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Refinements of the MODIS Land-Surface Temperature Products

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Abstract

The new refinements for V5 product generation executive code (PGE16) of MODIS Land-surface Temperature/Emissivity (LST) products include: (1) the grid size for LST/emissivity results from the day/night algorithm is changed to 6km x 6km (exactly 5.56km) from 5km x 5km (exactly 4.63km in V4). (2) Increase the number of sub-ranges of viewing angles to 16 from 5 (in V4) in the interim data file for the day/night algorithm. (3) Add an option for combined use of Terra and Aqua MODIS data in the day/night LST algorithm. (4) The effect of slopes in the 6km grids is considered in the QA of the LST/emissivity results from the day/night algorithm. (5) The viewing angle dependent generalized split-window method is fully incorporated into the day/night algorithm. (6) Not make temporal averages in the generation of the 1km LST product (MOD11A1 and MYD11A1) per request of the user community. (7) Use the surface air temperature interpolated (as in v3.0.0 PGE16) from the atmospheric temperature profile in MOD07. The V5 PGE16 code has been tested with Terra and Aqua MODIS data in July and August 2002 in two tiles (h08v05 and h09v05). The comparisons between daily LSTs retrieved from the day/night method and the incorporated split-window method with MODIS data collected on 4th July 2002 (Julian day 185) indicate that the mean and standard deviation of the differences are -0.02K and 0.15K for daytime LSTs, -0.05K and 0.23K for nighttime LSTs in tile h08v05. They are -0.01K and 0.20K, -0.07K and 0.34K in tile h09v05. The maximum standard deviation is less than 0.4K for all days in these two months. This indicates that the refined day/night algorithm consistently gives reliable results. Retrieved emissivities are well correlated with landcover and NDVI images. The histograms of differences between daily LSTs retrieved from the day/night method and the independent generalized split-window method with MODIS data in August 2002 in tiles h08v05 and h09v05 and their cumulative histograms in one month show that the mean and standard deviation of differences are less than 0.1K and 0.5K. This means that the LSTs retrieved by the split-window method using the classification-based emissivities in bands 31 and 32 dependent on land cover types are not too far from the LSTs retrieved by the day/night algorithm. Therefore, validated LSTs in 1km LST products (MOD11A1 and MYD11A1) can be used to in-directly validate the LSTs in 6km LST products (MOD11B1 and MYD11B1) thru the Aggregated_from_1km SDS in M*D11B1 in relatively homogeneous areas.

1. New Refinements for V5 PGE16 Code

The following major refinements have been made for V5 PGE16 code in order to improve the quality of MODIS Land-surface Temperature/Emissivity (LST) products in the next (Collection 5) reprocessing.

1.1, The grid size for LST/emissivity results from the day/night algorithm is changed to 6km x 6km (exactly 5.56km) from 5km x 5km (exactly 4.63km in V4) so that it has the same 0.05^{o} size of climate model grids in latitude for most CMG land products.

1.2, The number of sub-ranges of viewing angles is increased to 16 from 5 (in V4) in the interim data file for the day/night algorithm so that a maximum of 16 sets of daytime and nighttime data can be stored for each 6km grid without significantly increasing the file size by optimizing the data structure.

1.3, An option for combined use of Terra and Aqua MODIS data in the day/night LST algorithm is implemented so that it is possible for the day/night algorithm to use pairs of day and night observations at nearly equal zenith angles in the same azimuth plane.

1.4, The effect of slopes in the 6km grids is considered in the QA of the LST/emissivity results from the day/night algorithm.

1.5, The viewing angle dependent generalized split-window method (Wan and Dozier, 1996) is fully incorporated into the day/night algorithm (Wan and Li, 1997).

1.6, The temporal average performed in the generation of the V3 and V4 1km LST product (MOD11A1 and MYD11A1) will not be made in V5 per request of the user community. After this change, LSTs in 1km and 6km products are all from instant MODIS observations. This change also makes it easy to validate the 1km LST product and to remove cloud-contaminated LSTs in the 1km LST product.

