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USING RADARSAT IMAGERY TO ASSESS RESIDUAL ENVIRONMENTAL EFFECTS OF THE VIET NAM WAR (1961 - 1975)

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PHASE IIb REPORT

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EXECUTIVE SUMMARY

This report documents the results of Phase IIb of the Hatfield Consultants Ltd. RUDP project, "Using Radarsat Imagery to Assess Residual Environmental Effects of the Viet Nam War (1961-1975)", and contains the primary technical output of the project. This report is contained within two volumes: Volume 1 - an interpretative report; Volume 2 - a folio of remote sensing imagery, with supporting annotation and visual information. An appended CD-Rom contains electronic copies of imagery presented in Volume 2 and Appendix A2.

Project objectives addressed in Phase IIb included: acquisition of new Radarsat imagery of study areas in central and southern Viet Nam and Laos; collection and acquisition of secondary information, such as other remote sensing imagery and land use information; remote sensing image processing; and extensive ground-truthing and interpretation of processed Radarsat scenes in Viet Nam and Laos.

Radarsat imagery of areas heavily impacted during the Viet Nam war through herbicide applications, aerial bombardment, and other war-induced changes, was interpreted through ground-truthing studies, supporting historical, topographic and land use information, and aid from Vietnamese forestry specialists. An assessment of the ability of Radarsat imagery to discriminate specific land use, forest cover and coastal features was made. Additionally, the utility of Radarsat imagery as a tool for environmental monitoring and management was evaluated.

Single-date Radarsat data was limited in its ability to discriminate land use and forest cover features, although it was effective at discriminating land/water interfaces. Scenes of identical beam mode and incidence angle collected on different dates varied in their ability to discern many features, even those without an expected seasonal variation in radar backscatter, such as plantation forests. Images taken at high incidence angles (e.g., S7) were more effective at discriminating land uses and cover than lowincidence angle imagery (e.g., S2).

Multi-temporal Radarsat scenes were very effective at highlighting areas of seasonal agriculture, and allowed discrimination of broad land use and cover categories in most lowland areas of Viet Nam. Single-date and multi-temporal Radarsat scenes both were less effective than SPOT-XS or Landsat MSS imagery at discerning boundaries between certain upland non-seasonal land cover types, such as boundaries between forests and uncultivated grasslands.

In the study areas examined, environmental consequences of war remained apparent in 1997 to different degrees and in different ways. In Quang Tri province near the former demilitarized zone (DMZ), an area of heavy bombing and herbicide applications, barren land remains prevalent; barren areas and replanted forest plantations were visible in single-date and especially multi-date imagery. In areas of steeper terrain such as Khe Sanh and the A Luoi valley, barren areas resulting from intense bombardment and/or herbicide applications were not visible in Radarsat imagery, likely due to foreshortening effects in areas of steep topography. The Ma Da

forest of southern Viet Nam exhibits numerous linear areas of uncultivated grasslands where herbicides were applied intensively during the war; natural forest has regenerated around these areas, but not along these heavily-sprayed "lines" through the forest. Areas of the Ca Mau peninsula of southern Viet Nam where native mangrove forests were destroyed by herbicides have been converted to small-scale shrimp aquaculture. Much of the Rung Sat mangrove forest near Ho Chi Minh City has been actively and successfully rehabilitated with new mangroves with protected status. When combined with historical herbicide application data, Radarsat imagery was effective at indicating areas with potential high risks from chemical contamination, such as newly-built reservoirs, and areas of extensive human settlement and agriculture.

Generally, Radarsat was highly effective at discerning coastal features such as fishing and aquaculture structures in formerly cleared areas, somewhat effective at discriminating barren areas resulting from herbicide applications, but not effective at discriminating remaining effects of bombardment (such as the numerous craters in the Plain of Jars area of Laos). These latter features were likely at or below the resolution limit of Radarsat fine mode, and could not be discriminated from speckle in the Radarsat scenes.

While not as effective as optical imagery at discerning different forest cover and land use features, particularly in steep terrain, Radarsat data, particularly multi-date scenes, were highly effective at discriminating land use patterns in flat to slightly hilly terrain, and in coastal areas. The ability of Radarsat to penetrate cloud cover, and the ability to effectively schedule image acquisition, makes Radarsat data particularly useful for environmental management and monitoring applications in Southeast Asia. While limited by the non-calibrated nature of radar data, and the effects of foreshortening in steep areas, Radarsat data could be of high utility and value for specific applications such as land use mapping in lowland areas, basemapping of coastal areas for environmental assessments, study design for contaminant studies, flood monitoring and floodplain delineation and change detection in agriculture forestry, aquaculture, and urban development throughout Southeast Asia.

1.0 INTRODUCTION

"Environmental damage was an important tactic as well as a repercussion of the Second Indochina War of 1961 to 1975. The strategy involved the destruction of the natural resource base essential to the agrarian society. The theatre of these operations was mainly southern Viet Nam. The result was not only heavy direct casualties and continuing medical complications, but also the widespread disruption and degradation of productive ecosystems." (World Bank 1995a)

1.1 THE VIET NAM WAR AND ITS IMPACTS ON THE ENVIRONMENT

Numerous areas within Indochina require rehabilitation from environmental damage caused by the Viet Nam war (second Indochina war). Environmental damage includes forest and other vegetation removal as a direct consequence of herbicide applications, soil erosion caused by bombing and shelling, vegetation burning and clearing by bulldozer/Rome plough, and wetland draining. Excluding herbicide application, the following activities were carried out by the U.S. military between 1961 and 1975 in Viet Nam (World Bank 1995b):

- B-52 saturation bombing, particularly with high explosive ordnance. Approximately 12 million tons of bombs and shells were dropped, creating over 20 million craters and displacing approximately 3 billion m^3 of soil. Further, millions of unexploded bombs and shells still contaminate the land;
- clearing of approximately 325,000 ha of forest, crops and villages by bulldozer/Rome Plough, to deny cover, food and shelter;
- burning of *Melaleuca* forests in the Mekong Delta by napalm bombing (large areas of grasslands and other vegetation were also burned using various incendiary devices); and
- wetland draining, especially in the 800,000 ha Plain of Reeds area which led to soil desiccation and a decrease of soil pH to near 3.9 and water pH to near 2.8.

Impacts of defoliant spraying are more subtle and pervasive than the environmental impacts of the bombing and associated soil erosion, burning, wetland drainage and land clearance. Hong and San (1993) and the World Bank (1995b) documented some of the environmental war damage as follows:

- 36% of all mangroves destroyed;
- 20 million m^3 of commercial timber destroyed;
- 4.9 million ha of forest shrapnel-damaged;
- 51,000 ha of inland, 124,000 ha of mangrove, and 27,000 ha of *Melaleuca* forests lost;

- 30% of rubber plantations destroyed; and
- widespread destruction of wildlife and fisheries resources.

1.1.1 Herbicide Spraying

The rationale for spraying herbicides from the U.S. military perspective was to deprive opposing troops operating in the jungles of South Viet Nam of cover, thereby reducing their ability to remain undetected, and to increase the safety of American and South Vietnamese (USVN) troops patrolling these areas (Westmorland, 1976). Herbicides were also applied to rice fields and other crop land in South Viet Nam, to deprive local communist forces of food.

Herbicides were applied by air from fixed-wing planes and (less frequently) helicopter, and on the ground from trucks, river patrol boats, and by hand. The aerial spraying program, named Operation Ranch Hand, accounted for the vast majority of herbicides applied to the south Vietnamese environment. After initial testing in 1961, aerial spraying became operational in 1962 and peaked between 1967 and 1969. The aerial spray program terminated in 1971 as a result of intense public pressure and criticism from the international scientific community.

Two ecologists supported by the Society for Social Responsibility in Science wrote a vivid account of a spray mission (Neilands *et al.* 1972):

"The target area [the Plain of Reeds, in the Mekong delta] *was marked by smoke bombs, and we dove from our altitude of 4,500 feet to about 100 feet above the ground at the maximum descent allowable by the aircraft. There were seven aircraft in our flight, and they were staggered so that the spray from each plane overlapped the spray from the plain ahead of it. As we leveled off, one could see the spray emerging from the nozzles on the wings and the tails of the planes ahead of us. From our location between the pilot and the copilot we were able to see the operation readily. As we flew just above tree level, hundreds of herons, egrets and storks flew up in front of us and we may have hit some of these birds as we flew through them. At the beginning of the run our escort of F-100 fighter-bombers, going at tremendous speed, dropped cluster bomb units on either side of the target area. These produced large explosions and clouds of smoke in our path. The subunits then exploded in smaller balls of red fire looking like sparklers and spreading the antipersonnel pellets designed to keep down the heads of the antiaircraft gunners below is."*

More than 6,500 aerial spray missions are recorded in the HERBS data base maintained by the Chemical Operations Division, U.S. Military Assistance Command, Vietnam for the period of August 1965 to February 1971 (IOM 1994). Approximately 21.4 million gallons (97.2 million litres) of herbicides were applied to the Vietnamese environment over the duration of the spray program (IOM 1994).

Herbicides were applied to approximately 3.6 million acres (1.5 million ha), approximately 10% of South Viet Nam (Bengtsson 1976, Cecil 1986, IOM 1994) between 1965 and 1971. Most areas sprayed were inland and mangrove forests, although 14% of spray missions targeted

cropland comprising 177,000 ha upland crops and 59,000 ha rice paddy (World Bank 1994b). Roughly 34% of the target areas were attacked more than once and some areas, especially upland forests, were sprayed up to four times. Figure 1 illustrates the extent of aerial herbicide applications from 1965 to 1971, taken from the HERBS database.

In addition to chemical damage, there was associated physical environmental damage to habitats and wildlife from the air attacks in support of the spraying. This associated damage has never been investigated.

1.1.2 Herbicides, Agent Orange and Dioxin

The main chemicals used as defoliants and for crop destruction are presented in Table 1.1.

Table 1.1 Major herbicides used in the Viet Nam war (Neilands *et al.* 1972)

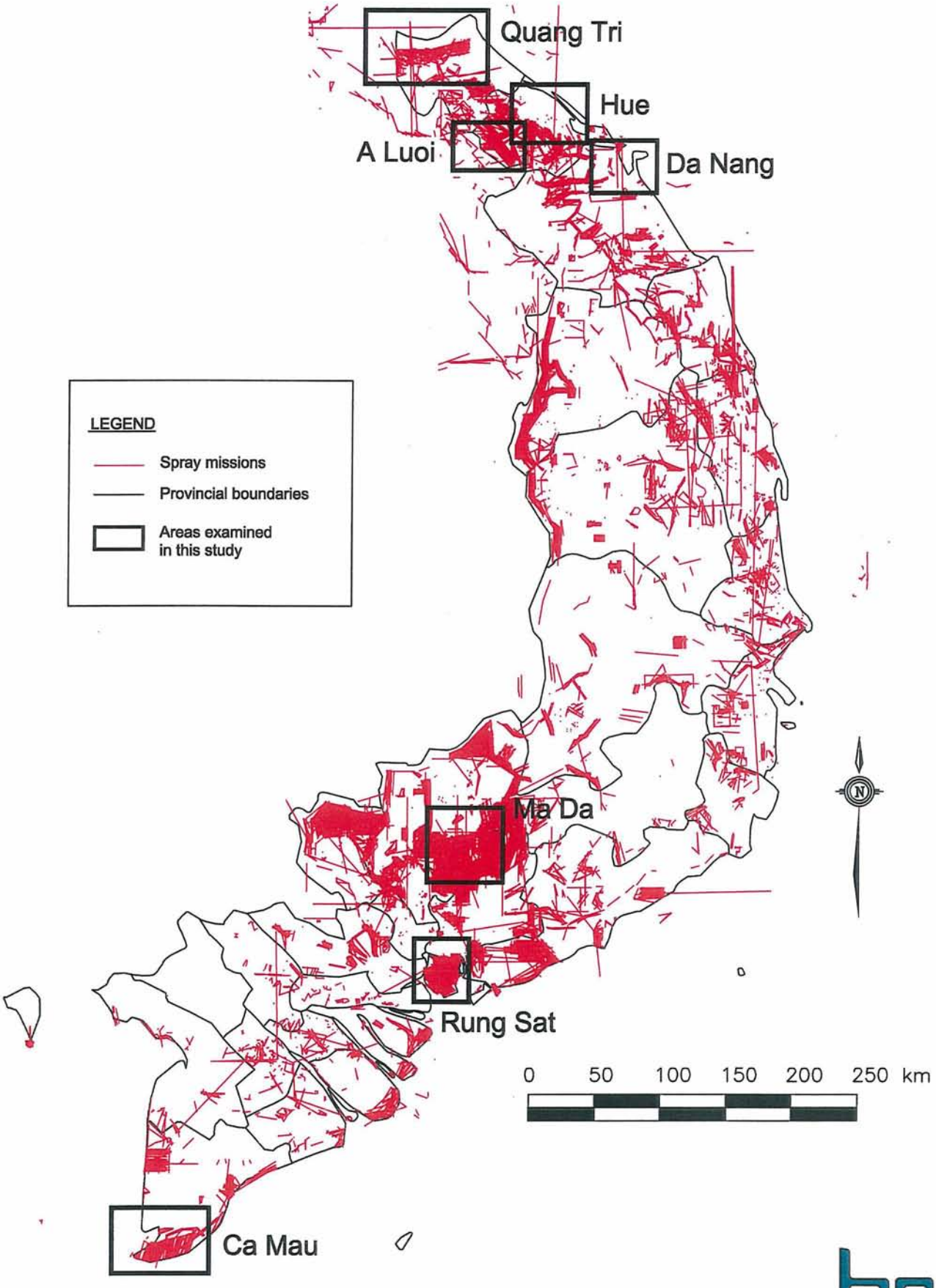
Herbicide	Major Target	Composition	Application
Agent Orange (mixture of 2,4-D and 2,4,5-T)	Forests	1:1 mixture of n-butyl esters of 2,4-dichlorophenoxyacetic acid and 2,4,5-trichlorophenoxyacetic acid	Undiluted; 3 U.S. gallons/acre
Agent White (mixture of 2,4-D and Picloram)	Forests	4:1 mixture of tri-iso-propanolamine salts of 2,4-D and 4-amino-3,5,6-trichloropicolinic acid in water	Undiluted; 3 U.S. gallons/acre
Agent Blue (Cacodylic acid)	Crops	6:1 mixture of sodium dimethyl arsenate and dimethyl arsenic acid in water	Undiluted; 3 U.S. gallons/acre

Agent Orange was a mixture of 2,4-D (2,4-dichlorophenoxyacetic acid) and 2,4,5-T (2,4,5-trichlorophenoxyacetic acid). Approximately 11.3 million gallons (51.3 million litres) of Agent Orange were sprayed during 4,109 of those missions (approximately 60% of the total herbicide volume sprayed).

It was discovered during the war that Agent Orange contained significant levels of tetrachlorinated dioxin (TCDD: 2,3,7,8-tetrachlorodibenzo-para-dioxin), a by-product created in the manufacturing process of 2,4,5-T. Dow Chemical, one of the manufacturers of Agent Orange, estimated levels of tetrachlorinated dioxin and furan (TCDD and TCDF) varied from less than 0.05 ppm to 47 ppm; the average dioxin content of herbicides used in Vietnam was estimated at 16 ppm (Bengtsson 1976). According to Gough (1986), approximately 90% of all Agent Orange was sprayed on jungle, 8% on food crops, and 2% was used by other branches of the military for "special purposes".

Unlike 2,4-D and 2,4,5-T which break down over a period of months, dioxin is a relatively stable compound. Dioxin persists in the environment and is magnified in the food chain (IOM 1994). Dioxin's estimated half-life in the environment ranges from 3.5 years (Westing 1984) to 10 years

Figure 1 Aerial herbicide spray missions in southern Viet Nam, 1965 to 1971.



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(Thu *et al.*1994). Concentrations of dioxins applied during the war persist in the Vietnamese environment today, and have been attributed to health and reproductive problems in Vietnamese citizens and American soldiers who served in Viet Nam (Schecter *et al.* 1995).

To place the above dioxin concentrations in context, it is helpful to consider the response of Canadian regulatory agencies to the detection of dioxins in some pulpmill effluents in the late 1980s. Dioxin concentrations in pulpmill effluent in Canada are typically expressed in units of pg/L or parts per quadrillion (ppq) [i.e., one part per 10^{15}]. Dioxin concentrations in Agent Orange were expressed in units of parts per million (ppm) [i.e., one part in 10^{6}]. This means that dioxin concentrations in Agent Orange were in the range of a billion (10^{9}) times greater than dioxins in pulpmill effluent.

1.1.3 Herbicides and Public Health Issues

"*Few issues manifest the ideological divisions in our society as powerfully as the Vietnam War, and no public health issue is more entangled with our unease about that war than the health effects of dioxin.*" Dwyer and Flesch-Janys (1995)

While dioxin contamination of the Vietnamese environment is not the direct focus of this project (see Section 1.3 for list of project objectives), it is relevant given the scope and likely impacts of dioxin in Viet Nam. An extensive literature exists on the Agent Orange/herbicide spraying health and ethics issues in Viet Nam including books (Whiteside 1971; Wilcox 1983; Westing 1984; Cecil 1986; Gough 1986; Schuck 1986; Young and Reggiani 1988), an annotated bibliography (Harnley 1988) and health-related studies on dioxins (Schecter 1994).

The majority of studies focused on potential human health impacts and were undertaken by medical experts and/or epidemiologists. A few studies have investigated the impacts of herbicide applications on individual ecosystem components (e.g., soils, mangroves), but there is no literature available on the relationships between dioxin concentrations in different ecosystem components. Establishing these relationships is obviously important when trying to assess risks associated with exposure by existing populations to residual enivornmental contamination by dioxins. In addition, herbicide applications made over 25 years ago may have resulted in long term alterations to land-cover and land-use patterns. Further studies are required to better understand whether observed changes in land-use and land-cover are impacted by residual environmental contamination, and if rehabilitation efforts need to consider dioxin contamination levels.

To better understand these issues, Hatfield Consultants Ltd. (HCL), in collaboration with the 10- 80 Committee, FIPI and other Vietnamese agencies, recently completed a comprehensive environmental sampling program for dioxins in areas of south and central Viet Nam (Hatfield Consultants Ltd., *in prep.*). Multiple ecosystem components were sampled for which Radarsat images provided valuable supplementary information, assisting the program in selecting suitable sampling sites, particularly in the Ma Da forest area.

Medical studies have evaluated health effects of dioxin contamination associated with herbicide spraying; two main areas of investigation exist:

- U.S. veteran health issues associated with military personnel who handled the herbicides; and
- epidemiological studies in Viet Nam which evaluate the effects of spraying on people resident within heavily sprayed areas.

Dioxin is taken up and measurable in tissues (fat and blood) and breast milk of people who live in sprayed areas (Schecter *et al.* 1985, 1989 a, 1995). For example, pooled blood samples collected in 1991-92 in southern Viet Nam yielded dioxin levels of 33 ppt, compared with less than 2.9 ppt in samples from north Viet Nam (Schecter *et al.* 1995). Verger *et al.* (1994) confirmed the correlation between dioxin levels in fat and estimated exposure to Agent Orange in south Vietnamese residents. The Government of Viet Nam, through the 10-80 Committee, remains actively involved in epidemiological studies of the health effects of dioxin contamination (Cau *et al.* 1994).

Establishing which ecosystem components are most contaminated by dioxins, and developing an understanding of potential exposure mechanisms to these dioxins by existing populations is critical from a human health perspective. Although herbicide spray missions stopped over 25 years ago, resident populations may still be exposed to levels of dioxins considered unacceptable by North American standards through the foodchain and the process of biomagnification. Further research is required to better assess risks involved, and to develop mitigation strategies if required.

1.1.4 Environmental Impacts of Herbicides

Initial environmental impact assessments associated with herbicide spraying and defoliation occurred during the Viet Nam war (Tschirley 1969; Orians and Pfeiffer 1970). These assessments evaluated the impacts of defoliation and, in particular, toxic effects of herbicide constituents. At the time of these assessments, however, the environmental effects of dioxin contamination were poorly understood.

Although the majority of attention has focused on medical issues, there have been some environmental studies of herbicide (including dioxin) impacts. Most environmental studies in Viet Nam have been limited in scope, and usually looked at a single ecosystem component in isolation. Lack of resources to undertake comprehensive ecological studies has hindered the understanding of the nature of long-term effects of war-time activities on the environment, and slowed remediation efforts. The Government of Viet Nam through the 10-80 Committee hosted two international conferences on the long-term health and environmental impacts of the war in 1983 and 1993 (Cau *et al.* 1994).

High levels of dioxin were measured in both fish and shellfish within southern Vietnamese rivers and coastal areas in the early 1970s (Anonymous 1974). During the mid-1980s, sediment samples from the Dong Nai River, a heavily sprayed area near the Ma Da forest, contained

elevated dioxin levels compared to sediment samples taken from an unsprayed reference area at the Red River near Hanoi (Schecter *et al.* 1989b).

Environmental impacts of dioxin residues, however, remain poorly understood in Viet Nam. HCL has completed the only integrated study tracing dioxin through local food chains ending with humans (HCL *in prep.*).

1.2 RESIDUAL ENVIRONMENTAL IMPACTS REMAINING TODAY

The long-term environmental legacy of herbicide spraying remains unresolved due, in part, to a lack of current data. Recorded opinions on the environmental impacts of herbicides vary. For example, Gen. William C. Westmorland, U.S. commander of ground forces in Viet Nam, was vaguely dismissive. Writing shortly after the war, he commented:

"*Some ecological damage may have resulted from the defoliants; how much and how permanent it is remains to be seen. Flying over much of the country as recently as 1972, I found Vietnam still a verdant land, which left me to question the truth of some of the more pessimistic allegations of permanent damage.*" (Westmorland 1976, p. 280).

It should be noted that the view of military experts on ecological damage probably have a similar credibility as ecological experts on military tactics. However, it was a common view of the U.S. military at the time. Other researchers and observers commented during and after cessation of herbicide applications:

"*The defoliation program has caused ecological changes. I do not feel that the changes are irreversible, but complete recovery may take a long time. The mangrove type is killed with a single treatment. Regeneration of the mangrove forest to its original condition is estimated to require about 20 years.*" (Tschirley 1969; Neilands *et al.* 1972).

"*It may take decades for some of the damaged forest lands to recover, partly because the invading bamboo and grasses may be difficult to eradicate, and partly because nutrient minerals previously tied up in forest vegetation may have been released and then leached out of sprayed forests by heavy tropical rains.*" (Boffey 1971).

Our increasing understanding of the hazards posed by organochlorines in general, and dioxins in particular, has to a large extent vindicated early concerns expressed by scientists and the consistent claims of by Viet Nam veterans (both U.S. and Vietnamese).

The World Bank stated:

"*One of the least understood and potentially most detrimental aspects of the war is how the modification in species distribution that it caused may have permanently changed the biodiversity of Viet Nam.*" (World Bank 1995b).

Environmental consequences of the war remain an important domestic Vietnamese issue and a major research area within the 1991 National Plan for Environment and Sustainable

Development of Viet Nam (Can 1992). Nation-wide deforestation, caused in part by the war, has reduced total forest cover from approximately 44% of total land area in 1943 to less than 25%, including a high proportion of "bare" land accounting for 37% of the land area (GOVN/GEF 1994).

There are now a number of accepted generalizations on residual herbicide impacts on Vietnamese forest ecosystems (FIPI 1991, Hong and San 1993, Boi 1994, Hong *et al.* 1994):

- trees vary in susceptibility, but all forest types have susceptible species with particularly high proportions of species in mangrove and *Melaleuca* forests;
- spray-resistant trees such as *Irvingia malayana* and *Parinari annamense* were among the only large living trees in some areas;
- invasion of opportunistic species such as bamboos, and grasses such as "American grass" (*Imperata cylindrica)* hamper natural reforestation and change forest composition;
- these grasslands experience more dry-season wild fires, which destroy tree seedlings and prevent reforestation;
- forest wildlife was killed or migrated from damaged forests;
- leaf-drop from defoliation of mangroves provided a short-term pulse of organic matter into local food webs, but also increased local biological oxygen demand (BOD - a measure of the oxygen required by bacteria to consume organic material in water) and increased turbidity (suspended material in water), reducing growth of phytoplankton (suspended plant cells in water);
- exposed forest soils became much more subject to erosion, especially during wet season rains;
- changes in forest hydrology caused decreased water retention and increased incidence of flooding;
- exposed mangrove soils experienced increased temperatures, higher evaporation, higher rates of oxidation, desiccation and pH changes towards acidic sulfate conditions;
- regeneration in unflooded mangrove areas has lagged significantly behind flooded mangrove areas which are more easily reforestation; and
- defoliated mangrove areas permitted easier access for wood cutting, frequently resulting in overharvesting.

1.3 FOREST IMPACT ASSESSMENT USING AERIAL PHOTOGRAPHY AND REMOTE SENSING

Foresters have used air photos and remote sensing images to assess war damage to Viet Nam's forests (Ashton, 1986, Boi 1994; Ha and Boi 1994). Currently, the Forest Inventory and Planning Institute (FIPI) conducts national forest mapping and inventory on a project-by-project basis, usually in collaboration with foreign aid projects, and with the aid of some satellite imagery (Landsat TM and SPOT-XS), extensive field visits, and limited aerial photography. Experience in Viet Nam with Radarsat data is limited.

1.4 FOREST TYPES OF VIET NAM

Aston (1986) stated that defoliants had substantially different effects on different types of forest vegetation in Viet Nam. It is therefore important to understand forest characteristics in the assessment of war damage and subsequent reforestation progress. The literature varies as to forest classification in Viet Nam. The national biodiversity action plan (GOVN/GEF 1994) lists the following nine forest types with their attributes:

Mangrove

Coastal salty wetland forests that reach their greatest complexity and height in southern Viet Nam compared to the north. These forests were particularly susceptible to herbicide application. Mangrove forests are the dominant forest types in the Rung Sat and Ca Mau study areas, and also occur to lesser degrees in coastal areas near Hué and Da Nang, the other study areas in this project.

Melaleuca

Forests in occasionally-flooded (by brackish water), delta, ascidic peat soils replaced much larger historic peat swamp forest formations. These forests were often destroyed during the war through aerial applications of napalm. *Melaleuca* forests are most common in the Ca Mau peninsula, north of the area of mangrove forests.

Freshwater Swamp

Flooded forests in low lying areas inland of mangroves.

Monsoon

Includes dry dipterocarp highland forests (dominated by the important timber family *Dipterocarpaceae*) and some coastal dryland forests.

Lowland Evergreen/Semi-evergreen Broadleaf

Tropical formations in the south and sub-tropical in the north. The Ma Da area supports forests of this type, as well as monsoonal dipterocarp species.

Hill Evergreen/Semi-evergreen Broadleaf

Found in scattered localities at higher elevations that its lowland counterpart.

Karst Limestone

Distinct forests in rocky, limestone-rich areas with caves, such as Quang Tri province.

Montane Evergreen/Mixed Coniferous

Highland formations that can have marked regional variations and high levels of regional endemism. These forests are known to occur in central and south-central Viet Nam.

Sub-alpine

Forest formations unlike any others that are confined to the highest mountains primarily above the cloud layer. These forests are generally confined to the mountainous north of Viet Nam.

1.5 HATFIELD CONSULTANTS LTD. PROJECT OBJECTIVES

Project objectives included:

- collection of Radarsat imagery of areas of Viet Nam and Laos expected to show a diversity of forest cover, land use, coastal features and changes in land use as residual effects of the Vien Nam war and subsequent recovery;
- acquisition of secondary sources of land cover information regarding these areas (e.g., topographic, forest cover and land use maps, aerial photography, other remote sensing imagery) for evaluation in comparison with Radarsat images;
- interpretation of Radarsat images with the aid of these secondary data sources, aided by Vietnamese remote sensing and forest mapping experts;
- evaluation of Radarsat image utility in identifying specific land cover features (e.g., forest cover and type, water bodies, agricultural crops, roads, human settlements, etc.) and coastal features (shorelines, mangrove, wetlands, etc.);
- assessment of Radarsat synthetic-aperture-radar imaging as a tool for environmental monitoring and management in Viet Nam, and comparison of Radarsat's abilities with non-radar-based remote sensing technologies; and

- demonstration of Radarsat capabilities and possible uses to experts in remote sensing and environmental management in Southeast Asia and Canada.

2.0 METHODS

2.1 PROJECT SCHEDULE AND PHASES

The project was broken into Phases I to III, of which Phase II was the largest and split into IIa and IIb. Descriptions of each phase appear below.

2.1.1 Phase I (April 1996 to February 1997)

During Phase I, the technical scope of the project was defined, specific goals, objectives and tasks were assigned, and preliminary Radarsat images were obtained for parts of Viet Nam. Images were obtained of Ho Chi Minh City and Rung Sat areas, Ma Da forest and Tri An reservoir area (Song Bé and Dong Nai provinces), and A Luoi valley and Hué areas in central Viet Nam (Hué province).

These preliminary images, taken during July and August 1996 during monsoon season in central Viet Nam, were examined to determine the ability of Radarsat to identify specific land cover features such as forest cover, crop cover, land use, roadways, etc. This preliminary analysis suggested that Radarsat was largely effective at highlighting differences between various types of land cover and forest type.

2.1.2 Phase IIa (March to May 1997)

Field trips were undertaken by HCL staff and their Vietnamese agency counterparts to inspect areas for which Phase I imagery was collected. Hand-held Global Positioning Systems were used to identify the field team's locations. Through comparison of visible land and forest cover features with the georeferenced Radarsat images of the area, we assessed whether the Radarsat imagery was successful at highlighting specific land cover features. Results generally were positive, with many forest types and land and coastal features distinct in the imagery.

An important aspect of the visit to Viet Nam and Laos by HCL staff was discussions with appropriate government organizations and individuals for acquiring supporting information and expertise to aid in the interpretation of Radarsat imagery during later project phases. Based on the results of field studies, final decisions were made regarding which areas to collect more imagery for Phase IIb.

2.1.3 Phase IIb (June 1997 to February 1998)

This report details findings of this, the major technical phase of the project. Objectives of this phase included:

- obtaining new Radarsat imagery of study areas in south and central Viet Nam and Laos;
- collecting and digitizing secondary information (e.g., basemaps, herbicide application data, land use information) to be used in interpretation of the Radarsat imagery;
- digital image processing of Radarsat scenes and supporting remotely-sensed data (i.e., Landsat and SPOT imagery);
- interpretation of Radarsat imagery:
  - through comparison with secondary data sources;
  - through discussions and image interpretation with remote sensing staff in Viet Nam and Laos; and
  - through ground-truthing of study areas of Viet Nam and Laos;
- detailed assessment of the capabilities of Radarsat imagery to identify specific land and forest cover and coastal features; and
- evaluation of the utility of Radarsat imagery as a tool in environmental monitoring and management.

2.1.4 Phase III (January to March 1998)

This phase will include an evaluation of the potential market for commercial Radarsat imagery in Southeast Asia, based on Phase IIb results. Travel to Viet Nam, Laos, and other Southeast Asian countries will be undertaken to present and discuss results with remote sensing experts and environmental managers.

2.2 SELECTION OF STUDY AREAS

Viet Nam was the major focus of this project due to its wide variety of terrain, the general inability of other remote sensing information (e.g., LANDSAT, SPOT) to be collected during monsoon, and particularly due to the land use changes over the past 30 years as a result of the Viet Nam war (1961-1975).

Numerous areas of Viet Nam, particularly in the south near Ho Chi Minh City and in central Viet Nam near Hué and Quang Tri, experienced extreme forest cover and land use changes during the war. Some of these changes (resulting from bombing, herbicide spraying, land clearing) have left lasting visible changes in forest cover and land features. In the past 25 years, many areas have been converted to agriculture, reforested, or left barren. The recovery of land and subsequent land use changes following the war have resulted in complex patterns of land features, which are well-suited for field-testing of remote sensing imagery.

The HCL project area also included Laos, which has experienced similar changes in forest cover and land use over the past 30 years. The limited accessibility of many areas of Laos enhanced the potential of remotely-sensed imagery as an important tool in environmental monitoring and

management. Initially, Cambodia was a focus, but increasing political instability there warranted avoidance.

Specific study areas in Viet Nam are presented in Figure 2; these included:

- Quang Tri province, including the former demilitarized zone (DMZ);
- Thua Thien Hué province, including Hué city and the A Luoi valley;
- Da Nang province, including the city of Da Nang;
- Ma Da upland forest, northeast of Ho Chi Minh City;
- Rung Sat mangrove forest, south of Ho Chi Minh City; and
- Ca Mau peninsula, at the southern tip of Viet Nam.

In Laos, two areas were chosen for study:

- the Plain of Jars, Xieng Khouang province, northern Laos, including the town of Phonsavan; and
- the Bolavens Plateau/Pakse area, Champasak province, southern Laos.

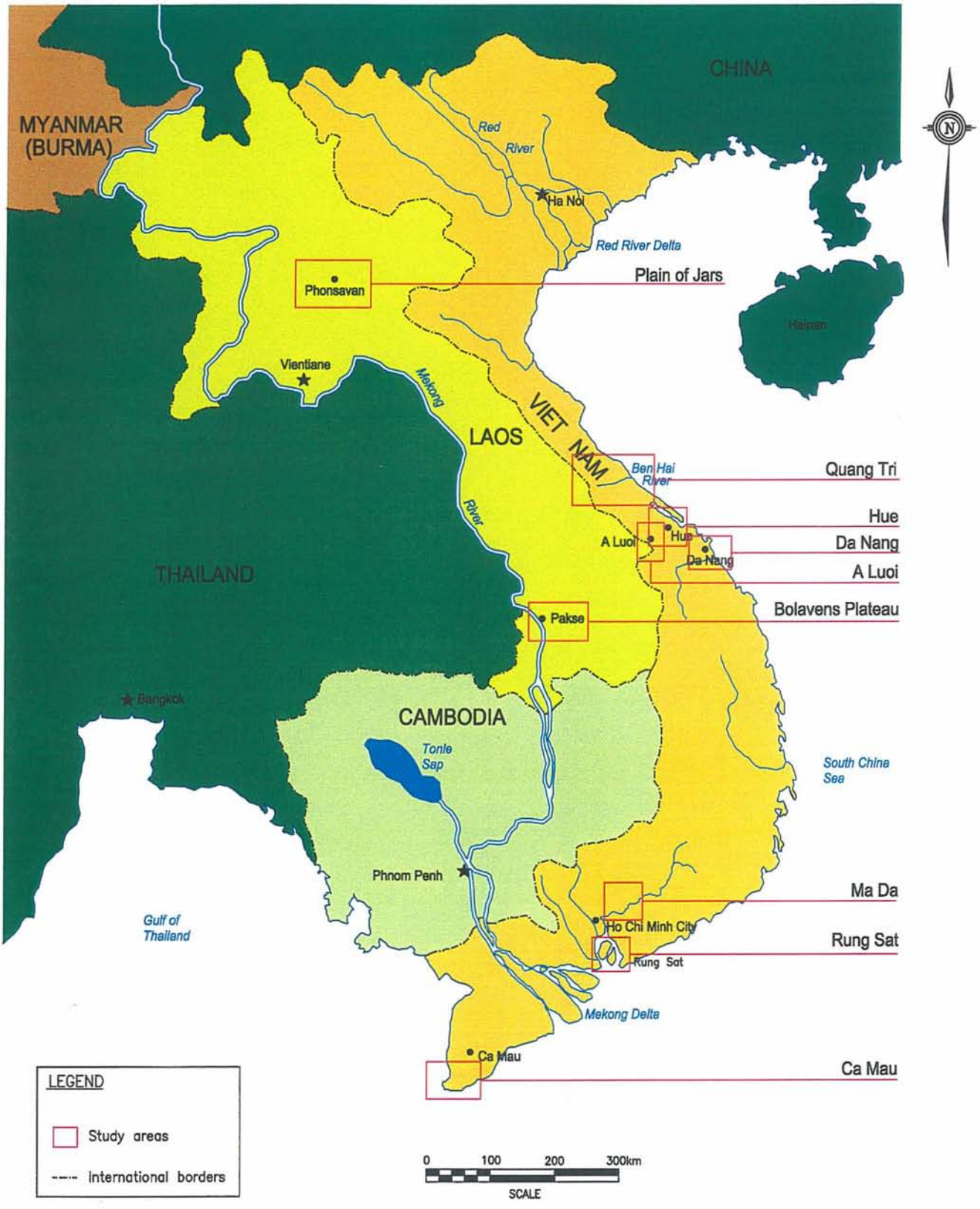
Initially, study areas in the Vietnamese provinces of Dac Lac (in the central highlands of southern Viet Nam) and the Plain of Reeds (southwest of Ho Chi Minh City and north of the Mekong River delta) were to be included in the project. However, Radarsat image acquisition conflicts encountered during Phase IIb of the project prevented image collection in these areas. Throughout this report, the official name of the Lao People's Democratic Republic (Lao P.D.R.) is used interchangeably with its informal name, Laos.

