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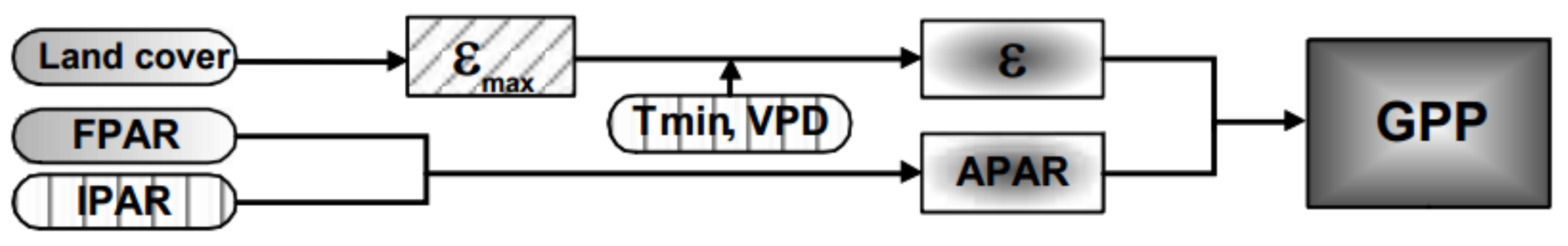
Incorporation of a Soil Moisture Constrain to the Global GPP Product (MOD17A): A case study on the coterminous US.

Ajit Govind[1], Christophe Moisy[1], Gaëtan Fauvre[1, 2],
Jean-Pierre Wigneron[1] and Steve Running[3].

Introduction

The gross primary productivity (GPP) is the fundamental ecological indicator that governs the global carbon (C) cycle. To date, the most widely used global scale terrestrial GPP estimate have been the MOD17A product. The MOD17A is produced by combining (i) the observations of vegetation abundance estimated by the MODIS sensor (namely fPAR) and (ii) meteorological forcings, employing the classical light use efficiency approach. In the approach, a landcover specific maximum light use efficiency (ε_{max}) is constrained by 2 meteorological parameters, the ambient minimum air temperature (Tmin) and ambient vapour pressure deficit (VPD) to return the actual ε. This ε is further combined with the absorbed photosynthetically active radiation (APAR) to return the estimates of GPP. Thus, it is assumed that at the global scale, the plant ecophysiology and hence the photosynthesis can be captured by the spatio-temporal dynamics of Tmin and VPD (e.g. Zhao et al. 2005).



From an ecohydrological point of view, however, at the local scale, ecophysiology of terrestrial vegetation is greatly governed by the spatio-temporal patterns of soil moisture (SM) owing to its role in controlling the stomatal dynamics. The SM factor can be a limitation to plant growth both at the deficit (<-15bar) and excess conditions (>-0.33bar). Considering this, we believe that incorporation of a SM constrain to the MOD17A algorithm could significantly improve the GPP estimates in those regions of the world where SM is a limitation for plant growth (e.g. arid and semi-arid regions, water-saturated regions etc).

