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# A 2-YEAR CLIMATOLOGY OF LAND-SURFACE ENERGY FLUXES USING THE ALEXI MODEL


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## 1. INTRODUCTION

Energy and moisture exchange at the earth's surface is a response to the continuous streams of solar and thermal radiation within the earth-atmosphere system. Solar radiation impinging upon the earth's surface provides the necessary energy to evaporate water from the soil and vegetation (latent heat) and also to warm both the atmosphere through sensible heat fluxes and the soil through thermal conduction. Sophisticated models, such as the Atmospheric Land-surface Exchange Inverse (ALEXI) model [Anderson et al. 1997) and Mecikalski et al. (1999)], are capable of providing reasonably accurate estimates of the various components of the energy balance over regional and continental scales with very high horizontal resolution.

The ALEXI model includes a two-source (plant and substrate) land-surface model that couples conditions inside the plant canopy to fluxes from the substrate, plants and atmosphere. Given an estimate of fractional vegetation cover, the two-source model (TSM) partitions the satellite-observed radiometric temperature of a heterogeneous scene into soil and canopy contributions. The TSM has been coupled with a simple model of atmospheric boundary layer (ABL) development (McNaughton and Spriggs 1986) so that near-surface air temperatures are simulated and consistent with modeled fluxes.

Lower boundary conditions for ALEXI are provided by GOES thermal infrared observations taken at two times during the morning. The use of time-differential surface radiometric temperature measurements reduces the model sensitivity to errors in absolute temperature due to sensor calibration and surface emissivity corrections. The ABL model relates the increase in air temperature above the canopy and the resulting growth of the ABL to the time-integrated flux of sensible heating from the surface. GOES-derived downwelling shortwave and longwave radiation and TSM-modeled upwelling shortwave and longwave radiation are used to estimate the net radiation. Following Norman et al. (2000), the soil heat flux is related to the net radiation just above the soil surface. This information, along with a system of surface energy equations, is used to estimate other components of the energy balance, such as canopy transpiration and soil evaporation rate. By assuming a constant evaporative fraction, hourly meteorological data such as satellite-estimated cloud fraction cover can also be used by ALEXI to generate daily-integrated fluxes.

The ALEXI model has been used to generate high-resolution (10-km) maps of surface energy fluxes (such as sensible, latent and ground heat fluxes), land surface characteristics (such as leaf area index and fractional vegetation cover), and hydrological conditions (such as potential evapotranspiration (PET) and available water fraction) across the continental United States nearly continuously since April 2002. Such an extensive climatology allows us to examine seasonal flux variations across different regions and land surface types as well as to examine intraseasonal and interannual changes in vegetation characteristics and energy and water fluxes across regions characterized by extreme hydrological conditions. In this paper, we present a preliminary comparison of vegetation characteristics and modeled energy fluxes for two regions that experienced both drought and excessively wet conditions during different portions of this climatology.

## 2. RESULTS

### *2.1 Southeastern United States*

Abnormally dry conditions prevailed across a large portion of the southeastern United States during April 2002. Monthly rainfall across much of this region was generally less than 125 mm with


