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# STUDIES OF IMAGES OF SHORT-LIVED EVENTS USING ERTS DATA

Contract NAS 5-21858

Final Report

For the period September 18, 1972, to February 28, 1974



Principal Investigator
Dr. William A. Deutschman

April 1974



Prepared for

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

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15. Supplementary Notes

16. Abstracts

We report on the results obtained from the study of 19 short-lived events reported by the Center for Short-Lived Phenomena taken by the Earth Resources Technology Satellite. We report techniques for studying the events and representative detection criteria. We conclude that the ERTS images are a valuable tool in the study of these events.

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## PREFACE

The object of this program was to determine the feasibility of observing short-lived events with the ERTS satellite and to establish event-detection criteria applicable to different categories of events. Of the 222 events we evaluated, we decided that 53 of them might be detected by the ERTS sensors. Nineteen were subsequently photographed by ERTS and studied by us. We conclude from this program that ERTS photographs are a useful and economical way for individual investigators to obtain data about short-lived events. Larger events can be detected on the photographs without knowledge of their exact location. If the general area is known in which an event (e.g., a remote volcano, flood, or vegetation change) is expected to occur, the ERTS photograph can be used to determine if it actually did occur. Small-sized events can be studied if their location is known. Furthermore, from images of the events, we have received useful scientific data that cannot otherwise be easily obtained.

We recommend that ERTS continue to study short-lived events. Furthermore, complete cloud-free coverage of the earth surface should be obtained for all seasons so that images taken before an event will be available. Future satellites should have a high-resolution, pointable camera in order that several-day coverage of an event is possible.

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## 1. INTRODUCTION

The Smithsonian Astrophysical Observatory (SAO), in conjunction with the Center for Short-Lived Phenomena (CSLP), undertook a joint program to study short-lived environmental events with images from the Earth Resources Technology Satellite (ERTS). Our program had three goals: to notify the ERTS project of events that could be observed by ERTS so the satellite could obtain pictures of them; to study pictures of events to determine which classes of events could be detected, what information could be obtained, and what techniques were best suited to analyzing the images; and to study the feasibility of using ERTS data to detect short-lived events in areas that had few or no correspondents reporting to CSLP. This report discusses the results that we obtained by studying 19 of the more than 200 events reported by CSLP during the course of this contract.

## 2. EVENT STATISTICS

During the project, we evaluated 222 events reported by the Center for Short-Lived Phenomena. The events were classified into three types:

A. Minor events, which probably could not be detected with the ERTS sensors.

B. Routine events, which could be detected with the ERTS sensors but were of average scientific interest.

C. Major events, which were of such scale and importance that requests for ERTS data were immediately relayed to the ERTS scheduling office.

One hundred sixty-nine events were classified as type A for one of two reasons: The event was several months old because of slow reporting from the field, and hence all detectable features had disappeared; or the event was obviously too small to be detected by the ERTS sensors. We did, however, study several of these event areas after the fact to ensure that our expected threshold for event detection was adequate. The 48 routine events for which we requested ERTS images are listed in Table 1. The five major events that occurred during the program were as follows:

| Event Name | Date |
|---|---|
| Piton De La Fournaise Volcanic Eruption | October 12, 1972 |
| Typhoon Bebe and Funafuti Storm Ridge | October 21, 1972 |
| Managua Earthquake | December 23, 1972 |
| Western Szechwan Earthquake | February 6, 1973 |
| Asama Volcanic Eruption | February 7, 1973 |

Several events that would have been classified as major events were placed in the routine category if they occurred in the normal U.S. coverage zone. We did this since we knew pictures would be taken anyway and did not want to burden the system with unnecessary requests for coverage.

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Table 1. Events for which ERTS coverage was requested.

| Event No. | Event Name |
|---|---|
| 1 | Alaid Volcanic Eruption |
| 2 | Transandean Pipeline Oil Spill |
| 3 | Pah River Forest Fire |
| 4 | Spanish Olive Fly Insect Plague |
| 5 | Spanish Grouse Extermination |
| 6 | Pennsylvania Martin Bird Mortality |
| 7 | Tanker "Tamano" Oil Spill |
| 8 | Sitka Earthquake |
| 9 | New Ireland Earthquake |
| 10 | Bear Forest Fire |
| 11 | Vanikoro Island Earthquake |
| 12 | African Snail Infestation |
| 13 | Massachusetts Red Tide |
| 14 | "Republica de Colombia" Oil Spill |
| 15 | Karthala Volcanic Eruption |
| 16 | "Texanita" Oil Spill |
| 17 | Banda Sea Earthquake |
| 18 | Sakurazima Volcanic Eruption |
| 19 | Anak Krakatau Volcanic Eruption |
| 20 | Bad Schandau Earth Flow |
| 21 | Salem, Massachusetts, Oil Spill |
| 22 | Meuse Valley Toxic Gas Emission |
| 23 | Mt. Merapi Volcanic Eruption |
| 24 | Miami Palms "Lethal Yellowing" |
| 25 | Great Lakes Flooding |
| 26 | Florida Red Tide |
| 27 | San Juan Oil Spill |
| 28 | Big Sur Mud Slide |
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| 30 | Somalia Cyclone Storm Damage |
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| 32 | Ritter Island Volcanic Eruption |
| 33 | Atlantic Oil Spill |
| 34 | Cimarron River Oil Spill |
| 35 | Funafuti Storm Beach |
| 36 | Acatenango Volcanic Eruption |
| 37 | Ochrup Oil Spill |
| 38 | Pacaya Volcanic Eruption |
| 39 | Mississippi River Oil Spill |
| 40 | Vestmannaeyjar Volcanic Eruption |
| 41 | Oakland Estuary Oil Spill |
| 42 | "Irish Stardust" Oil Spill |
| 43 | Fuego Volcanic Eruption |
| 44 | Lake Ripley Oil Spill |
| 45 | Missouri–Mississippi Floods |
| 46 | Williamsburg Natural-Gas Escape |
| 47 | Morganza Floodway Opening |
| 48 | Kilauea Volcanic Eruption |

The entire 222 events evaluated are also divided into 10 categories. Table 2 lists the categories of events, the number of events that occurred during the course of the program (evaluated), and the actual number of events for which we received pictures (studied).

