12.3 DISAGGREGATION OF GOES-LAND SURFACE TEMPERATURES USING MODIS OBSERVATIONS

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1. INTRODUCTION

Spatial and temporal sampling of the land surface temperature is vital to determining the land-surface energy exchange with the atmosphere (Dickinson, 1992), in the assessment of the earth's hydrological cycle and optimum utilization of water resources in agriculture (Price, 1982). Satellite-based Land surface temperature (LST) retrievals have been accomplished using both polar orbiting sensors (Prata and Platt, 1991; Wan and Dozier, 1996) as well as geostationary orbiting sensors (Sun and Pinker, 2003). Polar-orbiting satellites provide a more uniform global view of the earth, a restricted range of view zenith angles, shorter atmospheric path lengths, better accuracy and higher spatial resolution (~ 1 km) than feasible with geostationary satellites. However LST retrievals are available at most twice a day. Geostationary satellites, on the other hand, orbit the earth at the same speed as the earth's rotation and capable of providing frequent measurements of LST. However, due to their large instantaneous field of view, the spatial resolution (~ 4km at nadir) achieved is often inadequate to distinguish different land-cover types.

The potential advantages of both polar orbiting and geo-stationary satellites have been combined in a recent study (Inamdar and French, 2008), by employing the MODIS (Moderate Resolution Imaging Spectroradiometer) instrument on board the EOS (Earth Observation System) TERRA and AQUA satellites as a calibration source for the GOES (Geostationary Environmental Satellite) satellite, to yield a diurnal cycle of LST, initially at the spatial scale of the GOES imager pixel (~ 4km), followed by further processing to upgrade to a 1 km scale. The potential benefits of 1 km resolution over 5 km are illustrated in Fig. 1, where extracts of thermal infrared and vegetation index area from a semi-arid region in the U.S. Southwest were compiled and composited (Fig. 1). Shown are histograms of the Normalized Difference Vegetation Index (NDVI) (top) and LST (bottom) where 5 km data are plotted as dashed histograms and 1 km data as solid ones. The importance of 1 km resolution data lies with the significantly increased variability compared with 5 km resolutions. In this particular example, standard deviation of observed values increased 22% for NDVI and 1.3 K for LST; these are significant effects where changes on order of 10% for NDVI and 0.5 K for LST are important for energy balance estimation.

The disaggregation procedure in the earlier study (Inamdar et al, 2008) utilized the negative relationship between LST and the NDVI, and the sub-pixel (4 km) distribution of NDVI. However, an important draw-back of the LST-NDVI correlation is that it is found to be robust only over the crop-land and not so good over the open shrub-land and grasslands of the semi-arid and arid regions which comprise the bulk of our study region in the south west United States. Further, the degree of correlation also varies during the diurnal temperature cycle and is well-defined only close to the peak of the diurnal cycle of LST. In the present study, we employ instead the 1 km gridded emissivity product retrieved from MODIS in conjunction with GOES brightness temperatures in the thermal infrared in a split-window scheme for cloud-cleared GOES pixels. The inhomogeneities in the GOES-measured brightness temperatures at the sub-pixel scale (< 4 km) have been ignored, as a first-order approximation. The retrieved LST values have been found to be more stable, and a modified technique based on the median diurnal cycle filter has been developed which not only improves and smoothens the final LST product, but also fills up observational data gaps. The retrieved LST values have been compared against ground truth at the Southern Great Plains and other surface sites over the southwest US.

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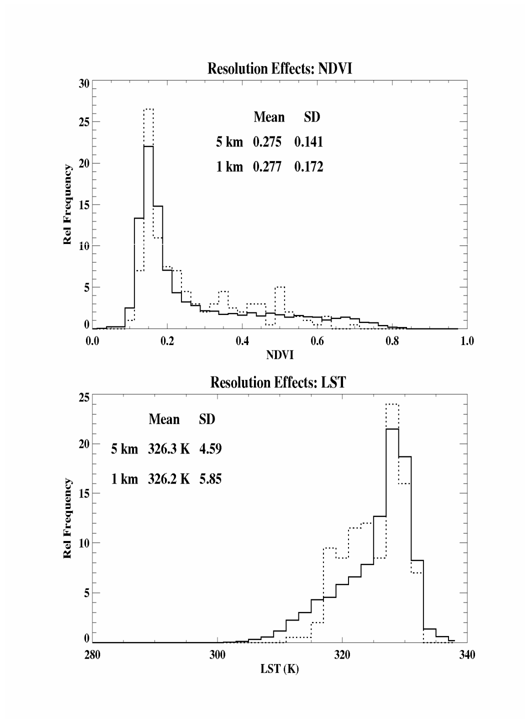