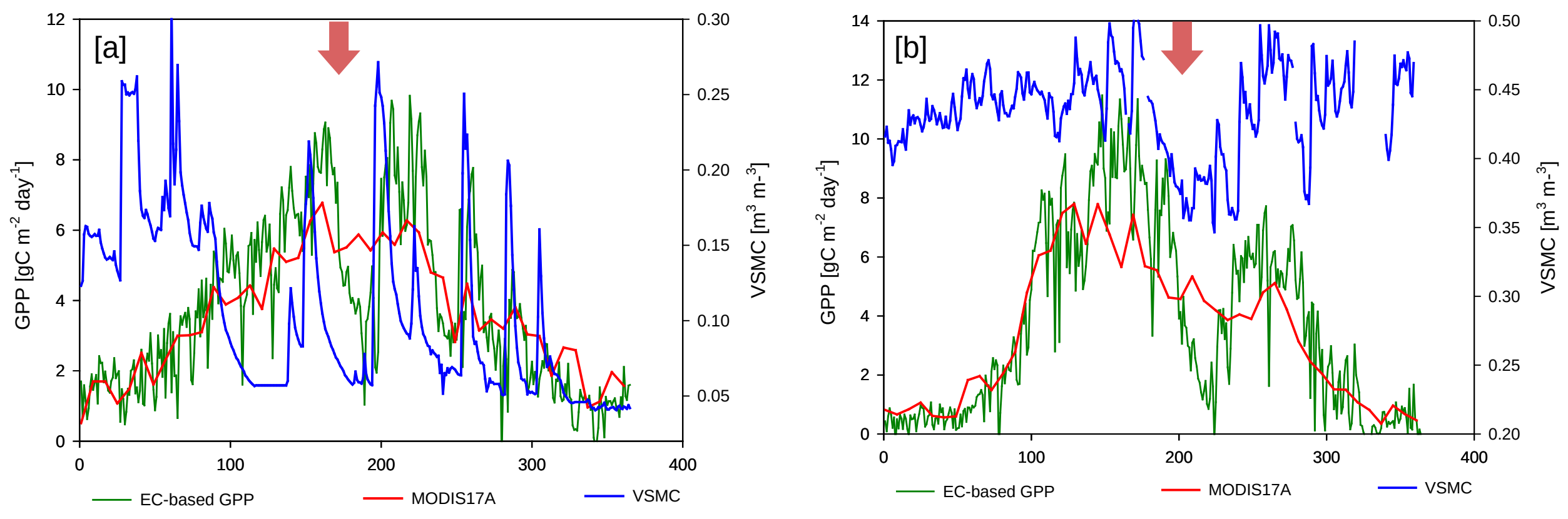
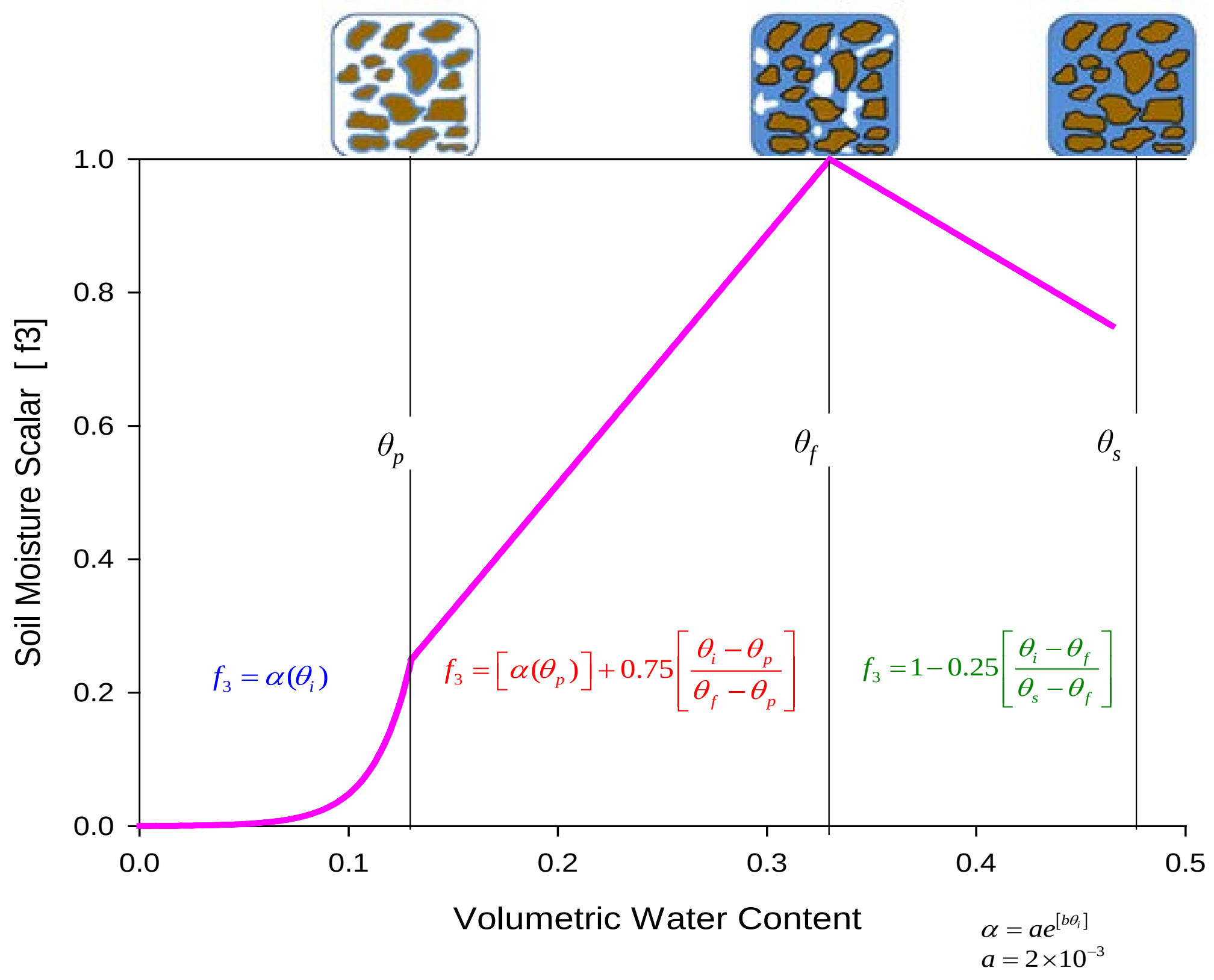


