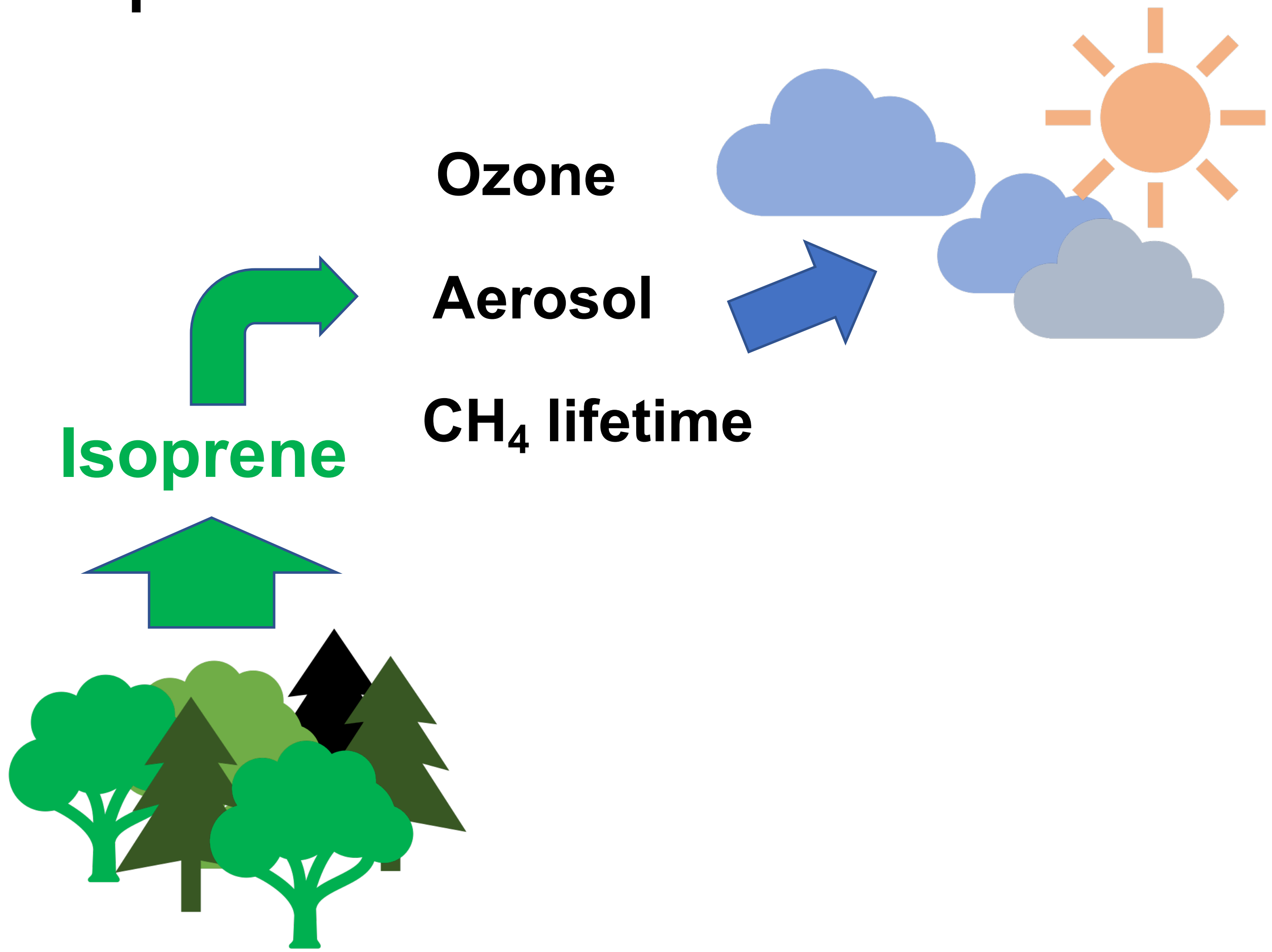
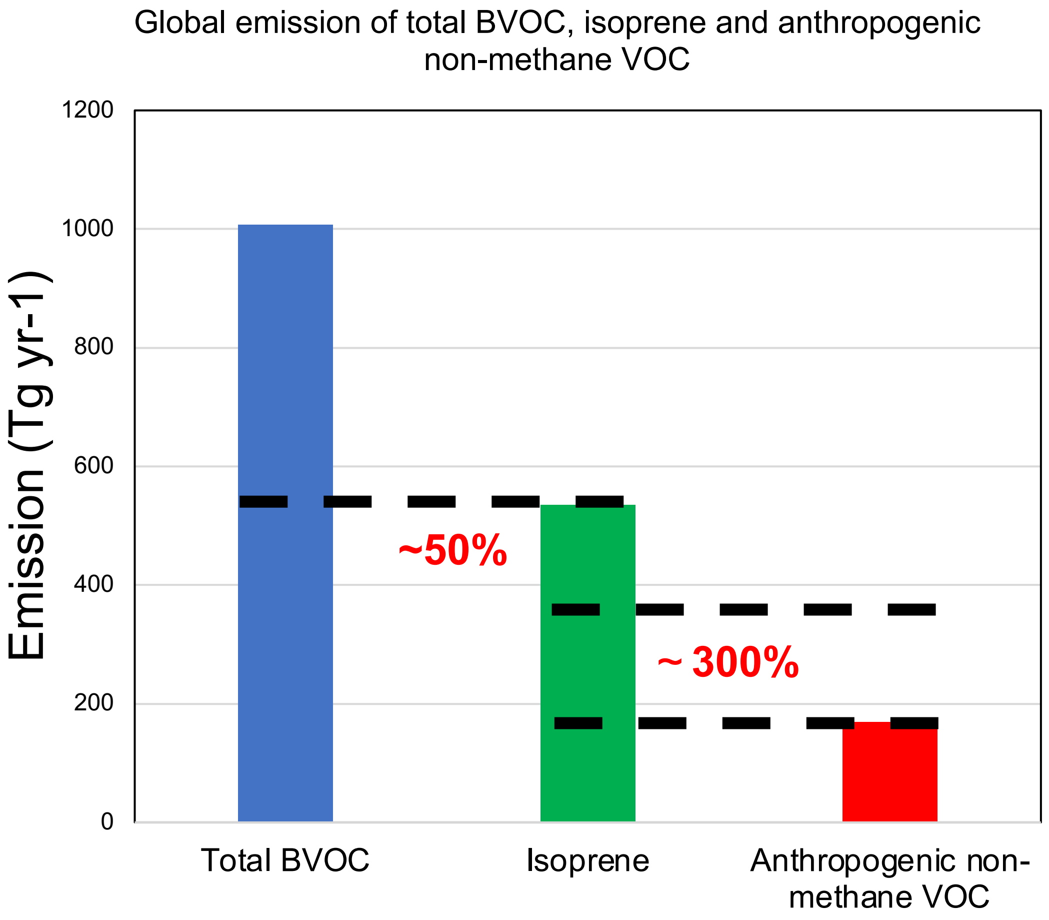
Modeling isoprene emission response to drought and heatwaves within MEGAN using evapotranspiration data and by coupling with the Community Land Model

Hui Wang[1*], Xinchen Lu[2], Roger Seco[3], Trissevgeni Stavrakou[4], Thomas Karl[5], Xiaoyan Jiang[1], Lianhong Gu[6], Alex B. Guenther[1*]

1. Department of Earth System Science, University of California, Irvine, California, USA
2. Department of Environmental Science, Policy and Management, University of California, Berkeley, California, USA
3. Institute of Environmental Assessment and Water Research (IDAEA-CSIC), Barcelona, Catalonia, Spain
4. Royal Belgian Royal Institute for Space Aeronomy (BIRA-IASB), Brussels, Belgium
5. Department of Atmospheric and Cryospheric Sciences, University of Innsbruck, Innsbruck, Austria
6. Environmental Sciences Division and Climate Change Science Institute, Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA

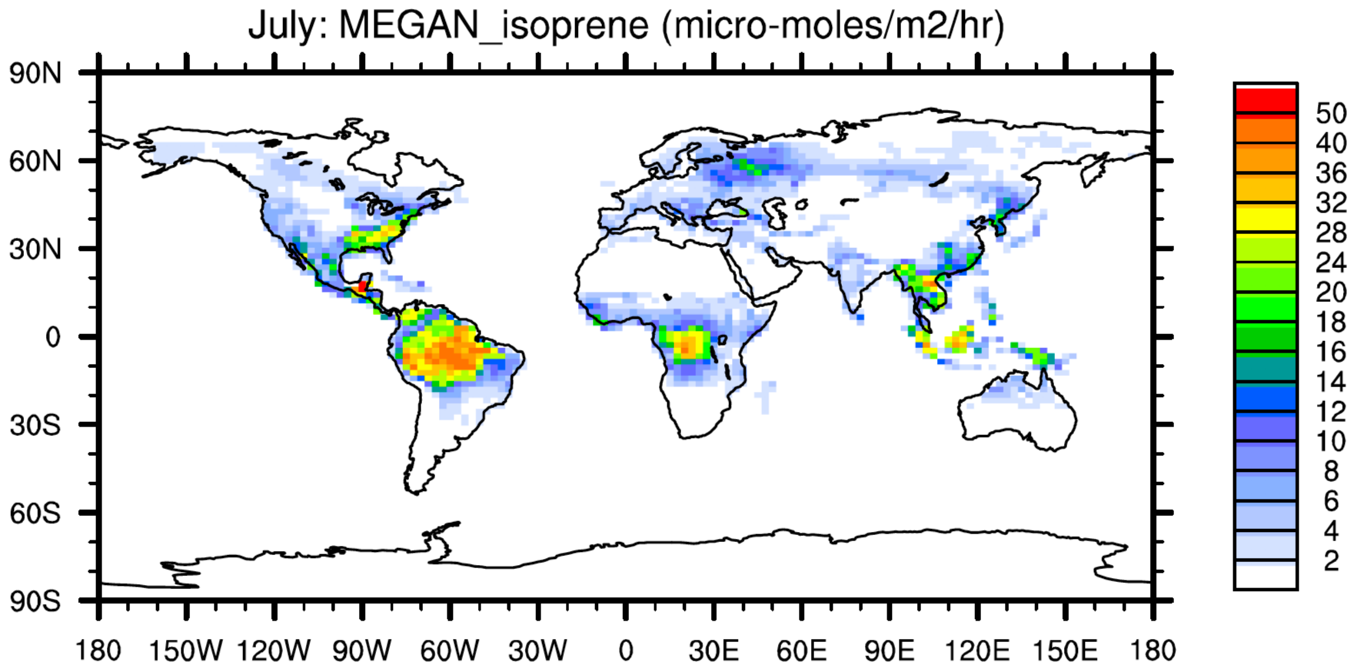
Isoprene


Ozone
Aerosol
CH_4 lifetime
Isoprene


Global emission of total BVOC, isoprene and anthropogenic non-methane VOC
Emission (Tg yr-1)
1200
1000
800
600
400
200
0
~50%
~ 300%
Total BVOC
Isoprene
Anthropogenic non-methane VOC

Modeling for isoprene emission

The Model of Emissions of Gases and Aerosols from Nature (MEGAN)



$$E = \varepsilon \cdot C_{ce} \cdot LAI \cdot \gamma_T \cdot \gamma_P \cdot \gamma_A \cdot \gamma_{CO_2} \cdot \gamma_{SM}$$

- Temperature
- Radiation
- Leaf age
- CO_2 concentration
- Drought

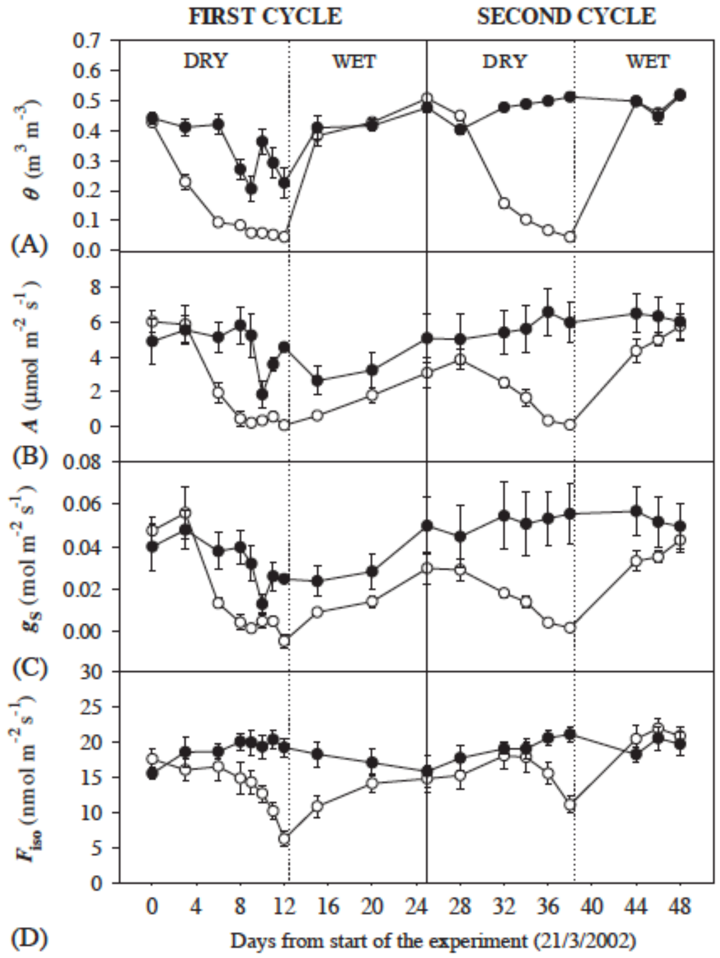
(Guenther et. al, 2012)

Isoprene emission has drought resistance

Table 3. Effect of water stress on isoprene emissions and other gas-exchange parameters in live oak plants. Means are geometric except for net photosynthetic rate and moisture content; all are based on four plants. SGD: standard geometric deviation; SD standard devition. The plants were on a 16-h photoperiod with a PPFD of 550 μmol m^{-2} s^{-1} and a leaf temperature of 29±1° C during the light

Days from watering	Moisture content (%)	Isoprene emission rate (μg C dm^{-2} h^{-1})	Net photosynthetic rate (mg CO_2 dm^{-2} h^{-1})	Transpiration rate (mg H_2O dm^{-2} h^{-1})	Leaf conductance (cm s^{-1})
1	76	14.0	4.80	398	0.093
2	53	13.9	3.97	373	0.079
3	36	14.9	1.22	224	0.024
4	26	14.0	0.09	131	0.008
5	24	7.0	−0.26	97	0.005
	SD 5.37	SGD 1.53	SD 1.54	SGD 1.31	SGD 2.24

(Tingey et al., 1981)



Soil Water Content

Photosynthetic rates

Stomatal conductance

Isoprene emission

(Pegoraro et al., 2004)

