The Space Congress® Proceedings

1980 (17th) A New Era In Technology

Apr 1st, 8:00 AM

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ABSTRACT

This system used data from the Geostationary Operational Environmental Satellite (GOES) to derive and display surface temperature distributions throughout peninsular Florida on cold nights. These distributions, in conjunction with ground meteorological data, provide inputs to mathematical models which predict temperature distributions up to 10 hours in advance. This system is being developed by scientists at the University of Florida Institute of Food and Agricultural Sciences (IFAS) in cooperation with and sponsored by the National Aeronautics and Space Administration (NASA), Kennedy Space Center (KSC) supported by the National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS). The system has been installed in the NWS facility at Ruskin, Florida, and has been operated in an experimental mode by NWS forecasters for the past three winters. The primary purpose of the system is to provide a tool for use by NWS weather forecasters to permit more timely more complete and more accurate temperature data for use by agricultural interests on nights when their crops are threatened by a cold wave. This better information can result in more timely decisions in the use of frost protection techniques thus deriving substantial benefits in terms of cost savings and crops protected and salvaged.

INTRODUCTION

Because of its temperate climate, Florida is a major producer of agricultural crops subject to cold weather damage. Among the foremost of these is citrus, with over 800,000 acres in production. This represents about 1/3 of Florida's agricultural production. Approximately 10%, or 88,000 acres, are equipped with frost protection systems, including oil burning grove heaters, wind machines, and irrigation systems (1). The most commonly used is the heater. The cost of frost protection has escalated dramatically with recent escalation in oil prices.

Improved cold weather prediction can save money in several ways. One is in minimizing unnecessary standby time by crews and supervisors which has been estimated to cost $36,000 per hour statewide. Another is in reduced costs of unnecessary activation of frost protection systems, such as savings in energy consumed. A third is in increased crop yield when protective systems are employed successfully.

It is the responsibility of the Federal-State Agricultural Weather Service at Ruskin, Florida, operated by the National Weather Service (NWS) of the U. S. Commerce Department's National Oceanic and Atmospheric Administration (NOAA) to alert growers when cold weather is likely to be severe enough to pose a hazard to their crops. Specific minimum temperature forecasts are issued routinely November through March. The procedures for issuing these forecasts are discussed in more detail in the Appendix. The temperature is normally expected to drop below 36°F about fifty times each winter. Under these conditions, many vegetable and ornamental crops are threatened. Most citrus is subject to damage when the grove temperature drops below 28°F for three hours or more. When such conditions threaten, which occurs about twelve times each winter, citrus growers with freeze protection systems set up standby operations to initiate action if necessary. A major freeze is relatively rare, occurring on the average of about once every five years.

BACKGROUND

As an agent of the State, the Institute of Food and Agricultural Sciences (IFAS) at the University of Florida has traditionally played a major role in cooperation with other State and Federal agencies in support of Florida agricultural interests. This has included support to the NWS temperature forecast function in monitoring temperature measuring stations, in analyzing data, and in the development of predictive models. This included early work in development of the radiation balance model by Jim Georg and Dr. John Gerber.

Another area of significant IFAS activity involved support to the State in evaluating the impact of the proposed restoration of Lake Apopka. Florida agricultural interests have long known about the warming effects of large bodies of water (3). This has led to the concentration of citrus groves where suitable land is found near large lakes, such as south of Lake Apopka, and lagoons, such as the Indian River. The dependence of growers on such natural freeze protection systems was a major factor in the development of the Florida Satellite Freeze Forecast System (SFFS).

With increasingly serious pollution of Lake Apopka, extensive studies were initiated to identify a technique for cleaning the lake after the sources of pollution were removed. The most promising approach was to drain the lake, exposing the sediment laden bottom for an extended period of time. This was expected to consolidate and solidify the bottom so that, on reflooding, it would remain firm and not become resuspended.

However, draining the lake would pose a serious threat to citrus groves dependent on the lake waters for freeze protection. In support of the Lake Apopka restoration project, studies were initiated to better delineate the lake effect and pinpoint the adverse impact of a low lake level during cold weather.