Fig. 1. Histogram of the distribution of vegetation index over a sample of southwest region (100 km x 50 km) (top) and the corresponding LST (bottom). The dotted and solid lines represent 5 km and 1 km resolution respectively.

2. DATA

The primary streams of data used in the present study comprise:

1) the brightness temperatures in the 3 infrared bands (3.9 μm, 11 μm and 12 μm) of the GOES-10 Imager (positioned at 135^0 W longitude covering the US southwest region and part of the Pacific Ocean);
2) the 1 km LST and surface emissivity in the thermal infrared window bands 31 (11 μm) and 32 (12 μm). The geo-location information available for every 5 km (5 by 5 pixels) resolution has been linearly interpolated to 1 km.

3. METHODOLOGY

The focus of our study is the southwestern region of US (Fig. 2). This choice is based on the following reasons: (i) prevalence of generally favorable sky conditions in the region; (ii) accessibility of surface LST validation sites; (iii) availability of both kinds of satellite data; (iv) opportunity to address problems created by low

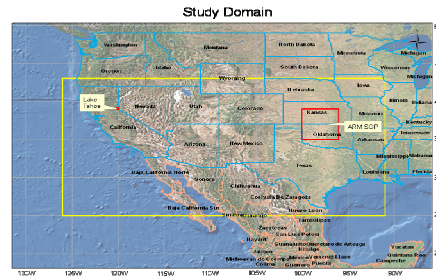

Fig. 2. The focus of study is the semi-arid and arid regions of the US Southwest.

emissivities over the semi-arid and arid regions, and (v) the need to supply diurnal LST data to researchers evaluating the hydrological cycle in a water-scarce region.

The processing of primary data sources to obtain the desired half-hourly 1 km LST product is accomplished through a series of complex sub tasks, which involve: cloud-screening of GOES data, collocation of GOES and MODIS pixels, use of a generalized split-window scheme, and application of a semi-empirical diurnal model filter to fill data gaps and smoothen out the fluctuations.

3.1 *Cloud-screening*

One of the important requirements of successful LST retrieval from satellites is the effective removal of cloudy radiances. But cloud-clearing over land surfaces is a very challenging task. We employ here a combination of schemes: initial evaluation of the GOES brightness temperatures in 11 μm for spatial coherence at small and large scales (Závody et al, 2000), followed by the four-step Bispectral Threshold and Height method (BTH) (Haines et al, 2003). Full details of the scheme are described in Inamdar et al (2008, in press). The performance of the cloud-screening is demonstrated in Fig. 3, wherein the cloud cover predicted by our scheme is compared with that of MODIS for a specific day. One can see many similarities between the images, indicating good performance of our cloud screening procedure, although there are a few regions of underperformance such as in the state of Nebraska, Colorado-New Mexico border and northern Texas. The median filtering (described later) compensates for some of the deficiencies of the BTH scheme.

3.2 *Matching and Merging of GOES and MODIS data*

The cloud-cleared GOES pixels are collocated with the 1 km MODIS pixels, yielding for each

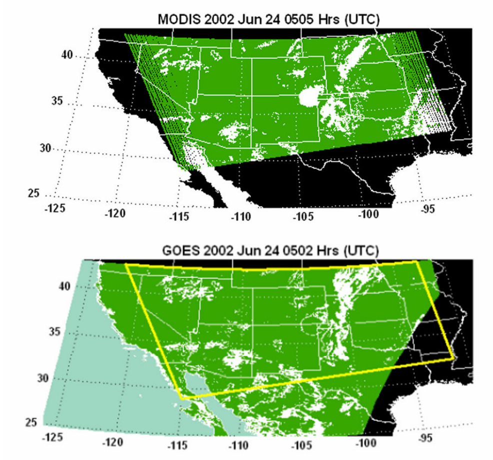

Fig. 3. Comparison of GOES-10 cloud masks with MODIS for June 24, 2002 (05:05 hrs UTC). The domain which corresponds to the modis swath area in the top panel is shown outlined in yellow border in the bottom panel.

