CHAPTER IV

RESULTS

Four case studies were selected to examine GHCC GOES-8 Imager and Sounder skin temperature retrievals. The case studies were selected from times throughout the calendar year to study not only the performance of the retrievals and the differences between the Imager and Sounder products, but also the seasonal variation in the performance of the retrievals. Instead of trying to select and analyze a period of continuous cloud-free days, two to four week periods were selected and only the relatively clear days from those periods were used for the case studies. The exception is the case study using data from July 2000. This case study was chosen to coincide with the available data from the GOES-11 satellite, and cloud cover was persistent during much of this period. The three other case studies include groups of days during September 2000, January 2001, and April 2001. The September case can be considered as a late summer or early fall case, the January case is a good example of wintertime performance, and the April case provides details of the retrieval performance during springtime.

The following results are derived from analysis of ST retrievals from the GOES-8 Imager and Sounder. As previously shown in Figure 3.1, statistics were computed over three domains (CONUS, SE, and ocean), for single pixel, 3x3 pixel averaged, and 5x5 pixel averaged retrievals. The satellite derived ST retrievals are compared to ground truth data from the Oklahoma ARM site, and to SSTs from buoys. Finally, striping and retrieval comparisons are made between GOES-8 and GOES-11.

4.1 GOES-8 Imager and Sounder Inter-Comparisons

The GOES-8 Imager is currently used to provide the ST retrievals for operational use at GHCC. Retrievals are also produced from GOES-8 Sounder data. The Sounder will have to provide the data for retrievals from future satellites and may also provide benefits over the current Imager product. It is therefore of importance to study the similarities and differences between the products from the two instruments.

There are several differences between the Imager and Sounder to consider when comparing the two products. The most important factor is the difference in spatial resolution. The Imager IR channels, with a spatial resolution of 4 km, are able to distinguish surface and cloud features four times as small as those detected by the Sounder with its 8 km resolution. The Sounder provides only 64% coverage, compared to the Imager's 100% coverage, with the Sounder sub-sampling resulting from the 8 km resolution but 10 km spacing of the Sounder pixels. It would appear that the Imager's capabilities to retrieve ST are superior to the Sounder's, but there are additional factors to consider.

The calibration of the sensors can have a large affect on the ST retrievals. As previously discussed, and will be discussed in more detail in Section 4.3, GOES Imager and Sounder calibrated IR images are susceptible to random noise and striping. The amount of striping present within an image is the controlling factor for the amount of averaging required, and this averaging requirement can vary between instruments. There are also differences in the spectral band intervals of the channels from the two instruments used in the PSW technique. These spectral band differences can be expected to cause differences in the ST retrievals because of their differing sensitivities to water vapor absorption and their effect on the retrieval process. This work concentrates on examining the differences in spatial resolution and sensor calibration between the two GOES-8 instruments. The following discussion focuses on the differences in spatial resolution between the GOES-8 Imager and Sounder and the averaging required by the two products to remove the random noise and striping.

4.1.1 GOES-8 Imager and Sounder Image Comparisons

Observations of Imager and Sounder ST images reveal preliminary details about the two products. Figure 4.1 shows a selection of ST images from the case studies for single pixel (upper panels) and averaged retrievals (middle and lower panels). Initial visual comparisons of the single pixel resolution images shown here, and other images studied during the research, reveal striping in both the Imager and Sounder retrievals for all times and seasons. The amount of striping varies with time and season, but there does not appear to be a pattern in the magnitude of the striping errors either diurnally or seasonally. There can be a significant change in the striping from one time to the next; however, there are not particular times of the day or the year when the striping errors are always appreciably higher or lower than at other times. A definitive improvement in the Imager versus Sounder (or vice versa) striping errors is also not seen.

(a)

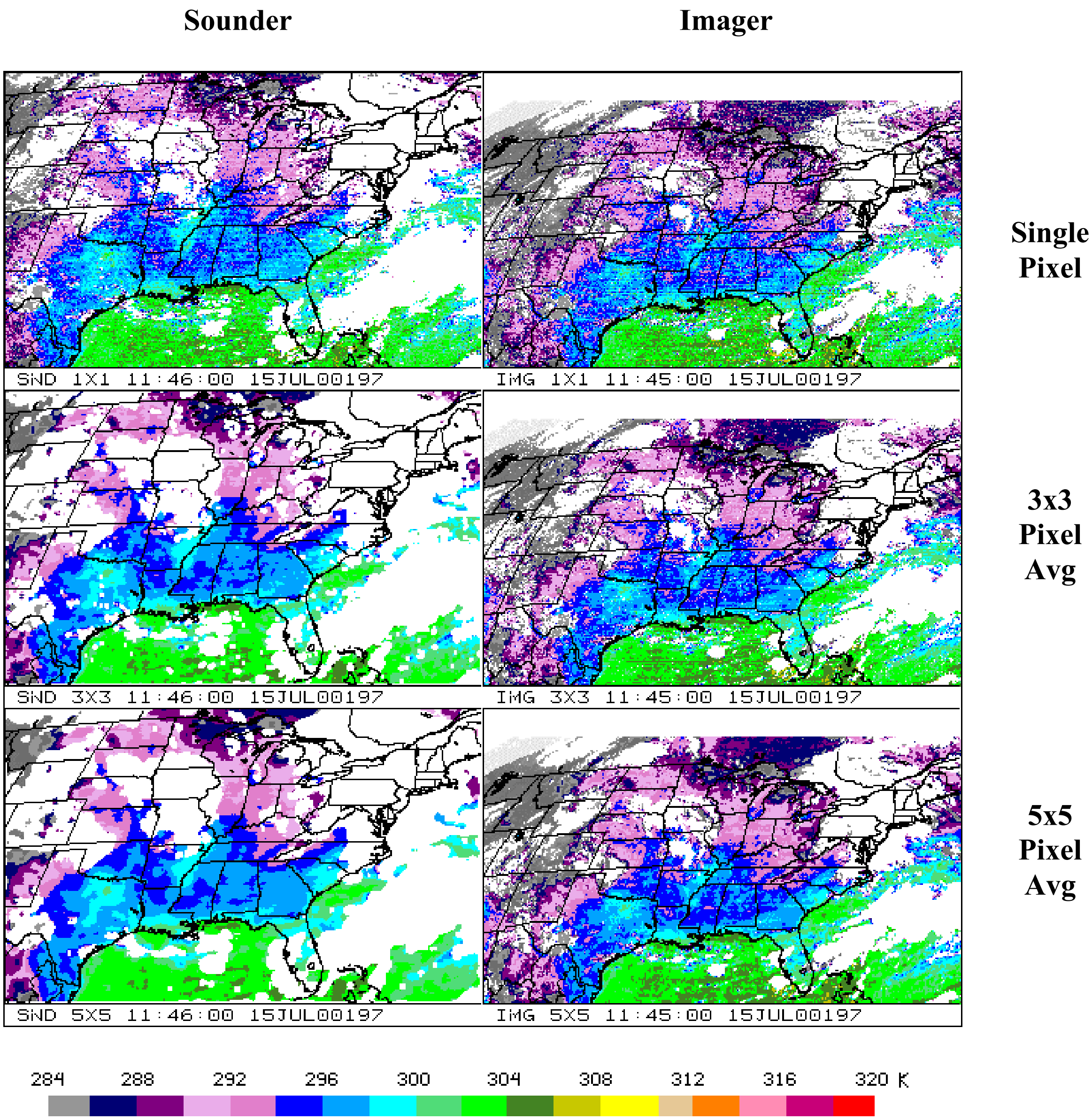


Figure 4.1 Skin temperature retrievals from the GOES-8 Sounder (left panels) and Imager (right panels) at single pixel resolution (top panels), 3x3 pixel averaged retrievals (middle panels), and 5x5 pixel averaged retrievals (bottom panels) at 1145 UTC on 15 July 2000 (a), 1445 UTC on 19 September 2000 (b), 1745 UTC on 22 January 2001 (c), 2045 UTC on 25 April 2001 (d), and 2345 UTC on 29 September 2000 (e).

(b)

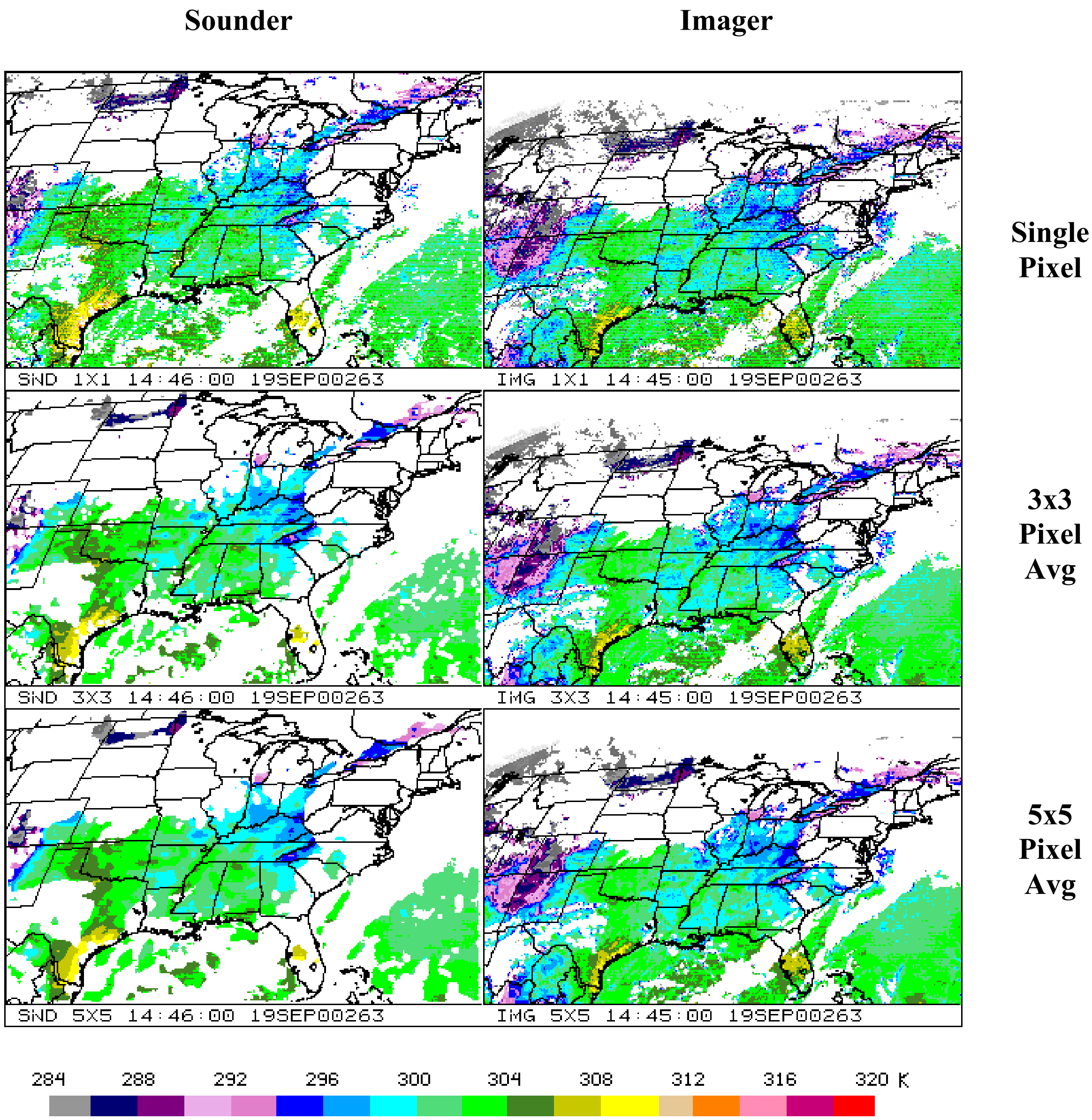


Figure 4.1 (continued).

