2006

Diurnal Temperature Range Over the United States: A Satellite View

D. Sun
George Mason University

R. T. Pinker
Univ Maryland

Menas Kafatos
Chapman University, kafatos@chapman.edu

Recommended Citation

Sun, D., Pinker, R.T., Kafatos, M. (2006) Diurnal temperature range over the United States: A Satellite View, *Geophysical Research Letters*, Vol. 33, L05705, 2006. doi:10.1029/2005GL024780

Diurnal temperature range over the United States: A satellite view

Donglian Sun,[1] Rachel T. Pinker,[2] and Menas Kafatos[1]

Received 30 September 2005; revised 28 November 2005; accepted 20 January 2006; published 4 March 2006.

[1] Diurnal temperature range (DTR) is an important climate change index. Information on this parameter comes primarily from sparse and unevenly distributed observations of shelter air temperature. In this study, five years of GOES-8 based estimates of land surface temperature (LST) over the United States are used to evaluate DTR at high spatial resolution. The spatial and temporal patterns that emerged show a high degree of consistency with independent satellite estimates of the Normalized Difference Vegetation Index (NDVI). Specifically, the arid regions in the western and central U.S. have larger DTRs than the eastern United States or the northwest coast. When stratified by four major surface types, the western U. S. DTRs over these surface types are larger than over the eastern part. It is also observed that urban areas have the lowest DTRs especially over the polluted eastern U. S. The similarity of the DTR spatial and temporal patterns and variations of the independent satellite based vegetation index are encouraging and suggest that satellite based estimates of DTR carry a strong signal on surface conditions which are responsive to climate change.

Citation: Sun, D., R. T. Pinker, and M. Kafatos (2006), Diurnal temperature range over the United States: A satellite view, *Geophys. Res. Lett.*, *33*, L05705, doi:10.1029/2005GL024780.

1. Introduction

[2] Diurnal temperature range (DTR) is an important index of climate change [*Karl et al.*, 1984] and is susceptible to urban effects [*Intergovernmental Panel on Climate Change*, 2001]. It is also affected by land use changes [*Kalnay and Cai*, 2003], vegetation [*Collatz et al.*, 2000], soil moisture, and clouds [*Dai et al.*, 1999; *Trenberth*, 2003; *Stone and Weaver*, 2003]. As stressed by *Braganza et al.* [2004], mean surface temperature alone is not as useful an indicator of climate change as the change in daily maximum and minimum temperatures. Trends in mean surface temperature are due to changes in either maximum or minimum temperature, or relative changes in both. The recently reported surface warming over land is associated with relatively larger increase in daily minimum temperature rather than in maximum temperature [*Karl et al.*, 1993; *Easterling et al.*, 1997]. Till recently, most information on DTR came from station observations of surface air temperature (SAT) or from numerical model simulations. Several studies based on climate model simulations suggest that DTR changes may be due to effects of human-induced increase in atmospheric greenhouse gases (CO_2) and sulfate aerosols [*Park and Joh*, 2005; *Karoly and Braganza*, 2005; *Schnur and Hasselmann*, 2005]. However, *Collatz et al.* [2000] claim that increasing atmospheric CO_2 produced little change in the DTR, and *Zhao and Pitman* [2005] pointed out that increase in greenhouse gases affected both the maximum and minimum temperature, and therefore, resultant changes in the DTR were small.

[3] *Gallo et al.* [1996] evaluated DTR of SAT over the Unite States. *Seidel et al.* [2005] found that the DTR of air temperature from radiosondes observations is larger at the surface than in the upper atmosphere. It is of interest to use satellites for evaluating DTR because of their ability to provide full spatial coverage. Moreover, the satellite sensed skin temperature (radiative temperature) is directly related to surface-atmosphere energy exchange processes and therefore, directly sensitive to surface changes such as soil moisture and land cover/land use (LC/LU). Station observations are sparse, unevenly distributed, and suffer from differences in elevation, time of observation, and nonstandard sitting [*Peterson*, 2003]. The use of satellite-based estimates of DTR can provide consistent information over large areas [*Gallo and Owen*, 1999]. The DTR from SATs is different in nature from the satellite-based estimate of DTR, since satellites observe the skin temperature (e.g., radiative temperature) under clear sky conditions while DTR of SAT at 2m from meteorological station observations integrates the effects of clouds. It can be expected that the satellite based DTR will be higher than the one observed from SAT due to the mitigating effect of clouds [*Sun et al.*, 2006].

