

Climate change and zoonotic infections in the Russian Arctic

Boris Revich^{1*}, Nikolai Tokarevich² and Alan J. Parkinson³

¹Institute of Forecasting, Russian Academy of Sciences, Moscow, Russia; ²Paster Institute of Epidemiology and Microbiology, Saint-Petersburg, Russia; ³Arctic Investigations Program, Division of Preparedness and Emerging Infections, National Center for Emerging and Zoonotic Infectious Diseases, Centers for Disease Control and Prevention, Alaska, Anchorage, USA

Climate change in the Russian Arctic is more pronounced than in any other part of the country. Between 1955 and 2000, the annual average air temperature in the Russian North increased by 1.2°C. During the same period, the mean temperature of upper layer of permafrost increased by 3°C. Climate change in Russian Arctic increases the risks of the emergence of zoonotic infectious diseases. This review presents data on morbidity rates among people, domestic animals and wildlife in the Russian Arctic, focusing on the potential climate related emergence of such diseases as tick-borne encephalitis, tularemia, brucellosis, leptospirosis, rabies, and anthrax.

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The distribution of the flora and fauna of the Russian North underwent considerable changes during the second half of the 20th century. For example, between 1960 and 1983, the border between the predominantly forest-type and tundra-type landscapes shifted northward from 67°12'N to 67°30'N in the Russian Plain region near the Pechora river. During this period, forests advanced by 35 km, an annual average rate of migration of about 1.5 km/year (1). The dominant type of vegetation determines many properties of an ecosystem, such as the fauna species composition, which is quite sensitive to climate change. For example, there has been a rapid northward migration of certain bird species, such as the blackbird (*Turdus merula*), which has advanced northward during recent decades and now nests in southern Archangelsk and the Karelia taiga up to a latitude of 63°N. Twelve new species of birds now nest in the northern taiga ecosystems in the western part of the Russian Plain; these species have not been previously observed in these regions (2). During the 20th century, many species of mammals have also advanced northwards: the field mouse (*Apodemus agrarius*), the small mouse (*Micromys minutus*), the campagnol (*Microtus arvalis*), the brown hare (*Lepus europaeus*), the hedgehog (*Erinaceus europaeus*), the wild boar (*Sus scrofa*), and others (3). These birds and mammals are hosts to an array of pathogenic organisms

that can cause infectious disease in humans. For example, the ground-nesting forest birds participate in the epizootic cycle of tick-borne encephalitis. Small mammals are often a reservoir for tick-borne encephalitis, hemorrhagic fever with kidney syndrome, Q fever, tularemia, pseudo tuberculosis, leptospirosis and other infectious diseases that occur in Russian Arctic.

Climate change in Russian Arctic

Climate change in the Russian Arctic is now more evident than in many other regions of the world. While the average global temperature has increased by 0.7°C during the last 100 years, temperature increases in the Arctic have been greater. In the Russian Arctic, between 1955 and 2000, the following increases in the annual average temperatures have been reported: 1.2°C for the whole territory of the Russian North, 1.4°C in Middle Siberia, and 1.1°C in Yakutia (4). The average temperatures of the surface layer of Arctic permafrost have increased by 3°C during the same period. In the 20th century, the total area of the permafrost in the Northern hemisphere has diminished by 7% (5). Although, the rate of climate warming in the Subarctic zone is less than in 1951–1980 and if compared to the same rate in many other regions of the world. The magnitude of warming is somewhat smaller in the western part of the Russian Arctic, compared to the eastern part (6). For example, the

temperature increases in Kola Peninsula are quite small. Even though most Russian regions reported increases in winter temperatures, this phenomenon has not been observed in the Kola peninsula, where there has been a trend of increasing summer and winter temperatures in the Murmansk region over several recent years (7,8).

Modelling of heat exchange dynamics in frozen ground has shown that permafrost temperatures will likely continue to increase in the Vorkuta and Nadym regions (9). For example, by the middle of the 21st century, surface temperature of permafrost will likely increase by 1.5–2°C in Western Siberia and Yakutia, and by 1.0–2.0°C in Chukotka and the northern part of the Far East (10). The total area of permafrost will decrease by 10–12% during the next 20–25 years and the south frontier of the permafrost zone will shift to the north-east by 150–200 km during the same period (11).

