A modeling approach to predict the flu epidemic using the prevalence data

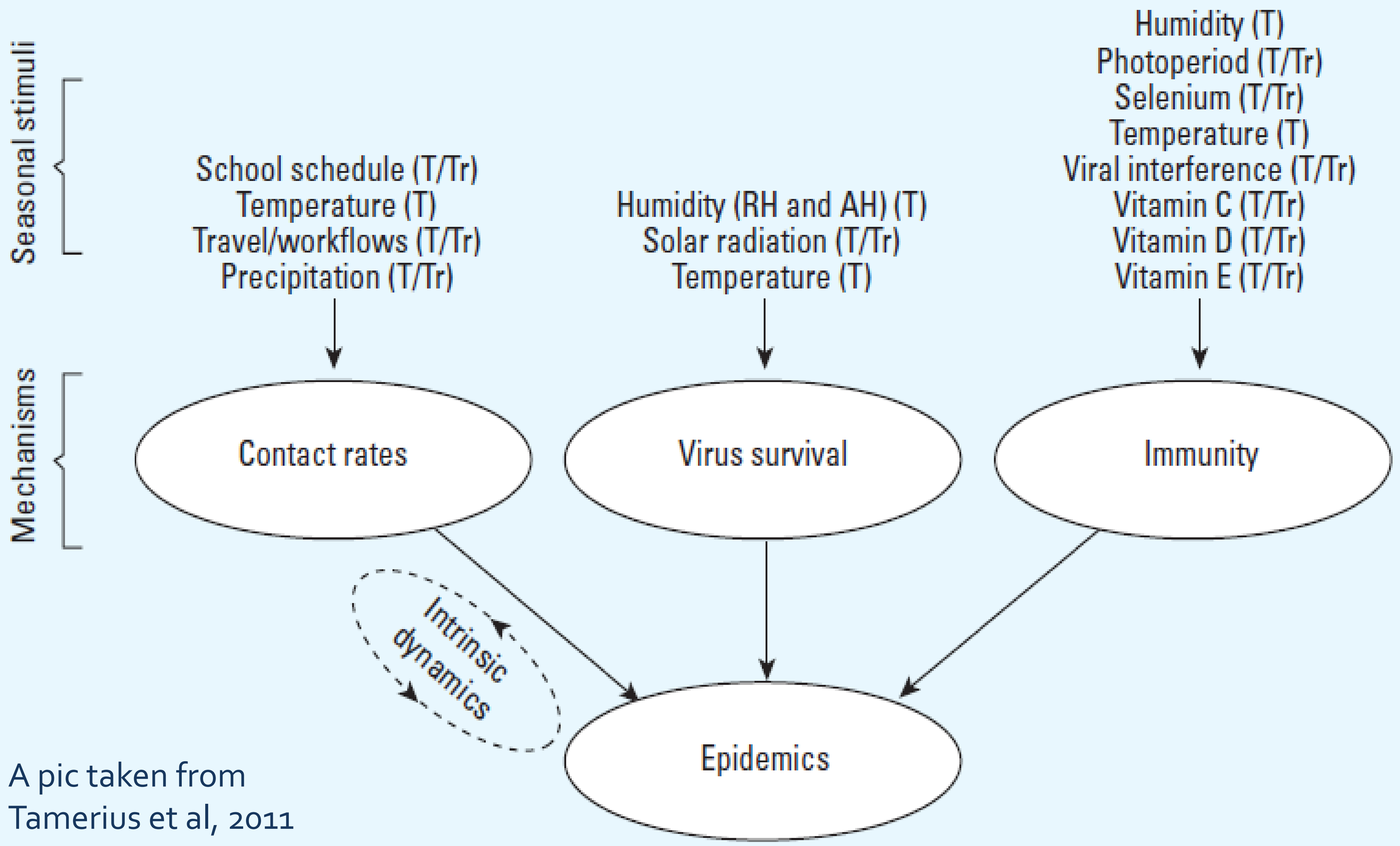
Sergey Ivanov,
eScience Research Institute,
ITMO University,
Saint Petersburg, Russia

Vasiliy Leonenko,
eScience Research Institute,
ITMO University,
Saint Petersburg, Russia

Literature review

- L. A. Rvachev, O. V. Baroyan. (1969) An attempt at large-scale influenza epidemic modelling by means of a computer. Bull Int Epid Assoc, Vol 18 (22-31).
- A. A. Romanyukha, T. A. Sannikova, I. D. Drynov (2009, 2011)
- M. A. Kondratyev et al, 2013.
- Researchers from abroad (various works)

What external factors are the most influential?



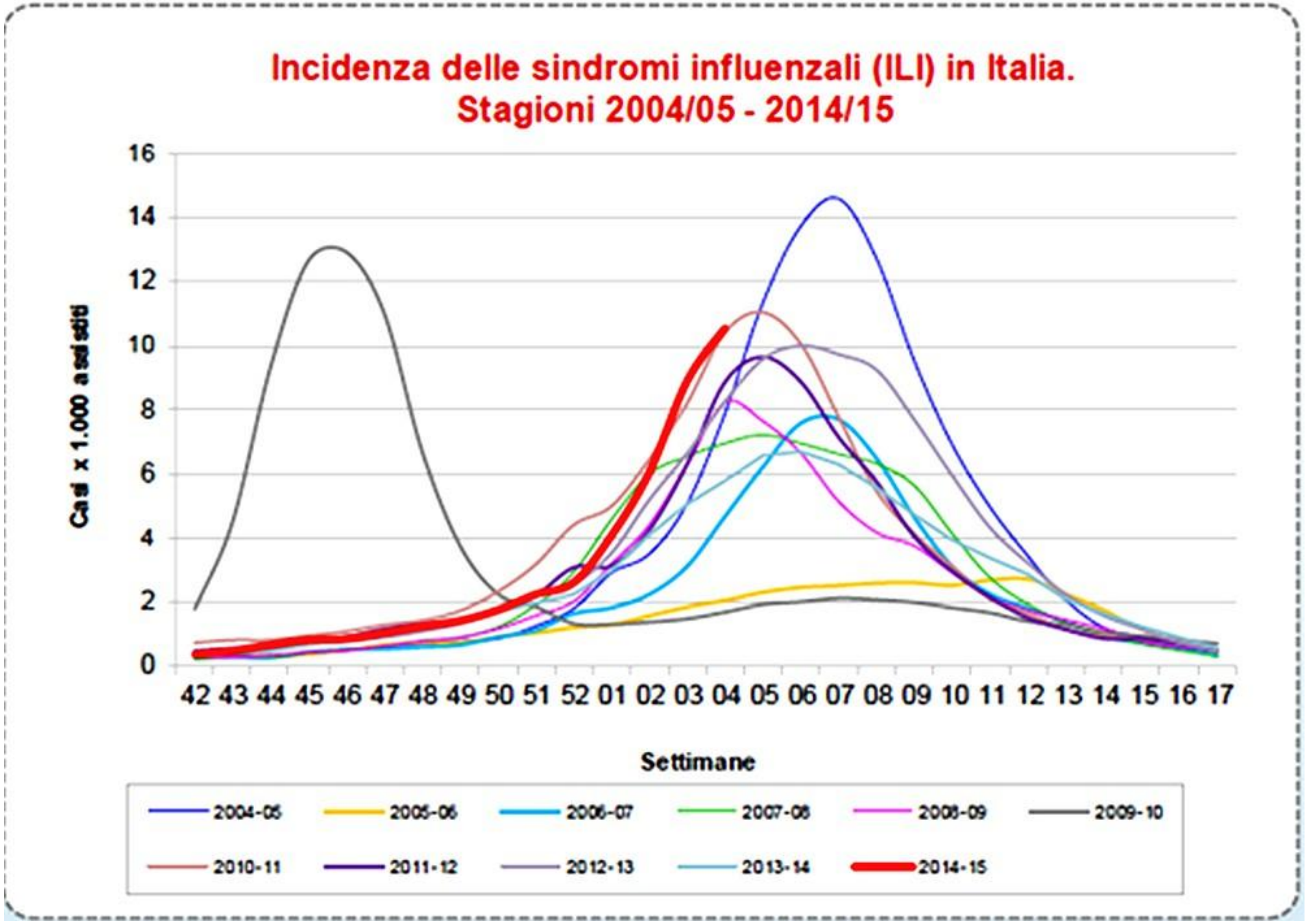
A pic taken from
Tamerius et al, 2011

Tamerius et al., 2011:

- „Past observations that influenza epidemics occur in the winter across temperate climates, combined with insufficient knowledge about the epidemiology of influenza in the tropics, led to the perception that cool and dry conditions were a necessary, and possibly sufficient, driver of influenza epidemics. Recent reports of substantial levels of influenza virus activity and well-defined seasonality in tropical regions, where warm and humid conditions often persist year-round, have rendered previous hypotheses insufficient for explaining global patterns of influenza.“

J. Tamerius, M. I. Nelson, S. Z. Zhou, C. Viboud, M. A. Miller, W. J. Alonso. (2011) Global Influenza Seasonality: Reconciling Patterns across Temperate and Tropical Regions. Env. Health Persp., 119 (4)

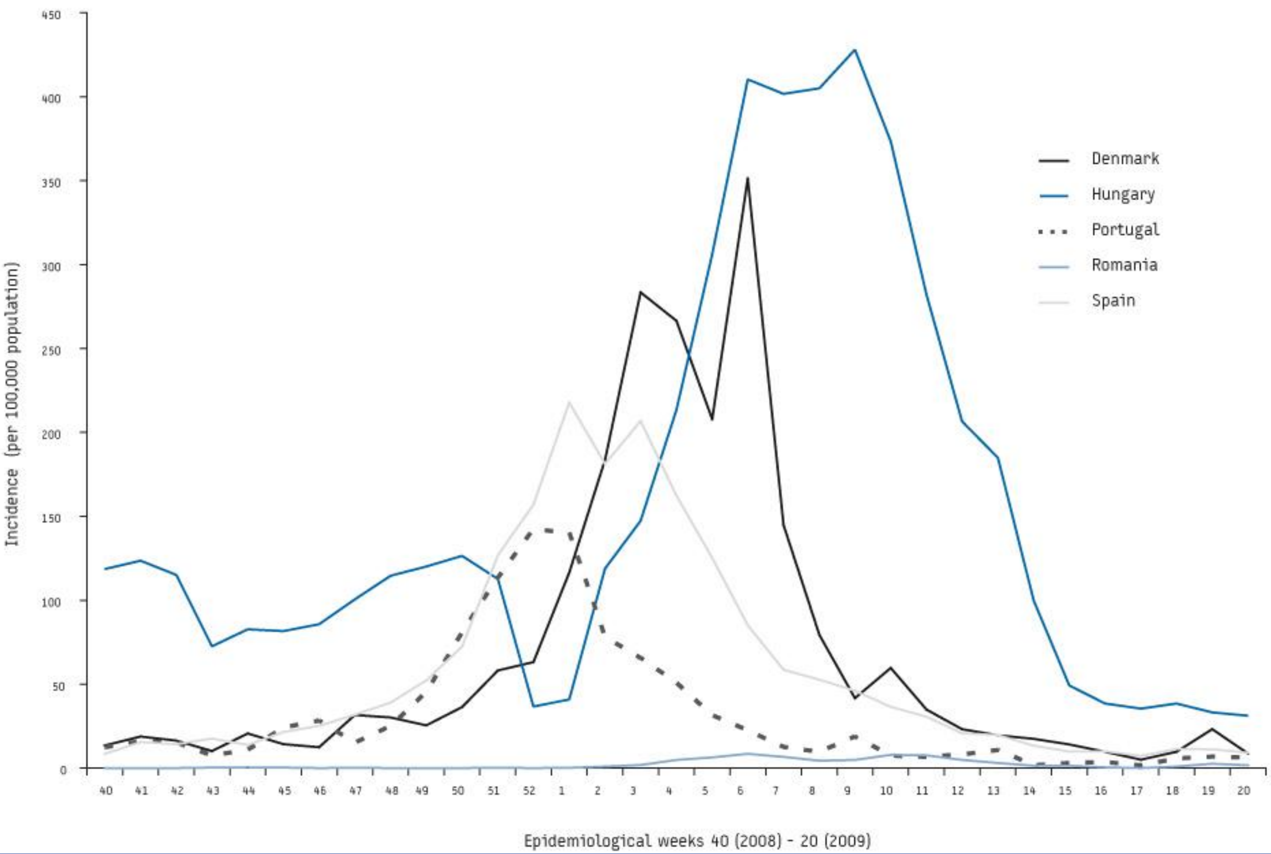
Flu incidence in Italy



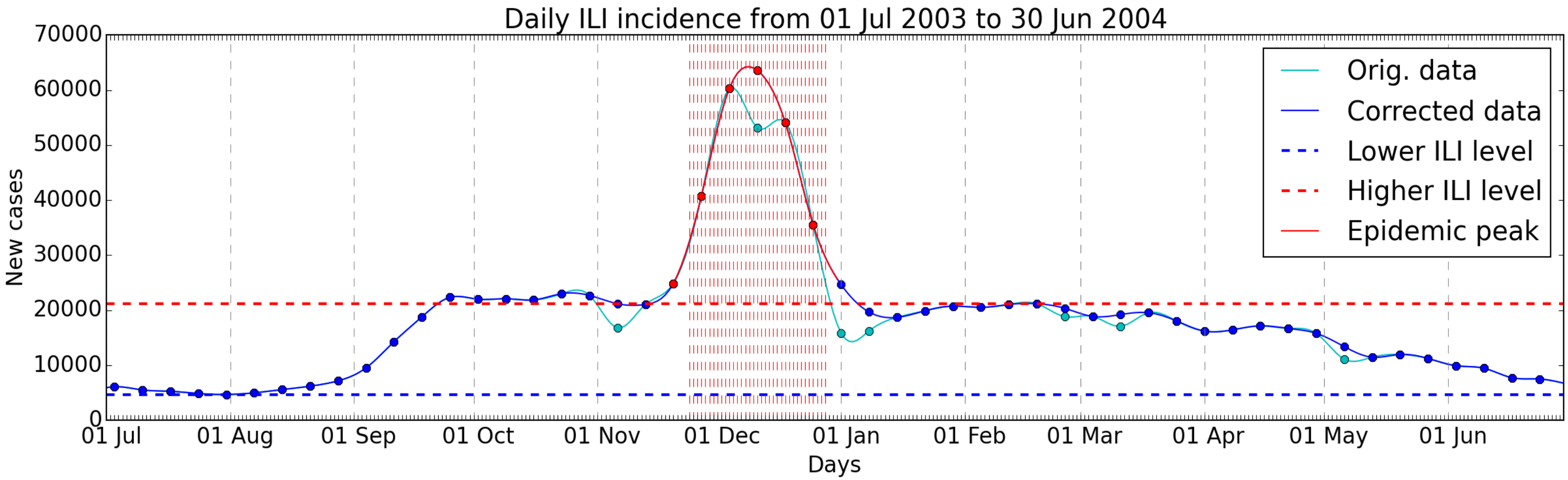
Flu incidence in several EU countries

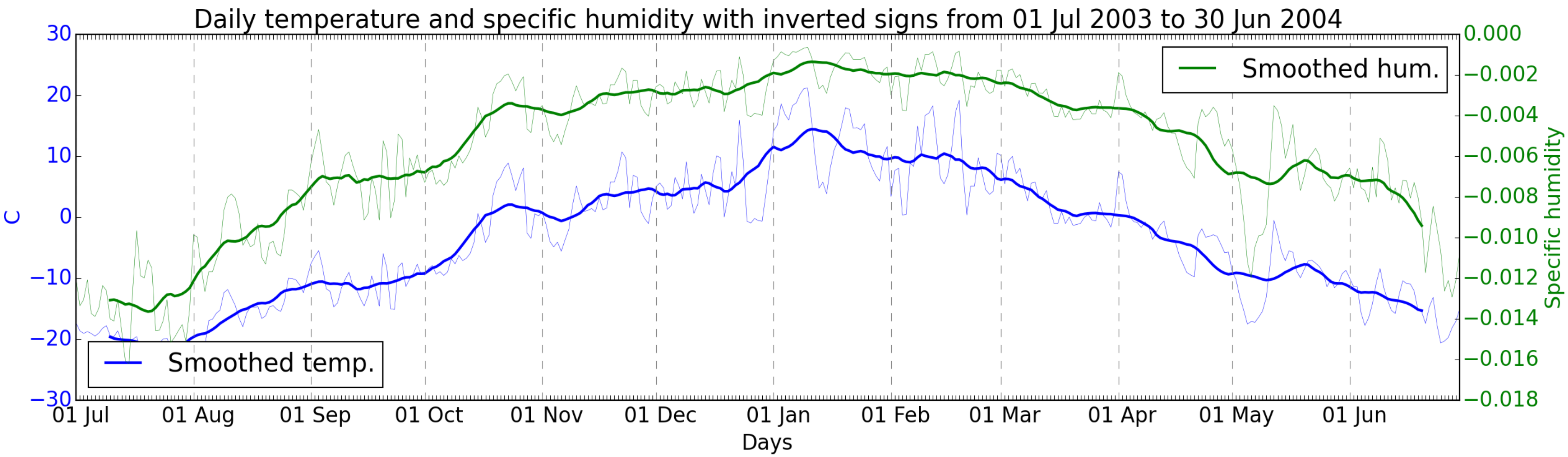
FIGURE 1

Influenza-like illness (ILI) incidence (cases per 100,000 population) reported by the national influenza sentinel surveillance systems in Denmark, Hungary, Portugal, Romania, and Spain, influenza season 2008-9*