2.3 RADARSAT AND OTHER REMOTE SENSING DATA ACQUISITION

2.3.1 Radarsat Imagery

Some Radarsat images were collected during Phase I, but most imagery was collected in Phase IIb, following final study area selection and image assessments in Phase IIa. Table 2.1 lists all Radarsat imagery collected during this project.

Figure 2 Locations of study areas, Phase IIb.



VN614: MEKONG4.DWG

Table 2.1 All Radarsat images collected (Phases I and II).

Study Area (Coverage)	Beam Mode – Incidence Angle	Look Direction	Orbit Number	Collection Date
A. Central Viet Nam				
Quang Tri & Hué province	Standard-7	Ascending	6230	January 13, 1997
Quang Tri & Hué province	Standard-7	Ascending	10689	November 21, 1997
Hué city	Fine-4	Ascending	4272	August 29, 1996
Hué city, A Luoi valley	Standard-4	Ascending	4029	August 12, 1996
A Luoi valley	Fine-3	Ascending	3929	August 5, 1996
Quang Tri province	Fine-2	Ascending	9417	August 24, 1997
Da Nang city	Standard-7	Ascending	9074	July 31, 1997
Da Nang city	Standard-7	Ascending	10445	November 4, 1997
Central Viet Nam	ScanSAR Narrow 2	Ascending	4372	September 5, 1996
B. Southern Viet Nam				
Rung Sat mangrove forest	Fine-4	Descending	3964	August 7, 1996
Rung Sat mangrove forest	Standard-2	Ascending	9174	August 7, 1997
Rung Sat mangrove forest	Fine-5N	Descending	9560	September 3, 1997
Ma Da upland forest	Standard-6	Descending	4307	August 31, 1996
Ma Da upland forest	Standard-7	Ascending	4072	August 15, 1996
Ma Da upland forest	Fine-5F	Ascending	9217	August 10, 1997
Ca Mau peninsula	Standard-7	Descending	9352	August 19, 1997
Ca Mau peninsula	Standard-7	Descending	10724	November 23, 1997
Ca Mau peninsula	Fine-3	Descending	11067	December 17, 1997
Southern Viet Nam	ScanSAR Narrow 2	Descending	4207	August 24, 1996
Southern Viet Nam	ScanSAR Narrow 2	Ascending	4172	August 22, 1996
C. Laos				
Plain of Jars	Fine-2	Ascending	9117	August 3, 1997
Plain of Jars	Standard-7	Descending	5929	December 23, 1996
Bolavens Plateau/Pakse	Standard-7	Descending	5922	December 22, 1996
Bolavens Plateau/Pakse	Standard-7	Descending	9009	July 26, 1997

2.3.2 Problems Encountered During Radarsat Image Acquisition

During Phase IIb, difficulties were encountered in the Radarsat image acquisition process. Two study areas were abandoned because of conflicts in image acquisition with other requests. Of

eight images initially scheduled for collection during summer and fall of 1997, four were removed from the acquisition schedule due to "priority conflicts".

These conflicts generally arose due to the narrow time window available for image acquisition between the solar eclipse blackout period from mid-June to mid-July, and the Antarctic Maneuver in mid-September. Numerous user requests from multiple Order Desks competed for satellite time and our acquisitions were sometimes removed from the schedule for higher priority images.

In order to prevent abandonment of several study areas, HCL attempted to acquire the closest possible substitute imagery of areas where our original order had been cancelled. This often necessitated acquisition of imagery of different beam mode or look direction than intended. In some cases, this reduced the quality and interpretability of the final scenes produced (e.g., by preventing multi-temporal analyses or including only parts of desired study areas).

By mid-August 1997, it was clear that cancelled image orders seriously threatened project success. These concerns were communicated to the RUDP program administrator and the CCRS Order Desk, and efforts were made to reestablish image acquisition orders. Through the efforts of the Order Desk and the program administrator, cancelled imagery for some study areas was successfully rescheduled. However, two study areas (Dac Lac and Plain of Reeds) were abandoned due to image acquisition conflicts.

2.3.3 SPOT-XS and Landsat-1 Imagery

To supplement Radarsat imagery and facilitate a comparison of different remote sensing technologies with Radarsat, supporting SPOT and Landsat imagery was acquired (Table 2.2).

Black and white photographic copies of Landsat-1 (MSS) imagery, collected late in the Viet Nam war (1973 to 1975), was acquired from the U.S. Geological Survey. These were used to examine large-scale effects of war that were visible in Landsat imagery (primarily herbicide spray damage). The electronic data of one Landsat-1 image (of Ca Mau peninsula) was collected for use in change detection in conjunction with newly-acquired Radarsat data.

SPOT-XS data were also collected for A Luoi valley and Ma Da, to examine differences between SPOT-XS and Radarsat data to detect different land use and cover features. Supplementary remote sensing images collected during this project are listed in Table 2.2.

Table 2.2 Supporting Landsat and SPOT-XS images collected.

Study Area (Coverage)	Type of Imagery	Media Format	Image Number	Collection Date
A. Central Viet Nam				
Quang Tri province	Landsat-1 MSS	B & W negative	LM2134048007507390	March 14, 1975
A Luoi valley/Da Nang	Landsat-1 MSS	B & W negative	LM2134049007507390	March 14, 1975
A Luoi valley	SPOT-XS	Digital file	274-318	March 5, 1996
B. Southern Viet Nam				
Ma Da upland forest	Landsat-1 MSS	B & W negative	LM1134052007300290	January 2, 1973
Ma Da upland forest	Landsat-1 MSS	B & W negative	LM1133052007300190	January 1, 1973
Rung Sat mangrove forest	Landsat-1 MSS	B & W negative	LM1133053007305590	February 24, 1973
Rung Sat mangrove forest	Landsat-1 MSS	B & W negative	LM1133053007301990	January 19, 1973
Ma Da upland forest	SPOT-XS	Digital file	276-327	March 5, 1996
Ca Mau province	Landsat-1 MSS	Digital file	LM1135054007300390	January 3, 1973
C. Laos				
Plain of Jars	Landsat-1 MSS	B & W negative	LM2138047007536590	December 31,1975
Bolavens Plateau	Landsat-1 MSS	B & W negative	LM1135049007303990	February 8, 1973

2.4 PRODUCTION AND ANNOTATION OF SELECTED RADARSAT SAR IMAGE MAPS

This section details Radarsat SAR image processing and preliminary analysis during fall, 1997.

2.4.1 Objective

The objective was to produce a series of Radarsat SAR image maps of selected study areas and to annotate the data set for optimum utility for HCL's follow-up ground-truthing in Viet Nam and Laos.

2.4.2 Main Tasks

The digital image processing procedure followed standard SAR data analysis guidelines as previously established and executed during Phase I. The processing steps involved are specified below. In addition, a series of color composite images were produced in order to enhance and increase their information content through either multi-temporal Radarsat SAR data composites or through fusion of optical SPOT, Landsat MSS and Radarsat SAR data. The production of composite data sets is also detailed below.

Following the creation of a series of digital image maps and generation of hard copy output products, a Radarsat SAR and composite image analysis procedure was carried out to provide a first-order interpretation as a guide for further field work. This procedure followed standard image interpretation rules with particular consideration to Radarsat SAR data parameters; notably resolution, imaging mode, incidence angle and orbit characteristics, as well as environmental implications, such as seasonal effects, terrain, land cover and man-made features.

2.4.3 Image Processing

This employed commercially available software tools and standard image processing procedures for SAR image analysis and integration with other remote sensing data sets. Data accuracy and Radarsat image quality issues are also addressed in this section.

2.4.3.1 Tools

PCI EasiPace software was used for digital Radarsat SAR image processing. Commercial printing facilities were accessed for 600 dpi color and black & white hard copy output generation on 8.5"x11" Kodak photo quality paper. Copies of these prints were created using a Xerox Majestik continuous-tone laser copier/printer.

2.4.3.2 Image Processing Procedure

The digital Radarsat SAR image processing procedure may be subdivided into a series of individual steps to optimize the geometric fidelity of the data sets and achieve suitable image enhancement for hard copy out put and further analysis during field inspection. These steps are summarized below.

Data Extraction:

- conversion of Radarsat CEOS 16-bit image format to PCIDSK (*.pix*) file using EASI; and
- extraction of orbital segments using EASI.

Image Enhancement:

- reduction of SAR speckle noise by applying a filtering routine in EASI; most useful results were obtained using a Gaussian type MAP/Gamma filter (gamma = 1) with a 3x3 or 5x5 pixel window size; and
- application of image contrast enhancements with either a linear or a linear piece stretch using ImageWorks and EASI.

Geometric Processing:

- creation of georeferenced output image space with orbital segment reference data and the WGS84 ellipsoid and a UTM projection using EASI;
- collection of ground control points (GCP's), provided in the orbital segment as corner and centre points, using EASI; and
- rectification of Radarsat image data into an image map with WGS84 ellipsoid and UTM projection using GCPWorks.

Hard Copy Output Generation:

- sub-scene selection using ImageWorks;
- scaling of 16-bit data format (Fine & Standard Mode) to 8-bit output format using EASI;
- if necessary, enhancement of the 8-bit image for printer output by applying a linear stretch LUTs while maintaining contrast levels using ImageWorks and EASI;
- determination of suitable scale number & scale bar and image annotation; and
- creation of map output as an image file and conversion to a TIF format using EASI.

The generation of color composite imagery relied on two basic procedures. The first was the generation of Radarsat SAR composites, involving multi-temporal SAR data sets of two different dates only. These two dates are displayed in two different red-green- and/or-blue (RGB) channels, and a ratio image (Scene 1:Scene 2, or Scene 2:Scene 1) is displayed in the third remaining channel, thus providing a composite image product. In the case of the Landsat MSS - Radarsat SAR data set integration, a second procedure was chosen to optimize visual representation of the composite data. This involved operator assisted channel input, whereby each of the 1973 Landsat MSS channels 4, 5 and 6 was individually merged with the 1997 Radarsat SAR data according to an individually weighted percentage, e.g. 45% Landsat MSS Channel 6 and 55% Radarsat SAR, and the three resulting images were then displayed through RGB color guns.

2.4.3.3 Image Accuracy and Quality Issues

It should be noted that the accuracy with which radar and optical data are presented in the image maps is in most instances relative and rarely absolute. At issue are location accuracy of the satellite data in the x, y and z dimensions and the radiometric accuracy of the Radarsat data as it relates to radar sensor stability and production of composite data sets.

With regard to geometric accuracy required because each Radarsat scene has been geo-referenced only in the x and y dimension by means of ground control points, or GCP's such as corner and centre points; this tends to yield x, y accuracies on the order of several hundred metres for most Radarsat Standard Mode and Fine Mode products. The within-scene locational accuracy as a function of terrain elevation and radar illumination-angle and -direction has not been addressed

given the absence of detailed DTM data for most study areas. In hilly and mountainous terrain, small radar incidence angles and slope foreshortening effects are particularly noticeable resulting in local positional inaccuracies on the order of several tens to several hundred metres. The effect is less prominent in relatively flat terrain, for example coastal plains.

It should be noted that in the case of unreliable or unavailable topographic map reference data, the Radarsat ephemeris data has been used as input for generating the UTM grid annotation on the image maps. In two cases, the UTM grid did not match precisely when comparing the multi-temporal Radarsat data for the Ma Da and Rung Sat areas. In the case of Ma Da, the mis-registration was on the order of a few kilometers; in the case of Rung Sat, it was on the order of several hundred metres. Reasons for these mismatches are not clear, but may be related to different satellite positional accuracy estimates for the 1996 and 1997 data sets. This uncertainty has potentially important implications for integrating GPS waypoint measurements into the Radarsat data sets.

Since quantitative data analysis was not a prime objective in this project, no attempt has been made to radiometrically correct and calibrate the different Radarsat images for scene-to-scene variation in brightness (beta nought). Therefore, the radar gain-dependant look-up tables (LUT's) have not been removed. These LUT's have been applied at the SAR processor for each scene in order to achieve a visually pleasing rendition of the SAR data. As a result, the colour composite imagery is not suitable for meaningful quantitative analysis. However, it is suitable for quantitative image assessment and the field verification purposes for which it is intended in the first instance.

The earlier Radarsat data for the Ca Mau coastal area contained radiometric problems related to the now well-known analog-to-digital converter (ADC) problem of the Radarsat system. This has resulted in generally darker image tone for those coastal regions in the scene which are characterized by considerable area of water in the near-range portion of the image swath. The Ca Mau study area was clearly affected by this ADC problem during the first round of data acquisition. The problem was avoided during the second round of data acquisition by requesting that the data be acquired with a fixed gain setting. The resulting image product was of good quality.

2.4.4 SAR Image Interpretation

A simple SAR image interpretation procedure was adopted to assist ground reference data collection and to provide field crews with a first-order image interpretation of significant SAR image features, as displayed in the Radarsat SAR data set of Viet Nam. Significant features in the context of HCL's investigation included knowledge of terrain, land cover and associated elements, transportation/access corridors, and man-made features. Of particular interest are those features related to the assessment of, or helpful in, the identification of environmental impacts of war damage.

2.4.4.1 *Interpretation Elements*

During this project, most image maps have been produced as single-band SAR gray tone images. The information content of these black and white images is limited in comparison to multi-band color renditions. However, there are several important considerations for SAR image interpretation, including standard photo interpretation elements such as tone (colour), texture, pattern, shape, size, association, as well as Radarsat specific considerations such as time/date of SAR data acquisition, radar look-direction (illumination direction) versus 'target' orientation, radar incidence angle, as well as imaging mode, resolution, area coverage/scale.

The same interpretation elements as well as sensor and environmental considerations apply when examining colour composite images. Merging multiple sets of Radarsat and/or optical satellite data generally increases the latent information content, which can be exploited to advantage by the image analyst. In the case of Radarsat, a frequently used technique of image composition is the collection of multi-temporal data sets (i.e., those acquired at different dates with each image date displaying some degree of change in radar backscatter for a particular feature compared to the previous date).

It is particularly important to correctly interpret color rendition as a function of the individual RGB display channel, signature contents and change. In the case of Radarsat color composite image production, two dates were available. These images, plus a ratio image of those two dates, were displayed through red, green and blue color guns for the most effective color rendition of changes that occurred between the two dates of data acquisition.

2.4.4.2 *Study Areas*

During the course of the image processing exercise, a series of black-and-white as well as color composite image maps was produced for the study areas; these included the following:

- Quang Tri province and the former demilitarized zone (DMZ);
- the A Luoi valley;
- the cities of Hué and Da Nang and their environs in central Viet Nam;
- the Ma Da upland forest;
- the Rung Sat mangrove forest, south of Ho Chi Minh City;
- the Ca Mau peninsula in Southern Viet Nam;
- the Plain of Jars in northern Laos; and,
- the Pakse/Bolavens Plateau region in southern Laos.

A folio of image maps and related annotation are contained in Volume 2 of this report.

For the image maps displayed in the folio, the display pixel spacing (DPS) may provide the most appropriate measure of the observable detail. This value, expressed in metres, is calculated as follows: DPS = Image width / (printer resolution x display width). The image degradation of the print product versus the pixel spacing of the original digital product is directly related to the DPS value. Degradation does not occur in the case where the DPS is the same as the original pixel spacing, for example 12.5 m for Standard Mode Path Image products. Typically, the following DPS values should be used as a guide when assessing the various Radarsat scenes: overview images at a scale of 1:250,000 in standard mode have a DPS value of approximately 50 m; this is 4x the original pixel spacing of 12.5 m and represents a considerable degradation of the actual image content. On the other hand, the detailed scenes displayed at a scale of 1:70,000 have a DPS value of approximately 13 m; this is very close to the original pixel spacing of 12.5 ng the 'full' image content.

2.5 SUPPORTING GEOGRAPHIC AND ENVIRONMENTAL DATA ACQUISITION

In addition to ground-truthing of study areas, supporting historical, topographic, and land cover maps of each study area were acquired in Viet Nam and Laos to aid in image interpretation and feature detection. In Viet Nam, topographic maps of various ages and scales were acquired for each study area; generally, 1:50,000 scale topographic maps, made by American geographers during the war and updated by the Vietnamese in the mid-1970s and early 1980s were the most recent map series available. In addition to these map sheets, the Forest Inventory and Planning Institute (FIPI) provided 1:1,000,000 scale digital maps (in MapInfo format) of forest cover to HCL for use in this project. These maps were derived from Landsat TM data compiled in 1992 (Mr. Phung Tuu Boi, FIPI, *pers. comm.*), and covered all of our study areas. Digital maps of soil types in each study area were also provided. In Laos, recent topographic maps at 1:1,000,000 and 1:100,000 scale were acquired for each study area.

2.6 GROUND-TRUTHING OF RADARSAT SCENES

2.6.1 Viet Nam

All study areas in Viet Nam were visited during November/December 1997, with the exception of Da Nang which was visited in early 1996 and in June 1997. Senior staff from FIPI in Hanoi accompanied the ground-truthing team to all study areas; numerous regional staff from local forestry offices were included to ensure we had the best exposure within each study area to ground-truth features and locations of interest.

Each study area was visited for approximately two days. Each day, a route would be chosen which would allow the study team to visit as many desired features/locations as possible by vehicle. One member of the ground-truthing team would collect regularly-spaced waypoints using a handheld GPS (Garmin 45XL or GPSII), and dictate land cover features into a portable dictaphone. Another team member would take photographs of areas or features of interest. Radarsat scenes of each area (typically 1:250,000 and 1:50,000 scale, to match topographic

maps) were consulted regularly, to ensure that features of interest in each scene were ground-truthed. Active ground-truthing lasted typically from 08:00 to 18:00. Each evening, GPS waypoints were entered and dictated notes transcribed into Microsoft Word tables. Waypoints were double-checked for transcription accuracy, then cleared from computer memory, so that each day of ground-truthing had a unique set of waypoints.

The complete schedule of ground-truthing and details of all waypoints collected during ground-truthing in November/December 1997 appear in Appendix A1.

2.6.2 Laos

Similar methods were followed when ground-truthing in Laos, although the study team was not accompanied by Lao government officials. This limited our ability to ground-truth comprehensively in the two Laos study areas. HCL staff were advised by the cooperating agency in Laos to be low-key in ground-truthing efforts. Therefore, notes were taken by hand and GPS waypoints were only taken at major features of interest. Compensating for this lack of waypoints were 1:100,000 topographic and land cover maps of each study area.

2.7 COOPERATING AGENCIES IN VIET NAM AND LAOS

2.7.1 Viet Nam

The counterpart agency in Viet Nam was the Forest Inventory and Planning Institute (FIPI). FIPI has worked with HCL previously on projects related to Agent Orange/dioxin contamination in sprayed areas of central and southern Viet Nam, and have a relatively well-developed remote sensing capability. More importantly, FIPI has a strong field presence throughout Viet Nam, with six regional offices throughout the country, and numerous field workers very familiar with the forest of Viet Nam. FIPI was very supportive of this project, and handled most logistical arrangements required for in-country travel and accommodation.

The Remote Sensing Center of the General Department of Land Administration in Hanoi provided SPOT-XS imagery. The remote sensing section of the Ministry of Science Technology and Environment (MOSTE) in Hanoi provided technical advice.

2.7.2 Laos

Our counterpart agency in Laos was the Environment Data and Information Division of STENO, the Science, Technology and Environment Organization, affiliated with the Prime Minister's Office. Remote sensing is poorly developed in Laos; this office does some land and forest cover mapping work with SPOT-XS (in conjunction with the Mekong Committee and foreign aid agencies), but little more. While initially enthusiastic about our project, they did not provide active in-country support (i.e., accompanying staff and regional government clearances) for our project upon our arrival for ground-truthing in December 1997.

This limited the ability of the ground-truthing team to work and travel openly in Laos, which in turn limited our ability to ground-truth as many features as would have occurred with strong government support such as we received in Viet Nam. However, the ground-truthing team did visit each study area and complete preliminary ground-truthing of Radarsat scenes.

3.0 RESULTS

3.1 VIET NAM

3.1.1 Quang Tri and the Former Demilitarized Zone (DMZ), Central Viet Nam

3.1.1.1 Historical Impacts

Quang Tri province in central Viet Nam was likely the region most heavily impacted by the war. It was the northern-most province of the former Republic of Viet Nam (South Viet Nam); north of Quang Tri across the Ben Hai River, lay the Democratic Republic of Viet Nam (North Viet Nam), until reunification in 1975. Many of the Vietnamese place names commonly known in the West from the war, such as Khe Sanh, Camp Carroll, and the Rockpile, are found in this region of central Viet Nam.

During the war, an area five kilometres from either side of the Ben Hai River separating North and South Viet Nam was classified as a neutral demilitarized zone (DMZ). Some of the most intense fighting and aerial bombardment of the war occurred just south of the DMZ, where American and South Vietnamese (USVN) troops attempted to prevent North Vietnamese army (NVA) troops and supplies from reaching across the Ben Hai River to resupply Communist National Liberation Front (NLF, or Vietcong) soldiers in South Viet Nam.

Many large battles took place in the region immediately south of the demilitarized zone, with devastating results to the local populace and environment. Particularly hard-hit areas included the Con Thien area, location of an American firebase and observation post, and Khe Sanh, near the Lao border. Engagements generally followed a similar pattern: artillery shelling by NVA placements, then assault of American and South Vietnamese (USVN) positions by NVA and NLF troops. Typically, this was countered by entrenchment of USVN troops and massive American air strikes, by tactical fighter-bombers and strategic B-52s, which carried bomb loads of 60,000 pounds each (Summers 1995). Also supporting USVN observation and surveillance in the region was the McNamara Line, a string of electronic listening posts extending from National Highway 1 to Con Thien, and, of more important and lasting effect, aerial herbicide applications to native forests, to deprive NVA and NLF troops of cover. Herbicide spray missions in Quang Tri province between 1965 and 1971 are shown in Plate 1 of Volume 2 of this report.

Natural forest cover in Quang Tri province ranges from dense rainforest in mountainous areas near the Lao border, to open, flat rice-growing areas and dunes in lowlands near the coast. Topography near the coast is relatively flat, including several wide expanses of dunes and areas of white, sandy soil of low productivity.

Two areas of Quang Tri were chosen for close examination: the Con Thien area, north of Dong Ha, and the Khe Sanh area near the Laos border (Plate 1). Con Thien was an American observation post which was heavily attacked by NVA and NLF troops several times during the war. Herbicides were applied to most of the surrounding forests; both areas were very heavily shelled and bombed. War-era American topographic maps of the Con Thien area append every town name within several kilometres of Con Thien with "...(Destroyed)". The most fierce fighting occurred in fall of 1967, in a siege where over 2,000 NVA troops were killed, and over 40,000 tons of bombs were dropped around Con Thien by American tactical and strategic bombers, including 790 sorties by B-52's (Summers 1995).

The Con Thien/Dong Ha area also experienced ground battles and artillery bombardment during the North Vietnamese Tet offensive of 1968 and the final Eastertide offensive in 1972, when the North Vietnamese took effective control of much of central Viet Nam.

Khe Sanh was the site of perhaps the best-known battle in central Viet Nam during the war. Khe Sanh was a remote American airfield near the Lao border, an observation post near the DMZ. In spring 1967, 40,000 NVA troops lay siege to the airbase, defended by over 5,000 U.S. Marines. While Khe Sanh was not of large strategic importance, the battle was considered crucially important by the American president, Lyndon Johnson, who demanded a written guarantee from the U.S. military that Khe Sanh would not fall (Karnow 1983).

To ensure that it did not fall, the U.S. military launched a massive aerial bombing campaign called Operation Niagara, named for the steady rain of bombs that were dropped on Khe Sanh for three months. During that period, over 24,000 tactical bombing sorties and 2,700 B-52 missions were flown over Khe Sanh, with over 110,000 tons of bombs dropped in the area surrounding Khe Sanh (Summers 1995). U.S. positions were also supported by artillery and troops from nearby Camp Carroll and the Rockpile, both indicated in Plate 1.

By the end of the siege, over 10,000 NVA and over 500 American soldiers had been killed. Having held the base, the Americans abandoned Khe Sanh and destroyed the airbase on their own that summer.

3.1.1.2 Post-War Changes in Land Use, Residual Environmental Impacts, and Radarsat Feature Detection

- Plate 1 Quang Tri Province and Former DMZ, Central Viet Nam (1:250,000, S7)
- Plate 2 Dong Ha/Con Thien, Central Viet Nam (1:100,000, S7/S7 multi-temporal)
- Plate 3 Khe Sanh/Lang Vei, Central Viet Nam (1:100,000, S7/S7 multi-temporal)

Two Radarsat images of Quang Tri province were acquired; January 13, 1997 (from archive) and November 21, 1997. Both were standard mode, with a high incidence angle of S7. Ground-truthing of this area was conducted during mid-November 1997, using processed scenes from the single January 13 image. The January 1997 image was used as the background for Plate 1, which also shows GPS waypoints collected during ground-truthing studies. These two processed

single-date scenes are included in Appendix A2, along with all other supporting imagery discussed in Section 3.0.

The November, 1997 image was ordered in the hope that multi-temporal scenes would yield better discrimination of different land cover features than the single-pass scenes yielded. This was the case. Plate 2 is a multi-temporal (S7/S7) 1:100,000-scale image of the town of Dong Ha (lower right), the Cam Lo river, the Con Thien area (centre), and the former DMZ (top). Several features are immediately visible.

Purple areas correspond to paddy cultivation of rice. In the January image, rice fields returned weak (i.e., dark) radar backscatter (likely due to water in the rice paddies), and are difficult to distinguish from other features of similar backscatter, such as the large arrowhead-shaped feature along the eastern edge of the image. In the November image, rice fields return a strong (i.e., bright) radar backscatter (likely due to mature rice with little water), and are difficult to distinguish from towns, forests, and croplands which also returned relatively strong backscatter. Combination of these two images into a multi-temporal scene, however, allowed clear delineation of areas of rice cultivation.

The arrowhead-shaped formation, dark red in the scene, is an area of relatively barren, white sand dunes.

The war destroyed most of the natural forests in the lowlands of Quang Tri, leaving barren fields of grasses and scrub. Intensive efforts by the Vietnamese to revegetate this area continue, but are hampered by poor soil conditions (Mr. Phung Tuu Boi, FIPI, *pers. comm.*). The area of most intensive forest plantation development has occurred east and west of the three reservoirs visible in the image (two of which were recently constructed). These forest plantations appear as a lighter, irregular area in the upper-centre of the image. Various roads amongst the plantations are visible at the western edge of this feature. Trees planted include eucalypts, rubber, cashew, and pine. Darker (red) areas surrounding this patch of bright return, visited by HCL staff in November 1997, were predominately barren, with sparse to dense growth of tall grasses and few if any trees. Some small plantations of young eucalypt were observed in these areas. Barren areas in the immediate vicinity of the lower two reservoirs in this scene also appear dark red compared with the surrounding features (Plate 2, facing page).

An interesting difference between the two images used to compose this multi-temporal scene is visualized in the multi-date scene as the darker, slightly purple, rectangular area in the western centre of the area of brighter return (plantation). This area yielded clearly different return in the January 13 image, but is barely distinguishable in the November 21 image (Plate 2, facing page). Ground-truthing along the southern edge of this feature in November indicated that it was planted with young rubber, with more mature rubber plantation and cashew plantation south of it. Reasons for the different return in each S7 are unclear. A portion of the darker area visible in the January 13 image follows a small river drainage, suggesting greater moisture on or around the vegetation or soil in this area was repsonsible for this darker return.

Another interesting difference between each image is the visibility of roads in and around the area mentioned above. These roads are much clearer in the November image. Similarly, a large

powerline, visible bisecting the dunes in the right of the scene, is more clearly distinguished in the November S7 (i.e., individual towers can be easily discriminated) than in the January S7. Different weather conditions on the day of acquisition may help explain the greater visibility of the powerline, but less so the different returns in the rubber plantation. Greater surface moisture during acquisition of the January image is a possible explanation.

In addition to the powerline, other linear features are plainly visible, including National Highway 1 (left of the powerline) and the Reunification railway (left of Highway 1). These features are most visible when running north-south, perpendicular to the view angle of the satellite. The railway turns to east-west for a short distance in the upper right of the scene, and becomes difficult to resolve in the image.

Other features visible in this image include the reservoirs (differences in water levels between the different dates are apparent in the multi-temporal scene), and major human settlements, including the towns of Dong Ha, Cam Lo, and Gio Linh. Dry-land crops of various types are distinguished from rice and generally from dense forest by their strong backscatter return, and sometimes by a yellowish tone, indicating stronger return in the January image than in the November image – the opposite of rice.

Plate 3 is a multi-temporal scene of the Khe Sanh/Lang Vei area, southwest of Dong Ha near the Lao border (demarcated by the Xe Pon River in the scene's southwest corner). This multi-temporal scene was constructed from the same two images discussed above. The overwhelming effect of foreshortening in steep terrain greatly limited the ability of Radarsat to distinguish land cover or land use patterns.

Much of the area from Dong Ha to Khe Sanh was heavily sprayed by herbicides, particularly hilltops and upper slopes of valleys along Highway 9 (Plate 1); many linear areas of barren grassland are apparent along the hillsides in this area (Plate 3, facing page). These barren areas are not visible in the steep terrain shown in this scene. Many areas along Highway 9, from nearby the Rockpile to Khe Sanh, have been replanted with eucalypt or pines; these replanted areas are generally found only along the road.

Near the former site of Khe Sanh airbase itself, situated north of Khe Sanh village and west of the Rao Quang River (visible flowing NW-SE in this image), the airfield (approximately 10m wide) remains barren. The area surrounding it supports coffee and other highland crops; small bomb craters were evident in areas near the airfield, but none large enough to be discriminated by a standard-mode Radarsat scene.

Much of the plateau area surrounding the former airbase appears slightly purple, suggesting greater radar return in the November scene than the January scene. This roughly circular area corresponds to the area of the former airbase and runway, now surrounded by sparse coffee plantation. However, such purple speckling also is common throughout the image, suggesting it may be an artifact of the multi-temporal scene generation process, which was undertaken without ortho-rectification to a detailed digital elevation model.

Large areas of Quang Tri province still exhibit war damage. The extent of replanted forest remains low to moderate, with replanted areas generally supporting monocultures of economic tree species with low ecological value, compared with the more biodiverse native forests which existed in this region before the war. Generally poor soil conditions, unexploded ordnance hazards, and thick growth of light-starving grass species, have limited the rehabilitation of deforested areas.

Another possible lingering effect of war in Quang Tri is residual contamination of herbicide-sprayed areas by dioxins (Agent Orange by-products). The construction of new reservoirs in northern Quang Tri has flooded areas of heavy herbicide application, possibly reintroducing these contaminants from the soil into the human food chain. Active freshwater fisheries were not apparent in these reservoirs, but some fishing is probable.

3.1.2 A Luoi Valley, Central Viet Nam

3.1.2.1 Historical Impacts

The A Luoi valley, commonly called the A Shau valley by Americans during the war, is a narrow valley southwest of Hué along the Lao border, and was a major supply route along the Ho Chi Minh Trail from North to South Viet Nam during the war. American outposts were established in this area in the early 1960's. All but A Shau (A So), at the south end of the valley, were abandoned in 1965; A Shau, the site of an airbase, was overrun in summer 1966 (Summers 1995). The valley was of great strategic importance to NVA troops moving into South Viet Nam, and considerable American efforts were spent to limit the flow of personnel and materiel through this region. To limit the ability of NVA troops to move under cover, the A Luoi valley was heavily bombed and very heavily sprayed with herbicides (Plate 4). Ap Bia, better known in the West as "Hamburger Hill" after a 10-day American offensive operation in 1969 to take this strategically-located hill overlooking the Ho Chi Minh Trial, is located just west of Ta Bat, in the hills separating A Luoi from the Lao P.D.R.

The A Luoi valley is very remote from the rest of Viet Nam, and inhabited primarily by tribal groups, different in culture and language from lowland Vietnamese. Even by Vietnamese standards, the residents of this area are extremely poor, and subsist on slash-and-burn agriculture, some rice cultivation, and modest fish farming and animal husbandry.

FIPI (1991) stated that all forests in the valley were destroyed by herbicides, with slow restoration observed after 17 to 18 years. They speculated that over 100 years would be needed for full reforestation. A FIPI forest cover map of the A Luoi valley created in the early 1990's shows most land in the area, particularly on steep slopes surrounding the valley, to be barren or poor forest. FIPI (1991) concluded that the most rapid way to rehabilitate sprayed areas was through active reforestation using a suite of species including pines (*Pinus keyisa*).

3.1.2.2 *Post-War Changes in Land Use, Residual Environmental Impacts, and Radarsat Feature Detection*

- Plate 4 Overview, A Luoi Valley, Central Viet Nam (1:250,000, S7)
- Plate 5 A Luoi Valley, Central Viet Nam (1:250,000, S7/S7 multi-temporal)
- Plate 6 Detail, Northern A Luoi Valley, Central Viet Nam (1:50,000, F3)
- Plate 7 A Luoi Valley, Central Viet Nam (1:250,000, SPOT-XS)
- Plate 8 Detail, Northern A Luoi Valley (1:70,000, F3/SPOT-XS)

Three Radarsat images of the A Luoi valley were acquired and processed: the two S7 images discussed above, which extended as far south as A Luoi, and a fine mode F3, acquired on August 5, 1996. In addition, a SPOT multi-spectral (SPOT-XS) scene of the valley, taken March 5, 1996, was acquired for comparison and combination with the Radarsat data. Ground-truthing was undertaken in November 1997, by other HCL staff who also collected samples of soil, sediment, fish, livestock and human blood for analysis of dioxin contamination under the auspices of another project.

Plate 5 is a 1:250,000-scale multi-temporal scene of the A Luoi valley and surrounding hills. The southwest third of the image, west of the A Luoi valley, is in the Lao P.D.R.; a short distance of Highway 1 between Hué and Quang Tri is visible in the northeast corner of the scene. Although many areas of the hills surrounding the valley, particularly along the road to Hué (Plate 4) are barren of all vegetation except grasses, these barren areas are not visible in the highly-foreshortened steep terrain of the Radarsat image.

