Conf-940131--2

PARAMETERIZING ATMOSPHERE-LAND SURFACE EXCHANGE FOR CLIMATE MODELS WITH SATELLITE DATA: A CASE STUDY FOR THE SOUTHERN GREAT PLAINS CART SITE

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For
Fifth Conference on Global Change Studies
23-28 January 1994, Nashville, Tennessee

The work was supported by the U.S. Department of Energy, Office of Energy Research, Office of Health and Environmental Research, under contract W-31-109-ENG-38.

ANL/ER/CP-80788

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1. INTRODUCTION

The exchange of momentum, heat, water vapor, and trace gases between the lower atmosphere and land surfaces is ultimately governed by near-surface, small-scale processes, but global climate models can simulate processes only over much larger scales. Thus, parameterization to scale up atmosphere-land surface exchange fluxes is necessary to improve model capabilities for incorporating subgrid land surface processes. However, because of large spatial and temporal variations in topography, soils, vegetation, cloud cover, and radiation, the integration or parameterization is not straightforward.

Land surface parameterization schemes developed for use in global climate models (GCMs) include the Biosphere Atmosphere Transfer Scheme (BATS) (Dickinson, 1984) and the Simple Biosphere Model (SiB) (Sellers et al., 1986), which consider the vertical structure of the canopy but often assume constant horizontal distribution within a grid cell. Other schemes were proposed to include fractional areas and statistical distributions in parameterizing land surface heterogeneities in large scale models (Abramopoulos et al., 1988; Entekhabi and Eagleson, 1989; Avissar, 1992).

High-resolution satellite data provide detailed, quantitative descriptions of land surface characteristics over large areas so that objective scale linkage becomes feasible. With the aid of satellite data, Sellers et al. (1992) and Wood and Lakshmi (1993) examined the linearity of processes scaled up from 30 m to 15 km. If the phenomenon is scale invariant, then the aggregated value of a function or flux is equivalent to the function computed from aggregated values of controlling variables. The linear relation may be realistic for limited land areas having no large surface contrasts to cause significant horizontal exchange. However, for areas with sharp surface contrasts, horizontal exchange and different dynamics in the atmospheric boundary may induce nonlinear interactions, such as at interfaces of land-water, forest-farm land (Avissar and Pielke, 1989), and irrigated crops-desert steppe (Coulter et al., 1992). The linear approach, however, represents the simplest scenario, and is useful for developing an effective scheme for incorporating subgrid land surface processes into large-scale models.

Our studies focus on coupling satellite data and ground measurements with a satellite-data-driven land surface model to parameterize surface fluxes for large-scale climate models. In this case study, we used surface spectral reflectance data from satellite remote sensing to characterize spatial and temporal changes in vegetation and associated surface parameters in an area of about 350 x 400 km covering the southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site of the U. S. Department of Energy's Atmospheric Radiation Measurement (ARM) Program.

2. CHARACTERIZING SEASONAL AND SPATIAL VARIATIONS OF VEGETATION CONDITIONS AT THE SGP CART SITE WITH SATELLITE DATA

Because a green leaf strongly absorbs incident radiation of wavelength 0.4-0.7 μm and reflects and transmits most incident radiation of wavelength 0.7-1.1 μm, indices measuring the contrast in spectral reflectances in the red and near-infrared channels of satellite data can be used, in combination with a canopy radiation transfer model, to determine the amount of green leaf area. One of the most commonly used indices is the normalized difference vegetation index (NDVI), which is defined as the difference between the reflectances in near-infrared and red bands normalized by their sum. The biweekly average NDVI data derived from the red channel (channel 1) and the near-infrared channel (channel 2) of the Advanced Very High Resolution Radiometer (AVHRR) on NOAA satellites are used in this study. The data were processed by Gallo (1992) to correct for cloud and sun angle effects, with resolution reduced from 1.1 km to about 15 km. The images were extracted for the 350 x 400 km CART area, within which several large subregions have different predominant land uses (Figure 1), as determined with Landsat 5 images (Policastro et al., 1992). The large differences in land use should enhance spatial and seasonal variabilities of vegetation conditions in the area.

