LAI (*in situ*, simulated, Landsat-derived, and MODIS): A comparison within an Oak-Hickory Forest Complex in southwestern Virginia, USA.

John S. Iiames, PhD and Ellen Cooter, PhD

U.S. EPA, Office of Research & Development, National Exposure Research Laboratory, Environmental Sciences Division, Research Triangle Park, NC

ABSTRACT

The United States Environmental Protection Agency's Environmental Sciences and Atmospheric Modeling Analysis Divisions are investigating the viability of simulated (i.e., 'modeled') leaf area index (LAI) inputs into various regional and local scale air quality models. Satellite LAI retrievals were generated from *in situ* collected LAI then regressed against Landsat ETM+ normalized difference vegetation index (NDVI) values at a 30 m spatial scale. This LAI surface map was then aggregated to 990 m to compare this product to the National Aeronautics Space Administration (NASA) 1 km Moderate Resolution Imaging Spectroradiometer (MODIS) MOD15A2 8-day composite LAI product. Next, LAI results from the biogeochemical Environmental Policy Integrated Climate (EPIC) model developed by the U.S. Department of Agriculture (USDA) were explored. The EPIC model was designed primarily for managed agricultural field crop ecosystems, but also includes managed woody species that span both xeric and mesic sites (e.g., mesquite, pine, oak, etc.). EPIC site-specific results were calibrated using observations from one oak-hickory site in southwestern Virginia, USA for the year 2002. These results will allow for the comparison to satellite-derived LAI retrievals for 2002 (i.e., MODIS) to detect seasonal patterns of LAI on this site, eventually being tested over a wide range of soil types and forest species. Models such as EPIC are needed for current and future climate applications for which satellite LAI retrievals cannot be performed. One regional climate application, the Community Multiscale Air Quality Model (CMAQ), relies on output from the weather research model (WRF) where LAI is based on deep soil temperature, expected maximum LAI and a fixed seasonal profile. A more detailed temporal and spatial EPIC- and/or MODIS-derived LAI input is likely to improve model estimates of meteorological condition and biogenic emission estimates due to improved spatial and temporal LAI estimates.

Disclaimer: This work is done in support of EPA's Sustainable Healthy Communities Research Program. The U.S. Environmental Protection Agency funded and conducted the research described in this paper. Although this work was reviewed by the EPA and has been approved for publication, it may not necessarily reflect official Agency policy. Mention of any trade names or commercial products does not constitute endorsement or recommendation for use.

LOCATION

The EPA_Fairystone validation site is located in both Henry and Patrick Counties in Virginia (36.771ºN, -80.092ºW), approximately 20.7 km WNW of Martinsville, Virginia (Figure 1). This Blue Ridge eastern foothills site, managed by the Virginia Department of Inland Game and Fisheries, is 409.2 m above mean sea level and is defined by well drained mesic Typic Hapludult soil types. This site is dominated by chestnut oak (> 60.0%), along with black oak, white oak and red maple comprising the dominant overstory. This overstory ranged from a mean minimum and maximum diameter at breast height (dbh) of 20.5 cm and 31.3 cm, respectively. Stocking values ranged from 143.9 trees per hectare (T/H) to 466.7 T/H for the dominant-codominant canopy class. The mean maximum and minimum height of this stand was 14.6 m and 22.1 m, respectively.

METHODS

EPIC-modeled LAI - The EPIC biogeochemical model (v.1102) was used to model forest plot LAI and canopy height for the EPA_Fairystone validation site. EPIC simulates competition among up to 10 different crop or tree species for nutrients, water and light. Here, LAI was simulated for an 80-year old forest plot comprised of chestnut oak, pignut hickory and red maple tree species. Age and height for each species at maturity were estimated from United States Department of Agriculture (USDA) Forest Service (USFS). *In situ* measured stand characteristics (height, diameter, age, stem density) for each species and historical temperature and precipitation were input into the model. Relative humidity, radiation, and wind speed were statistically simulated within EPIC. A soil representation of the Fairystone area was ingested into the model and its characteristics evolved over the simulation period. Plot-level LAI was then computed as the sum of LAI for each competing tree species. Modeled EPIC LAI was then compared within $\pm$1 standard deviation to plot level LAI measured over six 2002 dates (10 April, 30 April, 01 May, 25 June, 08 July, 04 September). *In situ* LAI was estimated from the optical estimation technique integrating measurements from the Tracing Radiation and Architecture of Canopies (TRAC) instrument and digital hemispherical photography (DHP).

