLE 1: DETAILS OF THE AVHRR SENSOR

ORBITAL CHARACTERISTICS

Orbit altitude	833-870	km
Orbital inclination	98.8	degrees
Orbital Period	102	minutes
Equatorial crossing time (odd)	2:30(D)-14:30(A)	hours (local time)
Equatorial crossing time (even)	7:70(D)-19:30(A)	hours (local time)
Repeat Period	9.2	days
Revisit capability	12	hours

SPECTRAL RANGES FOR AVHRR CHANNELS

Channel 1	Visible	0.58-0.68	µm
Channel 2	Near infra-red	0.72-1.10	µm
Channel 3	Mid infra-red	3.55-3.93	µm
Channel 4	Thermal infra-red	10.3-11.3	µm
Channel 5	Thermal infra-red	11.5-12.5	µm

INSTRUMENT GEOMETRY

Ground resolution (nadir)	1.1 x 1.1	km
Ground Resolution (edge)	2.4 x 6.9	km
Swath width	2700	km
Radiometric resolution	10	bit

DATA PRODUCTS

HRPT and LAC	1.1 x 1.1	km
GAC	3.5 x 5.5	km
GVI	12 x 20	km

Table 1: Characteristics of the AVHRR sensor

THE NOAA AVHRR RECEIVING STATIONS USED BY THE PROJECT

The preceding section discussed the aspects of freely available AVHRR data which make it suitable for routinely monitoring Indonesia. As already mentioned, any user with an AVHRR receiving station can access and use the free data stream for their specific monitoring purposes. The whole of Indonesia can be covered every day, (although the AVHRR can not observe the surface if cloud is present), and the sensor is sensitive to variations in diverse environmental parameters. This section gives an overview of the receiving stations acquired by the project as well as their installation and operational use.

Overview of receiving station

The LARST (see Downey et, al, this issue) receiving station comprises a motor-driven horn antenna, an AVHRR receiver and two standard Personal Computers, each fitted with a satellite interface card and extra Random Access Memory (RAM) to allow capture of the AVHRR images. The integrated user-friendly software allows users to plan which satellites will be captured, and the specific areas that will be collected. Once these are specified, the capture program is initialised, and the station automatically collects imagery of the required area or areas. During image collection, the motor drives the antenna to accurately follow the satellite, ensuring noise-free reception. Integrated software packages allow the display and processing of the captured data. More details of the receiving station are given in Box 1.

Installation

In June 1995, two such NOAA AVHRR receiving stations were installed in Jakarta, one at BPPT and one at BMG. The total time taken to complete installation was approximately one full working day at each site. No technical difficulties were encountered during either installation, and both units successfully captured their first image at the first attempt. The experience underlines the ease of installation and the robustness of the equipment used.

Training

At each site, personnel were trained to perform routine image capture and processing. At BMG, sixteen meteorologists and engineering staff were given a two day training course in image collection and basic processing. At BPPT, four of the Application Group staff were given similar training, and one of the team independently collected sixteen images during the following week. Operational AVHRR image collection then began.

Operational AVHRR image collection

The purpose of operational AVHRR image collection at BPPT was to:

1. prove the *ability* of the low cost, PC-based AVHRR receiving station to reliably collect real time AVHRR images.

2. *provide daily AVHRR images* of each Application Group's study areas as the basis for developing all of the demonstration applications in the following papers.

3. prove that data reception and data use can be easily achieved at low cost within the same organisation. Traditionally, there has been a distinct separation of duties between those receiving and those using the data, often resulting in a time-lag in data availability, and possible obsolescence of obtained satellite data.

At BPPT, an image acquisition schedule was established to ensure reliable and routine capture of marine and terrestrial study areas. Figure 1 shows the areas which were regularly collected by the BPPT Application Groups.

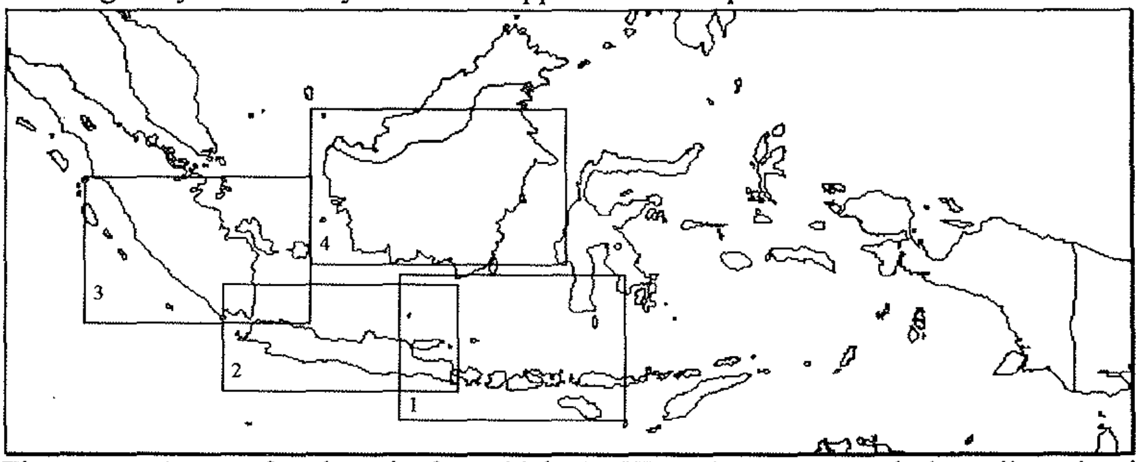

Figure 1: Areas of Indonesia for which AVHRR data was regularly collected using BPPT's AVHRR receiving station.

The Marine Group collected daily imagery over known upwelling areas around South Sulawesi, East Java - Bali and around the Sunda islands (Area 1 in Figure 1). The Watershed and Land Use/Crop Yield groups chose Java (Area 2) as their data collection area as it is sufficiently large to demonstrate the AVHRR's large-area-monitoring capability, and for good accessibility for ground validation field visits.

Operational image capture was a complete success. The *ability* was proven by BPPT staff successfully collecting and archiving AVHRR imagery for the full 10 month period from installation until present. Other papers in this issue confirm how the AVHRR images were successfully transformed into the environmental information required by the Application Groups.

Table 2 give some statistics to summarise the success of operational AVHRR image collection and information generation.

Installation time	1 day
Training time to allow routine capture	2 hours
Number of images collected: June 1995 - March 1996	439
Number of images now on archive	320
Number of images processed into environmental information by the application groups	80
System down-time	0 Hours
Total cost for data	0 Rp

Table 2: Statistics indicating the success of real-time reception at BPPT during the 1 year project

Flexibility of operational image collection for time-sensitive environmental monitoring

It is worth noting here some experience with local reception which demonstrate its time-sensitive aspect. As BPPT controlled their own data collection, priorities could be changed depending on the location and timing of important environmental events, or to provide greater acquisition frequency over particular areas during periods of ground data collection. During the 1995 dry season, when vegetation fires were anticipated, the receiving unit was programmed to collect imagery of Sumatra (Area 3, Figure 1) and Kalimantan (Area 4) for vegetation fire monitoring. These two additional areas were collected in direct response to requests from the Indonesian Ministries of Forestry and the Environment. AVHRR imagery of Sumatra was provided to the UK-Indonesia Forest Sector Support Programme based within the Ministry of Forestry. This imagery was subsequently used to map burning patterns in South Sumatra (see N Jewell, this issue). Fire maps of Sumatra and Kalimantan, and coordinates of probable vegetation fires extracted from the AVHRR data (see Box 4 for more details) were also produced and delivered to the Ministry of Environment, often within one day of data collection.

Collection priorities were also changed to capture every possible overpass of the North Java Sea to Lombok Straits area during the Marine Group's 'sea-truth' validation cruise of the area (Farahidy et. al., this issue). The receiving station reliably collected AVHRR data of the required area from all overpasses, ensuring the match-up datasets which were subsequently used to calibrate AVHRR images to estimate sea surface temperature. Here, the assured AVHRR coverage of the cruise area allowed the monitoring capability to be improved.

The land-based application groups also benefited from capturing the data themselves. Before going into the field, they collected up-to-date AVHRR images of the field-visit area. The match-up AVHRR and field data obtained, greatly assisted interpretation of the AVHRR data.

All of these examples show that when end-users control reception, there is the possibility of tailoring satellite and field data collection to meet very specific environmental monitoring needs. The following section shows how BPPT processed the collected AVHRR data into time-sensitive environmental information.

EXTRACTING INFORMATION FROM AVHRR DATA

The captured AVHRR image is, immediately after capture, a data file which needs to be processed before it can be interpreted. This file is not information in itself, and so must be processed in order to extract useful information. Three main processing stages are required, namely pre-processing, generation of basic products and integrated interpretation. Pre-processing is a pre-requisite to basic product generation which is a pre-requisite to integrated interpretation. The latter stage involves the use of a Geographic Information System (GIS) and yields the greatest amount of useful information. All three stages were implemented at BPPT using simple and automated techniques. Figure 2 shows a diagram of the information extraction chain. The chain starts with the identification of specific information needs and represents how appropriate AVHRR imagery were collected and pre-processed by the application groups in response to that need. Basic products are then generated and combined with additional information in GIS to create thematic products which deliver the required information. The stages processing stages are now discussed.

PRE-PROCESSING

Each image was pre-processed using software packages supplied with the receiving unit. Pre-processing involved converting the raw AVHRR data file into physical parameters, namely reflectance for channels 1&2 and brightness temperature for channels 3,4 and 5. It also adjusted each images spatial geometry to that of a standard geographical map projection. Simple batch files were written at BPPT to preprocess and calibrate the data and transform it to standard geographical windows which defined for each application group's areas of interest.

During preprocessing, each image was visually examined to see whether the areas of interest (Figure 1) were cloud free. Completely cloudy images were deleted from the hard disk, whilst relatively unaffected images were visually scrutinised. Visual observations of such phenomena as hot spots (vegetation and industrial fires, hot volcano tops), marine areas showing cold water upwelling were also noted at this point. The observations were transcribed in to an image log, which gave particular detail over the application groups designated study areas.

The end result of pre-processing was two time series of multi-date, calibrated, 5 channel AVHRR imagery, geometrically standardised to cover the fixed geographical windows of Java and the Marine Group study area (Figure2, areas 2 and 3 respectively).

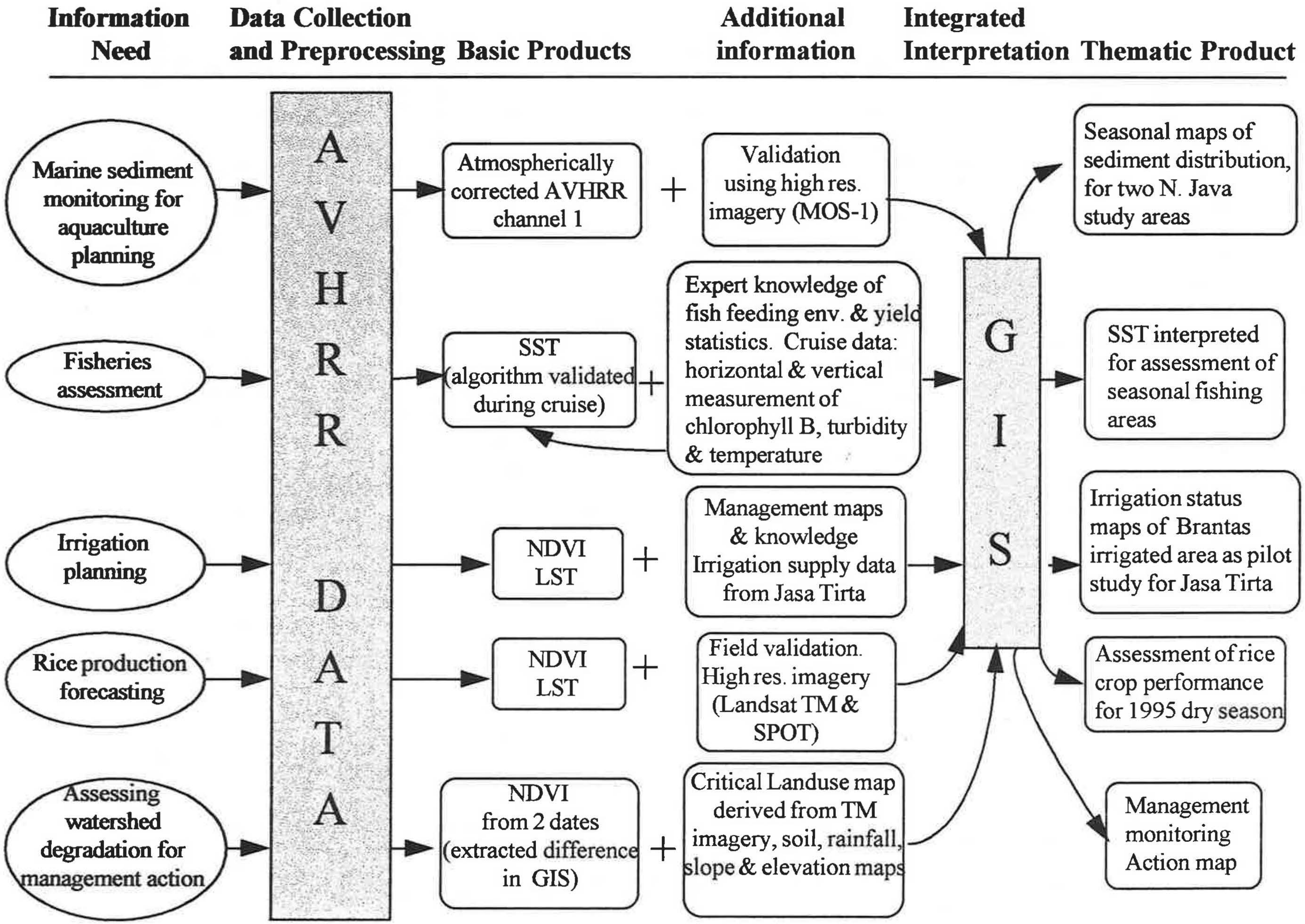

Figure 2: schematic flow, from information need to thematic information products

Two additional processing stages were applied to the images by the BPPT team to extract useful information from the preprocessed images. Basic Products were first derived and then a GIS was then used to allow Integrated Interpretation. These two stages are described below.

BASIC PRODUCT GENERATION

Basic products may be defined as pre-processed images that have been numerically transformed to show basic types of information focussing on one particular theme. For example, Vegetation Index products were derived from the preprocessed AVHRR channel 1 and 2 data to indicate amounts of green vegetation distributed across the image area. Sea Surface Temperature (SST) products were derived from the thermal channels to estimate water surface temperature across the image. Table 3 lists some of the basic products generated by the project, and describes the sensitivity of each to surface characteristics. Boxes 2 and 3 in Annex 1 give more detail of the physical principles behind each product.

BASIC PRODUCT	***SENSITIVE TO.....***
NDVI	quantities of green vegetation
LST	Land Surface Temperature
SST	Sea Surface Temperature
Atmospherically corrected AVHRR Channel 1	Marine sediment concentrations
False Colour Composite	vegetation greenness and suspended marine sediment (via visual interpretation)
Cloud mask	Cloud cover at time of image acquisition. Used to remove cloud affected pixels from all other products

All basic products were created using BPPT's Integrated Land and Water Information System (ILWIS) GIS / Image Processor. The tools and the approach were highly flexible, allowing products to be generated as required from any published algorithm. The result was products time series for the marine and land application group-study areas. The following papers give full descriptions of the use of the basic products in diverse environmental monitoring studies.

INTERPRETATION AND INTEGRATED ANALYSIS

Spatial interpretation

Different products derived from the same pre-processed AVHRR image tell us about the *spatial* distribution of each product parameter at the time of image acquisition. For example, NDVI images indicate the spatial variability of green vegetation, whilst LST will show variability in the land temperature. The spatial interrelationship between different products is often significant. For example, flooded rice fields prior to planting will be characteristically unvegetated (low NDVI) and cool (Low LST).

Temporal interpretation

Time series of products were used to follow the temporal evolution of surface characteristics. Consecutive products were viewed side by side to allow spatial changes occurring through time to be visually interpreted.

Whilst such product interpretations can reveal much about the evolution of the surface, the information extraction was enhanced still further by cross-referencing the basic products with other more detailed (though much less frequently acquired) information of specific areas within a GIS.

Integtated GIS analysis

A GIS was used to allow integrated analysis of the complete time series of AVHRR products in the context of more detailed information sources. The GIS capabilities allowed several improvements (ranked from simplest to most sophisticated) to the information that could be extracted from the AVHRR products.

- Placing the AVHRR products in their context

Digital maps of showing e.g. rivers, administrative boundaries, watershed management irrigation blocks and other themes were digitally overlain on the products to place them in the context of known local information. Field survey information was also plotted on the products to provide detailed validation at specific points. High resolution satellite imagery were also registered and overlain with the AVHRR products to aid interpretation in specific studies (see Hartanto this issue).

- spatio-temporal analysis

The GIS tools were used to quantify spatial and temporal variation of AVHRR products in a more rigorous and automated way than is possible using visual interpretation. Spatio-temporal changes were assessed by the digital subtraction of products acquired on different dates. Temporal changes at specific locations were also derived by extracting from the time series successive product values, and plotting them against time. The resultant 'temporal profiles' summarise variation in surface conditions at a particular point (as measured by the product) through time. The technique was useful for monitoring seasonal crop characteristics and performance (using NDVI / LST profiles) and the strength and timing of marine upwelling events (using SST profiles).

- Producing new thematic information appropriate to management information needs. The flexibility and power of the GIS tools allowed specific information needs expressed by environmental managers to be modeled using the integrated AVHRR and ancillary data. Hartanto et. al., (this issue) demonstrates how AVHRR products were combined with ancillary critical land status data within a GIS for a watershed degradation study. Decision rules were set up in the GIS to create a thematic *Monitoring Action* map of possible (AVHRR-derived) land degradation sites within critical watershed areas (from ancillary data). The map therefore highlights specific areas meriting more detailed field - checking by the Watershed Management company., in a much more focused way than would be possible using AVHRR alone.

CONCLUSIONS

This project has proven the capability of low cost, PC based receiving station to operationally collect real time AVHRR data with a high degree of reliability. BPPT staff successfully collected free NOAA AVHRR images of both the marine and terrestrial study areas as well as for the whole of Java. This established a substantial information resource upon which to base environmental monitoring applications as demonstrated in other parts of this issue.

AVHRR data reception and use were achieved at low cost within the same organisation by non-reception experts. The experience has shown that when information *users* control their own satellite *reception*, they can tailor image and field data collection to meet very specific environmental monitoring needs. The lag between satellite reception and information use is largely removed.

Environmentally sensitive parameters were extracted from the AVHRR data, and interpreted with differing degrees of sophistication according to the information need. GIS tools allowed the information-content of the free, regularly acquired AVHRR data to be put in context and enhanced by more detailed (though less frequently acquired) information at specific areas. An ideal monitoring system is synergistic, combining the relative strengths of free, repetitive, coarse scale coverage with more detailed validation of specific areas.

The techniques could benefit future environmental monitoring at the local to national scale. These could provide regular monitoring information, and benefit from feed-back from field studies to validate and improve methodologies. Nationally, the approach fits well into the existing remote sensing structures, bringing highly accessible, repetitive large area coverage to existing high resolution capability. The AVHRR overviews could provide the means of extrapolating the detailed studies up to the national scale, and form the basis of a regularly updated and sustainable national monitoring system.

ANNEX 1: BOXES REFERRED TO IN THE TEXT

BOX 1: THE LARST NOAA AVHRR RECEIVING STATION

The receiving unit uses a motor - steered horn antenna with dual low noise amplifiers. The antenna is only 1.5 m long with a 0.75 m square cross section. It is linked to a receiver operating on both AVHRR transmission frequencies (1698 and 1707 MHz), which in turn is connected via a satellite interface card to a standard PC. The system is capable of acquiring the AVHRR's full HRPT (High Resolution Picture Transmission) data stream with an image width of 512 to 2048 pixels wide, for all 5 channels at full 10-bit resolution. The number of lines acquired is restricted only by the period during which the over - passing satellite is in view of the antenna, and by the amount of RAM on the PC.

The image acquisition software allows the user to specify an area of interest, and to view graphically all possible satellite overpasses within the next few days. The user can see where in the swath their area of interest lies, and program the station to capture images of specific areas from any of the available satellite overpasses. During data collection, the antenna is driven by its motor to accurately track the satellite while it collects the entire area required. Images are recorded first into the computer's memory, and saved on to the hard disk as soon as data collection is complete.

BOX 2: VEGETATION INDICES

The low reflectance of green (living) plants in the visible region (observable by the red channel of AVHRR) is due to strong chlorophyll absorption, while their high reflectance in the near-infrared (channel 2 of AVHRR) results from the scattering of light on cell walls and structures. This combination of spectral behaviours in the red and near-infrared is very specific to vegetation. Vegetation indices are commonly applied to AVHRR Channel 1 and Channel 2 daytime imagery to enhance the contrast between living material and other natural targets. The empirical approach allows assessments of the amount and state of vegetation on the ground.

NDVI

The NDVI (Normalised Difference Vegetation Index) (Rouse et al. 1974) is the most widely used vegetation index and archived data exist back to the early 1980's (Tucker, et al. 1994). Its formula is simple and given by

$$NDVI = (ch2 - ch1) / (ch2 + ch1)$$

where ch1 and ch2 are the red and near infrared reflectance (expressed as a percentage) respectively.

The NDVI equation produces values in the range of -1.0 to 1.0. Typically, small but positive index values of 0.0 to 0.2 correspond to bare soils, and larger values of 0.2 to 0.6 indicate increasing presence of green vegetation. Largely negative values indicate water. As the NDVI doesn't discriminate clouds very well (values around 0.0), data must be used with an appropriate cloud mask.

NDVI data is frequently composited over 10 day periods (3 dekads per month), the normal reporting period for meteorological and agricultural services, to best represent (cloud free) the area of interest (Holben, 1986). It is important to note that, even though widely used, NDVI has some limitations due to atmospheric, soil background, and bidirectional effects (e.g., Kaufman, 1989, Huete et al., 1985, Goward et al., 1991, Cihlar et al. 1994). As a consequence, other indices have been developed (e.g., Qi et al. 1994, Pinty and Verstraete 1992, Huete 1988, Baret et al. 1991, Kaufman and Tanre 1992).

Vegetation indices have been extensively used in studies to document various vegetation aspects, including leaf area index and biomass assessment, and used in models to study photosynthesis, carbon budget, water balance, yield prediction, etc (e.g., Pinty et al. 1993, Tucker and Sellers, 1986). Whereas the use of vegetation indices is appropriate for some studies, their use for quantitative estimation of vegetation must be done carefully. Further information on Vegetation indices can be found in *e.g.* Tucker (1979), Huete (1988), Pinty *et al.* (1993) and Flasse and Verstraete (1994).

BOX 3: SURFACE TEMPERATURE

All bodies, regardless of their nature, emit radiation as a function of their temperature. The AVHRR sensor includes three channels (Channels 3,4, and 5) that are sensitive to such thermally emitted radiation and can be used to measure the amount of radiation emitted by a surface.

However radiation has traversed the atmosphere before being detected by the AVHRR sensor and during the journey, some surface emitted radiance will have been absorbed, and added to, by gases in the intervening atmosphere. The combination of two of the three AVHRR channels 3,4, and 5, can be used to correct for these atmospheric effects.

Land Surface Temperature

Land surface temperature is one of the key parameters in the physics of land-surface process on a regional as well as a global scale. As it is practically impossible to obtain reliable estimates of surface temperature from ground-based measurements over large spatial and temporal scales, the use of satellite measurements in the thermal infrared is, for the moment, the only way to have access to global and uniform estimates of surface temperature. However, the applicability of remote sensing data in quantitative studies is limited by the accuracy that can be achieved with such measurements. Therefore, the acceptable error will depend on the aim of the study. For the estimation of the surface energy balance or regional evapotranspiration rates, for example, highly accurate temperature estimates is a critical component (Price 1982, Seguin and Itier 1983). For other applications, such as the analysis of the spatial pattern of the temperature field, for instance, the absolute accuracy is not such a limiting factor and the relative accuracy between neighbouring pixels is acceptable (Vogt 1992).

Two main problems arise in retrieving land surface temperature from the measurement of radiance emitted by the land surface. The first problem, as mentioned earlier is related to atmospheric absorption and emission. The second is related to the problem that land surfaces do not react as idealised 'blackbodies', as indicated by the concept of emissivity. In order to overcome these problems, different methods have been developed such as single channel methods, multi-angle methods and split-window methods. Of these, the split-window methods are by the far the most widely applied (e.g. Price (1984), Becker (1987), Coll et al. (1994), França and Cracknell (1994)).

At BPPT, and for the purpose of our demonstration examples, we have implemented the algorithm proposed by Price. It has been widely used. It results in a significant correction of the atmospheric water vapour influence due to the strong weight given to the difference in brightness temperatures from channels 4 and 5. Even with unknown or roughly estimated emissivities, the algorithm has been proven to provide reasonable results, especially in tropical environments with moist atmospheres.

We have assumed that the emissivity in channel 4 and 5 and equals 0.96
Price's formula then reduces to:

$$LST = (T4+3.33(T4-T5)) \times 1.004$$

where:
LST = Land Surface Temperature, in degrees Kelvin
T4 = brightness temperature in AVHRR channel 4, in K
T5 = brightness temperature in AVHRR channel 5, in K

Sea Surface Temperature
Because water surfaces are much more homogeneous than land surfaces, water is the simplest substance to deal with when converting measurements of surface emitted radiance back to estimates of surface temperature.

However, radiation has traversed the atmosphere before being detected by the AVHRR sensor. While some radiance, emmitted by the surface, is absorbed y the atmosphere, gassess in the intervening atmosphere can also emit radiance. Combinations of AVHRR channels 3,4, and 5 can be used to take into account these atmospheric effects.

There are two main types of algorithms. The Split window uses Channels 4 and 5 whereas the Triple window adds in data from Channel 3. Additionally, the algorithms can be corrected for angular effects, when the sensor is "looking" at an angle (which is most of the time). These are called Split and Triple Window Angular algorithms.

The project used a split window algorithm to derive SST. The ILWIS calculation function was used to generate SST images from suitable pre-processed imagery collected by the receiving unit according to Mc Millin and Crosby's (1984) formula:

$$SST = T4 + (2.702 \times (T4 - T5)) - 0.582$$

where:

SST = Sea Surface Temperature, in degrees Kelvin
T4 = brightness temperature of AVHRR channel 4, degrees Kelvin
T5 = brightness temperature in AVHRR channel 5, degrees Kelvin

Farahidy et.al., (this issue) gives details of why the algorithm was chosen, and how its accuracy in terms of absolute SST prediction were assessed by the project.

BOX 4: FIRE DETECTION

Fire detection from NOAA data is achieved by a number of methods, all of which utilise the dominating effect of hot fires in channel 3 signals. The simplest algorithm is to set a channel 3 brightness temperature threshold, whereby all pixels appearing hotter than the threshold temperature are classed as a fires, and all other pixels are classed as background. The project initially used the simple channel 3 thresholding approach, but it was found to mis-classify certain types of highly reflective clouds and water bodies as fire. It was also difficult to set a single channel 3 threshold which would reliably detect fires on imagery acquired both day and night and from different NOAA satellites. A more robust technique was therefore sought which would eliminate the false positives, and reliably and automatically detect fires no matter which satellite data was used, and which could use fixed detection thresholds independently of diurnal variations in background temperature.

Such a technique was implemented which performed fire detection by analysing the spatial variability of thermal signals in a pixel neighbourhood. This approach, called contextual approach, was developed and is used by the Natural Resources Insitute (Flasse and Ceccato, 1996), and was implemented at BPPT and BMG during the 1995 burning season. It comprises two phases: A - Potential Fire Detection (a selection of pixels which could potentially be fires) and B - Potential Fire Confirmation (a final decision about those pixels using contextual information from their immediate neighbourhood).

Phase A is roughly selects all pixels that may be a vegetation fire. It uses channel thresholds low enough to keep any possible fire yet high enough to reject most background pixels. In order to increase the performance of the algorithm water body and cloud masking were included. These removed most of the (meaningless) false positives due to sunglint and highly reflective clouds.

Phase B of the fire detection algorithm confirms whether the potential fire (PF) selected in Phase A is definitely a fire, based on knowledge of the PF and its neighbourhood. In this way, the algorithm automatically adapts to local conditions. Statistical information is then extracted about the neighbouring pixels to the PF pixel. This information is extracted automatically for a variable size context window, around the PF, until there is a minimum amount of relevant background pixels. A decision is then taken comparing the PF and its surroundings.

The contextural algorithm implemented at BPPT and BMG provided output of the fire information in two different ways. The first was as print out of basic fire maps. These showed the location of detected fires as red dots plotted on a map of Indonesia. Areas covered in cloud at the time of image acquisition were coloured in grey to allow the user to assess where undetected fires could be burning under the cloud cover. The second form of output was as a text file which listed the geographic coordinates of all detected fires. The fire locations could either be printed directly, or exported to a Geographic Information System to be viewed in the context of available management maps of the fire-affected area. As mentioned earlier, images, and processed fire information were routinely given to the Ministries of Forestry and Environment during the dry season.

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VALIDATING REMOTELY SENSED ESTIMATES OF SEA SURFACE TEMPERATURE IN SUPPORT OF MARINE MONITORING PROGRAMMES IN EAST JAVAN WATERS

By

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ABSTRACT

A reliable procedure for estimating sea surface temperature (SST) from satellite imagery is an essential component for regularly monitoring the oceanic conditions around Indonesia. Regular, extensive *in situ* monitoring is far too costly and time-consuming given the geographical extent of Indonesian waters. The ability to estimate sea surface temperature fields remotely from satellite provides a temporal and spatial coverage otherwise impossible to obtain by any other method. The accuracy of remotely sensed SST estimates over Javan waters has been examined by using a match-up dataset consisting of *in-situ* (research cruise) data and NOAA AVHRR satellite imagery collected at the BPPT ground station. This study compares the accuracies of a number of published SST algorithms and indicates how further algorithms maybe derived. The analysis suggests that the currently utilised CSIRO algorithm (McMillin and Crosby, 1984) gave an error of ±0.8 °C (root mean square deviation) with night time AVHRR data. Certain algorithms tested appeared to improve upon this and results show that regular maps of SST for the whole of Indonesia can be produced to an accuracy of better than ±0.8 °C. Further analysis indicates that the night time observations are more representative of the bulk SST. Temperature profiles suggest that this is due to the diurnal thermocline being built-up during daylight hours, making the near-surface waters less representative of the upper water column. Results show that this thermocline is completely broken down at night. The methodology for accurately and remotely estimating the oceanic SST for the whole of Indonesia has now been developed and implemented at the BPPT receiving station. This situation significantly lessens the need for expensive and time-consuming *in situ* sampling campaigns. The SST data are suitable for use in a wide variety of oceanographic applications, such as investigations into water circulation patterns and upwelling phenomena. The accompanying paper (Hendiarti *et al.*, 1996) explains these applications in further detail, this paper will describe how the remotely sensed estimates of SST were derived and validated.

INTRODUCTION

Sea surface temperature is a fundamental parameter for a broad range of oceanic research applications, such as those concerned with water circulation, throughflow and upwelling. Such work is intertwined with that dealing with water productivity estimation, with the hope of eventually predicting potential areas having maximum fish abundance (Sachoemar, 1996). Sea surface temperature can generally be monitored in two ways, (i) using *in situ* measurements such as cruise or fixed buoy data or (ii) using remotely sensed data from satellites. *In situ* measurements are intrinsically accurate and can be efficient and cost effective if we are interested in the coverage of small areas and time-scales. However if wide-area repetitive coverage (and simultaneous high spatial density sampling) is required then satellite monitoring of SST is the only realistic source of information since large-scale research cruises can cost hundreds or thousands of dollars per day and usually take many days or weeks to complete. The primary objective of this study was to develop and validate techniques for accurately monitoring ocean temperature conditions around Indonesia using AVHRR satellite data, this being directly received at the BPPT ground station. Once validated the regular observations of SST are to be used to provide information on water circulation, upwelling and other oceanic phenomena.

To achieve this objective and to ensure the accuracy of the remotely sensed estimates of sea surface temperature we compared two separate datasets. The first was the AVHRR satellite data, collected daily by BPPT, the second was a set of *in situ* measurements of bulk sea surface temperature, made during a September research cruise. Once these datasets are cross-calibrated BPPT will be more able to confidently and accurately monitor large areas of the sea surface without the need for regular high-cost cruises. This ability is extremely cost-effective and of use in a wide variety of oceanographic, climatology and fisheries based studies. The companion papers in this volume indicate certain applications considered by our group.

TECHNICAL DETAILS

Overview of the AVHRR/2 Instrument

The BPPT ground station collects data from the US NOAA polar orbiting satellites which pass over Indonesia many times a day. These satellites carry the AVHRR/2 instrument, which has been the fundamental apparatus for remotely estimating sea surface temperature for many years. This instrument makes measurements of the amount of thermally emitted radiation arriving at the sensor in a number of different 'thermal' wavebands (AVHRR channels 3,4,5 having wavelengths 3.7 μm, 11 μm and 12 μm respectively). When viewing the sea surface the sensor is measuring the amount of thermal radiation emitted by the water and these measurements can be easily converted into values of radiative temperature, actually termed 'brightness' temperatures.

The atmosphere absorbs some of the thermal radiation as it passes from the sea surface to the sensor and so these brightness temperature measurements will not be a truly accurate measure of the water surface temperature. This is especially true in the tropics where the high atmospheric water vapour content will tend to absorb the thermal radiation more strongly. Because of this the wavebands of the AVHRR sensor have been chosen to result in a different and distinct atmospheric effect for each channel. Using data combinations from two or three of these channels it is possible to correct for the effect of the atmosphere and thus accurately estimate the actual temperature of the emitting sea surface. Different geographical regions require different combinations of AVHRR channel data and this study is aimed at investigating the ability of these data combinations to accurately estimate the true SST of Indonesian waters. Once validated such techniques can be applied operationally to produce reliable, cheap and repetitive information on Indonesia-wide sea surface temperature distribution.

Overview of the in situ (cruise) dataset

An *in situ* dataset of actual sea surface temperatures was required to calibrate the AVHRR channel combinations aimed at accurately estimating the true temperature of the sea surface. During September 1995 a five day research cruise was conducted around Java, the cruise track and particular sampling points being illustrated in Figure 1. The highlighted points (in the north-west corner) indicate where water temperature measurements were taken for later comparison with the satellite derived brightness temperatures. Two methods of *in situ* temperature measurement were used during the cruise. The first (bridge) method used the Meteorological Station Pommar/M04-3412-3000 instrument which automatically logged information on actual water temperature (at ~ 2 m depth), along with corresponding data such as position and time for each reading. The second method used bucket sampling to collect and measure the temperature of surface water samples every 30 minutes.

