



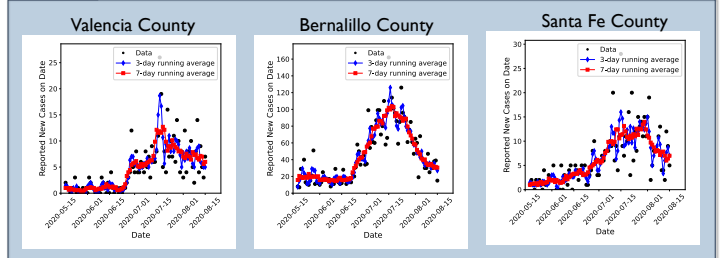
Development of a Spatially Regularized Detector for Emergent/Re-emergent Disease Outbreaks

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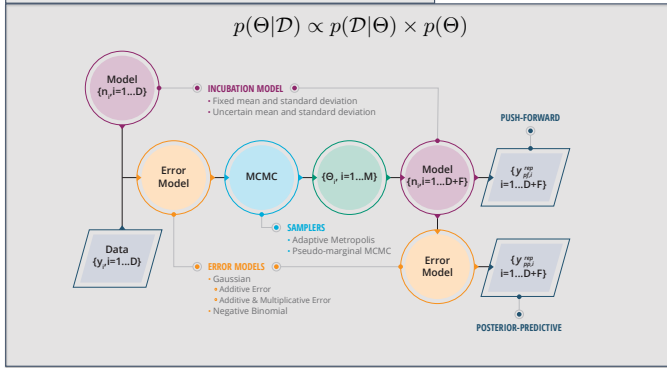
Summary

We propose a Bayesian framework to detect outbreaks of emerging diseases. Our method triggers when the observed case-count data disagree significantly from forecasted levels. In contrast, forecasting allows us to use socioeconomic parameters and spatiotemporal data on disease prevalence to compensate for low-quality epidemiological information. The proposed framework assumes correlations between adjacent regions to account for spatio-temporal correlations in the disease spread rate. Posterior distributions are approximated via Markov-Chain Monte Carlo. Results computed with COVID-19 data from New Mexico, US, are used to demonstrate the method.

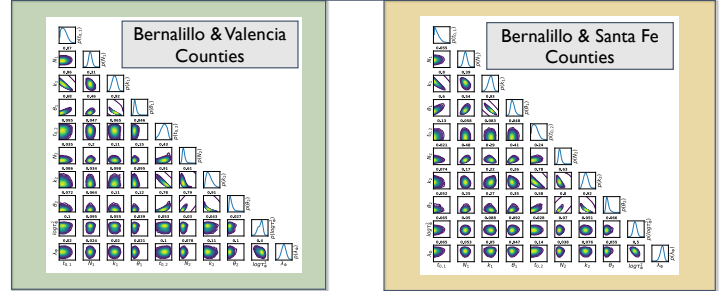
Data \mathcal{D}



Epidemiological Model Inference Workflow



Marginal Posterior Densities



Epidemiological Model

The epidemiological model consists of two components: an infection rate model and an incubation rate model. These models are combined through a convolution into a forecast of number of cases that turn symptomatic daily.

Infection Rate:

$$f_{\Gamma}(t; k, \theta, t_0) = \theta^{-k} (t - t_0)^{k-1} \exp(-(t - t_0)/\theta) / \Gamma(k)$$

Incubation Model:

$$F_{LN}(t; \mu, \sigma) = \frac{1}{2} \operatorname{erfc} \left(-\frac{\log t - \mu}{\sigma \sqrt{2}} \right)$$

Daily Symptomatic Cases for day i :

$$n_i = \int_{t_0}^{t_i} \left(\sum_{j=1}^K N_j f_{\Gamma}(\tau - t_0 - \Delta t_j; k_j, \theta_j) \right) \times (F_{LN}(t_i - \tau; \mu, \sigma) - F_{LN}(t_{i-1} - \tau; \mu, \sigma)) d\tau$$

Likelihood Model

Focus on spatial correlations:

$$\mathcal{L}_{\mathcal{D}} = \prod_{i=1}^{N_d} \frac{1}{(2\pi)^{N_r/2} \det \Sigma_i^{1/2}} \exp \left(-\frac{1}{2} (Y_i^{(o)} - Y_i^{(p)})^T \Sigma_i^{-1} (Y_i^{(o)} - Y_i^{(p)}) \right)$$

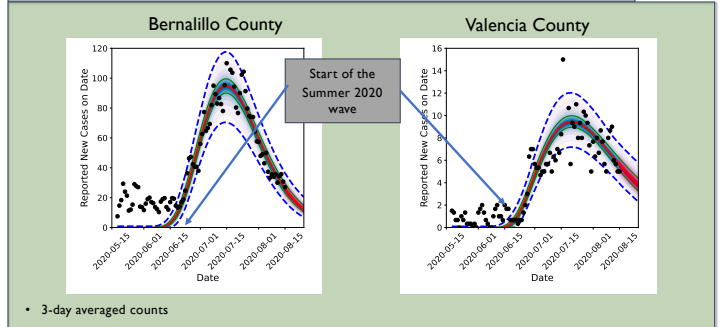
Account for proximity between regions and employ an additive-multiplicative error model:

$$\Sigma_i = \frac{\tau_{\Phi}^2}{1 - \lambda_{\Phi}^2} [I + \lambda_{\Phi} W] + \operatorname{diag}(\sigma_a + \sigma_m Y_i^{(p)})^2$$

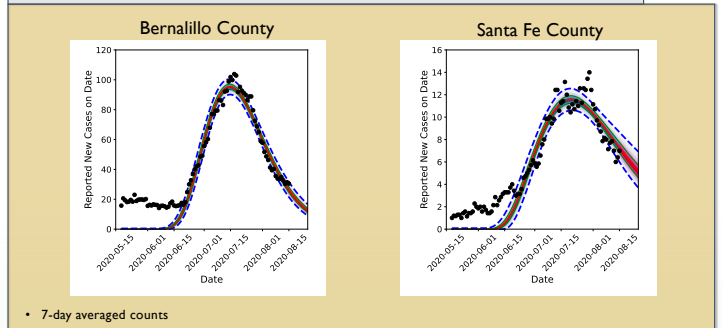
Spatial correlations:

$W : w_{kk} = 0, w_{kl} \in [0, 1]$ Off-diagonal entries account for mixing between adjacent regions (counties)

Posterior Predictive Distributions: Bernalillo & Valencia Counties



Posterior Predictive Distributions: Bernalillo & Santa Fe Counties



References:

- P. Blonigan, J. Ray, C. Safta (2021). Forecasting Multi-Wave Epidemics Through Bayesian Inference. *Archives of Computational Methods in Engineering*, doi:10.1007/s11831-021-09603-9
- C. Safta, J. Ray, K. Sargsyan (2020). Characterization of partially observed epidemics through Bayesian inference: Application to COVID-19. *Computational Mechanics*, doi:10.1007/s00466-020-01897-z