matched domain, a set of GOES 10 imager brightness temperatures in the thermal infrared channels of 11 μm, 12 μm together with the MODIS LST and also the surface emissivities in MODIS bands 31 and 32. Each area sampled by GOES is under a MODIS overpass at least once every day, permitting collection of a sufficiently large sample of matched data pairs representative of the spatial domain under study. The merged GOES/MODIS parameters for each day are input into a split-window regression scheme (Wan and Dozier, 1996) allowing us to "calibrate" the GOES brightness temperatures in terms of MODIS-measured LST. The split-window scheme is then applied to each 1 km domain employing the GOES brightness temperatures for the overlapping GOES pixel. The required surface emissivities have been retrieved from the MODIS monthly 1 km gridded product.

3.3 *Diurnal Modeling*

The procedure described above yields distribution of half-hourly LST values at 1 km resolution over the entire spatial domain under study. However, since the cluster of LST values includes cloud-contaminated pixels which have evaded detection in the BTH cloud-clearing scheme, an additional screening procedure is needed. For this, median compositing followed by modeling of the median composites into a diurnal temperature cycle (DTC) is adopted. The DTC derived from a monthly median composite approximates a cloud-free version of the most frequently encountered day in the interval (Göttsche & Olessen, 2001). To model a DTC for these LSTs, we implement a slightly modified form of the Göttsche model, wherein we choose the sum of a harmonic and a hyperbolic decay term to describe the effects of solar forcing during the day and decrease of surface temperature at night (Inamdar et al, 2008). In order to fill up gaps in GOES observations for a specific day, we first determine a median offset between the median DTC and the LST values for the day and add the median offset to the median DTC wherever GOES observations are missing. In summary, the process of median compositing and DTC modeling , i) can be used to replace values missing due to technical problems or brief cloud cover; ii) the DTC can summarized by using a set of 5 model parameters instead of a set of 48 half-hourly observations per pixel per day; and iii) the model parameters are not influenced by outliers, and aid in isolating individual outlier observations.

4. RESULTS

Performance of the present model was tested against ground truth by choosing two different surface types (a crop land and an arid site) and seasons (summer and winter):

1) the Southern Great Plains (SGP) central facility (C01) operated by the Atmospheric Radiation Measurement (ARM) program; and
2) the Desert Rock (DRA) in Nevada.

We make use of the upwelling and down-welling longwave flux components as measured by radiometers mounted at the sites and broadband surface emissivity to estimate the surface radiometric temperature or LST.

Comparison of the 1 km DTC for the two sites for selected clear-sky days during the summer (June 2002) and winter (January 2003) months are shown in Figs 4 – 7. The time units shown on abscissa (in UTC hour) extend for 2 consecutive days (48 hours), with the location of the solar noon shown by a vertical line. Thus, reference to UTC hours greater than 24 represent time counted over two consecutive days. The central SGP facility and Desert Rock site are denoted as C01 and DRA respectively in Figs 4-7. The radiometric measurements at the site represent 15 minute averages, and thus presence of clouds can be detected as discontinuities or spikes in the time series. A set of nearly clear sky days were hand-picked for each site by visual inspection of the observed DTC. While the dotted curve (Figs 4-7) represents the LST measurements at the site, the LST values obtained from the present scheme contain a mix of those retrieved from the clear-sky GOES observations, wherever available (denoted by a '+' symbol), and filler values (represented by filled circle symbols) where GOES observations are lacking due to clouds or otherwise. The latter data points substitute gaps in GOES observations and have been generated as per the procedure outlined in Section 3.3. All the data points in each of Figs 4-7 have also been shown individually as a scatter plot with accompanying statistics in Fig. 8.

Comparisons shown in Figs 4-7 reveal that, while the summer months show excellent agreement, the winter months display a slight negative bias. The post-sunset period is seen to be cloudy on most of the days for the central SGP facility (Fig. 5) during January 2003, contributing to the negative bias. Another reason for the disparity can be attributed to the cold bias of the MODIS LST values (shown by filled circle symbols in the bottom right panel of Fig. 8), which propagate into the final 1 km LST product in the processing. Uncertainties related to the surface emissivity, which was used in retrieving the LST from radiometer measurements, could also result in an over-estimation of measured LST which might explain the apparent cold bias in MODIS LST.

