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RESEARCH ARTICLE

The influence of weather and climate on patients with respiratory diseases in Vladivostok as a global health implication

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Abstract

Purpose To identify the formation of meteopathic reactions in patients with respiratory diseases under the influence of extreme weather changes in Vladivostok.

Methods The short-term meteopathic reaction in patients with respiratory diseases to the impact of "Weather Complex", consisting of nine weather parameters, on the day of patient's examination and on 1 and 2 days before the examination, was assessed. 146 acclimatized residents of Vladivostok (29 patients with chronic bronchitis, 51 patients with controlled asthma, 39 patients with uncontrolled asthma and 27 healthy volunteers) were examined. Pulmonary function (PF) was studied by spirography and by body plethysmography.

Results The adaptive-compensatory response of PF in patients with respiratory diseases to weather decreases depending on the disease severity, resulting in the development of meteodependence. The impact of "Weather Complex" on a human body is primarily reflected in PF, and the reaction of metabolic parameters is manifested with a 1–2 days time lag. Glutathione peroxidase and glutathione reductase, key factors in maintaining oxidative cell balance, play the most important role in the formation of a compensatory response to weather. In the light of the global health implication, recommendations are suggested to adjust the treatment of patients with respiratory pathology in specific conditions of abruptly changeable weather.

Conclusions The maritime monsoon climate creates an additional strain on both respiratory system and systems that ensure the peroxidation balance worsening bronchopulmonary pathology.

Keywords Weather · Monsoon climate · Respiratory diseases · Pulmonary function · Peroxidation processes · Global Health implication

Introduction

The problems of global climate change are the most recognized in modern society; one of the main consequences the most discussed is the increase in frequency of extreme weather day-to-day changes due to the imbalance of the climate system [1], leading to the raise in chronic respiratory diseases that are among the leading causes of morbidity and mortality worldwide [2–4]. The etiology of bronchopulmonary diseases is largely determined by the influence of weather conditions on the respiratory system. Literature review shows that both particular meteorological parameters and certain combinations of weather factors can affect respiratory morbidity and mortality [5–12]. Normally human body adapts to weather changes after living in certain climatic conditions for a long time; but when these changes are the most abrupt, physiological processes in body, especially in children, elderly and sick people, cannot adjust and so-called meteopathology or meteopathic reaction is developed [13–15]. That is why we suppose that weather largely determines the course of bronchopulmonary diseases – directly through an impact on the respiratory tract or indirectly through a change in

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the intensity and nature of immunometabolic processes, reducing the effectiveness of their treatment [16, 17]. However, the mechanisms of these processes have not been sufficiently studied. There are conflicting results related both due to different research approaches, and to the features of heterogeneous weather conditions effect on human body. Therefore, the study of the nature of the response of patients with a respiratory disease is an important for understanding the mechanism of pathogenesis in the progression of meteopathic reaction, defined as a "function of the intensity of the influencing weather factors, as well as the individual's adaptive capability" [18, 19].

Vladivostok is a large city near the Pacific Ocean. According to Köppen-Geiger Classification it has a Warm Summer Continental Climate [20, 21]. Based on climate classification by Alisov [22] widely used in Russia, Vladivostok is located within a temperate monsoon climate zone and is marked by its high variability with frequent changes in weather patterns during the year from season to season and during the day. The climate of Vladivostok is characterized by low temperatures and high wind speed in winter, sultriness with high temperatures and high humidity in summer; high cloudiness and fogs, which reduce the duration of solar radiation during the warm part of the year. This climate with high temporal gradient of weather parameters develops a specific response in patient with bronchopulmonary pathology [23, 24]. The rate and magnitude of weather changes form the level of adaptive response of the body to external influences [10, 16, 17], causing increased physiological load on PF and on body of residents of the region as a whole. The weather factors particularly influence the mucous membranes of the respiratory tract that contact with the external environment. In this regard, the study of PF is essential for the diagnosis of violations of the lung ventilation as a response to the external stress.

Oxidative stress plays a key role in the pathogenesis of chronic lung diseases [25–28]. Reactive oxygen species can enhance inflammation directly and through the formation of lipid peroxidation (LPO) products [29, 30]. Oxidative stress has important consequences for the respiratory system and the body as a whole. However, nowadays there is practically no information about the impact of abrupt weather changes on the parameters of lipid peroxidation and antioxidant protection in patients with respiratory pathology.

The climate change in the study area manifests itself in more frequent and extreme weather patterns, raising climate variability [31, 32]. In light of all above mentioned, the aim of the paper is to identify the mechanism how short-term meteopathic reactions are formed in patients with respiratory diseases under the influence of the abrupt and extreme weather changes in maritime monsoon climate of Vladivostok.

Materials and methods

Data

The subjects consisted of 146 acclimatized residents of Vladivostok examined during 2012–2017 at the Research Institute of Medical Climatology and Rehabilitation Treatment (the Clinical Department). In total 486 patients living within the neighboring district of the city were tested within the five-year period, of which only those patients whose date of examination on the day and the previous days coincided with extremely sharp weather changes were selected. Chronic bronchitis (CB) was diagnosed in 29 people, controlled asthma was diagnosed in 51 people, uncontrolled asthma was diagnosed in 39 people. The control group included 27 healthy volunteers, living in Vladivostok at least for 5 years, without respiratory diseases, non-smokers with normal pulmonary function, comparable in sex and age with the examined groups of patients. Asthma and CB were diagnosed in accordance with the Global Strategy for Asthma Management and Prevention (2015) and the International Classification of Diseases 10th revision (2010). The study protocol was approved by the Ethics Committee of the Vladivostok branch of Federal State Budgetary Science Institution «Far Eastern Scientific Center of Physiology and Pathology of Respiration» – Institute of Medical Climatology and Rehabilitative Treatment and was performed in accordance with the ethical standards in the Declaration of Helsinki (2013). Informed consent was obtained from all individual participants included in the study.

