From Miami to Madison: Investigating the Relationship Between Climate and Terrestrial Net Primary Production

David Zaks[1], Navin Ramankutty, Carol Barford, and Jon Foley

Center for Sustainability and the Global Environment (SAGE)
Gaylord Nelson Institute for Environmental Studies
University of Wisconsin
1710 University Avenue, Madison, WI 53726, USA
1: zaks@wisc.edu

Introduction

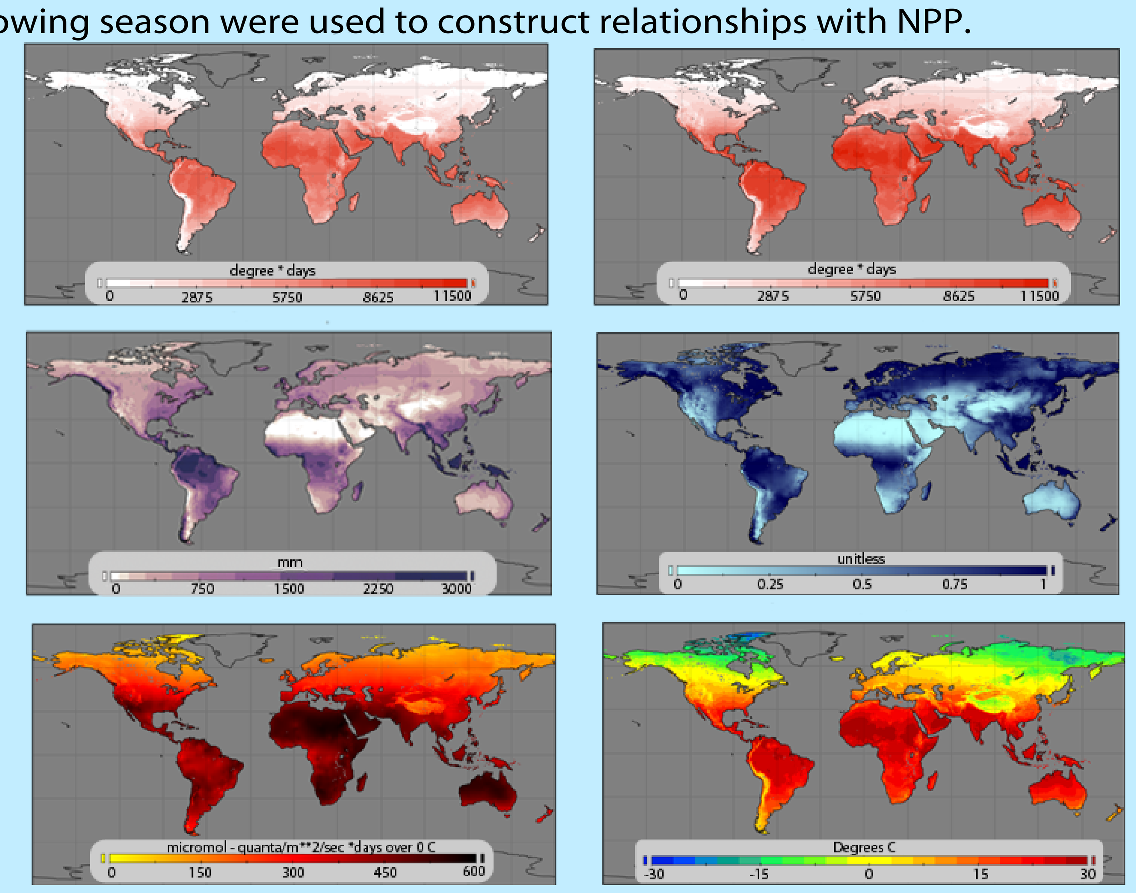
There is a high level of uncertainty regarding the spatial and temporal patterns of the global carbon cycle. This uncertainty can be reduced by improving our understanding of the factors that control net primary productivity (NPP). Here we present a suite of empirical models that illustrate how ecophysiological variables control patterns of NPP.