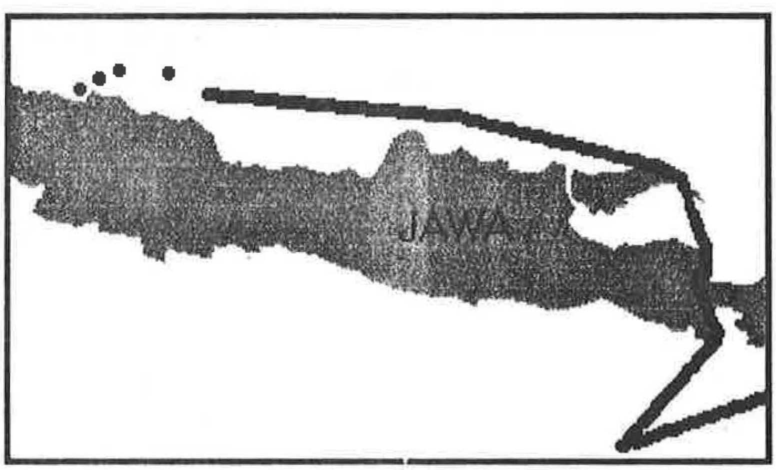


Figure 1. The location of the cruise sampling points taken during September 1995

METHODOLOGY

Once collected the *in situ* SST data were converted into a format compatible with the satellite data analysis software. The bridge and bucket *in situ* temperature measurements were compared and the BPPT AVHRR image archive was searched for relatively cloud-free images collected during the five day cruise period. Two

AVHRR datasets were selected, a night-time NOAA 14 file collected on 20 September 1995 and a daytime NOAA 14 file collected on 22 September 1995. The satellite data analysis software was used to convert these AVHRR datasets into separate brightness temperature images for each AVHRR thermal channel. These separate channel images were then projected onto a latitude/longitude grid so that the location of the *in situ* measurements of temperature could be overlain using a geographical information system (GIS). The GIS was then used to extract the value of the AVHRR channel brightness temperatures at the location of each *in situ* SST measurement. GIS analyses were also used to discount cloud-affected pixels from the study. These cloud-cleared values of AVHRR brightness temperature and corresponding *in situ* SST then formed the basis of the match-up dataset used in the study.

Initially the brightness temperature datasets were used as input to the following published SST algorithm currently used operationally by CSIRO Australia (McMillin and Crosby, 1984) :

$$\text{Actual SST } (^\circ\text{C}) = T4 + 2.702 * (T4 - T5) - 273.73 \quad (1)$$

where,
T4 = brightness temperature (Kelvin) in AVHRR channel 4
T5 = brightness temperature (Kelvin) in AVHRR channel 5

The SST estimates produced using this algorithm were then compared to the actual SST values measured during the research cruise. An estimate of the accuracy of this algorithm could then be produced and, if was found to be satisfactory, the algorithm could be used operationally at BPPT. Further SST algorithms were then tested for their suitability for use in Indonesia.

RESULTS AND DISCUSSIONS

Daytime vs night-time SST estimates

Oceanographic research activities put a heavy emphasise on the measurement of bulk sea surface temperature since, amongst other things, the data will be used to investigate circulation patterns in near-surface water (Hendiarti *et al,* 1996). It is therefore important that SST estimates are representative of the whole of the near-surface layer, say the top 5 - 10 metres, and not just the first meter or so of the water column. Fixed stations were sampled during the cruise in order to investigate the magnitude of the diurnal thermocline, this being caused by solar-induced heating of the upper water layer during daylight hours. Figure 2 demonstrates the build-up of a diurnal thermocline during the day, the thermocline being rapidly broken down after sunset. It is clear that during the daytime *in situ* temperature measurements taken at the very surface will not be truly representative of the upper water column. This is not the case after night-fall where the water temperature is almost constant from 0 to 10 m depth.

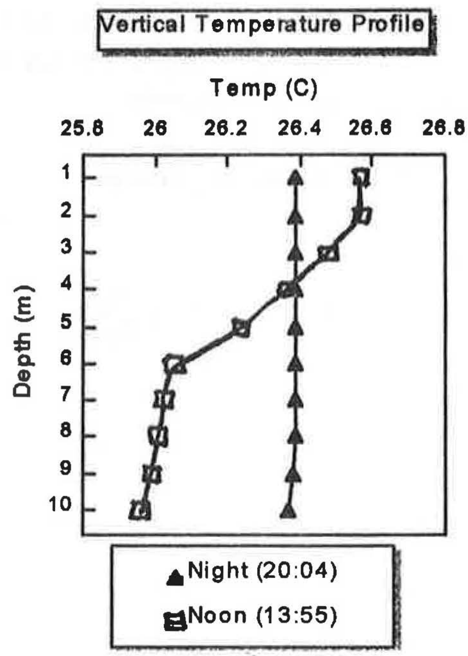


Figure 2. Vertical temperature profile showing the near-surface diurnal thermocline.

Further investigations showed that SST readings made using the bridge instrumentation were more stable than temperature measurements made using the sampling bucket . This fact was attributed to the bridge temperatures being taken at a lower depth than the water sampled using the bucket method. Because of this the bridge temperatures were less affected by the diurnal thermocline, while the bucket sampled water was grossly affected by this daytime phenomena. Figure 3 shows that at night the bridge and bucket temperatures were almost equivalent but during daylight hours large temperature differences were apparent. These results caused the study to utilise the bridge temperature readings as the accurate *in situ* dataset, these readings being more representative of the upper 10 m of the upper water column.

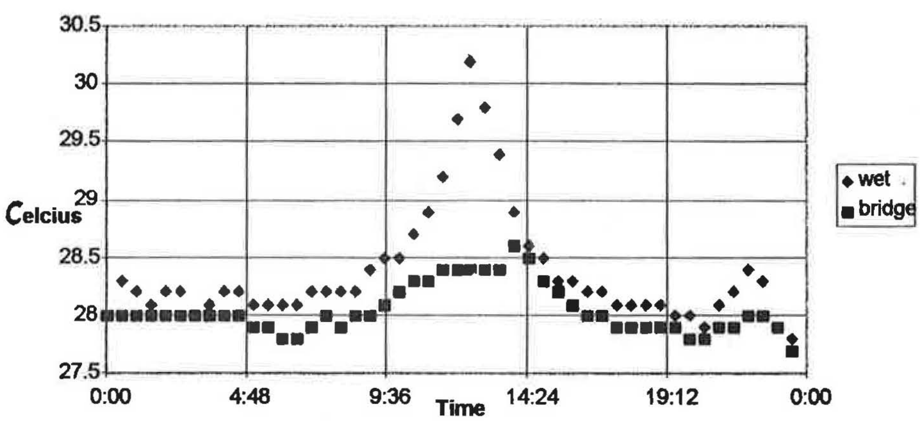


Figure 3. The bridge and bucket temperature measurements.

Next the AVHRR channel brightness temperatures were examined at each point sampled on the cruise track. Figure 4 shows the relationship between the AVHRR channel 4 brightness temperatures (measured here in °C) and the corresponding values of the bridge SST. Clearly this single brightness temperature measure is a poor estimate of the actual SST. The channel 4 brightness temperature is around 5 °C lower than the SST and shows a high degree of scatter.

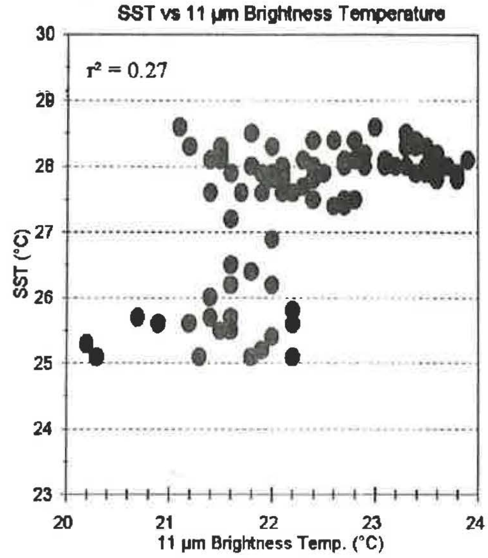


Figure 4. The highly scattered relationship between the actual bridge SST and the AVHRR channel 4 brightness temperature.

Theory states that the magnitude of the difference between the actual SST and the AVHRR channel 4 brightness temperature should be directly proportional to the temperature difference between the AVHRR channel 4 and channel 5 brightness temperature measurements. This is a consequence of both these variables being related to the amount of atmospheric absorption occurring between the sea surface and the satellite. These variables are plotted in Figure 5 and the relationship clearly shows much less scatter than the single channel measure shown in Figure 4.

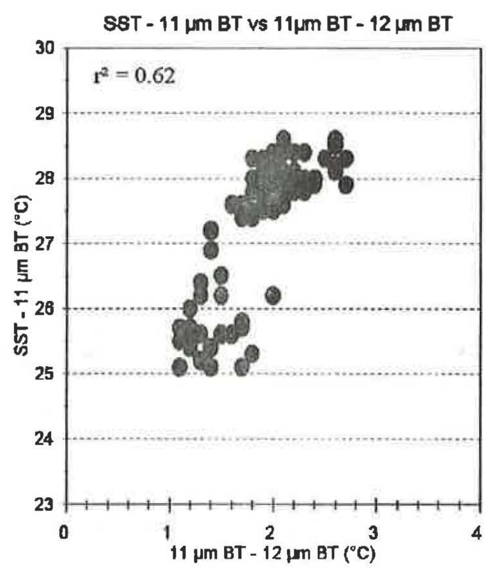


Figure 5. The highly-correlated relationship between the two measures of atmospheric absorption discussed in the text.

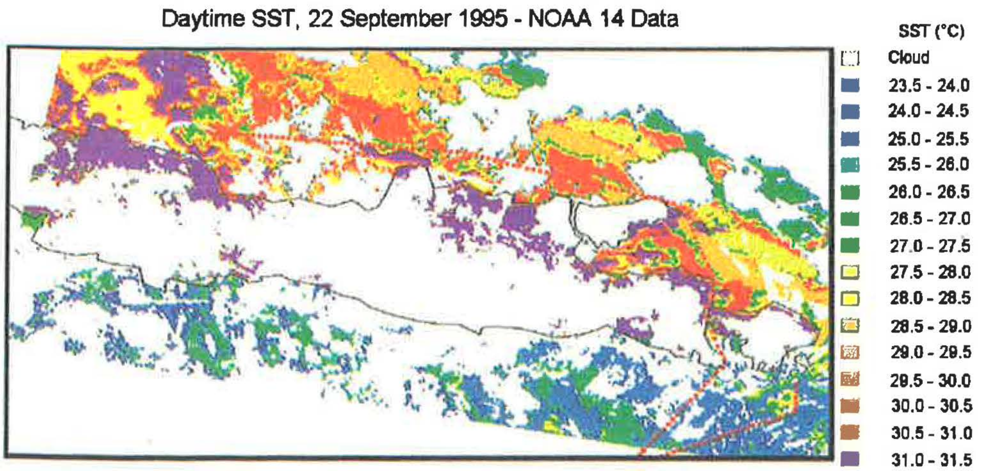
The relationship shown in Figure 5 can be represented as :

$$(SST-T4) = k(T4 - T5) + b \qquad (2)$$

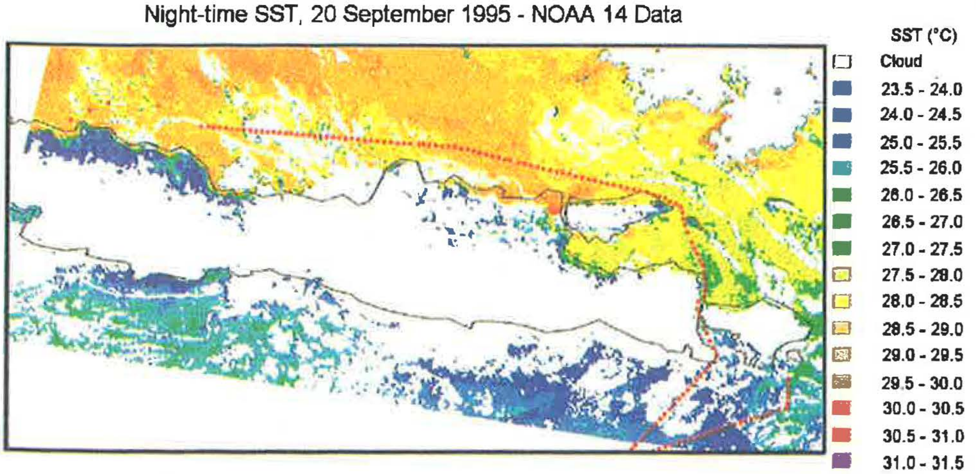
where k and b are constants dependant upon the type of atmosphere the satellite is viewing the surface through (e.g. tropical, mid-latitude etc.)

This equation can be re-arranged to provide a measure of the actual SST, given the values of AVHRR channel 4 and 5 brightness temperature at the relevant location. This is how sea surface temperature algorithms, such at that given as Equation 1, can provide an accurate estimate of the true SST value from the satellite data alone. However, in the tropics the accuracy of these algorithms may be diminished due to the high concentrations of radiatively absorbing water vapour present in tropical atmospheres. For this reason it is vital that we validate the CSIRO algorithm with an independent *in situ* dataset, such as that collected during the cruise period.

The results of applying the CSIRO SST algorithm (Equation 1) to the daytime and night-time NOAA 14 data are shown in Figures 6(a) and 6(b).



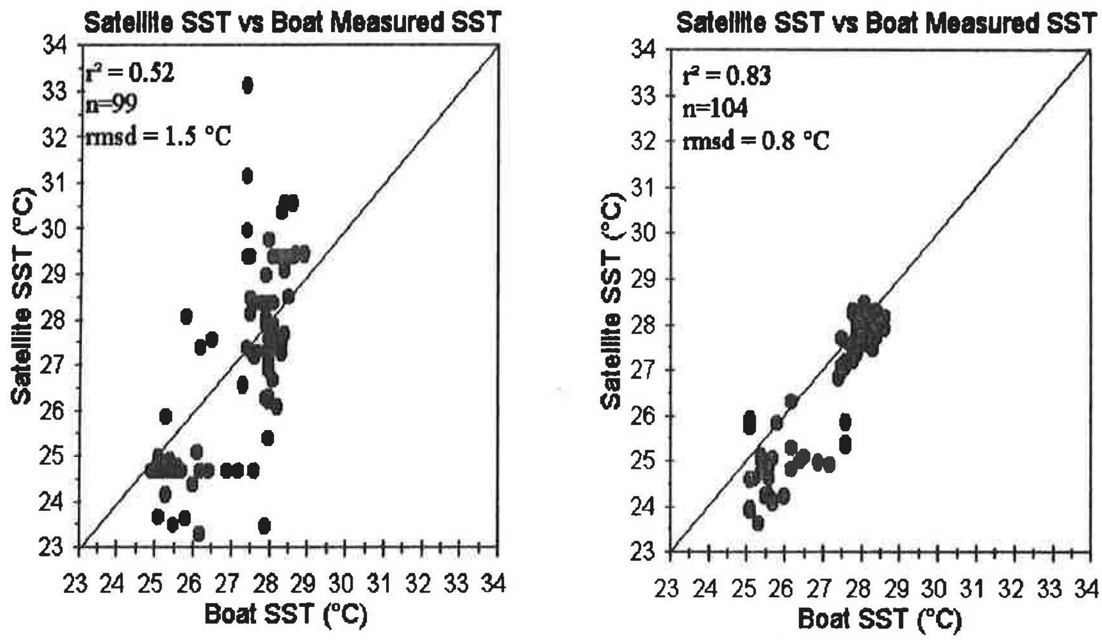
(a)



(b)

Figure 6: Daytime and Night-time surface temperature maps derived from the CSIRO SST algorithm

Figures 7(a) and 7(b) illustrates a comparison between the values of remotely estimated sea surface temperature and the *in-situ* measurements of temperature for the daytime and night-time images shown in Figure 6.

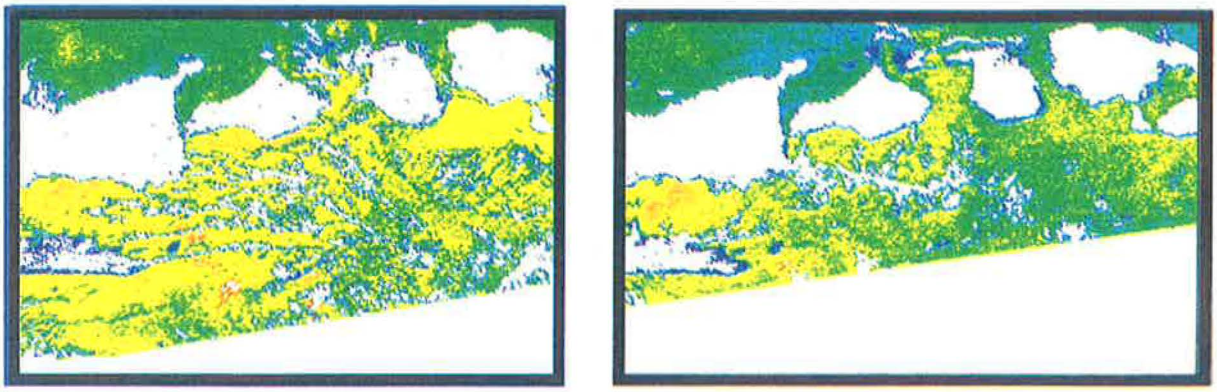


(a) Daytime data (b) Night-time Data

Figure 7. The accuracy of the remotely sensed estimates of SST using the CSIRO algorithm (Equation 1) on daytime and night-time AVHRR data.

The dataset shown in Figure 7 includes all the cloud-free locations sampled on the research cruise. The results indicate that the accuracy of the night-time SST estimates is significantly higher than that of the daytime estimates (±0.8 °C and ±1.5 °C respectively). By understanding that the satellite is only receiving radiation from the very top of the water column we can explain this day/night difference quite simply. We suggest that the accuracy difference is primarily caused by the diurnal thermocline affecting the near-surface water during the day and thus making the remotely estimated surface temperatures significantly different than the *in situ* temperature measurements taken at 2 m depth. This effect is not apparent at night and thus night-time data afford increased accuracy of remote temperature estimation. The temperature profile data shown in Figure 2 validate this hypothesis.

The CSIRO algorithm was then applied to two near-coincident AVHRR images covering a similar area but taken from two different NOAA satellites, NOAA 14 and NOAA 12. The results show that the sea surface temperatures derived using data from the two different satellites are within ±0.5 °C of one another. Figure 8 shows the results visually. This result confirms that the validated SST algorithm is generally applicable to data from the range of NOAA satellites, this being an important consideration since a new NOAA satellite is launched every two years.



(a) NOAA 14 SST image (b) NOAA 12 SST image

Figure 8. The results of applying the CSIRO algorithm to a near coincident NOAA 14 and NOAA 12 dataset.

ACCURACY IMPROVEMENTS USING ADDITIONAL SST ALGORITHMS

For comparative purposes, a number of different sea surface temperature algorithms were then applied to the brightness temperature dataset extracted from the night-time NOAA 14 image. The accuracy of these algorithms was calculated and compared to that of the CSIRO algorithm (Equation 1). The SST algorithms tested included those of Yokoyama and Tanba (1991), Llewellyn-Jones *et al* (1984) and algorithms used operationally for global SST measurement (Kidwell, 1991). Algorithms using combinations of all three AVHRR channels were tested (triple window algorithms), along with the more common two channel (split window) algorithms such as Equation 1. The results show that the only algorithm to improve on the accuracy of the CSIRO algorithm was the two channel algorithm of Yokoyama and Tanba (1991), shown as Equation 3. This algorithm gave an rmsd accuracy of 0.6 ^{o}C, slightly better than the result using the CSIRO methodology. The Yokoyama and Tanba (1991) algorithm was derived for use in waters around Japan. Although this is an encouraging result, and that it is likely that the deep summer monsoon affects atmospheric conditions in Japan and Indonesia similarly, caution is required in extrapolating regionally derived algorithms to other areas at different latitudes. Further work, over a variety of seasons and years will be required before the Yokoyama and Tanba (1991) algorithm could be applied confidently and routinely to compensate for the atmospheric effect present in the Indonesian data. Figure 9 shows a graphical comparison of these two algorithms.

$$SST\ (°C) = 3.33 * T4 - 2.33 * T5 + 0.53 \quad (3)$$

where T4 = 11 μm brightness temperature (K)
T5 = 12 μm brightness temperature (K)

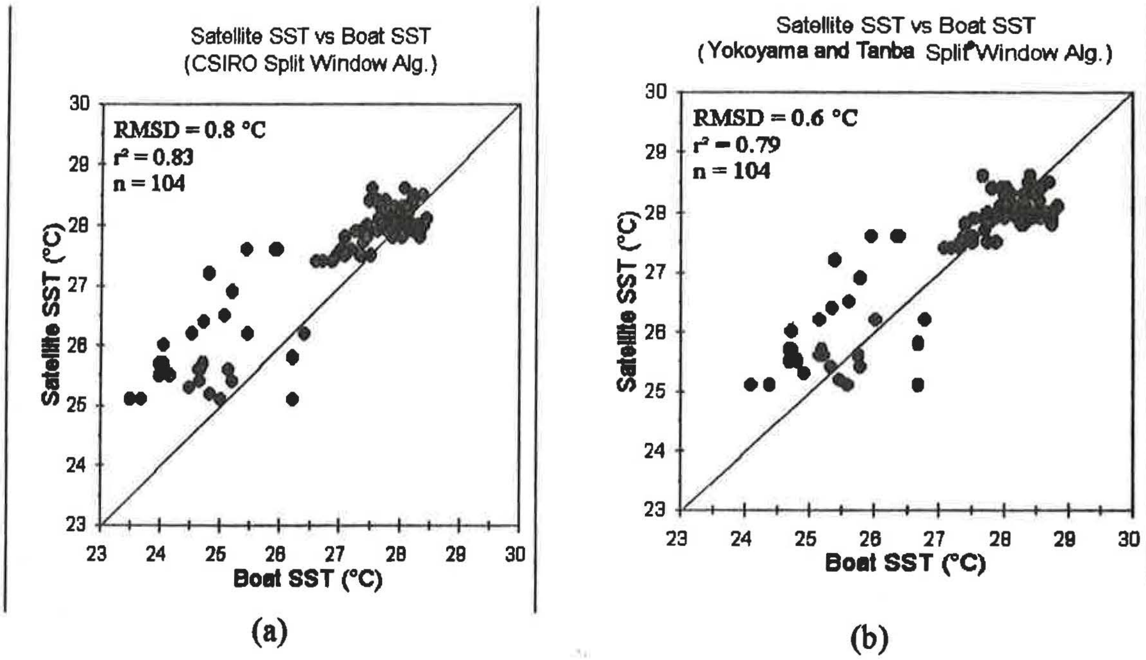


Figure 9. A comparison of the results using the CSIRO and Yokoyama and Tanba algorithms.

Finally we attempted to derive a new algorithm empirically from the match-up dataset. This was done by regressing combinations of satellite derived brightness temperatures against the actual *in situ* measurements made from the boat. The most accurate newly derived algorithm utilised all three AVHRR wavebands, this agreeing with the results of Llewellyn-Jones *et al* (1984) who stated that use of the 'low absorption' 3.7 μm waveband may be necessary for accurate retrievals of SST in humid tropical conditions. The derived 'triple window' algorithm had an rmsd accuracy of ± 0.5 °C and the relationship with the actual SST measurements is shown in Figure 10. However, the algorithm has been derived for a specific set of conditions since only wet season (September) data has been used in it's derivation. Again, before such an algorithm could be used with confidence further derivations and tests on an expanded and independent *in situ* dataset would be necessary.

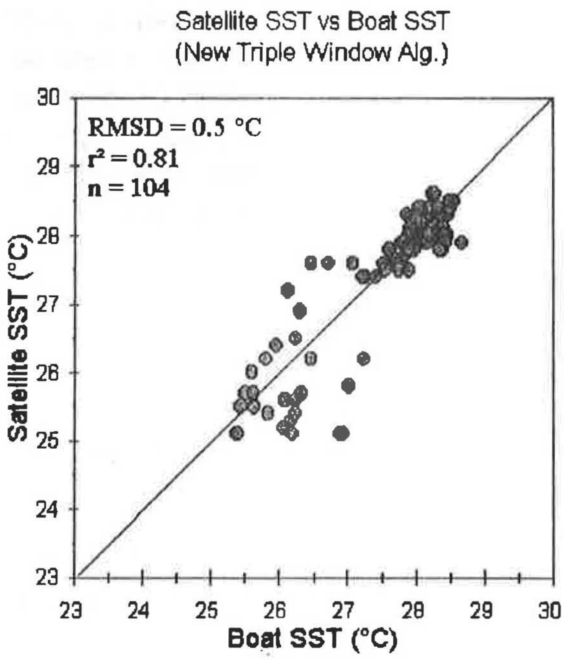


Figure 10. The accuracy results of the newly derived triple window algorithm.

SUMMARY

The applicability of AVHRR sea surface temperature algorithms to retrieve accurate values of Indonesia-wide SST was investigated. The study utilised a match-up dataset constructed from *in situ* measurements of near surface water temperature, taken during a research cruise, and locally received satellite data collected during the cruise period. The results suggest that the use of the CSIRO SST algorithm with night-time AVHRR data can produce repeatedly accurate maps of SST, accurate to around ±0.8 °C. This accuracy is sufficient for all current operational purposes. Daytime AVHRR data can also be used for SST estimation but provides information less representative of the whole of the upper water column. This fact was attributed to the build-up of the daytime diurnal thermocline, this being absent during night-time data collection.

A series of published SST algorithms were tested and only the dual channel algorithm of Yokoyama and Tanba (1991) succeeded in improving on the accuracy of the CSIRO algorithm. The Yokoyama and Tanba algorithm, derived for use in Japanese waters, provided an accuracy of ± 0.6 °C when compared to the *in situ* dataset.

Initial studies indicated that newly derived night-time triple window algorithms maybe able to further improve the accuracy of temperature estimation. One such algorithm gave an rmsd value of ± 0.5 °C but the dataset from which this algorithm is derived covers only one week of the year. An expansion in temporal coverage would be needed to ensure the robustness of any such newly derived algorithms.

Indonesia-wide SST maps can now be produced using any of the currently operational NOAA satellites and the need for expensive and time-consuming sampling cruises is thus lessened. These maps of remotely estimated sea surface temperature provide a temporal and spatial coverage impossible to gain by any other method. As such they will be useful in many oceanographic and fisheries related applications. We refer the reader to Hendiarti et al. (1996) for a fuller discussion of such applications.

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HENDIARTI, N., SACHOEMAR,S.I., WINARNO,B., PATTERSON,G., WOOSTER,M., DOWNEY,I., TRIGG,S. (1996), Remote monitoring of upwelling events south-east of Java in relation to fish catch and oceanographic data. Proceeding of Workshop on Direct Reception of Satellite Data for Integrated and Sustainable Environment Monitoring In Indonesia, April 16, 1996, BPPT Teknologi, Jakarta, Indonesia

REMOTE MONITORING OF UPWELLING EVENTS SOUTH-EAST OF JAVA - RELATIONSHIPS WITH FISH CATCH AND OCEANOGRAPHIC DATA

By

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ABSTRACT

Regular observation of local sea surface temperature (SST) patterns allows water circulation phenomena to be detected and the evolution of such features tracked throughout the season. These features are of direct importance to Indonesian fisheries since the associated upwelling brings nutrient rich water from deep in the water column up to the surface where increased light levels allows the phytoplankton to photosynthesise more efficiently. The potential for near-surface primary production is thus increased by such upwelling events, this production feeding associated fish stocks. This paper indicates how seasonal patterns of upwelling and circulation can be remotely monitored using locally captured NOAA AVHRR data. Data obtained from remote monitoring studies are compared to fish catch statistics and additional oceanographic data collected during two research cruises.

INTRODUCTION

Indonesian waters cover a wide area with the national exclusive economic zone approaching 8 million km^2. Consistent, regular temperature monitoring over such an extensive area can only be performed using data from suitable Earth-orbiting satellites. The National Oceanic and Atmospheric Administration (NOAA) Polar Orbiting satellites carry an Advanced Very High Resolution Radiometer (AVHRR) which provides thermal infrared data suitable for conversion into accurate measurements of sea surface temperature with around 1 km^2 spatial resolution (Robinson *et al* 1984). These satellites pass over the ocean areas around Indonesia a number of times every day and thus estimates of SST can be produced on a very regular basis. This paper discusses preliminary results from a long term Indonesian SST monitoring study carried out using data collected between 1991 and 1995. The retrospective AVHRR data for this study was collected by the Darwin and Alice Springs satellite data reception facilities between 1991 and 1994. Real-time data for 1995 were collected locally in Indonesia by the BPPT NOAA AVHRR reception system installed in June 1995. The BPPT ground station is a part of the Indonesia - United Kingdom Environmental Monitoring Project, sponsored by the British Overseas Development Administration.

BACKGROUND

In some areas of the worlds oceans (especially along the West coasts of the continents at subtropical latitudes) prevailing winds drive the surface water seaward. This off shore transported water is replaced by deeper, nutrient rich, ocean water in a process called upwelling. These upwelling areas are the richest biological regions of the oceans and where the largest fish populations occur. Approximately 50% of the worlds sea food resources are caught in these limited areas which represent less than 0.2% of the worlds oceans (IOMAC 1991). The precise location of these highly productive zones is of obvious importance for fishing fleets in their efforts to optimise catches in terms of frequency and tonnage. Table 1 indicates the relative levels of productivity of different ocean regions.

Province	% of ocean	Mean productivity (g C m^2yr^{-1})	Total primary production (tons C yr^{-1})	No. of trophic levels	Efficiency (%)	Fish production (tons fresh weight)
Open Ocean	90.0	50	16.3×10^9	5	10	16×10^5
Coastal Zone	9.83	100	3.6×10^9	3	15	12×10^7
Upwelling Regions	0.17	300	0.18×10^9	1.5	20	12×10^7
Total	100.0	450	20×10^9			24×10^7

Table 1. Provinces of the ocean according to their levels of primary organic Carbon production and estimated fish production (Petterson *et al* 1989).

Thermal conditions such as ocean frontal zones and upwellings, where strong temperature gradients exist, have historically been important as indicators for fishing localities over all of the worlds oceans. Ship based measurements of sea surface temperatures have traditionally been made by fisherman and from this experience it is possible to gain regional knowledge of the optimal temperature requirements for different species. Obtaining a spatial overview and details of the mesoscale structure of SST is difficult from ship measurements and so remote sensing offers a great deal of information. Measurements of the ocean surface layer, frontal boundaries and upwelling systems can be made at frequent intervals and this information can be passed directly to fleets. This technique has been systematically used in the Japanese fisheries (Taeishi 1992) and is now being more widely tested in European and South American waters (Barbieri *et al* 1987).

Upwelling waters in Indonesia show the general characteristics associated with such phenomena around the world. The upwelling waters are cold and have a high salinity. The waters have a high chlorophyll concentration and are rich with phosphate and nitrate based nutrients. When such waters reach the surface layers (i.e. the photic zone) increased primary productivity can be expected due to increased nutrient abundance and incident light levels compared to deeper water. Generally speaking the more upwelling that occurs the more primary production might be expected. Because the associated food chain is relatively short, this will have a commensurate influence on the amount of fish which are either spawned or that can be supported in the area.

During the northerly (wet) monsoon from October to March, the direction of currents along the whole of the western coast of the South China Sea is southerly. Water from the South Equatorial current of the Western Pacific feeds in to this circulation via the east-west passages in the Indonesian archipelago, finally finding its way south-east into the Banda Sea. Currents flow along the southern coast of Sumatra and Java in a southerly direction until they turn seawards in the region of Lombok and Sumbawa to join the origin of the South Equatorial Current. During the south east (dry) monsoon of April to September, a dry wind comes to southern Indonesia from Australia. During this period, flow is reversed and water from the Pacific Equatorial current flows westwards via the passages between the Moluccas and Western New Guinea, feeding the northerly coastal monsoon current of the South china Sea and the South Equatorial current of the Indian Ocean (Sitepu and Rokhmin Dahuri 1995).

The principal biological consequence of this monsoon system is to generate upwelling phenomena which in turn support the biological productivity of those marine waters. In August, off the northwest coast of Australia and particularly along the southern coast of Java and Sumbawa, the southerly (dry) monsoon induces strong upwelling. This is an important source of water for the South Equatorial current of the Indian Ocean (Wyrtki 1962) and originates at depths sufficient to bring up nutrient rich water along the coast of Java and in the Bali Strait where large populations of sardines are supported. During this season, there is also a significant upwelling along the northern coast of Irian Jaya. During May to August, a less strong upwelling occurs in the eastern part of the Banda Sea along the shelf edge of the Arafura Sea and surface temperature decreases by about 2° C. Further west, off Macassar, water from the Flores Strait and the Macassar Strait meets, and flows into, the Java Sea. High surface salinities in June and July suggest upwelling as a consequence (Wyrtki 1961, Sitepu and Rokhmin Dahuri 1995)

Upwelling phenomena off the South of Java therefore show a relationship to water circulation in this area during the southeast monsoon. The water mass from Pacific ocean comes into contact with that in the Indian ocean, this being influenced by winds at the surface. The Pacific Ocean water mass has a lower temperature than the Indian ocean water and when large volumes intrude into the Indian ocean it will bring with it water rich in nutrients and phytoplankton as a result of the upwellings. Observations of the meeting of these water masses can provide an indication of the increased productivity that might be associated with this phenomena. NOAA AVHRR data and coincident cruise data were collected during 1995 to investigate such phenomena and these are described below.

Long term SST observations also support the monitoring of regional and localised water mass patterns and diurnal changes in the condition of the near-surface ocean. Such data can support the investigation of El Niño Southern Oscillation (ENSO) related phenomena. El Niño is a warm current of transequatorial Pacific Ocean origin which appears irregularly every 5 to 10 years off the coast of Peru (the Southern Oscillation). Unusually extended periods of increased ocean water temperatures in this region have led to catastrophic failures of anchovy fisheries in Peru and have also been linked with abnormal climatic changes (such as droughts, floods, etc.) elsewhere in the world (Sitepu and Rokhmin Dahuri 1995). Time series analysis of SST data may therefore allow an assessment of the effects of ENSO related events on fish stocks, water circulation and regional climates, the latter which may have a bearing on the terrestrial applications presented elsewhere in these proceedings.

Tropical regions can present difficulties for the application of remotely sensed SST techniques as high atmospheric water vapour content and local heating from the atmosphere can degrade the accuracy measuring the surface thermal signature. There is therefore a need to properly calibrate the satellite data with field data such as that obtained from thermistors carried on board research and commercial ships. These data provide a useful gauge for local conditions and also act as vital calibration sources.

DATA COLLECTION METHODOLOGY

Two research cruises were conducted during our study. These cruises were conducted under the activities of the Global Research Network System Program, a co-operative venture between BPPT - LIPI - LAPAN, Indonesia and JAMSTEC, Japan. The first cruise occurred during the northwest monsoon (7 - 11 March 1995) and the second during the southeast monsoon (20 - 25 September 1995). The cruises collected 'sea truth' data on the biological, physical, and chemical state of the ocean. These data were used to define the different seasonal conditions that exist in Indonesian waters and, perhaps most importantly, allowed the remotely sensed SST algorithms to be validated for operational use.

Both cruises collected water samples, temperature and salinity data using a Conductivity-Temperature-Depth (CTD) instrument (Guideline with Rosette System) and associated bucket and Niskin bottles. These measurements were made every 5 to 10 m, to a depth of 200 m for the March cruise and 300 m for the September cruise. These cut-off points were determined by the base of the chlorophyll concentration, as given by fluorometer measurements.