[4] One can argue that perhaps, the satellite based estimates of DTR (directly related to surface conditions), are a better index of climate change than SAT which includes a feedback effect of climate change (effect on clouds), and as such, is more difficult to interpret. Moreover, uncertainties exist about cloud cover extent. *Dai et al.* [1999] point out that clouds have increased during the last 4–5 decades over the United States and many other regions where DTR was reported to decrease. Due to the damping effect of clouds on DTR they see a strong link between the two (also supported by *Karl et al.* [1993]). However, more recent studies based on global scale satellite observations [*Rossow and Duenas*, 2004] claim that there has been a steady decrease in cloudiness in the last 20 years raising questions about the cloud link to DTR.

[5] Most surface temperature retrievals from satellites are based on polar orbiters. Surface temperature, especially land surface temperature (LST) has a strong diurnal cycle, which cannot be captured at the temporal resolution (approximately two views per day) of polar orbiting satellites. *Jin and Dickinson* [2002] and *Sun and Pinker* [2005] estimated diurnal range of surface skin temperature

[1]Center for Earth Observing and Space Research, George Mason University, Fairfax, Virginia, USA.

[2]Department of Atmospheric and Oceanic Science, University of Maryland, College Park, Maryland, USA.

0094-8276/06/2005GL024780$05.00

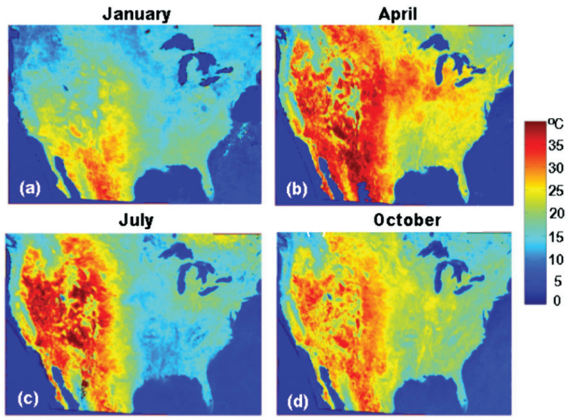

Figure 1. Spatial distribution of DTR derived from the GOES-8 observations for different months as averaged from 1996 to 2000 (a) January, (b) April, (c) July, and (d) October.

from the Advanced Very High Resolution Radiometer (AVHRR) on polar orbiting satellites corrected for diurnal effects by using typical diurnal patterns derived from climate model simulations and GOES observations, respectively. Geostationary satellites provide good diurnal coverage, which makes them attractive for deriving information on LST diurnal cycle. *Sun and Pinker* [2003] introduced a new split window algorithm (daytime) and a new triple-window algorithm (nighttime) for LST retrieval from the Geostationary Operational Environmental Satellite GOES-8. When compared with ground observations, the root mean square (RMS) error is about 1 ~ 2°C and the bias error is less than 1.0°C for both daytime and nighttime. In this study, we investigate the spatial variations in the diurnal range of surface skin temperature as derived from GOES-8 observations using the method of *Sun and Pinker* [2003]. The data and methodology used will be briefly described in section 2; section 3 will present results; and discussion and conclusions will be given in section 4.

2. Data and Methodology

2.1. Data

[6] • The mean target brightness temperature and cloud cover fraction as derived from GOES-8 observations. These are available as a by-product from a NOAA/NESDIS operational insolation product generated in support of the GEWEX (Global Energy and Water Cycle Experiment) Continental-scale International Project (GCIP) and the GEWEX Americas Prediction Project (GAPP) activity and as archived at the University of Maryland (http://www.meto.umd.edu/~srb/gcip) [*Pinker et al.*, 2003].

[7] • Satellite based classification of land cover from the NOAA/AVHRR 1-km resolution University of Maryland product [*Hansen et al.*, 1998] (http://glcf.umiacs.umd.edu/data/landcover/); it includes 14 International Geosphere-Biosphere Programme classes [*Townshend*, 1992].

[8] • The normalized difference vegetation index (NDVI) data from the Global Inventory Monitoring and Modeling Studies (GIMMS) (http://glcf.umiacs.umd.edu/data/gimms/) [*Zhou et al.*, 2003; *Tucker et al.*, 2006].

2.2. LST Retrieval Algorithm

[9] The LST retrieval methodology is described by *Sun and Pinker* [2003]. Briefly:

$$T_s(i) = a_0(i) + a_1(i)T_{11} + a_2(i)(T_{11} - T_{12}) + a_3(i)(T_{11} - T_{12})^2 + a_4(i)(\sec\theta - 1) \quad (1)$$

where i is the surface type index [*Hansen et al.*, 1998], θ is the satellite-viewing angle, T_{11} and T_{12} are the brightness temperatures at 10.8 and 12.0 μm channels (http://www.meto.umd.edu/~srb/gcip), a_0 to a_4 are coefficients and Ts is the derived skin temperature.

