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Near Real-time Derived Products from MODIS

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1. Introduction

In 2002, NASA established the Short-term Prediction Research Transition (SPoRT) Center at Marshall Space Flight Center (MSFC) in Huntsville, Alabama as a vehicle to transition unique observing, modeling, and data assimilation capabilities (developed under the auspices of Earth Science Enterprise) to selected National Weather Service (NWS) Forecast Offices and associated decision makers (Goodman et al. 2004). This activity follows a "test bed" approach where unique data and analysis techniques are made available to NWS forecasters for real time assessment and use. The SPoRT program provides near real-time data, analysis and forecasting techniques, and training and participates with the NWS forecasters and decision makers in the assessment of new products and forecast capabilities. This interaction provides immediate feedback into the utility of the data in the operational environment.

As part of the SPoRT program, the timely infusion of high spatial resolution NASA satellite science products into model data assimilation and initialization systems is being tested in order to improve mesoscale short-term weather forecasts. One satellite parameter that has shown promise in providing observational information about the complex effects of soil moisture and vegetation on the surface energy budget is land surface temperature (LST). Currently, the Moderate Resolution Imaging Spectroradiometer (MODIS), one of NASA's Earth Observing System (EOS) mission instruments onboard the Terra and Aqua satellites, provides remote sensing measurements that can be used for the retrieval of LST. However, the EOS science team's MODIS LST products are not available in near real-time for use in an operational data assimilation test-bed system.

At the SPoRT center real-time MODIS L1B data is obtained from the University of Wisconsin direct broadcast system that ingests and processes the raw MODIS data with the International MODIS/AIRS Processing Package (IMAPP) (Strabala et al. 2003). From this data a near real-time LST product is derived using a fast computational regionally applied physical retrieval algorithm developed at MSFC that uses MODIS data from channels with spectral characteristics similar to those planned for GOES-R. This product, referred to here as the MSFC LST product, is currently being evaluated for use in data assimilation experiments. As part of this evaluation, the MSFC LST product is being compared to the EOS MODIS LST Level-2 product. This paper shows some preliminary results from these comparisons.

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2. Retrieval Algorithm and Methodology

The MSFC MODIS retrieval algorithm is an implementation of a perturbation solution of the radiative transfer equation to obtain skin temperature (ST) and total precipitable water (TPW), where ST refers to land and sea surface temperatures. The basic algorithm was first developed by Jedlovec (1987) and subsequently evaluated by Guillory et al. (1993) and Suggs et al. (1998) as applied to GOES measurements. The algorithm requires at least two longwave infrared window channel radiance observations to simultaneously solve for perturbations or departures of ST and TPW from estimates of these quantities. Also required by the algorithm for an observed scene are profiles of estimated temperature and water vapor mixing ratio from which channel transmittances are calculated. A perturbed profile of the mixing ratio and the associated channel transmittances are also needed. From these profiles and a guess skin temperature, a scene radiance is calculated along with coefficients used in solving for the perturbations of ST and TPW from the first-guess ST and moisture profile. Details of the formulation of the algorithm equations can be found in Suggs et al. (1998). Applying the algorithm to MODIS measurements requires providing the first-guess profiles with zenith angles consistent with the MODIS observations.

The methodology of executing the algorithm in a real-time setting requires that the first-guess information be compiled and calculated before the actual MODIS pass. The required guess atmospheric profiles are obtained from an operational model forecast valid within one hour of the MODIS observation times. The guess ST is taken from the model surface air or skin temperature. The satellite orbital pass is predicted, and the MODIS viewing geometry is calculated to obtain satellite zenith angles used by the forward radiative transfer model and to adjust the model moisture profiles. The radiative transfer model used to calculate the MODIS channel transmittances is based on the Pressure-layer Fast

Algorithm for Atmospheric Transmittance (PFAAST) (Hannon et al., 1996).