MODIS LAI Validation – Plot-level LAI was scaled to the moderate LAI resolution for the MODIS LAI product (1 km² resolution) through the creation of a satellite-derived LAI surface map (LAI-SM). This LAI-SM was derived from: (1) the collection of *in situ* LAI measurements via indirect optical measurements, (2) the correlation of land cover specific LAI estimates with spectral values retrieved from high resolution imagery (30 m), and (3) the aggregation of these 30 m cells to coarser spatial resolutions (e.g., 990 m). Six 1 km² evaluation cells within a 1 km distance from the plot-level data were calculated and compared to the MODIS LAI product (Figure 2). The MOD15A2 8-day LAI product was downloaded from the United States Geologic Survey (USGS) (https://lpdaac.usgs.gov/), and then smoothed using the Savitzky-Golay smooth function in the TimeSat software package. Pixels with low quality flags were assigned with zero weight in the data smoothing process, thus they had no impact in the smoothing function. The MODIS LAI Layers were then re-projected from the sinusoidal grid projection to an Albers Equal-Area Conic projection. Finally, the mean LAI LAI-SM values and variability about the mean ($\pm$1 standard deviation) were then compared to MODIS MOD 15 A2 LAI within $\pm$1 date from the target LAI comparison date (Figure 3).

RESULTS

EPIC-modeled LAI - Plot-level LAI during the growing season dates (June and September) showed a mean LAI of 2.6 and a range of 1.5-3.5. Simulation results show the site is dominated by chestnut oak with LAI values within, or very close to one standard deviation of observed LAI and suggests that EPIC is able to accurately simulate plot level green up and leaf expansion (Figure 4). No conclusion can, however, can be made regarding EPIC's ability to simulate senescence and leaf fall because of a lack of plot-level data.

MODIS LAI Validation – MODIS mean LAI values were consistently higher than LAI-SM values, over twice the LAI-SM value for the June (5.9 [MODIS] vs. 2.5 (LAI-SM]) and May (4.0 [MODIS] vs. 2.0 (LAI-SM]) dates (Figure 5).

FUTURE RESEARCH

EPIC-generated LAI will be estimated over a 12 x 12 km area centered over this research site using forest data extracted from the (1) USFS Forest Inventory and Analysis (FIA) program (forest biometrics), (2) 2000 Shuttle Radar Topography Mission (canopy height), National Landcover Dataset (NLCD) (land-cover), USGS National Gap Analysis Program (forest species types), USDA Natural Resources Conservation Service soil survey (soils), and the National Oceanographic Atmospheric Administration National Climatic Data Center (climatological). EPIC LAI will then be compared to MODIS LAI from the same area.

