0.00001 [*Frankel et al.*, 2000]. Only three sets of hazard maps, with 10%, 5%, and 2% PE in 50 years, were published, however. The three maps represent only three specific points on the hazard curves. All other points on the curves would also be equally valid choices. Having so many choices from PSHA makes it difficult for users and policy-makers to scientifically choose one.

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Author Information

Zhenming Wang, Edward W. Woolery, Baoping Shi, and John D. Kiefer

For additional information, contact Zhenming Wang, Kentucky Geological Survey, 228 Mining and Mineral Resources Building, University of Kentucky, Lexington; E-mail: zmwang@uky.edu

Satellite Data Help Predict Terrestrial Carbon Sinks

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Accurate estimates of how much CO_2 ecosystems can absorb will be fundamental to successful systems of international carbon accounting. NASA's Terra satellite platform, with the moderate resolution imaging spectroradiometer (MODIS) instrument on board, provides a new era of observations for carbon cycle assessments. Direct input of satellite vegetation index "greenness" data from the MODIS sensor into ecosystem simulation models can be used to estimate spatial variability in monthly net primary production (NPP), biomass accumulation, and litter fall inputs to soil carbon pools. Global NPP of vegetation can be predicted using the relationship between leaf reflectance properties and the fraction of absorption of photosynthetically active radiation (FPAR) [*Knyazikhin et al.*, 1999].

Predicted net ecosystem production (NEP) flux for atmospheric CO_2 in 2001 was estimated as an annual net sink of +3.6 Pg (1 billion metric tons) of carbon. NEP is computed as NPP minus soil microbial CO_2 fluxes, excluding the effects of small-scale fires and other localized disturbances or vegetation regrowth patterns on carbon fluxes. Our NASA Carnegie-Ames-Stanford Approach (CASA) model results for NEP in 2001 reflect observed climate patterns between and among major continental areas of the terrestrial biosphere (Figure 1). For instance, above-average temperatures were strongly associated with positive NEP (net sink fluxes) across the high-latitude zones of eastern Canada and Eurasia. Positive NEP fluxes were also associated with the heavy rainfall reported in eastern Europe, Siberia, Australia, West Africa, and southern Africa. Negative NEP (net source fluxes) was associated with severe droughts reported in south Asia, eastern Africa, northern China, and northern and eastern coastal South America.

As documented in *Potter* [1999], predicted monthly NPP flux, defined as net fixation of CO_2 by vegetation, is computed in NASA-CASA on the basis of light-use efficiency. Monthly production of plant biomass is estimated as a product of time-varying surface solar irradiance, and FPAR from the MODIS sensor, plus a constant light utilization efficiency term (emax) that is modified by time-varying stress scalar terms for temperature and moisture effects. The NASA-CASA model is designed to couple monthly NPP patterns to soil nutrient mineralization and microbial respiration of CO_2 from soils worldwide. The NASA-CASA soil model uses a set of compartmentalized difference equations with a structure comparable to the CENTURY ecosystem model.

First-order decay equations simulate exchanges of decomposing plant residue (metabolic and structural fractions) at the soil surface.

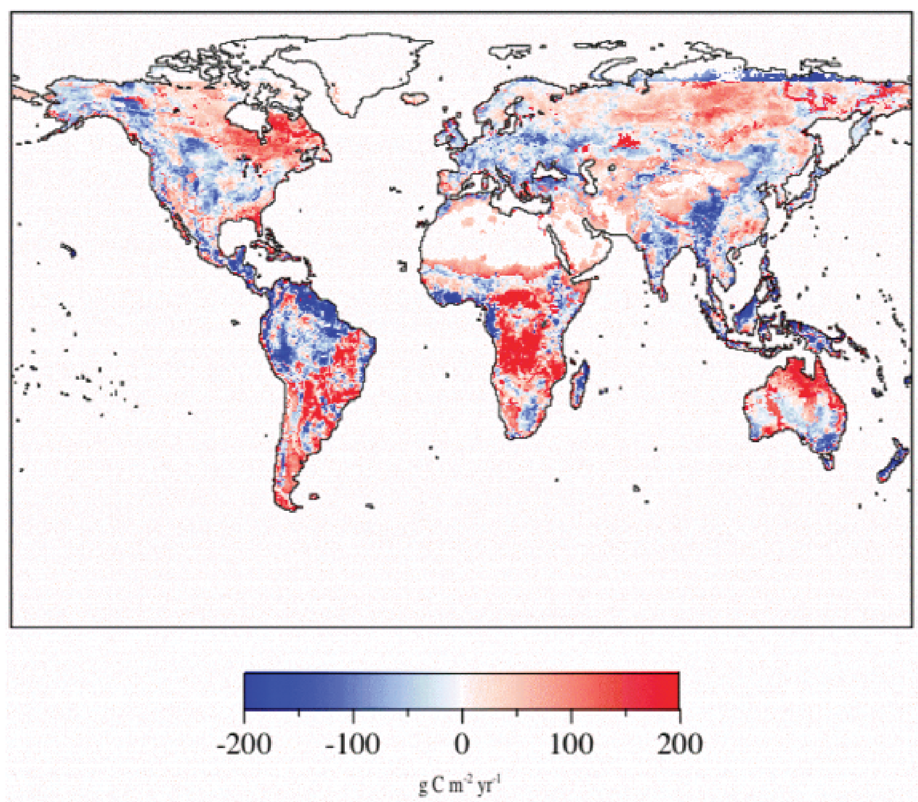

Fig. 1. Predicted global distribution of annual net ecosystem production fluxes in 2001. Net annual source areas are shown in blue, while net annual sink areas are shown in red.

