A SIMPLE GOES SKIN TEMPERATURE PRODUCT

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Abstract

A skin temperature image product is easy to generate from the split-window bands of the GOES Imager or Sounder. This product can be used to monitor land and ocean surface skin temperatures as well as temporal changes of those temperatures. In addition, other satellite instruments with split-window bands besides GOES are capable of providing this product. Comparisons of the skin temperature product with the Sea-Surface Temperature derived product imagery from the GOES Sounder are very good. But this product has an advantage since it is created from only two bands of the GOES Imager with a simply-applied algorithm. Real-time skin temperature images using this algorithm are routinely available on-line for both the GOES Imager and Sounder, and could easily be generated locally by the NWS forecaster.

1. Introduction

An image product that is easily generated from the GOES split-window bands can be used to monitor surface skin temperature changes. This product, a variant of GOES thermal infrared images corrected for low-level atmospheric absorption, is available at the same high spatial and temporal resolution as the images used to generate it. The small transmittance difference between the split-window bands (the infrared window, band-4, 10.7 :m; and the dirty window, band-5, 12.0 :m, on the GOES-8 through 11 Imager) can be used to correct these bands for the effects of atmospheric absorption, arriving at a skin temperature image product.

The chief use of the skin temperature product is to determine changes or boundaries in the low-level temperature. Color enhancements are used to quickly quantify the skin temperature and its variations and help track changes over time. Variations in surface heating are related to both surface types and low-level moisture. Also, when compared to shelter temperatures, the skin temperature can be used to indicate the temperature lapse rate near the surface, at times indicating the presence of low-level temperature inversions.

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Examples of this product generated from the split window bands of both the GOES Imager and GOES Sounder have been produced. For the Sounder a change in the atmospheric correction factor is needed due to spectral differences in the split-window bands. Also, the split-window difference temporarily disappears from the GOES Imager starting with GOES-12, due to a change of the 12.0 μm band to a more opaque 13.3 μm band intended for cloud detection. A skin temperature product is not as easily generated from the larger spectral (and transmittance) separation of those bands. However the split window difference remains on the GOES Sounder and will again be available on the imager on the GOES-R series currently under development, the first of which is scheduled for launch in 2012. In the interim the split window difference is available through instrumentation on many polar-orbiting satellites.

2. Analysis of Skin Temperature

Based on the work of McMillin and Crosby (1984), the split widow bands (band-4, 10.7 µm; and band-5, 12.0 µm, on the GOES Imager) can be used together to correct one of them for the effects of atmospheric absorption. The formula is

$$T_{sfc} = T_{10.7} + \eta \cdot (T_{10.7} - T_{12.0})$$

where

$$\eta = \frac{1 - \tau_{10.7}}{\tau_{10.7} - \tau_{12.0}}$$

and τ is atmospheric transmittance (see Kidder and Vonder Haar 1995, pages 219–225, for details). This derivation is similar to sea-surface temperature algorithms (McClain et al. 1985), but it is simpler.

MODTRAN (Berk et al. 1989) calculations for the standard mid-latitude atmosphere show that for the GOES Imager $\tau_{10.7}$ is about 0.68 and $\tau_{12.0}$ is about 0.57. This means that the correction or scale factor η is approximately 2, which is applied to the temperature differential between the two bands and added to more transparent 10.7 μm band. The resulting product is closer to the actual radiative skin temperature than either of the input bands.

Examples of T_{sfc} product images for the GOES-8 (GOES-east) and GOES-10 (GOES-west) Imager are shown in Figure 1. T_{sfc} appears quite similar to the usual $T_{10.7}$ image, but with slightly more noise because it is a combination of two bands. Still, most (about 98%) of the variance in the skin temperature product comes from the infrared window (10.7 μm) image, and only a very small amount (about 2%) of the variance comes from the split-window difference added back into the infrared image. A color enhancement is used to emphasize variations in temperatures affecting the land and ocean surfaces, whereas gray shades are used for cloud top temperatures. The break point between land and ocean skin temperatures and cloud top temperatures varies by latitude and season and can be adjusted using the color enhancement applied to the skin temperature product.

The time evolution of $T_{10.7}$, $T_{12.0}$, and the temperature correction $[2 \cdot (T_{10.7} - T_{12.0})]$ over Norman OK on a mostly cloud-free day (11-12 May 1998) are compared in Figure 2. The 0000 and 1200 UTC temperature soundings are also shown. GOES Imager band-5 (12.0 µm) is more sensitive to water vapor than is band-4 (10.7 µm); i.e. band-5 is more sensitive to the atmosphere than band-4. When the atmospheric temperature decreases with height, $T_{12.0}$ is normally cooler than $T_{10.7}$, and the temperature correction is positive. When the atmospheric temperature increases with height (a temperature inversion), the correction can be negative. In any case, T_{sfc} is closer to the actual skin temperature than either $T_{10.7}$ or $T_{12.0}$.