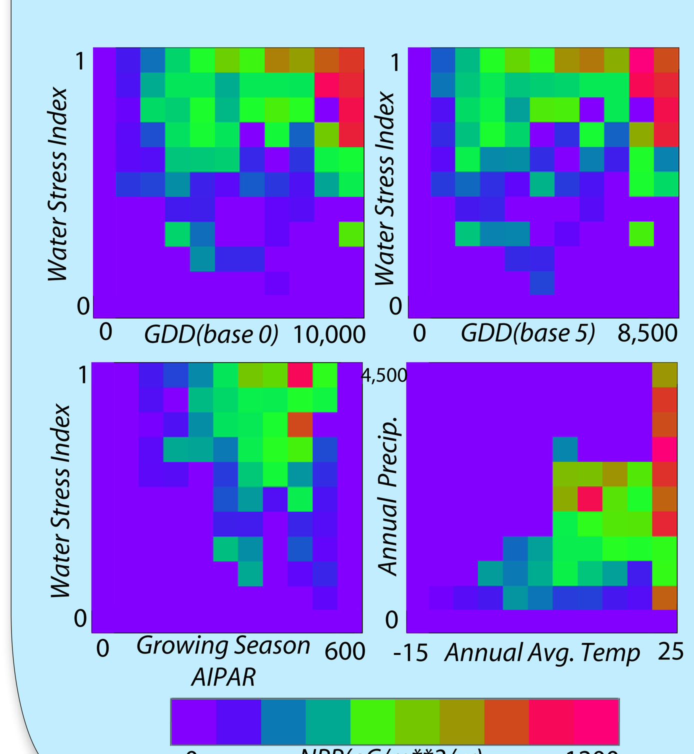
The "Miami Model" (Lieth, 1975) was the first global scale empirical model of terrestrial NPP. Recently improved field methodologies for estimating NPP coupled with their increased spatial coverage, and the increased resolution of gridded climate data has led us to reexamine the relationships between climate and NPP.

Model Construction

A database of over 2,000 observations of NPP was assembled from the literature, with a large portion from the Global Primary Production Data Initiative (GPPDI) (Scurlock et al. 1999). Observations from permanent pasture, crops, wetlands, or other intensively managed sites were omitted from the database.

Temperature and precipitation, or their proxies, are commonly used to predict NPP. Observed annual-mean temperature and precipitation (Leith, 1975) have been shown to yield "reasonable estimates" of global patterns of productivity (Adams et al. 2004), and were used by the Miami model. In this study, in addition to temperature and precipitation, we also test the predictive power of growing degree-days, a moisture index, and the average incident photosynthetically active radiation during the growing season were used to construct relationships with NPP.