The NDVI images extracted for the CART area for different months of 1991 are shown in Figure 2. According to the land use types shown in Figure 1, the elongated area from the southwest corner to the upper middle boundary consists primarily of crops (mostly winter wheat); the northeast quadrant and the west side are primarily rangeland; the northwest quadrant is crops mixed with rangeland; and the southeast quadrant is wooded land mixed with rangeland. In January, the NDVI data plotted in

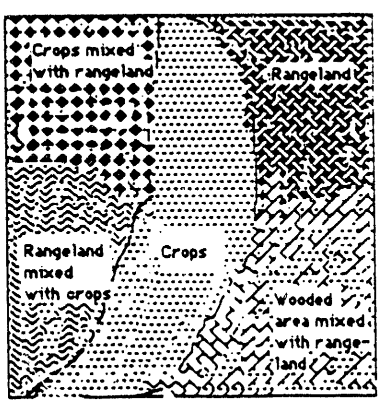

Figure 1. Land use types in the southern Great Plains CART site.

Figure 2 show relatively large values for the areas with winter wheat and low values for the areas with grass and trees, as is expected for the climate in the area. As the seasons progress, the NDVI for the crop areas gradually increases, indicating an increase in the size of crop canopies, and the NDVI values for the southeast wooded area increase to a similar level by April when the trees in the area became greener. The grasslands in the northeast quadrant and near the west boundary turn green much later than other areas. By June, the NDVI values for the crop belt decrease sharply, as winter wheat matures and harvesting begins, while the east side of the area is still occupied by green vegetation. (The lower NDVI for the western rangeland could be caused by the difference in moisture conditions between the west and east sides.) The green cover in the wooded area in the southeast lasts longest.

3. MODELING SURFACE PARAMETERS FROM THE SATELLITE DATA

To include spatial variations of vegetation conditions in modeling atmosphere-land surface exchange processes, we incorporated the AVHRR data into a satellite-data-driven land surface model (SATMOD) to derive the spatial distribution of surface parameters essential to surface fluxes. SATMOD uses a canopy bidirectional reflectance submodel (Gao, 1993a, 1993b) to improve coupling of the land surface model with satellite data, which are strongly influenced by the satellite's viewing geometry. The bidirectional reflectance submodel is used to estimate the canopy leaf area index (LAI) and canopy spherical reflectance (albedo) from directional surface reflectances remotely sensed by satellites. By linking canopy radiation transfer with mass transfer processes at leaf level, the SATMOD is able to integrate leaf resistances and fluxes from individual leaves to the full canopy according to the radiation distribution within the canopy and the total canopy LAI estimated from satellite data.

Figure 3 compares modeled albedo to measurements taken at a tallgrass prairie in Kansas during the First International Satellite Land Surface Climatology Project (ISLSCP) Field Experiment (FIFE). In this calculation, the

