TECHNICAL MEMORANDUM

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151290

EXTENSION OF SURFACE DATA BY USE OF METEOROLOGICAL SATELLITES

Job Order 92-105

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Houston, Texas

Contract NAS 9-12200

For

HEALTH APPLICATIONS OFFICE
LIFE SCIENCES DIRECTORATE

National Aeronautics and Space Administration
LYNDON B. JOHNSON SPACE CENTER
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TECHNICAL REPORT INDEX/ABSTRACT

(See instructions on reverse side.)

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13. ABSTRACT

Ways of using meteorological satellite data to extend surface data are summarized. Temperature models are prepared from infrared data from ITOS/NOAA, NIMBUS, SMS/GOES, or future Landsat satellites. Using temperatures for surface meteorological stations as anchors, an adjustment is made to temperature values for each pixel in the model. The result is an image with an estimated temperature for each pixel. This provides an economical way of producing detailed temperature information for data-sparse areas, such as are found in underdeveloped countries. Related uses of these satellite data are also given, including the use of computer prepared cloud-free composites to extend climatic zones, and their use in discrimination of reflectivity-thermal regime zones.

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SUMMARY

After an introduction to the needs of data-sparse areas, ways of using meteorological satellite data to extend surface data are summarized. After these general comments, a specific system is suggested for the extension of meteorological data from surface stations for neighboring areas, using information from infrared sensors of meteorological satellites. Models are prepared from infrared images of ITOS/NOAA, NIMBUS, SMS/GOES, or future Landsat satellites. These models are adjusted, by zones, to daily mean air temperatures as reported from existing standard weather stations to produce complete grids (or images) of temperature information. The products can be images or tabular data, both of which can present daily mean air temperature estimations at 1 to 10 kilometer resolution over large areas.

The system is applicable to mean air temperatures, and with certain modifications, to summations of degree-days and averages; it can also be easily adapted to the production of user-oriented thematic products. It can produce data for normally data-sparse areas, and once the model is made, it can do so at a very modest cost. It can also be used retroactively and could be most beneficial to developing countries.

A temperature model, called the delta-T field, was used in the Screwworm Eradication Data System. Experience with this model suggests that a system based on a model can work quite well.

1. INTRODUCTION

This report discusses some new ways of machine processing of remotely sensed data. It presents some ways of taking past imagery data from a sensor, processing it in a hybrid system with a few point data from ground stations, to get real-time imagery data, rather than acquiring images in real-time. These systems could be useful for two reasons: (1) data can be obtained to extend surface data in data-sparse areas; and (2) certain data can be obtained much less expensively. These procedures are available for many users who cannot afford the high cost of extensive computer operations.

1.1 DATA-SPARSE AREAS

The greatest need for satellite data exists in countries that are underdeveloped. Despite the need, these countries lack the means for developing sophisticated computer systems. Since they also lack adequate transportation and good communication systems for distributing real-time data, especially in meteorology and climatology. However, until recently, even the most basic systems have been quite expensive.

1.2. LESSONS FROM THE SCREWWORM PROJECT

The screwworm eradication program in Mexico, an experimental system developed by NASA's Health Applications Office, has provided a constructive example. To summarize, high resolution radiation temperatures from the ITOS/NOAA meteorological satellites were registered to a common grid, and then were used to estimate mean air temperatures. From these, products were prepared that predict screwworm behavior. Satellite data were processed daily to produce estimated air temperature, heat summations, and many other valuable products (ref. 1).

Although the screwworm program used ITOS/NOAA satellites, it could have used geosynchronous SMS/GOES satellites, or polar-orbiting NIMBUS satellites. Whereas NIMBUS satellites are experimental, the ITOS/NOAA and SMS/GOES satellites are operational with few sensors, high redundancy, and high reliability. SMS/GOES satellites are limited to the western hemisphere, although similar satellites will be launched in 1978 for the rest of the world. The SMS/GOES satellites produce half-hourly data, day and night, but the ITOS/NOAA and NIMBUS satellites furnish data once by day and once by night.

The Screwworm Eradication Data System has shown the great utility and practicality of several kinds of data at grid points covering large land areas. The most useful proved to be daily mean air temperature images, registered to preexisting maps from satellite data with a ground resolution of several kilometers. Also useful were products derived from these temperatures, such as heat summations.

1.3 HYBRID SYSTEMS WITH BOTH SATELLITE AND GROUND DATA

On an operational basis it is always possible to combine surface and satellite data. From the beginning, the screwworm program required some soil moisture information that could not be derived from the present generation of meteorological satellites. In addition, daily weather station temperature data were substituted for satellite data from areas hidden by clouds, producing a hybrid system. The next logical step was not taken, which would be to use satellite data only for extending surface data. This is an attractive possibility, especially because of the lower cost.

The screwworm project showed how expensive the daily real-time use of satellite data can be. The logistics of handling images on computer tapes turned out to be a major problem, and the

Figure 1. – Composite day infrared image from VHRR of ITOS-F/NOAA-4.

