Relationships between photosynthesis and formaldehyde as a probe of isoprene emission

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NASA SEAC4RS Science Team Meeting
Pasadena, California, April 2015

Isoprene is fundamental in chemistry-climate interactions….but direct large-scale long-term isoprene emission measurements do not exist

- Two readily available global long-term observational datasets hold information about isoprene emission variability
  - Gross Primary Productivity (GPP)
    - Isoprene production directly linked to photosynthesis 70-90% (*Affek and Yakir, 2003; Delwiche and Sharkey, 1993; Karl et al., 2002*)
  - Satellite HCHO column variability (HCHOv)
    - Isoprene oxidation generates HCHO in high yield and isoprene dominates VOC budget over continents (*Barkley et al., 2008; Barkley et al., 2013; Fu et al., 2007; Millet et al., 2008; Palmer et al., 2001, 2004*)

- Neither is a perfect indictor of isoprene emission variability
  - Isoprene-photosynthesis decoupling due to different temperature optimums, short-term drought response, CO_2-response, onset times in deciduous
  - HCHOv uncertainties in retrieval, oxidation chemistry, distinguishing isoprene contribution

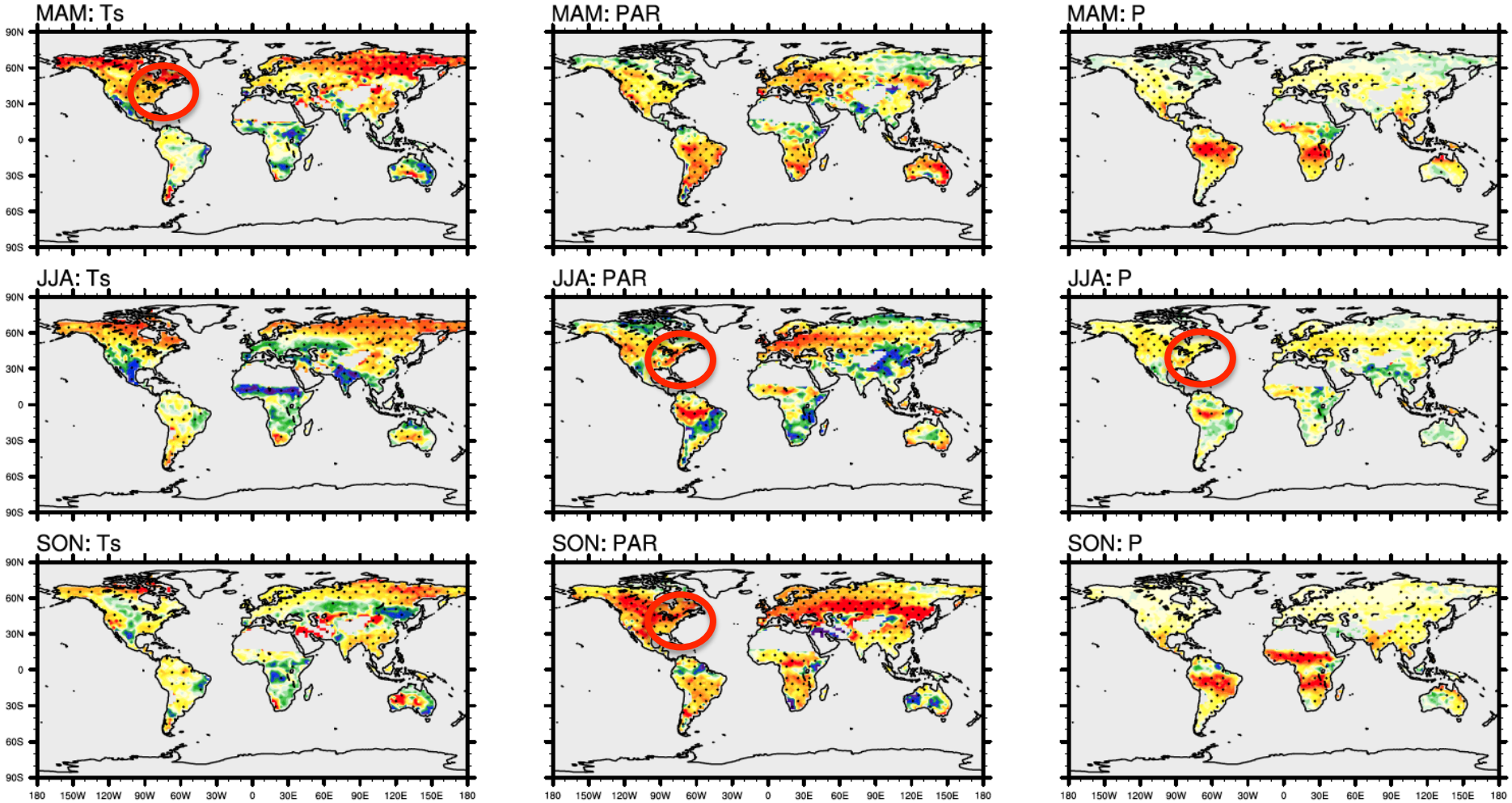
- What can we learn about isoprene by combining these datasets?