[10] The coefficients in equation (1) are derived from GOES-8 forward simulations using the moderate resolution atmospheric radiance and transmittance model (MODTRAN) as provided in *Sun and Pinker* [2004]. The period 1996 to 2000 is selected for this study since improved information on clear sky radiances and cloud cover is available (X. Li et al., Toward improved satellite estimates of short-wave radiative fluxes: Focus on cloud detection over snow: 1. Methodology, submitted to *Journal of Geophysical Research*, 2005; R. T. Pinker et al., Toward improved satellite estimates of short-wave radiative fluxes: Focus on cloud detection over snow: 2. Results, submitted to *Journal of Geophysical Research*, 2005). Clear conditions are selected to calculate skin temperature (T_s) if cloud cover fraction (CCF) less than 10% is reported. The retrieved T_s is used to calculate the DTR (maximum-minimum T_s) for clear days (daily CCF < 10%).

3. Results

[11] The five-year average DTRs for the four mid-seasons show geographical differences, with western and central U. S. being systematically higher than those of the eastern U. S. or the northwestern coast (Figure 1). Over the western U. S., DTR is larger in spring and summer than fall and winter. Over the eastern part, DTR is larger in spring and fall than in summer and winter (dividing line between west and east is about 100°W). Discussion of all plausible causes of the observed differences is beyond the scope of this paper.

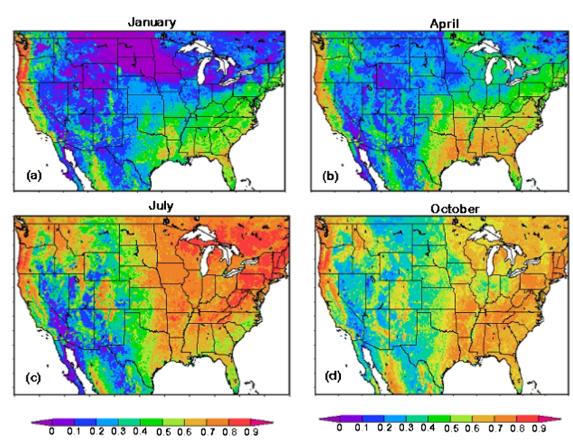

Figure 2. Spatial distribution of NDVI derived from AVHRR observations for different months as averaged from 1996 to 2000 (a) January, (b) April, (c) July, and (d) October.

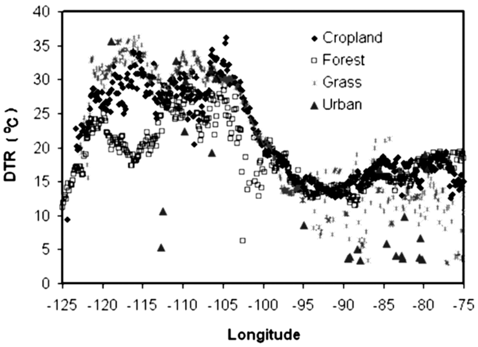

Figure 3. Meridional mean DTR derived from GOES-8 for cropland, forests, grassland and urban surfaces for a five-year average July.

We have looked at the primary ones such as soil moisture, evaporation, and vegetation distribution. The distribution of surface soil moisture for the same time period shows that the western and central U. S. are dry, while the eastern U. S. and northwestern coast are wet [*Willmott et al.*, 1985]. Evaporation distribution obtained from the ECMWF 40 Years Re-Analysis (http://data.ecmwf.int/data/d/era40_mnth/) also indicates high values in the east as compared to the west, especially during warm seasons. High evaporation over the wet region during daytime reduces the maximum temperature, and consequently the DTR [*Zhao and Pitman*, 2002]. The vegetation index NDVI for the same time periods is shown in Figure 2. A remarkable resemblance between high vegetation and low DTR can be seen for all four mid-season months. Evapotranspiration from vegetation contributes significantly to the decrease in DTR during summer in the eastern United States [*Durre and Wallace*, 2001]. Moreover, the smaller DTR areas over the eastern United States are found to have higher sulfate aerosol emissions than the western U. S. [*Chin et al.*, 2000]. Sulfate aerosols scatter solar radiation back to space and tend to cool the surface during daytime and may result in a decreased DTR [*Stone and Weaver*, 2003].