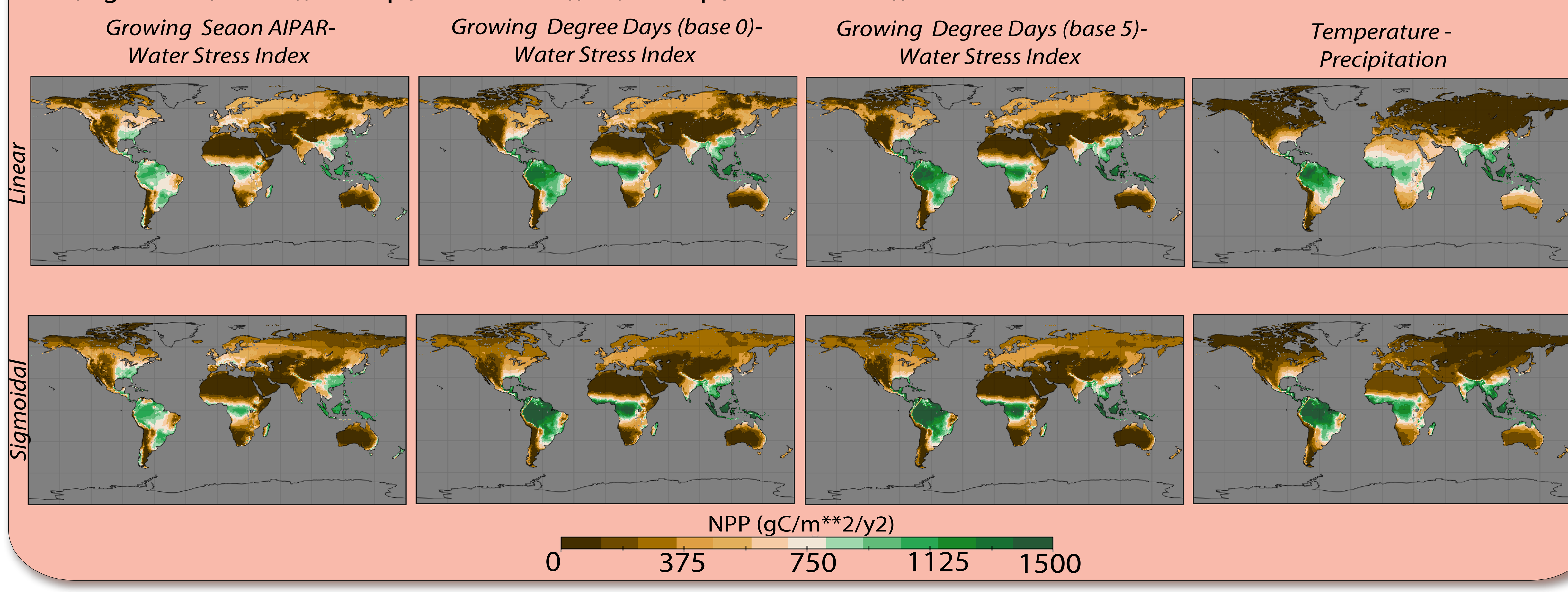


We hypothesize that NPP is a function of temperature and moisture conditions. Accordingly, we defined models of NPP as function of a pair of climate variables at a time. Since light and growing degree-days are highly correlated, they were not considered together within our model. A 100-cell matrix was established to represent the climate space for the pairs of climatic variables. Each axis represents the range of one independent climate variable, and NPP is shown by the gradient of colors. The 25th, median and 75th quartiles were reported for each cell, and were used to fit 3 separate empirical models. Since there are no observations of zero NPP, we added dummy NPP points with zero value, where one of the climate variables was zero.

Model Simulations of Global NPP

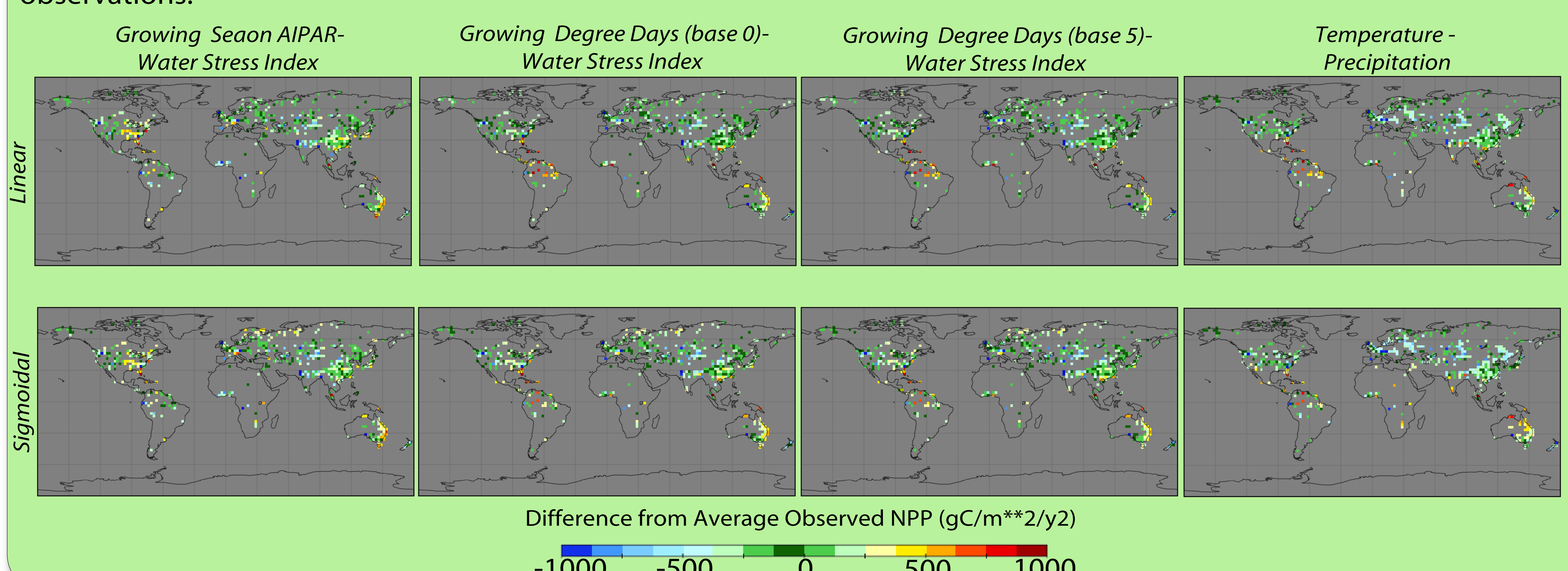
Applying the empirical equations to the input climate datasets results in global maps of NPP. The model coefficients were determined by minimizing the least squared error between the observations and simulations. Linear and sigmoidal functional forms were chosen to relate the climatic variables to NPP:

NPP(Linear) = max(0, a * Heat + b * Water – c)
NPP(Sigmoidal) = a / ((1 + exp(b – c * Heat)) * (1 + exp(d – e * Water))

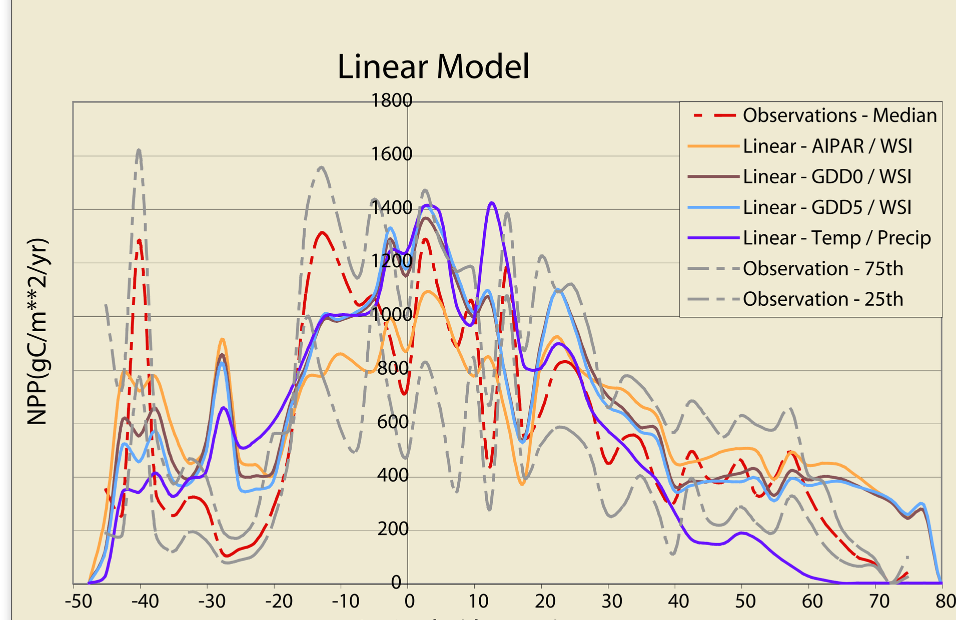


Observation Comparison

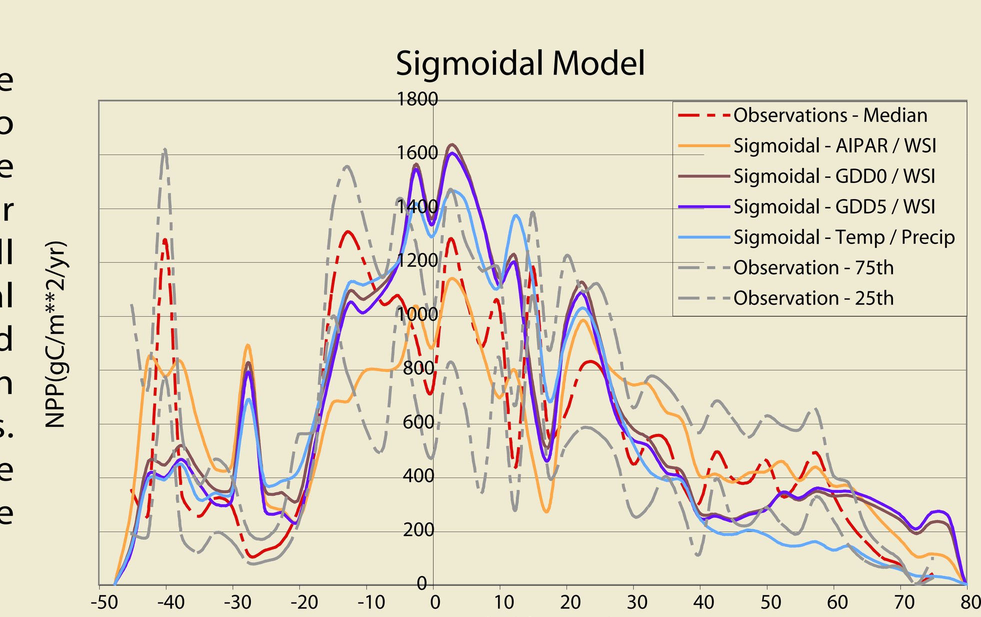
The large reference dataset allows for rigorous validation of the model.These spatial estimates are compared to the observations to determine the accuracy of the model, both in the patterns of NPP distribution and magnitude. Both the model and observations are averaged over 2.5°grid cells, displayed as the median model deviations from the observations.