1.7, The surface air temperature will be interpolated (as in v3.0.0 PGE16) from the atmospheric temperature profile in MOD07 because the science data set of Surface_Temperature in new MOD07 has been changed to regression-based retrieval of skin temperature from the GDAS surface temperature that was used in the old MOD07.

2. Test Results of V5 PGE16 Code

The V5 PGE16 code has been tested with Terra and Aqua MODIS data in July and August 2002 in two tiles, h08v05 mostly in dry weather condition, and h09v05 partly in dry in the west portion and in wet weather condition in the east portion. Fig. 1 shows the daytime LSTs retrieved from Terra MODIS data on 25 August 2002 (h08v05 in the left and h09v05 in the right). Fig.2 shows the comparison between daytime (in red) and nighttime (in green) LSTs retrieved from the day/night method and the incorporated split-window method with MODIS data collected on 4th July 2002 (Julian day 185) in tiles h08v05 and h09v05. The mean and standard deviation of the differences are -0.02K and

0.15K for daytime LSTs, -0.05K and 0.23K for nighttime LSTs in tile h08v05. They are -0.01K and 0.20K, -0.07K and 0.34K in tile h09v05. The maximum standard deviation is less than 0.4K for all days in these two months. This indicates that the refined day/night algorithm consistently gives reliable results.

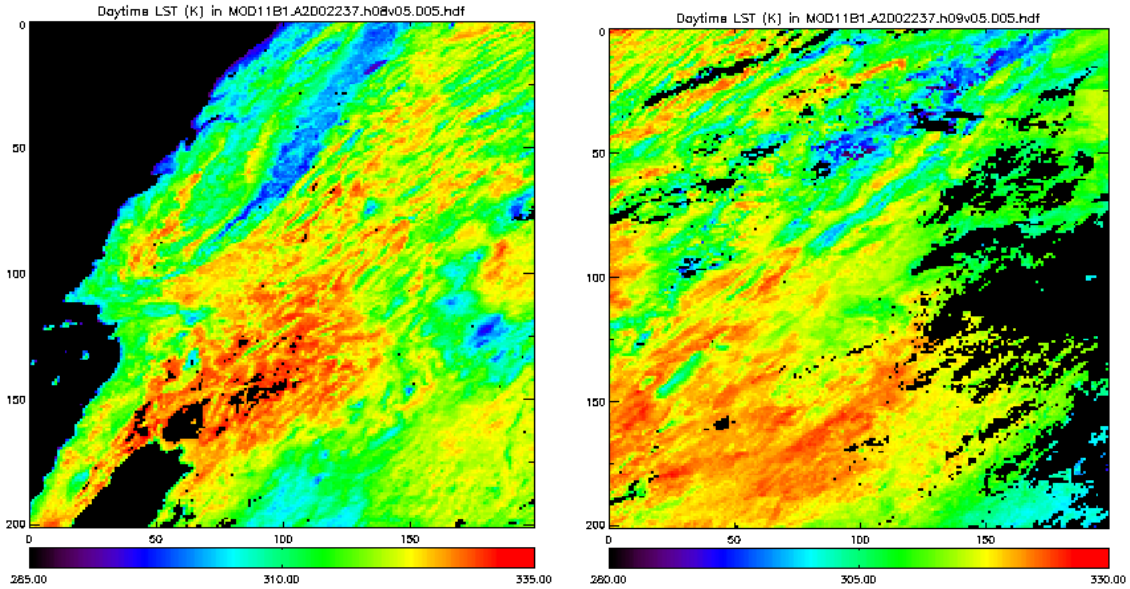


Fig. 1, daytime LSTs in mod11b1 in tiles h08v05 (left) and h09v05 (right).