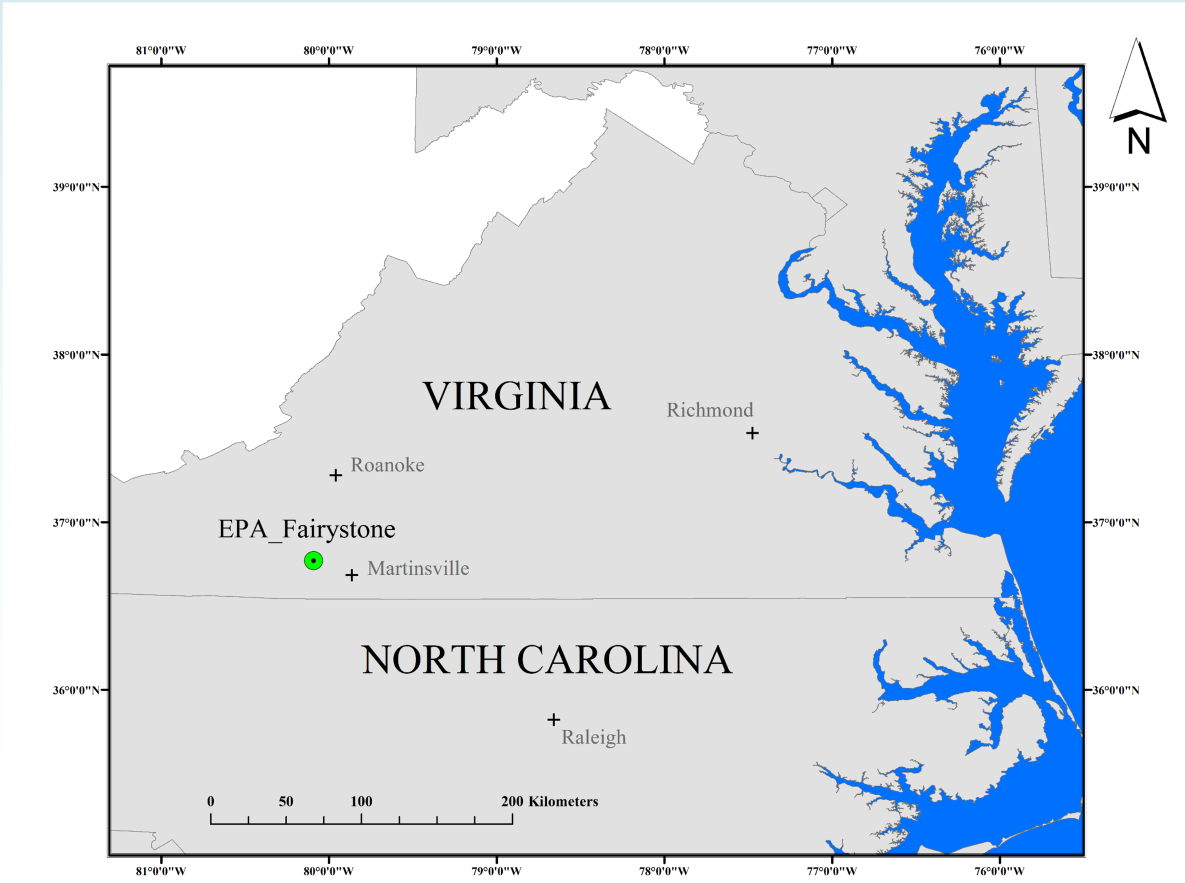

Figure 1. EPA_Fairystone location in southwestern Virginia