Unfortunately, the dirty or split-window band-5 on the GOES Imager disappeared when GOES-12 became operational as GOES-east in place of GOES-8. The new band-6 at 13.3 :m, meant for analysis of low clouds, is too opaque to be used together with the window band-4 to produce a skin temperature product. However, there are other satellite instruments that contain the split-window bands that can be used to produce a skin temperature product.

3. GOES Sounder and other instruments

Nearly the same split-window spectral bands are present on the 19-band GOES Sounder, on the Advanced Very High Resolution Radiometer (AVHRR) on polar-orbiting NOAA satellites, and on the Moderate Resolution Imaging Spectroradiometer (MODIS) on EOS-AM/Terra and EOS-PM/Aqua. Because the bands are spectrally different, a recomputed correction factor is necessary: such as $\eta \approx 3$ for AVHRR (Price 1984). Table 1 lists the wavelengths, transmittances, and scale factors computed for each of these instruments (based on a standard mid-latitude atmosphere) in addition to the GOES Imager. Although the spectral bands vary only slightly, the scale factor more than doubles for the GOES Sounder and MODIS.

Examples of T_{sfc} product images for the GOES-8 (GOES-east) and GOES-10 (GOES-west) Sounder are shown in Figure 3. In this case the scale factor is much larger (4.4) than for the GOES Imager or for the NOAA AVHRR instrument, but about the same as would be used for the MODIS split-window bands.

4. Comparison to Sea-Surface Temperature Derived Product Images

As a validity check, the GOES Imager skin temperature product can be compared to the GOES Sea-Surface Temperature (SST) product, which is a Derived Product Image (DPI) generated operationally from the GOES Sounder. The SST DPI is an image product that is the result of a temperature and moisture retrieval at each image pixel (Hayden et al. 1996). Since this product is produced over both land and ocean, it is not strictly a sea-surface product, but that terminology is used by the developers and will be used here to distinguish it from the skin temperature product featured in this article.

Figure 4 contains a comparison of the Imager skin temperature product with the Sounder SST for approximately the same time (1445/1446 UTC respectively) on 15 January 2003. The same rainbow-color enhancement used on the skin temperature product in previous figures is used here as well. However the Sounder SST product employs a similar but shifted color enhancement that cannot easily be matched to that of the skin temperature product due to the different scaling of the SST as an image product. Note some of the warmer (yellow) features of the sea surface seen in the Gulf of Mexico and off the east coast of Florida. These features are not seen as well in the lower (10 km) resolution Sounder SST product. In both images clouds are shaded grey.

The images in Figure 4 are only one of several times that the two image products were compared on that day. Figure 5 shows a time-series of values from both the skin temperature product (top) and SST product (bottom). The vertical axes display the temperatures for each product. The product times range from morning through evening as the temperature rises and falls again after the maximum surface heating has occurred. Each line in the figure represents the time-series for a single land-surface pixel over Florida, with many more pixels for the higher (4 km) resolution Imager product compared to the lower (10 km) resolution Sounder product. Land-surface pixels alone were chosen for this figure because they exhibit a significant rise and fall in skin temperature throughout the day (heating and then cooling), unlike ocean-surface pixels. The range of temperatures in the two products is similar, but some of the difference between the two products is due to both space and time resolution differences. The Imager product has been generated every half hour at 4 km resolution and the Sounder product has been generated every hour at 10 km resolution, the minimum interval between Sounder sectors available over the same geographic area.

A more-easily-followed comparison between the two products is shown in Figure 6, which is a scatter plot of 8835 matched pairs of land and ocean surface pixels between the two products given in Figure 4 (1445/1446 UTC on 15 January 2003). Both land-surface pixels over Florida and ocean-surface pixels surrounding Florida are shown in this figure, to include a large range in skin temperatures. The Imager skin temperatures are on the horizontal axis, and the Sounder SSTs are on the vertical axis. Because of spatial resolution differences between the products (4 km vs. 10 km for the Imager and Sounder respectively) several Imager pixels will match up with each Sounder pixel. This is one of the reasons for the broad scatter between the two products, as well as the fact that many pixels with similar temperatures are being compared. A dashed one-to-one line is drawn to show the equal-temperature relationship. Scatter plot values seem to be somewhat equally distributed around the equal-temperature line, with slightly more cooler values for the Imager product at the cool end, and slightly warmer values at the warm end compared to the Sounder product. The two products correlate at the 98% level, or an RMS difference of 0.11 K.