Climate change as a risk factor for infectious diseases in the Arctic

An in-depth discussion of possible relationships between climate change and infectious diseases in the Arctic took place at the meeting “Arctic Infectious Disease” in Copenhagen on September 23–24, 2010. For example the northward shift of forest ecosystems, which provide new habitats for the agents of infectious diseases, the increased morbidity among sea mammals, birds, fish and shell-fish, and consequent infections among humans (5).

Arctic animals host many microbial agents that can cause zoonotic infectious diseases, for example, hydrophobia/rabies (foxes), brucellosis (ungulates, foxes and bears), echinococcosis/cystic and alveola hydatid disease (dogs and rodents). Expansion of these infections will likely follow the northward migration of the corresponding host animal or bird populations. Migrating birds can carry infected ticks or viruses (e.g. West Nile Virus). An increase in winter temperatures improves the chances of animal or bird host survival as well as the survival and replication rate of the many insect vectors which can transmit infectious agents. As the number of hot summer days increases, infected mosquitoes, horseflies and ticks become more active. As a result, one might expect that more people will get bitten and be potentially exposed to the pathogens carried by these insects and tick.

In the early 1970s serologic studies of people and animals in the Russian Arctic confirmed the presence of antibodies to the agents of several potentially climate sensitive infectious diseases, including tularemia, leptospirosis, brucellosis, tick-borne encephalitis, and Q fever (12). A study in Taymyr peninsula confirmed the presence of tick-borne encephalitis virus among the populations of Siberian lemmings well beyond the traditional habitats of the ixodic tick. A recent study (13) confirmed the existence of northern reservoir of tularemia beyond the

North Polar circle. They also confirmed an outbreak of tularemia epizootic among lemmings in 1973 (13).

Virus infections

Tick-borne encephalitis and other tick-borne infections

Analysis of the long-term trends in the prevalence of tick-borne encephalitis has confirmed its cyclic nature, with periods of increasing and then decreasing morbidity. This is mainly attributed to natural variations in the density of populations of host animals and arthropod vectors; the level of resistance of animals to a particular infection; and the genetic properties of the infecting strain of virus (14). Encephalitis morbidity rates in the Russian Arctic peaked in 1996 and 1999 at 7.0 and 6.8 cases per 100,000 people respectively. In the 21st century, the trend in tick-borne encephalitis remains quite variable in different regions of the Russian Federation. Even though Russia has reported decreasing rates at the national level, several northern regions have experience an upward trend, for example, Archangelsk region, and Komi and Karelia republics (Fig.) (15).

The upward trend in tick-borne encephalitis in the northern European Arctic can be explained by a number of contributing factors. Climate change is becoming more pronounced at higher latitudes, affecting the biota, including ixodic ticks, which are the primary vectors for the infectious agents of encephalitis and borreliosis (Lyme disease, *Borrelia burgdorferi sensu lato*). Ticks also transmit the infectious agents of human monocytic ehrlichiosis *Ehrlichia chaffensis*, and human granulocytic anaplasmosis *Anaplasma phagocytophilum*. These diseases are relatively common in Russia (12).

The northern boundary of the ixodic tick habitat is determined by the ambient temperature. Warmer temperatures have increased the length of seasonal periods of tick activity and pushed this boundary north-east (16). Specimens of *I. persulcatus* are now being found in Yakutia, well beyond the area of its traditional habitat.

Every year about 100 cases of tick-borne encephalitis are registered in the Tiymen region which is endemic to this disease. The annual number of documented ixodes tick bites approaches 17,500. Russian medical statistics routinely report all hospital visits with tick bites (17).

Climate warming has reduced the average numbers of days with temperatures below -10°C in the Komi Republic. This increases the chances of tick survival during the winter. The natural habitats of the ixodic tick have shifted northward by 150–200 km during the last 40 years (18). About 5.5% of all tick specimens collected are infected with the tick-borne encephalitis virus (19). Since 1993, the number of registered tick bites has been steadily increasing. The number of administrative districts reporting tick bites in the Komi Republic increased

