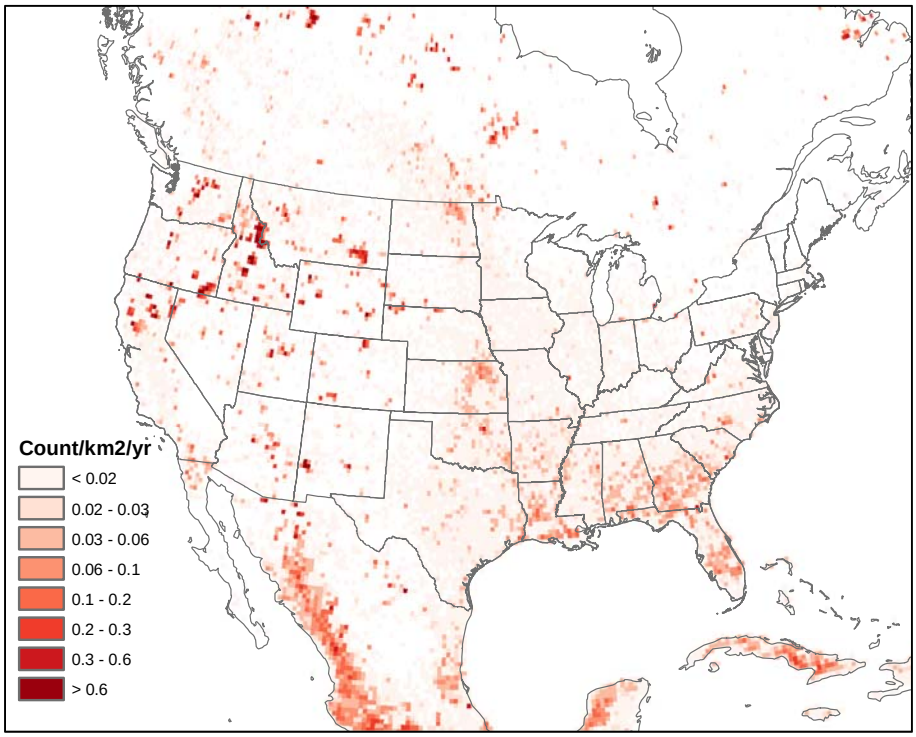
Executive Summary

The Fire INventory from NCAR (FINN) is a global fire emissions model that estimates daily emissions of trace gases and particles from open biomass burning. It is widely used in global and regional modeling studies. The overall objective of this project was to conduct targeted improvements to the FINN model that would benefit the global and regional air quality management and research communities, with a special focus on needs for Texas. The project produced FINN emissions estimates for fire events in 2012 (Figure ES1) to support air quality modeling efforts of the Texas Commission on Environmental Quality (TCEQ).

Figure ES1. Annual total MODIS Active Fire detection counts in 2012 (detection confidence estimate $\geq$ 20%).



A new algorithm for estimating area burned from satellite-derived fire detections was developed and incorporated into FINN to address a known under prediction bias for area burned. Improvements in the area burned estimation were accompanied by better spatial resolution in the characterization of land cover, new fuel loading data with greater spatial resolution for the United States, and incorporation of the new Vegetation Continuous Fields (VCF) Collection 5 product from the Moderate Resolution Imaging Spectroradiometer (MODIS) for estimating bare and vegetative cover. Crop-specific emission factors and fuel loadings developed by McCarty (2011) have been added to FINN as an option for users that have a land cover data resource that distinguishes major crop types typically found in the United States. Collectively, these modifications increased carbon monoxide (CO) emissions in TCEQ's photochemical modeling domain by 42% relative to the earlier version of FINN, primarily due to

increases in the area burned estimates. These modifications form the basis of the next generation of the FINN model, FINN v.2.