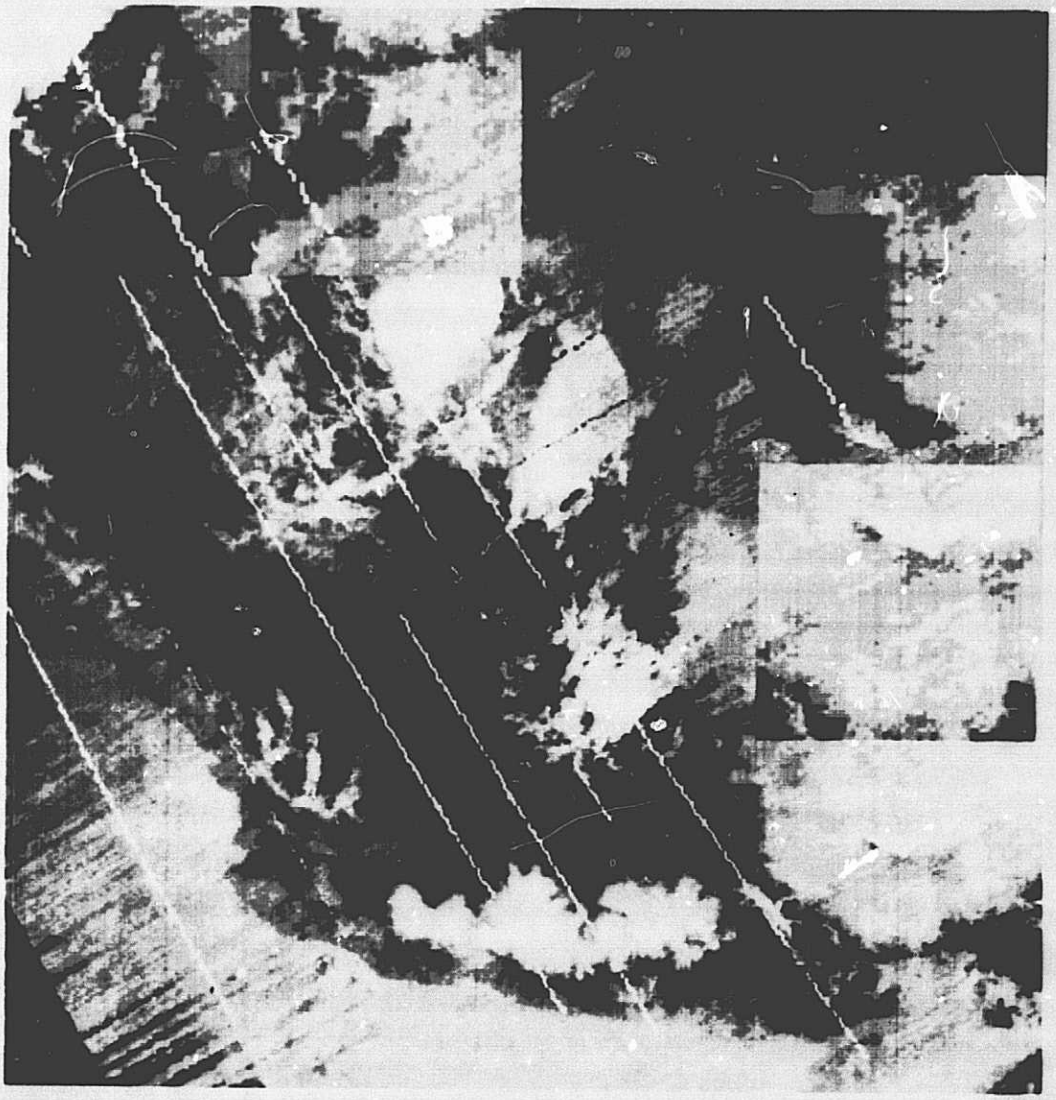

Figure 2. — Composite night infrared image.

Figure 3. — Composite visible infrared image.

extensive processing required to digitize, register, calibrate, and produce the various products was expensive. Although the type of data produced by the screwworm system would be useful for data-sparse areas, it would be much more feasible to produce the same information in a less expensive way, using hybrid systems.

2. COMPOSITE IMAGES

The methods used to prepare composite images were not new to the screwworm program. These techniques have long been used by oceanographers for measuring surface temperatures of the ocean. Still, the registration and calibration of images in the screwworm system probably provided the first opportunity for using these techniques over land. Certainly, it was the first time that registered images were available at resolutions of a few kilometers over an area as large as Mexico.

Figures 1 and 2 show day and night thermal infrared composite images prepared by D. Phinney and G. Arp, (ref. 2). These were combined by selecting the highest temperature for each pixel from several well registered images. In this way, clouds are automatically eliminated in favor of land if both represent the pixel in two different images. Figure 3 shows a composite of visible images; since clouds reflect more than anything else in the scene, the lowest radiant energy in this case is selected for each pixel. In both cases, the composites can be made from as many images as necessary to prepare absolutely cloud-free images. However, the greater the number of images, the greater the risk of problems caused by registration errors on one or another image.

2.1 USES OF COMPOSITES

Many potential uses of these images exist. Phinney and Arp have made imaginative use of them to extend emissivity measurements made on land. They took the three composite images and ran them through standard LARSYS clustering programs, which resulted in a delineation of what might best be called combination reflectivity-thermal zones or regimes for each of the four seasons of the year. They related these zones to zones of constant emissivity, which, they found, corresponded to vegetation zones.

2.2 COMPOSITES AS MODELS

Composites could also be used as temperature models for isolated areas, such as in Africa or Asia. This is a relatively inexpensive way of extending several kinds of temperature measurements to isolated areas, applicable to any area in which cloud-free images can be obtained. Although a few areas are always covered with clouds, some cloud-free images are available almost everywhere.

