

**Generalized Equilibrium Feedback Assessment (GEFA)**

## • References:

- Liu, Z., N. Wen, and Y. Liu, 2008: On the assessment of nonlocal climate feedback. Part I: The generalized equilibrium feedback assessment. *J. Climate*, **21**, 134–148, doi: 10.1175/2007JCLI1826.1.
- 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.
- 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.

## • 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  $\tau$  there is 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.