A geostatistical model for teleconnections

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Joint work with

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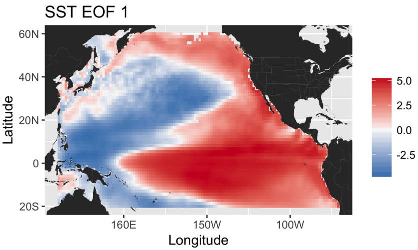
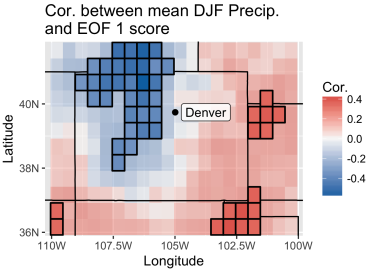
Motivation

- Estimate teleconnections and test for significance while
  - accounting for spatial dependence
  - accounting for impact of local factors





Contributions

Climate science

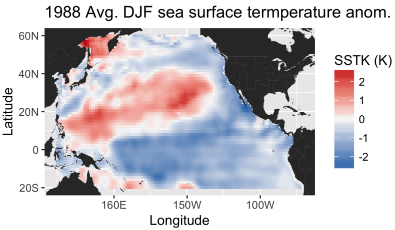
- Alternative to compositing by directly controlling for local covariates
- Alternative to post-hoc multiple testing corrections by directly accounting for spatial dependence

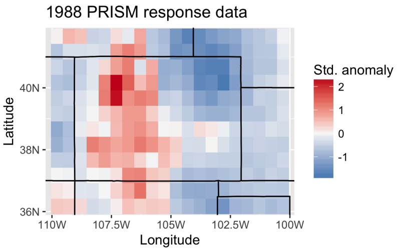
Spatial statistics

- Methodology for spatial modeling with remote effects

Case study: Colorado precipitation

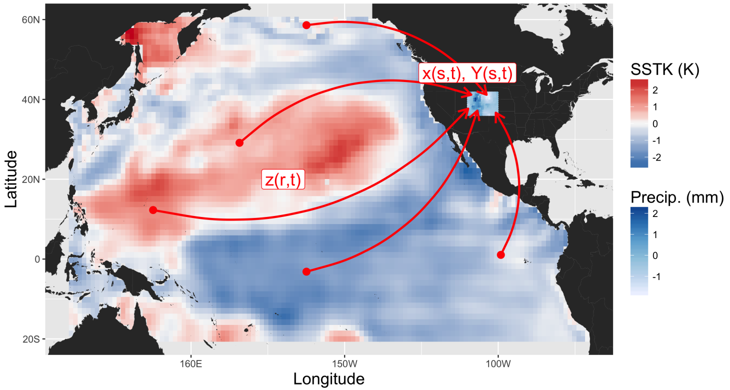
- (Reanalysis) Data (33 winters: 1981–2013)
  - $Y(\boldsymbol{s}, t)$: PRISM precipitation
  - $\boldsymbol{x}(\boldsymbol{s}, t)$: ERA-Interim covariates
- Local covariates: $TCWV$, T, Z_{700}, $Elevation$
- Local domain: 240 42km-resolution grid cells
- Remote domain: 5,252 78km-resolution grid cells





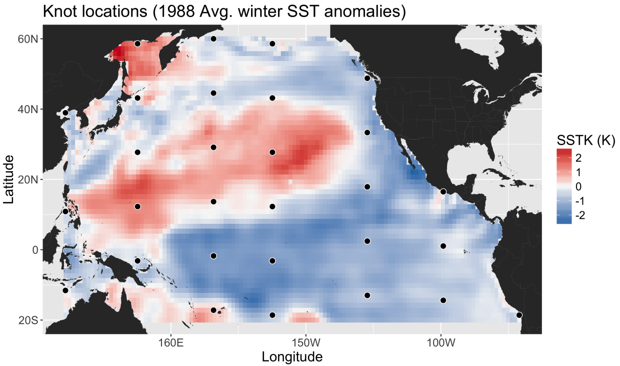
Remote effects spatial process (RESP) model

$$\underbrace{Y(\mathbf{s},t)}_{\text{Std. Precip. anomaly}} = \underbrace{\mathbf{x}(\mathbf{s},t)^T\beta}_{\text{Local effects}} + \underbrace{w(\mathbf{s},t)+\varepsilon(\mathbf{s},t)}_{\text{Spatial + Independent error}} + \underbrace{\int_{\mathcal{D}_Z} z(\mathbf{r},t)\alpha(\mathbf{s},\mathbf{r})d\mathbf{r}}_{\text{Teleconnection effects}}$$



