Soil Moisture Characterization for Biogenic Emissions Modeling

(AQRP Project 14-008)

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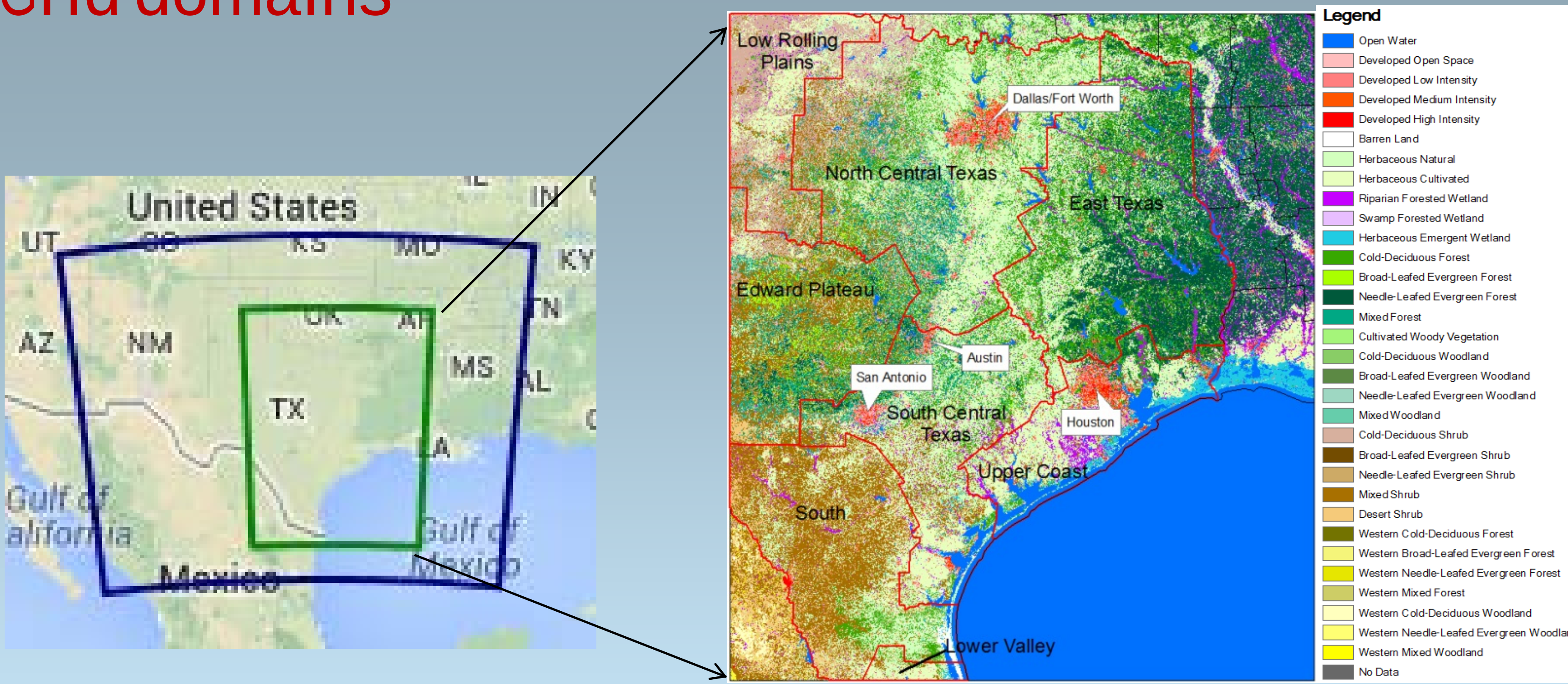
Primary objectives

- Investigate sources of observed and simulated soil moisture throughout the root zone with a geographic emphasis on eastern Texas

- Evaluate the sensitivity of MEGAN-predicted isoprene to different soil moisture representations especially during drought

Grid domains



- Left: 12-km (blue) and 4-km (green) TCEQ modeling domains
  *(Source: http://www.tceq.texas.gov/airquality/airmod/rider8/modeling/domain)

- Right: Land cover/land use within eastern climate regions.
  *(Sources: Popescu et al., 2011; NOAA)

Soil moisture data sources

- Ground-based (in-situ)
  - Direct (e.g., gravimetric)
  - Indirect (e.g., capacitance-based and neutron probe)
  - Sparse in eastern Texas
  - Our study utilized data from Soil Climate Analysis Network (SCAN) and Climate Research Network (CRN) at 5/10/20/50/100-cm depths during 2006-2013

- Satellite-based (Not used in our study)
  - Sensitive to near-surface soil moisture only (e.g, 0-5cm)
  - Retrievals use C-band (4-8 GHz) or L-band (1-2 GHz)
  - Passive retrievals more robust; active (i.e., scatterometers) at higher spatial resolution but more sensitive to surface roughness and vegetation
  - NASA’s Soil Moisture Active Passive (SMAP) launched January 2015 combines active (1.26 GHz; 9km) and passive (1.4 GHz; 36km) every 2-3 days

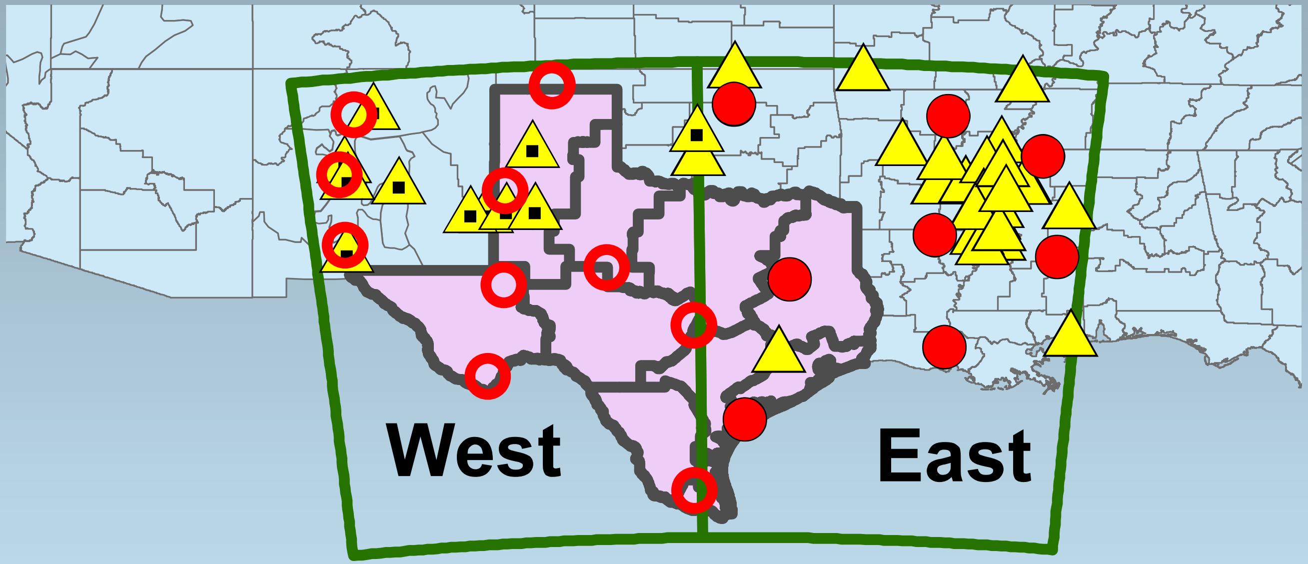
Soil moisture data sources (continued)

- Land surface models (LSMs)
  - Coupled (e.g. GCMs, weather forecasting)
  - Uncoupled
    - Of specific interest: Global Land Data Assimilation System (GLDAS) and North American Land Data Assimilation System (NLDAS) using the Noah, CLM, VIC, and Mosaic LSMs

- Our study utilized NLDAS-2 predictions
  - Driven by NARR and NCEP/CPC gaged daily rain
  - Gridded soil moisture predictions for 1979-present over root zone (0-200cm) at hourly temporal and 1/8th degree spatial resolutions
  - Recently evaluated for entire US including South Central

e.g., Xia et al, 2012, 2014; Cai et al., 2014ab

SCAN/CRN monitoring in 12km domain operational during at least a portion of 2006-2013