5. CONCLUSIONS

Techniques have been developed to disaggregate geostationary LST data using single time of day MODIS 1 km observations, gridded monthly 1 km emissivity data and a diurnal-scale model. The present study improves upon an earlier study (Inamdar et al, 2008), wherein negative correlation between the MODIS-derived NDVI and LST was used in the disaggregation process. However, in the present study, using data from US southwest, it is found that the most consistent and stable correlative estimators are obtained from 1 km MODIS emissivity data. Accuracies of LST estimates using 2002-2003 ground observations at the SGP and SURFRAD sites yield rms accuracies within 2 C. for the 1 km LST product.

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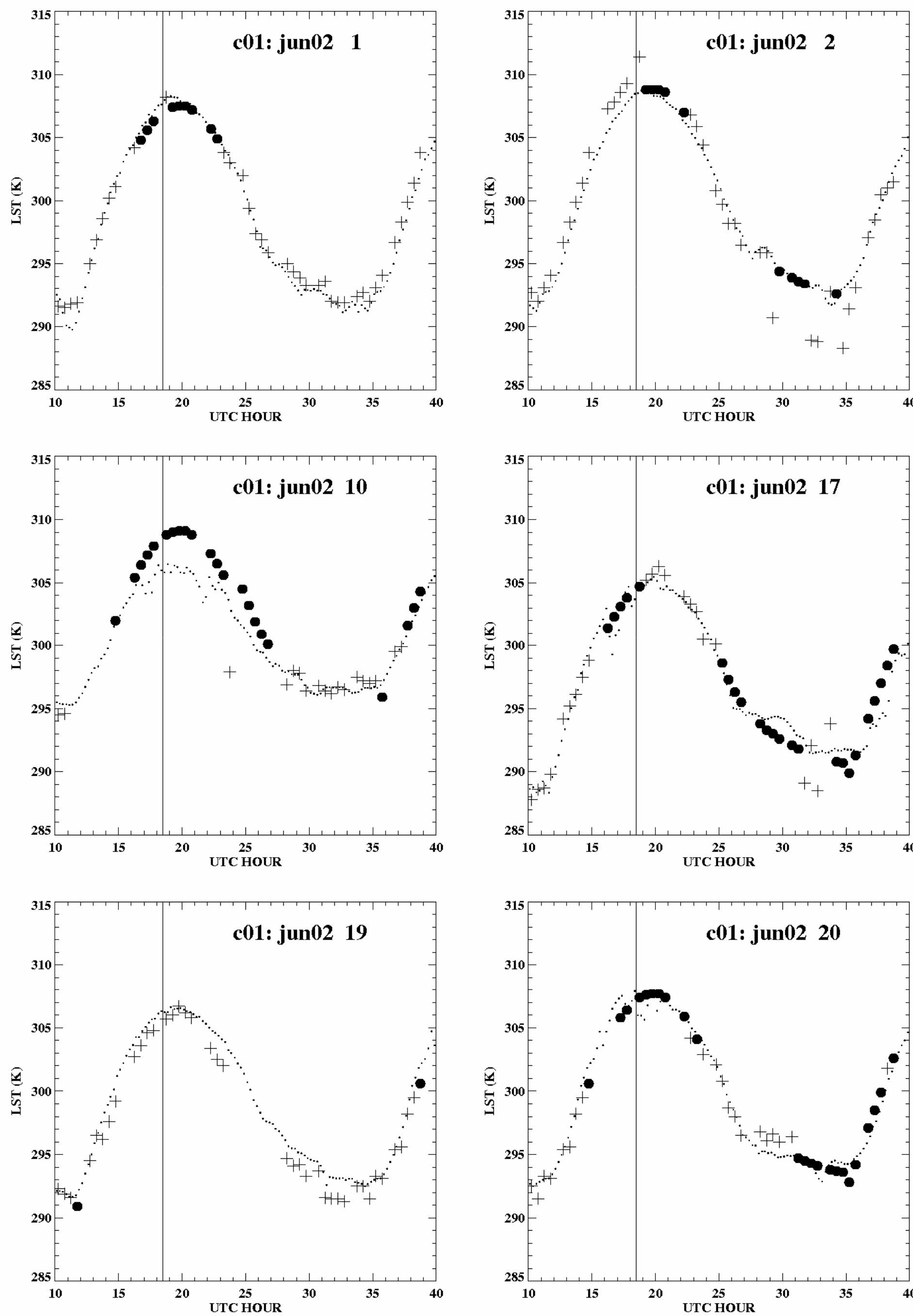