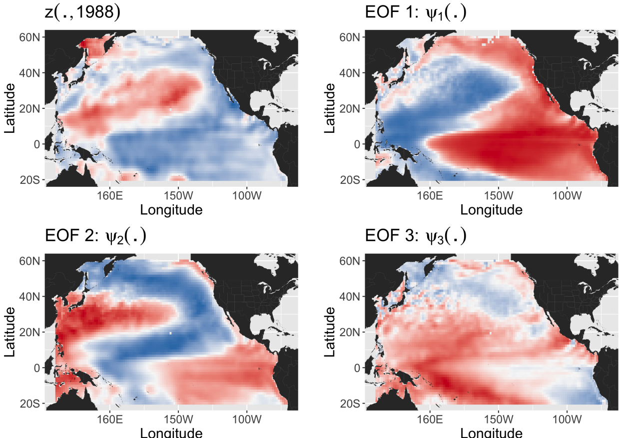
Remote effects spatial process (RESP) model

- Reduced rank approximation
  - Aggregate ocean data for more stable results
  - Aggregation parameters statistically optimized/estimated
  - $\alpha(\boldsymbol{s}, \boldsymbol{r}) = \sum_{j=1}^{k} h(\boldsymbol{r}, \boldsymbol{r}_j^*)\alpha(\boldsymbol{s}, \boldsymbol{r}_j^*)$



Remote effects spatial process (RESP) model

- Remote effects parameterization: Spatial basis fns.
  - Estimate teleconnections for EOFs or other patterns
  - $z(\boldsymbol{r}, t) = \sum_{k=1}^{K} a_k(t)\psi_k(\boldsymbol{r})$



Bayesian hierarchical implementation

$$\boldsymbol{Y}_t = \begin{bmatrix} \boldsymbol{Y}(\boldsymbol{s}_1, t) \\ \vdots \\ \boldsymbol{Y}(\boldsymbol{s}_{n_s}, t) \end{bmatrix} \sim \mathcal{N}\left(X_t\beta + \left(I_{n_s} \otimes \boldsymbol{z}_t^T\right)\tilde{\boldsymbol{\alpha}},\ \Sigma\right)$$

$$\tilde{\boldsymbol{\alpha}} \sim \mathcal{N}(\boldsymbol{0},\ \Sigma \otimes R)$$

$$\beta \sim \mathcal{N}(\boldsymbol{0},\ \Lambda)$$

$$\sigma^2 \sim \mathrm{Inv\text{-}Gamma}(k, \theta)$$

$$\rho \sim \mathrm{Uniform}(a, b)$$

X_t : Matrix of all local covariates for time t

$\tilde{\boldsymbol{\alpha}}$: Vector of teleconnection effects for all locations

Σ : Covariance matrix for Colorado locations

R : Covariance matrix for teleconnection effects $\boldsymbol{\alpha}(\cdot)$

$\boldsymbol{\theta} = \left(\sigma^2,\ \rho\right)$: Covariance matrix scale and range parameters

$(\Lambda, k, \theta, a, b)$: Hyperparameters

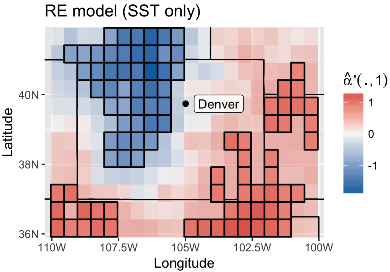
Case study: Parameter estimates

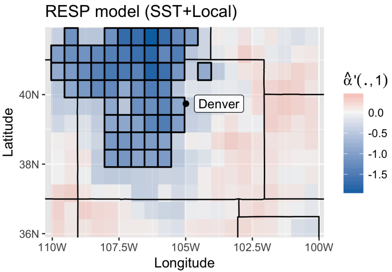
- Estimates account for remote covariates