Involvement by the National Aeronautics and Space Administration (NASA) John F. Kennedy Space Center (KSC) through sponsorship of IFAS research into heat transfer mechanisms began during early stages of the Lake Apopka restoration studies in 1973. Under its program for development and application of remote sensing technology to management of earth resources, NASA agreed to support the lake effect investigations by providing funds for IFAS research and making equipment and facilities available for collection and analysis of remote sensing data. Development of the radiation balance model was expanded during these studies by Dr. Jon Bartholic and Dr. Robert Sutherland. The results of this investigation, in conjunction with the operational availability of the Geostationary Operational Environmental Satellite (GOES) data, inspired the concept for the SFFS.

Development of the SFFS was formalized as a cooperative effort between NASA and NOAA in 1977 under sponsorship of NASA's technology transfer program. In support of this program NASA has provided funds to IFAS for system implementation and supporting research, and has procured the system hardware. NWS has provided the facilities for system operation, operating personnel, and some items of supporting preipheral equipment. In addition to the work performed under contract to NASA, IFAS has provided a backup computer system and has supported the program with additional personnel and equipment at State expense.

SYSTEM OPERATION

The operational concept of the SFFS is schematically shown in Figure 1. The key system elements are the surface temperature distribution data from the GOES satellite, the ground meteorological data from ten key stations located throughout the State, the central computer at the NWS Ruskin Station which contains the two math models (P-model and S-model) and the data output and display.

The SFFS will normally be activated at 6 p.m. on an expected "cold" night by the NWS forecaster at Ruskin. The National Meteorological Center (NMC) digital data files near Suitland, Maryland, will be automatically accessed and the most recent satellite temperature map will be displayed at Ruskin. The ten key stations will be automatically queried in sequence and the ground meteorological data acquired. This automatic data acquisition sequence will be initiated each hour as required. After two to three sets of data have been acquired (usually 6, 7, and 8 p.m.) the physical model will be activated to generate temperature predictions for each hour of the night at each of the ten key stations. The statistical model will then be activated to correlate the observed satellite temperature distribution with the predicted key station temperatures to produce the predicted temperature distribution map of the State. The models can be reinitiated periodically throughout the night to update the predictions with more recent data. Provisions are planned to allow the forecaster to simulate expected changes such as winds or cloud cover and to determine their effect upon predicted temperatures.

SYSTEM DESCRIPTION

The following paragraphs contain descriptions of the key system elements shown in Figure 1 and the communication links between them (4).

Satellite Data

The satellite data input is provided by the GOES-2 satellite orbiting the earth in a geostationary orbit at approximately 22,300 miles above the equator. The GOES sensor is the Visible Infrared Spin-Scan Radiometer (VISSR) which operates in the 10.5 - 12.6 micron wavelength band. The directly sensed brightness temperature is effectively the surface temperature in the absence of atmospheric moisture. However, some atmospheric attenuation normally occurs and the satellite sensed temperatures are generally somewhat lower than surface measurements. This effect is minimized (about $2^{o}F$) for Florida freezes, since they normally occur with the passage of cold fronts which are characterized by relatively moisture-free atmosphere. (2). This temperature difference can be corrected by use of ground truth measurements taken concurrently with satellite data.

Some difficulty has been experienced with the positional stability of the satellite data where a given landmark may be displaced on succeeding data maps. Under optimum conditions this apparent "wandering" of data pixels on a fixed map is expected to be controlled to approximately one pixel, which is acceptable for this application.

The digital data pixel represents a surface area about 8 x 8 km, and about 3,000 pixels are required to represent the land surface area of the Florida peninsula. The data are transmitted every 30 minutes from the satellite to the National Meteorological Center (NMC) operated by NOAA's National Environmental Satellite Service (NESS). The appropriate Florida sector is extracted at NMS and placed in temporary file available for access by the SFFS.

Early in the development of the SFFS, the satellite data input was obtained by re-digitizing the laser-fax GOES-TAP analog data. Concern about data distortion, availability of the appropriate grey scale conversion curve, and time required to re-digitize the data led to the decision to convert the system to direct use of digital data. Implementation of this decision has been in process for approximately one year.

A direct, automated telephone link has been established with the file management system at NMC. A special software driver has been developed for the NWS computer to cause it to appear as a terminal to the NESS file management computers through a port guarded by a Vadic 3456 modem. This modem is currently leased by the SFFS to permit other users of the satellite data to use the same port regardless of whether they approach the file manager by means of Bell modems or through Vadic modems. The Vadic 3467 has the capability to discern the nature of the modem from whence the interrogation is originating and mimic the communication protocol sufficiently to permit access to the port through different modems at the calling end.