[12] Figure 3 illustrates the 5 year average meridional mean DTR in July for the following selected LC/LU types: cropland, forest, grassland, and urban. There is a distinct difference in DTR between the west and east for each surface type, the DTRs being much larger over the west than over the east. In general, the DTR of grasslands are the largest followed by cropland, forests and urban areas. The larger scatter in grassland DTR in the east and seemingly smaller values than for cropland might be due to the smaller sample of grasslands in the east (2% of total pixels) than in the west (29%). For the other surface types the samples in east and west are comparable. Some DTR values of forests over the west coast are smaller than the surrounding pixels because the highly vegetated northwest (Figure 2) is included.

4. Discussion and Conclusions

[13] For the first time, the spatial and seasonal variation of satellite based estimates of DTR from surface skin temperature over the United States is shown. The satellite-derived DTRs show geographical patterns, which are highly consistent with those of the vegetation (NDVI). Satellite-derived DTR may be affected by a variety of additional factors, such as surface topography, soil moisture, soil composition and thermal properties, evaporation, sulfate aerosol distributions, and large and local scale climate. Since the satellite-based estimates are obtained for clear conditions only, they may serve as better index of climate change than DTRs of SAT that include the effect of clouds. It's expected that part of the spatial variations in satellite DTR could be explained by soil moisture, vegetation, aerosols, and LC/LU as described in this paper. Our results also confirm the simulation results of *Zhao and Pitman* [2002], which show that different mechanisms/parameters dominate over different regions and vary with different seasons. Further investigations of the quantitative relationship between satellite derived DTR and the above mentioned parameters will follow.

[14] **Acknowledgments.** This work was supported by the VAccess/MAGIC project, funded by the NASA's Science Applications Program. The work that resulted in the DTRs was supported under grants NA030AR4310045 and NA06GP0404 from the NOAA Office of Global Programs to the University of Maryland.

References

Braganza, K., D. J. Karoly, and J. M. Arblaster (2004), Diurnal temperature range as an index of global climate change during the twentieth century, *Geophys. Res. Lett.*, *31*, L13217, doi:10.1029/2004GL019998.

Chin, M., R. B. Rood, S.-J. Lin, J. F. Muller, and A. M. Thomspon (2000), Atmospheric sulfur cycle in the global model GOCART: Model description and global properties, *J. Geophys. Res.*, *105*, 24,671–24,687.

Collatz, G. J., L. Bounoua, S. O. Los, D. A. Randall, I. Y. Fung, and P. J. Sellers (2000), A mechanism for the influence of vegetation on the response of the diurnal temperature range to changing climate, *Geophys. Res. Lett.*, *27*, 3381–3384.

Dai, A., K. E. Trenberth, and T. R. Karl (1999), Effects of clouds, soil moisture, precipitation, and water vapor on diurnal temperature range, *J. Clim.*, *12*, 2451–2473.

Durre, I., and J. M. Wallace (2001), The warm season dip in diurnal temperature range over the eastern United States, *J. Clim.*, *14*, 354–360.

Easterling, D. R., T. C. Peterson, and T. R. Karl (1997), On the development and use of homogenized climate datasets, *J. Clim.*, *9*, 1429–1434.

Gallo, K. P., and T. W. Owen (1999), Satellite-based adjustments for the urban heat island temperature bias, *J. Appl. Meteorol.*, *38*, 806–813.

Gallo, K. P., D. R. Easterling, and T. C. Peterson (1996), The influence of land use land cover on climatological values of the diurnal temperature range, *J. Clim.*, *9*, 2941–2944.

Hansen, M. C., R. S. Defries, J. R. G. Townshend, and R. Sohlberg (1998), Global land cover classification at 1 km resolution using a classification tree approach, *Int. J. Remote Sens.*, *21*, 1331–1364.

Intergovernmental Panel on Climate Change (2001), *Climate Change 2001: The Scientific Basis: Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, edited by J. T. Houghton et al., 881 pp., Cambridge Univ. Press, New York.

Jin, M., and R. E. Dickinson (2002), New observational evidence for global warming from satellite, *Geophys. Res. Lett.*, *29*(10), 1400, doi:10.1029/2001GL013833.

Kalnay, E., and M. Cai (2003), Impact of urbanization and land use on climate change, *Nature*, *423*, 528–531.

Karl, T. R., G. Kukla, and J. Gavin (1984), Decreasing diurnal temperature range in the United States and Canada from 1941–1980, *J. Clim. Appl. Meteorol.*, *23*, 1489–1504.

Karl, T. R., P. D. Jones, R. W. Knight, G. Kukla, N. Plummer, V. Razuvayev, K. P. Gallo, J. Lindseay, R. J. Charlson, and T. C. Peterson (1993), A new perspective on recent global warming, *Bull. Am. Meteorol. Soc.*, *74*, 1007–1023.