Algorithm output example





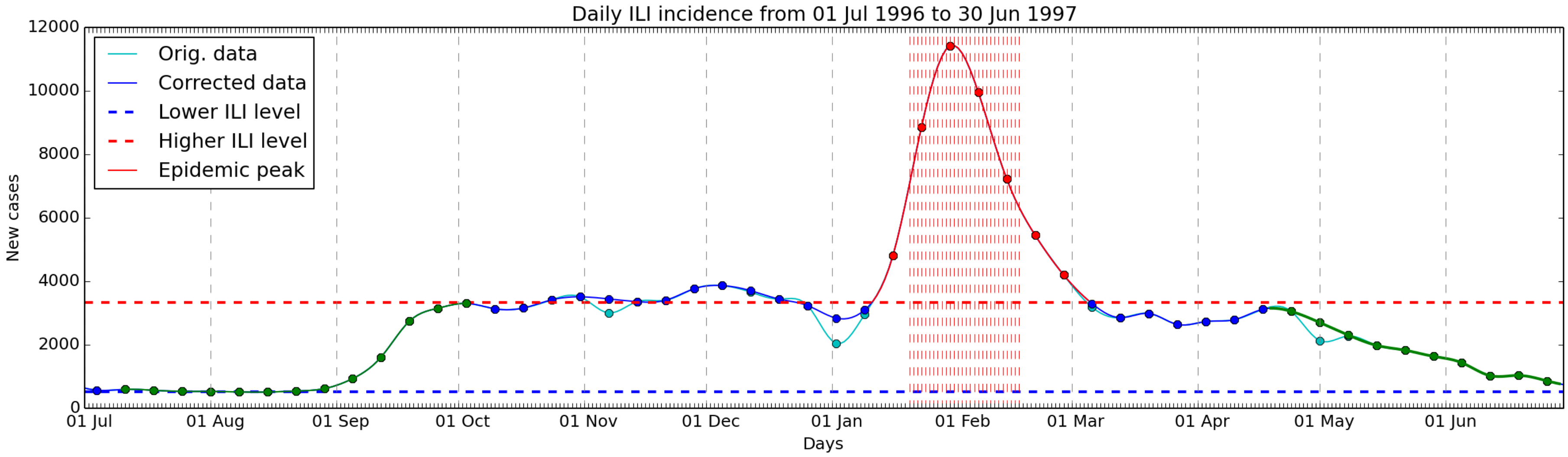
General research aims

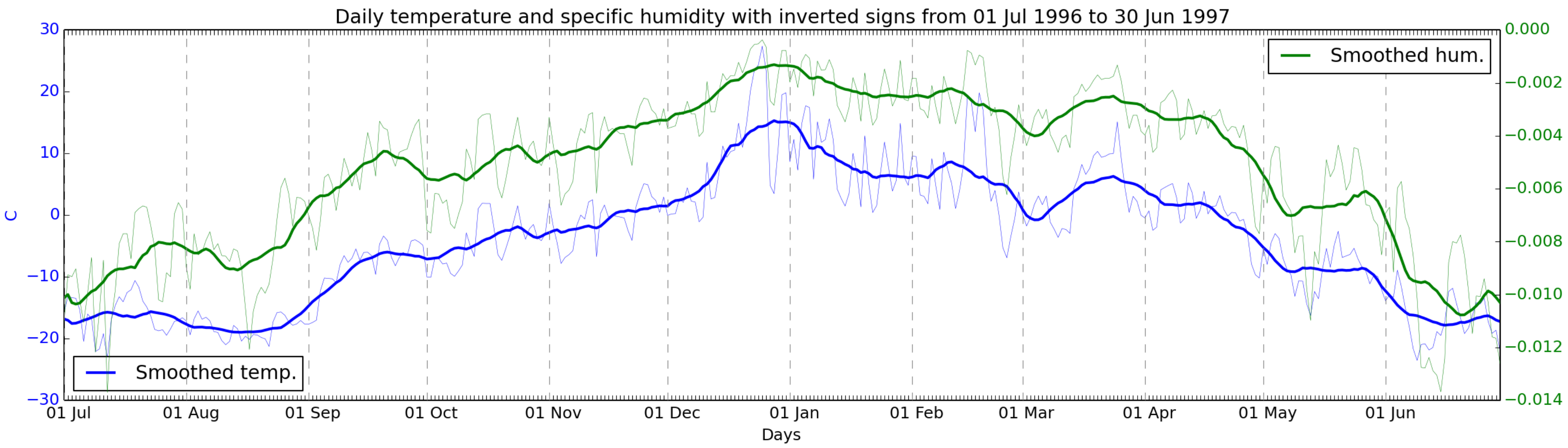
- Our idea: statistical modeling of seasonal ILI + mathematical modeling of flu outbreak
- Analyze the data (weekly ILI incidence in Saint Petersburg, 1985—2015)
- Find out which of the external factors have the strongest influence on ILI dynamics
- Start from simple compartmental model for ILI dynamics incorporating the above-mentioned factors to have a nice fit with data
- Investigate the possibilities for the epidemic forecasting with the model, particularly — predicting the moment of the epidemic onset

Data analysis

- The automatic algorithm is implemented which:
  - Corrects the incidence data by removing the outlier values (underreporting during holidays) and bringing them to daily format by interpolation
  - Plots the data on ILI incidence, temperature and humidity
  - Analyzes seasonal infection phases and collects statistics

Algorithm output example





Insights from data: No. 1

- In Saint Petersburg we do have two stable ILI incidence levels

- The transition from lower to higher ILI level usually occurs in the first days of September
  – Temperature falls?
  – Children go to school and infect each other?

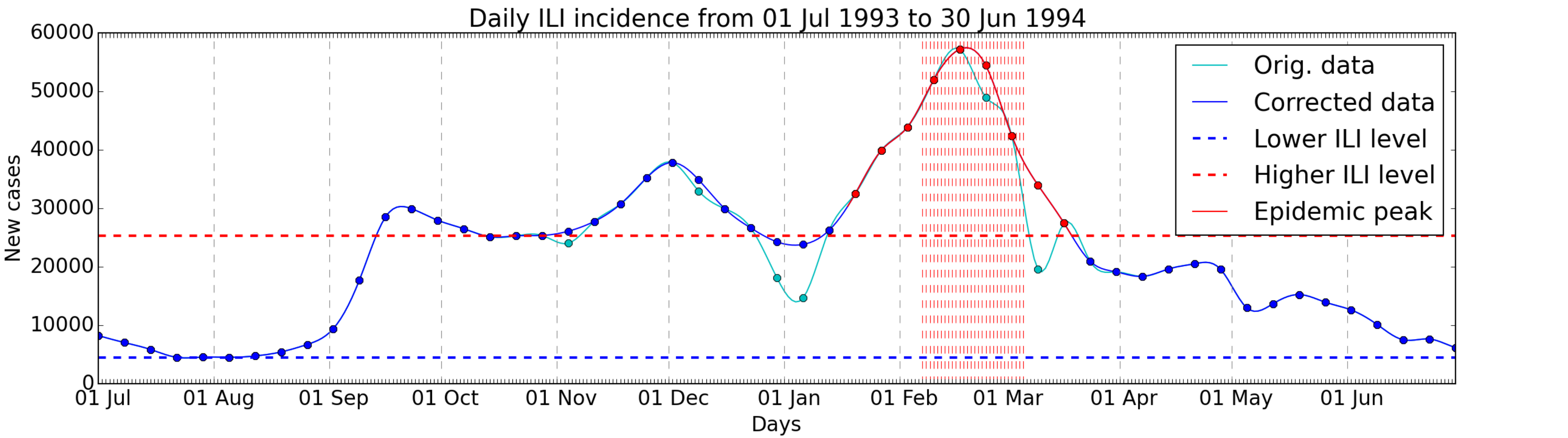
- Backward transition starts in April-May (it doesn't depend on the fact whether there was an outbreak in spring or not)