Although this scene was composed from the same two S7 images used to create the Quang Tri multi-temporal scene, the individual scenes were combined in reverse order, resulting in rice fields which appear orange instead of purple. This was done to provide best visual imagery for interpretation, as the inverted ratio of the S7's (i.e., the colour layer produced from statistically interpreting the spatial differences in data saturation between the two individual images) for this image provided a better saturation level and better results visually after its conversion to 8-bit data, than was achieved by combining the individual scenes in the same way as was done for Quang Tri.

Some rice cultivation (orange) is evident within the valley itself in the multi-temporal image. As with Quang Tri, the rice is difficult to discriminate from other wet areas (e.g., reservoirs) in the January 13 image alone, and difficult to discriminate from barren land and other agricultural land in the November 21 image alone.

Plate 6 shows the area immediately surrounding the town of A Luoi in the northern A Luoi valley at 1:50,000-scale, as imaged in fine mode (F3). Topography of surrounding hills is more detailed, but no more interpretable, than in the standard mode scenes, and rice paddy in this area, visible at 1:250,000 in the January S7, is difficult to discern from surrounding land, much of which is barren, uncultivated land (FIPI 1991). This is likely due to the timing of the fine mode image acquisition; the "moderate" backscatter from the rice fields in this image suggests the rice

was becoming mature, but had not grown dense enough to make it stand out from other surrounding land cover features.

Features which appear clearly in the fine-mode image include the meandering A Sap River, including gravel bars within the river channel, small reservoirs and fish ponds, and some roads and human settlement around A Luoi. The road to Hué enters the hills northeast of the bottom of the L-shaped curve in the river, and is not visible in the image in the steep hills bordering the valley.

Plate 7 is a SPOT-multispectral (XS) image of the area. It is immediately clear that forest cover, particularly in the hills and in steep terrain, is more easily discernable. Vegetation densities can be discerned to some extent, with dense forest appearing deeper red than poor forest and barren areas. Linear barren features in the hills bordering the A Luoi valley, possibly from herbicide application, are visible. Barren areas, and possibly slash-and-burn agriculture in the Ap Bia area are also evident. However, the SPOT-XS image does not clearly discriminate different agricultural land features, such as rice fields.

Plate 8 is a fusion of the SPOT-XS and Radarsat F3 images, showing the area surrounding A Luoi town. Addition of the Radarsat data to the SPOT data provides greater resolution of river channel morphology, reservoirs, and the road along the valley bottom, but reduces resolution of forest cover types in steeper terrain. Discrimination of rice is not aided by addition of the Radarsat F3, for reasons discussed above. Combination of the SPOT image with properly-timed single-pass or multi-temporal fine mode imagery would likely achieve this goal; however, this fusion would require a detailed digital elevation model for rectification, adding to the cost and complexity of this task.

Barren grasslands resulting from herbicide application are a lasting residual effect of the war on the people and environment of the A Luoi valley. Much of this remaining damage occurs in steep terrain, and could not be quantified using Radarsat technology.

3.1.3 Hué and Da Nang, Central Viet Nam

3.1.3.1 Historical Impacts

The areas surrounding Hué and Da Nang cities were not as widely affected by bombing or herbicide applications as other areas of central Viet Nam. Da Nang was the U.S. headquarters for central Viet Nam, where U.S. combat troops first landed in Viet Nam in 1965, and thus enjoyed relative security compared to other regions. Hué was the scene of some of the most intense ground-fighting of the war during the Tet offensive of January 1968, when NLF soldiers captured and held the Citadel at Hué for over a month before it was recaptured by USVN troops (Summers 1995). Hué and Da Nang fell quickly in March 1975, in the face of massive withdrawal of South Vietnamese troops further south.

Both Hué and Da Nang are situated along the South China Sea, and provided opportunities to evaluate Radarsat technologies in coastal areas.

3.1.3.2 Post-War Changes in Land Use, Residual Environmental Impacts, and Radarsat Feature Detection

- Plate 9 Hué City and Surroundings, Central Viet Nam (1:250,000, S4/F4 decolourized multi-temporal).
- Plate 10 Hué City and Surroundings, Central Viet Nam (1:250,000, S4/F4 multi-temporal).
- Plate 11 Da Nang City and Surroundings, Central Viet Nam (1:250,000, S7).
- Plate 12 Da Nang City and Surroundings, Central Viet Nam (1:250,000, S7/S7 multi-temporal).

Two Radarsat images of Hué were acquired, a standard mode S4 (August 12, 1996), and a fine mode F4 (August 29, 1996). Plate 9 is a decolourized multi-temporal scene (S4/F4) of Hué and its surroundings, extending to the South China Sea coast in the northeast corner of the scene.

These two images were not originally collected with the intention of merging them as a multi-temporal image, and their geographic coverage does not overlap completely within the study area. This provides an opportunity to examine different types of single-pass data and multi-temporal data in one scene. Plate 10 is a multi-temporal merge of these two images; the black-and-white portion of the image in the upper area of the scene is S4-only data, while the black-and-white portion of the scene along the right edge of the map is F4-only data.

As noted with Quang Tri and A Luoi, the multi-temporal data effectively highlights areas of rice cultivation (orange/yellow) from areas of forest cover or other land use (red). The rice appears orange and not purple due to the order of merging the two dates – areas of rice cultivation appear brighter in the August 12 scene than in the August 29 scene. Multi-temporal data from images taken only three weeks apart were still helpful in highlighting different land uses.

The old city and Citadel of Hué dominate the multi-temporal scene. Both fine and standard modes were effective at discriminating the moat around the old city and its general layout; the fine mode imagery was much more effective at highlighting details of the Citadel, including the Imperial Palace, which appears as a darker square near the river within the old city.

Near the mouth of the Perfume River, and between the mainland and the barrier islands visible in the scene, numerous fish and shrimp pens and fish nets were visible (Plate 10, facing page). The nets were long, V-shaped fences, fixed into the shallow bottom of the lagoon, with twine strung between bamboo poles approximately 1 m apart and 1 m high. These features and the pens (more permanent features bounded by earthen or net dikes) were much more clearly distinguished in the fine mode imagery than the standard mode imagery – a likely outcome, given the fine scale of these features. Both modes distinguished the land/sea interface very clearly.

Two Radarsat images were taken of the Da Nang area in 1997, one in late August 1997 and the other in early October 1997; both were standard mode (S7). Plate 11 illustrates Da Nang city (using the November image as a base) and herbicide applications in the surrounding area during the war. Da Nang city is located below the knob-shaped peninsula at the mouth of the Han River. Da Nang airport is clearly visible immediately southwest of the city. A breakwater, protecting the port of Da Nang behind it, lies at the mouth of the river. To the northwest of the city is another river, the Song Ca De; south of Da Nang lies China Beach, a long wide sand beach, and the city of Hoi An, near the mouth of the large Thu Bon River. Ground-truthing of Da Nang was not undertaken during the November/December ground-truthing trip; however, HCL staff are familiar with the area from other projects.

Plate 12 is a multi-temporal merge of the two images discussed above, and highlights many of the advantages of multi-temporal scene production. Areas of rice cultivation appear very clearly in purple; the seasonal floodplain of the Thu Bon River also appears purple, and can be discriminated from paddy by its contiguous connection with the river channel. Roads and bridges are highlighted by the different colours surrounding them. The coastal margin is very clear, as is the boundary between lowland agriculture and wet paddy agriculture and upland areas with steeper terrain and stable cover.

Several areas of dark red are apparent in the scene, particularly just inland from the ocean. One such area, near Tram Lake between Da Nang and Song Ca De, is in an industrial estate; the dark red areas within the estate (below the large area of rice cultivation) are generally white sand areas with little or no vegetation. This is consistent with barren sand dunes imaged in Quang Tri as well, and suggests that the other dark red areas surrounding the Thu Bon River are also dunes. There are several presumably dry-land agricultural areas which appear orange or yellow in the multi-temporal scene; it is unclear what these features are. Cham Island, a forested island with protected status, is visible offshore of the Thu Bon River.

3.1.4 Ma Da Upland Forest, Southern Viet Nam

3.1.4.1 Historical Impacts

The jungles of Ma Da, northeast of Ho Chi Minh City, were used by NLF (Vietcong) soldiers as covert bases of operation during the war, and supported a USVN airbase at Rang Rang, along the Ma Da River. Considerable conventional damage was done to some areas through bombing and shelling, but at a level not comparable to the massive firepower brought to bear in central Viet Nam. The Ma Da region fell within "War Zone D" of South Viet Nam during the war, which for some time was considered to be the location of the hidden NLF headquarters (Westmoreland 1976).

Due to its strategic location near Saigon (now Ho Chi Minh City), American and South Vietnamese forces attempted to deprive NLF forces from using the Ma Da forest as refuge. To achieve this, the Ma Da forest became perhaps the most heavily herbicide-sprayed area of Viet Nam during the war (Plate 13).

Ma Da was a research area for Ashton (1986) and FIPI (1991); FIPI estimated that more than 92% of the area was affected by herbicide application. Due to the low population density of this area, many areas were left to regenerate naturally after the war; areas south of the Ma Da River were more intensively rehabilitated and developed as forest plantation. Low, dense, scrubby forest has regrown in most other areas, although "lines" of barren, uncultivated grasslands remain in several areas. FIPI (1991) speculated that the invasion of opportunistic "American" grass and wild fires has retarded reforestation efforts. Why forest has regenerated naturally in some areas and not in others is unknown.

Ashton (1986) classified Ma Da forest as Seasonal Evergreen Dipterocarp, whose original canopy likely varied much in canopy structure.

3.1.4.2 Post-War Changes in Land Use, Residual Environmental Impacts, and Radarsat Feature Detection

- Plate 13 Overview, Ma Da Upland Forest, Southern Viet Nam (1:250,000, S7)
- Plate 14 Ma Da Upland Forest, Southern Viet Nam (1:100,000, SPOT-XS)
- Plate 15 Ma Da Upland Forest, Southern Viet Nam (1:100,000, F5)
- Plate 16 Ma Da Upland Forest, Southern Viet Nam (1:100,000, F5/SPOT-XS)

Three Radarsat images of the Ma Da forest were acquired in 1996 and 1997, as well as one SPOT-XS image, acquired from the archives of the Department of General Land Administration in Hanoi, Viet Nam. The three Radarsat images were an S7 (ascending) on August 15, 1996, an S6 (descending) on August 31, 1996, and a fine mode F5F (ascending) on August 10, 1997. Processed scenes from the S7 and F5F appear and are discussed in this report.

Plate 13 is a 1:250,000-scale overview of the Ma Da forest region, showing herbicide applications and ground-truthing waypoints from November/December 1997. The large reservoir in the lower right corner of the scene is the Tri An reservoir, which was created in the early 1980s. Northwest of the Tri An reservoir is the smaller Ba Hao reservoir. The Song Be river is visible in the lower left quadrant of the scene. The roughly round, flat-looking area northwest of the Tri An reservoir is the Ma Da forest proper. The small Ma Da River flows roughly northeast-southwest through this area, flowing into the Song Be river.

The Ma Da Forest Enterprise is responsible for the management of the forest south of the Ma Da River, while the Phu Binh Forest Enterprise is responsible for the forest north of the river. The area south of the river was more actively rehabilitated and reforested after the war, with a mix of eucalypt, rubber and teak. The area north of the river was sparsely populated, and therefore mostly left to regenerate naturally without active rehabilitation.

Rang Rang, the site of a USVN airfield during the war, and now site of a very small village, is located on the Ma Da River, in the approximately centre of the forest, along a seasonal road which connects Tri An with the town of Dong Xoai north of the forest.

Plate 14 shows a 1:100,000-scale SPOT-XS scene of the Ma Da forest. The Ma Da River roughly bisects the image from top-right to bottom-left. Rang Rang is located near the centre of the scene, along the road from the Ba Hoa reservoir below. Different land uses are apparent in the northwest corner of the scene; these are likely plantations of rubber, cashews and eucalypt, the species most frequently replanted in this area. Of most interest are the north-south linear features visible to the north of the Ma Da River. The areas surrounding these "lines" are composed of low, dense, naturally-regenerated forest, with occasional large *Invingia* trees, which were resistant to the applied herbicides, standing well above the rest of the forest canopy (Plate 14, facing page). Land cover within the lines themselves is generally uncultivated grassland. There is some scattered cultivation and new plantation forestry north of Rang Rang, and near the small, "exclamation point"-shaped reservoirs in the centre-left of the scene, but typically these lines support barren grasslands (Plates 14 to 16, facing pages). Generally, SPOT-XS imagery was very effective at showing breaks in forest cover and linear grasslands. The precise north-south direction of these grasslands lines up with herbicide applications during the war in this area.

Plate 15 is the Radarsat F5F scene of the same area. Some of the features visible in the SPOT image are also clear in the Radarsat scene – for example, delineation of roads and reservoir edges, but the linear grasslands, and sharp edges between forest and grassland, are far less clear than was the case with the SPOT image. The F5F was more effective than the S7 or S6 images at delineating these grasslands. Areas within the grasslands gave very different radar returns within the F5 image, with some areas returning very dark returns and some with radar returns barely darker or no different than the surrounding forest. These dark areas may be newly-tilled fields; some small plantations of rubber and eucalypt were observed near the north end of some grassland features. This fine mode scene displays a great deal of speckle, making it more difficult to resolve land cover features.

A multi-temporal scene of the area was generated using the F5 and S7 data (Appendix A2); this scene was not helpful at highlighting differences in cover and in fact tended to reduce contrast between areas visible in each image independently.

Plate 16 is a combination scene using SPOT-XS and Radarsat F5F data. The addition of radar data to the SPOT scene tends to sharpen edges of features visible in the scene, such as the road from Ba Hao to Rang Rang, the Ma Da River, and some of the grassland edges. Additionally, it provides much more information on the general topography of the area, particularly in the northeast of the image, which is more rugged. The radar data may provide information on new fields being worked and soil being tilled in the linear grasslands.

While much of the Ma Da forest has been rehabilitated, there remain several lingering effects of war in this area. The existence of the linear grassland features within forest which has otherwise regrown naturally remains a cause for concern and study. Reasons for natural regrowth in one area, and no regrowth immediately adjacent to it, are unknown. The sheer volume of herbicides applied to Ma Da also raises issues of chemical contamination of soil, livestock and ultimately people living in the area. Unexploded ordnance remains a threat to development in the areas north of the Ma Da River which were not actively rehabilitated immediately after the war.

3.1.5 Rung Sat Mangrove Forest, Southern Viet Nam

3.1.5.1 Historical Impacts

Rung Sat mangrove forest, south of Ho Chi Minh City but within its administrative borders, was the site of many minor skirmishes during the war between USVN riverine operations forces and NLF cells. Due to its proximity to Saigon, however, it was of major strategic importance during the war. Much of Rung Sat was heavily-sprayed with herbicides, to prevent NLF forces from sheltering in the mangrove forests, and reduce the chance of surprise attacks. Herbicide spray missions flown over Rung Sat between 1965 and 1971 appear in Plate 17.

The Society for Social Responsibility in Science funded the travel in March 1969 of American biologists to learn about the effects of defoliants (Orians and Pfeiffer 1970; Neilands *et al.* 1972). One of their field trips was to Rung Sat, from which they concluded that the mangroves were "extremely susceptible" to defoliants. Only one application was apparently necessary to "kill most trees". Most of the areas they visited remained "completely barren" although they had been sprayed several years earlier. They speculated that:

"*The unusual soil conditions of mangrove forests may result of a failure of the herbicides to be decomposed. If the molecules remain bound to the soil particles, they might influence seed germination for a long time.*"

The HERBS data base yielded 299 spray missions over Rung Sat between 1965 and 1970 which deposited 2,429 kg of Agent Orange, 1,300 kg of Agent White and 186 kg of Agent Blue, and destroyed approximately 57% of the area's mangroves (Hong and San 1993).

3.1.5.2 Post-War Changes in Land Use, Residual Environmental Impacts, and Radarsat Feature Detection

- Plate 17 Overview, Rung Sat Mangrove Forest, Southern Viet Nam (1:250,000, F5)
- Plate 18 Rung Sat Mangrove Forest, Southern Viet Nam (1:250,000, F4/F5 multi-temporal)
- Plate 19 Detail, Rung Sat Mangrove Forest, Southern Viet Nam (1:70,000, F4/F5 multi-temporal)
- Plate 20 Detail, Rung Sat Mangrove Forest, Southern Viet Nam (1:70,000, F4/F5 multi-temporal)

Three Radarsat scenes of Rung Sat were collected; a fine mode F4 in August 1996, an F5 in August 1997, and a standard mode S2 in July 1997. The fine mode imagery was chosen for further processing and interpretation, given its greater ability to highlight different land use features at scales of interest in this area. Multi-temporal imagery was most effective for discerning different land cover and land use features.

Plate 17 is a multi-temporal merge of the F4 and F5 scenes, with the S2 used as background to complete the image. This composite image allows comparison of these different beam modes and image types. It is immediately clear that the fine mode imagery not only provides greater resolution, but the low incidence angle of the S2 resulted in greater returns over the South China Sea in the south of the scene, and less distinct edges between different land features than is evident in higher incidence angle S7 imagery shown for other study areas. The Siagon River enters the scene from the northwest, flowing south and past Ho Chi Minh City, the outskirts of which are visible in the northwest corner of the scene.

Several land use features are apparent in this multi-temporal image; Plates 18 and 19 are larger-scale scenes of this multi-temporal merge, showing northern and southern sections of Rung Sat, respectively. Much of Rung Sat, particularly the central portion, is protected from human development, and has been actively rehabilitated through replanting of mangrove forests (Mr. Phung Tuu Boi, FIPI, *pers. comm.*). These mangrove forests, composed primarily of *Rhizophora* sp., range in age from a few years to approximately fifteen, and are clearly visible in the scene centre, and areas of regular radar backscatter, dissected by numerous large and small tidal channels. Mangrove forests in central Rung Sat are relatively small and young by natural mangrove forest standards, but these areas, heavily sprayed by herbicides during the war (Plate 17), have been rehabilitated toward their former pre-war state.

The northern portion of Rung Sat supports rice cultivation and other agriculture. Rice fields, which returned strong backscatter in August 1996 but dark backscatter in September 1997 (Plate 18, facing page), are clearly visible as purple areas in the scene. The most densely-cultivated fields in Rung Sat were not sprayed during the war, suggesting that they supported extensive rice cultivation at that time as well.

Small aquaculture ponds are also found throughout Rung Sat. These areas appear as regular, dark red features in Plate 18. These ponds are impossible to distinguish from rice cultivation in the August 1996 image alone. Although these small facilities are filled with water, the presence of narrow, earthen dikes in the ponds (Plate 18, facing page) may "brighten" the return from black to dark red. Barren, diked shrimp aquaculture areas also appeared dark red in Radarsat imagery of the Ca Mau peninsula (Section 3.1.6).

In the portion of northern Rung Sat which was heavily sprayed (i.e., east of the primary rice-growing area in Plate 18), little rice is grown. Some small fish ponds occur, but in much of the area a tall, thick natural grass (*Cyras* sp.) is cultivated for thatch. These fields of grass are harvested at irregular intervals, and may explain the yellow and orange tones visible in this area of the scene (i.e., areas of grass which were more mature in August 1996 than September 1997). Many of the other irregular agricultural areas observed in northern Rung Sat, such as the narrow, strong-backscatter areas dividing areas of rice cultivation in Plate 18, may be *Nipa* palm plantations. These wet-land crops are grown for thatch throughout northern Rung Sat, with other agricultural fields. Other features visible in the multi-temporal imagery include roads and canals. Areas of young (i.e., approximately 1 year old) mangrove visited during ground-truthing in December appear yellow in the image, suggesting that their growth between August 1996 and

September 1997 registered in the multi-temporal scene through increased backscatter in the 1997 image.

Southern Rung Sat has been replanted with new mangrove, but has also experienced other developments. Several areas of large, industrial-style shrimp farms are visible in Plate 19 (areas of regular, ordered squares of dark red or black). These shrimp farms were developed in the mid-1980's during the Asia-wide boom in shrimp aquaculture, but subsequently abandoned in the years following, due to acidification of the soil and softening shrimp markets. Some of these abandoned shrimp farms have been replanted with mangroves, with hopes of rehabilitating mangrove forest in these areas. Below-left of the centre of Plate 19 is such an example, with small mangroves replanted in a series of ten former shrimp ponds; these ponds appear the same colour as the mangrove forest, not the dark red or black of the other shrimp farms in the area.

Other large, dark features visible in the scene are salt farms, where salt water is flooded into large, shallow ponds, and held for evaporation to salt. These areas are visible in the upper reaches of southern Rung Sat, and near the southern shore. The town of Can Gio is visible in the image as an area of very strong backscatter in the southeast corner of the peninsula.

Also somewhat evident in the southern Rung Sat scene is the effect of tidal conditions on image composition. This is best illustrated by the green edge visible along the narrow spit in the upper right of Plate 20; comparison of this feature in the two component images (found in Appendix 2) shows that the tide was higher in the August 1996 image, and had obscured more of this spit. This intertidal area appears as a green fringe along the spit in Plate 20. It is interesting that this signature is not seen along the mangrove forest channels themselves; this is likely due to the fact that mangroves are intertidal species, and their canopy likely extends over the water's edge continually except perhaps during very low tides.

The Rung Sat forest has been rehabilitated to conditions approaching those found before herbicide applications destroyed much of the natural mangrove forests. Rehabilitation continues, with abandoned shrimp farms in southern Rung Sat also being replanted with mangroves. The new mangrove forests are still small and young, but through rehabilitation and their protected status, they persist.

3.1.6 Ca Mau Peninsula Mangrove Forest, Southern Viet Nam

3.1.6.1 Historical Impacts

Ca Mau has an important role in the history of mangrove defoliation in southern Viet Nam. In the summer of 1962, Ca Mau was the location of mangrove and *Nipa* palm herbicide tests by the U.S. military using Agent Orange. Neilands *et al.* (1972) reported that:

"*The mangrove vegetation was completely defoliated in about one week. Nipa palm was slower, turning yellow and loosing its leaves within five weeks. After five weeks 95% of the leaves had*

dropped, and the visibility of the ground from directly overhead had increased by 90% according to army studies."

Later, the Ca Mau area was the site of much spraying to deny cover to North Vietnamese troops active in this Mekong delta area. According to the HERBS data base, from 1966 to 1970 the tip of the peninsula lost approximately 52% of its mangroves after receiving 1,027 kg of Agent Orange and 285 kg of Agent White during 55 spray missions (Hong and San 1993). One ha of dense, mature *Rhizophora* forest in Ca Mau contained approximately 350 trees yielding about 100 m^3 of wood. Hong and San (1993) reported an estimate that herbicides caused the annual loss of 20-40 m^3 of timber and 60-100 kg of shrimp per ha of *Rhizophora* forest.

FIPI (1991) used Ca Mau as a research area given its mangrove (largely *Rhizophora apiculata*) cover of the area overall went from approximately 89% to 41%; a loss of over 31,000 ha. Further, there was considerable destruction of drier-land mangrove *Melaleuca* sp. also in the Ca Mau region. *Melaleuca* are often found in single-species stands in acidic, peat soils moistened by brackish water (USOM 1957).

3.1.6.2 Post-War Changes in Land Use, Residual Environmental Impacts, and Radarsat Feature Detection

- Plate 21 Overview, Ca Mau Peninsula, Southern Viet Nam (1:250,000)
- Plate 22 Ca Mau Peninsula, Southern Viet Nam (1973) (1:250,000, Landsat-1 MSS)
- Plate 23 Change Detection, Ca Mau Peninsula, Southern Viet Nam (1:250,000, MSS/S7 composite)
- Plate 24 Detail, Ca Mau Peninsula, Southern Viet Nam (1:50,000, F5)
- Plate 25 Detail, Ca Mau Peninsula, Southern Viet Nam (1:100,000, S7/S7 multi-temporal)

Four scenes were collected of the Ca Mau peninsula. Three were Radarsat scenes – a standard mode S7 acquired on August 19, 1997, an S7 acquired November 23, 1997, and a fine mode F3, acquired December 17, 1997. In addition, a Landsat-1 MSS image, collected January 3, 1973, was acquired from the U.S. Geological Service archives, and used for change detection analysis.

The S7 image collected August 19, 1997, was requested with Automatic Gain Control, which adjusts the gain of the satellite sensor in response to backscatter intensities. Unfortunately, this resulted in a drastic shift in gain during acquisition of the Ca Mau S7 image, and also resulted in a "washing out" of southern Ca Mau Radarsat data. Plate 21, which shows herbicide applications in Ca Mau during the war and GPS waypoints ground-truthed in November 1997, uses this August image as its background image. Despite efforts to minimize the negative effects of the gain shift, the effects of the gain shift on Radarsat data quality are apparent. The second S7, acquired November 23, 1997 with fixed gain control, was acquired in response to the gain problem encountered with the August image.

Interpretation of this multi-temporal scene is made difficult by the gain control problem inherent in the August image, which manifested itself most noticeably in this area of the peninsula. However, some features are evident. Rice-growing areas are clearly distinguished from shrimp farming and freshwater fish ponds in the multi-temporal scene, and appear purple along the upper edge of the image. Barren-cover shrimp farms and small freshwater fish ponds are both shown as dark red, with fish ponds (immediately below the rice) distinguishable by their geometry and size. The centre of Tam Giang III forest enterprise, visible by the cross-shaped intersection of east-west and north-south canals, supported tall, mature mangrove plantation previous to the typhoon, which was severely damaged by the typhoon (Plate 25, facing page). Effects on this mature patch of mangrove forest may be visible in the multi-temporal scene, which shows this forest as an area of white and blue, surrounded by darker, less well-forested areas. However, areas below the Cau Lon river also appear blue, but likely due to the increasing effects of gain shift on the August 1997 component image.

Commenting on the effects of herbicide applications on Viet Nam, General Westmoreland speculated that the spraying may have enabled agriculture through land clearance (Westmoreland 1976). This may have been the case in Ca Mau. Although population pressures are great enough that development of Ca Mau may have occurred regardless of the destruction of most existing mangroves by herbicides, the absence of dense forest cover may have facilitated construction of shrimp aquaculture ponds and aided the destruction of the remaining natural mangrove forest ecosystems.

3.2 LAOS

United States military policy was not to commit their ground forces in Laos, but to rely on air warfare to support generally covert operations. Between 1964 and 1973, approximately two million tons of U.S. bombs were dropped on Laos to support Lao royalist forces and Hmong resistance against the communist Pathet Lao in northern Laos, and more importantly, to destroy North Vietnamese units and disrupt the transport of North Vietnamese war supplies along portions of the Ho Chi Minh trail in Laos from North Vietnam into South Vietnam. By 1966, the U.S. was bombing with B52's. Particularly heavy bombing occurred from 1964 to 1969; all bombing stopped by 1973.

Unexploded ordnance (UXO) still affects many provinces, with 2,490 villages reporting local UXO, and approximately 2,400 km^2 remain seriously contaminated with UXO (UXO-LAO 1997a,b). Approximately 50% of the nation's total landmass has some level of UXO contamination (UXO-LAO 1997b). Areas worst affected are the Plain of Jars and Sam Neua areas of northern Laos, and Xepon, Saravan, and Attapeu provinces in southern Laos.

In 1965, the U.S. also began spraying herbicides to clear vegetation along the trail near the Vietnam border after learning that the North Vietnamese were using heavy equipment to improve the trail. Within six months, over 200,000 gallons (>900,000,litres) of herbicide had been sprayed along approximately 1,500 km of roads and trails in Laos (IOM 1994). The U.S. maintained a spray campaign against North Vietnamese infiltration routes in Laos with Agents Orange and White likely until 1971. However, precise estimates of herbicide applications and

war damage are not publicly available, as neither the American nor North Vietnamese military maintained official, public records of their activities in Laos, as both parties claimed to observe the "neutral" status of Laos.

Ground-truthing in Laos was limited by a lack of participation by government officials in the field studies (Section 2.5.1). As a result, field visits were by necessity somewhat cursory in nature.

3.2.1 Bolavens Plateau/Pakse, Southern Laos

3.2.1.1 Historical Impacts

The history of the U.S. involvement, particularly the air war, in southern Laos is less well recorded than that for the Plain of Jars in the north. In 1962, there was a large North Vietnamese force in southern Laos near the South Vietnamese border. Approximately 3,000 North Vietnamese troops, the largest contingent in Laos, occurred near the demilitarized zone and operated in support of the logistical back-door route into South Vietnam. In particular, there were three passes in the Annamite Mountains that funneled supplies into South Vietnam. After some early successes in controlling the Bolavens plateau through local villagers, U.S. influence decayed in 1966 and permitted the North Vietnamese easier use of the southern portion of the Ho Chi Minh trail.

3.2.1.2 Post-War Changes in Land Use, Residual Environmental Impacts, and Radarsat Feature Detection

- Plate 26 Overview, Pakse/Bolavens Plateau, Southern Laos (1:250,000, multi-temporal)
- Plate 27 Pakse and the Mekong River, Southern Laos (1:100,000, multi-temporal)

Two images of the Pakse/Bolavens Plateau area of southern Laos were acquired, both S7, one on December 12, 1996 (from archive), and one on July 26, 1997. These images were merged to form a multi-temporal scene (Plate 26). Plate 27 is a detailed view from this multi-temporal scene, of the town of Pakse and the Mekong River valley.

The Mekong River appears in the lower left of Plate 26. The town of Pakse is clearly visible at the centre-left of the image, at the confluence of the Xe Don and Mekong rivers. The eastern half of the image is taken up by the Bolavens Plateau, a high plateau which rises sharply from the Mekong valley. The funnel-shaped feature in the centre of the image is a gently-rising slope joining the lowlands with the plateau; steep river valleys occur on either side of this slope, creating the striking funnel shape in the image.

Land uses in the lowlands (Plate 26) include rice cultivation, visible in the image as dark blue areas. There is little rice cultivation visible in the image, and it is generally found along the river. This area of Laos is generally dry and hot, likely limiting rice cultivation to such areas.

Fish ponds are visible as regular shaped black areas, but are difficult to discriminate from rice in the prints of the multi-temporal scene. Steep karst hills rise from the lowlands, and are visible to the northeast and southwest of Pakse. Agricultural lands surround Pakse, and may be visible as yellow features in the multi-temporal scene.

On the Bolavens Plateau itself, the central town of Paksong is visible as a small area of bright return in the centre-right of the image. Surrounding land features include some rice plantation and dry land agriculture, coffee plantations, and several areas of grasslands, with newly planted pine trees (<2 m high) occurring in several of them. The grasslands are visible in the imagery as dark red areas to the east of Paksong.

A series of low hills occurs in the Bolavens Plateau, following a roughly north-south line across the plateau (Plate 26 and facing page). These hills are presumably volcanic in nature, given their shape and linear arrangement.

The Bolavens Plateau was fought over during the war of liberation in Laos, and also in part due to its proximity to the Ho Chi Minh Trial and the Cambodian and Vietnamese borders. However, military actions were generally small-scale; American involvement in the region was limited to training and covert operations with tribal groups in the area. No signs of war damage were visible in this area.

3.2.2 Xieng Khouang (Plain of Jars), Northern Laos

3.2.2.1 Historical Impacts

"The importance of the plain is geographical. Although less than ten miles across, it is the biggest area in northern Laos that is flat, or close to flat. Around it in all directions rise wild mountains, with spectacular limestone escarpments poking up here and there through the heavy forest canopy. The few roads of northern Laos converge in or near the Plain of Jars, and that makes it a favorite gathering point and logistical centre for any army." (Warner 1996)

As a result of a neutralist coup in Vientiane in August, 1960, the government essentially came under the control of the communists. By January, 1961 the U.S. CIA was funding Operation Momentum to arm and train ethnic hill people (Hmong, or Meo) to defend the Plain of Jars against communist (neutralist/Pathet Lao/North Vietnamese) forces in the civil war to control Laos. By summer of 1962 a peace agreement was in place allowing for a neutralist-royalist-Pathet Lao coalition. As well, there was a withdrawal of all foreign (American and Soviet) advisors and a withdrawal of some North Vietnamese (although 5,000 to 7,000 remained).

The Plain of Jars, named for mysterious, ancient stone jars found in some areas, was under the control of the Pathet Lao and their advisors while the Hmong and their American advisors controlled the surrounding highlands. In 1964, U.S. bombing began in the back-and-forth war to control this centre of strategic importance. The Plain of Jars was connected to Hanoi by a rugged road through the mountains, and was used as a staging area for American covert

operations in Laos. Several clashes occurred between the North Vietnamese-supported Pathet Lao and American-supported Hmong.

Often, North Vietnam provided troop battalions to support the Pathet Lao, and Americans provided massive air support to the Hmong, particularly in the late 1960s and early 1970s, when the war in Viet Nam was at its peak and then scaling-down. The plain was also along the flight line of American B-52s launched from Thailand to bomb Hanoi. B-52s would often drop loads of bombs (typically cluster bombs) on the plain on their return to Thailand if they had not dropped their complete contingent over Viet Nam, as pilots were forbidden to land while still carrying bombs (Warner 1996). Due to the intense bombing of this area of Laos by American B-52s, much of the area remains heavily impacted by UXO, which regularly kill and maim local people.

3.2.2.2 Post-War Changes in Land Use, Residual Environmental Impacts, and Radarsat Feature Detection

- Plate 28 Overview, Plain of Jars, Northern Laos (1:250,000, multi-temporal)
- Plate 29 Phonsavan, Plain of Jars, Northern Laos (1:100,000, multi-temporal)

Two Radarsat images of the Plain of Jars were acquired: a standard mode S7 (from archive), acquired December 23, 1996, and a fine mode F2, acquired August 3, 1997. Plate 28 shows the Plain of Jars as visualized by the S7 image.

The plain itself is a broad, relatively flat, high plateau, surrounded by high mountains. Most of the plain is barren grassland, with some agriculture practiced through seasonal burning of grasslands. Much of the land left uncultivated (Plate 28, facing page), largely because of UXO. Bomb craters are everywhere and many areas are considered too unsafe to farm.

The plain is roughly kidney-shaped, with the only town, Phonsavan, visible along the eastern margin of the plain. Two major roads connect to the plain, both at the eastern edge. One road follows a steep valley northeast from the plain toward Sam Neua and ultimately Hanoi; the other extends east-southeast from the plain from south of Phonsavan to the old capital of the province, Xieng Khouang, which was destroyed by bombing in 1969. Rice cultivation occurs along these valley bottoms.

The grasslands of the plain are very clear in the S7 image, and are easily distinguished from the surrounding steep terrain. Drainage patterns are easily distinguished, as most waterways support either rice cultivation or modest forest cover, which return stronger radar backscatter in this image than the surrounding fields.

Plate 29 is a multi-temporal merge of the S7 and the F2 scene, showing the area immediately surrounding the town of Phonsavan. Rice fields, often visible in multi-temporal imagery, appear pink in this scene, just east of the town of Phonsavan along the road to Sam Neua. Roadways in town are visible, as is the airport. Purple areas on some of the hills surrounding the town are areas which appear brighter in the F2 image, and may correspond to types of dry-land agriculture

or forest; however, it may as likely be an artifact of different foreshortening of steep terrain in the F2 and the S7, as no features were seen during ground-truthing which appeared to correspond to these features. The multi-temporal image is generally of little help in elucidating land cover features, and emphasizes the importance of creating multi-temporal scenes from imagery of similar mode if possible, and timing acquisition of component images to provide best changes to visualize features you wish to discriminate (e.g., rice).

Features not visible in either the standard or fine mode imagery of the Plain of Jars are the numerous bomb craters which dot the plain. These craters range in diameter from approximately two metres to ten metres, and are sometimes barren or grassy, and sometimes support shrubs or even trees growing within them. These features are at the edge of resolution of Radarsat fine mode imagery; even if they were visualized by the fine mode imagery, they would likely be interpreted as speckle and not differentiated from the rest of the landscape.