Weather data used are air temperature and humidity, dew point temperature, relative air humidity, solar radiation atmospheric pressure, precipitation, atmospheric phenomena, wind speed and wind direction during 2012–2017 from Primorsky Office for Hydrometeorology and Environmental Monitoring [33–35]. Mean daily weather data and data at 10 AM, the time of the patient examination (when it was different from the mean daily data), were used on the day of the patient's examination; mean daily data were used for weather assessment 1 and 2 days before the patient's examination. Mean daily data are calculated as an average of 8 daily temperature ratings in 3-h interval.

Apparent temperature (AT) describing the synergetic effect of air temperature, wind speed and solar radiation on human body was calculated using formulae by Steadman [36]:

$$AT = Ta + 0,348\,e - 0,70\,V + 0,70\,S/(V + 10) - 4,25 \quad (1)$$

where Ta – air temperature, °C; e – vapor pressure, hPa; V – wind speed, m s^{-1}; S – solar radiation, Wt m^{-2}.

The patient examinations were selected only for days with extreme weather changes determined as a “sharp” or “abrupt” when day-by-day variations where not less than 4°C for air temperature; 10 hPa for air pressure, and 9 m s^{-1} for wind speed [5, 6, 37, 38].

Measurements

Pulmonary function

The study of PF was carried out by spirography before and after using bronchodilator to determine the type of lung ventilation disorder, or bronchial patency; degree and reversibility of bronchial obstruction – bronchial constriction, forming such phenomena as shortness of breath and choking attack (VC – vital capacity (%); IC – inspiratory capacity (%); FVC – forced expiratory vital capacity (%); FEV1 – forced expiratory volume after 1 s (%); FEV1/VC – FEV1 in % of vital capacity (%); FEV1/FVC – FEV1 in % of forced expiratory vital capacity (%); PEF – peak expiratory flow (%); MEF75 – forced expiratory flow at 25% of FVC (%); MEF50 – forced expiratory flow at 50% of FVC (%); MEF25 – forced expiratory flow at 75% of FVC (%); MMEF75/25 – mean maximal expiratory flow between 25% and 75% of FVC (%); FET – forced expiratory time (s)). Another method applied was body pletismography using equipment «Master Screen Body» (Care Fusion, Germany) that allowed to study of static lung volumes – the volume of air remaining in the lungs after the maximum expiration-characterizes the defeat of small bronchi, manifested by shortness of breath and suffocation and bronchial resistance – the resistance of the bronchi during respiration (R IN – resistance inspiratory (kPa* s/l); R EX – resistance expiratory (kPa* s/l); R tot – bronchial resistance total (kPa* s/l); R tot (%); FRCplet – functional residual capacity (%); RV – residual volume (%); TLC – total lung capacity (%); RV/TLC – RV in % of TLC (%)).

Spirography is a method for assessing the functional state of the lungs by measuring the volume and rate of exhaled air to suggest or confirm the diagnosis. Body plethysmography is used to identify changes in the distal (small) bronchi and the airways with a diameter of less than 2 mm. This method allows revealing changes even at early stages of the disease. It allows more detailed assessing the ventilation capacity of the lungs, identifying pathological changes, which are not determined by routine spirography, and getting more information about the functional capabilities and reserves of the body.

Antioxidant system

The state of antioxidant system was assessed according to total antioxidant activity (AOA) of blood plasma (Randox Laboratories Ltd., the United Kingdom) and levels of antioxidant enzymes. The degree of decolouration of the solution of $ABTS^{\bullet+}$ radical cation, which is formed in the result of the oxidation of ABTS by ferrylmyoglobin, was evaluated by spectrophotometry to determine AOA. The levels of superoxide dismutase (SOD) (eBioscience, USA), glutathione peroxidase (GP), glutathione reductase (GR) and reduced glutathione (GSH) (MyBioSource, USA) in blood plasma were detected by enzyme-linked immunosorbent assay (ELISA) to assess the enzymatic component of the antioxidant system. The level of malonic dialdehyde (MDA) in the blood serum (Northwest Life Science Specialties, USA) was determined, and the ratio MDA/AOA was calculated to describe the prooxidant processes (Table 1).

The assessment of weather influence on the respiratory system

Weather has both separate and synergetic (“weather complex”, WC) effect on human body. To assess its impact on PF, Pearson’s (r) correlation analysis was used, emphasizing the intensity and strength of adaptive reactions of PF to climate effect. The study of the response of the “lipid peroxidation–antioxidant defense” (LPO–AOD) system (dependent variable “y”) to the impact of weather (independent variable “x”) was conducted by regression analysis, where the independent variables were particular meteorological parameters and WC as their combined effect. The probabilistic statistical method of information entropy analysis (Claude Shannon’s formula) was used to obtain quantitative information about the WC [39–42].