CTD data processing was performed using the BPPT-developed SUKONDAL software. The water samples were used to derive information on water pigmentation using fluorometric, spectrophotometric determination and High Performance Liquid Chromotography (HPLC). To trap the phytoplankton contained within the water samples, the samples were filtered using a Nucleopore Filter (Costar Corp. USA) - pore size 0.4 μm with a 47 mm diameter. Individual filters containing the filtrates were then soaked in a small bottle of N, N - dimenthyl formamide (Wako Pure Chemical Industries Ltd, Japan) to extract the pigments. The filters were stored for at least 24 hours in a refrigerator before pigment analysis was carried out. To calculate the chlorophyll-a concentration of the sample spectrophotometric determination was used, according to the formula of Moran (1981).

Sea surface temperature observations were made using data from the NOAA AVHRR instrument. A time-series dataset was constructed covering the years 1991 to 1995. This dataset was produced by processing data from AVHRR channels 4 and 5 with the SST algorithm developed by McMillin and Crosby (1984). The accuracy of this algorithm was validated using data from the September cruise and was found to be better than 0.8 °C for night-time imagery and better than 1.5 °C for daytime imagery (see previous paper by Farahidy *et al* in these proceedings). The resultant SST images were geo-referenced to a standard cartographic projection (Nilson and Tildesley, 1986) so that values of SST could be easily read off at the appropriate geographic coordinate. For the years 1991 to 1994 we utilised AVHRR data received, processed and archived by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Darwin and Alice Springs, Australia. For 1995 AVHRR data from NOAAs 9, 11, 12 and 14 was received directly using the ground station installed at BPPT - Jakarta. All NOAA data was processed using ground-station software (BURS, UK) and the ILWIS and IDRISI image processing packages running on standard PC computers.

RESULTS AND DISCUSSION

CTD castings provided data on the temperature profile with depth. Figure 1 indicates the different conditions of sea temperature present during the individual seasons. After dark, during the southeast monsoon, the sea surface temperature range for this location on 10° 00' South and 113° 30' East is 26.15 - 26.19° C. For a similar time and location during the northwest monsoon the SST ranges between 28.24 and 28.28° C. Clearly the water surface temperature during the southeast monsoon is around 2 °C cooler than that during the northwest monsoon.

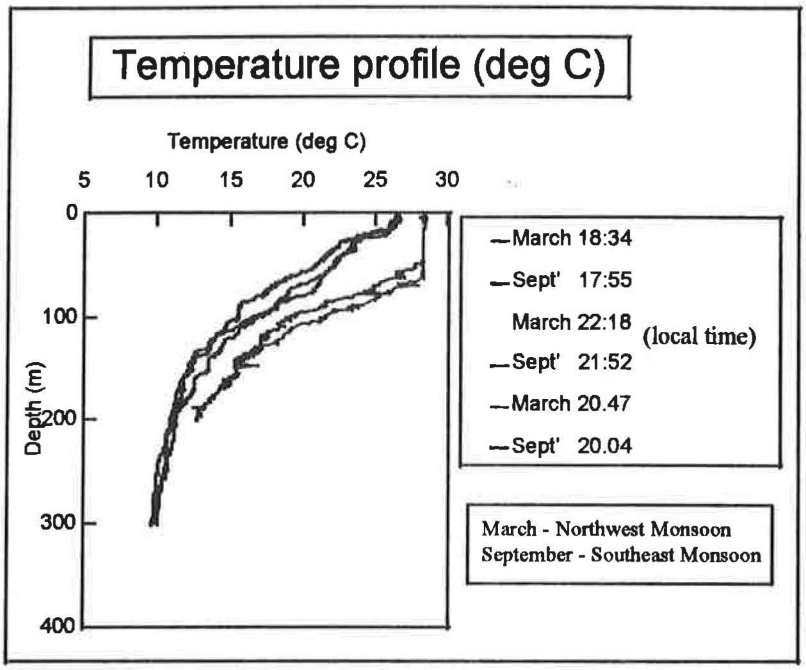

Figure 1. Sample profiles of temperature with depth taken from CTD measurements.

The temperature profiles show the depth of thermocline layer during both monsoon periods. For the southeast monsoon cruise the mixed layer is 10 to 25 m deep, the thermocline extending down to about 150 m. For the northwest monsoon cruise the mixed layer is 50 to 80 m deep, the thermoclinic layer descending to around 200 m. The thermal data shows that during the northwest monsoon the water mass is in a more stable condition compared to that during the southeast monsoon.

Chlorophyll concentrations were observed during the cruises on 10° 00' South and 113° 30' East, using fluorometric determination techniques, to establish whether or not this was the case. The highest concentrations were detected during the southeast monsoon, the period of most pronounced upwelling (N.Hendiarti *et al* 1995). Measurements were made between 15:00 to 22:00 local time, with the maximum concentration of 2.38 μg/l at 15 m depth observed at 22:00 hours. During the northwest monsoon measurements were made between 16:00 to 05:00 local time, with the highest concentration of chlorophyll observed at 20:00 hours local time. The maximum concentration (0.29 μg/l) was much lower than the dry monsoon and occurred at a depth of 60 - 75 m. Spectrophotometric determination detected the maximum chlorophyll concentration in September at 15 - 25 m with 0.39 μg/l and in March at 70 - 80 m with 0.18 μg/l.

There was marked difference in chlorophyll levels between the two monsoon seasons with higher concentrations observed in the upwelling period (September cruise), when compared to the non-upwelling period (March cruise). In an equatorial region, such as Indonesia, information about the chlorophyll concentration is extremely valuable, both oceanographically and with relation to fish location. It is clear from the discussion above that it is possible to relate knowledge of the SST distribution to chlorophyll abundance in the region and that NOAA SST information could thus be used as an indicator of likely primary productivity.

Remotely sensed estimates of sea surface temperature allow long-term changes in SST to be investigated and conclusions about their relative importance to be made. Inspection of the CSIRO 1991-1994 SST archive indicated that the water is generally warmer during the northwest monsoon than during the southeast monsoon. The SST images showed relatively warmer water to the north of Java, Bali and Lombok during both seasons whilst the southern waters were relatively cool.

Figure 2 shows SST four images selected from the CSIRO archive data. These images were all taken during the southeast monsoon, and are dated 8/8/91, 3/9/91, 27/8/92 and 24/7/93.

The 8 August 1991 image (Figure 2) shows temperatures as low as 21.5 °C within a large strong upwelling area to the South of Java and Bali. The upwelling water body appears to cover a broad area, from southern Java coast to Sumbawa. The image also shows what may be an indication of the throughflow in the Bali Strait and Lombok Strait passages.

The 3 September 1991 image shows is interpreted as showing the effects of a small scale upwelling to the south east of Java and around Nusa Penida, this being termed a weak event. Both 1991 images show suggest that upwelling occurs south of Java and Bali during the southeast monsoon, with the strength of apparently stronger in August than in September.

The 27 August 1992 image, shows a possible upwelling phenomena south of East Java and around Nusa Penida, again termed a weak event. This condition is very similar to that in the September 1991 image. From the time-series it can be seen that the period of most upwelling in 1992 was from the end of July to the beginning of August. The upwelling conditions appear much reduced by the end of August 1992.

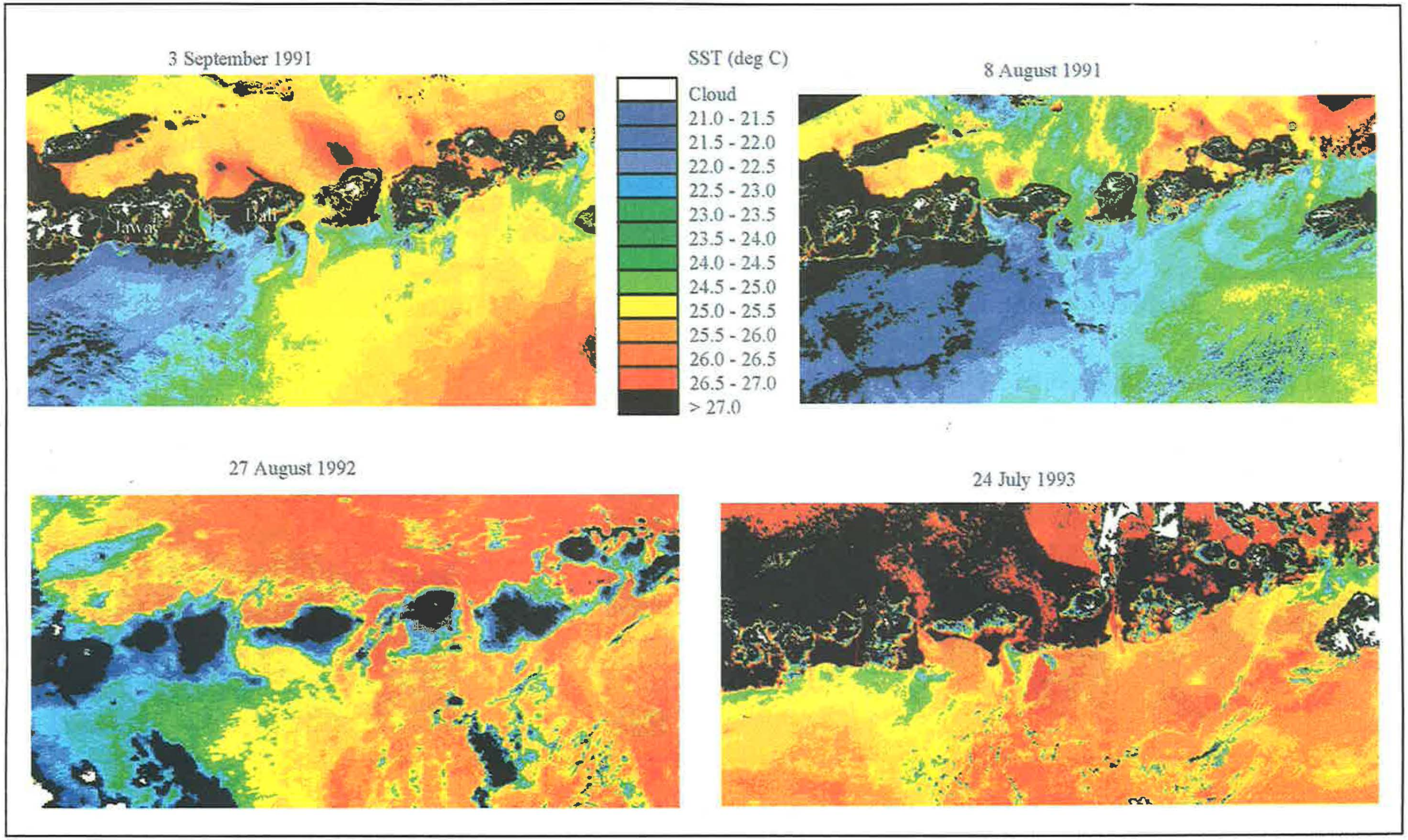

Figure 2 : SST map produced using AVHRR data archived by CSIRO, Australia

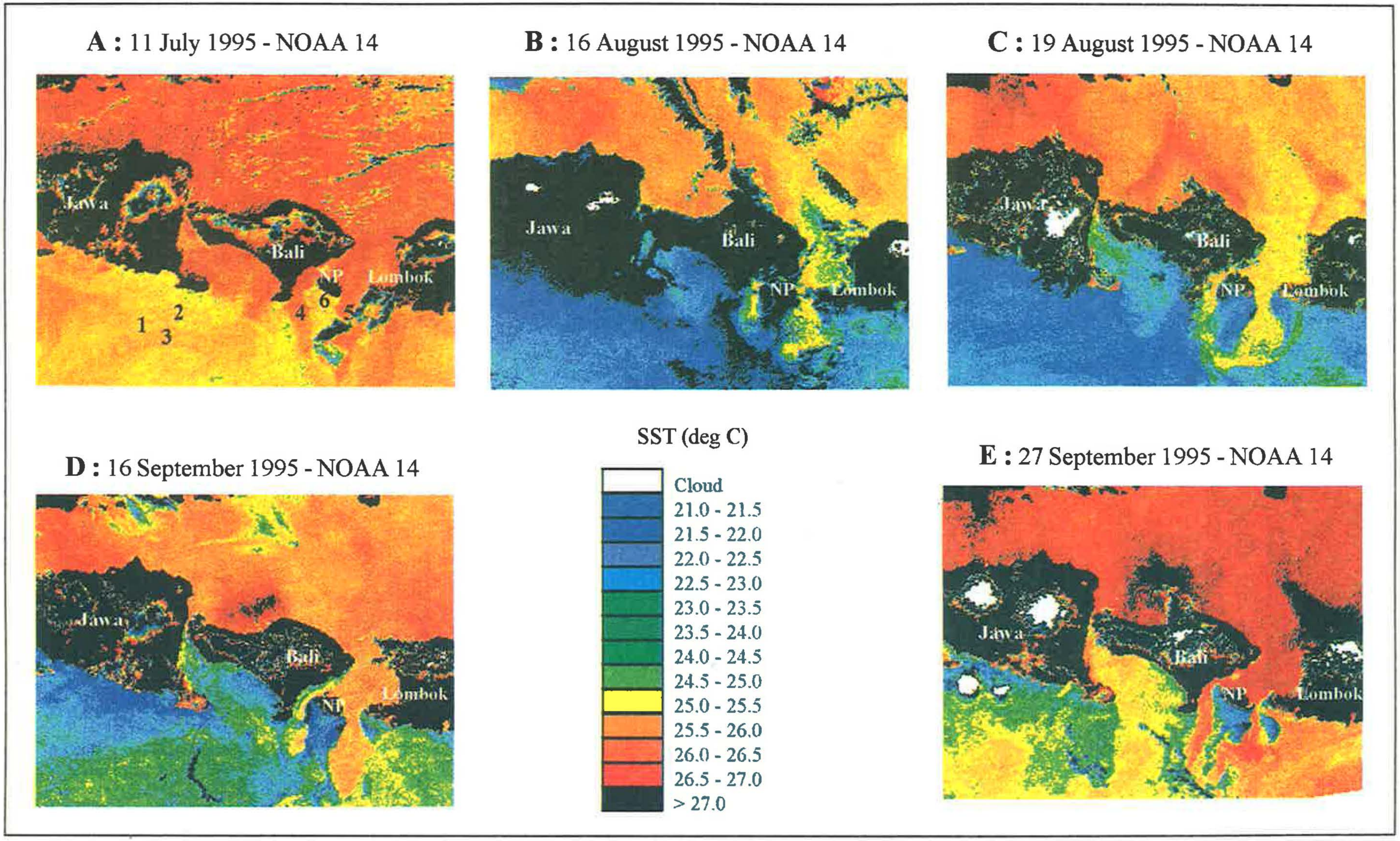

Figure 3 : SST images collected by BPPT receiving station with the locations of the points selected for time series analysis

The 24 July 1993 image again shows the warm water conditions north of Java and a very weak upwelling event south of Nusa Penida. This condition is similar to that seen in the other years at this time. A shortage of (cloud free) archived imagery for 1994 prevented detailed investigations for the following year.

Imagery captured locally by BPPT and processed into SST enabled near-real time investigation of sea surface temperature in the area during 1995. Figure 3 shows SST images produced using AVHRR data collected by the BPPT receiving station between July and September 1995. These images were all collected during the southeast monsoon, on 11/7/95, 16/8/95, 19/8/95, 16/9/95 and 27/9/95. These images show the spatio-temporal changes of SST, and may therefore be used to infer upwelling phenomenon.

The 11 July 1995 image (Figure 3.A) shows warm water to the north of Java and a very weak upwelling phenomena to the south of Nusa Penida. SST is distributed between 25.0 and 27.5 ° C. The difference in surface temperature between maximum and minimum is about 2.5 °C. This condition is similar to that seen in the other years at this time. No upwelling was detected south of Java. Figure 3A show the locations chosen for monitoring of upwelling phenomena and throughflow events with a time series of SST images. (See Figure 4 later).

The SST images from August 16 and 19, 1995 (figure 3.B and 3.C) show strong upwellings covering a broad area from the south of east Java to south Bali. Temperatures within this area range between 22.0 and 27.0 °C, giving a difference in temperature between maximum and minimum of about 5 °C. These images appear to show the surface manifestation of throughflow of water through the Bali and Lombok Straits. Upwelling appears stronger on 16 August than on 19 August.

The September 16, 1995 image (figure 3.D) shows a small scale and weak upwelling phenomena to the south of Java and Nusa Penida. Strength of upwelling appears much reduced by this time. The SST image from 27 September 1995 (figure 3.E) indicates a weak upwelling in south of Nusa Penida. The surface temperature are now warmer than before both to the north and south of Java.

The time series of SST images from 1995 suggest that upwelling commenced in mid July to the South of Java and Bali, reached maximum strength in the middle of August, and diminished to a weak phenomenon by the end of September.

Figure 4 shows the locations of the six points marked on Figure 3A, superimposed on a black and white SST image acquired on 16 September 1995. The locations were chosen to investigate in more detail variations in upwelling and throughflow events. On the image, the darker the water colour the colder the water. Relatively cold water indicative of upwelling is observed to the south of Java and Bali with what is believed to be throughflow in the spaces between Bali-Nusa Penida, and Nusa Penida-Lombok.

Points 1, 2 and 3 are located in the Indian Ocean south of east Java and near Banyuwangi port. This port is the main fish landing site of the area and these locations were used to investigate the relationship between the magnitude of the upwelling events and the fish catch statistics collected at Banyuwangi port.

Points 4, 5 and 6 are located in the Bali Strait and near Nusa Penida. Point 4 is located close to Bali, point 6 South of Nusa Penida island, and point 5 in the Lombok strait close to Lombok island. SST data from these points were used to investigate the temperature of the different water masses in one transect near the Bali Strait. It was proposed that such measurements could potentially indicate the variability of the throughflow events occurring between the Islands.

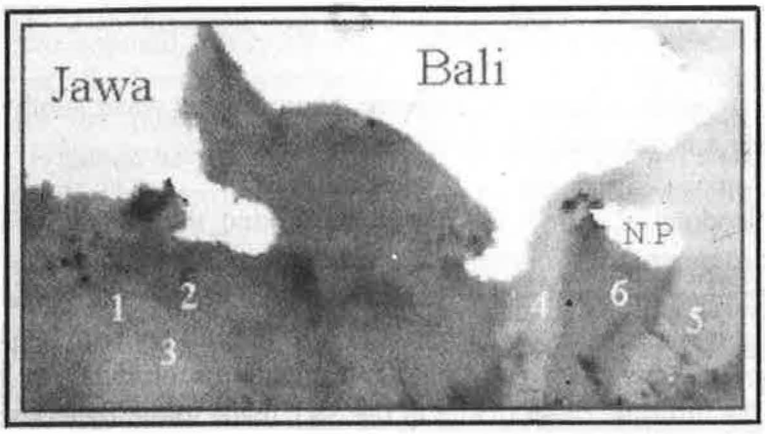

Figure 4 : The locations of the points selected for the time-series analysis of SST.

Figure 5 shows the temperature difference between point 6 (upwelling water) and the mean temperature of points 4 and 5 (through-flowing water) close to Nusa Penida island. The observation period was from June 1995 - November 1995. The figure shows that during the southeast monsoon point 6 has a lower temperature compared with point 4 and 5. This indicates the presence of upwelling south of Nusa Penida. The difference between the SST of point 6 and that of points 4 and 5 became negative sometime in June 1995 (~Julian Day 160) and ceased to be negative during late September 1995 (~Julian Day 190). This result indicates that upwelling events were occurring south of Nusa Penida happened from June until September, with throughflow in and around the Lombok and Bali straits. The magnitude of the temperature difference between the monitored points becomes more negative from the onset of the upwelling in June until sometime in August (~Julian Day 240). From the end of August the SST difference decreases until the cessation of permanent upwelling conditions in late September.

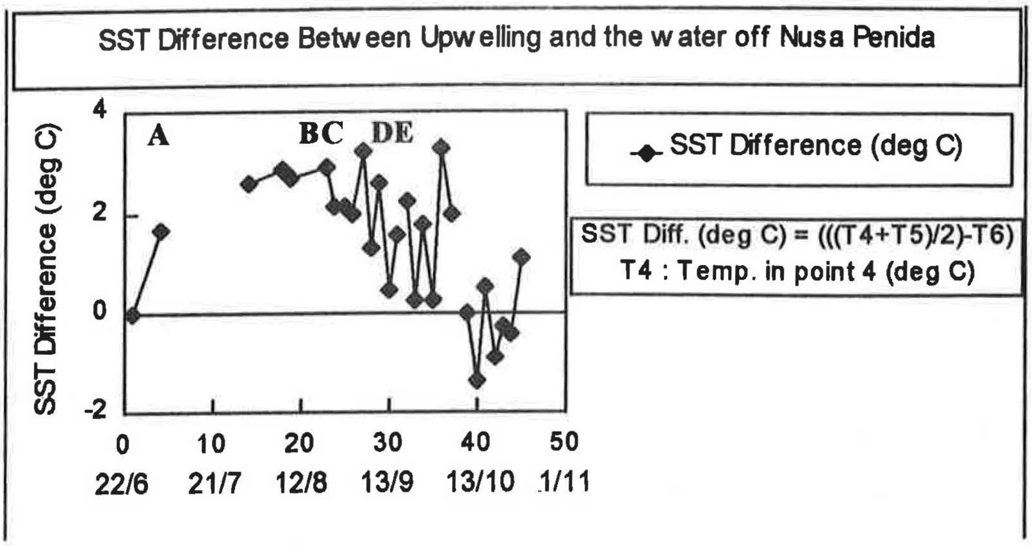

Figure 5. The temperature difference between the upwelling water south of Nusa Penida and the surrounding warm water throughflow.

The most productive period for fish catch around the Islands of Bali and Nusa Penida is the third quarter of the year, although the actual magnitude of the fish catch is quite variable, as given in port landing statistics. By monitoring the upwelling waters in the way indicated it is clear that the most productive periods for fishing are related to the periods of maximum upwelling, and thus likely maximum productivity. This is a first step in relating the information available in the SST maps to the fisheries productivity of Indonesia waters. Fish catch statistics for Banyuwangi port are generally less variable and Figure 6 shows the mean SST value of points 1,2 and 3, well within the fishing grounds of this port. During the observation period (June - November 1995) the mean SST value for the area drastically decreased in June and July (~ Julian Day 150 - 210) and increased again from October until November (~Julian Day 270 - 290). The low SST values detected between July and September 1995 correspond with the south east monsoon period and indicate the presence of upwelling phenomena as seen in the archived images shown in Figure 3.

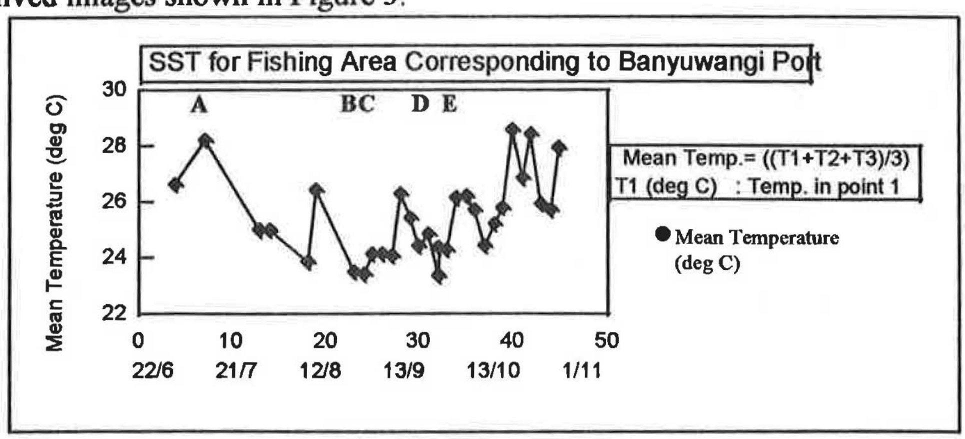

Figure 6 : The temporal variation in sea surface temperature for the South Banyuwangi fishing ground.

Some of the principal fish types caught by Indonesian fishing vessels are species of Tuna and Sardine and previous studies have related the location of these species to remotely sensed estimates of SST. These fish usually reside in near-surface water with a temperature between 18 and 25 °C. The remotely sensed data indicates that the SST range during south east monsoon is between 22.0 - 27 °C, upwelling areas showing temperatures about 21.5 - 23 °C. Tuna are thought to aggregate on the oceanic side of fronts associated with these upwelling features (Fiedler and Bernard 1987). Certain previous studies indicate that a 20 % saving in search time, with commensurate fuel savings, can be gained when using SST maps to locate frontal temperature regimes sometimes associated with the shoaling of sardine and tuna (Yamanaka 1982, Tameishi *et al* 1992). Using the SST maps produced by BPPT the possibility now exists to conduct these kinds of study of fish location in Indonesian conditions. now With chlorophyll concentration data from the now non-operable coastal zone colour scanner instrument, flown onboard the NIMBUS 7 satellite, this reduction in search time was reported to potentially decrease even further, possibly to values approaching 50 %. This further indicates the potential value of remotely sensed estimates of chlorophyll concentration. It should be possible to upgrade the BPPT ground station to receive data from the next CZCS-type instrument when it flies on the Seastar satellite in 1996/97.

Figure 7 shows the fish catch per unit effort (CPUE) statistics from Banyuwangi port for 1991 - 1994 (Place of Fish Catchment in Banyuwangi Port, Report of Fish Catch Statistic data for 1991 - 1994 period, 1995). The data were classified into quarter periods : quarter 1 (January-March), quarter 2 (April-June), quarter 3 (July-September) and quarter 4 (October-December). Layang, selar, teri, kembung, tuna, cakalang and tongkol fish are the major pelagic fish species landed at the port and for each of these fish types the total catch is greater than 12,000 tons per year. In almost every year the third quarter coincided with the highest volume of pelagic fish catch. This quarter also shows maximum upwelling in the region, as evidenced by the results in Figure 6. It is clear that there is appears to be a consistent relationship between the presence and duration of upwelling, as indicated on the remotely sensed maps of SST, with higher catches of economically important fish catches during the detected upwelling periods.

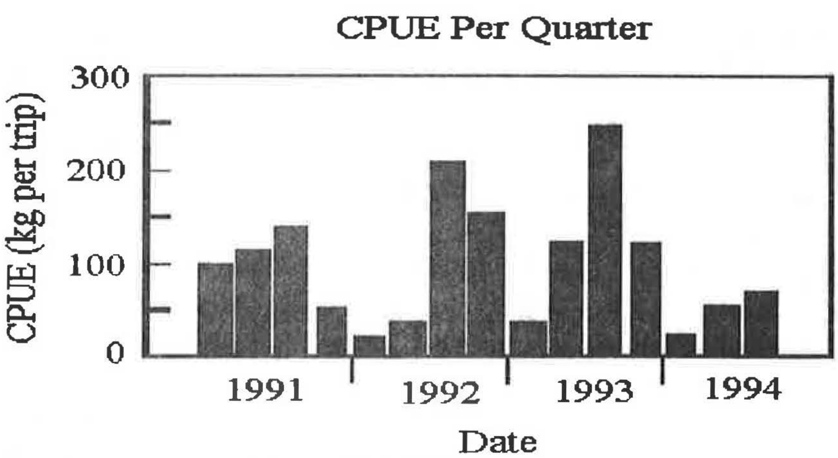

Figure 7. Fish CPUE (Catch per Unit Effort) data from Banyuwangi Port.

CONCLUSION

NOAA AVHRR data has been shown to provide a unique ability to regularly and accurately monitor the sea surface temperature structure for the whole of Indonesia. Time series of such data indicate phenomena that agree with independently collected cruise data on SST patterns and phytoplankton distribution. Such long-term datasets allow seasonal changes to be investigated and the locations and magnitudes of upwelling regions to be estimated and compared to fish-catch statistics.

The upwelling phenomena observed during the south east monsoon (May-September) in the Indian ocean waters south of east Java and Bali exhibit temperatures around 2 °C lower than those during the north west monsoon season. In addition, waters sampled during the south east monsoon period show higher concentrations of phytoplankton during this time. The presence of lower SSTs and higher levels of chlorophyll coincides with the most productive period in terms of economically important fish catch.

As well as having potential applications in the management of Indonesian fisheries, regular SST imagery of the region offers evidence to assist In the understanding of major oceanographic events such as ENSO and the throughflow of water from the Pacific Ocean to the Indian Ocean.

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OBSERVATIONS OF SEASONAL SEDIMENT INPUTS AT THE COASTAL ZONE FROM NOAA DATA

By

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ABSTRACT

Sediment discharged into the coastal zone is known to adversely affect the marine environment. For Indonesia, economic implications have included a marked decline in the productivity of shrimp aquaculture in recent years. Monitoring water quality is important to efforts at reducing sedimentation and in planning. The capability of low spatial resolution (1 km^2) NOAA AVHRR data to detect and monitor the seasonal distribution of water-borne sediment was demonstrated for parts of the northern coastal zone of the Island of Java, Indonesia. Simple qualitative methods of atmospheric correction and image enhancement (radiance subtraction and density-slicing) were applied to highlight areas of sediment reflectance. Suspected sediment plumes were detected along the coast line of northern Java and partially validated using high resolution data of the same geographical area. The results agree with the hypothesis that high sediment intrusions occur from the rivers during the wet season, with lower intrusion during the dry season. Further work is needed to investigate the possibility of obtaining from AVHRR data quantitative information on sediment concentration.

INTRODUCTION

Being an archipelago, Indonesia has a long coastline of approximately 81 000 km. This habitat is important for many reasons but in recent times the coastal zone has become the site of a large and economically successful shrimp culture industry. A decade ago Indonesia was one of the worlds largest shrimp producers and more than 75 % of production came from shrimp aquaculture in the coastal zone. More recently however the production of shrimp has been in decline, a situation directly related to the intensive nature of land utilisation in certain areas of Indonesia. Such pressure often leads to increased watershed degradation due to over exploitation of highland vegetation with consequently increased soil erosion. This erosion makes rivers turbid in the rainy season and can seriously influence the water quality in the coastal zone. Suspended particulate matter often causes silting up of shrimp ponds and, with concentrations greater than 100 mg/l, can destroy shrimp eggs and cause shrimp mortality, by obstructing their gill systems. (Bose et al, 1991). Sedimentation can also reduce primary productivity by reducing water transparency. These factors, along with the intensification of the culture system and poor environmental management have greatly reduced shrimp production during the last fifteen years (Populus 1995). This situation means that the monitoring and control of sediment inputs into the coastal zone is now important to protect these economically important organisms from disease and to maintain shrimp culture productivity.

The potential of remote sensing for water quality monitoring/sediment detection, and as a possible information source for aquaculture systems, has been reported by several authors. Cheney and Rabanal (1984) report work carried out on the remote estimation of actual suspended sediment concentrations, though they warn of an overlap with information of chlorophyll content. Ritchie and Cooper (1988) report the success of quantitative remote monitoring of sediment concentrations in a small inland water body using 80 m resolution Landsat MSS data. These and other studies describe how radiation in the visible part of the spectrum penetrates the sea surface and is absorbed and scattered within the water medium. The presence of suspended particles can cause significant "backscatter" towards the remote sensing instrument, thus giving the water a cloudy appearance. In this way the Landsat MSS, Landsat TM, SPOT HRV and CZCS sensors have all allowed false colour composite images to be prepared which clearly highlight sediment concentration and plumes on optical imagery. Additional density-slice enhancements from single band imagery has been used to map qualitative sediment concentrations, although reliable calibration requires the collection of in situ water samples at the time of the satellite overpass (Meaden, 1991).

High resolution satellites such as SPOT and LANDSAT offer excellent spatial resolution (10 to 30 m) but the cost of the basic data is generally thousands of dollars per scene, far too high for use in routine monitoring. Additionally, the revisit period of such instruments is tens of days, meaning short duration events are often missed and, especially in Indonesia's tropical conditions, subject to great difficulties with cloud obscuration. The Coastal Zone Color Scanner (CZCS) instrument overcame many of these limitations, providing cheap, moderate resolution data optimised for monitoring sediment and chlorophyll concentrations in the coastal zone. The instrument had a good frequency of coverage and the data have been used in many retrospective studies of the coastal environment. Unfortunately the instrument failed in 1986 and scientists and managers await the next generation instrument with interest. Meanwhile, to fulfill the current need, locally received AVHRR data seem to offer the only viable alternative for low cost repetitive coverage. These data are freely available on a daily basis and can be locally received from the polar orbiting NOAA satellites. The daily mid-afternoon NOAA 14 overpass occurs at a suitable time for measuring the amount of visible radiation scattered by particles within the upper water column. The data thus have potential for obtaining information on sediment plumes and their distribution. The short revisit period and wide area coverage make it a potentially useful tool for low resolution routine monitoring of sediment inputs to all Indonesia's waters. This paper attempts to demonstrate the capability of AVHRR data in the spatio-temporal mapping of coastal suspended sediment, specifically seasonal monitoring. The paper will describe the preliminary results of two sediment detection studies based on areas in the northern Coast of Java (Cirebon-Tegal and Jepara coast area).

METHODOLOGY

The BPPT NOAA receiving station was used to collect a relatively cloud-free time-series of AVHRR data covering the Island of Java between June and October 1995. Two study areas were selected for their known susceptibility to sedimentation. Figure 1 shows the location of these two areas, (1) Cirebon-Tegal and (2) the Jepara coastal region.

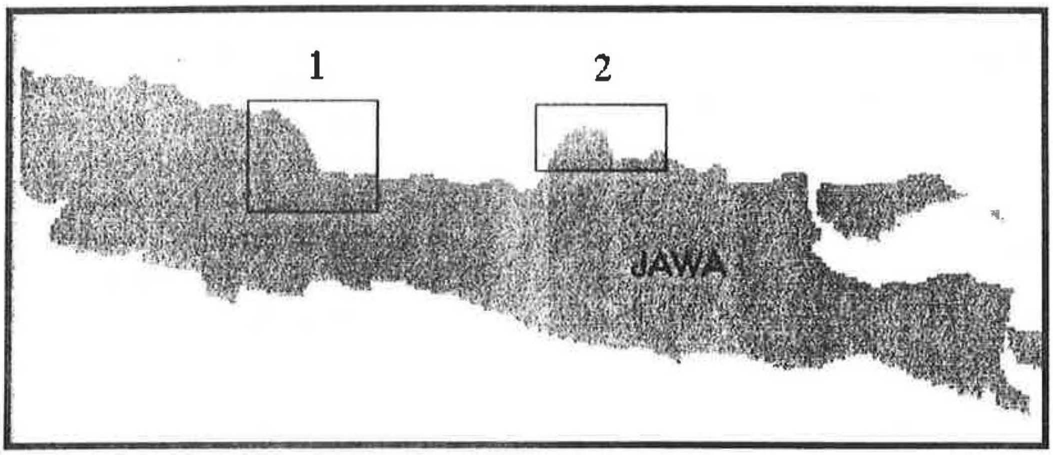

Figure 1: Study area of Northern Coast of Java (Cirebon-Tegal and Jepara coast area)

Each received data set was pre-processed into geo-coded images corresponding to the amount of reflected light received by the visible and near infra-red channels of the sensor (channel 1 and 2 respectively). Because water absorbs almost all the incident near infra-red radiation, the visible channel (channel 2) alone was used for sediment detection. A simple atmospheric correction was applied to the channel 1 data of each area by first calculating the mean channel 1 radiance received from pixels covering deep offshore water. Such 'clear water' sites would be expected to show minimal reflection as the water contains negligible backscattering particles. Thus the radiance measured at these sites will be due, in the main, to atmospheric scatterers and not to water-borne constituents. We then subtracted this value of 'clear-water radiance' from all the channel 1 radiance's received by the sensor, thus making an approximate correction for the effects of the atmosphere and highlighting the areas of high water reflectance (i.e. those containing large concentrations of water-borne scatterers such as suspended sediment particles). The greater the value of the water reflectance, the greater the suspected sediment concentration within that pixel. Theoretically the actual correlation between the atmospherically corrected channel 1 reflectance and the sediment concentration is given by :

Channel 1 Reflectance = m * ln (sediment concentration) + c (1)

where m and c are constants determined by comparison with in situ datasets.