5. Summary and Conclusions

A simple surface skin temperature image product that can be constructed from GOES Imager or Sounder data (or polar-orbiting AVHRR or MODIS data) has been presented as a tool to improve weather analysis and forecasting by monitoring changes in land and ocean surface skin temperatures. This product is being generated on a continuing real-time basis from both GOES Imager and Sounder data on operational systems at CIRA and made available on on-line at: http://www.cira.colostate.edu/RAMM/rmsdsol/ROLEX.html. This is the type of product that should be available to forecasters: simple, easily-produced, reliable, and physically based. Because of its simplicity, the skin temperature product could easily be generated locally on AWIPS[1] for use by the NWS forecaster.

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Stanley Q. Kidder is a senior research scientist at the Cooperative Institute for Research in the Atmosphere (CIRA). He is author (with T.H. Vonder Haar) of the book *Satellite Meteorology: An Introduction* (Academic Press, 1995). He received the M.S. and Ph.D. degrees in Atmospheric Science from Colorado State University in 1976 and 1979 respectively; and the B.S. degree in Physics from Harvey Mudd College in 1971.

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[1] AWIPS = Advanced Weather Interactive Processing System

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Figure Captions

Figure 1: Skin temperature product images at 4 km resolution for the GOES-8 (top) and GOES-10 (bottom) Imager on 4 September 2002 at 1615 and 1600 UTC respectively. A special "rainbow-color" enhancement is applied to emphasize variations in land and ocean surface skin temperatures. Gray shades are used for clouds.

Figure 2: (Top) Time sequence of GOES-8 $T_{10.7}$, $T_{12.0}$, and the temperature correction used for Norman OK on 11-12 May 1998. (Bottom) 0000 and 1200 UTC temperature soundings at Norman OK on 12 May 1998.

Figure 3: Skin temperature product images at 10 km resolution for the GOES-8 (top) and GOES-10 (bottom) Sounder on 11 September 2002 at 1546 and 1601 UTC respectively. A special "rainbow-color" enhancement is applied to emphasize variations in both land and ocean surface skin temperatures. Gray shades are used for clouds.

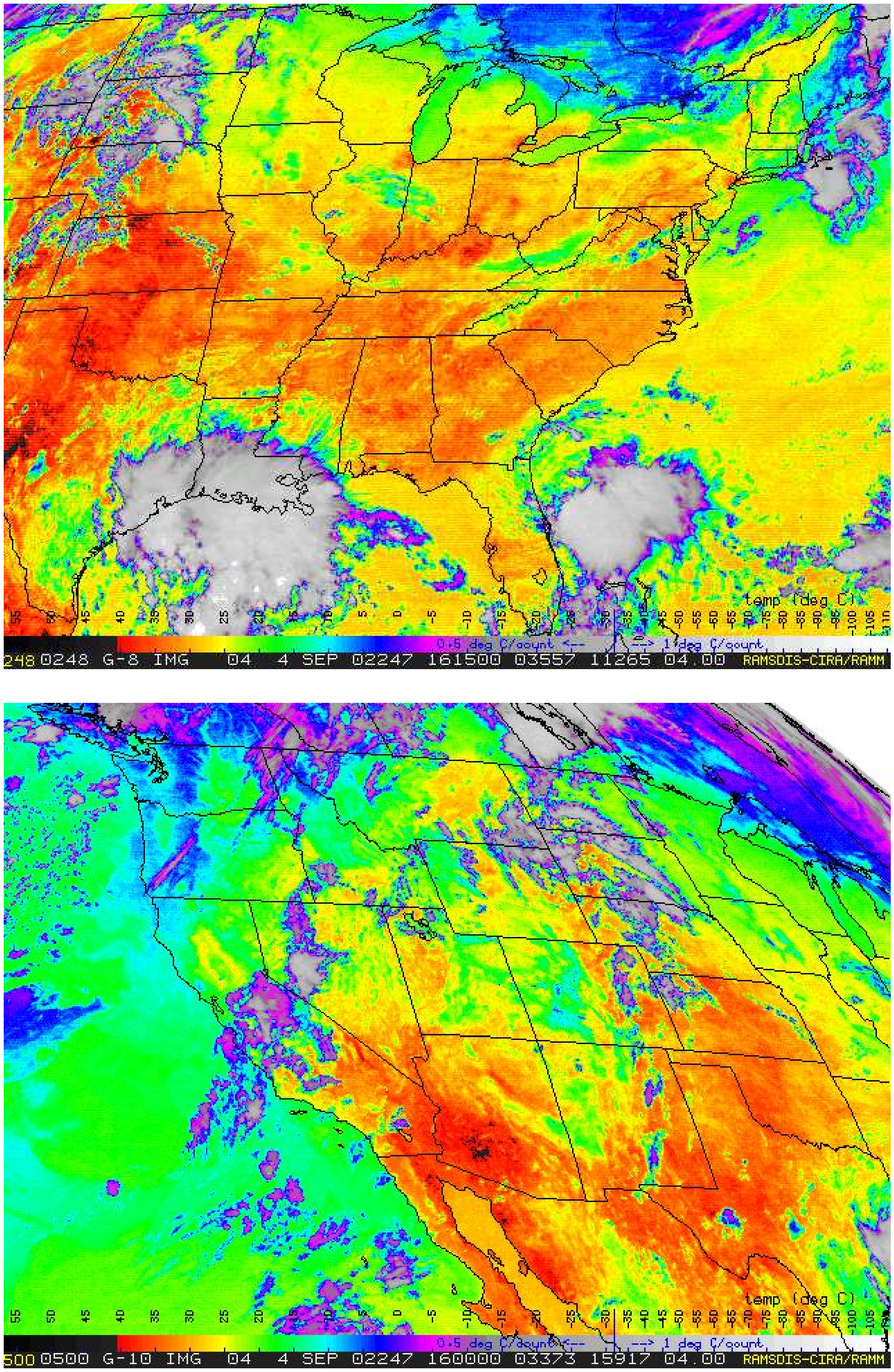
Figure 4: Imager skin temperature product vs. Sounder (land and ocean) SST product for 1745/1746 UTC respectively on 15 January 2003. The color enhancement is that used in previous figures. A similar but somewhat-shifted color enhancement has been applied to the Sounder SST product. Gray shades are used for clouds in both images. White contours on the images are shelter temperatures.