These images, then, can be related to climatic data such as mean isotherms. For example, climatic zones can probably be extended simply by comparing ground measurements with patterns on composite night thermal infrared images. Beyond these qualitative uses, these models can be used to extend data from sparse networks of ground weather stations, as discussed in the next section.

3. EXTENDING MEAN AIR TEMPERATURE MEASUREMENTS

3.1 USE OF MODELS IN THE SCREWWORM PROGRAMS

In the screwworm eradication program, a way was needed to handle cloudy areas and other areas for which data was lacking. Since only one satellite pass could be processed per day, and since Mexico is wider than a single satellite pass, there was always some missing data. In addition, coverage was often lost because the southern portion of Mexico at Tehuantepec was just at the limit of line-of-sight reception.

As originally designed, there was no provision for background images, such as would be required for introducing a temperature model. An algorithm was written into the system which brought forward yesterday's data if today's was missing for any reason; that is to say, yesterdays temperature values were used as a non-adjustable model for today's temperature. Unfortunately, this led to serious errors which propagated into virtually all products of the system. As the need became more obvious, ways were found for incorporating background images into the system to supply missing data.

3.2 THE HYBRID SCREWWORM SYSTEM

Boatright generated the algorithm actually incorporated into the screwworm system (ref. 3). His algorithm generated a temperature model internally from the system and applied it to areas with missing data. Generating the model internally requires regular real-time data processing, appropriate for the screwworm data system, but difficult for the data-sparse areas. For under-developed countries, an external model would be preferable.

It should be noted that the use of this model in the screwworm program made the difference between a fully operational system

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It should be noted that the use of this model in the screwworm program made the difference between a fully operational system and one that was only marginally useful. For cloudy areas it produced results that were usually as good as the data derived from the satellite, and often much better (ref. 4).

3.3 MEAN AIR TEMPERATURES

The screwworm system was not designed to produce radiation temperature, the data most directly derivable from satellites. Instead, it produced mean air temperatures derived statistically from the radiation temperatures by an algorithm defined and implemented by Phinney (ref. 1). For missing data, the mean air temperature was obtained from reported mean air temperature from ground stations in the international network, and extended to other areas by using the internal model.

It is important to note that the screwworm data system is a prototype hybrid system, which extends surface data by satellite techniques when satellite data are lacking. It has worked well in the past and it has produced valuable data.

4. ELIMINATING THE SATELLITE

The very success of the screwworm system brings up the question of using satellite data for this use. Do we actually need satellite data, once we have the satellite-derived model? As far as the screwworm program is involved, this question has not been resolved. However, the same program demonstrates conclusively that mean air temperatures can be estimated quite well in data-poor areas. After a model is constructed, there exists a truly economical way of extending mean air temperature estimates from a limited number of reporting stations. In particular, this type of system will give dense data in areas where an extensive network of ground stations cannot be established.

4.1 ADVANTAGES OF A SYSTEM WITHOUT SATELLITES

Some advantages of such a system are listed below:

- It can provide mean air temperatures that are otherwise unobtainable because of lack of stations, clouds, or other factors. It should be especially useful for the developing countries.
- Once the temperature model has been prepared, the system is extremely economical. Since extensive calculations need only be performed on the surface station reports, computation is simple and can be performed on very small computers.
- It bypasses the atmospheric attenuation problem for routine processing of satellite infrared data. This is important because variations in moisture content of the air can cause two or three degrees centigrade errors in radiant temperatures. Although some ground humidity measurements will give useful data, there are no available humidity sensors for the entire atmosphere that can be incorporated into operational systems. Errors caused by variations of humidity can propagate into the mean air temperature in the screwworm system, but the

quantitative error it causes is only now becoming known. This problem is mostly bypassed if a good model is used.

- A mean air temperature is not an instantaneous one; it is averaged over a day. Therefore, some compensation for cloudiness effects and other variables is inherent.

- The horrendous registration problem is also bypassed. By the same token, a large amount of operator interaction is also bypassed.

4.2 DISADVANTAGES OF A SYSTEM WITHOUT SATELLITES

Some of the disadvantages of this kind of system are listed below:

- Errors in temperature can be caused by mixed cloudy and clear areas. The error will tend to be smaller if the influence zones (areas whose temperatures are referred to the same ground station) are smaller (the number of ground stations is increased). However, the mean air temperature is itself an average. On a given day the reporting station has probably been both clear and cloudy and the effect should average out.

- For areas that are very cloudy, it may be difficult to obtain cloud-free images to make the model. In some cases it may be necessary to make a model using altitude data only. Models for parts of Panama, for example, would be difficult to construct any other way. However, once a good model is made, data would be extremely good, probably better than areas with variable cloudiness.

- The model may not be linear, as was the one used in the screwworm system. It may be necessary to modify the model according to some function of temperature or other variable.

4.3 DISCUSSION

The system is an interesting empirical one that is directly tied to surface reports. It is exact at the controlling stations, and its precision depends more on proximity to a ground station than it does to a theoretical concept of thermal radiation and balance. It uses the power of hybrid systems, borrowing the best features of both surface and satellite systems, at least if a satellite-derived temperature model is used. Values get better as the number of stations increase, and grow poorer as they become more sparse. The degree of accuracy of such a system needs to be determined.

This system can also be used retrospectively. Weather conditions of ten years ago can be studied if weather station data is available.

