DOI: https://doi.org/10.17816/humeco648668 EDN: JVEJYU

Circannual Variations in Partial Oxygen Density Depending on Solar Activity Level and Climatic Zone

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ABSTRACT

BACKGROUND: Some medical weather classifications identify reduced partial oxygen density in the air as a key parameter affecting human well-being. This parameter can be modulated not only by meteorological factors but also by the helio-geophysical environment. It should be noted that synoptic combinations with elevated oxygen content are not considered among the weather types, although several studies have shown that hyperoxia can have adverse effects on health.

AIM: To assess the influence of circannual variations in solar activity on the changes of atmospheric partial oxygen density in subarctic and subtropical regions.

METHODS: Calculations of partial oxygen density were based on daily average values of air temperature, atmospheric pressure, and relative humidity of the ambient air. Sunspot number data were obtained from publicly available sources provided by the Royal Observatory of Belgium. Data from 2007 (a year of low solar activity in the 23rd solar cycle) and 2001 (a year of high solar activity) were compared. Wavelet analysis was used for mathematical processing.

RESULTS: The mesor, amplitude, coefficient of variation, and rhythm spectrum of sunspot numbers differed significantly between the years of low (2007) and high (2001) solar activity. In 2001, the dominant rhythm was close to a semiannual cycle. In 2007, the rhythm of sunspot numbers was 27.27 days. In Khanty-Mansiysk, the seasonal range of partial oxygen density was ~147 g/m^3 in 2001 and ~70 g/m^3 in 2007. The annual cycle was characterized by prevailing hyperoxia, with upper values reaching 395 g/m^3 (normal: 285 g/m^3). In Polokwane, the winter–summer variation in partial oxygen density in 2001 was approximately 24 g/m^3 (virtually the same as in 2007, 30 g/m^3), which falls into the category of unfavorable hypoxic weather. In the year of high solar activity (2001), a polyrhythmic pattern of both stable and transient rhythms of partial oxygen density was observed in both subarctic and subtropical regions.

CONCLUSION: In the subarctic region, wintertime values of partial oxygen density were high in the year of low solar activity and very high in the year of high activity. Seasonal fluctuations between hyperoxia and hypoxia extended far beyond the range of favorable weather types. Fluctuations in partial oxygen density characteristic of the subtropical climate consistently remained within hypoxic ranges, regardless of solar activity levels. During the year of elevated solar activity, both examined regions exhibited polyrhythmic patterns of partial oxygen density, indicative of desynchronosis. It is recommended that medical weather classifications be expanded to include "hyperoxic day" and "hyperoxic weather type."

Keywords: extreme weather conditions; oxygen; hypoxia; hyperoxia; North.

To cite this article:
Ragozin ON, Muthelo L, Shalamova EYu, Gudkov AB, Radysh IV, Ragozina ER, Pogonysheva IA. Circannual variations in partial oxygen density depending on solar activity level and climatic zone. *Ekologiya cheloveka (Human Ecology).* 2025;32(1):32–41. DOI: 10.17816/humeco648668 EDN: JVEJYU

Received: 29.01.2025 **Accepted:** 26.03.2025 **Published online:** 02.06.2025

DOI: https://doi.org/10.17816/humeco648668 EDN: JVEJYU

Цирканнуальные вариации парциальной плотности кислорода в зависимости от уровня солнечной активности и климатического пояса

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АННОТАЦИЯ

Обоснование. Существуют медицинские классификации погоды, где определяющим параметром, влияющим на самочувствие человека, является снижение в воздухе парциальной плотности кислорода, которая может модулироваться не только метеофакторами, но и гелиогеофизической обстановкой. Необходимо отметить, что среди типов погод не рассматриваются синоптические комбинации с повышенным содержанием кислорода, хотя в ряде исследований установлено негативное воздействие гипероксии на здоровье.

Цель. Оценить влияние окологодовых вариаций солнечной активности на динамику парциальной плотности кислорода атмосферного воздуха в субарктическом и субтропическом регионах.