The assessment of the meteodependence of the respiratory system on weather changes was carried out by the analysis of the PF response to the effect of weather on the examination day (actual climatic factors) and on previous 1 and 2 days (previous climatic factors).

The meteopathic reaction of a human body to the impact of climate was assessed in two stages. The direct influence on PF system was studied at the first stage. The indirect effect on the “lipid peroxidation–antioxidant defense” (LPO–AOD) system was studied at the second stage. Methods of the study at the first and second stages were different. PF system is the most open system and is therefore a more sensitive system in the human body, so the response to weather effect was considered according to the severity of respiratory diseases. The indirect impact of weather on the LPO–AOD system creates a delayed effect on human, so the main task was to identify the trigger weather parameters that induce the meteopathic reactions of this system and to assess its reaction to “weather complex” [37].

Stage 1. Direct influence of weather on pulmonary function

The study of the direct effect of weather on PF was conducted based on the assessment of inter-systemic and intra-systemic relations that are formed under its influence of on the human

Table 1 Analyzed blood parameters

Parameter of the LPO-AOD system	Physiological function
Malondialdehyde (MDA)	Product of lipid peroxidation. Reacts with DNA. One of the key markers of lipid peroxidation and oxidative stress.
Antioxidant activity (AOA)	An assessment of the integrated antioxidant system which encompasses all biological components. Prevents toxic effects of reactive oxygen species.
Glutathione (GSH)	The major endogenous antioxidant, participating directly in the neutralization of free radicals and reactive oxygen compounds. Forms stable bonds with toxic compounds, neutralizing their negative impact and contributing to their harmless elimination from the body.
Glutathione reductase (GR)	Enzyme that reduces of oxidized glutathione. The ratio reduced/oxidized glutathione is a key factor in maintaining the oxidative balance of the cell.
Glutathione peroxidase (GP)	Antioxidant enzyme that neutralizes hydrogen peroxide. Its activity largely determines the dynamics of pathological processes.
Superoxide dismutase (SOD)	Antioxidant enzyme that converts superoxide anion-radicals to molecular oxygen and hydrogen peroxide. A powerful inhibitor of free radical oxidation in the body that protects biomolecules (proteins, nucleic acids, etc.) from oxidative damage.

body. As a result, the complex weather impact on the diagnostic systems of PF was estimated analyzing the *inter-systemic* relations, and tension of PF system according to the nosological form was determined by analysis of the *intra-systemic* relations.

The module "Multiple correlation" (STATISTICA8) with selection of pair correlations r for values with $p < 0.05$ was used to calculate of inter-systemic and intra-systemic relations [43]. The determination of inter-systemic relations (P_{inter}) was conducted using a rectangular matrix, because we studied two different systems (PF and weather). To establish the intra-systemic parameter (P_{intra}) we used a square matrix to evaluate relations between indicators of PF system implying a background influence of weather.

Actual values of the pair correlations r with statistical significance $p < 0.05$ were summed and then divided by the expected maximum sum of the correlation relations with $R = 1.0$ to calculate P_{intra} and P_{inter}:

$$P_{inter} = \frac{\sum_i^n r}{\sum_i^N R} \times 100 \qquad (2)$$

where P_{inter} – a parameter of inter-systemic tension (%) as an indicator of PF compensatory reaction; n – a number of selected correlation relations (p < 0.05); r – a actual value of a correlation relation (p < 0.05); N – a maximum number of probable correlation element of a matrix; R – a maximum value of a correlation relation equal to 1.0. P_{intra} – a parameter of intra-systemic tension, calculated similarly to P_{inter}: since a square matrix was used for the estimation of P_{intra}, the number of expected relations in P_{inter} was divided by 2 (diagonally). P_{inter} assessed the activity of compensatory reaction of PF to the weather impact; $\sum P_{inter}$ (a sum of P_{inter} values) described the response of PF that was diagnosed by different methods. P_{intra} characterized the degree of strain in PF system depending on severity of the disease and climatic features.

Stage 2. Indirect influence of weather on LPO–AOD system

The next stage of the study included the analysis of the response of biochemical blood parameters (the LPO–AOD system), which react to the weather effect *indirectly*. At this stage of the study the activity of the response of peroxidation parameters to the impact of particular weather parameter and weather conditions as whole in WC was determined taking into account a time lag of the reaction of 1 or 2 days [44]. The module "Multiple regression" in the program STATISTICA8 was a tool for calculating the "response" of subsystems and particular indicators of the LPO-AOD to the weather effect. The analysis of the regression dependence (R_{regres}) as a response of the LPO–AOD system to the impact of WC and particular trigger weather parameters, estimated the reaction of the system to previous weather changes on 1 and 2 days before the examination.

Results

The calculation of the direct effect of weather conditions on PF was carried out in two directions. First, values of P_{intra} (%) for the diagnostic systems of PF (body plethysmography, spirography before and after bronchodilator test) depending on the severity of the respiratory diseases were determined. Secondly, values of P_{inter} (%) that characterized the compensatory reaction of PF to the influence of weather on the examination day, 1 and 2 days before the examination was estimated.

The calculation algorithm of P_{inter} and P_{intra} by formulas 1 and 2 was shown by the example of the control group of subjects who reacted to air temperature and humidity, dew point temperature, atmospheric pressure, precipitation, wind speed and direction, weather phenomena and apparent temperature (Table 2 and 3). The correlation matrices were used in both cases: a square matrix – for the calculation of P_{intra}, a rectangular matrix – for the calculation of P_{inter}.