5. CONSIDERATIONS ON A NO-SATELLITE SYSTEM

For screwworm data processing, D. Phinney implemented the zone of influence system shown in figure 4. Each zone has a reporting meteorological station somewhere near its center. Since the microclimate is mostly controlled by distance, the distribution of zones roughly surrounds the stations. Since distance is even more important than surface structure, the drawing of zones is best done in this way.

5.1 TEMPERATURE MODEL

The temperature model is a consistent set of temperatures for the influence zones or for the entire field. It is to be applied according to the temperature reported by the central station in each zone. For example, if the model value for a central station is 20 degrees, and the station reports 25 degrees, 5 degrees will be added to all elements in that zone.

This discussion concerns only mean air temperatures. It could also be extended to extreme values. However, the most useful applications may well involve heat summations and averages, which are discussed in the next section.

5.2 SUMMATION PRODUCTS

Heat summations seem to be the most important factor governing maturation of crops. According to some formulations, if water is accessible and soil conditions are adequate, the degree-day formulation will predict harvest dates very well. However, in isolated areas, it is quite difficult to measure these factors. The system discussed here will estimate summations even more precisely than it estimates mean daily temperature, since the summations are more highly smoothed.

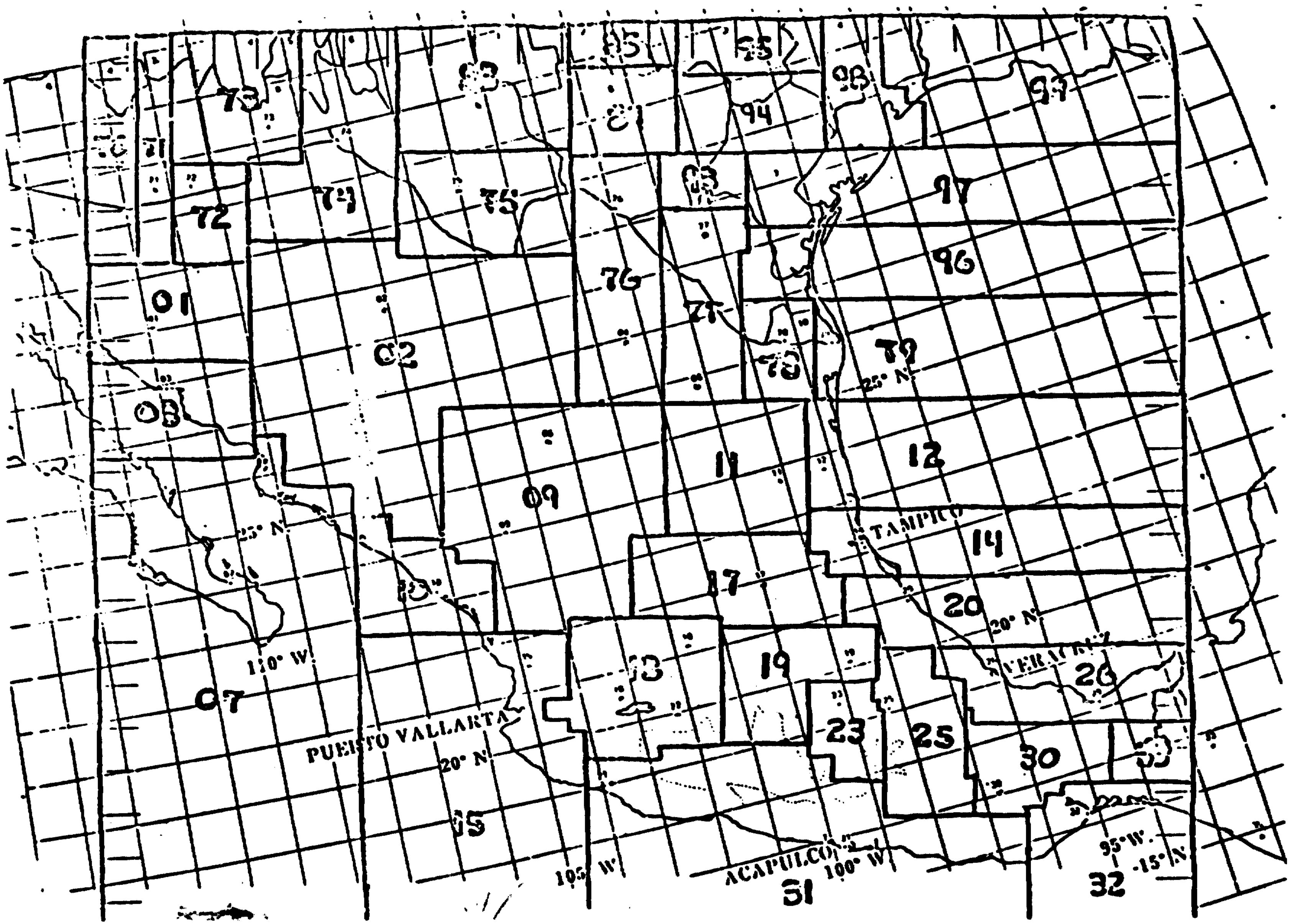


Figure 4. — Zones of influence.

