Observed Vegetation-Climate Feedbacks in the United States

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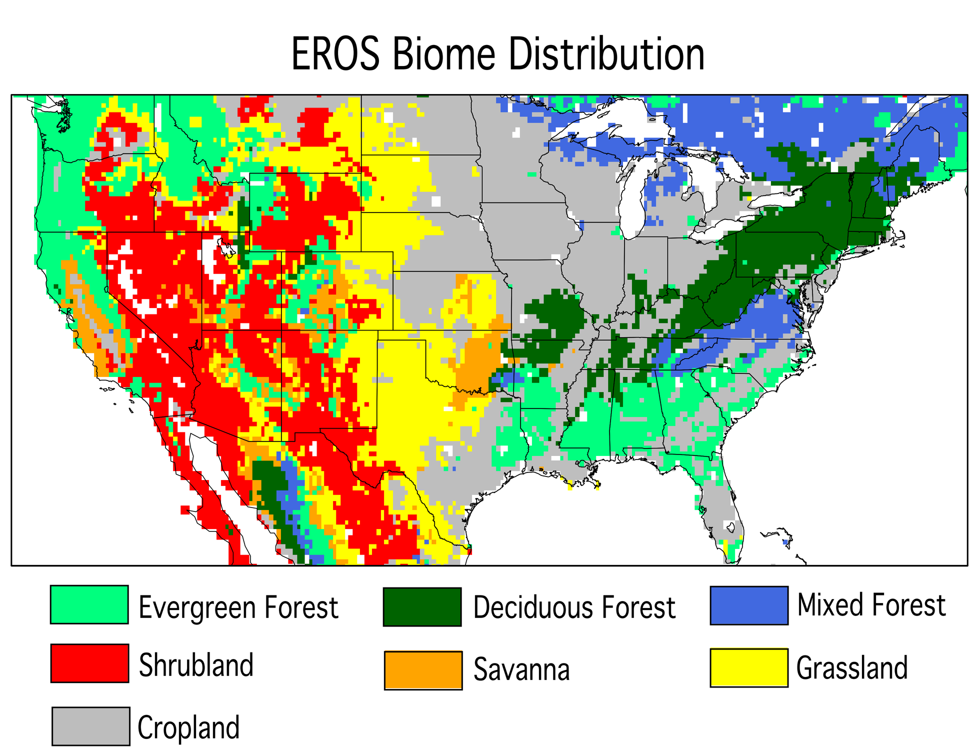
ABSTRACT: Observed vegetation feedbacks on temperature and precipitation are assessed across the U.S. using satellite-based fraction of photosynthetically active radiation (FPAR) and monthly climate data for 1982-2000. This study represents the first attempt to spatially quantify the observed local impact of vegetation on temperature and precipitation over the U.S., for all months and by season. Lead-lag correlations and feedback parameters are computed to determine the regions where vegetation substantially impacts the atmosphere and to quantify this forcing. Temperature imposes a significant instantaneous forcing on FPAR, while precipitation's impact on FPAR is greatest at one-month lead, particularly across the prairie. An increase in vegetation raises the surface air temperature by absorbing additional radiation and, in some cases, masking the high albedo of snow cover. Vegetation generally exhibits a positive forcing on temperature, strongest in spring and particularly across the northern states. The local impact of FPAR on precipitation appears to be spatially inhomogeneous and relatively weak, potentially due to the atmospheric transport of transpired water.

OBJECTIVES

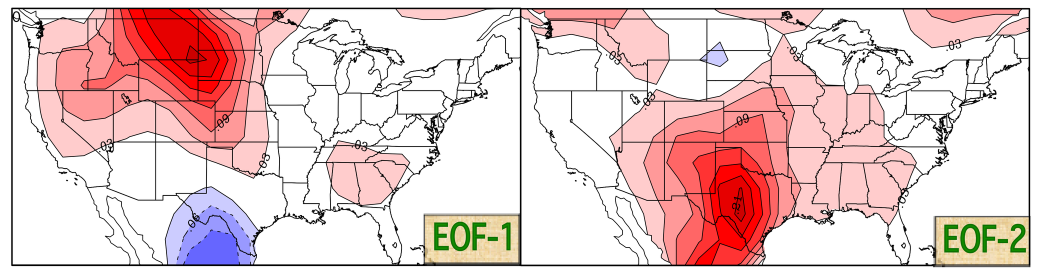
1. Quantify the observed impact of vegetation on temperature and precipitation across the U.S. using a statistical feedback parameter
2. Investigate the relationship between climate and vegetation across the U.S. using instantaneous and lead/lag correlations.
3. Investigate variability in U.S. vegetation and climate.
4. Determine the decorrelation time (memory) of U.S. vegetation.