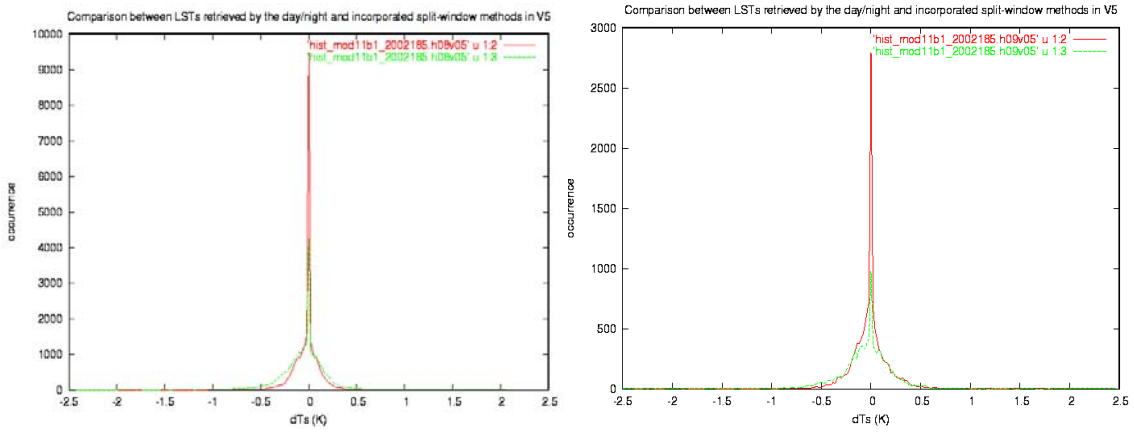


Fig. 2, comparisons of LSTs retrieved from the day/night and incorporated split-window methods in tiles h08v05 (left) and h09v05 (right).

Fig. 3 shows the cumulative histograms of the differences between daytime (in red) and nighttime (in green) LSTs retrieved from the day/night method and the independent generalized split-window method with MODIS data in August 2002 in tiles h08v05 and h09v05 based on all V5 MOD11B1 products in the month. The mean and standard deviation of differences are less than 0.1K and 0.5K. This means that the LSTs retrieved by the split-window method using the classification-based emissivities in bands 31 and 32 dependent on land cover types are not too far from the LSTs retrieved by the day/night

algorithm using pairs of day and night MODIS data in seven TIR bands plus the information provided in MOD07, MOD10, MOD35 and MOD43 products.
Therefore, validated LSTs in level-2 and 1km LST products (Wan et al, 2002 and 2004)) can be used in-directly validate the LSTs in 6km LST products thru the scientific data set Aggregated_from_1km in the 6km LST products in relatively homogeneous areas.
But it is not always possible to use this approach in V4 due to the temporal average in the generation of 1km LST products.

