Meningitis Incidence in Ethiopia: association with environment/meteorology

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1. Background

Environmental/meteorological time series may be useful for short-term forecasting of meningitis epidemics.

We already know that epidemic risk varies seasonally. (Molesworth et al, 2003; Sultan et al, 2005; Thomson et al, 2006). What we want to know is whether unexpected departures from the seasonal pattern ("anomalies") can be predicted from readily available environmental/meteorological time series?

Data: Monthly time series, July 2004 to June 2008 (1997 to 2000 in Ethiopian Calendar) of meningitis incidence in Southern Nations, Nationalities and People's Region (SNNPR), and monthly averaged sea-surface temperature (SST) over the NINO3.4 region (5N to -5S,170W to 120W).

Methodology: State-space modelling (Durbin and Koopman, 2001) of bivariate times series of incidence and SST.

2. Model

DATA = TREND + ANOMALY + NOISE

Notation:

$\boldsymbol{Y}(t) =$ number of incident cases in month t
$\boldsymbol{X}(t) =$ value of predictor variable in month t
$\boldsymbol{\mu}(t) =$ trend in month t
$\boldsymbol{A}(t) =$ anomaly in month t
$\boldsymbol{Z}(t) =$ noise in month t

Modelling the trend: annual sine-cosine wave plus harmonics

$$\mu(t) = \sum_{k=1}^{p} \{\alpha_k \cos(2k\pi t/12) + \beta_k \sin(2k\pi t/12)\}$$

Terms with $k > 1$ give flexibility.

Modelling the anomaly: serially correlated stochastic process

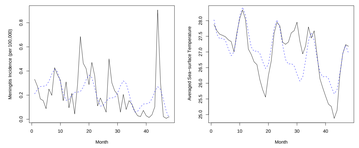
$$\sigma^2 = \mathrm{Var}\{A(t)\} \qquad \rho(u) = \mathrm{Corr}\{A(t), A(t-u)\}$$

Modelling the noise: independent perturbations (white noise)

$$Z(t) \sim \mathrm{N}(0, \nu^2)$$

3. Exploratory analysis

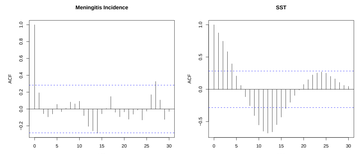
Trend



Monthly incidence (left) and monthly average sea-surface temperature (right) with fitted trends.

- linear trend captures long-term increase over study-period
- annual and six-month cosine-sine waves capture seasonal trend

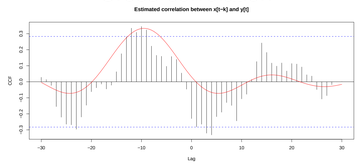
Autocorrelation



Autocorrelation functions of residual monthly incidence and residual monthly averaged sea-surface temperature.

- sharp drop at 1 month time-lag (low signal-to-noise ratio)
- decaying quasi-cyclic patterns thereafter

Cross-correlation



Cross-correlation function of residual meningitis incidence and residual SST, with fitted model.

- shifted version of SST autocorrelation
- consistent with common anomaly term $\boldsymbol{A}(t)$, with lead-lag relationship between environment and incidence

4. Model re-visited

Exploratory analysis suggests modelling current incidence anomaly as lagged version of SST anomaly, with quasi-cyclic correlation structure.

$$\begin{aligned} \boldsymbol{Y}(t) &= \boldsymbol{\mu}_Y(t) + \boldsymbol{A}_Y(t) + \boldsymbol{Z}_Y(t) \\ \boldsymbol{X}(t) &= \boldsymbol{\mu}_X(t) + \boldsymbol{A}_X(t) + \boldsymbol{Z}_X(t) \\ \boldsymbol{A}_Y(t) &= \boldsymbol{A}_X(t-\tau) \end{aligned}$$

$$\rho(u) = (\phi/u)\sin(u/\phi) \quad \text{(quasi-cyclic variation)}$$

5. Prediction

Meta-theorem: for any statistical model that describes the joint distribution of observed data $\boldsymbol{D}$ and an unobserved target for prediction $\boldsymbol{T}$, the best (in mean-square sense) predictor of the target is the conditional mean of the target given the data.

Our problem: given data $\boldsymbol{D} = \{(\boldsymbol{X}(s), \boldsymbol{Y}(s)) : s \leq t\}$, predict $\boldsymbol{T} = \boldsymbol{A}_Y(t')$ for any future time $t' > t$.

6. Current work

- Stage 1: refine predictive model for national incidence
- Stage 2: embed region-wide model within a spatio-temporal model for local incidence,

$$\boldsymbol{A}(x,t) = \boldsymbol{A}_0(t) + \boldsymbol{A}_1(x,t)$$

References

Durbin, J. and Koopman, S.J. (2001). *Time Series Analysis by Stat Space Methods*. Oxford: Oxford UNiversity Press.

Molesworth, A. M., L. E. Cuevas, S. J. Connor, A. P. Morse and M. C. Thomson (2003). Environmental risk and meningitis epidemics in Africa. *Emerging Infectious Diseases*, **9**, 1287–1293.

Sultan, B., K. Labadi, J. F. Guegan and S. Janicot (2005). Climate drives the meningitis epidemics onset in West Africa. *PLOS Medicine*, **2**, 43–49.

Thomson, M. C., A. M. Molesworth, M. H. Djingarey, K. R. Yameogo, F. Belanger and L. E. Cuevas (2006). Potential of environmental models to predict meningitis epidemics in Africa. *Tropical Medicine and International Health*, **11**,781–788.