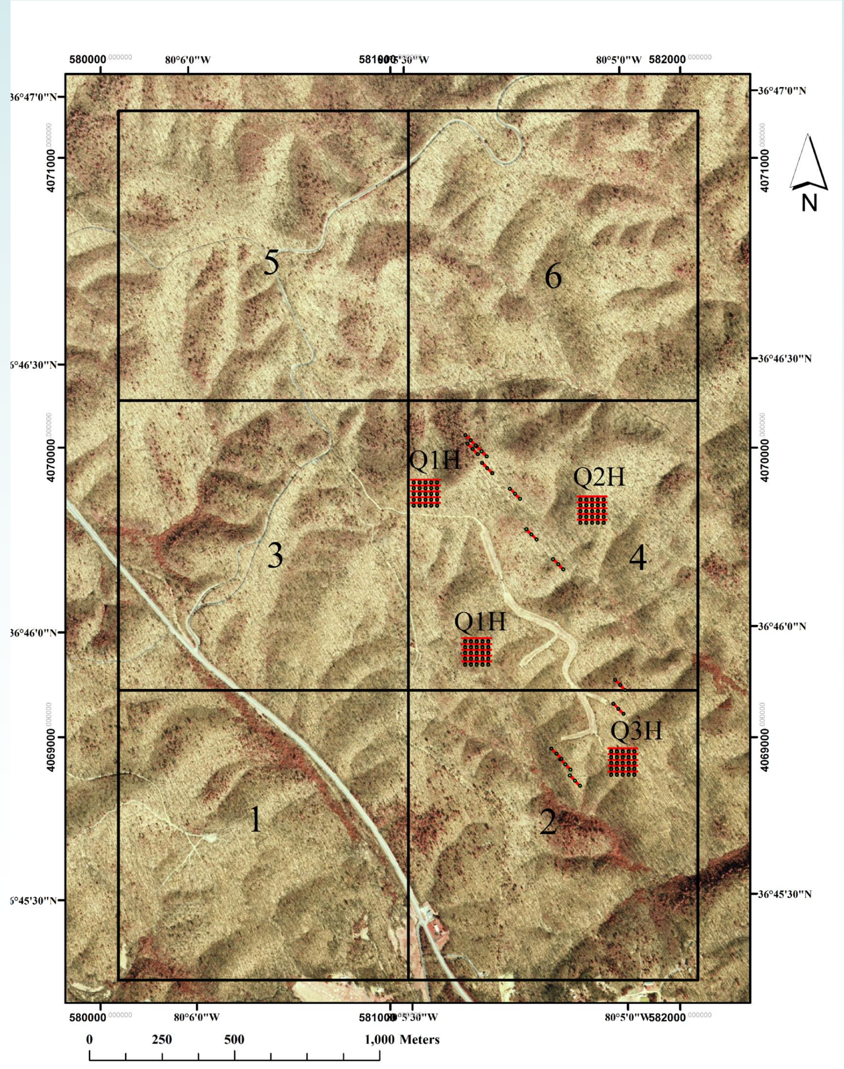

Figure 2. EPA_Fairystone quadrant locations (Q 1-4 H) and six 1 km² MODIS validation cells