(c)

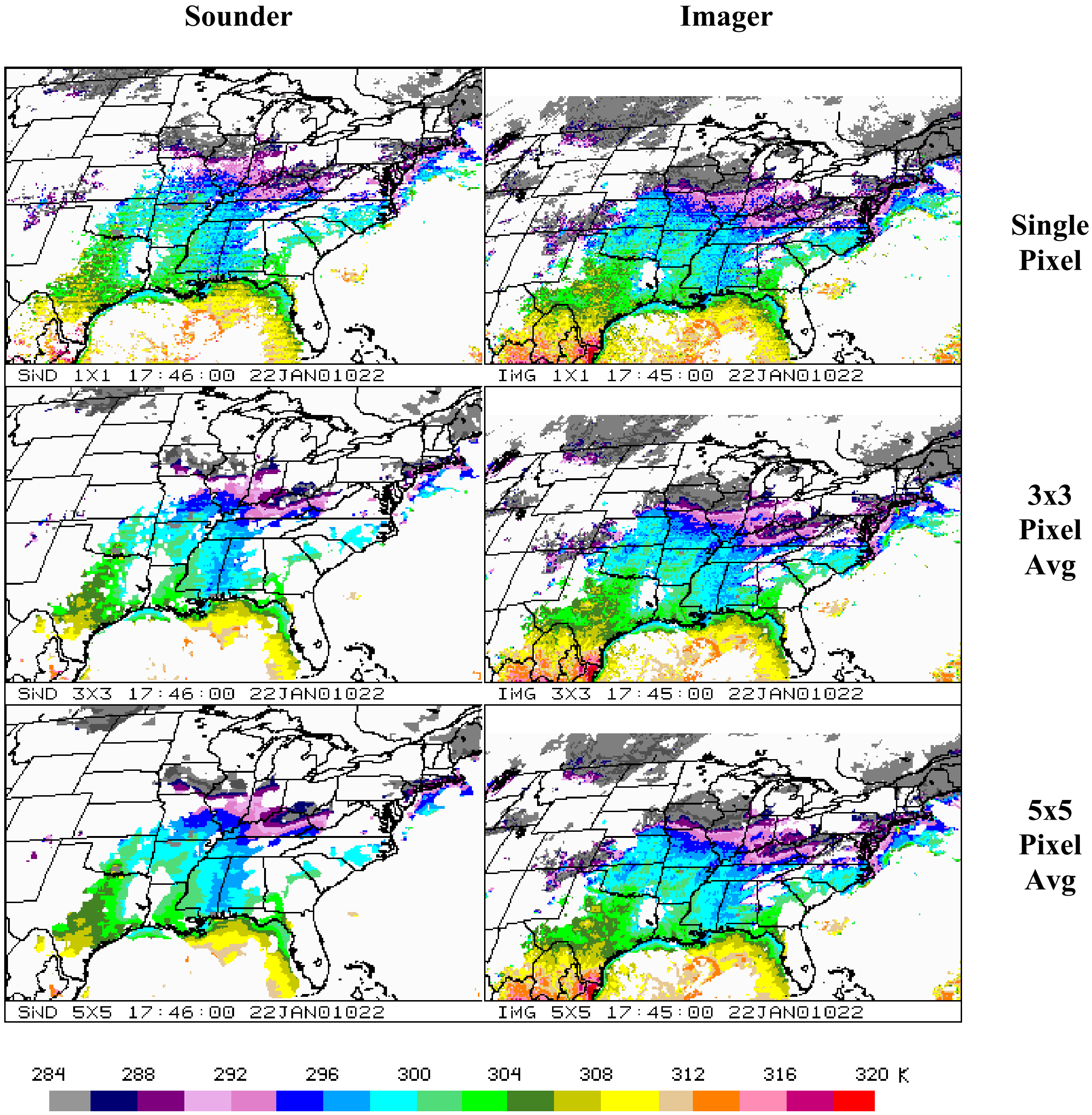


Figure 4.1 (continued).

(d)

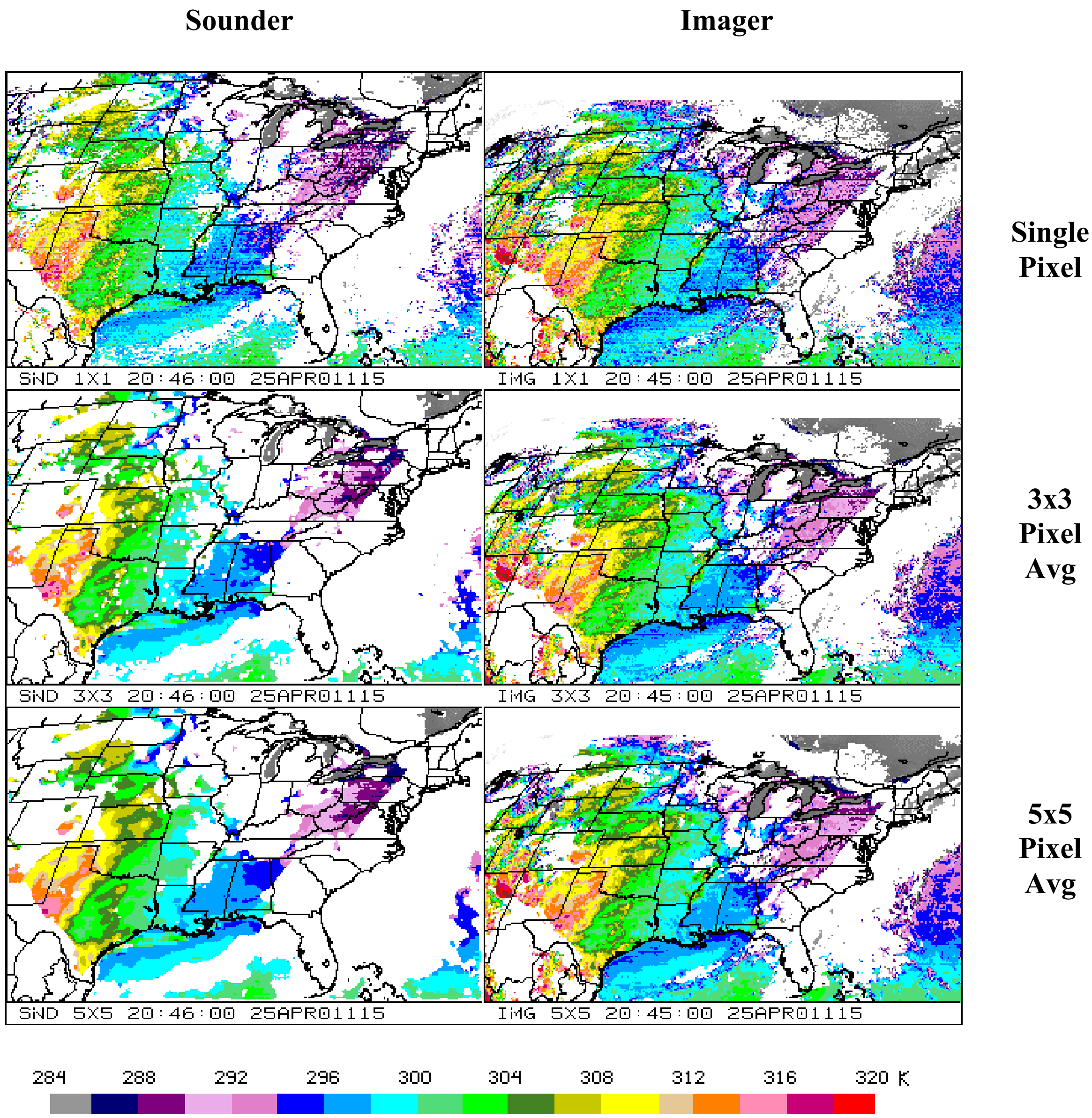


Figure 4.1 (continued).

(e)

