

Generalized Equilibrium Feedback Assessment (GEFA)

• References:

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- Wang, F., M. Notaro, Z. Liu, and G. Chen, 2014: Observed local and remote influences of vegetation on the atmosphere across North America using a model-validated statistical technique that first excludes oceanic forcings. *J. Climate*, **27**, 362–382, doi: [10.1175/JCLI-D-13-00080.1](https://doi.org/10.1175/JCLI-D-13-00080.1).
- Yu, Y., M. Notaro, F. Wang, J. Mao, X. Shi, and Y. Wei, 2018: Validation of a Statistical Methodology for Extracting Vegetation Feedbacks: Focus on North African Ecosystems in the Community Earth System Model. *J. Climate*, **31**, 1565–1586, doi: [10.1175/JCLI-D-17-0220.1](https://doi.org/10.1175/JCLI-D-17-0220.1).

• Principle:

- Variability of an atmospheric variable A over time is presumed to have a forced component from multiple slowly-evolving boundary conditions \mathbf{O} and internal variability N : $A(t) = \mathbf{B}\mathbf{O}(t) + N(t)$ where \mathbf{B} is a vector of feedback weights. \mathbf{O} can be local land factors or from remote land or ocean. Mean annual cycles and long-term trends are first removed from all fields.
- For a time scale τ there is a time series of trailing boundary forcings $\mathbf{O}(t - \tau)$. Lagged covariance matrices can be estimated by applying the transpose:

$$\mathbf{C}_{AO}(\tau) = A(t)\mathbf{O}^T(t - \tau)/L$$

$$\mathbf{C}_{OO}(\tau) = \mathbf{O}(t)\mathbf{O}^T(t - \tau)/L$$

$$\mathbf{C}_{NO}(\tau) = N(t)\mathbf{O}^T(t - \tau)/L = 0 \text{ by assumption}$$

- The feedback vector is then estimated as: $\mathbf{B} = \mathbf{C}_{AO}(\tau)\mathbf{C}_{OO}^{-1}(\tau)$
- There exists a variant called Stepwise GEFA (SGEFA) applicable to short data sets (see: Yu et al. 2018).

• Data needs:

- Both local and nonlocal feedbacks can be assessed, depending on source (locations) of forcing time series used to assess of atmospheric variability.
- Forcings \mathbf{O} should have a much redder spectrum than the atmospheric variables examined, appropriate to the chosen time scale.
- Well suited to a wide range of data sets including model output, particularly if time series are long (multiple years).

• Observational data sources:

- The slow manifold of \mathbf{O} makes this well suited to forcing variable data sets that have incomplete, frequent missing or irregularly sampled data, such as polar-orbiting satellite measurements that have a multi-day repeat cycle, or occasional cloud obscuration.

• Caveats:

- GEFA metric is intrinsically linear, so may not detect nonlinear or threshold-triggered forcings well.
- As with other correlation metrics, causality is not assured.