National Aeronautics and Space Administration

A Unified MODIS Land Surface Temperature (LST) Product using an Uncertainty Analysis Approach

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Introduction

- NASA has identified a major need to develop long-term, consistent, products with well defined uncertainty statistics - termed Earth System Data Records (ESDRs).
- Land Surface Temperature (LST) and Emissivity (LSE) have been identified by NASA as an important ESDR.
- LST&E products are generated with varying accuracies depending on the input data and algorithmic approaches:
  - Standard MODIS LST products (MOD11) use a split window algorithm with classification-based emissivities.
  - A new MODIS LST product (MOD21) use a physics based approach, termed the Temperature Emissivity Separation (TES) algorithm, designed for ASTER LST retrievals.
- Validation has shown that these products are complementary, i.e. the split-window approach has higher accuracy over graybody surfaces and the TES algorithm has higher accuracy over arid regions.
- A logical question then becomes how do we exploit the unique advantages of each product to generate a unified LST product?

The MOD21 LST Product

The ASTER Temperature Emissivity Separation (TES) algorithm has been adapted to MODIS data to retrieve LST and emissivity in bands 29, 31 and 32. TES is designed to solve the ill-posed LST problem by using an empirical relationship to predict the minimum emissivity observed from a given spectral contrast, or minimum-maximum emissivity difference (MMD).

The empirical relationship is referred to as the TES calibration curve and is derived from a subset of spectra from the ASTER spectral library. The calibration curve can be adjusted for any sensor's spectral response function in the TIR.