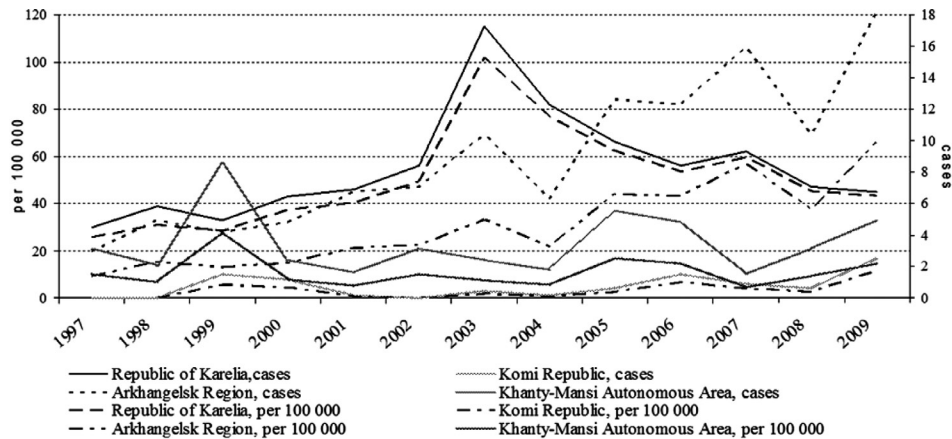


Fig. Trends in tick-borne encephalitis morbidity for selected territories of Russian North, 1997–2009 (15).

from 6 in 1999 to 17 in 2009. There have also been gradual changes in the geographic distribution in the number of tick bites and human cases of tick-borne encephalitis. Before 2001, 2–3 times more tick bites were reported in the southern districts than in the north. But since 2006 this trend reversed with more tick bites and human cases of tick-borne encephalitis occurring in the northern districts when compared to the southern districts (20). A sero-survey using enzyme immunoassay showed that 3.6% of an urban population in Syktyvkar city and 3.8% of a rural population had antibodies to tick-borne encephalitis virus, evidence of a prior infection (19).

In the past, the northern boundary of the tick *I. persulcatus* in the Arkhangelsk region, ran along the 62°N parallel, with only a small area extending north of this latitude into the flood plain of the Severnaya Dvina river (21). The number of registered tick bites has increased even though the total population of the Arkhangelsk region has decreased. For example, only 200–350 tick bites were registered annually in the 1980s; this number reached 1500 in the early 1990s, and 6000 in 2007. A time series analysis of tick bites, stratified by the three geographical zones within the Arkhangelsk region (north, central and south), shows a temporal trends in annual numbers of tick bites closely followed the trends in annual temperatures. The average rate of tick-borne encephalitis morbidity has increased fifty times between the 1980–1989 and 2000–2009 time periods. At the same time there has been a northward shift in cases (22).

The evolving spatial and temporal patterns in tick bites and tick-borne encephalitis in the Russian North to some extent corresponds with the estimated climate-induced changes in the *I. persulcatus* habitat. These changes have been modelled using simple empirical models linking the probability of tick survival to the environmental variables such as air temperature and precipitation (22). Other northern European countries have also reported

relationships between climate change and changing habitats. There has been a northward shift in the habitat of *Ixodes ricinus* and some other insects in Northern Sweden, which is on the same latitude as the Arkhangelsk region in Russia (23). These shifts have been explained by the changes in air temperature, and fewer days with temperatures below -12°C , and as a result tick-borne encephalitis morbidity rates, tick populations and tick life expectancy in northern Sweden has increased as have the animal host populations which support the tick (24). The two tick species that carry the tick-borne encephalitis virus differ in their biological properties. *I. persulcatus* is more resistant to cold and lives further north; it carries the tick-borne encephalitis virus more frequently than *I. ricinus* (25). This explains to some extent, why tick-borne encephalitis morbidity in Scandinavian countries is lower than it is in the Russian North. Rates of disease per 100,000 population in 2008, were 0.4 in Finland, 0.2 in Norway, 2.4 in Sweden, 5.6 in the Arkhangelsk region and 6.8 in the Karelia Republic (26), where up to 9.6% of ticks have been shown to be infected with the tick virus (27,28).

