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AN OVERVIEW OF THE DEVELOPMENT OF REMOTE SENSING TECHNIQUES FOR THE SCREWWORM ERADICATION PROGRAM

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ABSTRACT

This paper reports the current status of remote sensing techniques developed for the screwworm eradication program of the Mexican-American Screwworm Eradication Commission. A review of the type of data and equipment used in the program is presented. Future applications of remote sensing techniques are considered.

INTRODUCTION

The screwworm is the larval stage of the fly *Cochliomyia hominivorax* (Coquerel). It is distinctive in that the larvae feed only on living tissue, the population density is relatively small, and the female fly mates only once in her lifetime. The latter traits make the screwworm fly vulnerable to the sterile male technique for its eradication (see ref. 1). The screwworm fly lays its eggs in open wounds, and the resulting larvae can kill or cripple an animal within a few days. One of its favorite wounds is in the navel of newborn animals (refs. 1 and 2); therefore, little wildlife exists where screwworms are present. In fact, before the eradication program, a major chore of southern ranchers was to treat screwworm-infested animals.*

In the United States, the screwworm caused an economic loss of over 100 million dollars annually before the eradication program began. The latest estimates indicate that the losses without a screwworm program could exceed 200 million dollars a year (refs. 3 and 4).

Although there are no overwintering screwworm fly populations in the United States, the insect survives in Mexico; and as the weather warms, the flies spread northward into the United States (ref. 5).

To reduce the impact of this overwintering population and to prevent reestablishment of the screwworm in the United States, a

*An excellent survey of the developments leading to the sterile-male techniques developed by the U.S. Department of Agriculture for the eradication of screwworms is given in "The Eradication of the Screwworm Fly" by E. F. Knipling, *Scientific American*, 203:54-61, 1960. A more detailed review is presented in "Eradication of the Screwworm Fly" by A. H. Baumhover, *JAMA*, 196:240-248, 1966.

barrier of sterile flies was established (shown in fig. 1). This barrier extends to 480 km deep and stretches along the U.S. and Mexican border from the Pacific coast to the Gulf of Mexico. Up to two hundred million flies per week are dropped in the barrier and in isolated outbreak areas in the southwestern United States. Maintenance of the barrier costs 12.5 million dollars annually but does not totally protect the United States (ref. 6).

The United States and Mexico have agreed on a cooperative program to eradicate screwworms in northern Mexico, moving the barrier to the Isthmus of Tehuantepec, where the barrier would be only 177 km wide. The cost of maintaining this new barrier has been estimated at 1.5 million dollars, less than one-eighth of the cost of the present barrier.

REVIEW OF THE TECHNICAL PROBLEM

The screwworm fly in most infested areas has a low population density. For effective eradication, the local population must be overwhelmed with flies sterilized using radioactive cobalt and cesium gamma rays. These sterile flies are distributed from the factory to regional staging zones where they are delivered by aircraft in accordance to a daily flight schedule planned by the area epidemiologist. The flightlines are based on field case reports, personal experience, knowledge of spraying operations, and estimates of the effects of weather.

The environment is extremely important to the eradication program. If it is too cold, the screwworms die; if too hot and dry, they desiccate. For maximum efficiency in inundating an area with sterile flies, it is best to choose a time in which the adult population has already been reduced by weather factors and the new pupae have not yet emerged (ref. 3). If a system can be devised for predicting these areas, enormous savings are possible through the efficient use of flies. The present cost of producing and distributing these sterile flies is $0.001 each. Since 500 million flies will be dropped each week, even a 10 percent decrease in flies liberated represents savings of 2.5 million dollars annually.

To efficiently define the local environment for release of flies, it is necessary to have good support from either ground weather stations or from some other source.

In Mexico, a limited network of meteorological stations exists and even more limited communications connect them. Further, the terrain is complicated by extremely varying topography. To supplement the existing weather data from Mexico, additional climatological stations must be activated at an estimated annual cost of several million dollars, or satellites or aircraft can be utilized to collect environmental data.

In 1970, the Health Applications group of the Lyndon B. Johnson Space Center (JSC), National Aeronautics and Space Administration (NASA), decided to plan an experiment which would determine the feasibility of remote sensing to assist the Mexican-American screwworm commission in defining weather parameters of importance to screwworm eradication. A detailed study was made of various options and it was decided to suggest use of the Improved TIROS Operational Satellite (ITOS) (fig. 2) as a basic source of satellite data. A project plan was then developed for implementing a system that could provide planning information on where flies should or should not be dropped (fig. 3) based on weather parameters.

TECHNICAL REQUIREMENTS TO ACHIEVE PROJECT OBJECTIVE

The basic objective of the project was to determine the specific earth environment conducive to the growth of the screwworm fly and to develop remote sensing techniques useful to an eradication program. For the development of a remote sensing system, the environmental factors affecting the screwworm had to be quantified, a capability of processing ITOS data had to be developed, the relationship of satellite data to screwworm populations had to be demonstrated, and a processing system capable of daily production of environmental data for all of Mexico had to be developed.

Quantifying Environmental Factors Affecting the Screwworm

The screwworm has been extensively studied by agricultural scientists for more than 30 years. They had noted that a relationship seemed to exist between weather and the screwworm population. This relationship, however, had never been sufficiently demonstrated or quantified; therefore, an extensive literature search was undertaken (ref. 7).

The cycle of the screwworm (fig. 4) was studied to determine the environmental factors (fig. 5) that seem to affect population growth. They are the same as those that affect other insects and plants. The problem was to determine the effect of various aspects of the environment on each phase of the screwworm life cycle and on the total life cycle. The most rewarding investigation dealing with the overall effect of weather on the total life cycle was a 6-year retrospective study of available meteorological data (ref. 7). A typical plot of data showing the number of screwworm cases and the weather is shown in figure 6.

The weather conditions for each phase of the life cycle were plotted against the screwworm's life cycle; the modeling study resulted in the definition of a weather potential for screwworm growth (ref. 8). The weather conditions for each phase of the life cycle were plotted against the resulting growth per insect generation (fig. 7). Many factors, other than weather (e.g., availability of host animals, predators, and presence of an eradication program), may modify the population growth per generation. It becomes apparent from the study, however, that the potential growth of populations can be determined for various conditions.

Establishing Satellite Data Processing Capability

ITOS satellite radiometric data were obtained from the National Oceanic and Atmospheric Administration (NOAA) receiving station at Wallops Island, Virginia. The analog tape was mailed directly to JSC where it was displayed on a Visacorder for selecting the desired areas. The useful portion was duplicated, and 5 days of data stored at JSC on one reel. Data collected were archived, and a selected number of days in this time period were digitized, calibrated, and made into color-coded images.

NOAA digitized tapes were not used since, at the time the project began, digital tapes were not routinely available and digital data would have occupied too large a portion of a storage facility when weighed against the potential use for a specific day of data.

Although ITOS has several radiometers, only the very-high-resolution radiometer (VHRR) is being used. The VHRR is a two-channel scanning radiometer sensitive to energy in the visible band and from 10.5μ to 12.5μ in the infrared band. The size of the picture element (pixel) is approximately 0.9 km at the subsatellite point and degrades to about 1.45 km at the edge of its scan. The satellite observes each point on Earth twice a day and has a scan width of about 1,900 km. The NOAA satellite contains redundant VHRR sensors that are operated in tandem, 180° out of phase with each other. The visible data from one sensor are time-multiplexed with the infrared data from the second and transmitted continuously as one data channel. The signal may be received from anywhere in the world with the proper receiver and antenna. However, the signal is weak and the reception requirements are stringent.

Registration of the data was one of the more difficult technical problems to overcome. A computer software program for registering data over an area of several hundred miles was written for the development program, and it was found to be accurate within one pixel. Although this registration program was satisfactory for a test and development phase, another program had to be developed for the daily routine registration of data obtained on all of Mexico daily for the production system. Before registering data over an entire country, the analog signals should be nonlinearly digitized, either through a software resampling program or by use of a hardware function generator as was done in the production system. If nonlinear digitization is not done, the registration program will be very inefficient in computer processing time.

Techniques were also developed for correcting the data for atmospheric attenuation and surface emissivity. The atmospheric attenuation correction was derived by modifying and adding to basic correction programs developed by the National Environmental Satellite Service (NOAA). From a series of tests, it appeared that the results were satisfactory provided that one remained in the same air mass. The importance of emissivity correction can be determined from figure 8. Emissivity correction is difficult and is still under study. A promising new method may shortly be reported as a result of studies in Mexico and in the southwestern United States.

A problem in developing a useful system for recording environmental factors from satellites is that the satellite records radiometric temperatures and all surface meteorological reports are made as air temperature. A strong correlation of radiometric temperature to air temperature, however, was found (see fig. 9). Moreover, air temperature was not necessarily needed at a certain time of day but rather an average for the day or averaged over several days. By using multiple regression techniques for conversion from radiometric to daily air temperature, satisfactory accuracies have been obtained.