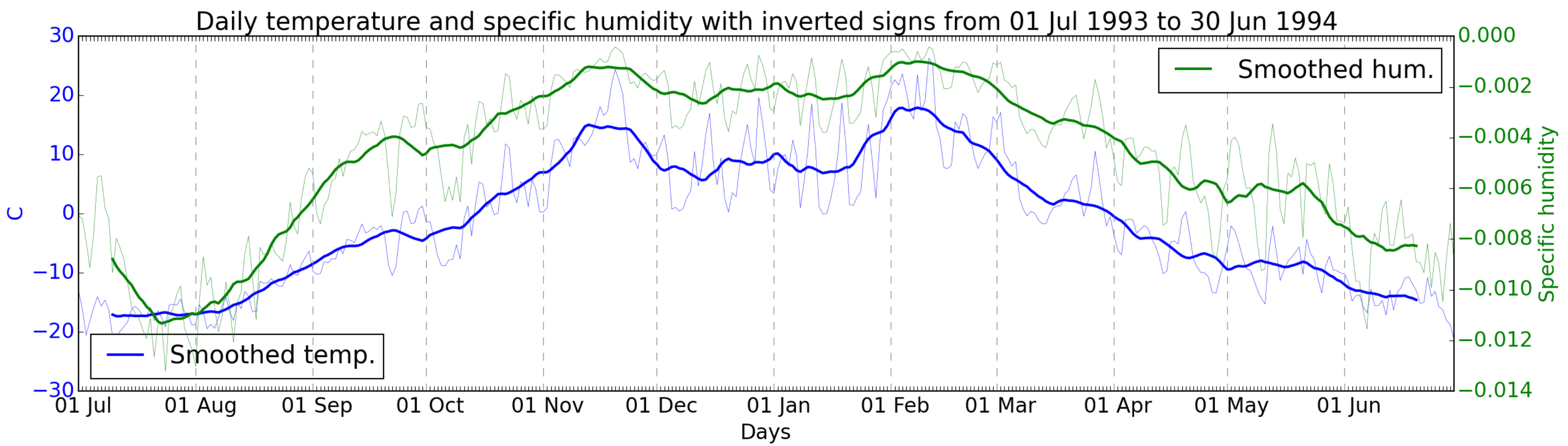
Insights from data: No.2

— Could the dynamics of ILI apart from the flu outbreak period („background ILI“) be explained by temperature and humidity fluctuations?

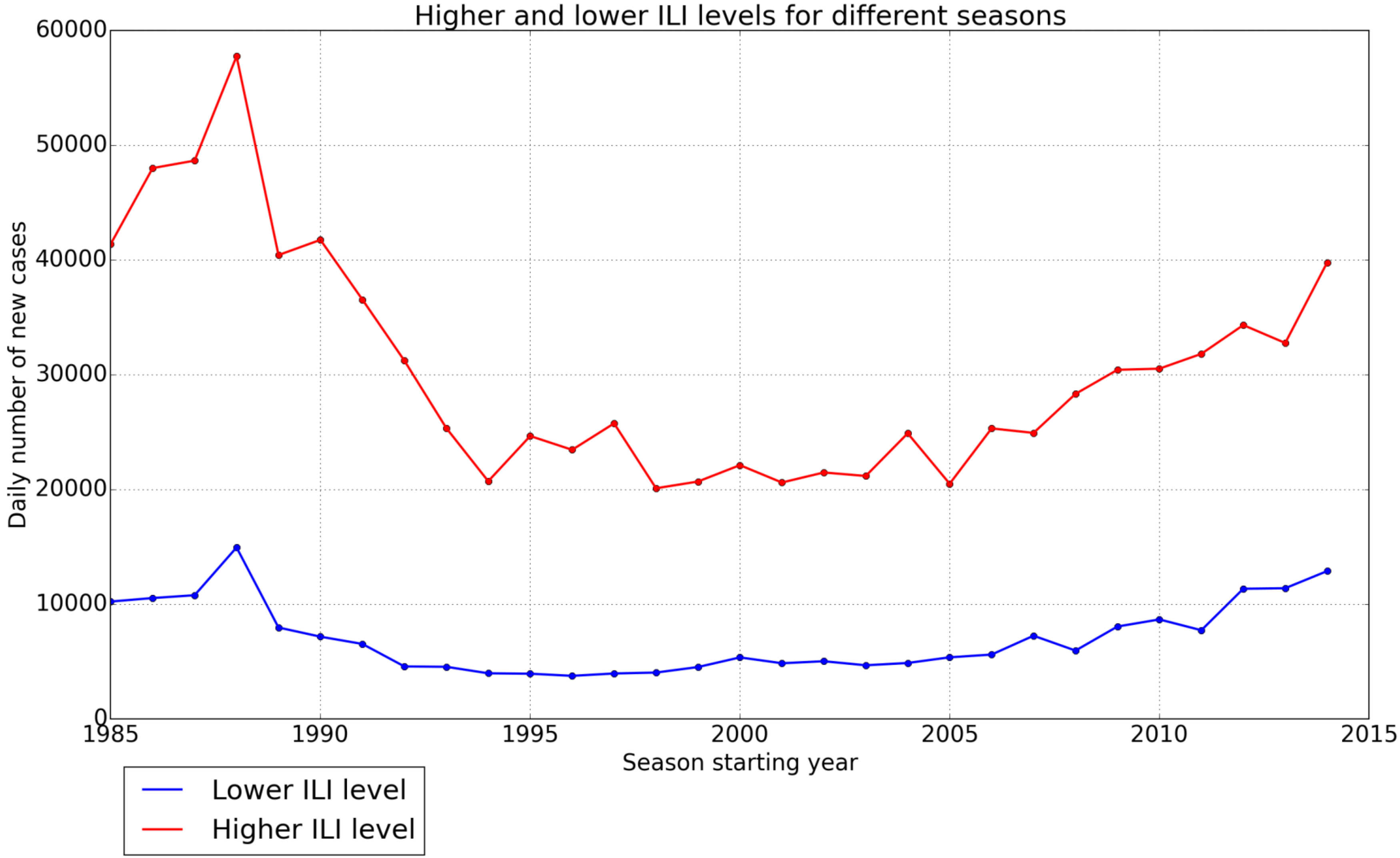
— In some cases it definitely looks like that!
But… in others not.