Drought may affect isoprene emission indirectly

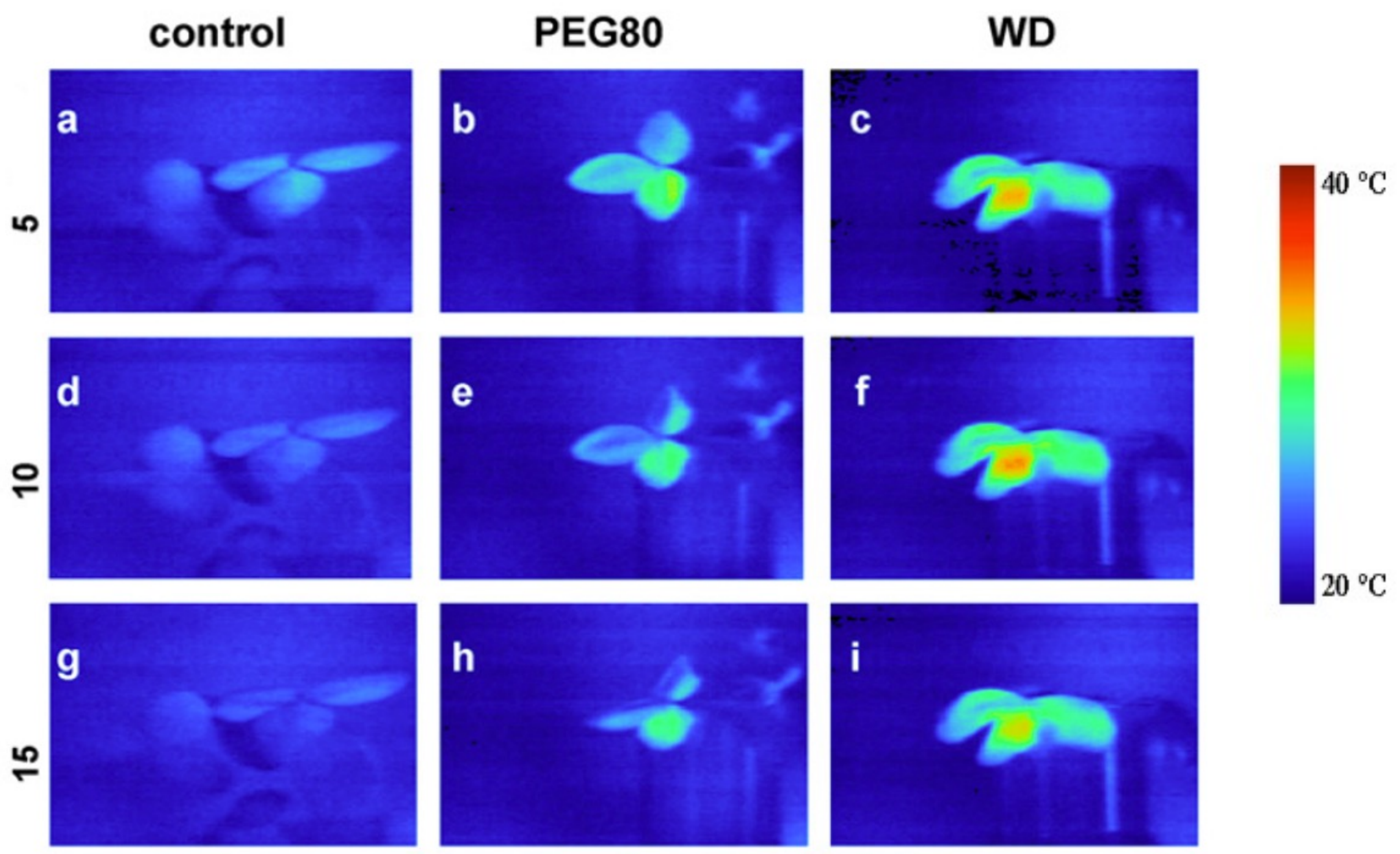
Water Stress

Stomatal Conductance

Transpiration

Leaf Temperature

Isoprene emission



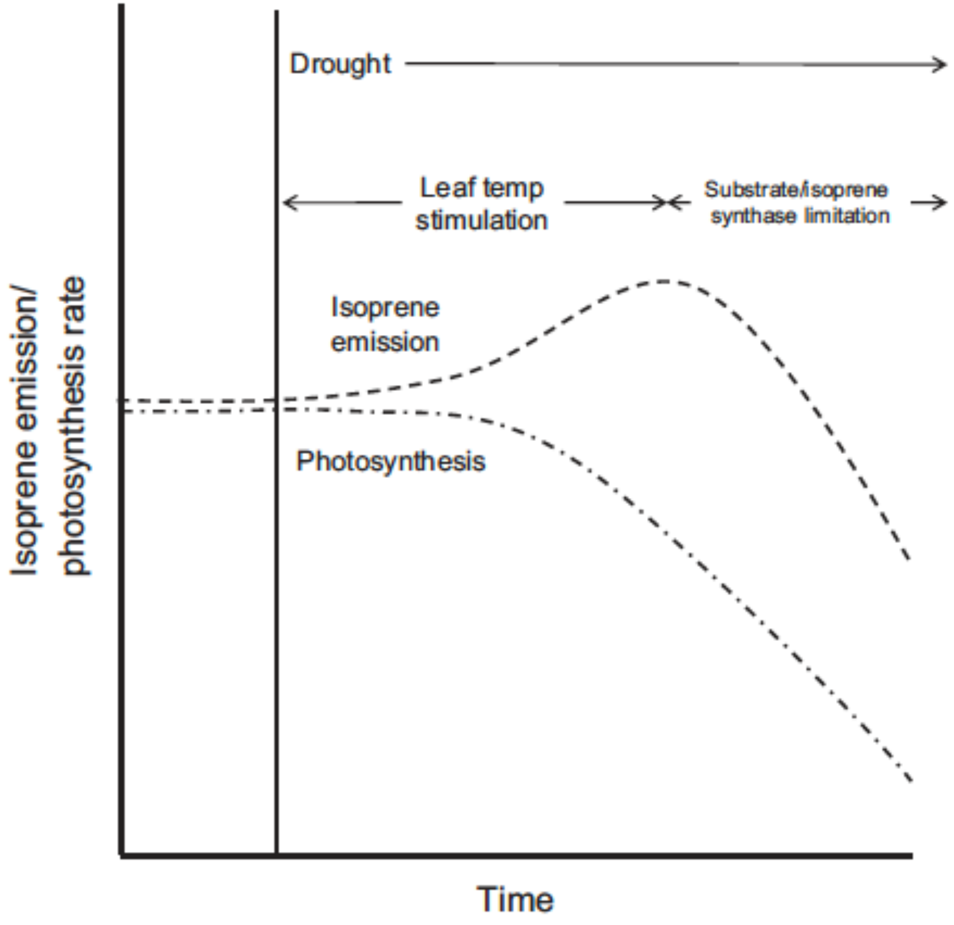
(Reynolds-Henne et al., 2010)

The impact of drought on isoprene emission

- **Mild or moderate drought:**
  Have no impact or increase isoprene emission indirectly.

- **Severe Drought:**
  Decrease isoprene emission.

1. How to measure the severity of drought?
2. What's threshold to active the impact of drought?
3. How to quatify the impact of drought?



(Potosnak et al., 2014)

Drought algorithm in MEGANv2.1

$$\begin{cases} \gamma_{SM} = 1 & (\theta > \theta_{\mathrm{w}} + \Delta\theta) \\ \gamma_{SM} = (\theta - \theta_{w})/\theta_{\mathrm{w}} + \Delta\theta & (\theta_{w} < \theta < \theta_{\mathrm{w}} + \Delta\theta) \\ \gamma_{SM} = 0 & (\theta < \theta_{w}) \end{cases}$$

- θ: Soil moisture
- θw: Wilting point
- $\Delta\theta = 0.04\ \mathrm{m}^3/\mathrm{m}^3$

(Guenther et al., 2012)

1. How to measure the severity of drought?
   Using soil moisture.
2. What's threshold to active the impact of drought?
   The wilting Point (θw) and the critical soil moisture (θ_1).
3. How to quatify the impact of drought?
   Using the linear equation above.

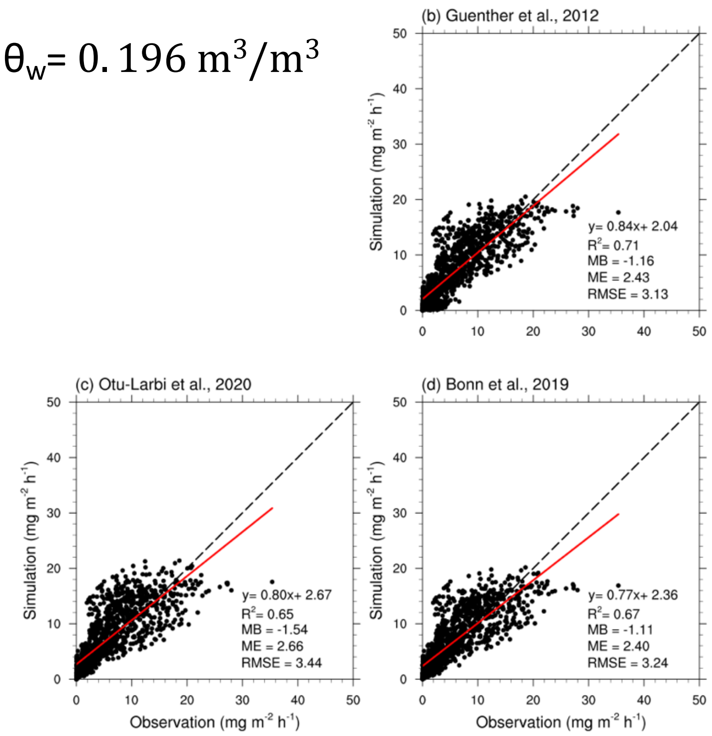
Limitations about soil moisture-based drought algorithm

1) Uncertainty of thresholds;
2) Inconsistences of soil moisture values among different datasets/layers;
3) Neglecting the impact of atmospheric vapor pressure deficit;
4) Ignoring the indirect impact of drought on isoprene through increased leaf temperature.

