WEATHER FOREAST AS A QUANTITATIVE PREDICTOR FOR COMMON COLD

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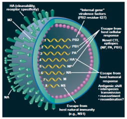
“The Four Horsemen whose Ride presages the end of the world are known to be Death, War, Famine, and Pestilence. But even less significant events have their own Horsemen. For example, the Four Horsemen of the Common Cold are Sniffles, Chesty, Nostril, and Lack of Tissues”.

Sir Terry Pratchett

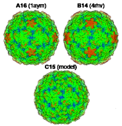
Different viruses and interactions with cells



H#N#

Orthomyxoviridae

H1-H18, N1-N11

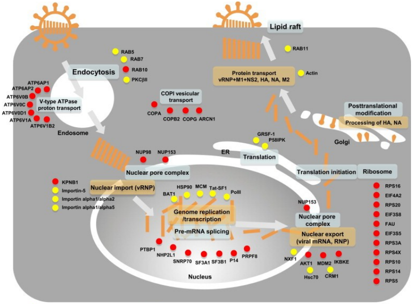


RV-A, RV-B, RV-C

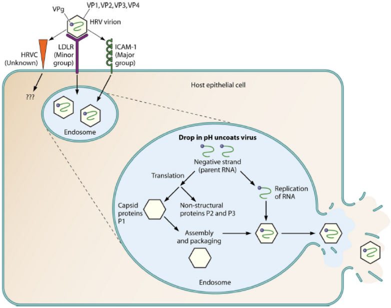
Picornaviridae, gen. *Enterovirus*

$>$ 100 serotypes

Influenza virus life cycle

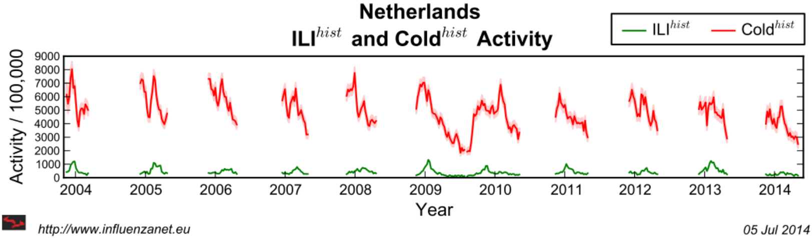


Rhinovirus virus life cycle



SOURCES: Webster R.G. A Molecular Whodunit *Science* **293** (2001), 1773-1775; Watanabe T.,Watanabe S., Kawaoka Y. Cellular networks involved in the influenza virus life cycle *Cell host & microbe* **7** (2010) 427-439; Jacobs S.E. et al. Human Rhinoviruses *Clinical Microbiology Reviews* **26** (2013) 135-162; www.virologyhighlights.com/the-common-cold-in-3d/

Empirical clinical difference



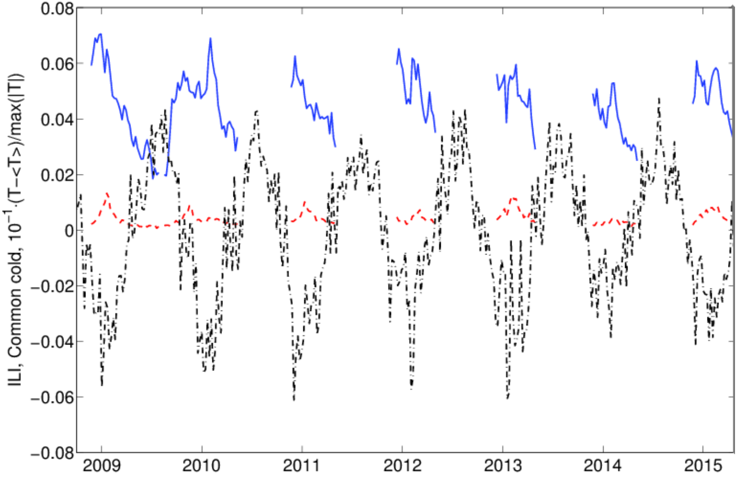
Influenza:

- fever or feverishness (chills);
- malaise, headache (at least one of them)
- muscle pain and simultaneously cough, sore throat, shortness of breath (at least one of them)
- measured temperature $\geq 38^{o}$C.