The division between U.S. and non-U.S. events for the events we attempted to study is shown in Table 3.

Table 2. Number of events evaluated and studied, by event category.

| Event Category | Events Evaluated | Events Studied |
|---|---|---|
| Major Vegetation Changes | 7 | 1 |
| Forest Fires | 3 | 2 |
| Insect Plagues | 0 | 0 |
| Floods | 8 | 2 |
| Volcanoes | 21 | 8 |
| Landslides | 40 | 1 |
| New Islands | 1 | 1 |
| Storm Effects | 4 | 0 |
| Oil Spills | 39 | 2 |
| Other | 99 | 2 |

Table 3. Division of routine and major events between U.S. coverage and non-U.S. coverage.

Evaluated 222 CSLP Event Notification Reports

Issued 53 Event Notification Reports:

- 22 U.S. Events
- 31 Non-U.S. Events

Received Data for 19 Events:

- 7 U.S. Events
- 12 Non-U.S. Events

## 3. A SAMPLE OF EVENTS STUDIED

In this section, we discuss some of the events studied in detail. Four categories of events – fires, oil spills, volcanoes, and storm effects – have been chosen to illustrate different types of short-lived events and different techniques used to analyze them. The information obtained from these events and some conclusions about their detectability are also included. On the whole, we find ERTS images very useful for studying short-lived events. The techniques mentioned here for detecting these and other events will be discussed in Section 4.

### 3.1 Alaska Fires

Seven fires in Alaska along the Kayukuk River between 151° and 156° West longitude and 66° and 67° North latitude were studied to determine the detectability of fires in Arctic tundra regions. The general nature of the terrain was tundra forested with white spruce along the creeks and mixed with birch and aspen along the lower slopes. One fire, the Pah River fire, was burning on the first ERTS pass (see Figure 1) but had stopped by the final ERTS pass studied. The fires ranged in size from a few thousand to 250,000 acres. The ages of the burned areas were from 0 to 3 years. This region gave us the chance to study the detection criteria for fire, how well fires could be separated from the surrounding vegetation, and the time scale before new vegetation covered the burned areas.

We used both digital mapping and direct enlargement to determine the size of the burned area. Several of the fire areas were digitized on the microphotometer. The resolution of the digitizing spot was slightly less than four picture-resolution elements and hence is slightly degraded, but it is still adequate for these studies. Decision plots based on the density in spectral band 5 (0.6 to 0.7 micrometers) versus that in spectral band 7 (0.8 to 1.1 micrometers) were

