# Upscaling of Land Surface Temperature over the Changwu Area of China

## 地表面温度に対する空間スケーリング手法の提案と中国・黄土高原南部への応用

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## 1. Introduction

Land surface temperature (LST) is the skin temperature of the Earth's surface. As an important factor controlling most physical, chemical, and biological processes of the Earth system, its accurate representation at a large-scale is of great concern in numerous environmental studies. The representation is complicated by the heterogeneous land surface. Within a satellite sensor's instantaneous field of view (IFOV) (e.g. 1-km), there often exist a number of land covers such as forest, grassland, bare soil, and buildings. The effects of spatial heterogeneity can be released by scaling approach. Practically, it is common to aggregate the small-scale LST into the large scale using a statistical approach such as simple averaging or the areally weighted averaging to represent LST over a large area. Such kind of statistical approach has been put into the debate in that it may violate energy balance equation. The nonlinear effects due to heterogeneity might also lead to significantly different representation of LST. Surface heterogeneity involves not only the composition heterogeneity such as different land covers but also topographical heterogeneity. Lipton and Ward (1997) assumed the linearity in the Plank function and the unity of surface emissivity to develop an approach for investigation of the satellite-view biases in the retrieved surface temperatures in mountain areas.

To account for both composition and topographical heterogeneity, an approach for LST scaling was developed in this paper, based on the Stefan-Boltzmann law and terrain correction approach used in remote sensing as well. It was further modified oriented to satellite-derived LST. A terrain area over the Loss Plateau of China was selected for examination. In addition, this study took the advantages of MODIS and ASTER sensors onboard the TERRA. ASTER was designed to collect data for geological and environmental applications and provide a good sampling of the multi-spectral thermal infrared (TIR) spectral emissivity variations at a fine spatial resolution. MODIS was designed to collect data at a moderate spatial resolution with almost daily coverage of the Earth. The simultaneous observations eliminate the differences in ASTER and MODIS LST products due to time difference.

## 2. Methodology

The radiant emittance from an object into the hemisphere follows the Stefan-Boltzmann (S-B) law (e.g., Slater 1980)

$$M = \varepsilon\sigma T^4 \tag{1}$$

where $M$ is the radiant emittance ($Wm^{-2}$), $\sigma$ is the S-B constant ($5.67*10^{-8}Wm^{-2}K^{-4}$), and $T$ is the LST (K), and $\varepsilon$ is the surface emissivity. This equation is generally applicable to the homogeneous case.

To the heterogeneous area composed of a number of surface objects, applying the S-B law needs incorporation of the local details. At an ideal fine scale (F-scale), a regular grid spacing or pixel with an equal size may represent a homogenous surface such that it satisfies the S-B law. At a coarse scale (C-scale), a grid spacing or pixel usually denotes a heterogeneous surface. In a physical sense, heterogeneity is closely related to the specific object or process. *M*, *T*, and $\varepsilon$ were set to be the parameters in equation (1) at the C-scale, and $M_i$, $T_i$, and $\varepsilon_i$ the parameters at the F-scale where the subscript *i* denotes pixel *i*. Over a horizontal flat area, the irradiance at the C-scale is the areal average of the irradiance from all the nested F-scale grid spacings in terms of energy balance. From equation (1), the following equation can be derived

$$T = \left(\frac{1}{n\varepsilon}\sum_{i=1}^{i=n}\varepsilon_i T_i^4\right)^{1/4} \tag{2}$$

Over a terrain area, for simplification the Lambertian surface is assumed within the regular grid spacing. As each terrain element has its own slope and aspect, the radiance along satellite-view path from the terrain element at the C-scale grid spacing is the average radiance from the nested F-resolution grid spacings, weighted by $\sec\alpha_i / \sum \sec\alpha_i$, where $\alpha$ is the local slope angle. It has

$$T = \left(\frac{\sum \varepsilon_i T_i^4 \cos\gamma_i \sec\alpha_i}{\varepsilon \cos\gamma \sum \sec\alpha_i}\right)^{1/4} \tag{3}$$

where $\gamma$ is the angle between the satellite-view path and the normal to the terrain element.