To validate this relationship fully, a more comprehensive atmospheric correction methodology would need to be developed, along with a detailed cross comparison study of satellite and in situ data. For now our work concentrates on qualitative comparisons between seasonal datasets.

RESULTS

Figure 2 shows the seasonal variation in sediment distribution for the Jepara coastal area as interpreted from NOAA imagery. Generally, the water reflectance appeared low in June during the dry season (Figure 2a) suggesting low suspended sediment levels, except for a small zone with apparently high water reflectances close to the north east coast. Apparent concentrations were higher in October during the wet season (Figure 2c) with a broad dispersal plume covering a much wider area. The situation in the July image (Figure 2b) appears to lie somewhere between these two extremes. This seasonal data set also appears to show eastwards dispersal of the sediment in October, this being consistent with the eastward current and wind direction reported to exist during this period by Wirtky (1961). Figure 3 shows similar variations in the Cirebon-Tengal coastal area. Figure 4 shows the drainage patterns for the study areas in question. In the Jepara region (Figure 4a) it can be seen that many rivers from the radial drainage pattern of the Muria mountain discharge near the apparent source of the observed sediment plume. It is thus likely that these rivers are transporting soil from the highland region into the coastal zone around Jepara.

However, interrogation of coastal charts of the region indicated that the water depth was rather low, some 3 to 12 m up to 10 km offshore. There were concerns that what was being interpreted as sediment may have been, in fact, the sea bed. Though other studies have used AVHRR data to monitor sediment loads in such shallow waters a final confirmation was needed to ensure that the observed high water reflectance's were due to suspended sediment particles and not solely to sea-bottom reflectance. High resolution (50 m) visible channel data obtained from the MESSR sensor onboard the Japanese MOS satellite was acquired for the area. This data set confirmed the presence of rivers transporting sediment into the coastal region (Figure 5a) and clearly showed coastal eddies containing water-borne suspended sediment (Figures 5b and 5c). It thus confirmed that at least some of the radiance received by the AVHRR was due to suspended sediment particles, the concentration of these appearing to change with the season.

A similar seasonal pattern was found at Cirebon-Tegal coastal area (see Figure 1 for location). Here an apparent dispersal plume is observed in June 1995 (Figure 3). The shape of the coast line of this study area suggests that sediment will be transported eastwards by the river flow (Figure 4b), and will be trapped in the eastern side even if the surface current changes to westward in June.

DISCUSSION

The changes in seasonal sediment concentration detected by processed NOAA AVHRR data appear to match those associated with the onset of the wet season in Java. Furthermore the AVHRR data appear to be able to provide spatial detail on sediment loading, for example information on how far offshore sediment is being transported near the water surface. Comparisons with high resolution data indicate the satellite is observing 'real' sediment plumes and not just bottom reflectance. Additional work is needed to further validate these hypotheses and to attempt to calibrate the satellite imagery with in situ measurements.

As a final example of the utility of the AVHRR product, a simple density slice (i.e. where ranges of channel 1 pixel values are differently coloured) of the October 1995 Jepara image is shown as Figure 6. If in situ datasets were available such an image could be related to actual suspended sediment concentrations in the offshore waters. Seasonally produced data products such as these could be used to indicate suitable new sites for shrimp-aquaculture by identifying areas not prone to excessive sedimentation. Furthermore sites already used for this purpose could be monitored and remedial action taken if sediment concentrations appeared to be reaching critical levels.

CONCLUSION

Using freely acquired NOAA AVHRR imagery, it appears possible to monitor seasonal patterns of sediment dispersal along the North Java coastline. AVHRR-derived sediment dispersal patterns for two study areas were consistent with those derived from high resolution satellite imagery for the same areas. This suggests that the AVHRR data were detecting variations in suspended sediment, and not just the sea bottom. The basic methodology could be improved to derive more quantitative assessments. This work would involve calibrating the corrected AVHRR channel 1 reflectances against in-situ measurement of sediment concentrations at the time of AVHRR collection. The techniques have great potential for low cost, operational monitoring of water quality Indonesia-wide in support of sediment reduction measures and aquaculture planning

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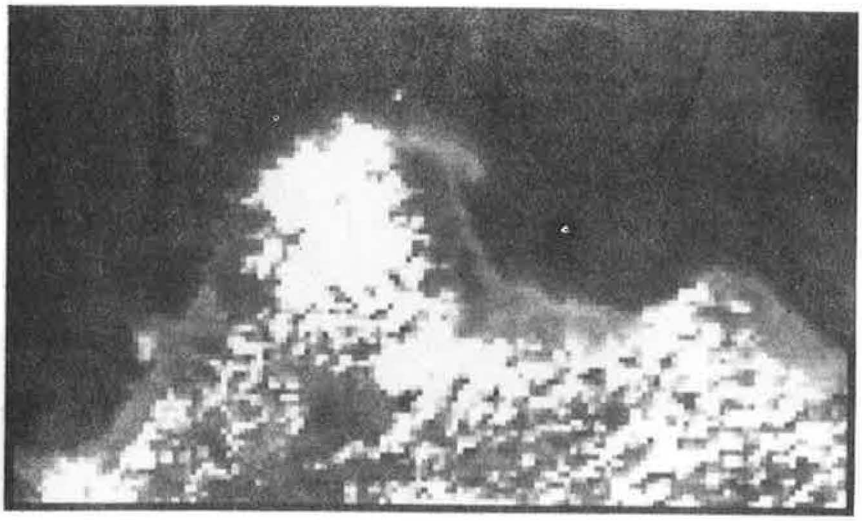
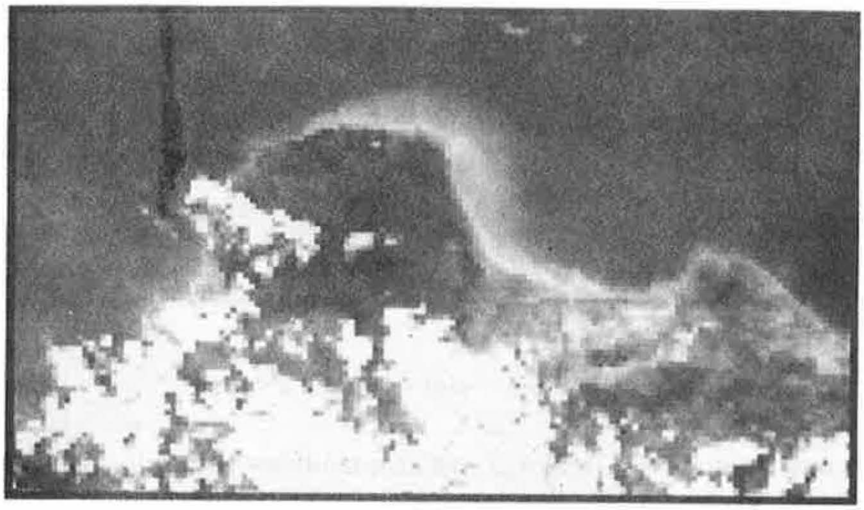
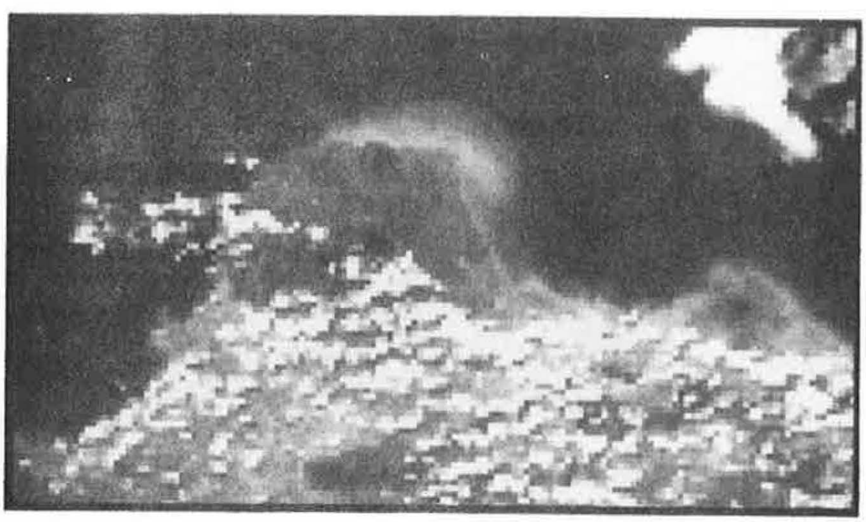


(a) June 1995

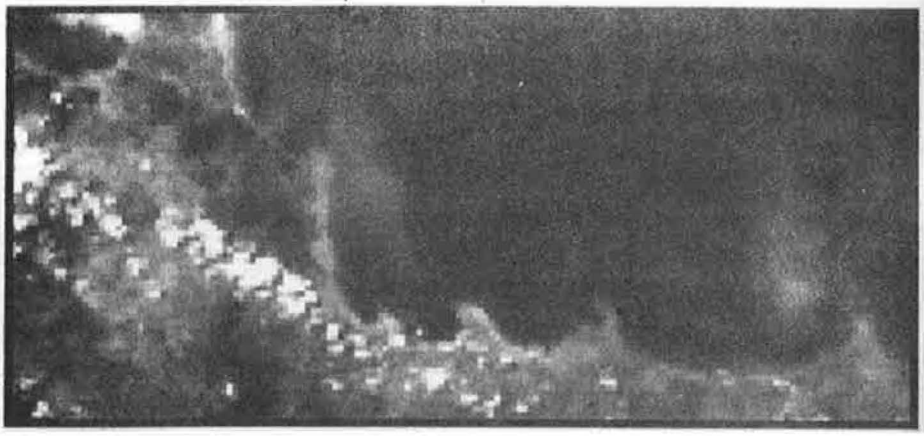


(b) July 1995

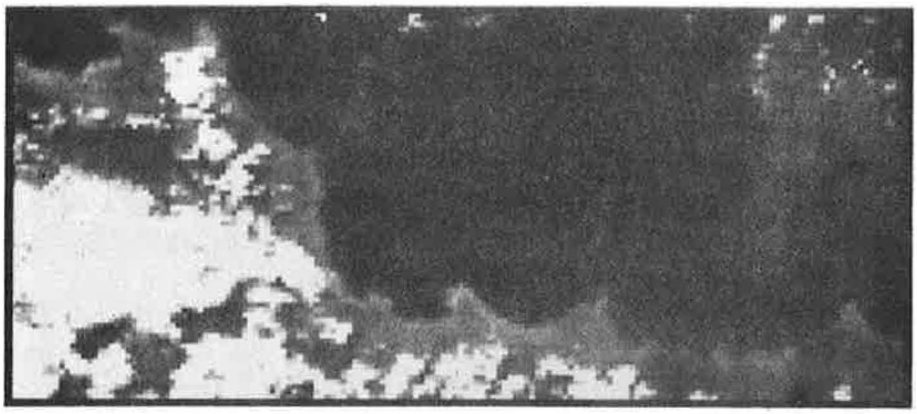


(c) October 1995

Figure 2: AVHRR-observed seasonal sediment plumes, Jepara coastal region.



(a) June 1995



(b) July 1995

Figure 3: AVHRR -observed sediment patterns, Cirebon-Tegal coastal area.

(a) Jepara coastal region

(b) Cirebon-Tegal coastal region

Figure 4: Maps of the river systems within the study regions

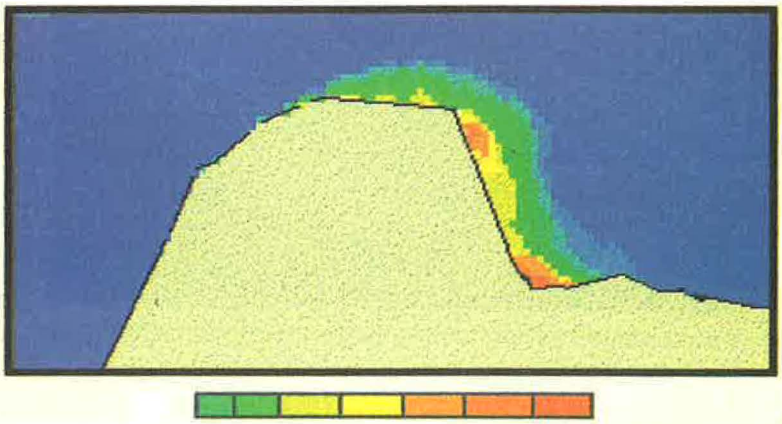
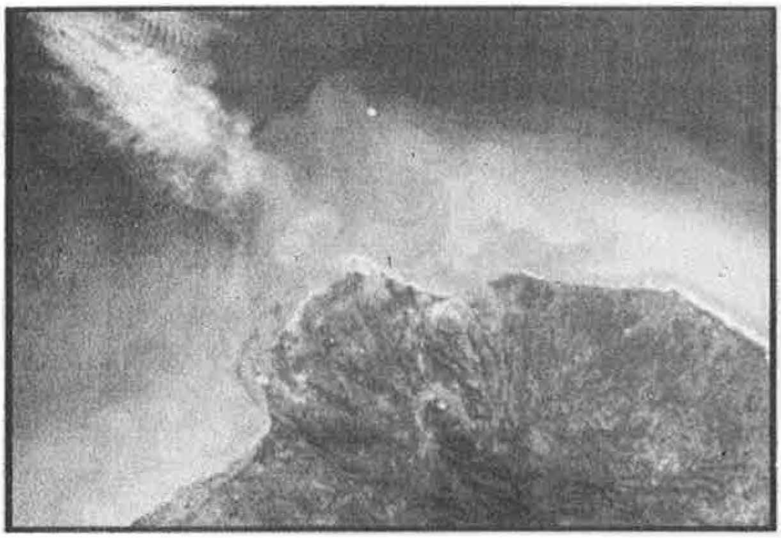
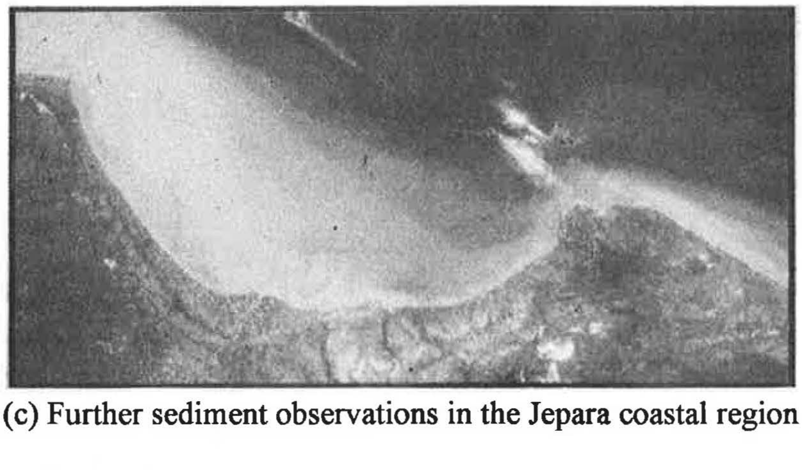


Figure 6: Density-sliced AVHRR channel 1 image of the sediment plume at Jepara area in October 1995.

(a) River inputs into the coastal region.



(b) Near-shore eddies containing suspended sediment particles.



(c) Further sediment observations in the Jepara coastal region

Figure 5: High spatial resolution (MOS) imagery of the Jepara coastal region.

LOCAL SATELLITE DATA ACQUISITION AND VIDEO PRESENTATION FOR OPERATIONAL WEATHER FORECASTS

By

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ABSTRACT

The BMG Operational Meteorology Group of the Indonesia-UK Environmental Monitoring Project started to receive NOAA AVHRR data in June 1995 following the installation of a PC based receiving station at BMG in June 1995. Sixteen meteorologists and engineering staff were trained to use the operational software provided for image collection and analysis. The large area synoptic AVHRR coverage allowed detailed temperature structures of clouds and oceans to be observed. BMG have a role to monitor and exchange data on fires with other ASEAN countries. In October 1995, the contextual fire detection software (Trigg et.al, this issue) was installed at BMG and staff were trained to map vegetation fires using the NOAA AVHRR data source. Fires were detected in both Sumatra and Kalimantan.

Routine NOAA image capture at BMG is ongoing and the application group have explored the possibility of integrating other meteorological satellite data sets such as GMS and Tiros Operational Vertical Sounder (TOVS) data, also transmitted by NOAA. BPPT's Weather Modification Technical Unit has recently linked up with the BMG application group to further develop the synergy between BMG's operational role and application driven research.

The next step will be the installation of a system for producing weather forecast presentations. The equipment will allow meteorologists to combine GMS, and NOAA cloud images with supplementary meteorological graphics into an attractive audio-visual presentation recorded on video media.

DEVELOPING A METHODOLOGY FOR EXTRACTING LAND USE AND CROP INFORMATION FROM NOAA AVHRR DATA

By

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ABSTRACT

When using NOAA AVHRR data to monitor the seasonal performance of vegetation, it is essential to ensure that the information extracted is representative of the cover type being considered. AVHRR data have a coarse spatial resolution compared to the intricate mixed cropping patterns occurring throughout much of Indonesia. Unless a sensible sampling strategy is adopted to locate homogeneous land units at the AVHRR scale, the AVHRR measurements will tend to average the properties of mixtures of cover types, yielding less than optimal useful information.

This study shows how the Land Use and Crop Yield Group investigated and initialised appropriate sampling strategies during the project. High resolution satellite imagery combined with field validation was used to provide detailed information on land cover units within a Central Javan study site. The field checked imagery provided an excellent means of stratifying the land cover into relatively homogeneous units. Such stratification allowed multi-temporal NDVI indicators to be extracted from within 'pure' land cover units at the AVHRR resolution. This gave confidence that variations in the AVHRR indicators were due to seasonal changes occurring within single land cover types. This paper discusses how practical sampling strategies can be adopted to maximise the usefulness and reliability of information extracted from NOAA data. Mubekti et all (this issue) develops this discussion by showing how the growth stages of rice were accurately followed using NDVI profiles that were carefully located within relatively uniform rice production areas.

INTRODUCTION

NOAA AVHRR data are transmitted at a 1km spatial resolution. In this paper we give a case study demonstrating a prototype sampling strategy that was established to optimise the reliabiliy and interpretability of information extracted from this relatively coarse data.

For an area as large as Indonesia, routine monitoring is difficult. The NOAA AVHRR data is unique in providing directly accessed large area coverage each day, and represents a potential solution. However, the frequent coverage is achieved at the expense of the AVHRRR's spatial resolution. Care is needed to ensure that relevant measurements are extracted.

One possible way of quantifying the NOAA AVHRR data is to perform field validation visits. Such visits can observe vegetation *in situ* and provide accurate information on crop state and type at specific locations. However, field observations alone are difficult to directly relate to AVHRR products due to the vastly different scales of observation.

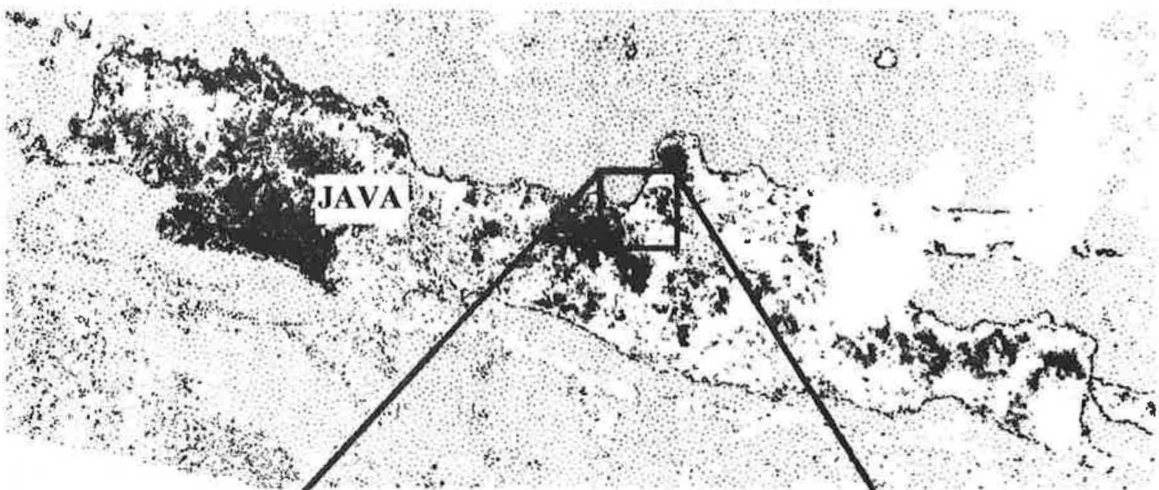
High resolution surveys from aerial photography, optical and non-optical satellites provide greater detail at an intermediate scale between AVHRR and ground observation. Where available, they therefore offer a useful means of extrapolating field-mapped vegetation units up to the AVHRR scale. Landsat TM imagery has a ground resolution (or pixel size) of 30 m whilst multi-spectral SPOT imagery has a 20m pixel size. This detailed coverage can be used in conjunction with field survey to stratify areas into homogeneous units at the scale of AVHRR observation.

This paper gives the progress made by the project in demonstrating field and high resolution techniques for stratifying land cover into relatively homogeneous units suitable for routine monitoring at the AVHRR scale.

COMPARISON OF AVHRR AND HIGH RESOLUTION IMAGERY OF THE SEMARANG AREA

Figure 1 shows an NDVI product (see Trigg et al, box 2, this issue) of Java. It was created from a single image recorded on the 14th July 1995 by BPPT's AVHRR receiving station. The advantages of using AVHRR for routine monitoring are clearly evident from the instantaneous view obtained of the whole of Java. The image is displayed at such a scale so that the image has a smooth texture, and individual pixels can not be seen.

Figure 1: NOAA AVHRR NDVI product of Java acquired on 14th July 1995.
Area shown in Figure 2 is boxed.



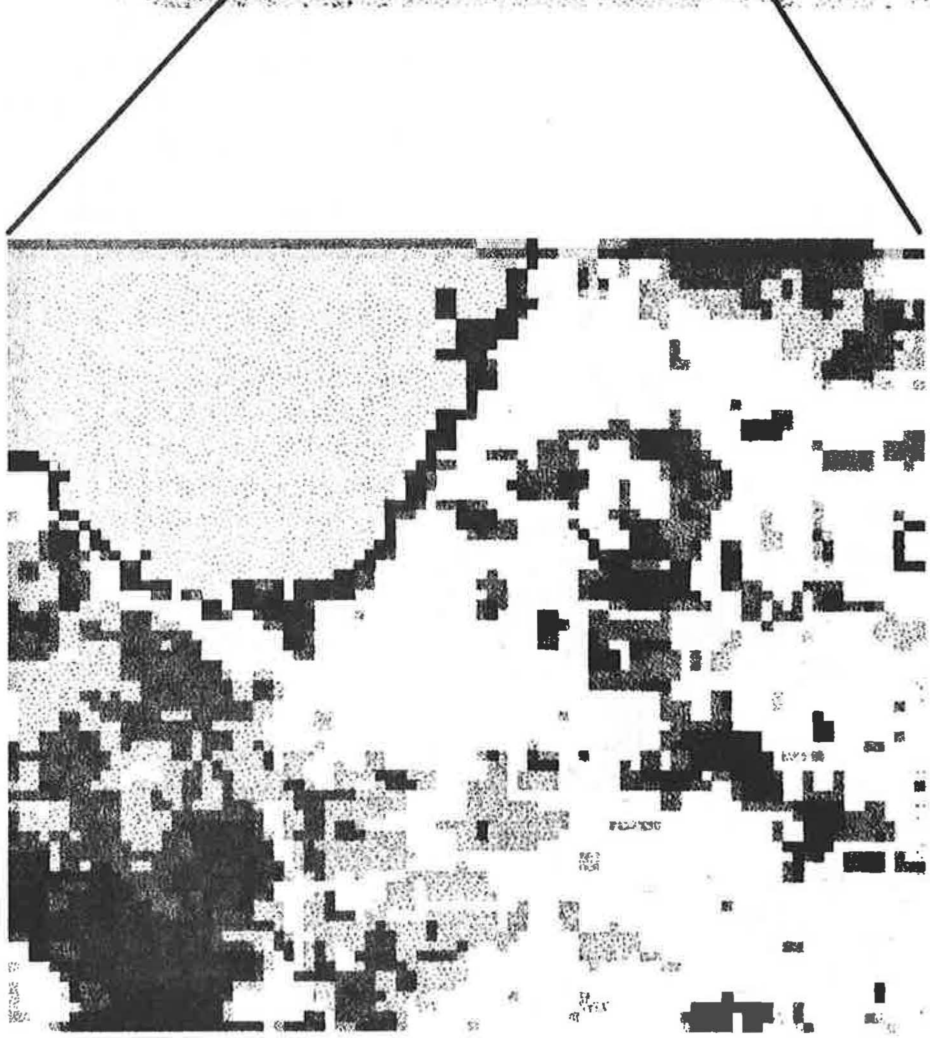


Figure 2: Enlarged area boxed in Figure 1showing detail of the Semarang study area

Figure 2 shows an enlargement of the NDVI product for an area around Semarang. Now, the image has a much grainier appearance, and individual 1.1 km x 1.1 km pixels are clearly visible. As mixed cropping is practiced within the area, many of the AVHRR pixels will comprise complex mixtures of different cover types which can not be resolved by the sensor.

Initial ground surveys conducted in July 1995 in the Semarang area at around the time of the NDVI product date tried to relate NDVI to vegetation characteristics observed in the field. The field team used a Global Positioning system (GPS) to determine their location within the study area. The NDVI image product (Figure 2) was taken to into the field using a laptop computer. Using a simple image processing system, the field team interrogated NDVI values at any GPS-determined location to assess the general correspondence between NDVI and vegetation greenness. The NDVI product (Figure 2) shows a large area with low NDVI around Semarang. The field visits found that this was a large area of harvested rice, explaining the low NDVI as a bare soil and rice stubble surface. The surrounding area had higher NDVI because it comprised still green plantation and garden crops. Difficulties were however encountered when trying to make more detailed comparisons. Except in the large, relatively homogeneous forested areas, it was difficult to determine whether the land cover observed in the immediate vicinity of the field team was extensive enough to be homogeneous at the AVHRR resolution. Also, due to the coarseness of the NDVI product, it was difficult to be sure that NDVI values were extracted for the correct pixel. More detailed information was needed to stratify the area into relatively homogeneous units from within which AVHRR measurements could be confidently made.

DEVELOPING AN APPROPRIATE SAMPLING STRATEGY

The demonstration initialised a sampling strategy using the best available information for stratifying the study area into broad land cover units. The scope was limited within this one year project to exploring and demonstrating initial methodologies rather than to fully implement all of the techniques. The approach used selective field-validation of Landsat TM and SPOT images obtained of the study area as the basis for performing the stratification.

Landsat TM and SPOT false colour composite ('FCC' - enhanced imagery suitable for land cover interpretation) imagery of the area were geometrically corrected to a standard UTM map projection. Figure 3 shows a Landsat TM FCC of the entire study area. Note the improved detail compared with the NDVI product (Figure 2) which allows variation within the AVHRR pixel to be investigated.

From the SPOT imagery, A4 sized imagettes of particular sub areas within the Semarang study area were printed in colour at 1:25000 (Figure 4) and 1:10000 (Figure 5) scale with the UTM grid overlain. The 1:10000 scale imagette was visually interpreted in BPPT's remote sensing lab to separate out the main land cover units. Topographic maps of the

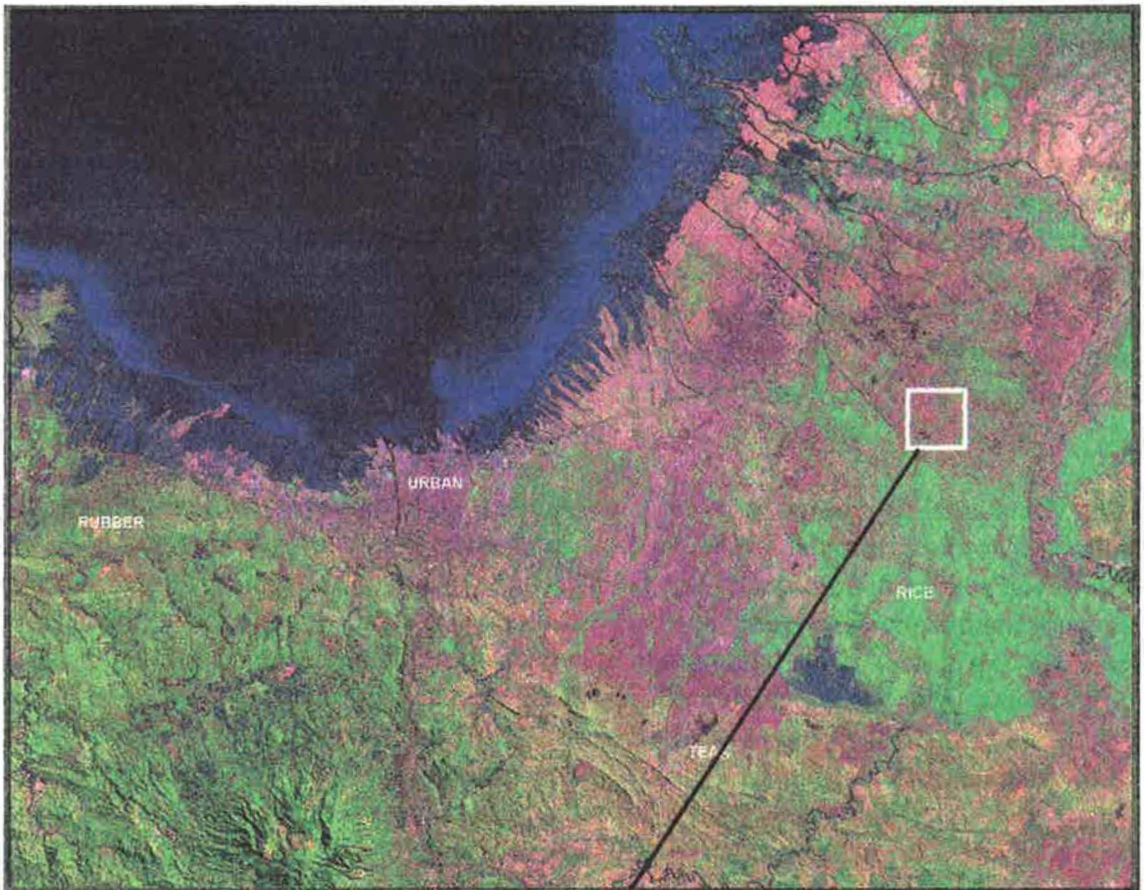


Figure 3: Landsat False Colour Composite for the same area as in Figure 2

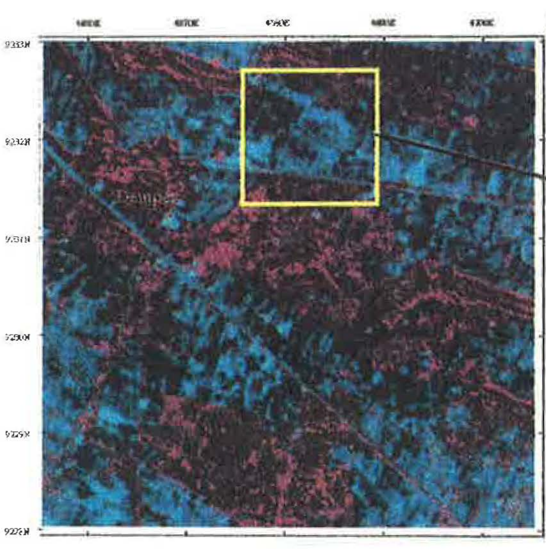


Figure 4: SPOT imagette(1:25000 scale)

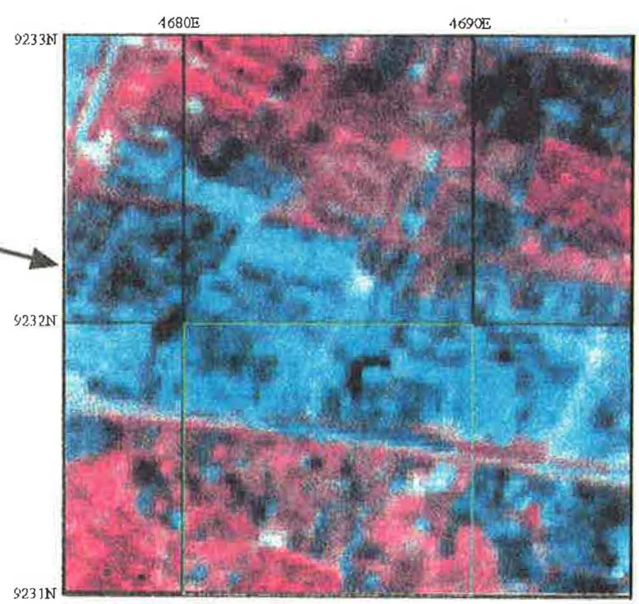


Figure 5: SPOT imagette (1:10000 scale)

area at the two imagette scales were photocopied onto transparency film and accurately overlain on the imagettes. The 1:25000 scale imagette plus topographic detail (showing roads and towns) allow straightforward navigation to the more detailed imagette area. Once the team was within the 1:10000 scale imagette area, a Global Positioning System was used to locate the teams exact position. Each of the land units that had been interpreted on the 1:10000 scale imagette was then visited to establish the cover type that each represented. An excellent correspondence was found between the land units that had been interpreted in the lab, and those observed in the field. The field visit simply allowed the actual cover type represented by each unit to be confidently determined. Conceptually, the approach was like 'colouring by numbers', with the visual interpretation as the initial line drawing of different polygons, and the field visit deciding what colour (land cover type) was assigned to each polygon. Using this technique, the entire imagette area was rapidly mapped into broad land cover units.

With more time, this approach could be used as a basis for stratifying large study areas into relatively homogeneous land cover units. As an initial demonstration of a possible sampling and mapping strategy, a non-alligned random sample of imagettes covering 1 percent of the Semarang study area was produced. In practice, each constituent imagette of the 1 percent sample would be divided into major land units (using the approach described above) according to a standardised classification scheme. This would allow broad, relatively homogeneous land units, such as rice, upland cultivation, and urban areas to be defined on the 1 percent imagette sample. The interpreted imagettes would then be used to train a supervised classification of a high resolution image broad-scale land cover units, each sufficiently large for AVHRR-based monitoring..

As a further demonstration, NDVI profiles (see Trigg et.al, this issue) were extracted from relatively homogeneous teak forest, rubber plantation and urban areas identified by visual interpretation of the high resolution imagery. Figure 6 shows the profiles.