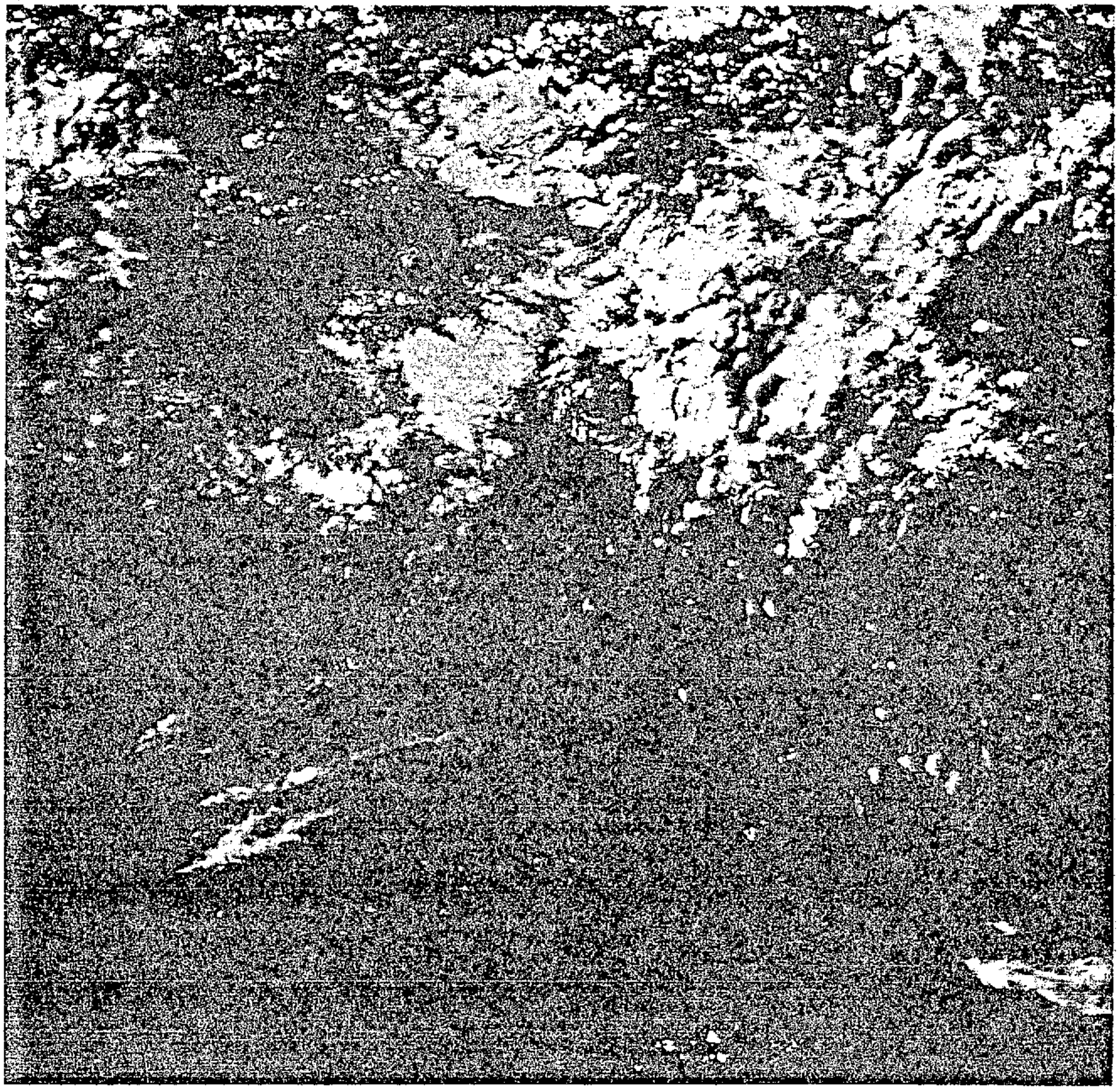

Figure 1. ERTS image of the Pah River fire in central Alaska.

created. From point groupings in these areas, we determined specific classifications for tundra, burned areas, water and clouds, and cloud shadows. These density classifications were used to assign one of these identifications to each spatial point, and a digital map was then printed, the number of fire points counted, and the area of the fire determined.

The second technique employed positive prints of the fire area enlarged to a scale of 1:250,000. The fire areas were traced on transparent graph paper, and by counting the number of squares within the fire boundary, we determined the area of the fire.

Both these techniques produced the same results, but measuring the enlarged positive prints was much easier, quicker, and did not require any specialized equipment. It is a procedure that anyone with a standard darkroom can use.

The areas burned are listed in Table 4. We note that in many cases, the sizes of the fires as measured from the ERTS photographs are approximately 30% smaller than the figures obtained from the Bureau of Land Management. In two cases, our values are significantly larger. The combined Rocky Bottom–Crooked Creek–Double Point Mountain fire was not contained by the time the fire crew was assigned to another fire, and it apparently burned for quite a while. The Norutak Lake fire was reported to be out when the crew left. Either it restarted or another unreported fire burned in the same area.

We also searched for old fires to determine for how long a burned area could be easily identified. We located two fires that were at least two seasons old. We were not able to find any older fires without prior knowledge of their location, but we did find evidence of several 3-year-old fires when we knew the locations in advance.

We conclude that the ERTS photographs are an efficient way of determining the location and extent of fires in remote regions of Alaska. From examination of a series of pictures taken at the end of the fire season, the larger fires were detected and measured. We detected no small fires, but extrapolating downward from the 2000-acre Bettles fire (see Figure 2), we would place 100 acres