Relationship of Satellite Data to Screwworm Population

To demonstrate the relationship of screwworm activity with satellite data, two test sites were established: one near McAllen, Texas, and the other near Fortín de las Flores, Veracruz, Mexico. The Texas test site has flat terrain, relatively clear days and nights, an abundance of ground truth, and the presence of an ongoing eradication program. The Fortín test site is almost completely opposite in character with its rugged terrain, extensive cloudy periods, lack of an eradication program, and limited ground truth (except that which could be established locally by project personnel). The results achieved in each test site were different, as one might expect, and are, therefore, considered separately.

The McAllen test site was established before activation of the international agreement between NASA and the Comisión Nacional del Espacio Exterior (CONEE), the Mexican space agency, to participate in the screwworm program. Because of the high-quality data obtained during early studies, work in this test site was continued and expanded to cover additional areas in Texas for the duration of the developmental phase of the project. This test site was operated as part of a cooperative arrangement with scientists from the U.S. Department of Agriculture (USDA) experiment station in Weslaco, Texas. In exchange for ground truth data, NASA provided processed satellite imagery. Records of screwworm activity throughout South Texas were correlated with surface and satellite observations.

The Mexican test site has an approximate radius of 150 km. This area lies on the southeastern edge of the Mexican highlands where the ground descends precipitously towards the coastal plains. Elevation varies from near sea level to above 2,000 m. In the Mexican test site, an office was established and equipped with a radio for daily communications with JSC. Establishing and operating the Mexican test site presented some problems. First, as a developing country, Mexico has protective tariffs that strictly control all equipment entering and leaving the country. Second, it has stringent work permit regulations to protect jobs for Mexican nationals. Third, it has strong labor rules and a comprehensive social security system for which industry is taxed according to complex laws. Last, administrative practices in Mexico are more deliberate than is customary in the United States. The approach taken to solve these problems was to subcontract a Mexican company responsible for hiring personnel, supplying equipment and office space, and meeting the legal obligations.

Local inspectors hired by the subcontractor were trained by the USDA screwworm research staff at Mission, Texas. Their duties included baiting traps, collecting and sorting flies, visiting ranchers for screwworm case reports, and making presentations to local ranch associations.

Forty fly traps were placed in selected areas having rather well-defined roadways for ease of servicing. Weekly visits were made to the traps and selected ranches. Larval samples were collected during these visits for screwworm verification. A Mexican scientist, either from CONEE or from the joint screwworm commission, served as test site director with a U.S. supported scientist as the backup.

Approximately 20 meteorological stations were established in the test area to measure the variation in local climate. Sites for the stations largely reflected areas that were easy to service and yet representative of the general area. Weather parameters measured included daily maximum/minimum air temperature, daily total precipitation, continuous air temperature, continuous relative humidity, soil moisture (once a week), and soil temperature (once a week).

The results obtained from the two test sites varied widely. Figure 10 shows the correlation of the satellite radiometric surface temperature to air temperature in the McAllen test site at shelter height at the time of satellite passage. Data obtained by satellites at varying orbits over the Texas test area were used in this figure, and the best-fit regression line is shown. The root-mean-square (rms) estimate of error was 1.9° C.

Figure 11 shows a few of the data sets obtained from NOAA-3 as it passed over the Mexican test site and the best-fit regression line. The rms estimate of error was 2.53° C. As is evident, data from this test site were less useful than the data from the McAllen test area for developing algorithms, probably because of map accuracy problems. When the same geographic position of a small meteorological station was plotted on three different Mexican maps, the resultant latitudes and longitudes were different for all three. The radiometric data show considerable scatter, which might be expected with uncertainty in the precise location of the ground meteorological station. When combined with the possible registration error (2 km), sizeable position errors can be produced.

For example, consider the meteorological station at Los Carriles, which is located in an area of rapid change in altitude and terrain. An uncertainty of 2 minutes in either the latitude or the longitude can result in a positional error of 1.4 km or 1.5 resolution elements (pixels) in the satellite data. This is not a large degree of uncertainty considering the conflicting information contained in maps of this area. The computer registration error on the order of 2 resolution elements would result in a possible location error of 3.5 elements in the radiometric map. Figure 12 shows a computer printout of the area around this station for August 28, 1974, and a circle of 3.5 resolution elements in radius. As can be seen from the accompanying temperature analysis, this radius of possible location can result in a variation of 10° C in temperature range.

The Screwworm Eradication Data System (SEDS)

Two contractors were assigned to support the screwworm project; the Lockheed Electronics Company, Inc., was responsible for developing basic research and development techniques and the Aeronutronic Ford Company for designing the hardware and software and for integrating all into the daily production system, known as SEDS. Dr. Charles Barnes of the Bioengineering Systems Division was responsible for overall systems development as related to the screwworm eradication program and was the technical monitor of the basic research, established system requirements. Mr. Robert Spaulding of NASA/Ground Data Systems Division was the technical monitor for the development of SEDS. As Lockheed developed basic algorithms, programmers or engineers from Aeronutronic Ford implemented them into SEDS. SEDS is now operational; however, additional capabilities, such as emissivity corrections, still need to be added. Some coefficients also need to be refined on the basis of analyses conducted over many days. Even so, it appears that the accuracy of SEDS at this time is within 2.5° for estimating mean daily air temperature averaged over 4 days. These accuracies are expected to improve as coefficients are refined and the emissivity correction is added.

Figures 13 through 16 show representative products of the SEDS. Figure 13, the product designed for use by epidemiologists, shows areas in which conditions are favorable for screwworm growth. This product is prepared from data presented in Figures 14 through 16, all of which are produced from temperature data. In addition, it incorporates the Crop Moisture Index for Mexico, prepared at JSC using programs of the U.S. Department of Agriculture.

The data that SEDS is now producing daily must be evaluated by the developers and potential users. Field tests will assist in refinement of the algorithms and increase accuracies before actual operational evaluations can be made. This evaluation will be completed in 1976, at which time the daily processing of data is expected to resume if the current evaluation proves favorable.

THE FUTURE OUTLOOK

Many who are familiar with the results of the work achieved by this small group believe that there are many other applications which could use daily radiometric temperatures over extended periods. Indeed, in any application in which the response variables are temperature dependent, the techniques developed for screwworm eradication should be useful. These may include frost warnings, crop yield predictions, or plans for shrimp harvesting or for the eradication or control of other insects. Certainly the developments described in this paper are at a very early stage. With the approaching launch of more sophisticated meteorological satellites having improved radiometers and moisture sensors, new avenues of remote sensing may be opening. The potential for using and correlating data from several different kinds of sensors could create the synergism needed to solve some of the most difficult remote sensing problems.

ACKNOWLEDGMENTS

A list of people who have contributed their special talents to the growth of a work of this magnitude is endless; however, we would like to give special recognition to a few. Mr. Russ Koffler, NESS/NOAA, gave much needed aid to all phases of the project from its conception to the present. Mr. Paul Nixon, ARS/USDA, gave special aid in the collection of ground truth. Dr. Richard Davis has contributed through his in-depth reviews of the project.

The development of the daily production system, SEDS, was the result of a concentrated effort by many. In particular, however, Bob Spaulding, Charles Parker, and Dave Young are among the NASA scientists who made significant contributions. The excellent work performed by Norman Hines, Paul Audel, Hal Halpin, Steve Jorgenson, James and Sharon Boatright, Jack Biddle, and Earl Miller of Aeronutronic Ford in designing and integrating a production system must be acknowledged. From the Lockheed Electronics Company, the list of persons to be acknowledged must include Dale Phinney for developing the basic algorithms, Everett Thompson for satellite processing techniques, Gerald Arp for his emissivity work, and Morgan Gibson for collecting, analyzing, and reporting screwworm data, and Lorrain Giddings who worked numerous detailed problems, and Alberto Broce who directed the Veracruz test site effort.

Our many Mexican friends have also contributed in both a scientific way and in moral support during times of political stress. First are Engineers Raul Higuera and Sergio Padilla of the Mexican Space Commission, Aguilar Anguiano of the Mexican Meteorological Service, and Dr. Marco A. Villaseñor, Director of the Mexican-American Screwworm Eradication Commission.

We sincerely appreciate the support of NASA management in providing funds for this series of experiments.

