

# WEATHER FORECAST AS A QUANTITATIVE PREDICTOR FOR COMMON COLD

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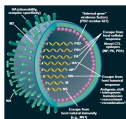
<http://rccmp.kursksu.ru/postnikov>

“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”.

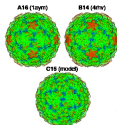
*Sir Terry Pratchett*

The screenshot shows two web pages side-by-side. The left page is 'Flu News Europe' from the ECDC (European Centre for Disease Prevention and Control). It features a navigation menu with options like 'Primary care data', 'Hospital data', and 'By country'. Below the menu is a 'Flu Trends' section with a map of Europe showing flu activity levels by region. The right page is the 'Influenzanet' website, which displays a map of Europe with location pins for participating countries. A banner at the bottom of the Influenzanet page states: 'Currently 23940 volunteers from 10 participating countries are contributing to Influenzanet: Belgium Denmark France Ireland Italy Netherlands Portugal Spain Sweden United Kingdom'.

# DIFFERENT VIRUSES AND INTERACTIONS WITH CELLS

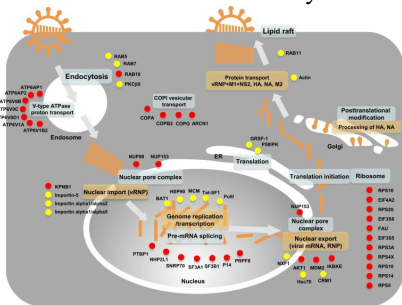


H#N#  
*Orthomyxoviridae*  
 H1-H18, N1-N11

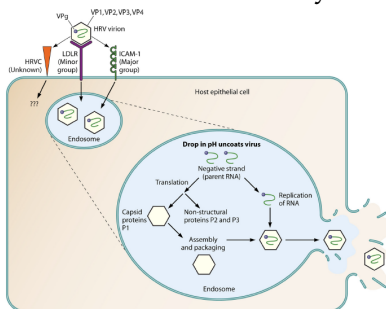


RV-A, RV-B, RV-C  
*Picornaviridae*, gen.  
*Enterovirus*  
 > 100 serotypes

## Influenza virus life cycle

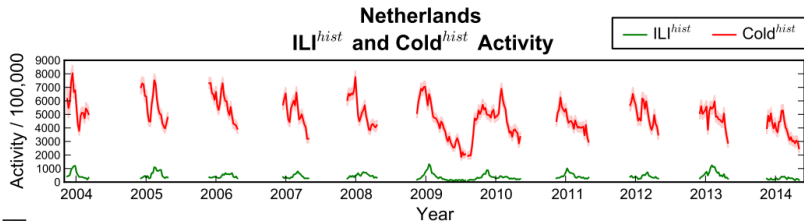


## Rhinovirus virus life cycle



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/](http://www.virologyhighlights.com/the-common-cold-in-3d/)

# EMPIRICAL CLINICAL DIFFERENCE



<http://www.influenzanel.eu>

05 Jul 2014

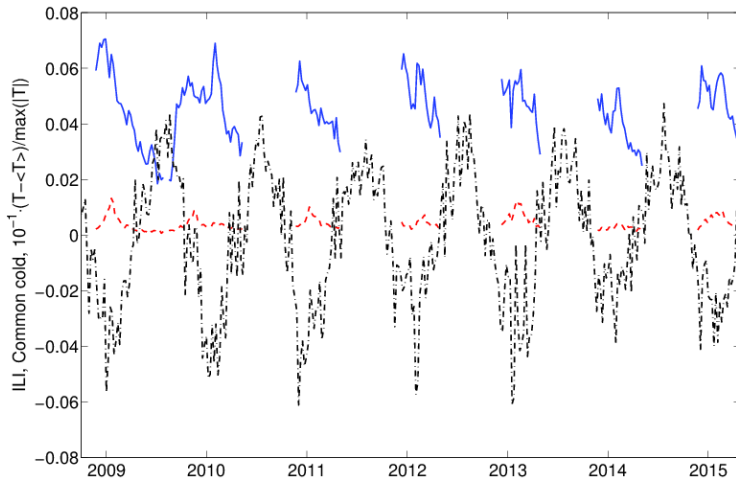
## Influenza:

- 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  $\geq 38^{\circ}\text{C}$ .

## Common cold:

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

# FLU AND AMBIENT TEMPERATURE VARIATIONS



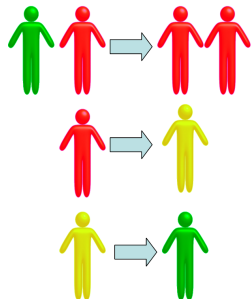
The Netherlands: common cold, influenza, air temperature

# SIRS MODEL WITH THE VARIABLE COEFFICIENT

Individuals: **S**uccceptible, **I**nfected, **R**ecovered, **S**uccceptible

Characteristic times:  $\tau$  – recovering,  $\theta$  – loss of immunity

Kinetic scheme:



ODEs:

$$\begin{array}{l}
 S + I \xrightarrow{k} 2I \\
 I \xrightarrow{\tau^{-1}} R \\
 R \xrightarrow{\theta^{-1}} S
 \end{array}
 \quad
 \begin{array}{l}
 \frac{dS}{dt} = -kIS + \theta^{-1}R, \\
 \frac{dI}{dt} = kIS - \tau^{-1}I, \\
 \frac{dR}{dt} = \tau^{-1}I - \theta^{-1}R
 \end{array}$$