The northward expansion of tick populations also increases the risks of infection by other infectious agents carried by the tick. *I. persulcatus* is frequently infected with the agents that cause tick borreliosis (29) and human monocytic ehrlichiosis (30). Samples of *I. persulcatus* collected in the Sverdlovsk region also had the RNA of the tick-borne encephalitis virus (2% of samples), the DNA of *A. phagocytophilum* (0.3%), *E. muris* (5.4%), and *B. burgdorferi s. l.* (10.7%). The red field mouse, being the principal host of *I. persulcatus*, also had DNA of *A. phagocytophilum* (19.0% of blood samples), *E. muris* (5.0%), *B. burgdorferi s. l.* (4.8%) (31). These findings suggest the need for improved diagnostics of tick-borne infections and for more public education on the use of protective clothing and insect repellents.

Rabies (hydrophobia)

Human rabies is contracted mainly through bites of wild animals (wolves, foxes, dogs) and is also observed in reindeer, horses, and cows. Climate-induced changes in habitats and migration routes of wild animals may facilitate the spread of this infection (32).

Epizootic rabies rates have increased on the Taymyr peninsula since 2003. Rabies cases have been described among Arctic foxes, wolves, dogs and reindeer (33,34). The same trend has been observed in the Nenets autonomous district, where epizootic rabies was first documented in 1938, when the veterinary service was established. Rabies has been found among 13 species of animals (35). Eighty percent of wild mammals are infected with rabies in Northern Yakutia. In the Nenets autonomous district, 4.9% of common foxes and 9.8% of Arctic foxes have this disease. Since 2007, the Komi Republic is listed among high risk regions with respect to rabies. Occasional cases of human rabies have been reported in the Yamalo-Nenetski autonomous district, Yakutia, Magadan and other regions of the Russian North. Between 1946 and 2006, 259 deaths from this disease have been registered in Siberia and the Far East (36).

Bacterial infections

Leptospirosis

Natural reservoirs of leptospira (the causative agent of leptospirosis) commonly include small mammals (rats and mice), pigs, cattle and domestic dogs. Human leptospirosis has not been observed in most regions of the Russian North, although single cases have been registered in the Karelia, Komi, Murmansk regions and Yakutia. The highest numbers of human cases have occurred in the Archangelsk region with disease rates of 1.78 per 100,000 in 2008 and 0.3–1.32 per 100,000 during other years (37). Leptospirosis was first reported there in 1962–1963, when leptospira (serovar *hebdomadis*) were found in the serum of reindeer and cattle (38). In the 1970s, a natural floodplain reservoir of leptospirosis was described in the Archangelsk region, when leptospira serovar *Grippotyphosa* were found mainly in field mice and muskrats. The mean infection rate among these animals was 16.8% (39). These leptospira hosts live in the floodplains near human settlements, placing the residents of these settlements at risk for leptosporosis. The largest outbreak of human leptospirosis in the Russian North-West happened in the Archangelsk region in the mid-1980s, when more than 80 people were infected. An etiologic survey of human leptospirosis was conducted in 1990–2000. It showed that 74.7% of human cases caught the disease from small wild mammals which carry the leptospira serovar *Grippotyphosa* (40). A serologic survey of 121 small wild mammals in the Archangelsk region in

2009 found leptospira antibodies in 21 animals (17.4%). Over the last decade there has been a 40% increase in officially reported rates of human leptospirosis in the Archangelsk region. Between 2001 and 2009, 119 cases of human leptospirosis were registered in this region.

Leptospira antibodies have been found in 9–30% of the population in selected districts of Yakutia (41). Human leptospirosis is routinely observed in Khanty-Mansiysk (42). Natural reservoirs of leptospira exist in the Kraskoyarsk region, where leptospira specific antibodies have been found in 12.1% of blood samples of seven species of mammals: mice, rats, gophers, etc. (43). Leptospira bacteria can survive for long time under low temperatures, which creates conditions for existence of very stable foci of this disease in circumpolar regions. Persons at most risk for infection in these regions include deer breeders and hunters.

Brucellosis

Tens of thousands of local indigenous people work in the reindeer-breeding sector of the Arctic economy. Brucellosis in farmed reindeer presents a risk for people who work in this industry and for people who consume reindeer meat. Wild reindeer live in small populations in several regions from Murmansk to Chukotka. Brucellosis in reindeer has been found in many territories from Yamal to Chukotka. The rate of infection among reindeer varies from 0.9–60.0% in Taymyr (44), to 1.2–12.4% in the Evenkia autonomous district, to 1.0–35.7% in Chukotka, to 60% in Yakutia. Among 14 administrative districts of Magadan region, 11 were declared to be high risk for reindeer brucellosis (45). For comparison, a serological survey in Alaska showed that to 9% of caribou, to 25% of wolves, and to 46% of seals have been infected with brucella in the past infection (46).