In the case of satellite-derived data, there often remains terrain effect uncorrected. Terrain induced angular effect can be corrected using the cosine method (Teillet et al. 1982). The following equation can be derived

$$T = \left(\frac{\sum \varepsilon_i T_i^4 \sec\alpha_i}{\varepsilon \cos\gamma \sum \sec\alpha_i}\right)^{1/4} \tag{4}$$

In addition, there may remain more or less adjacency effect uncorrected in the satellite-derived data over the terrain area. The effect can be accounted for by the terrain-view factor with a trigonometric function (Kondratyev, 1969). A scaling function for LST with correction for both terrain induced angular and adjacency effects can be derived as

$$T = \left(\frac{2\sum \varepsilon_i T_i^4 \sec\alpha_i - \pi \bar{L} \sum (\sec\alpha_i - 1)\cos\gamma_i}{2\varepsilon \cos\gamma \sum \sec\alpha_i}\right)^{1/4} \tag{5}$$

In general, equation (3) can be used for LST scaling over the terrain area while equations (4) and (5) oriented to satellite-derived LST with the terrain and adjacency effects uncorrected.

## 3. Study materials & data processing

The study area is located at the Loess Plateau of China, which belongs to the semi-arid climate zone. The dominant land covers include agricultural field, grassland, bare soil surface, forestland, and inland water surface. This area has the highly variable topographical features suffering from serious soil erosion in the plateau. The elevation of the area ranges from 819 to 1464 m with an average of 1172.2 m. The mean of slope is 10.9 degrees with a standard deviation (S.D.) of 8.4 degrees, and the maximum slope is 37.5 degrees.

ASTER surface emissivity and surface temperature products, dated on 10 May 2005, were acquired. They have a spatial resolution of 90-m and served as the F-scale data in this study. Figure

1 shows the ASTER LST image. MODIS MOD11_L2 LST data, covering the study area, dated also on 10 May 2005, was also acquired. The LST data have a spatial resolution of 1-km and served as the C-scale data. The scattered white pixels were flagged in the MODIS LST products.

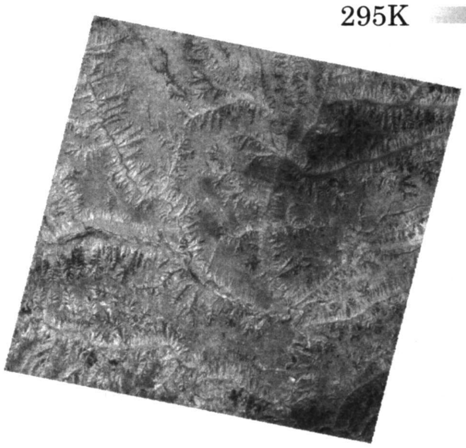


Fig.1. ASTER LST image dated on 10 May 2005.

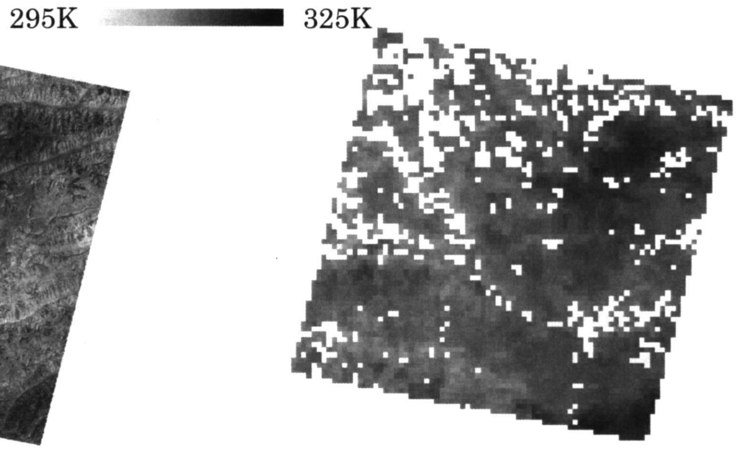



Fig.2. MODIS LST image coverage.