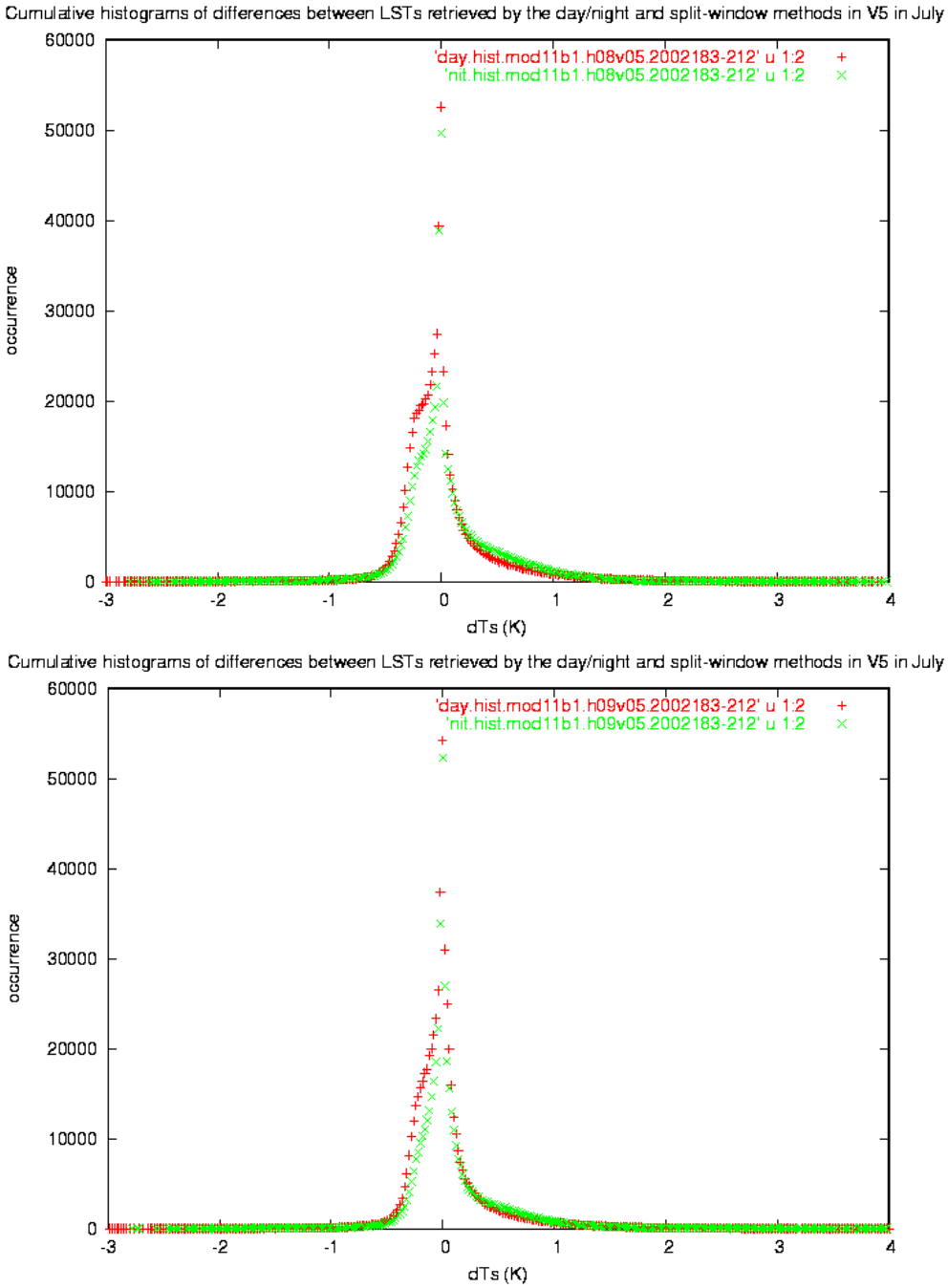


Fig. 3, cumulative histograms of differences in LSTs in the 6km LST product (MOD11B1) in August 2002 in tiles h08v05 (top) and h09v05 (bottom).

As shown in Fig. 4, the emissivities retrieved in V5 PGE16 are more reliable and well correlated with landcover and NDVI although NDVI is not used as input of PGE16.