	Posterior mean	95% HPD	VIF
β_0	0	(-0.058, 0.059)	1
β_{TCWV}	**0.491**	(0.424, 0.554)	1.2
β_T	**-0.302**	(-0.362, -0.241)	1.1
$\beta_{Z_{700}}$	**-0.149**	(-0.224, -0.078)	1.2
β_{ELEV}	0	(-0.049, 0.046)	1
σ_w^2	0.322	(0.303, 0.341)	
σ_α^2	0.004	(0.003, 0.005)	
$\tilde{\sigma}_\varepsilon^2$	0.093	(0.086, 0.099)	
ρ_w	37.11	(35.766, 38.332)	
ρ_α	6.657	(1.306, 11.166)	

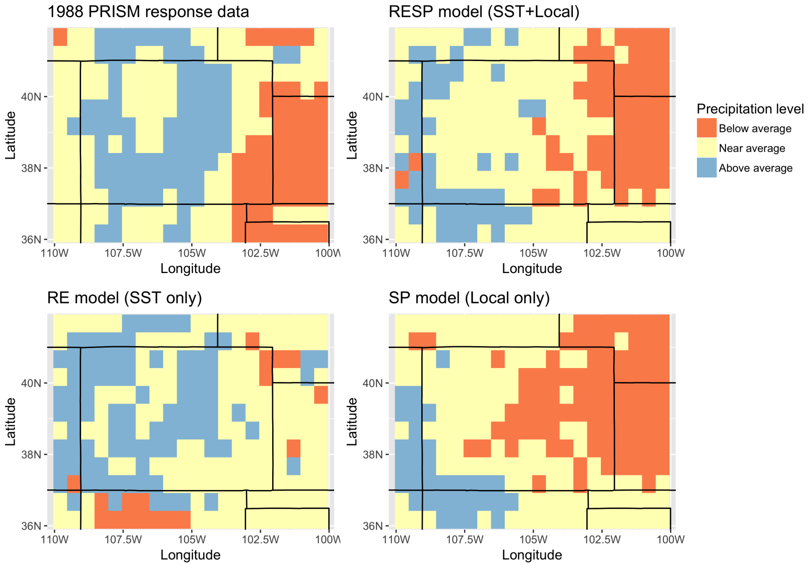
Case study: Teleconnection estimates

- RE model uses spatial dependence to "interpolate" significance in correlation maps
- RESP model suggests positive (red) teleconnection effects are fully expressed through local covariates



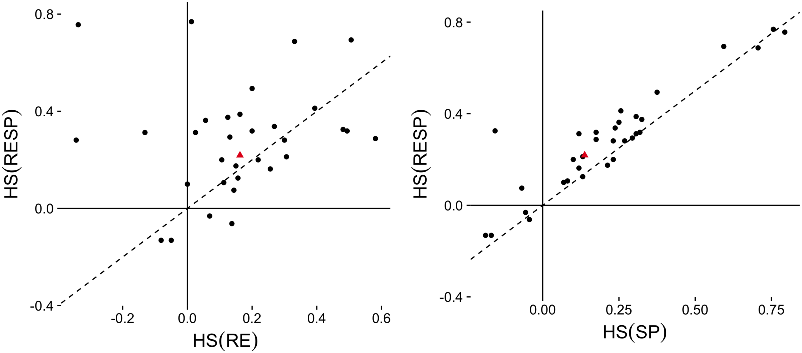


Case study: Data fit



Case study: Model comparison

- Fit measured with Heidke skill: $HS \propto P\Big(\hat{Y}(\boldsymbol{s}, t) = Y(\boldsymbol{s}, t)\Big)$



Conclusions and future work

- Conclusions
  - A new class of spatial statistics problems in which distant locations are correlated.
  - Geostatistical model that incorporates both local and spatially remote covariates modeled via different spatial processes.
  - A more formal framework than previously available for studying teleconnection patterns while accounting for local covariates and spatial dependence.
- Possible future work
  - GLM version of model to study teleconnection impacts on annual number of rain events.
  - Extension to allow temporal variation to account for changing teleconnections.

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