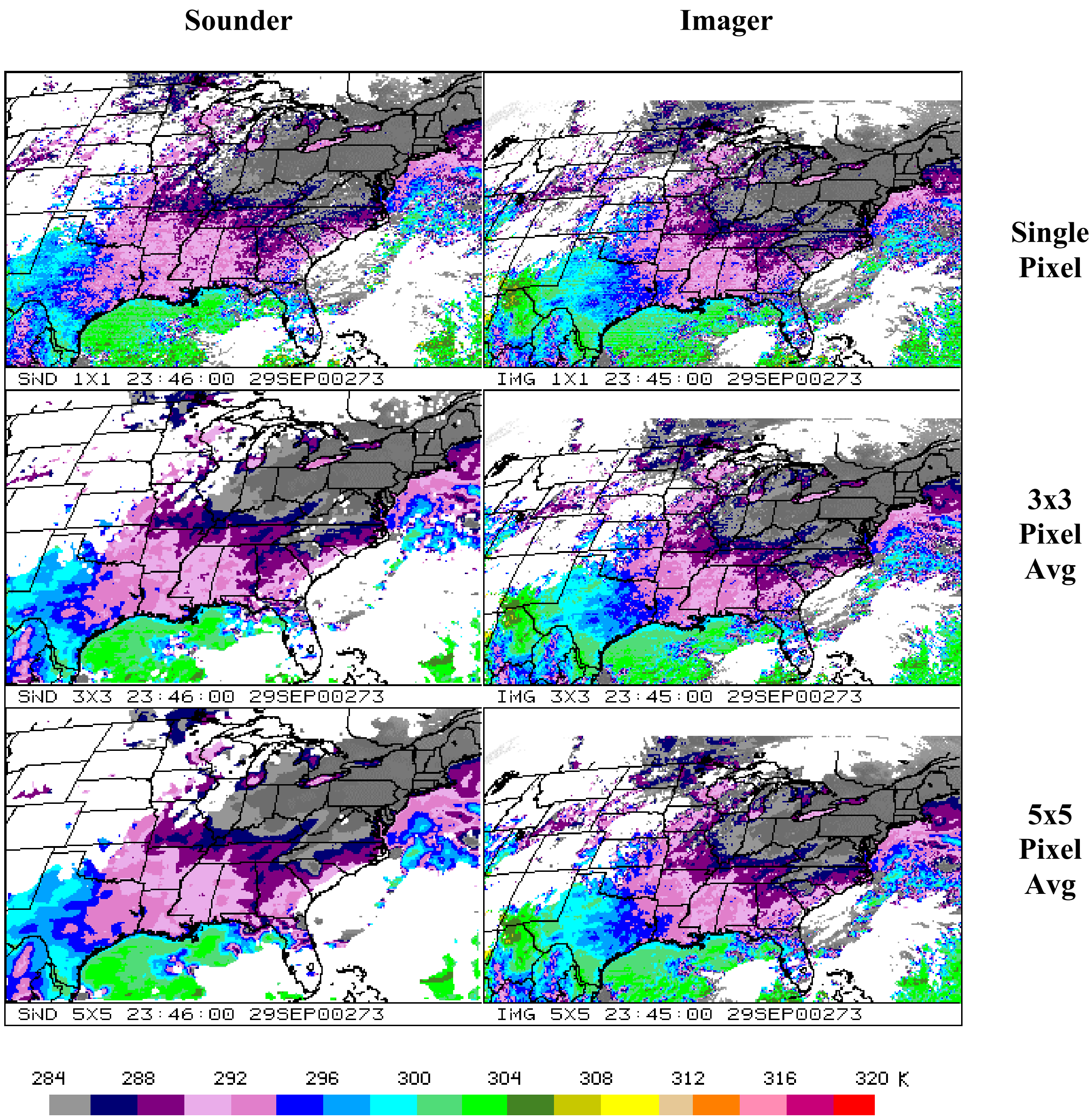


Figure 4.1 (continued).

One instrument does not noticeably outperform the other in terms of striping errors. For example, at 1145 UTC on 15 July 2000 (Figure 4.1(a)) the striping visually appears slightly worse in the Imager scene, but at 1745 on 22 January 2001 (Figure 4.1 (c)) the Sounder striping is slightly worse. It is obvious that single pixel retrievals are influenced by random noise and striping, and that averaging of the data is required to remove these influences.

The middle and lower panels of the images shown in Figure 4.1 are the same retrievals as the upper panels but are single pixel spaced retrievals averaged from 3x3 and 5x5 pixel boxes, respectively. The spatial averaging is of the brightness temperatures from the two channels used to produce the retrievals, not of the ST retrievals. In terms of striping and noise, the Sounder 3x3 pixel averaged retrievals exhibit an improvement over the Imager retrievals with the same amount of averaging. However, the 3x3 Sounder product does not display as much spatial variation as the 3x3 Imager product. In the images shown in Figure 4.1, the 3x3 and 5x5 Sounder products reveal almost no striping errors, but the spatial variation decreases with the increase in the number of pixels averaged. An additional disadvantage of the averaged Sounder products is the high number of pixels labeled as cloudy. The cloud mask algorithm applied to the Sounder data tends to over-determine clouds, and during the averaging process the number of cloudy pixels increases and more valid ST retrievals are lost. The 3x3 Imager products still show some of the striping, although the striping is much reduced from the corresponding single pixel retrievals. In cases with high striping errors, the striping still persists in the Imager 5x5 products.

With respect to random noise and striping, there does not appear to be an obvious choice for a ST product between the Imager and Sounder. The amount of striping seen in the single pixel retrievals from both instruments is normally very similar. The Sounder has the advantage of less striping in its averaged products, but the Imager's averaged products reveal more natural spatial variation of ST. The current cloud mask algorithms cause problems by over-determining and under-determining clouds for the Sounder and Imager products, respectively. Depending on the application of the ST products, the Imager or the Sounder may be favorable in terms of their cloud masks. Future improvements in the cloud mask products (Jedlovec and Laws 2001) will help to relieve these problems, and the selection of a ST product will be based solely upon accuracy, striping, and resolution of the data.

The overall accuracy of the ST retrievals is hard to determine because of the limited amount of skin temperature measurements made *in situ*. It is therefore of interest to inter-compare the magnitudes of the Imager and Sounder ST products. Study of the images in Figure 4.1 and other images from the case studies reveal some general trends. The GOES-8 Sounder ST product generally tends to be slightly warmer than the Imager product during the early morning hours. Notice in Figure 4.1(b) how the Sounder product is slightly warmer relative to the Imager product over the North Alabama region. During the day the Imager and Sounder exhibit very similar magnitudes and patterns of temperature (except in the regions influenced by cloud contamination). In the 2345 UTC image (Figure 4.1(e)), the Sounder retrievals appear slightly cooler than the Imager retrievals. Notice over Louisiana the Sounder product is mostly pink in color, but the

Imager product has a large portion of the state colored blue (up to 2 K warmer). The same pattern can be seen over Texas.

Overall, the magnitudes of the Imager and the Sounder STs are in good agreement, but there are variations in the differences between the two products. With respect to the Imager product, the Sounder product generally begins the day warm and then cools towards the end of the day. This relationship is seen throughout the seasons. Further analysis will study this relationship and help determine whether the bias is a result of the retrieval algorithm or instrument measurements.

The following sections provide quantitative analysis of the GOES-8 Imager and Sounder ST retrievals. The magnitudes of the temperatures are inter-compared and also compared to ground truth data. The striping issue is evaluated by analysis of the standard deviation (SD) of the temperature from the mean value.

4.1.2 GOES-8 Imager and Sounder Mean Temperature Comparisons

For the three different domains, the mean temperature for both the Imager and Sounder was computed for single pixel (1x1), and 3x3 and 5x5 averaged retrievals. The mean temperatures are computed using the two methods described in Section 3.3. Recall that method 1 uses the same number of pixels for the Imager computations as for the Sounder computations (the Imager and Sounder pixels are collocated). Method 2 utilizes all the clear pixels available within the domain for each instrument. Results are presented from the four case studies.

4.1.2.1 CONUS Domain Comparisons

Figure 4.2 shows plots of the mean temperature as a function of time computed over the CONUS domain from four different days throughout the year. For each case study multiple days were analyzed, and the plots in Figure 4.2 present representative examples. The statistics presented in Figure 4.2 were computed from single pixel retrievals. The lines are labeled as either '1' (solid lines) or '2' (dashed lines) and these numbers represent the first and second computation methods, respectively. Only the mean temperatures calculated from single pixel resolution retrievals are shown, since the mean temperatures computed from the averaged retrievals are very similar in magnitude to the single pixel computations.

Notice that the dashed red (Sounder) line is indistinguishable from the solid red line. This is because the sample sizes used by the two different methods are very similar for the Sounder and therefore produce equal or very close statistics. On the other hand, the Imager statistics are computed using vastly different sample sizes and therefore differences are generally seen between the statistics. Much of this difference between the mean temperatures is a result of the large difference in sample size and cloud contamination of the Imager retrievals computed using method 2. Recall that method 1 uses the combination of the Imager and Sounder cloud masks, and therefore the Imager statistics computed using method 1 are normally more cloud-conservative with less cloud contamination effects than method 2 results. A good indication of the amount of cloud contamination affecting the method 2 Imager retrievals is the difference between the two Imager computed mean temperatures. In most cases, the mean temperature calculated using all the clear Imager pixels is less than the mean computed by method 1 as in

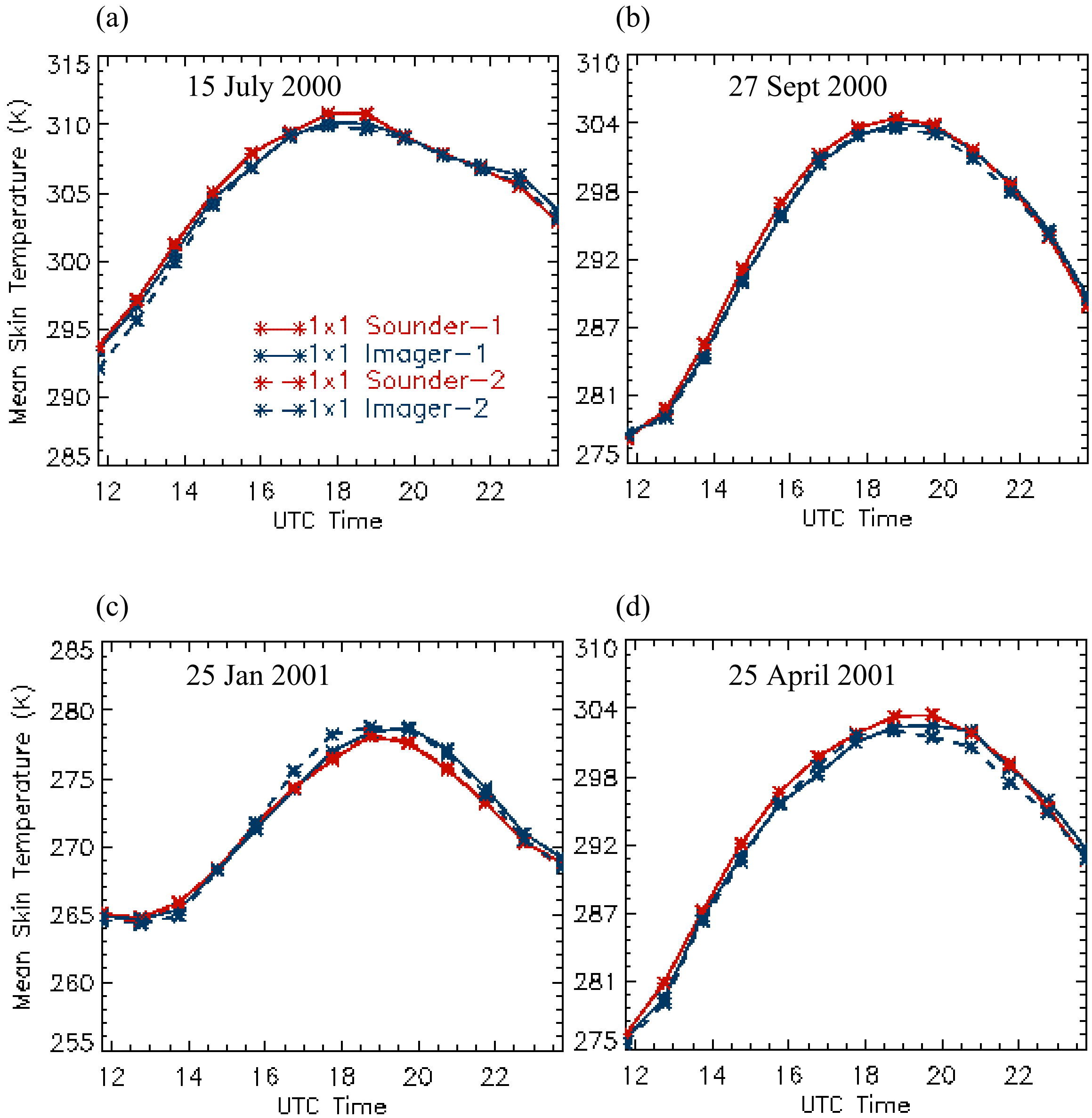


Figure 4.2 Mean skin temperature values computed from single pixel resolution retrievals over the CONUS domain.