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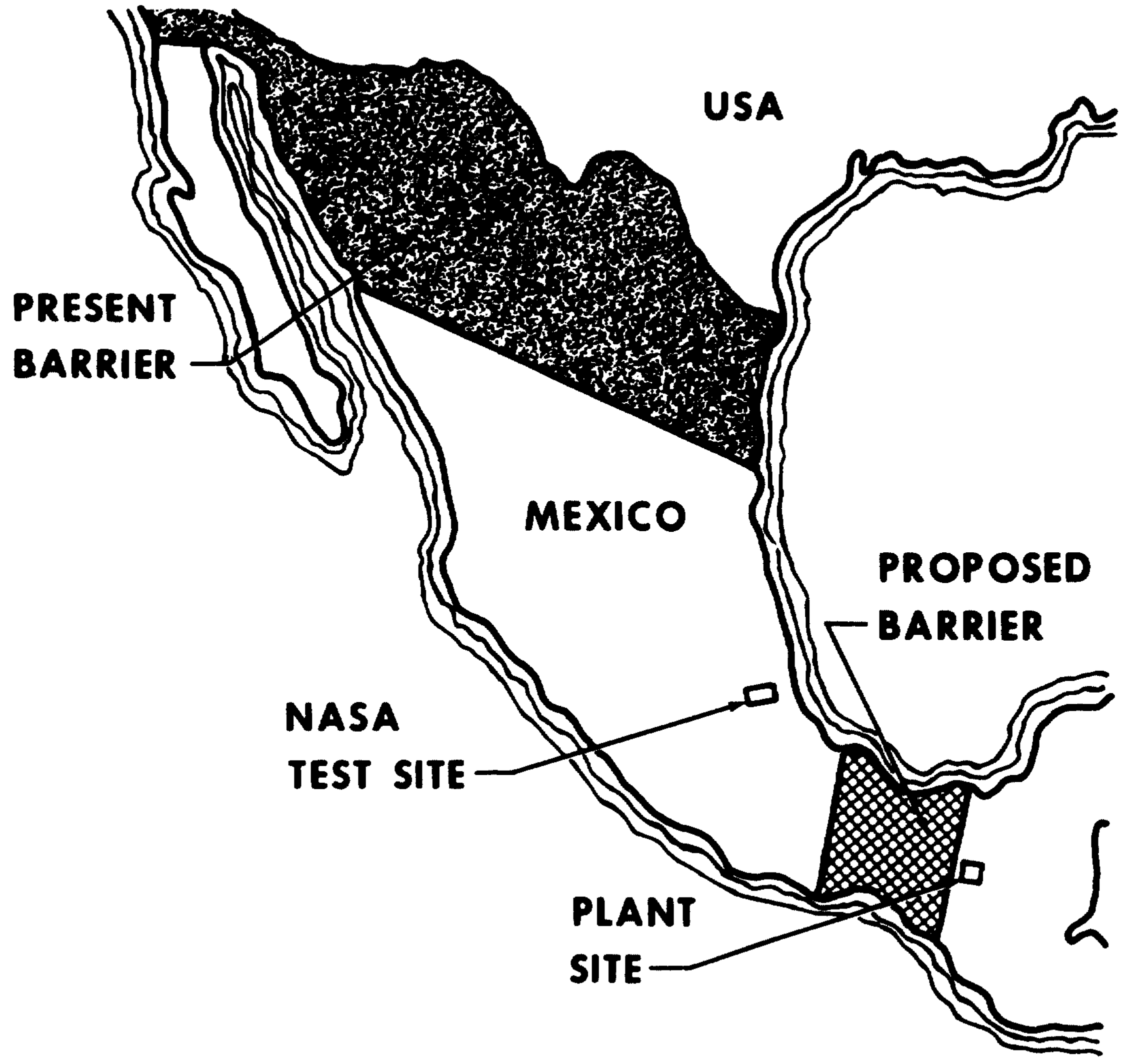


Figure 1. – Present and proposed screwworm fly barrier.

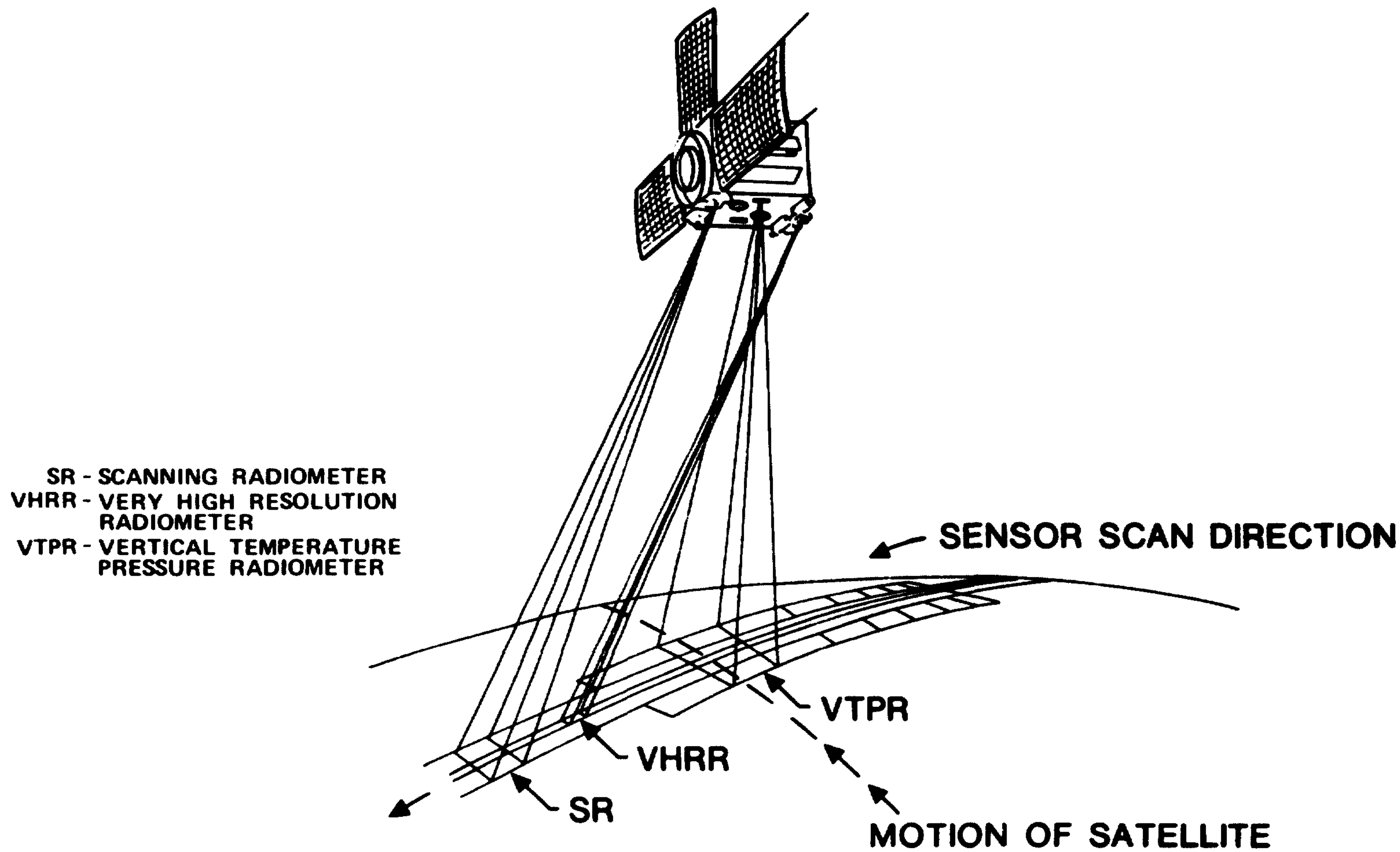


Figure 2. — The Improved TIROS Operational Satellite utilized in the screwworm eradication project.

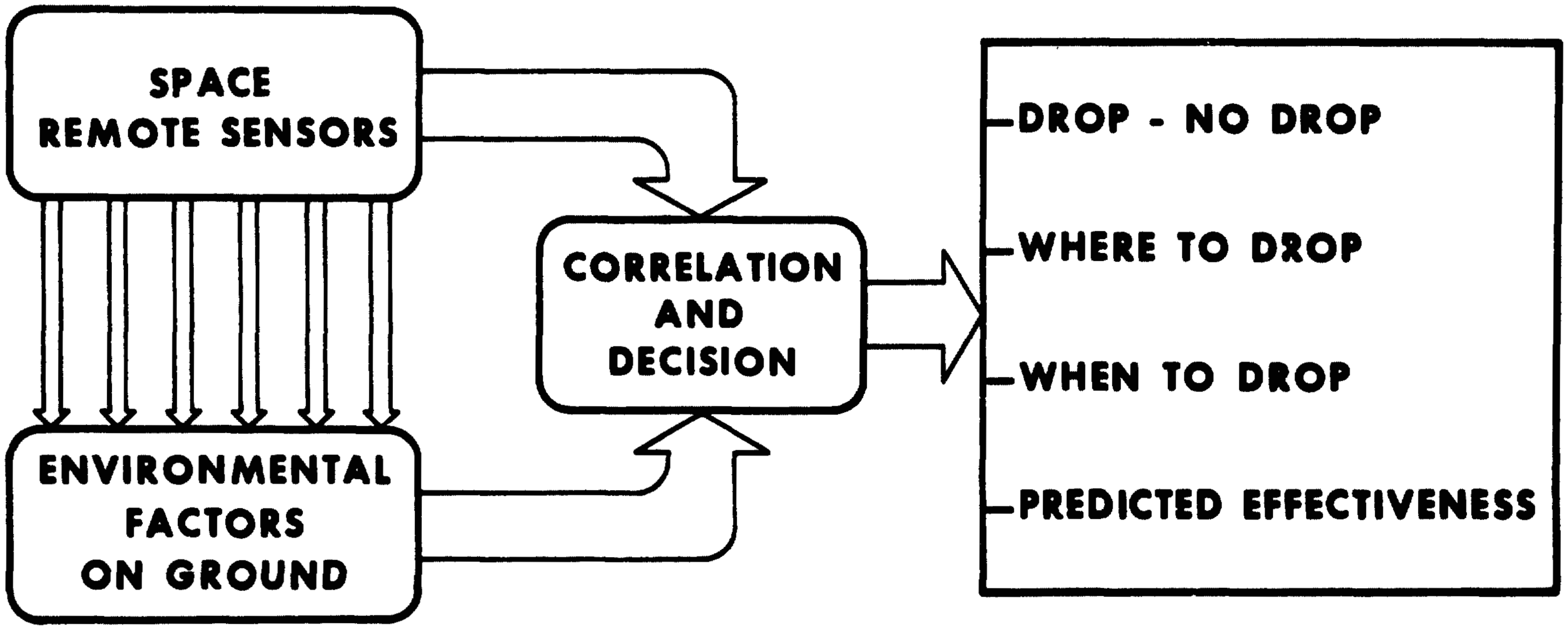


Figure 3. — System for providing planning information of where male sterile flies should or should not be dropped.