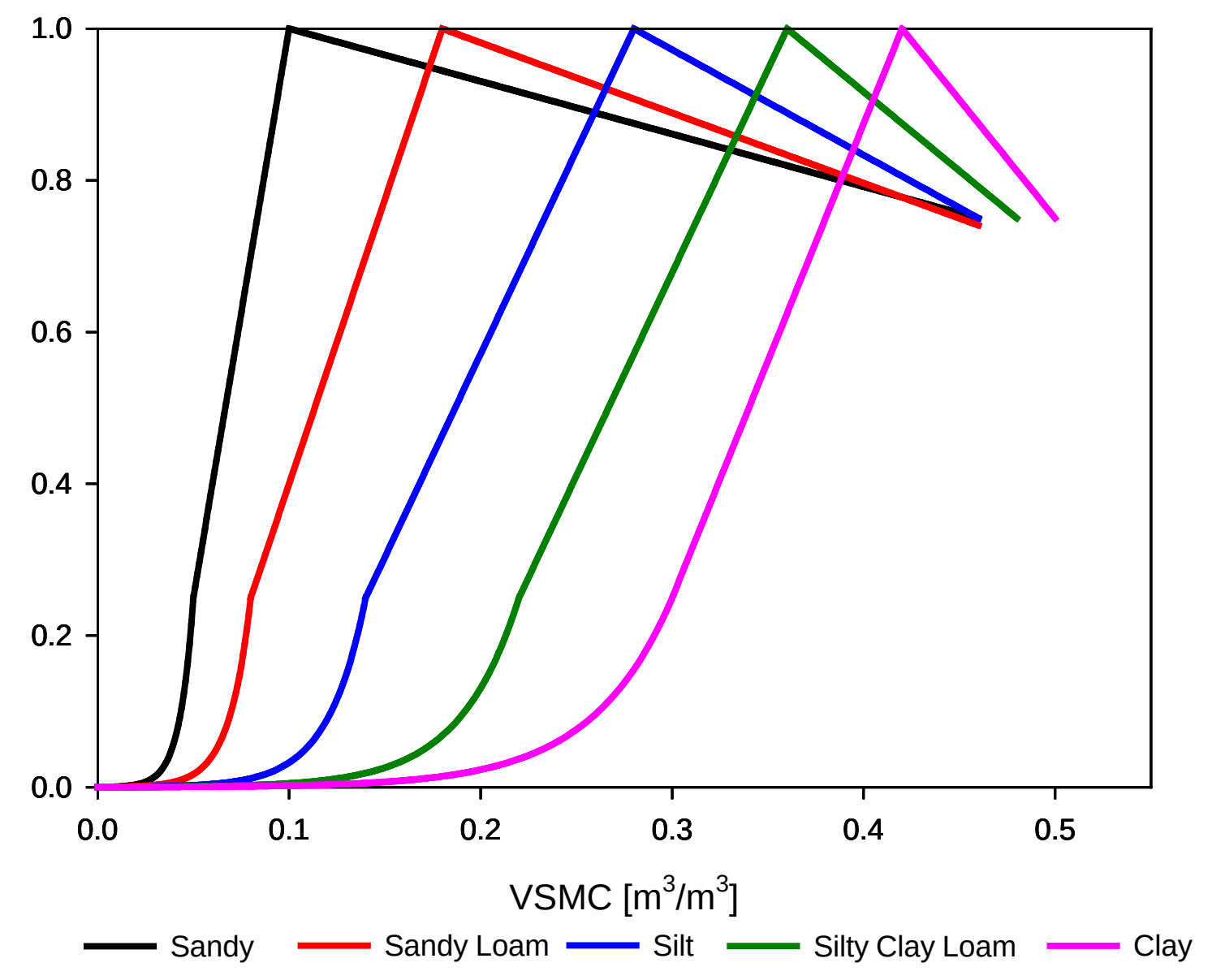
illustration to show the mid growing season decline in GPP congruent with VSMC decline in 2 semi arid locations (a) Freeman Ranch Mesquite Juniper-Texas (2005) (b) Goodwin Creek-Mississippi (2006)

We modified the official MOD17 algorithm by incorporating an additional scalar (f3) that constrains the landcover-specific ε_{max}. The calculation of f3 in a spatially and temporally explicit manner requires information on soil texture and time series of global soil moisture. The f3 is calculated based on soil texture-specific hydraulic thresholds i.e. Volumetric Water Content (VSMC) at Permanent Wilting Point, θ_p; VSMC at Field Capacity, θ_f; and VSMC at Saturation, θ_s, besides ambient VSMC (θ_i). It is conceptualized that when the θ_i falls below the θ_p, f3 exponentially reduces to 0, implying a water stress due to drought. When the θ_i lies between θ_p and θ_f, the f3 increases linearly as a function of θ_i upto 1 (when $\theta_i = \theta_f$). However, a SM increase beyond the θ_f decreases f3 implying a water stress due to waterlogging. The texture-specific soil hydraulic thresholds are parameterized based on the values shown in Table-1 , following Saxton and Rawls (2006)



$$\alpha = a e^{[b\theta_i]}$$
$$a = 2\times10^{-3}$$
$$b = 7.12\,\theta_p^{-1.001}$$

Nature of the SM-scalar for a hypothetical soil texture that has a PWP of 15%, FC of 33% and a porosity of 46%. Note the exponential decline in f3 below the PWP (values 0.0 and 0.25), the linear increase between PWP and FC (values 0.25 and 1.0) and the slow decline beyond the FC (values 1.0 and0.75). In this way, the water stress



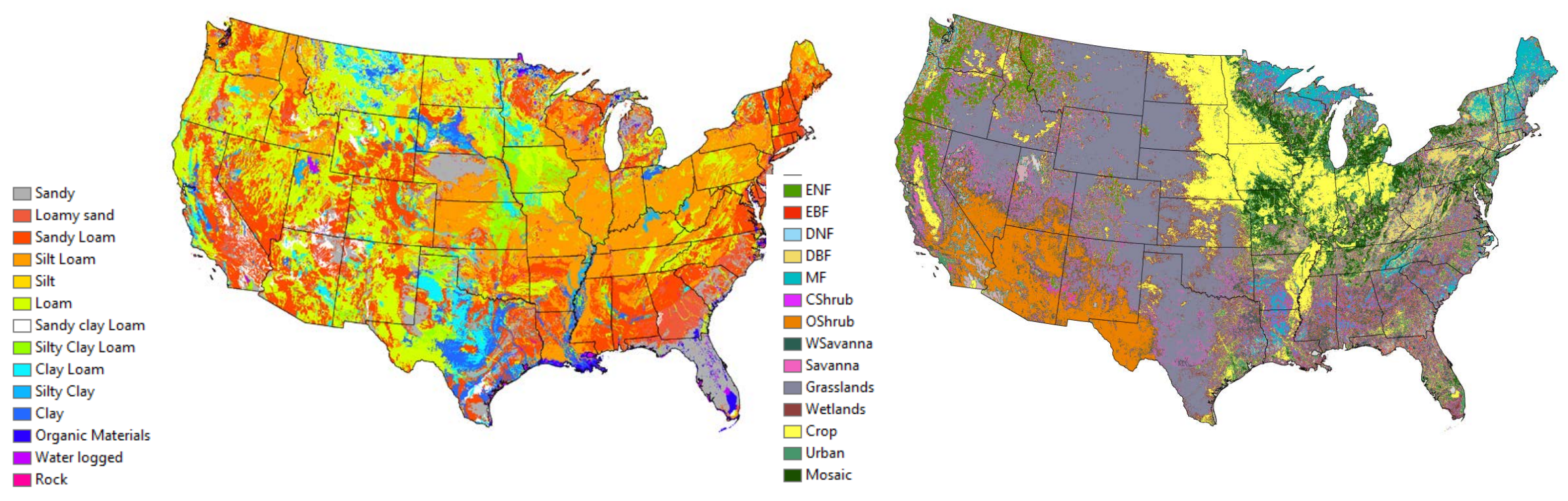
Nature of the SM-scalar for different types of soil textures.