90-m slope angle and aspect angle of the terrain area were generated from 90-m DEM data, which was segmented from the 3-arc-second Shuttle Radar Topography Mission (SRTM) data. 900-m DEM data was generated from the 90-m DEM data resampled with the cubic convolution algorithm. The 900-m slope angle and aspect angle was then determined.

ASTER LST data were scaled from 90-meter to 900-meter using equation (5). For comparison, the Lipton and Ward (L-W) approach (1997) was also adopted here from the perspective of spatial scaling, although originally it was not developed for scaling propose but for addressing the satellite-view biases in retrieved LST in mountain area. The equation for LST scaling can be described as follows

$$T = \frac{\sum T_i \cos\gamma_i \sec\alpha_i}{\sum \cos\gamma_i \sec\alpha_i}. \qquad (6)$$

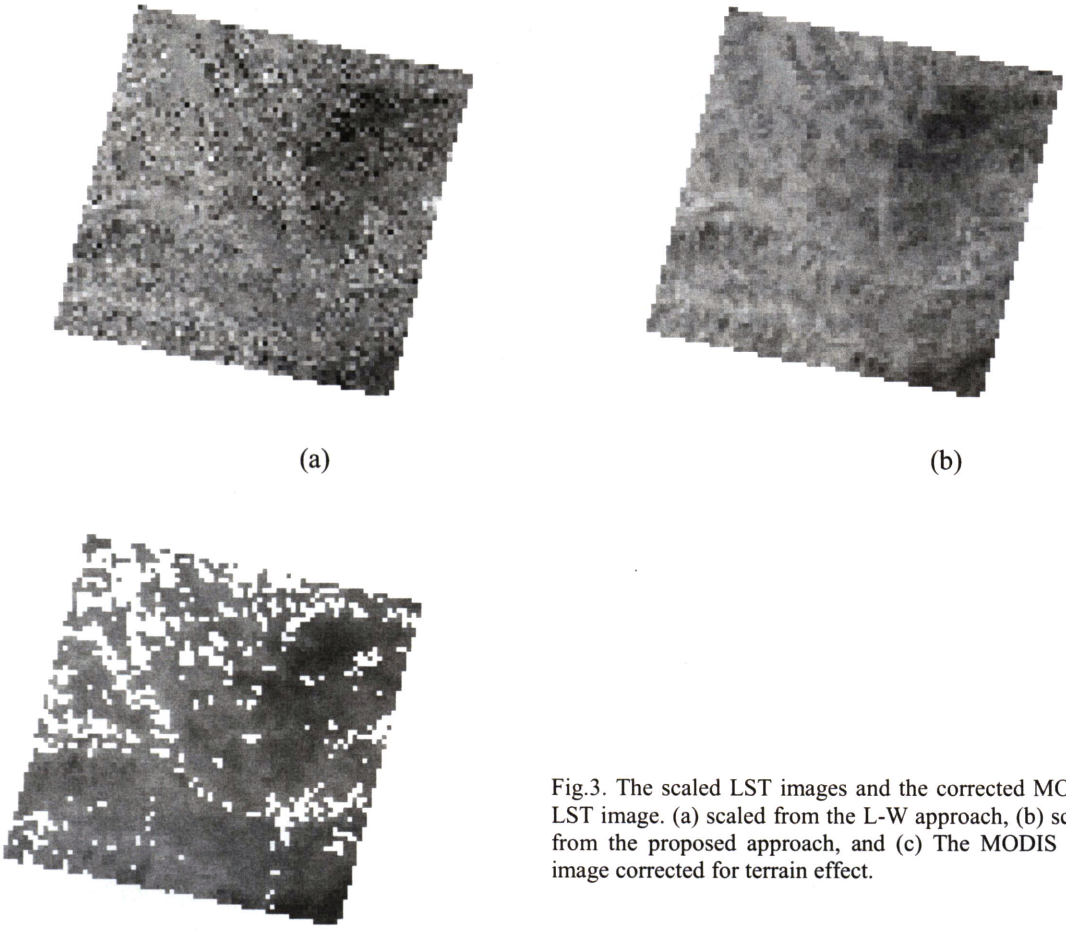
## 4. Results & discussions

Table 1 shows the statistical properties of the original 90-m ASTER product. The LST had a range of 34.4K, indicating a large LST variation over the study area. The original MODIS product had the LST range (14.7K) and S.D. (2.59K) smaller than that of ASTER, indicating the reduced LST variations at the relatively large-scale. The mean of MODIS LST was lower than that of ASTER. To the same area, the means of the LST from different sensor are expected to be the same, but this is not the case. It was unclear why the mean of MODIS LST was lower than that of ASTER.