Residual war damage continues to severely limit the rehabilitation and development of this area because of the ubiquity of UXO. Inability to work in the fields and forests keeps the local people in poverty, which in turn hinders their ability to rehabilitate these areas to productive land. International organizations are active in helping to remove UXO. However, it will be a considerable time before many of these areas are rehabilitated to the point of productive use.

4.0 SUMMARY AND CONCLUSIONS

4.1 RESIDUAL ENVIRONMENTAL EFFECTS OF THE VIET NAM WAR

The focus of this investigation was to evaluate the utility of Radarsat imagery to assess residual environmental effects resulting from the Viet Nam war (1961 to 1975). During the war, U.S. forces employed deliberate destruction of the environment as a military tactic to deny cover and food to opposition forces. These tactics were employed throughout large areas of Viet Nam, Laos, and Cambodia. Approximately 10% of the surface area of South Viet Nam was directly affected. Poor records were kept for Laos and Cambodia, and there is no accurate assessment of ecological damage in these countries.

This study attempted to identify residual impacts resulting from the following five tactics employed by U.S. lead forces, which caused environmental damage:

- herbicide spraying to deny opposition forces vegetation cover and food;
- clearing of forests, agricultural land, and villages by bulldozer (Rome ploughs);
- burning of *Melaleuca* forests, grasslands and other vegetation by incendiary devices;
- use of high explosive ordnance, particularly B-52 saturation bombing; and
- draining of wetlands, particularly in the Plain of Reeds area.

While ground-truthing the region in 1997, the ecological effects of the Viet Nam war were evident in areas throughout Viet Nam and Laos. Most profound perhaps were the large-scale changes to land-use and land-cover in war damaged areas. In many cases, trying to differentiate between changes resulting directly from warfare and those caused by population increases (Vietnam's population has doubled since the war), increased agricultural demands, forestry, etc. was difficult. However, in many areas war-related damage remains clearly visible, particularly impacts related to herbicide applications and bombing.

For example, in Quang Tri province and A Luoi, barren grasslands still occupy large areas formerly covered by thick, native forest. Despite significant efforts by the Vietnamese government to establish plantation forests, much of central Viet Nam north of Hué remains covered with scrubby grassland, unproductive for humans or wildlife. In Ma Da, natural revegetation and plantation forestry have returned much of the formerly thick multi-story forest to treed cover, but in a more biologically impoverished form than previous to the war. Linear uncultivated grasslands occur in areas heavily sprayed by herbicides during the war, despite regrowth of natural forest in adjacent (probably less heavily sprayed) areas. In Rung Sat, reforestation efforts have been largely successful at returning this area to a state resembling its pre-war condition. Intensive replanting and enforced protection of mangrove forests in this area have reduced the environmental impacts of herbicide applications here considerably. However,

expanding shrimp farming activities now pose a significant threat to re-established mangroves, particularly in Ca Mau.

In areas of south Viet Nam heavily sprayed with herbicides, there is additional concern regarding chemical contaminants in the environment, particularly dioxin. Studies of dioxin contamination of soil, sediment, fish and livestock in A Luoi by HCL, and studies throughout Viet Nam by Vietnamese scientists have shown that significant levels of these contaminants exist throughout the southern Vietnamese environment, levels which could have important implications to the health of wildlife and local people (HCL *in prep.*).

In all areas, but particularly Quang Tri province in Viet Nam and the Plain of Jars in Laos, UXO is a significant threat to people. Bomb craters were usually less than 5 metres in diameter, and consequently not detectable in Radarsat imagery, even when filled with water. In addition, encroachment by vegetation and filling in by farmers have removed much of the physical evidence of intensive bombing in most areas.

In the Plain of Jars, evidence of heavy bombing was clearly visible during ground truthing exercises, however, these features could not be resolved in Radarsat imagery. In some areas, bomb craters have been enlarged and are now fish ponds; these are generally not visible unless sufficiently large.

Intensive bombing has resulted in changes to land-use patterns, both positive and negative. For example, human activity in affected areas remains severely curtailed, allowing natural vegetation and wildlife to become reestablished in some areas; however, rehabilitation efforts have been hindered, and farmers are prevented from returning to previously productive areas. This is particularly true in border regions of Cambodia and Laos where political instability has prevented systematic demining and UXO removal.

Residual effects of wetland drainage in the Plain of Reeds area, southwest of Ho Chi Minh City, could not be evaluated due to cancelled Radarsat image orders. Further, image acquisition problems, ground-truthing time limitations and a lack of supporting secondary information prevented *Melaleuca* forests in southern Viet Nam from being evaluated.

4.2 RADARSAT AS A TOOL FOR ENVIRONMENTAL MONITORING AND ASSESSMENT

4.2.1 Feature Detection

Based on our experience in Viet Nam and Laos, Radarsat imagery provided much useful data, once a steep learning curve had been overcome. The quality of images (and extractable information) improved markedly between project Phases I and II, largely as a result of improved digital image processing. Single-date data were found to provide useful information on coastal features, some forms of agriculture (if timed properly), land cover (e.g., forest cover vs. barren areas) and patterns of settlement. Significant amounts of information on land cover was lost in

images of even moderately rough terrain. The ability to interpret images and extract useful information was, therefore, significantly greater in relatively flat areas.

Multi-temporal composite images were extremely useful for monitoring seasonal changes on croplands, floodplains, and forests, and generally reduced the effects of image collection conditions on interpretation of scenes. Either single-date or multi-temporal imagery would be useful for developing or updating digital base maps for environmental impact assessments (EIAs) or other environmental surveys. EIAs are frequently required in remote areas for which there is often little supporting data, and poor quality maps. For example, for most of Viet Nam, the most current series of topographic maps dates from the mid-1960s to mid-1970s. In a country such as Viet Nam, with intense population pressures on a relatively small land base and the added effects of war damage, 30-year old maps are not typically representative of current land use patterns. Similarly, digital land cover maps acquired from FIPI, based on early 1990's Landsat-TM imagery, did not accurately represent land cover features visible in 1996/1997 Radarsat imagery or 1997 ground-truthed information. Acquisition of optical remote sensing data throughout most of Southeast Asia is difficult given the common occurrence of haze, smoke and clouds.

4.2.2 Change Detection

Change detection (i.e., monitoring) using multi-temporal image composites is a particular strength of Radarsat imagery. Features that were detected in multi-temporal images included: forest clearing (e.g., Ma Da), replanting (e.g., Ca Mau, Ma Da, Quang Tri), reservoir filling/emptying (Quang Tri), and growth of urban areas (e.g., Rung Sat). Multi-temporal data were most effective when images were collected using the same beam mode, and at higher incidence angles (e.g., S7 or F5). Change detection was also effective when comparing new Radarsat data with historical optical imagery, as was done for the Ca Mau peninsula (Plate 23).

4.2.3 Comparison of Radarsat with Other Remotely-Sensed Data

Radarsat data provided generally complementary information to that provided by more traditional optical satellites. SPOT-XS and Landsat data were easier to interpret for land-cover and land-use information (e.g., forestry, plantations, farms, etc.). However, optical satellites cannot deliver data more or less on demand (an important feature of Radarsat) given unfavourable atmospheric conditions which are prevalent throughout the region; this is an important feature in planning and executing environmental studies. In hilly areas and rough terrain, Radarsat images provided useful information regarding the lay of the land (e.g., Bolavens plateau in southern Laos); however, important land-cover information was not detectable.

Multi-temporal Radarsat data were more effective in discriminating specific types of agricultural land uses (e.g., rice, dryland cropping) than optical imagery. Radarsat's ability to discriminate between different land uses is most evident in the multi-temporal images of Da Nang, Rung Sat, and Quang Tri, which effectively discriminated between numerous and varied cultivated areas and surrounding forests. This ability suggests that multi-temporal Radarsat imagery may be highly effective in construction of basemaps of land cover and use in environmental assessments on relatively level terrain.

For coastal zone management and aquaculture applications, Radarsat data was particularly helpful. It provided good delineation of land/water interfaces, structures protruding into or over the water (e.g., aquaculture facilities, jetties, bridges, etc), and floating objects such as boats.

Radarsat also has potential for monitoring urban and regional patterns of settlement. Features such as houses, roads and other substantial infrastructure are visible; with multi-temporal composites, changes in these features can be readily tracked through time.

4.2.4 Environmental Applications of Radarsat in Southeast Asia

A number of applications for Radarsat were identified; these include:

- flooding and disaster monitoring (e.g., in Ca Mau following Typhoon Linda);
- land use mapping using multi-date imagery (e.g., rice and dryland agriculture, forestry);
- mapping destruction and rehabilitation of mangrove forests and other sensitive coastal areas; and
- forestry mapping (although not in rough terrain).

In many regions of Asia, monitoring and controlling illegal forestry activities is an important environmental task. Satellite imagery can inform regulatory agencies on events in remote areas. Optical imagery is poorly suited to this task due to its inability to record through cloud cover. In addition, Radarsat can be used to update land-cover maps over large areas on a regular and cost-effective basis. These maps frequently form the basis for environmental management plans. Standard-mode Radarsat imagery provided sufficient resolution to discriminate land use features of interest and covered large geographic areas, for example:

- monitoring urban development and assisting with developing effective planning strategies; and
- coastal zone management, including planning of aquaculture facilities.

In many areas studied, obtaining accurate digital elevation models was difficult. For example, in the A Luoi valley region, 1950-era topographic maps were hand-digitized at considerable expense. Radarsat imagery may provide a cost-effective alternative.

Although other remote sensing techniques can be used effectively for many of the above applications, poor atmospheric conditions thorough much of the region may result in unacceptably long delays before suitable data can be acquired. This provides Radarsat with a significant advantage.

4.3 RECOMMENDATIONS

War time activities have resulted in large-scale changes in land-use patterns throughout Indochina. The environmental consequences of these changes are generally not well understood. Many of these changes are negative and have resulted in resource underutilization. In addition, the environments of Viet Nam, Cambodia and Laos face considerable pressure resulting from rapidly increasing populations and widespread poverty.

Efficient and sustainable resource utilization is essential for the long-term economic well being of the region. For example, rehabilitation of barren land is a priority in Viet Nam (e.g., Quang Tri, A Luoi valley, and Ma Da forest), and clearing of heavily-mined areas of Laos (e.g., Plain of Jars) and Cambodia is important to recover valuable agricultural land. Development of environmental management and remediation plans requires many types of information including accurate and up to date land-use and land-cover data. Radarsat has demonstrated that it can provide valuable data, which, when supplemented with other information, can enhance the ability of government and industry to develop and implement environmental monitoring and management plans.

The following recommendations are made:

- Training and demonstration projects are required throughout the region to further demonstrate the utility and cost-effectiveness of Radarsat as a component of effective environmental management.

  Regulatory agencies in Viet Nam, Laos and Cambodia, due to poor infrastructure and limited funding, lack adequate environmental and spatial data to develop effective management plans. Remote sensing can help fill this gap.

- More research is required before "routine" classification of Radarsat imagery is possible.

  Considerable field work and ground-truthing was required to extract the maximum amount of information from each image. This is, in part, because areas selected were particularly remote and deficient in supporting data. As project members gained experience in interpreting images, they were able to extract more information from each scene. The use of properly-timed, multi-temporal imagery was far superior to single-date imagery in visualizing and effectively interpreting land use and cover patterns.

- Further research is required to refine Radarsat digital image processing techniques so that improved land-use and land-cover information can be obtained in rough terrain.

  Many of the areas in the developing world under greatest pressure from human-induced changes are in hilly or mountainous regions, as increasing population and development pressures force people further away from lowlands and coastal areas.

- Improvements are required so that data requests are driven by end-user application needs and not only by those clients with in-depth knowledge of radar backscatter, beam modes, incidence angles, etc.

  The number of products available from Radarsat and the number of order desks requesting imagery tended to complicate data acquisition requests. Information provided by this and other RUDP programs may help streamline this process. Order desk staff generally were very helpful with technical issues regarding image acquisition. However, easily-interpreted explanations and guidelines for application-appropriate Radarsat image acquisition would greatly benefit potential users with little previous experience with radar or remote sensing generally, such as environmental consultants and managers.

- A better understanding of the impacts of weather conditions on image quality, such as current or recent rainfall and smoke/cloud/haze, is required.

  The differing ability to distinguish rubber plantations and interspersed roads in Quang Tri, between two standard-mode S7 images of the same area, highlights this confounding issue. The use of multi-temporal imagery helped to lessen weather effects on single-date Radarsat data.

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Appendices

Appendix A1

Trip Report and Ground-Truthed GPS Waypoints, November-December 1997

APPENDIX A1 TRIP REPORT AND GROUND-TRUTHED GPS WAYPOINTS, NOVEMBER-DECEMBER 1997.

Table A1.1 Summary of Radarsat study team field activities, November-December, 1997.

DATE (dd/mm)	Radarsat STUDY TEAM ACTIVITIES
16/11	Study team (Martin Davies/Grant Bruce) arrived in Ha Noi.
17/11	Study team met separately with 10-80 Committee and FIPI for planning and data acquisition.
18/11	Radarsat workshop at FIPI office (12 participants, listed below).
19/11	Study team traveled to Hué and met at the FIPI sub-office to plan field trip and acquire data.
20/11	Ground-truthing at Hué airport/dong ha areas; data on the 109 waypoints.
21/11	Ground-truthing at Khe Sanh/Lang Vei areas; data on the 71 waypoints.
22/11	Ground-truthing along coast northeast of Hué; data on the 34 waypoints.
23/11	Study team traveled to Ho Chi Minh City.
24/11	Day 1 ground-truthing at Ma Da forest; data on the 63 waypoints.
25/11	Day 2 ground-truthing at Ma Da forest; data on the 95 waypoints.
26/11	Study team traveled to Ca Mau, southern Mekong River Delta.
27/11	Day 1 ground-truthing in the Ca Mau area; data on the 95 waypoints.
28/11	Day 2 ground-truthing in the Ca Mau area; data on the 104 waypoints.
30/11	Study team traveled to Ho Chi Minh City.
01/12	Ground-truthing in the Rung Sat area; data on 72 waypoints.
05/12	Study team traveled to Vientiane, Laos
06/12	Ground-truthing in the Pakse area, southern Laos
07/12	Ground-truthing in the Bolavens Plateau area, southern Laos.
08-09/12	Ground-truthing in the Plain of Jars area, northern Laos.
12/12	Study team returned to Canada.

A Radarsat workshop was undertaken at the FIPI office in Ha Noi on November 18, 1997, to outline the project, and to present the capabilities and technical specifications of the Radarsat satellite, and its various applications. Invitations were extended to various organizations in Ha Noi by FIPI staff; in addition to several FIPI staff, remote sensing professionals from the General Department of Land Administration also attended the workshop. After the workshop, the study team discussed details and schedules for the forthcoming field program, and reviewed supporting data collected by FIPI. The team took also received 1:50,000 topographical maps, land cover maps and digital files of the study areas for use in image interpretation. Senior FIPI staff from Hanoi accompanied Radarsat field staff on all fieldwork in central and southern Viet Nam. In addition, FIPI staff from regional FIPI offices ("sub-FIPI's") throughout the country were involved in and aided field work.

Table A1.2 Radarsat Workshop at the FIPI Office in Ha Noi, November 18, 1997.

Workshop Participants	Organization
Tran Van Hung	Remote Sensing Section – FIPI
Vu Tien Dien	Remote Sensing Section – FIPI
Vo Van Hone	Remote Sensing Section – FIPI
Haguang Tuy	Remote Sensing Section – FIPI
Cau Uri Hien	Remote Sensing Section – FIPI
Thai Qvoc Bao	Remote Sensing Section – FIPI
Nguyen Huy Meong	Environment Section – FIPI
Nguyen Quoi Dung	Resources Section – FIPI
Mai Ky Quing	Resources Section – FIPI
Dis Viel	Resources Section – FIPI
Tran Hieu Minh	Environment Section – FIPI
Chu Hai Tung	General Department of Land Administration, Remote Sensing Centre

Ground-truthed GPS waypoints are provided in this appendix, in roughly chronological order. Waypoints were collected using handheld Garmin 45XL and GPSII receivers.

On November 24, the study team travelled together with staff from Hatfield Consultants Ltd. involved in dioxin sampling in herbicide-sprayed areas, to Ma Da forest northeast of Ho Chi Minh City for cooperative ground-truthing and sampling.

On December 5, the study team travelled to Vientiane, Laos. The Lao agencies were less organized to accommodate the study team's needs, and suggested that the study team travel independently and unofficially to study areas in Laos to ground-truth the Radarsat scenes. This limited the team's ability to travel and work openly in rural Laos.

Table A1.3 Contacts made during field studies, November/December 1997.

Name	Position/Organization
Mr. Phung Tuu Boi	Head, Environment Section, Forest Inventory and Planning Institute (FIPI), Hanoi
Dr. Nguyen Manh Cuong	Head, Remote Sensing Section, FIPI
Dr. Nguyen Huy Phon	Deputy Directory, FIPI
Prof. Hoang Dinh Cau	Chairman, National 10-80 Committee, Hanoi
Dr. Nguyen Huu Duc	Biologist, National 10-80 Committee, Hanoi
Dr. Hoang Trong Quynh	Medical Doctor, National 10-80 Committee, Hanoi
Dr. Dung	Medical Doctor, National 10-80 Committee, Hanoi
Mr. Nguyen Hoai Phuong	Head of International Cooperation Section, FIPI
Mr. Nguyen Minh Tuong	Senior Consultant, Euroconsult-BMP Mangrove Rehabilitation Project
Mr. Wandert Benthem	Team Leader, Euroconsult-BMP Mangrove Rehabilitation Project
Mr. Thai Triem	Forestry manager, Dong Ha
Mr. Cong Nam	Forestry technician, Dong Ha
Dr. Le Sau	Director, Forest Inventory and Planning Institute (FIPI)
Mr. Nguyen Huu Bach	Director, FIPI Office #4, Hué
Dr. Tran Duy Dien	Deputy Director, FIPI Office #2, Ho Chi Minh City
Mr. Nguyen Van Son	Director, Ma Da Forest Enterprise, Dong Nai
Mr. Nguyen Tan Binh	Director, Phu Binh Forest Enterprise, Dong Nai
Mr. Thanh	Ministry of Agriculture and Rural Development, Ca Mau
Mr. Thein	Director, FFA184 Enterprise, Ca Mau
Dr. Luong Thi Minh Xuan	Director, National 10-80 Committee office, Ho Chi Minh City
Mr. Ngo Ut	Director, FIPI Office #2, Ho Chi Minh City
Mr. Peter Guy	Viet Nam - Canada Environment Program (VCEP), Hanoi
Dr. Ngyuen Hoang Yen	Remote Sensing Section, Ministry of Science, Technology and Environment (MOSTE), Hanoi
Dr. To Quang Thinh	Director, Remote Sensing Centre, General Department of Land Administration
Mr. David Dix	Commercial Counsellor, Canadian Embassy, Hanoi
Mr. Michael Eiland	First Secretary of Science, Technology and Environment, U.S. Embassy, Hanoi
Dr. Michael Linnan	Medical Epidemiologist, U.S. Center for Disease Control, U.S. Embassy, Hanoi
Mr. Pho Muangnalad	Director, Technology Development and Promotion, Science, Technology and Environment Organization (STENO), Vientiane, Laos
Mr. Phouvong Sayalath	Director, Environmental Data and Information Section, STENO, Vientiane, Laos
Mr. Sitha Pouyavong	Deputy Director, Environmental Data and Information Section, STENO, Vientiane

GROUND-TRUTHING RESULTS

NOVEMBER 20, 1997: Hué To Dong Ha and former demilitarized zone.

Waypoint	Easting	Northing	Comments
1-1	0787299	1814960	Hué airport
1-2	0785545	1816405	Heading north from Hué airport. Built-up area along road, low scattered concrete/bamboo houses, evergreen and palm plantations beyond.
1-3	0784162	1817496	Flat land on either side of road for a few kilometers, small villages on left. On right, mixed plantation with rolling hills beyond.
1-4	0783368	1817914	Cross small stream/river.
1-5	0782483	1818106	Wide flat area of rice fields, three small anti-aircraft placements on right. Railway track 20 m to left of road with a fourth anti-aircraft placement.
1-6	0780528	1819244	Village (narrow strip development of small houses and shops) along road, mixed plantation along both sides of road.
1-7	0777704	1820889	Bend in road, lots of low concrete, mainly single story buildings before Hué.
1-8	0777684	1821272	Crossing 15 metre wide river canal, urban area.
1-9	0773585	1822823	Walls of citadel visible, urban development near road.
1-10	0772934	1823684	Cross bridge about 20-m wide – metal scaffolding on bridge. Middle bridge to Hué is a low concrete bridge which is why it may be more difficult to see on the Radarsat image. Bridges furthest to the east and west have substantial metal frames which may explain why they are easier to see. Just past way-point 10, lots of rice cultivation.
1-11	0770943	1824951	200 – 300 metre wide rice fields along side road with forest plantations beyond.
1-12	0770028	1825439	10 meters to left, railway line 10 meters running parallel to road, foothills start a few kilometers away. Rice and intermittent forested areas in the background.
1-13	0751231	1835126	Just passed a small village.
1-14	0749311	1836771	To left, rolling hills and homes scattered along the road. *Eucalyptus* sp. and evergreen forest plantations. On right, railway is about 20 m from highway. Some rice cultivation, scrub land, and young *Eucalyptus* sp. plantations.
1-15	0748061	1837313	Just passed the boundary between Hué and Quang Tri.
1-16	0747182	1837962	Crossed over a small river. On left is a railway bridge ~200 m away.
1-17	0746149	1839341	Railway crosses road.
1-18	0745671	1840285	Town of My Chang on both sides of road; market visible. Large river (Song Tac Ma) visible.
1-19	0744891	1841035	Tree plantations on left. Railway is 10 m away. Rice cultivation to right.
1-20	0743409	1842718	Soil changes from red clay to white sand. *Cassia* sp. tree plantations on both sides of road.
1-21	0742969	1843453	Cross a 10 –15 metre wide stream. Little village on either side of stream. Sparse *Pinus* sp. plantation on either side of road and patches of bare land.
1-22	0741035	1845088	*Cassia* sp. plantation and intermittent barren land.
1-23	0738841	1846872	Cross small river. On right, rice and mixed crop cultivation. On left some rice cultivation with intermittent forest plantations.
1-24	0736948	1848360	On right, sparse *Cassia* sp. plantation. Lots of exposed white sand on either side of road

Waypoint	Easting	Northing	Comments
1-25	0733706	1852052	Old Quang Tri city (totally destroyed during American war) – road passes over a dry moat.
1-26	0732639	1852202	Crossing over main river (Song Thach Han) at Quang Tri. Large bridge, mixed crops and some forest.
1-27	0732144	1853585	Mixed crops on right and grazing land/grasses to right of road.
1-28	0731157	1854801	Barren white sandy soil on both sides of road.
1-29	0730732	1855360	Passed old Quong Tri airport wrecked Huey helicopter and some other American war debris on left (airport is on right side of road). Sparse grass and pasture land, soil mainly white.
1-30	0729544	1856739	Rice on both sides of road. Railway approximately 300 m on the left.
1-31	0727187	1858082	Rice cultivation and sparse forest cover.
1-32	0725781	1859200	Entering town of Dong Ha.
1-33	0725493	1859711	Lots of rice cultivation on both sides of road.
1-34	0721310	1860455	Highway 9 (which connects Dong Ha with border of Laos and runs generally east west) Road follows south bank of Song Mieu Giang river. Some rice and mixed crop vegetation between road and river.
1-35	0719624	1859801	Mixed *Pinus* sp. and *Eucalyptus* sp. plantation on right (river approx. 200 m away). Some rice cultivation between river and road. On left, land-cover consists of sparse forest and scattered homes.
1-36	0718937	1859321	Large cement factory in front and to the left. Power line right of way.
1-37	0718315	1859127	New bridge being built over Khe Treo stream (tributary of Song Cam Lo river).
1-38	0718178	1859076	Narrow (one car width) metal suspension bridge over main river. Brick factory on right and cement factory on left. Mixed crops.
1-39	0717040	1859050	To the right is a large flooded area (depression) and a large factory beyond the flat lands.
1-40	0716165	1859009	To the left, scrub land and gently rolling hills for as far as you can see. Near road, *Eucalyptus* sp. and *Pinus* sp. plantations.
1-41	715239	1858934	To the right of the road, rice and mixed crops. To the left, hills are visible about 1 km away with rice cultivation between road and hills.
1-42	714260	1859088	Rice on both sides of road, to the left some forest plantation is visible about 1 km away (behind the rice).
1-43	713844	1859383	Turning right (north) at village of Cam Lao towards the river.
1-44	713884	1859599	Rice on both sides of road for 600 - 700 meters. Some pastureland for cattle.
1-45	714354	1860603	**Photo 1-7** and **1-8**. Crossing bridge over Kam Lao river. Root crops on both sides of river. Some forest, ecalypt and cashew trees.
1-46	714006	1861088	Dry rice fields and mixed forest on both sides. Mixed forest.
1-47	713461	1861646	Heading uphill. Rice, mixed forest, **Photos 1-9 and 1-10** looking left.
1-48	713130	1862219	Plantation of young *Pinus* sp. on right, some cleared plantation that was harvested last year.
1-49	713108	1862769	*Pinus* sp. plantation on both sides on both sides of road. At a distance of about 500 meters rice and dry land cultivation begins.
1-50	712844	1863014	On left of road, mixed cultivation with forest plantation beyond. **Photos 1-11 (left) and 1-12 (right).** On right, *Pinus* sp. plantation.
1-51	712968	1863948	Cashew (?) plantation on right. Looking left, end of *Pinus* sp. (*Pinus khaysia* or *Pinus merkusii*) plantation – start of a 3 meters high *Eucalyptus* sp. plantation. **Photo 1-13**.
1-52	713085	1864813	Grassy scrub, with young *Eucalyptus* sp. plantation all around. **Photo 1-14 and 1-15** looking west. River and huge factory visible. **Photo 1-17**, picture of topo map showing where we are. Before plantation, area was all American grass **(Photo 1-18)**.
1-53	712852	1865520	More mature *Cassia* sp. plantation, some pastureland.

Waypoint	Easting	Northing	Comments
1-54	712581	1866164	Gently rolling hills on both sides of road.
1-55	712219	1866854	On right, fringe of *Eucalyptus* sp. with *Acacia* sp. along road. To left, on top of a hill – patches of *Pinus* sp. visible in larger plantations of *Eucalyptus* sp.
1-56	712281	1867463	To the right, a small stream 2 meters wide. On left, terraced rice for a distance of approximately 400 – 500 meters
1-57	712228	1867883	Middle of small village, thicker vegetation. **Photo 1-19**.
1-58	712164	1868868	Mixed crops on right, some rice and trees on left.
1-58b	712063	1869026	Junction of road.
1-59	711787	1869403	On right, Cashew trees and small dry-land crops. Edge of mature rubber plantation. To the left, land drops off – cassava and cashews.
1-60	711171	1869677	Rubber plantation on both sides of road for several hundred meters. Beyond plantation is barren land. Trees on left side of the road are older than those on the right.
1-61	710196	1870070	Lots of mature rubber as far as you can see, road is sloping down.
1-62	709371	1870768	Junction of road, small village. Road splits to right, we went straight. Large rubber trees on both sides of road.
1-63	708900	1871661	Mixed trees and dry land crops on both sides with houses interspersed. Passed a village school.
1-64	708612	1872400	Soils changes back to white sand, sparse plantation with patches of grass and barren land.
1-65	708649	1872812	Wet area with terraced rice crops.
1-66	708394	1873884	American grass, barren land looking south and southwest. **Photos 1-20 and 1-21**. **Photo 1-22** of forest cover map showing where we are.
1-67	708337	1874454	Barren land – tilled soil.
1-68	707959	1875601	War memorial near Ben Hai river on small hill – 10,000 dead buried. Reservoir and wall surrounding monument. Area surrounded by scrub and occasional large trees. Suspension bridge over river just beyond (north) of war memorial. Most of surrounding area is planted with eucalyt.
1-69	707663	1875586	Bridge across Ben Hai river. **Photo 1-23 (east) 1-24 (west).** Mixed forest and barren land.
1-70	708328	1874436	**Photo 1-25** looking left at some recently tilled barren land.
1-71	712102	1869028	On right rubber plantation. To left homes and mixed small crops.
1-72	713287	1869521	Road is now dirt. Sparse village, small crops, banana, bamboo, papaya.
1-73	713295	1869524	Large body of water visible approximately 1 km away.
1-74	713756	1869487	Pass through a small village.
1-75	714136	1869445	Pass a powerline right of way. Rubber plantation on the right. On left, rice fields.
1-76	714795	1869598	On left there is 300 – 400 m of mature plantation forest, trees about 10 meters high.
1-77	715662	1870011	On right, 6 metre tall rubber plantation. On left mixed crops, homes and some rice.
1-78	716279	1870181	Rice fields on either side. Some large rubber trees. Driving between the lower two reservoirs visible on the Radarsat image.
1-79	717735	1870114	Mature rubber on right. Mixed crops on left.
1-80	718163	1870140	Rubber plantation, natural forest, and some bamboo on right, and reservoir to left.
1-81	718441	1870218	Left turn onto a small track – walk along it to reservoir.
1-82	718354	1870451	Rubber plantation on right of track, *Eucalyptus* sp. plantation to left. **Photo 2-1** of reservoir looking north, **Photo 2-2 and 2-3** looking east across lake at buildings. Clear barren area appears darker on image.
1-83	719071	1870121	Rubber, rice, and some cleared areas. Drove past a depression which shows up dark on image – drainage for reservoir.

Waypoint	Easting	Northing	Comments
1-84	720132	1869549	Both sides of road scrubby crops and palms, beyond that is wetlands, maybe paddy.
1-85	720390	1869610	Low lying area with rice on either side. Surrounded by fairly tall plantation, scattered small fishponds. White sandy soil, eucalpyt on either side of road which is 3-4 m high
1-86	720990	1869941	Road crosses a small bridge, ditch 1-2 meters wide (irrigation channel).
1-87	721302	1870027	Fish ponds on right, crossed railway tracks, approaching Highway 1.
1-88	721486	1870095	Rice for at least 1 km on either side of road; power lines to the east, parallel to road.
1-89	721344	1871253	Northern most end of rice paddy. Rice may continue away from road.
1-90	721244	1872109	Village, large concrete buildings.
1-91	720687	1874239	Small power line crosses road. War memorial on left
1-92	720965	1874673	Bend in highway, plantation forest on right. Rubber plantation to left.
1-93	720429	1875680	Rice fields on both sides for several km.
1-94	720115	1876390	Irrigation canals running perpendicular to road on right.
1-95	719711	1877242	Lots of rice. **Photos 2-5 (west) and 2-6 (east).** Lines on Radarsat are irrigation channels.
1-96	721029	1873137	Right turn on paved road drove for a couple of hundred meters (road doesn't show well on image)– streaky looking dark areas on image are barren land.
1-97	720614	1873030	200 m from highway, past line of trees, south of us is *Eucalyptus* sp. plantation, north is a graveyard and barren land. **Photos 2-7 (N) and 2-8 (S).**
1-98	721627	1868435	Rice and mixed crops.
1-99	721716	1867513	Rice cultivation.
1-100	721936	1866558	Turn right off highway towards first reservoir on image, passed some fishponds and rice between highway and railway.
1-101	721539	1866558	Cross railway, *Eucalyptus* sp., rice and fish ponds on right. Large new irrigation canals on left.
1-102	721018	1867000	Young *Eucalyptus* sp., but mostly barren and clear, recently logged. Big earthen dam in front.
1-103	720391	1867168	Just before dam, irrigation ditch, rice and scrub land.
1-104	719987	1867509	Mature rubber plantation below dam. Dam built in 1992.
1-105	719814	1867367	On dam. Most of surrounding area forested. **Photos 2-9 and 2-10** are of the dam; **Photos 2-11 and 2-12 (east) and 2-13 (south)** are of the vegetation. White spots in image are buildings, dark spots are paddy.
1-106	721958	1866353	Passed small river, lots of rice cultivation.
1-107	721583	1863846	Lots of rice and wetlands on either side or road.
1-108	722564	1862680	Coming into Dong Ha, some rice cultivation on both sides or road.
1-109	723592	1861740	Just before bridge coming into Dong Ha.

November 21, 1997: Khe Sanh and Lang Vei, Quang Tri province.

Waypoint	Easting	Northing	Comments
2-1	714130	1859205	On Highway 9 between Dong Ha to Khe Sanh where a new bridge has been built. Raised paddy for about 3 km and foothills with plantation forest (planted in late 70's).
2-2	713359	1859509	Village, and rice fields on left, mixed plantation and pasture land on right.
2-3	711614	1858871	Western edge of village, 1 km or rice fields on left with forest behind. Road is about 6 m wide. Homes and small fringe of rice on right.

Waypoint	Easting	Northing	Comments
2-4	710646	1858113	Less flat (beginning of rolling hills), no rice on right – open scrub land on right.
2-5	710313	1858021	Open scrub land on right with *Eucalyptus* sp. behind, on left mixed crops, trees and homes.
2-6	709866	1857907	Some rice on left and open scrub land. Pasture land and barren land on right.
2-7	709271	1857818	Young plantation and some rice on left. Homes, forest and scrub on right. Beginning of hills.
2-8	708810	1857952	Scrub land on hills, with very young scattered *Eucalyptus* sp. plantations.
2-9	707267	1857370	Hills with young *Eucalyptus* sp. and scrub-land.
2-10	705953	1857310	On right, hills low scrub with plantation of *Piper nigrum* in foreground, and to left are young *Eucalyptus* sp. plantations. **Photo 2-14** (looking north across the river). **Photo 2-15** (east looking back at Highway 9), River about 1 km away. **Photo 2-16** is a Renault bus. The hills of **Photo 2-14** were forested before war and cleared by spraying.
2-11	705510	1857111	Big concrete factory on right. Down by river a little reservoir and dry land cultivation. To left is mature plantation with some clear areas on the hills.
2-12	704455	1856867	More *Piper nigrum* trees on right. *Eucalyptus* sp. and cassava on left, American grass spread throughout *Eucalyptus* sp. plantation.
2-13	703575	1856719	*Piper nigrum* plantation on right, trees beyond plantation shows banding between barren area (covered with low green scrub) and natural forest (same to left).
2-14	702672	1856323	Steep ravine to right, slopes to left are forested and barren on top.
2-15	702245	1856380	Crossing river, right runs parallel to the right of the road. Clear hills with a bit of scrub – same on left, topography starting to get steep.
2-16	701541	1856748	Following river, 50 m to the right, crops and homes between road and river. Beyond river is forest for about 1 km, tops of hills are bare. Young *Eucalyptus* sp. to the left.
2-17	700263	1856796	Hills forested on bottom, cleared on top – just scrub. On left is a large bare rock hill (quarry).
2-18	699489	1856647	Just west of cleared hill (quarry) – mainly forested hills on left with some barren areas. To the right is fairly flat with Karst mountains. Low green scrub on hills
2-19	698276	1855644	**Photo 2-20** (north – looking at the Rockpile – wartime American artillery position) and **2-21** (northwest – shows spray line clearly). Village and six year old *Eucalyptus* sp. to east, plantation also across river. **Photo 2-22** is of land-use map showing plantations
2-20	697966	1854840	**Photo 2-23 and 2-24** – looking left at cleared hills covered with American grass and some natural forest, small bridge crossing. To right small village and scrub, beyond are cleared hills.
2-21	697646	1851955	Near end of wide flat valley area, some cleared plots a couple of ha. Totally empty on right, villagers are planting fruit trees and terraced rice in front. To left hills with both natural forest and cleared spray areas.
2-22	698646	1850052	**Photo 2-25** looking left, hills have shifting agriculture, some patches of natural forest. Cleared scrub land or cleared agricultural land.
2-23	698958	1848748	Heading south, southwest, shifting agriculture plots to left and right.
2-24	700001	1847462	Power line along hills to right 700 m, large metal towers 20 m high. Hills and pasture land, mainly scrub. To left are larger hills that are generally barren with patches of natural vegetation.
2-25	700449	1846860	Crossing a stream 5 metre wide.
2-26	700399	1845529	Driving along river (on left, approx. 30 wide), barren hills with some natural forest. Some Karst hills on left.
2-27	699587	1845573	Crossed a creek with two bridges.
2-28	698698	1844643	River to left, rolling barren hills. Steep hill to right.
2-29	697225	1843795	Crossed a bridge over a creek, river still to left. Steep hills with patches of natural forest.