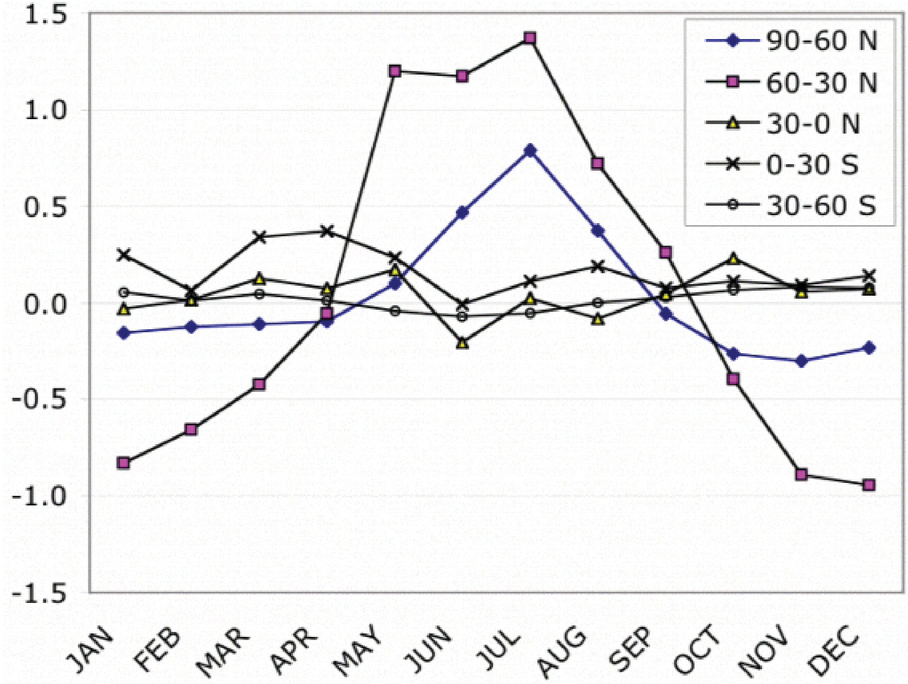

Fig. 2. This graph compares predicted monthly net ecosystem production fluxes in 2001 for 30° latitude zones. Units are Pg C mo^{-1}.

The model also simulates surface soil organic matter (SOM) fractions that vary in age and chemical composition.

Whereas previous versions of the NASA-CASA model [*Potter*, 1999] used a normalized difference vegetation index (NDVI) to estimate FPAR, the current model version instead relies on MODIS canopy radiative transfer algorithms [*Knyazikhin et al.*, 1999], which are designed to generate improved FPAR products as inputs to carbon flux calculations. These radiative transfer algorithms for the MODIS instrument account for attenuation of direct and diffuse incident radiation by solving a three-dimensional formulation of the radiative transfer process in vegetation canopies. Monthly composite data from channels 1 and 2 of the MODIS sensor have been processed and aggregated over the global land surface to 0.5° resolution, consistent with the NASA-CASA climate driver data from NCEP re-analysis products [*Kistler et al.*, 2001].

Predicted terrestrial NPP for the globe in 2001 was estimated at 52.6 Pg C, which is slightly higher than the previous NPP range of between 45 and 51 Pg C/yr for 1982–1998 [*Potter et al.*, 2003]. There was, nevertheless, a marked upward trend predicted in terrestrial NPP beginning in the early 1990s. This is consistent with the NASA MODIS science team's NPP modeling results over the time period of 1982–1999 [*Nemani et al.*, 2003].

Predicted seasonal patterns in NEP were most pronounced for the northern latitude zones between 60° and 30°N, wherein total NEP sink fluxes exceeded +0.5 Pg C per month from May to August, becoming negative (net C source) during all other months except September (Figure 2). The predominantly tropical latitude zones between 30°N and 30°S were far less seasonal in terms of NEP, with monthly total fluxes consistently between -0.5 and +0.5 Pg C year-round.

According to the World Meteorological Organization [*WMO*, 2001], global average surface temperature in 2001 was the third- warmest on record, 0.42°C above the 1961–1990 average. The end of La Niña brought a return of warmer sea surface temperatures to the central and eastern equatorial Pacific in 2001, and was a contributing factor to higher global surface temperature this year. In contrast, cold winter weather affected large areas in central and southern Siberia, northern India, and the Andean region. Heavy rainfall events affected areas of the upper Midwest of the United States, Great Britain, eastern Europe, Siberia, Australia, West Africa, and southeastern Africa. Drought affected central and southern Asia, eastern Africa, northern China, and eastern South America.

The NASA-CASA model result for NEP in 2001 reflects each of these observed climate trends among and within major continental areas of the terrestrial biosphere. In a study of 17 years of NASA-CASA results, *Potter et al.* [2003] demonstrated that temperature warming events are significantly associated with positive NEP (net sink fluxes) in high-latitude tundra, grasslands, and boreal forest areas, whereas major drought events are significantly associated with negative NEP (net source fluxes) in tropical evergreen forests, temperate deciduous forests, croplands, grasslands, and savannas worldwide.

Using MODIS land products, numerous relatively small-scale patterns are being identified throughout the world where terrestrial carbon fluxes may vary between net annual sources and sinks from one year to the next. Predictions of NEP for these areas of high interannual variability will require further validation of carbon model estimates, with a focus on both flux algorithm mechanisms and potential scaling errors to the regional level.

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Author Information

Christopher Potter, NASA Ames Research Center, Moffett Field, Calif.; Steven Klooster and Vanessa Genovese, California State University-Monterey Bay, Seaside; and Ranga Myneni, Boston University, Mass. For additional information, contact Christopher Potter; E-mail: cpotter@mail.arc.nasa.gov