5.2.1 AVERAGE MEAN TEMPERATURE

The simplest summation product is the mean air temperature averaged over several days. In the screwworm project, it was found most convenient to maintain two such averages, one over four days and the other over fourteen days. In the computation of data for a complete image, the daily mean air temperature is averaged over the desired days, and this new average extended by the model. If the model is at all good, the system will produce very detailed information with a high precision and resolution. The computations that need to be made are truly minimal.

5.2.2 DEGREE-DAY SUMMATIONS

The degree-day formulation can be more complicated if degree days are accumulated over some base temperature. For example, for the summation of degree days over 20 degrees, a 30 degree day would accumulate 10 degree days, a 20 degree day would accumulate no degree days; and a 10 degree day would also accumulate 0, <u>not</u> a -10 degree day. This feature slightly increases the complexity of the calculations. It will still be economical, except in varied terrain or in transitional periods, such as early spring or late fall.

5.2.3 COMPUTATIONAL SIMPLICITY OF SUMMATION PRODUCTS

Note that in most cases, daily mean temperatures do not need to be calculated. For example, if a five-day mean air temperature is needed, ground station data is averaged over these five days, and data are extended by use of the model. The entire calculation is not different than the daily mean air temperature calculation.

For degree day summations, the situation is more complex. In general, mean air temperatues would be needed only for those days colder than a given temperature, and then only the affected zones would need to be calculated; the rest could be handled on the basis of control station temperatures.

5.3 APPLIED PRODUCTS

One of the important contributions of the screwworm program was a demonstration of the usefulness of secondary products, that is, numerical interpretation of the data in terms of variables of interest. Figure 5 shows a specific example of this. Although this figure is labeled short-term temperature average, it displays the effect of a four-day temperature average on a screwworm population. For example, on the original figure in color, deep red indicates that the interpreted value is numerically 3, suggesting that an existing population from one generation to the next will grow by a factor of 3. If it has a density of 300 per square mile, it will be closer to 1000 in the next generation because of favorable temperature.

This is a simple and useful form of interpretation that can also be done economically. If screwworms were to be eradicated from South America using daily satellite data, as in the screwworm data system, several new receiving stations would need to be built for receiving and processing satellite data (the present screwworm program uses data from existing NOAA stations, which are not within line-of-sight of satellites over South America). However, the system described here would provide a cost-effective substitute.

For agriculture, these applied products can be prepared inexpensively. For example, if optimal temperatures for growing corn are known, the interpretation can be programmed very easily by incorporating a lookup table or an explicit function.