The same calculation algorithm of P_{inter} and P_{intra} was used for the patients with CB or asthma (controlled or uncontrolled) under the weather influence on the examination day, on 1 and 2 days before the examination. The sums of P_{inter} ($\sum P_{inter}$), which were grouped according to the degree of disturbance of the lung ventilation capacity (control group, patients with CB, controlled asthma and uncontrolled asthma) the diagnostic systems and climatic parameters, were analyzed to study the adaptive-compensatory reaction of PF (Table 4).

Values of P_{intra} for residents of Vladivostok vary, and changes in the ventilatory lung function depend on the disease severity. If we assume that the normal values were $P_{intra} = 18–25\%$ (PF in the control group) the group of patients with CB with $P_{intra} = 26–28\%$ had minimal changes in PF. A significant increment of P_{intra} (1.5–2 times, up to 43%) indicates the most marked violations of the lung ventilation of the asthma patients. It is manifested in the greatest degree in the uncontrolled form of the disease. Thus, the population of Vladivostok living in the maritime monsoon climate has increased strain on the PF system, especially in uncontrolled asthma ($P_{intra} = 39–43\%$) (Table 4).

The compensatory response of PF to the effect of weather was evaluated by P_{inter}. The healthy subjects had total $\Sigma P_{inter} = 30.6\%$. The method of body plethismography is the most informative for diagnosis in the control group ($\Sigma P_{inter} = 14\%$) (Table 4). The analysis of total ΣP_{inter} in different pathologies showed a clear dependence of a decrease in the adaptive capacity of PF depending on the severity of the respiratory disease ($\Sigma P_{inter} = 3.4–13.8\%$) (Table 4). It can be assumed that the impact of the local weather causes a decrease in the compensatory reaction (P_{inter}) in the diseases of respiratory system characterized by a high intra-systemic tension of PF system (P_{intra}).

The indirect effect of the climate on human body purports the influence of weather factors and the weather complex on the parameters of human blood. In our study this effect was studied by the analysis of the response of the parameters of the LPO–AOD system. The response was evaluated by regression relations (R_{regres}). The dependent variables were the components of the LPO–AOD system (prooxidant system – MDA, MDA/AOA; antioxidant system – AOA, SOD, GSH, GP, GR). The independent variables were weather parameters and WC (actual and previous, on 1 and 2 days before the examination) (Table 5).

The LPO–AOD system in patients with respiratory pathology responded with a lag to changes in “weather complex” on 1 and 2 days before the examination ($R_{regres} = 0.42–0.50$) that had an impact on the results of blood test on the examination day. However, the influence of the change in actual weather (the examination day) on the response of the LPO–AOD system in this subjects greatly decreased ($R_{regres} = 0.31–0.38$) (Table 5). As the result, the reaction, which mediates peroxidation processes, causes a fairly rapid response of the system to weather loads – within 1 or 2 days. The integral criterion characterizing the LPO–AOD balance (MDA/AOA) is the best to demonstrate the reaction of the human body to weather factors. Wind direction, wind speed and air pressure, as specific factors of the regional climate, had the greatest negative effect. The response of the LPO–AOD subsystems to the influence of winds was practically homogeneous (the LPO system – $R_{regres} = 0.38–0.40$; the AOD system – $R_{regres} = 0.34–0.44$) (Table 5). Definite variables, such as air temperature and relative humidity, played an important role in the response (Table 5).

Discussion

The impact of climate and weather conditions on humans is different in nature and intensity of the mechanisms. A recent

Table 2 Intra-systemic parameter (P_{intra}) in the diagnostic system of body plethysmography in the control group under the influence of Weather Complex on the examination day

Parameters of body plethysmography	R IN	R EX	R tot	FRCplet, %	RV, %
$P_{intra} = \sum_i^n 7.83/7.83/\sum_i^{N/2} 32 \times 100 = 25\%$					
R EX	0.82				
R tot	0.89	0.90			
R tot, %	0.88	0.91	1.00		
RV, %				0.65	
TLC, %				0.87	
RV/TLC%					0.91

Table 3 Intra-systemic parameter (P_{intra}) in the diagnostic system of spirography (before bronchodilator test) in the control group under the influence of Weather Complex on the examination day

Parameters of spirography before bronchodilator test	VC or VCmax, %	IC, %	FVC, %	FEV1, %	FEV1/VC or VCmax	FEV1/FVC, %	MEF75, %	MEF25, %
$\boldsymbol{P_{intra} = \sum_i^n 16.53/\sum_i^{N/2} 72 \times 100 = 23\%}$								
IC, %	0.76							
FVC, %	0.98	0.70						
FEV1, %	0.88	0.70	0.92					
FEV1/FVC, %		0.63			0.85			
PEF (%)	0.64							
MEF75, %	0.68		0.66			0.68		
MEF50, %	0.75		0.78	0.70			0.79	
MEF25, %				0.64	0.68			
MMEF75/25, %				0.70	0.76			0.90
FET, s							0.74	

study of the effect of climate as a static characteristic of air on human mortality has shown that it can be caused by moderately suboptimal temperatures rather than extreme heat or cold [45]. At the same time, it was observed that mortality can be associated with dynamic changes in weather conditions, especially in patients with respiratory diseases [46]. The short-term increase in ambient temperature and relative humidity is shown to have significant adverse associations with lung function in a susceptible population [47]. At the same time, the mechanisms of short-term dependence on weather in patients with respiratory diseases have not been studied. However, these studies are vital for the individual correction of treatment, especially those patients actively reacting to 1–2 days short-term abrupt changes in the dynamic air environment, which cause an exacerbation of the disease.