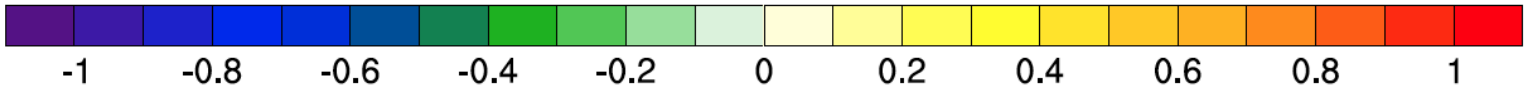
Meteorological drivers of monthly mean GPP 1982-2011

Ts = surface temperature

PAR =photosynthetically active radiation

P =precipitation



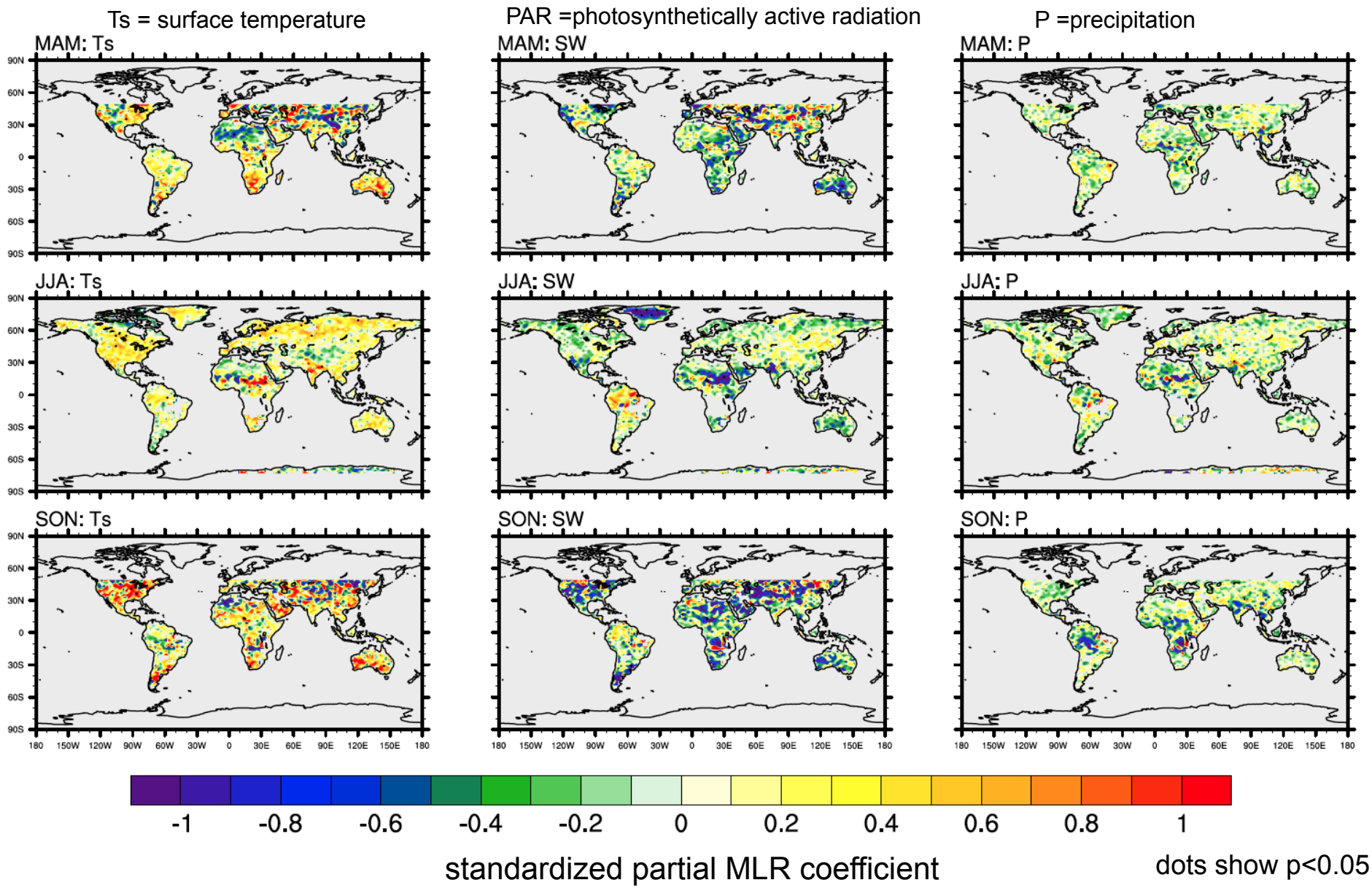


standardized partial MLR coefficient