Karoly, D. J., and K. Braganza (2005), Attribution of recent temperature changes in the Australian region, *J. Clim.*, *18*, 457–464.

Park, H. S., and M. Joh (2005), Climate change due to the gradual increase in atmospheric CO_2: A climate system model sensitivity study, *Key Eng. Mater.*, *277–279*, 595–600.

Peterson, T. C. (2003), Assessment of urban versus rural in situ surface temperature in the contiguous United States: No difference found, *J. Clim.*, *16*, 2941–2959.

Pinker, R. T., et al. (2003), Surface radiation budgets in support of the GEWEX Continental-Scale International Project (GCIP) and the GEWEX Americas Prediction Project (GAPP), including the North American Land Data Assimilation System (NLDAS) project, *J. Geophys. Res.*, *108*(D22), 8844, doi:10.1029/2002JD003301.

Rossow, W. B., and E. Duenas (2004), The International Satellite Cloud Climatology Project (ISCCP) web site: An online resource for research, *Bull. Am. Meteorol. Soc.*, *85*, 167–172, doi:10.1175/BAMS-85-2-167.

Schnur, R., and K. I. Hasselmann (2005), Optimal filtering for Bayesian detection and attribution of climate change, *Clim. Dyn.*, *24*, 45–55.

Seidel, D. J., M. Free, and J. Wang (2005), Diurnal cycle of upper-air temperature estimated from radiosondes, *J. Geophys. Res.*, *110*, D09102, doi:10.1029/2004JD005526.

Stone, D. A., and A. J. Weaver (2003), Factors contributing to diurnal temperature range trends in twentieth and twenty-first century simulations of the CCCma coupled model, *Clim. Dyn.*, *20*, 435–445.

Sun, D., and R. T. Pinker (2003), Estimation of land surface temperature from a Geostationary Operational Environmental Satellite (GOES-8), *J. Geophys. Res.*, *108*(D11), 4326, doi:10.1029/2002JD002422.

Sun, D., and R. T. Pinker (2004), Case study of soil moisture's effect on land surface temperature retrieval, *IEEE Trans. Geosci. Remote Sens. Lett.*, *1*, 127–130.

Sun, D., and R. T. Pinker (2005), Implementation of GOES-based land surface temperature diurnal cycle to AVHRR, *Int. J. Remote Sens.*, *26*, 3975–3984.

Sun, D., M. Kafatos, R. Pinker, and D. Easterling (2006), Comparison of seasonal variations in diurnal temperature range as observed from satellites and surface observations, *IEEE Trans. Geosci. Remote Sens.*, in press.

Townshend, J. R. (Ed.) (1992), Improved global data for land applications: A proposal for a new high resolution data set, *IGBP Rep. 20*, Int. Geosphere-Biosphere Programme, Univ. de Paris, Paris.

Trenberth, K. E. (2003), "Comment on impact of urbanization and land-use change on climate" by E. Kalnay and M. Cai, *Nature*, *423*, 528–531, doi:10.1038/nature 01675. (Available at http://stephenschneider.stanford.edu/Publications/PDF_Papers/Trenberth_KalnayComment.pdf.)

Tucker, C. J., J. E. Pinzon, M. E. Brown, D. Slayback, E. W. Pak, R. Mahoney, E. Vermote, and N. El Saleous (2006), An Extended AVHRR 8-km NDVI data set compatible with MODIS and SPOT vegetation NDVI Data, *Int. J. Remote Sens.*, in press.

Willmott, C. J., C. M. Rowe, and Y. Mintz (1985), Climatology of the terrestrial seasonal water cycle, *J. Clim.*, *5*, 589–606.

Zhao, M., and A. J. Pitman (2002), The regional scale impact of land cover change simulated with a climate model, *Int. J. Climatol.*, *22*, 271–290.

Zhao, M., and A. J. Pitman (2005), The relative impact of regional scale land cover change and increasing CO2 over China, *Adv. Atmos. Sci.*, *22*, 58–68.

Zhou, L., R. K. Kaufmann, Y. Tian, R. B. Myneni, and C. J. Tucker (2003), Relation between interannual variations in satellite measures of northern forest greenness and climate between 1982 and 1999, *J. Geophys. Res.*, *108*(D1), 4004, doi:10.1029/2002JD002510.

M. Kafatos and D. Sun, Center for Earth Observing and Space Research, George Mason University, Fairfax, VA 22030, USA. (dsun@gmu.edu)

R. T. Pinker, Department of Atmospheric and Oceanic Science, University of Maryland, College Park, MD 20742, USA.