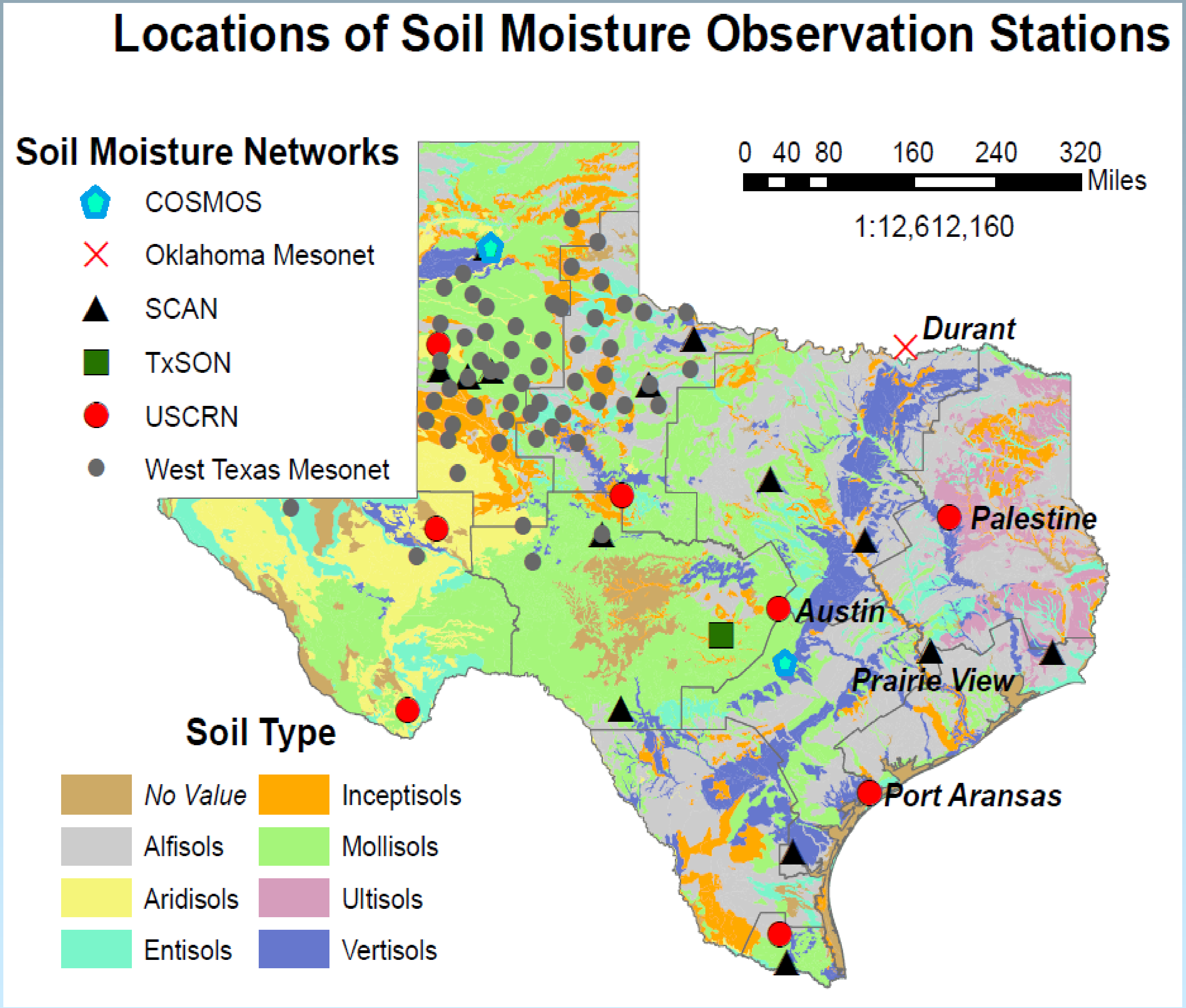

USCRN sites in West 12km domain


SCAN sites in West 12km domain

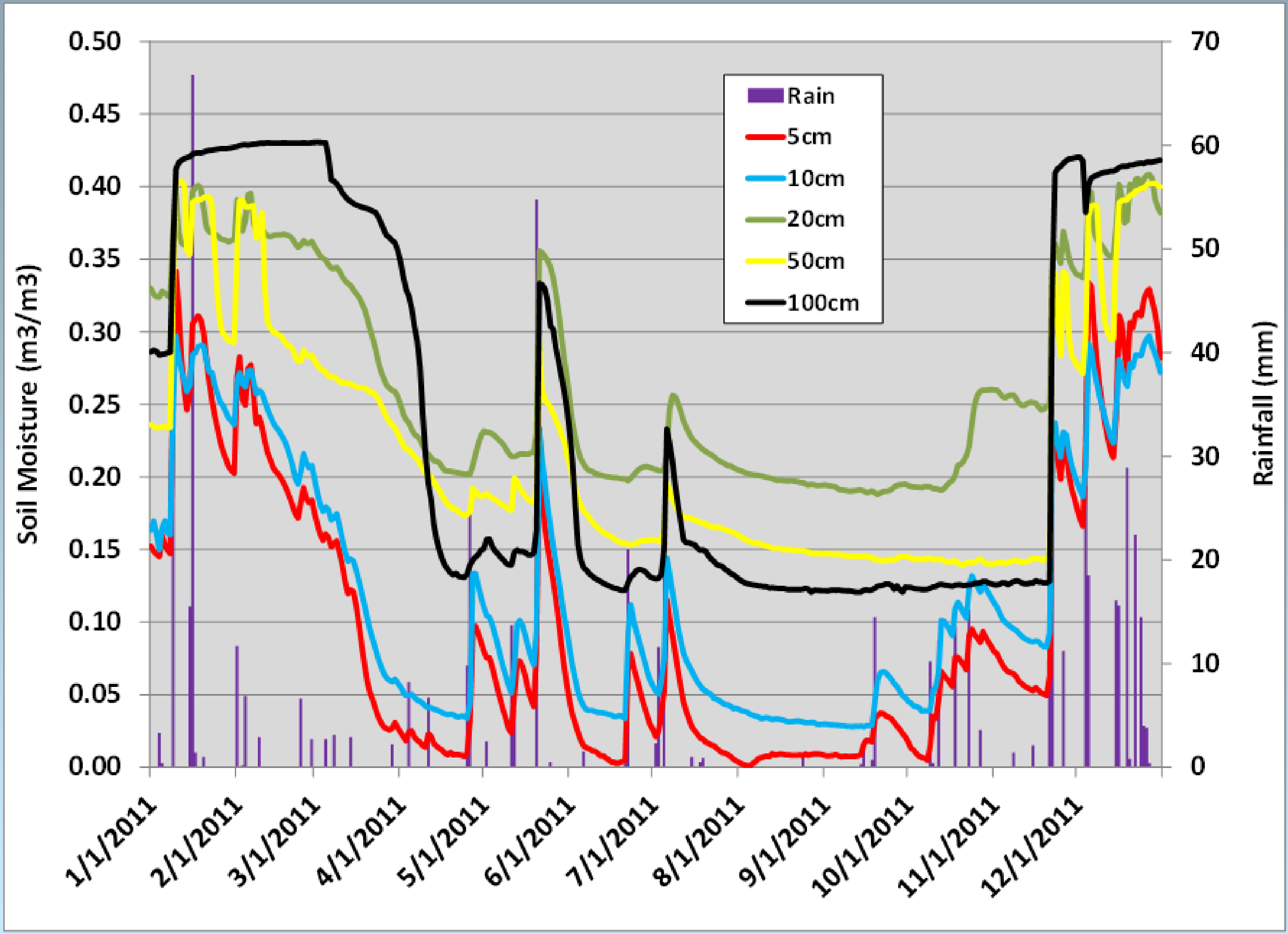

USCRN sites in East 12km domain


SCAN sites in East 12km domain

In-situ soil moisture monitoring in Texas



Daily average in-situ soil moisture: Palestine; 2011



- Soil moisture tends to increase with increasing depth
- Much drier soils during summer compared to winter
- Note impacts of periodic rainfall events

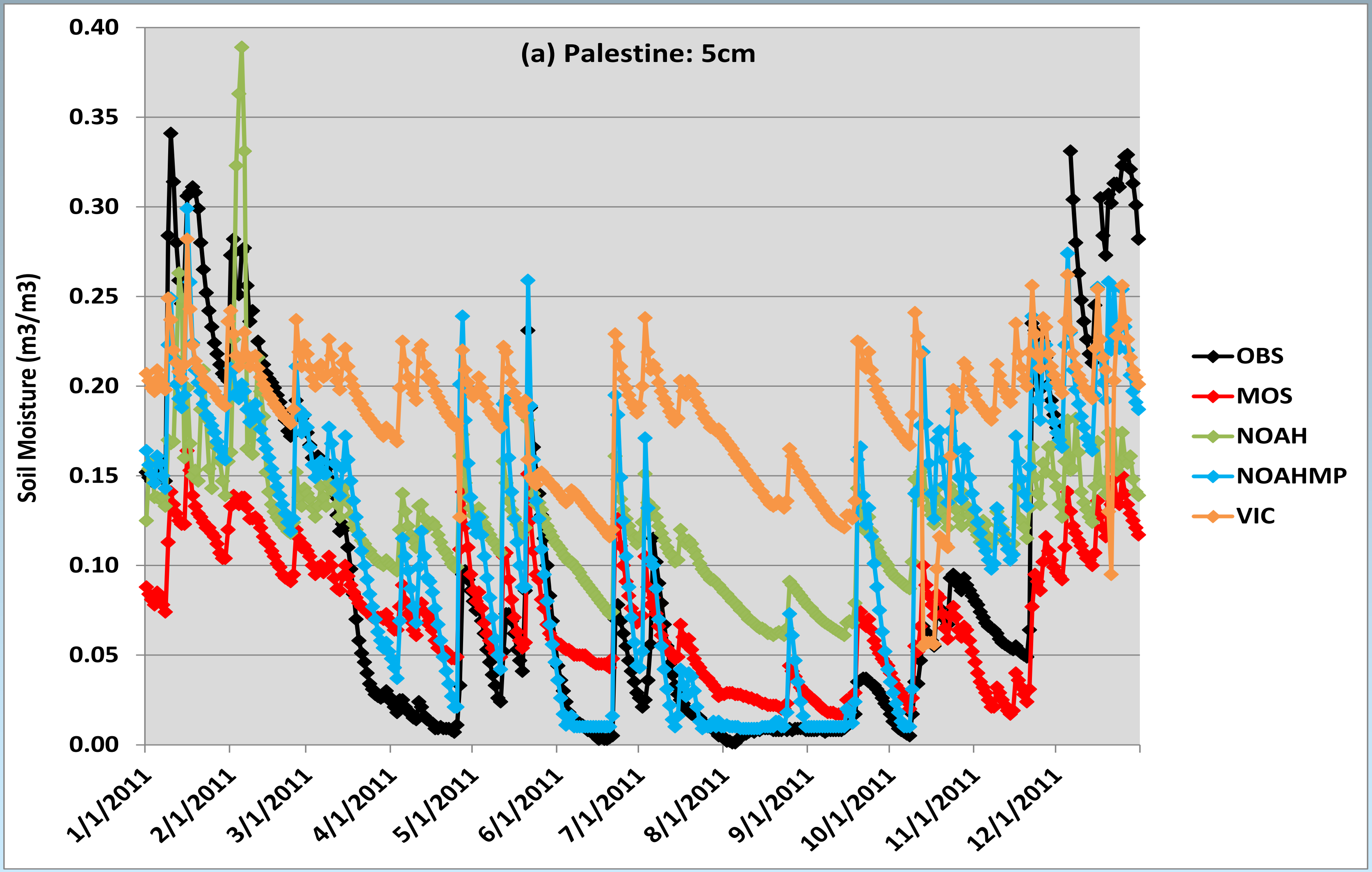
North American Data Assimilation System Phase 2 (NLDAS-2)

- Our work employed 4 LSMs
  - Noah: Land component in NOAA NCEP Eta and CFS, WRF, GFS
  - Mosaic: Uses a tiled approach to account for sub-grid vegetation variability
  - Variable Infiltration Capacity (VIC): Hydrologic model
  - Noah with multi-parameterization options (Noah-MP): Incorporates recent LSM developments (e.g., prognostic leaf models, dynamic groundwater, multilayer snow) that have also been incorporated into CLM4
  - Soil moisture results for Noah, Noah-MP, Mosaic, and VIC were vertically interpolated to the Noah soil layer structure (4 fixed layers 0-10, 10-40, 40-100, 100-200cm)

Comparison of in-situ and NLDAS-2 datasets (caveats)

