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THE ASSESSMENT OF 18 AND 19 JAN. 1997 FREEZES IN FLORIDA USING NOAA SATELLITE AVHRR DATA

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Abstract. **The wide spatial variation of freeze temperature distribution in Florida is very difficult to assess using conventional ground-based measurements. Thus, the NOAA satellite AVHRR images were implemented in this study to create the temperature distribution over peninsular Florida for 18 and 19 Jan. 1997 freezes. The thermal band of the AVHRR images were also compared with 82 weather stations measurements. Deviations between ground-based point temperature and satellite-derived temperature for these two freeze days were within 3°C in 85%, within 2°C in 63%, and within 1°C in 35% of the samples taken. This result implies that using NOAA satellite AVHRR images is a feasible means to assess the freeze temperature distribution in Florida.**

Temperature is a major influencing factor in agricultural production systems. Particularly, freeze temperature data play an important role in many agriculture activities, such as freeze protection, freeze zone identification, and freeze damage assessment. In the past, surface temperature estimation over large-scale regions was estimated from point measurements. Because of the wide spatial and temporal variabilities of temperature distribution and the lack of information concerning the optional sampling pattern design for point temperature measurement, little is known about the accuracy of conventional temperature estimation for a region.

Fortunately, remote sensing can provide a nearly continuous set of spatial and temporal data and appears to be a feasible means of solving this problem. Satellite thermal infrared data are able to describe the surface temperature distribution of a given area at intervals from 30 minutes to several days. For instance, Shih and Chen (1984), Schoff and Volchok (1985), Chen and Allen (1987), Cooper and Asrar (1989), and Lathrop and Lillisand (1987) have researched the estimation of lake and sea surface temperature using satellite data provided by Geostationary Operational Environmental Satellite (GOES), Heat Capacity Mapping Mission (HCMM), and Landsat Thermatic Mapper (TM), and High Resolution Picture Transmission (HRPT) data, respectively. In the meantime, Shih and Chen (1987) used GOES thermal images to map freeze zones for citrus and consequences for water management. Furthermore, the Automatic Picture Transmission (APT) data that come from the National Oceanic and Atmospheric Administration (NOAA) polar-orbiting satellite Advanced Very High Resolution Radiometer (AVHRR) have been used to study the lake surface temperature distribution (Xin and Shih, 1991 and 1993). Although the resolutions of HRPT (1 km by 1 km nominal) and APT (4 km by 4 km) are much higher than that of GOES (8 km by 8 km), both HRPT and APT have not been widely used in freeze temperature assessment. Their lack of use could be due to the difficult conversion of digital numbers to brightness temperatures in APT images. This conversion must be determined from the image telemetry grey-levels and the values of the satellite sensors' views of empty space and of an internal blackbody. Moreover, there is a non-linear relation between the grey-level digital numbers (DNs) and brightness temperatures (Planet 1988). Therefore, the temperature conversion procedure for APT data is inconvenient compared with that for HRPT and GOES data. Furthermore, another argument against using NOAA polar-orbiting satellite images in both HRPT and APT systems produce several hours repeatable data while the geostationary GOES satellite yields 30 minutes repeatable data. Consequently, it is difficult to assess the freeze occurrence using the polar-orbiting satellite data. In other words, HRPT and APT data could miss the coldest temperature that occurred on the ground surface. Thus, the feasibility of using the NOAA-AVHRR data to assess the freeze temperature needs to be studied further. Therefore, the main objective of this study was using the HRPT data to assess the 18 and 19 Jan. 1997 freezes that occurred in Florida. The specific objectives were to 1) introduce the general information of the NOAA polar-orbiting satellite AVHRR images, 2) calibrate the thermal band of NOAA-AVHRR images for surface temperature, 3) study the suitability of NOAA satellite overpassing time for freeze temperature assessment, 4) compare both satellite-derived and ground-based temperatures, and 5) map 18 and 19 Jan. 1997 freezes using satellite-derived temperatures.

Materials and Methods

Climatological Data

Two types of ground-based temperatures were used in this study: minimum temperature and hourly temperature.

Minimum Temperature: the minimum temperatures measured on 18 and 19 Jan. 1997 at 82 weather stations in peninsular Florida (Fig. 1) were obtained from the National Climatic Data Center (NCDC). These minimum temperatures were used to calibrate the NOAA-AVHRR images.