The resulting first-guess information is provided on the same grid as the model forecast. Since the first-guess information can be obtained from the latest model forecasts, the utility of this retrieval approach is that it provides a near real-time high resolution update of a model's forecasted ST and TPW.

3. LST Retrievals

The MSFC LST retrievals in this case study were calculated at 1 km resolution using infrared radiances from the longwave window channels 31 (10.8 – 11.3 um) and 32 (11.8-12.3 um) of MODIS on both the Aqua and Terra satellites. The first guess field was obtained from 35 km resolution model forecasts produced by the Penn State University National Center for Atmospheric Research Mesoscale Model Version 5 (PSU/NCAR MM5). These forecasts are generated on an operational basis at the SPoRT Center. Model forecasts of 16-18 hours valid within 1 hour of the MODIS pass were used. The first-guess ST was taken from model surface air temperature, and a constant surface emissivity of 0.98 was assumed for each MODIS channel. The cloud mask used in creating the LST product was the EOS standard product (MOD 35) produced by the University of Wisconsin direct broadcast system (Strabala et al. 2003).

The EOS LST retrievals are from the MOD11 and MYD11 Level-2 products obtained from the Land Processes Distributed Active Archive Center (LP DAAC), located at the U.S. Geological Survey's EROS Data Center. The Level-2 1 km resolution LST is produced from a generalized split-window algorithm that uses radiances from the MODIS longwave window channels 31 and 32 (Wan and Dozier 1996). The accuracy of the LST retrievals is considered to be better than 1 K (Wan et al. 2004). The associated emissivities in these channels are obtained by inferring their values from a classification-based look up table (Snyder et al., 1998) according to pixel land cover types determined from MODIS products of land and snow cover. The inferred emissivities in this spectral region are seen to be fairly constant and near 0.98 for all natural land types except rocks and sand. Emissivities produced by this method are available as part of the Level-2 LST product.

4. LST Comparisons

Terra-MODIS day and night LST retrievals for 6 May 2004 are shown in Fig. 1, while Aqua-MODIS daytime LSTs for the same day are shown in Fig. 2. The top panels in both figures show the EOS Level-2 product while the second panels show the MSFC product. The difference between the products are shown in the bottom panels. Both the EOS and MSFC LST products show detailed temperature variations characteristic of differential cooling during the night and heating during the day. This differential cooling and heating is seen to be associated with variations in terrain elevation, land use, vegetation, and soil moisture. This is especially evident in the daytime LST values.

The Terra-MODIS LST daytime products (Fig. 1) show a strong east-to-west temperature gradient correlating with the decrease in vegetation and drier climate. This gradient is especially evident over Kansas and Oklahoma where the eastern parts of these states are characterized by row crops, pines, and deciduous trees, while vegetation in the western part of these states is primarily wheat and natural grass. Also seen over the western United States are the effects of mountains. Note the cool mountain tops in western Colorado and the hotter plains in the eastern part of the state. In the Southeast (Fig. 2) relative warmer temperatures are seen over the Mississippi River delta associated with farm lands with newly planted crops. Relatively cooler temperatures are seen over the Appalachians. Both the EOS and MSFC products depict these regional temperature variations.

Within the regions mentioned above and elsewhere, significant fine scale spatial variations (less than 10 km) in LST are seen. These variations, on the order of 2-4 K at night and 2-6 K during the day, are associated with urban areas, rivers, lakes, and other local terrain features. It is this fine scale LST structure that has the potential of providing additional information in model assimilation systems with resolutions less than 10 km. Again both the EOS and MSFC products depict this fine scale structure.

The bottom panels in Figs. 1-2 show the difference between the EOS and MSFC LST products (EOS–MSFC) discussed above. For the Terra-MODIS nighttime retrievals over the lower midwestern and southern United States, LST values are seen to be mostly cooler than the EOS values. LST differences are seen to be between ± 1 K for 75% of the region with a few isolated areas having LST differences greater than 1 K. Overall, the mean difference is 0.7 K (Table 1).

