Empirical Modelling of Spatio-temporal Variation in Meningitis Incidence

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Where did 2009 go?

- Key objective: **short-term forecasting**
  - spatial scale: **district-level**
  - time-scale: **weekly**
  - forecast lead-time: **1, 2, ... weeks**
- Funding applications:
  - Menigitis Research Foundation: **uncuccessful**
  - Medical Researxh Council: **pending**
  - **... ?**
- PhD recruitment: **Michelle Stanton, Lydiane Agier**

Outline

- **Ethiopian data: weekly time-series at woreda-level, July 2002 – June 2008:**
  - **number of incident cases**
  - **land-surface temperature**
  - **rainfall**
- **Exploratory analyis:**
  - **temporal: country-wide incidence**
  - **spatial: woreda-level incidence**
  - **spatio-temporal: animation**

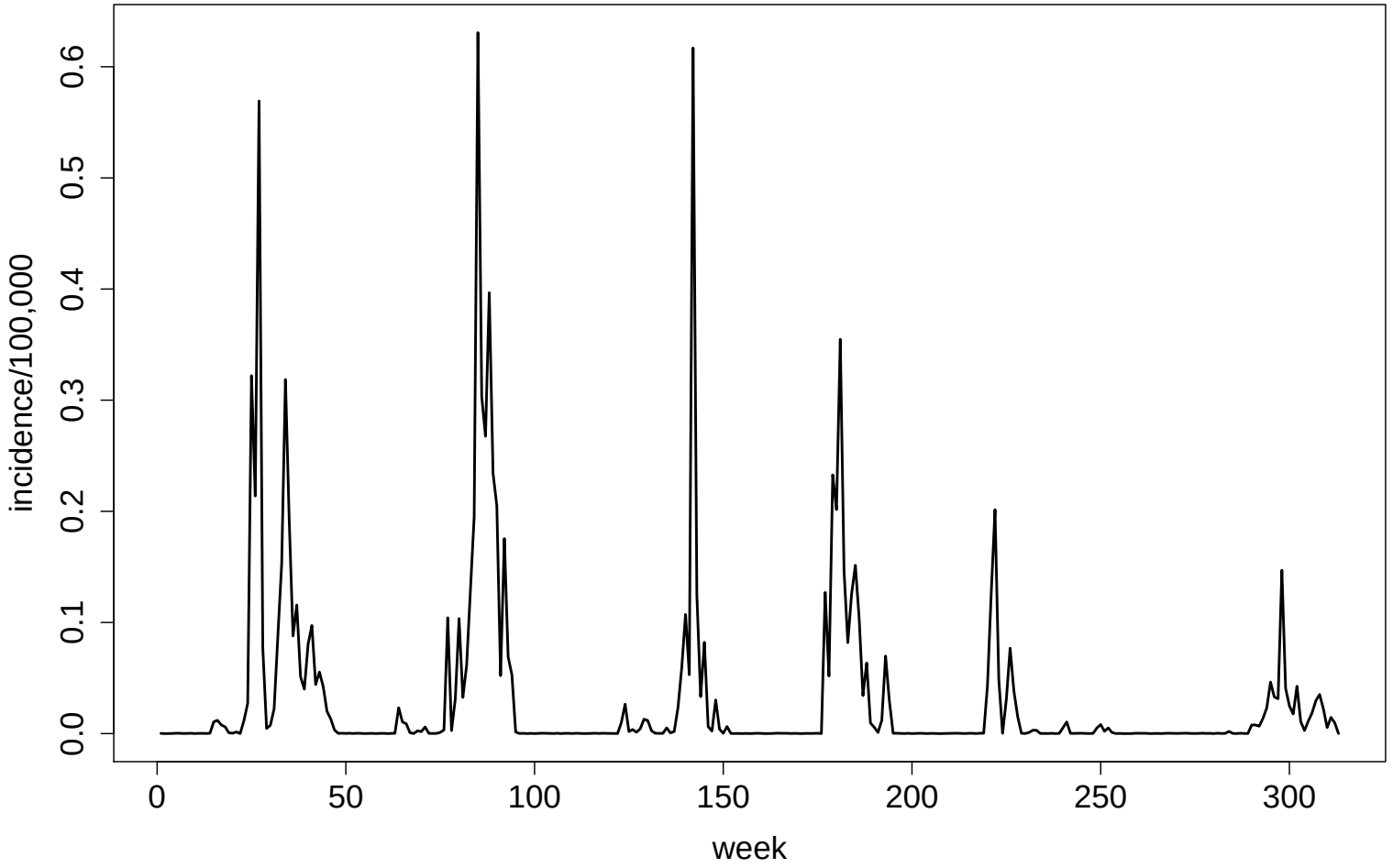
- **Proposed modelling framework:**
  - **multiplicative decomposition of incidence into temporal and spatio-temporal components**
  - **regression adjustments for time-lagged environmental variables**
  - **stochastic model to mimic short-term spread of epidemic amongst neighbouring woredas**

Ethiopian data: temporal structure

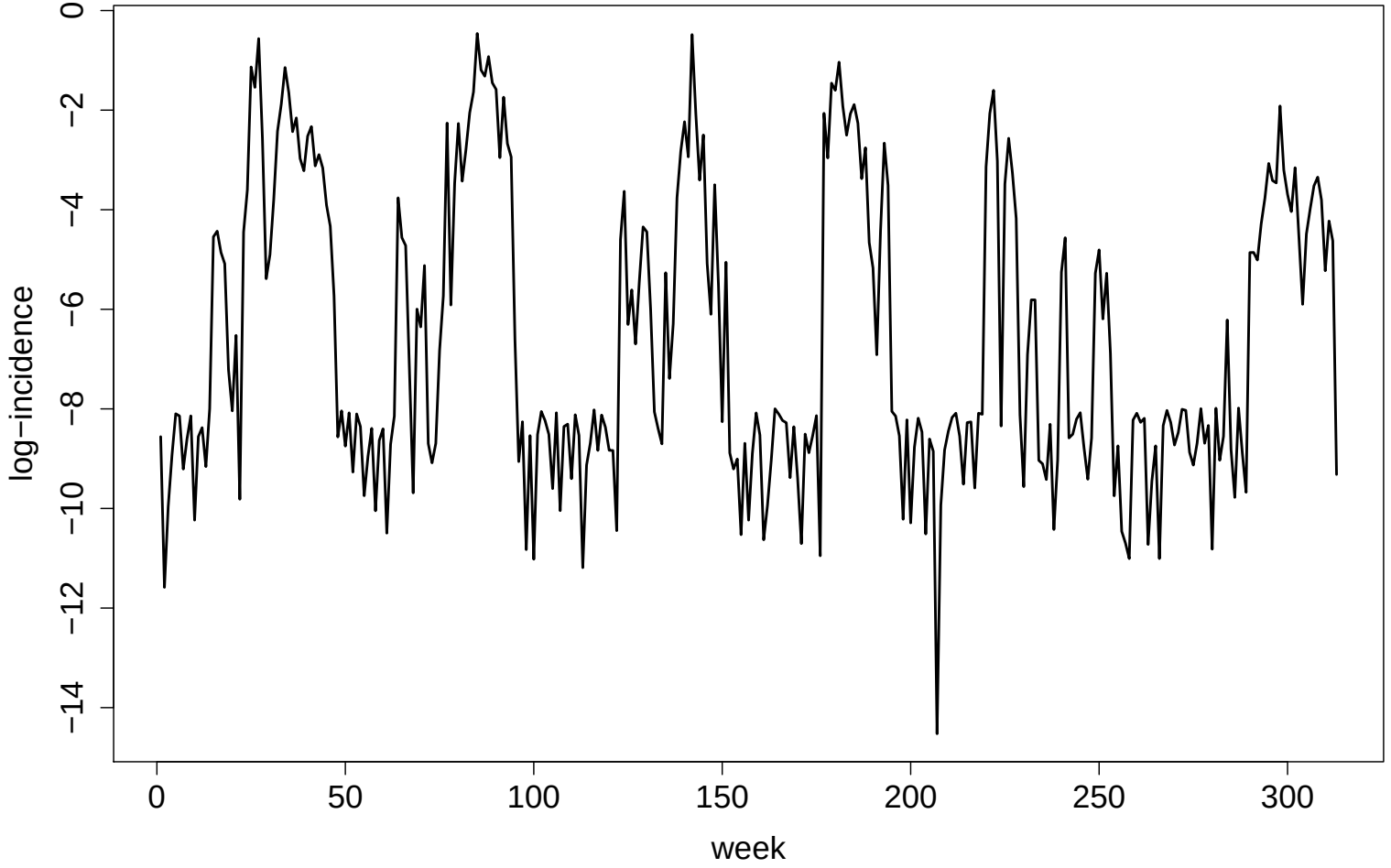
Time series at weekly intervals in each of 567 woredas:

- **incident counts, July 20002 to June 2008**
- **average land surface temperature (LST)**
- **total rainfall (TR)**
- **LST and TR mapped onto woredas, using the IRI Data Library**

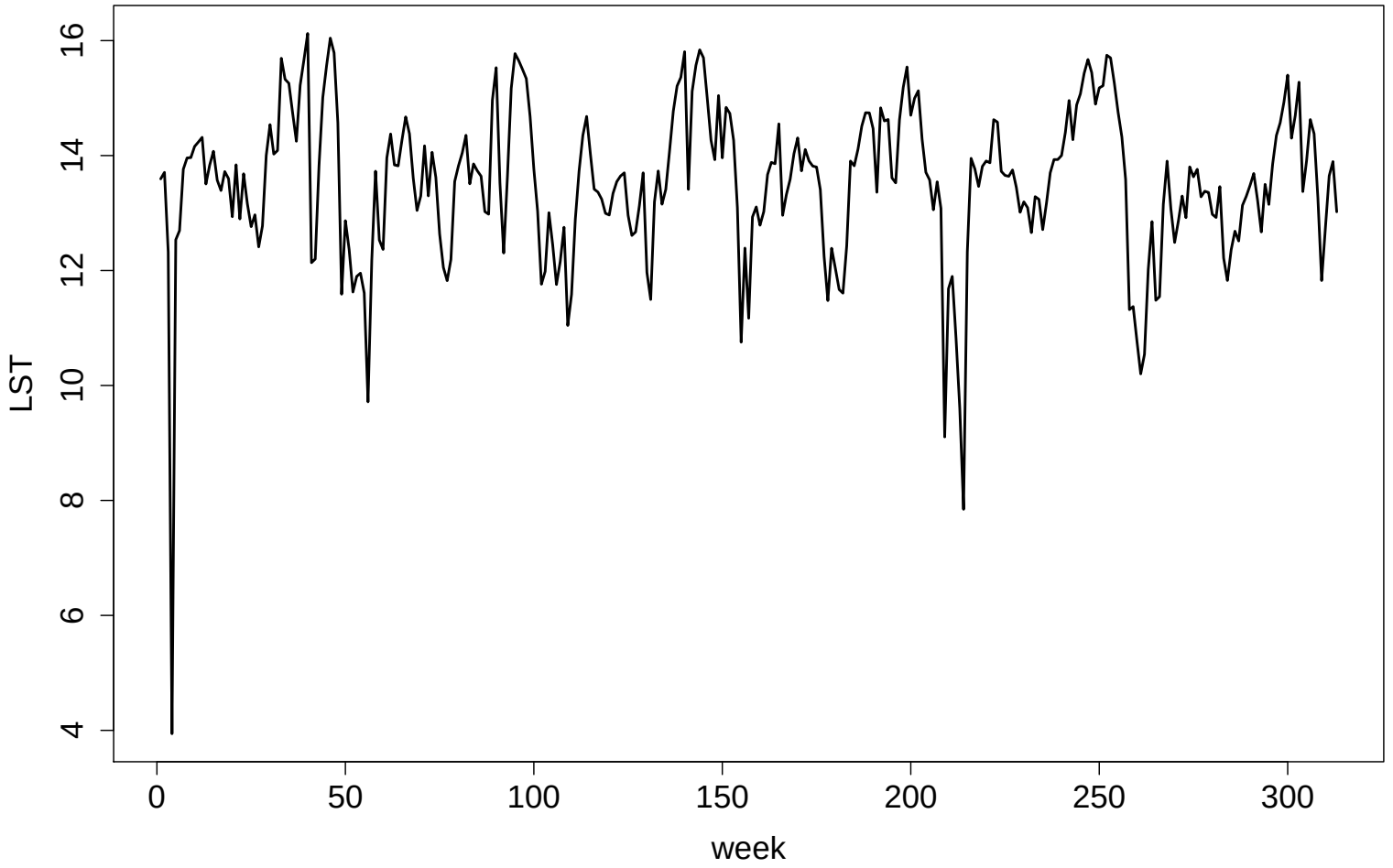
Ethiopian data: weekly national incidence