Hourly Temperature: The hourly temperatures were measured on 18 and 19 Jan. 1997 at Gainesville and Lake Alfred weather stations, which had been installed and maintained by the Institute of Agriculture and Food Sciences (IFAS), University of Florida (Fig. 1). These hourly temperatures were used mainly for studying the suitability of NOAA polar-orbiting satellite overpassing time for freeze temperature assessment. In the meantime, these hourly temperatures were also analyzed in terms of three periods of 24 hours, 48 hours, and freeze hours (i.e., the period with temperatures below zero).

NOAA-AVHRR images

Surface temperatures were derived from the NOAA polar-orbiting satellite AVHRR thermal-band imagery. The HRPT from the NOAA-12 AVHRR images were the primary sources of satellite images in this study. The NOAA-AVHRR has five spectral bands from visible to thermal infrared (0.58 µm to 12.5 µm) (Table

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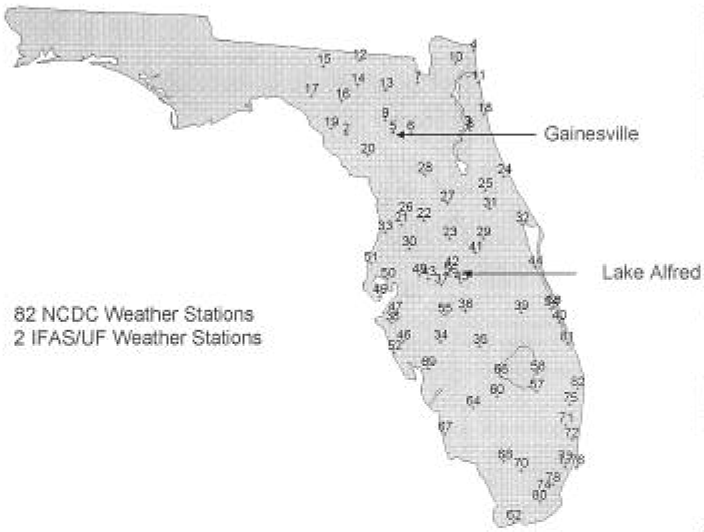

Figure 1. Distribution of 82 weather stations from the National Climatic Data Center in peninsular Florida and two IFAS/UF weather stations located in Gainesville and Lake Alfred.

1), and a spatial resolution of approximately 1.1 × 1.1 km (Kidwell, 1991). The overpassing times on 18 and 19 Jan. 1997 were 0722h and 0703h, respectively.

Since the NOAA satellite are polar-orbiting, successive images of the ground location will not conform to the same pixel positions. Therefore, one of the most important problems in processing HRPT imagery is how to deal with pixel registration at an acceptable level of accuracy. Basically, there are two ways to deal with this problem: (1) Theoretical computation, in which satellite navigation data are used to estimate the geographic coordinates of pixel center; and (2) ground-control registration. Brush (1988) has indicated that the accuracy of pixel registration for NOAA satellite imagery is difficult to determine from telemetry due to the inaccuracy of the satellite clocks and the eccentricity of the orbits, thus limiting the usefulness of theoretical computation. The regression of ground-control points to image pixels can be used to define a transformation. The ERDAS (ERDAS, 1996) image-processing package was used for geometric correction. Each HRPT image was resampled to 1 km × 1 km and rotated by ERDAS to reduce the distortion.

Temperature Conversion from the Satellite Images

As table 1 shows, bands 4 and 5 of the NOAA-AVHRR images are in the thermal portion of the electromagnetic spectrum, and are sensitive to the temperature on the ground. The surface radiant temperature from NOAA-AVHRR was calculated using the equation (Kidwell, 1991):

$$T_{rad}(E_i) = \frac{c_2 v}{1n\left(1 + \frac{c_1 v^3}{E_i}\right)} \qquad (1)$$

where c_1 is a constant = 1.1910695×10^{-5} (mW m^{-2} ster^{-1} cm^4);
c_2 is a second constant = 1.438833 (cm K);
v is the central wave number (cm^{-1}); and
E_i is the radiance value from band I (mW m^2 ster^1 cm).

The central wave number for detecting temperature in the near-freeze range is 2639.61 cm^{-1}, 921.0291 cm^{-1}, and 837.3641 cm^{-1} for band 3, 4, and 5 respectively (Kidwell 1991).