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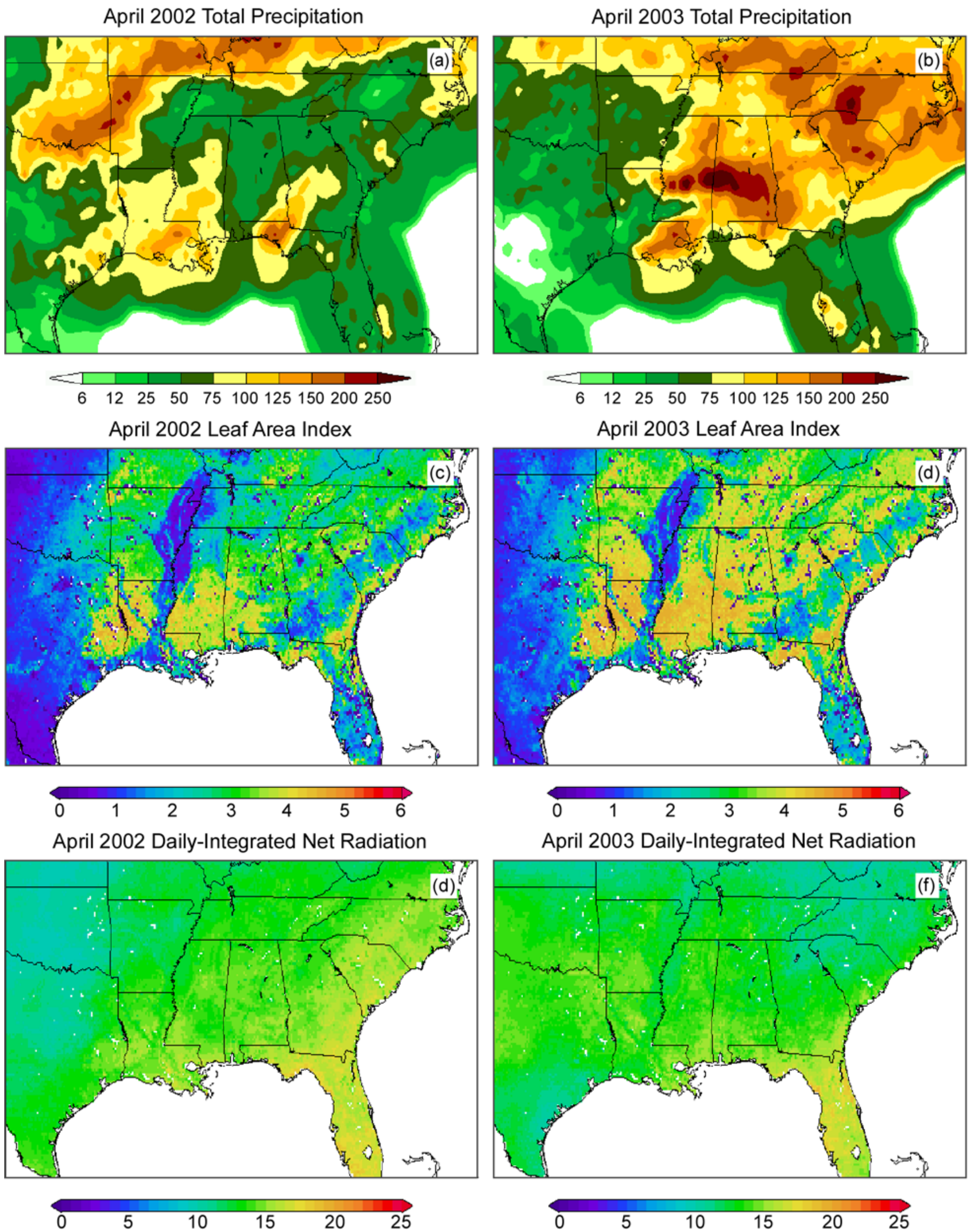


Figure 1. (a) Total precipitation for April 2002. (b) Same as (a) except for April 2003. (c) Average leaf area index for April 2002. (d) Same as (c) except for April 2003. (e) Daily-integrated net radiation (MJ $m^{-2}$) for April 2002. (f) Same as (e) except for April 2003.