The timing of the data transmission over the 1200 Baud telephone link is as follows. The entire sector of digital satellite data that had been selected for analysis (includes peninsular Florida) is composed of 129 x 129 or 16, 641 characters (pixels). Each character consists of 10 bits. The period of time involved in the transmission of the map is 166, 410 bits divided by 1200 bits per second or 2.3 minutes to receive a satellite map from Washington by phone line. (Digitizing the analog map arriving over the laser-fax circuit had required more than 10 times the period.) So far a typical voice grade line has generally been sufficient for this transmission.

At present time, gaining access to the NOAA/NESS file manager is not a problem because only one other customer normally competes for the port. This may become a problem in the future if the number of users exceeds the number of ports available to the file manager and the time that the manager has to service the requests is exceeded.

Key Stations

Currently there are 10 key weather stations over peninsular Florida that provide ground meteorological data to the SFFS. In the early phases of system development, the key stations were manned and data was transmitted verbally on request. Due to a number of operational problems, it was decided to automate the key stations as part of the general system upgrade which included conversion to digital satellite data.

The elements of the automated key station are diagramed in Figure 2. Thermistors are used to measure temperature at six levels, i.e., air temperature at 9 m, 3 m, and 1.5 m, surface temperature, and soil temperature at 10 cm and 50 cm. The air temperature probes are shielded from nocturnal radiation loss.

Wind speed is sensed at the 10 m level by a light-chopper anemometer. Counts are accumulated by a pulse counter so that the wind speed reported is the average over a previous 30 minute period.

Four of the key stations have net radiometers. These are currently of the shielded type but problems with moisture on and within the shields may force a change to a ventilated type.

The remote terminal units (RTU) are Darcom D303's. Such units have been used quite successfully to remotely monitor gas line flow for several years. They consists of a data coupler which functions as a modem to connect the RTU with a voice grade telephone line and facilitate 300 Baud data transmission. There are up to eight analog input ports with eight bit resolution (see block diagram in Figure 2). Six of these are assigned to temperature sensors, one to the net radiometer, and one to a reference voltage to provide a check on the analog to digital conversion. Darcom has developed a handshake system involving tones, timing, and a security code password format to assure that only bona fide master terminals have access to the RTU's data. The operating program is stored in non-volatile memory so that the system restarts without loss of operating functions in the event of long term power loss or severe power transients.

The operating firmware directs the RTU's microprocessor to gather and store information from inputs. Upon interrogation from the master computer, the firmware directs the microprocessor to check the validity of the interrogation, respond to the master station's commands and transmit the data. There are much more elaborate RTU's available that provide more flexibility in the scanning and integration of data prior to and during interrogation. However, the Darcom is quite inexpensive (about $800 each) and seems to provide an acceptable solution in this application.

MASTER COMPUTER & SOFTWARE

The automated data acquisition as well as the processing of the data collected is handled by a Hewlett-Packard 21MX-M minicomputer with 128 K Bytes of memory. Two 12589A Autodialers are necessary; one handles the 1200 Baud transmission from MNC through a Vadic 3400 modem and the other the 300 Baud transmission from the key station Darcoms through a Vadic 800. A 15 M Byte disc system facilitates the storage of sufficient maps and predicted temperature distributions to support after the fact analysis of the data.

To assist in system software development and troubleshooting, and as backup to the NWS computer during operation, it has been found necessary to establish a backup computer capability at IFAS, Gainesville. This consists of an IFAS owned HP 21MX-E with 64 K Bytes of memory and two 12589A Autodialers.

Physical Model

The Physical Model (P-model) is illustrated schematically in Figure 3. It accepts both satellite and key station data and uses energy balance techniques to predict future key station temperature which it passes to the Statistical Model (S-model). The P-model may be instructed to make predictions from one to 10 hours in the future. In effect the P-model assesses the temperature of the soil surface, i.e., a surface exposed to radiant cooling, and the heat stored beneath the surface that is available to replenish the heat lost from the surface to the cold sky. It moderates this heat loss by estimating the rate at which heat from the layer of air above the surface will provide heat to the cooled surface and in the process take on a lower temperature. The stability of this layer is indicated by the temperature profile above the surface and by the wind speed indicated at the top of the tower. In some cases the net radiant loss is measured directly by a net radiometer and this information is used collectively in an energy budget model to predict the rate at which the surface and adjacent air layer will cool assuming the conditions do not change during the night.