Figure 5: Time-series of Imager skin temperatures (top) and Sounder (land) SSTs (bottom) for 7.5 and 7 hours respectively on 15 January 2003. Lines are time-series of temperature for land-surface only pixels over Florida, showing warming and then cooling as the day progresses.

Figure 6: Comparison of the Imager skin temperatures (horizontal) and Sounder (land and ocean) SSTs for matched pairs of pixels (over Florida and the surrounding ocean) at 1445/1446 UTC respectively on 15 January 2003. The dashed line is a one-to-one equal-temperature relationship. The two products have a high correlation of 0.98 and a low RMS difference of 0.11 K.

Table 1: Wavelengths, Transmittances and Scale Factors for Various Satellite Instruments with Split-window Bands.

Satellite and Instrument	Wavelength (um)		Transmittance		Scale Factor
	8_1	8_2	J_1	J_2	0
GOES-8/11 Imager	10.7	12.0	0.71	0.57	2.1
GOES Sounder	11.0	12.0	0.65	0.57	4.4
NOAA AVHRR	10.8	12.0	0.68	0.57	2.9
EOS MODIS	11.0	12.0	0.65	0.57	4.4



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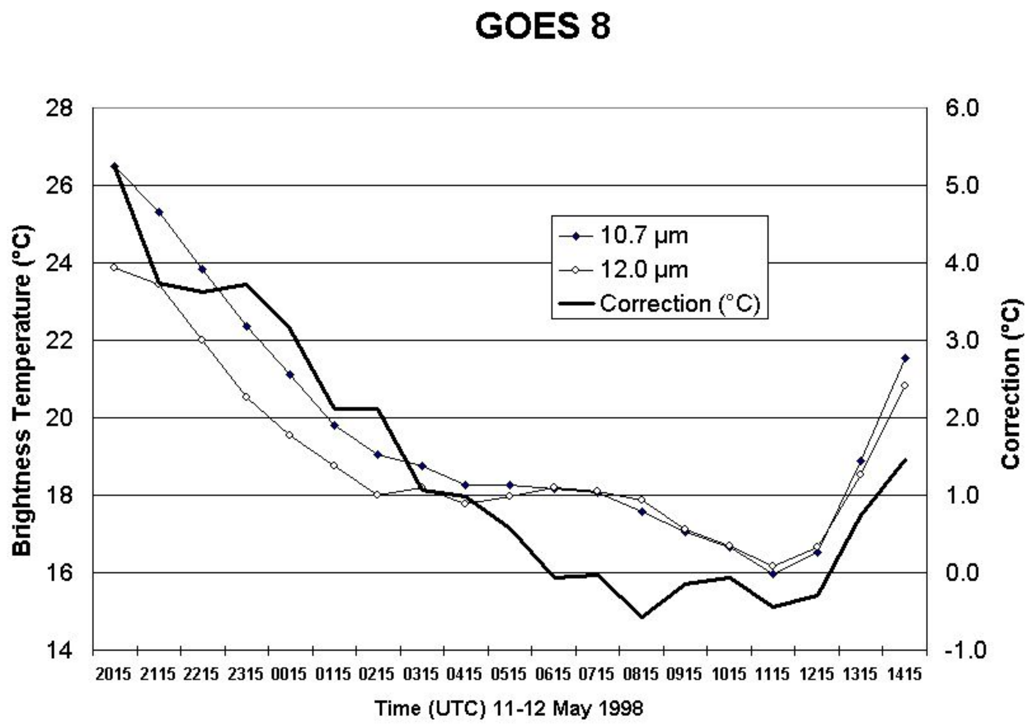