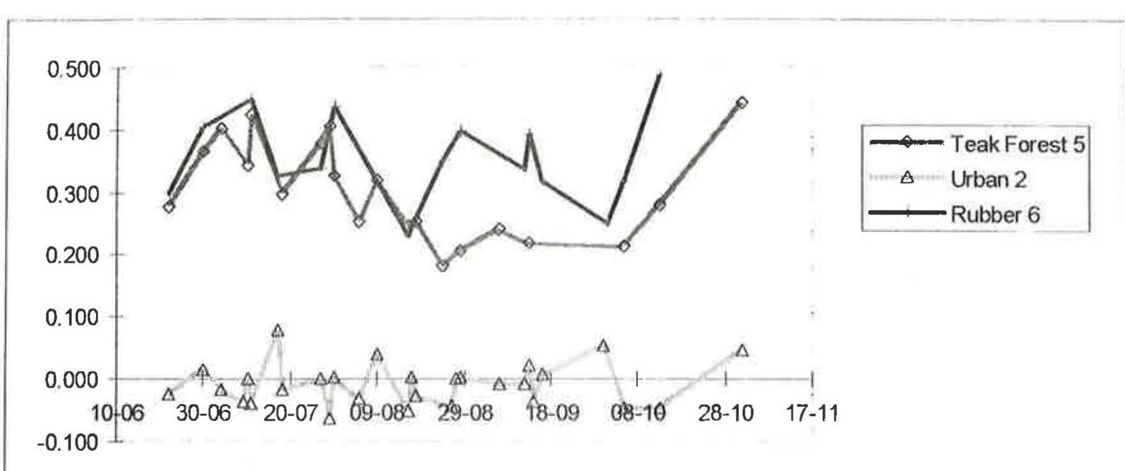


Figure 6: NDVI profiles extracted for relatively homogeneous land units identified on the high resolution imagery.

The axes are scaled as date (x-axis) against NDVI (y axis). The profile for the urban location is relatively stable, showing low NDVI values throughout the year. This reflects the small proportion of green vegetation present. The profiles for teak and rubber show consistently higher NDVI values throughout the period of observation, suggesting more abundant green vegetation. Both of these profiles show a slight decline from June to September followed by sudden increases in October, possibly related to an increase in the numbers of green leaves towards the end of the period. Mubekti et. al, (this issue) show similarly derived NDVI profiles for different rice growing areas in Java. The profiles were extracted from known rice growing areas which were identified using both high resolution satellite and topographic map data. This study was very encouraging, with the profiles detecting the different rice growth stages, and aspects of the crops performance through time. It is highly likely that the good results are a direct consequence of the careful selection of homogeneous rice growing sites from which to extract the profiles.

THE POTENTIAL FOR MONITORING ANNUAL TRENDS

Once the area is stratified into broad land cover units, NOAA Global Area Coverage (GAC - see Malingreau et.al, 1992) data can be used to derive seasonal NDVI norms for each unit, allowing a crops contemporary development to be compared to its normal performance. GAC data are freely available for the last 10 year period. It is produced onboard the NOAA satellite by sampling the 1km AVHRR data to 4 km resolution by averaging along-scan groups of four samples out of five and skipping every third scan.

Seasonal NDVI norms derived from the GAC data for each cover type could be used to assess NDVI products of the current season. This could, for example, allow the performance of the current years crop to be assessed to see if it is better or worse than normal. Although not implemented during this demonstration phase, the technique has great potential for providing qualitative information on relative yields expected.

DISCUSSION AND CONCLUSION

Although remote sensing developments generally strive to improve image resolution, large area, real time repetitive coverage is still only possible using coarse resolution AVHRR data. However, the complex cropping patterns present throughout Indonesia require that care is taken when extracting AVHRR indicators. This care is needed to ensure that AVHRR measurements are taken within, and are therefore representative of, broadly defined land cover units. In this study, high resolution Landsat and TM satellite data was found to provide a good basis for stratifying land cover in to broad units for subsequent routine AVHRR-based monitoring. Other studies (Mubekti et. al, this issue) have shown that good quality map information, as was available for Java, can also be successfully used to perform the stratification.

The study has demonstrated appropriate strategies for maximising the quality and reliability of AVHRR indicators when extracted from within homogeneous units at the AVHRR scale. The approach is highly synergistic, combining the known relative strengths of field, map, and low and high resolution satellite data to optimise the quality of information obtained from NOAA time series. The next paper (Mubekti et.al 1996) shows how NDVI profiles, extracted using similar techniques to those described above, have great potential for giving qualitative, pre-harvest rice production forecasts.

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THE ROLE OF NOAA AVHRR FOR ACQUIRING INFORMATION ON RICE PRODUCTION IN INDONESIA

By

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ABSTRACT

The Land Use and Crop Yield working group of the Indonesian-UK Environment Monitoring Project (see Downey, this issue) has evaluated preliminary techniques for providing an early, qualitative assessment of the Indonesian rice harvest. The techniques use freely available NOAA data combined with more detailed high resolution satellite, map and field data. This paper details the basic theory and the project's progress towards extracting useful information on rice development from NOAA AVHRR data (collected at BPPT) for qualitative and timely pre-harvest assessments. A description of the typical rice development cycle is given, followed by the principles of using NOAA for monitoring rice development. Details are given on how NOAA can be used to monitor crop greenness, and its approximate temperature, at regular intervals throughout the growing season. The implications for crop yield forecasting are briefly described. Two case studies are then presented. The first, for the Krangkeng area of Java, compares NOAA Vegetation Index and land surface temperature indicators with field information to check the idealised model. The second looks at five additional rice production areas in Java to assess differences in crop calendars and vegetation greenness between sites. Where possible, field data is used to verify NOAA interpretation. Initial results are encouraging, with a good correspondence between NOAA and field observations. This correspondence suggests that free NOAA data, integrated with more detailed field and satellite studies, could provide the basis for a national (pre-harvest) production forecasting system.

INTRODUCTION

Previously an importer of rice, the Republic of Indonesia declared self sufficiency in its production in 1984. Even so, in the last two years, imports have been necessary in order to meet the demands of domestic consumption. The agricultural sector is given a high priority in Phase II of Indonesia's Long Term Development Plan, one objective of which is to maintain self-sufficiency despite population growth. The availability of information on rice growing conditions to producers, distributors and government is essential in the context of food security. At present, agricultural statistics are collected manually from the farm level and assimilated up to the national level. As a result, annual yield statistics become available long after the season has ended, and may contain errors due to the many iterations of combining the statistics.

Data transmitted by the AVHRR sensor onboard NOAA can be accessed freely throughout the season using a PC-based satellite receiver (Trigg *et al.*, this issue). The broad swath width and repetitive coverage of the AVHRR mean that all of Indonesia's rice growing areas can be observed many times (cloud permitting) during the rice growing cycle. This, combined with the capability of extracting rice development indicators from the data, means that there is great potential for deriving pre-harvest rice production assessments from AVHRR.

This paper shows how rice status indicators were extracted from AVHRR data collected by the project's receiver during the 1995 growing season. Idealised indicators are first given as a basis for interpreting AVHRR indicators derived for six different study areas within Java. It is found that there is a good agreement between the idealised and real NOAA indicators for the six sites. Areas of rice cultivation were located in the NOAA data set, and qualitative seasonal measurements extracted, which show differences between locations. This demonstration shows great potential for development into a national pre-harvest rice production forecasting system suited to support the national effort of self-sufficiency. A further paper (Rahmadi *et al.*, this issue) details implications for irrigation assessment.

PRINCIPLES OF USING NOAA FOR RICE MONITORING

Typical stages in rice cultivation (modified from Malingreau *et al.* 1986) are given as a basis for NOAA observation of rice (see Box 1):

BOX 1: The Stages of Rice Development

Fallow: at the end of the growing season, the soils are usually left bare and dry. A grass cover may appear if soil moisture is available.

Flooded: at the onset of the rains or with the arrival of irrigation water the fields are flooded for puddling. The water depth varies from 2 or 3 to 15 cm. The plants are sown in nurseries before transplantation. After 25 to 35 days - depending on labour availability - the plants are transplanted in clusters of 1 to 10 plants and planted in lines (10 to 20 clusters per m2).

Growing crop: the new high-yielding tropical rice varieties complete their life cycle within 110 to 120 days. Vegetative, reproductive and ripening phases can be recognised.

a) *The vegetative stage* (duration dependent on variety) is characterised by an increase in plant height, an increase in the number of tillers and a development of leaves.

b) *The reproductive phase* (25 - 35 days),when the plant is characterised by a decrease in the number of tillers, the development of a panicular leaf, and the formation of panicles.

c) *The ripening phase* (25-35 days). The number of leaves decreases, the remaining leaves changing colour in ascending order, and decreasing in moisture content. In some systems, irrigation is stopped during the latter part of this period, in others the field may remain flooded up to harvest.

Stubble: When a hand-held knife is used for harvest, a large amount of straw is left in the field. Plant remains are hauled away, burned or later incorporated into the soil.

RICE PRODUCTION

Agricultural production (P) is the result of crop performance over a given area:

$$P = Y \times A$$

Where Y = yield
A = acreage

Rice production monitoring systems therefore need to provide indicators of crop yield and the area planted.

The total area of rice grown annually in Java varies considerably. Major controls are water availability (either rainfed or irrigated), and the cropping pattern (*i.e.* one or two crops per year). During years of low rainfall, less water is available, and rainfed areas may not be planted. At these times, irrigation areas with low irrigation priority may not be irrigated at all, and so not yield a crop. If two rice crops instead of one are planted, this effectively doubles the area planted when calculating annual production. Calculations of annual production therefore cannot assume fixed areas of rice, and need to account for annual variability in total area planted and the number of rice crops yielded.

Rice yield within a given planted area is less variable than in the past, due to new, more resilient rice strains. However, during drought, areas may suffer from water deficiency, with a negative effect on survival and yield. The rice production forecasting system should therefore be able to identify water-stressed areas with probable low yield.

The temporal aspects of rice production deserve special attention because of their importance in monitoring. Ideally the temporal resolution of the monitoring system should be such that no significant changes occur between observations.

The scale of production is also significant to monitoring. At the catchment level, rice fields do not present continuity in space because of topographic variation or competing land uses. In many parts of Indonesia however, a hierarchical unit called the golongan can be recognised which consists of a large group of fields. This unit exhibits cohesiveness in the sense that it shows continuity in space and uniformity in time. AVHRR, with a spatial resolution of 1.1 km at nadir has been suggested as an appropriate production monitoring tool at this scale (Malingreau 1986).

USING NOAA AVHRR TO MONITOR THE RICE CROP

The basic theory of using NOAA AVHRR to provide indicators of rice production is now given. Figure 1 represents the AVHRR sensor onboard NOAA observing the rice crop throughout its growth cycle.

Soils, flooded fields, growing, ripening and harvested vegetation reflect different amounts of solar radiation back into space for measurement by NOAA. Chlorophyll strongly absorbs visible light whilst reflecting near infra-red radiation. The more net photosynthesis in a rice field, the less visible radiation and more near infra-red radiation is reflected back into space. This dynamic effect may be enhanced by the Normalised Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) indicators derived from NOAA data (See Trigg *et al.* this issue).

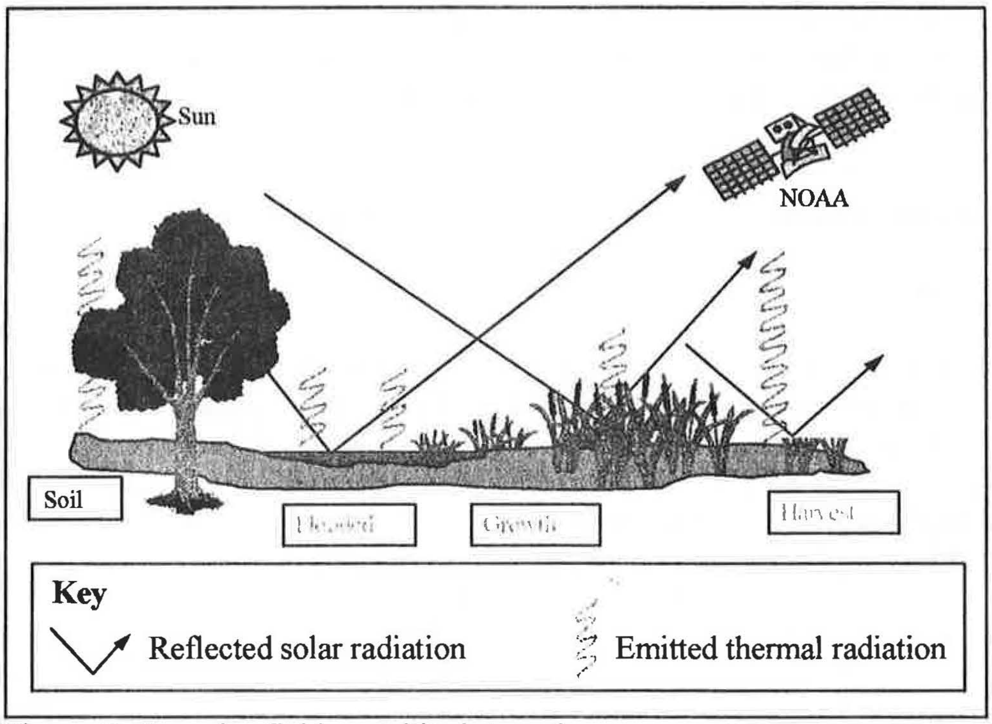


Figure 1: Sun- rice field - satellite interactions.

Variation of NDVI and LST during the rice-growing season is dependent on the dynamic evolution of both land cover type (mainly soil, water and vegetation) and the vegetation's net photosynthesis. Their temporal development in response to these changes can be derived (at the 1 km AVHRR grid size) from imagery acquired regularly throughout the rice-growing season. Figure 2 shows idealised temporal profiles of NDVI and LST for one AVHRR grid cell in a rice growing location monitored throughout an entire growing season. The figure is consistent with Malingreau's (1986) interpretation of similar rice vegetation greenness indicators extracted from Landsat MSS (Multi Spectral Scanner) data.

During the fallow period, bare soil is the dominant surface. Usually dry, it is hot (*high LST*) and shows little or no photosynthetic activity (*low NDVI*). Once the area is flooded and subsequently planted (several weeks later, to allow full saturation), then water (*negative NDVI*) is the dominant surface, with the young rice plants comprising only a small fraction of the irrigated area. The rice field will be relatively cool (*low LST*) at this stage due to the cooling effect of the water. Malingreau (1986) found that 4 to 5 weeks rice growth after transplanting was necessary before the vegetation could be detected using the MSS vegetation greenness indicators. It is therefore assumed that at least four to five weeks of vegetative growth will be necessary before the rice plants can be detected in the AVHRR's signal.

Net total photosynthesis increases with vegetation growth (*increasing NDVI*). As growth occurs, vegetation will begin to exert the major influence on the NDVI signal, so that NDVI becomes positive and continues to rise throughout the vegetative phase.

NDVI is expected to peak at the time of heading, soon after full cover has been reached. Surface temperature remains relatively low (*low LST*) during the vegetative stage due to the combined cooling effects of evaporation and transpiration.

During flowering and ripening, photosynthesis decreases (*decreasing NDVI*) as the vegetation gradually yellows and heats up (*increased LST*) and there is decreased evapotranspiration. After harvest, stubble will appear hot (*high LST*) and there is no photosynthesis (*low NDVI*)

The idealised NDVI and LST profiles in Figure 2 give a useful basis for interpreting the temporal development of single rice growing locations on the scale of the NOAA resolution cell. Once an idealised profile is established, it is possible to suggest how differences in the crop's vigour and crop growing calendar might be manifest as differences in NDVI and LST profiles for different sites. The following discussion is limited to NDVI for simplicity.

Integrated NDVI (INDVI - the area under a single NDVI curve) can be used to infer differences in production between different rice growing sites. Figure 3 shows idealised NDVI profiles for two different rice growing sites.

Although both profiles show the same temporal evolution (i.e. common times for main profile features), one curve shows consistently higher NDVI values than the other. This means that the area under the upper curve is greater than that under the lower curve and so it has a greater INDVI. As INDVI is related to production, the upper curve can be used to represent normal production whilst the lower curve indicates lower production.

A delay in planting between two sites should appear as a time lag in their respective NDVI profiles as shown in Figure 4.

In favourable areas, up to two rice crops and a further secondary crop may be grown in one year. Figure 5 gives the expected NDVI profile for an area which yields two rice crops followed by a further secondary crop in a single year.

The above discussion shows the basic theory for using NDVI and LST to monitor the stages in rice development. According to the theory, information on whether or not a rice crop is grown, the number of rice crops grown each year, and relative yields are obtainable from AVHRR data.

The next section gives real NDVI and LST observations for the 1995 growing season, where possible corroborating AVHRR observations with details of actual crop calendars obtained for the different locations. All NOAA data was collected by the project receiver at BPPT, and processed by the Land Use and Crop Yield group into the required images and profiles (Trigg *et al.*, 1996, this issue). The examples illustrate the progress made towards the objective of rice yield forecasting. The subsequent discussion gives details of further work needed to reach the overall objective.

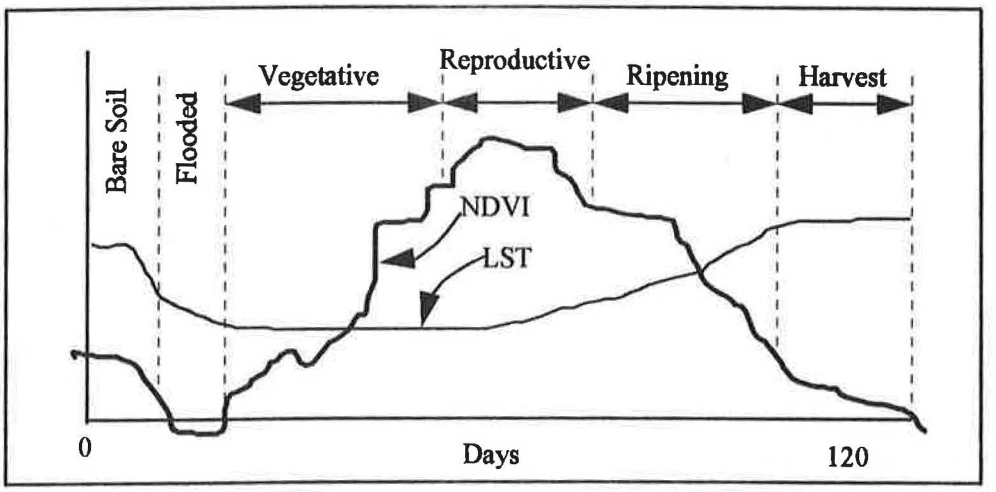


Figure 2: Idealised NDVI and LST temporal profiles for a single rice growing site

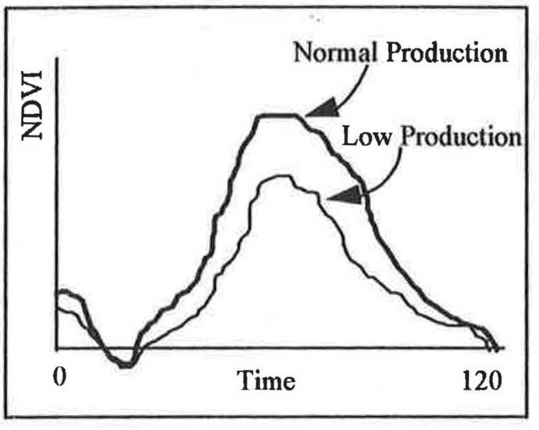


Figure 3: Idealised NDVI profiles for normal and low production rice sites

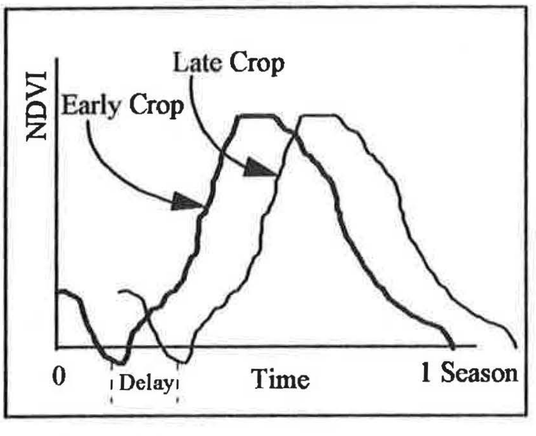


Figure 4: NDVI profiles expected for delayed planting between two sites

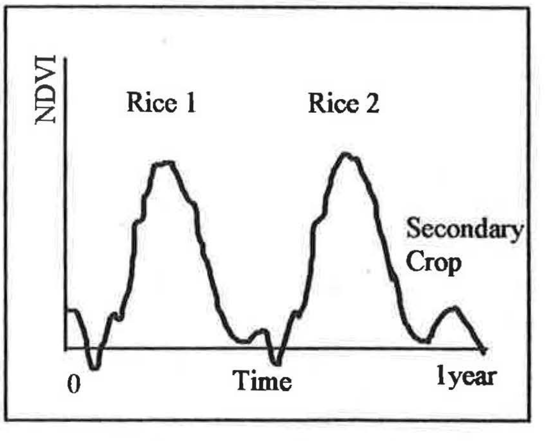


Figure 5: NDVI profile for one site with two rice crops followed by secondary crop

MONITORING JAVANESE RICE GROWING AREAS USING AVHRR

Time series of NOAA AVHRR data were processed at BPPT, as describe in Trigg *et al.*, this issue.

EXAMPLE 1: RICE MONITORING IN THE KRANGKENG AREA, EASTERN JAVA USING NDVI AND LST.

The Krangkeng study area is located approximately 80 km east of Jakarta and covers an area of approximately 30km^2. The predominant crop being irrigated is rice. A team from the Land Use and Crop Yield group visited local farmers and agricultural authorities within the area to obtain information on the 1995 crop and irrigation calendar.

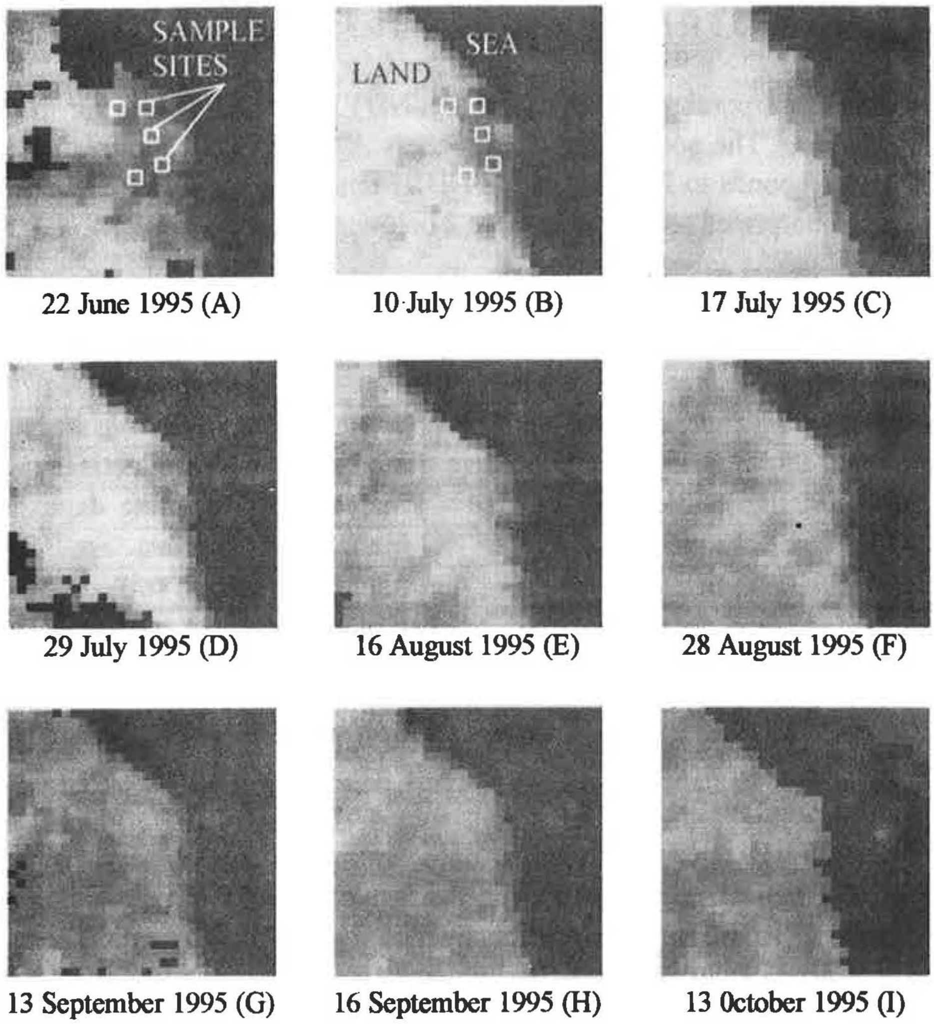
Irrigation water is, for the entire area, supplied by the Renthang dam to the west. Water supply is prioritised across the study area with distance from the dam so that its western part (closest to the dam) receives water preferentially to the eastern part (furthest from the dam). This means that the eastern rice fields only begin to receive irrigation water once the irrigation demands of the western area have been satisfied, typically one month after the west. The eastern area is not irrigated during occasional years of no western surplus, thus limiting the area that can be planted.

A SPOT satellite image of Krangkeng was first stratified into rice / non rice areas by visual interpretation. Five NOAA pixels were chosen within the eastern (low, late irrigation supply) area and their NDVI and LST profiles extracted from the time series. Median NDVI and LST values (from the five pixel locations) were plotted for the period June to October 1995. (The median value was used to reduce the effects of atmospheric noise). Nine 30 x 30 pixel NDVI imagettes of the study area, spaced in time to cover the rice growing cycle, were extracted from the time series to allow the eastern NDVI and LST profiles to be placed in the context of spatio-temporal NDVI over the entire study area.

Figure 6 shows the nine NDVI imagettes, each with its date of acquisition and lettered A though to I. NDVI is represented using a linear grey scale so that low NDVI values appear dark and higher NDVI values appear increasingly bright. The sea therefore appears black due to its low NDVI. Cloud is also displayed in black, the most cloud - affected dates were 22 June and 29 July, accounting for black pixels predominantly in the north and south of each image respectively. The five pixel positions, from which median NDVI and LST values were extracted, are displayed on the first two imagettes to aid location.

By visual interpretation of the nine imagettes, the west-east growing season split appears to be manifest on the time series of NDVI imagettes. On 22 June, bright (high NDVI) pixels, indicative of growing vegetation, dominate the western part, whilst low NDVI values (dark) remain in the east. By 10 July, all but the eastern sample area has

Figure 6: The nine NDVI imagettes of the Krangkeng study area



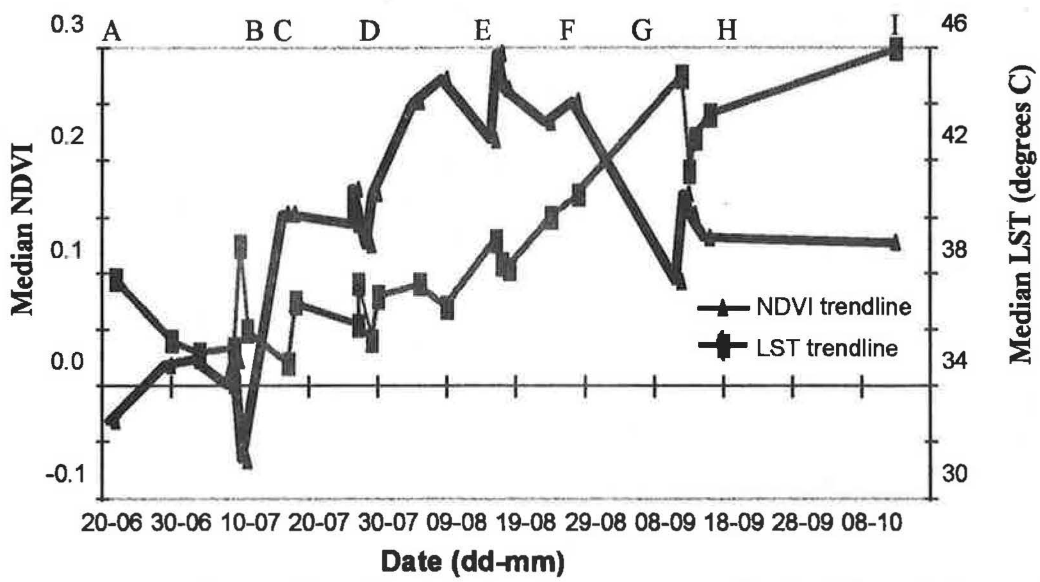


Figure 7: Median NDVI and Land Surface Temperature profiles for 5 (boxed) rice pixels

high NDVI (vigorous growth), whereas by 28 August, the area of vegetative growth has shifted to the east of the study area, the western part already having low NDVI values. Maximum NDVI values are 0.5 for the western part and 0.3 for the eastern part.

Figure 7 shows the temporal variation of median NDVI and LST values for the five pixels in the eastern area. The positioning of the letters A through to I drawn along the top of the profiles corresponds to lettering of the NDVI imagettes in Figure 6. Six main stages are tentatively interpreted as shown in table 2 below:

	Date (dd-mm)	NDVI	LST	Interpretation
Stage 1	before 10-07	low	low	Flooded fields / vegetative stage
Stage 2	10-07 to 19-08	increasing	low	Vegetative stage
Stage 3	19-08 to 29-08	peak - small decrease	increasing	Reproductive stage
Stage 4	29-08 to 10-09	decreasing	increasing	Ripening stage
Stage 5	10-09 (approx.)	low	high	Harvest
Stage 6	10-09 - 15-10	low	high	Bare soil

Table 2: Rice growing stages interpreted from Median NDVI and LST profile.

The interpretation was performed based on the idealised curves shown in Figure 2. In general there is a good correspondence, with real NDVI and LST rising and falling, and interrelated according to expectation. A harvest date of around 10 September is interpreted, as this time marks the end of a continual decline in NDVI (ripening) and increase in LST (bare soil). Given this harvest time, and a 110 day variety of rice, we would have expected a transplanting date during the last 10 days of May. In this case, the rice crop would have been growing for over 1 month before NDVI became significantly positive after 10 July. From 10 July onwards, NDVI gradually increased, peaked and then decreased, suggesting that the tail-end of the vegetative stage and the full reproductive and ripening stages were monitored.

Although the real NDVI and LST profiles show a good correspondence with their idealised shape and interrelation given in Figure 2, ground data is needed to determine whether the interpretation is valid. Interviews with farmers and local agricultural authorities in the Krangkeng area in February 1996 lend corroborative evidence that the above NOAA measurements are detecting significant stages in the crop growing cycle. Rice was transplanted in the area during the third week of May 1995, one month after transplanting in the western area (which has higher irrigation priority). The NDVI imagettes appear to pick up this spatial pattern, with a front of high NDVI pixels, initially in the west, migrating to the east, and followed by low NDVI values interpreted as ripening and harvest. Peak seasonal NDVI values in the west are typically 0.5 or more, whereas in the east, peak values rarely exceed 0.35, an observation also consistent with the lower irrigation priority given to the eastern area, and a lower percentage of the total area planted to rice crops (as opposed to other crop types).

EXAMPLE 2: COMPARISON OF NDVI PROFILES FOR FIVE JAVANESE TEST SITES.

NDVI profiles were derived for a further five test sites in Java. This was to allow interpreted crop calendars and relative vegetation vigour to be compared and contrasted between sites. The following information was of particular interest for differential production assessment:

- planting, vegetative stage, heading, ripening and harvest times for each site
- different planting times between sites
- different Integrated NDVI between sites (relative yield indicator)

The five test sites selected were:
1. Sukamandi area, West Java
2. Lemahabang in West Java.
3. Indramayu in West Java (to the west of the Krangkeng area, previously described)
4. Dempet in Central Java
5. Mojosari in East Java.

The location of each site is given in Figure 8. The.Sukamandi area is managed by Perum Sang Hyangseri, a semi-private rice estate company controlled by the government, and has more that 3000 acres of well irrigated fields used for rice seed extension (it also include a large governmental research station). Lemahabang, Sukamandi and Indramayu are located in West Java's main rice production area, whilst Dempet and Mojosari are used to represent Central and East Java respectively. All five test sites were chosen in known areas of mostly rice fields by reference to a 1:25000 scale land use map. At each site, the centre (lat/long) coordinate of a homogeneous rice area (at the 1 km AVHRR grid cell) was identified from the map. NDVI profiles for each of the five coordinates were then extracted from the NDVI time series.

Figure 9 shows NDVI plotted against time for the period June to October 1995 for the five test sites. For each data set, a moving average trend line has been fitted to reduce the effects of atmospheric noise on the NDVI profile, and to aid interpretation. Four of the five profiles show the expected progression of a general rise, peak and fall in NDVI for a complete growth cycle. Each of the five areas will be discussed briefly.

The Indramayu and Lemahabang sites have the same source of irrigation water (the Jatiluhur dam) and are managed by traditional farmers. Their profiles both rise sharply in mid-July indicating similar planting dates. Transplanting is interpreted for June at each site, with maximum NDVI occurring at around the end of July and in mid to late August for Indramayu and Lemahabang respectively. The curve for Indramayu has consistently lower NDVI and declines more abruptly than that for Lemahabang. The lower Integrated NDVI for the former site, suggests a lower relative yield, or a mixture of other crops.

