European Journal of Epidemiology (2005) 20: 263–270
DOI 10.1007/s10654-004-6518-3

INFECTIOUS DISEASE EPIDEMIOLOGY

North Atlantic weather oscillation and human infectious diseases in the Czech Republic, 1951–2003

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Accepted in revised form 22 November 2004

Abstract. Longitudinal correlation between the North Atlantic Oscillation large-scale weather system (NAO) and the annual incidence rate of 14 viral, bacterial and protozoan national notifiable human diseases in the Czech Republic was examined. In simple correlation, cases of salmonellosis, erysipelas, infectious mononucleosis and toxoplasmosis were positively correlated with the winter NAO index, while hepatitis A and shigellosis were negatively correlated, and the other diseases tested (rubella, mumps, chickenpox, tick-borne encephalitis, Lyme borreliosis, leptospirosis, tularemia and scarlet fever) were uncorrelated with NAO. However, 8 of the 14 diseases also revealed a significant time trend, either increasing (infectious mononucleosis, salmonellosis, erysipelas, toxoplasmosis) or decreasing (hepatitis A, scarlet fever, leptospirosis, shigellosis) during the period. When the effect of NAO on incidence of the diseases was then controlled for calendar year using partial correlation analysis and detrended regression, only toxoplasmosis and infectious mononucleosis were found significantly positively correlated with the NAO when the index was lagged 1 or 2 years, and leptospirosis was correlated negatively with a lag of 2 years. Large-scale weather changes as described by NAO therefore do not seem to be a crucial factor in the fluctuation of annual incidence rate of the majority of tested infectious diseases in the Czech Republic, while other factors, especially social and public health circumstances, are obviously more important.

Key words: Climate change, Cluster analysis, Incidence rate, Large-scale weather, NAO, Temperature, Weather factors

Introduction

Climate change is often considered as the cause for the emergence, retreat or spread of certain human infectious diseases, but scientific evidence is still sparse and equivocal: while some studies support this claim, others do not [1–16], and further investigations and new approaches are necessary. El Niño Southern Oscillation system (ENSO) of atmospheric circulation in the tropical Pacific might affect some vector-, rodent-, or water-borne diseases in America, Australia, southern Asia and eastern Africa, either directly (through extreme precipitation and temperature) or indirectly (through ecological changes of the transmission cycles). For instance, high precipitation caused by the 1992–1993 ENSO signal reportedly preceded an increase in rodent abundance and the following 1993–1994 outbreak of hantavirus pulmonary syndrome in humans in the US. Four Corners region [8], or the incidence of visceral leishmaniasis in Brazil [14]. Another major large-scale weather world system is the North Atlantic Oscillation (NAO), a dominant mode of the climate variability that affects profoundly the weather in Europe and eastern North America [17]. The effect of NAO on human infectious diseases has not yet been studied, except for a partial analysis carried out in Lyme borreliosis [18].

The aim of the study was first to find temporal (annual) co-fluctuation in the incidence of 14 notifiable infectious diseases in a Central European country (Czech Republic), from 1951 to 2003. Second, the association between a large-scale climate indicator/descriptor (NAO) and these infectious diseases was investigated.

Methods

To examine long-term co-fluctuations among human infectious diseases in the Czech Republic, annual (1951–2003) incidence data for 14 viral, bacterial and protozoan diseases (Figure 1) were gathered from the national notifiable diseases surveillance database EPIDAT at the National Institute of Public Health, Prague (former Institute of Hygiene and Epidemiology). Descriptive statistics of the annual incidence and the number of years of selected notifiable infectious diseases are shown in Table 1. In diseases with national vaccination campaigns, only the records