Seasonal migration of wild moose reindeer and very extensive reindeer farming creates an increased risk of infection for humans. Improved epizootic control of brucellosis in the Taymyr municipal district has helped to decrease the rate of this infection among reindeer by a factor of 10 to 15 times (44). Brucella bacteria are highly resistant to environmental conditions. In Yakutia and the Far East, up to 10.5–23.0% of the indigenous people who work in the reindeer processing plants have been infected with Brucella in the past. A similar epidemic situation has been observed previously in the Arctic territories of USA and Canada (47). In the 1970s, annual average rate of brucellosis in Chukotka was 31 cases per 100,000. Since 1997, brucellosis rates have fallen considerably, and now only occasional cases have been registered in these territories. In 2004 there were only 2 cases of brucellosis in Taymyr, and in 2002 there were only 4 cases in Yakutia. This corresponds to a rate of 0.56 cases per 100,000 and 0.41 cases per 100,000, respectively. However in Yukutia the percent of those persons who

have had infection are much higher among reindeer-breeders (4.8–5.6%) than among tanners and skimmers (1.2–4.7%) (32).

Brucella may infect humans through the consumption of infected meat of wild animals. A new concern is the finding of brucella in marine mammals (48) raising the possibility of human infections through contact with, or consumption of marine mammal meat.

In the Russian Arctic the rates of registered cases of brucellosis may be higher because of inadequate diagnostics and absence of laboratory services in remote regions. More accurate assessment of brucellosis in both the human population and wildlife will require major improvements in diagnostics and laboratory practices. Effectiveness of preventive measures greatly depends upon timeliness and reliability of information provided by the local veterinary service (49,50).

Tularemia

Francisella tularensis, the causative agent of tularemia, has been found in more than 20 mammals that inhabit the Russian Arctic, including hares, beavers, muskrats, squirrels, field mice, and others. Natural reservoirs of *Francisella tularensis* have been described in the Kola peninsula, and the Yamal, Taymyr and Yakutia Republics, mostly in the Lena, Vilui and Aldan river valleys. *Francisella tularensis* is mainly harboured by the water mouse (*Arvicola terrestris*). Epizootics among mice usually precede human epidemics. Tularemia has been registered in Yakutia since 1944, in the Komi Republic since 1949, and in the Murmansk region since the 1950s. Tularemia outbreaks have also been reported in Norilsk and Vorkuta in 1964 (51,52). In the Komi Republic, natural reservoirs of tularemia are mostly found in the Pechora, Vychegda and Mezen river valleys. The northern boundary of these reservoirs runs along 67°40'N, beyond the Polar Circle. Natural reservoirs of tularemia are unevenly distributed, and reflect tularemia disease prevalence patterns. Researchers have established a spatial correlation between counts of *Arvicola terrestris* and the numbers of human tularemia cases in the Komi Republic. They also described active natural reservoirs of tularemia in the Inta district (a forest tundra zone) and Pechora district (a north taiga subzone). Antibodies to *Francisella tularensis* have been found in 2.5% of serum collected from reindeer. *Francisella tularensis* has been cultured from the skin of hares. A survey of 234 indigenous inhabitants of Chukotka (Chukchi and Eskimo) showed that 27 blood samples (11.5%) had antibodies to *Francisella tularensis* indicating that these people were previously infected (53). Similar findings have been reported in Alaska, where 6–17% of surveyed indigenous inhabitants tested positive (46). Outbreaks have also been reported in the north districts of the Krasnoyarsk region: in Turukhansk district, Taymur

autonomous district and Norilsk city. Outbreaks occur every three or four years, matching the fluctuations in the size of host rodent populations (54).

In the summer of 2002 a continuous sluggish epizootic of tularemia was described on Wrangel Island (Chukotka, 71°N), when 3.4% of lemmings were found to be serologically positive for *Francisella tularensis*. The size of lemming population diminished in 2003–2005 (54). So far, only occasional cases of human tularemia are registered in the Komi republic, Nenetsky, Khanty-Mansiysky and Taymyr autonomous districts. Since 2007, the tularemia prevalence has gradually increased in the Arkhangelsk region. In 2009, 24 people contracted tularemia, bringing the standardized rate of this infection in the Arkhangelsk region to 2.0 cases per 100,000. Tularemia rates in other northern European countries vary greatly, reaching between 13 and 732 cases per 100,000 in the Swedish province Dalarna (56).