DATA:

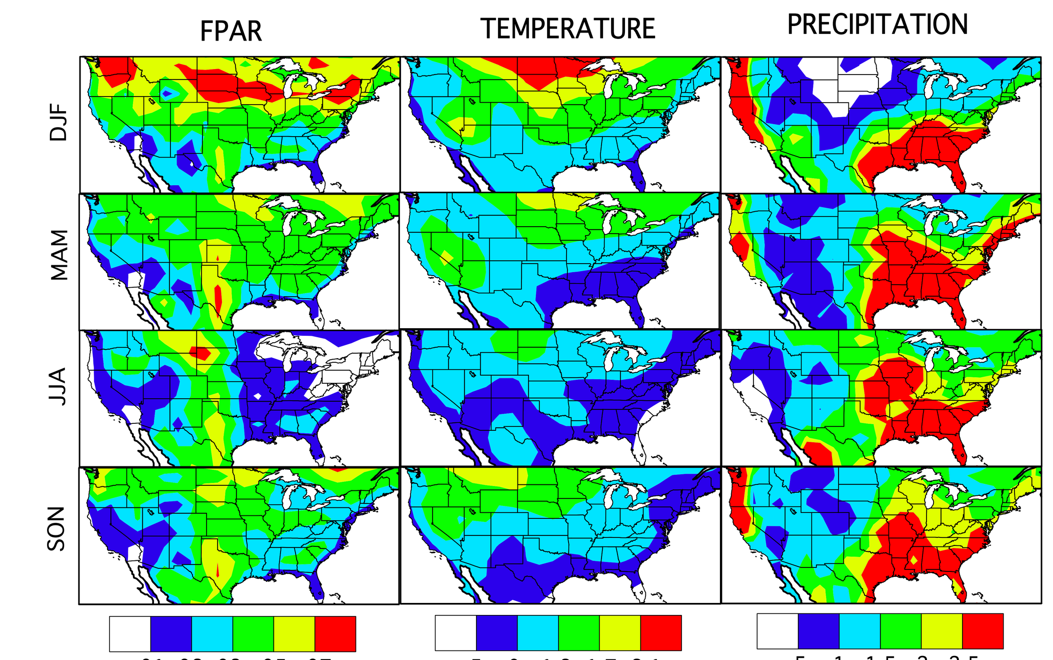
Vegetation is assessed using Pathfinder Version 3 AVHRR FPAR data (Myneni et al. 1997). FPAR represents a measure of vegetation activity. All data is obtained for 1982-2000. The data is interpolated to a 2.5˚x2.5˚ grid, converted to monthly anomalies by removing the annual cycle, and linearly detrended. The sources of monthly climate data are the NCEP-NCAR Reanalysis (Kalnay et al. 1996) for surface air temperature and CPC merged analysis of precipitation dataset (Xie and Arkin 1997). The AVHRR-based biome distribution is retrieved from EROS Data Center's Global Land Cover Classifications (Loveland et al. 2001).



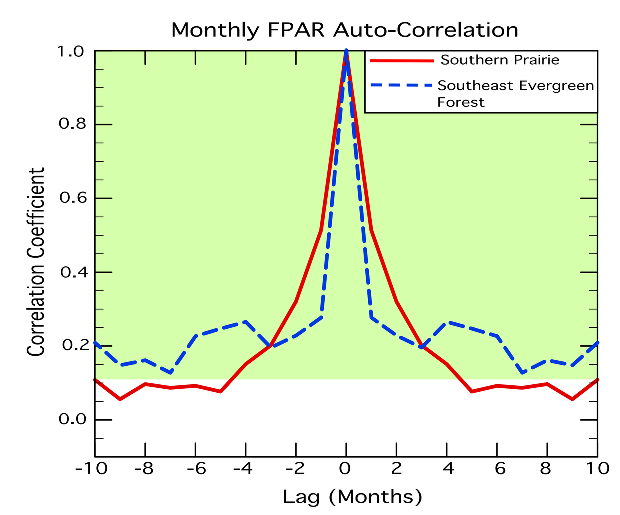
Biome distribution from EROS data Center's Global Land Cover Classifications dataset. Classifications are merged into 7 categories for simplification.