Table-1 The texture specific hydraulic parameters that are used to construct specific SM-scalars after Saxton and Rawls (2006).

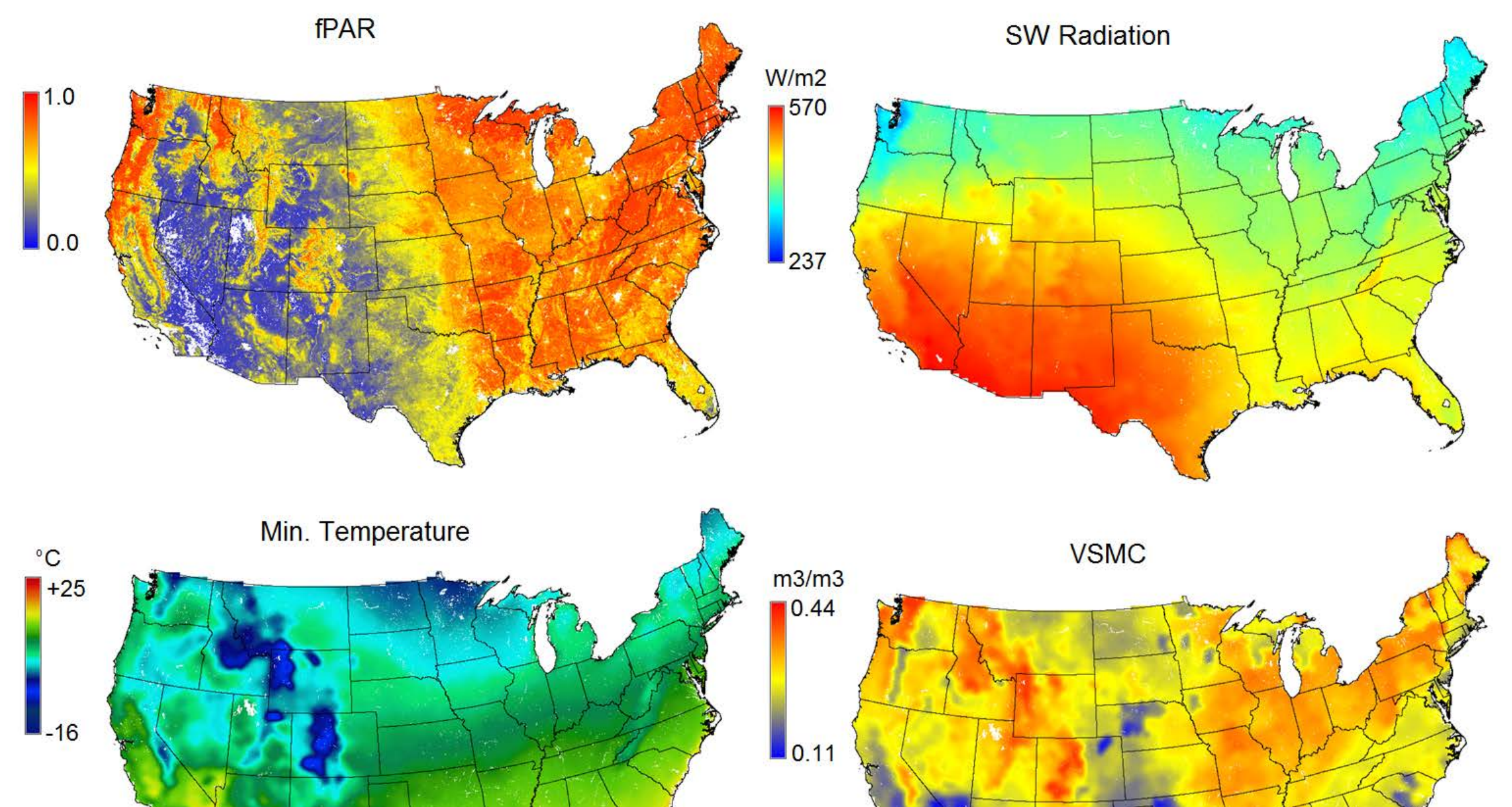
Texture	Wilting Pt. [15Bar]	Field Cap. [0.33bar]	Saturation [0 Bar]
Sa	0.05	0.10	0.46
LSa	0.05	0.12	0.46
SaL	0.80	0.18	0.45
L	0.14	0.28	0.46
SiL	0.11	0.31	0.48
Si	0.06	0.30	0.48
SaCL	0.17	0.27	0.43
CL	0.22	0.36	0.48
SiCL	0.27	0.38	0.51
SiC	0.25	0.41	0.52
SaC	0.30	0.36	0.44
C	0.20	0.42	0.50
Organic	0.20	0.50	0.60

