in locales, including Honolulu and Washington's Yakima River Basin.

At the briefing, USGS also announced the release of 15 studies on the health of major U.S. river basins, bringing the total number of NAWQA regional studies issued to 51. The program, which began in earnest in 1991, originally had a goal of completing 60 studies during its first decade, though that number later was reduced to 51. During its second decade, the program is budgeted to complete just 42 follow-up studies at a "decreasing intensity of work," Miller noted. He said the program, funded at about $62 million annually, is 30–40% below its operating level in the early- to mid-1990s due to inflation. The Bush administration has proposed level funding for FY2005.

For more information, visit the Web site: http://water.usgs.gov/nawqa/.

—RANDY SHOWSTACK, Staff Writer

GEOPHYSICISTS

The following AGU members have been elected as members of the National Academy of Sciences in recognition of their distinguished and continuing achievements in original research.

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Donald V. Helmberger is the Smits Family Professor of Geophysics and Planetary Science at the California Institute of Technology, Pasadena. He is an AGU Fellow and has been a member (Seismology) since 1985.

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FORUM

Assessing "Global Warming" with Surface Heat Content

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Although climate change and variability involves all aspects of the climate system [*Pielke*, 1998], the assessment of anthropogenically-forced climate change has focused on surface temperature as the primary metric [*Mann and Jones*, 2003; *Soon et al.*, 2004]. Our contribution only addresses this very specific (and limited) metric of the climate system. The term "global warming" has been used to describe the observed surface air temperature increase in the 20th century. However, this concept of "global warming" requires assessments of units of heat (that is, Joules). Temperature, by itself, is an incomplete characterization of surface air heat content.

Pielke [2003] used the concept of heat changes in the ocean, for example, to diagnose the radiative imbalance of the Earth's climate system. The oceans, of course, are the component of the climate system in which the vast majority of actual global warming or cooling occurs. In this contribution, we use the more limited application of the term "global warming" to refer to surface air changes.

The heat content of surface air (i.e., z right above ground level, so that z = 0 can be assumed) can be expressed as:

$$H = C_p T + L q$$

where C_p is the specific heat of air at constant pressure, T is the air temperature, L is the latent heat of vaporization, and q is the specific humidity [*Haltiner and Williams*, 1980]. The quantity, H, is called moist static energy and can be expressed in units of Joules kg^{-1}. The surface dry static energy can be written as

$$S = C_p T.$$

Surface air temperature trends that have been reported monitor S. The monitoring of H, however, is the more appropriate metric to assess surface global warming.

To investigate the effect of monitoring variations of H in time, we have calculated both H and S for the year 2002 in Fort Collins, Colorado, and at the Central Plains Experimental Range (CPER) of the U.S. Department of Agriculture's Agricultural Research Service located 60 km northeast of the city (Figure 1). Both locations offer high-quality temperature and humidity observations. The Fort Collins site is on a university campus with nearby buildings, parking lots, and irrigated grass, while the CPER site is an ungrazed natural grass area. To facilitate the comparison with temperature, we calculated an effective temperature as

$$T_E = H/C_p.$$

As shown by *Pielke* [2001], in terms of heat content, at 1000 mb, an increase of 1°C in the dewpoint temperature produces the same change in H as a 2.5°C increase in temperature. This means, for example, that a decrease of 1°C of the dewpoint temperature, but a 1°C increase in the temperature, actually is a reduction of heat content in terms of Joules kg^{-1} of the air!

The plots of T and T_E (with the corresponding values of H and S on the right axis) for 2002 illustrate that when the absolute humidity is low (such as on cold winter days), T and T_E are nearly equal. However, there are large differences in these values in the growing season when the absolute humidity is higher. Dry days, however, have less heat content than more humid days with the same air temperature.

The average differences of the annual averaged maximum and minimum temperature for the two sites for dates where data was available from both locations (the value at Fort Collins minus the value at the CPER site) are 0.25°C and 1.86°C, respectively. The differences in T_E, however, are larger (2.69°C and 4.20°C).

For the growing season part of 2002, the differences in the average maximum and minimum value of T were 0.91°C and 1.82°C, while the corresponding values of T_E were 3.48°C and 4.96°C. The value of T_E provides a more accurate characterization of surface heat content and is the more appropriate metric for assessing surface global warming.

The different variation of H, as contrasted with S, as a function of land use could help explain the results reported in *Kalnay and Cai* [2003], in which they concluded that land use change could explain at least part of the