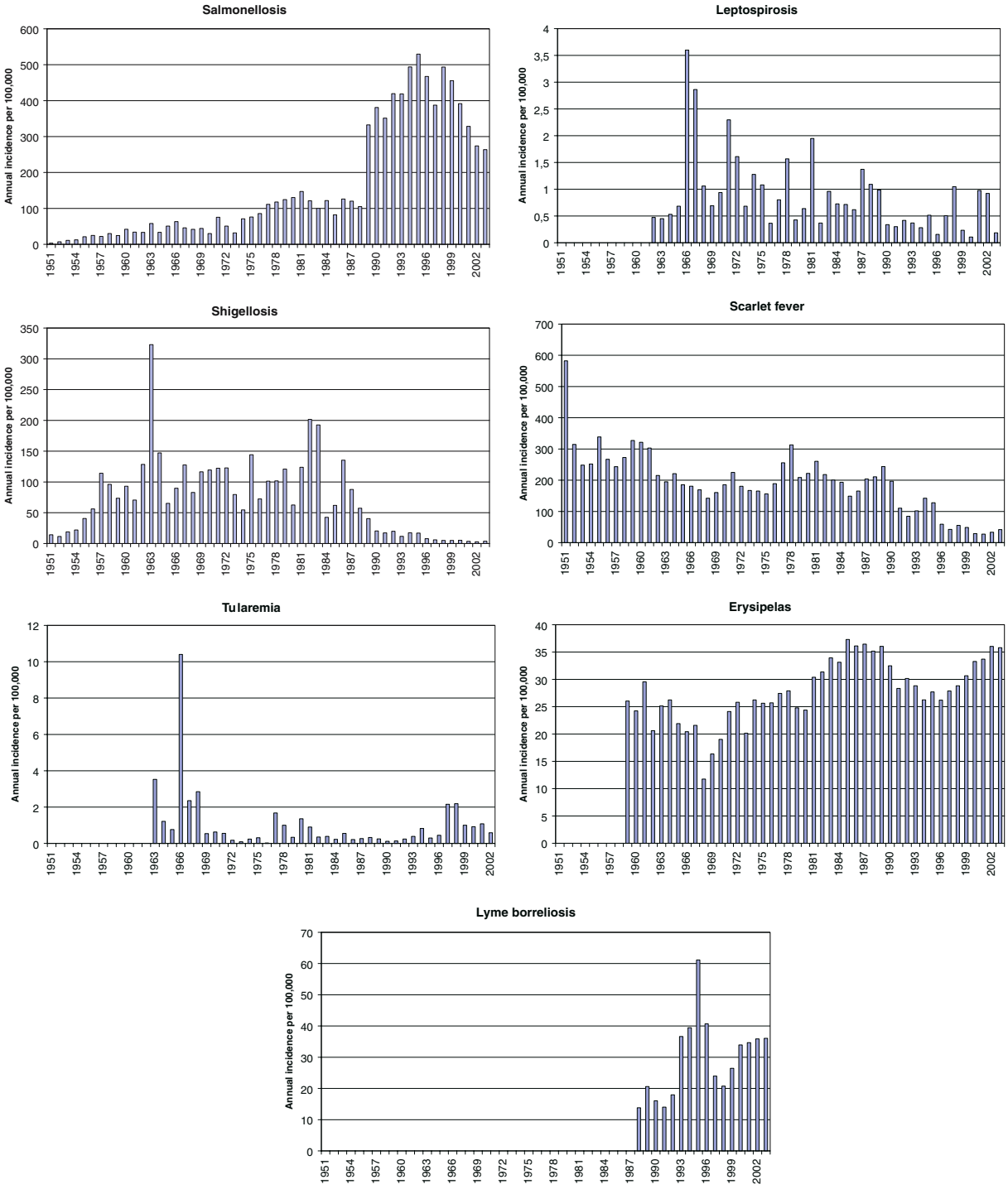

Figure 1. Annual incidence rate of 14 notifiable infectious diseases in the Czech Republic, 1951–2003. (EPIDAT, National Public Health Institute, Prague).

prior a specific campaign had started were used. The incidence data were expressed per 100,000 inhabitants; the total population of the Czech Republic (*c*. 10 million) did not vary much in the period 1951–2003: between 9.080 and 10.363 million (Czech Statistical Office, http://www.czso.cz/csu).