Example

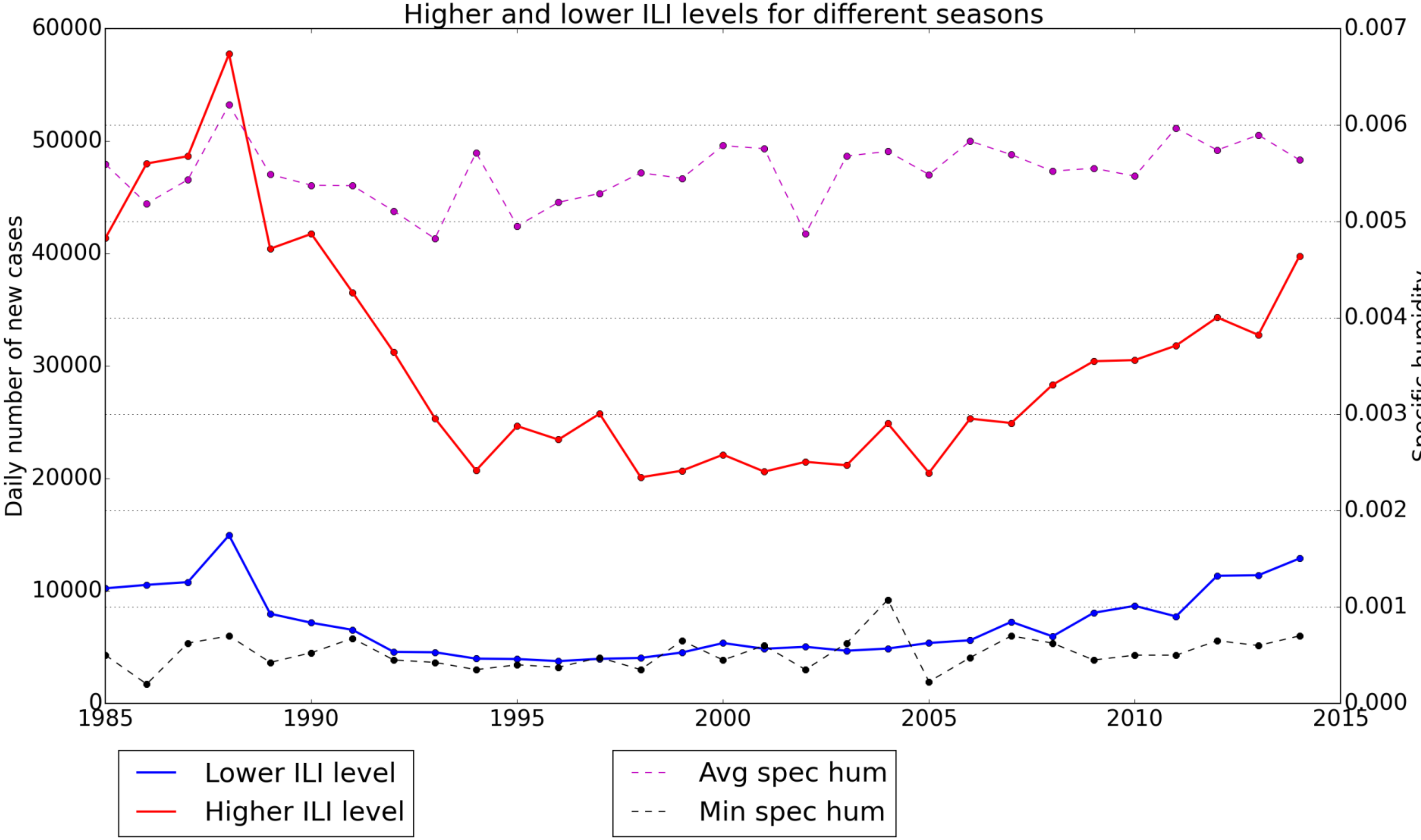

Daily ILI incidence from 01 Jul 1993 to 30 Jun 1994
New cases
60000
50000
40000
30000
20000
10000
0
01 Jul
01 Aug
01 Sep
01 Oct
01 Nov
01 Dec
01 Jan
01 Feb
01 Mar
01 Apr
01 May
01 Jun
Days
Orig. data
Corrected data
Lower ILI level
Higher ILI level
Epidemic peak


Daily temperature and specific humidity with inverted signs from 01 Jul 1993 to 30 Jun 1994
C
30
20
10
0
−10
−20
−30
Specific humidity
0.000
−0.002
−0.004
−0.006
−0.008
−0.010
−0.012
−0.014
01 Jul
01 Aug
01 Sep
01 Oct
01 Nov
01 Dec
01 Jan
01 Feb
01 Mar
01 Apr
01 May
01 Jun
Days
Smoothed hum.
Smoothed temp.

Some additional considerations



Some additional considerations

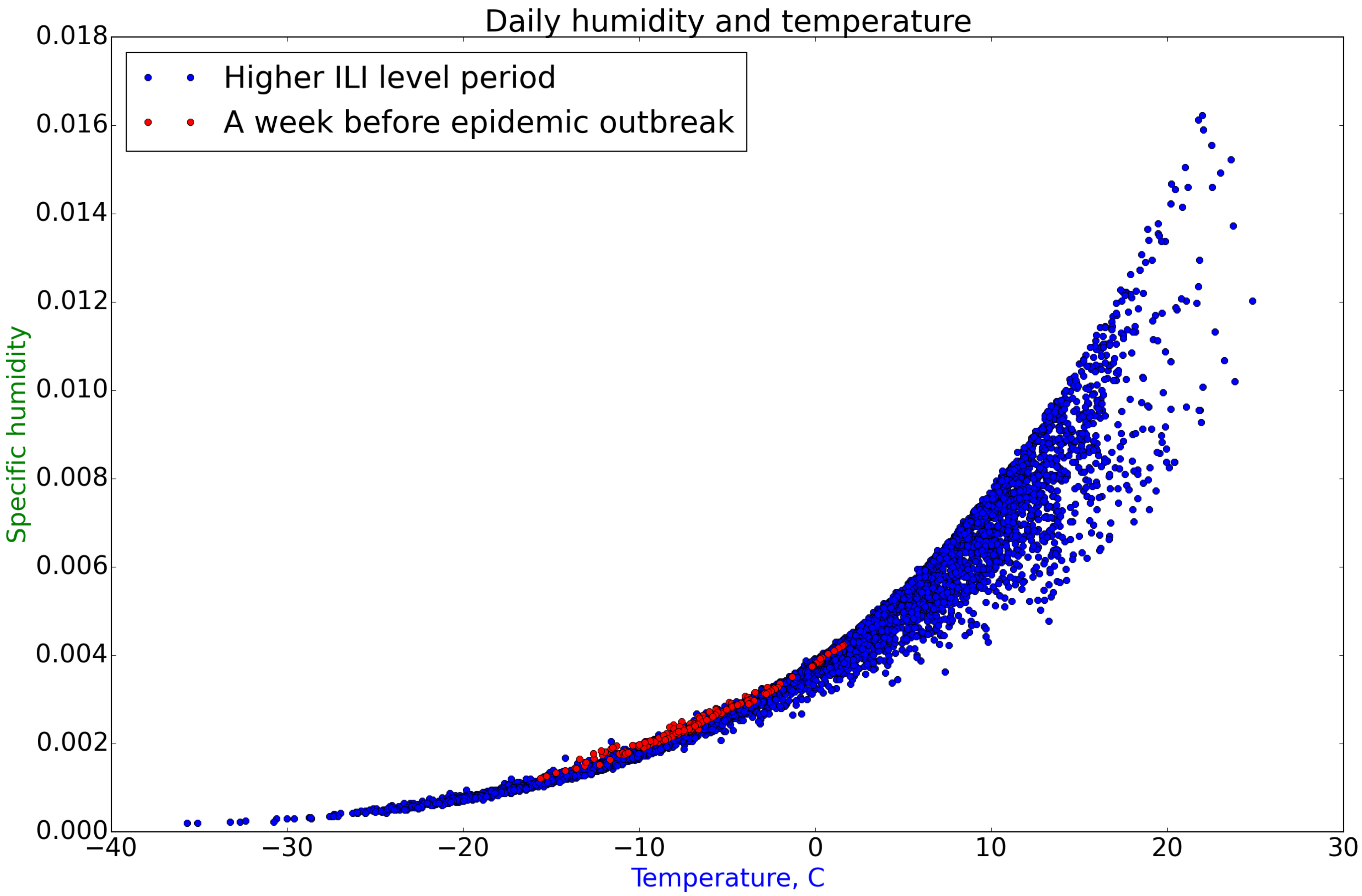


Insights from data: No. 3

— Are the flu outbreak parameters, such as its starting moment, duration and peak height, sufficiently defined by temperature and humidity factors?

— Could be true at least for the outbreak start (requires further investigation)