Fig. 4. Diurnal cycle of 1 km LST (+ symbols) predicted by the model, compared with that of the ground-measured LST (dotted line) at the ARM SGP central facility for selected cloud-free days during June 2002. Observational data gaps in GOES, due to clouds or otherwise, are indicated by filled circle symbols (see text in section 3.3).

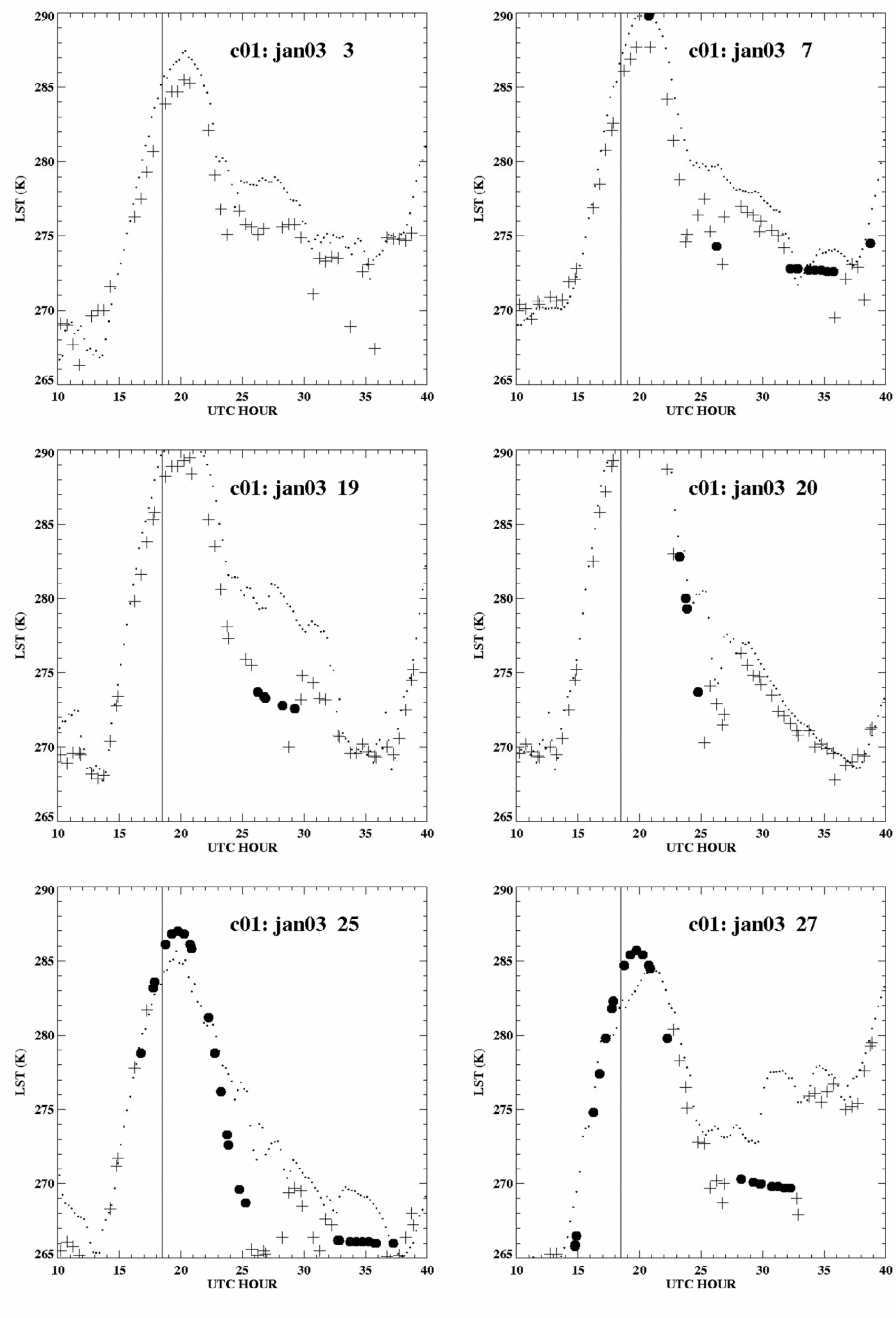

Fig. 5. Same as Fig. 4, except for ARM SGP site during Jan 2003.