The NAO winter ('extended winter' – December to March) index values for the years 1951–2003 (Figure 2) were extracted from the URL http://www.cgd.ucar.edu/~jhurrell/nao.html [17], and their correlation with the annual incidence of particular diseases was estimated. Extended winter index of the NAO is based on the difference of normalized sea level pressure between Lisbon (Portugal) and Stykkisholmur/Reykjavik (Iceland). Generally, positive NAO index values indicate stronger-than-average westerlies over the middle latitutes, i.e. more intense and more frequent winter storms crossing the Atlantic Ocean toward Europe, and thus a milder winter and the whole year in Europe. When the winter

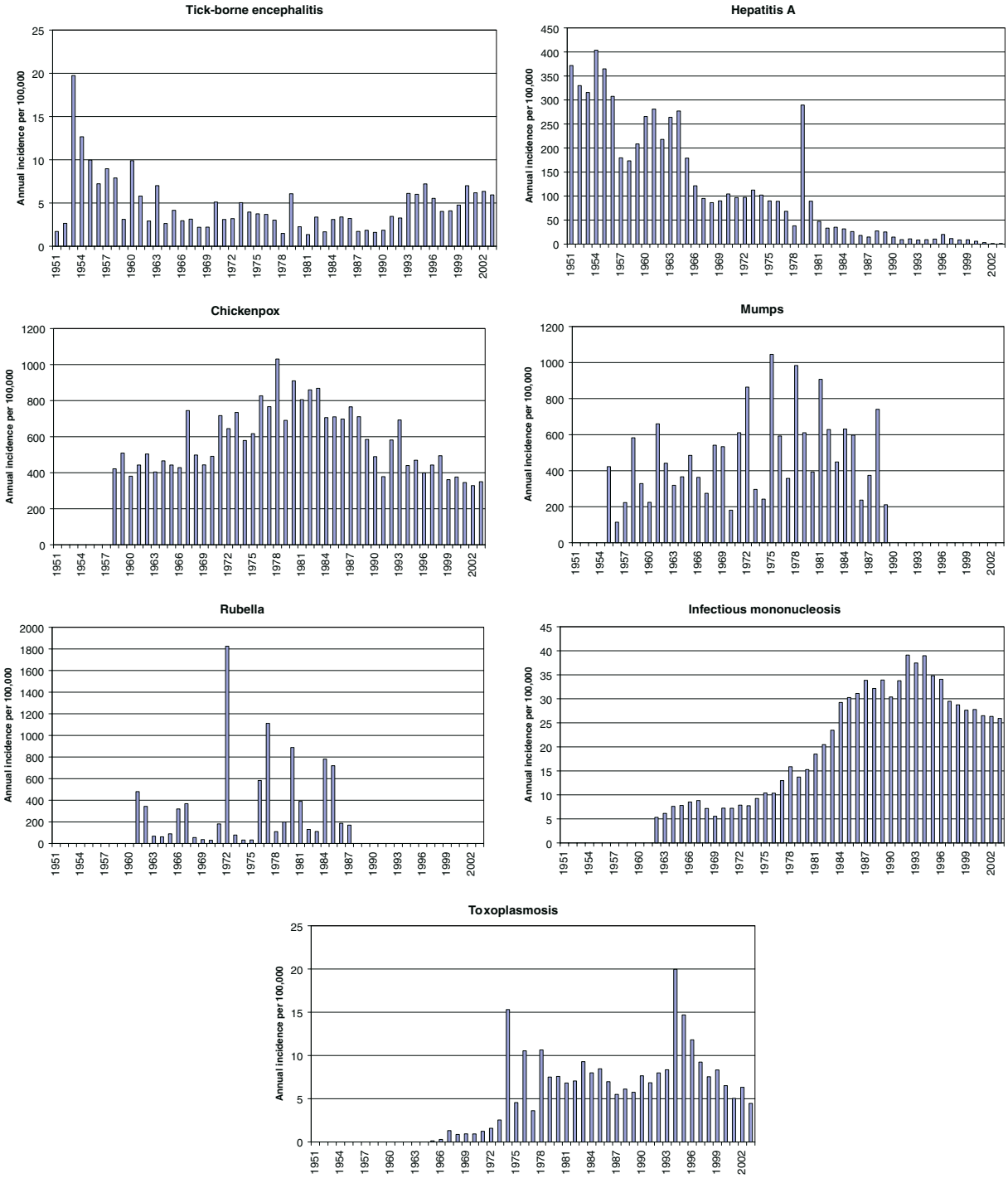

Figure 1. (Continued)

NAO index is higher than normal, it means a warmer and slightly drier weather over central Europe in that year, and *vice versa* [17]. The long-term correlation coefficient between the winter NAO index and the mean annual air temperature in Czechland was $+0.78$ ($p < 0.001$) while that between this index and local precipitation (-0.30) was insignificant (E. Tkadlec, personal communication).