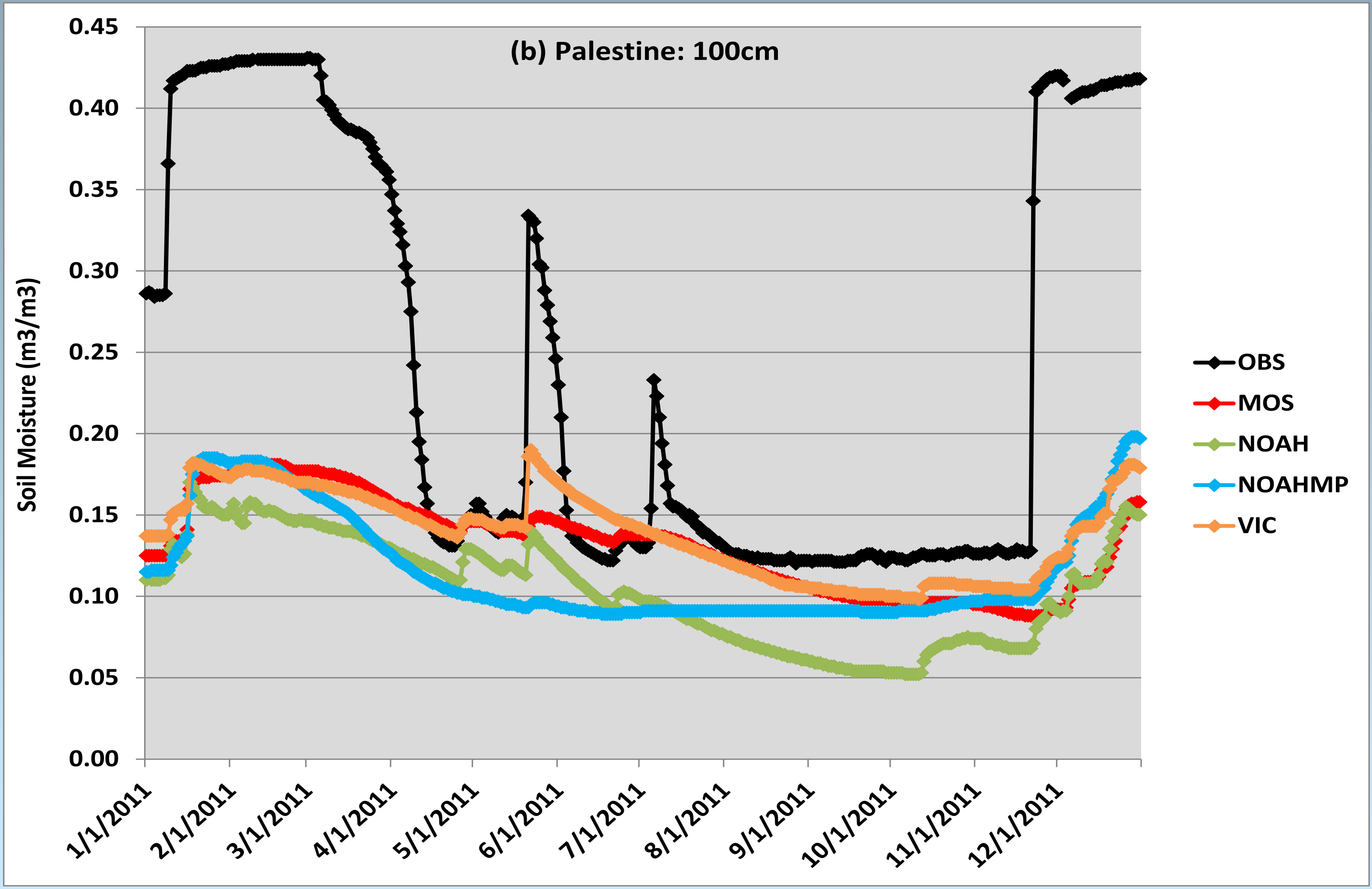
- The inter-comparison of in-situ measurements and NLDAS-2 predictions are affected by a number of uncertainties, including (but not limited to):
  - In-situ observations are a point measurement whereas the NLDAS-2 simulations represent average conditions over a larger area (i.e., 1/8 degree horizontal spatial resolution).
  - Site-specific soil type differs from NLDAS-2 descriptions.
  - Uncertainties in the NLDAS-2 model structure and parameterizations.
  - Crucial processes may not be directly considered by NLDAS-2 but impact soil moisture at specific locations (e.g., irrigation, groundwater processes)
  - Uncertainties in the meteorological forcing data that drives the NLDAS-2 simulations.
  - Interpolation-induced bias.

Daily average in-situ (OBS) and NLDAS-2 soil moisture: Palestine; 2011 (5cm)



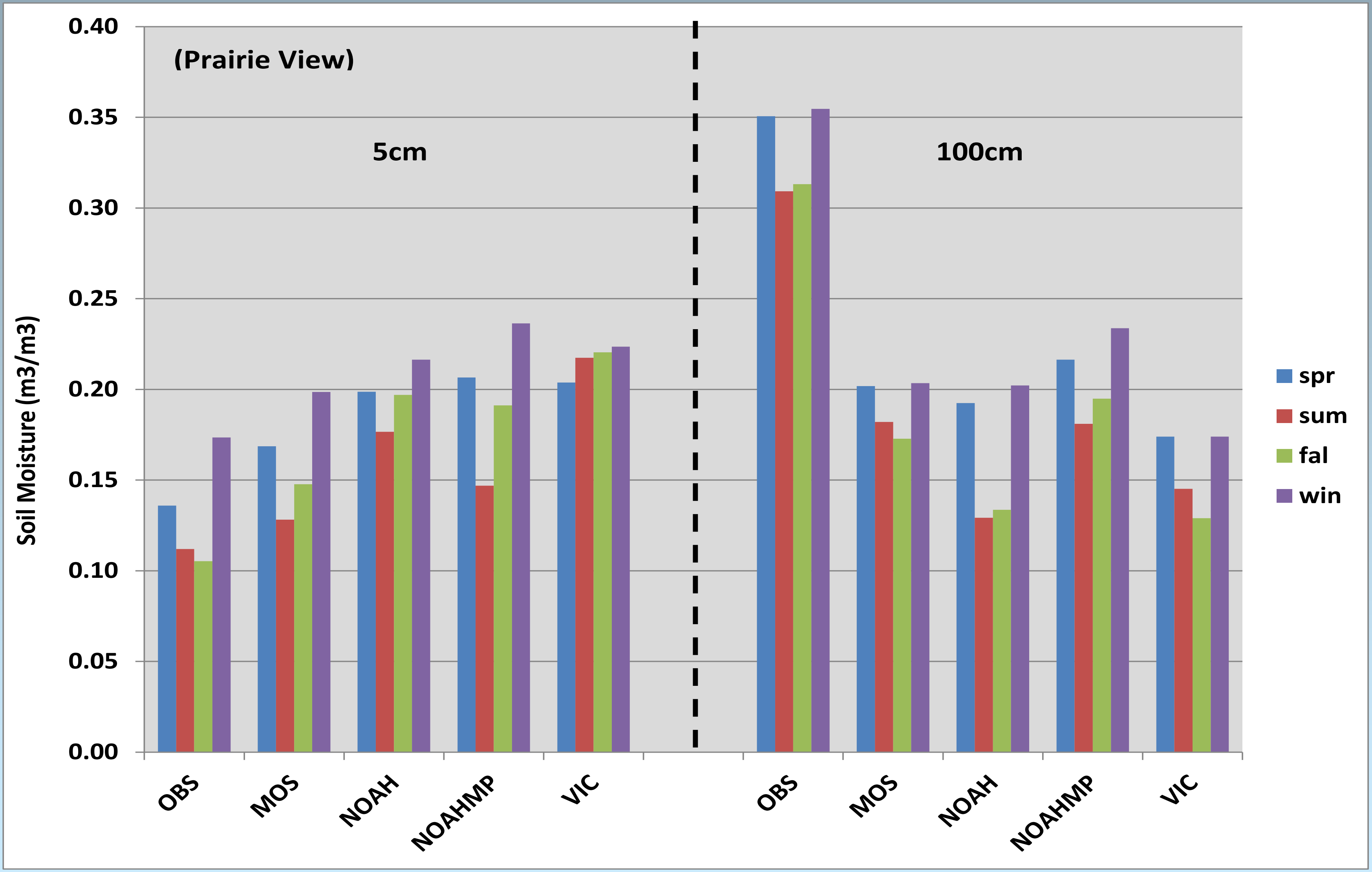
- VIC characterized by little seasonality and is too wet during growing season
- Noah-MP generally shows best agreement

Daily average in-situ (OBS) and NLDAS-2 soil moisture: Palestine; 2011 (100cm)



- All models show little seasonality and are biased too dry during winter and spring
- VIC and Mosaic show best agreement with observations

Average seasonal soil moisture at Prairie View 2006-2013



- Directionality of seasonality well-simulated (except VIC)
- NLDAS-2 deep soil moisture is too dry

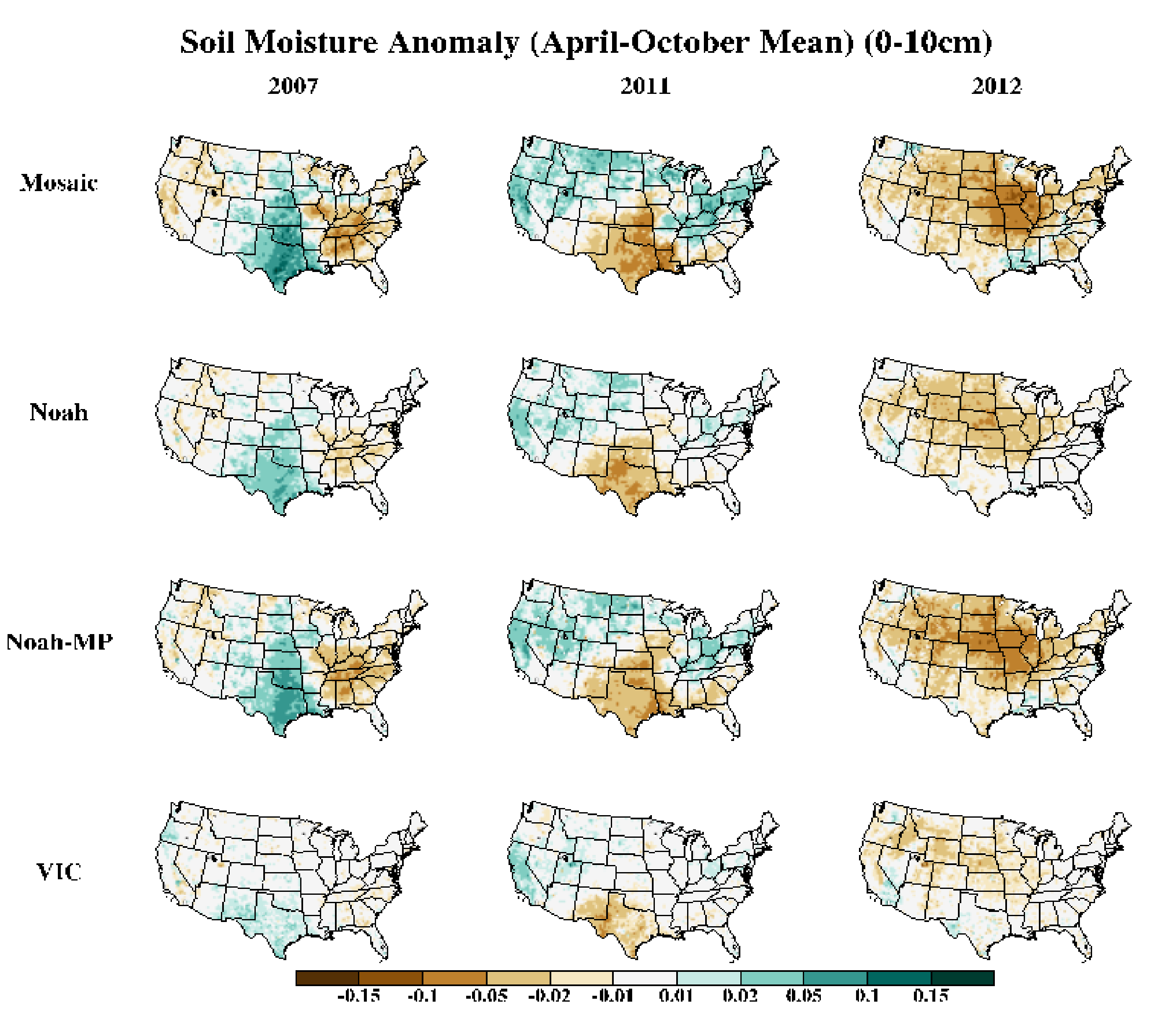
Overall results for in-situ to NLDAS-2 comparisons