***Sa**, Sand; **L**, Loam; **Si**, Silt; **C**, Clay.*

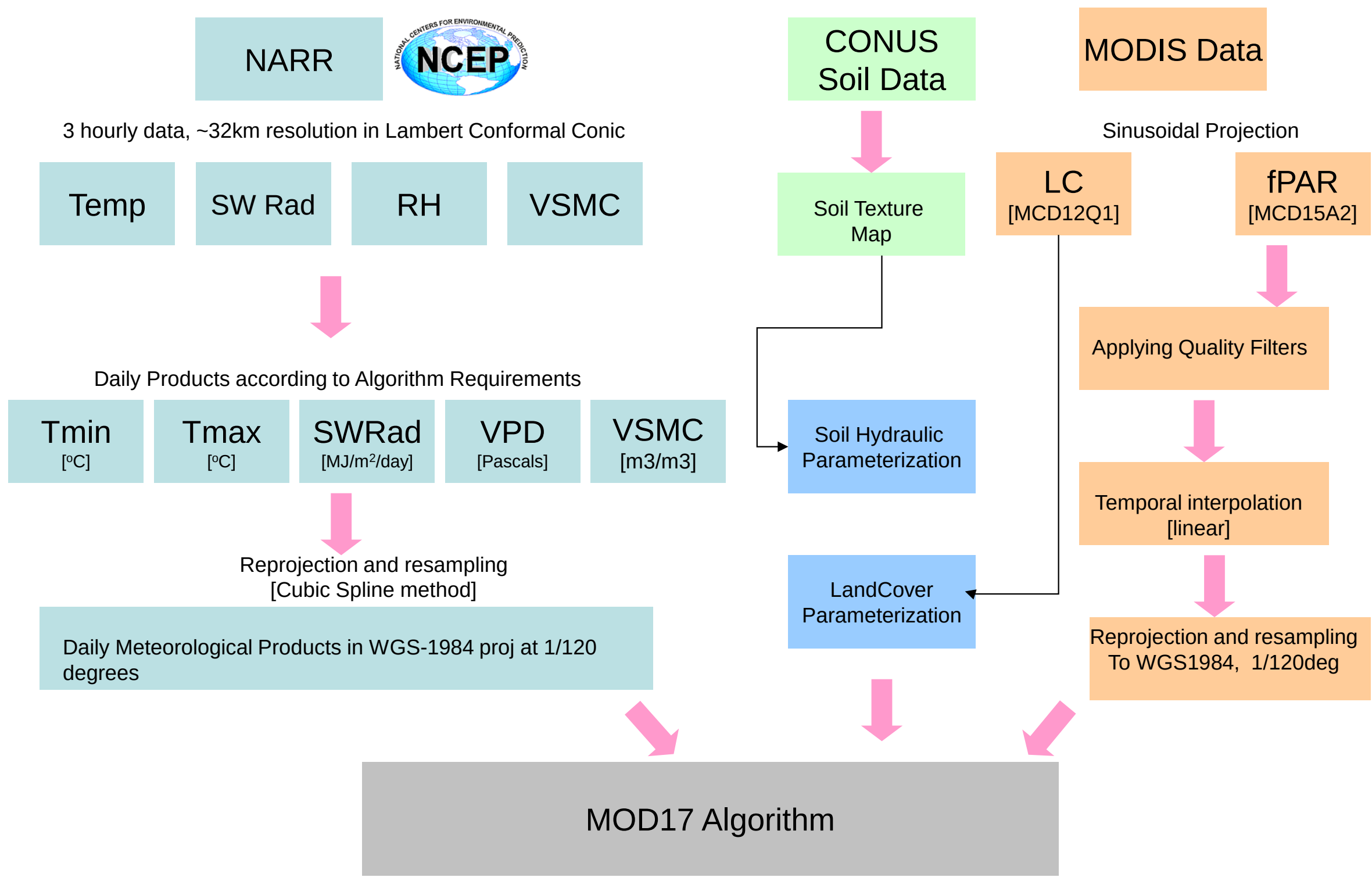
The modified MOD17 algorithm was run to simulate the GPP dynamics over the coterminous US for the year 2008. All the input datasets were prepared at 1/120 deg resolution in the WGS 1984 projection. The meteorological input datasets were obtained from the NCEP North American Regional Reanalysis (NARR) product available at 32 km resolution (Lambert projection) and was geostatistically downscaled to 1km resolution and reprojected to WGS 1984. The time series of the fPAR (MCD15A2) product and the landcover product (MCD12Q1) was reprojected to WGS 1984 projection after necessary quality flags were applied. In order to perform GPP calculations at daily time-steps, the 8 day fPAR products were linearly interpolated in time to derive daily fPAR products. The soil texture data was obtained from the CONUS database and was made consistent with the other datasets.



The figure above shows the spatial distributions of near-surface soil texture classes on the coterminous US. It can be observed that large areas of Silty Clay and Clay soils can be found in Texas, South Dakota and North Eastern Montana. Silty Clay and Clay Loam types can also be found along the course of the Mississippi river. The Silt Loam and Loam textural classes constitute the most predominant soil texture in the Mid-Western states and the mountain west states, respectively. Sandy soils are predominant in the east coast states (mainly Florida) and Western Nebraska and South West arid regions. The landcover map is also displayed to provide an idea about the dominant vegetation type in these locations. The following figures provide details about the spatial distribution of meteorological and biophysical (fPAR) parameters across US. The values presented here are annual average values.



The annual average SW radiation map shows the higher levels of insolation in SW US and lowest in the Pacific North West and North eastern states. The lower Tmin in Idaho, Montana, Wyoming and Colorado imply a temperature-limited primary productivity in these locations. Note that the VSMC are higher in these locations. Regions having the lowest magnitudes of ambient VSMC are concentrated in southern US and also Florida, but, their plant availabilities depend on the inherent soil texture.