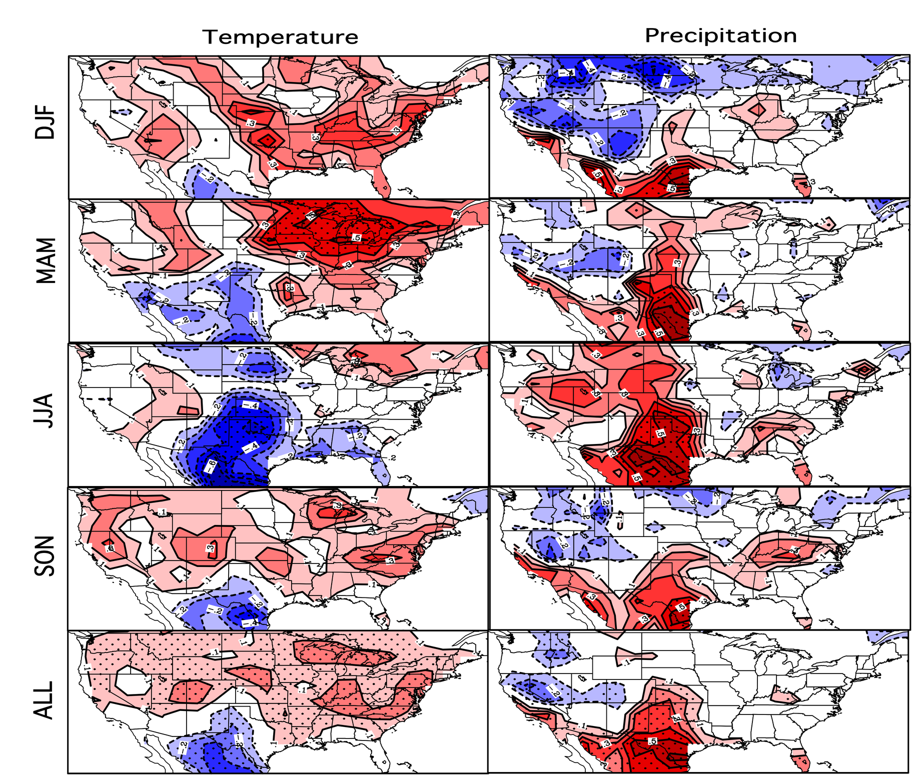
Unrotated (EOF) empirical orthogonal function patterns (modes 1 and 2) for JJA FPAR anomalies. The percent explained variances are 38% for EOF-1 and 19% for EOF-2. The north-south dipole of FPAR is evident across the prairie.