Common cold:

- runny or blocked nose, sneezing, cough, or sore throat (at least two of of these symptoms);
- no more complicated symptoms/allergy

Flu and ambient temperature variations



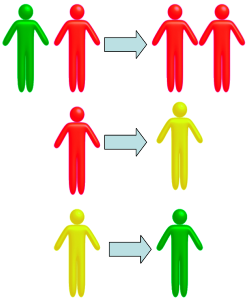
The Netherlands: common cold, influenza, air temperature

SIRS model with the variable coefficient

Individuals: Succeptible, Infected, Recovered, Succeptible

Characteristic times: τ – recovering, θ – loss of immunity

Kinetic scheme:

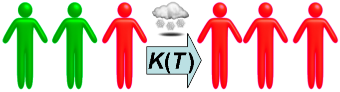


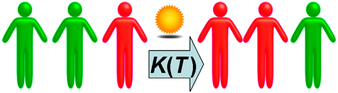
$$S + I \xrightarrow{k} 2I$$
$$I \xrightarrow{\tau^{-1}} R$$
$$R \xrightarrow{\theta^{-1}} S$$

ODEs:

$$\frac{dS}{dt} = -kIS + \theta^{-1}R,$$
$$\frac{dI}{dt} = kIS - \tau^{-1}I,$$
$$\frac{dR}{dt} = \tau^{-1}I - \theta^{-1}R$$

Probability to catch flu – weather influence: $k = k_0\left[1 + \kappa\left(T(t)\right)\right]$





Useful change of variables

In the system

$$\frac{dS}{dt} = -kIS + \theta^{-1}R,\ \frac{dI}{dt} = kIS - \tau^{-1}I,\ \frac{dR}{dt} = \underline{\tau^{-1}I - \theta^{-1}R}$$

denote $N = \underline{\tau^{-1}I - \theta^{-1}R}$, then since $S = 1 - I - R$,

$$\begin{aligned}
\frac{dR}{dt} &= N, \\
\frac{dN}{dt} &= -k\left(\tau N + \left[1 + \tau\theta^{-1}\right] R\right)\left(N + \theta^{-1}R\right) + \\
&\quad \left(k - \tau^{-1} - \theta^{-1}\right) N + \theta^{-1}\left(k - \tau^{-1}\right) R.
\end{aligned}$$

For $k = k_0 = \text{const}$, the stable stationary point:

$$R_s = \frac{1 - \tau^{-1}k_0^{-1}}{1 + \tau\theta^{-1}}, \quad N = 0$$

Expansion around $(R_s, 0)$, i.e. $R = R_s + r$

The resulted sufficiently non-homogeneous ODE system:

$$
\begin{aligned}
\frac{dr}{dt} &= N, \\
\frac{dN}{dt} &= R_s\theta^{-1}\left(k - \tau^{-1} - k\left[1 + \tau\theta^{-1}\right]R_s\right) - \\
&\quad -\left(\tau^{-1} + \theta^{-1} + R_s k\left[1 + 2\tau\theta^{-1}\right] - k\right)N - \\
&\quad -\theta^{-1}\left(\tau^{-1} + 2R_s k\left[1 + \tau\theta^{-1}\right] - k\right)r - \\
&\quad -k\tau N^2 - k(1 + \tau\theta^{-1})Nr - k\theta^{-1}\left[1 + \tau\theta^{-1}\right]r^2.
\end{aligned}
$$

The highlighted term:

- does not depend on variables N and r
- is equal to zero if and only if $k = \text{const}$ and determines the direct outer excitation of epidemic oscillations around this point by the temperature variations

Explicit temperature-disturbed form

Full system ($k = k_0\left[1+\kappa\left(T(t)\right)\right]$):

$$
\begin{aligned}
\frac{dr}{dt} &= N, \\
\frac{dN}{dt} &= R_s\theta^{-1}\tau^{-1}\kappa\left(T(t)\right) - \\
&\quad -\left(\tau^{-1}+\theta^{-1}+R_s k\left[1+2\tau\theta^{-1}\right]-k\right)N-\theta^{-1}\left(k-\tau^{-1}\right)r- \\
&\quad -k\tau N^2-k(1+\tau\theta^{-1})Nr-k\theta^{-1}\left[1+\tau\theta^{-1}\right]r^2.
\end{aligned}
$$