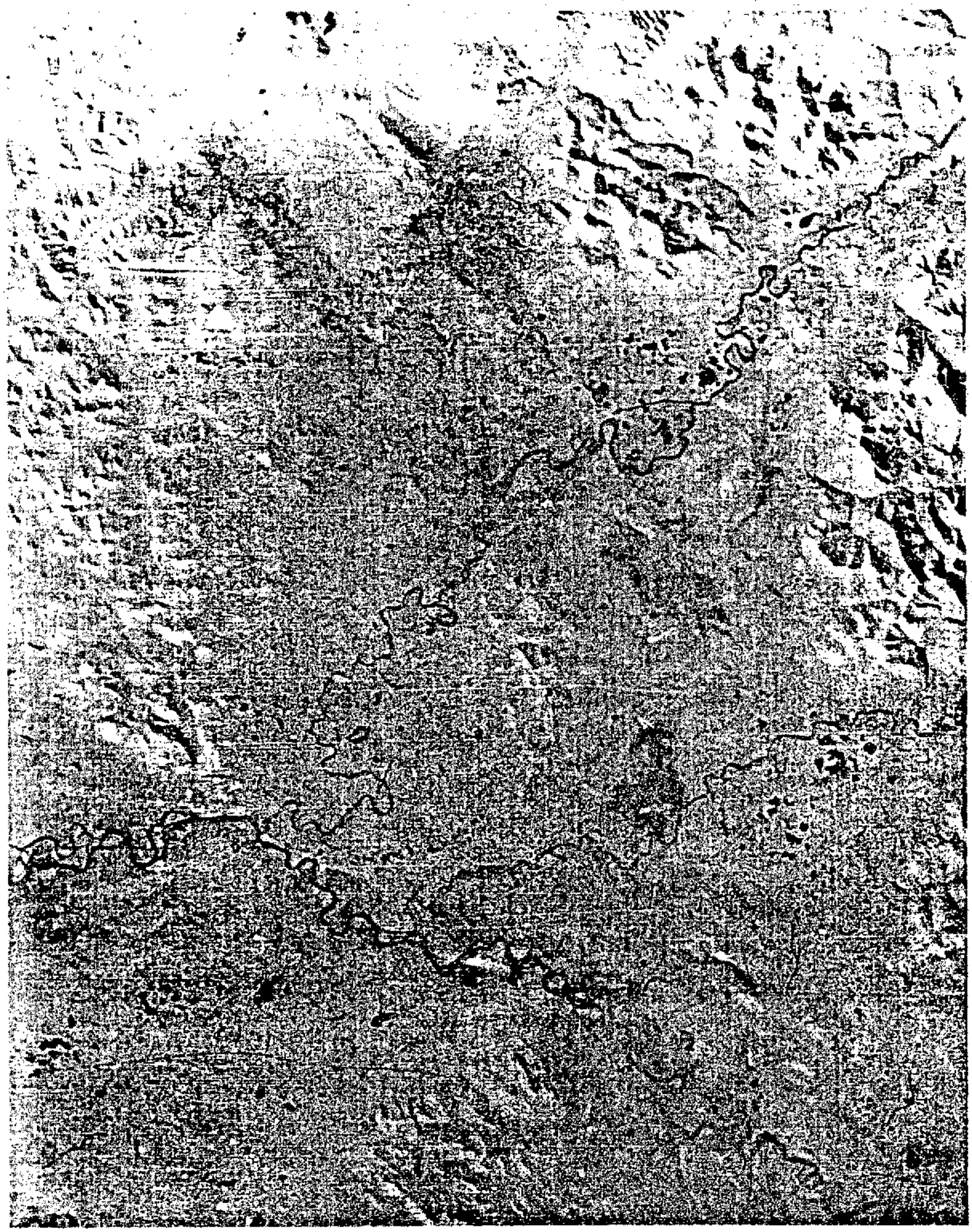

Figure 2. Bettles fire, an example of a small fire that is easily seen on the ERTS images.

as a minimum for locating unknown fires. This proved to be a reasonable estimate when compared to the size of easily detected lakes.

Table 4. Comparison of ERTS and Bureau of Land Management measurements of the size of the Alaska fires studied.

| Fire | ERTS Measurements (acres) | Bureau of Land Management Measurements (acres) |
|---|---|---|
| Norutak Lake | 6, 300 | 2* |
| Bergman Creek | 23, 760 | 32, 000 |
| Rocky Bottom–Crooked Creek–Double Point Mountain | 12, 480 | 5, 340† |
| Bridge | 253, 000 | 243, 800 |
| Bettles | 2, 090 | 3, 000 |
| Fickett Creek | 5, 110 | 150 |
| Pah River Fire | 94, 730 | 120, 000 |

*Fire apparently restarted.

†Fire was not out when crew left.

## 3.2 Oil Spills

The one oil spill detected originated at a break in the Texas–New Mexico pipeline on October 9, 1972. Some of the 255, 000 gallons spilled entered the San Juan River and were trapped behind three cable-laced log booms placed across the river near Nakai Creek. Two days after the spill, oil-soaked debris backed up for some 800 feet above the booms. The lower boom was removed after a few days, and the upper boom remained in place until early December.

We examined four consecutive ERTS frames of the river from the New Mexico border to the Colorado river – the entire length of the spill – by comparing before-and-after scenes in spectral regions 5 and 7 on the blink microscope. The regions behind the containment booms were instantly visible, but no other oil along the river was detected. The lower debris disappeared after the lower boom was removed and the upper debris remained, confirming that we were observing the contained oil and debris and not some other feature. Close examination of the 70-mm positives showed a light line across the river, which we believe is the actual boom. The final scene was taken after all the booms were removed and all evidence of the spill was gone.

The technique of comparing before-and-after scenes to determine the area of the oil spill was successful in the region where the oil was contained behind the boom, but it did not show any evidence of oil on the rest of the river, thus indicating that a fairly large and thick oil slick is needed for detection to be successful. We predict that oil spills on rivers will be very hard to detect, while spills on water bodies that do not disperse rapidly will be more discernible. The 18-day frequency of ERTS does, however, reduce its usefulness in studying oil spills.

## 3.3 Sakurazima Volcano

Sakurazima Volcano started erupting on August 17, 1972, and continued to eject ash and smoke through early December. A detailed report of the day-by-day activity is contained in the CSLP Annual Report for 1972, pp. 136-138. ERTS pictures were requested, and two cloud-free scenes were obtained on October 9 (Figure 3) and December 2 (Figure 4). The volcanic cloud is immediately apparent on the second scene, where two major puffs of smoke and three minor ones are evident. The first scene also shows a small cloud over the summit of the mountain. Its volcanic origin was confirmed by Dr. Y. Sawada of the Japan Meteorological Society. Dr. Sawada also sent us extensive data about the location of ash fall from the eruption, but we were unable to detect any areas of ash fall. Since no lava flows occurred during the eruption, we could not search for changes in the existing lava beds.