The Terra-MODIS daytime retrievals over the western United States also indicate that the MSFC values are cooler than the EOS values for most of this region. However, exceptions are found in the central part of this region mostly over the Rocky Mountains where the MSFC LST values are 1-3 K warmer than the EOS values. The mean difference for the entire region is 0.03 K with 73% of the region having LST differences less than ± 1 K.

For the daytime Aqua-MODIS LST values over the southern United States (Fig. 2), good agreement exists between the EOS and MSFC LST products with the MSFC values, again, being slightly cooler than the EOS values with 93% of the region having LST differences less than ± 1 K and an over all mean difference of 0.3 K.

With the exception of the Rocky Mountain region and cloud edges, the larger differences (greater than 1 K) between the products are mostly characterized by small regions with a constant bias that does not appear to be terrain influenced. LST differences over the Rocky Mountains and Southwest, however, appear to be terrain influenced. Preliminary analysis suggests that these larger LST differences may be attributed to potential weaknesses in the MSFC retrieval algorithm and methodology. One methodology issue contributing to the LST differences is the constant emissivity used by the MSFC algorithm.

Figure 3 shows Terra-MODIS channel 31 and 32 emissivities used by the EOS algorithm to produce the Level-2 LST product. Over the southeastern United States emissivities are seen to be relatively constant with values near 0.98. The only significant departures from 0.98 are seen for urban areas and water bodies. Examples of possible emissivity effects associated with urban areas can be seen in the Terra-MODIS nighttime LST differences (Fig. 1, bottom left panel) where urban areas such as Detroit, Nashville, and Birmingham are visible. LST differences over many of the larger water bodies in the same image are also in contrast with their surroundings by exhibiting a LST difference of opposite sign.

For the midwestern United States, emissivities are seen to very significantly with the changing terrain type from east to west. Though it is difficult to see direct correlations of emissivity variations with the LST differences in Fig. 2 (bottom), one area that stands out is the Great Salt Lake Dessert. Here, LST differences are greater than 3 K.

Table 1. EOS and MSFC LST comparison statistics for regions depicted in Figs. 1 and 2.

Satellite	Time UTC	Mean Difference (K)	% of values less than ±1 K
Terra	0400	0.65	75
Terra	1740	0.03	73
Aqua	1915	0.3	92

5. Summary

A preliminary comparison of a near real-time MODIS LST regional product with the EOS LST Level-2 product was performed. Overall, the MSFC LST product agrees well with the EOS product having differences within ± 1 K for at least 73% of the product regions covering much of the midwestern and southern United States. The MSFC product exhibits an overall cool bias but depicts spatial differential heating and cooling variations almost identical to the EOS product. Discrepancies between the products occurred mainly over the Rocky Mountains region, near cloud fields, and in areas where the EOS emissivities varied significantly from the assumption used in the MSFC algorithm. Further work on improving the MSFC retrieval algorithm and methodology is planned, especially the incorporation of a variable emissivity in the retrieval process.