Linearized simple second-order ODE:

$$
\frac{d^2r}{dt^2}+\lambda\frac{dr}{dt}+\omega_0^2 r = R_s\theta^{-1}\tau^{-1}\kappa\left(T(t)\right),
$$

where both positive

$$
\lambda = \tau^{-1}+\theta^{-1}+R_s k_0\left[1+2\tau\theta^{-1}\right]-k_0,\ \omega_0^2=\theta^{-1}\left(k_0-\tau^{-1}\right)
$$

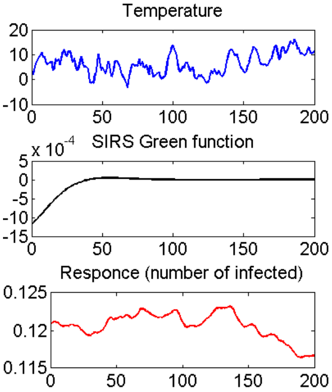
Solution of the linearized ODE

Linear ODE with time response delay:

$$\frac{d^2r}{dt^2}+\lambda\frac{dr}{dt}+\omega_0^2 r = R_s\theta^{-1}\tau^{-1}\kappa\left(T(t-\Delta)\right)$$

Infected:

$$I=\frac{\tau}{\theta}(R_s+r)+\tau\frac{dr}{dt}$$



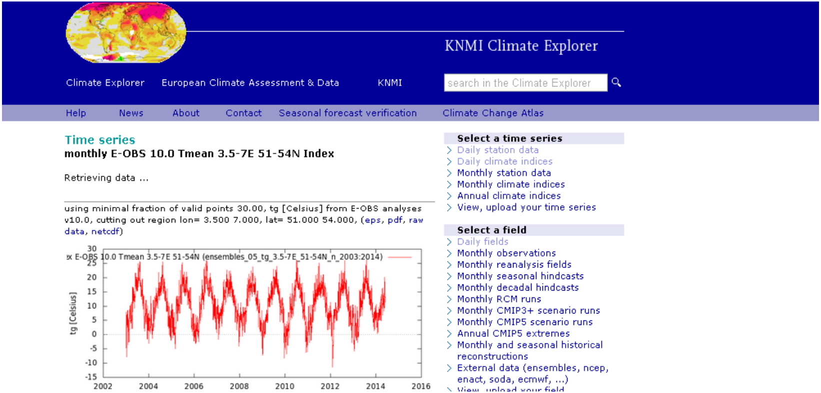
The solution:

$$I(t)=\frac{\tau}{\theta}R_s+\frac{R_S}{\theta}\int_0^t\kappa(t'-\Delta)G(t-t')dt',$$

expressed via the Green function:

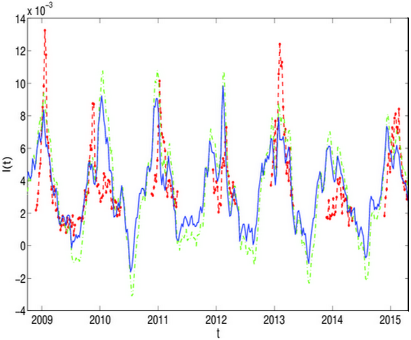
$$G(\xi)=\frac{1}{\omega}e^{-\frac{\lambda}{2}\xi}\left[\left(\theta^{-1}-\frac{\lambda}{2}\right)\sin(\omega\xi)+\omega\cos(\omega\xi)\right]$$

Sources of data

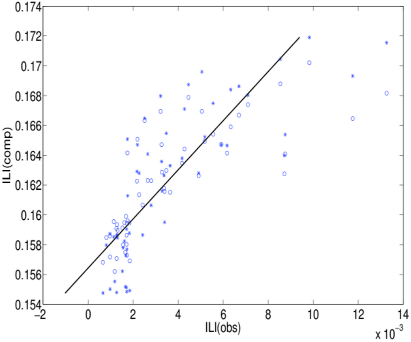


TEST: INFLUENZA DYNAMICS ($\mathbf{R_0} = 1.68 \pm 0.56$)