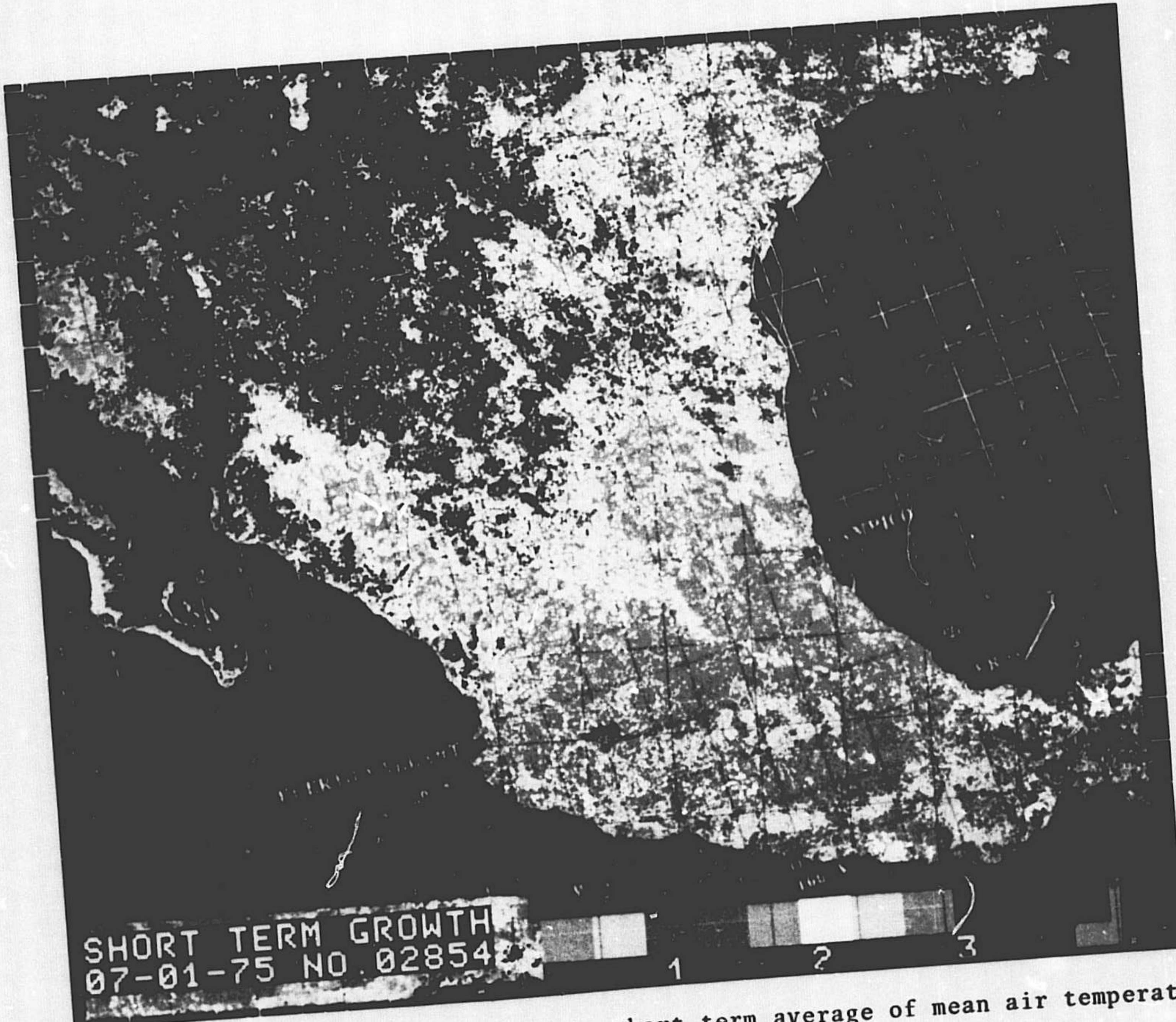


Figure 5. — Screwworm potential due to short term average of mean air temperature.

6. SPECIFICS OF A SIMPLE SYSTEM

The comments in this section are addressed to the construction of a minimal system for production of temperature products. Assume that an isolated area of eastern South America, in Brazil, is to be studied. The system will produce one of each product that has been previously mentioned.

6.1 TEMPERATURE MODEL

Images will need to be collected for the area of interest. An arrangement would be made with the National Environmental Satellite System of the National Oceanic and Atmospheric Administration (NESS/NOAA) to record a series of day and night images from nearly consecutive days. Images might also be taken from receiving stations within line of sight. All these images need to be registered to a common grid. Then the images must be converted into cloud-free composite images which will serve as base for the models. These will need to be converted into a consistent mean air temperature map, perhaps using the same algorithm as used by Phinney.

These operations taken together are quite complex and constitute the most expensive part in the system. However, they need to be done only once (or at most, a few times), and they can be done on any large computer system.

If raw imagery for some regions is not available, other models can be constructed. The simplest ones involve the encoding of altitude information from topographic maps, which are generally adequate for this use. For some areas, side-looking airborne radar images might furnish the altitude data, which would later be converted to a self-consistent temperature image.

6.2 EQUIPMENT AND CALCULATIONS

After the model is made, day-by-day operations and equipment are economical. A modest computer with only limited memory will be adequate. The model must be furnished to the computer, which would require a card reader, a tape drive, or some other device for handling a large array of numbers. The results of the calculations, which also consist of large arrays, can be produced in several forms. Appropriate devices include typewriters or line printers on the least expensive system; however, preparation of images in other forms would require more expensive devices such as tape drives and television monitors.

Meteorological data will need to be received from ground stations, by phone or by telegraph. All will need to be examined for consistency. Missing reports could be simulated from the nearest stations, and obvious errors, such as decimal points, could be corrected. These data might then be entered into the system by the typewriter input for the typical small computer.

For daily mean air temperature, the model could be read from the appropriate device. Corrections to the model would be made in a single pass. Based on the surface data and the output, the mean air temperature for that day would be produced as a map or image.

For the average temperature of a given week, the surface temperature reports would be averaged, using the same data as used above. The average is then fed into the computer in the same way.

To prepare a degree-day sum image for all days in which temperatures are above the base temperature, the sum of the daily temperatures are used. For days which might produce negative values, individual passes through the computer summing positive values for each pixel and bypassing negative ones are used. This would be longer, but since it is only an occasional operation, is would not be burdensome.

It will also be possible to calculate some applied products. In this case, the lookup table or the function itself must be incorporated in computer memory and applied to the data.

6.3 DISPLAY OF RESULTS

The end use and the available money will control the options needed for display of data. For some uses, simple tables of data may be sufficient, and greymaps, or symbol density maps, can be made on the typewriter of the typical small computer. Figure 6 shows a sample symbol density map. More expensive and complex images can be produced in any of a number of grey scale formats, as well as in color.

For more traditional uses and if the computer is large enough for contouring programs, images can be produced on a plotter of some sort. However, in general, contours can easily be plotted by hand on greymaps.