Figure 4.2(a) and (b). However, the first method mean may be greater than the second method mean at some times, particularly during colder seasons, as in Figure 4.2(c,d), suggesting that the difference in sample size also plays a significant role. During the colder months the cloud contamination has a lesser effect on the mean temperatures because of the overall lower skin temperatures. The larger sample size of the Imager retrievals can cause the mean computed using all the clear Imager pixels to be warmer than the mean computed using the same number of pixels for the Imager and Sounder statistics.

Comparisons of the solid lines in Figure 4.2 show good agreement between both the magnitudes and trends of the Imager and Sounder mean temperatures. The plots presented in Figure 4.2 are generally representative of the results for their respective case studies. As discussed in the image comparisons, there is a bias between the two sets of retrievals. This bias between the Imager and Sounder retrievals varies with season, and from day to day, but there are general patterns that persist. Figure 4.3 contains plots of the average difference (Sounder minus Imager) between the mean temperatures computed for each case study period for the two different computation methods. The average values plotted in Figure 4.3 were computed from 4 days for each of the July, January, and April case studies, and from 7 days for the September case study. For these 19 case days, method 1 statistics produce an average absolute difference between the Sounder and Imager mean temperatures of 0.7 K, with a maximum difference value of 2.7 K. The method 2 statistics produce an average absolute difference of 1.0 K, with a maximum difference value of 4.5 K.

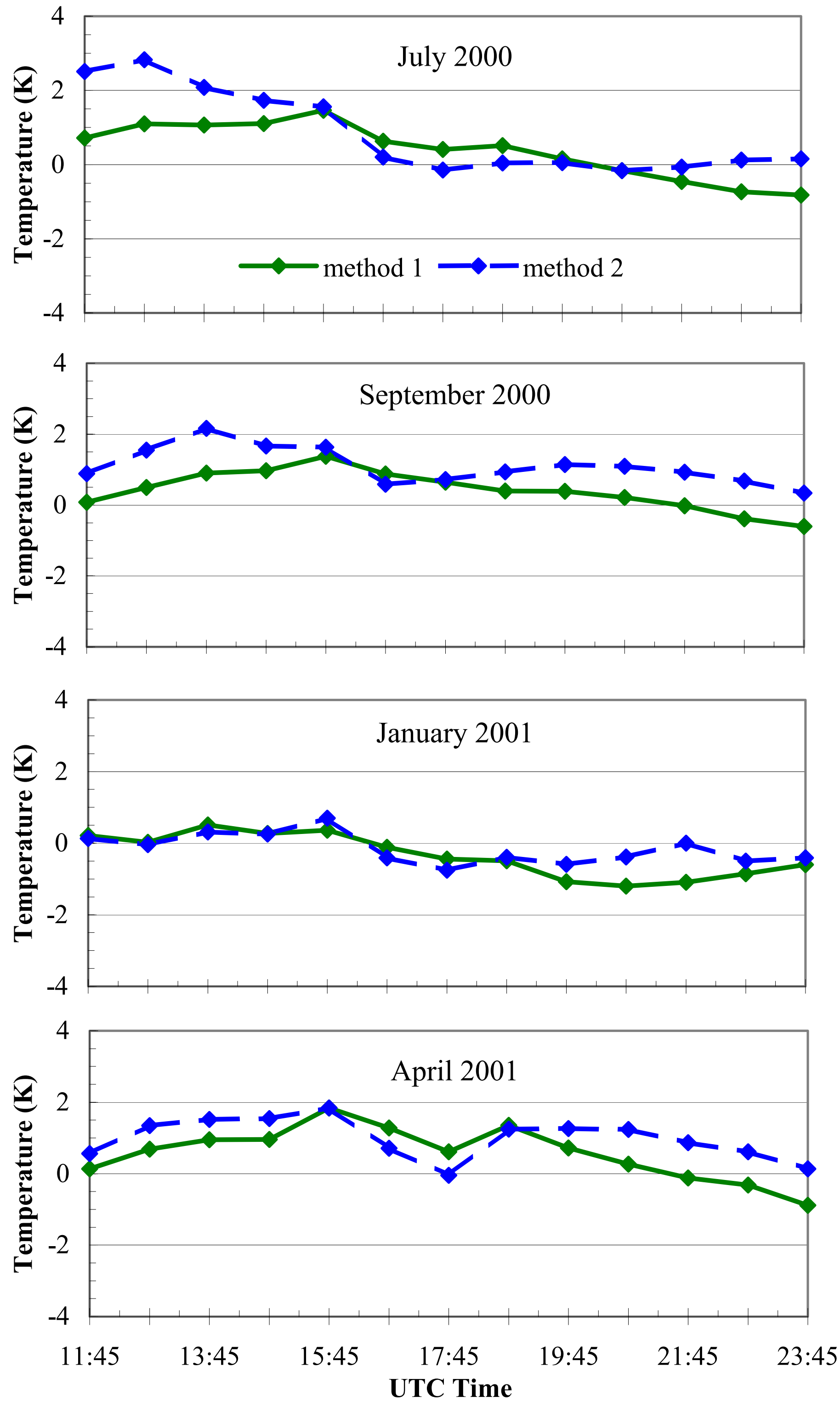


Figure 4.3 Average differences between Sounder and Imager mean temperatures (Sounder – Imager) computed over the CONUS domain for the four case study periods.

Figure 4.4 contains scatter plots of Imager and Sounder mean temperatures computed over the CONUS domain for the 19 case study days from single pixel retrievals. The two plots in Figure 4.4(a) and (b) were produced using method 1 and method 2 respectively. The scatter plots and the corresponding correlation coefficients of 0.998 (method 1) and 0.997 (method 2) indicate good agreement between the Imager and Sounder mean temperatures. The slightly smaller correlation coefficient for the method 2 results is reflecting the differing cloud masks, spatial resolutions, and area coverage between the Imager and the Sounder that results from using all the clear pixels.

Notice that the plots in Figures 4.2 and 4.3 for the January case deviate from the patterns exhibited by the other three cases. January 2001 had typical seasonal weather, and therefore the results are probably representative of the wintertime retrieval performance. The PSW algorithm is not expected to perform as well during wintertime for a number of reasons. First, the cloud detection method does not perform as well during wintertime especially during early morning and late afternoon times. The cloud detection method as currently designed, works well only during daylight hours. The decreased daylight hours therefore causes poor cloud detection in the early morning and late afternoon. The cloud detection method also has problems during wintertime because of the cold surface temperatures. If the surface is cold, then the bi-spectral temperature difference between the cloud tops and the surface may not be great enough for the clouds to be detected.

The later rising of the sun also causes problems for the algorithm itself. The algorithm's performance is known to degrade in the presence of temperature inversions (Suggs et al. 1998). During nighttime an inversion layer often occurs with the air

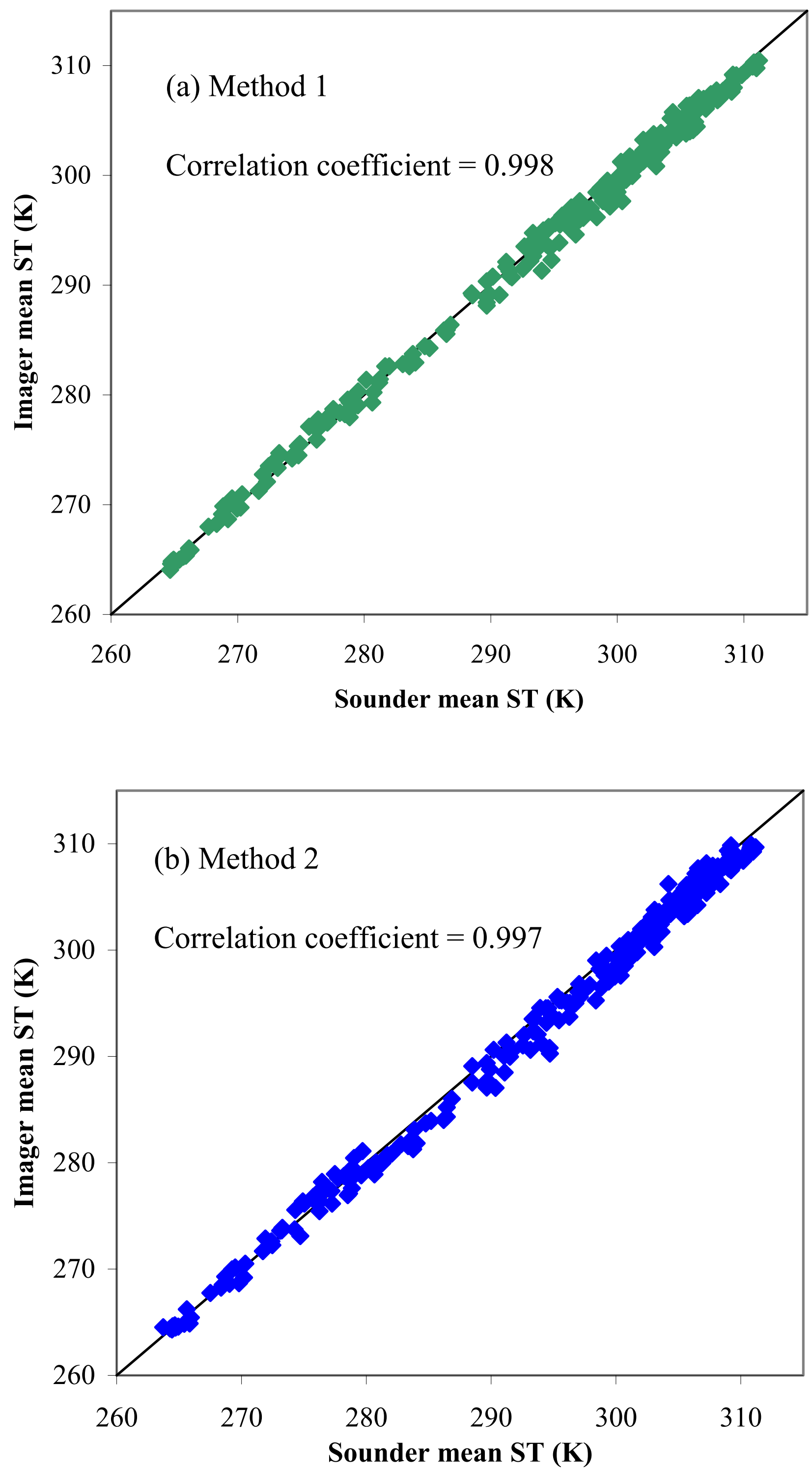


Figure 4.4 Scatter plots of mean Sounder and Imager temperatures computed over the CONUS domain using method 1(a) and method 2(b).

temperature above the surface increasing with height. These temperature inversions normally occur during cloud-free conditions during which the surface radiates heat into the atmosphere and cools faster than the air above it. Near-surface temperature inversions dissipate once the sun has risen and the solar energy heats the surface. During wintertime, the sun rises later and therefore temperature inversions remain later into the day and can still be present when the retrievals begin.