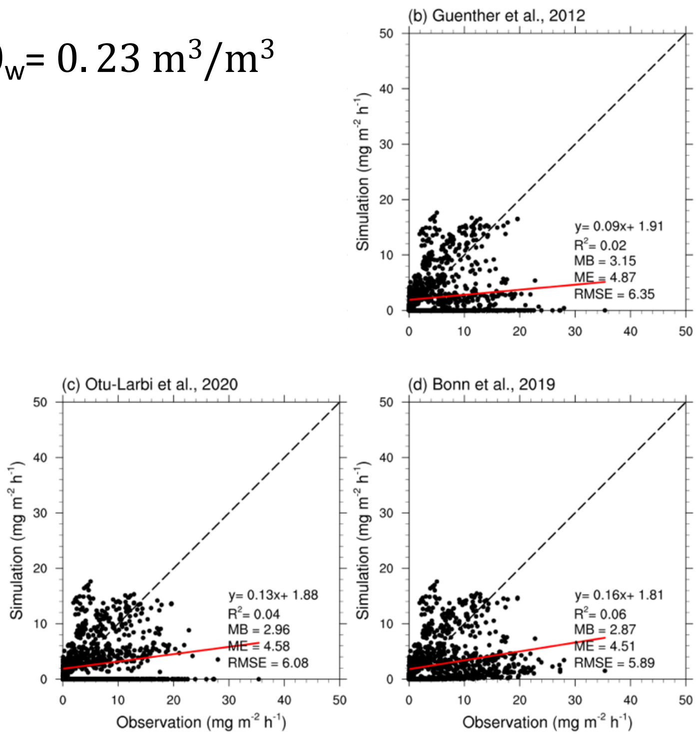
Limitations about soil moisture-based drought algorithm

Uncertainty of thresholds

- $\theta_w = 0.196\ m^3/m^3$



- $\theta_w = 0.23\ m^3/m^3$



3.4. Uncertainty of isoprene emissions to soil moisture

In order to test the sensitivity of isoprene predictions during drought to the specific soil moisture database employed, MEGAN simulations were conducted for North Central and East Texas using the Mosaic soil moisture database in place of the Noah MP database. As demonstrated in Table 2, the Mosaic simulations for the all-time record drought year 2011 predicted dramatically lower isoprene emissions compared to those for the basecase (i.e., impact of soil moisture not considered) and Noah MP runs. Maximum reductions were −69% for the North Central summer compared to −12% for Noah MP. An investigation of upper-level soil moisture values revealed that Mosaic tends to predict lower moisture availability compared to Noah MP; crucially, the Mosaic wilting point values are almost a factor of two greater than those for Noah MP. The difference in the wilting points between the NLDAS-2 databases is significant because θ_{wilt} is a threshold value below which γ_{SM} is set to zero (ref. Eq. (4)).

(Huang et al., 2015)

Online drought response algorithm based on the Community Land Model

- Drought indicator: soil water stress function (β_t)

$$\beta_t = \sum w_i r_i$$

*** Wilting factor (w_i). Vertical root discribution factor (r_i) at layer i;**

- Drought algorithm:

$$g_s = m \frac{A_n}{C_s/P_{atm}} h_s + b\beta_t$$

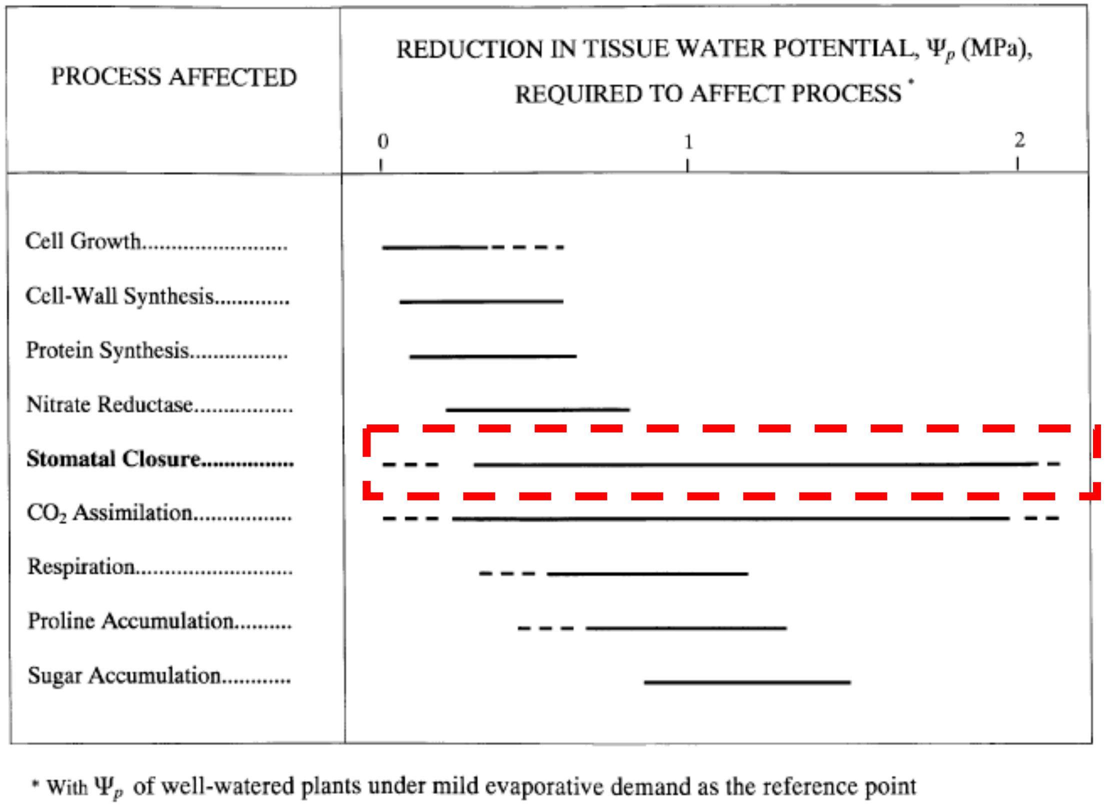
$$\begin{cases} \gamma_{SM} = 1 \; (\beta_t \geq 0.6) \\ \gamma_{SM} = \; V_{cmax}/\alpha \;\; (0 < \beta_t < 0.6) \\ \gamma_{SM} = 0 (\beta_t = 0) \end{cases}$$

*** Stomotal conductance (g_s) response to drought (β_t);**

*** Subtrate supply (Vcmax) response to drought (β_t);**

(Jiang et al., 2018)

Water stress indicator



(Porporato et al., 2001)

ET is the actual evapotranspiration (evaporation and transpiration).