Материалы и методы. Для расчёта парциальной плотности кислорода использовали ежедневные среднесуточные значения температуры, атмосферного давления и относительной влажности окружающего воздуха. Данные о числе солнечных пятен получены из общедоступных материалов Королевской обсерватории Бельгии. Сравнивали данные за 2007 г., как наиболее спокойный год 23-го цикла солнечной активности, и за 2001 г., когда активность солнца была высокой. Для математической обработки применяли вейвлет-анализ.

Результаты. В годы спокойного (2007 г.) и активного (2001 г.) солнца значимо отличаются мезоры числа солнечных пятен, амплитуда их колебаний, коэффициент вариации и спектр ритмов. В 2001 г. наиболее мощным являлся ритм, близкий к полугодовому. В 2007 г. динамика числа солнечных пятен составляла 27,27 сут. В Ханты-Мансийске размах сезонных колебаний парциальной плотности кислорода в 2001 г. был ~147 г/м^3, в 2007 ~70 г/м^3. В годовом цикле превалирует гипероксия с верхней границей 395 г/м^3 (норма 285 г/м^3). В Полокване в 2001 г. зимне-летняя вариация парциальной плотности кислорода составляет ~24 г/м^3 (практически не отличается от 2007 г. — 30 г/м^3), что попадает в разряд неблагоприятной гипоксической погоды. В год активного солнца (2001 г.) обнаруживается полиритмия постоянных и вставочных ритмов парциальной плотности кислорода как в субарктическом, так и в субтропическом регионах.

Заключение. В субарктическом регионе в зимний период наблюдаются высокие значения парциальной плотности кислорода в год спокойного солнца и очень высокие — в год активного солнца. Сезонная вариативность состояния «гипероксия/гипоксия» выходит далеко за рамки благоприятного типа погоды. Для субтропического климата характерны колебания парциальной плотности кислорода в пределах гипоксического статуса вне зависимости от уровня солнечной активности. В год высокой солнечной активности в обоих исследованных регионах выявлена полиритмия парциальной плотности кислорода как признак десинхроноза. Медицинские классификации погод рекомендуем дополнить такими пунктами, как «гипероксический день» и «гипероксический тип погоды».

Ключевые слова: экстремальные погодные условия; кислород; гипоксия; гипероксия; Север.

Как цитировать:
Рагозин О.Н., Мутэло Л., Шаламова Е.Ю., Гудков А.Б., Радыш И.В., Рагозина Э.Р., Погонышева И.А. Цирканнуальные вариации парциальной плотности кислорода в зависимости от уровня солнечной активности и климатического пояса // Экология человека. 2025. Т. 32, № 1. С. 32–41.
DOI: 10.17816/humeco648668 EDN: JVEJYU

Рукопись поступила: 29.01.2025 **Рукопись одобрена:** 26.03.2025 **Опубликована online:** 02.06.2025

DOI: https://doi.org/10.17816/humeco648668 EDN: JVEJYU

日光活动水平与气候带对氧密度年周期变化的影响

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摘要

论证。在医学气象分类中，影响人体舒适感受的一个关键因素是空气中氧密度的下降，而该参数不仅受气象条件的调节，还可能受到太阳地球物理环境的影响。值得指出的是，在这些天气类型中尚未纳入富氧的天气组合，尽管已有研究证实高氧状态可能对健康产生不利影响。

目的。评估太阳活动的近年周期变化对亚北极和亚热带地区大气氧密度动态的影响。

材料与方法。为计算氧密度，使用了每日的平均气温、大气压和相对湿度值。关于太阳黑子数的数据来自Royal Observatory of Belgium公开发布的资料。比较了第23太阳活动周期中最为平静的年份2007年和太阳活动最为活跃的年份2001年的数据。数学分析采用小波分析法。