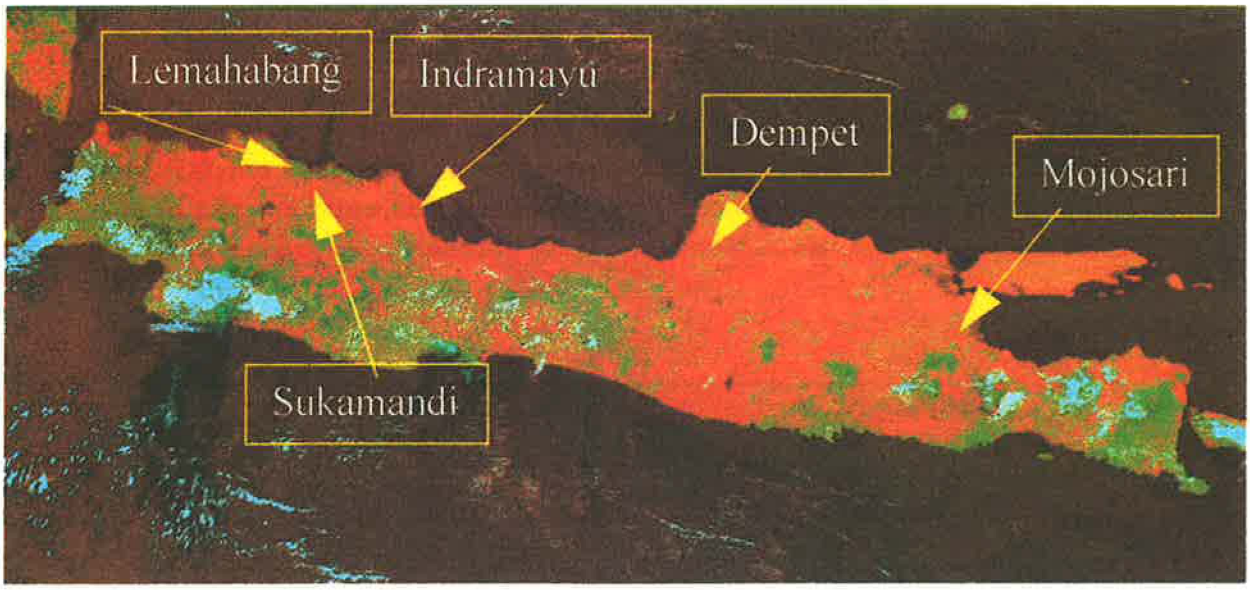


Figure 8: Location map for the five Javanese test sites

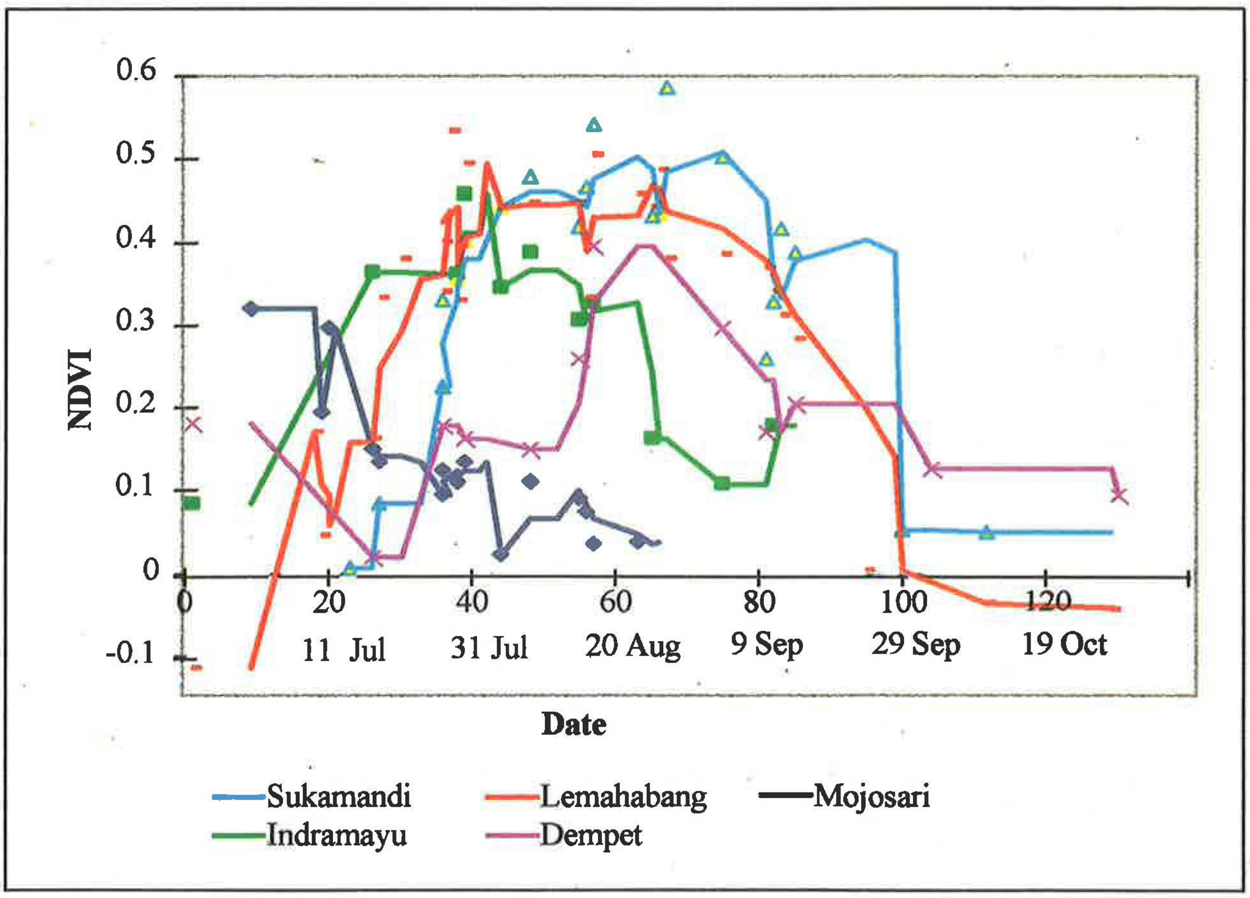


Figure 9: NDVI profiles from June to October 1995 for the five Javanese test sites

The Sukamandi test site is well managed in terms of rice cultivation, but also in terms of statistical data collection. Ground data was obtained for the same period as the AVHRR data to allow a more comprehensive comparison between field and satellite observations. The field-derived statistics for the Sukamandi test site are presented in Table 3.

Variety	Area (ha)	Execution		Harvest time Est.	Production (est.)
		Seeding	Transplanting		
Self-manage					
IR-64	429.39	28/4-23/5-95	20/5-2/7-95	18/8-20/9-95	2125.10
Memberamo	80.07	19-23/5-95	12-21/6-95	11-15/9-95	400.35
Kalimutu	4.00	18/5-95	5-17/6-95	9/9-95	9.00
Gajahmungkur	2.75	18-26/5-95	12-16/695	2/9-95	4.50
Cibodas	49.13	4-16/5-95	9-23/6-95	3-13/9-95	195.00
Sub total	565.34				2,733.95
Co-manage					
IR-64	1641.35	23/4-30/5-95	18/5-22/6-95	16/8-26/9-5	6562.28
B. Solo	130.72	28/4-23/5-95	20/5-25/6-95	21/8-16/9-5	521.92
Way Seputih	30.18	2-5/5-95	20-23/5-95	3-6/9-95	120.72
Way Rarem	66.92	6-30/5-95	8-22/6-95	2-9/9-95	208.20
Cisanggarung	15.18	22/5-95	17-20/6-95	23/9-95	60.72
Jatiluhur	7.18	11/5-95	3/6-95	28/8-95	28.72
Cisadane	238.73	4/4-25/5-95	8/5-15/6-95	1/9-11/10-5	954.00
PB 42	97.22	15/4-6/5-95	10-30/5-95	28/8-18/9-5	388.00
Ciliwung	20.09	11-12/5-95	10-15/6-95	8-10/9-95	80.00
IR-74	44.96	10-20/5-95	29/5-14/6-95	13-23/9-95	179.00
Lusi	15.85	3-8/5-95	30/5-2/6-95	15-28/9-95	63.00
Sub total	2,308.38				9,166.56
Total	2,873.72				11,900.51

Table 3: Crop-calendar and rice production for Perum Sang Hyangseri, Sukamandi, 1995 Planting Period 1995.

The table shows that transplanting occurred from early June to early July. Harvest is estimated to be between the middle of August and the end of September. The NDVI profile for Sukamandi shows low NDVI values in the middle of July, consistent with the rice crop still being in the early part of the vegetative phase, so that the spectral reflectance of the rice fields is mainly from the water layer. The steady increase in NDVI from mid July to early August, followed by a levelling out and sharp decline in the end of September - early October is also consistent with completion of crop development and harvesting occurring in late September.

The Mojosari profile is truncated, with a sharp decline between the middle and end of July to a possible harvest date in early August. This suggests that the Mojasari growing season was well in advance of that for the other sites. This was probably a single wet season crop, planted late as it is a coastal site (unless it was a non-homogeneous rice crop).

In the Dempet area, harvesting of the second rice crop was completed in the middle of July, after which a secondary (soybean) crop was planted. According to local farmers, paddi-paddi-secondary crop shifting is usually practised in a 1 year cycle in this area. Full soybean canopy cover occurred around 17-27th August and harvest started at around the end of September. The NDVI profile begins to rise in mid-July, peaks towards the end of August, and has fallen to a low level by the end of September. The field observations are highly consistent with the NDVI observations.

DISCUSSION

As discussed earlier, crop production is the result of crop growth over a given area. The studies have compared interpretations based on AVHRR NDVI and LST indicators with (where available), crop calendar information obtained from the field. Initial results suggest that aspects of crop performance and extent can be identified using free AVHRR data.

Once sufficient growth has occurred (perhaps 4 or 5 weeks after transplanting), the NDVI images appear to follow spatially the development and maturation of the rice crop in different areas. This is extremely useful in assessing the total area planted each year, given that the area is highly variable from year to year.

The NDVI and LST profiles for the Krangkeng area correlated well with both their idealised profiles, and with crop calendar information obtained for the monitoring period. The NDVI profile showed the characteristic low - rise - peak - fall succession as expected for emergence, vegetative growth, full cover and ripening of the rice crop, and its interrelation with LST was consistent with expectation. This underlines AVHRR's potential for operationally following the important stages in the rice growing cycle in large, homogeneous rice areas.

The five additional profiles also seemed to follow the field-described development stages of rice crops and also of secondary crops. Although a relatively short time span was covered, it may be envisaged that the paddi-paddi-secondary crop succession would also be monitored, if the monitoring period were extended. This is highly significant for production forecasting since the number of rice crops grown per year (i.e. one or two) affects the net total area planted, and hence total production.

Yield indicators may also be obtainable. It is apparent that there are great differences in INDVI (the area under each curve), which suggests differing crop performance between locations. As discussed earlier, INDVI has been related to production since it gives a measure of how much net photosynthesis occurred through time at each site. The profiles therefore demonstrate the potential for assessing differential yields at different locations.

Before rice production forecasting can become operational, more work is needed. Large studies including field observations as well as image interpretation are necessary. Rice areas must be carefully described in terms of NDVI/LST (or other appropriate indicators) in order to be able to reliably recognise and therefore measure planted rice surfaces. Furthermore, INDVI needs appropriate calibration using real rice crop yield figures. In addition, long-term normal trends for annual variation of the indicators must be established in order to put the actual estimation into its context, and therefore assess its deviation to normality. This would allow the newly acquired estimation (e.g. NDVI) to be placed in the context of normal seasonal trends, and the performance of the current year's crop to be placed in the context of normal performance. Historical Global Area Coverage (GAC) NDVI data are freely available for the whole of Indonesia, for the last 10 years. Although recorded at a much degraded resolution compared to the AVHRR data, the GAC may still be used to derive seasonal NDVI norms for relatively homogeneous rice growing areas.

An ideal rice production forecasting system would integrate freely acquired, low resolution AVHRR data with more detailed high resolution satellite (Rabaute T. 1995) and field survey to produce timely forecasts across all Indonesia's major rice growing areas. Combining low resolution, systematic and repetitive coverage with more detailed surveys improves the accuracy of the NOAA forecasts whilst benefiting from the validation that the more detailed studies can offer.

CONCLUSION

This preliminary study suggests that freely available NOAA AVHRR data are potentially an extremely useful addition to an Indonesia-wide rice production forecasting system. In this case, using a low cost PC-based receiver, images of the whole of Java were collected for an entire rice growing season. The study could easily be extended to provide for nation-wide, routine monitoring of rice development.

It has been shown that NOAA's acquisition frequency and channels have potential for broad-scale determination of important parameters in assessing total annual production. The total area of rice planted annually and the relative performance between different rice growing areas, as well as different season/years.

More field work and data analysis are needed to better define NOAA's capability and limitations, especially in less homogeneous rice growing areas. However, preliminary results suggest that free NOAA data, captured daily, could be used to improve the temporal context and interpretability of high resolution surveys.

It is recommended that research is undertaken to develop an operational rice production forecasting system for Indonesia, which incorporates and combines the relative strengths of field, high resolution satellite (SPOT, Landsat, ERS-1) and NOAA data to allow a detailed temporal and spatial assessment of annual rice production. This is seen as an important and technically feasible step in providing rice production forecasts in support of Indonesia's national program to achieve and maintain self-sufficiency in rice production.

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IDENTIFYING LAND USE CHANGES IN CRITICAL AREAS FOR WATERSHED MANAGEMENT.

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ABSTRACT

The ability to monitor vegetation loss over land areas susceptible to degradation is of great potential use to watershed management. Such information can assist in prioritising land use planning, rehabilitation and regulation activities to preserve and protect critical areas. This in turn can help to reduce soil erosion and associated sedimentation problems, improving water conservation and reduce the possibility of flooding. The paper demonstrates a prototype technique for inexpensively monitoring land use changes occurring within critical watershed areas. The magnitude of AVHRR-derived vegetation changes is cross-referenced with critical land status as a basis for prioritising management action. A study area was defined in the upper Citarum watershed of West Java. Vegetation status was monitored between June and October using vegetation indices (NDVI) derived from satellite data (AVHRR) collected in 1995 using the BPPT NOAA ground receiver. A Monitoring Action map was produced by combined analysis of the vegetation status and critical land status maps. It prioritises appropriate monitoring and monitoring actions dependant on the magnitude of vegetation changes with respect to critical land status. This paper indicates the great potential of this approach for cost effective identification of detrimental land use changes in remote watershed areas. The approach is highly flexible, and could be enhanced in numerous ways according to specific management requirements. Incorporation of further knowledge on the area (from local or satellite sources) such as seasonal trends is seen as an essential further step to increase the robustness of the technique.

INTRODUCTION

In Indonesia, as elsewhere, watershed management is tending towards holistic monitoring and control of entire river catchments as single units, from the upper watershed, with its springs and generally forested cover, to the delta in the sea and its important fishery resorts. The integrated management is complex. It includes management of water distribution and quality as well as the land use for the whole watershed. A key element in such management is the timely and cost effective monitoring of events.

Jasa Tirta is a private company responsible for the integrated management of the entire Brantas watershed in eastern Java. Management is undertaken as a first pilot project in Indonesia, which, if successful, will be implemented for the whole country. So far it is already regarded as a successful example. Management includes the control of water quality and distribution from numerous reservoirs to agricultural irrigation schemes, industrial and domestic users within the catchment. Several meetings were held with Jasa Tirta's managerial and technical staff in order to find out which area of the management could benefit from the use of low resolution satellite data. Three main areas were identified: rain fall estimations, irrigation planning and land use changes.

Even though Jasa Tirta already has a good network of rain gauges (directly connected to the central control unit in Malang), it is not exhaustive, and in many other watersheds it is poor. Use of the Geostationary Meteorological Satellite (GMS) was suggested but since reception of GMS data is not currently possible this application was delayed.

The rapid identification of land use changes is important to operational watershed management. It can highlight land degradation problem areas that require special attention. Vegetation changes such as clearance of forest land for agriculture or tree cutting for timber or fuel wood increase soil erosion (e.g., Sudarmanto and Suriatanuwijaya, 1989; Braden, 1982) with detrimental effects downstream, including increased sediment load in rivers, losses to reservoir capacity, and adverse effects to local fisheries. Reduced vegetation also decreases rainfall interception and soil capacity for water retention, leading to increased runoff, e.g. recent floodings in Jakarta are believed to have been caused by land degradation in the Puncak area and have raised presidential concerns (Simbolon and Sari 1996).

While irrigation planning is covered in Rahmadi et al. (1996, this issue), this paper focuses on how watershed management can benefit from detection of land use changes via the use of NOAA-AVHRR data (Trigg et al., 1996, this issue, describe the satellite and its data reception and processing in BPPT). A prototype methodology is given to show how management response to observed land use changes might be prioritised according to critical land status.

The watershed issues mentioned for Brantas are relevant to most watersheds. The Upper Citarum watershed (West Java) was chosen for this demonstration, because ancillary data were readily available.

THE UPPER CITARUM STUDY AREA

The upper Citarum watershed is located in West Java as shown in Figure 1.

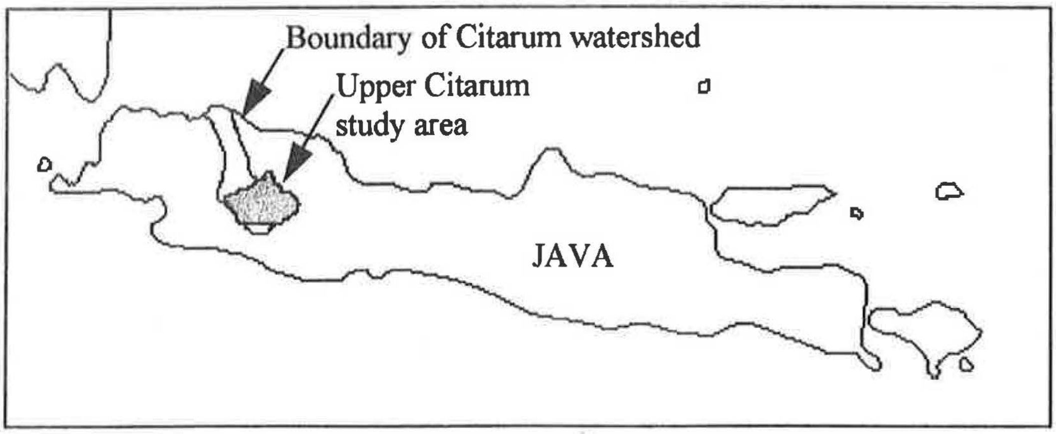


Figure 1: Location of the upper Citarum watershed.

The area encompasses a huge volcanic basin, fringed by forested mountains. Bandung, the third largest city in Java, lies at its centre and has a population of over 2 million, with a further 3 million living in the surrounding area. Such has been the growth of the city that in 1989 its administrative boundaries were extended, doubling the area of the city overnight. The expansion of suburban development has degraded many areas of natural vegetation. The forests at the periphery of the basin are now experiencing degradation at their margins.

Three major dams are present within the Citarum watershed, namely Jatiluhur, Saguling and Cirata. Of the three dams, only Saguling lies within the upper Citarum study area. The water is used primarily to generate Hydro Electric Power, but also for crop irrigation and lake aquaculture. Preventing sedimentation into the dams is a major concern. In February 1996, almost all of the fish stock of Jatiluhur suddenly died. Although no conclusive explanation has been found, one possibility is that the fish mortality was caused by heightened sediment input.

THE LAND STATUS DATA

Recognising the vulnerability of the upper Citarum watershed, the Land Use and Land Cover Change (IGBP 1993) working group of the International Geosphere Biosphere Programme (IGBP) (IGBP 1994) funded the production of a *critical land status* study. It was undertaken by BPPT (Hartanto, 1995). The study developed techniques for modelling critical land status as a basis for land rehabilitation and land use planning. An up-to-date land use map was first produced via supervised classification of a Landsat TM satellite image dated August 1994, using an old land use map to train the classifier. The Land Use map is shown in Figure 2:

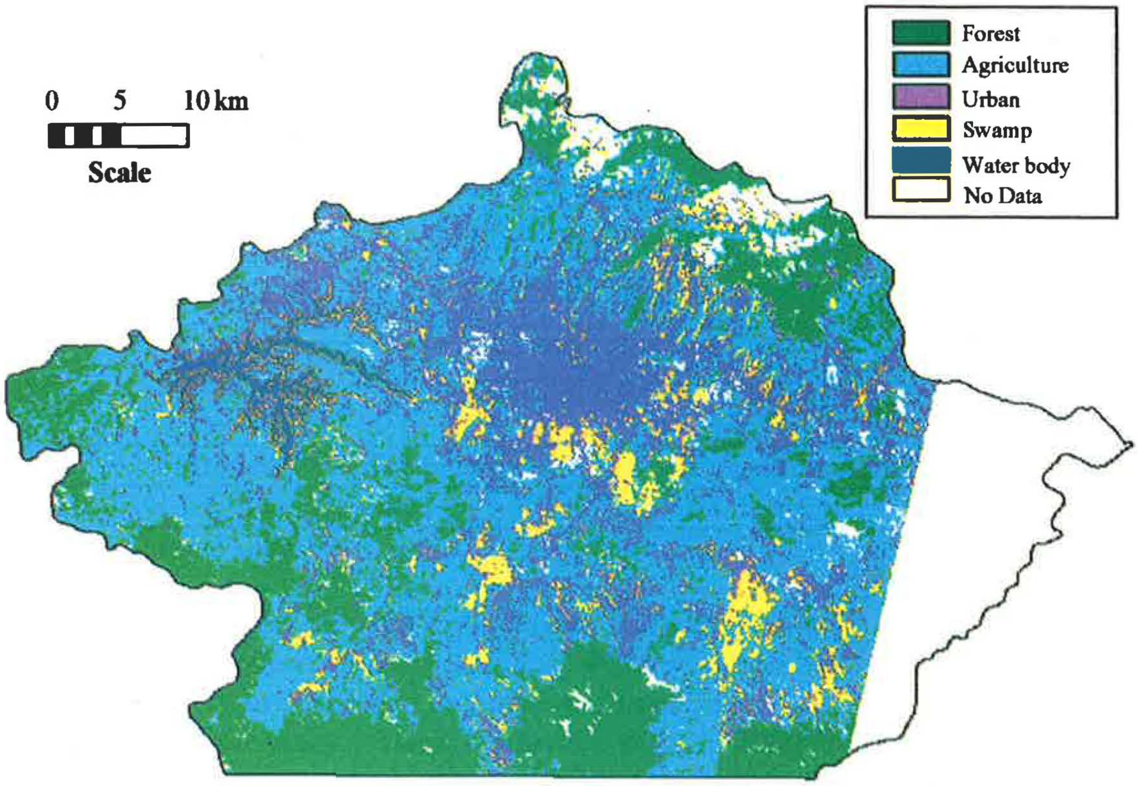


Figure 2: Land use map of the Upper Citarum study area

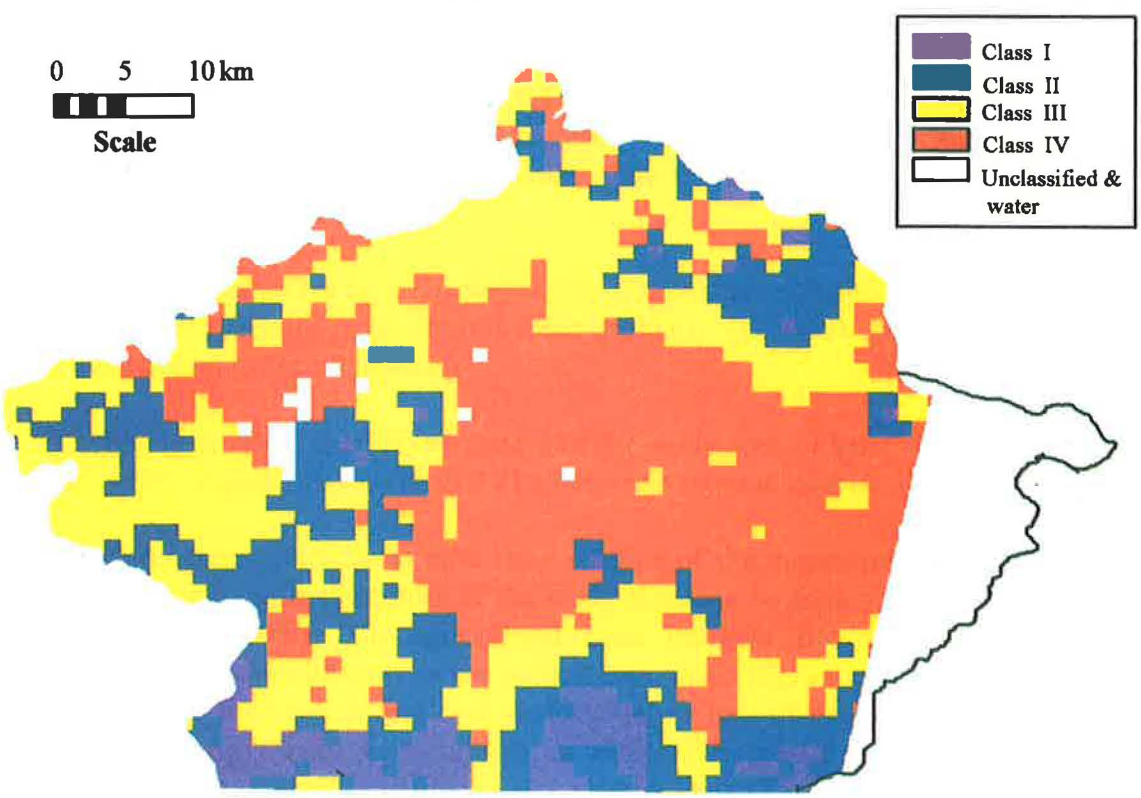


Figure 3: IGBP Critical Land Status Map (990m grid)

Critical land status was modelled via multiple regression of the land use (Figure 2) with four additional variables, namely soil type, slope, elevation and rainfall. In order to reduce the demands on data processing, the model was generated at a 1km grid

The critical land status map comprises four categories indicating the land's susceptibility to degradation (Table 1).

CLASS	LAND STATUS
I	Protected area unsuitable for development
II	Area which could support limited development, but only under certain strict criteria
III	Areas suitable for development and existing agricultural areas
IV	Existing urban area

Table 1: Land status

Figure 3 shows the final Critical Land Status map. Class I areas are designated where the combined effects of local land use, soil type, slope, elevation and rainfall make the area especially susceptible to degradation. It can be seen that most Class I areas are at the periphery of the study. These are mainly areas of forest in the highlands, with fragile soils, steep slopes, and high annual rainfall. The welfare of such areas is essential for the sustainability of a well balanced watershed.

AVHRR DATA FOR VEGETATION MONITORING

Vegetation status was monitored between June and October 1995 using free AVHRR data collected by the project's NOAA ground receiving station (Trigg et al., 1996, this issue). The NDVI (Normalised Difference Vegetation Index) is the most widely used index to monitor vegetation from satellite data and has been routinely computed at BPPT (Trigg et al., 1996, this issue).

NDVI is sensitive to green vegetation, i.e. healthy and photosynthesising vegetation). Values will typically range from 0 (bare ground), 0.15 (low green vegetation cover), to 0.6 (abundant green vegetation).

Figure 4 shows two NDVI images of the study area. Figure 4(a) shows NDVI on 14 July 1995. Figure 4(b) shows NDVI almost two months later on 13 September 1995.

These maps allow us to infer the evolution of the vegetation cover between July and August. Bandung, at the centre of the study area, can be seen on both NDVI images as an area of low NDVI. The agricultural areas between Bandung and the forests have significantly reduced NDVI on the second date, inferring reduced photosynthetical activity as would be expected during crop maturation, or loss of vegetation due to harvest (bare soils remaining). Small forested areas, as well as fallow land show a decrease in greenness resulting from forest seasonality or as a consequence of the progressing dry season. Only the dense tropical forest, skirting the study area, show no significant changes between the 2 months, and remain the same throughout the year.

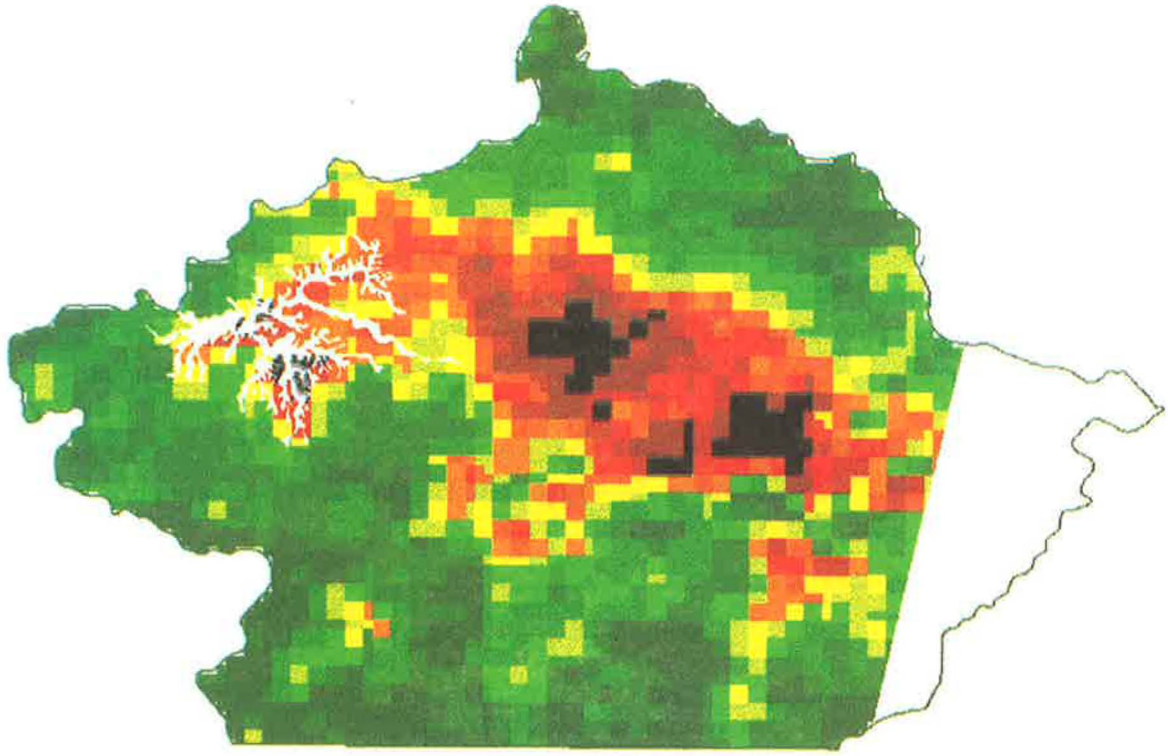
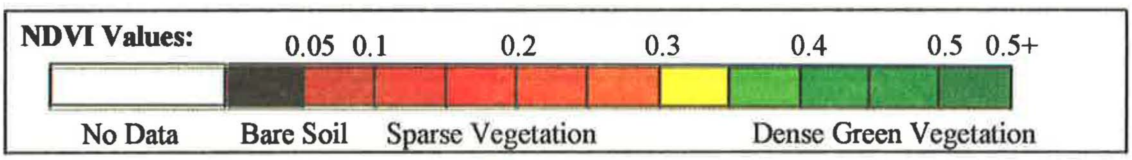


Figure 4(a): NDVI image of upper Citarum study area, 14 July 1995.



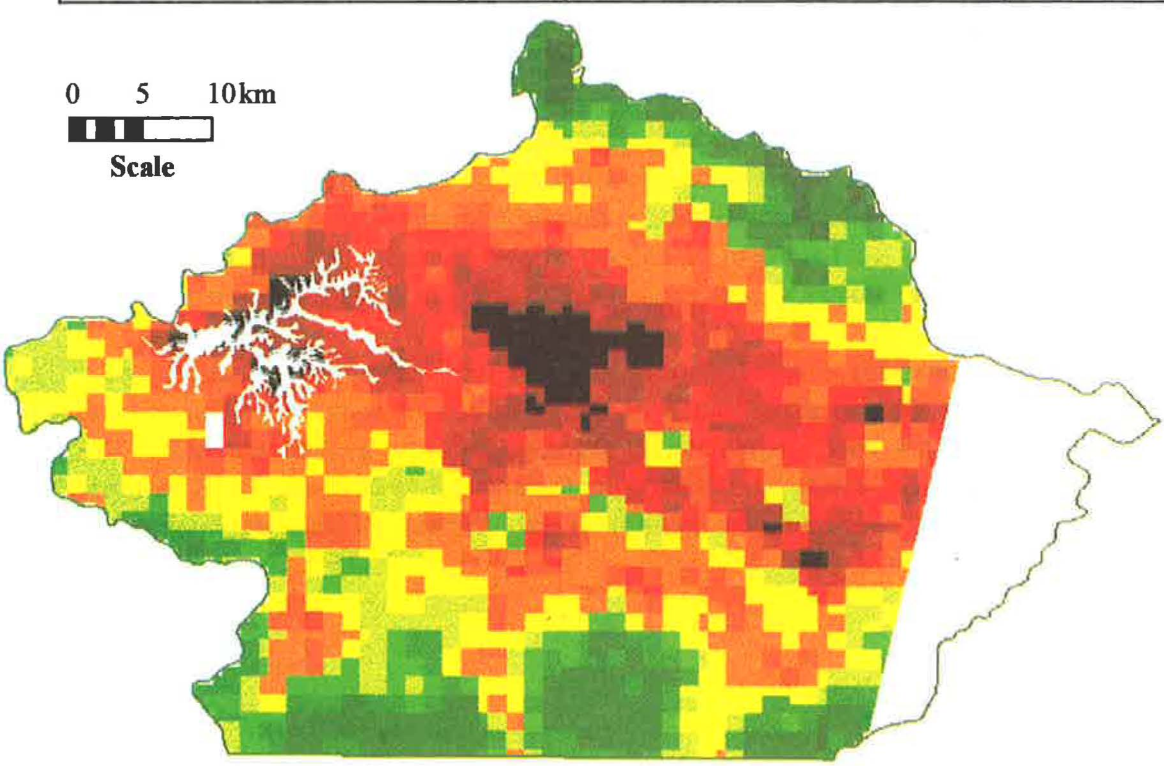


Figure 4(b): NDVI image of upper Citarum study area, 13 September 1995.

ASSESSING LAND USE CHANGES IN CRITICAL AREAS

Changes in green vegetation between the two dates were assessed quantitatively by subtracting the 14 July image from the 13 September image to produce an NDVI difference image. Positive NDVI values in the difference image indicate an increase in NDVI between dates and hence infer increased green vegetation between dates. Negative differences are interpreted as a reduction of green vegetation between dates. Areas with similar NDVI on both dates generate small NDVI differences, implying no changes between dates.

To allow for NDVI imprecision and data noise, the NDVI difference image was classified into five broad ranges of changes as shown in Table 2. The results are shown in figure 5.

NDVI Difference Class	Class Range (NDVI difference)	Interpretation
1	> +0.2	substantial increase in green vegetation
2	+0.1 to +0.2	slight increase in green vegetation
3	+0.1 to -0.1	no significant change
4	-0.1 to -0.2	slight decrease in green vegetation
5	< -0.2	substantial decrease in green vegetation

Table 2: Vegetation changes classes

Vegetation change classes 4 and 5 in Figure 5 suggest reduced green vegetation between dates, and hence possible sites of detrimental land use changes. It is important, however to incorporate additional information to help assess whether class 4 and 5 areas really do merit concern as possible land degradation sites. For example the agricultural areas surrounding Bandung, as expected, are characterised by negative differences. This is due to the normal ripening rice and harvest of rice between the dates, and is no cause for concern. Further information is clearly needed to prevent false alerts being issued over normally ripening, non-critical areas such as paddy rice or vegetation seasonality.

The critical land status map (Figure 3) was cross - referenced with the NDVI difference images (Figure 5) within a GIS to demonstrate one possible way of refining NDVI difference images into management action maps. This allowed observed NDVI differences to be assessed in the context of critical land status. An example of decision matrix was established to classify the combined data sets into appropriate monitoring action, as shown in Table 3.