Another factor to consider for all retrievals, but particularly wintertime retrievals, is the assumed surface emissivity values for the GOES channels. Channel emissivities are assumed constant for both channels at 0.98 for the PSW algorithm. However, assuming constant surface emissivities can be a significant source of error since a 0.01 change in surface emissivity can cause a skin temperature change of up to 2 K (Prata 1993). From Faysash and Smith (2000), split window channel emissivities for the ARMCART region for summer were assumed to be 0.98, but for the winter season assumed to be 0.966. Obviously, the channel emissivities vary throughout the year as surface cover conditions change. Prata (1994) suggests using emissivity of 0.98 for well-vegetated surfaces. The PSW technique emissivity assumption appears to be more accurate during the summer than during the winter. Wintertime can also be expected to produce a larger range in emissivities because of the varying surface covers, including snow, dry brown farmlands and coniferous forests. All these factors contribute to a decrease in accuracy in the wintertime retrievals, and also may also cause different trends and relationships between the Imager and the Sounder to occur.

Returning to Figure 4.3 and the January case, the Imager and Sounder mean temperatures are found to be very similar at the 1145 and 1245 UTC retrieval times. The

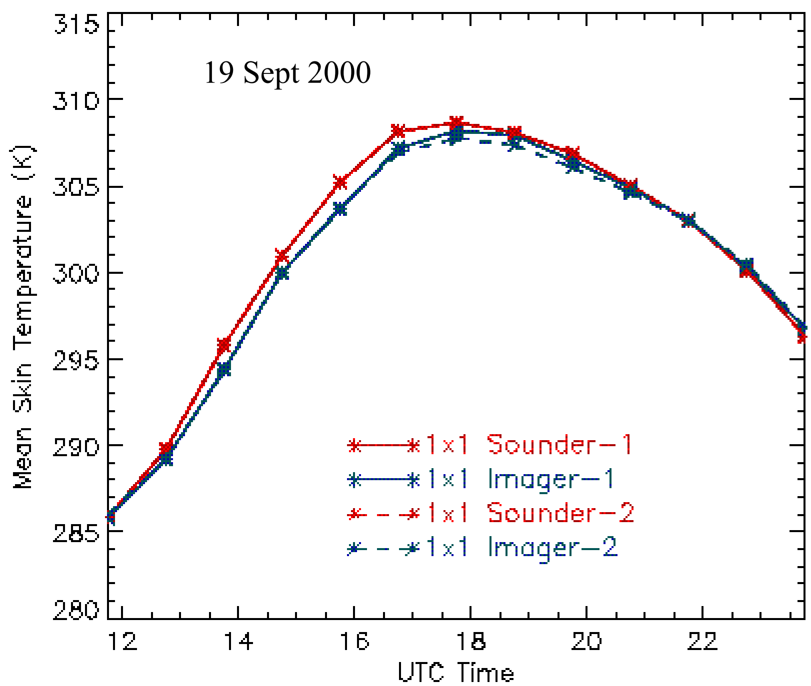
Sounder temperature then becomes slightly warmer (less than 1 K) than the Imager temperature for the next 1-3 hours. During the 14-17 UTC time frame the temperatures are again very similar, with the Imager temperature becoming the warmer of the two. The Imager temperature remains the warmest for the remainder of the day, with the largest differences of 1-1.5 K occurring at 1945 and 2045 UTC.

The following discussion focuses on the statistics computed using method 1 to avoid cloud contamination issues. For the majority of the spring, summer and fall cases examined for this research the following observations hold true. The mean temperatures computed from the Imager and Sounder CONUS retrievals for the April, July and September cases are for 78% of the cases in agreement by 1 K, and for 97% of the cases in agreement by 2 K. The mean temperatures computed from the two instruments are very similar during the first hour of retrievals. The Sounder retrievals then become slightly warmer and remain so during the daytime heating and the warmest hours of the day. Starting at approximately 1945-2045 UTC, the Imager retrievals become the warmer product and continue to be for the remainder of the day.

4.1.2.2 Southeast Domain Comparisons

Comparisons of the mean temperatures computed over the Southeast domain from single pixel resolution retrievals for two case days are presented in Figure 4.5. For each case study period several days were studied and the results shown in Figure 4.5 are representative of the total dataset. The case on September 19, 2000 (Figure 4.5(a)) was a day with very few clouds, and thus very little cloud contamination, as can be deduced by the similarity of the two sets of Imager values. The pattern of the bias between the

(a)



(b)

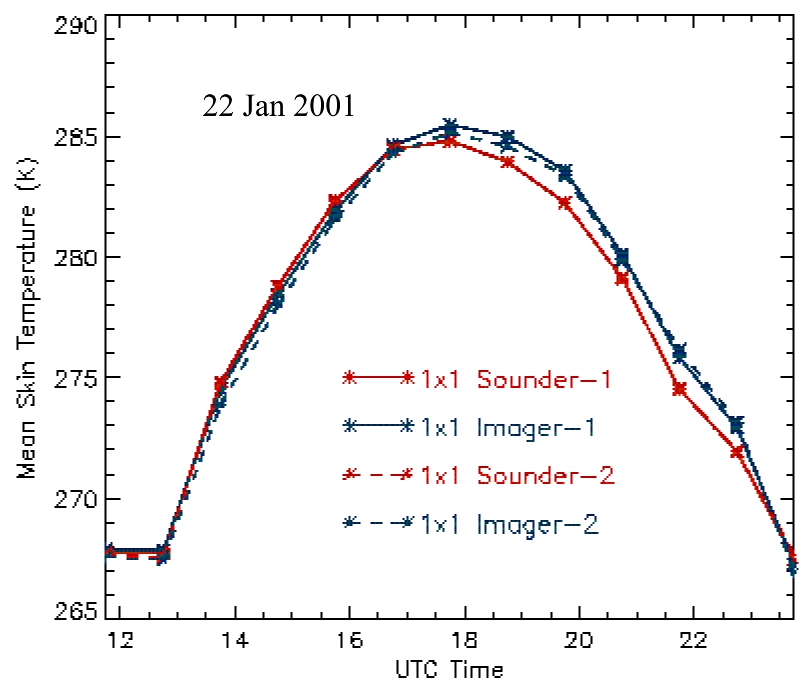


Figure 4.5 Mean skin temperature values computed from single pixel resolution retrievals over the SE domain.

Imager and Sounder products for the summer and fall CONUS domain cases is again exhibited by the September 19 SE domain case. The Imager and Sounder mean temperatures are very similar for the first couple of hours, the Sounder temperatures are warmer by 1-1.5 K during the peak heating time frame, and then the Imager produces slightly warmer temperatures from 2245-2345 UTC.

The second plot (Figure 4.5(b)) presents a wintertime case on January 22, 2001. Again, the bias between the Imager and Sounder differs from that exhibited during the warmer seasons, and the differences between the mean temperatures range from approximately 0 K at 1145-1245 UTC, to 1.5 K at 1945-2145 UTC. The differences between the mean temperatures for the September 19, 2000 and January 22, 2001 cases are presented in Figures 4.6(a) and (e), respectively. Also shown in Figure 4.6 are the computed differences between the NESDIS Imager and Sounder ST mean temperatures (b), the differences between the NESDIS and GHCC Imager mean temperatures (c), and the differences between the NESDIS and GHCC Sounder mean temperatures (d). The NESDIS plots are included to help determine the cause of the bias between the Imager and Sounder ST products.

The cause of the bias between the Imager and Sounder products is unknown. Since the bias varies with time and also displays seasonal variations, it is probable that the bias is not a result of the PSW algorithm but of calibration errors in the satellite data itself. An algorithm-produced bias would be expected to affect both products since retrievals are generated using the same assumptions and first-guess data. Solar heating of the instruments on the GOES satellites varies by both season and time of day, and one instrument may be affected more by the changes in solar heating than the other.

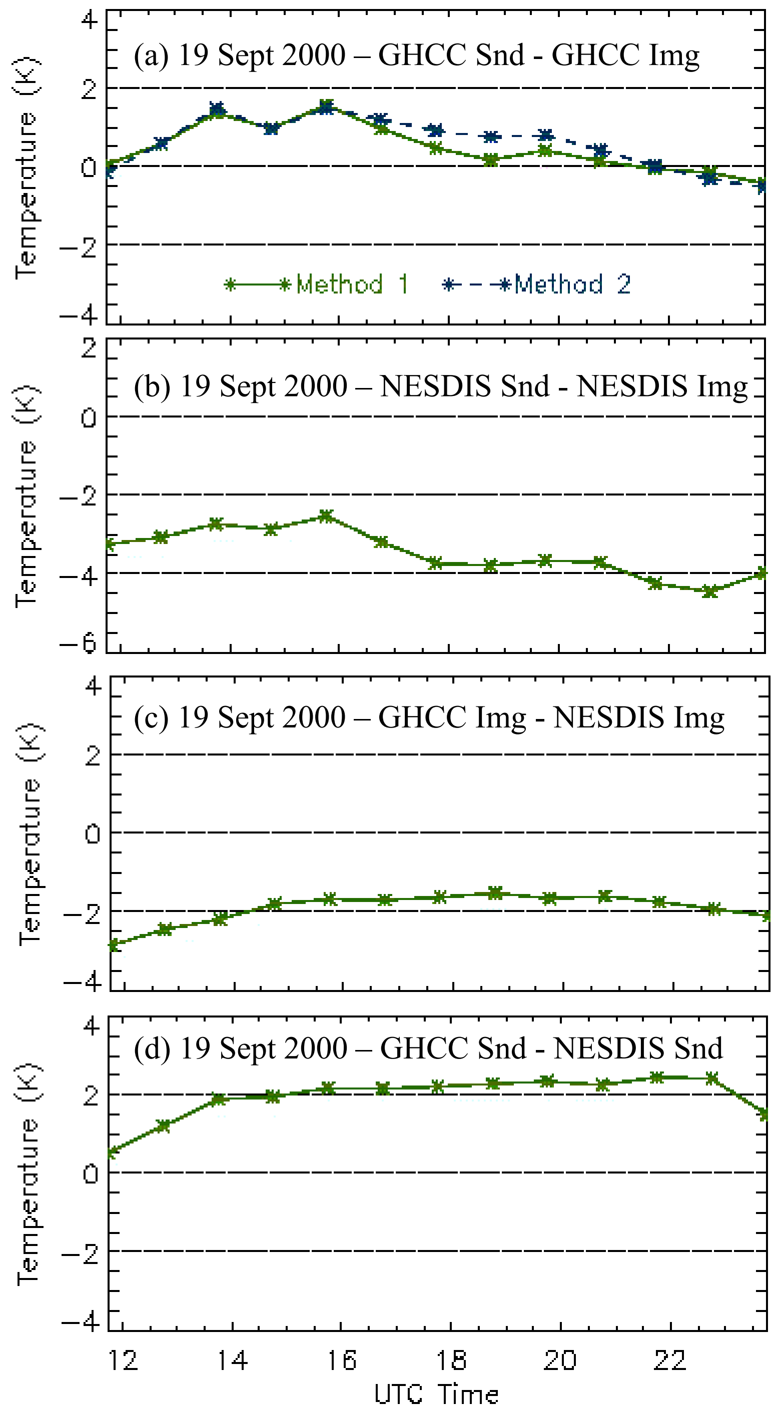


Figure 4.6 Differences between GHCC Sounder and Imager (a,e), NESDIS Sounder and Imager (b), NESDIS and GHCC Imager (c), and NESDIS and GHCC Sounder (d), mean temperatures computed over the SE domain.