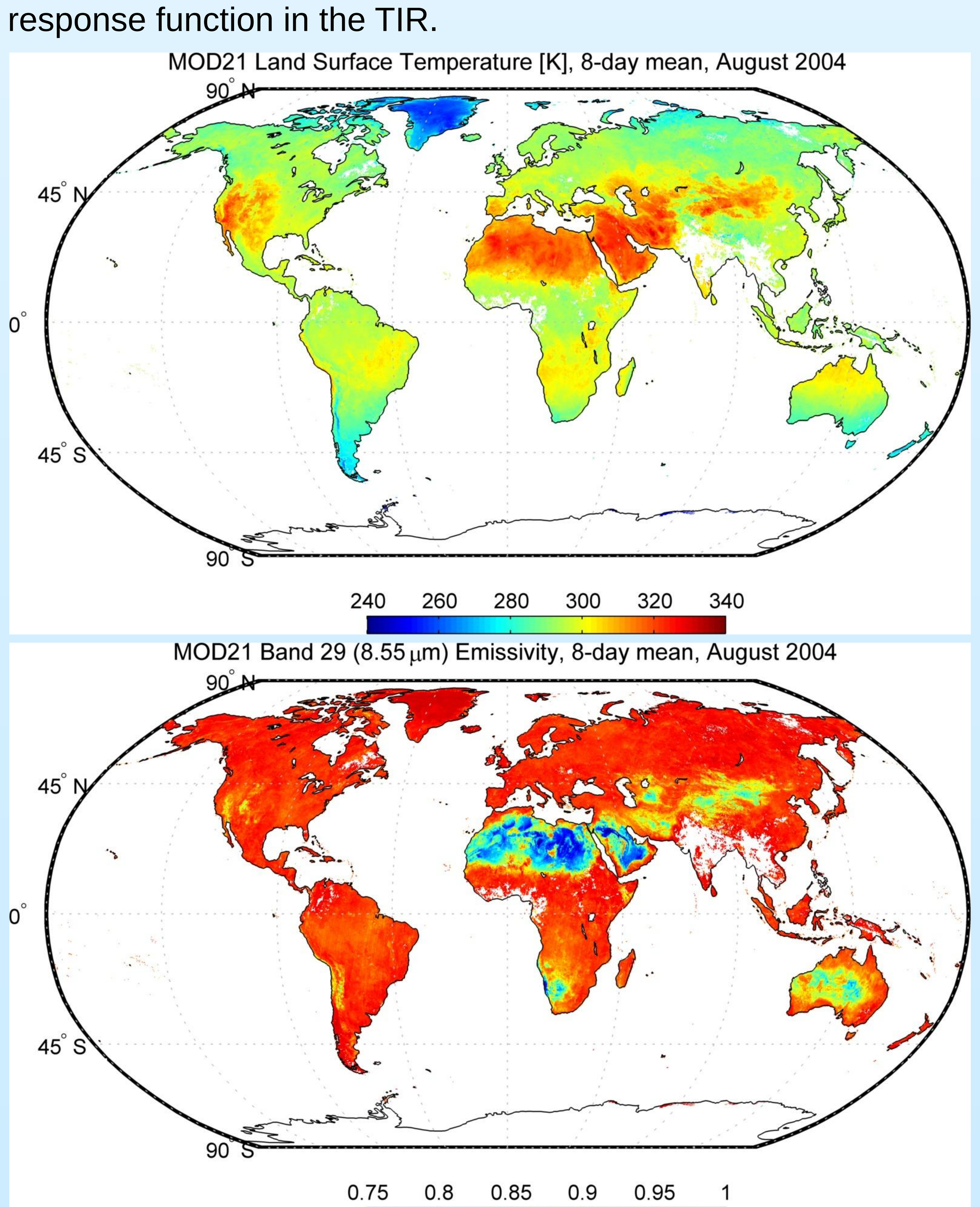

Figure 1. MODIS MOD21 8-day mean LST (top) and band 29 emissivity (bottom) during August 2004.

The LST&E Uncertainty Simulator (TEUSim)

- Based on radiative transfer calculations using the MODTRAN 5.2 RT model.
- Simulates 382 global radiosonde atmospheric profiles.
- For surface characterization, more than 90 spectra of rocks, soils, sands, vegetation, ice, water from the ASTER spectral library are assimilated.
- Separate contributions from measurement noise, atmospheric uncertainty, algorithm error, cloud contamination, and calibration errors are simulated.
- TES algorithm and split-window algorithm currently implemented but can be adapted to any LST algorithm and input sensor's spectral response.