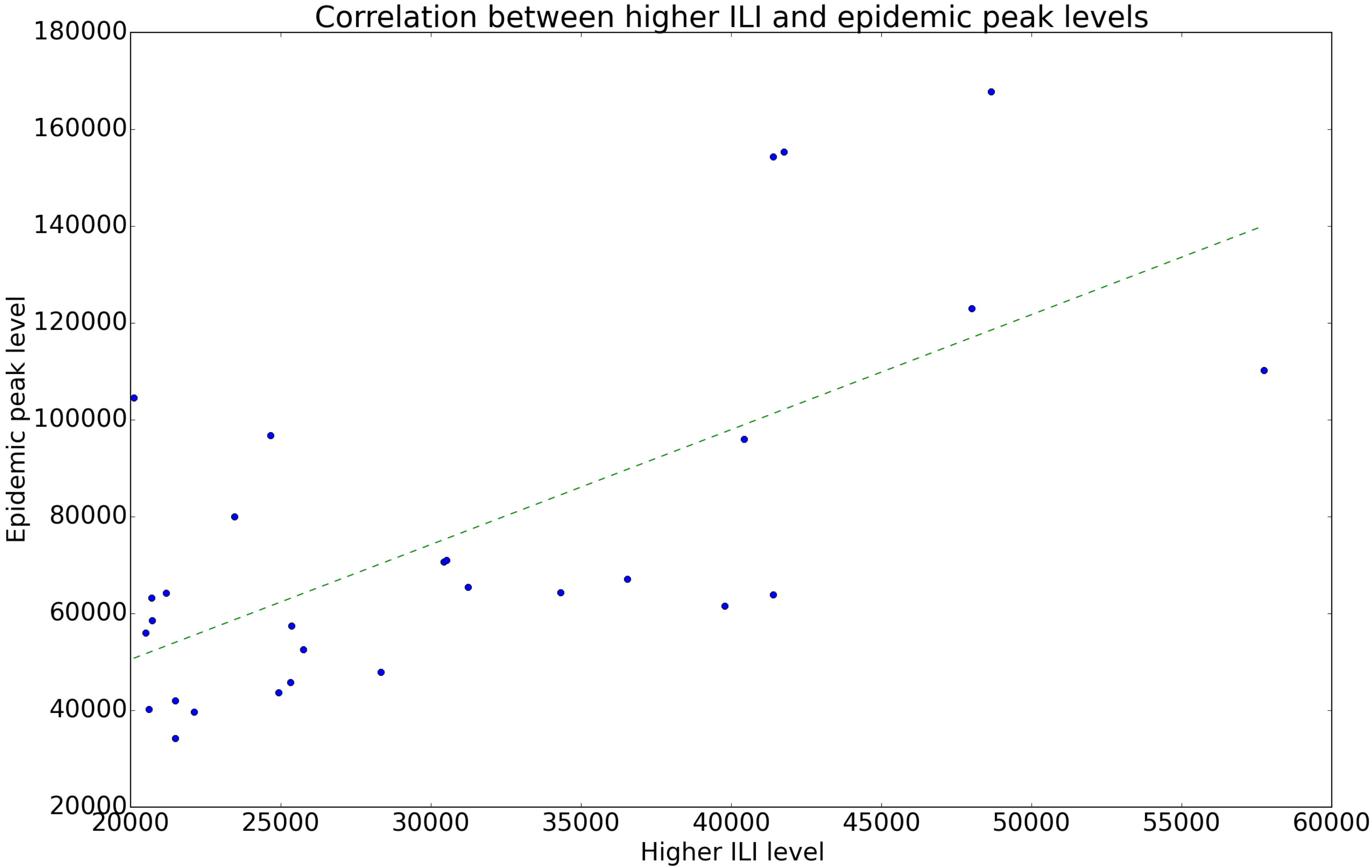
Weather parameters



Romanuykha et al, 2011:

- „…The morbidity level directly before the epidemic, as well as during the first three weeks, does not depend on air temperature. Starting with the fourth week, morbidity has a significant negative correlation with air temperature. Consequently, as temperature drops, epidemic duration increases.“

Seasonal/epidemics incidence correlation



SEIR flu outbreak model

$$\frac{dS}{dt} = -k_1 SI$$

$$\frac{dE}{dt} = k_1 SI - k_2 E$$

$$\frac{dI}{dt} = k_2 E - k_3 I$$

$$\frac{dR}{dt} = k_3 I$$

Fitted parameters:

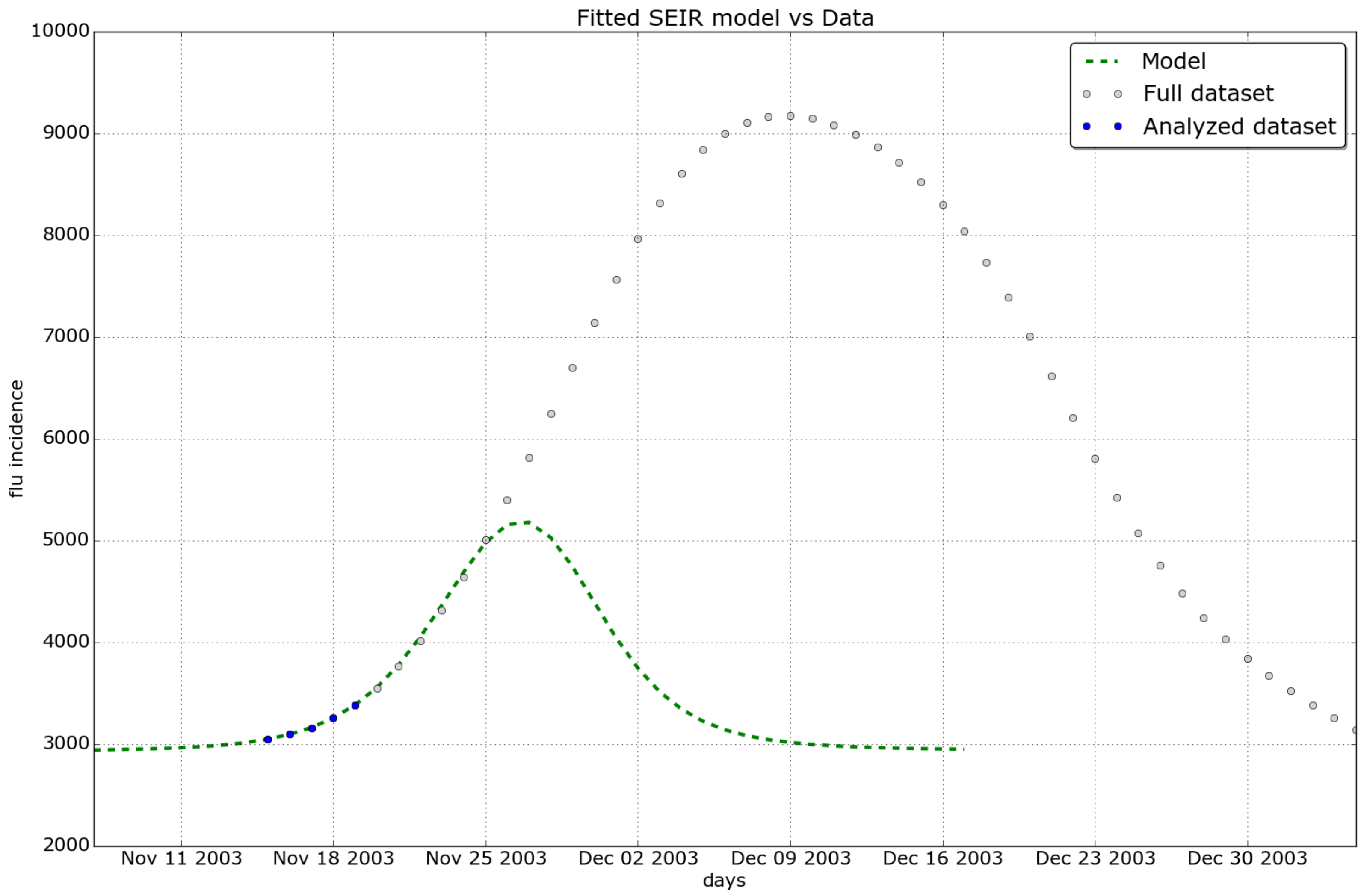
— k1,k2,k3

— The difference between the actual moment of epidemic start and the first point of the epidemic curve from the data