The atmospheric absorption is eliminated by the use of the split-window algorithm which takes advantage of different atmospheric absorption in two infrared channels in the thermal infrared windows (Vidal, 1991; Otte and Vidal-Madjar, 1992). The satellite- derived temperature was then calibrated with daily minimum temperature reported by the NCDC. Such calibrations are needed to reduce errors associated with thermal infrared measurements from space.

Table 1. Band width (micrometers) for NOAA-AVHRR polar-orbiting satellite.

Channel No.	Bandwidth, (μm)
1	0.58 - 0.68
2	0.725 - 1.1
3	3.55 - 3.93
4	10.30 - 11.30
5	11.50 - 12.50

Cloud Identification

One of the major problems in satellite temperature derivation is the correct identification and removal of cloud-contaminated pixels. The clouds or fogs could significantly affect the accuracy of temperature retrievals, even if a small fraction of cloud appears in the pixels. It is even more difficult for night-time images not only due to the unavailable visible channels but also the uniform low cloud at night is the most difficult cloud to detect with either the traditional IR threshold or spatial coherence methods (Saunders, 1986). In contrast to day-time images, band 3 of the AVHRR (3.7 μm) images at night appear broadly similar to the corresponding 11 μm images. However, Hunt (1973) reported that the emissivity of low cloud or fog at 3.7 μm wavelength is significantly less than at 12 μm producing a significant difference in measured brightness temperature between the two bands which is normally much greater than the difference caused by atmospheric absorption. Since the HRPT data available on 18 and 19 Jan. 1997 were respectively overpassing at 0722h and 0703h, the visible bands are bright enough to help identify the cloud condition. Thus, the cloud cover condition was determined in two steps using both temperature sensed from the thermal infrared bands 3 and 5, and from visible band 1. The first step uses the temperature difference detected in 3.7 and 12 μm (band 3 and band 5 of AVHRR data): if the brightness temperature difference ($T_{3.7}$-T_{12}) is greater than 5°C, then the pixel is flagged as cloud contaminated. The 5°C was suggested by Saunders (1986) and proved appropriate in this study. The second step is to examine whether the HRPT image is discernible using the visible band 1 to supplement the cloud identification. The cloud cover areas were then delineated and eliminated in this study.

Mapping of Surface Temperature

The temperature distribution was established using the software package SURFER for Windows (Golden Software Co., Golden, Colorado). The deviations between ground-based and satellite-derived temperatures were analyzed using a group system with 0.5°C interval for frequency analysis and a range system with 1°C increment for percentage computation.

Results and Discussion

Temperature Difference Between Gainesville and Lake Alfred

The hourly temperature differences between Gainesville and Lake Alfred are listed in Table 2. As Table 2 shows, three observations can be made. First, all hourly temperatures in Lake Alfred are significantly higher (at 1% level) than that in Gainesville during these two days of 18 and 19 Jan. 1997. Second, the temperature difference between Lake Alfred and Gainesville during the freeze period (i.e., 2000h 18 Jan. through 0900h 19 Jan.) was significantly higher (at 5% level) than that during other periods. This means that when the freeze temperature occurs in peninsular Florida, the Lake Alfred area could have a less crop damage as compared with the Gainesville area. Third, the standard deviation in the freeze period is 0.99°C which is only 50% of the 24-hour period temperature deviation. The relatively low standard deviation means that there was less variation of temperature during the freeze period. This outcome implies that the NOAA-AVHRR data overpassing time during the freeze period could be used to map the freeze temperature distribution.

Table 2. Comparison of hourly temperature differences between Gainesville and Lake Alfred in 1997.

		Temperature difference[z], °C		
Period	Hours	Mean	Std.	t-value
18 Jan.	24	2.67a[y]	1.71	7.65**[x]
19 Jan.	24	2.11a	2.89	3.57**
18 and 19 Jan.	48	2.39a	2.39	6.92**
2000h 18 Jan. through 0900h 19 Jan.	14	5.00b	0.99	18.95**

[z]Temperature in Lake Alfred minus temperature in Gainesville.
[y]Means with the same letter are not significantly different at 5% level as determined by t-test.
[x]**Very highly significant at 1% level.