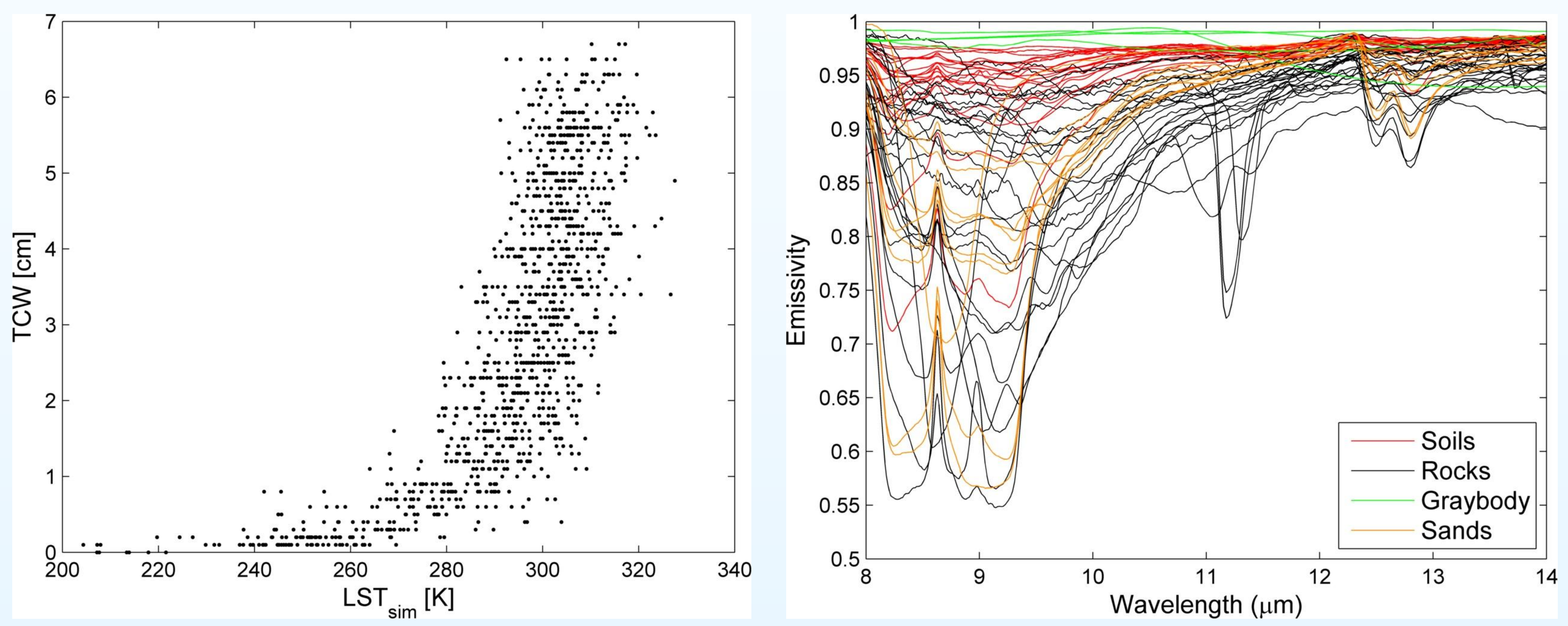

Figure 2. The distributions of simulated total column water (TCW) versus LST (Left) and emissivity spectra (right) used in the TEUS to simulate LST uncertainties