dots show $p<0.05$

GPP FLUXNET-derived (Beer et al., 2010; Jung et al., 2011)
Ts, PAR and P from NASA GMAO MERRA (Rienecker et al., 2011)

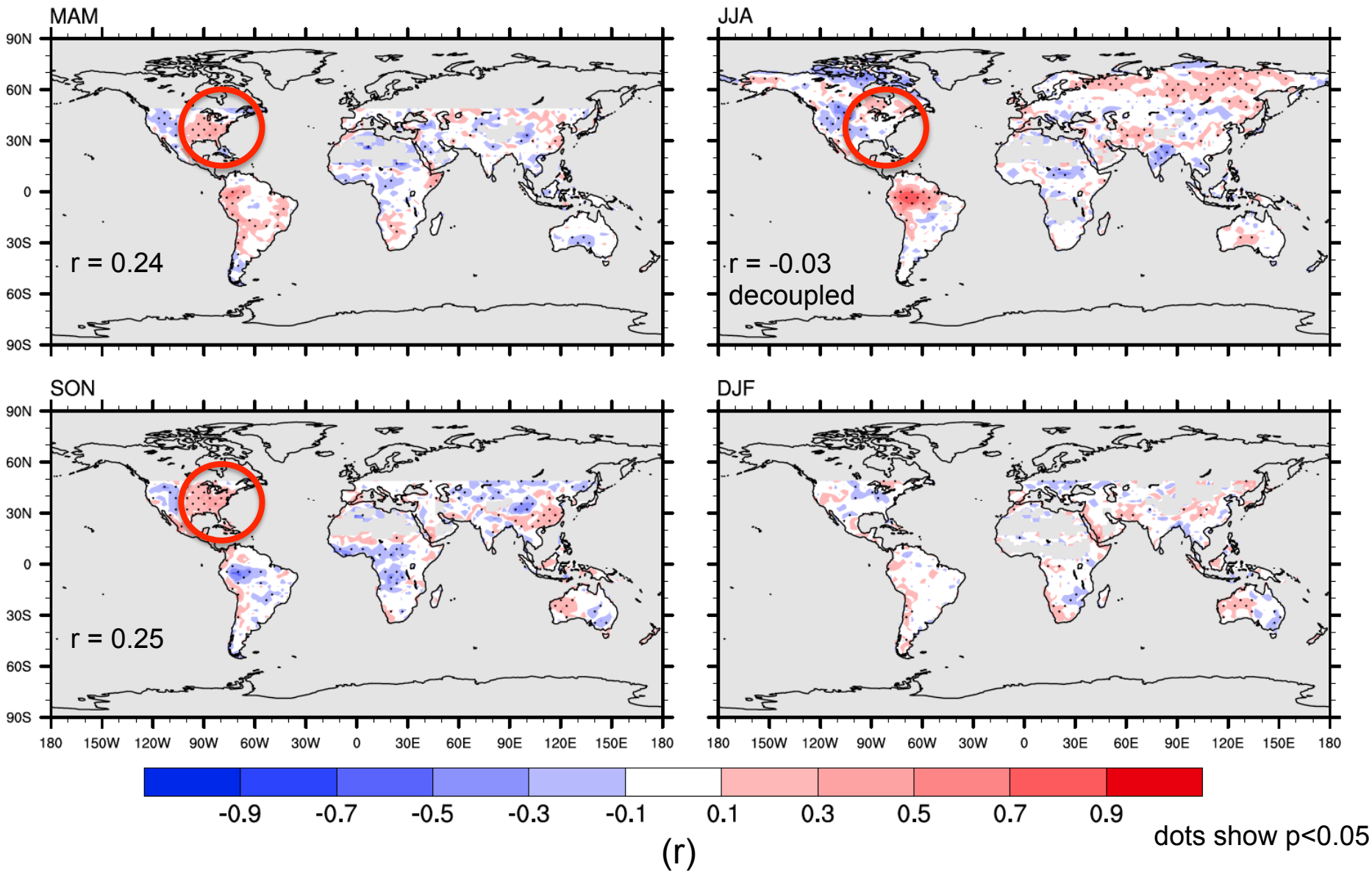
Meteorological drivers of monthly mean HCHOv 2005-2013