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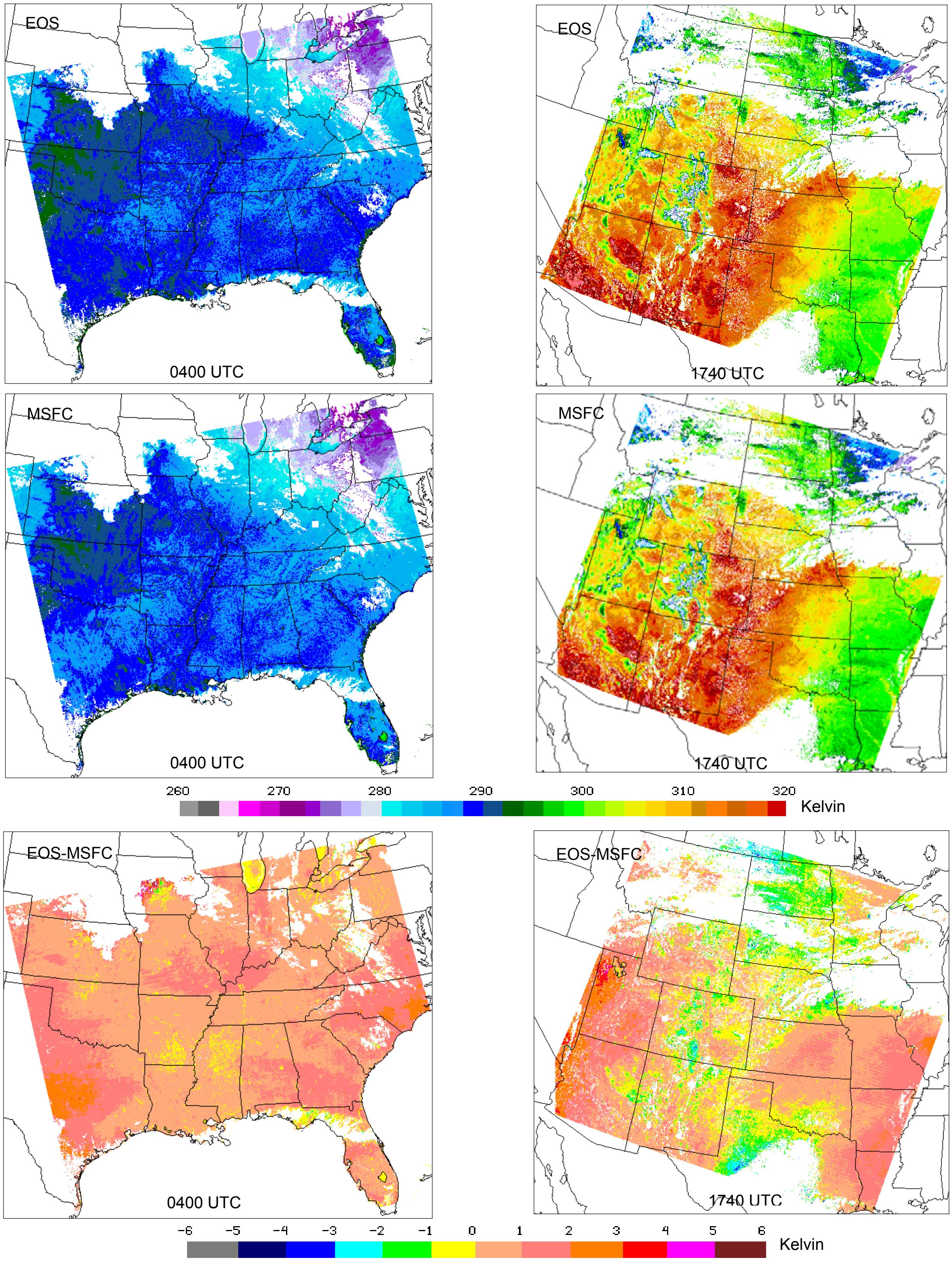

Figure 1. Terra-MODIS night and day LST for 06 May 2004. Top panels are the EOS MOD11 Level–2 LST product. Middle panels are the MSFC product. Bottom panels show the difference between the EOS and MSFC LST products.