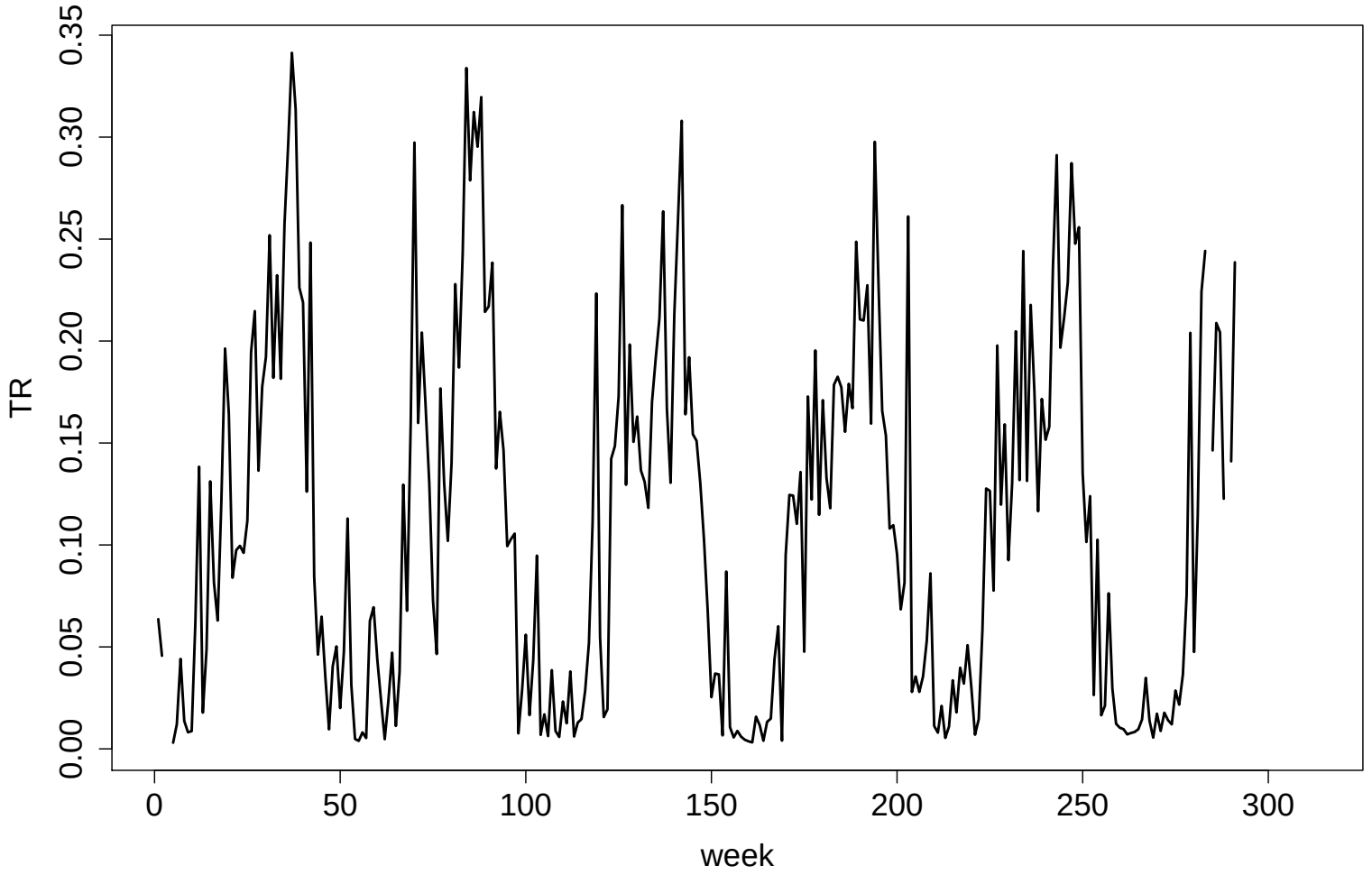
Incidence on log-scale



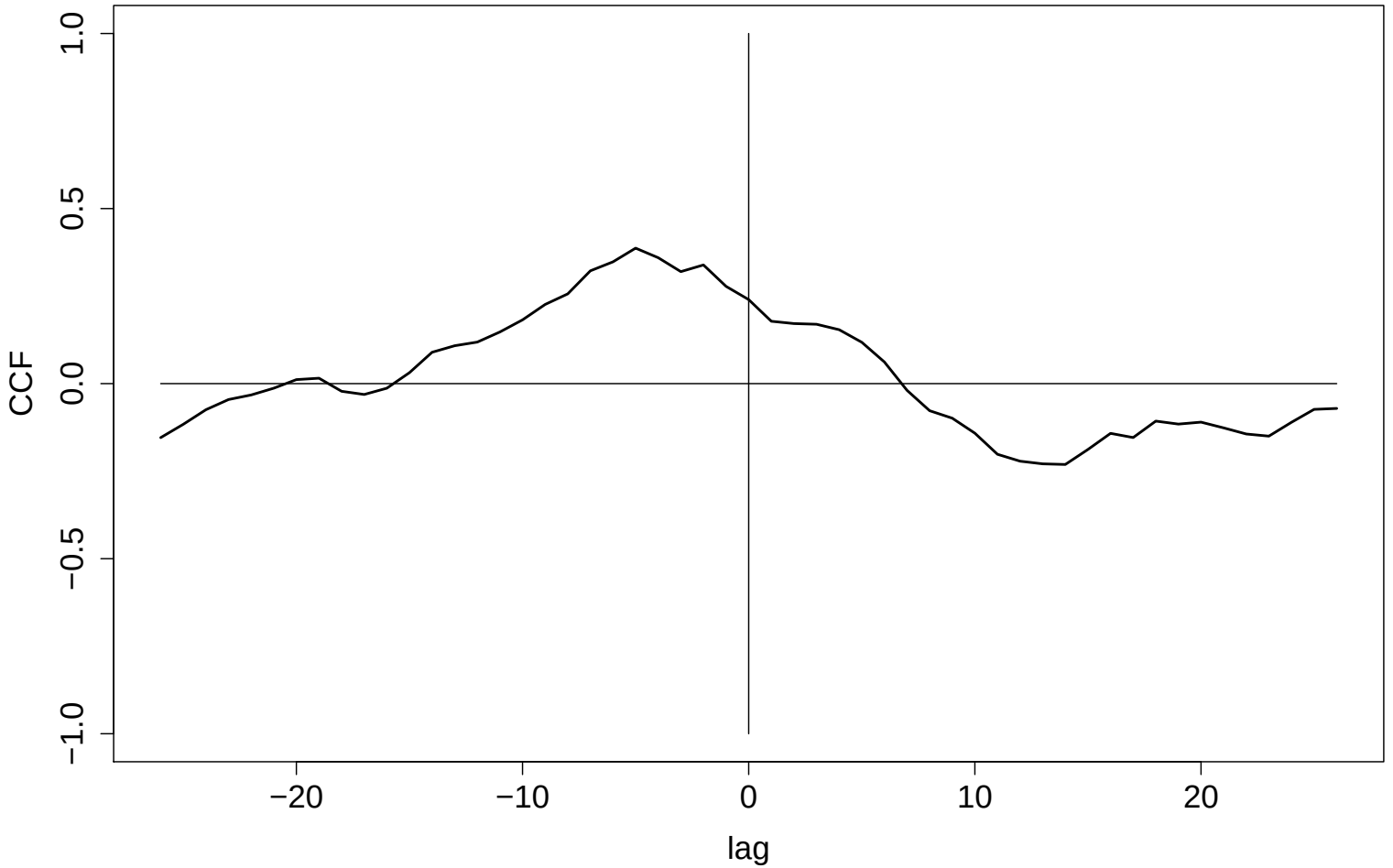
Land surface temperature



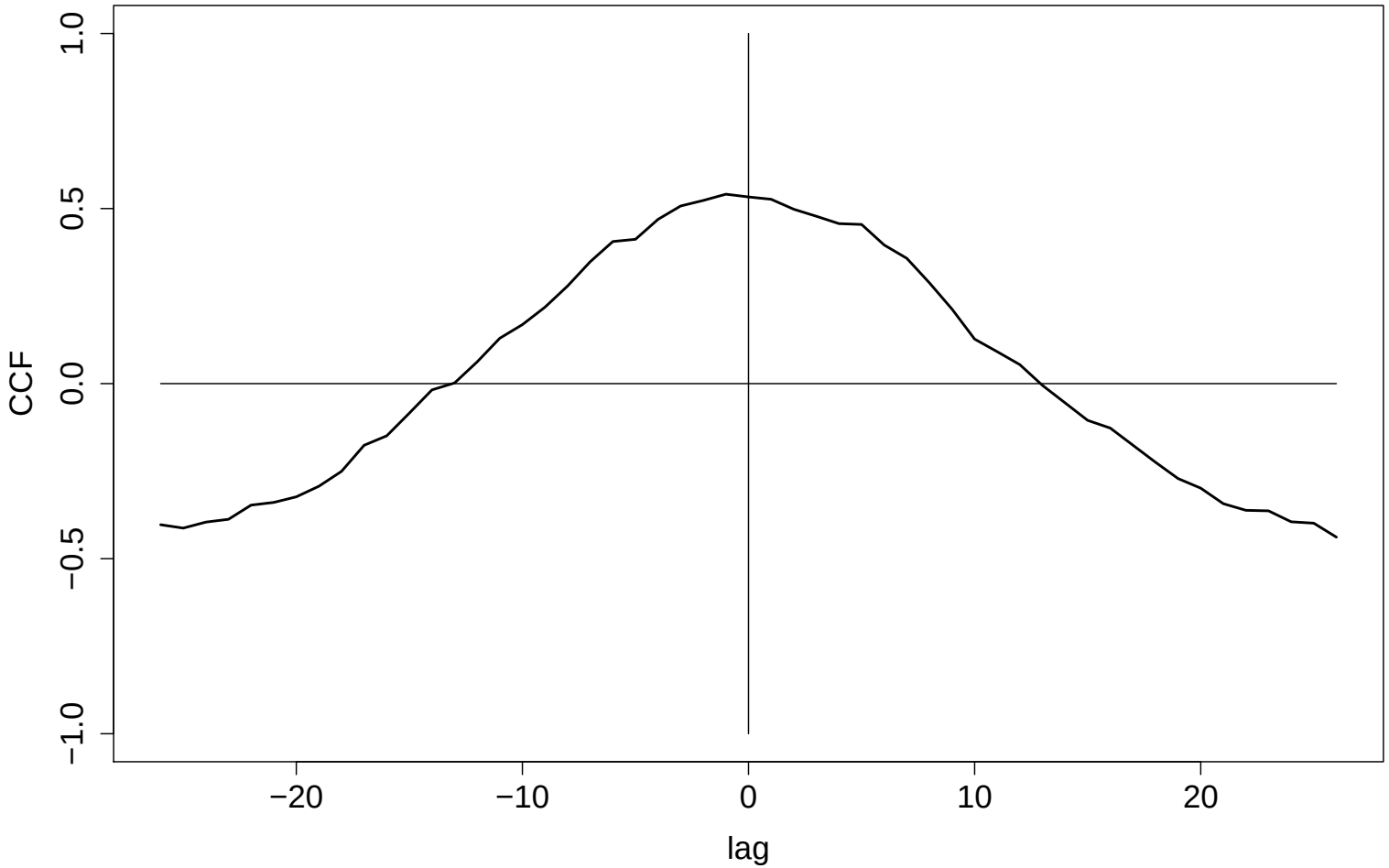
Total rainfall