结果。在太阳活动平静（2007年）和活跃（2001年）年份，太阳黑子数的中值、波动幅度、变异系数和节律谱存在显著差异。2001年最显著的节律接近半年周期。2007年太阳黑子数的变化节律为27.27天。在Khanty-Mansiysk，2001年氧密度的季节波动幅度约为147 g/m^3，2007年约为70 g/m3。全年周期内以高氧状态为主，其上限为395 g/m3（正常值为285 g/m^3）。在Polokwane，2001年冬夏季节的氧密度变化约为 24 g/m3（与2007年的30 g/m3 差异不大），均被归为不利的低氧型天气条件。在太阳活动活跃年（2001年），在亚北极和亚热带地区均发现氧密度存在主节律与插入节律共存的多节律现象。

结论。在亚北极地区的冬季，太阳活动平静年份的氧密度水平较高，而在太阳活动活跃年份则达到非常高的水平。“高氧/低氧”状态的季节性变异明显超出有利天气类型的范围。亚热带地区的氧密度波动始终处于低氧状态，且不受太阳活动水平的影响。在太阳活动旺盛年份，两个地区均观察到氧密度节律的多样性，可作为生物节律失调（desynchronosis）的一个指征。建议将“高氧日”和“高氧型天气”纳入医学气象分类体系。

关键词：极端气象条件；氧；低氧；高氧；北方地区。

引用本文：
Ragozin ON, Muthelo L, Shalamova EYu, Gudkov AB, Radysh IV, Ragozina ER, Pogonysheva IA. 日光活动水平与气候带对氧密度年周期变化的影响. *Ekologiya cheloveka (Human Ecology).* 2025;32(1):32–41. DOI: 10.17816/humeco648668 EDN: JVEJYU

收到: 29.01.2025 **接受:** 26.03.2025 **发布日期:** 02.06.2025

BACKGROUND

Extensive data have been accumulated on the effects of geophysical and weather-related factors on human health [1–3].

Russian researchers have made a significant contribution to the study of heliometeorotropic responses of the human body [4]. Meteorotropic reactions are observed in patients with cardiovascular, bronchopulmonary, gastrointestinal, dermatological, musculoskeletal, neurological, and psychiatric disorders [5, 6].

In northern regions, conditions arise that disrupt the temporal organization of psychophysiological functions due to the specific heliogeophysical conditions of circumpolar areas [7].

At present, the attention of specialists from various disciplines is increasingly focused on the influence of exogenous factors on the changes of oxygen content in near-surface air [8]. Several weather classifications identify partial oxygen density (POD), or gravimetric oxygen content, as the key factor affecting human health. These classifications distinguish hypoxic, spastic, indifferent, and hypotensive weather types, which may or may not require medical supervision [9, 10].

It should be noted that existing classifications do not account for weather types associated with elevated oxygen content, although several studies have demonstrated the adverse effects of hyperoxia on human health and well-being [11–15]. It is therefore relevant to assess the impact of solar activity levels—both high and low—on the formation of circannual rhythms of POD in the near-surface air layer across different climatic zones.

The work aimed to assess the influence of circannual variations in solar activity on the seasonal changes of atmospheric POD in subarctic and subtropical regions.

METHODS

To calculate POD (g/m^3), daily average values of ambient air temperature (T, °C), atmospheric pressure (P, mm Hg), and relative humidity (φ, %) were used. POD is directly proportional to atmospheric pressure minus the partial pressure of water vapor and inversely proportional to air temperature: $O_2 = 83 \times (P - φ)/T$. A direct correlation has been observed between POD and the partial pressure of oxygen in inspired and alveolar air, depending on physical characteristics [16].

Data on the daily relative sunspot number (Wolf number, W) were obtained from publicly available materials provided by the Royal Observatory of Belgium (Brussels)[1]. The year 2007, identified as the calmest year of the 23rd solar cycle (smoothed monthly minimum W = 2.2), was compared with 2001, a year of active sun (W = 180.3).

Wavelet analysis was used to evaluate the time series[2]. The results of the wavelet transformation show how the spectral composition of the time series changes over time.

The following parameters of the analyzed time series were determined: the average level (mesor, M ± m), rhythm amplitude (A, arbitrary units), periods of stable and transient (quantized) rhythms (days), and coefficient of variation (c_v, %). The statistical significance of the rhythms was assessed by performing multiple (5000) random permutations of the original time series levels. The reported *p*-value indicates the proportion of cases in which the energy of the extracted frequency component in the original series exceeded that in the permuted series.