Another function planned for the P-model is the use of key station measured data to calibrate the GOES observed map for temperature differences due to atmospheric moisture.

Statistical Model

The Statistical Model (S-model) is illustrated schematically in Figure 4. It uses the actual satellite measured temperature data as input and spreads the key station predicted temperatures out into the form of a map much as that expected to be observed by the satellite several hours in the future. This model capitalizes upon a principal that has been useful in horticulture for many decades, i.e., that every radiant freeze tends to be very similar to past radiant freezes. Another way to say this is to indicate that the temperature distribution under calm, clear, and dry nocturnal conditions is much more a function of the local topography than it is of any other feature.

The S-model operates on the principal of correlation coefficients which relate each satellite data pixel to the five nearest key stations. By examining this relationship for a large number of previous freezes, a statistical base is achieved whereby the coefficients can be calculated to reflect the influence of local topography.

OUTPUT PRODUCTS

The output product is in the form of a brightly color coded temperature map observed by the forecaster on the CRT display. The display used at Ruskin is a 19-inch Conrac solid state broadcast color monitor, RHB 19/RS. Figure 5 shows the SFFS in operation at Ruskin with a NWS forecaster at the console.

Available for display are the two types of maps--the map of the observed thermal distribution over peninsular Florida and, in a very similar format, the map of the predicted thermal distribution. A series of predicted maps is possible. The system operators control the length of time over which the predictions are made in addition to several features on both the observed and predicted maps. For example, the operators can control the span of temperature over which the eight available colors equally divide the temperature span into zones on the map in which those temperatures exist or are predicted to exist.

There are several options available to the forecaster for data display. The most commonly used is the direct display of either the observed or predicted map. Another option provides a split screen display showing two maps, such as observed and predicted for the same time, two sequential observed maps for trend analysis, or two predicted maps. The capability also exists to select an area of special interest and show it enlarged in the corner of the screen. An option has been provided to overlay geographical features such as forecast zone boundaries or major highways to facilitate location and analysis of data. Figure 6 shows an example of a split screen output display with a predicted and observed thermal map. Unfortunately the impact and value of the brillant colors of the actual display cannot be conveyed with this black and white reproduction.

The citrus community has followed the development of the SFFS very closely and have expressed strong interest in its operational implementation (5). Decisions as to dissemination of the output products beyond the Ruskin NWS station requires further information and experience with the system. However, provisions are available to allow the products to be accessed at Ruskin by interested users such as TV stations, grower organizations, or county agents.

SYSTEM STATUS

This paper describes the SFFS concept as presently designed and under development. The system has been installed at Ruskin for the past three years and has been operated by the NWS forecasters in an experimental mode. During this time the display of observed temperature distributions over the state has been demonstrated and utilized repetitively. All data collection options have been demonstrated and much data have been collected and stored for future analysis. The P-model has been operated using key station and satellite data obtained through the earlier manual and analog systems as well as the present automated digital systems. The S-model has been demonstrated using coefficients derived from both analog and digital data. However, further work is required in refinement and operation of the digital coefficients.

Although the SFFS has been assembled and the concept demonstrated, there are certain problems yet to be resolved before the system can be considered fully operational. Most of these problems are related to the recently implemented system upgrade in automating the operation and in converting to the use of digital data. These problems are expected to be resolved within the next year, after which plans are to turn the system over from NASA to NOAA/NWS for their operational use.

It is expected that certain system refinements will be desired on a continuing basis as further experience is obtained. Through their traditional role of cooperation with the NWS in support of the Florida agricultural community, the Institute of Food and Agricultural Sciences at the University of Florida will be available to assist in such refinements.

APPENDIX

Weather Forecast Operation

The Federal-State Agricultural Weather Service at Ruskin, Florida, is responsible for all temperature forecasts in the State. Once the new features and capabilities of the SFFS are routinely available and their reliability is proven operationally, it is expected that the system will assume a major role in the weather forecast program. At present, however, the SFFS is used only to supplement conventional systems for issuing temperature forecasts.