Cross-correlation: incidence vs LST

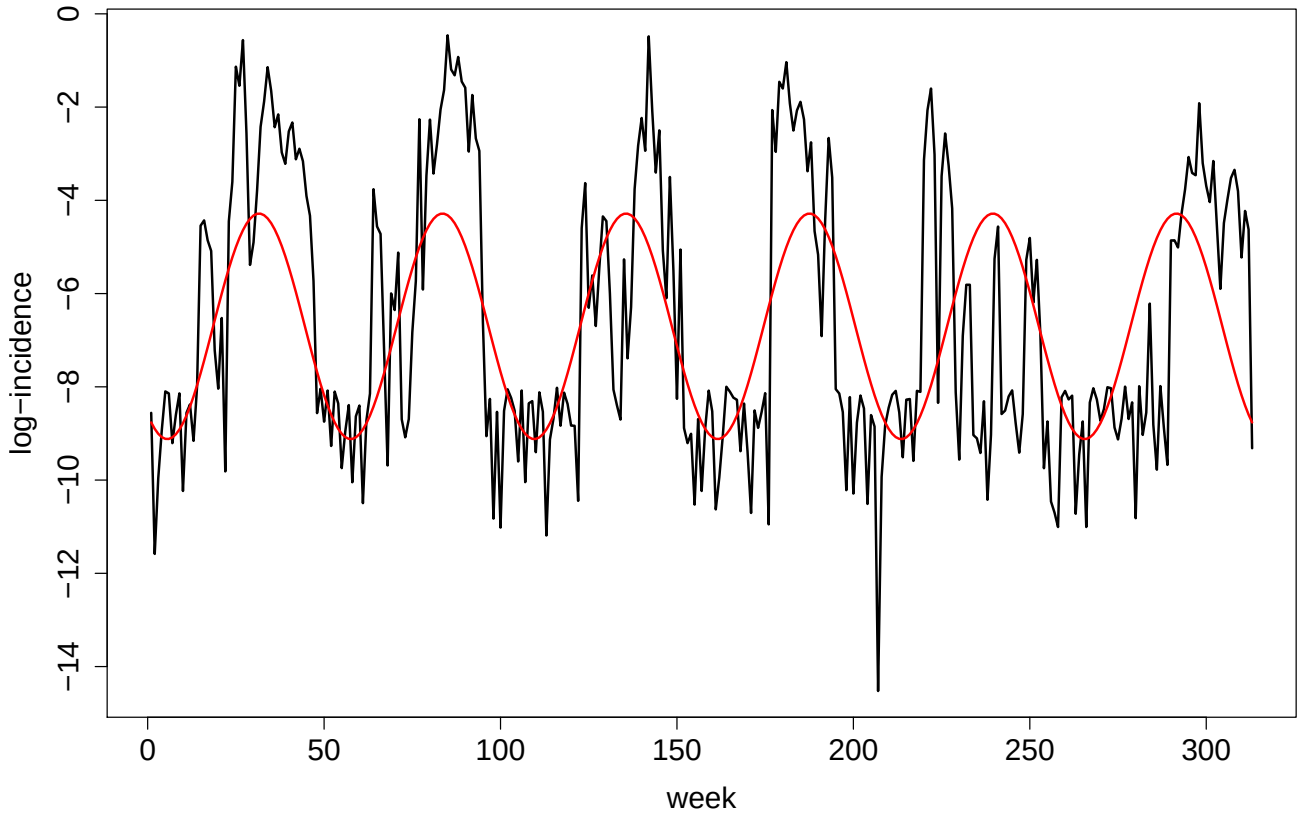


Cross-correlation: incidence vs TR



Regression model for country-wide incidence

INCIDENCE = SEASONAL × RESIDUAL