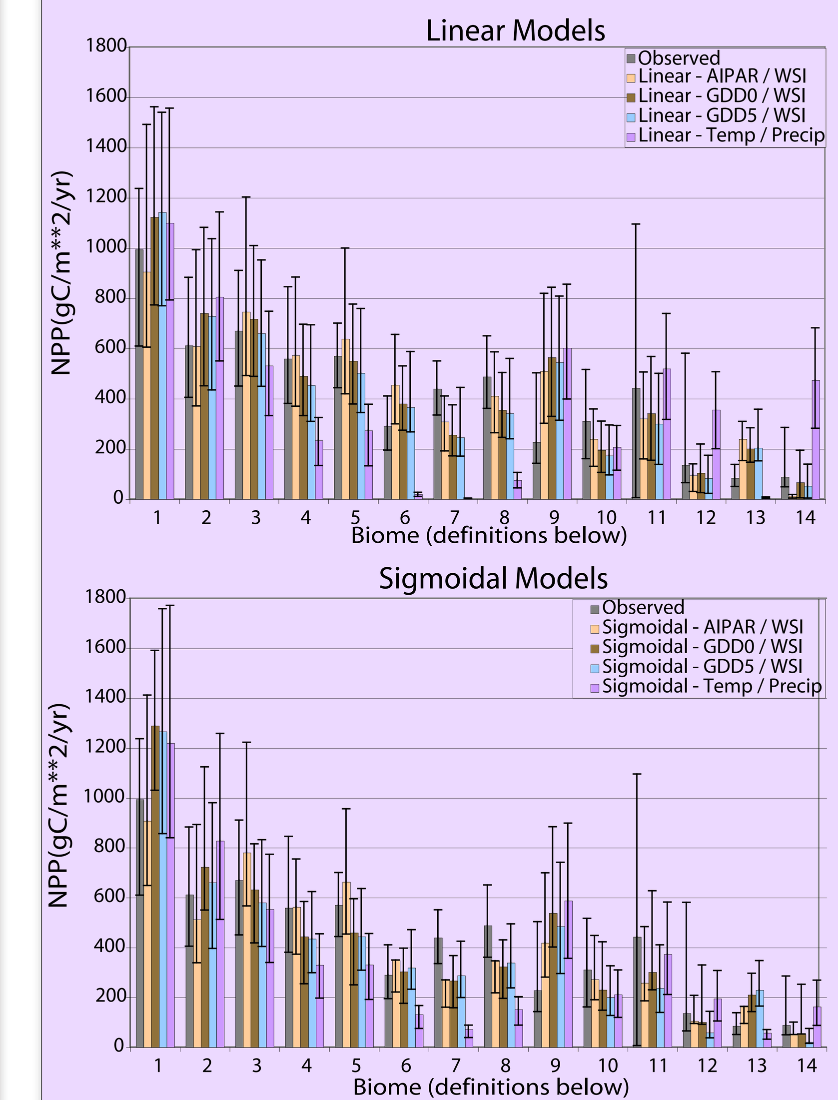
Latitudinal Comparison



Model results were summarized and compared to areas where observations were available, based on their latitudinal distribution. All models followed the general trends of low NPP in cold and dry areas, and higher NPP in warmer and wetter locations. The median model, 25th %ile and 75th %ile models are shown for comparison.