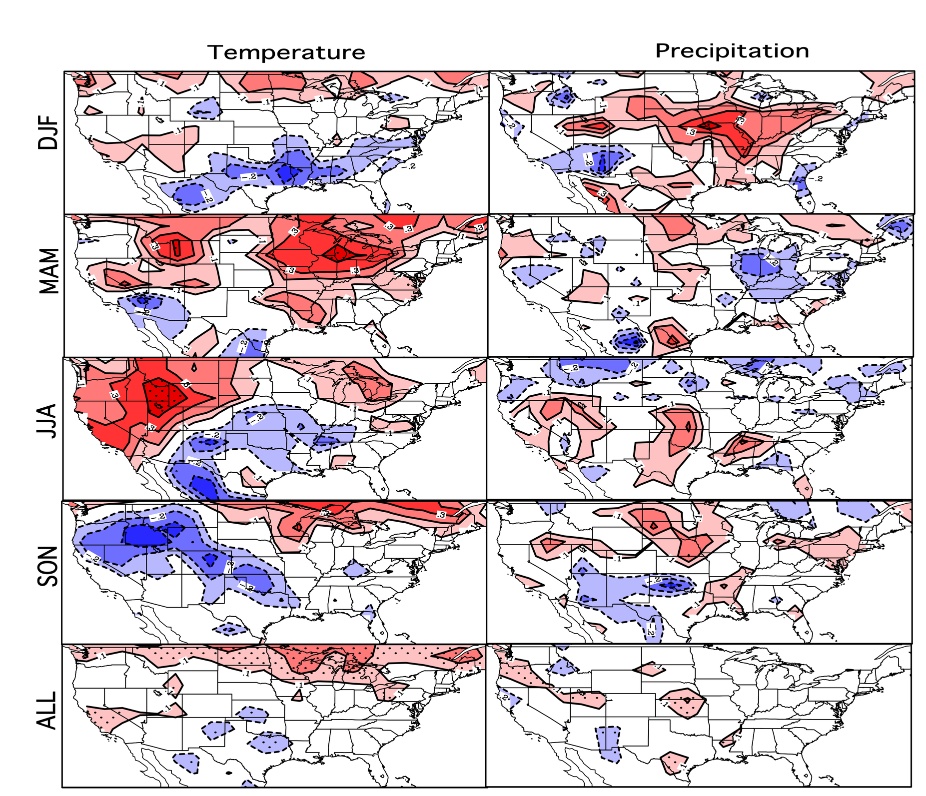
Standard deviation of monthly anomalies of FPAR, temperature (°C), and precipitation (cm/month) for the four seasons. Variability is greatest for FPAR over the central U.S. prairie, for temperature over the northern plains, and for precipitation over the Southeast, West Coast, and Corn Belt.



Temporal auto-correlation of monthly FPAR anomalies for the southern prairie (solid) and Southeast evergreen forests (dash). Correlation coefficients are shown at different time lags, up to 10 months. Shading indicates p<0.10. Both regions show a memory of at least 4 months. The evergreen forest exhibits relatively weak memory on the short time scale but significant cross-seasonal memory.



Lead/lag correlations between observed monthly anomalies of FPAR and both temperature and precipitation, with the **atmospheric variable leading** by one month. Dotted pattern indicates p<0.10. The largest positive correlations with temperature leading FPAR are identified over the upper Midwest in MAM. Correlations with precipitation leading FPAR are significant over the southern/central prairie.



Lead/lag correlations between observed monthly anomalies of FPAR and both temperature and precipitation, with **FPAR leading** by one month. These correlations are generally weak, especially for precipitation. FPAR anomalies are positively correlated with the next month's temperature over the northern U.S., particularly the Midwest in MAM and northern Rockies in JJA.

VEGETATION FEEDBACK PARAMETER

Frankignoul et al. (1998) studied ocean-atmosphere feedbacks using a statistical feedback parameter. We apply this methodology to vegetation-atmosphere feedbacks, assessing the instantaneous impacts of another slow changing component, vegetation, on the atmosphere. We use satellite-derived FPAR to represent monthly vegetation. FPAR has a longer memory or decorrelation time (4 months) than the atmosphere (1 week). Our calculations use monthly anomalies of FPAR and temperature (or precipitation) for 1982-2000.

F = FPAR
T = Temperature (or another atmospheric variable)
dt_a = Atmospheric response time (less than one week)
N = Climate noise generated by atmospheric processes
τ = Lead-time longer than the decorrelation time of atmospheric noise forcing (FPAR leading atmosphere)
λ = Feedback efficiency or feedback parameter.

The atmospheric variable can be divided into 2 components:

$T(t+dt_a) = \lambda F(t) + N(t+dt_a)$

We can neglect dt_a due to the fast atmospheric response (dt_a<1 week) and the use of monthly data. Thus, $T(t+dt_a) \approx T(t)$. Let τ=1 month. Multiply both sides by F(t-1), taking the covariance of both sides.