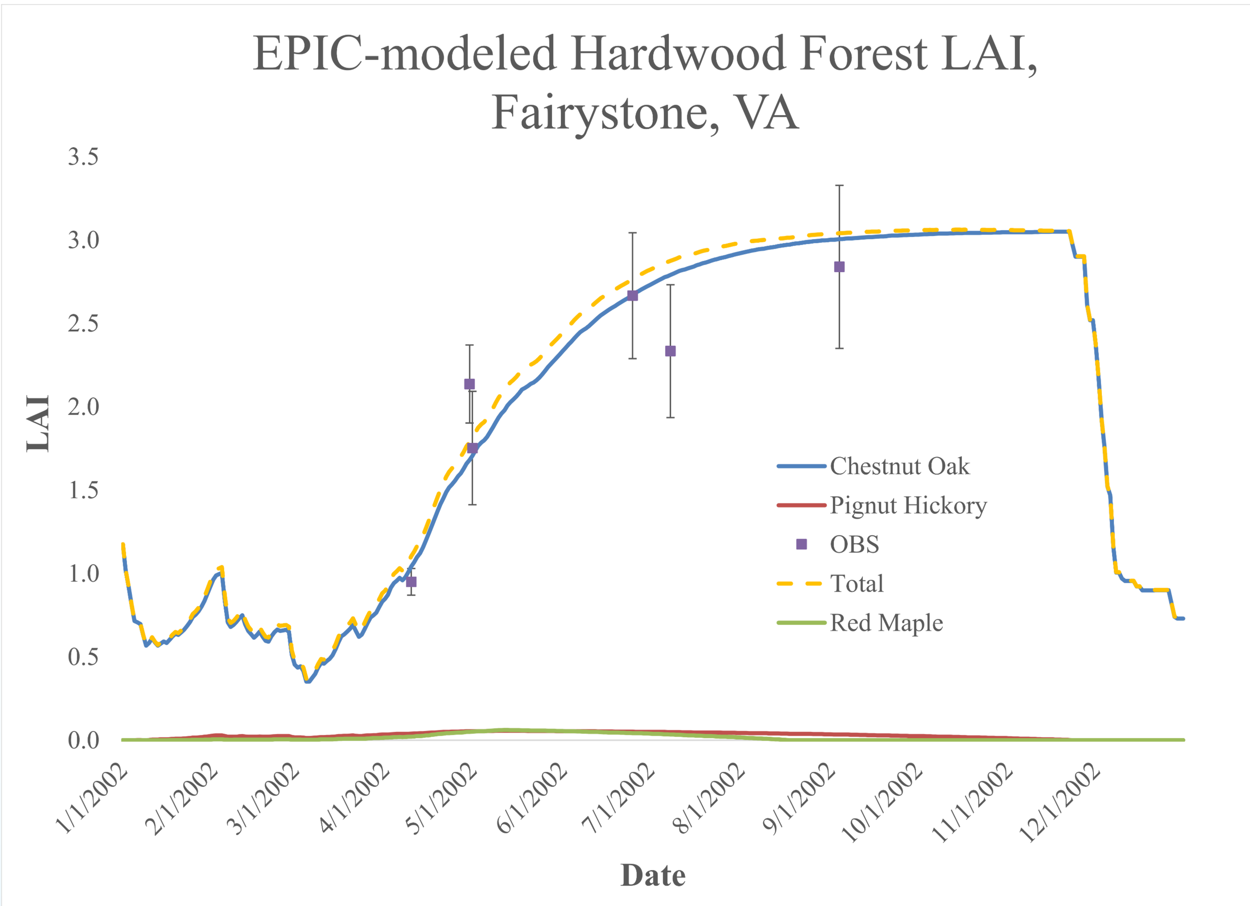

Figure 4. EPIC-modeled LAI from EPA_Fairystone validation site. Error bars signify the mean and $\pm$1 standard deviation. Note: Multiple error bars for one date refer to multiple quadrant LAI estimates.