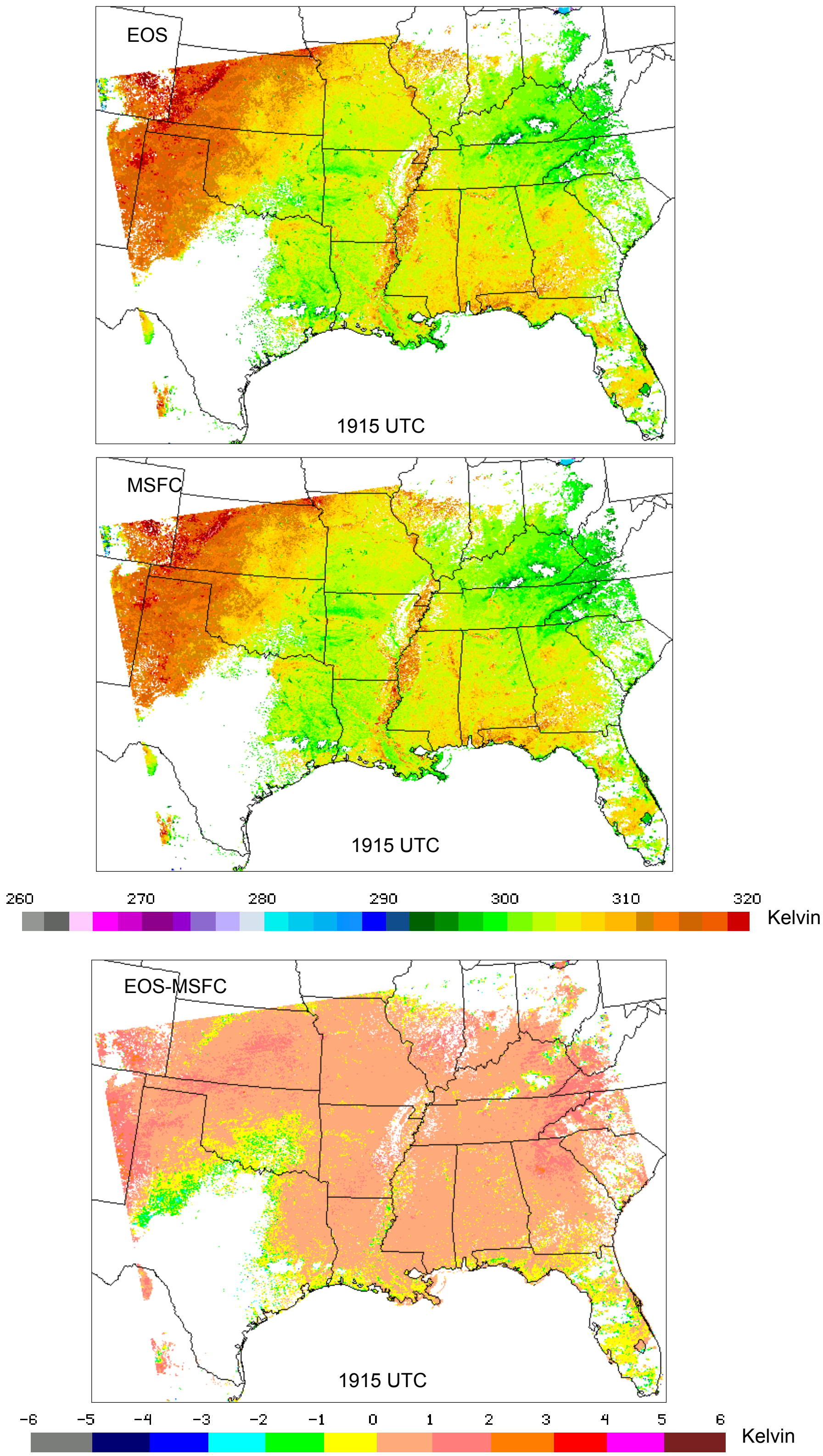

Figure 2. Aqua-MODIS daytime LST for 06 May 2004. Top panel is the EOS MYD11 Level–2 product. Middle panel is the MSFC product. Bottom panel shows the difference between the EOS and MSFC LST products.