Biome Averages

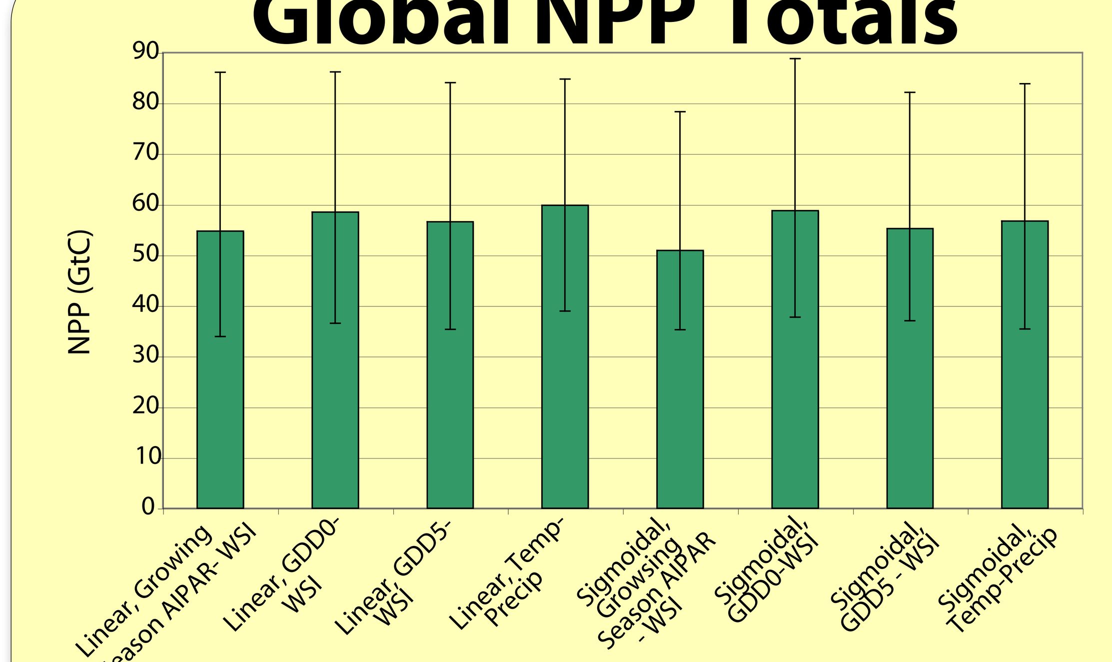


Model results and observations were compared on a biome basis to determine the models' ability to represent spatial patterns of NPP. Biomes were defined by Ramankutty and Foley (1999).

General trends were detected within both linear and sigmoidal models based on the climatic conditions of each biome. Highest values of NPP were observed and modeled in biomes where water and heat are not limiting, such as the tropical forests, and the lowest values of NPP in the desert (water limited) and the tundra (temperature limited). Both the linear and sigmoidal models estimated NPP values in the savannas that were much higher than observations.

1 Tropical Evergreen Forest/Woodland
2 Tropical Deciduous Forest/ Woodland
3 Temperate Broadleaf Evergreen Forest/ Woodland
4 Temperate Needleleaf Evergreen Forest/ Woodland
5 Temperate Decidious Forest/ Woodland
6 Boreal Evergreen Forest/ Woodland
7 Boreal Deciduous Forest/ Woodland
8 Evergreen/ Deciduous Mixed Forest
9 Savanna
10 Grassland/ Steppe
11 Dense Shruband
12 Open Shrubland
13 Tundra
14 Desert

Global NPP Totals



Global total NPP was summed for each model (25th, median, and 75th percentile). The median values converge around 55 GtC, and the envelope between the 75th and 25th percentile models generally falls between 40 – 80 GtC, the commonly cited range for global NPP (Cramer et al. 1999).

Concluding Remarks

- This study shows the effectiveness of using climatic variables in association with observed data to construct global models of net primary productivity.

- Although climate variables were strong predictors of NPP patterns, the uncertainty in our global NPP predictions remains high. Land use history, topography; micro-climate, and sampling and measurement methods may all add variability that is not represented by the models.

- The growing network of NPP observations has facilitated the construction of this model, but our study illustrates the need for standardization in sampling methodology.

Selected References:

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