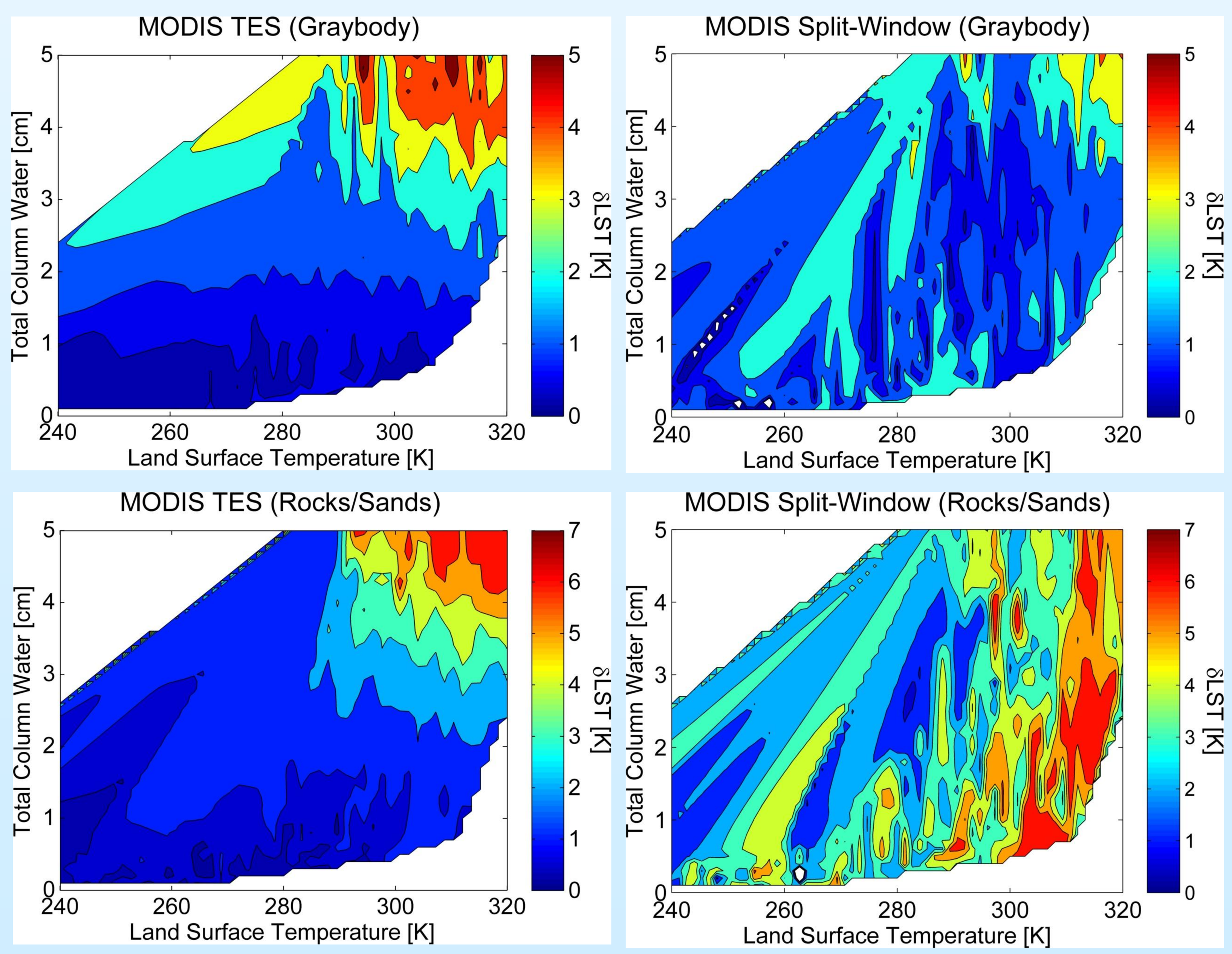

Figure 3. MODIS TES (left) and MODIS split-window (right) LST uncertainty distributions plotted versus total column water (TCW) and simulated LST for graybody surfaces (water, ice, snow, water) and bare surfaces (rocks, sands). Notice that in general TES uncertainties are higher for graybodies, but lower for bare surfaces, and the reverse is true for MODIS split-window.

Uncertainty Parameterization: Based on the simulation results, the uncertainties can be modeled according to total column water (*TCW*), and sensor view angle (*SVA*):

$$\delta LST = a_o + a_2 TCW + a_3 SVA + a_4 TCW \cdot SVA + a_5 TCW^2 + a_6 SVA^2 \quad (1)$$

A Unified MODIS LST Product

- The MOD11 and MOD21 LST products can be merged using pre-defined uncertainties and a weighting rule based on a ' combination of states of information' approach, e.g. Tarantola (2005).
- If T1 and T2 are two estimates of the same state with uncertainties δT1 and δT2, then the weights are simply proportional to the inverse of the uncertainties, and normalized to add up to one. This can be applied to the MOD11 and MOD21 LST products as follows:

$$\overline{LST} = \frac{1}{(w1 + w2)}(w1 \cdot LST_{MOD11} + w2 \cdot LST_{MOD21}) \quad (2)$$

Where w1 and w2 are weighting factors based on the uncertainty of each product's variance, $w = 1/\delta T$.

The variances are combined to produce a final uncertainty estimate:

$$\delta LST = (1/(w1 + w2))^{1/2} \quad (3)$$

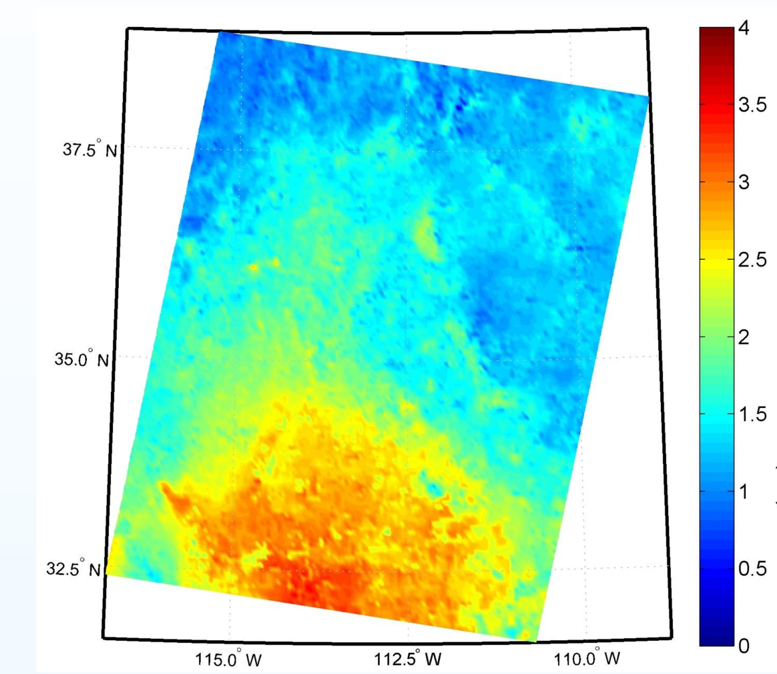

Figure 4. MODIS MOD07 total column water (TCW) estimate (cm).

