SIRS-EAKF Model In German Flu Forecasting

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What is the SIRS-EAKF model (again)?

The SIRS-EAKF model is a mechanistic that relies on state space estimation methods. The model has two frameworks to make forecast: SIRS and EAKF. Forecast accuracy of the model depends on factors in the prediction system:

▶ Model initial conditions

▶ Stochastic observation error

▶ Model misspecification

In particular, the first and the third factors can lead to error growth. In addition, the sensitivity to initial conditions can be crucial for forecasting.

First part of the model: Humidity-driven SIRS

This is a simple SIRS model modulated by local absolute humidity (AH) conditions is employed to simulate influenza outbreak dynamics. Assuming a perfectly mixed population, the model equations describing a local outbreak are:

$$\frac{dS}{dt} = \frac{N - S - I}{L} - \frac{\beta(t)IS}{L} - \alpha,$$

$$\frac{dI}{dt} = \frac{\beta(t)IS}{L} - \frac{I}{D} + \alpha,$$

where S = susceptible population, I = infected population are model variables. N = total population, $\beta(t)$ = contact rate at time t, L = average duration of immunity, D = mean infectious period, and α = the rate of infection introduction from external sources are model parameters.

The contact rate, $\beta(t)$, is forced by local AH conditions through

$$R_0(t) = \beta(t)D = e^{a \times q(t)+b} + R_{0min},$$

where $q(t)$ is observed specific humidity (a measure of AH), $R_0(t)$ is the basic reproductive number and R_{0min} are the minimum daily basic reproductive number.

First part together with the second part of the model: The SIRS-EAKF framework

The SIRS-EAKF system iteratively optimizes the distribution of state variables and parameters of the SIRS model using a sequential ensemble filtering technique called the Ensemble Adjustment Kalman Filter (EAKF).

The state vector at time t is $\mathbf{x}_t = (S_t, I_t, R_{0max}, R_{0min}, L, D)$. Once the observation O_t at time t is observed, the posterior distribution of the system state is obtained by incorporating the information from the new observation through Bayes' rule:

$$p(\mathbf{x}_t|O_{1:t}) \propto p(\mathbf{x}_t|O_{1:t-1})p(O_t|\mathbf{x}_t),$$

where $p(\mathbf{x}_t|O_{1:t-1})$ is the prior distribution of the system state, $p(O_t|\mathbf{x}_t)$ is the likelihood of observing O_t given the state $\mathbf{x}_t$, and $O_{1:t}$ are the observations taken up to time t.

The SIRS-EAKF framework (continued)

- ▶ In the EAKF, unobserved variables, such as the susceptible population S, and model parameters, are adjusted depending on covariant relationships with the observed variables.

- ▶ In Kalman filtering the intervariable relationships are assumed to be linear. As a consequence, the adjustments of unobserved variables and parameters are linearly related to the adjustment of the observed variable through their covariance, which is computed directly from the ensemble.

- ▶ To initialize the SIRS-EAKF system, an ensemble of state vectors was randomly selected from a collection of possible variable and parameter combinations.

Trajectory Adjustment with EAKF

► 1. For each observation of weekly incidence, the EAKF calculates an adjustment of the observed state variable using Bayes' Rule.

► 2. The unobserved state variables and parameters are then adjusted based on their prior covariance with the observed state variable.

The update, i.e., the adjustment of the prior state, can be interpreted as the EAKF estimate of the error of the state variables and parameters.

The Application of SIRS-EAKF in German Flu Forecasting Using Forecast Framework

We used the authors' initial parameters in the SIRS. Average daily absolute humidity was obtained from a representative station in Germany from 2012-2015.

Performance

Discussion & Challenges

- There are a large number of fixed initial parameters in the model that were generated using Latin hypercube. This could lead to error growth in the prediction system. Absolute humidity is also not a commonly available measurement.

- The model has high complexity. Particularly, the error correction part in the paper was not implemented since it involves imaginary numbers that R could not handle.

- Due to the complexity of the model and the fact that it relies on a large number of simulations to generate or update parameters, this model is difficult to replicate and requires a lot of fine-tuning.

Reference

► Pei S., Shaman J. Counteracting structural errors in ensemble forecast of influenza outbreaks. Nature Communicationsvolume 8, Article number: 925 (2017)