Pearson's correlation coefficients (r) compared pairwise annual incidence of the diseases, and UPGMA cluster analysis of the 14×14 correlation matrix was conducted with NTSYS-pc 1.60 [19]. Pearson's simple correlation and partial correlation coefficients were then calculated for comparison of disease incidence with NAO index. For instance, the winter NAO index for 1960 (that means December 1959 to March 1960) was paired with a specific disease incidence data (expressed per 100,000 inhabitants) of the year 1960. To eliminate the effect of calendar year (trend) in statistical analysis of the NAO influence, the data were detrended using two techniques: (i) partial correlation (a subprogram of the SOLO 4.0, BMDP

Table 1. Descriptive statistics of 14 selected notifiable human infectious diseases in the Czech Republic, annual number of cases of 1951–2003. The Czech population varied between 9.080 and 10.363 million in that period

Disease	Years	Avg	Median	Min	Max
Salmonellosis (A02)	1951–2003	16261	8685	296	54552
Shigellosis (A03)	1951–2003	7301	6465	286	31549
Tularemia (A21)	1964–2003	105	55	3	1021
Leptospirosis (A27)	1962–2003	89	68	11	353
Scarlet fever (A38)	1951–2003	18928	19178	2808	52881
Erysipelas (A46)	1959–2003	2822	2854	1153	3854
Lyme borreliosis (A69.2)	1988–2003	3034	3104	1429	6300
Tick–borne encephal. (A84.1)	1951–2003	467	374	140	1816
Chickenpox (varicella, B01)	1958–2003	58452	50801	33474	105898
Rubella (B06)*	1961–1987	35058	17877	2932	180300
Hepatitis A (B15)	1951–2003	11119	8822	114	37544
Mumps (parotitis, B26)*	1955–1987	48209	42995	10743	105539
Infect. mononucleosis (B27)	1962–2003	2120	2265	519	4028
Toxoplasmosis (B58)	1965–2003	680	706	13	2056

* National vaccination campaigns in the Czech Republic started in 1987.

Statistical Software, Los Angeles, CA) of incidence on NAO when YEAR was the variable controlled; and (ii) detrended correlation based on regression of incidence residuals after removing the time trend in each disease; NAO index was not detrended. The results of both techniques differed slightly, and they are therefore presented here in parallel.

Results

Dendrogram of the cluster analysis (Figure 3) shows the temporal correlation (co-fluctuation) among selected infectious diseases in the Czech Republic, 1951–2003. Three clusters of diseases similarly co-fluctuating were revealed at $r > +0.45$ ($p < 0.01$): (A) salmonellosis, infectious mononucleosis, toxoplasmosis and erysipelas; (B) tick-borne encephalitis and Lyme borreliosis; (C) hepatitis A and scarlet fever. The diseases of cluster C, as well as shigellosis, chickenpox, leptospirosis and tularemia, were inversely correlated with those of cluster A ($r \sim -0.25$).

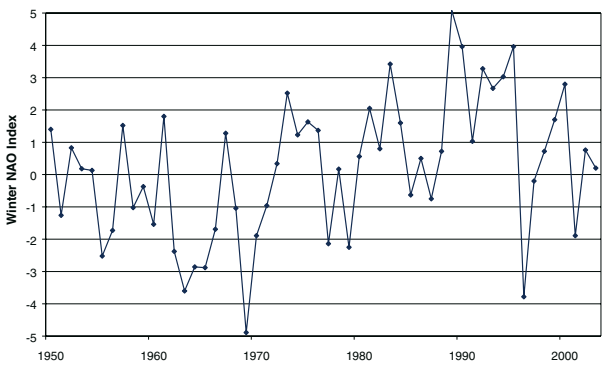

Figure 2. The winter NAO index values, 1950–2003. The correlation between the NAO index and YEAR was $r = +0.402$ ($p < 0.01$) in the period.