Khanty-Mansiysk, the capital of the Khanty-Mansi Autonomous Okrug–Yugra, is located at 61° N and 69° E. The climate is sharply continental, with harsh, prolonged winters featuring strong winds and blizzards, spring cold snaps, and late spring and early autumn frosts. Pronounced changes in photoperiod occur throughout the year: the shortest daylight duration is recorded on December 22 and reaches 5 h 32 min, whereas in summer, during the “white nights,” daylight reaches 19 h 17 min[3].

Polokwane is the administrative center of the Polokwane Municipality, Capricorn District, Limpopo Province (South Africa), located at 23° S and 29° E. Summer in Limpopo lasts from November to March (~5 months). During this season most annual precipitation occurs. Winter spans from June to August (~3 months) and is characterized by little to no precipitation. The province receives abundant sunshine throughout the year, especially in winter. Seasonal variations in photoperiod are minor, with a gradient of approximately 3 hours (10 h 39 min on June 22 and 13 h 36 min on December 22)[4].

RESULTS

Descriptive statistics of the Wolf number (arbitrary units) and intra-annual rhythms of solar activity for 2001 and 2007 are presented in Table 1 and Fig. 1.

Mean annual levels of W (arbitrary units), A (arbitrary units), and c_v (%) significantly differed between the years of low (2007) and high (2001) solar activity (see Fig. 1). The rhythm spectra also varied (see Table 1).

In 2001, the most prominent rhythm was close to a semiannual cycle (165.3 days), as well as rhythms with periods of approximately three months, two months, and one week (Table 1, Fig. 2). In 2007, the dynamics of W followed a 27.0-day rhythm, with the highest amplitude in spring and autumn

1 WDC-SILSO. Royal Observatory of Belgium, Brussels. Available at: http://www.sidc.be/silso/datafiles Accessed on: December 7, 2024.

2 Software for Studying Biological Rhythms Using Wavelet Analysis. Certificate of state registration of computer software No. 2014611398 of February 3, 2014.

3 Khanty-Mansiysk Center for Hydrometeorology and Environmental Monitoring. Available at: http://www.ugrameteo.ru. Accessed on: November 07, 2024.

4 Green Book: Adapting South African Settlements to Climate Change. Available at: https://greenbook.co.za. Accessed on: November 7, 2024.

DOI: https://doi.org/10.17816/humeco648668

Table 1. Intra-annual rhythms of solar activity in 2001 and 2007

Year	Period, days	Rhythm energy, arb. units	*p*
2001	165.3	4.55	0.001
	105.1	2.33	0.001
	59.7	1.08	0.024
	9.8	0.87	0.012
2007	27.0	4.08	0.001
	13.7	1.43	0.001
	8.7	1.04	0.001

and low-amplitude biweekly and near-weekly peaks in winter (see Table 1, Fig. 2).

No statistically significant differences in mean annual POD values or in the amplitude of circannual fluctuations were found across the examined climatic zones for different years of the solar cycle. However, significant differences were observed in the coefficient of variation of POD in the subarctic region between years of differing solar activity (Table 2, Fig. 3). There was also a marked trend toward differences in the POD coefficient of variation between the subarctic and subtropical regions during the year of low solar activity. In Khanty-Mansiysk, seasonal POD fluctuations in 2001 were more pronounced, ranging from 148 g/m^3 in summer to 395 g/m^3 in winter (compared with 260 g/m^3 in summer and 330 g/m^3 in winter in 2007). The variability of the hyperoxia/hypoxia state extends far beyond the scope of current medical weather classifications.

In Polokwane, the winter–summer variation in POD in 2001 (see Table 2) ranged from 262 g/m^3 in summer to 286 g/m^3 in winter and was virtually the same as in 2007 (260 g/m^3 in summer, 290 g/m^3 in winter), although the values fell within the range of unfavorable oxygen-related weather [17].