In the FINN emissions model, land cover and land use are used to assign emission factors and fuel loadings and, consequently, these input data are critical for the estimation of fire emissions. The MODIS Land Cover Type product has been used as the default resource for land cover characterization in FINN, but new global, U.S. national, and Texas regional products are now available alternatives. Annual FINN emissions estimates during 2012 were generated for seven land cover data products alone or in combination:

- Three simulations were conducted with global databases including the MODIS Land Cover Type (LCT), United Nations Global Land Cover (GLC-SHARE), and European Space Agency (ESA) Climate Change Initiative.
- Two simulations utilized a combination of U.S. national databases, including the U.S. Forest Service Fuel Characteristic Classification System (FCCS) with and without the U.S. Department of Agriculture National Agricultural Statistical Service Cropland Data Layer (CDL), and the MODIS LCT product outside of the U.S.
- Two simulations were conducted using a Texas (TCEQ) regional land cover product (Popescu et al., 2011) with and without the CDL, the FCCS in the remainder of the continental U.S., and MODIS LCT elsewhere.

Annual emissions estimates for CO, nitrogen oxides (NO_x), and fine particulate matter ($PM_{2.5}$) were compared between the simulations for six geographic regions: Texas, the Lower Mississippi Valley, Southeastern U.S., Great Plains, Western U.S. and Mexico (Figure ES2). Differences between simulations highlighted the complex sensitivity of emissions estimates from the FINN model to various land cover inputs and associated fuel loadings and emission factors. Within Texas, the global-scale ESA and GLC-SHARE products produced higher emissions estimates than the MODIS LCT product during 2012; the Texas regional product (with or without the CDL) produced emission estimates were 10% to 19% greater than the MODIS LCT product. Characterization of croplands had minimal effects on annual emissions estimates in Texas.

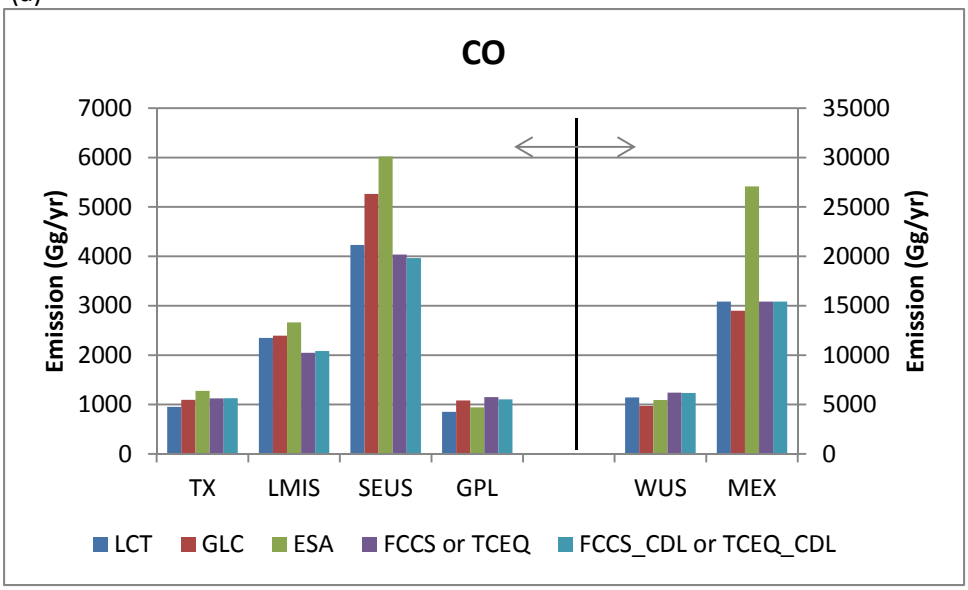
The Emission Processing System (EPS) underwent extensive updates to produce a new version (EPS v3.22) for the TCEQ as well as to accommodate use of the new area burned algorithm in FINN. CAMx simulations for a June 2012 episode obtained from the TCEP were performed with three different FINN outputs driven by different land cover products: the MODIS LCT, ESA, and Texas regional product with the Cropland Data Layer. In addition, a CAMx simulation for which all fire emissions were removed ("No Fire" case) was also conducted for comparison purposes.