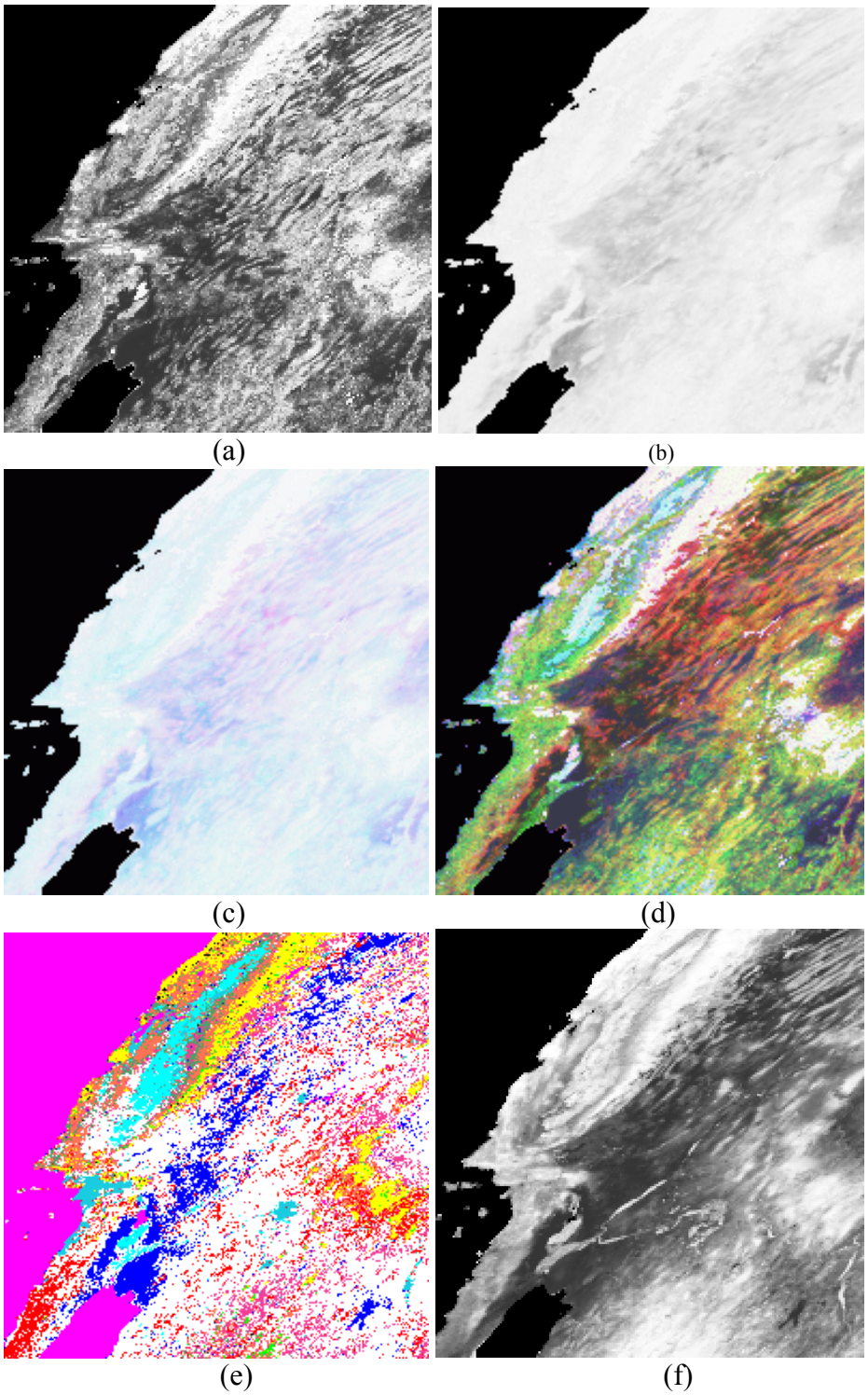


Fig. 4, Surface emissivities retrieved from MODIS data in August 2002 (a-d, see details in text), image of land cover types (e), and image of NDVI in Julian days 193-208 (f).

Figure 4 shows the emissivities in bands 22 and 29 in (a) and (b), respectively. Fig. 4(c) shows the color composite with emissivities in bands 22, 29 and 31 as RGB components. Fig. 4(d) is the color composite with the same components, each enhanced with the histogram equalization method before composition. The histograms of emissivities in bands 22, 29 and 31 are shown in Figure 5.