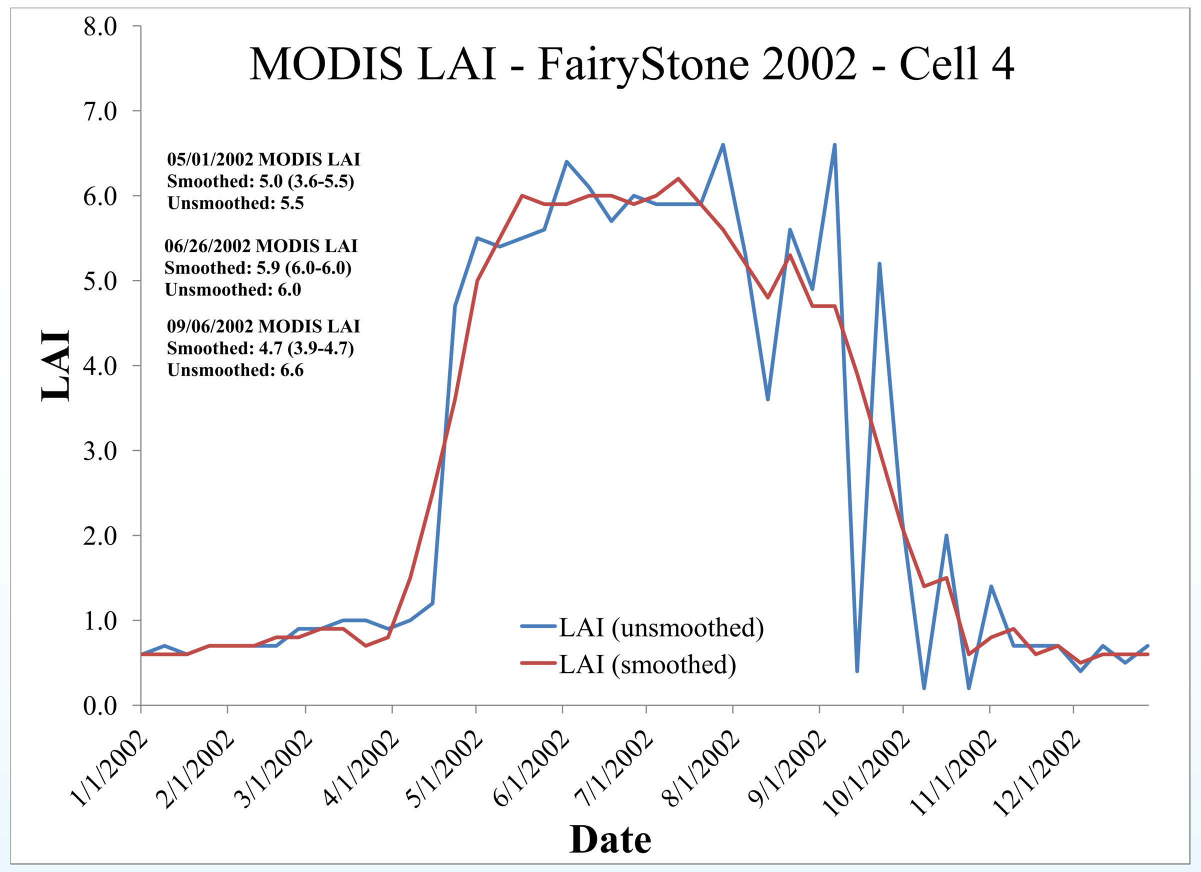

Figure 3. Raw and smoothed MODIS LAI (2002) and three date estimates (01 May 2002, 26 June 2002, 06 September 2002).

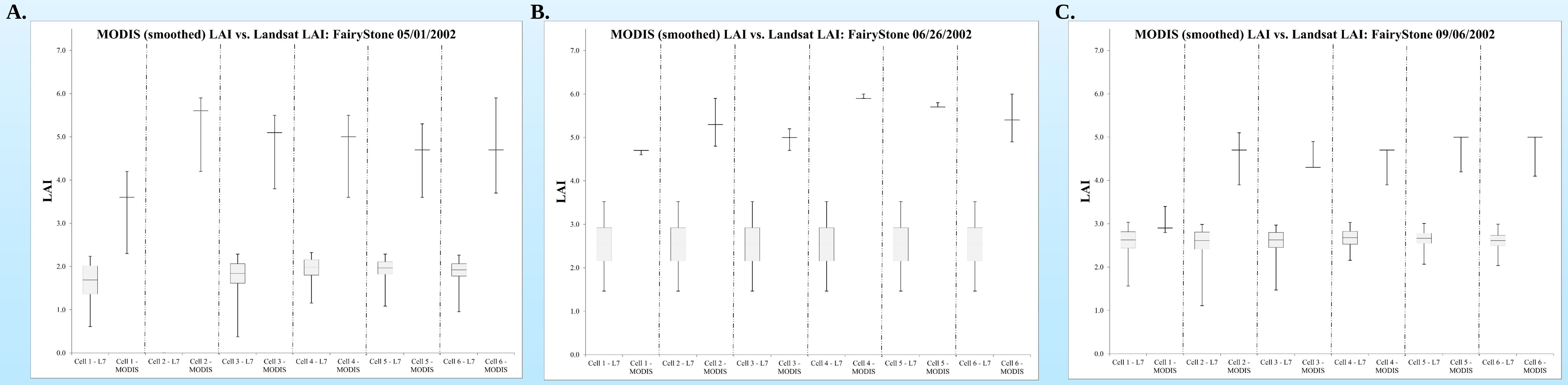

Figure 5. MODIS LAI estimates compared to LAI-SM LAI values: (A) 01 May 2002, (B) 26 June 2002, (C) 06 September 2002. Note: 'Landsat LAI' = LAI-SM