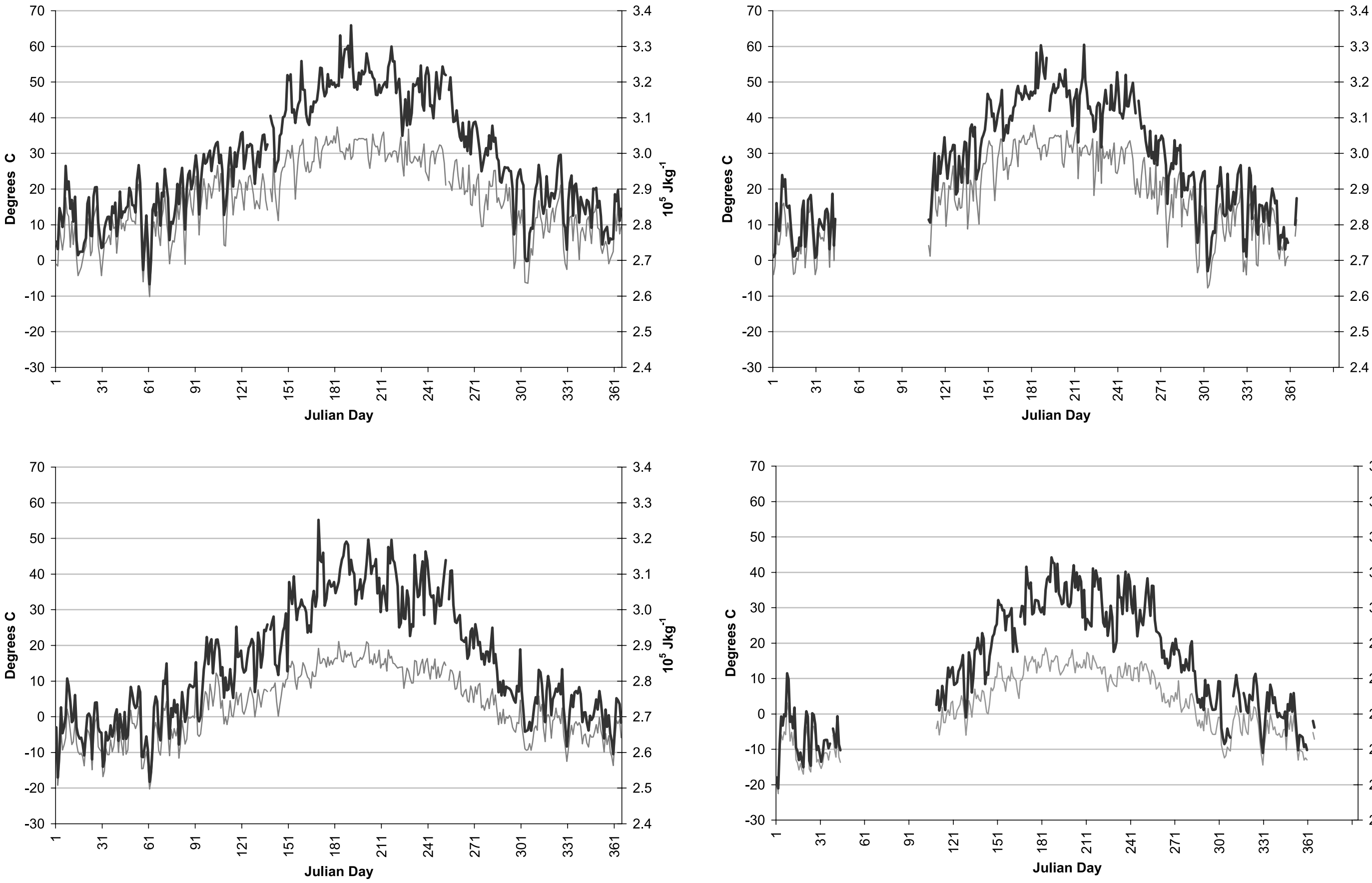

Fig. 1. T and T_E in °C (S and H, in 10_5 J kg^{-1}) for Fort Collins, Colorado, (left panels) and the CPER ungrazed site (right panels) are shown for 2002. The top two panels are for maximum daily temperature while the bottom two panels are for minimum daily temperature. The grey lines represent T (and S) while the black lines represent T_E (and H).

observed temperature changes in the eastern United States in recent decades. The difference in temporal trends in surface and tropospheric temperatures [*National Research Council*, 2000], which has not yet been explained, could be due to the incomplete analysis of the surface and troposphere for temperature, and not the more appropriate metric of heat content. Recent analyses of satellite data have reduced the differences, but have not eliminated the disagreement [*Christy et al.*, 2003; *Mears et al.*, 2003].

Surface air temperature alone does not capture the real changes in surface air heat content of the Earth system. Even using the limited definition of the term "global warming," the moisture content of the surface air must be included. Future assessments should include trends and variability of surface heat content in addition to temperature.

References

Christy, J. R., R. W. Spencer, W. B. Norris. W. D. Braswell, and D. E. Parker (2003), Error estimates of Version 5.0 of MSU/AMSU bulk atmospheric temperatures, *J. Atmos Oceanic Tech., 20*, 613–629.

Haltiner, G. J., and R. T. Williams (1980), *Numerical Prediction and Dynamic Meteorology. 2nd Edition*, 477 pp., John Wiley and Sons, New York.

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

Mann, M. E., and P. D. Jones (2003), Global surface temperatures over the past two millennia, *Geophys. Res. Lett., 30(15)*, 1820, doi:10.1029/2003GRL017814.

Mears, C. A., M. C. Schabel, and F. J. Wentz (2003), A reanalysis of the MSU channel 2 tropospheric temperature record, *J. Clim., 16*, 3650–3664.

National Research Council (2000), Reconciling observations of global temperature change. Panel on Reconciling Temperature Observations, Climate Research Committee, Board on Atmospheric Sciences and Climate, 104 pp., National Academy Press, Washington, D.C.

Pielke, R. A. (1998), Climate prediction as an initial value problem, *Bull. Am. Meteorol. Soc., 79*, 2743–2746.

Pielke Sr., R. A. (2001), Influence of the spatial distribution of vegetation and soils on the prediction of cumulus convective rainfall, *Rev. Geophys., 39*, 151–177.

Pielke Sr., R. A. (2003), Heat storage within the Earth system, *Bull. Am. Meteorol. Soc., 84*, 331–335.

Soon, W.-H., D. R. Legates, and S. Baliunas (2004), Estimation and representation of long-term (>40 year) trends of Northern Hemisphere-gridded surface temperature: A note of caution, *Geophys. Res. Lett., 31, L03209*, doi:1029/2003GRL019141.

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