Standard simple correlation analysis revealed three groups of infectious diseases according to their correlation with the winter NAO index (Table 2): (i) salmonellosis, erysipelas, infectious mononucleosis and toxoplasmosis were positively correlated; (ii) shigellosis and hepatitis A were negatively correlated; (iii) tularemia, leptospirosis, scarlet fever, Lyme borreliosis, tick-borne encephalitis, chickenpox, rubella and mumps did not show a significant correlation with winter NAO. When the NAO index shifted 1 or 2 years back was used, leptospirosis and tularemia also revealed a negative correlation with NAO. Importantly, most diseases were correlated significantly also with the calendar year, i.e. they revealed, within the period tested, an overall and significant trend of either increasing incidence (salmonellosis, erysipelas, infectious mononucleosis, toxoplasmosis), decreasing incidence (shigellosis, leptospirosis, scarlet fever, hepatitis A) or no significant time trend (tularemia, Lyme borreliosis, tick-borne encephalitis,

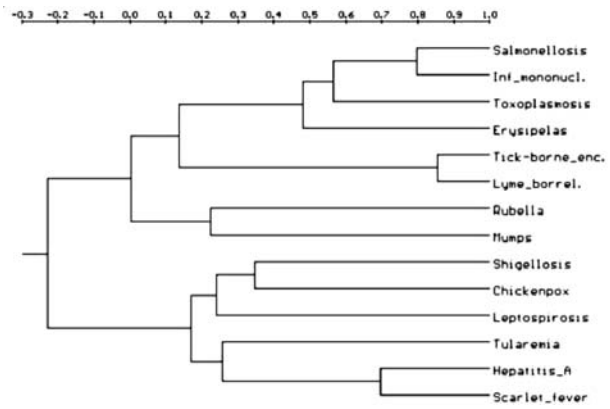

Figure 3. Cluster analysis of correlation in the annual incidence rate among 14 notifiable infectious diseases in the Czech Republic, 1951–2003. Axis shows correlation coefficient values: only those above 0.4 are significant.

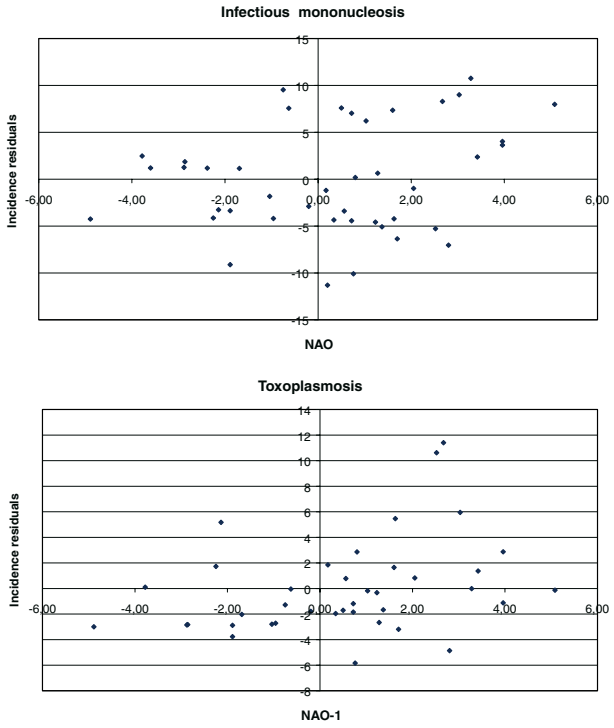

Figure 4. Regression of incidence residuals on NAO index.

chickenpox, rubella, mumps). To discriminate between the variables NAO and YEAR (calendar year), partial correlation analysis and detrended regression were applied using the variable control. The results are shown in Table 2: when the effect of NAO on incidence of the diseases was controlled for YEAR (i.e., that variable was eliminated), only toxoplasmosis and infectious mononucleosis were found significantly positively correlated with the large-scale weather situation with a lag 1 or 2 years, while leptospirosis correlated negatively with the NAO index lagged 2 years.