In early June of 2012, northwestern Mexico (Sierra Madre Occidental) exhibited high fire activity, which affected simulated ozone levels in the region as well as within downwind areas of the U.S. Fire activity in the Rocky Mountains of the western U.S. was pronounced later in the month. Regardless of the land cover product used for the fire emissions estimates, the median contribution of fire events to MDA8 ozone concentrations in Texas throughout the month of June was approximately 2 ppb (Figure ES3, which shows the contribution of all fires to the selected regions of interest). This contribution was likely associated with fires in northwestern Mexico that occurred every day for the initial two-thirds of the month. The maximum contribution of fires on predicted MDA8 ozone concentrations in Texas exceeded 40 ppb during the episode period. Differences in predicted MDA8 ozone concentrations in Texas ranged from -10 ppb to +21 ppb between the simulations that used FINN emissions estimates derived with

the ESA or MODIS LCT products and from -18 ppb to +33 ppb between the simulations using the FINN emissions derived from the TCEQ_CDL or MODIS_LCT products.

Figure ES2. Annual FINN emissions estimates for (a) CO, (b) NO_x, (c) $PM_{2.5}$ by geographic region (Texas, the Lower Mississippi Valley, Southeastern U.S., Great Plains, Western U.S. and Mexico). FINN estimates are shown using different land cover inputs: MODIS LCT, GLC-SHARE, ESA, and TCEQ and TCEQ_CDL (Texas and Lower Mississippi Valley) or FCCS and FCCS_CDL data products (Southeastern U.S. and Western U.S.). Note difference in scale for the Western U.S and Mexico.

(a)



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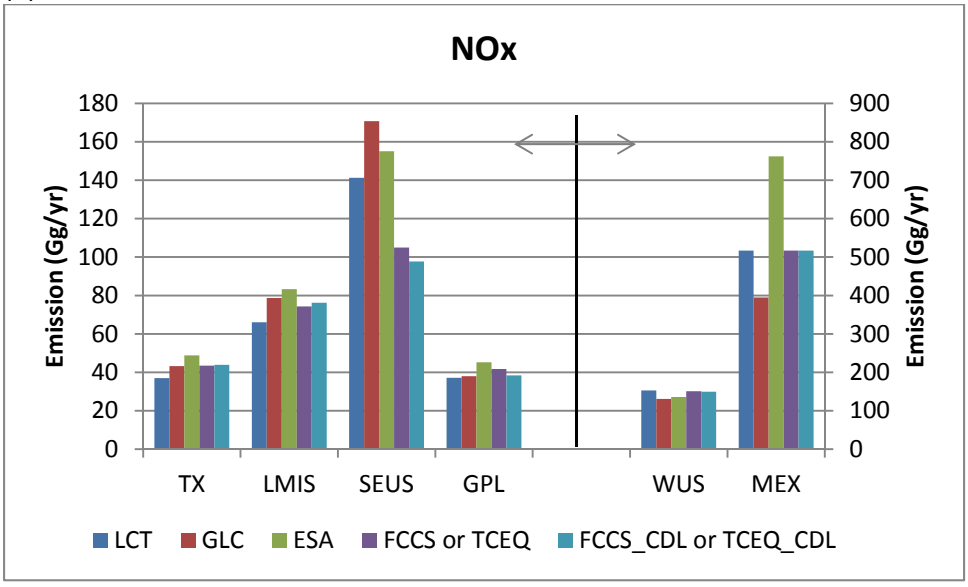