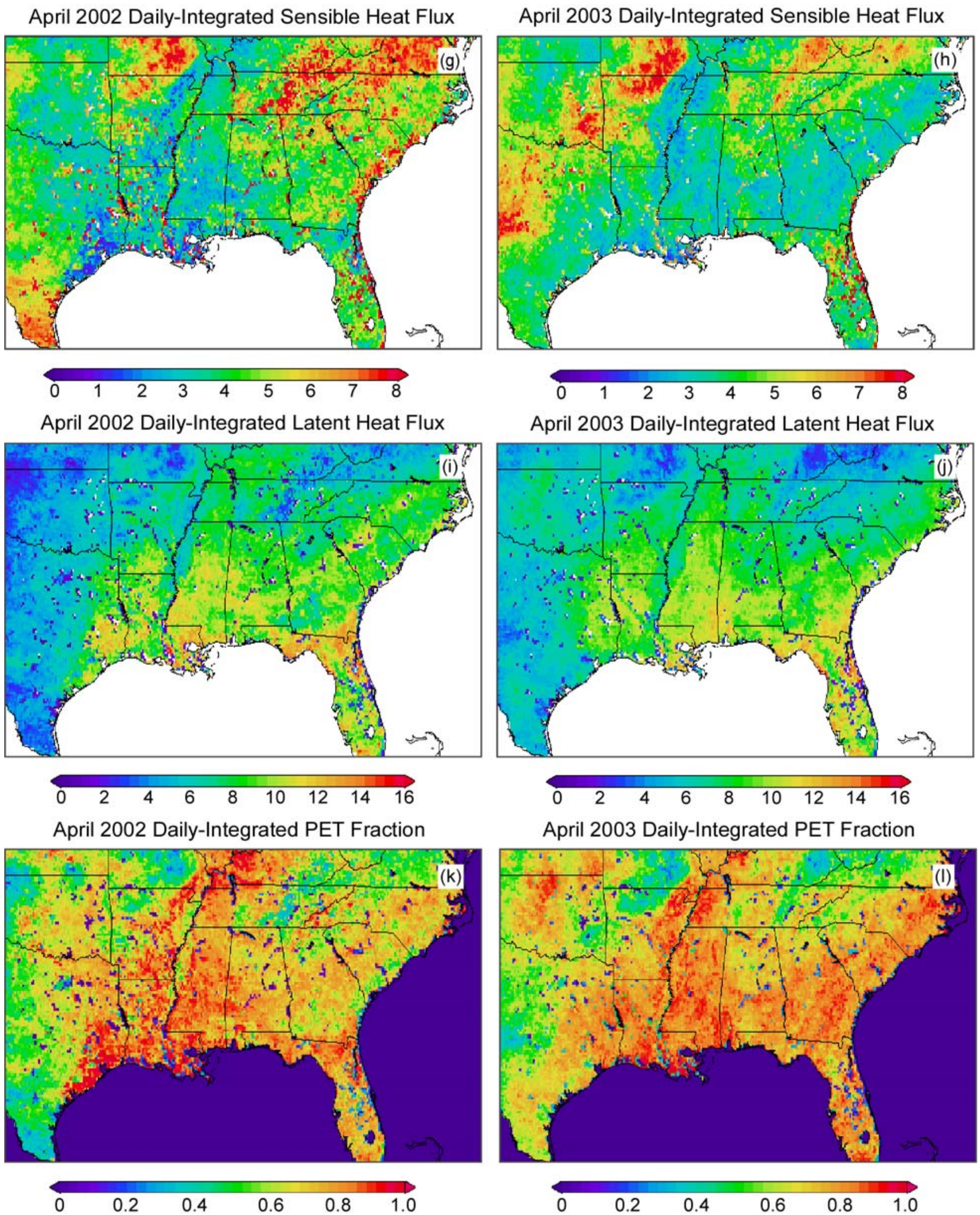


Figure 1, continued. (g) Daily-integrated sensible heat flux (MJ $m^{-2}$) for April 2002. (h) Same as (g) except for April 2003. (i) Daily-integrated latent heat flux (MJ $m^{-2}$) for April 2002. (j) Same as (i) except for April 2003. (k) Fraction (%) of daily-integrated potential evapotranspiration for April 2002. (l) Same as (k) except for April 2003.