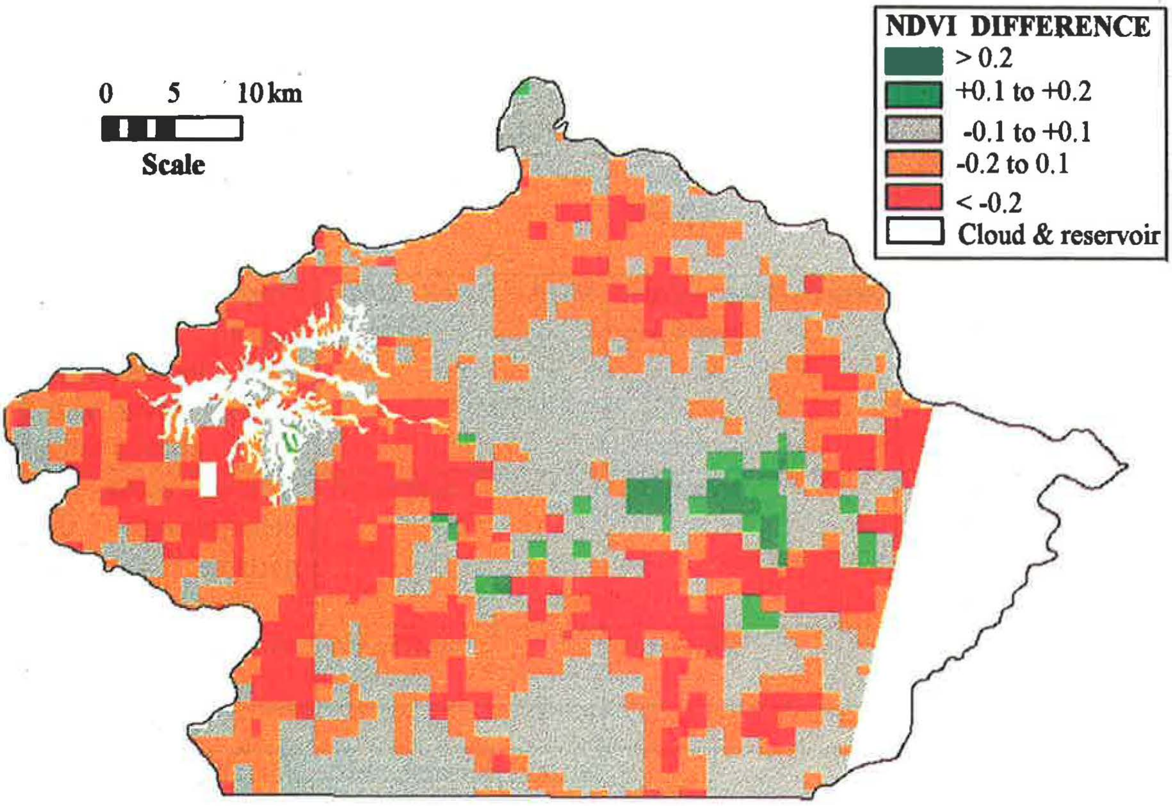


Figure 5: NDVI Difference Classes, NDVI (13 September 1995) - NDVI (14 July 1995)

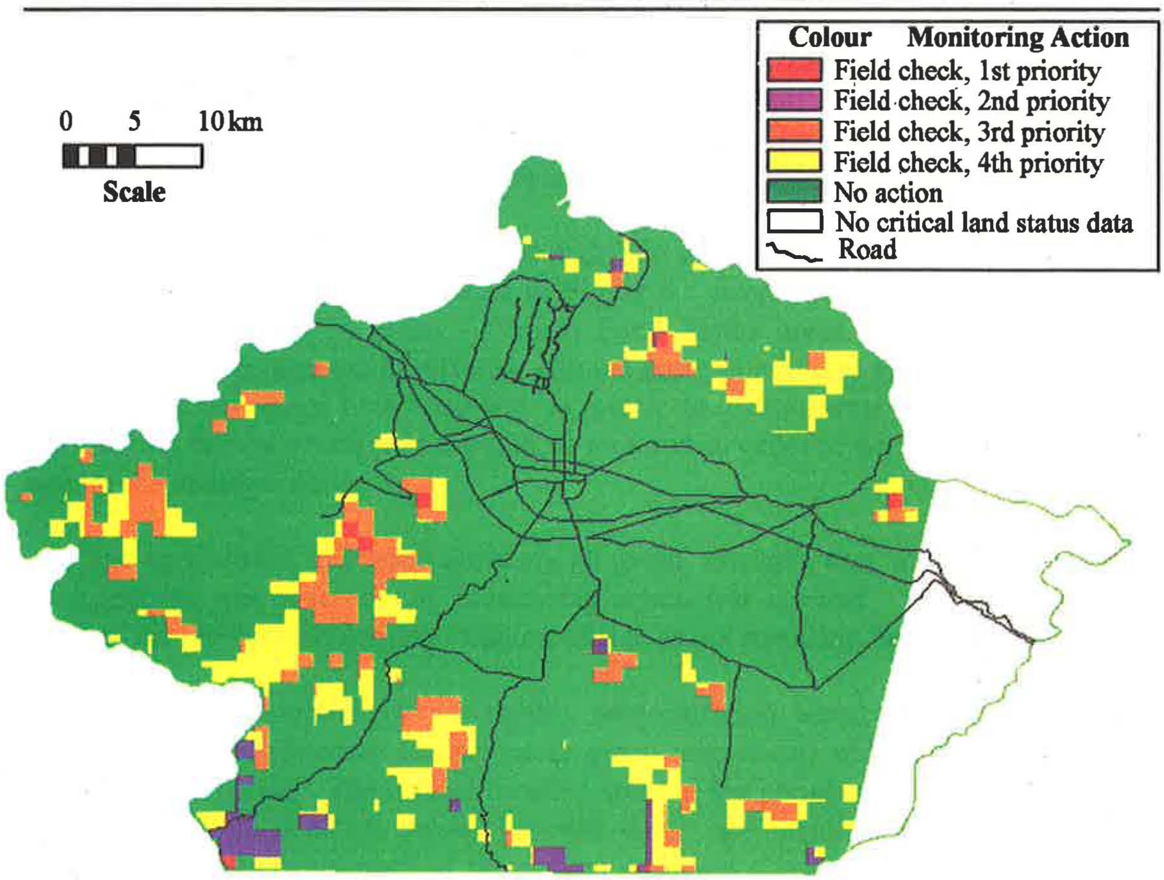


Figure 6: Monitoring Action Map

LAND STATUS CLASS	NDVI difference class 5 (much less green on 2nd date)	NDVI difference class 4 (slightly less green on 2nd date)	NDVI difference class 3,2,1 (same or greener on 2nd date)
I Protected area unsuitable for development	*Field check as priority*	*Field check, second priority*	*No action*
II Area which could support limited development, but only under certain strict criteria	*Field check, third priority*	*Field check, fourth priority*	*No action*
III Areas suitable for development and existing agricultural areas	*No action*	*No action*	*No action*
IV Existing urban area	*No action*	*No action*	*No action*

Table 3: Monitoring action decision matrix

Text in italics gives the monitoring decision to be taken. It can be seen that decreases in vegetation within protected areas (Land Status Class I) merits first and second-priority ground checks (dependent on the magnitude of decrease in NDVI). Decreases in vegetation in Class II areas are assigned only third or fourth priority field checks as their land status is less critical. Decreases of vegetation in Class III and IV areas (including agricultural areas) merit no action because the Land Status is not critical.

The result of applying the decision matrix to the NDVI and critical land status data is a *Monitoring Action* map, presented in Figure 6. Areas where no monitoring action is merited are coloured in green. Critical Land Status areas showing a diminution of vegetation are represented in different colours corresponding to the suggested monitoring actions. Roads have been overlain in black to demonstrate how additional useful information can be overlain in the GIS as required in order to best tailor a final thematic map to the manager needs.

The agricultural and urban areas are all green, meaning that, although some decrease in vegetation was observed, no monitoring action was merited. The map has therefore allowed for the normal ripening / harvest of rice as not requiring field checks.

Decisions to field-check are in this demonstration based on the assumption that negative NDVI differences (reduction in green vegetation) should not occur in critical (Class I and II) areas. The critical forested areas at the periphery of the study area which showed relatively constant values between dates, are mainly classed as 'No Action'. Nevertheless, significant parts of the critical areas are classified as 'Field Check' actions and need to be accounted for.

DISCUSSION

A Monitoring Action map such as presented in Figure 6 will allow the manager to find out where important events are apparently taking place (e.g. vegetation clearance in protected areas). It is therefore a tool which doesn't pretend to explain what is happening but rather to identify where attention must be given in priority. The exact cause and extent of the observed event will be fully described after field check.

One can however attempt to understand the information provided in a Monitoring Action map. For example, on Figure 6, two main areas are apparently flagged as important: i) a few sites around the urban area of Bandung (little red square), ii) the edges of the tropical forest (purple areas in the South). While the former may result of population pressure to expand the urban area of Bandung up to the small hills surrounding the city, the latter may be caused by farmer always looking for new agricultural lands. Such assumption will be confirmed or otherwise by the specialists team which will have been sent specially to that area. Because huge surveys to monitor the whole watershed will not be necessary anymore, focused effort will help better analysis of critical areas.

Of course, the precision and the usefulness of such thematic map is highly dependent on the rules initially implemented in the GIS. In the presented case, simple rules (the decision matrix) where built up and implemented to illustrate the potential of the combination of local knowledge with frequent AVHRR data to help the watershed management focusing resources.

The exact interpretation of this example is difficult. It may be that field checks would explain the negative NDVI differences as a factor of the normal defoliation in deciduous forest and tea plantation areas or as a consequence of forest fires. The technique needs therefore to incorporate as much knowledge and ancillary data as possible. For example, "normal" phenological trends could be accounted for by integrating a more detailed land use map to separate deciduous and coniferous forests and tea plantations, and by obtaining a knowledge of the phenology of each. Alternatively, normal seasonal NDVI trends could be extracted from historical NDVI data. Global Area Coverage (GAC) NDVI data are freely available from the Internet for the whole of Indonesia for the last 10 year period. They could be used to identify seasonal NDVI norms for critical areas, and hence eliminate 'normal' NDVI deficits from the management map. Fire occurrence information could also be integrated to confirm the loss of a large extent of forest (e.g. Jewell, 1996, this issue). Significant additional work is needed to improve and refine the technique to realise the full potential of the approach.

It must be emphasised that, even though the technique is demonstrated here on a relatively small area, due to the nature of AVHRR data, such work can easily be achieved for the whole of Indonesia (Trigg et al., 1996, this issue). The use of AVHRR data may be of even more benefit on Sumatra and Kalimantan, where deforestation rates are often of another order of magnitude.

This demonstration is mainly an example. There are many possible ways in which the approach can be used and adapted to best satisfy the management needs. Here the emphasis was given to the fact that diminution of green vegetation in a protected area would have an adverse consequence on the watershed. One can adapt the approach to take into account closeness to roads, administrative boundaries, climate information, etc.

Thanks to the daily AVHRR data, a Monitoring Action map of a spatial resolution of 1 km is the kind of product that can be issued regularly (e.g., weekly, monthly, as appropriate) to the watershed management board. Such information can help it to focus its resources (staff, vehicles, ...) on the areas under particular pressure, or requiring specific attention. Of course, regular update of precise land use will be advisable using for example high resolution satellite data (e.g., every two-three years).

CONCLUSION

This demonstration shows potential for combining frequently acquired NOAA imagery (at BPPT) with ancillary data within a GIS to highlight potential degradation areas needing management attention. The resulting thematic map, in this case a *Monitoring Action* map, can help watershed managers to focus resources directly where attention is apparently most needed.

The general approach is highly flexible, and could be enhanced in numerous ways according to specific management requirements.

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IRRIGATION PLANNING SUPPORTED BY NOAA AVHRR DATA

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ABSTRACT

During the dry season, water is very precious. When the demand for irrigation water starts overtaking its availability, the water manager has to make difficult choices. This paper presents how the use of NOAA-AVHRR data can contribute to the prioritisation of water delivery, as well as monitor the state and evolution of the crops. Case studies show how crop status and water availability indicators were obtained for the Brantas and Northern Citarum irrigation areas of Java for the 1995 growing season. These indicators could be used to help watershed managers assess the performance of the annual irrigation plan and prioritise water flow to balance the opposing demands of water conservation and irrigation demand.

INTRODUCTION

In Indonesia, as elsewhere, watershed management is tending towards holistic monitoring and control of entire river catchments as single units, from the upper watershed, with its springs and generally forested cover, to the delta in the sea and its important fishery resorts. The integrated management is complex. It includes management of water distribution and quality as well as the land use for the whole watershed. A key element in such management is the timely and cost effective monitoring of events.

Jasa Tirta is a private company responsible for the integrated management of the entire Brantas watershed in eastern Java. Management is undertaken as a first pilot project in Indonesia, which, if successful, will be implemented for the whole country. So far it is already regarded as a successful example. Management includes the control of water quality and distribution from numerous reservoirs to agricultural irrigation schemes, industrial and domestic users within the catchment. Several meetings were held with Jasa Tirta's managerial and technical staff in order to find out which aspect of the management could benefit from the use of low resolution satellite data. Three main areas were identified: rainfall estimations, irrigation planning and land use changes.

Even though Jasa Tirta already has a good network of rain gauges (directly connected to the central control unit in Malang), it is not exhaustive, and in many other watersheds it is poor. It was suggested to use the GMS satellite. Since reception of GMS data was not yet implemented, this application was kept for later.

While the land use change issue is covered in Hartanto *et al.*. (1996, this issue), this paper focuses on how watershed management, and more specifically irrigation planning, can benefit from some indication on the status of irrigated areas. Examples are first given on how indicators extracted from AVHRR data can be used to infer crop status and water availability. Brantas and Northern Citarum irrigation areas of Java for the 1995 growing season were chosen as study areas. A discussion is then given on how such information can be adequately used to help watershed managers assess the performance of the annual irrigation plan and prioritise water flow against the opposing demands of water conservation and irrigation demand.

IRRIGATION ISSUES IN THE BRANTAS WATERSHED

The Brantas River of East Java, has a catchment area of approximately 12,000 km2 and is the island's second largest river. There are four reservoirs (Sutami, Lahor, Selorejo, Bening) in the basin, with a total effective storage capacity of 267.8 million m3. There are fifteen major towns in the area (five Kotamadya and ten Kabupaten). Water from the river is used for a variety of purposes; agricultural, municipal, industrial, fisheries, flushing water and hydropower generation.

Jasa Tirta perform three main management activities:
Water quantity management. Jasa Tirta maintain and manage numerous dams within the catchment which are used for two main purposes:

- *Water storage*: Excess water is stored during the rainy season for flood prevention and control.
- *Water distribution*: Water is distributed from the dams for many purposes including for irrigation of agricultural crops, municipal and industrial water, fisheries, flushing water, and hydropower generation.

Water quality management includes water quality monitoring and control in order to maintain water quality condition for multiple purposes.
Maintenance of water resources infrastructure.

Within the Brantas catchment, irrigated rice covers an area of approximately 345,000 ha. These crops need about 2,300 - 2,500 million m3 of irrigation water per year and use approximately 80 % of the total available supply during the dry season. Table 1 gives details of the main irrigated areas.

Name of irrigation block:	*Area in hectares*
Lodoyo	2782
Mrican Kiri	12627
Mrican Kanan	16345
Bantas Kiri - Nganjuk	534
Brantas Kiri - Jombang	1736
Brantas Kiri - Mojokerto	3288
Brantas Kanan - Mojokerto	619
Delta Brantas	29435
Simowau	1445

Table 1: Main irrigated blocks

In order to allocate irrigation water to the different irrigation blocks, *Irrigation Services* first state requirements to Jasa Tirta, who then set pre-season allocations in consultation with local government. Irrigation management during the wet season is primarily concerned with regulating water fluxes to optimise supply for hydro-electric power generation. During the dry season, 80 % of the stored water is used for crop irrigation, and water demand can exceed availability. Jasa Tirta must therefore adjust supply to best meet the primary irrigation need.

Every year, as the dry season progresses, Jasa Tirta receives increasing demand by the farmers through the Irrigation Services. Very quickly the demand overtakes availability, and Jasa Tirta has to prioritise water distribution. It is extremely difficult to precisely assess water requirement and confirm farmers' requirements over the different irrigation blocks comprising the 345,000 ha irrigated area. It is considered that monitoring of irrigation fields with AVHRR data collected daily can contribute to this assessment.

REMOTE SENSING DATA TO MONITOR IRRIGATED FIELDS

Many studies have been carried out to monitor irrigated fields, mainly rice, with remote sensing data (e.g., Lepoutre *et al.*., 1991; Malingreau, 1984). Spatially high resolution satellite data (e.g., Spot, Landsat) provide capabilities to map precisely the land use, and consequently irrigated areas, as well as to assess the amount of vegetation on those areas. Nevertheless, their cost is high, and their temporal resolution low. On the other hand, low spatial resolution satellites, such as NOAA-AVHRR, can provide free data on a daily basis. Although their data have a coarser resolution, they provide a good basis for vegetation and irrigation field monitoring. Such an approach has been used in this project (Trigg *et al.*., 1996, this issue).

Several variables are of interest to the monitoring of irrigation areas; they include vegetation density, land surface temperature, evapotranspiration, net radiation, land water deficit. The scientific community has been working for a long time on these variables, and their estimation from satellite data, with some success. Nevertheless, the implementation of techniques to retrieve such variables to be used on an operational basis is complex. The NRI is currently involved in such issues, hence its support to this project.

Since the purpose of this work was to demonstrate how NOAA-AVHRR data can be appropriately used in irrigation monitoring, two simple indicators have been used:
i) The NDVI (Normalised Difference Vegetation Index) and the LST (Land Surface Temperature). The NDVI is an indicator of the presence of green vegetation. Its value increases with the photosynthetic activity and the health of vegetation. It is used widely to monitor vegetation.
ii) The precise estimation of water deficit of an area is difficult and complex. Although direct measurement of soil water deficit is impossible using AVHRR data, the latter can provide some information about it. This is a subject permanently evolving. For this study, it was decided to simply use the LST as an indicator of water deficit. This is because water and vegetation use solar energy to evaporate and transpire the available water, whereas bare soil simply heats up. The LST should therefore allow us to infer water deficit.

DATA AND METHOD

AVHRR data of Java were acquired and processed at BPPT (Trigg *et al.*, 1996, this issue). For the study period, from June to October 1995, time series of NDVI and LST images and profiles were extracted for the two study areas, the Brantas Watershed, in

East Java, and the Northern Citarum Watershed in West Java. Jasa Tirta's management map of the Brantas catchment was digitised to allow specific areas of irrigated crops to be identified in the NOAA data. Detailed information, also provided by Jasa Tirta, on the volume of water supplied to each irrigation block coincided with the acquisition of NOAA data for the study period. Irrigation supply was plotted on the NDVI / LST profiles in order to assess the interrelationship between water supply and the information extracted from the NOAA data. For the Northern Citarum area, no additional management information was available. The area is used as a contrast to the Brantas example.

Water deficit is assessed using LST images coloured to represent ranges in approximate surface temperature. This is based on the assumption that where the crop is relatively warm it has the least water available and hence the greatest water deficit. Cool areas are assumed to have lower deficit due to the cooling effects of surface water and evapotranspiration. NDVI is used to indicate levels of crop photosynthesis and abundance. Information on water supply is also used in the interpretation.

In the following examples it is shown how the use of NDVI and LST can be useful to infer information about the status of irrigation fields. The reader is referred to Mubekti *et al.*. (1996, this issue) for a detailed description on the relation between NDVI and LST with the various stages of the rice crop.

EXAMPLE 1: THE BRANTAS WATERSHED IRRIGATION AREA

Figure 1(a) shows a location map for the Brantas irrigation area in East Java. The location map is a false colour composite where ch3, ch2 and ch1 of AVHRR have been coded in red, green and blue respectively. Typically, green represents vegetation, red represents warm area, and white-blue represents clouds. The Brantas irrigation areas (digitised from the Brantas management map) have been overlaid in dark blue (new irrigation areas), and light blue (existing irrigation area to be rehabilitated).

Figure 1(b) shows NDVI maps of the irrigated area at four dates during the 1995 growing season. On 30 June, high NDVI values are evident over much of the irrigated area, indicating abundant photosynthetic activity, suggesting crops in the vegetative stage. On 24th July, NDVI is generally lower, suggesting reduced photosynthesis and hence probable crop ripening. By 16 August, low NDVI values predominate, except in small isolated areas, and by 13 September, almost the entire irrigated area gives low NDVI values as would be expected during the completion of ripening and harvesting. The NDVI time series therefore suggests that most of the crops were already at the egetative stage by 30 June and that most had ripened, and dried off by 13 September.

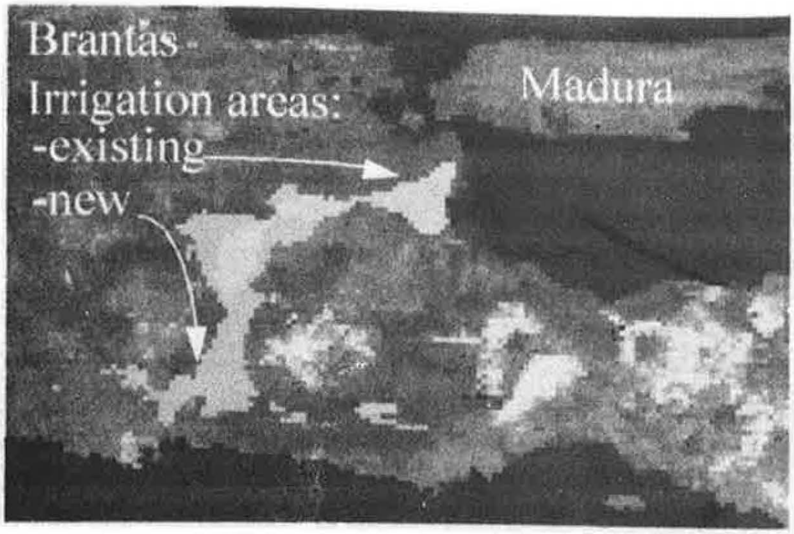


Figure 1(a): Location map for the Brantas innovated area

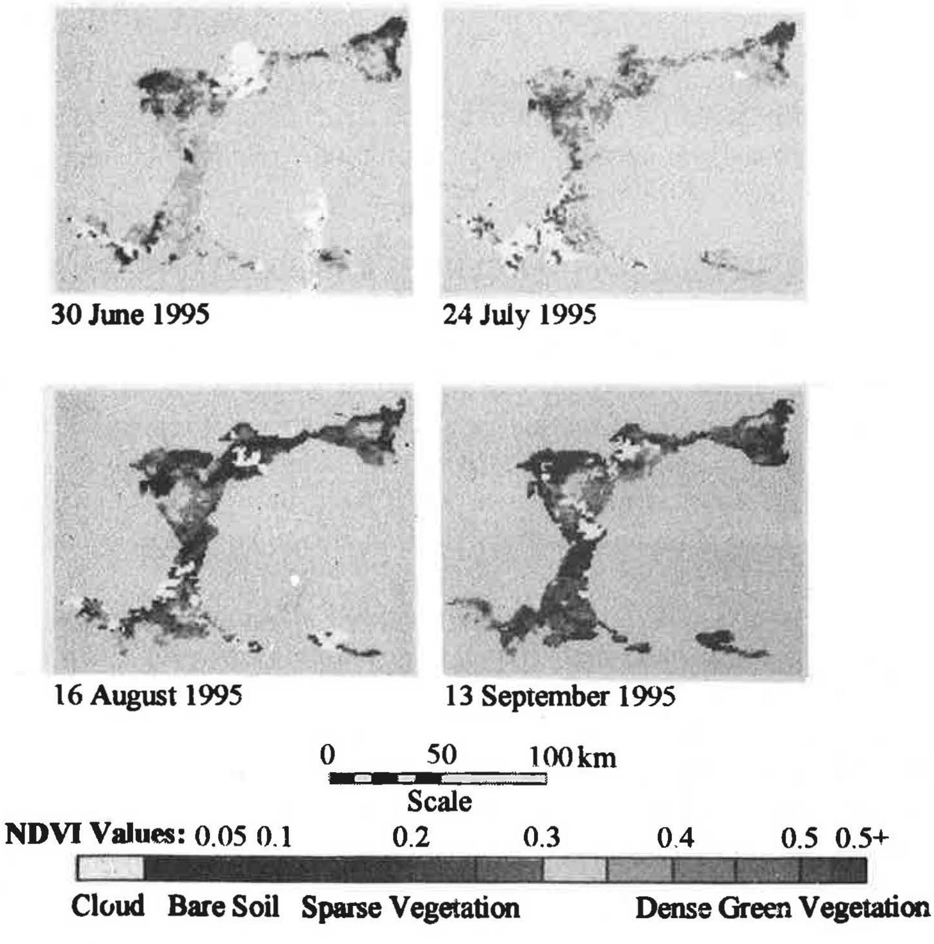


Figure 1(b): NDVI images for the entire Brantas irrigated area, 1995 growing season

Within this overall trend, substantial heterogeneities can be detected, demonstrating the value of the synoptic NOAA data for inexpensively assessing spatio-temporal crop status over the entire irrigated area.

It is specifically this heterogeneity, detectable by NOAA, which is of great interest to the irrigation planner when identifying and confirming those areas that really do need water. The following two examples, illustrated in figures 2 and 3, give more details of assessments for the Brantas Delta and Mrican Kiri irrigation blocks. In each case, NDVI and LST images are given for the irrigation block, for the same four image dates as in Figure 1(b) (A=30 June, B=24 July, C=16 August, D=13 September). Crop evolution is also demonstrated for one sample, through the interpretation of temporal profiles of NDVI and LST (the sample location is marked with an arrow). The amount of irrigation water that was supplied to the block is added on the profiles to show the interrelationship between the NOAA indicators and actual water supply. Henceforth, NDVI is used as a synonym with vegetation greenness (high NDVI = much green vegetation), and LST is used interchangeably with water deficit (as hotter surfaces have less water present and hence higher water deficit).

BRANTAS CASE STUDY 1: SIDOARJO, BRANTAS DELTA IRRIGATION BLOCK

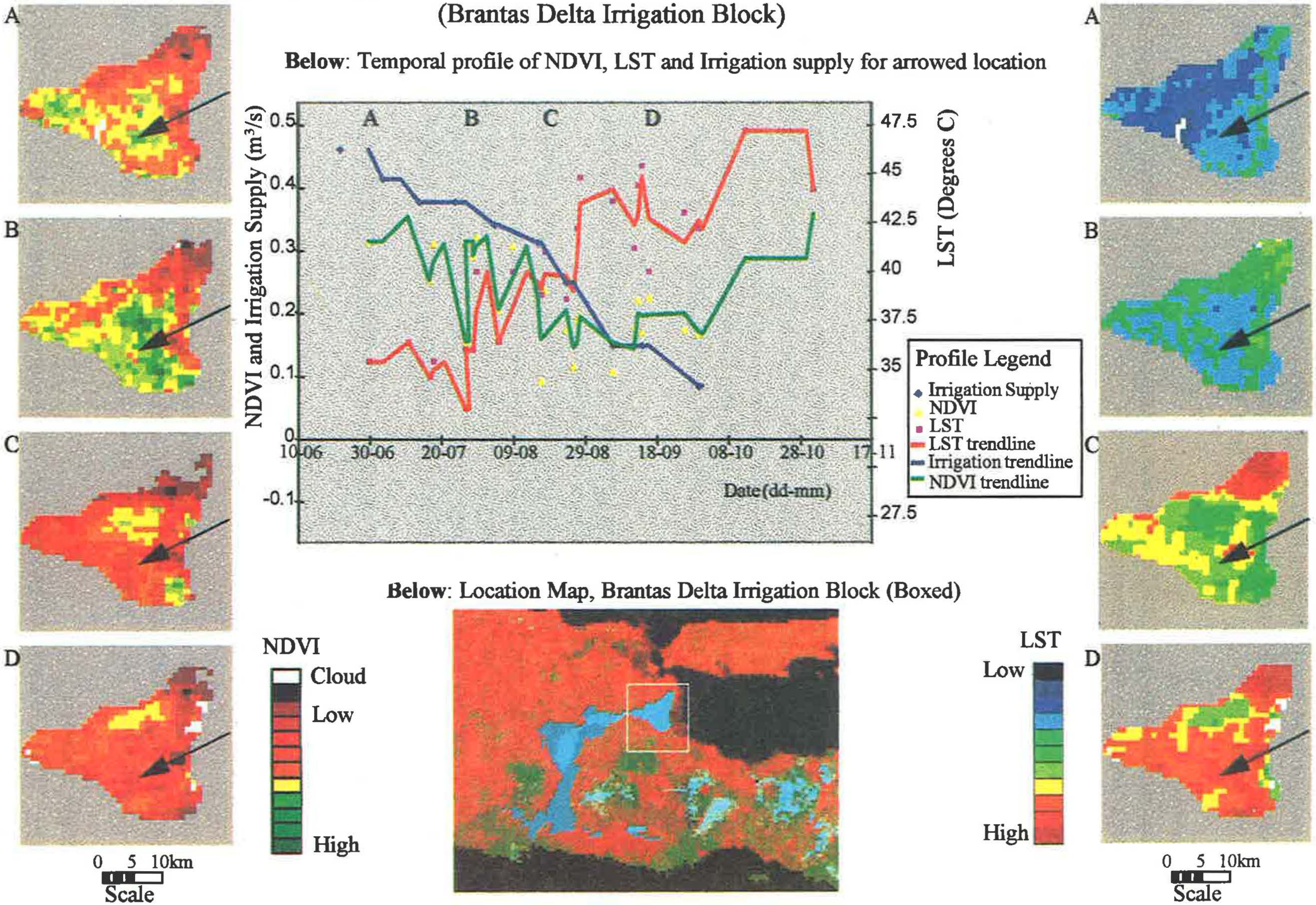
Figure 2 illustrates this case study. The location of the irrigation block is indicated on the NOAA images (similarly as Figure 1). The left column represents the evolution of the abundance of green vegetation (NDVI), and the right column that of water deficit (LST). The central graphs illustrate the evolution of the crop for that sample indicated with a black arrow. The case can be interpreted as follows.

(A) 30 June 1995: Upper delta is green (high NDVI on the left image), whilst the lower delta has low photosynthesis. Actual irrigation supply to the block (shown on the profile) was high. Water deficit on the right image is very low (blue colours) in the upper delta (as expected for high irrigation supply), whilst intermediate (green) in the lower delta. The above indicates that a vegetative stage crop is already present in the upper delta, with very low water deficit (low LST) due to the high irrigation supply. The temporal profile, (at the arrowed location), shows high vegetation, low temperature, high irrigation supply.

(B) 24 July 1995: Approximately one month later. The upper delta is generally greener, with the lower delta still unvegetated (left image). The arrow pixel is less green than for the previous image, suggesting ripening, and NDVI has dropped since the last image. Water deficit (right image) over the upper delta is slightly higher than for the previous image. This is consistent with a slight lowering of the irrigation supply (profile). On the temporal profile: high vegetation, low-intermediate temperature, slightly less irrigation supply.

(C) 16 August 1995: NDVI is much lower over the whole delta (left image) suggesting ripening. The surface temperatures are significantly higher as seen in green, yellow and

Figure 2: Monitoring the Status of Irrigation Fields
(Brantas Delta Irrigation Block)



red in the LST map (right). On the temporal profile: Much reduced photosynthesis (lower NDVI), higher surface temperature and much reduced irrigation supply all suggest the crop has ripened.

(D) 13 September 1995: The irrigation block has been harvested (completely red/yellow on NDVI map). Temperature is also high, suggesting high water deficit. On the temporal profile: no vegetation, dry soil, irrigation supply in minimum condition.

BRANTAS CASE STUDY 2: WIRUJAYENG IN MRICAN KIRI IRRIGATION BLOCK

Figure 3 illustrates this second case study in the same way for figure 2.

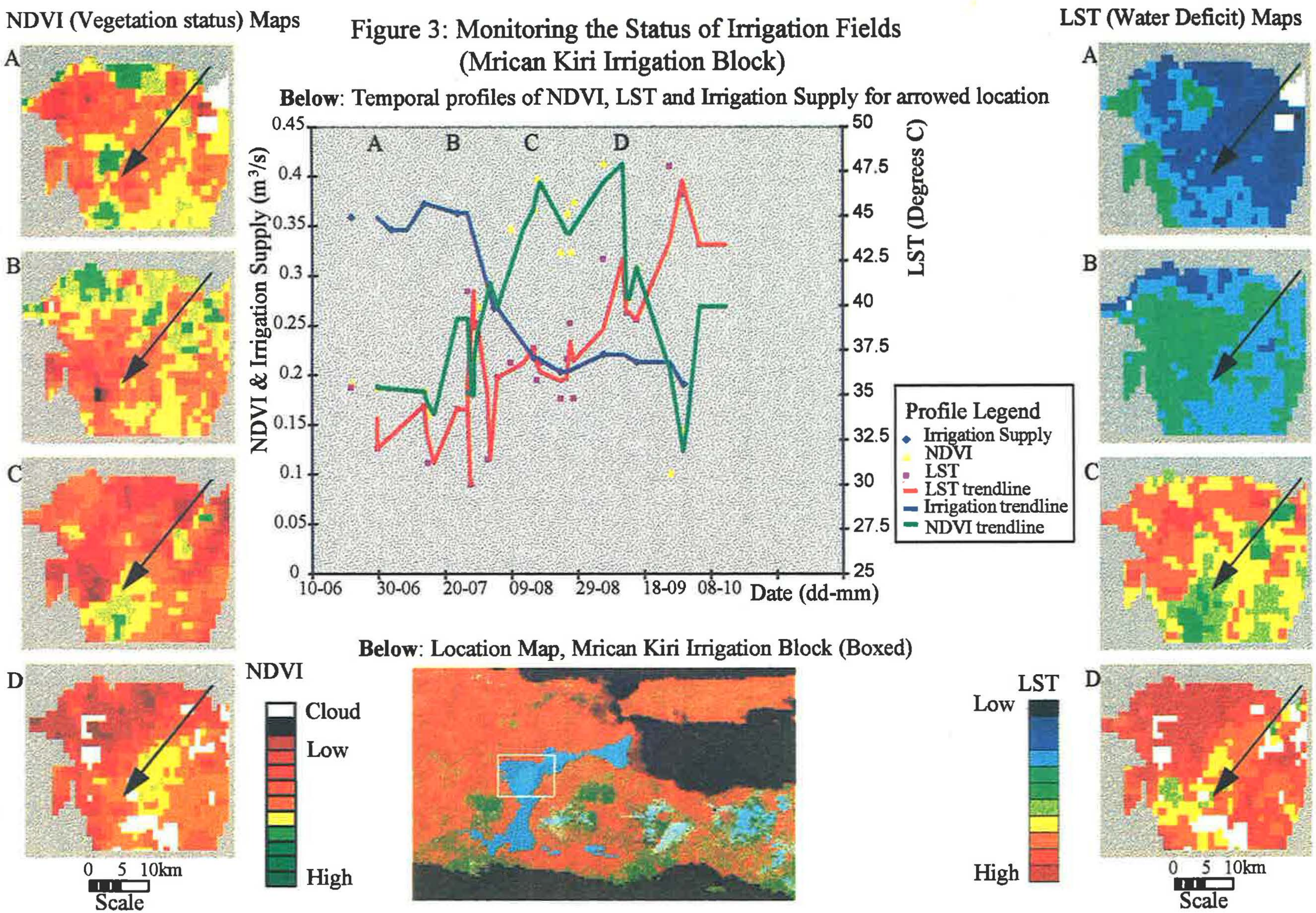
(A) 30 June 1995: around 50 % of the irrigation block appears to be photosynthesising (50% of block has high NDVI, left image). The entire irrigation block is cool (right image), suggesting low water deficit. At the arrowed position, the NDVI is low, accounting for the low NDVI in the profile and water deficit is very low, implying that the location is irrigated, but the crop (if planted) has not yet been detected on the NDVI. This is supported by the high irrigation water supply.
On the temporal profile: low NDVI (flooded, but early growth stage), low water deficit, high irrigation supply.

(B) 24 July 1995: NDVI is still high for around 50% of the area, with low to intermediate water deficits. The arrow pixel still gives a slightly higher NDVI value in the profile, suggesting that sufficient crop has grown for detection using NDVI.
On the temporal profile: higher NDVI, suggesting start of vegetation growth, low water deficit, suggesting area still well irrigated, high water supply, consistent with previous two observations.