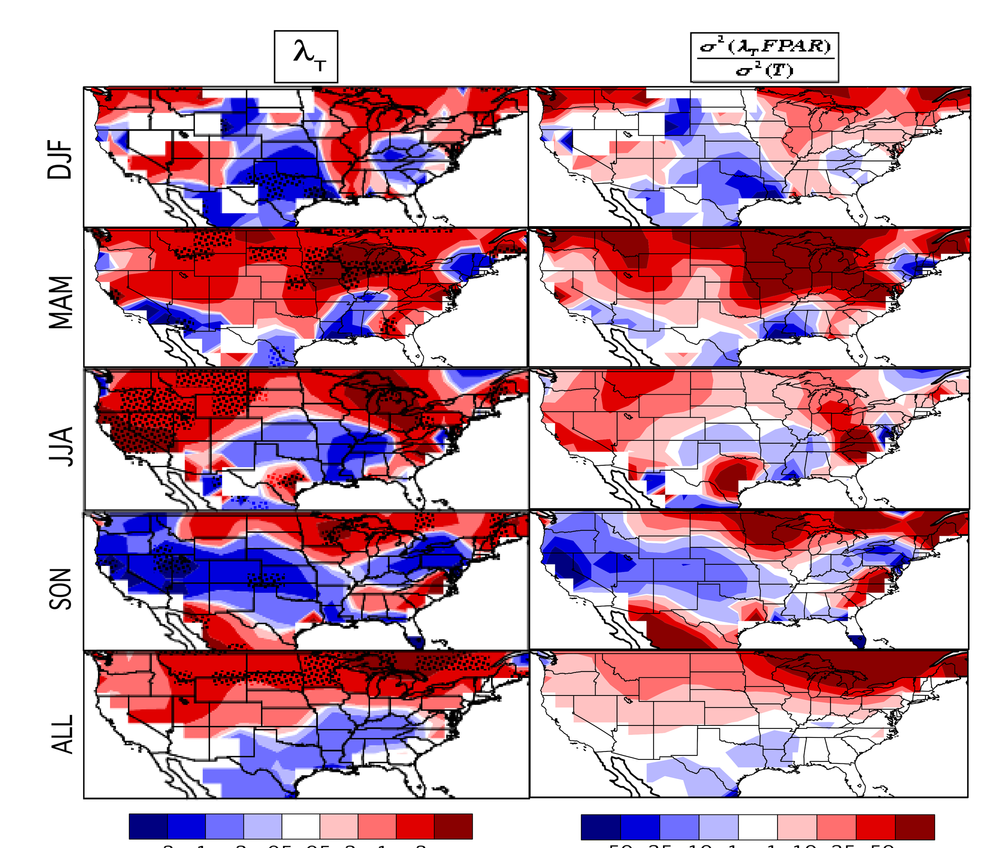
$\langle F(t-1)T(t)\rangle = \langle \lambda F(t-1)F(t)\rangle + \langle F(t-1)N(t+dt_a)\rangle$

Since the present atmospheric noise cannot affect the previous FPAR, there is no covariance between the noise and earlier FPAR, meaning $\langle F(t-1)N(t+dt_a)\rangle = 0$.

$\langle F(t-1)T(t)\rangle = \langle \lambda F(t-1)F(t)\rangle$

$$\lambda = \frac{\langle T(t)F(t-1)\rangle}{\langle F(t)F(t-1)\rangle}$$

The feedback parameter, λ, represents the ratio of the lagged covariance between the atmospheric variable and FPAR to the lagged covariance (auto-correlation) of FPAR. Even though FPAR leads T in this formula, the feedback response occurs "instantaneously" without lag, giving the atmospheric response to a vegetation change within the month.



Vegetation feedback parameter (˚C/0.1fpar) for monthly temperature anomalies, by season and for all months (left). Percent explained variance of the feedback-induced variability, by season and for all months (right). Dotted pattern indicates p<0.10 (based on Monte Carlo tests). Vegetation imposes a significant positive forcing on temperature across the northern U.S. (temperature increases 1-3˚C in response to an FPAR increase of 0.1). The positive feedback on temperature is significant over the Midwest in MAM and northern Rockies in JJA. The highest % explained variance is found in MAM.