Anthrax

Anthrax is primarily a disease of herbivores, humans are incidental hosts, such as workers who process infected animal products, or ingest improperly cooked infected meat. Between 1985 and 2008, 72 cases of anthrax occurred among humans living in Siberia. This corresponds to an annual average rate of 0.013 ± 0.005 per 100,000 people. People contracted anthrax after being exposed to infected cattle (86% of cases), horses (7%) and sheep (3%) (57). Past outbreaks among cattle and reindeer have resulted in more than 13,000 burial grounds in Russia containing the carcasses of infected animals. More than half of these are located on permafrost in Siberia the result of frequent epizootic cycles which caused death of 1.5 million deer in the Russian North between 1897 and 1925, and more recently in 1920 and 1931 in the Taymyr region and again in 1969 in Yakutia, Evenkia and Taymyr (58,59). Many of these burial sites do not meet Federal sanitary standards. (59–61). The spores of *B. anthracis* may survive in the environment for 60–70 years and perhaps even longer in permafrost. However, the warming of the Russian Arctic due to climate change will increase the rate at which permafrost melts. The greatest increases in permafrost temperatures are expected in Yakutia, eastern part of Nenetski autonomous district and Komi Republic (62). Computer simulations predict that permafrost temperatures in Yakutia will increase by 1.4°C (between now and 2020), and by 2.3°C (between now and 2050) (63). Such environmental events will result in flooding, and disruption of soil over these burial sites and release Anthrax spores onto the surface soil and vegetation which would be then consumed by grazing animals, also increasing the risk of infection in humans who come into contact with infected animal products (under cooked meat, hides, bone). Among all territories of Russian Arctic, the

greatest numbers of settlements at risk for Anthrax are in Yakutia 230, Archangelsk region 84, Karelia (48), Komi (28) and Taymyr (39) (64). For these regions increased monitoring of permafrost around known burial sites is needed, as is increased vaccination of domestic animals, and increased surveillance of disease in both animal and human populations.

Conclusions

A warming Russian Arctic will be associated with a northward expansion of plants and animal associations including their bacterial viral and parasitic flora. These associations will create favourable conditions for the emergence of infectious diseases in regions that were previously free of these pathogens. Several conclusions can be made regarding the potential emergence of zoonotic infectious diseases and their possible influence on the public health of the population of the Russian Arctic:

- (a) Monitoring of many zoonotic infectious diseases in the Russian Arctic is insufficient; The Russian Arctic is sparsely populated. Many people live in remote settlements with limited access to medical and public health services. Thus many infectious diseases may go undetected and result in an underestimate of the true rate of infection. Efforts should be made to evaluate and improve existing monitoring systems.
- (b) There is a need to improve laboratory diagnostics for many of these diseases. The finding suggest the need for improved diagnostics of tick-borne infections.
- (c) There is a need to educate medical providers, public health officials and the public on the role of climate change in the emergence of zoonotic infectious diseases and prevention strategies that can be used. A warming Arctic may also change social behaviour. In a warmer climate people tend to spend more time outdoors in recreational activities, which increases their contacts with vectors of zoonotic infectious diseases emphasizing the need to educate the population on measures that may prevent their exposure.
- (d) There is a need to raise awareness of at-risk populations to the potential for infection. These may include hunters and workers in the deer breeding and meat handling industries to the potential of infection from contact with meat, skins, and hides.
- (e) Anthrax cattle burial sites need to be more carefully monitored, for example, by regular visual check-ups of soil condition and bacteriologic analyses of soil samples.

In the Russian Arctic should be viewed in context of the unfavourable epidemiologic situation on the territories

endemic to natural-focal infections, such as anthrax. The authors recommend strengthened epidemiologic surveillance, implementation of new methods of diagnostics, and improvement in monitoring of anthrax cattle burial grounds.

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***Boris Revich**

Nachimovsky Av. 47
Moscow 117418
Russia
Email: revich@ecfor.ru