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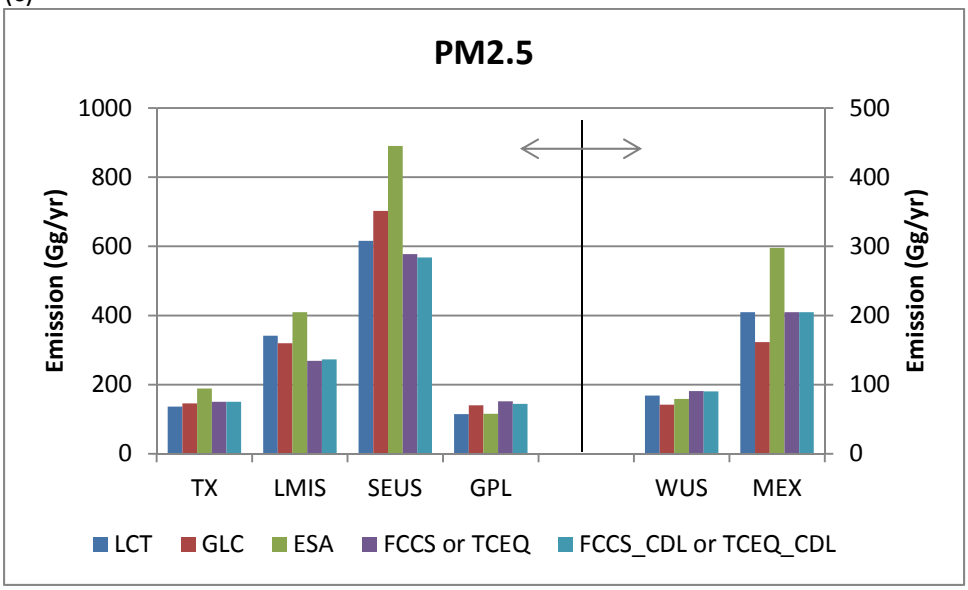

The project activities also resulted in the development and implementation of an approach for partitioning FINN NO_x emissions estimates into aged NO_z forms (i.e., nitrogen dioxide [NO_2], nitric acid [HNO_3], peroxyacetyl nitrate [PAN], C3 and higher peroxyacyl nitrates, and organic nitrates) to account for rapid NO_x oxidation in fire plumes. A CAMx simulation was conducted based on FINN emissions estimates driven by the TCEQ_CDL land cover scenario with NO_x partitioning implemented during EPS processing. Results from this simulation were compared to a similar CAMx simulation (TCEQ_CDL) without NO_x partitioning. Median differences in predicted MDA8 ozone concentrations between the simulations were within -0.5ppb for the six geographic regions, including Texas.

At this time, we recommend use of the following combination of land cover products in FINN to support Texas air quality modeling activities: the Texas regional land cover product with the Cropland Data Layer (TCEQ_CDL), the U.S. Forest Service Fuel Characteristic Classification System (FCCS) in the remainder of the continental U.S., and MODIS Land Cover Type (MODIS_LCT) product elsewhere. This combination provides the greatest spatial resolution and specificity in land cover and fuel loadings for the Texas regional domain and continental U.S. However, we note the importance of understanding the range of FINN emissions estimates that can be obtained with different land cover products and the strong need for *in situ* evaluation of fuel loadings. Future work should focus on validation of land cover and, in particular, fuel loadings in the United States. The algorithm in EPS that partitions NO_x into aged NO_z forms should reflect the evolution of scientific understanding; our initial approach is implemented as an option in EPS v3.22. Reconciliation of fire detection between varying satellite and ground-based incident resources remains an on-going need; and evaluation of the Visible Infrared Imaging Radiometer Suite (VIIRS) products, the latest of the series of earth observing detectors, should be considered in the future.

Figure ES3. Contribution of all fire events to MDA8 ozone concentrations in each geographic region during June 2012. The box represents 25th to 75th percentiles with a vertical line showing the median. Whisker stretches to the minimum and maximum values. The concentration axis uses inverse hyperbolic sine transformation ($\sinh^{-1} x \equiv \ln(x + \sqrt{1 + x^2})$) to facilitate interpretation.