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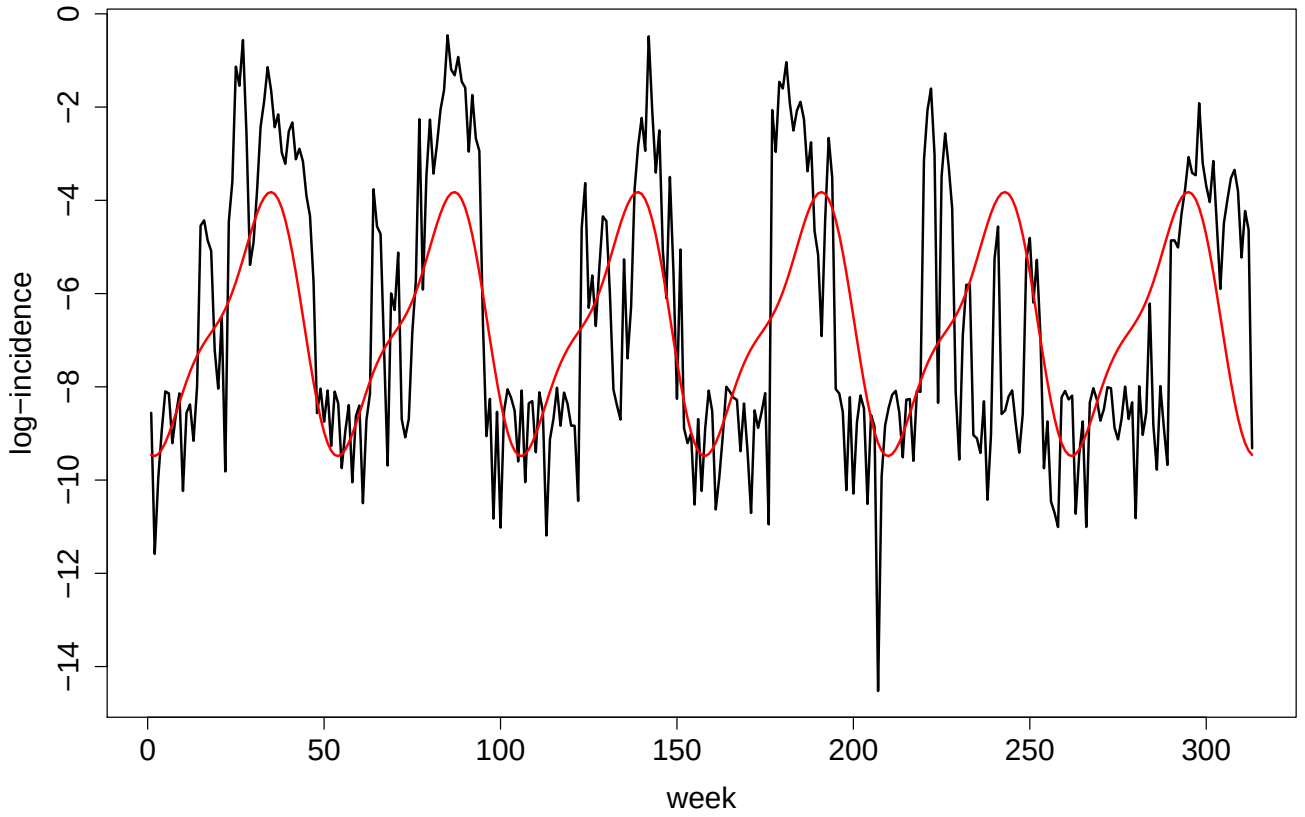
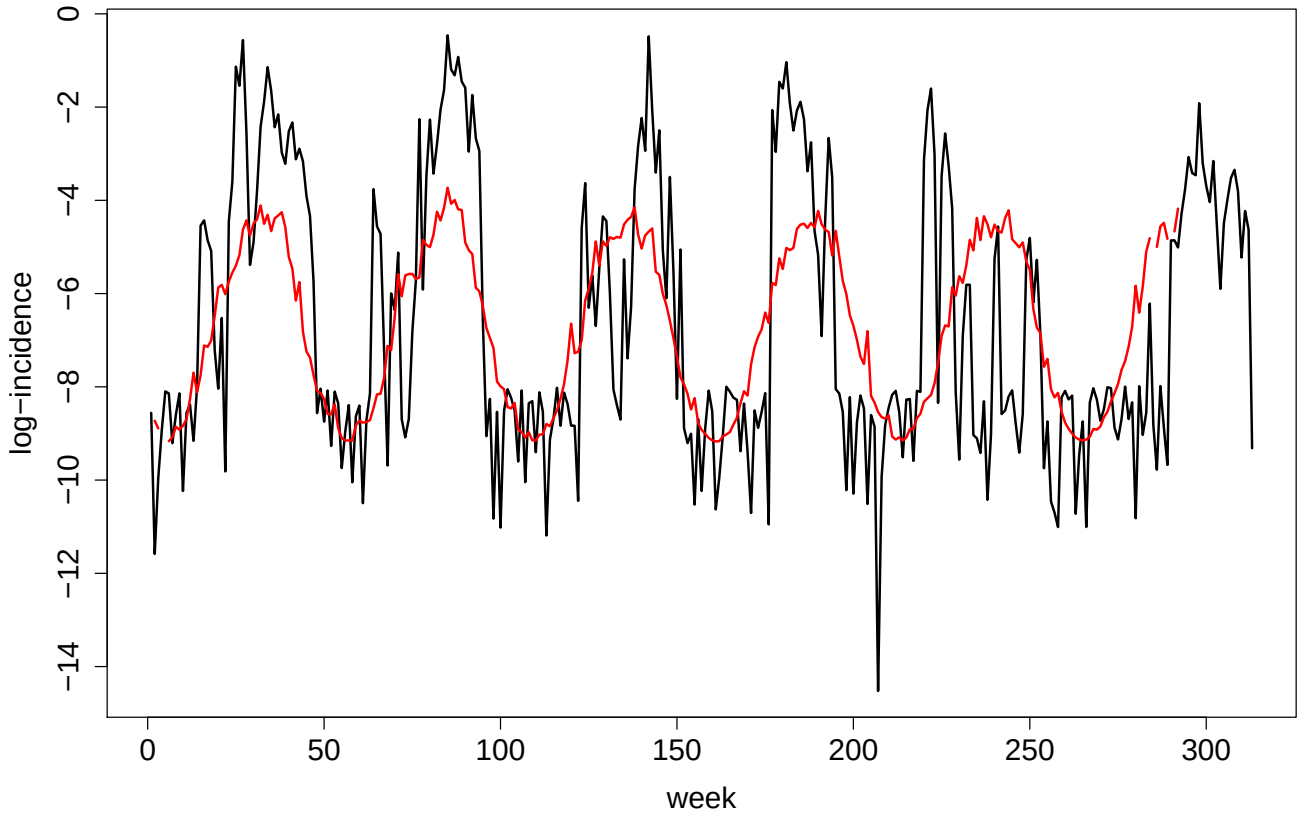
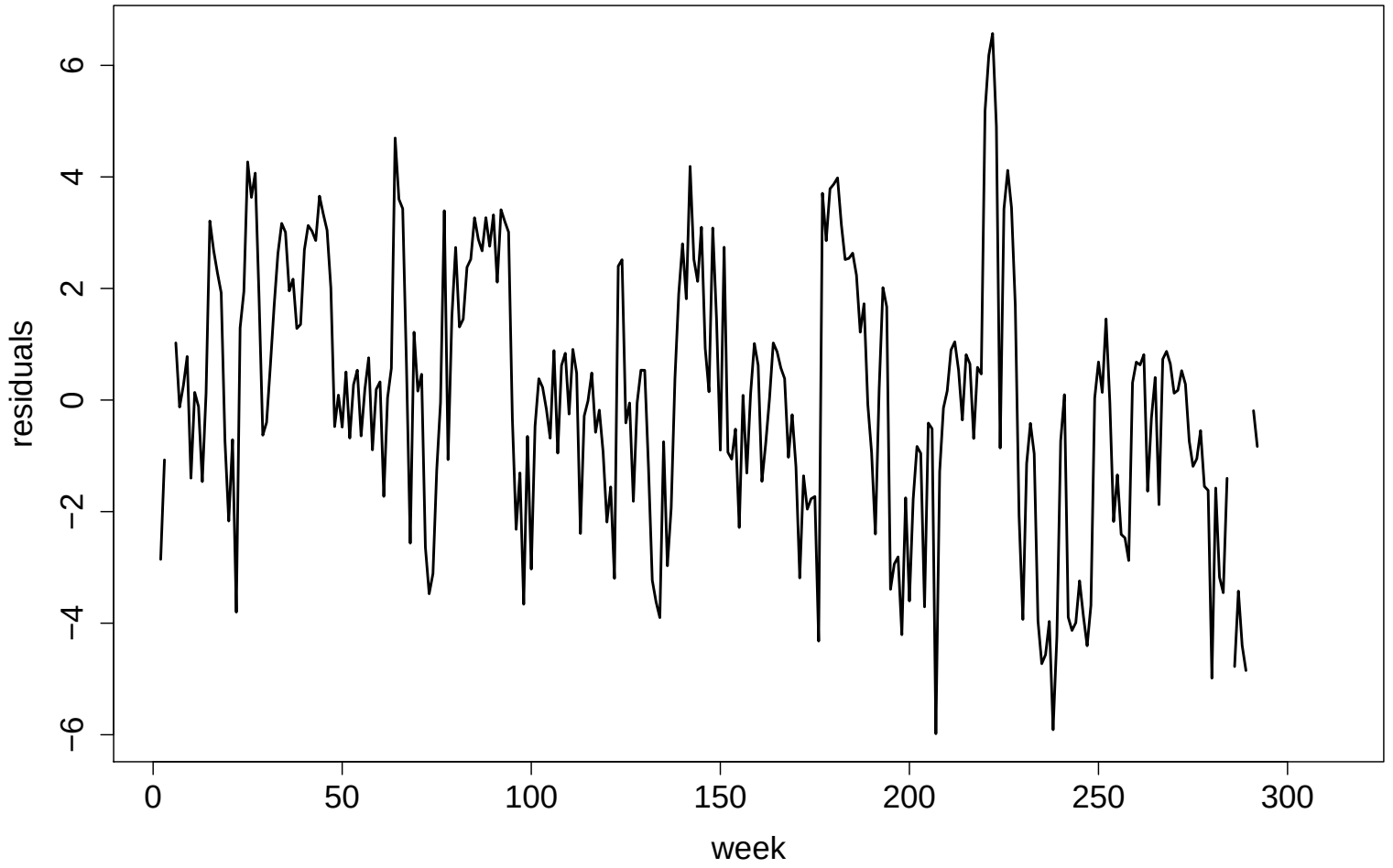