The monsoon climate of Vladivostok is characterized by aspects that negatively affect the human health: a long period of low winter temperatures, sultry weather in summer, weather instability as a whole with strong winds, sharp fluctuations in air pressure and daily temperatures [5, 6, 8, 23, 31, 32]. The differences in the change of the lungs ventilation capacity depending on the severity of the disease were recorded for the residents of Vladivostok.

The results for P_{intra} (%) and P_{inter} (%) evaluate the direct compensatory reactions (relations) of PF under the influence of climatic factors and the reaction of the tension of PF systems depending on the degree of disturbance in the lung ventilation. The nature of meteo-, or weather dependence of healthy subjects and patients with respiratory pathology in Vladivostok was assessed. Table 4 showed that healthy residents actively react to the changes in the weather complex 2 days before the examination ($\Sigma P_{inter} = 15\%$), indicating a high level of compensatory reserve in indigenous healthy population of the city. It may be related to the features of the monsoon climate in the region. The PF parameters of patients with CB react to changes in the WC 1 day before the examination with total $\Sigma P_{inter} = 6.9\%$. The changes in meteodependence were observed in the patients with controlled asthma who maintained quality of their life treating themselves by medicines. Significant decrease in the total $\Sigma P_{inter} = 8.6\%$ for patients with asthma compared to healthy volunteers and patients with CB was due to the effect of WC on the examination day ($\Sigma P_{inter} = 4.4\%$) and 2 days before the examination ($\Sigma P_{inter} = 3.5\%$). A sharp decrease in functional homeostasis in human body is observed in uncontrolled asthma, the most severe respiratory disease. It reveals a lack of compensatory reserve and the formation of a meteopathic impact of weather and climate as a whole on PF.

The results for indirect effect of weather conditions on the LPO–AOD system showed a general response of the blood system to the weather influence in patients with respiratory diseases, regardless of the disease severity. We studied the LPO–AOD system, because it is involved in the process of providing energy for cells and is the most important trigger for the chemical modification of cell membranes. The initiators of LPO may be environmental conditions, including weather and climate. The activity of LPO in this case is increased to a certain level, because it is balanced the AOD system. However, the capabilities of the AOD system are not unlimited and its depletion may occur, the rate of which depends on a number of factors [44]. Therefore, changes in the LPO–AOD system may be used as indicators in a comprehensive assessment of weather impact on human body.

The study has shown there is no pronounced response of peroxidation parameters to weather in healthy subjects and, accordingly, there is no need to induce compensatory antioxidant processes in them. We find that the integral criterion characterizing the LPO–AOD balance (MDA/AOA) demonstrate the reaction of the human body to abrupt changes in weather. The enzymes of the AOD system

Table 4 The activity of adaptive-compensatory relation (P_{intra}% and P_{inter}%, $p < 0.05$) between PF and Weather Complex in different respiratory diseases

Weather Complex (WC)	Methods of PF diagnosis			
	Body plethysmography	Spirography before bronchodilator test	Spirography after bronchodilator test	Sum of inter-systemic parameters ($\sum P_{inter}$%)
Control group				
Parameter of intra-systemic relation of PF system (P_{intra})	25	23	18	
WC on the examination day	5	2	0.6	7.6
WC 1 day before the examination	6		2	8
WC 2 day before the examination	3	5	7	15
$\sum P_{inter}$ of PF systems	14	7	9.6	30.6
Chronic bronchitis				
Parameter of intra-systemic relation of PF system (P_{intra})	26	28	26	
WC on the examination day		2.7	0.4	3.1
WC 1 day before the examination	4.0	1.6	1.3	6.9
WC 2 day before the examination		2.0	1.8	3.8
$\sum P_{inter}$ of PF systems	4.0	6.3	3.5	13.8
Controlled asthma				
Parameter of intra-systemic relation of PF system (P_{intra})	32	34	40	
WC on the examination day	0.4	1.0	3.0	4.4
WC 1 day before the examination		0.4	0.3	0.7
WC 2 day before the examination	1.4	1.4	0.7	3.5
$\sum P_{inter}$ of PF systems	1.8	2.8	4.0	8.6
Uncontrolled asthma				
Parameter of intra-systemic relation of ERF system (P_{intra})	43	39	41	
WC on the examination day	1.0		0.8	1.8
WC 1 day before the examination	0.6	0.2	0.1	0.9
WC 2 day before the examination	0.1	0.6		0.7
$\sum P_{inter}$ of PF systems	1.7	0.8	0.9	3.4

(GSH, GP and CO), which are involved to remove lipid hydroperoxides, hydrogen peroxide, and to reduce oxidized glutathione, have a significant importance for the response of the AOD system. GP and GR as key factors of the maintaining of oxidative cell balance play the most important role in the formation of the compensatory response to weather [48]. The activation of the glutathione unit of the AOD system is aimed at interrupting the chain reaction of lipid oxidation to inhibit stress-induced accumulation of LPO products [49].