Discussion

Our data have been based on notified cases of diseases per calendar year (this was the only format available in the older data in the 1950s and 1960s). However, there are infections which reveal distinct winter peaks of seasonal distribution, and their cycles or epidemics thus overlap two calendar years (e.g., tularemia). This might decrease the power of this study although the bias should not be regarded as too great.

To the best of the author's knowledge, cluster analysis has not been used before in the epidemiology for evaluation of temporal co-fluctuation of different infectious diseases in a specific area. The results obtained in this study using pair-wise correlation of diseases incidence combined with the cluster analysis are quite interesting, in that three clusters of similarly co-fluctuating diseases were found. While the mode of transmission is identical for the two tick-borne diseases in cluster B (principal vector of both tick-borne encephalitis and Lyme borreliosis is the *Ixodes ricinus* tick), epidemiological interpretation of the clusters A and C is not straightforward because transmission routes of particular diseases differ. However, these diseases revealed similar time trends in the period examined, either increasing (cluster A) or decreasing (cluster C). The consecutive analysis of a potential differential effect of large-scale weather on incidence of these diseases did not yield an unequivocal explanation of the co-fluctuation pattern.

The effect of NAO on infectious diseases has not been tested previously in Europe. One study [18] compared longitudinal incidence of Lyme borreliosis in south Moravia (Czechland) with the NAO, but no significant correlation was detected (similarly as in the present survey). However, prevalence of *I. ricinus* ticks infected with >50 borreliae correlated with NAO of the last year or of the year before last. Using the simple correlation analysis, two groups of infectious diseases revealed their correlation with the NAO index in the present study (salmonellosis, erysipelas, infectious mononucleosis and toxoplasmosis; hepatitis A and shigellosis) but they correlated significantly also with the variable YEAR. Increasing incidence trends of some diseases could be generally explained by either (i) real spread of particular disease (e.g., salmonellosis due to *S. enterica* serovar Enteritidis since 1989) or (ii) a better laboratory or clinical diagnosis of the disease combined with increased awareness among general practitioners (e.g., toxoplasmosis; or campylobacterosis and legionellosis of the diseases not included in this study because of insufficiently long-term records of them). On the other hand, a decreasing trend of some diseases might be caused by either (i) a real decrease of particular disease; (ii) improved general hygienic conditions (e.g., hepatitis A, shigellosis); or (iii) life style changes. For instance, mosquito-borne diseases can be hampered by decreased outdoor activity of humans (leptospirosis as well) combined with air-conditioning in living and working rooms.

There was a statistically significant correlation between the variables NAO and YEAR over the period tested ($r = +0.402$) reflecting the 'global climate warming' in Europe during the second half of the 20th century [20]. This is also shown in Figure 2 where a positive trend of NAO is obvious particularly for the time period from 1960 to 1995. To discriminate between the effects of variables NAO and YEAR, it was necessary to apply partial correlation analysis using the variable control technique, and detrended regression. When the effect of the large-scale weather situation on incidence of the diseases was then controlled for YEAR, only NAO lagged 1 or 2 years significantly correlated with toxoplasmosis and infectious mononucleosis (positively) or leptospirosis (negatively). Significant effect of NAO on the

Table 2. Correlation analysis between the winter NAO index, the annual incidence (per 100,000 population) of selected notifiable human infectious diseases in the Czech Republic, 1951–2003, and their time trends. NAO-1 and NAO-2 mean indices with a shift of 1 and 2 years back, respectively. Correlation coefficient values in bold are significant at $p < 0.05$