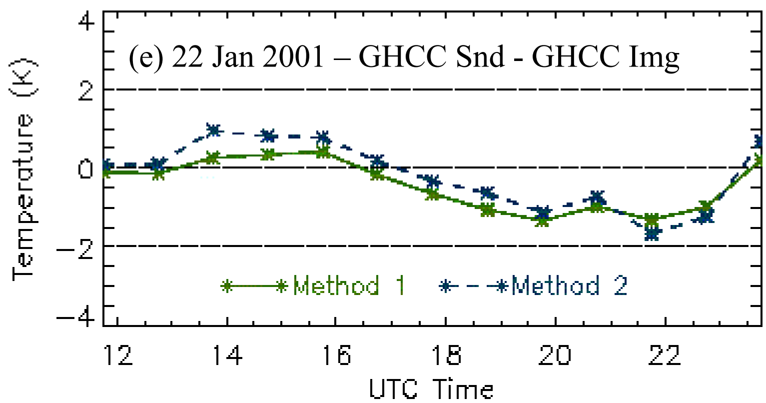


Figure 4.6 (continued).

Additionally, analysis of the NESDIS Imager and Sounder ST products (Lapenta et al. 2000) has revealed a similar relationship between their Imager and Sounder products. The NESDIS ST retrievals are produced using a similar but more complex technique than the PSW algorithm (Hayden et al. 1996). Since the differences in mean temperature between the Sounder and Imager exhibit comparable trends from two different techniques (Figure 4.6(a,b)), the bias between the two temperatures is most likely a result of calibration issues. The following discussion presents results of GHCC and NESDIS comparisons for the September 19, 2000 case covering the SE region. The NESDIS results were computed using the same number of pixels at collocated locations for the Imager and Sounder, on a 12 km spaced grid.

There is significant similarity between the GHCC and NESDIS plots shown in Figure 4.6 (a) and (b), respectively. The biases exhibited by the two separate ST retrieval methods are very similar in shape, although the NESDIS difference is much larger. Also notice that the biases between the NESDIS and GHCC methods for the same instruments

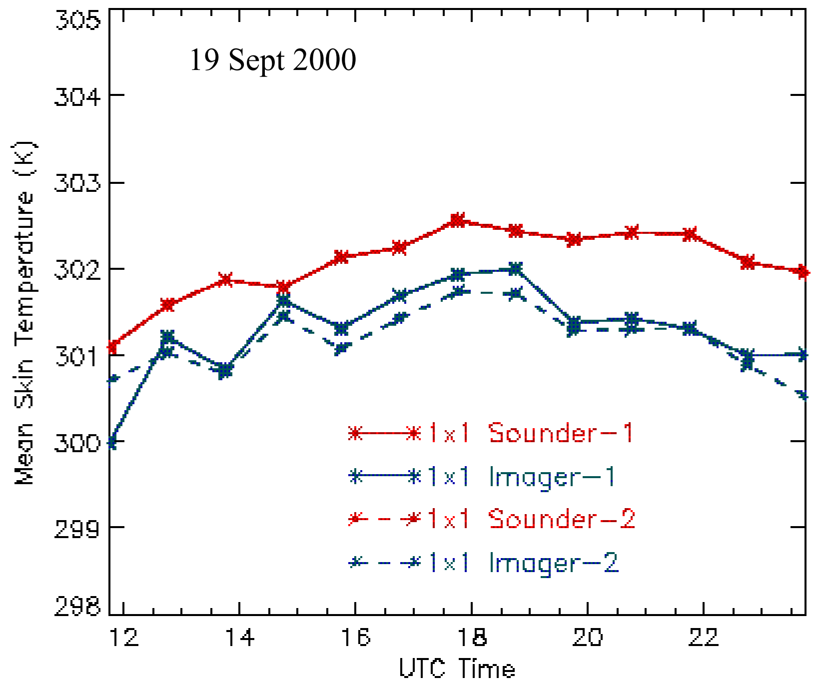
(Figure 4.6(c,d)) are fairly constant. Although there are biases between the methods of approximately –2 K and 2 K for the Imager and Sounder respectively, the bias remains consistent for much of the day. Thus revealing a general agreement in the overall diurnal trends of ST computed for each instrument by the NESDIS and GHCC methods. The 2 K bias between the GHCC and NESDIS products is the result of the algorithms and associated preprocessing differences, although the most accurate product is unknown.

4.1.2.3 Ocean Domain Comparisons

The PSW technique was intended for LST retrievals, not SST. The algorithm is able to produce SSTs, but the accuracy of ocean temperatures is not expected to be as high as that of the land temperature retrievals. As previously stated, a limitation of the forward radiative transfer code Simrad is that it provides guess information only to 1000 mb. Often the pressure over the oceans is greater than 1000 mb. Also previously noted, both Imager and Sounder ST retrievals exhibit striping errors over both the land and the ocean, and therefore SSTs can be expected to display inaccurate variations as a result of the striping. The change in temperature both spatially and temporally over the oceans is generally small; therefore, the striping and noise errors are a larger percentage of the overall temperature change over ocean than over land. The random noise and striping errors are therefore more noticeable over the oceans.

Figures 4.7 and 4.8 show Sounder and Imager oceanic mean temperatures and the differences between the mean temperatures, respectively, for two case days. Again, statistics were computed for many case days, and the cases presented here provide a good representation of the whole. Over the ocean the mean temperature would be expected to

(a)



(b)

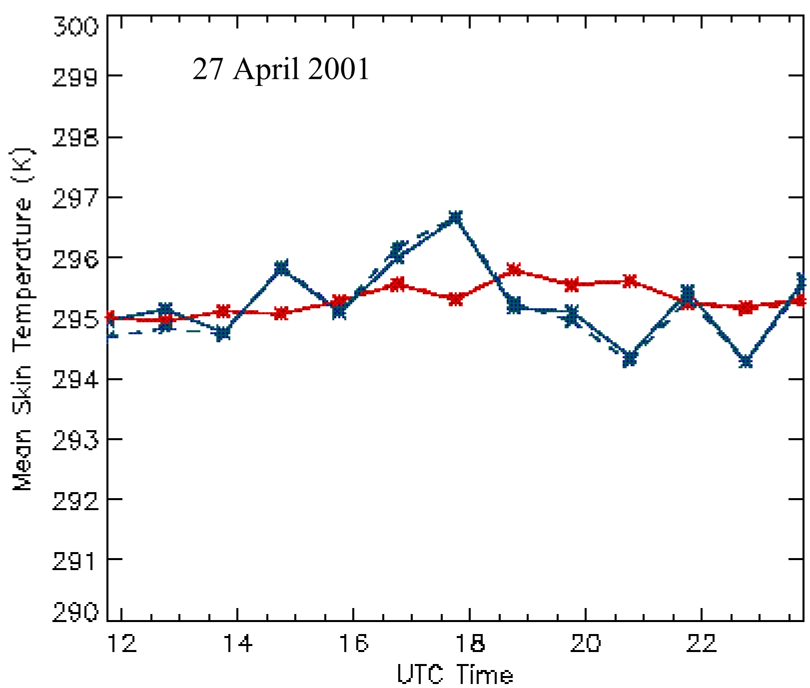
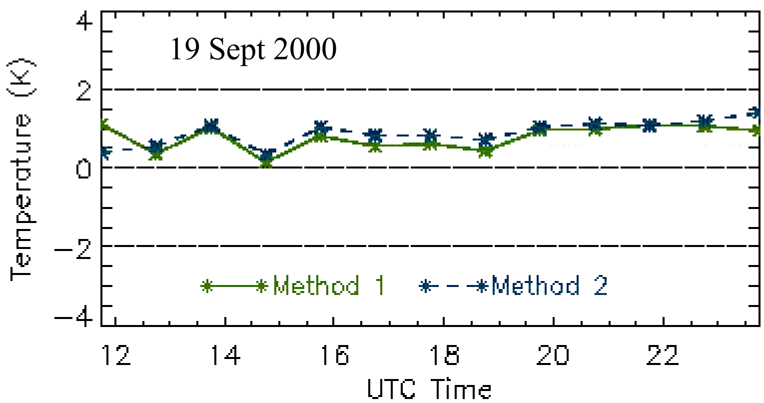


Figure 4.7 Mean skin temperature values computed from single pixel resolution retrievals over the ocean domain.

(a)



(b)

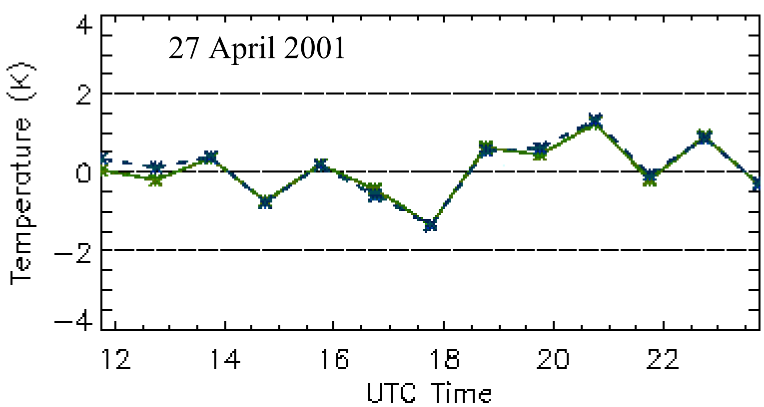


Figure 4.8 Differences between Sounder and Imager mean temperatures computed over the ocean domain for the two cases presented in Figure 4.6.