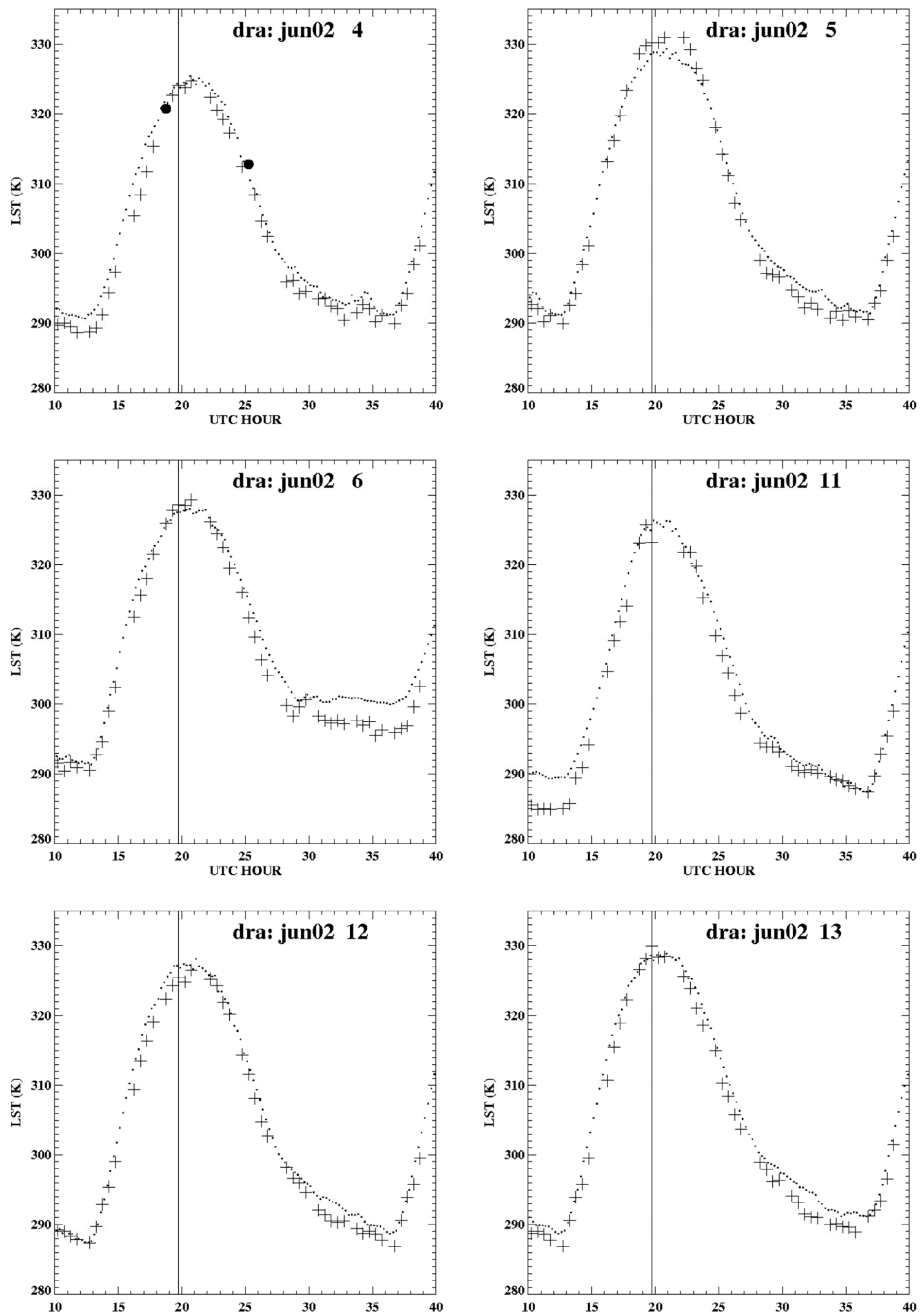

Fig. 6. Same as Fig. 4, except for the Desert Rock site (Nevada) during Jun 2002.