— Initial number of infected

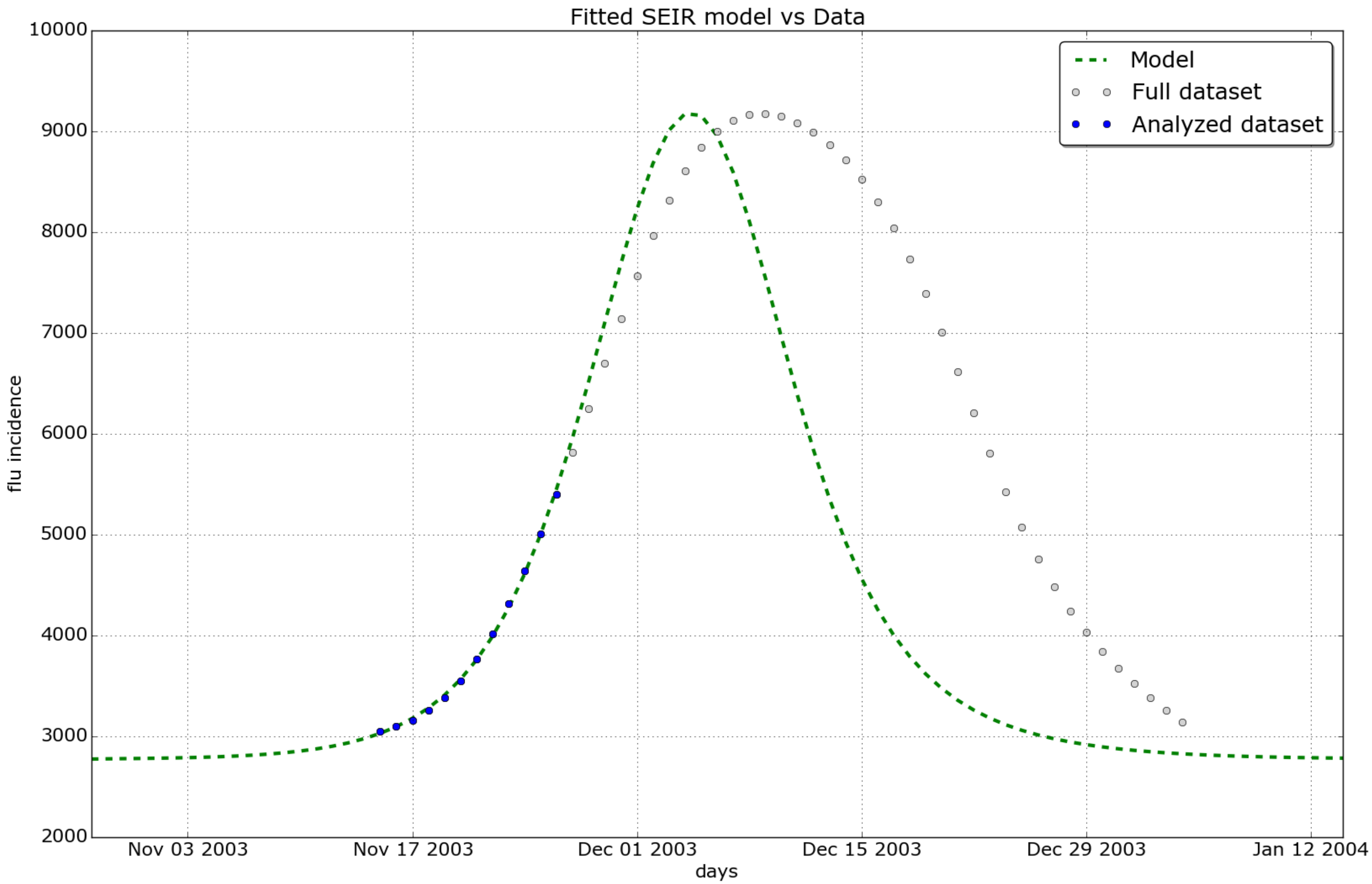
Using least squares method.

N=5



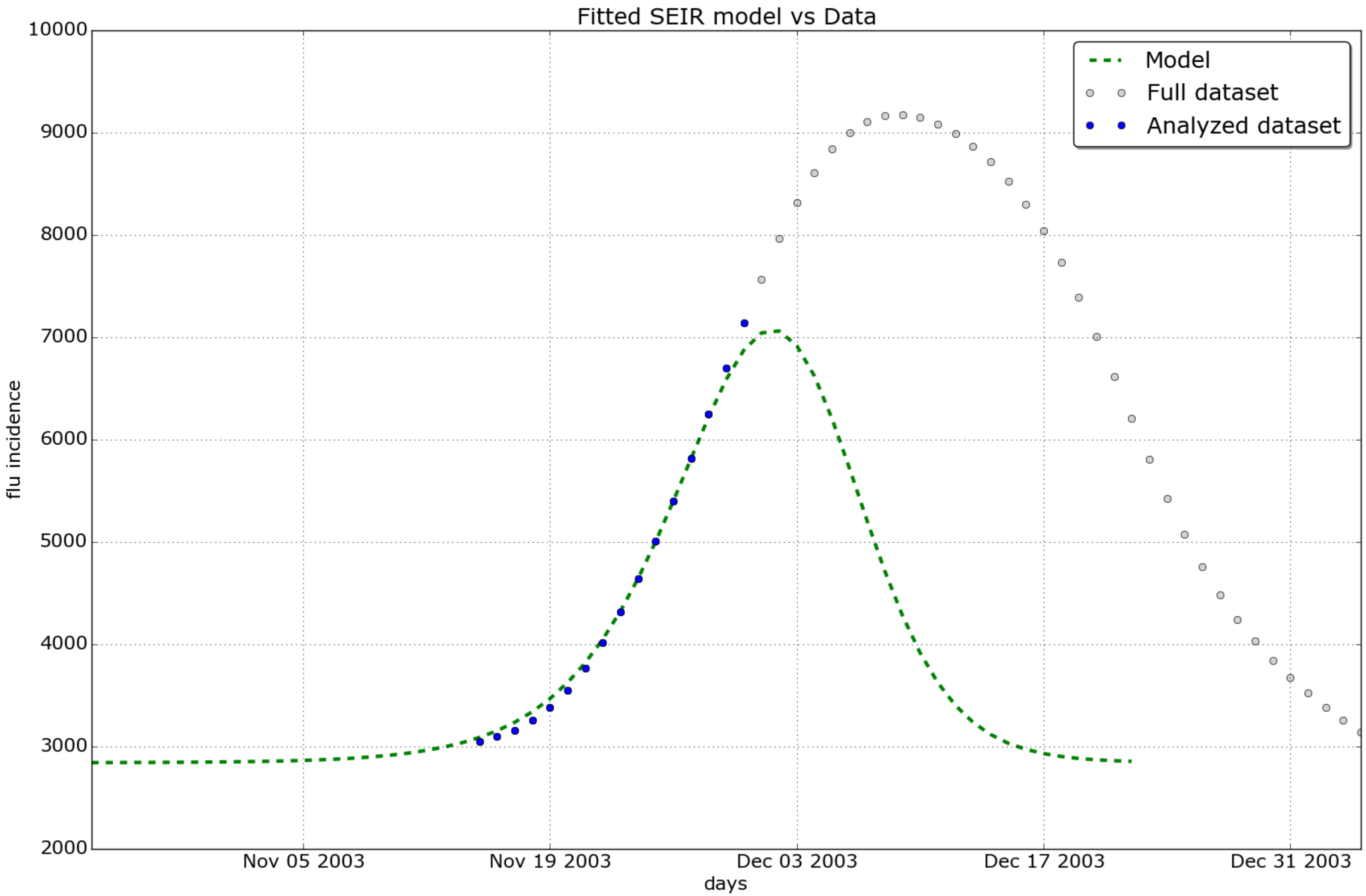
Fitted SEIR model vs Data
Model
Full dataset
Analyzed dataset
flu incidence
10000
9000
8000
7000
6000
5000
4000
3000
2000
Nov 11 2003
Nov 18 2003
Nov 25 2003
Dec 02 2003
Dec 09 2003
Dec 16 2003
Dec 23 2003
Dec 30 2003
days

N=12



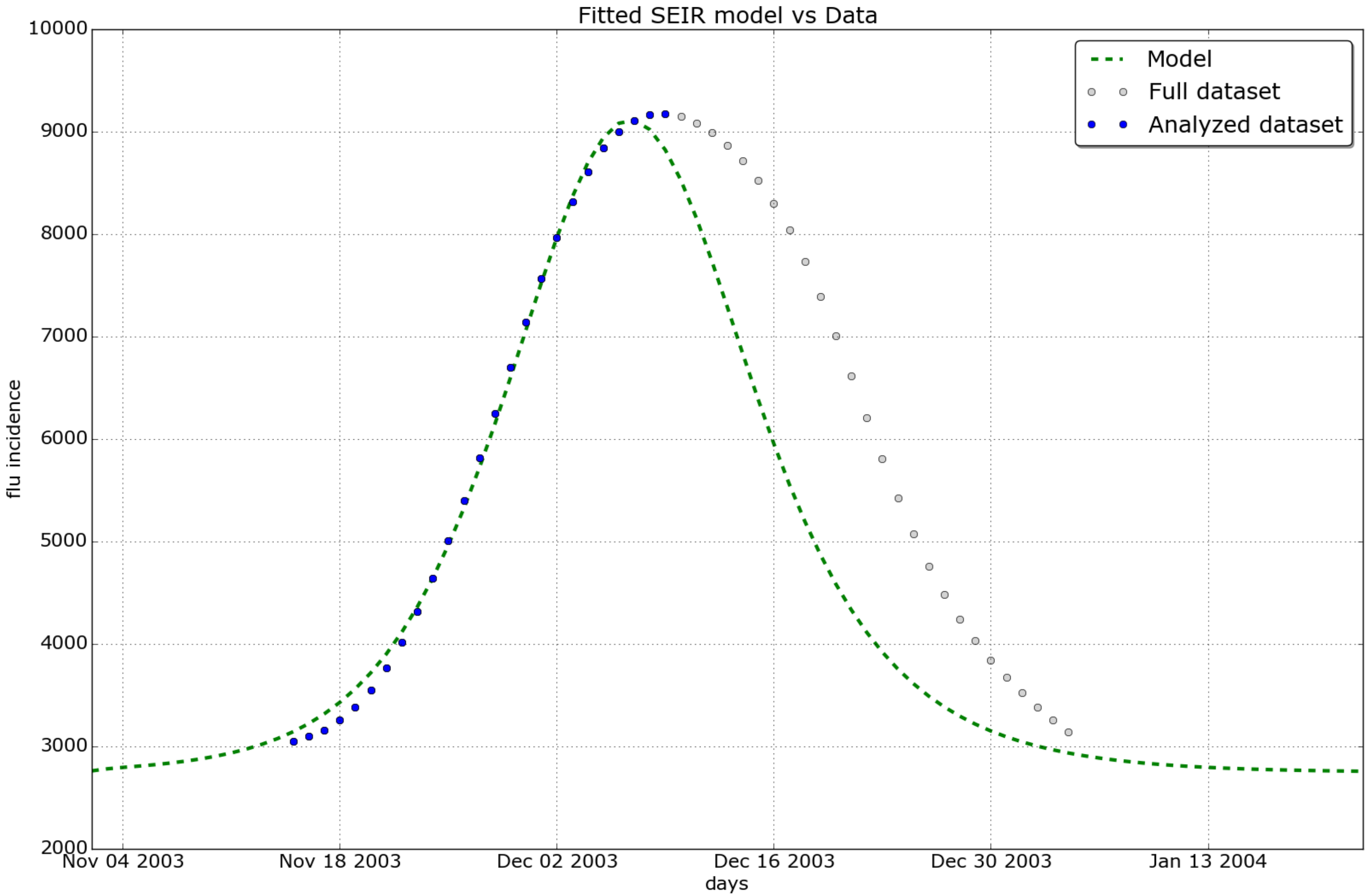
Fitted SEIR model vs Data
Model
Full dataset
Analyzed dataset
flu incidence
10000
9000
8000
7000
6000
5000
4000
3000
2000
Nov 03 2003
Nov 17 2003
Dec 01 2003
Dec 15 2003
Dec 29 2003
Jan 12 2004
days