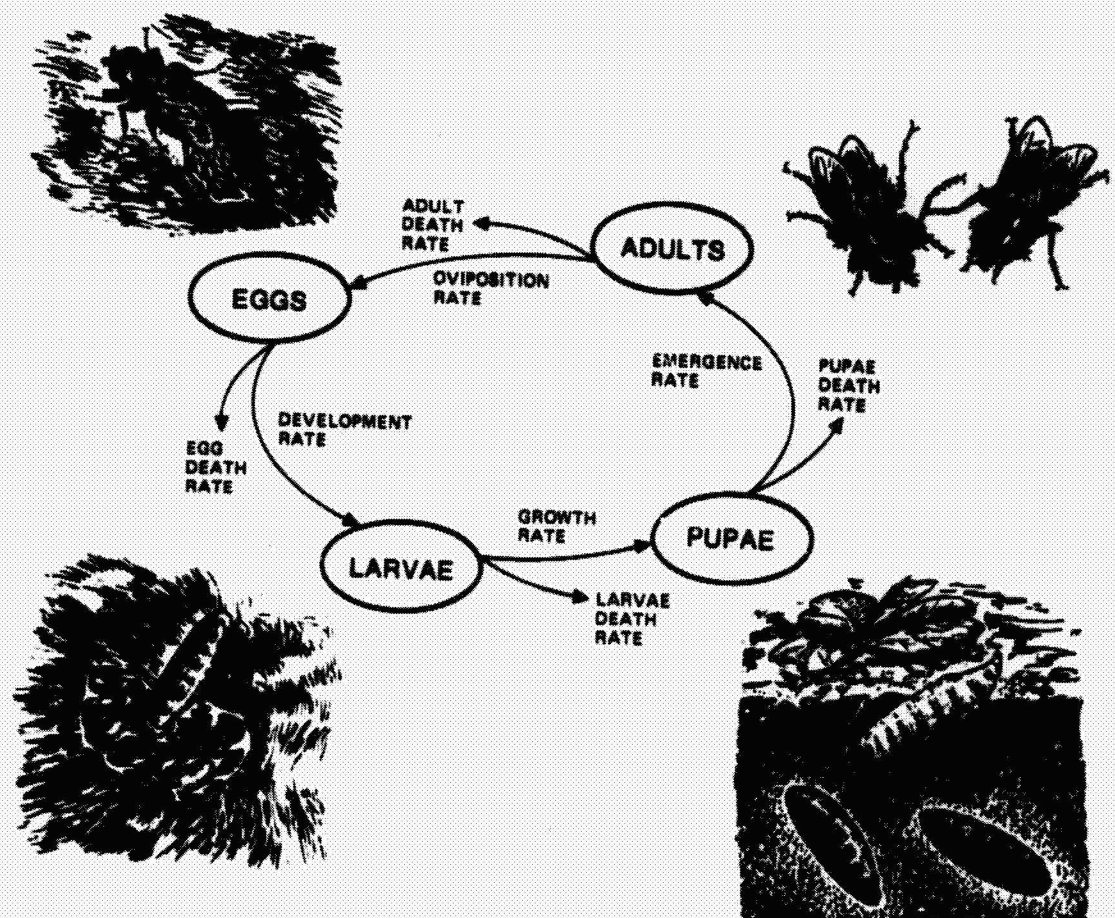


Figure 4. — Screwworm life cycle.

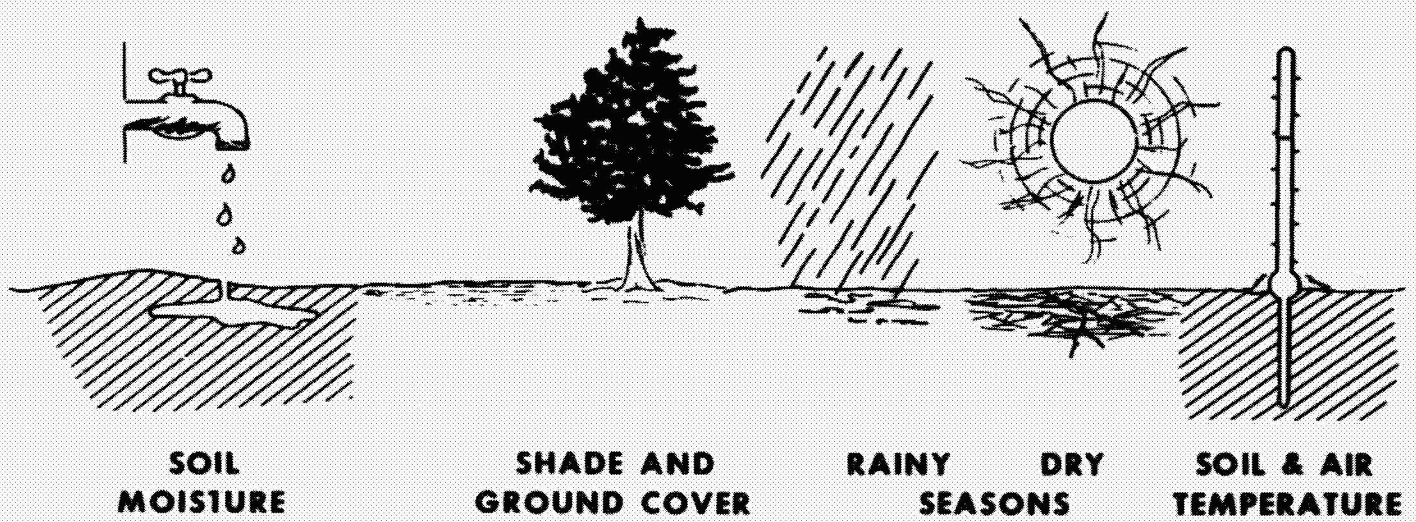


Figure 5. — Environmental factors affecting the life cycle of pupating insects.