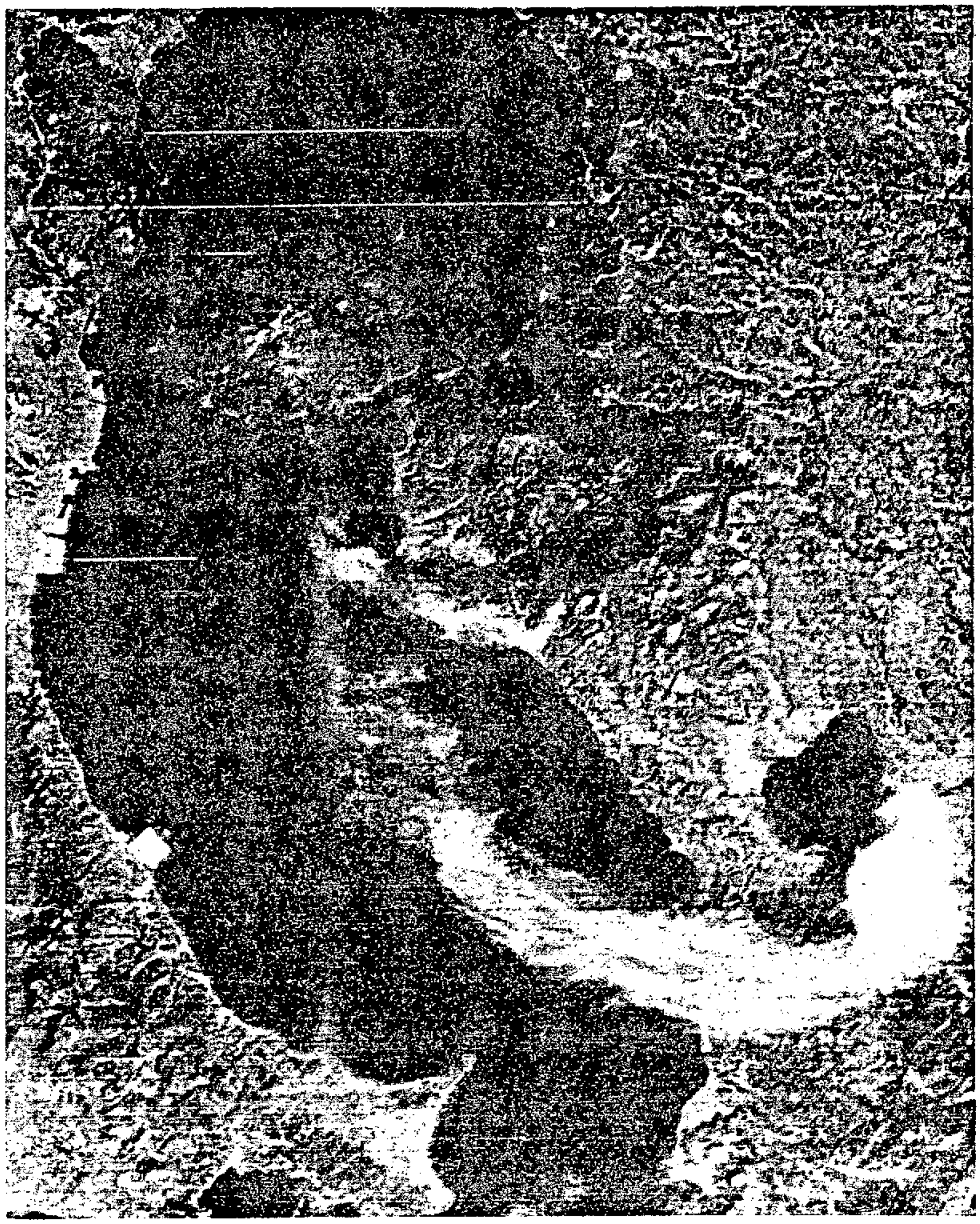

Figure 3. Volcanic cloud from Sakurazima Volcano, ERTS image from October.

Figure 4. ERTS photograph of Sakurazima Volcano. Note the small volcanic cloud above the summit.

We conclude that because of the smoke produced during an eruption, detection of volcanic activity is possible with the ERTS satellite. We expect that new lava flows over existing vegetation would be easily spotted because existing flows that are several hundred meters wide are easy to see. No conclusions can be drawn regarding the detection of new lava flows over existing ones.

## 3.4 Storm Effects

The following statement from the CSLP Annual Report describes the Funafuti Storm Ridge development during 1972:

> On 21 October, tropical cyclone Bebe struck the Funafuti Atoll as it moved west and south towards Rotuma and Fiji. The storm killed 6 people and rendered 800 more homeless, destroyed 95% of the dwellings and downed thousands of palm trees. On the day following the storm, residents of Funafuti discovered a large coral rubble ridge along the outer reef flats on the ocean side of Funafuti Island where nothing had existed the day before the storm. This new rubble ridge extended 15 kilometers along the southeast coast from Funafuti Island to the southern tip of the atoll.
>
> A scientific team was sent to Funafuti to examine the new beach and other damage caused by the storm. This group conducted extensive terrestrial and underwater surveys from 10 December to 24 December.
>
> The average height of the new beach was 12 feet and the average width of the new rampart was 100 feet. The beach was principally old, well-eroded, coral rubble averaging 9-10 cm in diameter. Indeed, only 5% of the mass of the new beach was derived from the skeletons of recently living reef organisms – chiefly corals. The depth and width of the new storm beach was generally the same whether it flanked the islands of the atoll or the inter-island reefs. The beach stretched continuously along all the shallow reef flats on the southeast coast, except across the deeper channels.