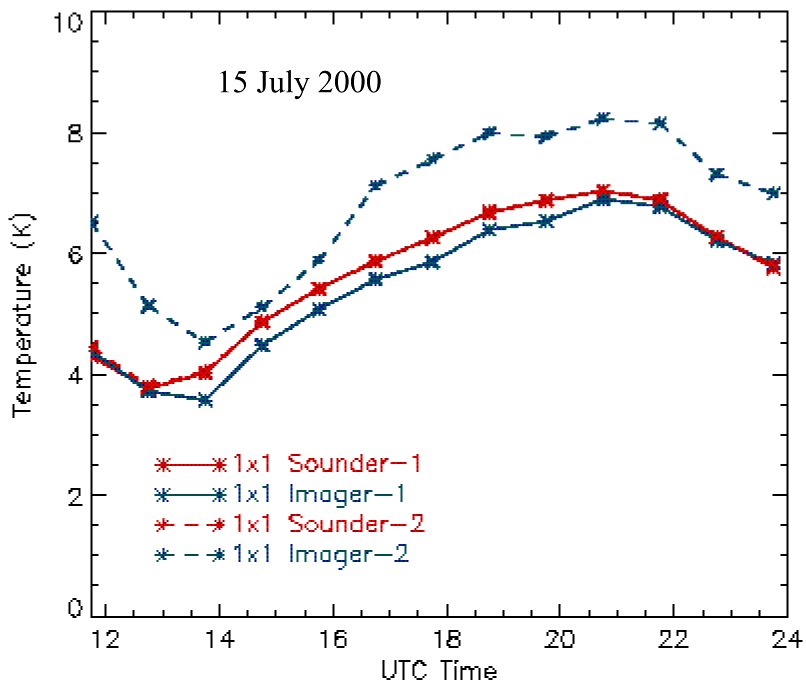
either remain constant or exhibit a slight warming and then cooling pattern during a daytime period. Because of the small range in temperature, time-to-time image calibration uncertainties are more apparent than over land regions. A slight diurnal warming and cooling trend is presented for the September 19, 2000 case (Figure 4.7(a)), but a large amount of variation is still present. The Sounder retrievals produce a slightly smoother daily temperature trend over the ocean than the Imager retrievals. Similar daily trends are seen for the same cases but for averaged retrievals (not shown). The average absolute bias between the Sounder and Imager SSTs (Figure 4.8, and plots not shown) computed from 12 clear-sky days using method 1 is 0.5 K, and the maximum bias is 1.8 K, with the Sounder product often the warmer of the two. The bias between the mean Sounder and Imager SSTs is below 1 K 87% of the time, and less than 2 K 100% of the time, for method 1 results. Using method 2 data, the average absolute bias between the Imager and Sounder mean oceanic temperatures is 1.1 K, with a maximum value of 3.8 K, and with 53% of the values below 1 K and 86% of the values below 2 K. The bias pattern exhibited over the land domains between the Imager and Sounder products (Figures 4.3 and 4.6) is not evident over the ocean. Again, the sensitivity of the retrieval algorithm to striping is most likely responsible for the lack of any discernable relationship between the Sounder and the Imager.

4.1.3 GOES-8 Imager and Sounder Standard Deviation Comparisons

For all the case study periods the standard deviation (SD) from the mean temperature using both computation methods was calculated. The standard deviation of ST is a measure of scene variations from at least three sources: the natural spatial variability of the surface temperature across the domain, the variation caused by striping and noise errors, and cloud contamination. To reduce the striping and noise contribution, averaging of ST retrievals is often performed. However, averaging also reduces the natural spatial variation of ST. The following section compares the SD values computed from Imager and Sounder retrievals at single pixel, 3x3 pixel averaged and 5x5 pixel averaged resolutions. Similar results were found for both the land domains; therefore, to avoid repetition, only results from the CONUS domain are presented. Results computed over the ocean domain mainly reflect the striping and noise components, and the Imager and Sounder values were found to be very similar. Therefore, the following discussion focuses upon the findings over the CONUS domain only.

Figure 4.9 presents two examples, typical of the results found for other days, of SDs computed over the CONUS domain at single pixel resolution. A general pattern is exhibited by both instruments throughout the year, although the pattern is not as obvious during the January case. The SD values often start out at 1145 UTC at a peak, and then dip down with the lowest values of the day from 1245 to 1445 UTC. The SD values then rise during the peak heating time of the day and reach a maximum, and then decrease as the surface temperatures decrease. This pattern shifts during the year as the time of maximum heating and cooling also shifts. The increase in SD corresponds to the peak heating time because of the large variation in temperature across the region occurring at this time. For many of the cases the 1145 UTC SD values for both the Imager and the Sounder products are larger than the values for the few hours following. This is most likely a result of cloud contamination. Although the Sounder cloud mask generally over-determines, the current version of the cloud mask algorithm for both

(a)



(b)

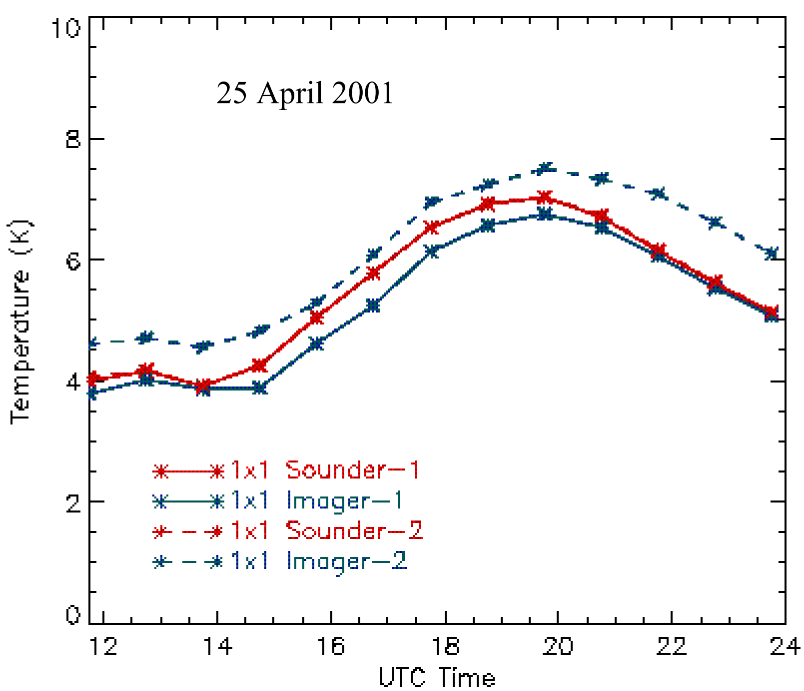


Figure 4.9 Standard deviation values computed from single pixel resolution retrievals over the CONUS domain.

instruments has significant problems during times with low sun angles, i.e., sunrise and sunset. As the cloud contamination diminishes with the rising sun, the SD values decrease.

The plots in Figure 4.9 have values computed using the two methods previously described. Again, no difference is discernable between the two sets of Sounder values because of the similarity in sample size. There are noticeable differences between the two sets of Imager values, with the SDs computed using all the clear Imager pixels having larger values. The Imager values computed using the same number of pixels as the Sounder computations (method 1, solid line) represent the SD from the mean temperature sampled at 10 km spacing. Method 2 (dashed line) provides results from all the available information the Imager provides. It is of interest to analyze the results computed using all the available data, and to discover any benefits from the higher spatial resolution of the Imager retrievals.

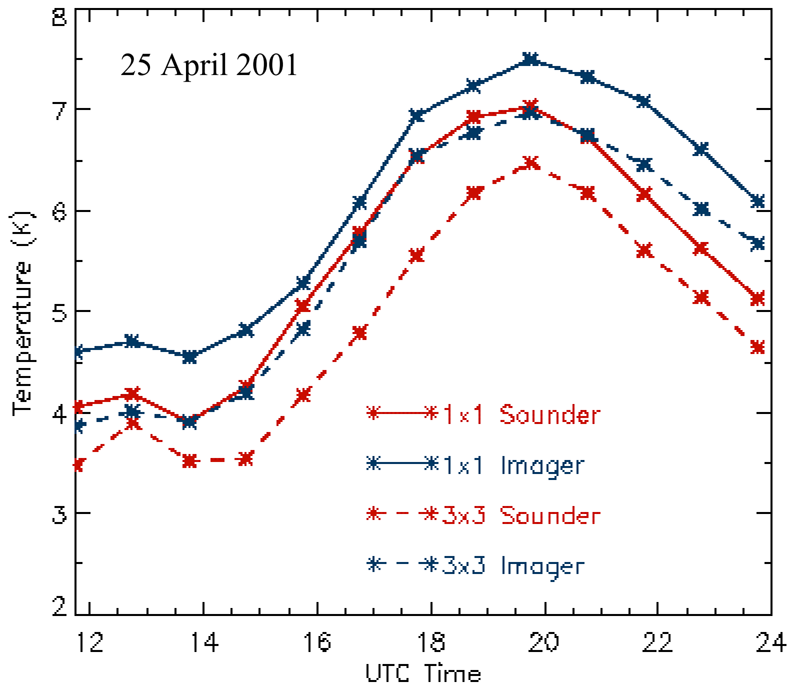
Comparing the method 2 SDs of single pixel retrievals from the Imager and Sounder in Figure 4.9 reveals larger values for the Imager retrievals. As previously mentioned, a portion of increase in the Imager values over the Sounder values is cloud contamination, but for clear days there is still a difference in the SD values and this suggests that the Imager is detecting a higher degree of natural variation of ST across the region. Larger SD values for the Imager are expected because of the Imager's finer spatial resolution, and the 100% coverage by the Imager compared to only approximately 64% coverage by the Sounder.

The SD values from both instruments at the single pixel resolution contain a noise component, and averaged retrievals can be expected to remove most of this noise. The plots in Figure 4.10 show a comparison of single pixel and 3x3 averaged retrievals (a), and a comparison of 3x3 and 5x5 averaged retrievals (b), all computed using method 2. In Figure 4.10(a), the solid red line (1x1 Sounder) and the dashed blue line (3x3 Imager) represent the SD of ST sampled by the Imager and Sounder at similar sampled spatial resolutions. The Imager retrievals are still at single pixel spacing, but each pixel is the average of its surrounding 3x3 pixel box. The Sounder retrievals are at single pixel spacing, but with no averaging. The Imager retrievals are averaged, and therefore both noise and natural variation components are reduced. These Imager and Sounder SD values are very close, with the only significant difference during the late afternoon hours. This observation suggests that for the same sampled spatial resolution single pixel Sounder retrievals detect a similar degree of natural variability as 3x3 pixel averaged Imager retrievals. However, the Sounder values still contain a striping and random noise component, and therefore the natural variability detected by the Sounder should be less than that indicated in Figure 4.10(a).

Figure 4.10(a) also shows the SD of ST for both Imager and Sounder 3x3 pixel averaged retrievals (dashed lines). As expected, the Sounder SD values have decreased from the single pixel results because of decreased components of both noise and natural variability. Also, the Imager again has the larger SD values for the same reasons (finer resolution, 100% coverage) as for those stated for Figure 4.9. Both Imager and Sounder 3x3 pixel averaged SD values have decreased by approximately 0.5 K from their single pixel SD values.