- NLDAS-2 LSMs generally capture relative changes in the spatial and temporal variations of soil moisture; however, absolute model biases may be large with the magnitude partially dependent on LSM, soil depth, and location

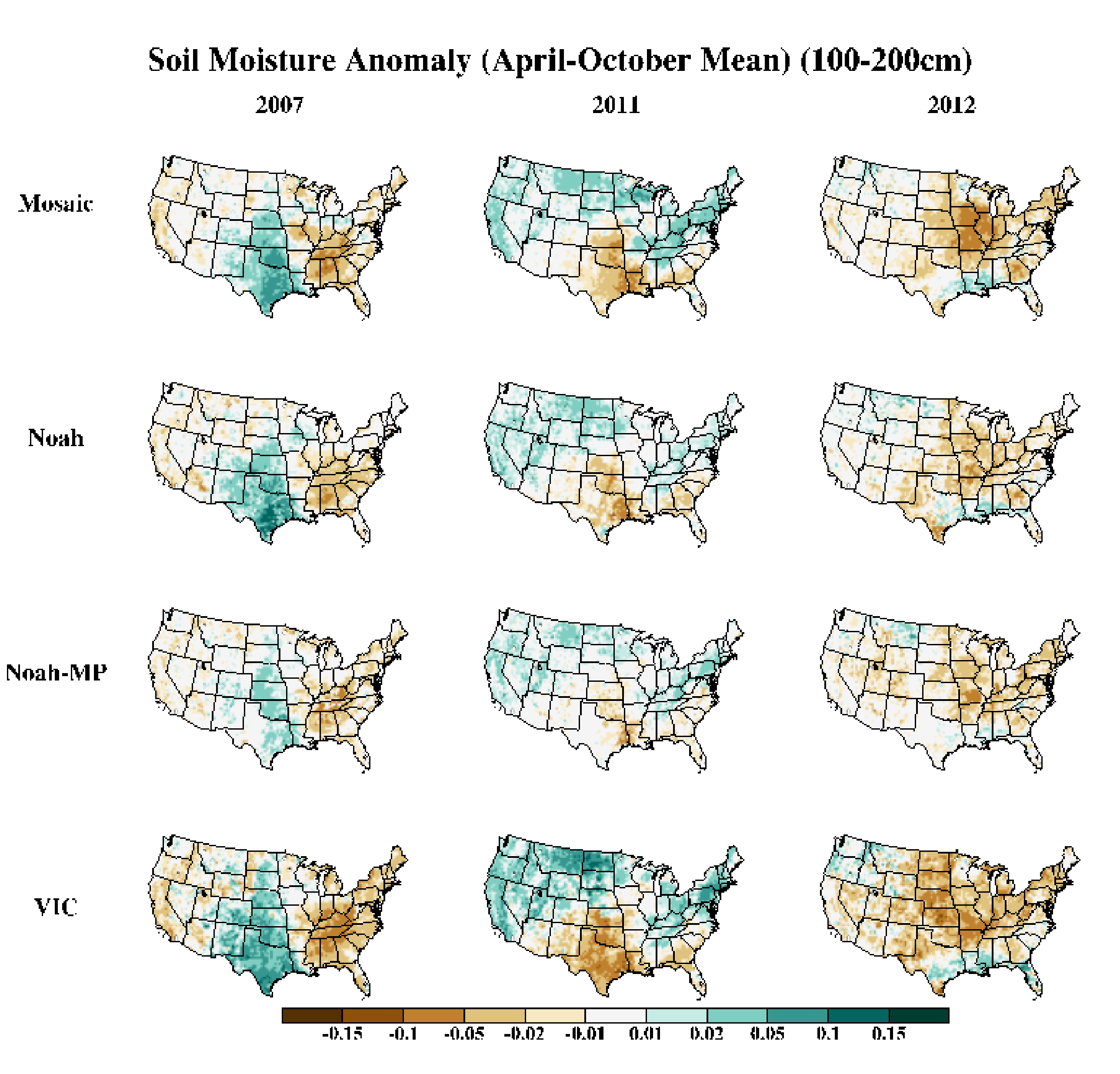
- For near-surface layers:
  - VIC shows poor seasonality and is too wet
  - Year-to-year directional variability is often captured by all models, including drought (next slide)
  - Dependent on season and location, either Noah-MP, Noah, or Mosaic may have the best agreement

- For deeper layers:
  - Noah-MP has overly weak temporal variation in eastern Texas
  - All models tend to be too dry

NLDAS-2 soil moisture anomalies for 2007, 2011, and 2012 relative to 2006-2013 averages (0-10cm)



NLDAS-2 soil moisture anomalies for 2007, 2011, and 2012 relative to 2006-2013 averages (100-200cm)



MEGANv2.1

The latest version of MEGAN (MEGANv2.1) is described in detail by Guenther et al. (2012). The emissions rate (F) of isoprene from terrestrial landscapes in units of flux (μg m^{-2} ground area h^{-1}) is calculated as:

$$F = \gamma \sum \varepsilon_j \chi_j \qquad \text{Eq. 1}$$

where ε is the basal emission factor for vegetation type j with fractional coverage χ_j; it represents the emission rate under standard environmental conditions defined in Guenther et al. (2006, 2012) including an air temperature of 303 K, solar angle of 60 degrees, photosynthetic photon flux density (PPFD) transmission of 0.6, LAI of 5 m^2/m^2 consisting of 80% mature, 10% growing and 10% old foliage, and volumetric soil moisture of 0.3 m^3/m^3. γ is the overall emissions activity factor that multiplicatively accounts for the effects of environmental variations on leaf age, canopy environment, and soil moisture such that:

$$\gamma = \gamma_{age} \cdot \gamma_{SM} \cdot \gamma_{CE} \qquad \text{Eq. 2}$$

with each of the individual gammas calculated as below:

leaf age: $\gamma_{age} = A_{new}F_{new} + A_{gro}F_{gro} + A_{mat}F_{mat} + A_{old}F_{old}$ Eq. 3

soil moisture: $\gamma_{SM} = \sum_{i=1}^{4} f_{root}^{i} \max(0, \min(1, (\theta^i - \theta_{wilt}) / 0.04))$ Eq. 4

canopy environment:

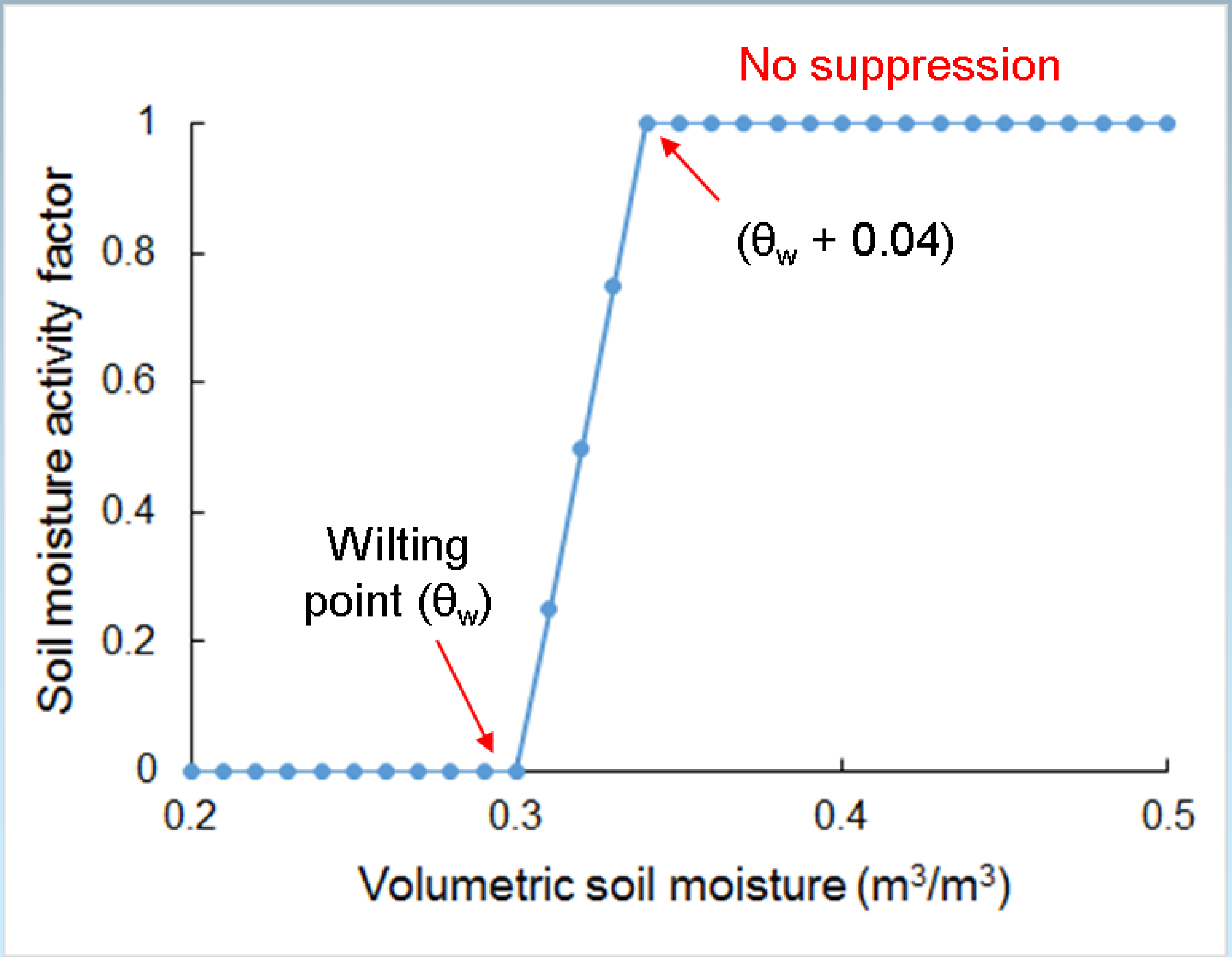
$$\gamma_{CE} = 0.56 \cdot \sum_{i=1}^{5} [(\gamma_T^i)_{sun} (\gamma_P^i)_{sun} f_{sun}^i + (\gamma_T^i)_{shade} (\gamma_P^i)_{shade} f_{shade}^i] \cdot LAI^{\,i} \qquad \text{Eq. 5}$$