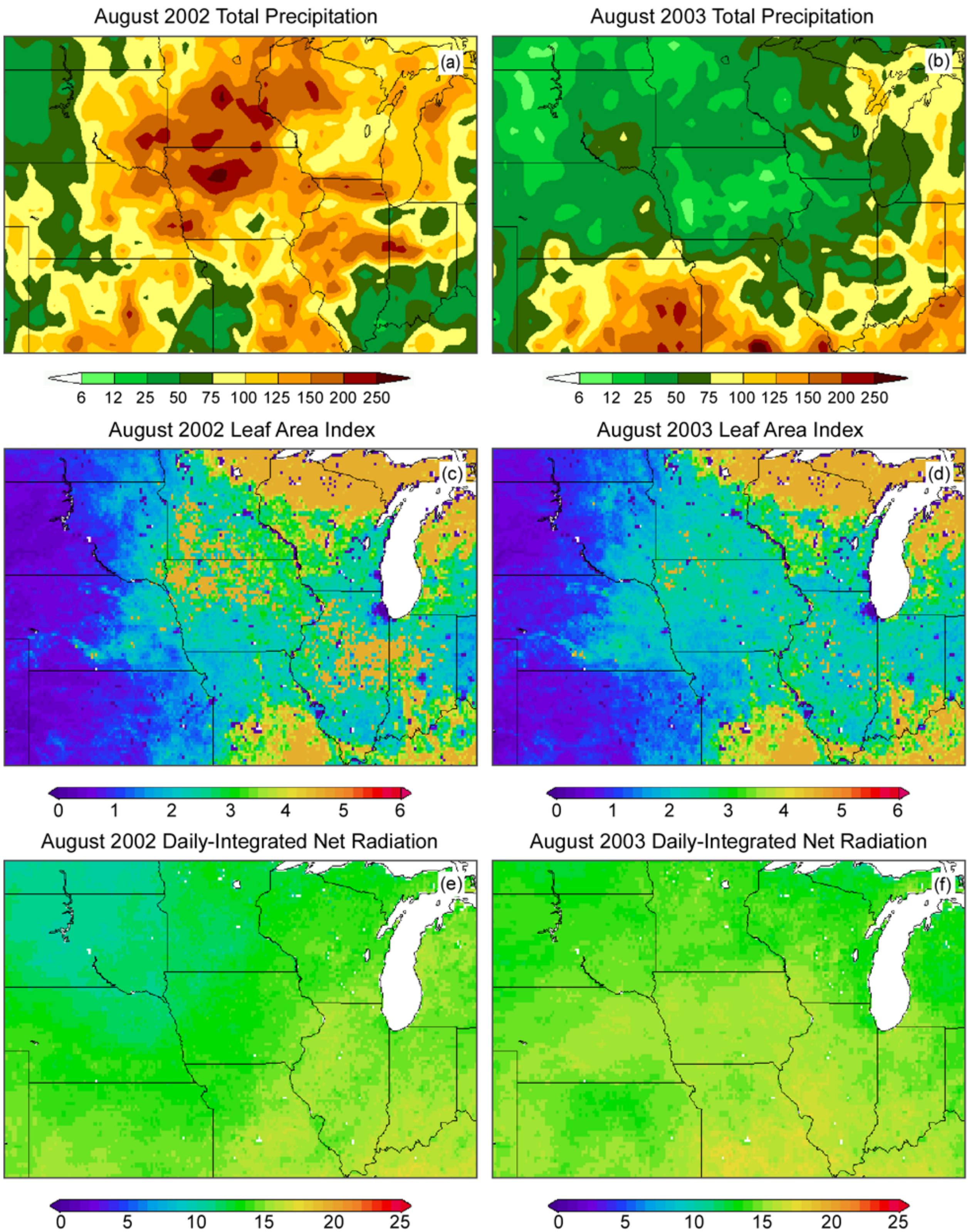


Figure 2. (a) Total precipitation for August 2002. (b) Same as (a) except for August 2003. (c) Average leaf area index for August 2002. (d) Same as (c) except for August 2003. (e) Daily-integrated net radiation (MJ $m^{-2}$) for August 2002. (f) Same as (e) except for August 2003.