Waypoint	Easting	Northing	Comments
2-30	694572	1843047	Left on other side of river is natural forest with bare patches of American grass.
2-31	694546	1843041	Hills on both sides of river, dense natural forest, with some bare patches
2-32	693894	1842699	Da Krong bridge – to north there is a river valley, mixture of forest and cleared areas, to south natural forest.
2-33	693717	1842523	On Da Krong bridge, **Photos 3-1 and 3-2** of bridge, **3-3** looking west, **3-4** looking east. West along river, dense natural vegetation, barren areas and agricultural land in distance. To south dense forest. **Photo 3-5** group photo
2-34	691694	1842368	Crossing small bridge over stream, small village, hills are half natural forest, half barren (shifting agriculture).
2-35	692079	1840487	Natural forest all around.
2-36	691561	1840074	Ahead are clearings with spots of natural forest.
2-37	690920	1840646	Crossing bridge over river, mixture of forest and scrub.
2-38	690347	1840103	Climbing up a switch back road. To left across river valley, hills are generally barren with some natural forest – American grass
2-39	689856	1839953	Still climbing hill, to left quite cleared areas.
2-40	689439	1840768	Near top of hill, coffee plantations.
2-41	689181	1840815	Coffee plantation – **Photo 3-6** looking west, **Photo 3-7** coffee plantation with bare hills in background. **Photo 3-8** looking in same direction (east) **Photo 3-9** looking to right hills with slash and burn
2-42	688444	1840584	Small village, coffee plantations on both sides, some banana – passed two army crews with metal detectors working within 1 m of road looking for mines/bombs.
2-43	687616	1840183	On ridge – to right across deep valley sparse forest, barren land and cleared land for agriculture – to left *Pinus* sp. (*Pinus khaysia* or *Pinus merkusii*) and thick forest.
2-44	687155	1839874	Large *Pinus* sp. plantation and river to left – on right acacia backed by *Pinus* sp.
2-45	686324	1839979	Driving uphill – *Pinus* sp. left and right. On left some cleared areas with American grass. Forest to right of road is 7 years old
2-46	685839	1840101	Entering Khe Sanh village.
2-47	685526	1839276	In Khe Sanh – big radio tower to right. To left *Pinus* sp. plantation.
2-48	684495	1838701	Still in Khe Sanh – to left sparse natural jungle, to right small reservoir, hills in distance are bare.
2-49	683235	1838362	Rice crops on right (small 200 x 600 m plots), to left are homes.
2-50	681710	1838218	Small rice fields and bare hills to right (scrubby and covered with American grass).
2-51	679162	1836785	Right – low hills with some straw huts, some shifting agriculture, ahead large escarpment with natural vegetation (in Laos). To left flatter, mixed barren and agricultural land.
2-52	678083	1835991	Near Lang Vei (old special forces base near Laos border), **Photos 3-10 and 3-11** looking South and SW, **Photo 3-12** looking back towards road (north) to left, can see river valley with banana and mixed crops and small village. **Photo 3-13** of Lang Vei valley. Tank battles were fought in valley. **Photo 3-14** of land-use map. Can see river (border with Laos) – area was not sprayed.
2-53	685606	1840138	Heading towards old Khe Sanh airbase, coffee plantations on both sides of road.
2-54	684683	1840820	Passing through small village (just huts) and coffee plantations. To the right are some foothills with cleared areas – Hill 950 cleared on top.
2-55	684194	1841295	Continue driving through a dispersed village and coffee plantations.
2-56	684091	1841529	On small dirt road, passing through village with small thatch and tin roof homes, coffee plantations.
2-57	683737	1841841	Young coffee plantation on both sides of dirt road.
2-58	683863	1842093	Khe Sanh airbase –mainly cleared with American grass, some small *Eucalyptus* sp. **Photo 3-15** of land-use map. Old runway is a clear red dirt runway approx. 2 km long and 10 meters wide. **Photo 3-16 through 3-20** form a panorama of the airbase going south to north through east. Hills 1015 and 950 to the north.

Waypoint	Easting	Northing	Comments
2-59	683525	1842134	Top end of airstrip. **Photo 3-21** is from the top end looking down.
2-60	683479	1842183	Young coffee plantations, and widely dispersed eucalpyt trees.
2-61	683441	1842340	Coffee plantations past airfield **Photo 3-22 and Photo 3-23.**
2-62	683297	1842464	Surrounded by coffee plantations. Can see Hill 861 (**Photo 3-24).** Coffee plantations are privately owned and are 3 years old (first harvest being collected).
2-63	684317	1842090	Driving down road past runway – mainly coffee, lots of small craters (2 m) visible (mortars and bombs).
2-64	684430	1841984	Plantation of *Aleurites montana* – **Photo 3-25** – 4 meters high planted in 1980.
2-65	684695	1841594	Open pasture land, barren grassy area, with *A. montana* species planted around.
2-66	685939	1840345	Between Khe Sanh airstrip and town, small village house. **Photo 3-26** looking left along road towards Da Krong – road sprayed on north but not south side.
2-67	689917	1839913	Right cleared and natural forest. Cleared areas was natural (not sprayed) maybe caused by fires. **Photo 3-27.**
2-68	692134	1840586	**Photo 3-28** of Da Krong river with some tribal village stilt homes. Pico, other tribals.
2-69	698137	1855430	Looking at the Rockpile. To right is scrub land. River valley and plantation to left.
2-70	699967	1856875	**Photo 3-29** – looking left at hills with natural forest and barren areas.
2-71	714703	1859368	Nursery near Cam Loa **Photo 3-30, 3-31 and 3-32** of plantation.

November 22, 1997: Around Hué city and coast.

Waypoint	Easting	Northing	Comments
3-1	777723	1826944	Strip development along road, small homes on left of road beyond a a few hundred meters rice cultivation.
3-2	777718	1826979	Road parallels small canal to left, urban development on both sides, small homes/farms and mixed crops.
3-3	777598	1827350	Paralleling larger canal to left – approx. 10 meters wide, small homes beyond canal.
3-4	778327	1827626	Crossed a small channel, larger canal still to left. Small homes and mixed cultivation on both sides.
3-5	778825	1828189	On right, leave village entering large rice fields with trees in distance.
3-6	778986	1828672	Channel still on left, small mausoleums, rice and water.
3-7	779493	1829481	On both sides of road, large rice cultivation, immediately to left is a small group of homes surrounded by trees. In distance 5 – 10 km away land rises and treed area visible.
3-8	780471	1829740	Rice eventually gives away to shrimp ponds on right for as far as you can see.
3-9	780651	1829868	Just crossed small bridge, fish traps (V shaped weirs).
3-10	780965	1830083	Small village, on narrow strip of land, lots of shrimp or fish traps approx. 1 metre high out of water.
3-11	781193	1830550	Left, small islands of mausoleums, on right are some shrimp ponds as far as you can see, bounded by dykes 1 m high and vegetated approx. 50 m on a side, some are larger.
3-12	782152	1831508	On right, small mangroves (1 ha in size) with shrimp farms beyond.
3-13	782342	1831987	Coming up to large narrow bridge, maybe mouth of Perfume river, shrimp and fish traps visible about 300 m wide, palm trees and homes visible on far side
3-14	782743	1832488	Far side of bridge, soil is sandy, heading towards beach.
3-15	782972	1832701	Almost at beach, small *Pinus* sp. plantation on right, homes along road.
3-16	783134	1832778	On beach, about 20 meters wide, large concrete structure south east about 50 meters away. **Photo 3-33** looking north and **Photo 3-34** looking south.

Waypoint	Easting	Northing	Comments
3-17	783031	1832840	Walking north along beach, about 20 meters wide, backed by *Pinus* sp. plantation.
3-18	782752	1832967	On beach, clearing in *Pinus* sp. strip, mausoleums and graves visible.
3-19	782781	1832429	Driving south along barrier island, homes and graves, and *Pinus* sp. along road.
3-20	783503	1832440	To right, 10 meters or so, open water with boats – lots of *Pinus* sp. between road and beach and open water.
3-21	784129	1832212	Large bay on right, fish weirs and mainland in distance, on left seashore is about 50 meters away.
3-22	784311	1831749	**Photo 3-36** and **3-37** of bridge to barrier island
3-23	784872	1831224	Open area full of fish-traps, some rice fields front onto the lagoon.
3-24	785268	1830997	Fish weirs to right
3-25	785551	1830776	Shrimp ponds to right and fish weirs beyond. **Photos 4-1 and 4-2** looking at shrimp ponds. Spoke to fishermen about V-shaped features on Radarsat image – unclear answer.
3-26	782471	1832137	On bridge returning from barrier island to mainland. **Photos 4-4 (south) 4-5** looking north **Photos 4-6 and 4-7** of fish weirs visible from bridge, **Photo 4-8** of more fish weirs.
3-27	781359	1830988	**Photo 4-9** of fish ponds with dikes on left.
3-28	780944	1830016	**Photo 4-10** of shrimp ponds that are penned but not diked.
3-29	780620	1829813	Crossing bridge **Photos 4-11 (left)** and **4-12, 4-13** to right (NW and SW) of shrimp ponds and a small plantation of palm.
3-30	780105	1829636	Recently planted rice fields on both sides and open channels/canals on right.
3-31	777020	1821979	Main roundabout in Hué city.
3-32	777670	1820873	Bend in highway, split in highway, low hills to left 50 – 100 m high
3-33	778959	1820042	On left of road, radio tower with wall around it, soil very wet/flooded.
3-34	778959	1820042	Same coordinates as before, on other side of road. On right, over railway line, low hills which are sparsely vegetated (S – SW).

November 19-22, 1997: A Loui Valley, central Viet Nam (Tom Boivin and Andrew Allan).

Waypoint	Easting	Northing	Comments
4-1	0766080 0766088	1809440 1809500	**November 19, 1997.** Road from Hué to A Loui. Measurement taken 0.5 km west of town of Bien Dien. Location is in eastern end of 1972 Keyhole satellite photo. Bien Dien is village of approx. 200 people. Relatively low population density, although several small dwellings are spread out throughout the region (show up on image). Agricultural zone. This is the start of area where spraying impacts may be clearly seen (small rolling hills are denuded). From here to A Loui, most hills are devoid of large trees along roadway. TB Roll 1, photos 16 and 17; HCL Roll 1, photos 9 (N) and 10 (NW). Video taken.
4-2	0761163 0761152	1809062 1809079	**November 19, 1997.** Road from Hué to A Loui. Measurement taken 5.0 km west of town of Bien Dien (town of Hong Tien). Hills very denuded (mainly scrub vegetation). Appears to have been heavily sprayed. Few settlements in area. Agriculture and replanted trees. Generally little land use in area. TB Roll 1, photos 16 & 17 (N), photo 22 (S); HCL Roll 1, photos 11 (NE), 12 (N) and 13 (S). Video taken.
4-3	0757277 0757255	1806196 1806228	**November 19, 1997.** Road from Hué to A Loui. 5 km east of DT Luong (according to road sign). Interface between denuded hills and treed areas. Hills getting larger as we head further west. Evidence of spraying is very clear just east of here. American grass is abundant in the area. HCL Roll 1, photos 14 (NW) and 10 (SE). Video taken.
4-4	0748643 0748647	1783273 1783277	**November 20, 1997.** A Loui District, A So village. In middle of village, in manioc field of Mr. Quynh Thien. Settlements, agriculture, hills. TB Roll 1, photos 31 (S), 32 (E), and 33 (N); HCL Roll 1, photos 19 (W), 20 (S), 21 (E) and 2 (N). Video taken.
4-5	0749151 (GPS II)	1783511	**November 20, 1997.** A Loui District, A So village. South end of village, 100 m south of US Airforce Base. HCL Roll 8, photos 8 (N), 9 (W), 10 (S) and 11 (E). Fish ponds in 9 (fish pond of Mr. Quynh Bien), old US airstrip is in area of photo 11. Video taken.
4-6	0749085 0749081	1783784 1783779	**November 21, 1997.** A Loui District, A So village. Runway for old US Airforce Base. Flatter, open area, shrubs and a few small trees, few dwellings to south. Many small holes dug where locals dig for scrap metal. A So village is north of here. Area is surrounded by hills. South end of A Loui valley is 5-7 km from here. Hills to east and west approx. 1 km away. Several bomb craters, most filled with water. Few are used as fish ponds in this area. TB Roll 2, photos 13 (N), 14(W), 15 (S) and 16 (E); HCL Roll 9, photos 15 (N), 16 (W), 17 (S) and 18 (E). Large concrete slab in photo 18. Video taken .
4-7	0748558	1783306	**November 21, 1997.** A Loui District, A So village. Fish pond owned by Mr. Quynh Thien (Pond #1). Sediment and fish samples collected for dioxin analyses. Video taken.
4-8	0748640	1783663	**November 21, 1997.** A Loui District, A So village. Fish pond owned by Mr. Quynh Toan (Pond #2). Sediment and fish samples collected for dioxin analyses. Video taken.
4-9	0748628	1783686	**November 21, 1997.** A Loui District, A So village. Fish pond owned by Mr. Quynh Rao (Pond #3). Sediment and fish samples collected for dioxin analyses. Video taken.
4-10	0749100	1783498	**November 21, 1997.** A Loui District, A So village. Fish pond owned by Mr. Quynh Bien (Pond #4). Sediment and fish samples collected for dioxin analyses. Video taken.
4-11	0741002 0740992	1795283 1795306	**November 21, 1997.** A Sap River at Ta Bat, in middle of valley. Agricultural area with extensive rice cultivation and fish ponds. Many areas reforested with pines. Sampling area in 1996 dioxin program. Some coffee plants recently planted along river. No rice planted along river; most land is used as grazing area. Feature visible on Radarsat/SPOT imagery is large sandbar in river. TB Roll 2, photos 17 (NW; A Sap River and sandbar), 18 (N; grazing area), 19 (W; A Sap R.), 20 (S; A Sap R.) and 21 (E; agricultural area). Video taken.

Waypoint	Easting	Northing	Comments
4-12	0741694 0741695	1795537 1795543	**November 21, 1997**. Large reservoir near village of Ta Bat. Used as source of irrigation water. TB Roll 2, photos 22 and 23 (E; large reservoir), and 24 (W; rice paddy cultivation). Video taken.
4-13	0742597 0742593	1796135 1796136	**November 21, 1997**. Photos taken to show 'lines' on small hilltops near Cho Bo Dot market (intersection of road to Hué). TB Roll 2, photo 25 (E). Video taken.
4-14	0741694 0741695	1795537 1795543	**November 21, 1997**. War memorial in A Loui. Tallest structure in valley. GPS taken outside front gate (could not enter). TB Roll 2, photo 26 (E). Video taken.
4-15	0736455 0736462	1803115 1803106	**November 21, 1997**. A No River, at north end of A Loui Valley (a few km south of checkpoint). Large river which flows into the A Sap. Much hillier terrain than in south end of valley, fewer people, fewer dwellings and less agriculture in the area. TB Roll 2, photo 27 (SW; downstream) and 28 (E; upstream). Video taken.
4-16	0738527 0738529	1800561 1800564	**November 21, 1997**. Rooftop of hotel, position indicates north end of 'downtown A Loui village'. TB Roll 2, photo 29 (NW) and 30 (E; behind hotel. Radio tower, replanted trees and homes are visible). Video taken.
4-17	0738736 0738759	1799618 1799626	**November 21, 1997**. Health Centre, A Loui. Position indicates south end of 'downtown A Loui village'.
4-18	0742466 (GPS II)	1796343	**November 22, 1997**. Hong Thuong fish hatchery. Several large fish ponds in area. Video taken.
4-19	0742589 0742595	1796318 1796318	**November 22, 1997**. Cho Bo Dot market. Location where 'cut' appears on Radarsat imagery. Feature is most likely the road leading from A Loui to Hué. Smaller hills in this area, where road passes. TB Roll 2, photo 33 (E; hills), 34 (W; Cho Bo Dot market), 35 (Cho Bo Dot market), 36 (Hué sign, 63 km marking) and 37 (S; looking down road towards A So). Video taken.
4-20	0745245 0745225	1802383 1803410	**November 22, 1997**. Road from A Loui to Hué, 50 km from Hué. Denuded hills, devoid of trees. Obvious evidence of intense spraying in area. TB Roll 3, photos 0-4 (E; towards Hué, along Bo River valley). Video taken.
4-21	0755939 0755963	1804657 1804654	**November 22, 1997**. Road from A Loui to Hué, 40 km from Hué. Villages, agricultural land. Nearby hills are denuded, but background hills are still covered with vegetation. Good place to examine on Radarsat imagery. TB Roll 3, photos 7-10 (panorama from W to E). Video taken.

November 24, 1997: Ma Da forest, southern Viet Nam (1).

Waypoint	Easting	Northing	Comments
5-1	721175	1227831	Crossing Dong Nai river with Tri An reservoir on right, river below dam is dry, and very rocky.
5-2	721503	1228492	North of Dong Nai river, narrow road about 5 m wide. *Eucalyptus* sp. plantations on both sides, American grass (different species from DMZ).
5-3	721802	1228988	Fork in road, turning left, reservoir ahead (Tri An)
5-4	721880	1229255	Young *Eucalyptus* sp. on both sides, Tri An reservoir also visible on both sides.
5-5	722933	1229118	Crossing bridge through part of Tri An reservoir, power line paralleling road to right.
5-6	724065	1228930	Ma Da hotel, near Ma Da Enterprise offices – Km 24, Highway 676.
5-7	724441	1228833	Passing through forest enterprise offices, small village buildings along road heading towards Cuy Song.
5-8	724548	1229027	Highway 322, dirt road, 5-6 m wide, mixed plantation of teak trees (mature) with some cassava.
5-9	724546	1229443	Crossing a causeway over water, with wetland fringe (part of Tri An).
5-10	724536	1230314	Running along 322, teak plantation on left (10 meters tall) on right scrub land backed by forest approx. 200 meters away.

Waypoint	Easting	Northing	Comments
5-11	724518	1230893	Natural forest on right, on left small patch of *Eucalyptus* sp. then natural forest.
5-12	724403	1231476	Natural forest on both sides. On right power-line right of way, bordered with approximately 20 m cleared land.
5-13	724221	1231939	Small wetland and marshland on right, on left small village with natural forest backing it.
5-14	723837	1232762	On left, beginning of teak plantation (18 years old, 7-8 m high and 30 cm trunk), on right natural forest.
5-15	723732	1233350	Passing end of teak plantation on left, natural forest continues on right.
5-16	723618	1233999	Forest opens up to wide grassland on right, small tree crops on left, sparse natural forest in distance on right.
5-17	723580	1234997	Some huts and manioc on left, mixed scrubby small trees on right, both backed by sparse natural forest.
5-18	723807	1235670	Scrub land on both sides of road for 200 m, natural forest beyond.
5-19	723567	1236513	Natural forest on right, on left mixed plantation and other large trees.
5-20	723484	1237005	Natural forest on right, teak on left, **Photos 6-3** and **6-4** looking forward, and **Photo 6-5** looking back along road.
5-21	723572	1237310	Km 9 of Highway 322, natural forest on right, teak on left.
5-22	723759	1237534	On right the natural forest has moved back 400 meters from road, with scrubs in-between, teak continues on left.
5-23	724346	1238451	Beginning of *Eucalyptus* sp. on right, End of teak and beginning of *Acacia* sp. on left.
5-23	724811	1239050	Mixed plantation on right, *Eucalyptus* sp. on left.
5-24	725576	1239366	Left turn on road, marked by Cay Sung sign. Natural forest on right, mixed plantation on left.
5-25	723853	1237628	Backtracked a little from waypoint 129, teak plantation on right side of road. **Photos 6-6 and 6-7** are of teak plantation on west, on east cleared grassland. **Photo 6-8** of field staff.
5-26	725875	1239759	Natural forest and *Eucalyptus* sp. on both sides.
5-27	725933	1241330	Edge of teak on left, (1/2 km away) and open forest on right.
5-28	726255	1242309	Teak on left, *Mimosa* sp. On right.
5-29	726378	1242650	Teak on both sides of road.
5-30	726253	1243254	On right, edge of teak and beginning of *Eucalyptus* sp. and some natural forest, on left teak continues. Some surviving large *Invingia* sp. trees.
5-31	725965	1245154	End of teak on left, on right and left *Eucalyptus* sp., approaching Ba Hao village.
5-32	726008	1245480	Beyond B Hoa village, reservoir on right with wetlands and to left homes and open scrubby area, also quite wet, some fish ponds. Crocodile farm to right.
5-33	725813	1245858	Small fishponds and crocodile farm, large cleared area. **Photos 6-11, 6-12, 6-13** of crocodile farm and fish ponds. Andrew collected pond sediment. *Tilapia mozambique* and grass carp. **Photo 6-14** of Andrew sampling sediments in fish pond.
5-34	725955	1246136	Driving uphill, jungle closing in, after being open for 1 km. Natural forest on both sides, low and dense.
5-35	725965	1246397	*Eucalyptus* sp. plantation on right, and mixed forest on left.
5-36	725239	1249811	*Acacia* sp. on both sides of road.
5-37	725117	1250097	On right a large opening of manioc, on left are cashew plantations.
5-38	724989	1250361	On right are *Eucalyptus* sp. plantations and on left are *Mimosa* sp. plantations.
5-39	724887	1250481	On right is scrub land and on left are sparse papaya trees, natural forest about 300 m away on both sides.
5-40	724615	1250687	*Eucalyptus* sp. on both sides, punctuated by 100-200 m breaks in vegetation.
5-41	724383	1250857	Small *Eucalyptus* sp. on right, dense older *Eucalyptus* sp. on left.

Waypoint	Easting	Northing	Comments
5-42	724302	1250943	Older *Eucalyptus* sp. on right, open area on left.
5-43	724246	1251023	*Acacia* sp. on right, *Eucalyptus* sp. and natural forest mixed.
5-44	723825	1251500	Tall *Acacia* sp. on both sides (15 m tall, 14 years old).
5-45	723480	1251907	On right low and scrubby bush with some young *Acacia* sp. On left small clearing then large *Acacia* sp. plantation continues.
5-46	723167	1252196	End on *Acacia* sp. on left and cashew plantations on right. Area opening up to wetland on right.
5-47	722753	1252577	On right open and flat area, some rice and forest visible in the distance. On the left is low scrubby forest.
5-48	722557	1252883	Low scrubby forest on both sides.
5-49	722403	1253065	Open barren area on right and left, some grass and bare soil, looks logged.
5-50	722101	1253250	Leaving logged square area and entering low scrubby forest.
5-51	721939	1253351	On right low mixed forest, low scrubs on left.
5-52	721757	1253433	End of clear area on left, mixed forest on both sides.
5-53	721236	1253618	**Photo 6-16 (south), 6-17 (north)**, just south of airstrip at Rang Rang, collect samples. To right of road is small thatch hut, with a small garden of cassava, backed by natural forest. On left is *Acacia* sp. plantation. **Photo 6-18** of large dead tree, **Photo 6-19** looking right at forest. **Photo 6-20** of Tom Boivin sampling soil.
5-54	720760	1254126	Soi Sai creek just before airfield, low *Acacia* sp. plantation on both sides of road.
5-55	720507	1254446	Road curves right, *Eucalyptus* sp. on both sides 10 m height.
5-56	720096	1254675	North end of airstrip, *Acacia* sp. and *Eucalyptus* sp. plantations.
5-57	719929	1254821	Open area, Rang Rang office of local forestry enterprise, low building with clay roof. Scrub-land with American grasses. **Photo 6-21** of building.
5-58	719674	1255048	Lots of cassava on left, beyond is village of Rang Rang.
5-59	719577	1255275	At Ma Da river, remains of old bridge to east, river now crossed using a small reaction ferry. **Photo 6-22** of ferry and **6-23** of destroyed bridge.
5-59a	719520	1255554	Across on north bank of Ma Da river on top of a small rise, opposite a small forestry check-point, clear view of sprayed area. **Photo 6-24** looking east.
5-60	719510	1255603	Off to left (west) of road, across from security post, north side of Ma Da river, small pod-like crops being cultivated (local name Vung). To north is grassland for 700 m then forest, to west same, to south the Ma Da river in distance. To the east is the road with lowlands growing cassava beyond, also visible is cleared land, with scattered large trees. **Photo 7-2** (south), **Photo 7-3** (north), **Photo 7-4** (south). We are located in the middle of a spray line according to aerial photographs taken in 1975. Walked N-NW along road through grassy area which started to close in, grassland ends. **Photo 7-5** south along road. Tall grass.
5-61	720352	1254565	Old air strip **Photo 7-5** (north) and **Photo 7-6** (south) show soil sample collection.
5-62	720349	1254566	Still at airstrip, west is *Eucalyptus* sp. 6-7 meters high, to right (east) are *Eucalyptus* sp. and some *Acacia sp.*
5-63	726588	1245135	At Ba Hao reservoir sampling pond sediments with Andrew Allen and Dr. Dung. **Photos 7-10, 7-12** of sediment collection, looking due north across reservoir, *Mimosa sp.* and *Acacia sp.* plantations. Big fish hatchery on north side of reservoir, with plantation forest behind.

November 25, 1997: Ma Da forest, southern Viet Nam (2).

Waypoint	Easting	Northing	Comments
6-1	687977	1240528	Highway 741, south of Song Be river, rice on both sides of road for several kms.
6-2	688452	1241225	Leaving rice area and entering small village which has some rubber trees and

Waypoint	Easting	Northing	Comments
			cashews growing around it.
6-3	688661	1241538	Young rubber plantation on left and mature rubber plantations on left.
6-4	689421	1242595	Village of Phouc Hoa.
6-5	689575	1242698	Cashew on either side of road, still in village of Phouc Hoa.
6-6	690037	1242991	Large rubber plantation on left, some cashew on right.
6-7	690543	1243226	Rubber plantations for as far as you can see on the right, rubber plantations also on left side of road.
6-8	692021	1244300	Just before bridge over Song Be river, rubber on right, cashews on left.
6-9	691910	1244517	On bridge over Song Be river. To our right (east) is the remains of a bombed bridge (destroyed during the war). **Photo 7-14** of bridge. Plantations visible behind bridge. South of river, area of large grasses and plants – could be corn. On north side of river, between bridges there is a small cashew plantation (50 m wide) with a rubber plantation behind it. Dry-land cultivation along south bank or river. **Photo 7-15** is looking at the SW river bank.
6-10	691875	1244811	Wide open area of grasses; rapidly closes into a village of cashews and other trees.
6-11	693125	1245846	Left, large clear area in midst of rubber plantation (about 400 m square), near village of Phu Gia.
6-12	695369	1247523	Near end of village of Phu Gia, cashew plantations on both sides.
6-13	695533	1248246	Crossing over large wet area with a stream and some rice growing in it. Some palms on edges of open area.
6-14	696614	1249423	On road, small scrubby plantation on both sides of road.
6-15	697172	1250340	Open area bounded by cashew plantation on right; cashew plantations on left also.
6-16	697491	1250726	Small ponds and wet areas on both sides of road with palm trees along fringes of wet areas, some rice being grown.
6-17	698534	1251278	Opening edge of a low rice growing area.
6-18	698741	1251530	Closing edge of rice growing area, going back to cashew and village huts. In distance, rubber plantations visible a couple of kilometers away.
6-19	698973	1252113	Big church on left.
6-20	698690	1252955	Small rubber plantation on left, with a small cashew plantation just beyond it. On right, mixed cashew, *Eucalyptus* sp. and homes.
6-21	699075	1254542	To right of road, open grassy area for 5-600 m, then a cashew plantation for 5-600 m, then a mature rubber plantation beyond that.
6-22	699215	1255050	To left, rice growing areas, scattered small homes/farms growing banana, maize, pepper etc.
6-23	699907	1256367	Large rubber plantation to right beginning. To left rubber about 4-500 m from road.
6-24	700020	1256938	Edge of rubber plantation on right, cashew and homes on left. A large power line is visible 400-500 m to the right.
6-25	700119	1257264	At Phu Binh forest enterprise office. **Photo 7-16, 7-17, 7-18, 7-19 and 7-20** are of the land-cover map from the forestry enterprise office (made in 1991).
6-26	699772	1257901	North of forest enterprise, road crossed underneath large powerline ~200m back. To left small pepper plantations, to right large open area for a few kilometers.
6-27	699288	1258752	Large field of cassava on right, mixed trees and homes on left.
6-28	699136	1259071	Large open wetland to right.
6-29	699231	1259579	Some fishponds and rice fields to the left and right. To the left about 200 m from road, there is a large mature rubber plantation.
6-30	699696	1261232	Village where we ate lunch.
6-31	699874	1257645	Heading south on Highway 741. Underneath large power-line which was mentioned earlier.
6-32	700033	1256846	Turned off Highway 741, driving through large rubber plantation.

Waypoint	Easting	Northing	Comments
6-33	700036	1255887	Still driving through rubber plantation, small cleared area behind and left.
6-34	700067	1254365	Sharp left turn, southern extent of rubber plantation about 100 m to right of vehicle.
6-35	700561	1254392	Very distinct north-south edge to rubber plantation, planted with very young rubber trees beyond the edge. **Photo 7-21**. To south there is a clear run of 100 m or so, followed by a cashew plantation which may extend to the highway.
6-36	700975	1254456	Near eastern extent of cleared area; cashew and *Eucalyptus* sp. plantation.
6-37	701162	1254196	Crossing small stream, with rice on either side.
6-38	701248	1254184	Edge of wet area, with young rubber trees (15 feet high, very skinny – 1 year old).
6-39	701766	1253989	Middle of young rubber plantation. **Photo 7-23.**
6-40	702234	1253729	Break in young rubber on right (house and small garden), on left plantation continues.
6-41	702443	1253584	Coming down off a plateau into a valley, vegetation is very scrubby, soil damp with some cashew and other small trees.
6-42	702576	1253144	Bottom of stream valley (called Rach Rat), some homes to right of road, a checkpoint dry-land tree crops.
6-43	702685	1253063	Beginning of cashew plantation, more to the right than to the left.
6-44	702790	1253032	End of cashews, now grassland and some young rubber trees.
6-45	703150	1253042	Mature rubber (4 years old, 20 feet high)
6-46	703685	1253128	Still driving through four year old rubber plantation. Dirt road is bordered by a cleared grassy strip 10-20 meters wide.
6-47	704090	1253112	Edge of young rubber, now into grass-lands with some small trees.
6-48	704267	1253134	Grass with small trees on both sides.
6-49	704804	1253233	Crossing over Suoi Tich (Tich creek). Some rice being harvested, some low trees, low wet area.
6-50	705379	1253359	Come into rubber on right 5-6 years old, on left, younger rubber maybe 2-3 years old.
6-51	705966	1253360	Edge of rubber on right, followed by open field. Rubber on left continues.
6-52	706133	1253356	Young rubber starts on right and finishes on left.
6-53	706207	1253460	Left turn. Young rubber on both sides of road, with grasslands between road and plantation edge.
6-54	706337	1253755	Young rubber (1 year old) on both sides of road.
6-55	706919	1253651	**Photo 7-24** of a large tree which survived spraying.
6-56	707543	1253567	Just coming down to Rach Be creek, large coffee plantation and tamarind on right, damming creek with an earthen dam.
6-57	707893	1253686	Coming into Cam So village, into low natural forest. This area is new (recently grown back) natural forest.
6-58	709054	1254484	Still in low natural forest. Road has been dead straight since last way point.
6-59	710723	1255441	Young rubber plantation. T-intersection in road, turn right. Area is sparsely settled which has hindered replantation. Still lots of unexploded ordinance.
6-60	710975	1255265	Young rubber on right, with cassava underneath, to left a fringe of cassava with natural forest behind.
6-61	710995	1254882	Turned onto a very narrow road. Surrounded by natural forest.
6-62	711250	1255284	Still in dense natural forest.
6-63	711339	1255544	**Photo 7-26**, near more southerly of two reservoirs which are visible in both Radarsat images. Some dead trees in lake. Road goes S-SW to N-NE with lake on west side. On western edge of lake is young rubber and on our side, young natural forest. The lake used to be wet land, but now it has been dammed. **Photos 8-1, 8-2, 8-3** are of reservoir.
6-64	711500	1255445	Walking along small track from lake into a small cleared grassy area. **Photo 8-4** of grassy area, roughly rectangular 200 X 500 m.

Waypoint	Easting	Northing	Comments
6-65	711439	1255693	**Photo 8-5** of grass lands.
6-66	711416	1255943	Left is young rubber, to right is a little young rubber and then grass land and mixed trees. Can see forest in distance to right.
6-67	711556	1256450	Low natural forest.
6-68	711654	1256477	Grass land and low natural forest, marks the boundary between two provinces (used to be in Song Be). Enter cashew plantation on left and natural forest on right.
6-69	711894	1256729	End of cashew plantation, cleared beyond that. Larger tear-dropped shaped reservoir is visible to left (which is visible in Radarsat images). To right are grass lands sloping down to river valley with natural forest beyond. **Photos 8-6 to 8-8.**
6-70	711958	1256838	**Photos 8-9, 8-10** looking south at a sharp edge of a rubber plantation. **Photo 8-11** was of young rubber plantation on north side of road. Plantation lines are running directly north-south.
6-71	712010	1257173	Young rubber on both sides of road, about 1 year old.
6-72	712263	1257633	End of rubber, beginning of natural forest.
6-73	712831	1258166	Natural forest.
6-74	713405	1258479	Natural forest.
6-75	713908	1258860	Still in natural forest, but more open, more bamboo and tall grasses.
6-76	713950	1258918	Crossing Suoi Sa Lac (Sa Lac creek) approx. 1-1.5 m wide and covered by vegetation.
6-77	714077	1259043	Cassava on left mixed with grass. On right, mainly grassland with mixed trees.
6-78	714648	1259638	Natural forest and grasses/*Eucalyptus* sp. on right. Same on left.
6-79	714662	1259712	In the middle of grassland with forest in distance – both sides.
6-80	714901	1259906	Edge of grassland, corresponds to spray line on map.
6-81	715084	1260000	**Photo 8-13** looking south at grass lands.
6-82	715227	1260122	**Photo 8-14, 8-15, 8-16, 8-17**, moving north to south through east. Shows sprayed cleared area with natural forest boundary.
6-83	715068	1260013	**Photo 8-18** still in sprayed area, showing land under cultivation – newly planted rubber plantation, near eastern edge of spray line.
6-84	716292	1259861	Edge of spray line
6-85	717370	1259677	Small cleared area (3-500 m wide), barren land on left, small cassava plantation on right.
6-86	717723	1259700	Just intersected Highway 322 (which we were on yesterday)
6-87	717917	1259014	Heading south towards Rang Rang on Highway 322. Moved out of an area that was cleared to right into natural forest.
6-88	718414	1258507	Natural forest on both sides of road.
6-89	718587	1258356	Just to left beyond 5 m of forest, another cleared area, to right natural forest.
6-90	719279	1257793	Leave forest, into barren area – just grasses and patches of soil. Left boundary is clear, with natural forest about 100 m away from road. Right edge is about the same.
6-91	719303	1257757	Still driving along cleared area, scattered large trees visible.
6-92	719533	1257396	Still grass lands to either side with occasional big tree.
6-93	719554	1256644	Cassava on left. Irregular boundary between forest and grass lands on right. Cassava on left gives away to natural forest very quickly.
6-94	719526	1256412	Grass land on left, forest on right. Fields of cassava punctuate grasslands on left.
6-95	719490	1255712	Back at Rang Rang check-post, just north of Song Be river (where we ended up yesterday).