The study of the effect of trigger weather parameters on the LPO–AOD system was carried out on the basis of the analysis of the changes in weather on the 1 and 2 days before the examination, the response to which reflect on blood parameters on the examination day. It was found that wind direction, wind speed and air pressure, as specific factors of the regional climate, had the greatest negative effect.

The bronchopulmonary pathology is accompanied by the development of the systemic oxidative stress. One of the reasons is the disregulation of the AOD system as the result of polymorphism of gene encoding the AOD enzymes. The intensification of oxidative stress has important implications for the course of the respiratory diseases [50]. The oxidative stress leads to direct or indirect damage of key cellular components, such as lipids, proteins and nucleic acids, and also inhibits DNA repair [51, 52].

In the light of the global health implication, the results of the study suggest that the presence of respiratory diseases in people living in a monsoon climate, contributes to the formation of meteopathic reactions. Special methods are proposed for patients with respiratory disease to mitigate the impact of abrupt weather changes: both individual specific measures, such as the correction of basic treatment doses, as well as non-specific ones, such as drug and non-drug measures

Table 5 The response (regression relations, R_{regres}) of parameters of the LPO–AOD system of patients with respiratory diseases living in Vladivostok to the impact of weather

Weather	Enzymes of the LPO system		Enzymes of the AOD system			
	MDA, μmol/l	MDA/AOA, c.u.	GSH, μg/ml	GP, ng/ml	GR, ng/ml	SOD, ng/ml
Weather Complex						
Actual WC (the examination day)		0.36 p = 0.003	0.32 p = 0.02	0.31 p = 0.02		0.38 p = 0.001
Previous WC (1 day before the examination)	0.43 p = 0.01	0.46 p = 0.003		0.42 p = 0.02		
Previous WC (2 days before the examination)		0.43 p = 0.01		0.51 p = 0.0004		
Weather parameters (2 days before the examination)						
Wind direction	0.39 p = 0.006	0.38 p = 0.008		0.4 p = 0.005	0.34 p = 0.04	
Wind speed, m s^{-1}		0.40 p = 0.005	0.34 p = 0.03	0.44 p = 0.0007		
Air temperature, °C				0.51 p = 0.0002	0.34 p = 0.03	
Air humidity, %					0.31 p = 0.001	
Air pressure, hPa	0.36 p = 0.02	0.41 p = 0.003		0.46 p = 0.0002	0.33 p = 0.04	

boosting body resistance. In addition, social changes in the physical environment are advised: individual microclimatic devices, air conditioning, etc. Further research should be done to develop therapeutic and preventive recommendations for patients with respiratory diseases under the influence of the marine monsoon climate of Vladivostok.

Conclusions

Thus, the impact of the maritime monsoon climate of Vladivostok and its variable weather on patients with the respiratory diseases induces the complex mechanism of the response of the human body and leads to the formation of meteopathic reactions that actively influence on PF (the most open system) and indirectly do on the LPO–AOD system. It is found that the tension of the PF systems of patients living in Vladivostok is intensified under the changes in weather depending on the disease severity. At the same time the adaptive-compensatory reaction of PF to the influence of weather complexes decreases depending on the disease severity and, as a result, the pathogenic process of meteodependence is formed. This process can be regarded as an increase in the tension of the functioning of physiological systems by a change of the adaptive mechanisms at all stages of the development of meteodependence. It is noted that the impact of the weather complex on the human body primarily acts on PF, while the response of metabolic parameters is manifested with a time lag of 1–2 days. Finally, changeable weather of the maritime climate creates an additional load for both respiratory system and systems that ensure the peroxidation balance forming prerequisites for worsening of bronchopulmonary pathology.

Compliance with ethical standards

Informed consent was obtained from all individual participants included in the study. All procedures performed in studies involving human participants were in accordance with the ethical standards of the Ethics Committee of the Vladivostok branch of Federal State Budgetary Science Institution «Far Eastern Scientific Center of Physiology and Pathology of Respiration» – Institute of Medical Climatology and Rehabilitative Treatment and with the Declaration of Helsinki (2013).

Conflict of interest The authors declare that they have no conflict of interest.

References

1. IPCC. Global warming of 1.5°C, an IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Summary for policy makers. 2018. Available online at: http://report.ipcc.ch/sr15/pdf/sr15_spm_final.pdf
2. GBD 2015 Chronic Respiratory Disease Collaborators. Global, regional, and national deaths, prevalence, disability-adjusted life years, and years lived with disability for chronic obstructive pulmonary disease and asthma, 1990–2015: a systematic analysis for the Global Burden of Disease Study 2015. Lancet Respir Med. 2017;5(9):691–706. https://doi.org/10.1016/S2213-2600(17)30293-X.
3. GBD 2015 Disease and Injury Incidence and Prevalence Collaborators. Global, regional, and national incidence, prevalence,

and years lived with disability for 310 diseases and injuries, 1990–2015: a systematic analysis for the Global Burden of Disease Study 2015. Lancet. 2016;388(10053):1545–602. https://doi.org/10.1016/S0140-6736(16)31678-6.