Regression model for country-wide incidence

INCIDENCE = SEASONAL × RAINFALL × RESIDUAL



Correlated residuals



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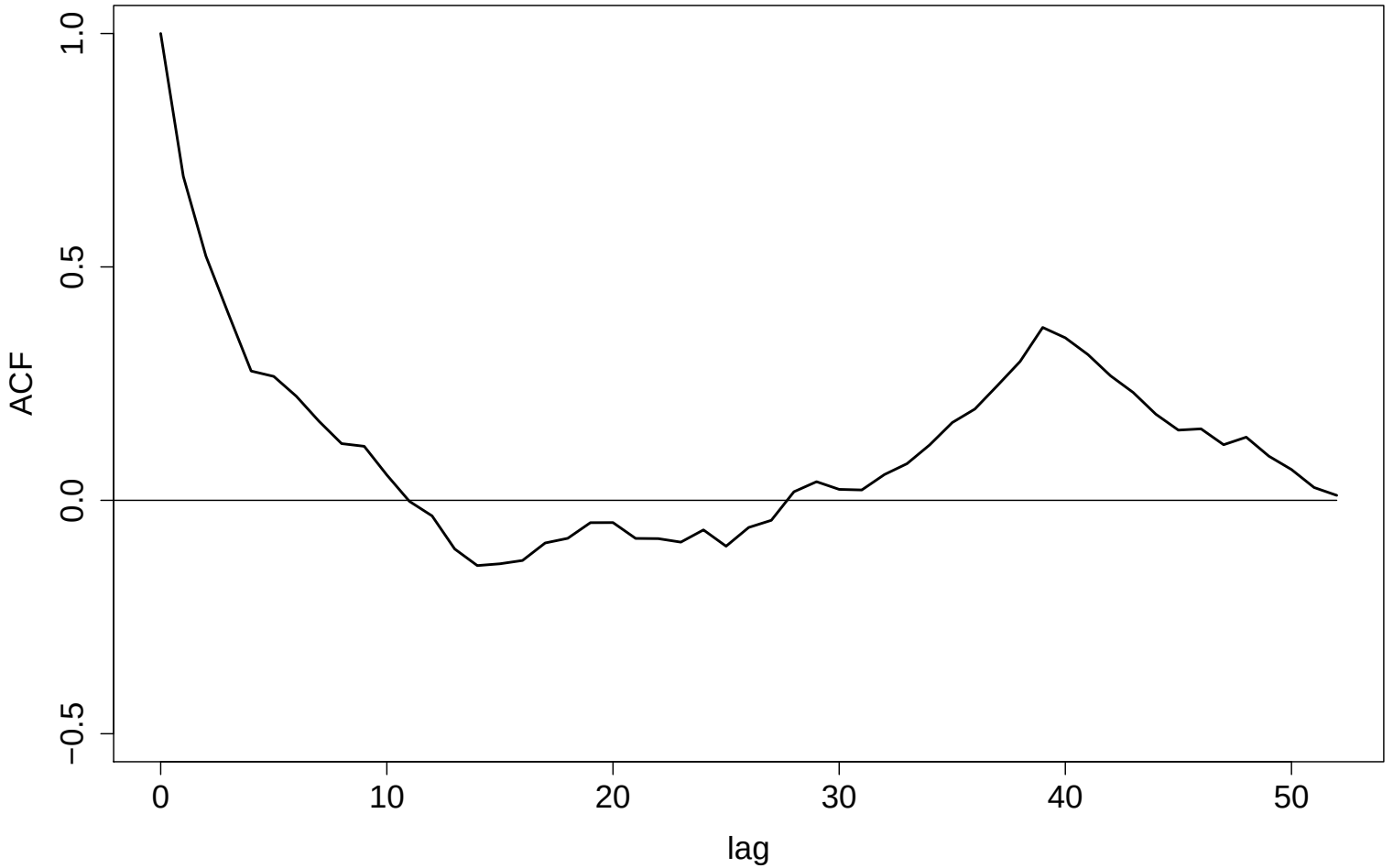