MEGAN soil moisture activity factor

- MEGAN simulates the impact of long-term soil water stress on isoprene emissions based on the difference between available soil moisture and wilting point (Pegoraro et al., 2004)
  - Permanent wilting point is the water content at which plants wilt and fail to recover when re-supplied with sufficient moisture (operationally estimated at 1.5 MPa matric potential)
- The soil moisture activity factor can only reduce isoprene emissions
- Our study used gridded NLDAS-2 soil moisture for 4 layers (0-10, 10-40, 40-100,100-200cm) and 0-200cm average wilting points as inputs to MEGAN

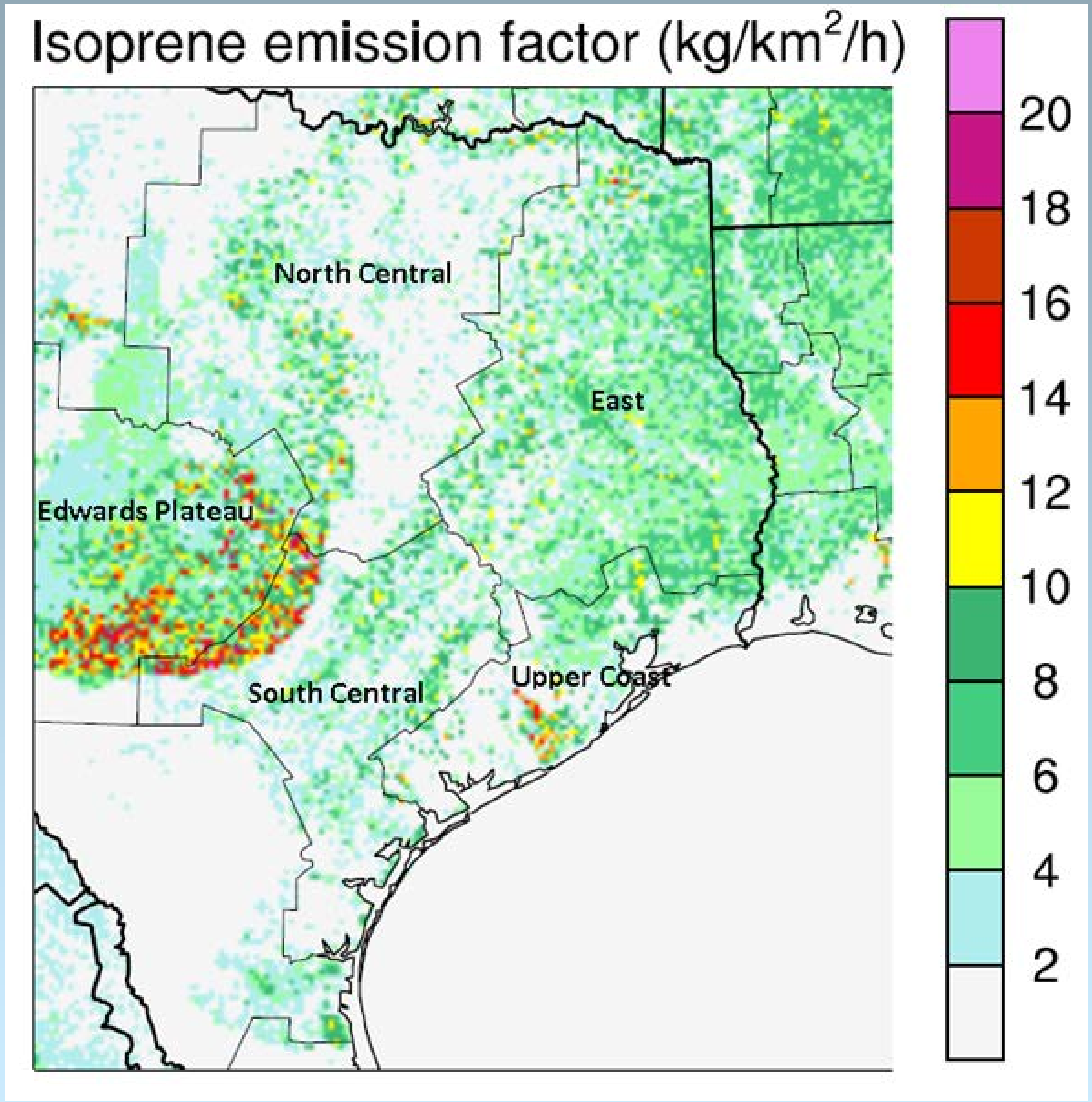
MEGAN soil moisture activity factor (continued)

- Soil moisture activity factor decreases linearly from a value of one at 0.04 m^3/m^3 above the wilting point to zero at and below the wilting point (Guenther et al., 2012)

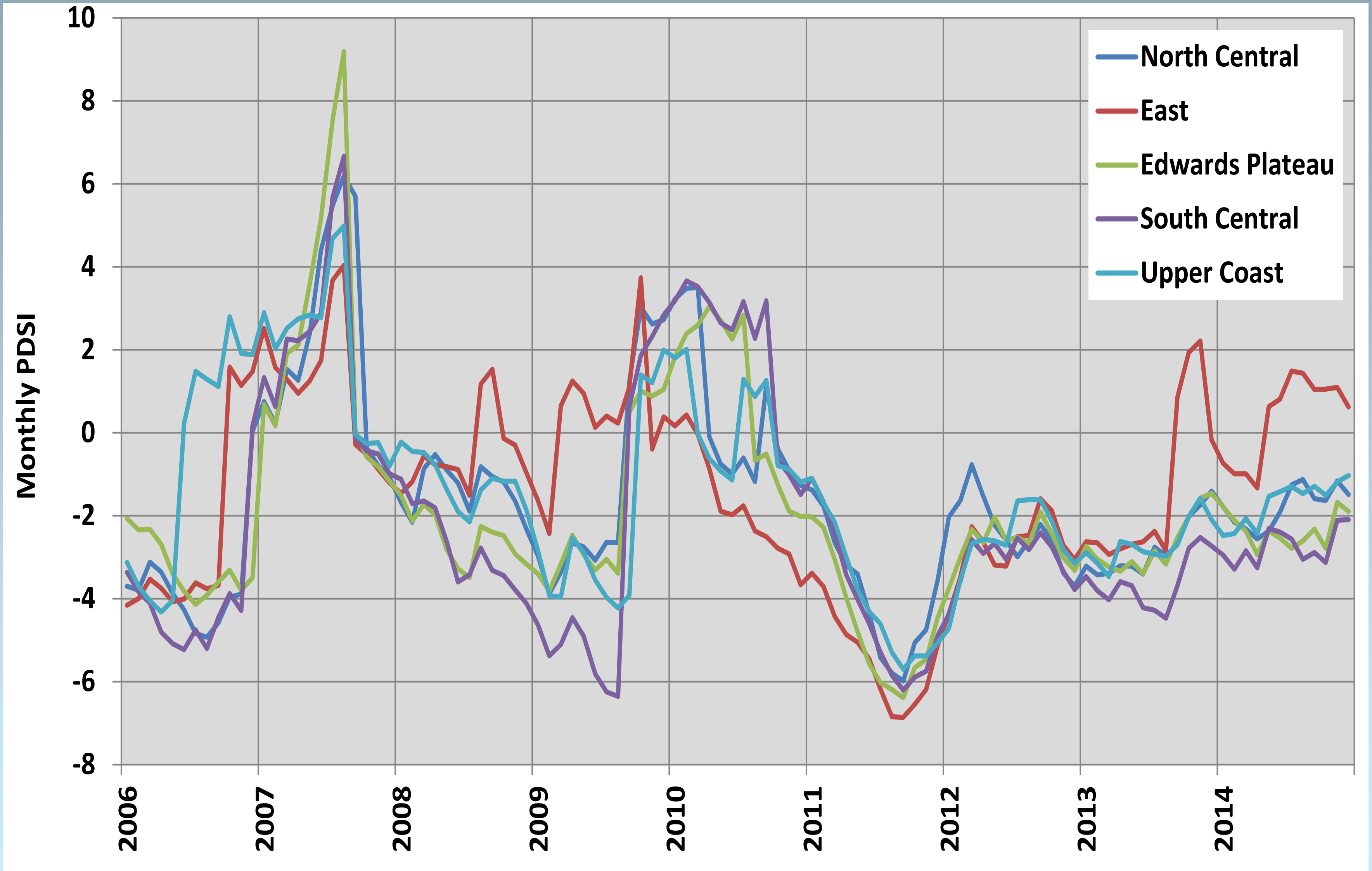


MEGAN configuration

- Default MEGAN gridded basal emission rates (ref. figure right)
- 1-km grid resolution over 4-km domain
- MODIS 4-day LAI
- 16 PFTs mapped from TCEQ's 36 categories
- PAR estimated as 0.45 times UAH 4km GOES-based insolation
- All other met inputs from NARR