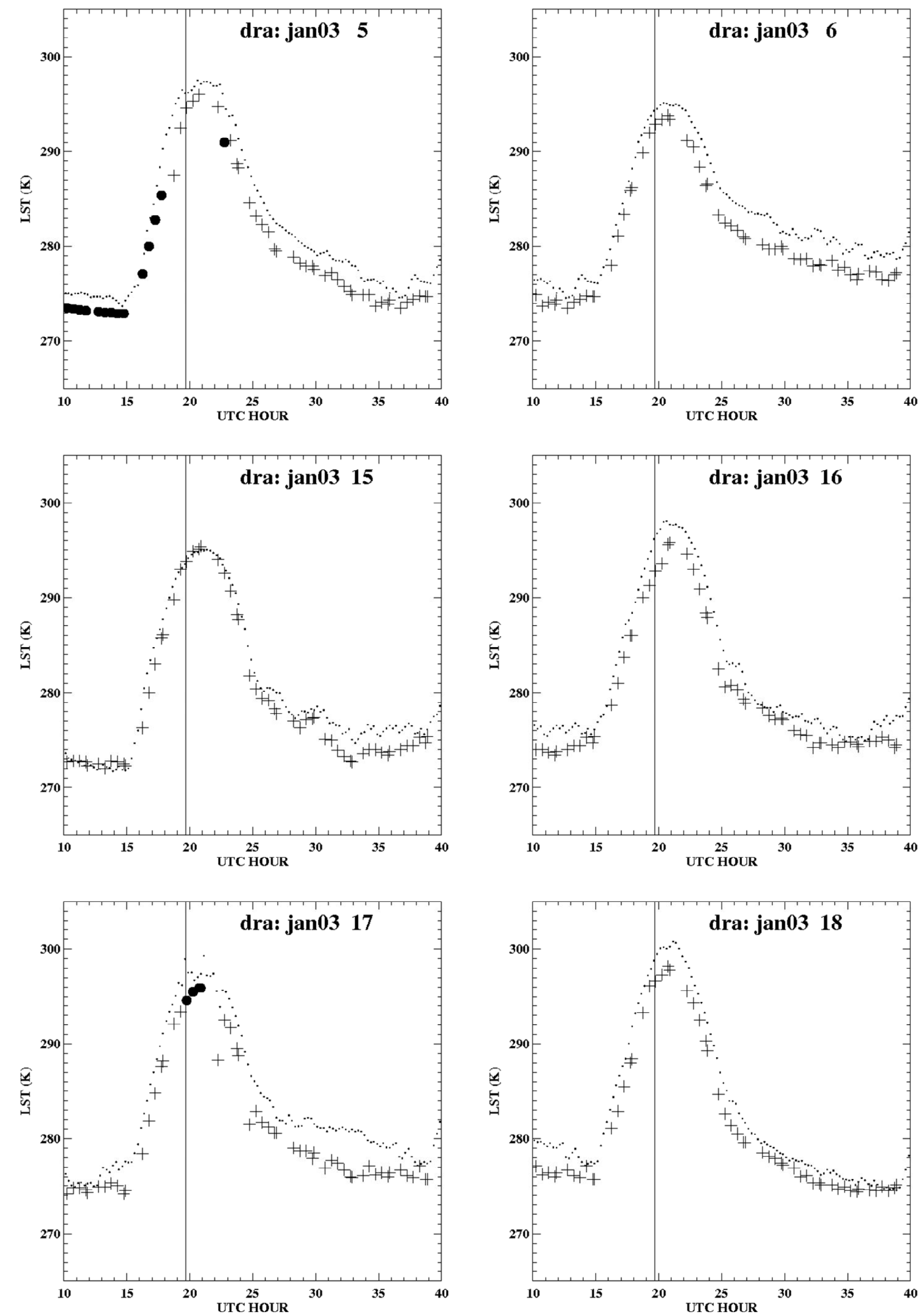

Fig. 7. Same as Fig. 6, except for Jan 2003.