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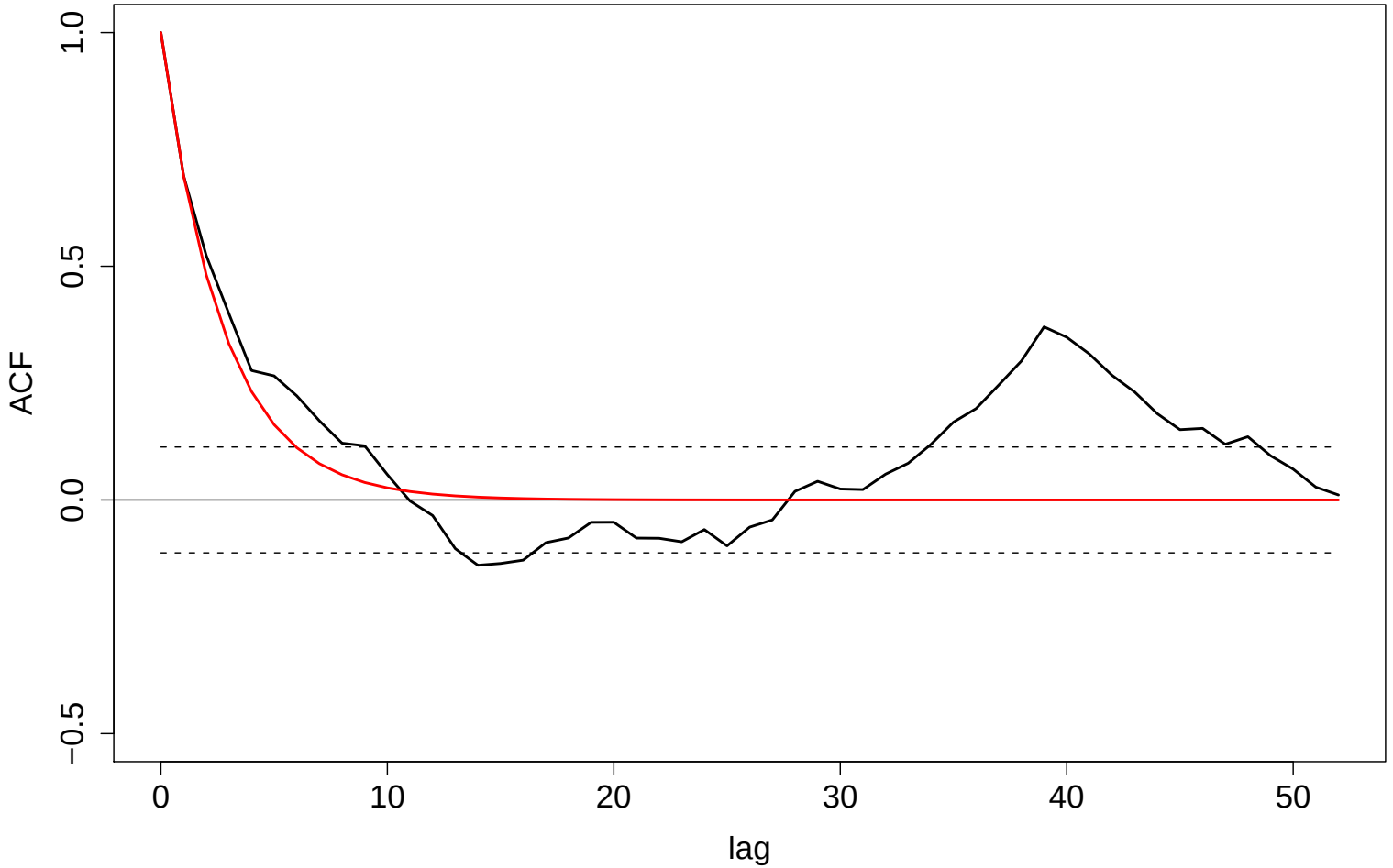


A dynamic seasonal model

$$
\begin{aligned}
Y_t &= \text{log incidence in week } t \\
&= A_t + B_t \cos(2\pi t/52) + C_t \sin(2\pi t/52) \text{residual}
\end{aligned}
$$

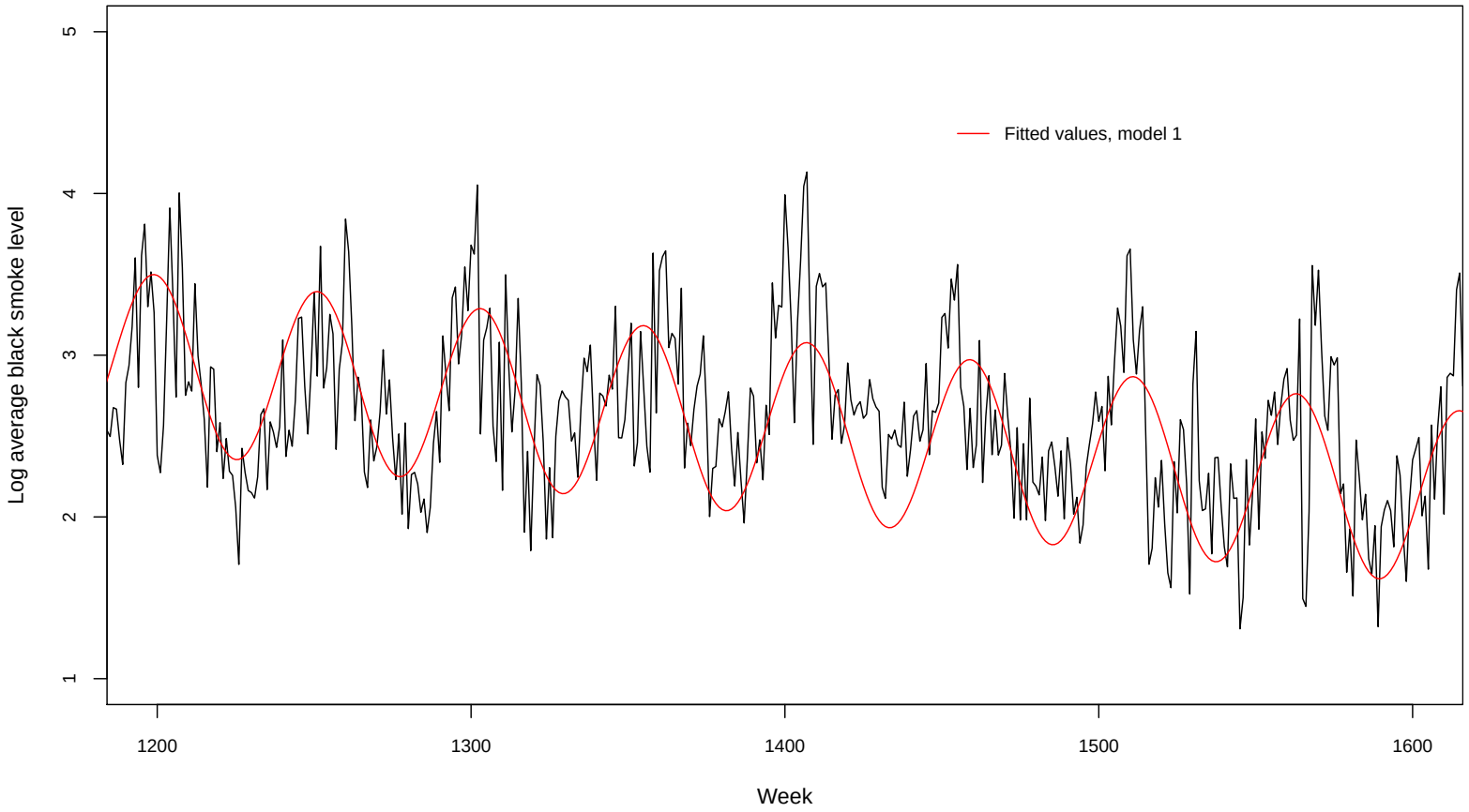
Regression coefficients modelled stochastically:

$$
\begin{aligned}
A_t &= A_{t-1} + \epsilon_t^A \\
B_t &= B_{t-1} + \epsilon_t^B \\
C_t &= C_{t-1} + \epsilon_t^C
\end{aligned}
$$