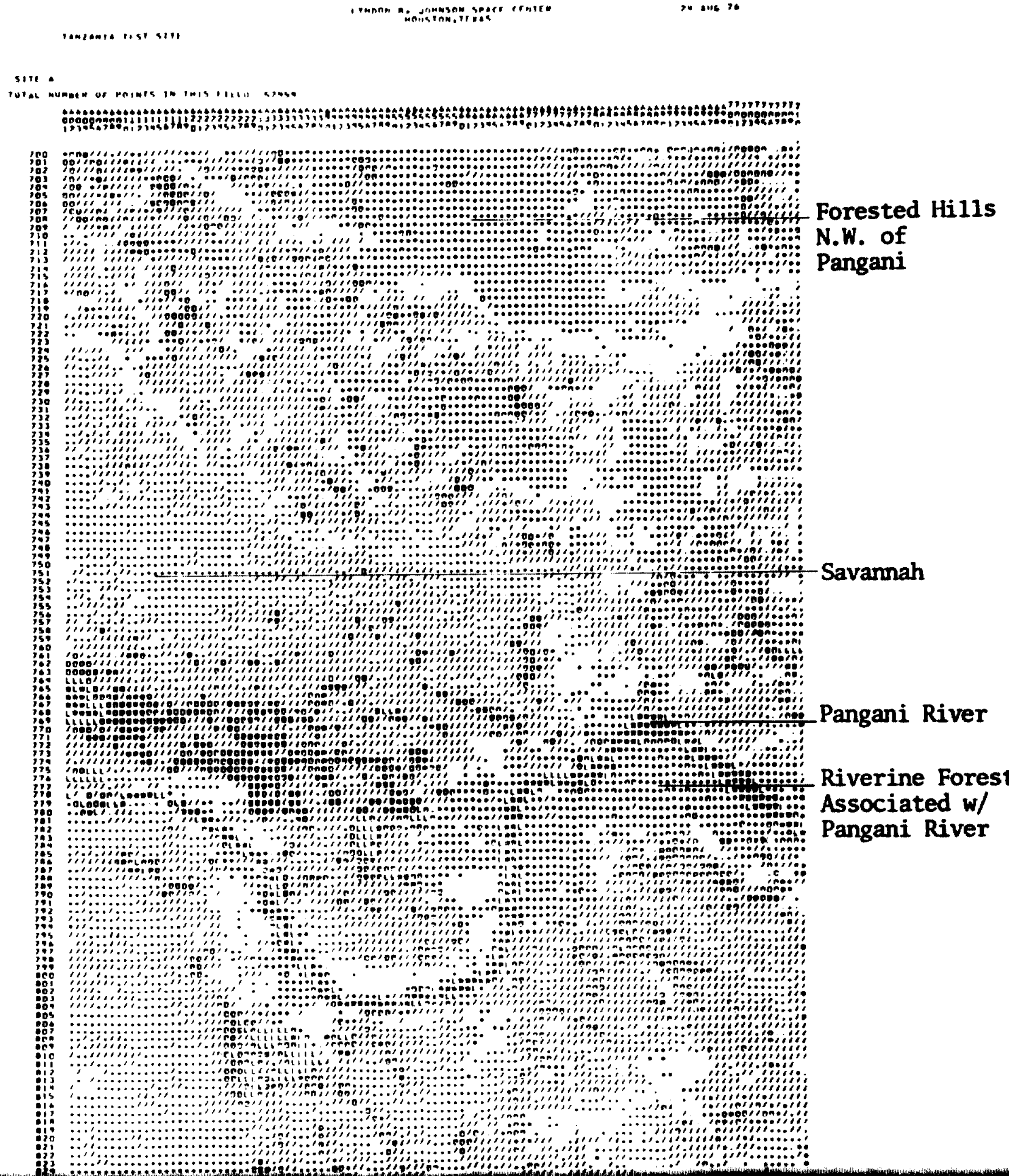
6.4 COMMENTS

It should be noted that the system benefits from close attention. For example, the regression equations used to relate mean air temperatures to night infrared radiation temperatures may need to be adjusted constantly. Therefore, the model should be checked constantly for systematic variations. For example, at one time during operation of the Screwworm Eradication Data System, a north-south bias showed up in the screwworm temperature model. Although this bias disappeared with time, other biases may well appear which will have to be handled by manipulating the model.

Archiving of data is extremely simple. In the screwworm project, the logistics of archives were burdensome; to allow data to be reprocessed, entire images needed to be stored. With this system, only data for control stations need be saved. In the screwworm program, this would have given a reduction in data storage of about 1 in 10,000 or so.

ORIGINAL PAGE IS
OF POOR QUALITY

Enlarged area in approximate test site region 5°29'S X 38°52'E
Scale ≈1:24,000
2 channel (2, 4), 7 class, soils analysis
Ground truth derived from jog series 1501 air, sheet SB 37-6, Ed. 2-6565