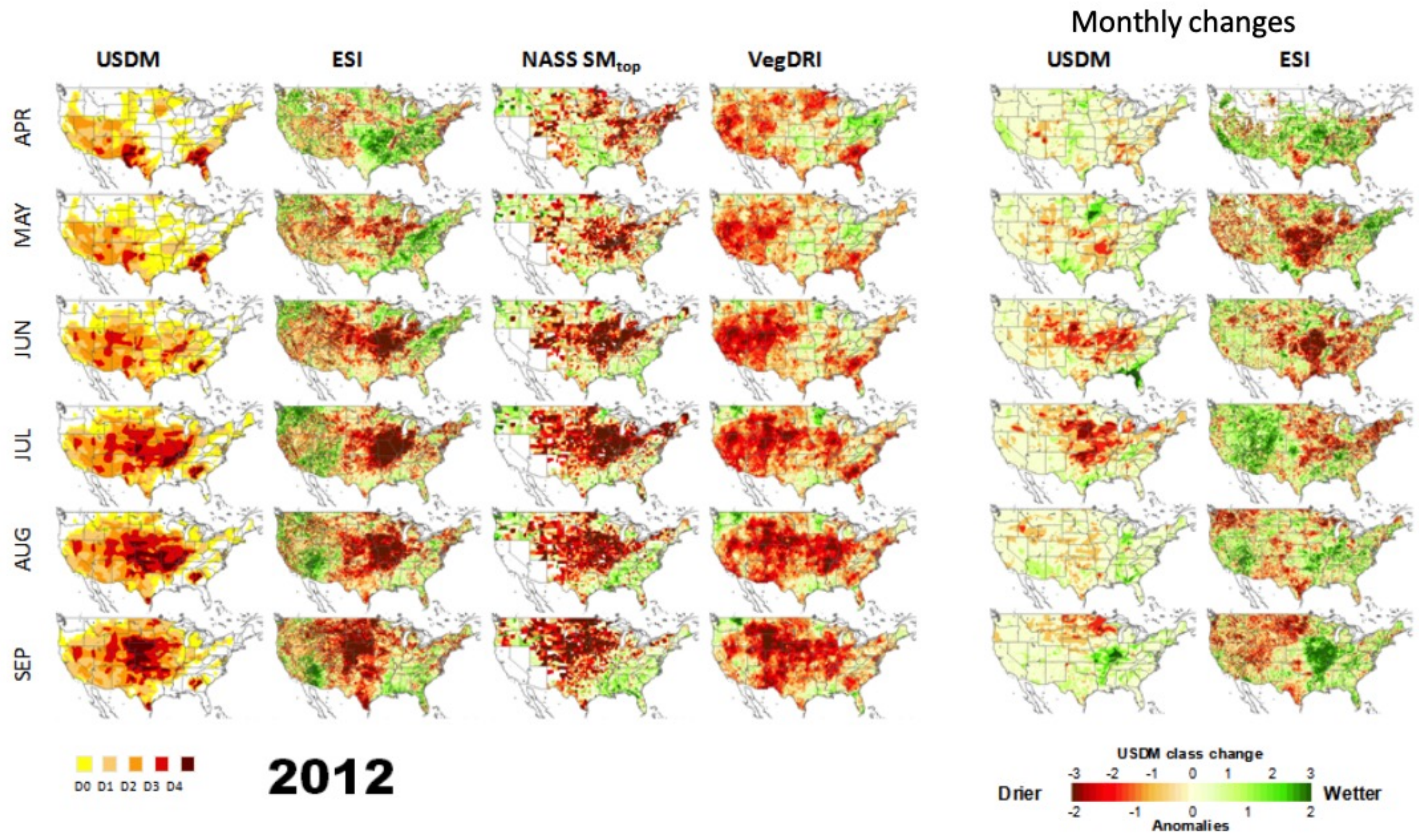
Evapotranspiration (ET)

$$f_{pet} = \frac{ET}{PET}$$

Potential Evapotranspiration (PET)

PET is generally defined as the amount of water that could evaporate and transpire from a vegetated landscape without restrictions other than the atmospheric demand (Lu et al., 2005).

Water stress indicator



Two remote sensing drought indicators are examined in this study—anomalies in ET and f_{PET}, which is the ratio of actual ET to PET:

$$f_{PET} = \frac{ET}{PET}, \qquad (1)$$

(Anderson et al., 2011)

ECOSTRESS

Algorithm

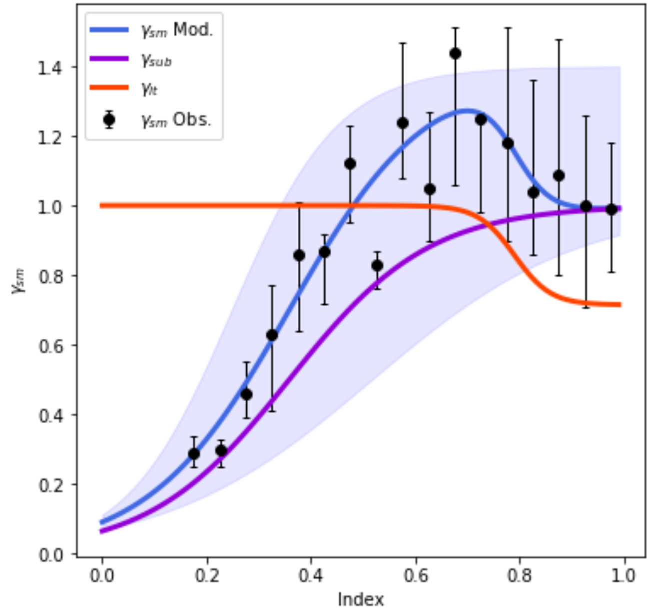
$$\gamma_{sm} = \gamma_{sm\_max} \frac{1}{1 + b_1 \cdot e^{a_1 \cdot (f_{PET} - 0.2)}} \cdot \left(1/\gamma_{sm\_max} + \frac{(1 - 1/\gamma_{sm\_max})}{1 + b_2 \cdot e^{a_2 \cdot (1.3 - f_{PET})}}\right)$$

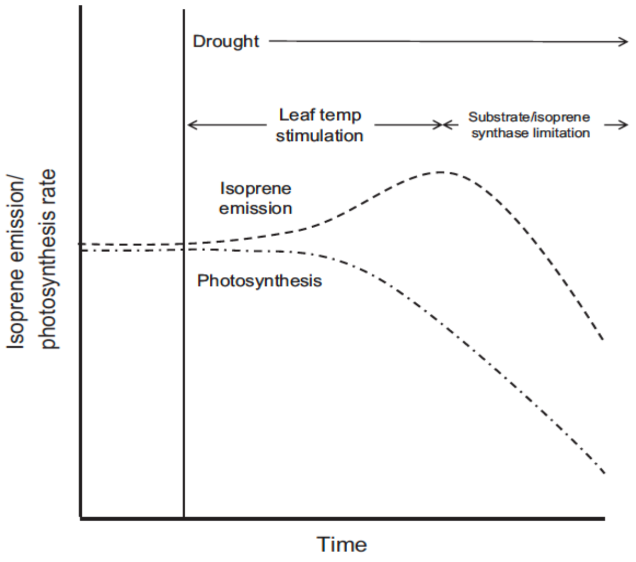
Drought factor for substrate supply (γ_{sm_sub}).

Drought factor for leaf temperature change (γ_{sm_fl}).

γ_{sm_max} : Maximum value of the γ_{sm} (=1.4).