4. GBD 2015 Mortality and Causes of Death Collaborators. Global, regional, and national life expectancy, all-cause mortality, and cause-specific mortality for 249 causes of death, 1980–2015: a systematic analysis for the Global Burden of Disease Study 2015. Lancet. 2016;388(10053):1459–544. https://doi.org/10.1016/S0140-6736(16)31012-1.
5. Voronin NM. Fundamentals of medical and biological climatology. Meditsina: Moscow; 1981. (in Russian)
6. Rusanov VI. Climate and human health. Proceedings of the WMO; WHO, UNEP-Symposium on Climate and Human Health in Leningrad 1986. WMO-WCP, Geneva 1987; 2:101–106.
7. Khanjani N, Bahrampour A. Temperature and cardiovascular and respiratory mortality in desert climate. A case study of Kerman, Iran. Iranian J Environ Health Sci Eng. 2013;10(1):11. https://doi.org/10.1186/1735-2746-10-11.
8. D'Amato G, Cecchi L, D'Amato M, Annesi-Maesano I. Climate change and respiratory diseases. Eur Respir Rev. 2014;23(132):161–9. https://doi.org/10.1183/09059180.00001714.
9. de Freitas CR, Grigorieva EA. The impact of acclimatization on thermophysiological strain for contrasting regional climates. Int J Biometeorol. 2014;58(10):2129–37. https://doi.org/10.1007/s00484-014-0813-9.
10. de Freitas CR, Grigorieva EA. Role of acclimatization in weather-related human mortality during the transition seasons of autumn and spring in a thermally extreme mid-latitude continental climate. Int J Environ Res Public Health. 2015;12:14974–87. https://doi.org/10.3390/ijerph121214962.
11. Vahedian M, Khanjani N, Mirzaee M, Koolivand A. Associations of short-term exposure to air pollution with respiratory hospital admissions in Arak, Iran. J Environ Health Sci Eng. 2017;15(1):17. https://doi.org/10.1186/s40201-017-0277-z.
12. Davis RE, Enfield KB. Respiratory hospital admissions and weather changes: a retrospective study in Charlottesville, Virginia, USA. Int J Biometeorol. 2018;62(6):1015–25. https://doi.org/10.1007/s00484-018-1503-9.
13. Havenith G. Temperature regulation, heat balance and climatic stress. Extreme weather events and public health responses. Berlin: Springer; 2005.
14. Omer SB, Sutanto A, Sarwo H, Linehan M, Djelantik IGG, Mercer D, et al. Climatic, temporal, and geographic characteristics of respiratory syncytial virus disease in a tropical island population. Epidemiol Infect. 2008;136(10):1319–27. https://doi.org/10.1017/S0950268807000015.
15. Anderson GB, Dominici F, Wang Y, McCormack MC, Bell ML, Peng RD. Heat-related emergency hospitalizations for respiratory diseases in the medicare population. Am J Respir Crit Care Med. 2013;187(10):1098–103. https://doi.org/10.1164/rccm.201211-1969oc.
16. Tseng CM, Chen YT, Ou SM, Hsiao YH, Li SY, Wang SJ, et al. The Effect of Cold Temperature on Increased Exacerbation of Chronic Obstructive Pulmonary Disease: A Nationwide Study. PLoS One. 2013;8(3):e.57066. https://doi.org/10.1371/journal.pone.0057066.
17. Gao Z, Li F, Upur H, Min J, Jing W, Jing J, et al. Effect of cold-dryness on pulmonary and immunologic function in chronic obstructive pulmonary disease model rats. J Tradit Chin Med. 2014;34(2):221–6. https://doi.org/10.1016/S0254-6272(14)60082-0.
18. Bucher K, Haase C. Meteorotropy and medical-meteorological forecasts. Experientia. 1993;49(9):759–68. https://doi.org/10.1007/BF01923545.
19. Lecha L. Biometeorological forecasts for health surveillance and prevention of meteor-tropic effects. Int J Biometeorol. 2017;62(5):741–71. https://doi.org/10.1007/s00484-017-1405-2.
20. Köppen W. Das geographische System der Klimate (The geographic system of climates). In: Köppen W, Geiger R. (Eds.): Handbuch der Klimatologie, Bd. 1, Teil C. Borntraeger, Berlin; 1936.
21. Kottek M, Grieser J, Beck C, Rudolf B, Rubel F. World map of the Köppen-Geiger climate classification updated. Meteorol Z. 2006;15:259–63. https://doi.org/10.1127/0941-2948/2006/0130.
22. Alisov BP, Poltoraus BV. Climatology. Moscow: Publishing house of the Moscow State University; 1974. (in Russian)
23. Veremchuk LV, Ivanov EM, Kiku PF. The habitat and morbidity of respiratory organs in the Primorsky region. Dal'nauka: Vladivostok; 2008. (in Russian)
24. Veremchuk LV, Yan'kova VI, Vitkina TI, Nazarenko AV, Golokhvast KS. Urban air pollution, climate and its impact on asthma morbidity. Asian Pac J Trop Biomed. 2016;6(1):76–9. https://doi.org/10.1016/j.apjtb.2015.10.001.
25. Kirkham P, Rahman I. Oxidative stress in asthma and COPD: antioxidants as a therapeutic strategy. Pharmacol Ther. 2006;111(2):476–94. https://doi.org/10.1016/j.pharmthera.2005.10.015.
26. Bargaglia E, Olivieria C, Bennetta D, Prasseb A, Muller-Quernheimb J, Rottolia P. Oxidative stress in the pathogenesis of diffuse lung diseases: a review. Respir Med. 2009;103(9):1245–56. https://doi.org/10.1016/j.rmed.2009.04.014.
27. Van Eeden SF, Sin DD. Oxidative stress in chronic obstructive pulmonary disease: a lung and systemic process. Can Respir J. 2013;20(1):27–9. https://doi.org/10.1155/2013/509130.
28. Alvarado A, Arce I. Antioxidants in respiratory diseases: basic science research and therapeutic alternatives. Clin Res Trials. 2016;2. https://doi.org/10.15761/CRT.1000163.
29. Rosanna DP, Salvatore C. Reactive oxygen species, inflammation, and lung diseases. Curr Pharm Des. 2012;18(26):3889–900. https://doi.org/10.2174/138161212802083716.
30. Caramori G, Casolari P, Barczyk A, Durham AL, Di Stefano A, Adcock I. COPD immunopathology. Semin Immunopathol. 2016;38(4):497–515. https://doi.org/10.1007/s00281-016-0561-5.
31. Vasilevskaya LN, Scabard OA, Lamash BE, Platonova VA, Makarenko EA. Peculiarities of long-term variability of temperature, precipitation and the timing of the onset of the second stage of the summer monsoon in Peter the Great Bay. Bull Feb RAS. 2013;6:71–82 (in Russian).
32. Rostov ID, Rudykh NI, Rostov VI, Vorontsov AA. Expressions of global climatic changes in coastal waters of the northern part of the sea of Japan. Bull Feb RAS. 2016;5:100–16 (in Russian).
33. Weather and climate. http://www.pogodaiklimat.ru (in Russian).
34. Weather forecast for Vladivostok, Primorsky Region. http://www.Primpogoda.ru (in Russian).
35. Regional Internet resource. http://vestiregion.ru (in Russian).
36. Steadman RG. A universal scale of apparent temperature. J Cim Appl Meteorol. 1984;23:1674–87. https://doi.org/10.1175/1520-0450(1984)023<1674:ausoat>2.0.co;2.
37. Ovcharova VF. Homeokines in weather hypoxy and hyperoxy. Proceedings of the WMO; WHO, UNEP-Symposium on Climate and Human Health in Leningrad 1986. WMO-WCP, Geneva 1987; 2:149–150.
38. Rakhmanov RS, Tarasov AV. Adaptive reactions of the organism under the influence of the sea climate on the health of the population in the regions of Russia. N. Novgorod: LLC "Stimulus-ST"; 2018. (in Russian).
39. Pokrovskiy OM. About the application of the Shannon's measure for the quantitative assessment of the informativeness of the systems of hydrometeorological observation. Proceedings of the main geophysical observatory named A.I. Voeykov. 1989;528:19–32. (in Russian).