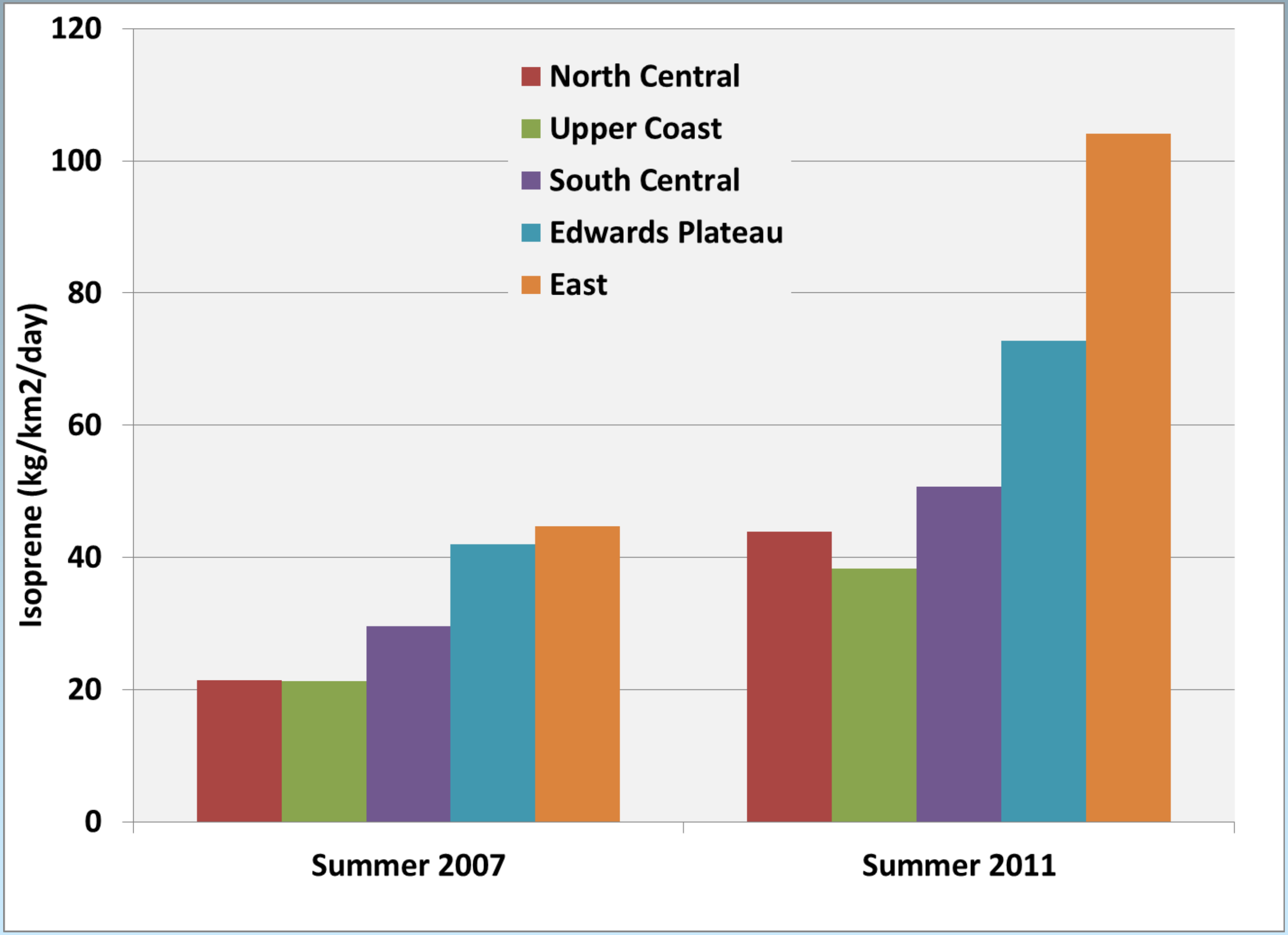


Monthly PDSI for five Texas climate divisions



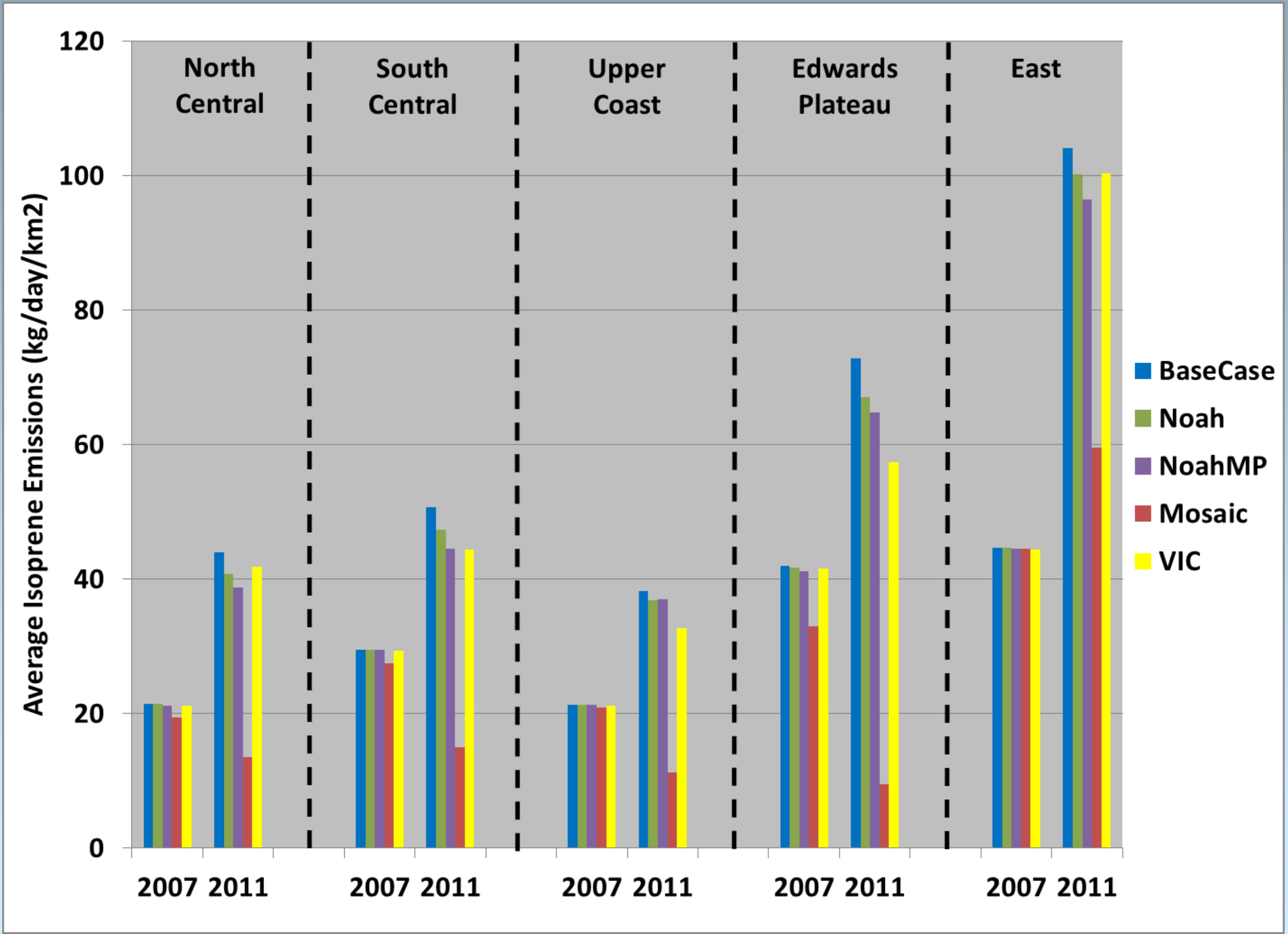
- Our focus is on years 2007 (wet), 2006 (dry) and 2011 (extremely dry)
- Today's presentation shows results for summers 2007 and 2011

Basecase isoprene estimates (impact of soil moisture not considered)

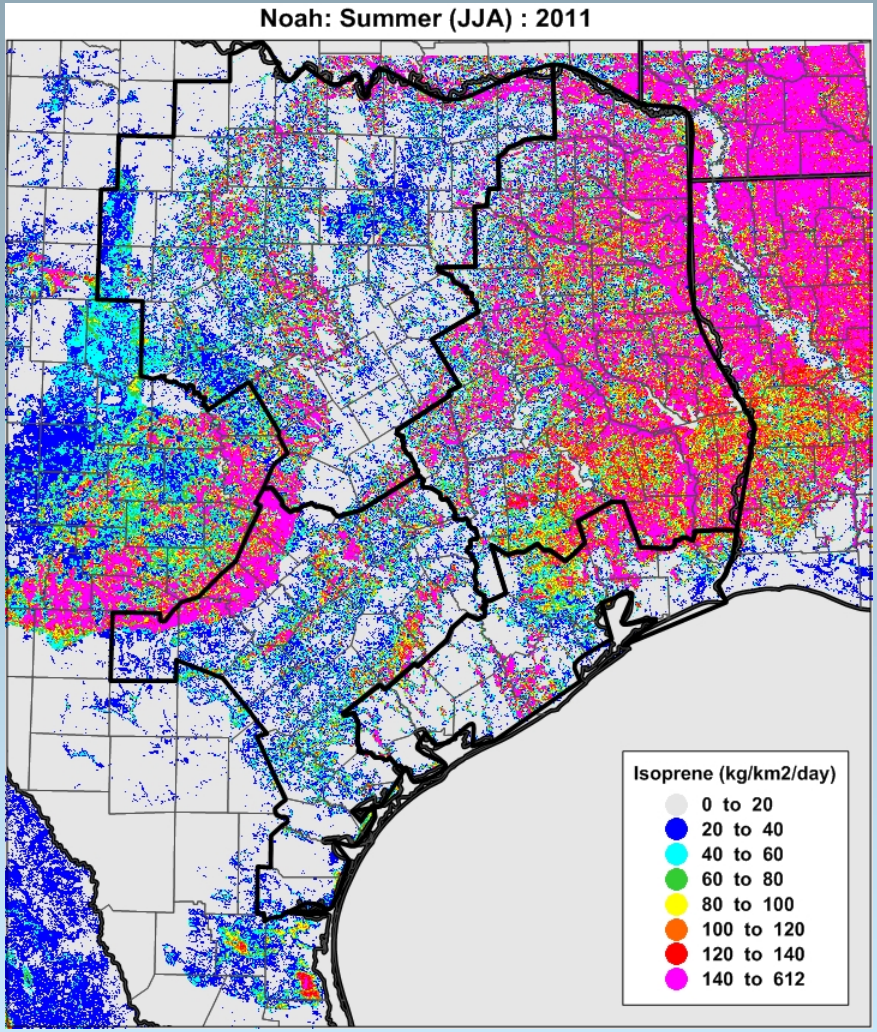


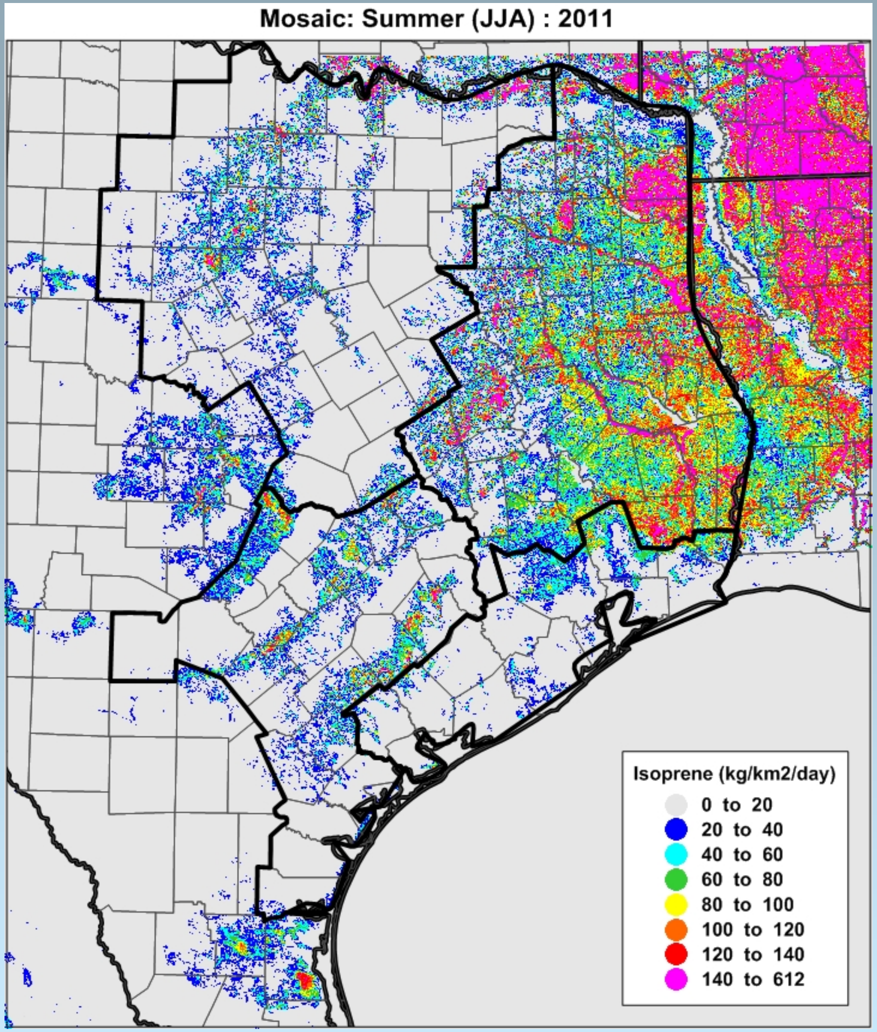
- Emissions for 2011 greater than 2007 driven by warmer temperatures
- Regionally-averaged emissions largest for East Texas