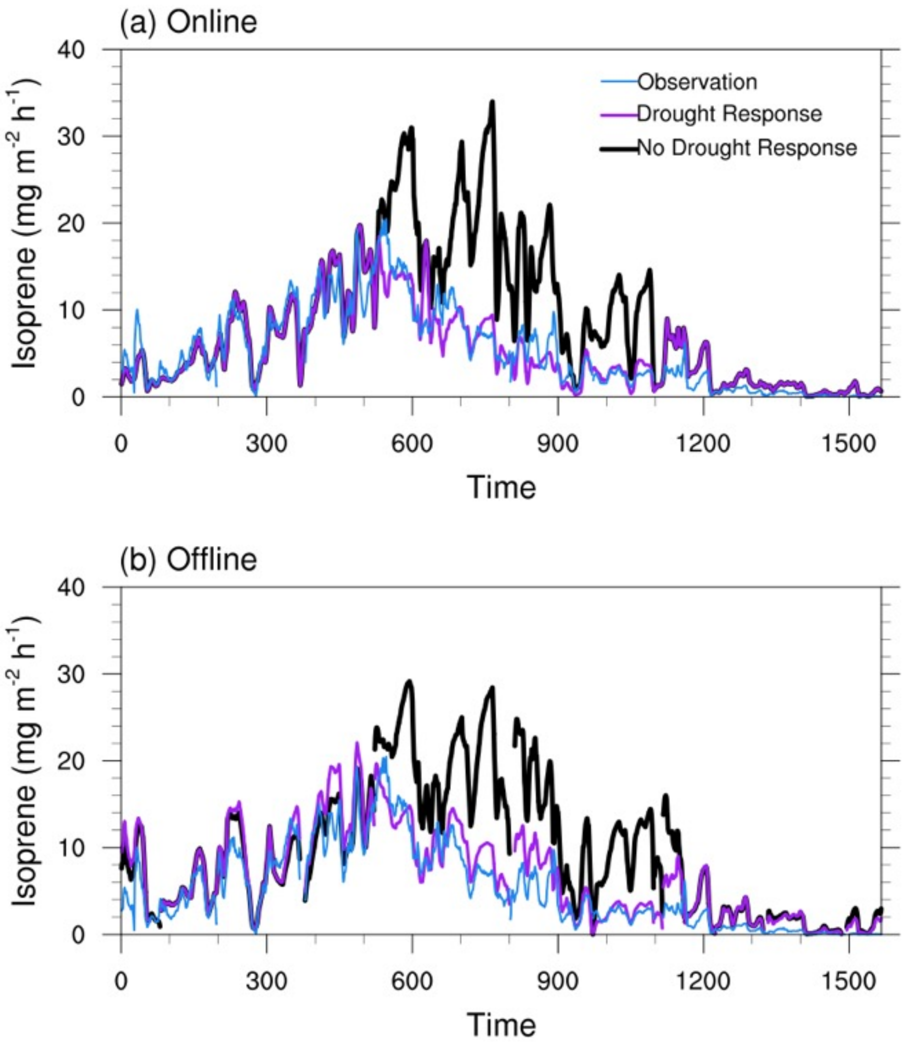
a_1, a_2, b_1, b_2: Empirical parameters.

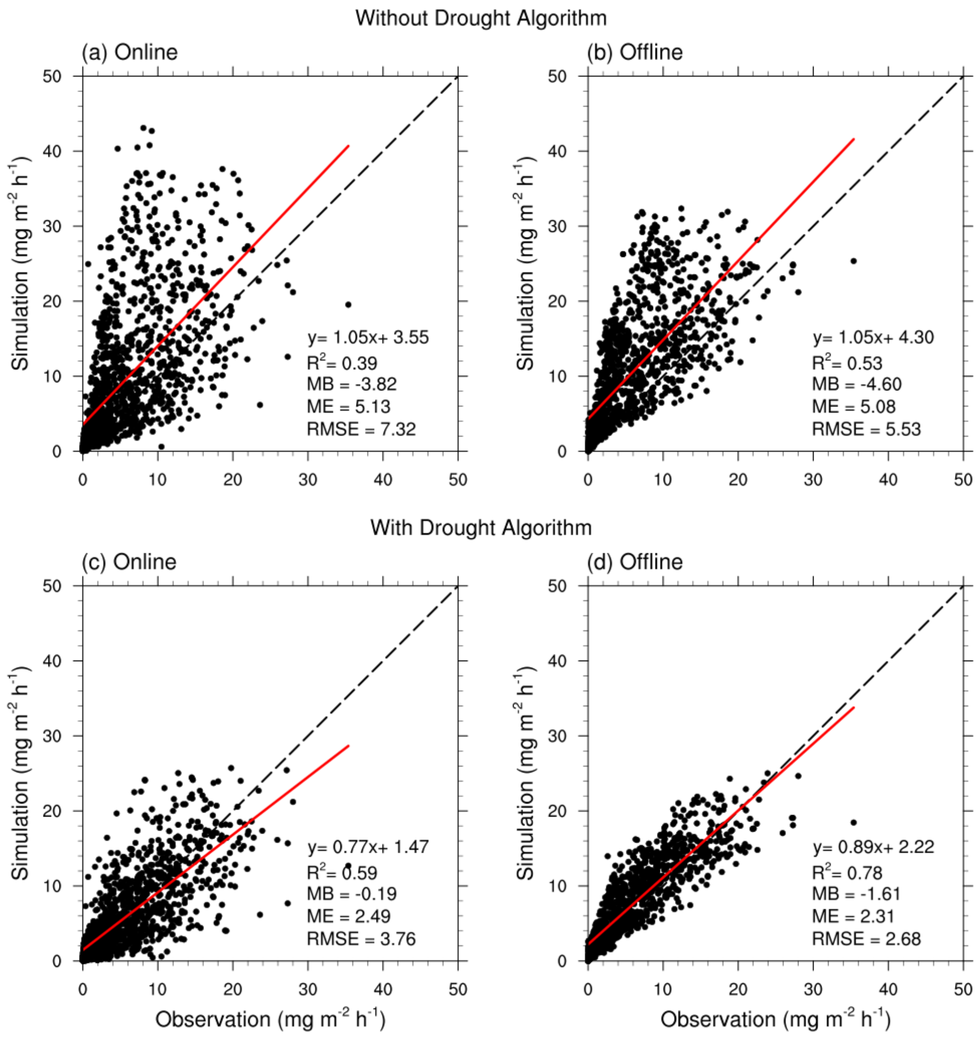




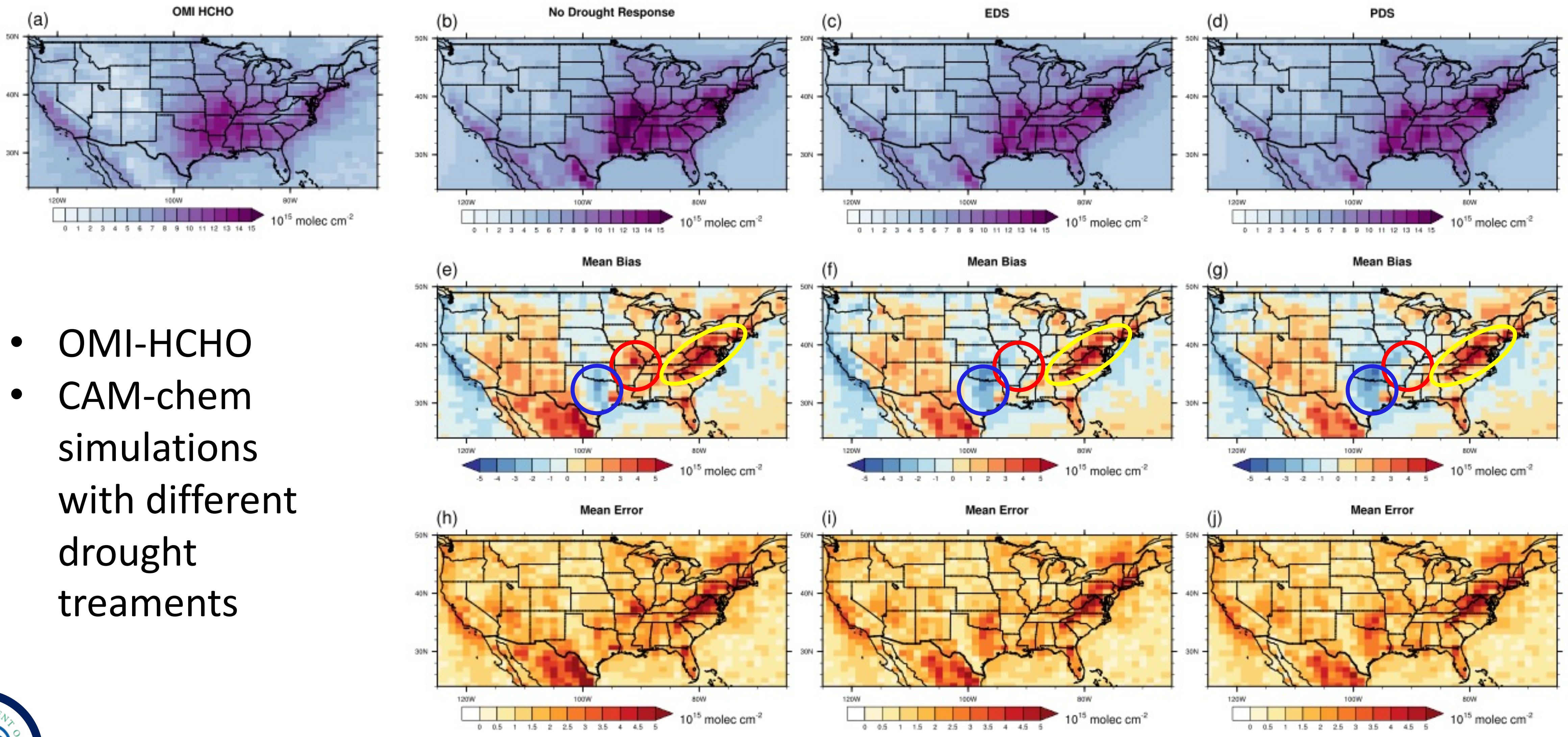
(Potosnak et al., 2014)