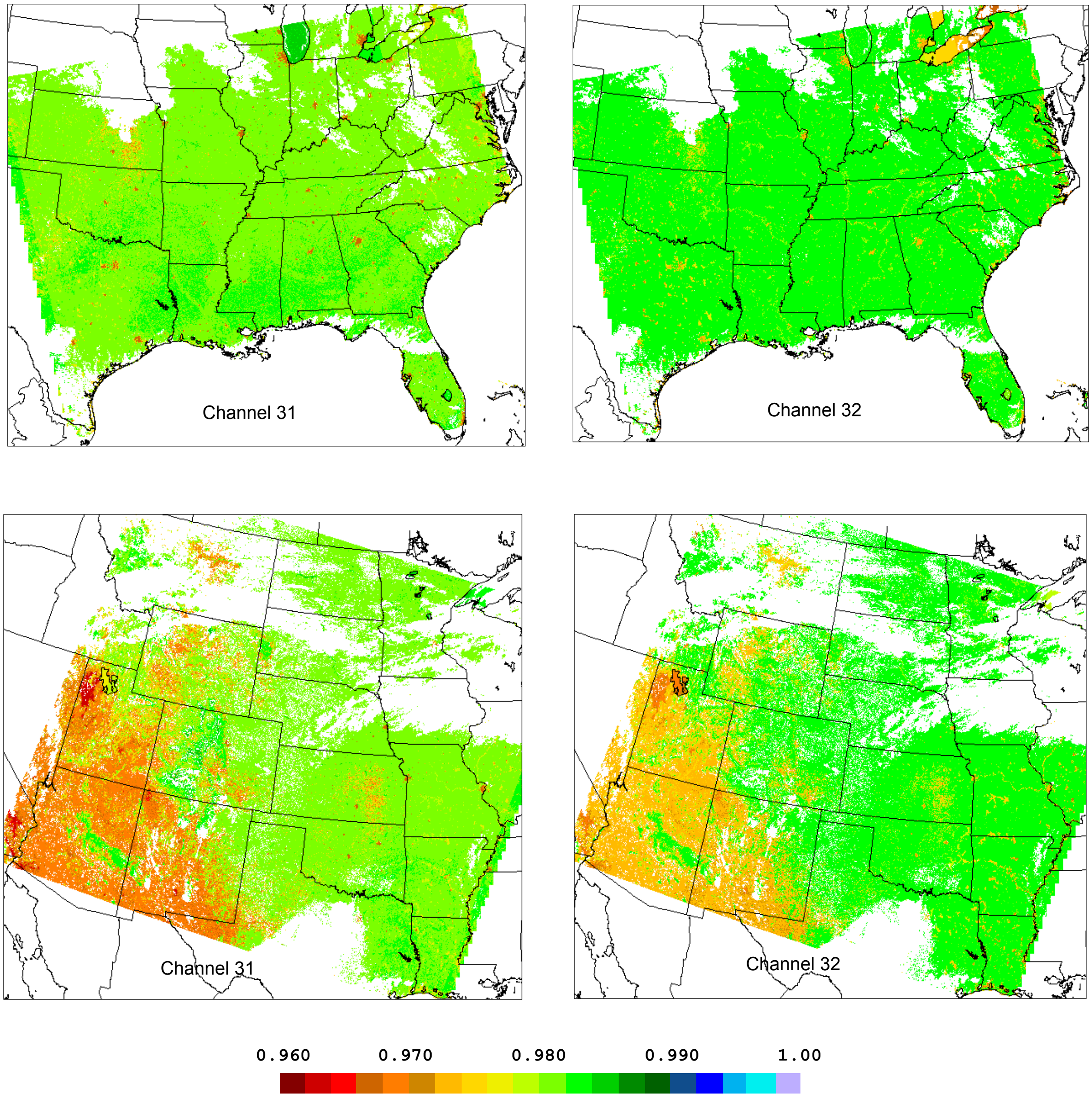

Figure 3. Terra MODIS channel 31 and 32 surface emissivities from the EOS MOD11 Level-2 data product of 6 May 2004. Top panels show emissivities from the Terra night pass (0400 UTC), bottom panels are from the Terra day pass (1740 UTC).