dots show p<0.05

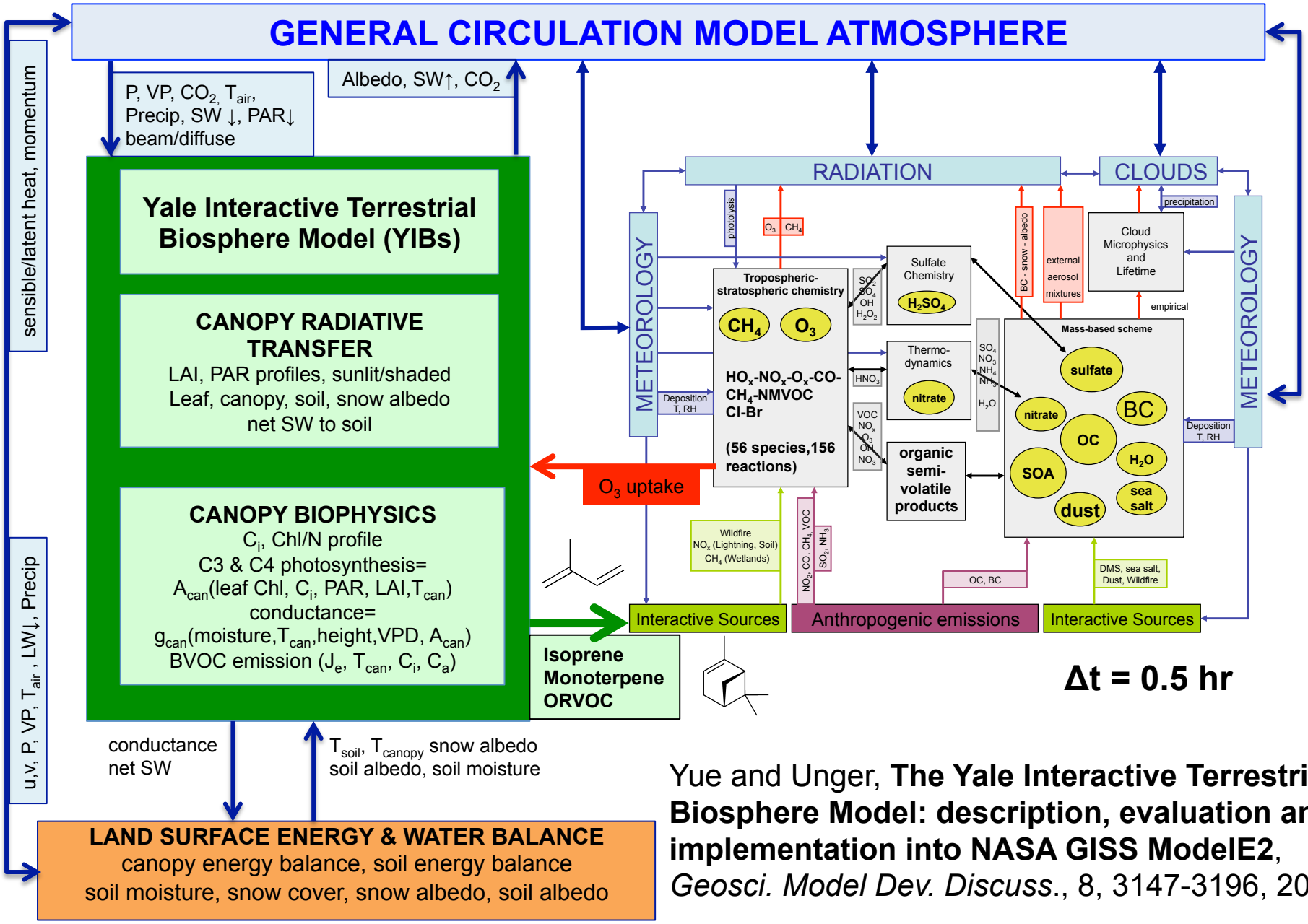
OMI HCHO fire-screened (*Barkley et al., 2013; González Abad et al., 2015*)
HCHOv local versus zonal mean anomaly