NARR

3 hourly data, ~32km resolution in Lambert Conformal Conic

Temp | SW Rad | RH | VSMC

Daily Products according to Algorithm Requirements

Tmin [ºC] | Tmax [ºC] | SWRad [MJ/m2/day] | VPD [Pascals] | VSMC [m3/m3]

Reprojection and resampling [Cubic Spline method]

Daily Meteorological Products in WGS-1984 proj at 1/120 degrees

CONUS Soil Data

Soil Texture Map

Soil Hydraulic Parameterization

LandCover Parameterization

MODIS Data

Sinusoidal Projection

LC [MCD12Q1]

fPAR [MCD15A2]

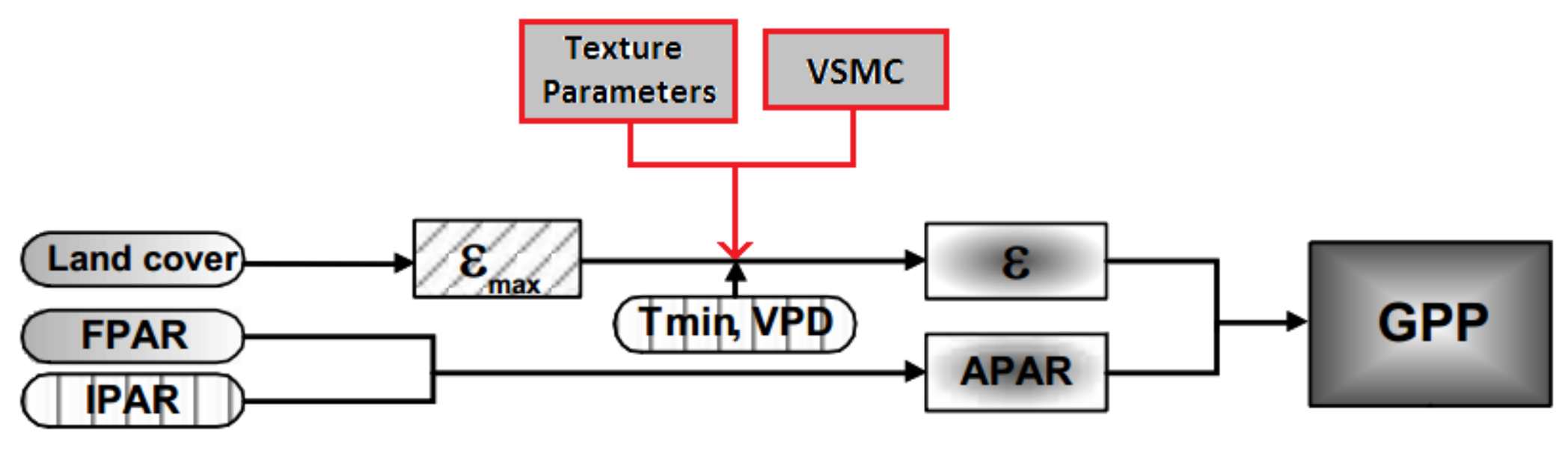
Applying Quality Filters

Temporal interpolation [linear]

Reprojection and resampling To WGS1984, 1/120deg

MOD17 Algorithm

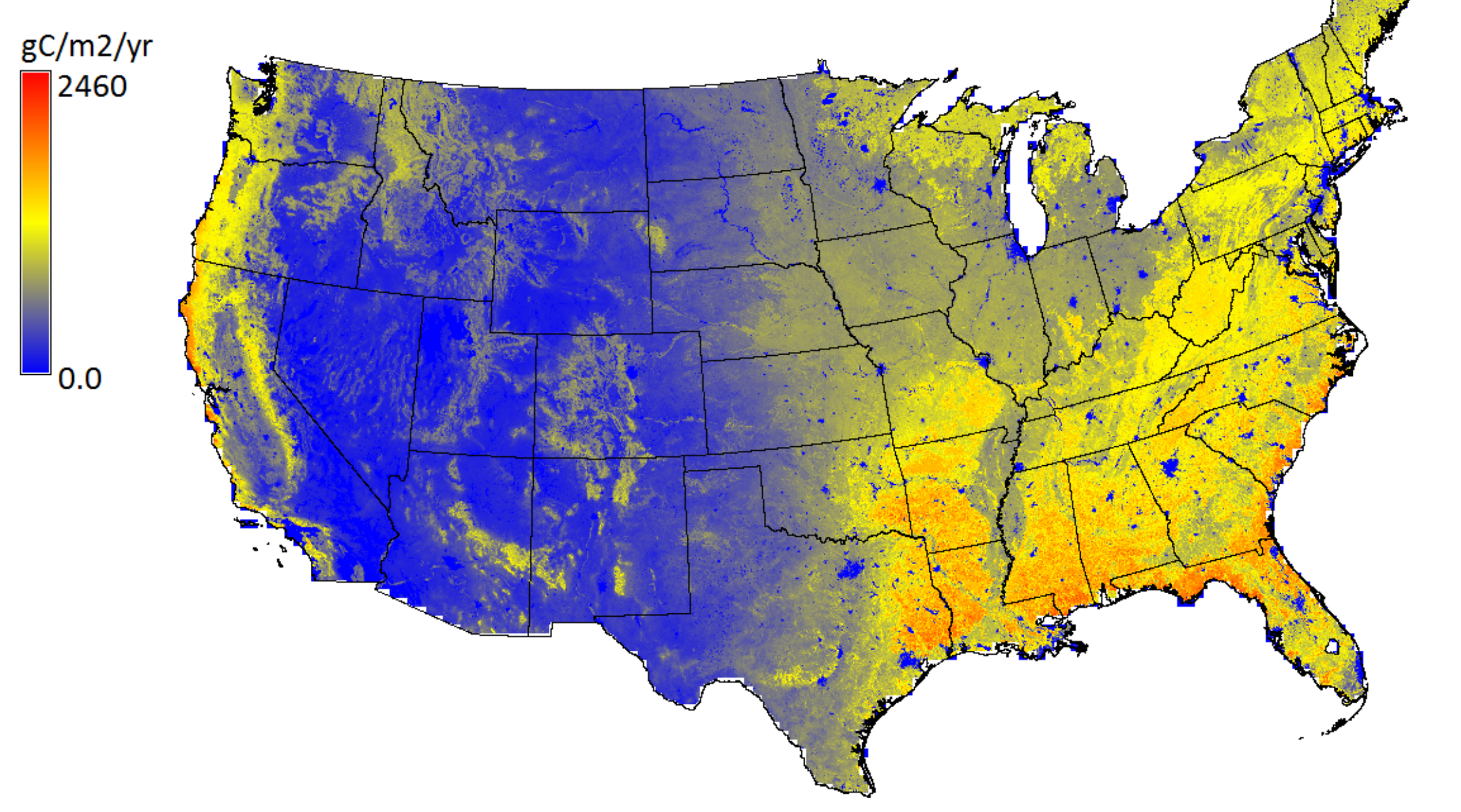
The above flow chart shows the overall methodology followed in this study.