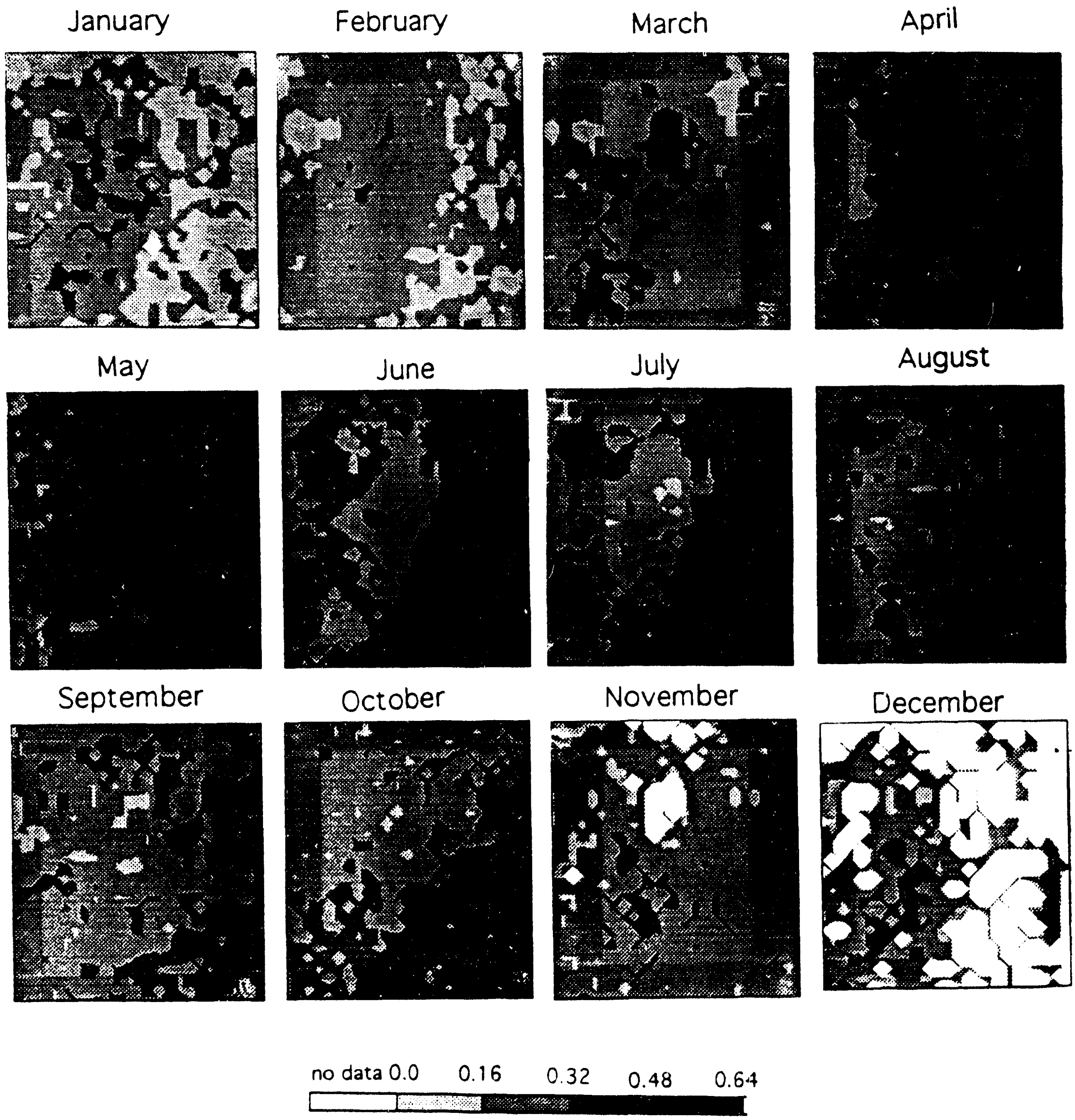

Figure 2. Average NDVI data from NOAA AVHRR, extracted for the CART area of about 350 x 400 km for different months of 1991. The data were processed by Gallo (1992), who used biweekly and spatial averaging to correct for effects of cloud and solar angle, with resolution reduced from 1.1 km to about 15 km.

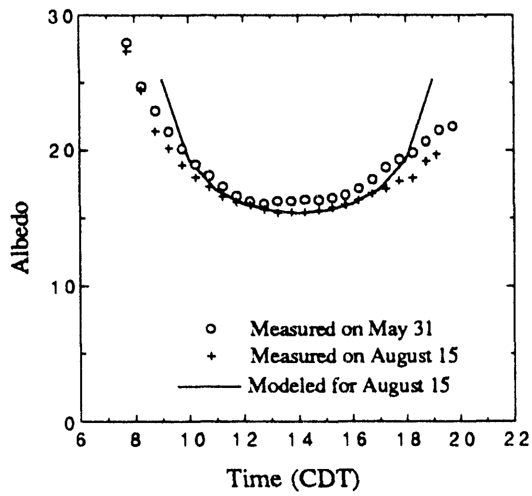

Figure 3. Modeled and measured surface albedo for the tallgrass prairie in Kansas during the First International Satellite Land Surface Climatology Project (ISLSCP) Field Experiment (FIFE) in 1987.

spectral data from Landsat 5 and SPOT 1 and the measured leaf scattering factors in the range of 0.3-3.0 μm were used. We also used the SATMOD to calculate albedo for the SGP CART site with the NDVI data shown in Figure 2. In the model computation we assumed a near-nadir viewing angle and a small solar zenith angle. However, the processed AVHRR data are composed from data acquired over a range of

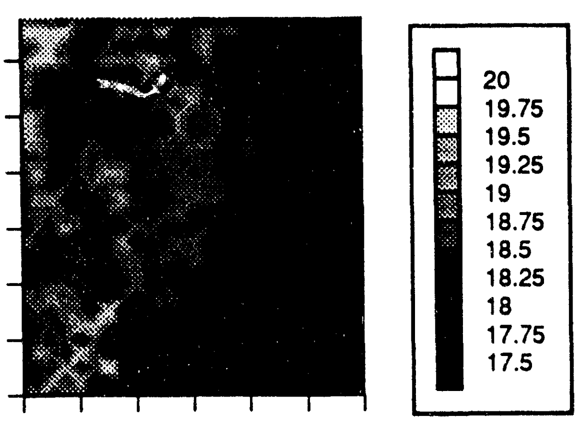

Figure 4. Surface albedo for the 350 x 400 km CART site, modeled with the SATMOD for July 1991 with assumed leaf scattering factors and the NDVI data in Figure 2.

viewing and solar angles. This difference may cause some uncertainty in modeling results. This uncertainty, however, should be minimized when real-time data with precise information about satellite viewing geometry are used.