In the year of high solar activity (2001), polyrhythmic patterns of both stable and transient POD rhythms were

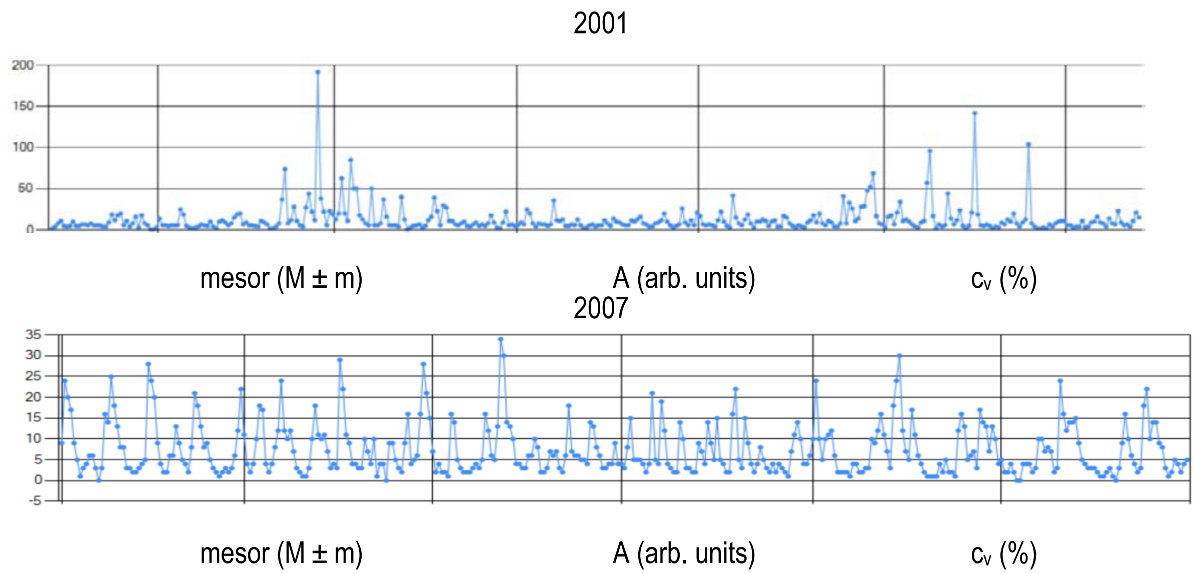

Fig. 1. Descriptive statistics of sunspot numbers (arb. units), 2001 and 2007: A, amplitude; c_v, coefficient of variation.

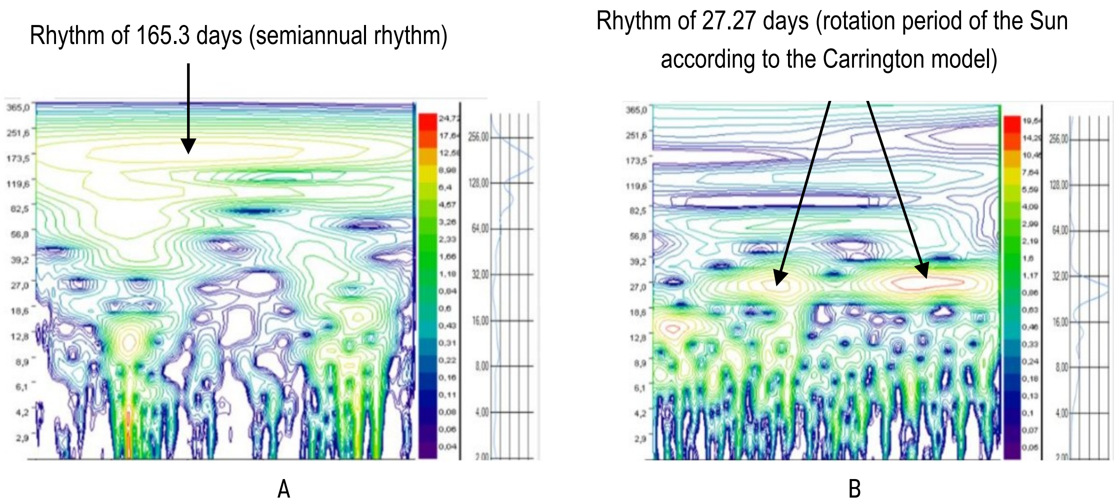

Fig. 2. Wavelet spectrograms of solar activity variations: A, 2001; B, 2007

Table 2. Descriptive statistics of partial oxygen density in Khanty-Mansiysk and Polokwane in 2001 and 2007