MOFLUX site validation

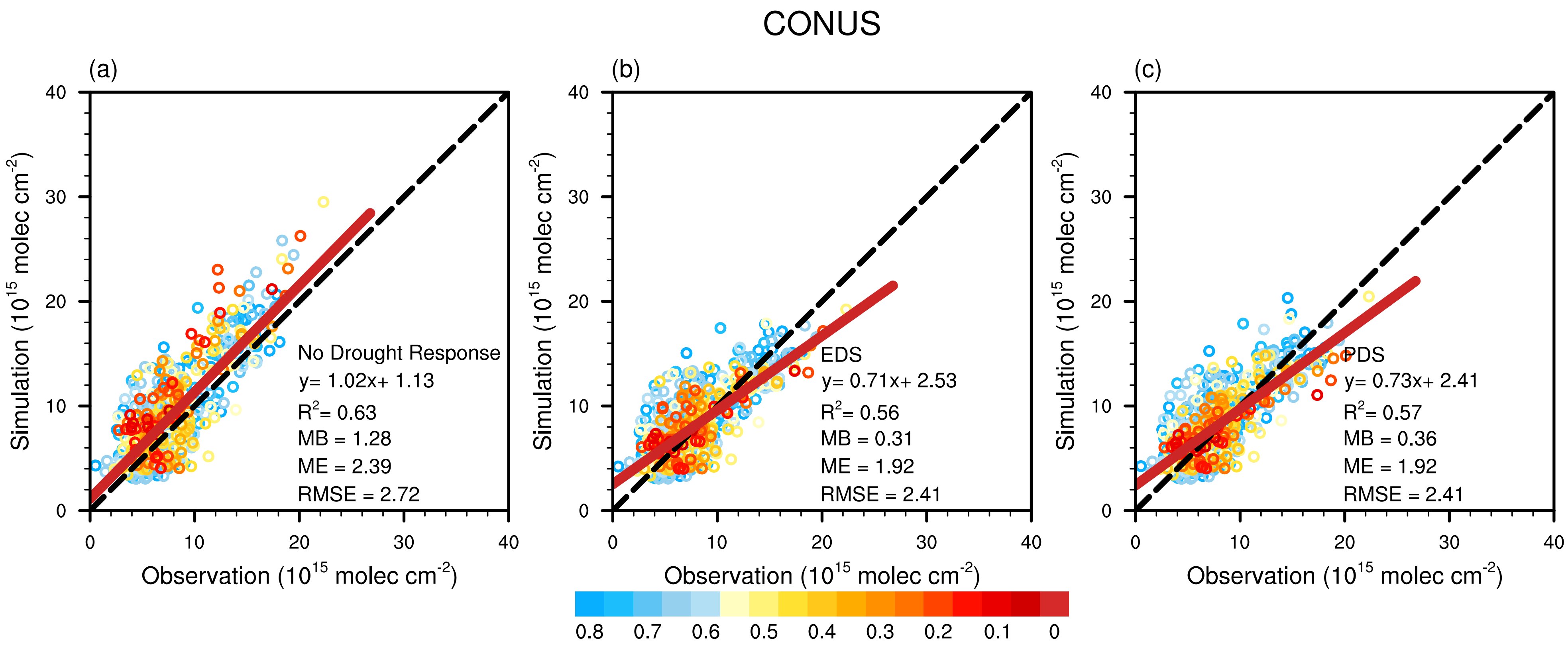




Horizontal comparisons of HCHO simulation error

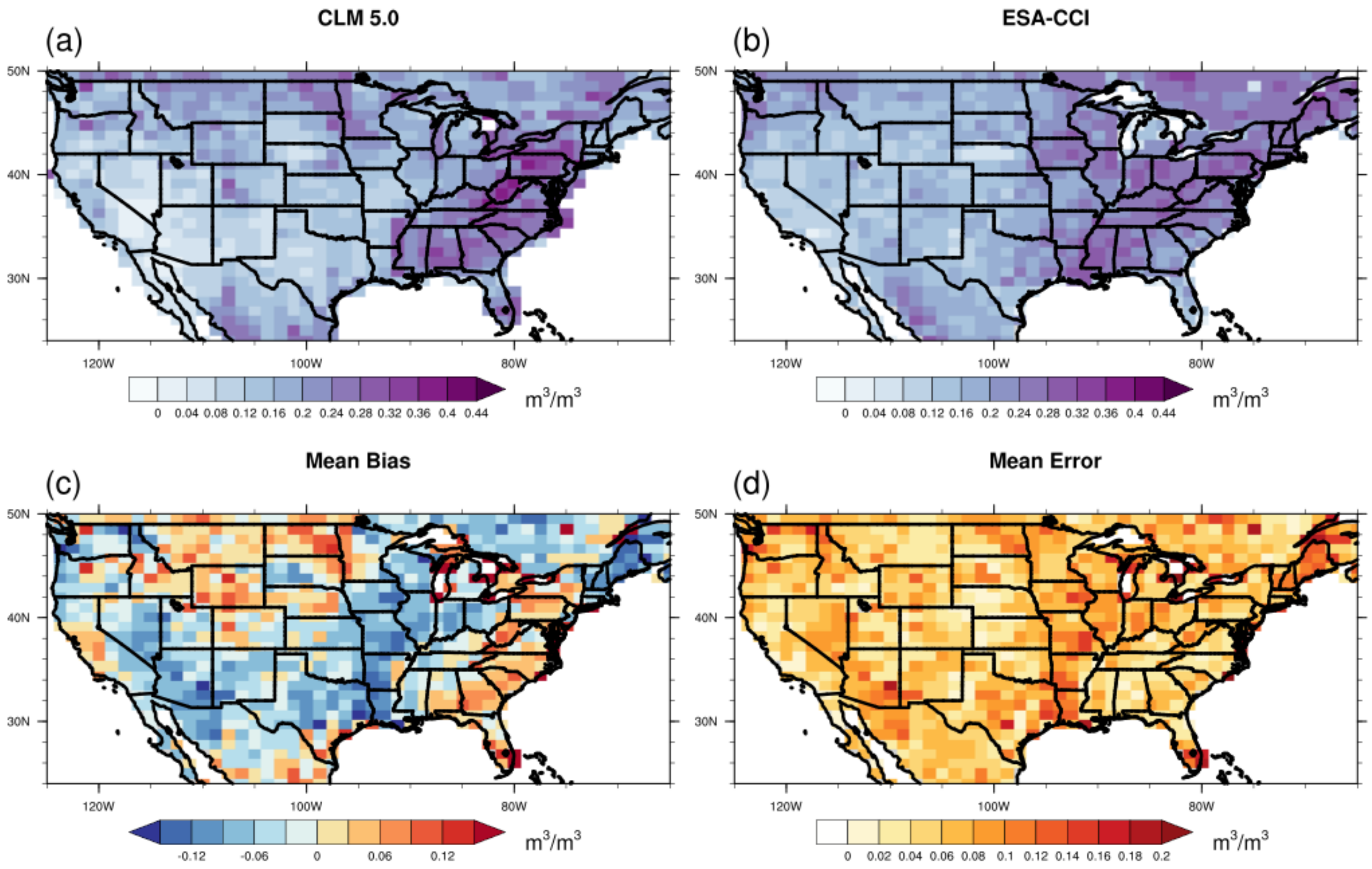


- OMI-HCHO
- CAM-chem simulations with different drought treaments

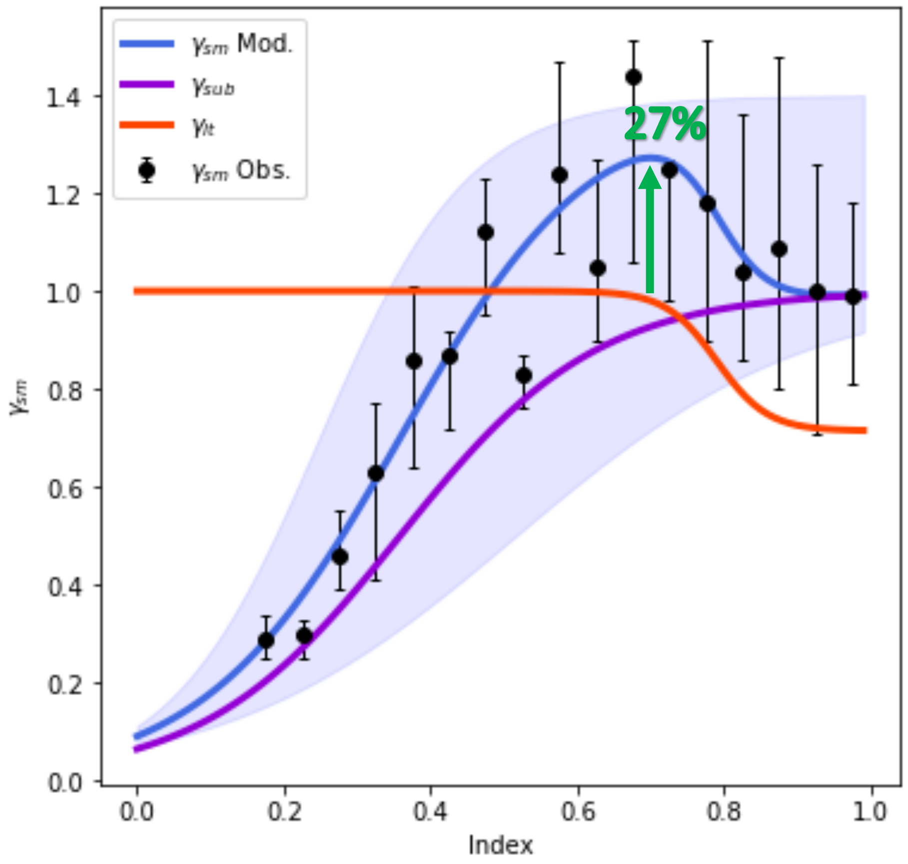


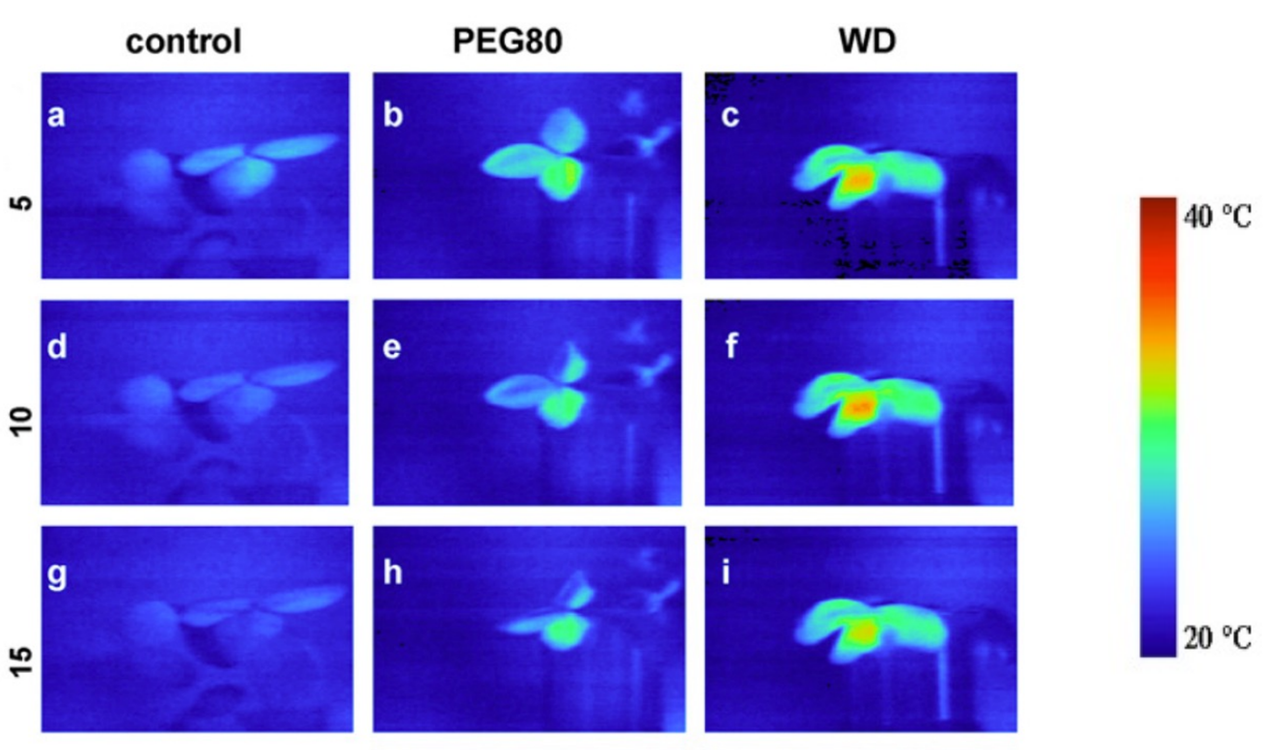
Comparison between the monthly OMI and CAM-chem HCHO vertical column densities in the CONtiguous United States (CONUS). The color of the points represents the severity of water stress.

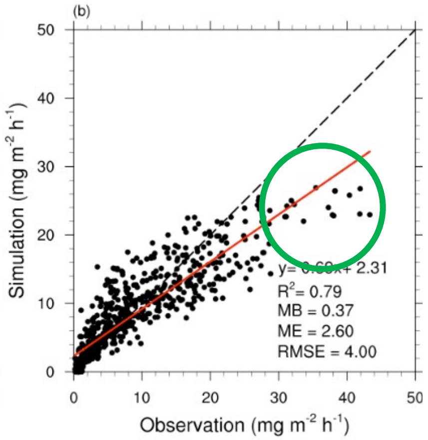
Validation of the surface soil moisture simulated by CLM

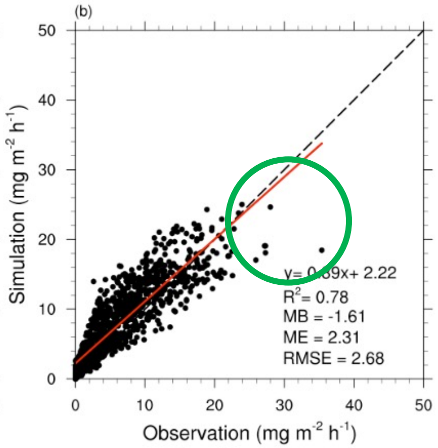


Weakness of the algorithm









Conclusions

- A better way to represent the water-stress in the isoprene emission model.
- A simple model framework for simulating the impact of water stress on isoprene emission.
- The inaccurate drought simulation can directly affect the modeling of drought impact on isoprene.

Wang, H., Lu, X., Seco, R., Stavrakou, T., Karl, T., Jiang, X., et al. (2022). Modeling isoprene emission response to drought and heatwaves within MEGAN using evapotranspiration data and by coupling with the community land model. *Journal of Advances in Modeling Earth Systems*, 14, e2022MS003174. https://doi.org/10.1029/2022MS003174

Thank you!