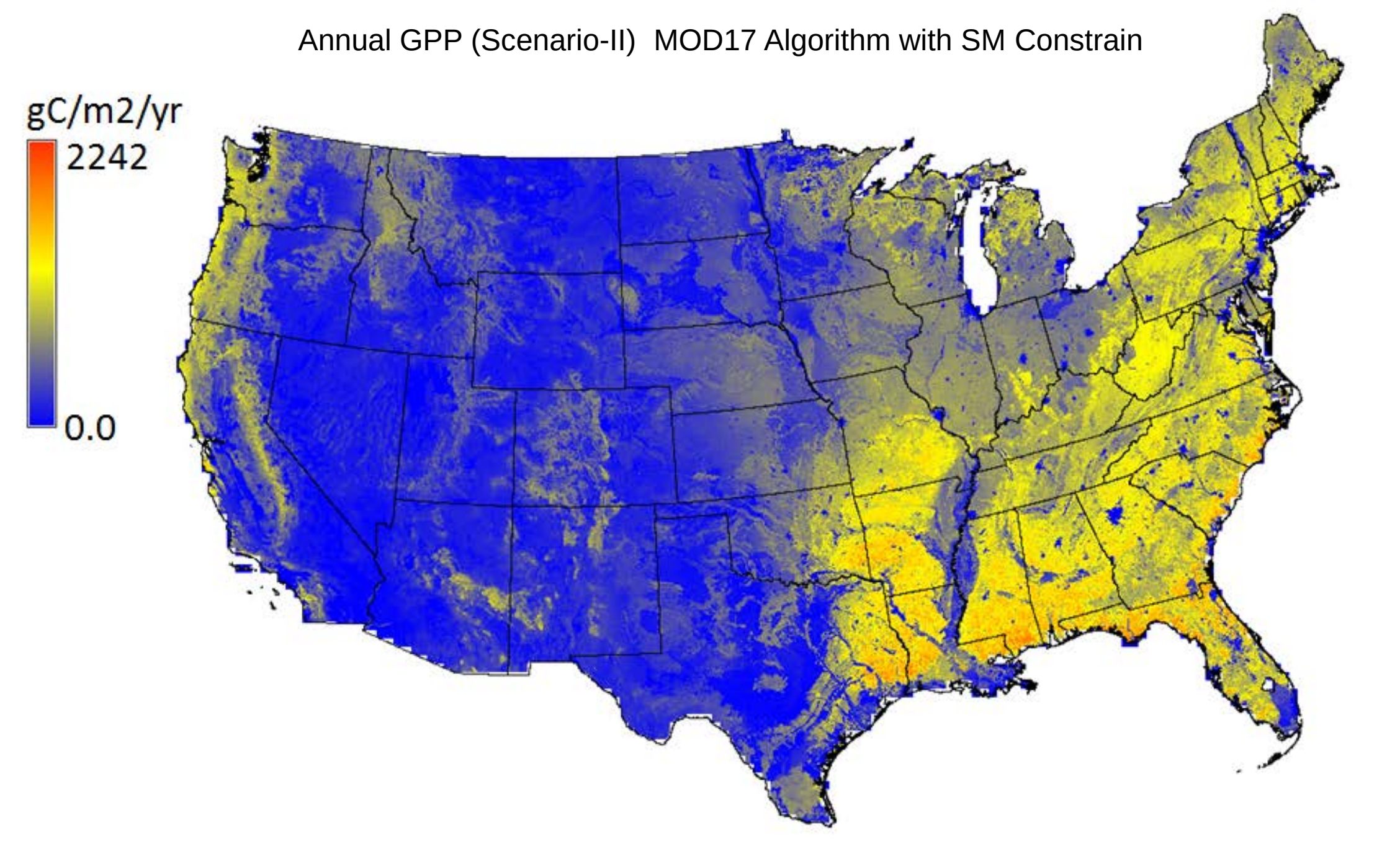
Results

We made two scenario runs. (1) The original MOD17 version without the SM soil moisture constrain (i.e. f3=1), (S1) and (2) with the SM constrain (S2). A spatial analysis of the two scenarios revealed that the effect of SM on GPP is important in arid and semiarid regions as a function of the inherent soil hydraulic properties that govern the plant water relations. These regions correspond to the Great Plains, Central Texas and the Central Valley of California. The highly arid zones in the mountain west (e.g. Columbia Plateau) did not show much difference, probably because the fPAR trends corroborates with the VSMC trends. Similarly, the humid zones in the north east US (New York, Vermont, Maine) also showed smaller differences between the scenarios implying that the classical approach works well in most of the regions except were the seasonality of SM is significant. The time series analysis of the two scenarios in various climatic settings implied that the anomalies are created mostly in the mid-growing and the autumn seasons