Indicator	Ханты-Мансийск | Khanty-Mansiysk		Полокване | Polokwane	
	2001	2007	2001	2007
Mesor. M±m	278.23±50.10	283.24±14.79	272.59±6.19	274.22±6.55
Amplitude. arb. units	79964.45	80445.13	74341.42	75237.27
Coefficient of variation. %	18.15*	5.22**	2.27	2.39

Note: **p* = 0.022; ***p* = 0.058.

identified in both the subarctic and subtropical regions [18]. Polyrhythmicity of POD (2001) was 5 in Khanty-Mansiysk and 4 in Polokwane (Table 3).

In the year of high solar activity (2001), five and four significant POD rhythms were identified In Khanty-Mansiysk (subarctic region) and in Polokwane (subtropics), respectively (see Table 3). In the year of low solar activity (2007), three significant intra-annual POD rhythms were observed in both regions.

DISCUSSION

Low solar activity is characterized by temporal stability of electromagnetic radiation across the entire spectral range and of the so-called solar wind—a weak flow of electrons, protons, and helium nuclei, representing a radial outflow of plasma from the solar corona into interplanetary space. Periodically, approximately every 11 years, solar activity increases (manifesting as sunspots, chromospheric flares, and prominences in the solar corona). During these periods, wave-type solar radiation intensifies at various frequencies, and streams of electrons, protons, and helium nuclei are ejected from the solar atmosphere into interplanetary space. The energy and velocity of these particles are significantly higher than those of solar wind particles. This particle flux propagates through interplanetary space and reaches the Earth's orbit after a certain time (12–24 hours) [19]. The Earth's magnetic field acts as a shield against the solar wind; however, some charged particles can penetrate the magnetosphere. This occurs primarily at high latitudes, where two so-called cusps are located—one in the Northern Hemisphere and one in the Southern Hemisphere [20]. These regions are characterized by specific features associated with the season (winter–summer) and the level of solar activity.

Human responses to heliogeophysical factors range from localized to systemic, are aggravated by anthropogenic risk factors, and exert a biorhythm-modulating, desynchronizing effect on the functional systems of the body [21].

Some authors hypothesize that biological systems are sensitive to weak electromagnetic fields of both artificial and natural origin and that magnetic pulsations, the oscillation frequencies of which lie within the range of low-frequency biological rhythms, may influence them [22]. A thermospheric response to magnetic storms has been observed, manifesting

Table 3. Structure of circannual rhythms of partial oxygen density in Khanty-Mansiysk and Polokwane in 2001 and 2007

City	Year	Period. days	Amplitude. arb. units	*p*
Khanty-Mansiysk	2001	325.9	35.51	0.001
		147.6	3.899	0.001
		83.8	1.604	0.001
		105.1	1.477	0.005
		27.0	1.059	0.003
	2007	291.1	35.52	0.001
		93.8	4.395	0.001
		147.6	3.081	0.002
Polokwane	2001	291.1	45.67	0.001
		83.8	1.088	0.010
		59.7	1.024	0.012
		131.8	0.998	0.015
	2007	291.1	44.30	0.001
		83.8	2.068	0.002
		24.1	0.692	0.042

as a more than tenfold decrease in the atomic oxygen to molecular nitrogen concentration ratio in high-latitude regions compared with the quiet geomagnetic level. Notably, this thermospheric response is 1.5 times more pronounced in the Northern Hemisphere than in the Southern Hemisphere [23].

In our study, we obtained evidence of a heliometeorotropic effect of solar activity level on the oxygen status. This effect is manifested as a pathological desynchronosis of the circannual variability in POD, with a hyperoxic accent in the subarctic region and a hypoxic one in the subtropics.