Summer averaged (2007 and 2011) isoprene emissions: basecase and NLDAS-2 scenarios



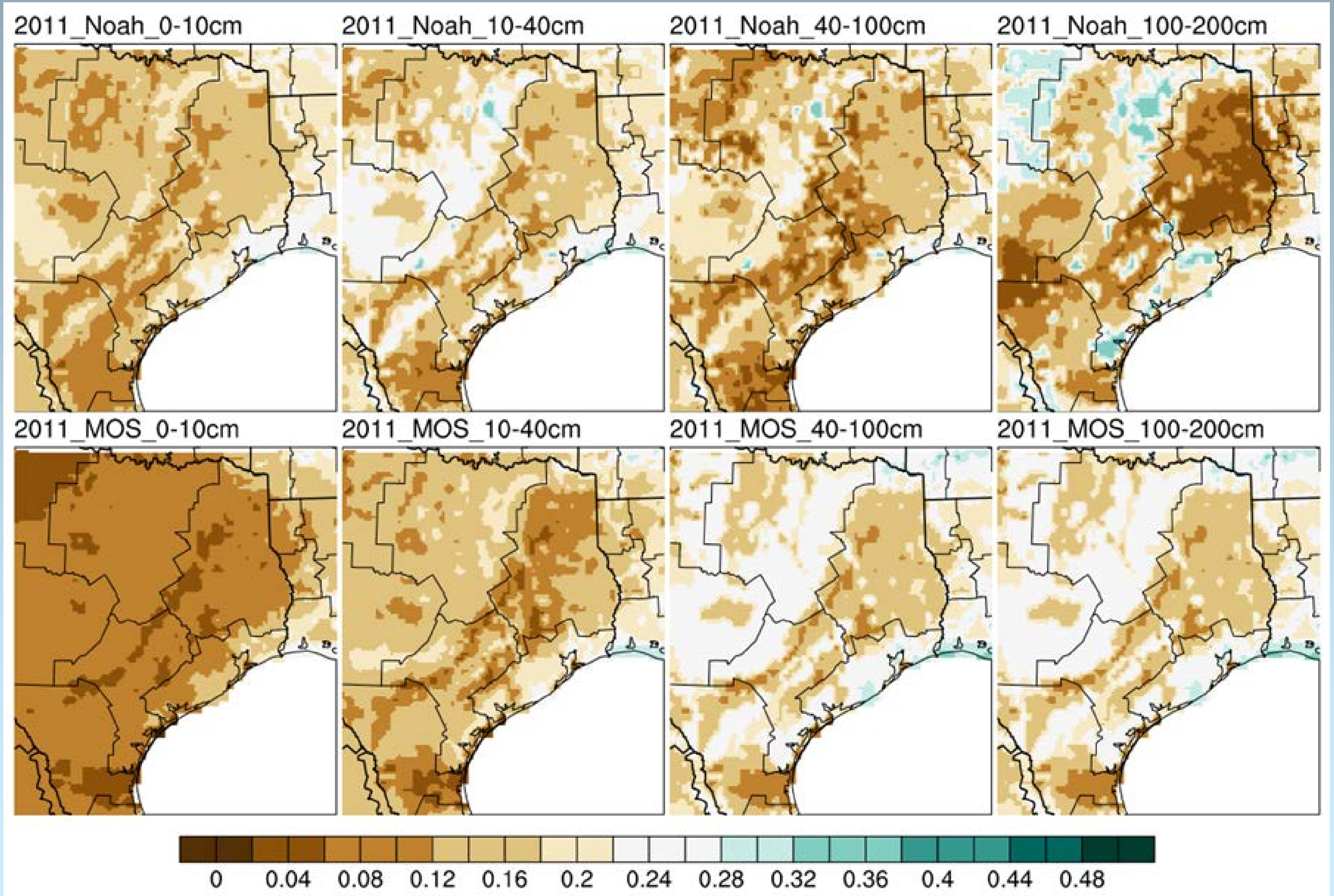
Noah (left) and Mosaic (right) summer 2011 isoprene



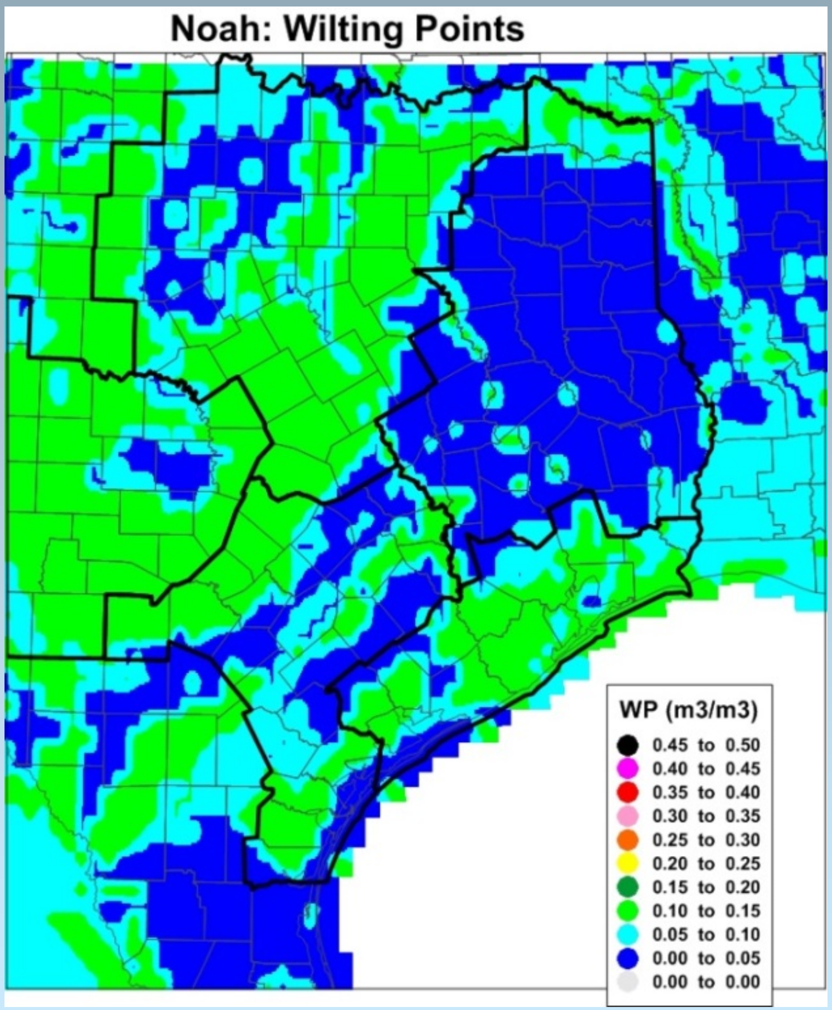


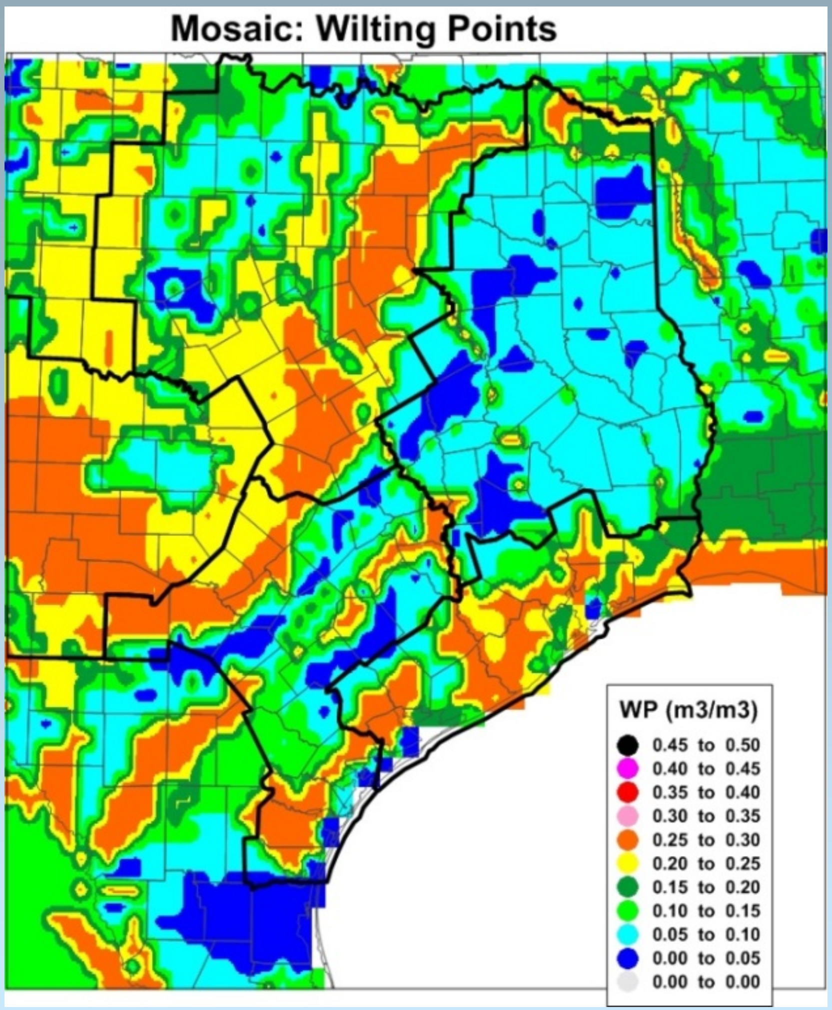
- Similar spatial patterns
- Mosaic results in lower predictions than Noah

Noah (top row) and Mosaic (bottom row) summer 2011 average soil moisture by depth