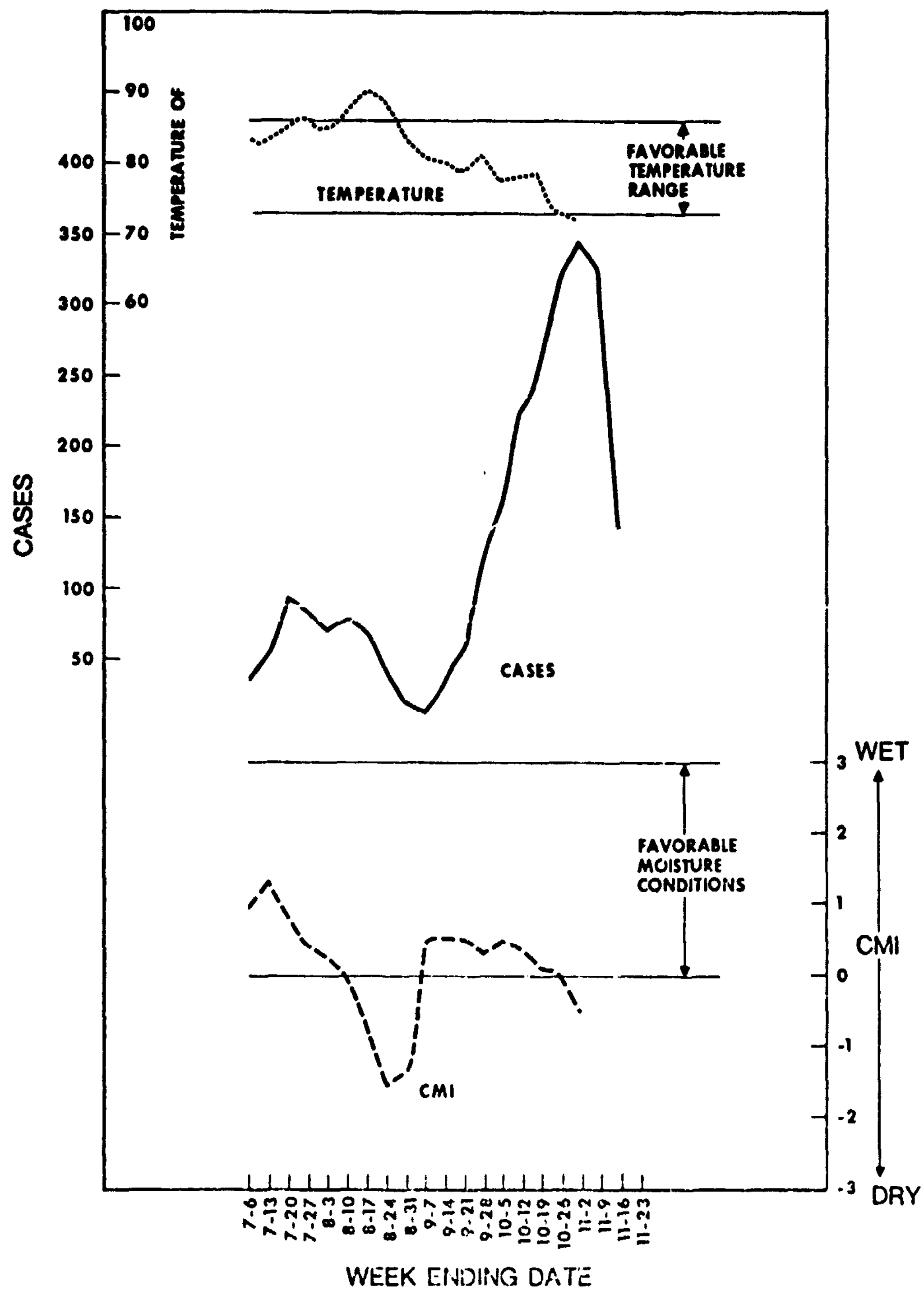


Figure 6. – Plot of data showing the number of screwworm cases and the weather.

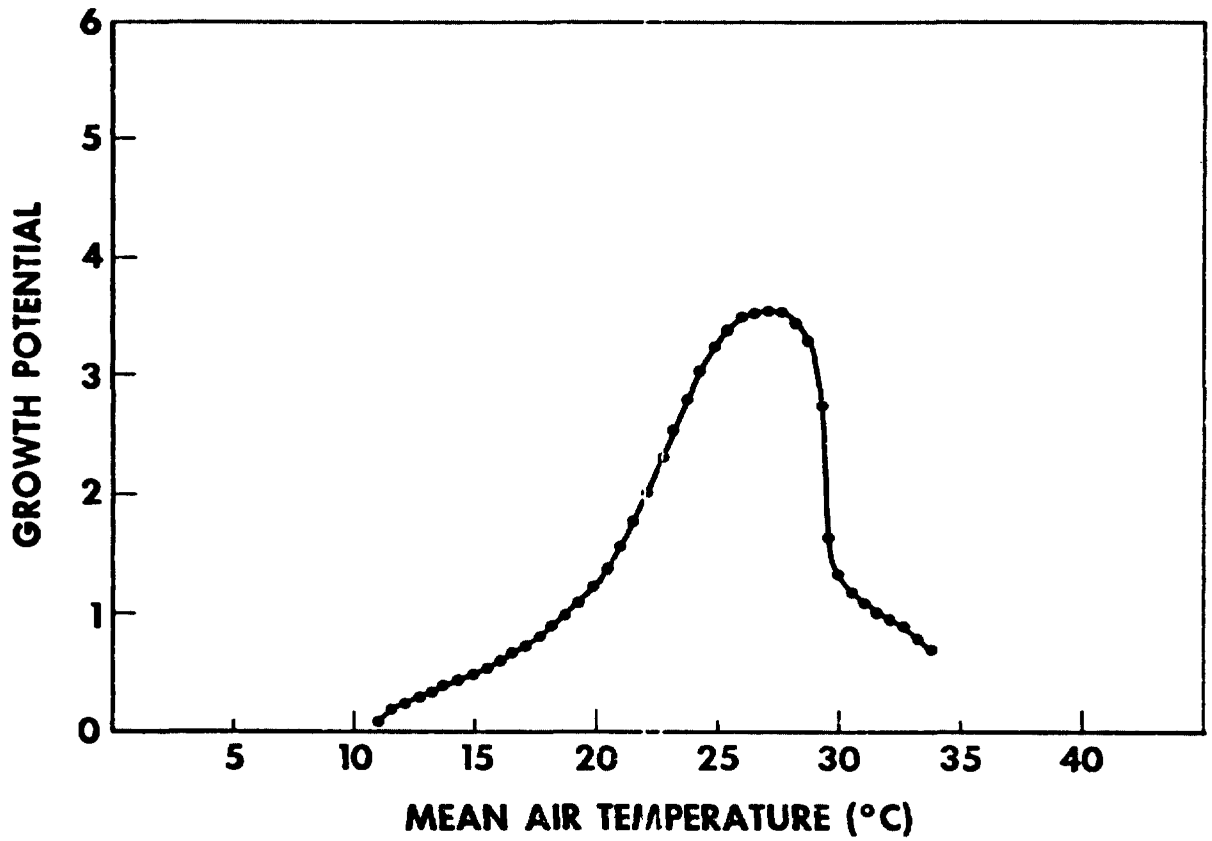


Figure 7. — Relationship between mean air temperature and growth per generation.

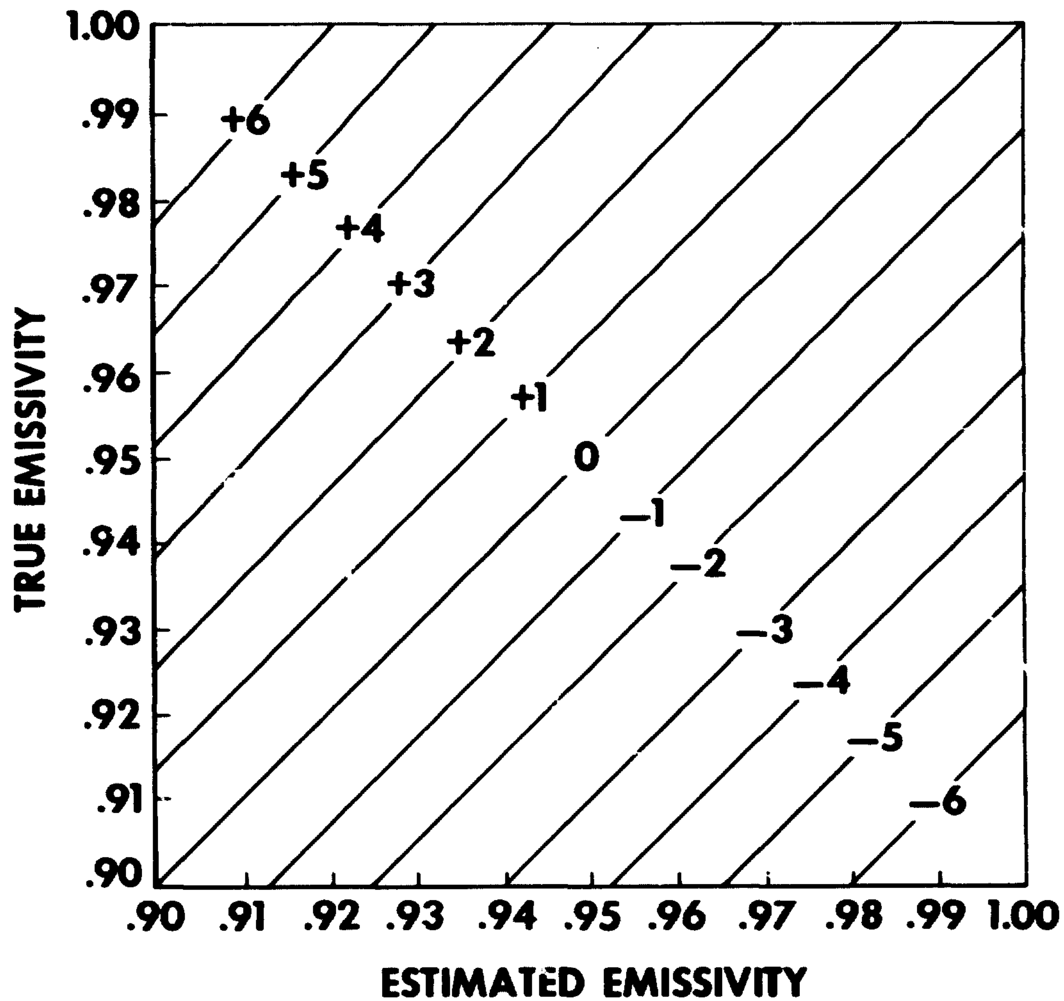


Figure 8. – Temperature error (°C) associated with an incorrect assumption of emissivity at 300° K.