Observed monthly mean GPP-HCHOv linear correlation 2005-2011



GPP and HCHOv in the summertime southeast U.S. are decoupled, v. weak anti-correlation signal

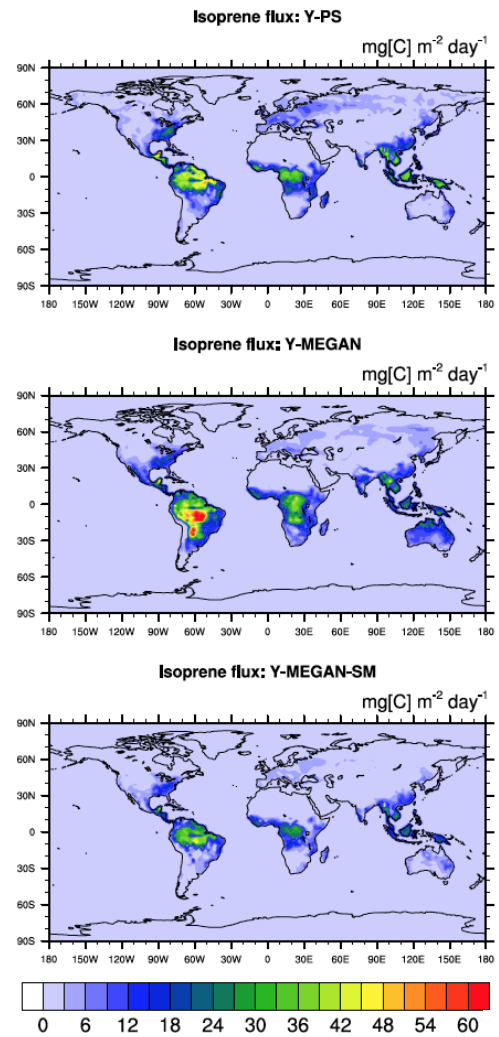
NASA GISS ModelE2-YIBS global carbon-chemistry-climate model



Yue and Unger, **The Yale Interactive Terrestrial Biosphere Model: description, evaluation and implementation into NASA GISS ModelE2**, *Geosci. Model Dev. Discuss.*, 8, 3147-3196, 2015

Isoprene emission from leaf to planet in a global carbon-chemistry-climate model

- NASA ModelE2-YIBs incorporates 3 leaf-level isoprene emission algorithms
  - **"Y-PS"** Function of electron transport-limited photosynthetic rate, C_i, Γ*, canopy temperature, soil moisture dependence through linkage to photosynthesis (*Unger et al., 2013*)
  - **"Y-MEGAN"** Empirical functions of canopy temperature (Arrhenius-type) and PAR (hyperbolic) (*Guenther et al., 1995, 2006, 2012*)
  - **"Y-MEGAN-SM"** MEGAN + additional empirical multiplier to account for soil moisture dependence (*Zheng et al., 2015*)
- Algorithms use the same PFT-specific isoprene emission potentials, identical canopy up-scaling, vegetation and meteorology input