Suitability of NOAA-AVHRR Data for Freeze Assessment

The hourly temperatures for 18 and 19 Jan. 1997 at Gainesville and Lake Alfred are plotted in Fig. 2. As Fig. 2 shows, the temperature during the period between 0000h and 0800h in the 19 Jan. 1997 was much lower than that in the 18 Jan. The NOAA-AVHRR satellite overpassing times on those two days are also depicted on Fig. 2. As mentioned above, the relatively low standard deviation during the freeze period could be beneficial to the implementation of the NOAA-AVHRR data in freeze temperature assessment. Fig. 2 also illustrates that the time of temperature sensed by the NOAA-AVHRR was nearly the time of coldest temperature actually occurred on the ground surface. This effect demonstrated that the NOAA-AVHRR with several hours interval of overpassing time could be used to assess the freeze temperature distribution in Florida.

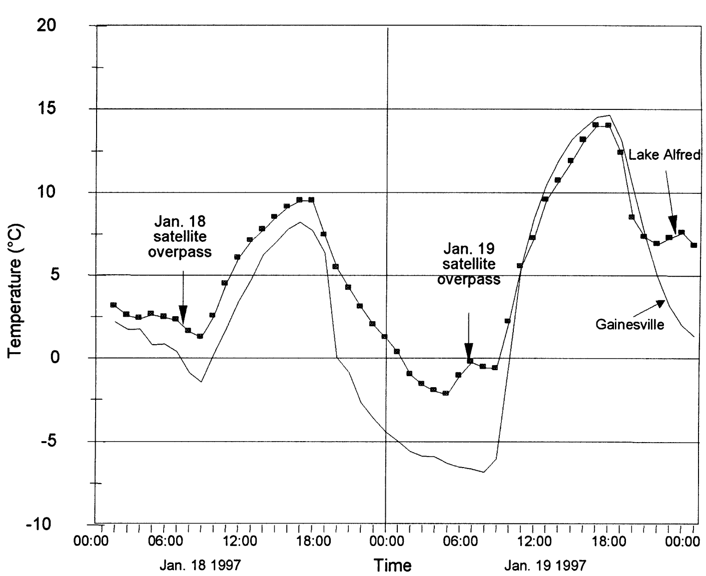

Figure 2. Hourly temperature in Gainesville and Lake Alfred during 18 and 19 Jan. 1997 freezes and NOAA satellite overpassing time.

Deviations Between Ground-based and Satellite-derived Temperatures

The absolute deviations between ground-based and satellite-derived temperatures were grouped into eight categories with 0.5°C interval, i.e.,0-0.5, 0.5-1.0, 1.0-1.5, 1.5-2.0, 2.0-2.5, 2.5-3.0, 3.0-3.5, and greater than 3.5°C. The number of weather stations falling within the corresponding category are given in Table 3. A total of 72 weather stations data were available for 18 Jan. 1997, while only 55 stations data were used on 19 Jan. 1997. Unused stations were either covered by cloud or lacked ground-based records. The deviations between ground-based and satellite-derived temperature could be caused by two reasons. First, the ground-based temperature was measured from a point of weather station instead of from an area of 1 km by 1 km as sensed by the NOAA-AVHRR data. In other words, the spatial resolution difference could contribute in part of the temperature deviation. Second, the weather stations' data were air temperatures which were measured 1.5 m above ground surface, while the satellite-derived temperatures were ground surface temperature which were sensed from the ground surface. There might have been a slight difference between ground surface temperature and air temperature. However, this difference may be negligible during freeze periods.

Table 3. Deviations between ground-based and satellite-derived temperatures, °C.

	Absolute deviations							
Date	0.0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	>3.5
18 Jan. 1997	17	13	12	6	7	8	6	3
19 Jan. 1997	10	6	9	7	7	6	7	3

Table 4. Percentages of the range of deviations between ground-based and satellite-derived temperatures.