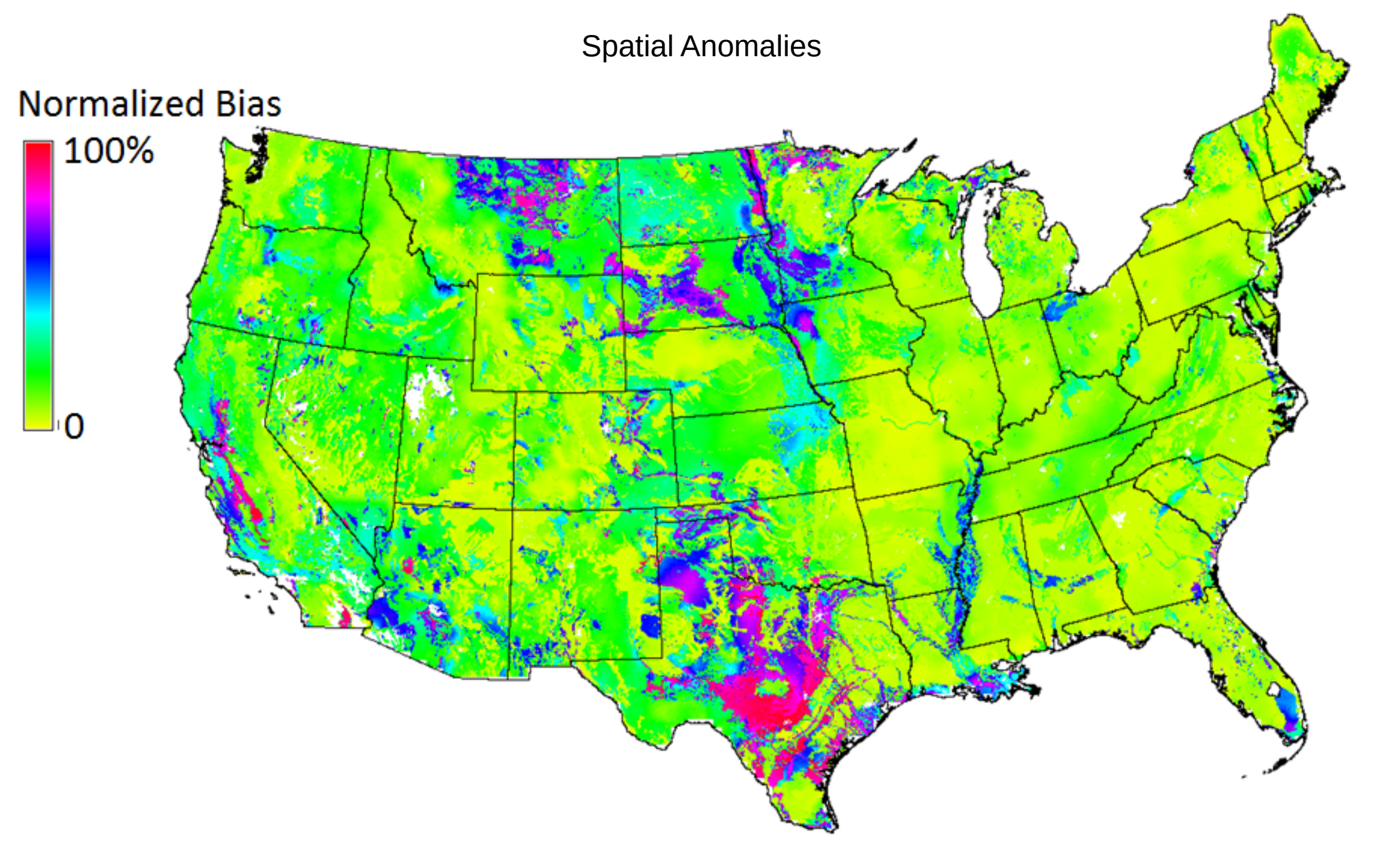
Annual GPP (Scenario-I) original MOD17 Algorithm



Annual GPP (Scenario-II) MOD17 Algorithm with SM Constrain



Spatial Anomalies



Conclusions

Because intuitively soil moisture is a primary factor that controls plant water relations and hence the primary productivity of terrestrial vegetation, we tried to understand the effect of SM on the estimates of terrestrial GPP by the MOD17 approach. We found that soil moisture dynamics can significantly control GPP in arid and semi-arid locations. Soils dominated with clayey soils in semiarid settings showed the largest biases implying that leaf abundance may not linearly correlate with plant productivity in such cases. With the availability of sensors such as AMSR-E onboard Aqua, MIRAS onboard SMOS and the SMAP mission, global estimates of SM is possible and offers a great opportunity to exploit the SM data to better understand the terrestrial C cycle. In this spirit, we performed an exploratory study to understand the effects of incorporating the SM into the MOD17 algorithm. A comprehensive analysis of site level GPP estimates vis-à-vis these MOD17-based approaches are underway. We also acknowledge the importance of considering the spatial differences in rooting depths.

Acknowledgements

We acknowledge the (i) reanalysis data (NARR) contributions from the PSD of NOAA, (ii) MODIS-fPAR (MCD15A2), (iii) MODIS-Landcover (MCD12Q1) and CONUS soil texture data providers. Secondly, we acknowledge (i) the AmeriFlux site PIs and (ii) Dario Papale (Universitá della Tuscia) whose datasets and GPP estimates, respectively, are being used for site level validations in this project. Finally, we thank INRA for providing computing resources.

References

Zhao, MS, Heinsch, FA, Nemani, RR, Running, SW (2005). Improvements of the MODIS terrestrial gross and net primary production global data set. REMOTE SENSING OF ENVIRONMENT, 95(2), 164-176.

Saxton, K. E. and Rawls, W. J.(2006), Soil Water Characteristic Estimates by Texture and Organic Matter for Hydrologic Solutions SOILSCI, 2006. 70:1569–1578.doi:10.2136/sssaj2005.0117

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