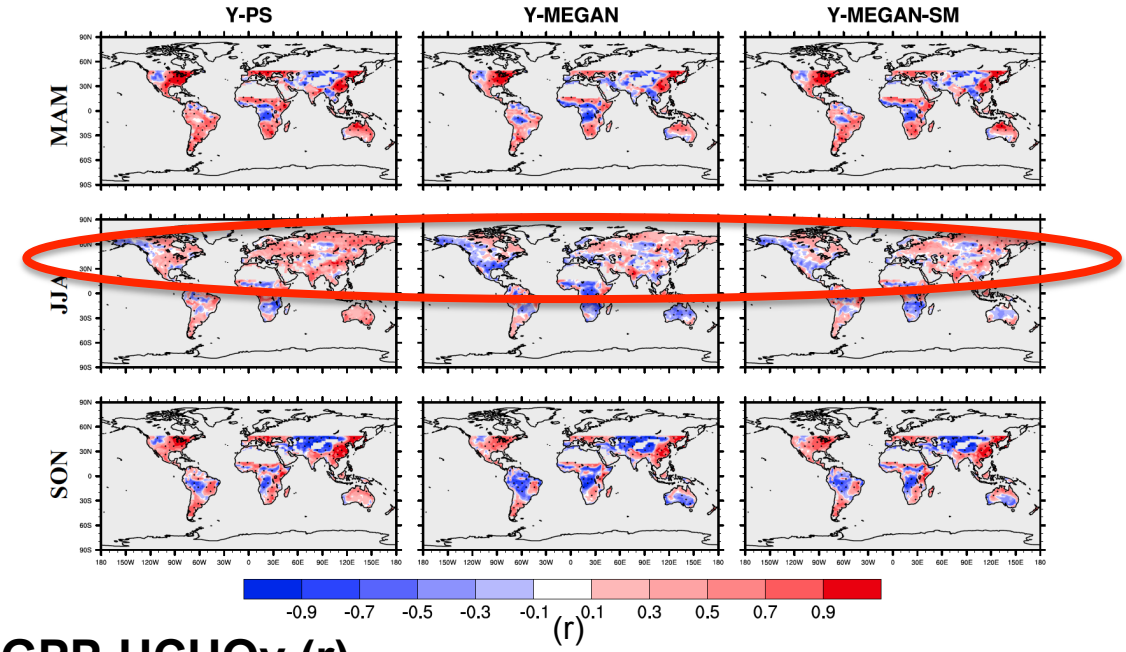


382 TgC/yr

452 TgC/yr

263 TgC/yr

Modeled GPP-HCHOv linear correlation for 3 isoprene schemes



Southeast U.S. GPP-HCHOv (r)

	Observations	Y-PS	Y-MEGAN	Y-MEGAN-SM
MAM	0.24	0.86	0.77	0.81
JJA	-0.03	-0.19	-0.62	-0.37
SON	0.26	0.68	0.52	0.61

- All models reproduce general seasonal pattern but overestimate observed GPP-HCHO (r)
- Y-PS does better job of reproducing observed GPP-HCHO (r) in summer
- Y-MEGAN predicts strong GPP-HCHO (r) anti-correlation in summer

Examining the model GPP-isoprene-HCHO system in the southeast U.S.

GPP-isoprene emission (r)