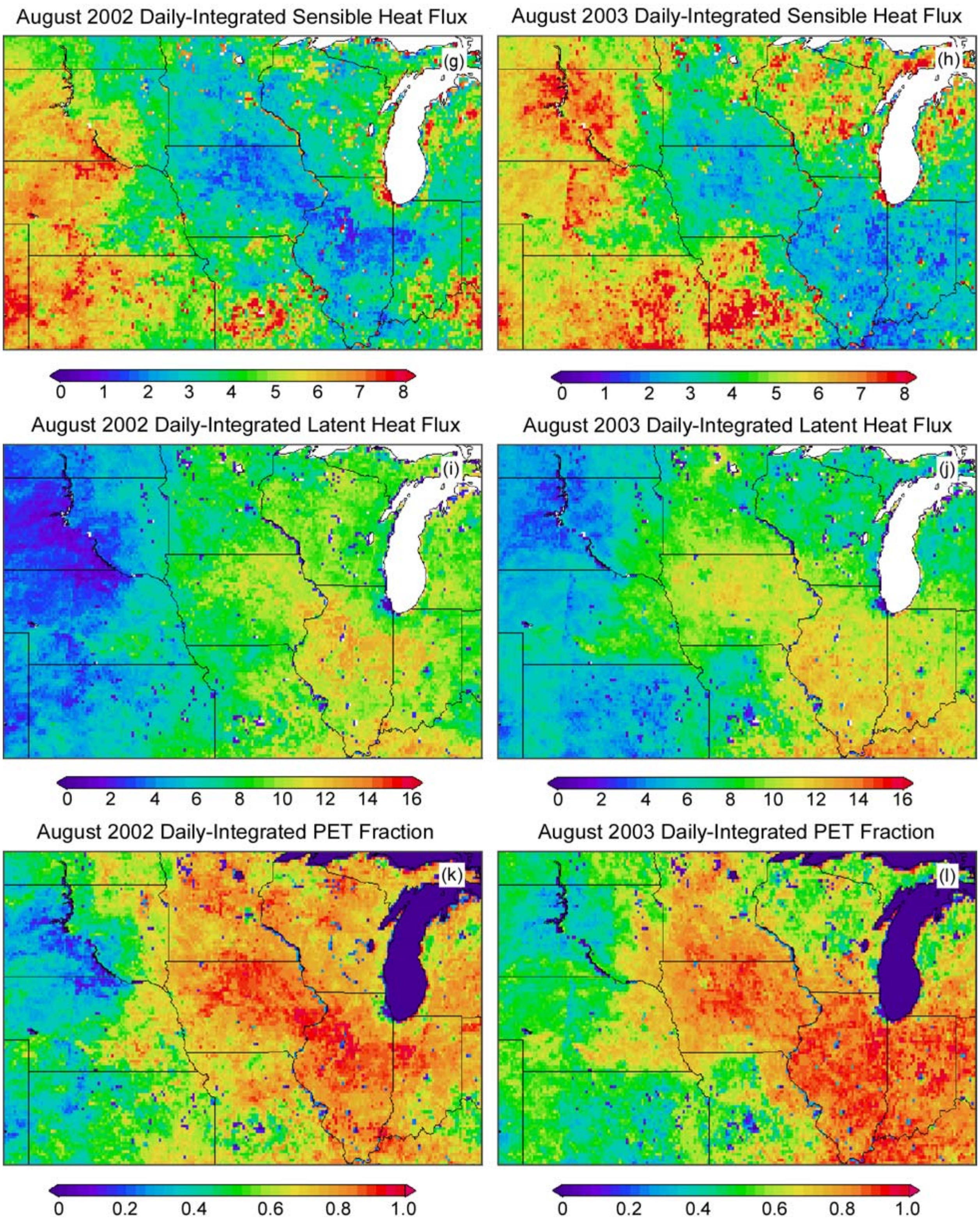


Figure 2, continued. (g) Daily-integrated sensible heat flux (MJ m$^{-2}$) for August 2002. (h) Same as (g) except for August 2003. (i) Daily-integrated latent heat flux (MJ m$^{-2}$) for August 2002. (j) Same as (i) except for August 2003. (k) Fraction (%) of daily-integrated potential evapotranspiration for August 2002. (l) Same as (k) except for August 2003.