November 27, 1997: Ca Mau peninsula, southern Viet Nam

Waypoint	Easting	Northing	Comments
7-1	517663	1011460	Heading south from Ca Mau – river about 60 m wide; *Nipa* palm backed by palm trees on both sides
7-2	517614	1009101	*Nipa* on left; *Nipa* and mangrove on right with rice fields behind on both sides; lots of boat traffic (5-10m long boats); numerous 1-3m wide channels coming off river
7-3	517268	1007376	Canal enters on right
7-4	517366	1006019	Large river connects on right; *Nipa* and mangrove on both sides
7-5	518113	1005874	Big bend in river; *Nipa* on left, young mangrove (~2 m) on right; tide more than half way out and falling
7-6	519056	1004330	Fork in the river- we go right; *Nipa* on right, mangrove on left; small homes on either side.
7-7	519489	1002398	Small village on right bank; about half of homes with tin roofs, half with thatch; *Nipa* on both sides with some mangrove (both sides)
7-8	519319	1001379	Small plantation of mangrove (*Rhizophora*) on right; *Nipa* on left
7-9	519237	998561	Small settlement on right bank; *Nipa* on both sides with palm trees, backed by rice
7-10	521906	994812	Town of Dam Doi; large buildings on right, some on left. Dam Doi is ~30 km from Ca Mau; large canals meet, large concrete bridge crosses river
7-11	521723	991857	Bottom end of Dam Doi; *Nipa* on right, *Nipa* backed by palm backed by rice on both sides.
7-12	523601	990089	*Nipa* and mangrove backed by rice
7-13	523510	988951	At Dam Doi bird sanctuary (129 ha) on east bank of river; mangrove trees were mostly blown over; **photos 8-23 and 8-24**
7-14	523687	987423	Small village; canal running east and west meet; *Nipa* backed by rice on right; mangrove forest on left.
7-15	523525	986100	Large church on right with some other thatch homes; *Nipa* backed by shrimp ponds on left; *Nipa* backed by rice on right.
7-16	525556	984702	*Nipa* on both sides; canals to shrimp ponds on left; no canals on right (suggests rice) – Mr. Thanh indicated that right of the river is an Agricultural zone, where rice and freshwater fish are grown.
7-17	526431	982170	At "highland" shrimp pond on left; dry due to low tide. Some Eucalypts and mangroves around ponds; **photo 8-25**
7-18	526519	979078	Small mangrove on both sides; some *Nipa* on right as well
7-19	526997	978283	At Nga Don canal junction – boundary between economic zone to north (rice, etc.) and forest zone to south. Canal is about 10 m wide. Tan Giang III forest plantation to south; shrimp ponds to east; rice to north (with *Nipa* on edge)
7-20	527303	976607	Large village (Vam Dam) along river; generally wood buildings with tin roofs. **Photo 9-1** of "scaffold" fishing net from shore; **photo 9-2** of destroyed brick factory beside Tam Giang Forest Enterprise office; **photo 9-2** of village
7-21	527685	975165	On Cua Lon River heading SE; mangrove on right backed by shrimp ponds; small homes and shrimp farms with some small trees.
7-22	527294	974880	"Scaffold net" on south bank – **photo 9-3**
7-23	526258	974142	"Scaffold net" on north bank; right side mangrove, clear areas and shrimp; homes on left side
7-24	525518	973512	Mangrove backed by shrimp farms on both sides
7-25	524717	973402	"Scaffold net" from left bank extending about ½ way onto channel
7-26	524112	973550	Turned right into Tam Giang III plantation; scaffold net at junction.
7-27	524151	974126	Thick mangrove on either side; many blown over

Waypoint	Easting	Northing	Comments
7-28	524153	974306	Small plantation of 1996 mangrove on left
7-29	524166	974520	End of small 1996 plantation on left; mature mangrove continues on right; **photo 9-6** of this plantation; **9-7** looking north at mature trees
7-30	524148	975514	Seedling forest starts; sparse tall trees, but several blown down
7-31	524118	976063	In centre of Tam Giang III – clear areas near "vertex" of canals; seedling forests in larger square plots to NE, NW, SE, SW; many blown over and destroyed; **photo 9-8** looking SE, **9-9** looking NE (also shows destroyed ranger station); **9-10** looking at surviving hut
7-32	524125	976236	Just north of above huts; irrigation canals for shrimp; **photos 9-11 to 9-13** looking W and NW; main canal ~5 m across; then 20 m of dike, then ~4 m of shrimp pond channel on all sides of the "vertex"; **photo 9-14** of shrimp canals within forest – about 2 m wide and spaced about 5 m apart; forest 37 years old
7-33	527964	976137	Walking through Vam Dam village; **photo 9-15** of destroyed school; dry upland shrimp ponds, some barren land, some canals
7-34	528049	976141	Past village, walking along canal 5 m wide; **photo 9-16** of shrimp pond canals.
7-35	528062	976334	**Photo 9-17** of irrigation canal for shrimp ponds.
7-36	528325	975705	Following channel into Tam Giang I; mangrove and *Nipa* with shrimp farms on both sides; channel is ~8 m wide
7-37	529317	974932	Canal running parallel to our canal about 5 m left of us (irrigation for shrimp); dike between is basically bare
7-38	529899	973755	4-way intersection, marks boundary between sparsely-forested shrimp farms to NW and barren land shrimp farms to SE; **photo 9-18 to 20** of barren shrimp farms
7-39	530227	974083	Following perimeter of barren-land (right) and treed shrimp farms to left (~3m high trees)
7-40	530957	974506	As above, although trees on left are more dense and larger (~ 5 m)
7-41	532082	975145	Corner T-interection – **photo 9-21** looking NW, **9-22** looking NE at boundary between barren-land and dense protection mangrove forest
7-42	532366	974708	Boundary canal between mangrove and barrens; **photo 9-23** of fishing boat and edge of mangrove; **9-24** and **9-25** of barren shrimp land (illegal farming practice)
7-43	528978	972804	Narrow channel (~6m); young mangrove with shrimp farm on both sides
7-44	528733	972647	Concrete buiding with tin roof on right; thick mangrove with shrimp ponds behind
7-45	527826	972555	Mangrove and shrimp on both sides
7-46	527426	972632	Barren-land shrimp pond on right; mangrove and shrimp pond on left
7-47	527171	972724	Several huts on right with scaffold net; mangrove with shrimp farms on left
7-48	526838	972772	Village with tin roofs on right; *Nipa* along banks on both sides
7-49	526705	972655	*Nipa* on both sides
7-50	526483	972181	*Nipa* ends on left, shirmp ponds and sparse mangrove begins; *Nipa* continues on right
7-51	526155	971829	Intersection of 2 channels; *Nipa* on right, mangrove and mangrove on left.
7-52	525836	971670	*Nipa* restarts on left; still *Nipa* on right – narrow fringe, however, with shrimp ponds behind
7-53	525528	971448	Barren-type shrimp farm on left; *Nipa* on right (~30 m) backed by shrimp ponds
7-54	524892	971164	Scaffold net on left hand side of channel, crosses most of river; *Nipa* and mangrove fronting shrimp farms on both sides
7-55	524212	970569	Channel opening up (~40-50 m); *Nipa* and mangroves fronting shrimp on right; mangrove fronting shrimp on left
7-56	523713	970218	Dry-land agriculture on left; mangrove and *Nipa* on right
7-57	522942	969905	Low, sparse mangrove fronting shrimp farms on both sides
7-58	522661	969728	Small homes on right with large scaffold net; near confluence of Cua Lon River; mangrove and shrimp farms on both sides

Waypoint	Easting	Northing	Comments
7-59	522042	969432	Mangrove on right (no shrimp?), much destroyed; large village on left
7-60	521832	969284	Past channel on right
7-61	521708	969199	Mangrove, larger ones missing most leaves on right (no shrimp?); village on left
7-62	520705	970267	Mangrove with shrimp on both sides
7-63	520638	970629	Large scaffold net made of 8 boats floating roughly mid-channel
7-64	520747	972144	Confluence of three big streams; into main channel, village on corner on right, some village on left as well.
7-65	520767	972881	Mangrove and shrimp farm on both sides; scaffold net
7-66	520790	973815	Muoi Bay (literally, "17") channel. Mangrove plantation on both sides; border between Tan Giang III and FFA 184
7-67	520841	974750	Mangrove on either side; scaffold net; some shrimp farming on edges of channel
7-68	520823	975582	Mangrove forest on right; several small E-W channels cross N-S channel
7-69	520775	976404	Scaffold net; mangrove and shrimp on both sides; SPOT image suggests right is mostly forest while left is mostly shrimp
7-70	520651	978087	Turned corner in channel; mangrove and shrimp on right; forest plantation on left
7-71	520097	978057	Large barren-type shrimp farm on left; low scrubby forest with rice behind it.
7-72	518789	978034	Small mangrove and *Nipa* on shrimp farm on left; *Nipa* and mangrove on right
7-73	518228	978030	*Nipa* and mangrove fronting rice on right; mangrove and shrimp on left
7-74	517393	978006	At shrimp farm on left side; **photo 10-1**; canal about 4-5 m wide, with smaller channels ~1-2 m wide
7-75	517313	977959	NW corner of shrimp farm; boundary marker between districts; young mangrove on dikes planted 1996
7-76	517296	977877	W-E channel (~4m) runs perpendicular from dike we're walking on (dike ~4 m wide)
7-77	517297	977796	Still walking SE on dike; fringe of mangrove; some *Nipa* planted along inside dikes in shrimp farm
7-78	516883	977777	Homes, *Nipa*, mangroves and shrimp farms on both sides
7-79	516502	977267	Channel banks lines with *Nipa*
7-80	516372	976606	Large, barren shrimp farm fronted by *Nipa* on both sides
7-81	515900	976182	Scaffold net extending across most of channel from right side
7-82	515000	975369	*Nipa* on right side; sparsely forested shrimp farm on left
7-83	514849	974763	6-7 m tall mangrove on left side; sparse mangrove on shrimp ponds on right
7-84	514853	974307	Channel at demonstration farm. **Photo 10-2** of destroyed wood from typhoon; photos **10-3,10-4** of channels within shrimp farm
7-85	514979	974404	Along twin channel in demonstration farm – canals ~2 m wide; trees about 11 years old, many blown over or missing most leaves
7-86	515097	974361	Looking at damage; tall mangrove on both sides
7-87	515287	974375	Perpendicular small channel crosses twin canals; tall mangrove on both sides
7-88	515340	974375	**Photo 10-6** of missing leaves on mangroves
7-89	515397	974348	T-intersection marking boundary of farm with other farms
7-90	515339	974182	Another twin set of canals running right from boundary channel; **photo 10-9**
7-91	515272	974150	Another twin set of canals running right from boundary channel
7-92	515211	974034	Boundary between three farms
7-93	515167	974006	Corner of farm, heading back toward home; boundary between two other farms runs diagonally away from this farm corner; **photo 10-10** of boundary dike
7-94	515004	974158	Twin channels running perpendicular right from walking dike; about 2 m channels with ~5 m low, non-vegetated dike running between them; *Nipa* on either side; mangrove outside of boundary

Waypoint	Easting	Northing	Comments
7-95	514924	974220	Intersection of several canals; almost back to house.
-	-	-	Photo 10-11 of FFE184 map at enterprise office – farm 0193 is the farm described in waypoints 84 to 95. **Photo 10-12** of Ca Mau peninsula showing forestry enterprise boundaries.

November 28, 1997: Ca Mau peninsula, southern Viet Nam

Waypoint	Easting	Northing	Comments
8-1	513560	974352	Leaving Tam Giang village; going down canal which separates FFE 184 and Tam Giang III. Sparsely-planted shrimp farms on either side with *Nipa*
8-2	512792	974016	Sparsely-planted shrimp farms on both sides; larger trees on left side shrimp farms
8-3	510561	973071	Shrimp farms with sparse *Nipa* and mangrove; slightly larger mangroves (~3m) on left.
8-4	510128	972370	Recently planted mangrove on shrimp farms on both sides
8-5	509505	971991	At boundary of Euroconsult 1996 and 1998 projects; **photo 11-8** of sign. On north bank, barren-land shrimp farm with some *Nipa*, on south side, thicker *Nipa* fronting shrimp farm.
8-6	509550	971931	Walking south across shrimp farming area. Area to left (east) is 1998 project area (mostly barren, little planting); on right (west) is 1996 project area, which was planted with mangroves using various forestry models – mangroves are small (~1 m).
8-7	509521	971918	**Photo 11-9** of canal with young mangrove on either side; **photo 11-10** of planted mangroves and boundary canal between neighbouring farms
8-8	509498	971893	**Photo 11-11** of lower-land mangrove planted 1996; shrimp canal in foreground of photo is being dug currently – not complete yet
8-9	509458	971834	Turned corner of dikes; walking down along dike; young mangrove on left, with small bushes (not mangrove) on right
8-10	509470	971643	Young mangrove on both sides; larger mangrove (~3m) to right about 100 m beyond young mangroves.
8-11	509443	971548	**Photo 11-12** looking south along twin channels running roughly straight N-S; to both sides is shrimp pond with small mangrove
8-12	509490	971219	Walking south along dike; corner of farm; turned right along another dike. To both sides is shrimp pond with small mangrove (some larger to east). **Photo 11-13** of MD and Thanh
8-13	509352	971214	Boundary between shrimp farm with young mangrove on east; larger mangrove (1994) to the west
8-14	509272	971203	Turned left (S). Shrimp farms to N and S. Young mangroves to both sides, with some larger mangrove to the north as well.
8-15	509246	971166	Turned right along dikes. Recently planted mangrove on shrimp pond on both sides.
8-16	509105	971109	Job to left, but continuing along dike between shrimp farms. Recently planted mangrove on shrimp farm on both sides.
8-17	508890	971088	Turned 90° left. Different model of farm – 10m wide blocks of young mangrove with channels all around, with high dikes between blocks.
8-18	508947	970931	To right is beginning of ~100m block of barren land (was attempted rice fields); to left is shrimp canals with small (1996) mangrove
8-19	508877	970827	End of dike at sluiceway into Cua Lon River. To right is end of clear area; to left is small open clear area as well, with E-W channels
8-20	507511	970769	Heading ~W along Cua Lon River; to left small mangrove; to right small village (Hung Vinh).

Waypoint	Easting	Northing	Comments
8-21	506826	970184	Hung Vinh still to right, some homes on left as well, with shrimp farms with few trees on left.
8-22	506085	969689	Turned left into small river on left; Ba Buoy Creek.
8-23	506237	968939	Shrimp farms on both sides with sparse young mangrove
8-24	506483	968710	Passed small canal to the right
8-25	506877	968108	Channel on left; shrimp farms on either side with young mangrove
8-26	506732	967258	Shrimp farms with mangrove fringe and sparse large mangrove and some young mangrove on shrimp farms
8-27	506908	966057	Same as above
8-28	507065	965849	Mature, dense mangrove along edge of river; shrimp farms behind along both sides
8-29	507203	965288	Shrimp farms along both sides; no trees visible on left, a few on the right
8-30	507489	964735	Concrete home on left, with thatch homes on same bank; sprarse mangrove over shrimp ponds on both sides
8-31	507655	964067	Channel to right (did not take); shrimp farms with sparse mangrove on both sides
8-32	507743	963922	Shrimp farms with moderate coverage of 2-3m mangrove on both side; may be more open areas in shrimp farms on left
8-33	508222	963368	Sparse, 2-3m mangrove on shrimp farms on both sides
8-34	509082	962909	Shrimp farms and small mangroves on both sides
8-35	509428	962984	Sharp S in the river – straight wide channel ~20 m wide; young mangrove with shrimp farms on either side
8-36	509822	962159	Canal meets larger canal; thatch homes with young mangroves over shrimp farms.
8-37	509881	962023	**Photo 11-16** looking down channel at moderate growth of mangrove on either side, with shrimp farms behind
8-38	510300	961155	Shrimp ponds and sparse mangrove on both sides
8-39	50562	960666	Meet larger river at T-intersection. To south (ahead) is mangrove forest (no shrimp) in Kiem Vang FFA, with shrimp farms on N side.
8-40	509973	959902	Shrimp farms on right, forest on left
8-41	509411	959685	Tilled fields of fairly barren cropland (**photos 11-17,-18**). Walking dike between two farms – area was converted a few years ago from shrimp to agriculture and now some agriculture to *Rhizophora* forest.
8-42	509349	959759	Slight turn in dike; cover as before (i.e. barren agricultural land).
8-43	509239	959866	Far-N dike on this farm; clear agricultural land continues 500m+ to north. Trees evident about 200m to west and 500m to east. **Photo 11-19** of bare fields looking north across other bare farmland; **photo 11-20** looking south, showing bare land, and tall mangrove on south side of river
8-44	509088	959064	Going down river; mangrove on left; fringe of mangrove with shrimp ponds on right.
8-45	508538	958473	Sparse, tall mangrove forest to left; shrimp? agriculture? to right (no canals evident).
8-46	508104	958178	Open area on left and right – left looks like young trees with a few older trees (many blown over)
8-47	507725	958063	Just ahead of canal entering on right. On right, was shrimp farm but has been converted to forest, same with left.
8-48	507150	957222	Confluence of canals. **Photo 11-23** looking south at sparse, tall mangrove trees in Kiem Vang FFA, with gated fence across river to prevent illegal logging. On right, small village (mostly thatch) with shrimp ponds behind.
8-49	506689	956992	Going into Kiem Vang FFE to ground-truth lines visible in 1:100,000 Radarsat image. Maps in FFE offices indicate that they are canals, and boundary of an area of young mangrove planted subsequent to recent harvest
8-50	507078	956990	Some large trees with shrimp on left (most blown over); young plantation to right
8-51	507326	957150	Large trees blown over on left and right

Waypoint	Easting	Northing	Comments
8-52	507873	956963	As 51
8-53	508147	956744	Shrimp pond on left; forest on right
8-54	508400	956463	Small canal running right and left; lots of blown down big trees
8-55	508569	956440	Shrimp farm on left; forest on right.
8-56	508555	956510	At shrimp farm. **Photos 11-24, -25** of damaged forest. Canals 2-3m wide with high dikes and lots of downed trees in sparse, tall mangrove forest. Creek ends at this shrimp farm. The tall trees were planted in 1976.
8-57	508605	956546	**Photo 12-1** looking up creek dike between end of creek and shrimp/forest study area. Forest in study area (photo 12-2) was thinned previous to typhoon, so much damage. Forest to south (photo 12-3) was not thinned, and much less was blown down.
8-58	508066	956804	Turning up channel to north. Shrimp farm with tall, sparse mangrove.
8-59	508280	957037	Channel and dike which are visible in Radarsat image. **Photo 12-4** of channel and bare dike; 12-5 of dike with home. **Photo 12-6** looking at severely damage mangrove forest on both sides. South bank has shrimp farm.
-	-	-	**Photo 12-7 and 12-8** of FFE forestry map – legend: yellow=agriculture; forest green= young *Rhizophora*; light green=new plantation (1995); purple=mixed older forest; turquoise=*Avicennia* forest; peach=barren shrimp farm or settlement. Wedge-shaped area on bottom of S forest is protection forest
8-60	506290	956547	Right: cut or blown down forest, perhaps with shrimp. Same on left, but no shrimp.
8-61	505725	956141	Mangrove (lots blown down) on left; right: small homes and cleared land (shrimp?)
8-62	505502	955641	Large river enters on left; thatch roofed homes along channel
8-63	505112	955259	Some tin-roofed homes on left. Entering a village. Low scrubby forest on both sides, maybe shrimp but no canals visible.
8-64	504694	955020	Scaffold nets of left bank; cover as 63
8-65	504124	954405	Canal on left; shrimp on left with scrubby forest
8-66	503753	954001	Canal enters on right. Some homes on either side
8-67	503394	953698	Canal enters on left. Flat open areas backed by sparse forest on both sides, probably shrimp.
8-68	502936	953367	Canal enters on right. Channel widens. Large ocean-going ships, large village.
8-69	502266	952995	At junction of Tan An village (large) and Rach Gio river (enters from N). Metal/wood walking bridge crosses Rach Gio
8-70	502184	953016	Corner of soccer field on town.
8-71	502217	953072	Middle of footbridge. **Photo 12-9** looking north on Rach Bio
8-72	501827	954323	Going north on Rach Gio.
8-73	501468	955027	Low mangrove on both sides, with shrimp. Beyond is protection forest says Mr. Thanh.
8-74	500943	955565	Shrimp farm with sparse vegetation to left; older mangrove with shrimp farm on right.
8-75	500217	956917	*Nipa* with shrimp farm to right; shrimp farms with sparse large trees, some young trees and *Nipa* on left with shrimp ponds.
8-76	500214	956937	Large shrimp farms on both sides, with young mangrove planted.
8-77	500416	958314	Mangrove backed by shrimp farm on both sides.
8-78	500138	959074	As 77, except with few very large mangroves along the river.
8-79	500153	959418	Large canals meet; likely at top of Kiem Vang FFE. Some very large mangrove on edges of river, fronting shrimp ponds and small mangrove on both dies
8-80	500517	959962	Some concrete homes on right. Relatively-barren shrimp farms with some young mangrove on both sides; no fringe along river
8-81	500618	960412	Shrimp farm to river is very barren; to left shrimp farm with some vegetation (~1m mangrove). Most of the shrimp farms along the river are either barren or with small

Waypoint	Easting	Northing	Comments
			trees only
8-82	501123	961708	Shrimp farm to left with several rows of large (3-4m high) mangrove on dikes; shrimp farm with moderately-high mangrove on left. On O Ding river now, not Rach Gio
8-83	501198	963362	Shrimp farms with young (0.5-1m) mangrove on either side.
8-84	501054	963982	Left: shrimp farm with tall mangrove (4m), slightly more mangrove on right side shrimp farms than previous along this river.
8-85	500022	967445	More shrimp farms on both sides – sparse cover of larger mangrove and moderate cover of small mangrove.
8-86	500014	967455	Coming into large river (Can Lon) with town (Nam Can).
8-87	498878	967884	Crossed Cua Lon River, in Nam Can
8-88	499328	968948	Heading north from Nam Can. Village on right; mangrove and shrimp farm on left (3-4 m high mangrove)
8-89	499672	970321	Young mangrove and shrimp farm on left; scrubby forest and powerline on right.
8-90	500059	971911	Young mangrove and shirmp farm on both sides.
8-91	500451	973192	Young mangrove and shrimp on both sides.
8-92	500743	973832	Small river entered on right. Young mangrove and shrimp ponds on both sides.
8-93	501613	975668	Young mangrove and *Nipa* in shrimp ponds on both sides.
8-94	502018	976683	Small river enters on right; *Nipa* fronting shrimp farms on both sides; some small mangrove in shrimp farms.
8-95	502022	978525	Turned onto another channel. Village. To north, rice and gardens behind homes; to south, *Nipa*, mangrove and shrimp.
8-96	502958	979428	To left, *Nipa* fronting coconut palms fronting gardens; to right, shrimp farms with young mangroves.
8-97	503375	979822	Barren shimp farm on right; mangrove, palm and rice on left.
8-98	504479	980190	Mangrove fronting shrimp on right; *Nipa* and mangrove fronting coconut palms fronting rice on left.
8-99	505404	988791	Kai Keo village on right; rice on left
8-100	505997	981087	Rice on left (**photo 12-10**); small river enters on right, through village. Shrimp farms on right further past village, with lots of vegetation fronting.
8-101	506689	981595	NO DESCRIPTION
8-102	507248	981734	*Nipa* fronting coconut palm fronting rice on both sides.
8-103	509701	984433	Rice on both sides, with *Nipa* and mangrove fronting
8-104	510232	985447	Fringe of flooded mangrove and *Nipa* fronting rice on both sides.
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December 1, 1997: Rung Sat mangrove forest, southern Viet Nam.

Waypoint	Easting	Northing	Comments
9-1	694213	1179618	At southern ferry dock across Saigon River. On south bank, small village with some trees
9-2	694487	1179159	*Nipa* and small fish ponds on both sides; still some homes.
9-3	694631	1178905	*Nipa* on both sides, with rice on left behind. Some homes.
9-4	694804	1178611	*Nipa*, some homes and small trees on both sides
9-5	695040	1178253	Small fish ponds on right with *Nipa*; same on left, but also grassy field on left.
9-6	695198	1177943	Recently cleared rice fields on left; *Nipa* and small fish ponds on right.

Waypoint	Easting	Northing	Comments
9-7	695272	1177710	Rice on both sides with some *Nipa* and trees; power line to right ~300 m away
9-8	695354	1177499	Left: patch of grasses, some homes, mostly rice. Right: rice fields
9-9	695583	1177104	School on right with rice behind. Homes and trees to left with rice behind.
9-10	695706	1176938	Soccer field on right; rice on left.
9-11	695932	1176612	*Nipa* backed by rice on both sides
9-12	696117	1176333	*Nipa* backed by rice on both sides
9-13	696495	1175804	*Nipa* backed by rice on both sides; **photo 12-11** looking right. Some small fish ponds on left.
9-14	696756	1175413	Rice to right with forest in distance (**photo 12-12**); rice and *Nipa* on left
9-15	696928	1175189	Lots of rice to right, with *Nipa* patches and some forest; Rice with *Nipa* to left.
9-16	697031	1175024	Canal running away from road to the right; small patch of forest along the canal; rice and *Nipa* on both sides
9-17	697941	1174556	Rice and *Nipa* on both sides
9-18	698275	1174415	Fish ponds on right backed by rice backed by *Nipa*; rice backed by *Nipa* on left
9-19	698922	1174151	Left at fork in road. Rice, *Nipa*, grasses, small fish ponds along road.
9-20	699200	1174218	Rice and patches of *Nipa* on both sides
9-21	699343	1174252	Open ponds on both sides among rice fields
9-22	699732	1174334	Rice with *Nipa* on both sides; small patch of forest to the left
9-23	699966	1174387	End of small patch of forest on left; rice and *Nipa* on both sides, some grasses on left as well.
9-24	700179	1174435	Road to right (we stay ahead). Grasses and *Nipa* to right; rice and *Nipa* to left. **Photo 12-13** left; **12-14** right; **12-15** left. Grass is *Cyras* – dried for thatch. Photo **12-16** of farmer with grass
9-25	700657	1174532	Grass on left; rice on right.
9-26	700812	1174580	Rice on right; fish pond and rice on left. Some *Nipa* and grass in background in distance on left
9-27	701070	1174664	Small canal follows road on left; *Nipa* and grasses on both sides
9-28	701178	1174636	Small open pond on left; *Nipa* and a few trees on left; grasses on right.
9-29	701707	1174421	At large canal (can't cross); ~50 m south of main river. Across river is *Nipa* and grasses. The grasses are natural (not planted), but they are fertilized. Most is harvested in August, but they cut some throughout year and do not cut all every year. *Nipa* can be cut every 4 month, regardless of season.
9-30	701704	1174422	[NO DESCRIPTION]
9-31	698965	1173966	Back on main road. *Nipa* and grasses on right. *Nipa* on left.
9-32	698996	1173634	Metal power line towers cross road. *Nipa* on both sides.
9-33	699066	1172937	*Nipa* on both sides, with some grasses on left. Powerline is ~30m from road on left, running parralel
9-34	699086	1172572	Crossing bridge. *Nipa* on south bank, mangrove on north bank
9-35	699145	1172363	Powerline crossed back to right side of road
9-36	699252	1172169	*Nipa* on left; *Nipa* and grass on right.
9-37	699333	1171878	Mangrove backed by cut *Nipa* on left; same on right, but *Nipa* uncut
9-38	699574	1171212	Cut *Nipa* and mangrove on right; *Nipa* and mangrove on left
9-39	699636	1170958	Road to left; barren field on right. Mangrove on right, *Nipa* on left.
9-40	699718	1170700	Few homes before bridge. *Nipa* and small trees (eucalypts, bamboo) on north bank, with mangrove further from bridge. Mangrove on south bank. Small transformer station to the right just south of bridge.
9-41	699841	1170197	Just before other bridge. Mangrove and fringe of eucalypt on both sides.

Waypoint	Easting	Northing	Comments
9-42	699632	1169702	Roads crossing left and right; road to left goes to shrimp farm that was ground-truthed in Phase IIa. We turned right. Mangrove on all sides, of different sizes to 10m
9-43	699285	1169725	Mangrove on left, mangrove with some scrubby bushes on right
9-44	698511	1169794	Homes with mangrove and *Nipa* on left, mangrove with some scrubby bushes on right
9-45	697827	1170154	*Nipa* on left; school on right
9-46	697673	1170298	Rice on both sides, with some patches of *Nipa* and trees on both sides
9-47	697195	1171134	Rice on both sides, some *Nipa*
9-48	696045	1171290	End of rice; *Nipa* and a few homes on either side
9-49	695708	1171318	End of road; *Nipa* and gardens with small homes on both sides
9-50	695733	1171306	-
9-51	695737	1171166	South down river; narrow road with homes on either side
9-52	695749	1171001	End of road – meets small canal ahead; inside village.
9-53	699782	1169120	Going south along main road; mangrove (4m) on both sides
9-54	699940	1168683	Crossing bridge; mangrove on both sides of both banks
9-55	700066	1168038	Turned right toward Ly Nhon village; tall mangrove on both sides, canal (3-4m wide) runs along left side of road, with small power line between canal and road
9-56	698198	1167457	3-4m mangrove on both sides
9-57	697908	1167364	Swamp and wetland on right, dikes and fish ponds on left; scrubby low mangrove on either side as well; **photo 12-17** looking right (N)
9-58	697598	1167279	Start of rice fields on right; some grasses beyond rice on right. To left, small dry-land crops with narrow canals between, with small mangrove in distance to left.
9-59	697020	1167099	Grass on right; newly-planted ('96?) mangrove on left. **Photo 12-18** looking right; **12-19** looking left.
-	695889	1167163	Swampy low mangrove on left; grass and rice on right.
9-60	695295	1167032	Swampy low mangrove on left; swampy area with some grass and rice on right.
9-61	694770	1166986	Newly planted mangrove to right; rice to left.
9-62	694250	1167193	Bend in road; young (96) mangrove to south, which corresponds to yellow/orange area in Radarsat image. **Photo 12-20** to left at mangrove, **photo 12-21** looking right at rice fields
9-63	700651	1167069	South along main road. Mangrove on both sides ~5 m high.
9-64	701360	1166352	Mangrove 3-5m high on both sides
9-65	701594	1166323	Shrimp farm, with forest surrounding. **Photo 12-22** of pond.
9-66	700077	1171067	Going east along road. *Nipa* and mangrove on right. Patches of mangrove on left. Lots of water on both sides.
9-67	700755	1170952	Fish ponds with *Nipa* on right. Fish ponds with young mangrove (~1 m), scrubby area and *Nipa* on left.
9-68	701365	1170955	Crossed wet area on both sides. *Nipa*, mangrove and scrubby areas on both sides
9-69	702516	1171021	Barren-looking agricultural areas on both sides; some *Nipa*.
9-70	703109	1171081	At corner; **photo 12-23,-24** panorama looking from N to W roads. Orange in image corresponds to fields of grasses inside corner.
9-71	703149	1171940	Grasses and *Nipa* on left. *Nipa* and clear areas on right.
9-72	703146	1172184	Large barren shrimp farm on right. Dikes and channels ~3m wide. *Nipa* beyond farm. To left, *Nipa* then small canal then more *Nipa*. **Photo 12-25** of shrimp farm.

December 7, 1997: Pakse/Bolavens Plateau, southern Laos.

Waypoint	Easting	Northing	Comments
-	-	-	**Photos 13-1** to **13-16** were taken around Pakse, but north (mostly outside) of the image; the cover near Pakse is similar
10-1	585764	1670980	**Photo 13-25-** at mouth of Se Don river looking across at forests; **Photo 13-26** looking east at the plateau in the distance. Took a boat from Pakse to Champasak and then drove to Wat Phou. Hills surrounding river densely forested flat-topped hills.
10-2	588367	1669262	Powerline crosses river, high towers, ~50m. ROW over Ph Saloa is scrubby, not distinct. Trees on either side of river, but only river banks are clearly visible
10-3	588921	1667674	Near bend in river, water/oil storage tanks visible and large tin roofed buildings on east bank of river (Phu Malong). Areas of trees with no leaves (deciduous ?) – e.g. south side of Phu Salao, patch at base of N side of Phu Malane – **Photo 13-28** of south Phu Salao
10-4	590072	1665461	Phu Malang (forested) on right, low mixed forest on left, small grassy areas and mixed forest.
10-5	592201	1663102	Small patch of flat rocks (mid-channel). Small willow covered flooded island near west side of river
10-6	592435	1662646	River narrows, becomes more turbulent. Small willow covered, flooded island near east bank, just south of waypoint 278. **Photo 13-29** of vegetation along bank, runs along both banks at most times
10-7	593280	1660286	Small village on west bank (scattered homes) with some dry crops visible. Just north of island (island mostly covered in trees) in west side of channel, island is mostly large boulder substrate, but some sand at margins.
10-8	593739	1658138	Many small islands (exposed or just with vegetation exposed) – treed west bank, some corn and banana on west bank.
10-9	594097	1656963	Small village on west side, homes in trees
10-10	594831	1655463	Banana and corn field with mixed trees (large) on west bank. To east, sandy island with grass, some crops and low shrubs
10-11	595946	1650141	Narrowing of river. Small island in middle is bare rock (flat). At north end of island is a small forest and grass. **Photo 13-30** of rice fields west of village road (taken from tuk-tuk) just one minute or so from Ban Phanon. **Photo 13-31** – past Champasak village and two bridges, shows table mountain with rice in foreground (rice on both sides, looking north). **Photos 14-1 to 14-6** panorama (north to south) of plain below Wat Phou, rice, small trees, fish ponds. Took a taxi back from Ban Moung to Pakse along Route 13. The highway is being improved by ADB. Trees have been cleared along approx. 100 metre wide strip. Villages and small towns, small industry spread out sporadically along highway. Plantation forest (teak) along both sides of road, some of the teak was mature (> 20 m tall). Some rice cultivation. Natural forest is visible on hills, 5-10 km distant
-	-	-	Drove towards the Bolavens plateau along route 23 to Pakxong through coffee plantations; just past turnoff to Pakxong, road is surrounded by uncultivated scrub with occasional big trees; .some large trees in small (approx. 250 m^2) plantations, mainly along north roadside; also some small plantation of small trees. A new major power-line (i.e., unstrung towers and ROW cleared) visible on right of road near Ban Nonsarat; many tall coffee plantation of different densities along road. **Photos 14-10 and 14-11** near km 29, power-line is near road. Near Lak 30 (km 30), power line crosses to left of road. Stopped at a viewpoint for Taat Phon waterfalls (a double waterfall).
11-1	621067	1678834	**Photos 14-12 to 14-15;** looking south. **Photo 14-16** looking north from other side of ridge at coffee on slope, mixed plantation, mostly coffee, but some other trees as well, fairly tall. We then drove back along route 23 to the junction of route 6/5 for approx. 50 km. Returned to Pakse by 6.00 p.m. Lak 42 powerline towers/ROW kiss road on left side. Power line ROW crosses road at 6 km to Pakxong sign (just before Lak 45). Entering Muong Pakxong, flat lots of cleared or grassy land on both sides of road. **Photos 14-17 to 14-23** taken just west of Ph. Thevada. Landscape is scrubby to right, grass with young pine (very small trees on left). Powerline still to right of road at a distance of approx. 50 m. Terrain opens to grassy plain with some

Waypoint	Easting	Northing	Comments
			pine plantation near the road.
11-2	638691	1677703	**Photos 14-24 and 14-25**). Pine plantation stops after approx. 500 m, at least another 1-2 km of grassland beyond
11-3	623684	1680027	looking SW at "entrance" to plateau. **Photo 14-26** just east of Lak 40. On road north towards Saravan, just past turnoff are grasslands with forest and coffee and then scrubby forest and coffee (2nd growth?). Lots of banana plantations just north of Lao Ngam (may be visible in image?). **Photos 14-29 and 14-30** outside Pakse, the side of a hill north of the road with leafless (deciduous?) trees

December 8-9, 1997: Phonsavan area, Plain of Jars, northern Laos.