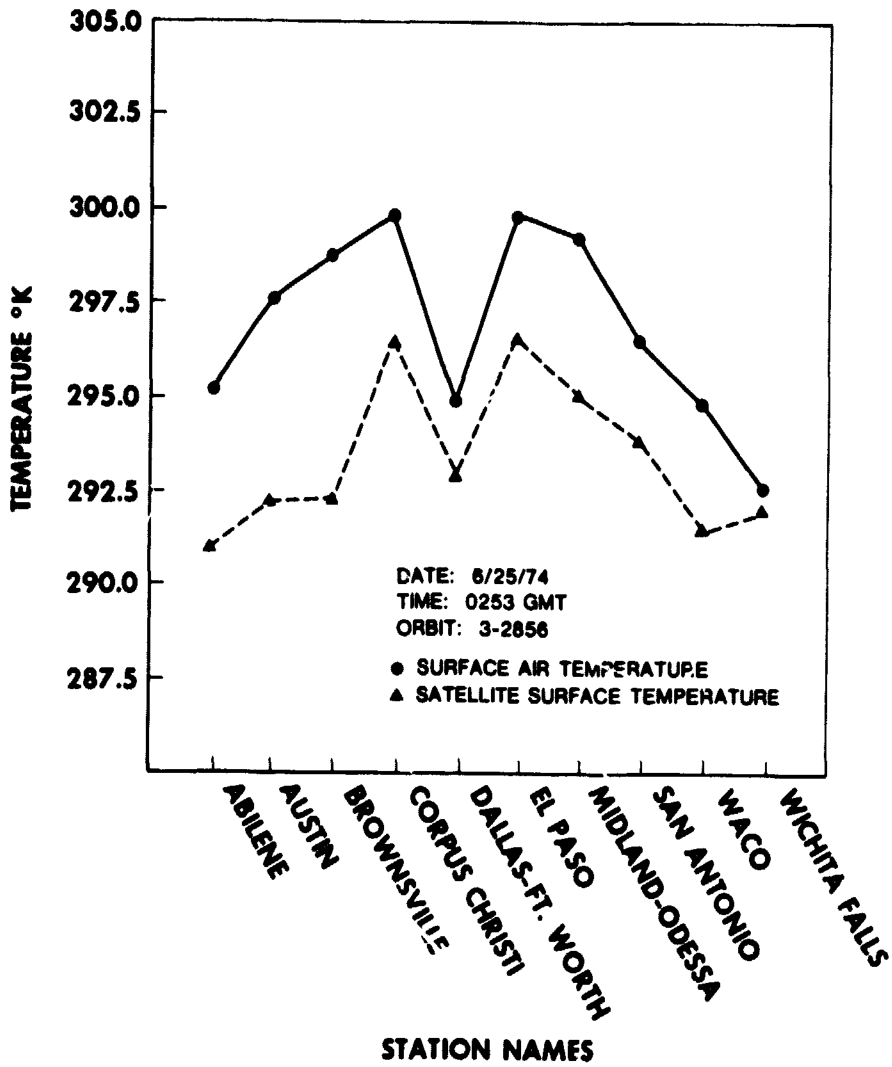


Figure 9. – Correlation of radiometric temperature to air temperature.

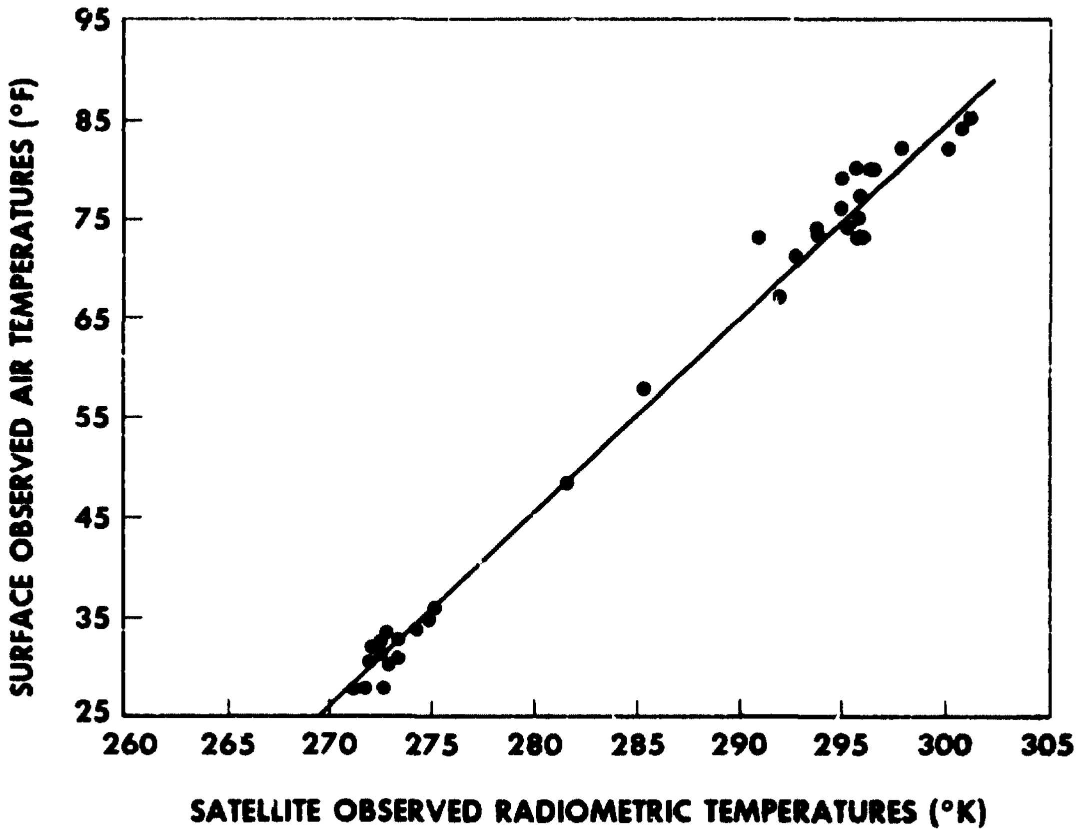


Figure 10. — Correlation of radiometric temperature to air temperature in the Texas test area.

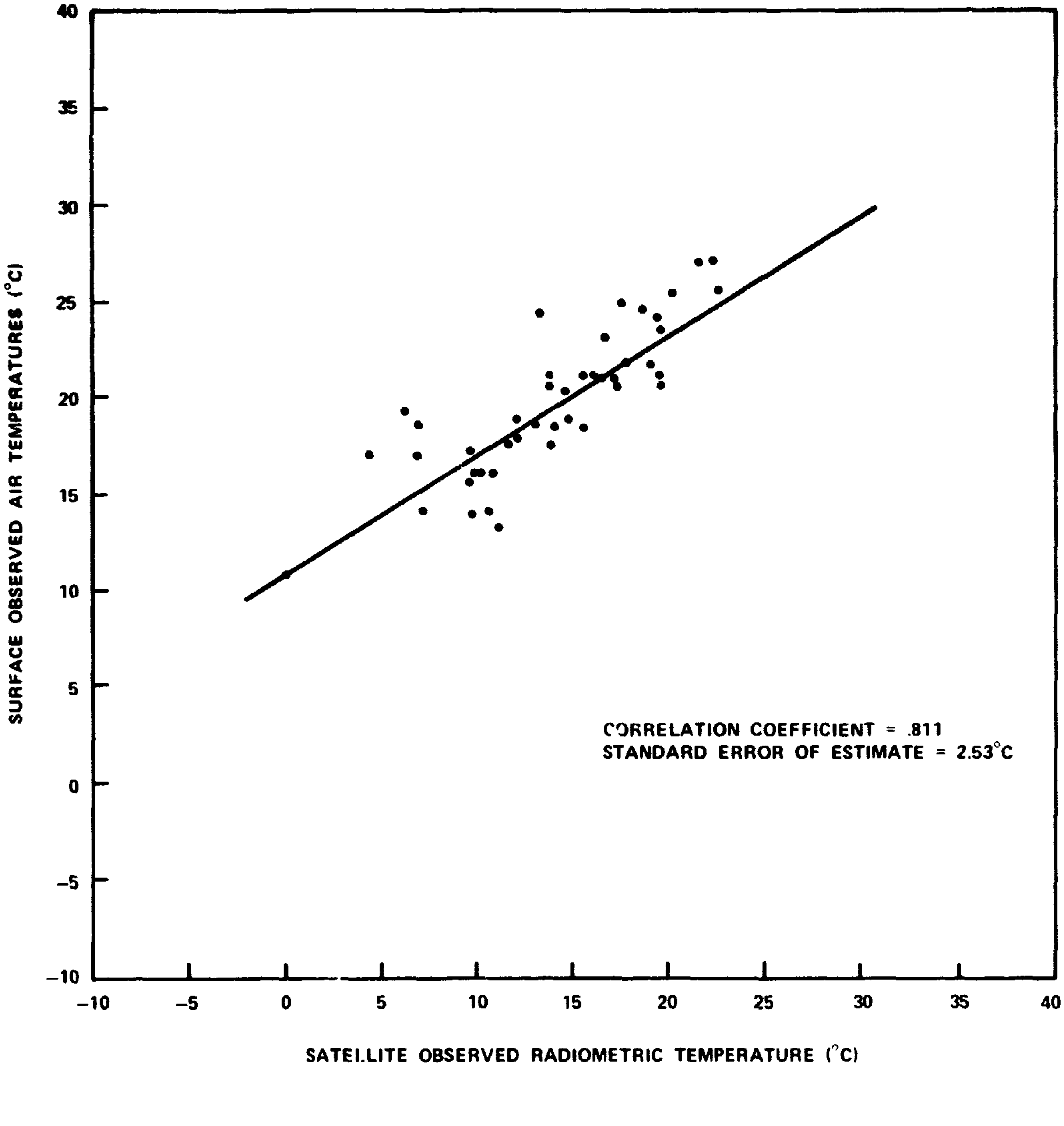


Figure 11. – Comparison of satellite data with surface temperature in the Fortín de las Flores test site.