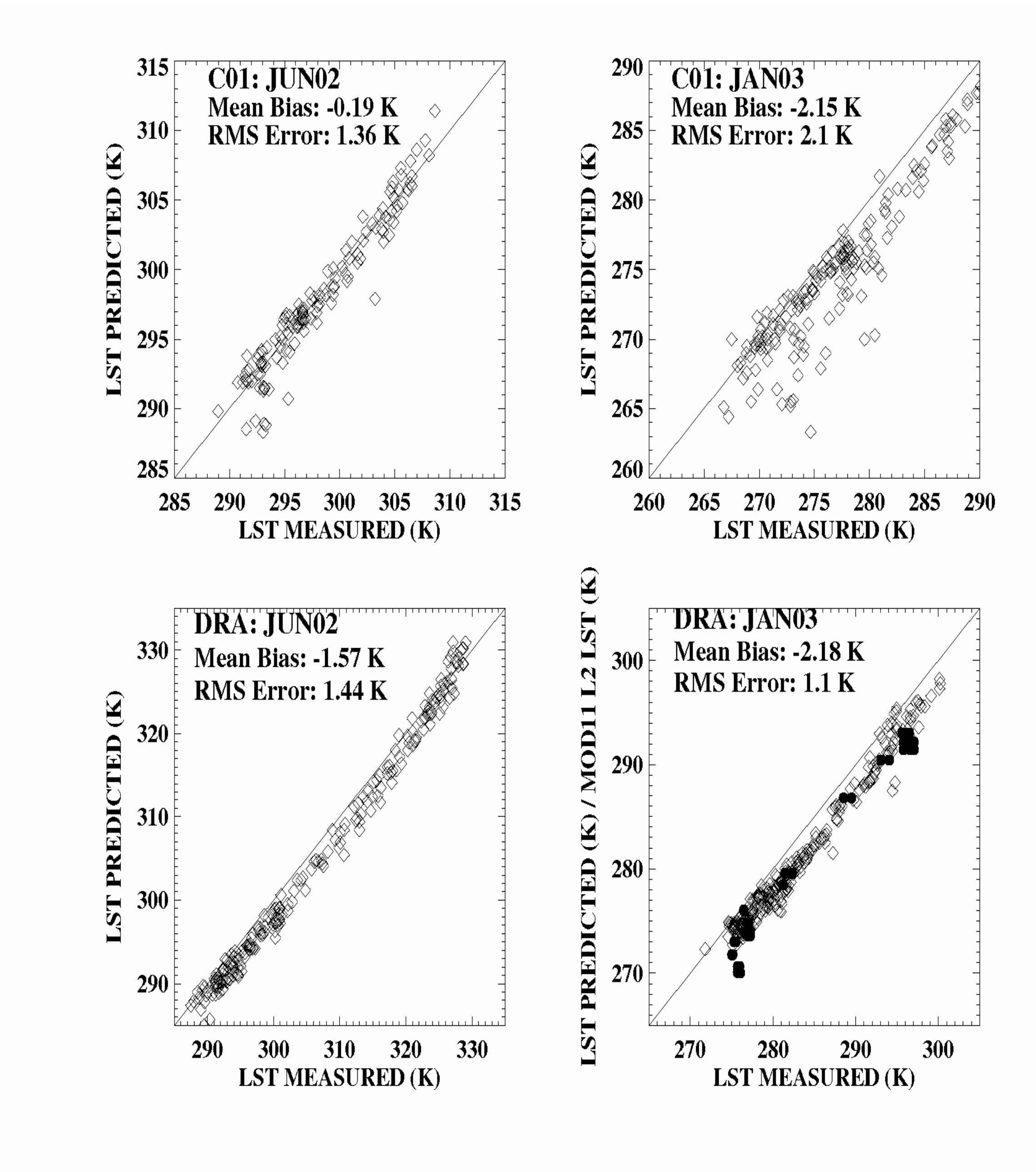

Fig. 8. Scatter plot of predicted 1 km LST versus groud-measurements corresponding to the data shown in Figs. 4 – 7. The filled circle symbols in the bottom right corner panel (for DRA site, Jan 2003) represent MODIS overpass measurements as retrieved from the MOD11 L2 product.