References:
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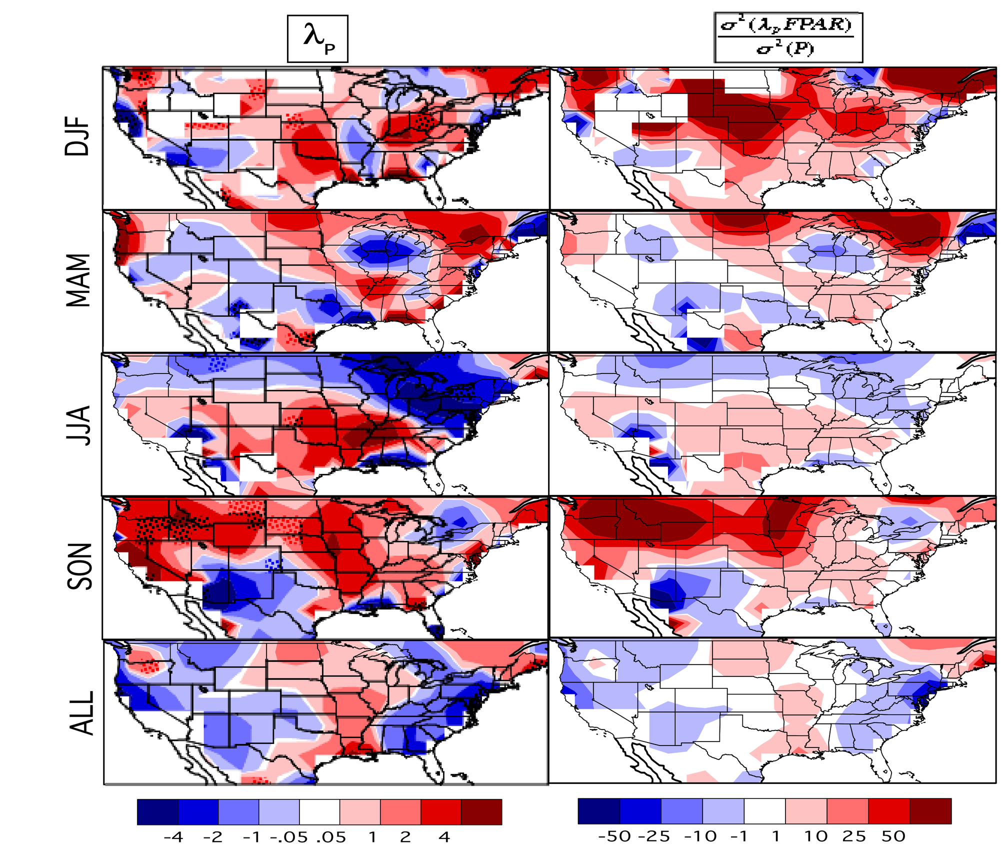

Vegetation feedback parameter (cm/month/0.1fpar) for monthly precipitation anomalies, by season and for all months (left). Percent explained variance of the feedback-induced variability, by season and for all months (right). Dotted pattern indicates p<0.10. The feedback parameter computed for all months is positive across the corn and soybean belt and negative over the winter wheat belt, although not statistically significant. During SON, significant positive feedback parameters are computed for the Northwest. There is little evidence of a dominant local positive feedback to precipitation, as most models simulate.

RESULTS

- FPAR exhibits a persistence time of a few months across the U.S.
- Temperature is a significant control of FPAR for much of the country, particularly in MAM, based on instantaneous correlations.
- Unlike temperature, correlations between FPAR and precipitation anomalies are larger when the atmospheric variable leads by one month.
- The largest interannual FPAR variability occurs over the central U.S. prairie, where a north-south dipole is identified.
- Correlations with FPAR leading by one month suggest a positive influence of vegetation on temperature over the upper Midwest in MAM and northern Rockies in JJA (albedo feedback).
- Correlations fail to identify statistically significant feedbacks of FPAR on precipitation.
- Based on satellite-derived FPAR and climate data for the U.S., the mean vegetation feedback parameters for temperature and precipitation are +0.9˚C/0.1fpar and -0.6 cm/month/0.1fpar, respectively, across all months.
- An increase in FPAR results in net warming and drying, although the effect of FPAR on precipitation is weaker than for temperature and the feedback parameter for precipitation is generally not statistically significant.
- The mean feedback parameter for temperature is most positive during MAM and JJA.
- Maps of vegetation feedback parameters for precipitation are spatially complex, although a positive forcing over the corn and soybean belt and negative forcing over the winter wheat belt are identified when computed across all months.

This poster summarizes the findings of Notaro et al. (2006) for the U.S. and reflects the methodology of Liu et al. (2006).