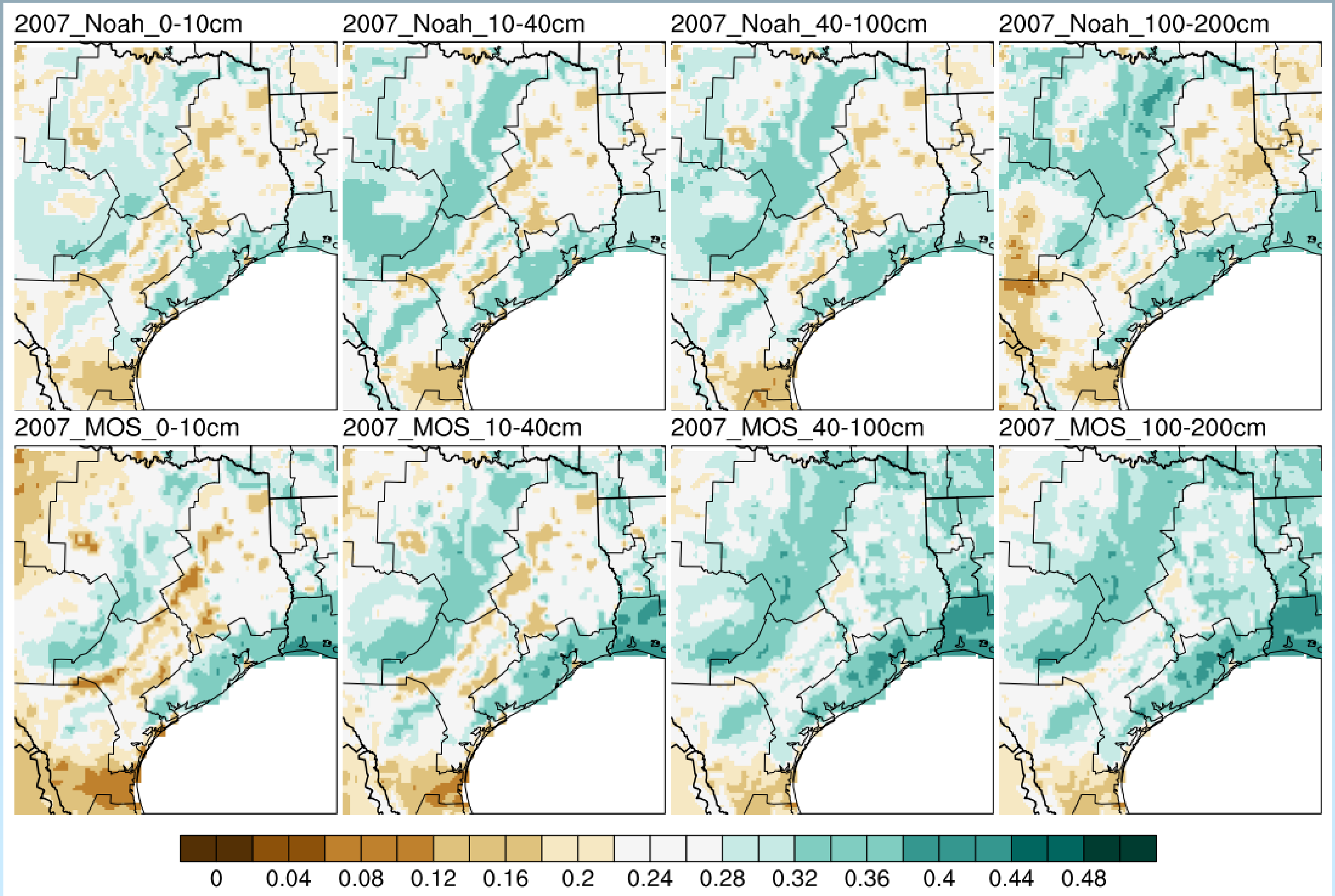
Noah (left) and Mosaic (right) wilting points



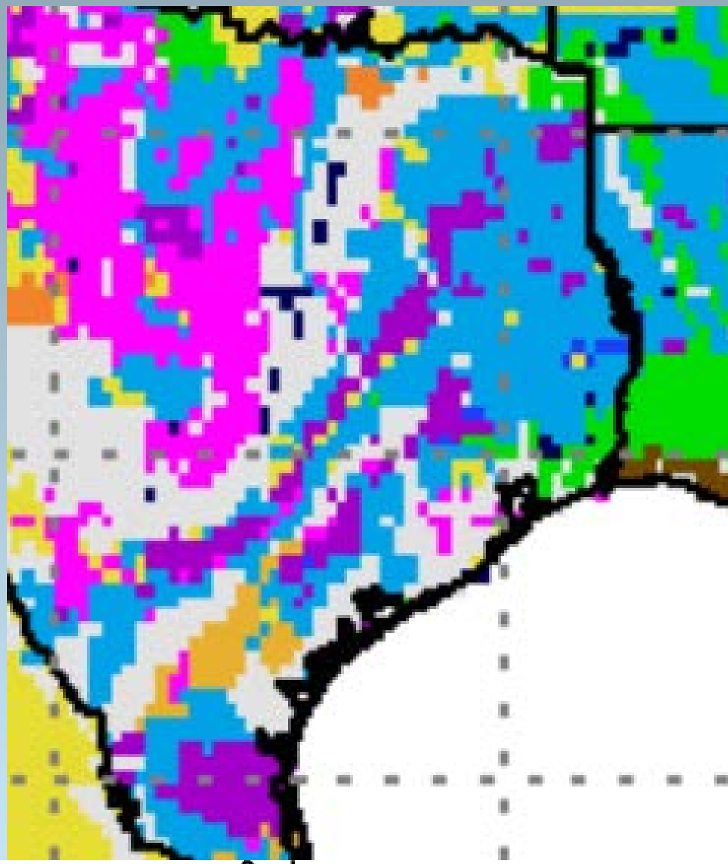


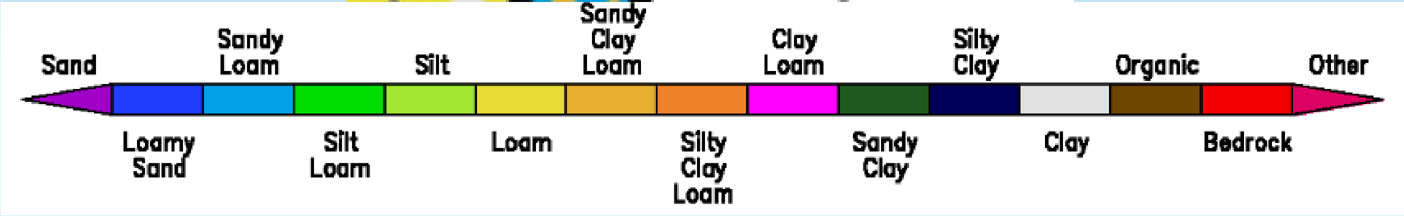
- Noah and NoahMP wilting points ~twice those of VIC and Mosaic

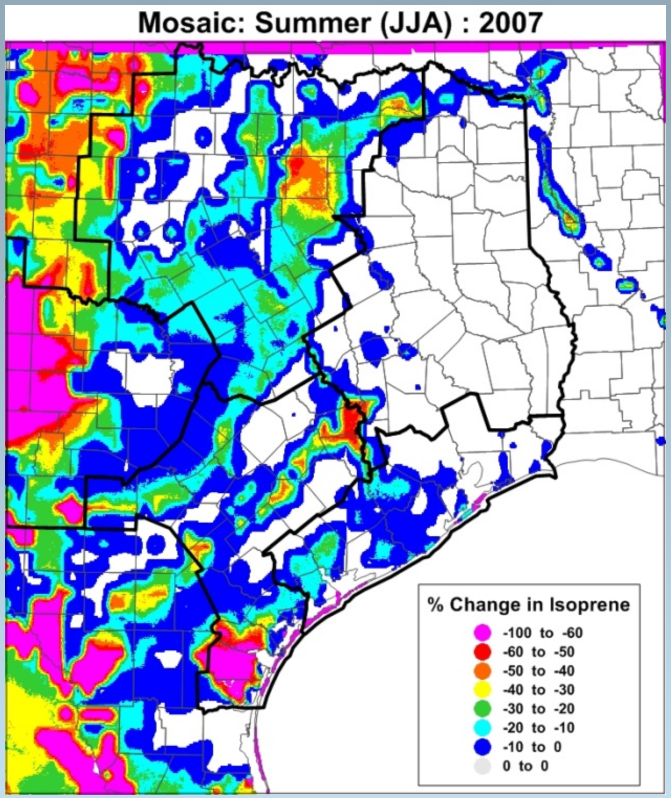
Noah (top row) and Mosaic (bottom row) summer 2007 average soil moisture by depth



NLDAS-2 soil texture (left) and percent reduction in summer 2007 Mosaic isoprene (right)







- Predicted isoprene reductions even during wet summer 2007 by Mosaic are most pronounced in regions characterized by clay soils

Summary of isoprene simulations

- Reductions in regionally-averaged isoprene during drought were within 15% of the base case with Noah, Noah-MP, and VIC soil moisture

- Mosaic-based predictions were often substantially less than basecase
  - Mosaic/VIC wilting points are twice as high as Noah/Noah-MP
  - For near-surface soil moisture, VIC has a wet bias while Mosaic is more similar to Noah/Noah-MP

- Isoprene predictions at limited eastern Texas in-situ locations that used observations were more similar to Mosaic results compared to the other LSMs (not shown)

- Overall NLDAS-2 MEGAN simulations demonstrate high sensitivity to both soil moisture and wilting point values

Recommendations for future work (extensions of current work)

- Investigate differences in LSM structure and physics to understand differences in LSM-specific soil properties (e.g., wilting points) and soil moisture biases

- Quantify effects of soil layer depth on predicted BVOC emissions. Investigate predicted emissions or LSM soil moisture by predominant soil/vegetation characteristics such as PFT, soil texture and/or wilting point

- Analyze emerging soil moisture observations in eastern Texas (e.g., in-situ SCAN, CRN, COSMOS, and TxSON measurements; SMAP satellite observations)

- Compare temporal and spatial patterns in MEGAN predictions to results from other environmental datasets (particularly satellite-based vegetation-dependent observations such as fluorescence, LAI, NDVI, etc.)

Additional areas for future work

- Recent research suggests a continued need for investigations to evaluate and improve the drought stress parameterizations and/or representations in models such as MEGAN (e.g., Potosnak et al., 2014)
  - Current algorithm is based on results from a single laboratory study (Pegoraro et al., 2004) that is highly sensitive to the specific soil moisture database (especially wilting points) employed

- Extensions of soil moisture algorithm to include additional BVOCs to isoprene such as monoterpenes; consideration of species-specific responses of BVOC emissions to both short- and long-term soil water deficits

- Additional ecosystem-level studies under a range of natural drought conditions would likely provide valuable insights toward improved BVOC predictions