	Percentages		
Range	18 Jan. 1997	19 Jan. 1997	Ave.
Within 1°C	41.7	29.1	35.4
Within 2°C	66.7	58.2	62.5
Within 3°C	87.5	81.8	84.7

The deviations were regrouped into three ranges with 1°C increments (i.e., within 1°C, 2°C, and 3°C, respectively) to compute the percentages falling within each range. The results were shown in Table 4. As Table 4 shows, the deviations for all samples of two days were 85% within 3°C range, 63% within 2°C range, and 35% within 1°C range. In the meantime, the deviation appears to be greater (i.e., less percentage) in the colder day (19 Jan.) than that in the warmer day. For instance, the percentage within 3°C range

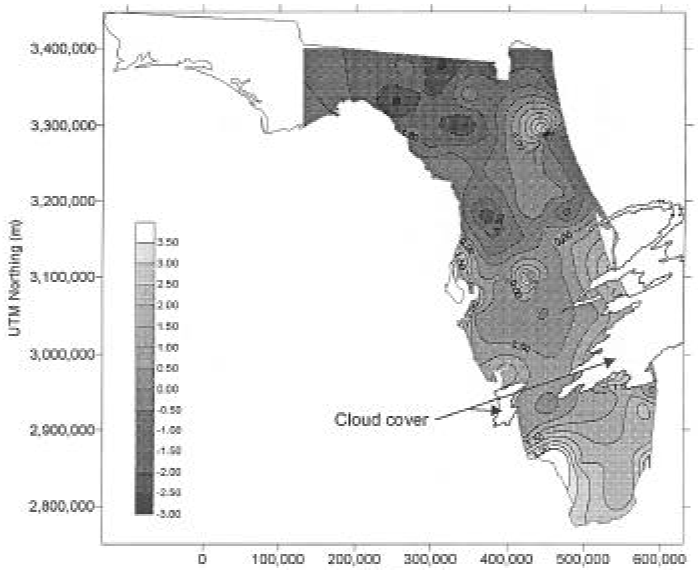

Figure 3. Satellite-derived temperature (°C) distribution for 18 Jan. 1997.

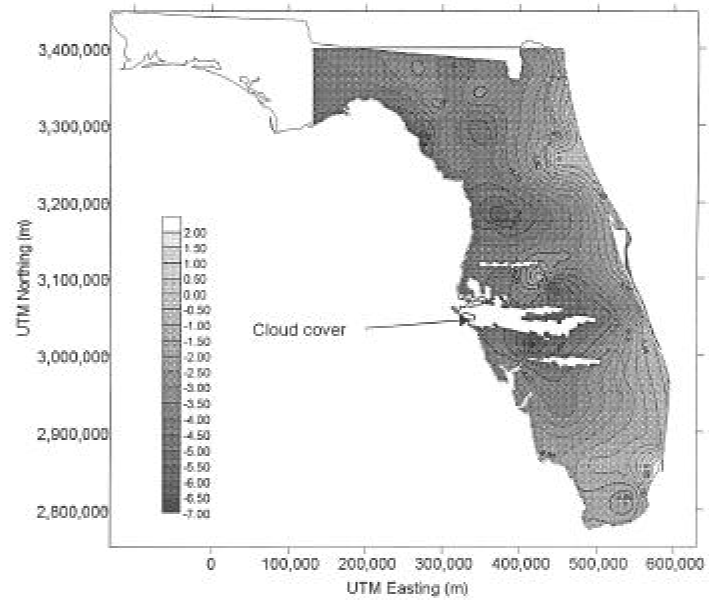

Figure 4. Satellite-derived temperature (°C) distribution for 19 Jan. 1997.

for 18 Jan. was 88%, while it was only 82% for 19 Jan. This outcome could be due to a more serious impact of oasis effect from the ground-based measurement during freeze periods.

Freeze Temperature Distribution

There was a nearly cloud-free HRPT image on 18 Jan. 1997 (Fig. 3), while there was partial cloud cover on 19 Jan. (Fig. 4). The maps of satellite-derived temperature distribution for 18 and 19 Jan. 1997, generated using the SURFER for Windows software, are depicted on Figs. 3 and 4, respectively.

Summary

The NOAA polar-orbiting satellite AVHRR images were implemented in this study to create the temperature distribution over peninsular Florida for the 18 and 19 Jan. 1997 freezes. Several findings are made as follows:

1. There was a larger spatial variation of hourly temperatures in the freeze period than that in the 24-hour period.
2. NOAA-AVHRR images gathered around 7 AM were suitable for monitoring freeze temperature distribution.
3. The deviations between ground-based temperature and satellite-derived temperature for all samples of a 48-hour period were within 3°C in 85%, within 2°C in 63%, and within 1°C in 35% of the samples.
4. The match between ground-based temperature and satellite-derived temperature is considered to be a remarkable result.

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