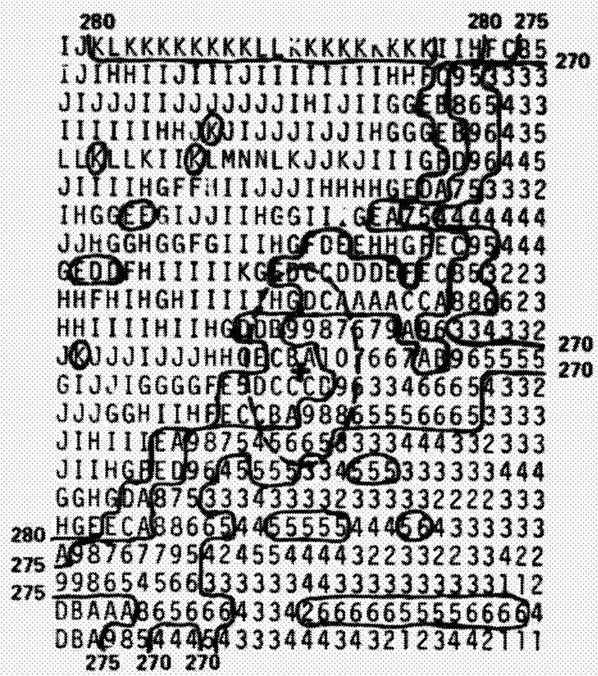
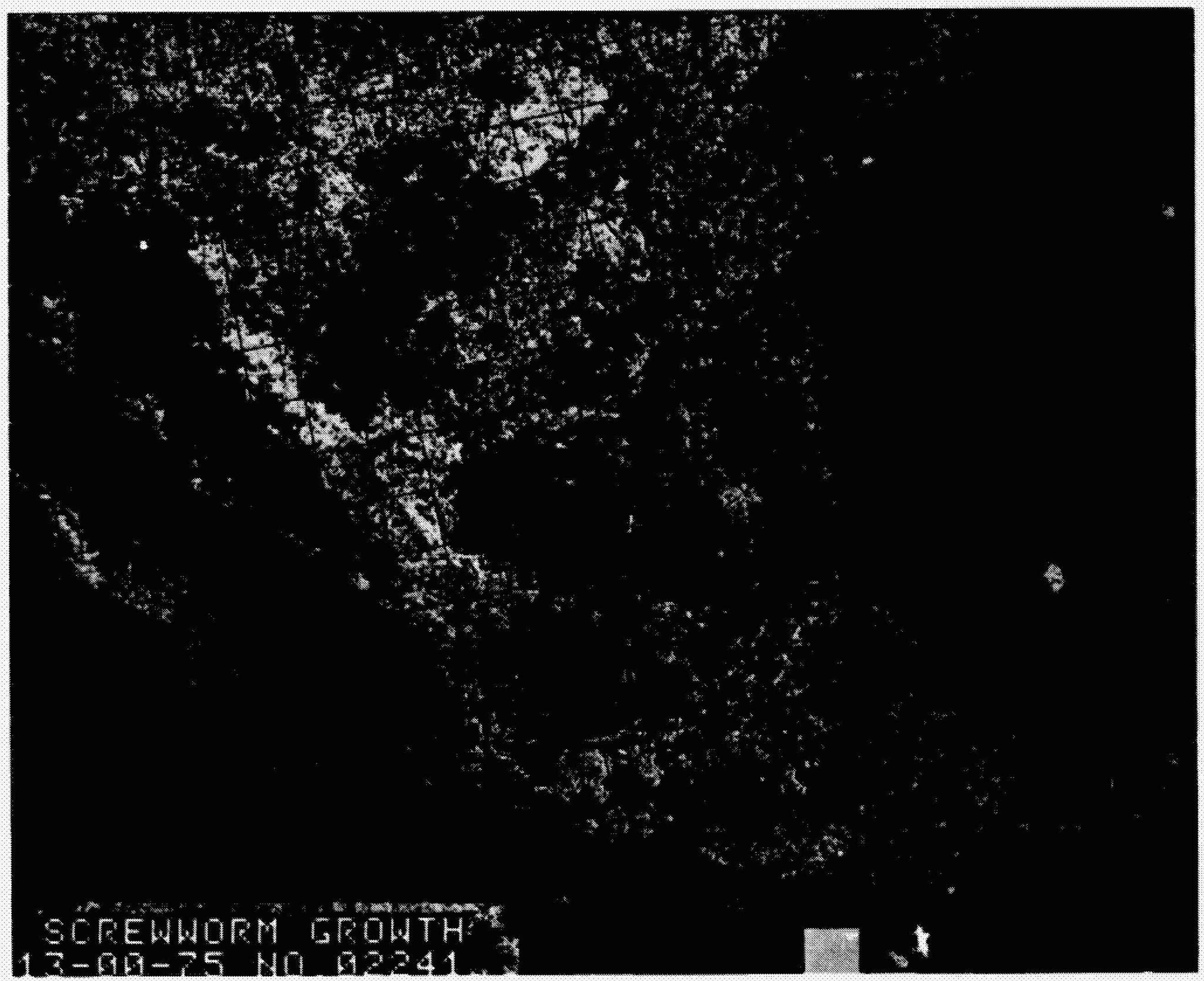


Figure 12. — Los Carriles with possible location error and temperature analysis, °K.



Screwworm Growth – Figure 13. – This image depicts the combined effects of temperature and soil moisture on screwworm populations. The potential for screwworm outbreaks as a function of weather increases as the colors shown move from blue through red.

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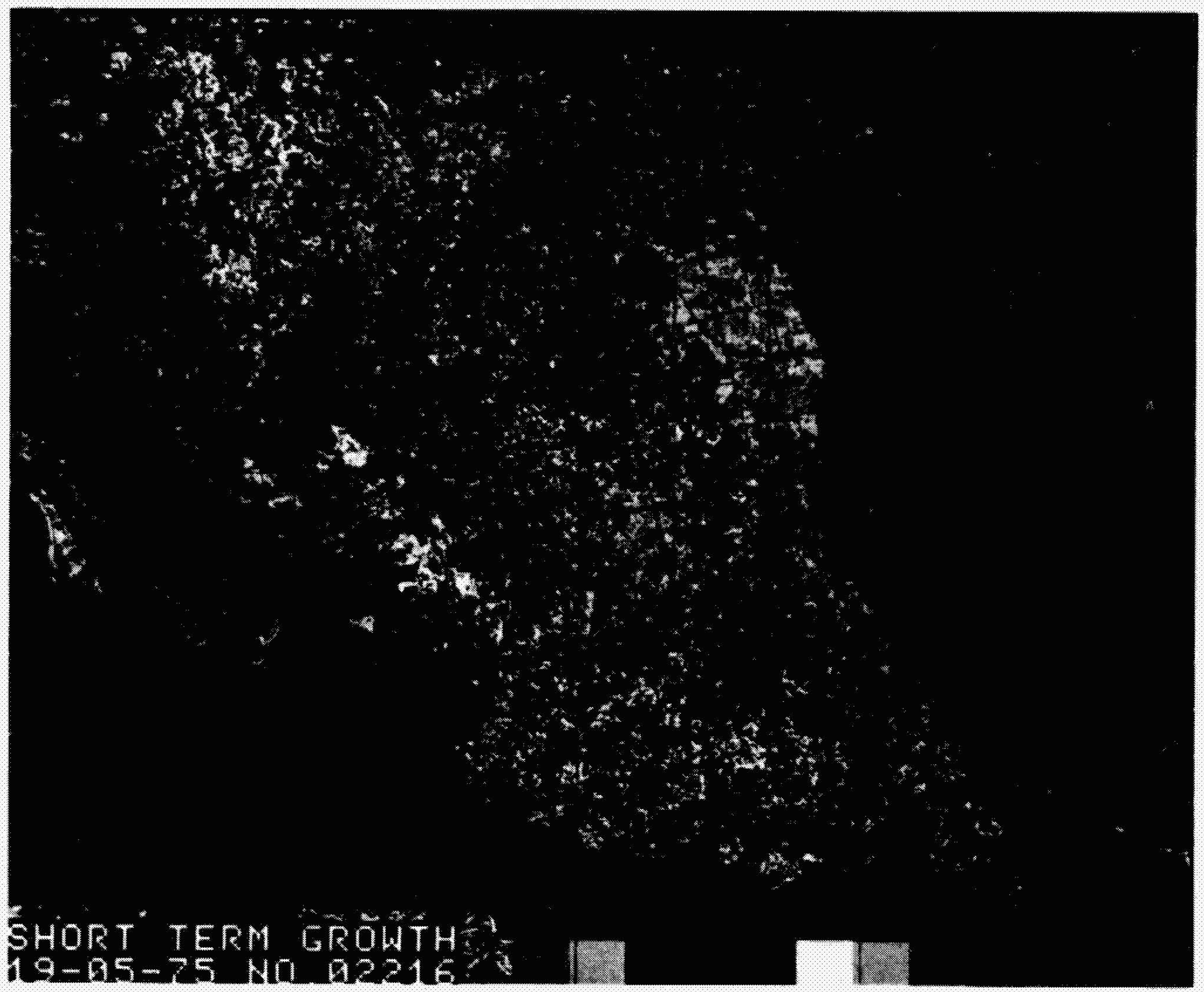

Short Term Growth – Figure 14. – The effect of short term variation in mean air temperature on the growth of screwworm populations is shown in this display. The particular impact of weather shown here is that of air temperature on the activity and survival of adult flies. It is color coded in the same manner as figure 13.