We obtained one set of photographs, from February 6, 1973 (Figure 5). Because no ERTS pictures were taken before the storm beach formed and because the new beach was only an extension of the existing one, we had to rely on size measurements to indicate the presence of the beach. We made microphotometer tracings of the island at a number of locations where the

Figure 5. ERTS image of Funafuti Island. Typhoon Bebe created a storm beach along the right-hand side of the island.

beach had formed and at several control points where the beach had not formed. We used spectral band 7 because the contrast between the water and the beach is a maximum in this band. Figure 6 is a sample tracing of this contrast, showing the width of the island. We compared our measured widths of the island at all locations with those measured on a map. The control areas agreed with the map measurements within meters. The areas where the storm beach was known to have formed were always wider than the map widths by 20 to 100 meters. Therefore, we were barely able to detect the newly formed beach.

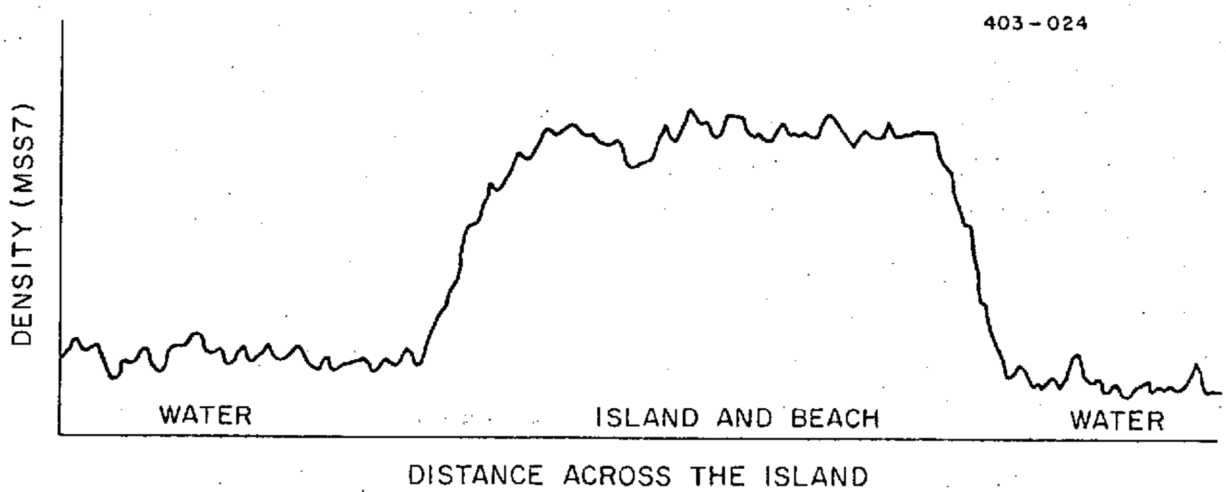


Figure 6. A densitometer tracing of Funafuti Island used to measure the new width of the island.

## 4. TECHNIQUES FOR OBTAINING DATA FROM ERTS IMAGES

Several techniques were developed to study and detect the phenomena observed by ERTS. Those we used were direct viewing of the scene, viewing composite scenes with a blink microscope, digital reduction of small areas of the scene, and direct viewing of color composites. The most successful one was the comparison of two frames with a blink microscope.

Direct viewing of the scenes was the technique employed in nearly all cases. It included the use of microfilm catalog prints available at the local data center, 70-mm positive and negative transparencies, and enlarged black-and-white prints of the scene.

The 70-mm transparencies, both positive and negative, were the prime data source for studying events. From them, we could determine the cloud cover over each event and obtain its location. Careful visual comparisons were made between the different spectral ranges and between pictures taken at different times. If an event was found, the most appropriate reduction method was chosen, as discussed below. If the event was not detected by direct viewing, one of the other methods was employed.

The most successful method was the blink microscope, which allows two transparencies to be superimposed so that they can be viewed in register in one eyepiece. The instrument can also be set so that alternate scenes can be viewed in rapid succession; i.e., the scenes blink on and off in the viewing eyepiece. Any change between the scenes flashes on and off while the remaining portion of the scene stays the same. The scenes can be before-and-after pictures in the same wavelength band or the same scene in different bands. Each type of comparison has its advantages: Burned areas are quickly separated from lakes, cloud shadows, and other dark features by comparing bands 5 and 7 of the same scene, while flooded areas are equally well separated from regular river channels by comparing before-and-after scenes in the same band and by comparing different bands in the same scene.

When color filters are placed in either or both light paths, different types of features can be distinguished and two-color composite frames can be created and studied visually. Attempts to make color-composite prints by photographing the composite scene and then obtaining a commercial print took so long that this process was ruled out. If it was necessary to measure a feature, the feature was visually transferred from the color projection to a black-and-white print and the measurements were made on the print.

In general, the color composite that blinked between two frames was the most successful way of finding short-lived phenomena. It rapidly displayed features that had changed with time or had different spectral signatures in different bands.

Digital techniques were also used to detect and measure short-lived events. We did not request the digital tapes available from Goddard Space Flight Center; rather, we digitized the individual frames on a digitizing microphotometer. We chose this procedure to eliminate the massive amounts of data processing and computer programing that would have been necessary to read and use the entire digital tapes. We pay a small penalty, however, because our digital values have been degraded by several stages of film processing and copying, but we feel this procedure is far better than having to process vast amounts of digital data. Access to small parts of a frame in the original digital mode would provide for better analysis. This would solve both problems – massive amounts of data and degraded data due to repeated conversion steps.

We used our digital data to create the standard type of decision plots – plotting each spatial point in a two- or three-dimensional density plot and then assuming that points that lie close together in density space belong to the same feature. A schematic two-dimensional example is shown in Figure 7. This technique was useful in separating gross features from those that had sharp boundaries, but it was not able to distinguish between fine details because of the degradation in resolution.