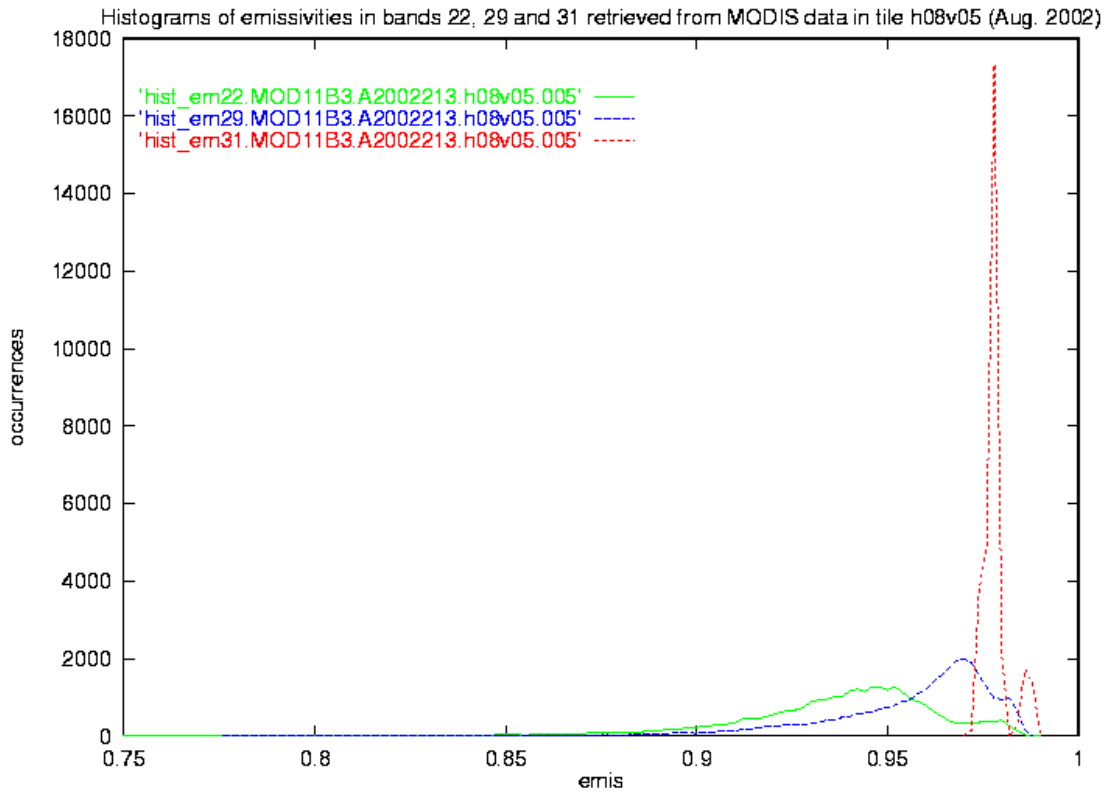
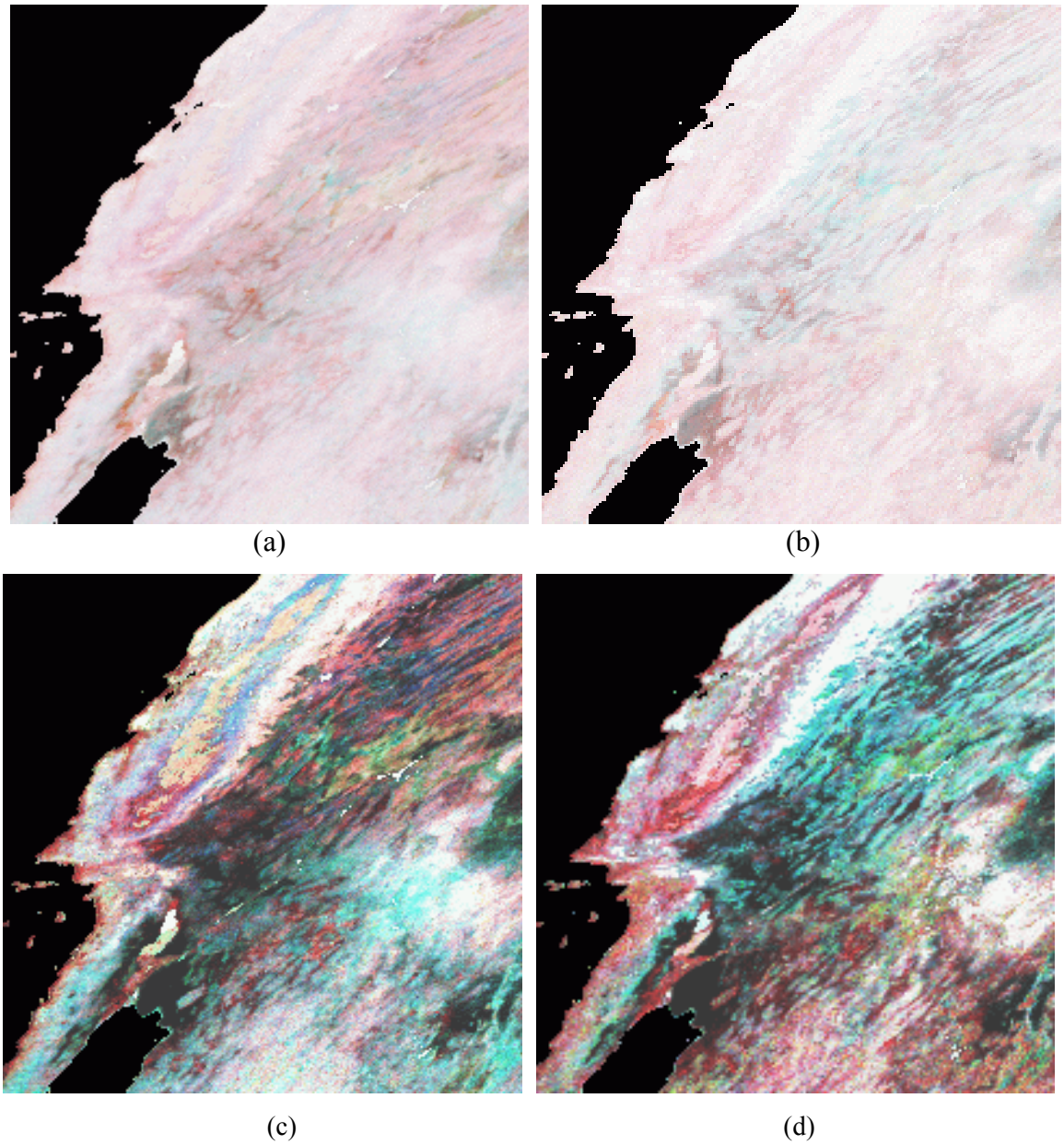