	Y-PS	Y-MEGAN	Y-MEGAN-SM
MAM	0.98	0.86	0.95
JJA	0.94	-0.39	0.79
SON	0.97	0.69	0.92

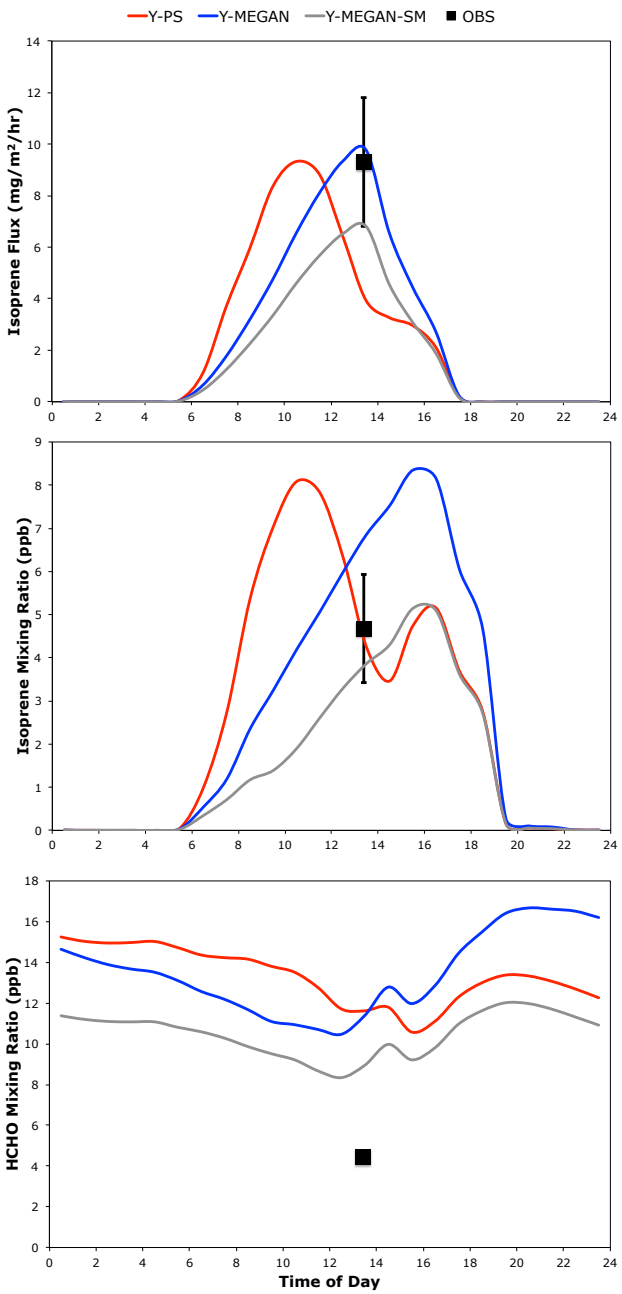
Isoprene emission-HCHOv (r)

	Y-PS	Y-MEGAN	Y-MEGAN-SM
MAM	0.88	0.97	0.91
JJA	-0.03	0.73	0.08
SON	0.71	0.94	0.80

In summer (JJA)

- Y-PS: isoprene emission correlated with GPP; anti-correlated with HCHOv
- Y-MEGAN: isoprene emission anti-correlated with GPP; correlated with HCHOv
- Y-MEGAN-SM behaves more like Y-PS
- **Isoprene algorithms that include soil moisture dependence demonstrate greater skill in reproducing the observed GPP-HCHOv on longer time-scales (interannual seasonal)**

NASA SEAC4RS airborne derived isoprene flux in southeast U.S.



- Ozarks SEAC4RS DC-8 Flight
  - September 6 2013 about 13:20 LT
  - Lat = 37.5°N; Lon = -91.4°W
  - 20m canopy top height
- Measurements
  - PTRMS isoprene (A. Wisthaler)
  - MMS vertical winds (P. Bui)
  - HCHO and isoprene concentrations (G. Wolfe)
  - Wavelet analysis of eddy covariance measurements (G. Wolfe)
- NASA GISS ModelE2-YIBs (Global Climate Model)
  - Nudged with large-scale u, v from NASA GMAO MERRA
  - Sub-daily output
  - 3 isoprene schemes
- Models demonstrate skill in reproducing isoprene flux and concentration
  - HCHO is overestimated

Discussion and Next Steps

- Soil moisture dependence of isoprene emission needs further research
- Water availability may be an important driver of vegetation-chemistry-climate interactions under future global change
  - Recent launch of NASA Soil Moisture Active Passive instrument
- Weekly (daily?) relationships between satellite GOME-2 SiF and HCHOv in eastern U.S. and the Amazon (collaboration with A. Michalak)
- Model evaluation of airborne estimated isoprene fluxes from NOMADSS NCAR C-130 (SAS 2013)
- Interpret NASA SEAC4RS flight case studies of BVOC-chemistry interactions using NASA ModelE2-YIBs
- Comments/questions/thoughts welcome!
- Thank you for listening

Zheng et al., Relationships between photosynthesis and formaldehyde as a probe of isoprene emission, ACPD, 15, 11763-11797, 2015