40. Shannon K. Researches on information theory and cybernetics. Izdatel'stvo inostrannoy literatury: Moskow; 2002. (in Russian)
41. Carter T. An introduction to information theory and entropy. Santa Fe; 2007.
42. Martin NFG, England JW. Mathematical theory of entropy. Cambridge: Cambridge University Press; 2011.
43. Mannam P, Srivastava A, Sugunaraj JP, Lee PJ, Sauler M. Oxidants in acute and chronic lung disease. J Blood Lymph. 2014;04(03): 1000128. https://doi.org/10.4172/2165-7831.1000128.
44. Borovikov VP. The program STATISTICA for students and engineers. Moscow: Computer press; 2001. (in Russian)
45. Gasparrini A, Guo Y, Hashizume M, et al. Mortality risk attributable to high and low ambient temperature: a multicountry observational study. Lancet. 2015;386:369–75 https://doi.org/10.1016/S0140-6736(14)62114-0.
46. Basu R, Samet JM. Relation between elevated ambient temperature and mortality: a review of the epidemiological evidence. Epidemiol Rev. 2002;24:190–202. https://doi.org/10.1093/epirev/mxf007.
47. Lepeule J, Litonjua AA, Gasparrini A, Koutrakis P, Sparrow D, Vokonas PS, et al. Lung function association with outdoor temperature and relative humidity and its interaction with air pollution in the elderly. Environ Res. 2018;165:110–7. https://doi.org/10.1016/j.envres.2018.03.039.
48. Yan'kova VI, Veremchuk LV, Vitkina TI, Gvozdenko TA, Golokhvast KS. The response of lipid peroxidation and antioxidant protection system to the combined effects of environmental factors in diseases of the respiratory system. Sibirskiy Nauchnyy Meditsinskiy Zhurnal. 2016;36(3):94–102 (in Russian).
49. Ray PD, Huang BW, Tsuji Y. Reactive oxygen species (ROS) homeostasis and redox regulation in cellular signaling. Cell Signal. 2012;24(5):981–90. https://doi.org/10.1016/j.cellsig.2012.01.008.
50. Gelpi RJ, Boveris A, Poderoso JJ. Biochemistry of oxidative stress. Physiopathology and Clinical Aspects: Springer International Publishing; 2016.
51. Wu NC, Liao FT, Cheng HM, Sung SH, Yang YC, Wang JJ. Intravenous superoxide dismutase as a protective agent to prevent impairment of lung function induced by high tidal volume ventilation. BMC Pulm Med. 2017;17(1):105. https://doi.org/10.1186/s12890-017-0448-9.
52. Rahman I. Oxidative stress, chromatin remodeling and gene transcription in inflammation and chronic lung diseases. BMB Rep. 2003;36(1):95–109. https://doi.org/10.5483/bmbrep.2003.36.1.095.