Conventional System. The large scale (synoptic) meteorological analysis is done at the NMC, mostly by computer. The large scale prognoses of the atmosphere are also performed at NMC using numerical models.

During the winter season a Florida temperature survey network is maintained to (1) provide a temperature climatology of the peninsula's agricultural areas, (2) provide data for use by the Florida Citrus Commission in its deliberation concerning a fruit embargo following freezes, and (3) provide forecast verification data. Also available are some local objectives or semi-objective forecast techniques: (1) A set of statistical regression equations, where, knowing the minimum temperature, the equation provides an approximation of temperatures at 300 locations on the peninsula, and (2) use of "economical net radiometers."

Using the above data and information available to him, the forecaster must use his knowledge and experience to arrive at temperature forecasts for the peninsula's agricultural areas. On a given night, the forecaster may have available to him, in real-time, about 50 temperature reports.

Satellite System. On a clear night the use of the satellite monitoring system is like having 3000 thermometers reporting back in real-time. A benefit to the forecaster already realized is that a temperature analysis done from conventional spot temperatures gives only a gross picture of the real temperature distribution. Even with 8 km pixels, the satellite gives a more realistic temperature picture. This is a particular help for new forecasters. Using the monitoring capability the past three winters, the forecasters have been able to issue statements and update forecasts to growers at two-hour intervals. Since there was not enough information to do this with confidence prior to introduction of the satellite read-out at the NWS, only three forecasts per day were issued.

Once the prediction models are in routine use, the forecaster plans to forecast the input parameters for the P-model. This will allow the use of this model for the morning forecast, i.e., using this tool for a 24-hour lead time rather than a 12-hour lead time.

REFERENCES

1. Bartholic, Jon F., "First Quarterly Report on Application System Verification and Transfer (ASVT) Satellite Freeze Forecast System" Contract No. NAS10-9168. NASA-KSC. 1978.

2. Chen, E., L. H. Allen, Jr., J. F. Bartholic, R. G. Bill, and R. A. Sutherland. "Satellite-Sensed Winter Nocturnal Temperature Patterns of the Everglades Agricultural Area" Journal of Applied Meteorology, Vol. 18, No. 8, August 1979.

3. Final Report, "Models to Predict Earth-Air Interface Temperature Regimes during Freezing Conditions - Phase IV" Contract No. NAS10-8920. NASA-KSC. Janaury 1978.

4. Martsolf, J. David, "Freeze Line System" To be published in the Proceedings of the Crop Modeling Management Workshop. Blacksburg, Virginia. January 28, 1980.

5. Martsolf, J. David, John E. Gerber, "Semi-Annual Report on Models to Predict Earth-Air Interface Temperature Regimes during Freezing Conditions - Phase VI" Contract No. NAS10-8920. NASA-KSC. December 1979.