Table 1. Statistics of LST products and the scaled LST (Unit: K)

| | ASTER | Scaled LST | | MODIS LST | |
|---|---|---|---|---|---|
| | LST | L-W approach | Equation (12) | Original | Corrected |
| Min | 296.0 | 296.9 | 300.9 | 300.7 | 301.0 |
| Max | 330.4 | 327.8 | 319.9 | 315.4 | 315.6 |
| Range | 34.4 | 30.9 | 19.0 | 14.7 | 14.6 |
| Mean | 311.8 | 311.6 | 311.7 | 309.4 | 309.5 |
| S.D | 3.95 | 4.19 | 3.22 | 2.59 | 2.59 |

The LST image scaled from the L-W approach is shown in Fig.3(a). The mean of the scaled LST was similar to that of the original ASTER LST. Compared to the original ASTER LST, the minimum increased minor to 296.9K while the maximum decreased to 327.8K, resulting in the reduced range of 30.9K. In contrast, S.D did not reduce but increased to 4.19K, suggesting the increased variation in the scaled LST. This contradicted to the reduction in LST at the large-scale, which gained from comparison of MODIS and ASTER LST, indicating the inappropriate of the L-W approach. The inappropriate was further proved from the visual interpretation that the scaled LST image (Fig.3(a)) did not match the MODIS LST (Fig.3(c)) well.



(a) (b) (c)

Fig.3. The scaled LST images and the corrected MODIS LST image. (a) scaled from the L-W approach, (b) scaled from the proposed approach, and (c) The MODIS LST image corrected for terrain effect.

In the proposed approach, the minimum LST was similar to that of MODIS. The maximum LST was much closer to that of MODIS, compared to that from the L-W approach. This resulted in the reduced LST range, also much closer to that of MODIS. Accompanying to this change, S.D decreased, indicating the reduced variation in the scaled LST. The visual interpretation suggested that the scaled LST image (Fig.3(b)) was pretty well matched the MODIS LST (Fig.3(c)), compared to that scaled from the L-W approach (Fig.3(a)). In addition, the correlation coefficient between the MODIS LST and the scaled LST was 0.75, higher than 0.57 that between the MODIS and that scaled from the L-W approach.

Notably, although the LST scaled from the proposed approach was closer to that of MODIS than that the L-W approach did, its statistical values (maximum, the mean, and S. D.) were yet generally larger or higher than that of MODIS. The maximum LST showed 4.3K difference compared to that of MODIS. The mean of the scaled LST was similar to that of the original ASTER LST, but 2.2K higher than that of MODIS. S. D. had the difference 0.63K to that of MODIS LST. A potential explanation to this unclear difference is that, the LSTs retrieved from ASTER and MODIS may be inconsistent. It is necessary to make investigations on the consistency between the ASTER and MODIS LST product.

## 5. Conclusions

To account for both composition and topographical heterogeneity, an approach for LST scaling was developed, based on the Stefan-Boltzmann law and terrain correction approach used in remote sensing as well. To release the terrain effects resident in satellite product, the proposed approach was further modified oriented to satellite-derived LST.

A terrain area over the Loss Plateau of China was selected for examination. The Lipton-Ward (L-W) approach was also adopted in the examination from the perspective of scaling. Incorporated with 90-m topographical data, 90-m ASTER LST and emissivity products were scaled up to 900-m using the two approaches. Results showed that the proposed approach smoothed the LST difference and reduced the standard deviation of LST but the L-W approach did not. This was further confirmed from the visual comparison with 900-m MODIS LST products.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