Figure 4.10(b) compares 3x3 to 5x5 pixel averaged retrievals for both sensors. Again notice the larger values of the Imager retrievals compared to the Sounder retrievals

(a)



(b)

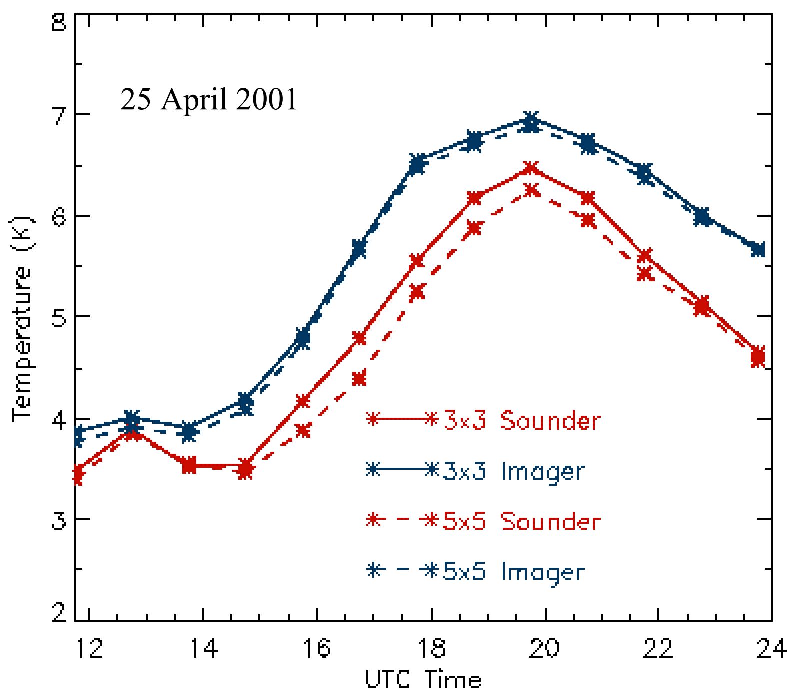


Figure 4.10 Comparisons of standard deviation values computed from single pixel and averaged retrievals over the CONUS domain.

with the same amount of averaging. This figure also reveals the relatively small decrease in SD values from the 3x3 to the 5x5 results. The largest decrease occurs between the single pixel retrievals and the 3x3 averaged retrievals. As seen in the image analysis (Figure 4.1, Section 4.1.1) , much of the striping is removed from single pixel retrievals, particularly from the Sounder retrievals, by averaging 3x3 pixel boxes. Comparisons between the 3x3 and 5x5 images revealed a decrease in natural variability, but most of the striping has previously been removed; therefore, the decrease in SD values is small.

Retaining the 4 km spatial resolution of the Imager retrievals but performing averaging appears to reduce to striping and random noise but preserve much of the natural variability of ST. At single pixel spacing, the Imager has approximately 15 pixels (with some overlapping occurring in the east-west direction) for every one Sounder pixel. The much higher number of pixels, the finer spatial resolution, and the 100% coverage of the Imager are significant advantages over the Sounder. Statistics computed by selecting only the closest Imager pixel to each Sounder pixel (i.e., method 1) as shown in Figure 4.9 reveal similar SDs for single pixel Imager and Sounder retrievals (solid lines). Therefore, the Imager's advantage is only retained at single pixel spacing. Images of retrievals produced using single pixel Sounder data often exhibit striping. Therefore averaging of Sounder retrievals is necessary to eliminate striping, but the sampled spatial resolution may be too coarse for some applications. If a fine resolution is not required, Sounder retrievals at single pixel spacing but averaged from 3x3 boxes may be the preferred choice. The Sounder 3x3 product exhibits less natural variation of skin temperature than the 3x3 Imager product, but the striping and noise are also less.

In summary, the Imager has the distinct advantage of a finer spatial resolution than the Sounder. At single pixel resolution both Imager and Sounder ST products display significant striping; therefore, averaging of the pixels is often required. The Sounder product has the advantage of less striping than the Imager product (as seen in Figure 4.1) when both are averaged from 3x3 pixel boxes. However, the 3x3 averaged Imager product provides more details about the natural spatial variation of ST than the corresponding Sounder product. The choice of either the Imager or Sounder ST product with respect to variability (both natural and as a result of noise) depends upon the required resolution of the data and its particular meteorological application.

4.1.4 GOES-8 Imager and Sounder ST Tendency Comparisons

Morning hourly skin temperature tendencies from the GOES-8 products are assimilated into the MM5 forecast model at GHCC; therefore, it is of interest to compare the tendencies from the Imager and the Sounder. Much of the systematic bias seen between the Imager and Sounder mean temperatures discussed in the previous sections is not present in the tendencies, especially during a time period of a few hours when the bias does not vary significantly. By assimilating the tendencies into the model, the errors resulting from systematic biases between the sensors and also any algorithm related systematic bias (although not readily apparent) are reduced or removed.

Plots of hourly tendencies computed over the CONUS domain are shown in Figure 4.11. For each instrument the tendencies are computed using retrievals from pixels determined to be clear for both hours (see Section 3.3 for description of the tendency computation method). The sample sizes of the computations are similar to

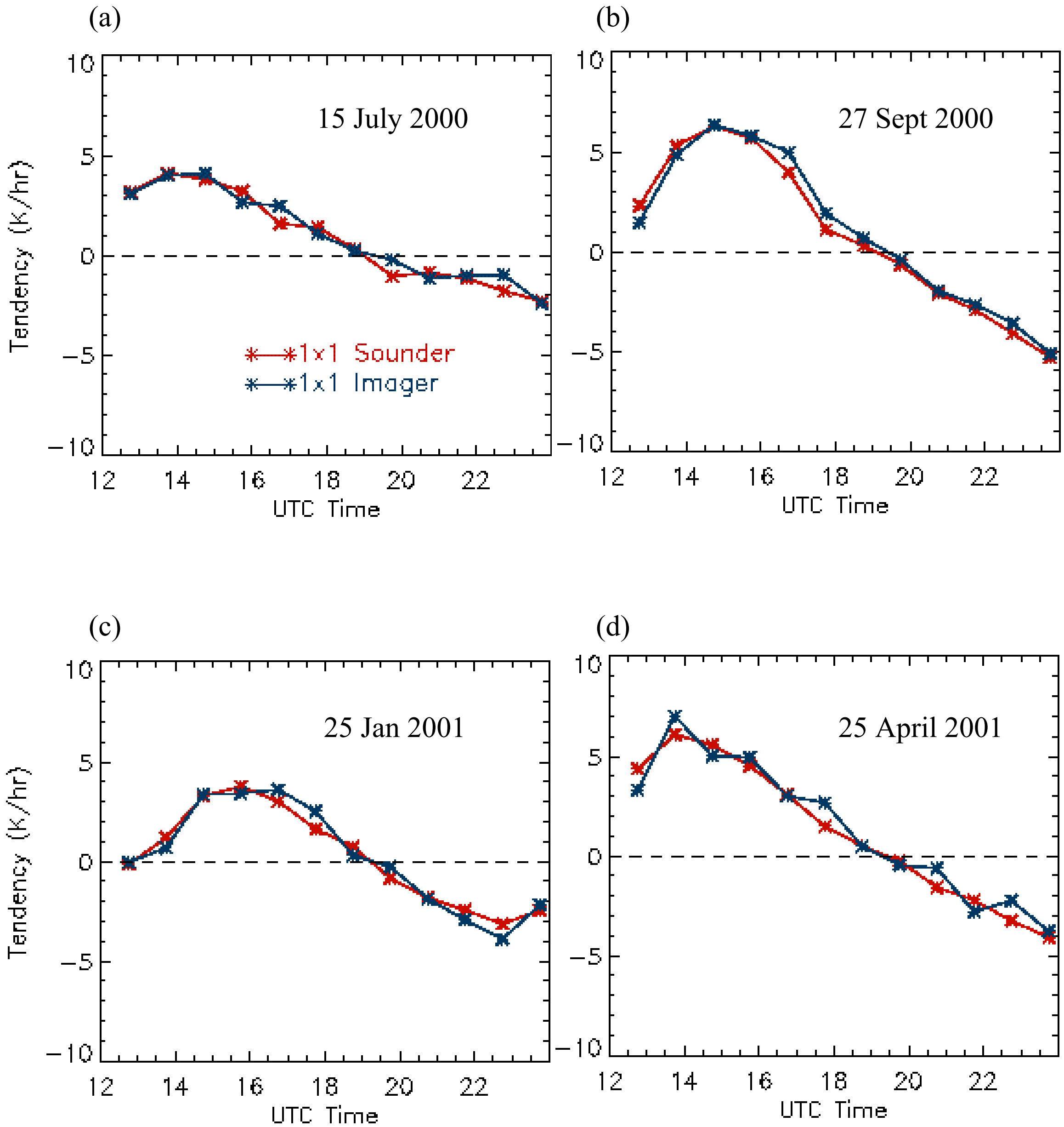


Figure 4.11 Skin temperature tendencies computed from single pixel resolution retrievals over the CONUS domain.

those used by the method 2 computations of mean temperature, with slightly lower values because of the presence of additional clouds in the second hour. The tendency value is plotted corresponding to the second hour of the one hour interval. Figure 4.11 contains plots computed from single pixel retrievals for (a) 15 July 2000, (b) 27 September 2000, (c) 25 January 2001, and (d) 25 April 2001. It is important to notice that the slope of the line does not indicate a warming or cooling but a change in the tendency; it is the location of the point in relation to the 0 K/hr line that determines the sign of the tendency. For example, looking at Figure 4.11(d) the Imager tendencies become less negative from 2245 to 2345 UTC, but indicating cooling at both times.

The plots in Figure 4.11 all show the largest heating rates in the early to mid morning period, with the highest rates of 6-7 K/hr occurring in September and April. The time of the largest heating rates changes with season, with a later time of 1445 through 1645 UTC for the January case, and an earlier time of 1345 UTC for the July and April cases. The January example exhibits the smallest tendency magnitudes with maximum heating and cooling rates of only 4 K/hr. The largest tendency magnitudes are displayed by the spring and fall examples, with both significant heating (6 to 7 K/hr) and cooling (-4 to -5 K/hr) rates. The summer example had the smallest range of tendencies of 4 K/hr to -2.5 K/hr.

As with the mean temperature comparisons, there is generally good agreement between the Imager and Sounder tendencies. For 94% of the cases the Imager and Sounder tendencies agree within 1 K/hr, and 100% cases agree within 1.5 K/hr. The average absolute difference between the Sounder and Imager hourly tendencies for the case days analyzed is 0.4 K/hr, with a maximum difference of 1.5 k/hr. The Imager and

Sounder tendencies have the same general trends and magnitudes, and again it is unknown which instrument is producing the most accurate plot. The lack of smoothness of the data in the plots may indicate time-to-time calibration errors. It has been suggested (Suggs et al. 2001) that the Sounder produces the smoother tendencies and thus the Imager product may still contain some irregularity in the radiance measurements or calibration despite 3x3 averaging. However, this research does not either confirm or reject this hypothesis because of the different relationships exhibited between the Imager and Sounder tendencies at different times.