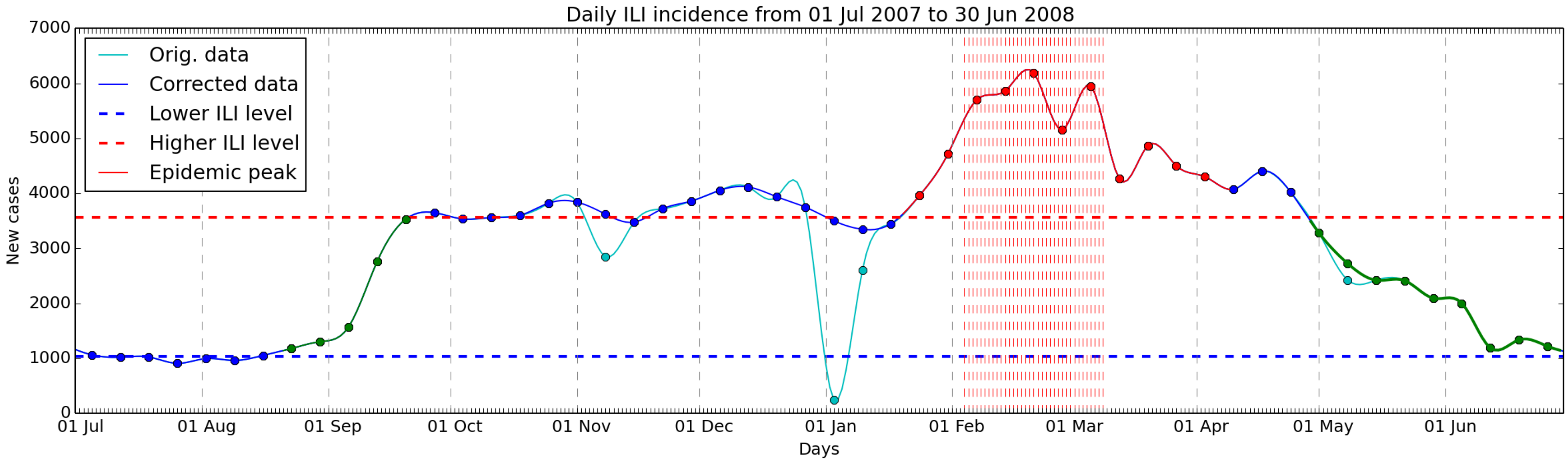
N=13



Fitted SEIR model vs Data
10000
9000
8000
7000
6000
5000
4000
3000
2000
flu incidence
Nov 05 2003
Nov 19 2003
Dec 03 2003
Dec 17 2003
Dec 31 2003
days
Model
Full dataset
Analyzed dataset

N=25


Fitted SEIR model vs Data
Model
Full dataset
Analyzed dataset
flu incidence
10000
9000
8000
7000
6000
5000
4000
3000
2000
Nov 04 2003
Nov 18 2003
Dec 02 2003
Dec 16 2003
Dec 30 2003
Jan 13 2004
days



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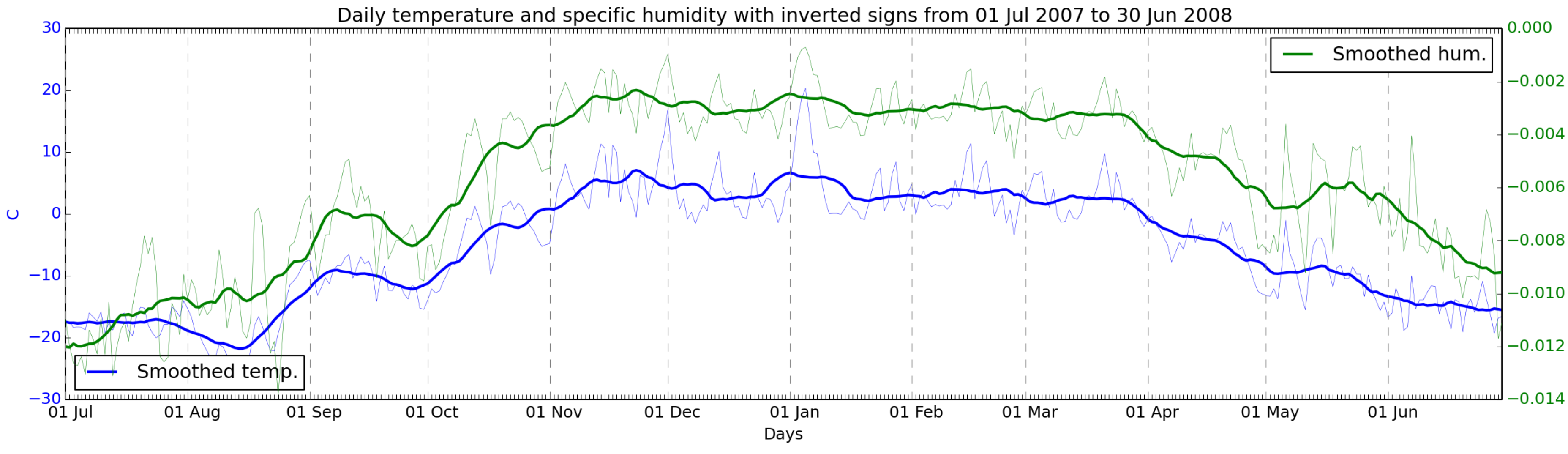
01 Jan
01 Feb
01 Mar
01 Apr
01 May
01 Jun
Days



Daily temperature and specific humidity with inverted signs from 01 Jul 2007 to 30 Jun 2008
Smoothed hum.
Smoothed temp.
C
30
20
10
0
−10
−20
−30
Specific humidity
0.000
−0.002
−0.004
−0.006
−0.008
−0.010
−0.012
−0.014
01 Jul
01 Aug
01 Sep
01 Oct
01 Nov
01 Dec
01 Jan
01 Feb
01 Mar
01 Apr
01 May
01 Jun
Days

What’s next?

- Continue playing with data to find possible correlations between different output data types
- Build the ILI background dynamics model
- Elaborate on the conditions for models switching (ILI background level $\longrightarrow$ flu outbreak)
- Handle the incidence data for other Russian cities and see if our assumptions still hold true

Thank you
for your attention!

E-mail: VNLeonenko@yandex.ru

Drawbacks

- The aim of the conventional ILI research is in:
  - Analysis of a flu outbreak without ILI seasonal dynamics (ignoring the prevalence in the interepidemic period)
  - Statistical modeling of seasonal ILI+ILI outbreak (not distinguishing the difference in the mechanisms of the two processes)