Time series (obs. *vs.* calc.):



Correlation plot* (season 2009):

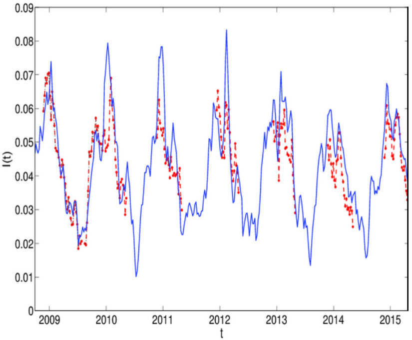


Results: in spite of qualitative similarity, the *quantitative correlation is low* for the both linearized and non-linear) models, i.e. one needs take into account transmission mechanisms.

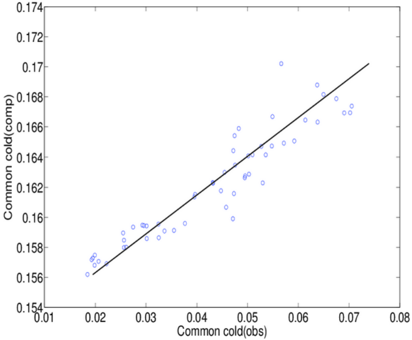
*Method: E.B. Postnikov, I.M. Sokolov. Robust linear regression with broad distributions of errors. *Physica A* **434** (2015) 257-267.

TEST: COMMON COLD DYNAMICS ($R_0 = 1.68 \pm 0.56$)

Time series (obs. *vs.* calc.):



Correlation plot* (season 2009):



Results: *quantitative* (corr. coeff.: 92%) correspondence between observations and the linearized model with 3 days delay (recovery time: 7 days; ∼ to the susceptible state: 28 days.).

Method*: E.B. Postnikov, I.M. Sokolov. Robust linear regression with broad distributions of errors. *Physica A* **434 (2015) 257-267.

Interpretation of the linearized ODE

Non-linear ODE

$$\frac{dI}{dt} = I\left[k(T(t))S - \tau^{-1}\right]$$

Details of linearization around the stationary state $S_s = (k_0\tau)^{-1}$ (for $k = k_0 = \text{const}$); $I_s \neq 0$: using $S = S_s + s$, $I = I_s + i$, $k(T) = k_0 + k_0\kappa(T)$,

$$\frac{dI}{dt} = k_0(I_sS_s - \tau^{-1}I_s) - \tau^{-1}i +$$

$$k_0(S_si + I_ss + is) + \kappa T(t)I_sS_s$$

$$T(t)(S_si\kappa + I_ss\kappa + is\kappa)$$

$$\frac{dI}{dt} = \left[k_0S_s - \tau^{-1}\right]i + k_0I_ss + \kappa T(t)I_sS_s.$$

Linearized ODE

$$\frac{dI}{dt} = k_0I_ss + \kappa T(t)I_sS_s$$

I. The contact infecting process

- I_s: a mean normal level of the infection present in a population;
- k_0: is a standard mean classic contact rate

II. The physiological stress-based illness

- $\kappa T(t)$: the variation of probability of a depressed resistance

Summary

- From the point of view of mathematical modelling, influenza and common cold are sufficiently non-equivalent.
- Excitation mechanism is applicable to common cold only.
- There is a principal possibility of common cold outbreaks estimation using short-time accurate weather forecasts , as well as determination of the "normal epidemic level" using local climate data.

Publications:

- E.B. Postnikov, Dynamical prediction of flu seasonality driven by ambient temperature: influenza vs. common cold. *European Physical Journal B* **89** (2016) 13
- E.B. Postnikov, D.V. Tatarenkov. Prediction of flu epidemic activity with dynamical model based on weather forecast. *Ecological Complexity* **15** (2013) 109113.

Thank you for attention!