Waypoint	Easting	Northing	Comments
-	-	-	Plain of Jars consists mostly of gently rolling, hilly grassland; gullies along the road were mostly under wetland cultivation (rice); steep hills surround the plain which had widespread evidence of large-scale bombing. Unsafe to go off-road because of UXO, so drove 50 km along Route 4 to Muang Khun (formerly the old capital Xieng Khouang, before it was destroyed in the war), and stopped at jar site #3. Also drove to jar site #1, then east along route 7 as far as Muang Kham. **Photo 15-17 to 15-25, photos 16-1 and 16-2** are a panorama from south to northeast from the ridge at Auberge guesthouse showing all of Phonsavan and surrounding hills.
12-1	328803	2137930	At Muang Khun, former capital of Xieng Khouang province. Destroyed during the war by extremely heavy bombing. **Photos 15-1 to 15-8** of road to village, at village, and land use along route 4 back toward Phonsavan.
12-2	303697	2135162	At Jar site#3. Photos **15-8 to 15-16** of land use along route to and from site.
12-3			At Auberge guesthouse. **Photos 16-3 to 16-11** are a 360 degree panorama from south to south clockwise.
12-4	306305	2149611	At Jar site#1. **Photo 16-12** looking NW from a hill just south of jars at Site 1. Rice visible in gully, surrounded by bare fields and young eucalyptus trees
12-5	305020	2149371	Muang Kham village along Route 7

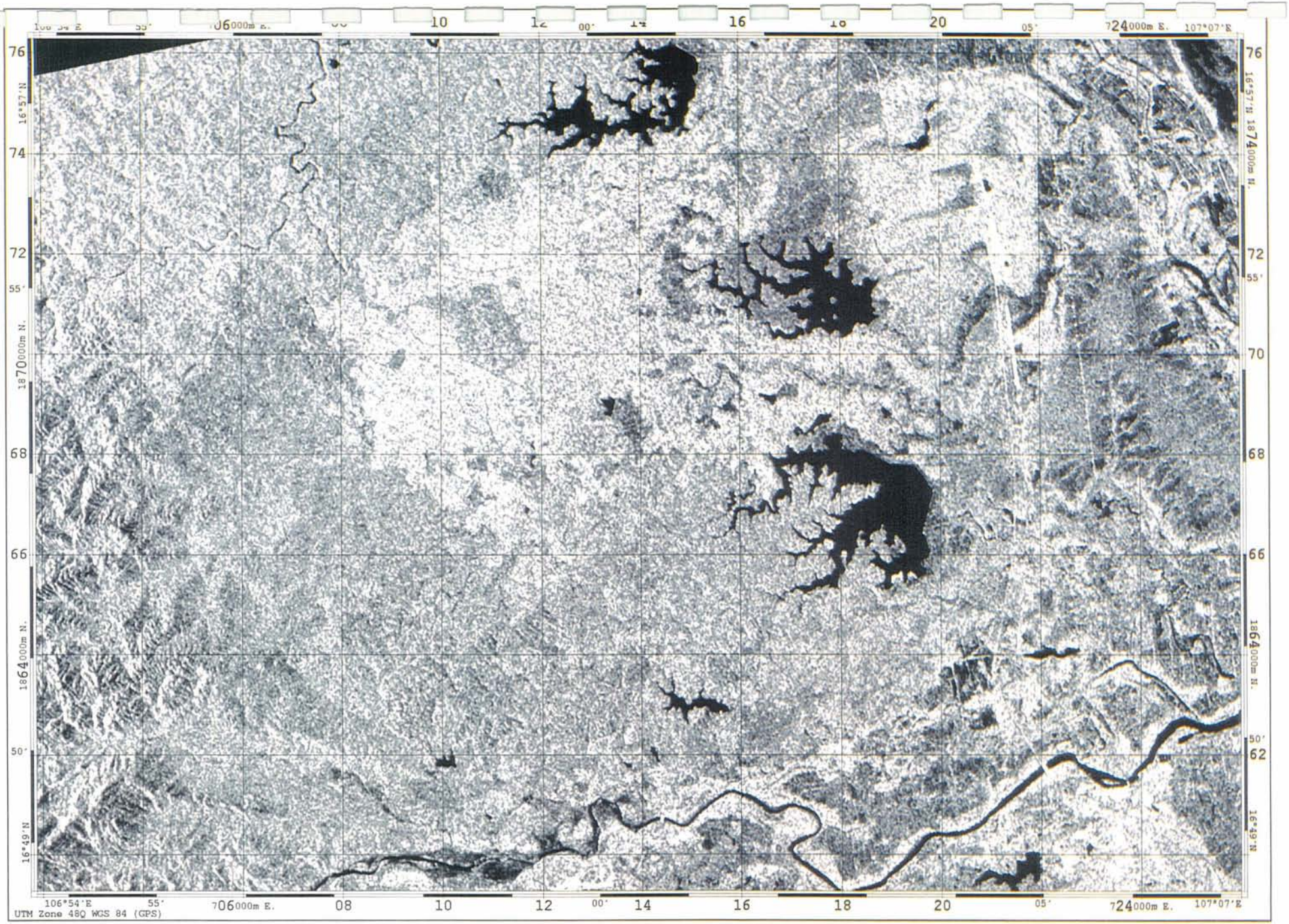
Appendix A2

Supporting Remote Sensing Imagery

APPENDIX A2 SUPPORTING REMOTE SENSING IMAGERY

Area Coverage	Image Type and Date	Scale
Dong Ha, Central Viet Nam	S7 (13-01-97)	1:100,000
Dong Ha, Central Viet Nam	S7 (21-11-97)	1:100,000
Khe Sanh, Central Viet Nam	S7 (13-01-97)	1:100,000
Khe Sanh, Central Viet Nam	S7 (21-11-97)	1:100,000
Overview, Quang Tri Province and former DMZ, Central Viet Nam	S7 (13-01-97)	1:250,000
A Luoi Valley, Central Viet Nam	S7 (13-01-97)	1:250,000
A Luoi, Central Viet Nam	S7 (21-11-97)	1:250,000
Hue, Central Viet Nam	S4 (12-08-96)	1:77,000
Hue, Central Viet Nam	F4 (29-08-96)	1:77,000
Da Nang, Central Viet Nam	S7 (31-07-97)	1:250,000
Da Nang, Central Viet Nam	S7 (04-11-97)	1:250,000
Overview, Ma Da Upland Forest, Viet Nam	S7 (15-08-96)	1:250,000
Ma Da Upland Forest, Viet Nam	S7 (15-08-96) + F5 (10-08-97)	1:100,000
Overview, Rung Sat Mangrove Forest, Southern Viet Nam	F4 (07-08-96)	1:250,000
Overview, Rung Sat Mangrove Forest, Southern Viet Nam	F5 (03-09-97)	1:250,000
Rung Sat Mangrove Forest, Southern Viet Nam	F4 (07-08-96)	1:70,000
Rung Sat Mangrove Forest, Southern Viet Nam	F5 (03-09-97)	1:70,000
Rung Sat Mangrove Forest, Southern Viet Nam	F4 (07-08-96)	1:70,000
Rung Sat Mangrove Forest, Southern Viet Nam	F5 (03-09-97)	1:70,000
Overview, Ca Mau Peninsula, Southern Viet Nam	S7 (19-08-97)	1:250,000
Overview, Ca Mau Peninsula, Southern Viet Nam	S7 (23-11-97)	1:250,000
Detail, Ca Mau Peninsula, Southern Viet Nam	S7 (19-08-97)	1:100,000
Detail, Ca Mau Peninsula, Southern Viet Nam	S7 (23-11-97)	1:100,000
Overview, Pakse and Bolavens Plateau, Lao PDR	S7 (22-12-96)	1:250,000
Overview, Pakse and Bolavens Plateau, Lao PDR	S7 (26-07-97)	1:250,000
Plain of Jars, Lao PDR	F2 (03-08-97)	1:70,000

These remote sensing images are included in electronic format in the CD-ROM bundled with this document.