Fig. 5, Histograms of surface emissivities in bands 22, 29 and 31 retrieved from MODIS data in tile h08v05 collected in August 2002.

The results retrieved by the refined day/night algorithm from MODIS data confirm that the land surface emissivities in band 31 (centered at wavelength 11μm) and in band 32 (at 12μm, not shown) vary in a narrow range. This is the basis of the classification-based emissivity method (Snyder et al., 1998) used to estimate emissivities in bands 31 and 32 for the split-window LST algorithm. However, there are great variations in the surface emissivities in the mid-wave infrared where MODIS bands 20-23 are located and in the 8-9μm region where band 29 is located. Laboratory measurements show that ε_{20}, ε_{22}, ε_{23} are more sensitive to the moisture in vegetation leaves. Retrieval of surface emissivities in bands 29, 31 and 32 is important not only for accurate LST retrieval but also for accurate estimation of the broadband emissivity and long wave radiation (Wang et al., 2005).

As shown in Figure 6, the spatial features in the retrieved land-surface emissivities, for example, in bands 29, 22 and 20, are well kept after changing the grid size to 5.56km (in

V5) from 4.63km (in V4). The values of retrieved emissivities in the V5 6km LST product are slightly larger.



(a) (b)

(c) (d)

Fig. 6, Comparison of the color composite images with surface emissivities in bands 29, 22, and 20 as RGB components in the V4 5km (a) and V5 6km (b) LST products. Note that the images in (c) and (d) are the composite images with the same components in (a) and (b) but each component is enhanced by the histogram equalization method before composition in order to provide better visualization especially on the paper in hard copies. Because of the histogram equalization, the color scales in (c) and (d) cannot be directly compared. The images in (c) and (d) are only used to show the spatial features.

3. Plan of Work in the Near Future

A validation field campaign at the Texas grassland was planned to conduct in March 2005. It was postponed to April due to bad weather conditions.

Some minor refinements to the PGE16 code may be made in the next several months based on the analysis of the results generated in the V5 land tests at the Team Leader Computing Facility. New code will be written for the new processes in the generation of daily LST products. One will be used to remove cloud-contaminated LSTs in the 1km LST (MOD11A1) product and another for the 6km LST (MOD11B1) product.

Acknowledgements

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