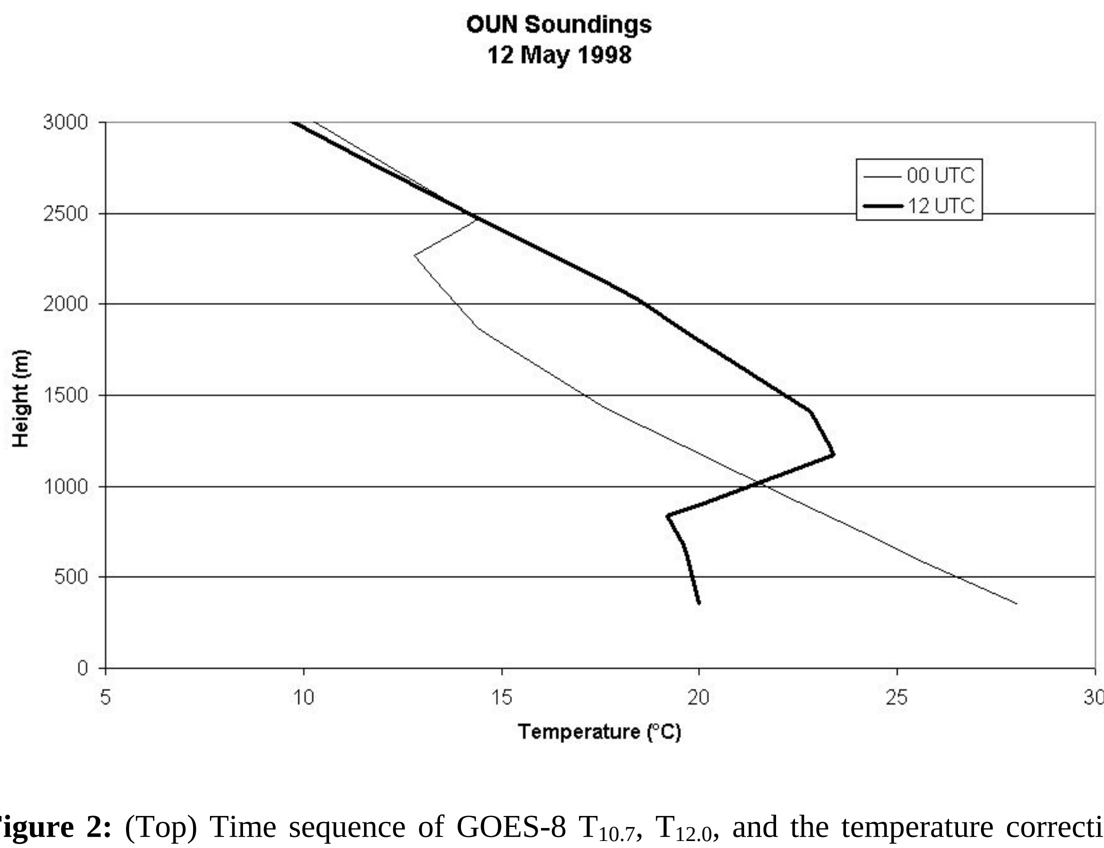