some areas receiving less than 75 mm (Fig. 1a). Drought conditions were particularly severe across the Carolinas and eastern Georgia, where substantial long-term precipitation deficits (> 250 mm) had developed during the preceding 12-month period. Above normal precipitation during the subsequent fall and winter, however, led to the development of very moist conditions by April 2003. With monthly precipitation totals in excess of 100 mm (Fig. 1b), many of the same regions that had experienced severe drought conditions during April 2002 were now characterized by excessively wet conditions. Favorable growing conditions during April 2003 were accompanied by a dramatic increase in the leaf area index (LAI; Fig. 1d). Although a portion of the increased plant matter appears to be associated with an earlier arrival of spring, it is also likely that the lower LAI during April 2002 (Fig. 1c) simply illustrates the adverse effect of the prolonged drought on plant development.

Sunny conditions during April 2002 greatly increased the net radiation and sensible heat flux (Figs. 1e, 1g) at the surface. Although drier conditions generally decrease the latent heat flux, it is apparent that similar moisture fluxes occurred during each month (Figs. 1i, 1j). It is likely that the increased net radiation, rather than the availability of soil moisture for evaporation, is the primary reason for the relatively high latent heat flux during April 2002.

In order to identify the presence of moisture-related stress, the average fractional PET was calculated for each month. The fractional PET, defined as the actual evapotranspiration divided by the PET, provides a clear estimate of plant stress because it normalizes out differences in evapotranspiration due to differences in net radiation (the PET decreases under cloudy conditions). Low fractional PET values indicate that evapotranspiration is not occurring at the maximum rate, which suggests that plants are experiencing moisture-related stress. Comparison of Figs. 1k and 1l clearly demonstrates that the vegetation was suffering from moisture-related stress during April 2002, which indicates that ALEXI is able to accurately depict drought-induced variations in evapotranspiration.

### *2.2 Midwestern United States*

Short-term rainfall deficits can severely impact grain yields if they occur during a sensitive stage of plant development. August is an especially important period across the Midwestern Corn Belt because sufficient rainfall is necessary both for pollination and the subsequent maturation of the corn crop. Adequate rainfall throughout the summer of 2002, including over 100 mm during August (Fig. 2a), contributed to excellent corn yields across the Midwest. Corn yields were lower during 2003, however, due to the development of drought conditions late in the summer (Fig 2b). The effect of this late-season dry spell on plant development is illustrated by the much lower LAI from western Minnesota into northern Indiana (Fig 2d). The drought-induced deterioration of the vegetation is most evident across eastern Iowa and Illinois, where the LAI is up to 40% lower than the LAI during August 2002. The daily-integrated latent heat flux (Fig. 2j) remained high during this dry spell due to the higher net radiation (Fig. 2f). Although the fractional PET also remained high, minor moisture-related stress is evident across the region, most notably in eastern IA. Since this dry spell continued to worsen as the month progressed, a more detailed daily or weekly analysis would likely reveal greater moisture-related stress than indicated by the monthly average.

## 3. CONCLUSIONS

In this study, we presented a comparison of vegetation characteristics and modeled energy fluxes for two regions that experienced both drought and excessively wet conditions. Our analysis revealed that both regions experienced an increase in net radiation and moisture-related stress (as measured by the fractional PET) and a decrease in the LAI during severe drought conditions. These energy and vegetation characteristics indicate that ALEXI is able to accurately depict drought-induced variations in plant health and the energy budget.


## 4. ACKNOWLEDGEMENTS

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