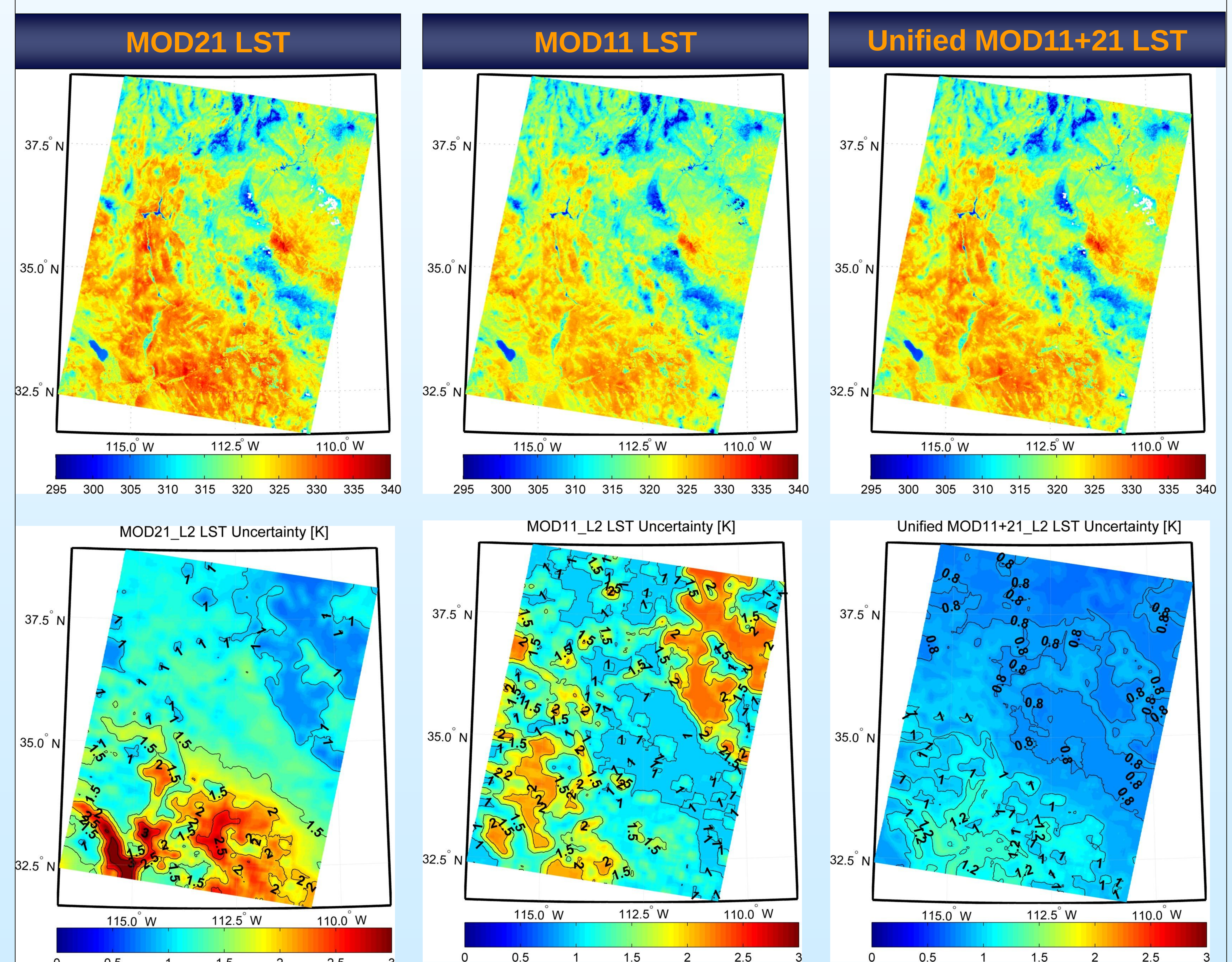

Figure 5. MOD21 (left) and MOD11 (middle) LST retrievals and associated uncertainties using equation (1) over the southwestern USA (California, Arizona, Utah). The unified MOD11+21 LST product (right) is derived by using a combination of states of information approach (equation 2), with final uncertainty calculated using equation (3).

MOD21 uncertainties are highest over humid regions over the Salton Sea and Imperial Valley agricultural district (southwest corner) shown in the MOD07 product (**Figure 4**), while MOD11 uncertainties are highest over bare regions of the Mojave desert and Colorado plateau (northeast corner). Note how the final uncertainties are lower than either of the original inputs since a 'conjunction' of probabilities of each product's uncertainty is calculated.

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