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



## USEFUL CHANGE OF VARIABLES

In the system

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

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 ( $k = k_0 [1 + \kappa (T(t))]$ ):

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

Linearized simple second-order ODE:

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

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:

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

Infected:

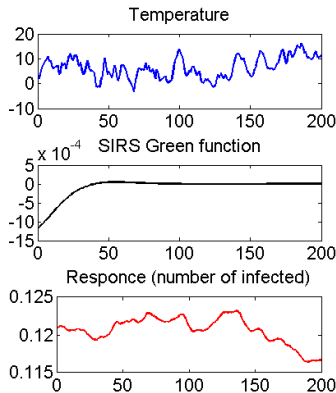
$$I = \frac{\tau}{\theta} (R_s + r) + \tau \frac{dr}{dt}$$

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

Influenzanet
Show/Hide Influenzanet map

## KNMI Climate Explorer

Climate Explorer
European Climate Assessment & Data
KNMI

search in the Climate Explorer

🔍

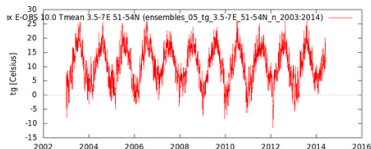
Help
News
About
Contact
Seasonal forecast verification
Climate Change Atlas

## Time series

### monthly E-OBS 10.0 Tmean 3.5-7E 51-54N Index

Retrieving data ...

using minimal fraction of valid points 30.00, tg [Celsius] from E-OBS analyses v10.0, cutting out region lon= 3.500 7.000, lat= 51.000 54.000, (eps, pdf, raw data, netcdf)



## Select a time series

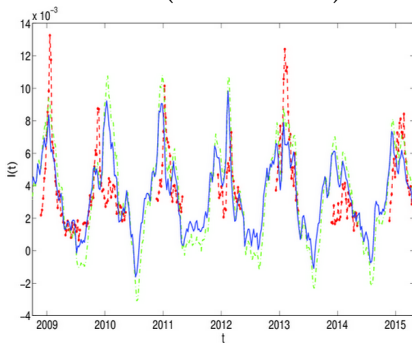
- > Daily station data
- > Daily climate indices
- > Monthly station data
- > Monthly climate indices
- > Annual climate indices
- > View, upload your time series

## Select a field

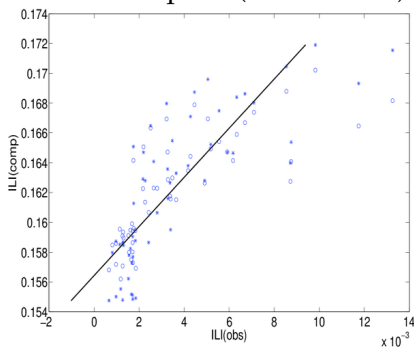
- > Daily fields
- > Monthly observations
- > Monthly reanalysis fields
- > Monthly seasonal hindcasts
- > Monthly decadal hindcasts
- > Monthly RCM runs
- > Monthly CMIP3+ scenario runs
- > Monthly CMIP5 scenario runs
- > Annual CMIP5 extremes
- > Monthly and seasonal historical reconstructions
- > External data (ensembles, ncep, enact, soda, ecmwf, ...)
- > View, upload your field

# TEST: INFLUENZA DYNAMICS ( $R_0 = 1.68 \pm 0.56$ )

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



Correlation plot\* (season 2009):

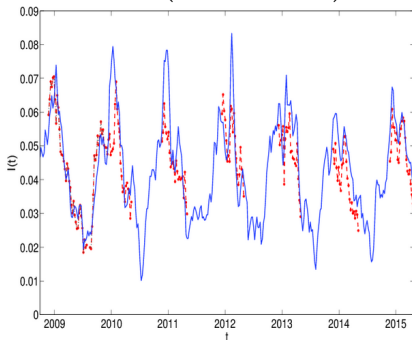


**Results:** in spite of qualitative similarity, the *quantitative correlation is low* for the both **linearized** and **non-linear**) models, i.e. one needs take into account transmission mechanisms.

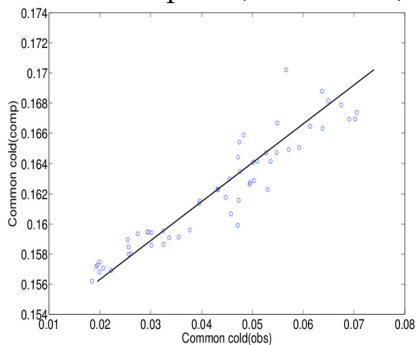
\*Method: E.B. Postnikov, I.M. Sokolov. Robust linear regression with broad distributions of errors. *Physica A* **434** (2015) 257-267.

# 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;  $\sim$  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  $S = S_s + s$ ,  $I = I_s + i$ ,

$k(T) = k_0 + k_0\kappa(T)$ ,

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

$$k_0(S_s i + I_s s + i s) + \kappa T(t) I_s S_s$$

$$\cancel{T(t)(S_s i \kappa + I_s s \kappa + i s \kappa)}$$

$$\frac{dI}{dt} = \left[ \cancel{k_0 S_s - \tau^{-1}} \right] i + k_0 I_s s + \kappa T(t) I_s S_s.$$

## Linearized ODE

$$\frac{dI}{dt} = k_0 I_s s + \kappa T(t) I_s S_s$$

### 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!