Values of surface albedo over the CART site modeled for July are shown in Figure 4, in which the spatial variation in albedo is primarily caused by the change in canopy NDVI values. The modeled albedo image, however, presents a preliminary result and should be examined with caution because several uncertainties must be quantified. For example, different radiation transfer submodels could be used for different canopy types in the area. In particular, forest canopies can have a much smaller NDVI value than short grass and crop canopies for the same level of LAI. Thus, the albedo for the forest area in the southeast quadrant is expected to be even smaller.

Figure 5 compares modeled canopy stomatal conductance (g_c) to measurements at the tallgrass prairie during FIFE. A similar approach was used to compute g_c for the CART site (Figure 6), but downward radiation was assumed to be the same for each pixel, and water stress effects were excluded. The modeled unstressed g_c primarily reflects the vegetation change in the area. To derive more realistic

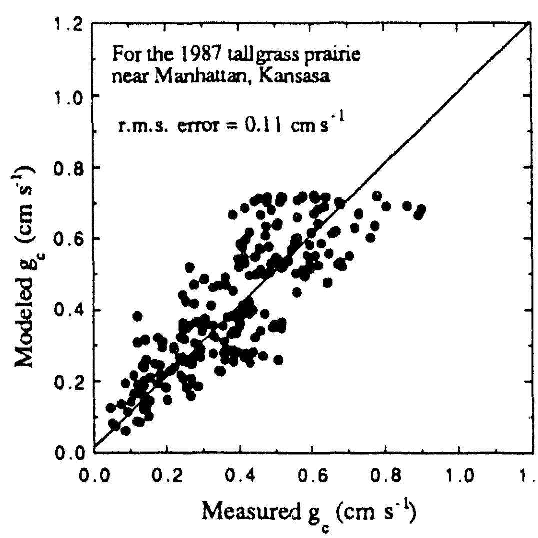

Figure 5. Modeled and measured canopy stomatal conductance (g_c) for the tallgrass prairie in Kansas during FIFE in 1987.

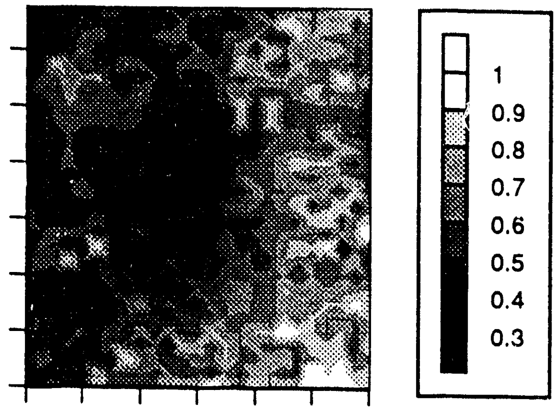

Figure 6. Unstressed canopy stomatal conductance for the 350 x 400 km CART site in July 1991, modeled with the NDVI values in Figure 2 and assumed, uniformly distributed values of mete-orological parameters.

spatial distributions of canopy stomatal conductance, the data on the spatial distribution in soil moisture content, incident solar radiation, etc., need to be incorporated. The data on the surface moisture condition could be derived from the combination of AVHRR thermal data with a simple soil hydrological model; the data on the spatial distribution of incoming radiation could be obtained from distributed ground stations and other satellite data. The initial results presented here, however, allow us to examine the spatial variability in surface parameters caused by vegetation changes in the CART site.

4. CONCLUSION

The spatial and seasonal variations in vegetation conditions in the SGP CART site were described by using surface spectral reflectance data from satellite remote sensing. By coupling these data into a land surface model driven by satellite data, we simulated spatial variation in surface parameters essential for estimating surface fluxes. With surface meteorological data and additional satellite data on radiation and cloud measurements, the SATMOD can be used to parameterize subgrid-scale surface fluxes for input to large-scale atmospheric models.

5. ACKNOWLEDGMENT

The work was supported by the U.S. Department of Energy, Office of Energy Research, Office of Health and Environmental Research, under contract W-31-109-ENG-38.

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