Executive Summary - Project: 14-008

The role of isoprene and other biogenic volatile organic compounds (BVOCs) in the formation of tropospheric ozone is recognized as critical for air quality planning in Texas. In the southwestern United States (U.S.), drought has become a recurring phenomenon that can impose profound and complex effects on human populations and the environment. Understanding these effects on vegetation and biogenic emissions is important as Texas concurrently faces requirements to achieve and maintain attainment with the National Ambient Air Quality Standard (NAAQS) for ozone in several large metropolitan areas. The primary objective of this project was to evaluate and inform improvements in the representation of soil moisture, a key input parameter for biogenic emissions estimates, through the use of simulated and observational datasets. The Model of Emissions of Gases and Aerosols from Nature (MEGAN) was used to explore the sensitivity of isoprene emission estimates to alternative soil moisture representations in the South Central U.S., with an emphasis on isoprene predictions within Texas during years with severe to extreme drought (2006 and 2011) and during an average to wet year (2007).

Analyses utilized available in-situ soil monitoring data collected during 2006-2013 at Soil Climate Analysis Network (SCAN) and Climate Research Network (CRN) locations. These soil moisture measurements are collected at depths ranging between 5cm and 100cm that span the root zone; however, observational locations are sparse and cannot be used to represent regional soil moisture conditions throughout eastern Texas. Soil moisture datasets used as input for MEGAN predictions were driven by North American Land Data Assimilation System Phase 2 (NLDAS-2) meteorological forcings and included four commonly-used LSMs: NASA's Mosaic, NOAA's Noah, Princeton's Variable Infiltration Capacity (VIC), and an enhanced version of the original Noah LSM that incorporates improved physics and multi-parameterization options (Noah-MP).

Key findings of the study include:

In-situ observations during 2006-2013 at four eastern Texas locations demonstrated wide variability in volumetric water contents with near-surface values <0.05 $m^3/m^3$ at Port Aransas and >0.25 $m^3/m^3$ at inland locations where soil moisture increased with increasing depth. Soil moisture was typically highest in winter and lowest in summer. The sparseness of in-situ observations demonstrated the need for additional sources of information on the spatial and temporal variability of regional soil moisture throughout eastern Texas.

A comparison of in-situ observations and NLDAS-2 predictions at the eastern Texas monitoring locations indicated that the year-to-year directional variability in seasonal average soil moisture values was often captured by the NLDAS-2 models; however, the magnitude of inter-annual differences could be substantially different than observed. In general, VIC showed the poorest agreement with observations and was consistently too wet in the near-surface layers. Noah-MP exhibited weak temporal variation at deeper layers and failed to reproduce the wet conditions during 2007 and the very dry soil moisture values during 2011.

Comparisons between all available South Central U.S. in-situ observations and NLDAS-2 predictions showed that modeled values captured relative seasonal and interannual changes in the spatial and temporal variations of soil moisture such as east-to-west gradients and the extent and evolution of drought potentially important for biogenic emissions modeling. The impacts of precipitation events and drought were often well-reproduced at different depths; however VIC, which had a consistent wet bias, did not simulate the extreme wet/dry periods. Depending on the specific location and season, the absolute model biases for all models could be large. Noah-MP, Mosaic, or Noah had the best agreement with observations in near-surface layers while all models predicted substantially drier soil moisture at deeper soil layers compared to observations.

Comparisons of changes in total water storage (TWS) observed by the Gravity Recovery and Climate Experiment (GRACE) with NLDAS-2 soil moisture anomalies were generally in agreement, including the extremely wet conditions in Texas during 2007 and extreme drought during 2011 as well as conditions during the 2012 central Great Plains drought. This finding was consistent with previous GRACE studies that showed the soil moisture deficit during 2011 in Texas was dominated by TWS depletion. The spatial pattern of simulated soil moisture showed some differences from the TWS changes, which could be related, in part, to groundwater and/or irrigation processes that are not included in the NLDAS-2 models. Future work should continue to evaluate LSMs such as NLDAS-2 with additional in-situ observations as well as satellite-derived soil moisture estimates as available.

MEGAN simulates the drought response of isoprene emissions through the soil moisture activity factor. The soil moisture activity factor scales between 0 and 1 depending on the soil moisture and wilting point (the soil moisture content below which plants cannot extract water from soil), representing a negative influence on isoprene emissions under drought conditions. Utilization of the Noah, Noah-MP, and VIC soil moisture databases within MEGAN to predict isoprene emissions during drought often showed wide variability among models dependent on the location, season, and year but regionally-averaged isoprene emission reductions were generally within 15% of the base case in which the impact of soil moisture was not considered. In contrast, simulations that employed the Mosaic database often predicted large emissions reductions during drought. Analysis of the Mosaic results showed that emissions reductions were sometimes predicted even during non-drought periods especially in regions dominated by clay soils. The substantial differences in Mosaic isoprene predictions from the other models were due, in part, to the relatively high wilting point database employed by Mosaic compared to the Noah models. Although there is large uncertainty in the evaluation of the NLDAS-2 LSMs due to sparse observational data within eastern Texas, the use of Noah is currently recommended based on the results and caveats from this work.

The MEGAN studies performed in this work (and others) highlighted the potential uncertainty associated with the specific soil moisture database, especially wilting points, utilized. This suggests a continued need for investigations to evaluate and improve the drought stress parameterizations and/or representations in models such as MEGAN. In situ monitoring locations are sparse and have hampered the ability to validate simulations of soil moisture as well as to incorporate observational data within MEGAN. Though beyond the scope of the current study, efforts to investigate differences in model structure and physics between the LSMs (even for a limited number of representative grid cells) would likely prove beneficial to understanding differences in the relevant LSM-specific soil properties (e.g., wilting points) as well as soil moisture predictions.