	Simple correlation				Partial correlation[a]			Detrended Correlation[b]		
Variable	YEAR	NAO	NAO-1	NAO-2	NAO	NAO-1	NAO-2	NAO	NAO-1	NAO-2
Salmonellosis	**+0.844**	**+0.437**	**+0.452**	**+0.374**	+0.199	+0.260	+0.160	+0.182	+0.240	+0.150
Erysipelas	**+0.644**	**+0.444**	+0.293	**+0.331**	+0.244	+0.005	+0.088	+0.220	+0.005	+0.080
Inf. mononucleosis	**+0.864**	**+0.523**	**+0.503**	**+0.538**	+0.281	+0.282	**+0.320**	+0.250	+0.254	+0.285
Toxoplasmosis	**+0.509**	**+0.430**	**+0.494**	**+0.557**	+0.314	**+0.364**	**+0.421**	+0.295	**+0.332**	**+0.372**
Shigellosis	**−0.363**	**−0.291**	**−0.337**	**−0.228**	−0.170	−0.230	−0.116	−0.156	−0.212	−0.109
Tularemia	−0.304	−0.135	−0.291	**−0.367**	−0.018	−0.180	−0.263	−0.017	−0.161	−0.229
Leptospirosis	**−0.417**	−0.075	**−0.397**	**−0.499**	+0.145	−0.264	**−0.382**	+0.128	−0.238	**−0.340**
Scarlet fever	**−0.770**	−0.166	−0.175	−0.163	+0.245	+0.203	+0.175	+0.225	+0.188	+0.164
Hepatitis A	**−0.872**	**−0.420**	**−0.326**	−0.249	−0.156	+0.017	+0.119	−0.142	+0.015	+0.111
Lyme borreliosis	+0.459	−0.076	+0.201	+0.117	+0.171	+0.387	+0.243	+0.152	+0.371	+0.238
Tickborne encephalitis	−0.268	−0.091	+0.024	−0.060	+0.019	+0.142	+0.036	+0.017	+0.132	+0.034
Chickenpox	−0.116	+0.226	−0.029	−0.061	+0.289	+0.020	−0.061	+0.278	+0.019	−0.010
Rubella	+0.159	+0.147	+0.157	+0.056	+0.092	+0.105	+0.001	+0.077	+0.081	+0.018
Mumps	+0.293	+0.141	+0.254	+0.111	+0.001	+0.162	+0.014	+0.001	+0.150	+0.013

[a]Controlled for YEAR (effect of YEAR excluded).
[b]Based on calculation of residuals in detrended regression.

three diseases calls for an attempt at its elucidation. In toxoplasmosis, a warmer year could enhance populations of rodents, main intermediate hosts of *Toxoplasma gondii*, and increase their infection rate with this protozoan. It takes several months before the definitive hosts of *T. gondii*, i.e. cats, start to catch infected rodents; this could result in a lag before the infection (oocysts from cats) comes closer to humans. Infectious mononucleosis, caused by EB herpesvirus, is a disease of predominantly young adults in Czechland, spreads from person to person by oropharyngeal route (e.g., by kissing) and predominates in spring. A positive NAO signal causes higher ambient temperatures and an earlier than normal phenological spring in Central Europe. These conditions may stimulate a higher than normal outdoor activity of young people, including dates with friends. For both diseases, these are just hypotheses that remain to be verified, or refused and replaced with more satisfactory explanations. The causation of negative association of leptospirosis incidence with NAO lagged 2 years remains obscure at present but it could be affected by a higher precipitation and resulting decreased populations of field rodents, main reservoir of *Leptospira interrogans* var. *grippotyphosa*, the most prevalent leptospiral serovar among patients in Central Europe.

The effect of the variable YEAR (i.e. the time trend) was much more pronounced than that of NAO in virtually all infectious diseases tested. However, these results do not exclude local or partial effects of NAO and climate changes on certain infections. For instance, tick-borne encephalitis was found to spread jointly with its vector (*I. ricinus*) to more northern latitudes in Scandinavia [9] and to higher elevations in Central Europe [21–22] at the end of 20th century, most probably due to the climate warming in that period.

Large-scale weather changes as described by NAO therefore do not seem to be a crucial general factor in the annual incidence rate of the majority of the infectious diseases tested in Czechland, while other factors, especially social and public health circumstances, are obviously more important. This study did not test for a relationship of the diseases with shorter-term weather or climatic factors although it is likely that these may influence disease patterns. Nevertheless, it could be worthwhile to examine the effect of NAO, as a large-scale weather indicator/marker, on the incidence of infectious (as well as non-infectious) diseases in other countries because the weather conditions and their epidemiological impacts in Central Europe may differ from those in other parts of Europe.

Acknowledgements

I am very obliged to Dr Č. Beneš (National Institute of Public Health, Prague) for supplementing the disease incidence data. This study was supported by the Grant Agency of the Czech Republic (206/03/0726).

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