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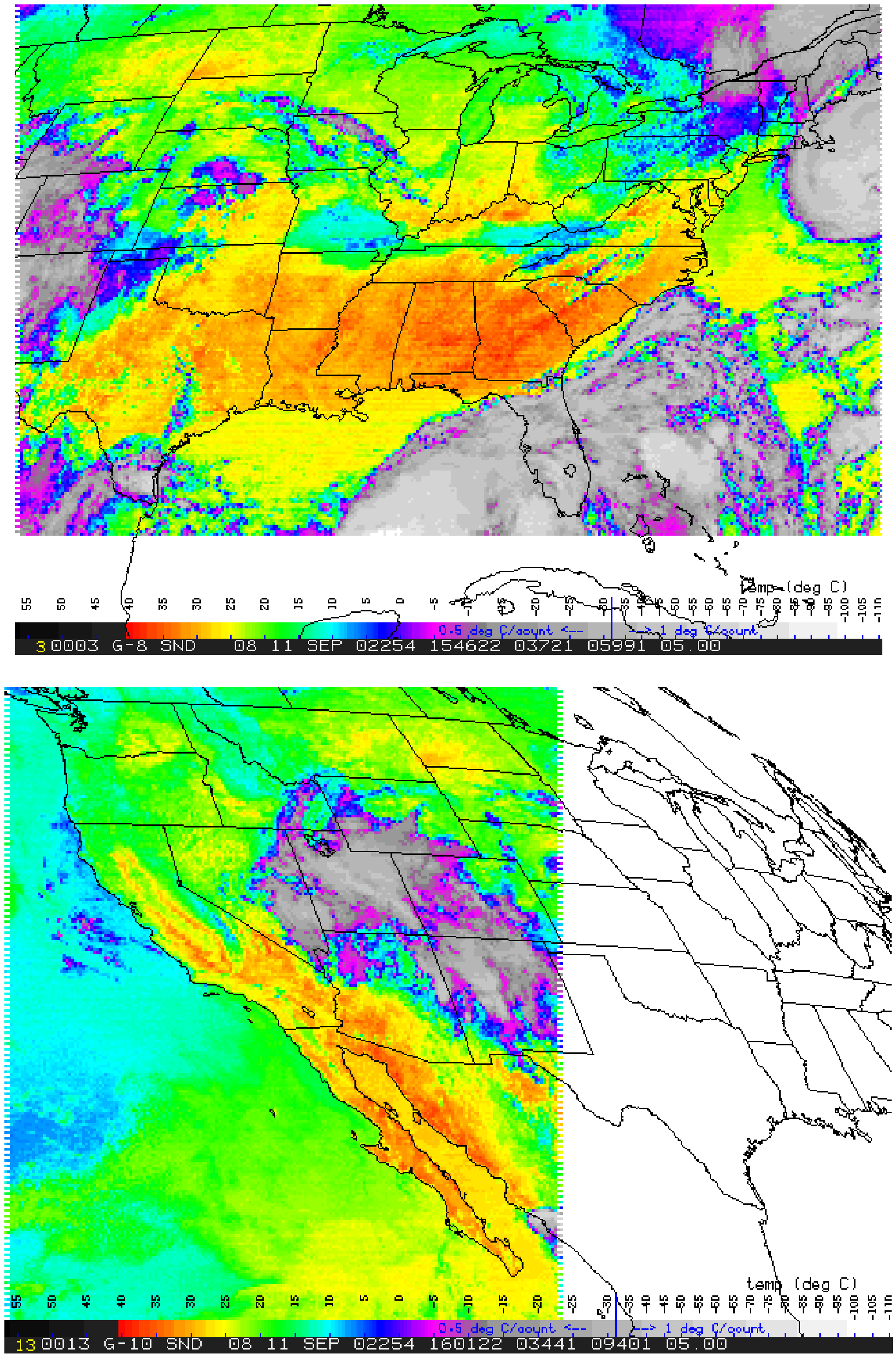