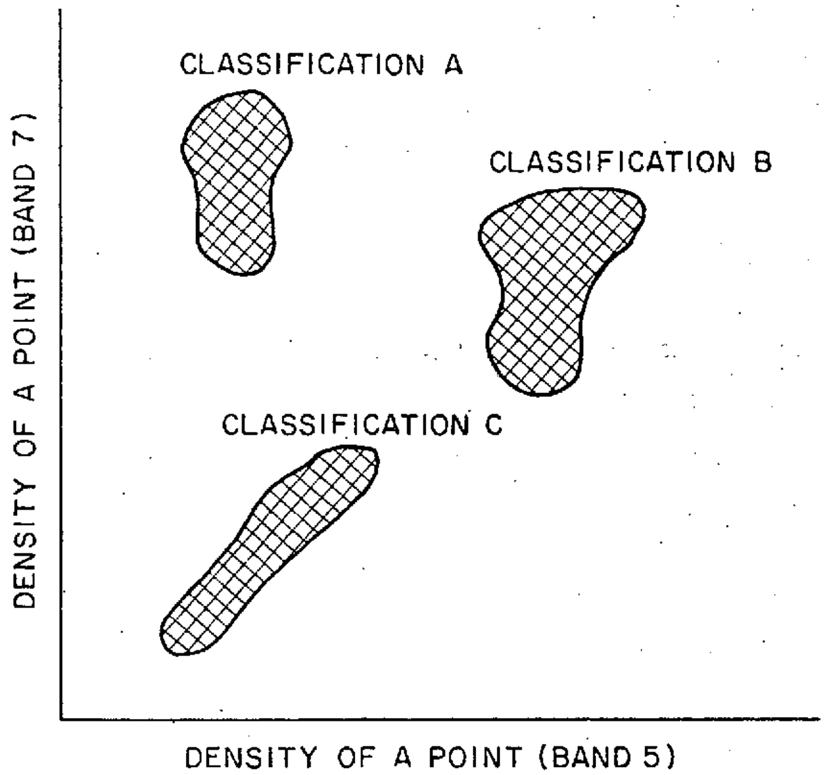


Figure 7. A schematic two-density decision plot showing how different items group together in different parts of the plot.

The densitometer proved very useful in determining the linear size of features or the density variation within a feature. An example of this technique is the study of the Funafuti Storm Ridge. The transparencies were traced perpendicularly to the shore line in both bands 5 and 7. By comparing these tracings, we determined the width of the island at that point. When this width was compared with that from existing maps, we found that we could detect the new storm ridge.

Data from the microphotometer and direct enlargements of the 70-mm transparencies were our principal means of obtaining quantitative data about events. The enlargement scale was carefully determined and checked against features on the enlarged prints. The features were then measured on the prints by one of the standard techniques described above. For small features, we generally placed a transparent grid over the feature and counted the number of squares; on large features, we found it more consistent and faster to cut the feature out of the picture, weigh it, and compare the weight with that of a known area. Each study, however, had its individual problems and its unique solutions.

In conclusion, the techniques used to study short-lived events with the ERTS data divided into two areas – those to detect the event and those to obtain measurable data after the event was detected. The most useful way to detect the events was to compare, by means of the blink microscope, two spectral bands of the same scene or a before-and-after scene in the same band. The most useful technique to obtain quantitative data about an event was direct measurements of enlarged prints of the scene.

## 5. SIGNATURES AND DETECTION LIMITS FOR SHORT-LIVED EVENTS

Here we will discuss the detectability of short-lived events and the specific signatures for a number of different events studied. All these criteria assume that the general location of the event is known; they are not criteria for detecting unknown events. Table 5 lists the 10 categories of events we have studied, a representative size of the smallest events or event features detected, and a broad estimate of the ease of detecting an event.

Table 5. Event detection criteria.

| Event Category | Size | Ease of Detection |
|---|---|---|
| Major Vegetation Changes | 400 meters | easy |
| Forest Fires | 100 acres | easy |
| Insect Plagues | – | – |
| Floods | 200 meters | easy |
| Volcanoes | – | moderate |
| Landslides | – | – |
| New Islands | – | – |
| Storm Effects | ~100 meters | difficult |
| Oil Spills | 100–1000 meters | difficult |
| Earthquakes | not detected | – |

### 5.1 Vegetation Changes

Major vegetation changes – i.e., where all the vegetation in a local area changed – were relatively easy to detect. Comparison of spectral band 7 before and after the event or comparison of bands 5 and 7 of the same scene with the blink microscope immediately showed the area of change. These events were especially apparent in flat areas but more difficult to discern in mountainous regions because of different shadow patterns in scenes taken at different times and because of frequently occurring clouds. Events where only one species in a mixed cover changed were difficult or sometimes impossible to detect. The Miami Palms Yellowing (see CSLP Annual Report for 1972, p. 89) is an example of this type of event. The palms covered a large land area in Florida but at such a low density that it was impossible to distinguish the individual trees affected from the remaining vegetation.

## 5.2 Fires

Forest fires were the easiest events to detect and were the only ones located without prior knowledge of the event. They are most easily found by comparing spectral bands 5 and 7 from scenes taken at the same time on the blink microscope. The burned areas are readily separated from small lakes and cloud shadows. One fire (Pah River fire) was observed while it was burning during two ERTS passes and was identified by the smoke plumes as well as by the burned area on the ground. Fires that were 2 years old were detected in the Alaska tundra region, and hence it is relatively easy to detect and measure accurately fire damage in these remote regions with ERTS data.