FOLDOUT FRAME

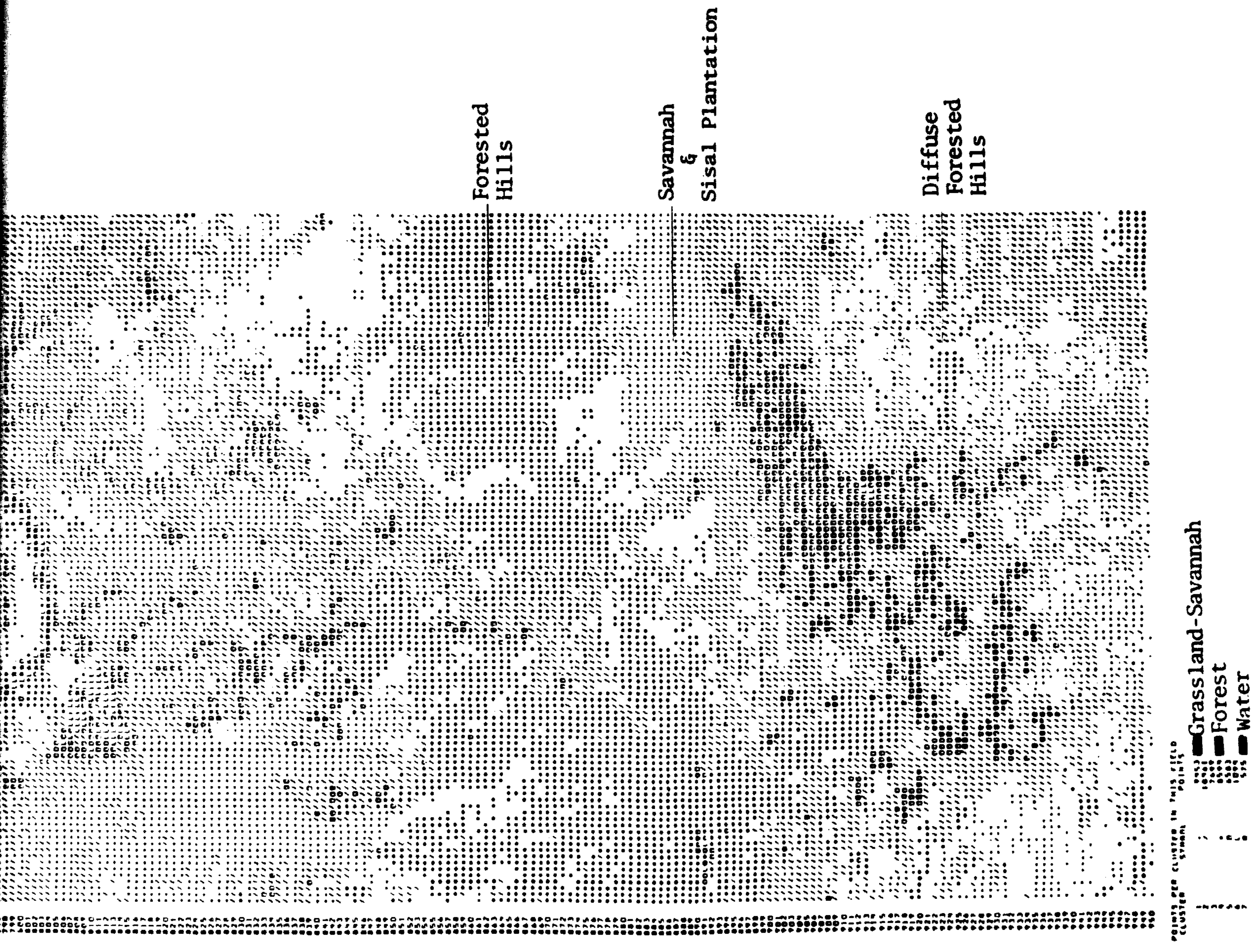


Figure 6. — Typical symbol density map (greymap).

The system is affected by bad data values. For example, in the screwworm program there were cases in which decimal points were misplaced somewhere in the communications link, probably by a telegraph operator reporting messages to Mexico City. However, since only a finite number of points are handled (20 or 30 in the case of the Screwworm Eradication Data System), an operator should be able to screen them quite easily.

7. SATELLITES

So far, the discussions have been limited to the ITOS/NOAA series of satellites, specifically NOAA-2 through NOAA-5. For resolution near 1 km, it is necessary to use the very high resolution radiometer of this satellite. This implies that recorded data will be used for preparation of background images since most areas of interest will not be in range of the existing ground station. On the other hand, if less resolution is needed, directly received images from the scanning radiometer of the same satellites, or the radiometers on any of the various SMS/GOES satellites, as well as other more experimental satellites, could be used to prepare background images.

If more than 8 km resolution is not needed, the Visible Infrared Spin Scan Radiometer of the SMS/GOES satellites will probably be the most useful. These remarkable operational satellites, operated by NOAA, furnish images every half-hour, day and night, offering much data that can be used to prepare the models. The two SMS/GOES satellites presently in operation furnish very fine images of the western hemisphere, and by 1978, new satellites will be placed in three locations over the rest of the world. The data from these satellites is very high in quality, providing, for example, a daily temperature map of all of South America. The geostationary orbit of these satellites offers another advantage, and registration problems are about the same from day to day. In addition, registration parameters will soon be furnished by NASA with each image tape. (Both NASA and NOAA are involved with the use of these satellites, but in general, tapes are only available from NASA.)

The lower resolution scanning radiometer of the NOAA satellites could also be used, as could data from the various NIMBUS satellites. The advantage of these sensors is that data are recorded as a matter of routine and are available for the entire world. The disadvantages are their 8-km resolution lower than ITOS/NOAA, and the need to register their data to maps. Still the registration needs to be done only enough times to ensure the preparations of a cloud-free composite from several images.

Two other sources of higher resolution radiation data cannot be bypassed. The Landsat-3 satellite will have a thermal scanner with a 300 meter resolution, allowing us to study areas quite intensively. Registration will be very simple with these images, and very fine models will be very easy to prepare. Models could also be prepared without satellites, using thermal scanner data from aircraft. This might be needed for very detailed studies of certain areas, but in general, this method involves many problems.

8. CONCLUSIONS

Using a model for meteorological data is not a new idea; it has been used by meteorologists in the past to solve some problems. However, the concept is now very feasible for wide practical application. The availability of satellite data makes the construction of temperature models much more feasible than before. A specific system such as described in section 6 is now feasible for many areas and many applications which were not feasible before.

It is appropriate here to say that this is not a cure-all system without theoretical or practical problems. It will have to be operated by a person who understands it well in order for it to work well. However, it is evident that for data-sparse areas this system should work well, furnishing data otherwise unobtainable.

The emergence of this system evolved as a byproduct of the space programs. Due to its successful use in the screwworm project, it can now be proposed as an inexpensive system to others. However, it needs to be tested intensively.

9. REFERENCES

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2. Ibid, P. 4-3 to 4-6

3. Boatright, J.: Screwworm Eradication Data System (SEDS) System Software Performance Specification. JSC-10090, section 3.8.

4. Reference 3, section 4-5.

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