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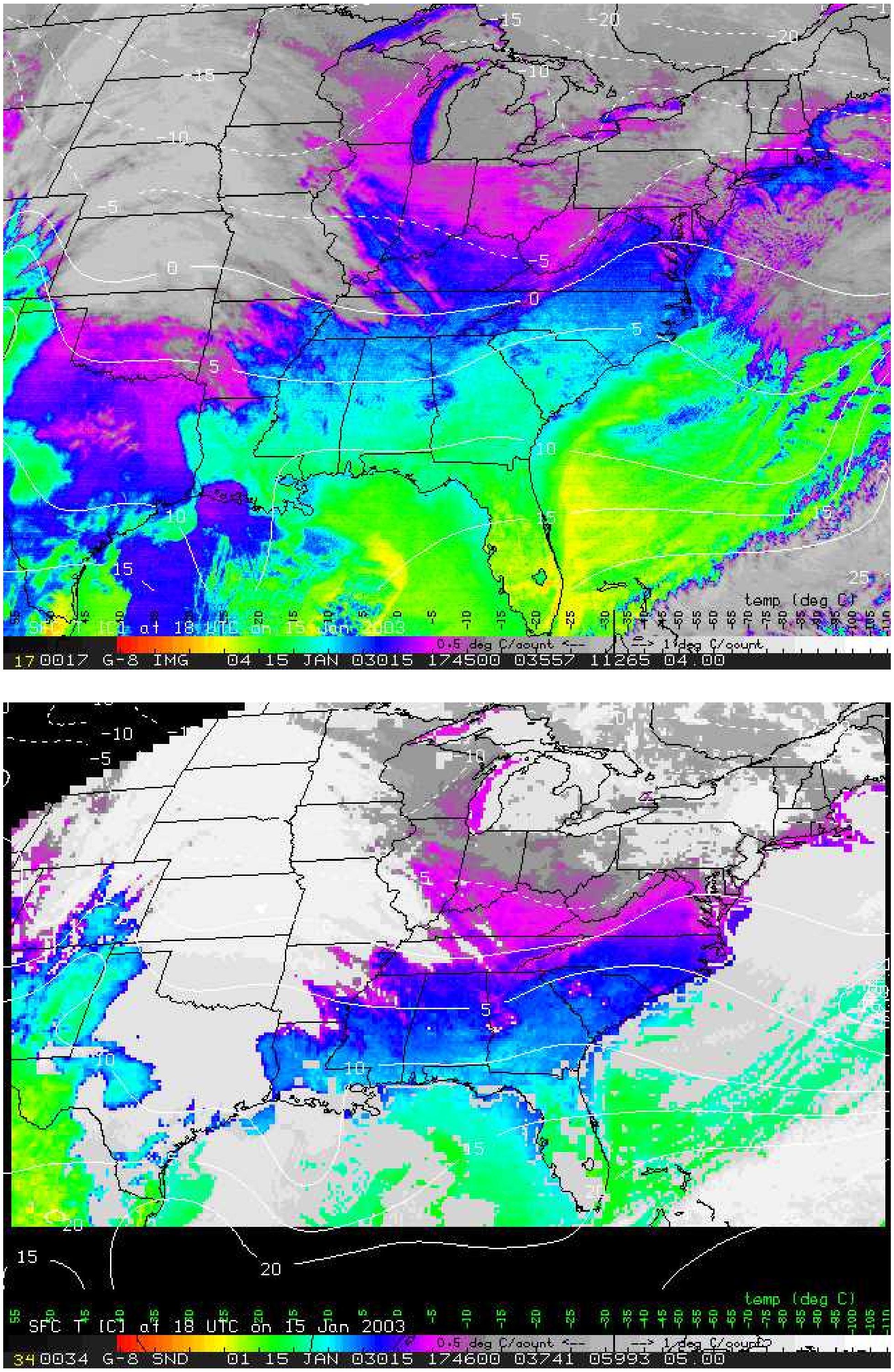

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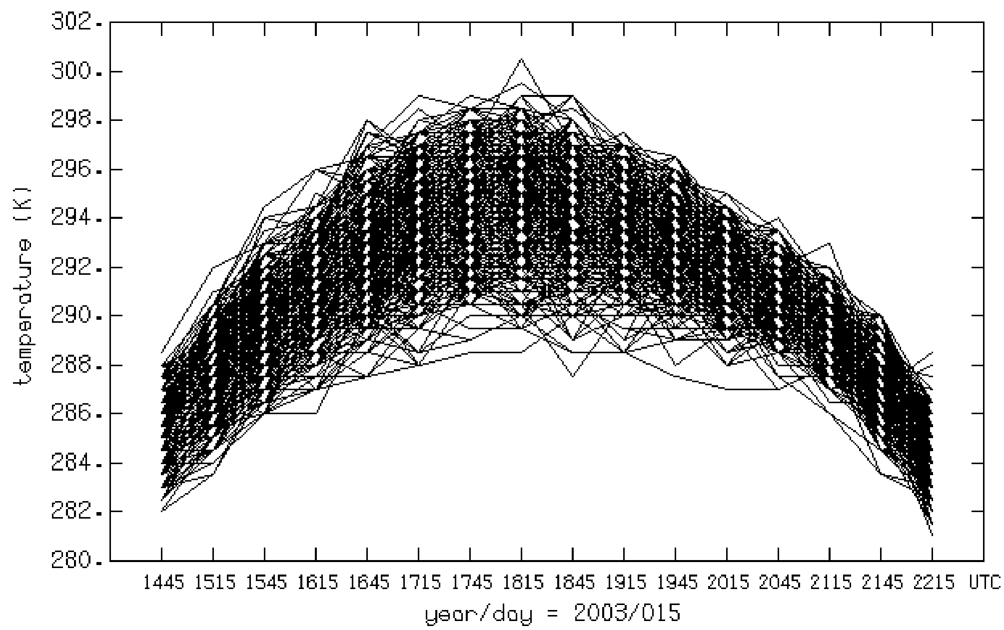