(C) 16 August 1995: Although the majority of the block now has low NDVI and intermediate to high temperature, (suggesting ripening / harvest), a small patch with high NDVI has emerged in the south west corner of the block. The arrow location is just within this patch, accounting for the higher NDVI plotted in the profile. The remaining vegetated patch is relatively cooler than the surrounding fields (right image), suggesting a higher water availability within it than for the surrounding area. Irrigation supply has decreased substantially from 24 July, as would be expected if most of the area had already ripened or been harvested.
On the temporal profile: vegetation greener, temperature slightly higher, irrigation water decreased.

(D) 13 September 1995: Most of the area again shows low NDVI suggesting the majority of the area is now in the advanced stages of ripening / harvest. However, the arrowed location is still within a green patch. The profile suggests that this is the time of peak crop maturity. The temperature at the arrow location has risen, suggesting higher

Figure 3: Monitoring the Status of Irrigation Fields (Mrican Kiri Irrigation Block)



water deficit, consistent with the low actual supply plotted on the profile. On the temporal profile: vegetation is still growing and has reached peak crop maturity. Temperature is higher than before, as expected for the low irrigation supply condition and the season (dry).

These two examples over the Brantas watershed illustrate how LST and NDVI can allow us to interpret and discover the status of the irrigation fields through the growing season. There is consistency in the interpretation of the NOAA indicators and actual water supply figures supplied by Jasa Tirta, suggesting that the interpretations are valid.

EXAMPLE 2, IRRIGATED AREA, NORTHERN CITARUM WATERSHED, EAST JAVA.

Results are given for an area of known irrigated rice at the north of the Citarum watershed in West Java as a contrast to the Brantas examples. Figure 4 illustrates the evolution of this entire irrigated using a similar approach as for Figures 2 and 3. Notice the difference in spatial scale, and also in the colouring of the LST map. Here, larger ranges in temperature have been coloured uniformly, so that there are only five colours to represent the full range of LST. Purple is coolest, progressing through blue, green and orange to red, the hottest colour. Four LST maps are given. They were specially selected as they were well spaced in time and cover the bare-soil to vegetative phase, with minimal cloud obstruction. On the four LST images, the "active" irrigated area (mainly along the coast line) contrasts with the rest of the image.

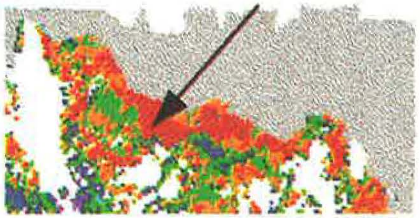
(A) 22 June 1995. The rice field area had low NDVI values and high LST. The time of the image was towards the end of the wet season, and the rice area is interpreted as being warmer than the surrounding areas. It is believed that fields are being prepared for rice transplanting, before the flooding. Area of variable and intermediate LST outside the paddy belt are interpreted as residual rain-fed vegetation.

(B) By 18 July 1995, it is believed that the fields have been flooded, and that the rice has been transplanted. The LST values has clearly dropped (due to the cooling effect of the water) over the rice area and NDVI values begun to increase (due to the beginning of the vegetation growth). In the area of rain-fed vegetation, LST started to increase (surface heating) due to the reduction of rains as the dry season started.

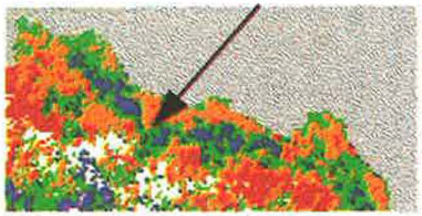
(C) 27 July 1995. The paddy rice area was still in the low LST categories, having lowered slightly from the preceding image reflecting the cooling effect of continued irrigation. NDVI had continued to rise, indicating further vegetative growth. Outside the irrigated area, low to intermediate LST persist, indicating that the unirrigated area has not warmed considerably.

(D) 15th August 1995. The majority of the land in the study area were in the highest LST, indicating surface heating due to the absence of rain or irrigation. Within the

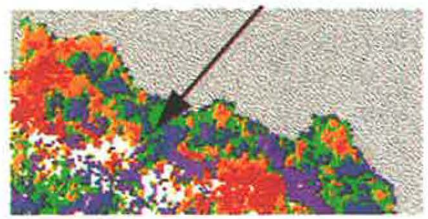
Water Deficit (LST) Maps



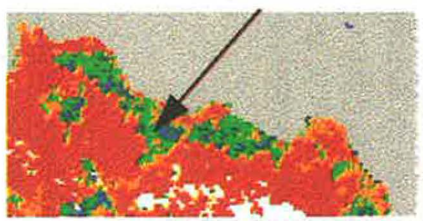
22 June 1995 (A)



18 July 1995 (B)

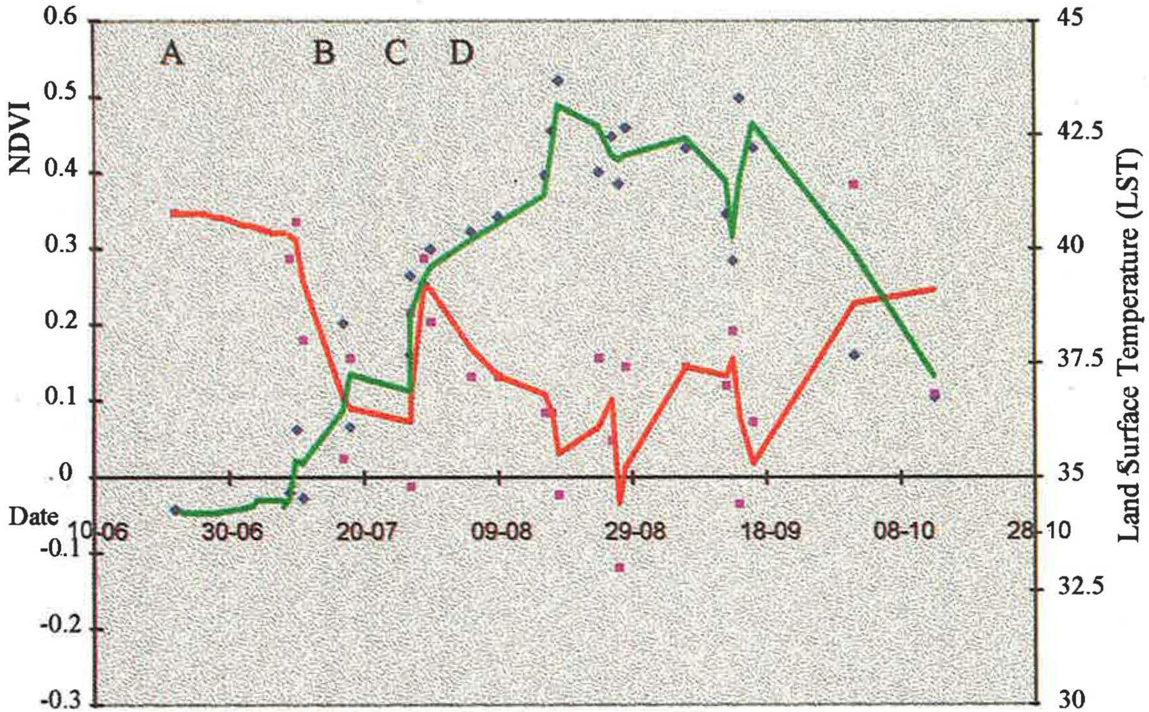


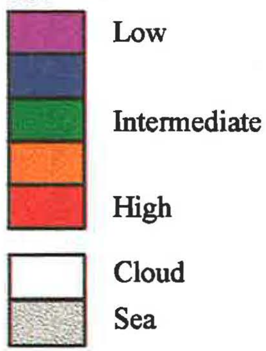
27 July 1995 (C)



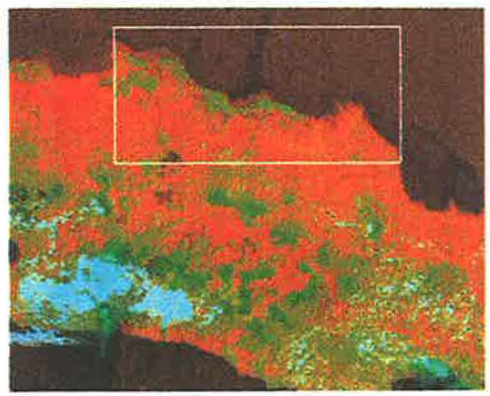
05 August 1995 (D)

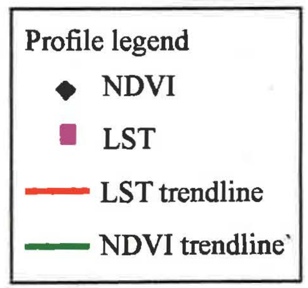
Figure 4: Monitoring the Status of Irrigation Fields
Northern Citarum Watershed





Below: Location Map, Northern Citarum Study area.





irrigated belt, LST was still significantly lower than the surrounding (unirrigated) area. This suggests the continued cooling presence of water. LST within the irrigated belt had by this time increased slightly in comparison with the previous date, probably due to beginning of the ripening and harvesting.

DISCUSSION

These examples clearly illustrate that both LST and NDVI indicators can assess the variable status of the irrigation fields. The actual general timing difference of rice growth between the Citarum and the Brantas irrigation fields is clearly identified: while the crop is starting its growth mid-July in West Java (probably for its second time), East Java is reaching the optimum of the growth, or even already ripening.

This confirms that the spatial changes observed within one irrigation area are indicating clearly what is happening. Therefore, one can combine NDVI and LST to help in making the appropriate decision for irrigation planning.

Irrigation management can be supported by such data in various ways, a few examples are given here:

Water needed: the areas needing more water can be identified. In Figure 3, frame C, it can be noticed that, the NDVI yellow area under the arrow (same level of vegetation), corresponds to different level of water deficit. From the various demands from that area, the management company will be able to prioritise the water supply to those areas most needing it.

Water surplus: on frame C of Figure 3, on the LST images, an area of lower requirements can be identified at the very top left (a green square slightly on the left at the top), whilst the NDVI image suggests that the area is unvegetated. Thanks to the frequent coverage, it can also be noticed with frame A, B and D that the crop on that area was at the optimum in B, and therefore that water was not needed anymore. This could be an useful way of controlling water wastes.

Action monitoring: on frame D of Figure 3, on the left of the arrow, a small area requiring less water can clearly be noticed (green area). The managing company can observe, there, that the water, which may have been requested in an area where no crop had yet been grown, had been distributed, and therefore control the implementation of its own decisions.

These examples demonstrate that, even by using simple approaches, daily coverage of AVHRR data can provide very valuable information to the irrigation management team. The approach needs of course to be fully validated and tailored to the actual need of the company. Better indicators such as more comprehensive water deficit index or evapotranspiration probably need to be implemented. By combining, in a GIS, a good validation, the invaluable local knowledge of the field, as well as the requirements of the irrigation, it is possible to best define the rules to implement in order provide an efficient, cheap, operational and reliable management map, to support decision making (similarly to Hartanto *et al.*., 1996, this issue).

CONCLUSIONS

The repetitive coverage, free availability and derivation of synoptic crop status and water deficit indicators from AVHRR have great potential for the operational supporting of decisions on water distribution.

This study illustrates the operational extraction of information on water deficiency within specific rice growing areas from time series of NOAA data. Results suggest that LST and NDVI images and profiles have great value for routinely support irrigation management team in assessing water deficit, water waste, and in monitoring the implementation of decisions, within the context of crop evolution over large irrigation belts.

The potential to support improved management is there. Further work is needed to reach efficiency by refining the techniques into operational and tailored methodologies. It is recommended that the work is advanced by establishing a NOAA station within an operational watershed management office, and assessing a complete irrigation season with simultaneously acquired NOAA data and ground observation.

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OPERATIONAL FOREST FIRE MONITORING AND PREDICTION IN SOUTH SUMATRA USING NOAA AVHRR DATA PLUS GIS TOOLS

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EXTENDED ABSTRACT

NOAA AVHRR data have been used to monitor forest fire operationally for some years in countries with extensive forest resources because of the repeat cover capability & high frequency of observation . The Government of Indonesia - European Union Forest Sector Support Programme (IFSSP) has installed a NOAA AVHRR receiver in the Biphut Forestry office in Palembang to provide real time information on fire activity in South Sumatra and to assist in eventually reducing the fire problem. The most immediate information outputs from the system are the locations of 'hot spots' indicating fire activity. A GIS database has been assembled which allows hot spots to be located in relation to current land use and land status. Another output is the development of an operational fire early warning system for the province through the application of GIS techniques. AVHRR- derived 5 and 10 day vegetation indices and hot spot locations, will be combined with other spatial information during the 1996 fire season to model fire hazard and fire risk over the province. AVHRR-derived fire information for 1995, made available through the UK-Indonesia Environmental Monitoring Programme has already enabled preliminary work to be done on the integration of AVHRR with other data. The projects own AVHRR receiver, installed in Palembang in January 1996 has already detected significant fire activity in South Sumatra which was successfully verified by a field visit made to the AVHRR-derived fire locations.

Forest fires in Indonesia have recently attracted considerable attention both nationally and within the broader SE Asia region. Much concern has been expressed at the effect of burning in reducing natural forest cover and due to the problem of large scale smoke and air pollution which may affect aircraft movement and shipping beyond national borders. The projects NOAA AVHRR receiving station installed in Palembang, South Sumatra will providing the provincial forest authorities (Kanwil and Dinas Kehutanan) with real time information on fire activity in the Sumbagsel (Sumatera Bagian Selatan) provinces of Bengkulu, Jambi, South Sumatra and Lampung.

Within the last fifteen years significant forest fire events have occurred in Indonesia and it is apparent that the risk of large scale fires with the capacity to cause very extensive damage is increasing. The peat swamp fires in E. Kalimantan during 1983- 84 and at Bukit Suharto in 1991 devastated thousands of hectares of forest. 1991 and 94 were significant years forest fire years South Sumatra at which time very extensive fire damage took place in peat swamp forest concessions and within Acacia mangium plantations. The 1995 season was relatively quiet by comparison to preceding years with respect to fire activity.

Although both Dinas and Kanwil forestry departments are users of the data, the Dinas, or provincial forestry service, is the main operational user in the sense that they are responsible for forest fire management activities at the smallest (local) level in the province, the forest 'resort'. Information from NOAA on the locations of fires in real time needs to be distributed rapidly from Palembang out to the resorts as quickly as possible.

The forestry departments current forest policy is to prohibit the use of fire as a means of land clearance, although since local enforcement is difficult, it is likely such clearance still continues in many areas. The NOAA system provides useful independent information on fire activity in real time. The EU system was installed on January 1996. Prior to this, some preliminary data for the month of September 1995 was provided by the UK-Indonesia Environmental Monitoring Project's AVHRR receiver. This allowed our project to obtain initial information on fire distribution during this short period.

Data was obtained and processed for 7 days in September 95, normally the month during which most burning activity takes place. The total number of observed fire events within the South Sumatra province during this period was 1749 points. Overlaying these points with land use maps within a GIS allowed us to estimate which land units were being most affected by fire. Preliminary results suggest that much of the fire activity occurs in agricultural areas and in dryland (Lahan Kering). Only 25% of the fires detected by the AVHRR occurred within forest lands. While the land use information may contain inaccuracies, these figures still give a general indication of where the fire activity is taking place.

Crossreferencing of the AVHRR hot spot maps with government - agreed forest use categories showed how fire activity increases with economic activity. Low fire counts were seen for Protection and Conservation areas, but increased with Limited Production and gave high fire estimates for production and convertible forest. This suggested that there may be a possible need to investigate further the fire activity in production and convertible areas of the province.

The numbers of AVHRR hot spots was compared to a 'drought index' that was created using standard meteorological parameters obtained from Palembang Airport. An encouraging convergence between the number of AVHRR hotspots the 'drought index' over a common monitoring period was found, showing an increase of fire activity with increasing drought conditions.

Since installation of the IFSSP's NOAA AVHRR receiver in Palembang on January 20, more than 600 fires have been identified. The distribution of fire locations, has shown a clear concentration of points in an area north of Jambi. A field visit was made to this area during 12-14 March 1996, and confirmed an extensive area of recently burned vegetation. The project's experience with field validation of detected AVHRR hot spots, and the integrated interpretations under active development underline the practical utility of local AVHRR reception for low cost, repetitive and sustainable fire monitoring over extensive areas.

THE USE OF NOAA DATA FOR FIRE DETECTION IN KALIMANTAN AND SUMATRA

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ABSTRACT

A total of 122 days (1 August - 30 November 1995) of satellite-based systematic monitoring of biomass fire in Kalimantan and Sumatera was implemented during the 1995 fire season. The image capture and fire detection processes were done by NOAA Satellite Small Ground Station operated by Indonesia Tropical Forest Management Programme, Ministry of Forestry. The equipment and software for this small station was provided by Natural Resources Institute and installed on 17 September 1993.

Based on this exercise, the following activities were successfully fulfilled: (a) optimal daily data acquisition of NOAA/AVHRR for Kalimantan and Sumatera, (b) daily hotspot detection of biomass fire, (c) testing of communication protocol for daily fire detection data to the Ministry of Forestry, (d) limited verification of hot spot detection data, and (e) consolidation of this experiment result into a Standard Operation Procedure (SOP) for biomass fire.

INTRODUCTION

The exploitation of Indonesia's natural forest, through private sector involvement, was started since 1967, with the introduction of regulation regarding forest exploitation, and incentives to safeguard investments.

The first natural forest management regulation was issued by the government in 1966, where forest utilization concession (HPH) was introduced. The second regulation was issued in 1972, which applied to all production forest, except tidal (mangrove) forests, with a rotation of 70 years. According to this regulation, the forests were managed under a combination of 3 systems : Indonesian selective cutting (TPI), clear cutting with natural regeneration (THPA), and clear cutting with artificial regeneration (THPB). The last regulation was issued in 1989, where TPI system has been modified to Indonesian selective cutting and replanting system (TPTI), and addition of more specific obligations for concessionaires to carry-out regeneration and reforestation.

In responding to the sustainable forest management requirement as stated by ITTO, further regulation was issued in 1991 (HIKKINDO, 1995), where HPH has been gradually adapted into the unit of Production Forest Management Units (KPHP). The main purpose of KPHP is to safeguard and to keep Indonesia's production forest as permanent forest under a sustainable forest management.

This paper will describe application of NOAA/AVHRR under the ITFMP for biomass fire monitoring in Kalimantan and Sumatera during the 1995's fire season. Fire is consider to be a pervasive threat to the permanent forest. The other threats are forest mismanagement practice by the concessionaires, encroachment, illegal cutting and failure to financially compete with other alternative forms of land use.

FIRE ISSUE IN INDONESIA

Biomass fire has become a serious international political issue in Indonesia during the 1990s, as its smoke is considered to be transboundary pollution to neighbouring countries. Figure 1 describes the general global implications of biomass burning adapted from Chuvieco and Martin (1994). From this context, smoke is a component of gaseous emission, which in the case of Indonesia will have main impact on regional air and sea transportation.

An International Workshop on long-term Integrated Forest Fire Management in Indonesia was convened in Bandung from 17-18 June 1992 by the National Development Planning Agency (Bappenas) and GTZ. As the result a framework for present and future activities of the public agencies, private sector and international donors in Integrated Forest Fire Management (IFFM) was developed (Bappenas, 1992).

Prior to the above workshop, a Preparatory Workshop was held on 13-14 February 1992 in Ciloto, West Java. Two documents were elaborated : (i) a comprehensive situation analysis on the present status of forest fire management in Indonesia, and (ii) an outline of components and the related field of activities which need to be considered and implemented to fully develop a well function IFFM system, suitable for the natural and socio-economic conditions of Indonesia.

The IFFM framework is based on five components, namely: organization and legal instruments, fire prevention incentives and disincentives programmes, vegetation management, pre-suppression and fire suppression.

Among these components, the pre-suppression is a relevant component to be addressed in this paper. The workshop considered three crucial sub-components of pre-suppression: (1) early warning system to predict and forecast irregular drought; (2) fire danger rating system to determine critical threshold which enabling IFFM to perform it tasks in the most economic way, and; (3) a combined conventional and satellite-based fire detection and reporting system.

The Indonesia Tropical Forest Management Programme (ITFMP) under its Project 2: Provincial Forest Management has responded to this critical Government need especially to the satellite-based fire detection sub-component. One of the stated objectives of this project is to establish a real-time fire detection and vegetation monitoring system based on NOAA. As a Programme under the Ministry of Forestry, it has adapted its monitoring capability not only for fires within or in edge of areas designated as permanent forest (KPHP), but also for biomass fire in general. The fire detection results are coordinated under the Center for Forest Fire Control at the national and local level (Pusdalkarhut-nas/da), which then passes the data to the National Coordination Team for Forest and Land Fire Control (TKNPKHL) or other end-users.

FIRE MONITORING WITH NOAA/AVHRR

In December 1990 - January 1991, an assessment of the potential of NOAA satellite for forest fire monitoring in Kalimantan and Sumatera was made by the Ministry of Forestry (INTAG, 1991). On this basis a clear need for timely data for vegetation and fire monitoring over large areas was identified and the potential of NOAA imagery was recognized.

According to Chuvieco and Martin (1994), application of remote sensing (including NOAA/AVHRR) for fire spot detection, can be classified into the following themes : (1) detection of fire spots, (2) cartography of burned areas, (3) estimation of gas emissions, (4) assessment of fire effects and plant cover evolution after the fire, (5) monitoring forest fuel conditions (vegetation moisture stress), and (6) development of risk models by the integration of image interpretation within a Geographic Information System.

Under the cooperation between the Ministry of Forestry (MOF) and Overseas Development Administration (ODA)/UK, the ITFMP has established a NOAA Satellite Small Ground Station (SSGS) in Palangkaraya, Central Kalimantan. The Station is successfully operating and first data was recorded on 17 September 1993.

After a few technical teething troubles, the system became fully operational at the beginning of 1994 (Schneider, 1995). Imagery was collected intermittently over the 1994 fire season (Sep.-Nov.). Most of the images captured were of Kalimantan since that was the area for which there was most local interest. A few example images were also captured for Sumatera.

Based on this experience, some significant problems were identified with the standard fire detection algorithm (multi-channel threshold) used in the BURL NOAA software. Recommendations were made for the development of more complex contextual algorithms appropriate to Indonesian conditions.

As the follow-up to the recommendations improved fire monitoring software was installed in June 1995. The software is based on the contextual algorithm which consists of two stages (Flasse and Ceccato, 1996): the first selects candidate pixels which could potentially be fires (PFs) and the second confirms or otherwise by comparing PFs with their immediate neighbours. Although this algorithm has not yet been tested exhaustively, details of first validation appears to be excellent. Only 15 per cent of the pixels detected by the algorithm as fires were misclassified. Therefore, as fire detection is 85 percent reliable, fire information must be interpreted carefully and integrated in their context.

EXPERIENCE DURING FIRE SEASON 1995

Experience in the 1994 fire season and improvement in fire detection software, have made the NOAA SSGS in Palangkaraya more ready for a systematic fire monitoring in 1995. The objectives of this monitoring experiment are : (a) optimal daily data aquisition of NOAA/AVHRR for Kalimantan and Sumatera, (b) daily hotspot detection of biomass fire, (c) testing of communication protocol for daily fire detection data to the Ministry of Forestry, (d) limited verification of hot spot detection data, and (e) consolidation of this experiment result into a Standard Operation Procedure for biomass fire.

In terms of fire management problems, remote sensing system could contribute to the three phases (Chuvieco and Martin, 1994): (a) pre-fire planning phase, which is directed to the optimum organization of resources for fire emergencies, (b) fire phase, which includes detection, suppression, and burned land mapping, and (c) post-fire evaluation phase, for the possibility to reduce the effects of fire. The 1995 fire monitoring experiment was mainly concentrate on the second phase, due to its relevancy to the ITFMP/Project-2 stated objective.

A brief result of this experimental monitoring is described below. The complete report was presented in two-volume documents (Raimadoya, 1995a). The first volume is the text report and the second volume is the compilation of fire detection data of Kalimantan and Sumatera.

Standard Operation Procedure

A basic operation framework concept for the role of NOAA SSGS in biomass fire monitoring within the Pusdalkarhut-nas/da scheme is presented in Figure 2 (Raimadoya, 1995). The main target of this framework is the daily distribution of fire detection data within **two-hours** after the acquisition of satellite signals. This data will then be used by the end-user at the national and the local level for further application.

Table 1 below provides the complete list of Quality Assurance and Quality Control documentation covered under this standard operation procedure. Example of raw fire detection data is given in Figure 3. This data are processed further into a map tile for each province as given in Figure 4. A tile is a delineated geographical area used as a base unit for data organization (Chou, 1992). It will be recognized easily that for our experiment, a province is divided into several tiles, and a tile is consist of several 1:250,000 scale map sheet unit.

Table 1. Documentation covered in the Standard Operation Procedure (SOP).

No.	Documentation #	Description
1.	1995/QA-1.0	Weekly Data Acquisition Plan (WDAP)
2.	1995/QC-1.0	Two-Line Element Updating
3.	1995/QC-2.0	NOAA Satellite Data Acquisition
4.	1995/QC-4.0	Block Image Processing
5.	1995/QC-5.0	Fire Detection Operation
6.	1995/QA-2.0	Fire Coordinates Data
7.	1995/QC-3.0	Daily Communication Protocol of Fire Coordinates Data
8.	1995/QC-6.0	Provincial Fire Coordinates Data

Fire Detection Data Verification

A limited exercise for the verification of fire detection data was done during the monitoring activity. Due to the limitation of staff in NOAA SSGS in Palangkaraya, Central Kalimantan, verification was only made to four images. The first three were done by ground checking for the surrounding area of Palangkaraya, Central Kalimantan, and the last one was done by flying into the detected two fire coordinates in Semayang Lake are of East Kalimantan and recorded the fire into small format aerialphotos. This aerialphoto mission was done under the cooperation with the Conservation Site Monitoring System (CoSMoS) Team of the National Research Council/Ministry of Research and Technology (Raimadoya, 1995b).

CONCLUSION AND PERSPECTIVES

Experience from the 1995's fire season has shown that NOAA/AVHRR data could be used effectively for fire detection purpose. It is also clear that the introduction of satellite-based fire monitoring, could be considered as capacity development exercise. It took several years to allow the Station staff to be ready for operational fire monitoring. As a capacity development exercise, this iterative process of fire monitoring is expected to be improved further in years to come. Which in turn will provide an operational SOP for fire detection in Indonesia.

Table 2. Verification result of fire detection data from five images.

Location	Image	Albedo (%)		Brightness (K)			Area (m^2)
Bukit Batu	21/10/95	1.4	1.6	321.8	285.5	285.4	100,000
		1.5	1.6	321.8	285.5	285.4	
		1.5	1.6	316.0	285.5	285.4	
Nyaru Menteng	23/10/95	5.7	10.7	315.4	301.3	296.3	10,000
AMACO	01/11/95	8.7	14.6	314.8	299.5	293.9	1,500
		8.7	14.9	314.6	299.4	293.6	
Tingang	01/11/95	7.4	12.5	317.1	298.8	293.6	10,000
Semayang	05/11/95						1,500
							10,000

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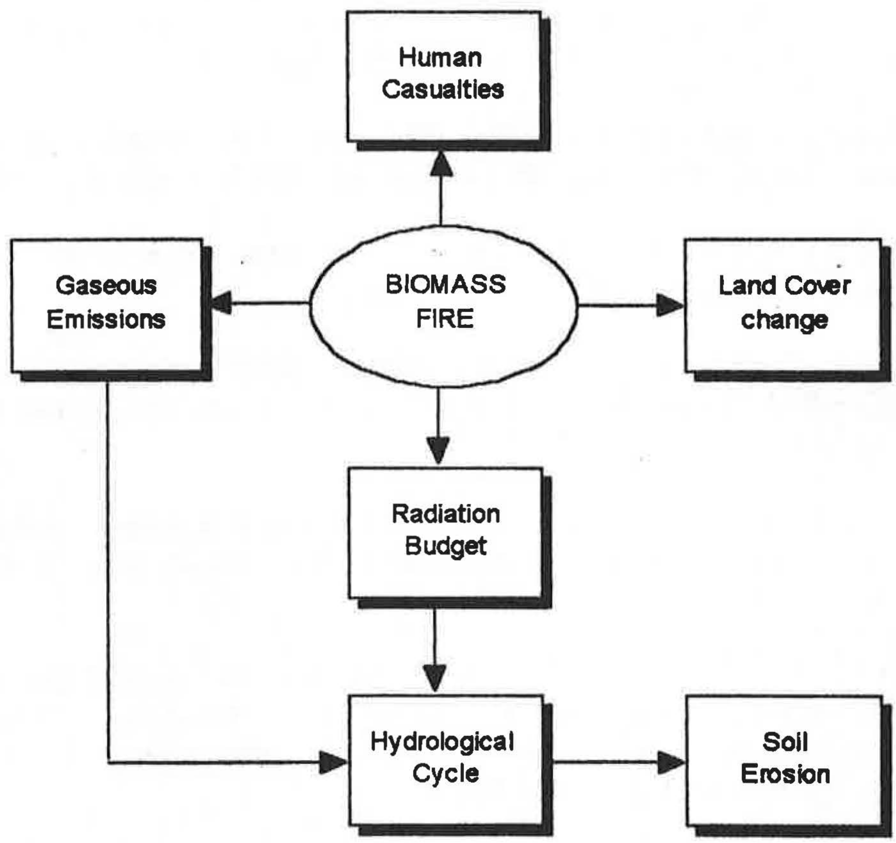

Figure 1. Global implications of biomass burning (adapted from Chuvieco and Martin, 1994).

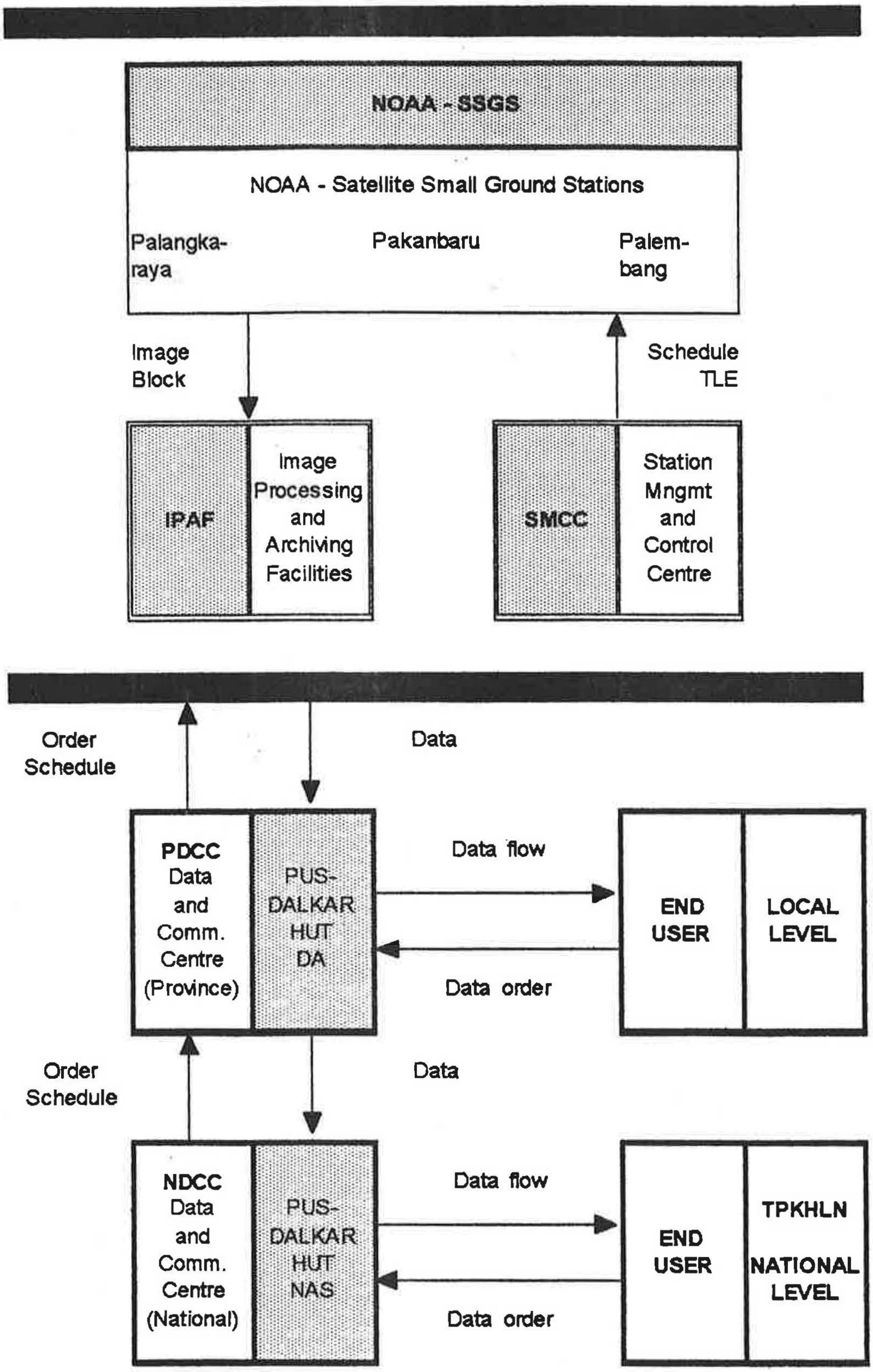

Figure 2. Basic operation framework of the Ministry of Forestry's NOAA Satellite Small Ground Stations system for biomass fire monitoring (Raimadoya, 1995).

Figure 3. Example of fire detection data.

SBKS NOAA PALANGKA RAYA FORM 1995/QA-2.0
DAFTAR KOORDINAT TITIK API (DKTA) 27/10/1995

KALIMANTAN (ALL)
IMAGE # SE38861F 08/08/95 06:32 GMT

1, 117.28, 5.68
2, 113.08, 3.22
3, 113.07, 3.21
4, 110.33, 1.49
5, 110.38, 1.45
6, 109.99, 0.59
7, 110.00, 0.60
8, 109.33, -0.09
9, 109.13, -0.49
10, 109.57, -0.44
11, 109.58, -0.44
12, 112.86, -1.96
13, 110.89, -2.42
14, 110.88, -2.43
15, 111.38, -2.45
16, 111.40, -2.45
17, 110.18, -2.71
18, 110.19, -2.71
19, 112.21, -2.57
20, 112.45, -2.53
21, 112.20, -2.59
22, 112.23, -2.58
23, 110.94, -2.88
24, 111.91, -2.73
25, 111.78, -2.82
26, 111.66, -2.93
27, 113.04, -2.73
28, 113.05, -2.73
29, 113.06, -2.73
30, 113.02, -3.07
31, 113.03, -3.07
32, 112.07, -3.23
33, 113.03, -3.08
34, 112.47, -3.25
35, 112.59, -3.24
36, 112.60, -3.24
37, 112.87, -3.33
38, 112.88, -3.33

END
Palangka Raya, 11 Agustus 1995
Process & Printed by Hendrik Segah S.Hut

*** Data koordinat belum diverifikasi kebenarannya. Pemakai data perlu mempertimbangkan masalah ini dalam interpretasi. Hapuskan teks diluar batas ini dan nomor urut koordinat, untuk pemrosesan data lebih lanjut dalam GIS