Can treat environmental variables similarly, but beware of over-elaboration

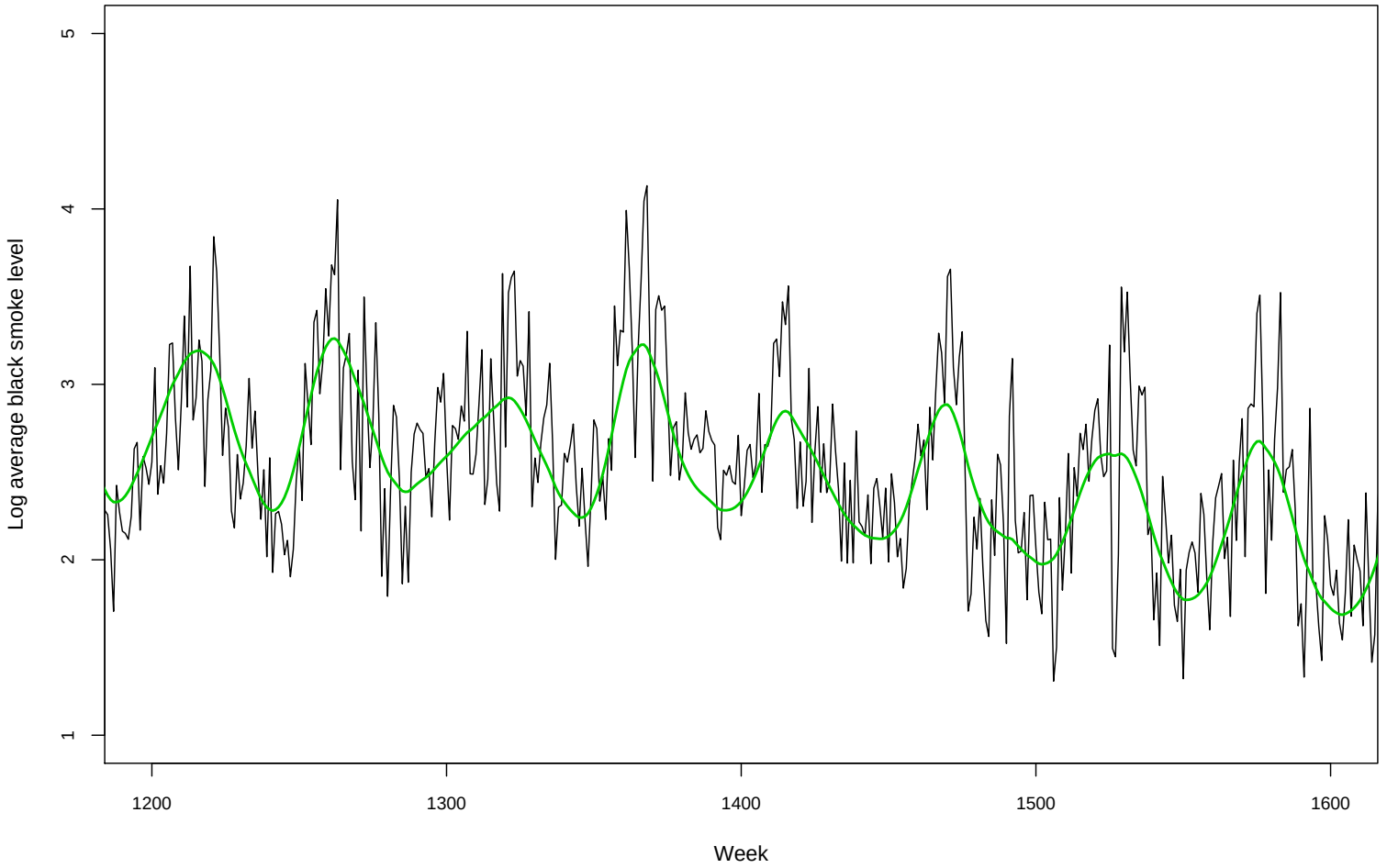
Seasonal variation in black smoke

Static model:

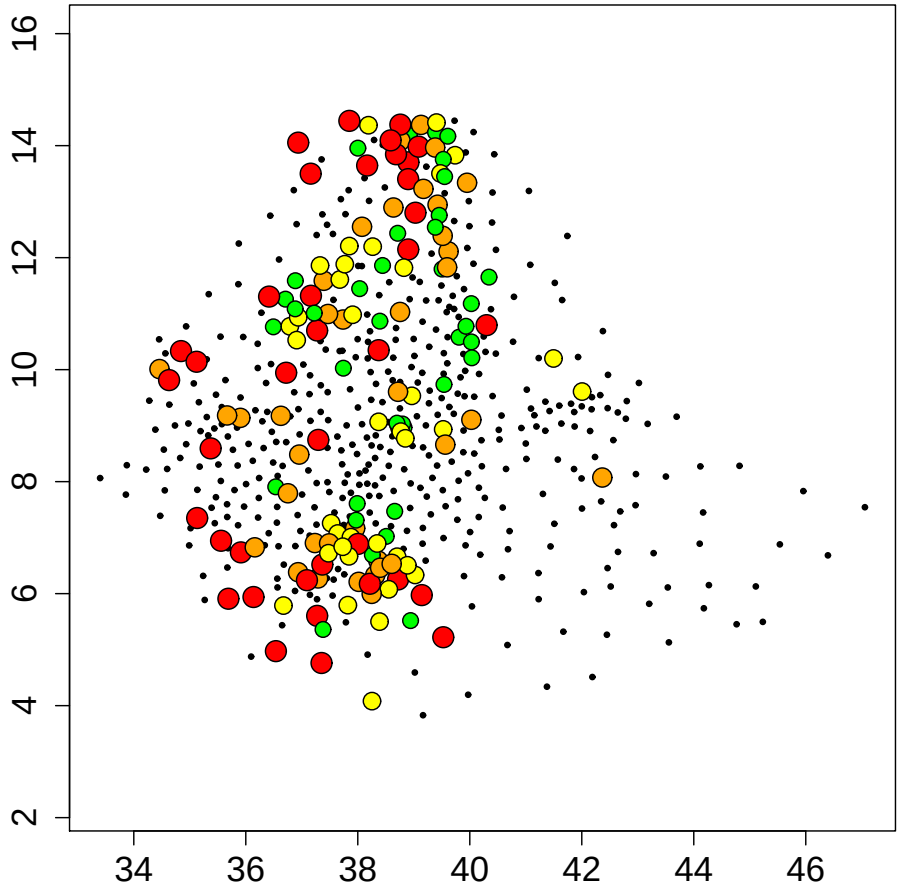


Seasonal variation in black smoke

Dynamic model:



Ethiopian data: spatial structure



Ethiopian data: spatio-temporal structure

Animation of incident counts

Ethiopian data: spatio-temporal structure

Animation of incident counts shows familiar epidemic structure:

- **long, quiescent periods punctuated by localised outbreaks**
- **local spread over short time-periods**

Dynamic spatio-temporal seasonal model

$$\begin{aligned} R_t(x) &= \text{risk in week } t \\ \log R_t(x) &= A_t(x) + B_t(x)\cos(2\pi t/52) + C_t(x)\sin(2\pi t/52) \end{aligned}$$

Regression coefficients modelled as random fields, for example:

$$A_0 = A_0(x) \qquad A_t(x) = \int A_{t-1}(x-u)w(u)du + \epsilon_t^A(x)$$

Conditionally independent Poisson counts:

$Y_t(x)$ =incidence in week t
$N_t(x)$ = population in woreda x

$$Y_t(x)|R_t(x) \sim \text{Poisson}\{N_t(x)R_t(x)\}$$

Take-home messages

1. **Spatial scale:**
    - analyse at finest available spatial resolution
    - interpret at policy-relevant scale
2. **Information synthesis:**
    - environmental covariates:
        - spatially sparse ground-truth (eg met-stations)
        - and spatially dense surrogates (eg satellite data)
        - and physically based models
    - GIS layers (eg transport routes)
    - social context (eg major population movements)

Take-home messages

3. Correlation is your friend:

   - what is happening here and now
   - can help to predict what will happen somewhere else

4. An honest answer to any prediction problem is a probability distribution

   - sensitivity (true positive)
   - specificity (false positive)
   - timeliness (forecast horizon)

5. Open-source software implementation for access and portability

   Examples: `www.lancs.ac.uk/staff/diggle`