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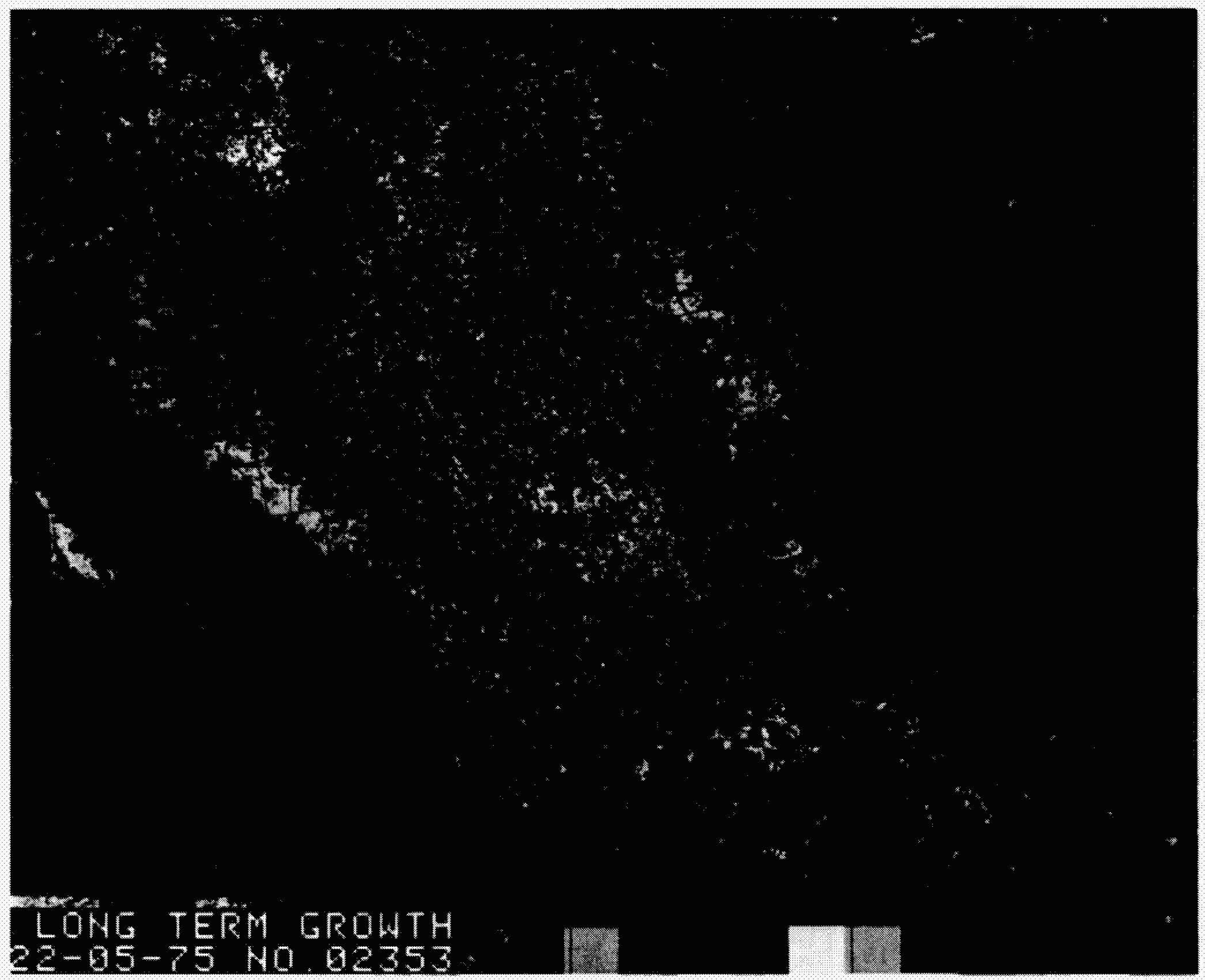

Long Term Growth — Figure 15. — This image shows the effect of temperature on the pupae phase of the screw-worm fly. A long term mean air temperature is calculated, and the correlated pupae survival and development are shown in color. It is color coded in the same manner as figure 13.

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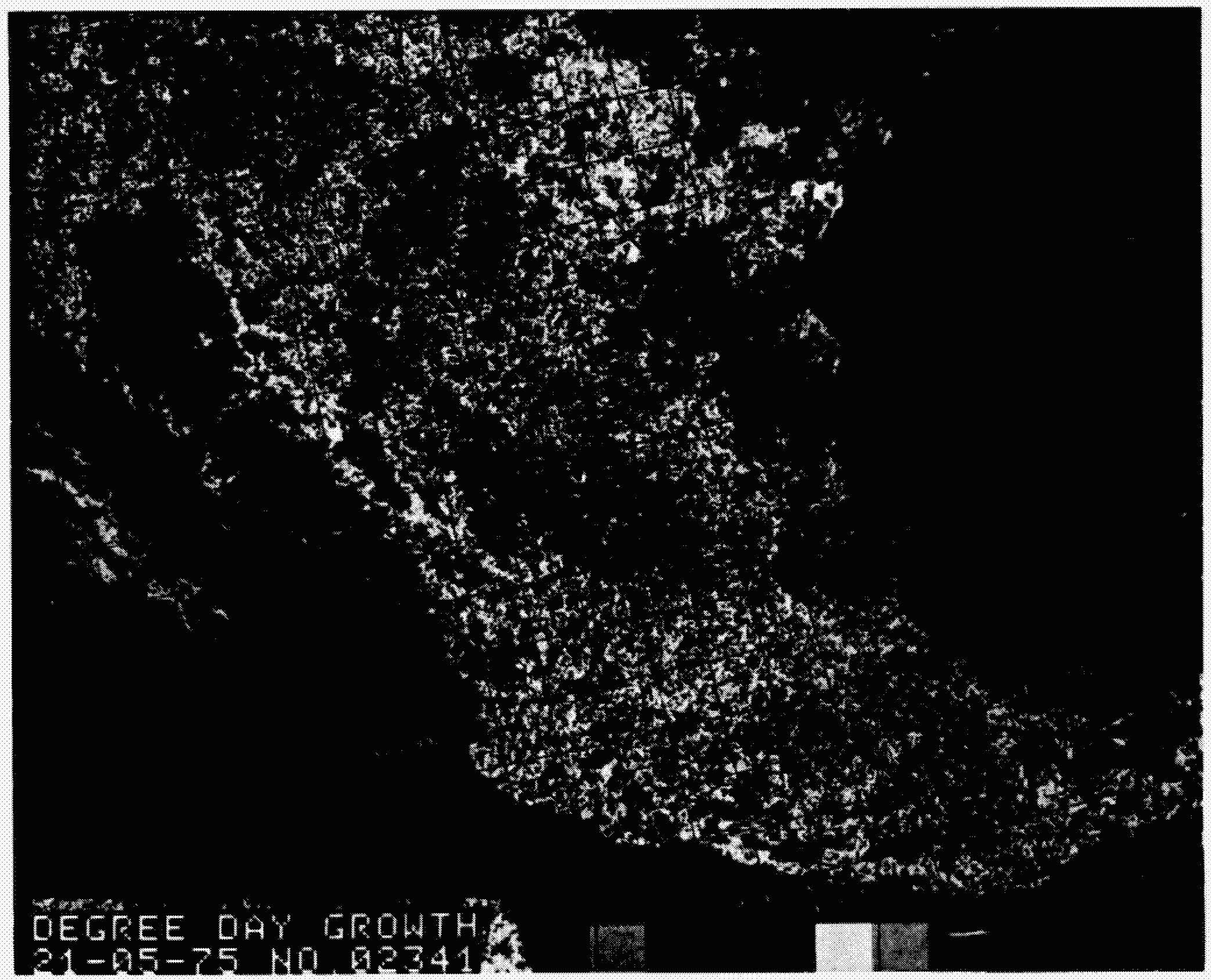

Degree Day Growth – Figure 16. – The length of the pupae phase is a function of temperature and is calculated through a modified degree day summation. The potential for screwworm development is shown here as a function of the length of the pupae phase. It is color coded in the same manner as figure 13.

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