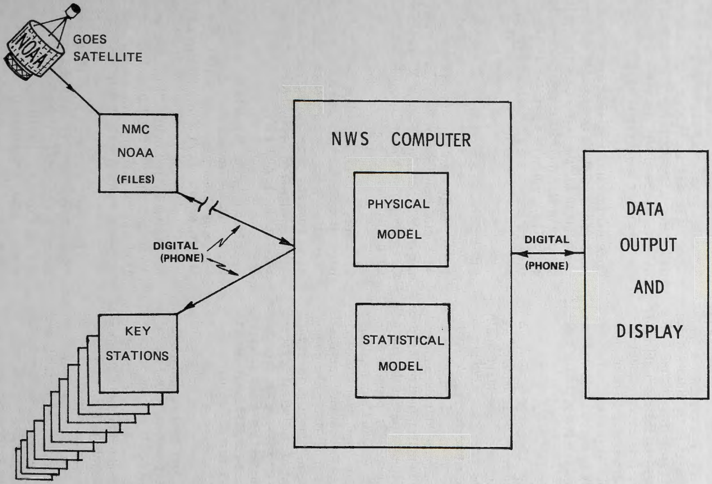

Figure 1: Schematic Diagram of the Florida Satellite Freeze Forecast System

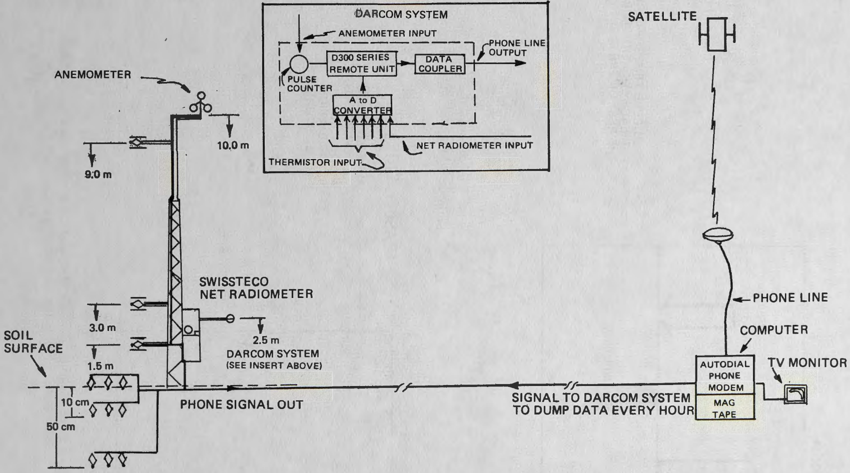

Figure 2: Diagram of a typical automated key station serving the SFFS.

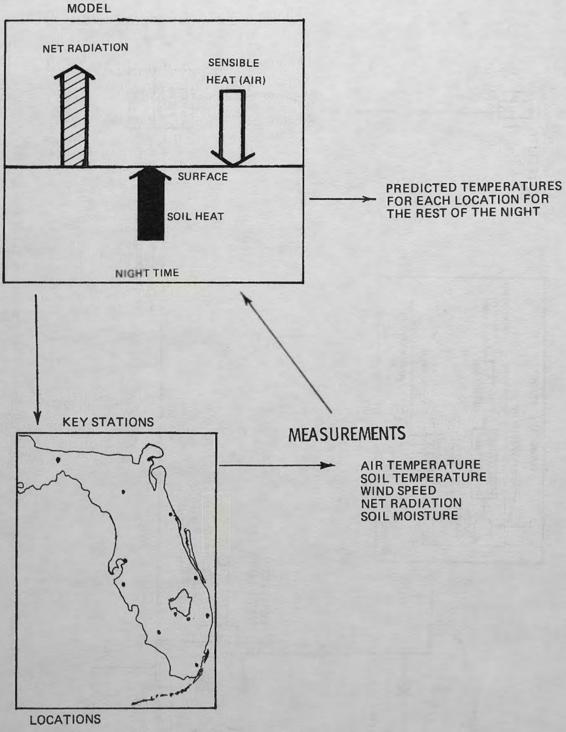

Figure 3: Physical Model (Radiation Balance Model) used to calculate key station temperature predictions.

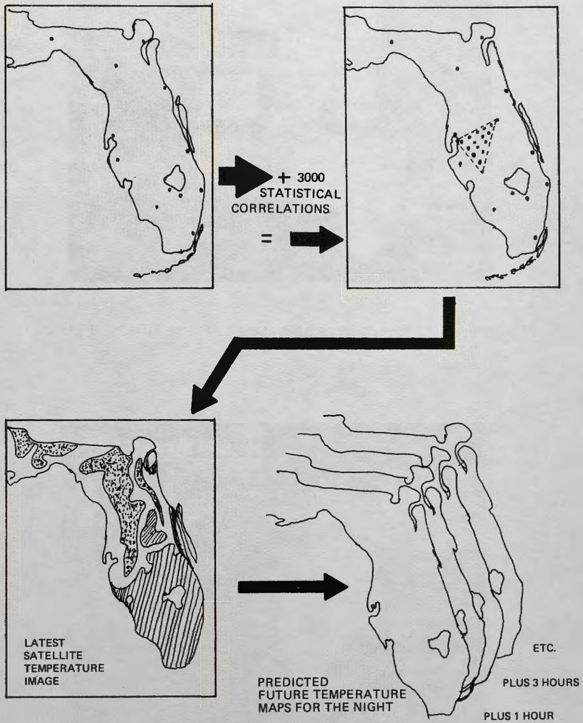

Figure 4: Statistical Model (S-model) which generates predicted temperature maps from key station predictions and observed satellite temperature maps.

Figure 5: NWS forecasters operating SFFS at Ruskin, Florida.

Figure 6: SFFS output display showing predicted map and actual map. (Actual display is in brilliant color).