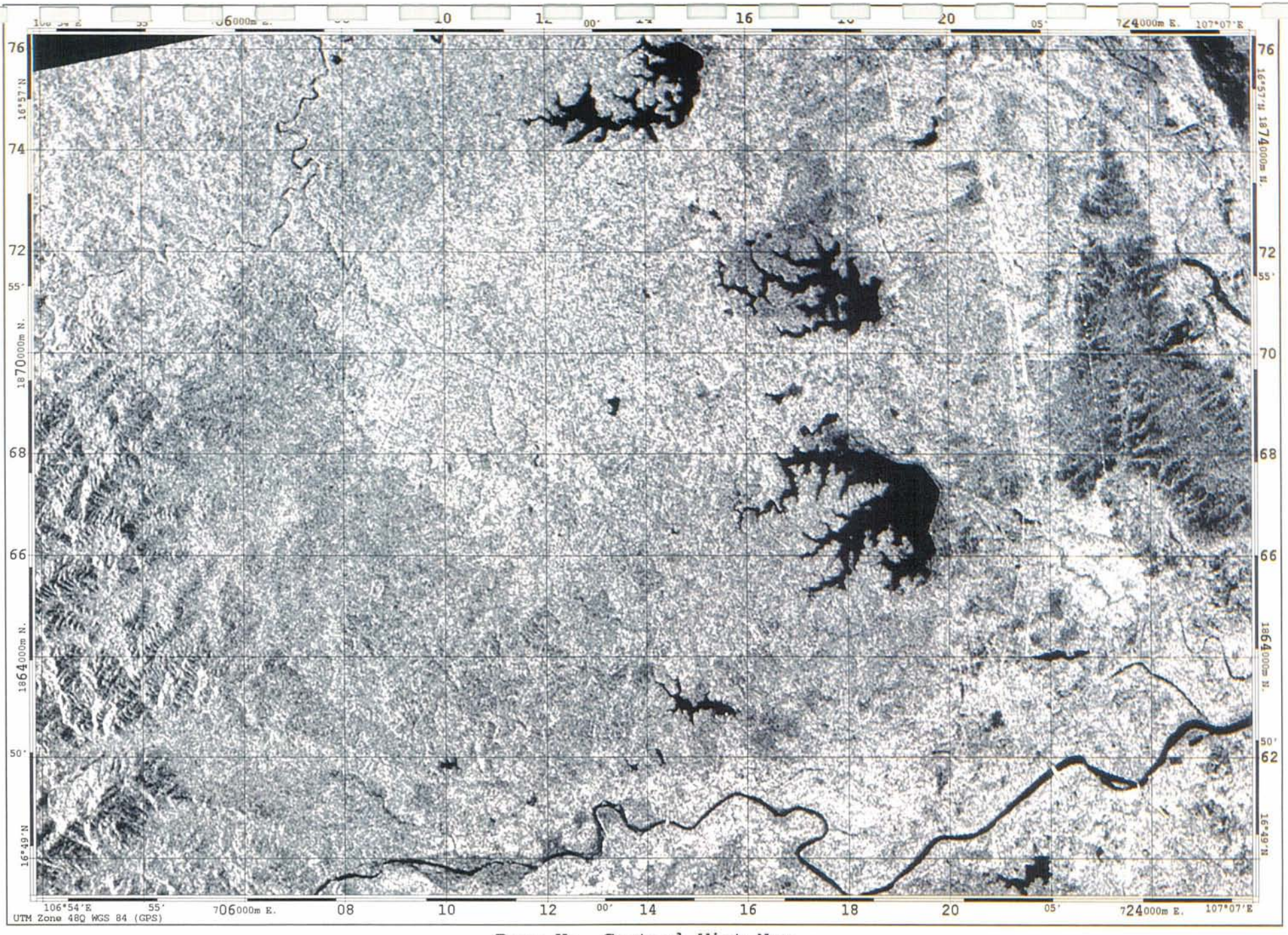
Dong Ha, Central Viet Nam

RADARSAT STANDARD MODE (S7), 13-January-1997

1:100 000 Scale

Kilometres 1 0 1 2 3 4 5 6 7

Miles 1 0 1 2 3 4 5



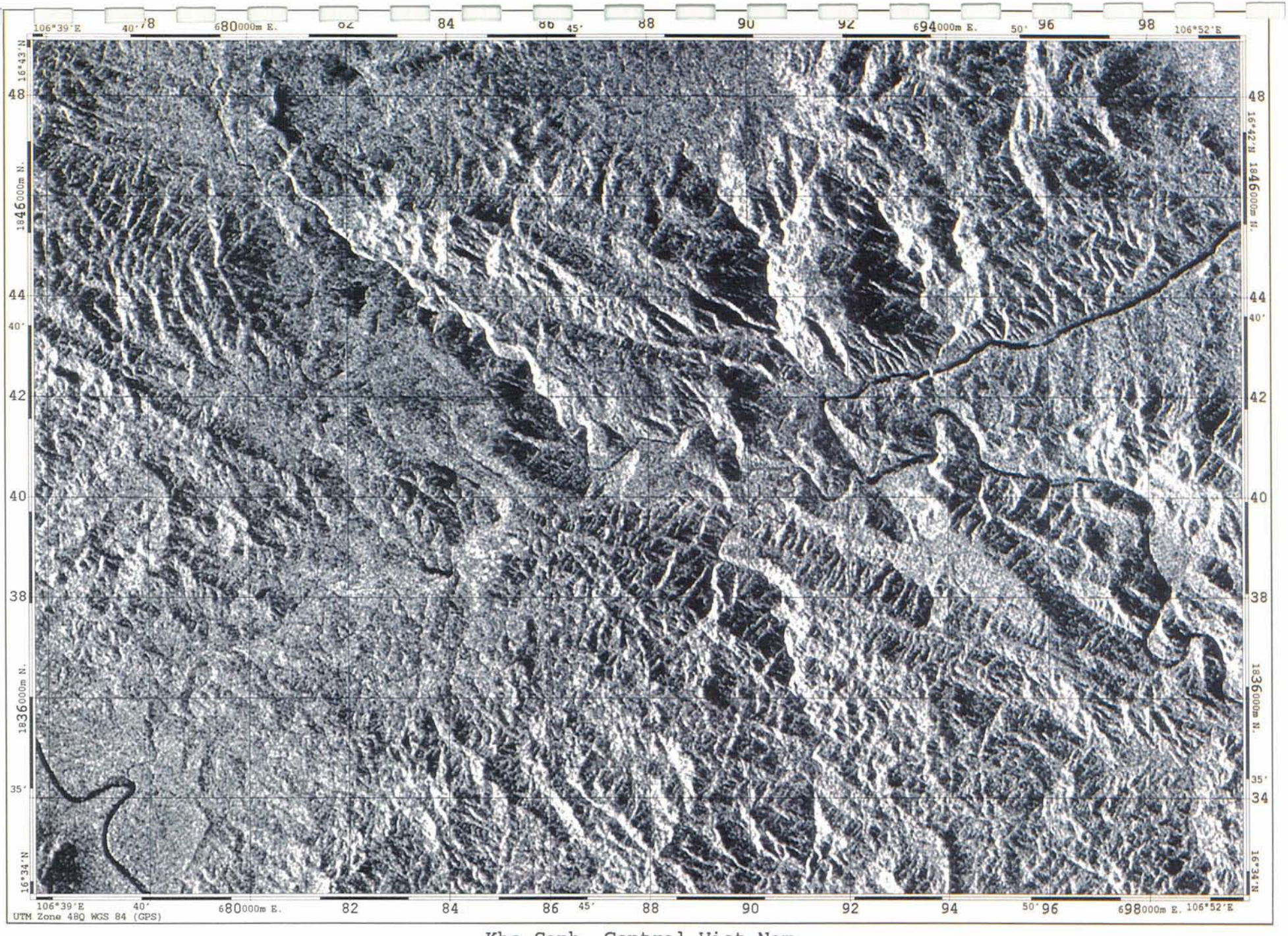
Dong Ha, Central Viet Nam

RADARSAT STANDARD MODE (S7), 21-November-1997

1:100 000 Scale

Kilometres 1 0 1 2 3 4 5 6 7

Miles 1 0 1 2 3 4 5



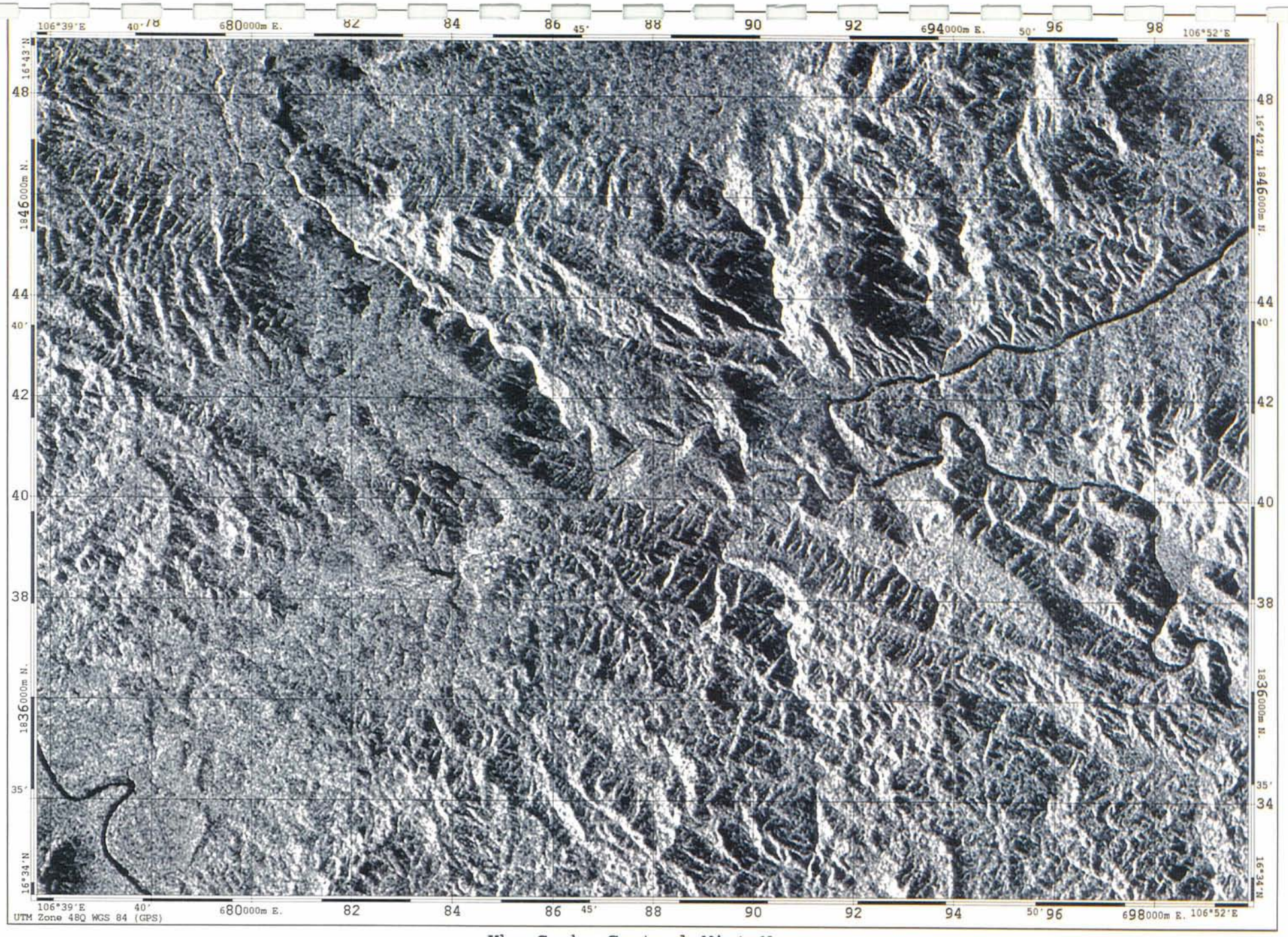
Khe Sanh, Central Viet Nam

RADARSAT STANDARD MODE (S7), 13-January-1997

1:100 000 Scale

Kilometres 1 0 1 2 3 4 5 6 7

Miles 1 0 1 2 3 4 5



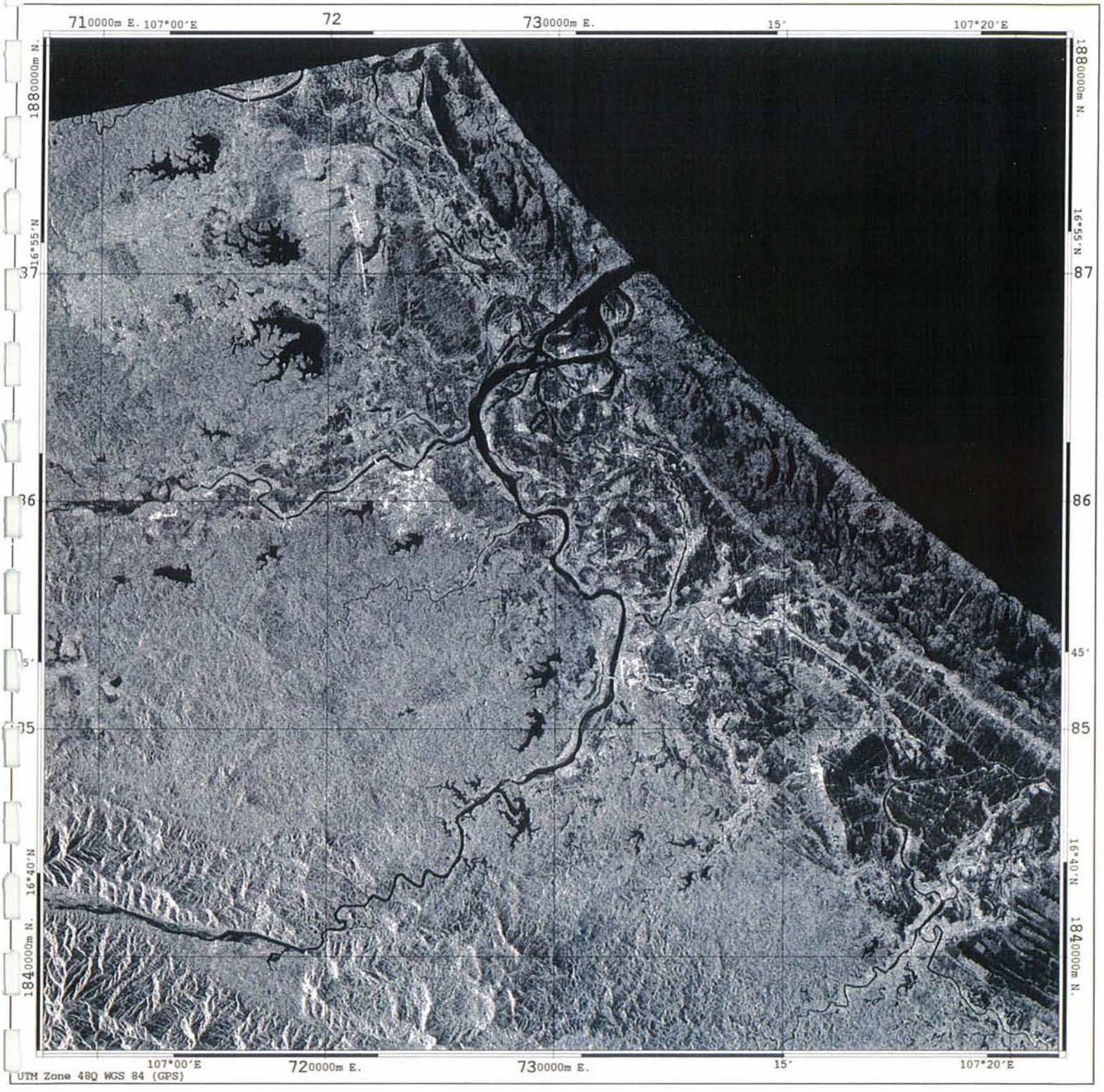
Khe Sanh, Central Viet Nam

RADARSAT STANDARD MODE (S7), 21-November-1997

1:100 000 Scale

Kilometres 1 0 1 2 3 4 5 6 7

Miles 1 0 1 2 3 4 5



Overview, Quang Tri Province and former DMZ, Central Viet Nam

RADARSAT STANDARD MODE (S7), 13-January-1997

1:250 000 Scale

Kilometres 10 0 10

Miles 10 0 10

A Luoi, Central Viet Nam

RADARSAT STANDARD MODE (S7), 13-January-1997

1:250 000 Scale

Kilometres 10 0 10

Miles 10 0 10

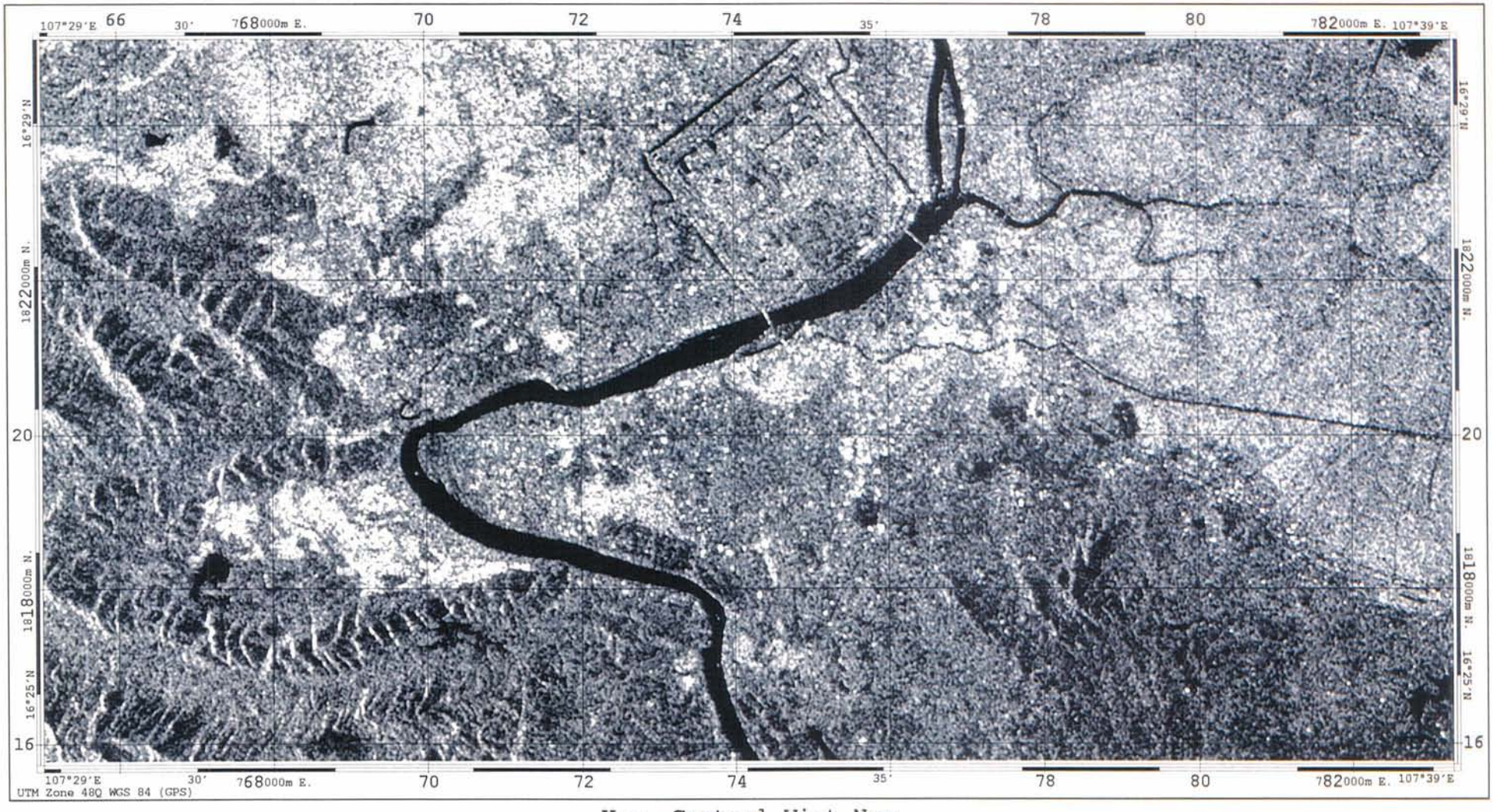
A Luoi, Central Viet Nam

RADARSAT STANDARD MODE (S7), 21-November-1997

1:250 000 Scale

Kilometres 10 0 10

Miles 10 0 10



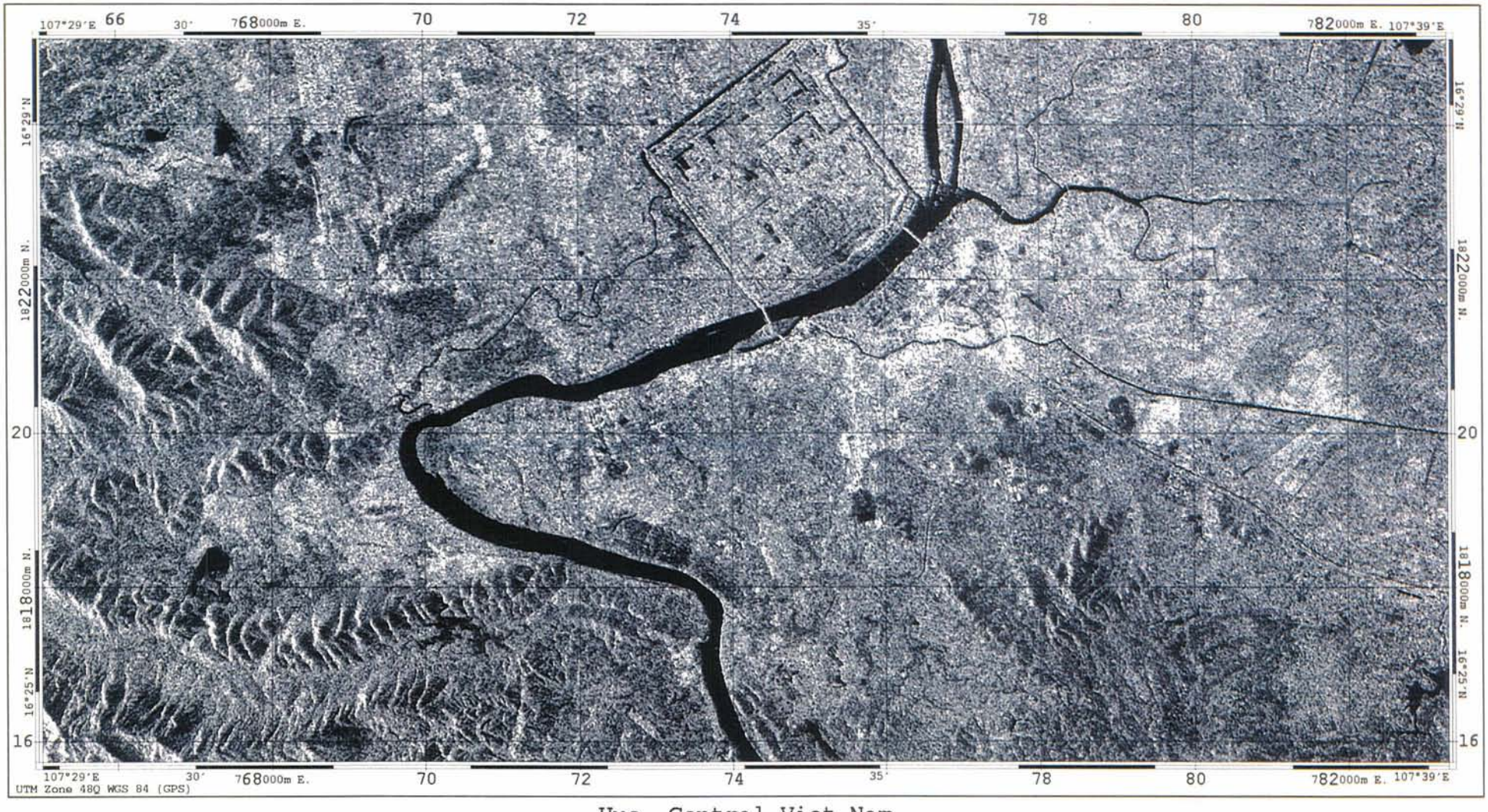
Hue, Central Viet Nam

RADARSAT STANDARD MODE (S4), 12-August-1996

1:77 000 Scale

Kilometres 1 0 1 2 3 4 5 6

Miles 1 0 1 2 3



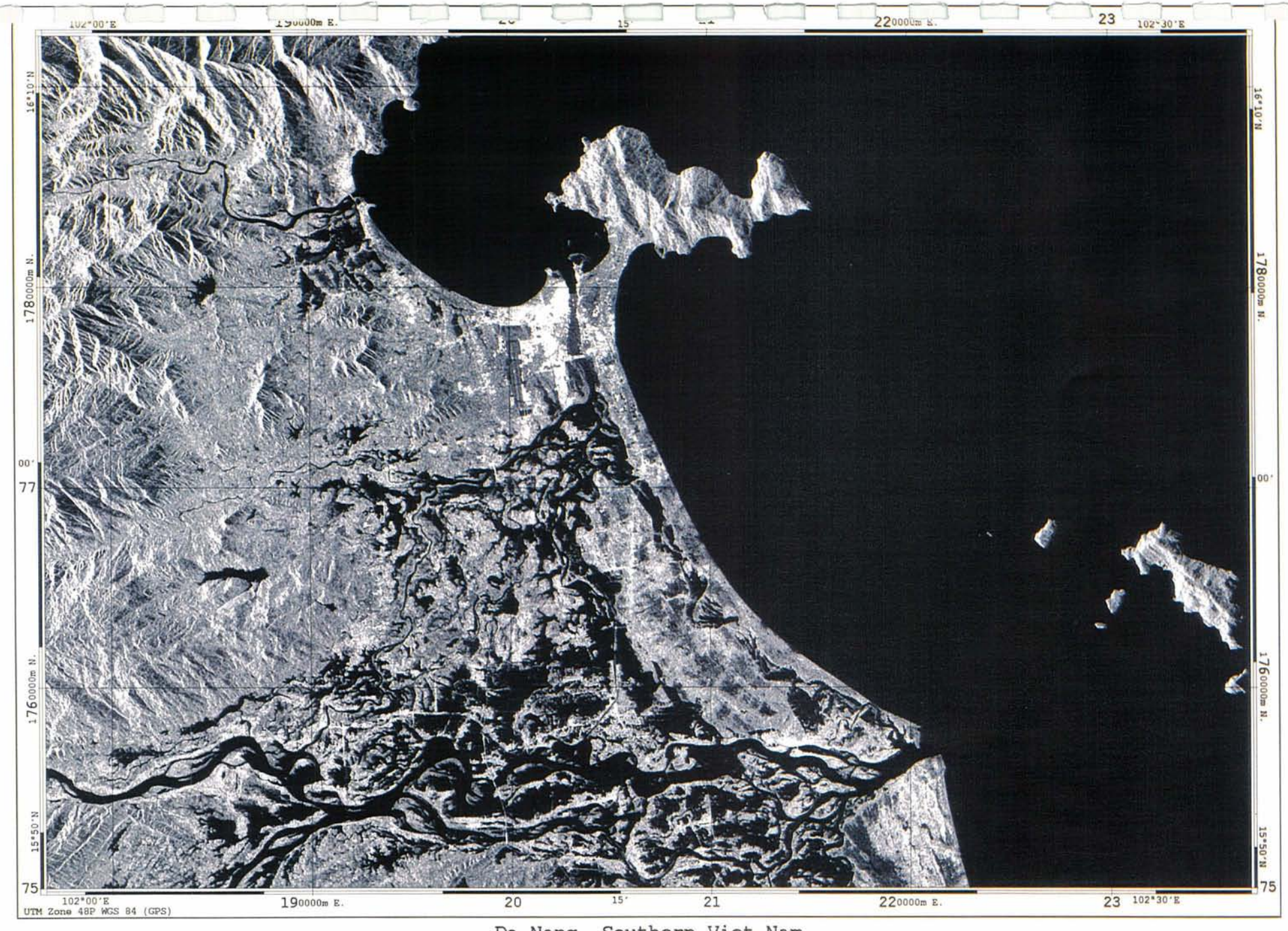
Hue, Central Viet Nam

RADARSAT FINE MODE (F4), 29-August-1996

1:77 000 Scale

Kilometres 1 0 1 2 3 4 5 6

Miles 1 0 1 2 3



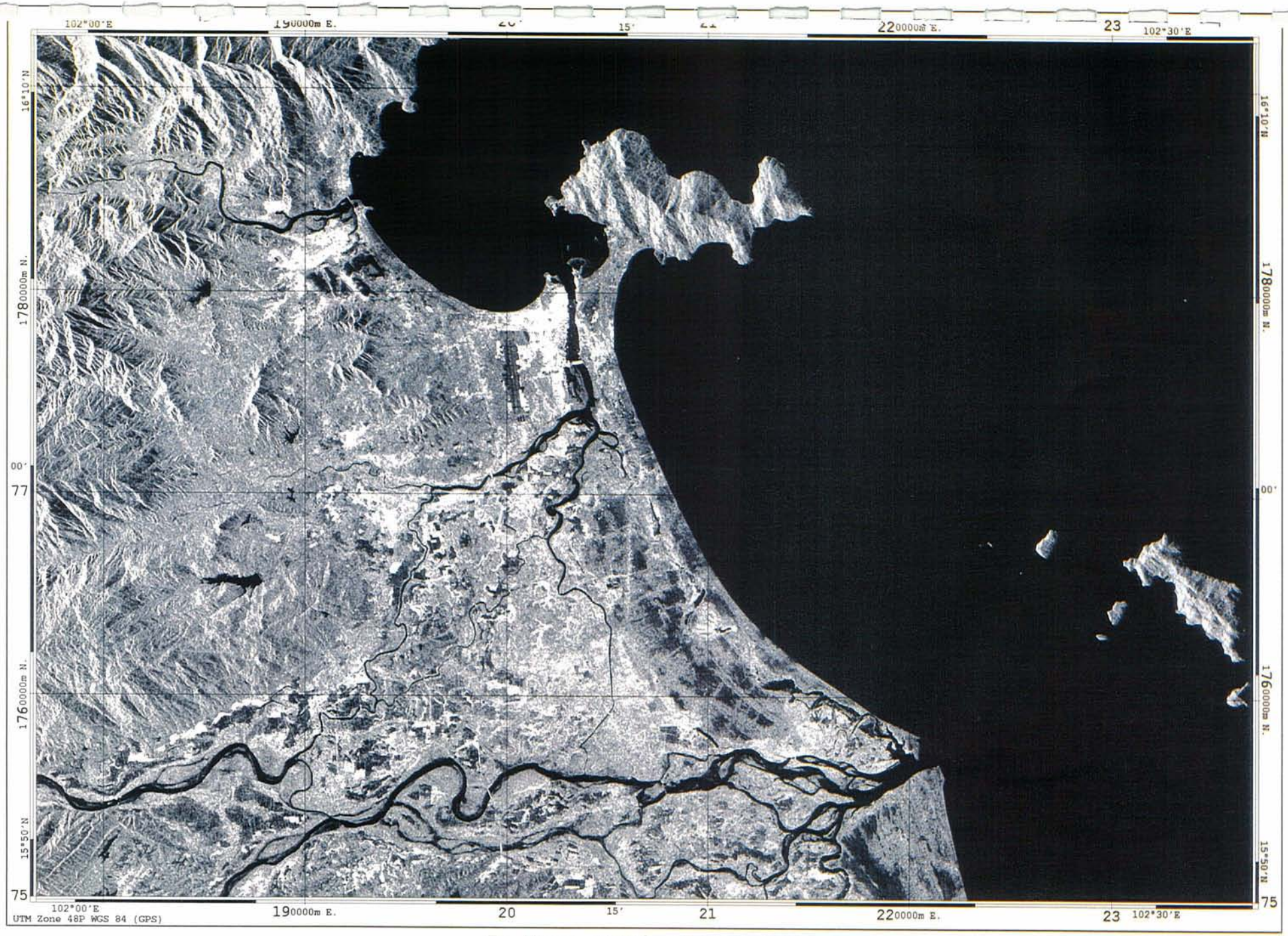
Da Nang, Southern Viet Nam

RADARSAT STANDARD MODE (S7), 31-July-1997

1:250 000 Scale

Kilometres 10 0 10

Miles 10 0 10



Da Nang, Southern Viet Nam

RADARSAT STANDARD MODE (S7), 4-November-1997

1:250 000 Scale

Kilometres 10 0 10

Miles 10 0 10

Ma Da Upland Forest, Viet Nam

RADARSAT S7/F5-S7-F5, 15-August-96 (S7) and 10-August-97 (F5)

1:100 000 Scale

Kilometres 1 0 1 2 3 4 5 6 7

Miles 1 0 1 2 3 4 5

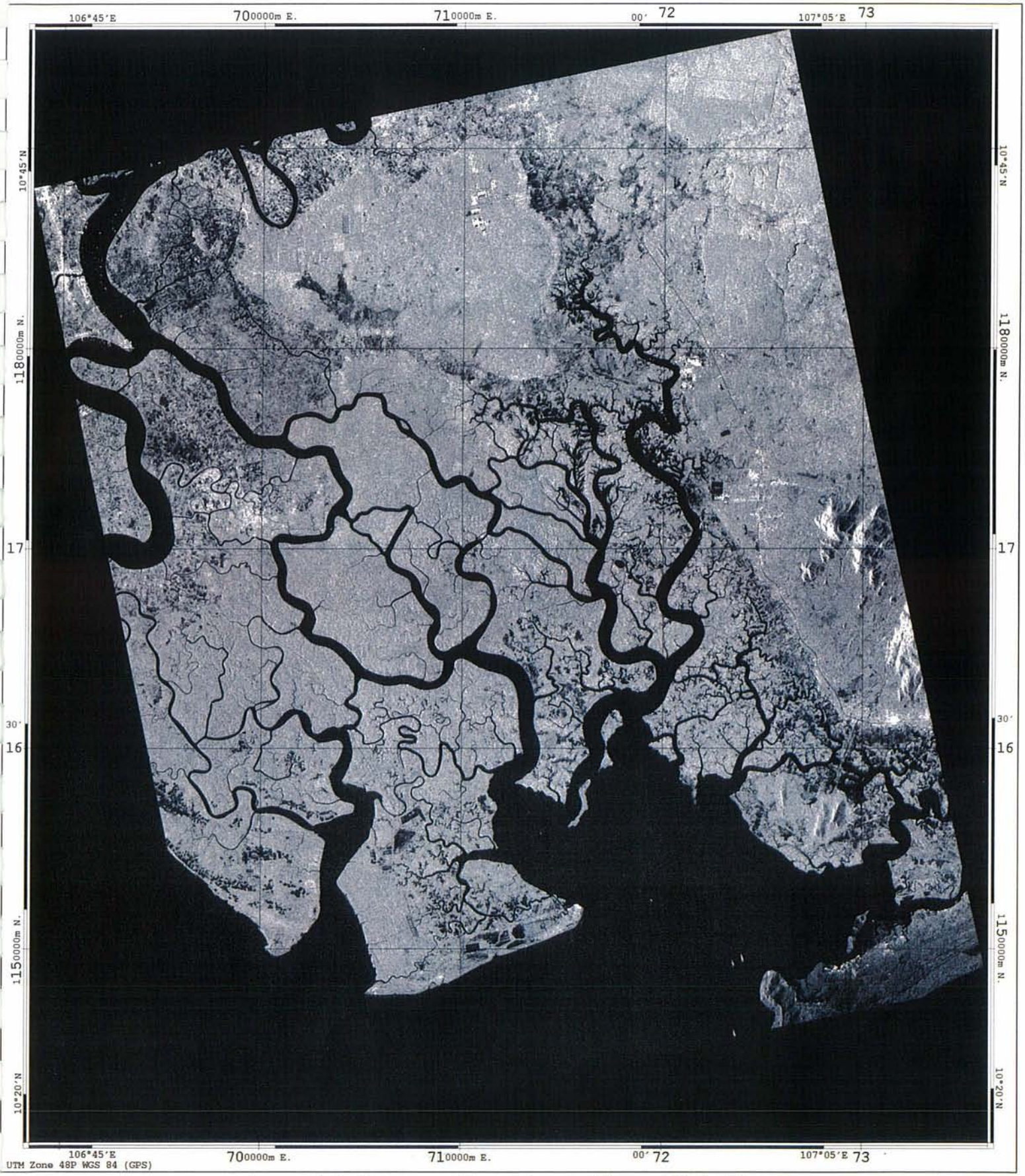
Overview, Rung Sat Mangrove Forest, Southern Viet Nam

RADARSAT FINE MODE (F4), 7-August-1996

1:250 000 Scale

Kilometres 10 0 10

Miles 10 0 10



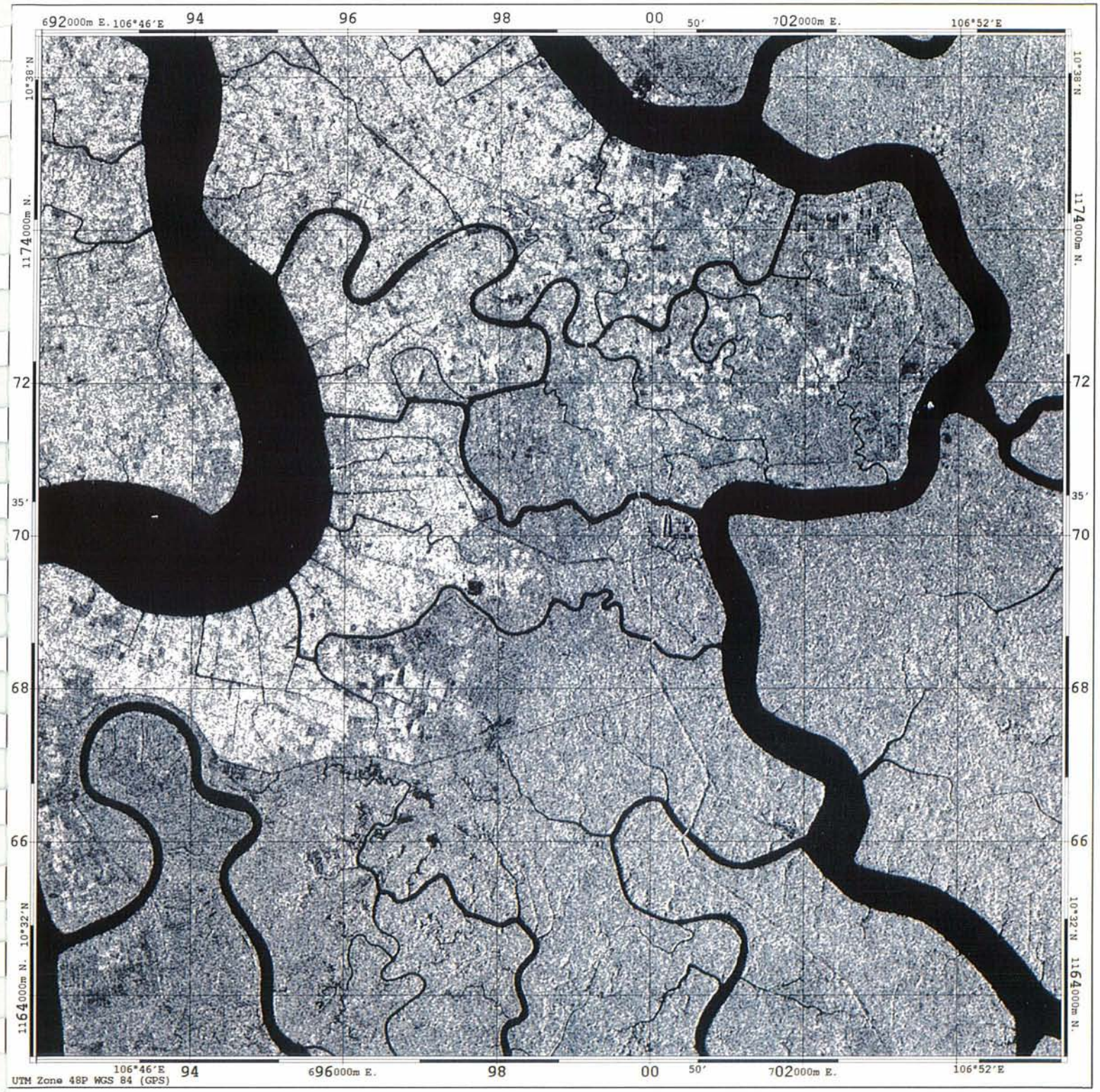
Rung Sat Mangrove Forest, Southern Viet Nam

RADARSAT FINE MODE (F5), 3-September-1997

1:250 000 Scale

Kilometres 10 0 10

Miles 10 0 10



Rung Sat Mangrove Forest, Southern Viet Nam

RADARSAT FINE MODE (F4), 7-August-1996

1:70 000 Scale

Kilometres 1 0 1 2 3 4 5 6

Miles 1 0 1 2 3

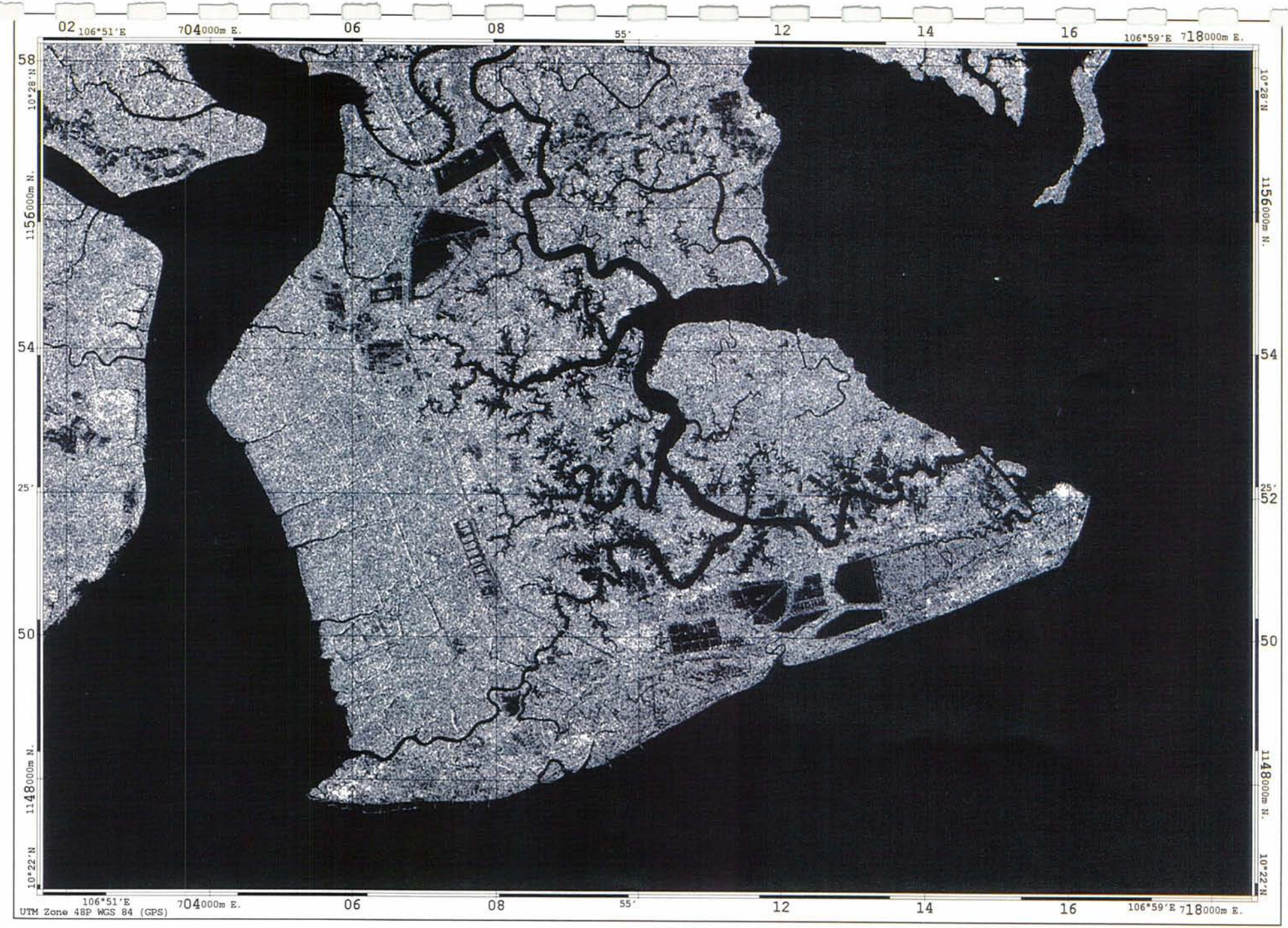
Rung Sat Mangrove Forest, Southern Viet Nam

RADARSAT FINE MODE (F5), 3-September-1997

1:70 000 Scale

Kilometres 1 0 1 2 3 4 5 6

Miles 1 0 1 2 3



Rung Sat Mangrove Forest, Southern Viet Nam

RADARSAT FINE MODE (F4), 7-August-1996

1:70 000 Scale

Kilometres 1 0 1 2 3 4 5 6

Miles 1 0 1 2 3

Rung Sat Mangrove Forest, Southern Viet Nam

RADARSAT FINE MODE (F5), 3-September-1997

1:70 000 Scale

Kilometres 1 0 1 2 3 4 5 6

Miles 1 0 1 2 3

Overview, Ca Mau Peninsula, Southern Viet Nam

RADARSAT STANDARD MODE (S7), 19-August-1997

1:250 000 Scale

Kilometres 10 0 10

Miles 10 0 10

Overview, Ca Mau Peninsula, Southern Viet Nam

RADARSAT STANDARD MODE (S7), 23-November-1997

1:250 000 Scale

Kilometres 10 0 10

Miles 10 0 10

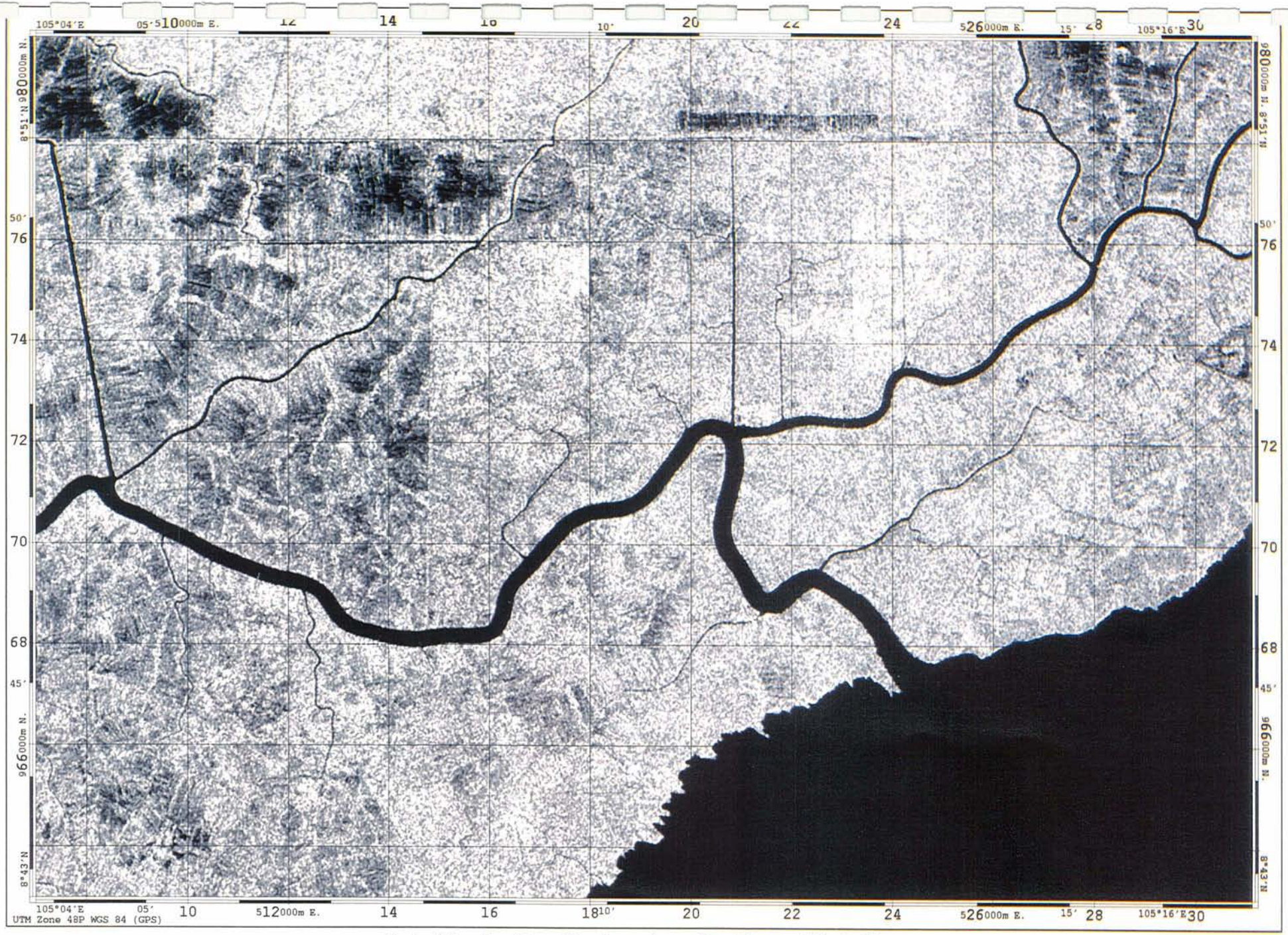
Detail, Ca Mau Peninsula, Southern Viet Nam

RADARSAT STANDARD MODE (S7), 19-August-1997

1:100 000 Scale

Kilometres 1 0 1 2 3 4 5 6 7

Miles 1 0 1 2 3 4 5



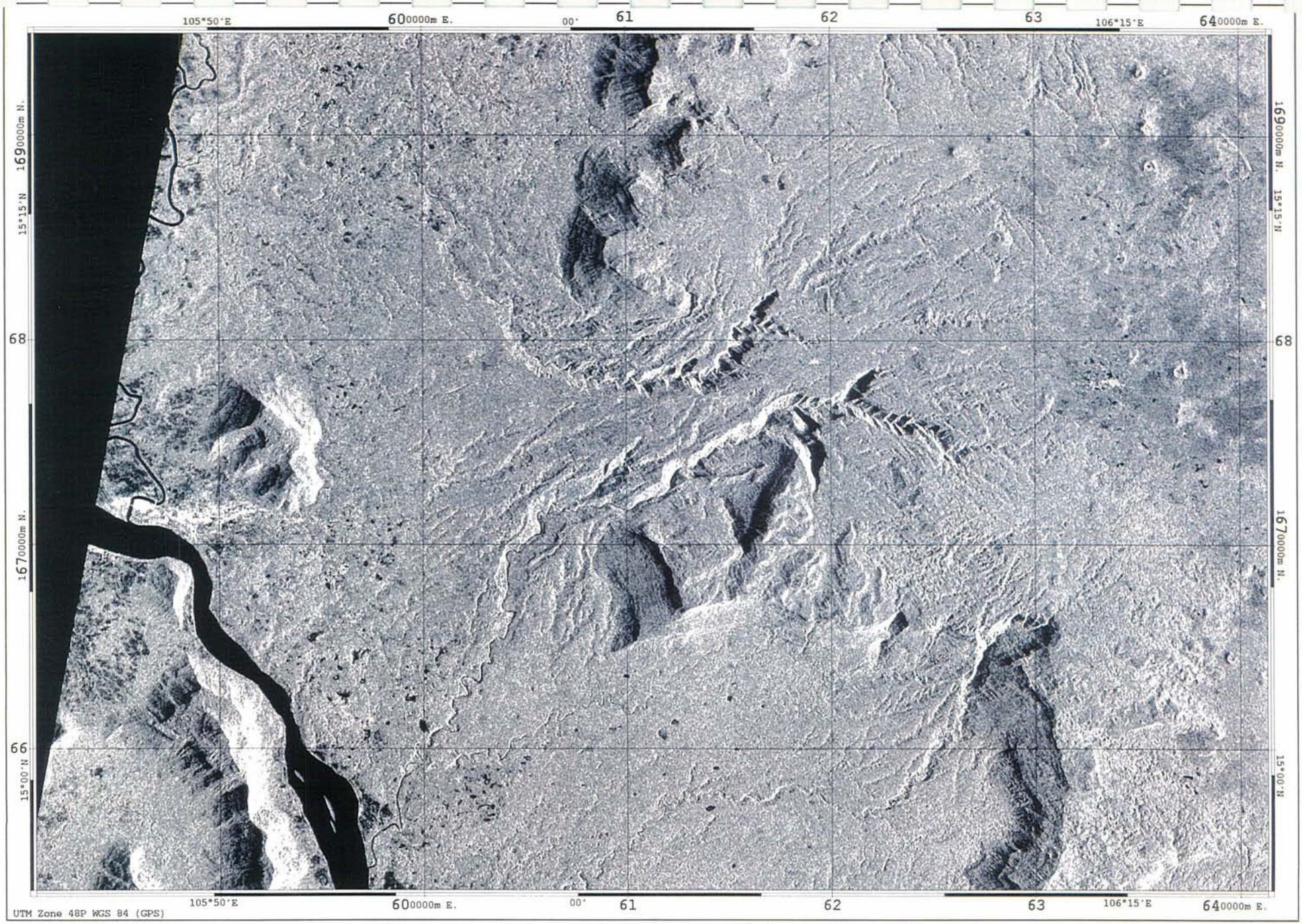
Detail, Ca Mau Peninsula, Southern Viet Nam

RADARSAT STANDARD MODE (S7), 23-November-1997

1:100 000 Scale

Kilometres 1 0 1 2 3 4 5 6 7

Miles 1 0 1 2 3 4 5



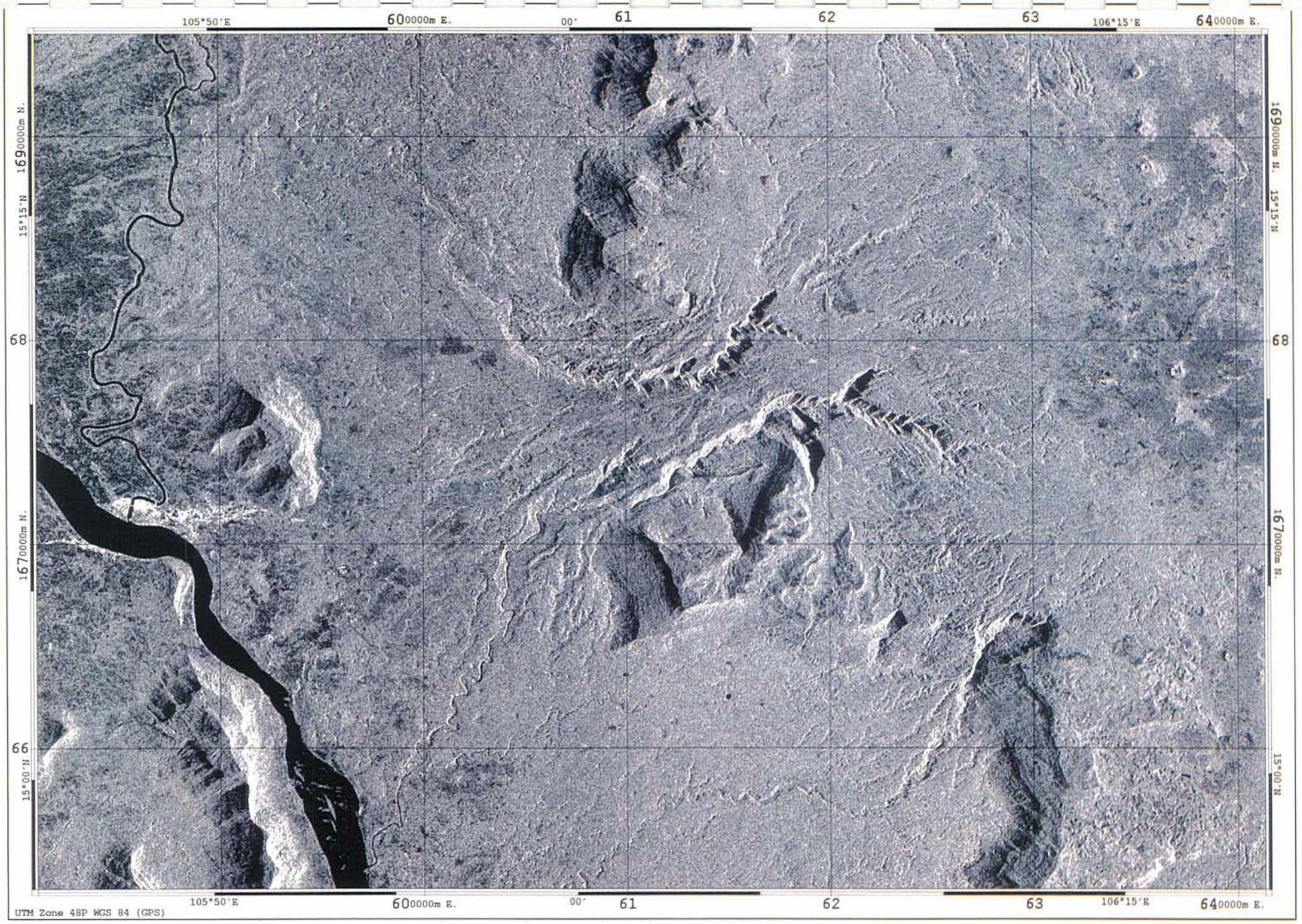
Overview, Pakse and Bolavens Plateau, Lao PDR

RADARSAT STANDARD MODE (S7), 22-December-1996

1:250 000 Scale

Kilometres 10 0 10

Miles 10 0 10



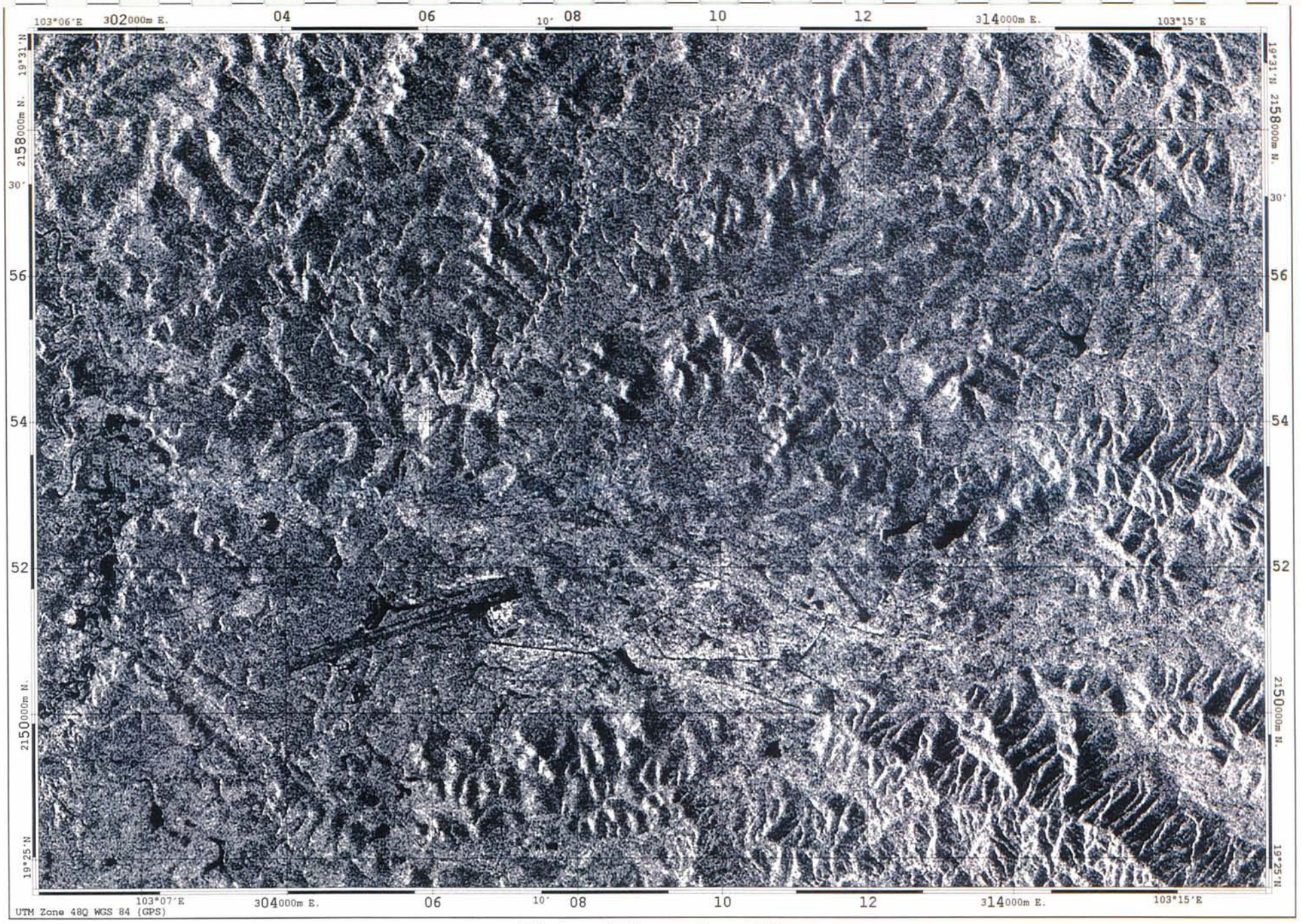
Overview, Pakse and Bolavens Plateau, Lao PDR

RADARSAT STANDARD MODE (S7), 26-July-1997

1:250 000 Scale

Kilometres 10 0 10

Miles 10 0 10



Plain of Jars, Lao PDR

RADARSAT FINE MODE (F2), 3-August-1997

1:70 000 Scale

Kilometres 1 0 1 2 3 4 5 6

Miles 1 0 1 2 3