## 5.3 Floods

Flooded areas are easily detected by comparing by means of band 7 a scene taken during the flood with one taken before or after flood stage. By using color filters, the two scenes are superimposed to produce a color-composite picture. Any two complementing colors can be used, but we chose a green filter for the flooded scene and red for the normal water level. Since water has an absorption band in this wavelength range, it will appear dark on the positive. The combination image will be composed of four color areas:

A. Dry areas have equal densities in each scene; they will be composed of equal amounts of red and green and will appear yellow.

B. Areas that had water on both frames will be dark on both and will appear black in the composite.

C. Flooded areas that were dry on the comparison frame will be dark on the flood scene and will appear red.

D. Areas that are wet but not flooded will be darker than the corresponding dry areas and will appear in shades from orange to yellow.

These colored areas can then be transferred to an enlarged print to determine the actual area of the flooded regions. Since this technique is very sensitive to changes in water level, it can be used to monitor small changes in the size of any body of water.

## 5.4 Volcanoes

Many volcanoes were studied, but the only changes detected were smoke plumes and clouds from the eruptions. We were unable to obtain scenes before the eruptions, so comparisons of before-and-after scenes were not possible. We did receive detailed reports from the Japanese Meteorological Society concerning the location of ash falls from Sakurazima Volcano. A careful observation of these areas with all our techniques failed to show any detectable signs of the ashes. We would expect to be able to detect new lava flows if previous pictures were available but are unable to determine how small this detection limit would be without some actual data.

## 5.5 Storm Effects

The one storm effect studied was the new beach reef created on the windward side of Funafuti atoll. Since we had no scenes of the atoll before the reef formed, we had to infer its existence by determining the current widths of the island at a number of locations and comparing them to those derived from a map. The width of the island was 100 to 150 meters wider along the side where the reef formed but not significantly wider at other measured control points. We therefore maintain that we detected the reef. We would not, however, consider this a valid detection limit for a feature that was not known to exist. We also infer from the study of small coral areas in the Funafuti lagoon that a new island could be easily detected if it was above or within a few feet of the surface and more than 100 meters in surface diameter.

### 5.6 Oil Spills

Of the two oil spills studied – the San Juan River Oil Spill and the Oakland Bay Oil Spill – we detected only the first. The oil and debris behind the oil-containment booms were located by comparing before-and-after scenes in spectral band 7. The water in both scenes appears black, while the area covered with oil and debris is lighter. The time scale for detecting spills by this technique depends on the dispersal time for the oil. The San Juan spill was detected on two successive passes but not on the third. In general, we would not expect an oil spill to be visible for more than one ERTS pass.

### 5.7 Earthquakes

We studied two regions that suffered severe earthquake damage – Managua, Nicaragua, Richter magnitude 6.25, and Szechwan Province, China, Richter magnitude 8.0. Scenes before both earthquakes were not available, so no comparisons could be made, but careful study of the pictures did not reveal any damage or changes in the topography. We therefore conclude that earthquake damage is not detectable unless it is manifested by large fracturing or displacement of linear features, such as roads or streams, neither of which happened in these cases.

## 6. CONCLUSIONS

The main conclusion of this study is that ERTS photographs are a useful and economical way for individual investigators to obtain data on short-lived events. The larger events can be detected without knowledge of their exact location; if the general location in which an event is expected to occur is known, the ERTS photograph can be used to determine if it did occur. Small-sized events can be studied if their location is known.

There are, however, a number of problems in using the satellite to gather the data: time lag of the 18-day cycle, cloud cover, and lack of ERTS photographs before an event occurred. This last problem, however, will diminish as more of the earth's surface is covered, and we hope that all the areas will be photographed once each season so that reference scenes will be available.

The time lag required for the satellite to pass over a given site and the cloud-cover problem both limit the usefulness of the data for studying rapidly changing events. The reaction time of the ground-control system was, in general, fast enough to schedule the shots requested on the next ERTS pass over the area, and at least one scene was scheduled and obtained on 2-day notice. Cloud cover, however, presented a serious problem to obtaining scenes on the first pass after the operations crew was notified. In several cases, we had to wait two or three 18-day cycles to get a clear picture of the event. For short-time-scale events, this is too long a period, and no usable data were obtained.

One of our hopes was that we would be able to obtain ERTS photographs of events quickly enough to send them to investigating field teams, but this proved impossible. We did, however, get some information from field investigations near the time of an ERTS pass and used these to interpret the ERTS picture.

Another goal was to determine the feasibility of using the ERTS photographs to identify unknown events. We found some fires that were reported as CSLP events by using the 1:1,000,000-scale positive prints, but it was a random and time-consuming process. We also attempted to use the microfilm catalog of pictures to locate events, but this, too, was not feasible, because of the low resolution and definition of the microfilm. We even had trouble finding events that were easily seen on the large prints. In fact, the microfilm was not even useful for deciding whether we should order 70-mm positives of events that we knew existed.

We do conclude that the blink-microscope technique with 70-mm positives in bands 5 and 7 is a useful way to find changes in the images and hence to locate short-lived events. However, since it takes an operator about 20 minutes to align and examine one frame, it would be impossible to process all the frames this way, but for localized areas, it could be done.