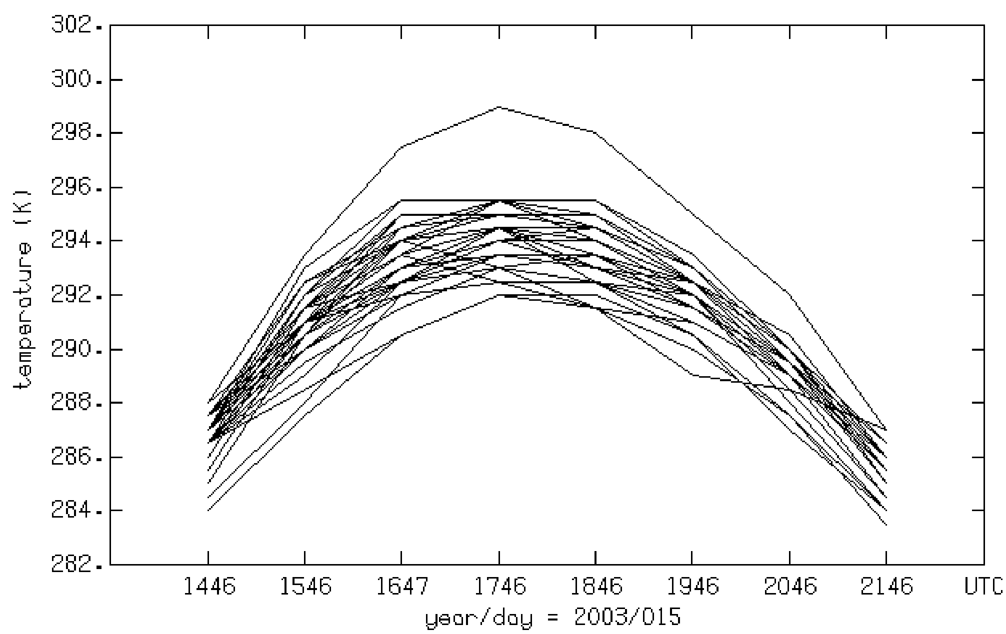

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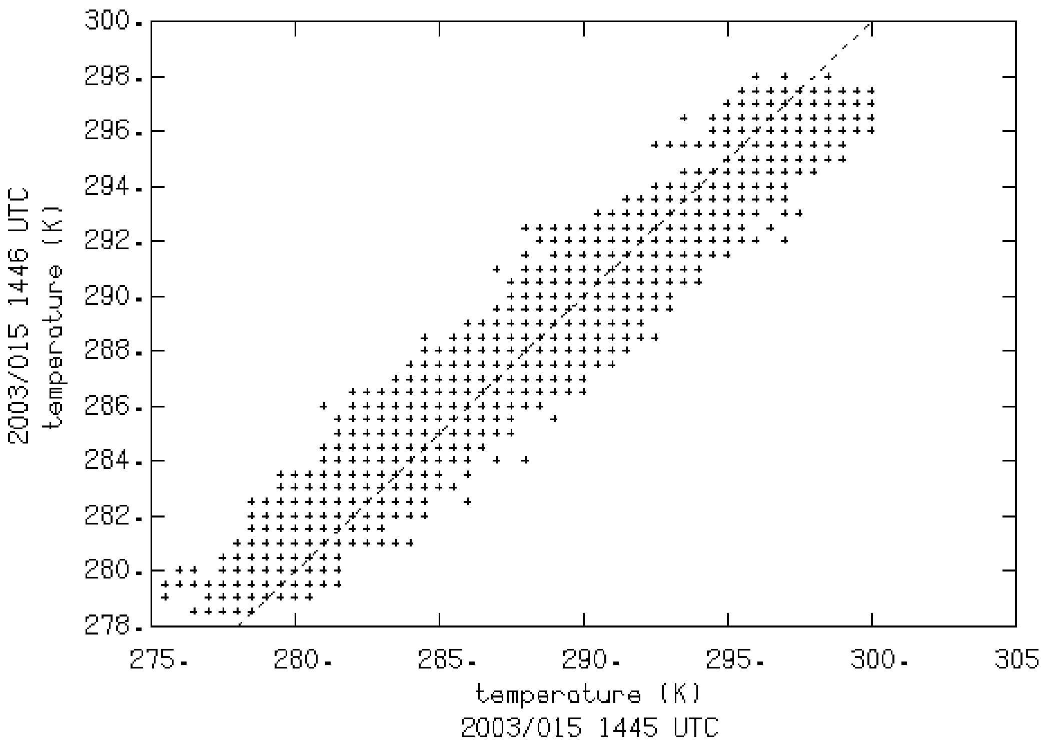

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