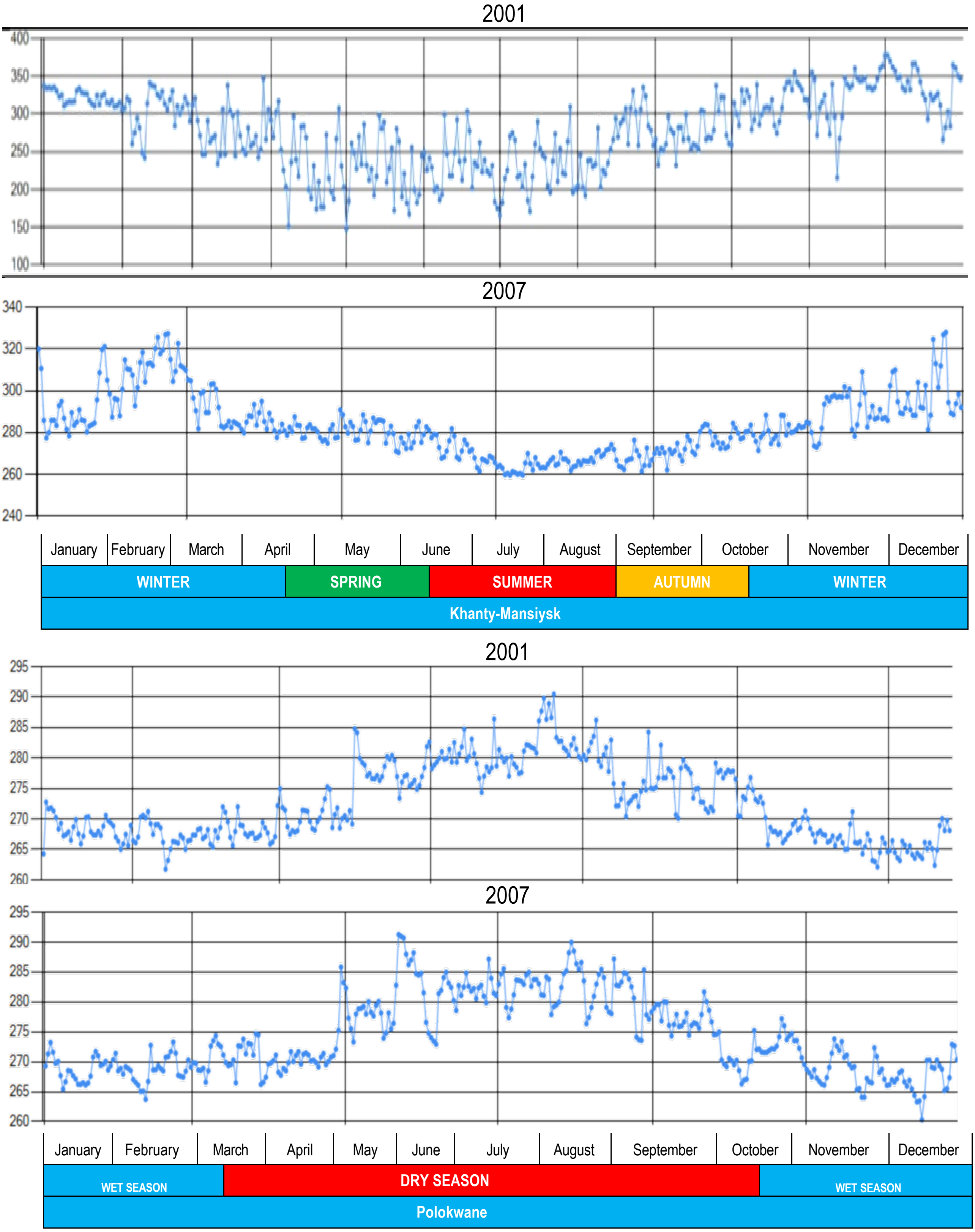

Fig. 3. Circannual changes of partial oxygen density in Khanty-Mansiysk and Polokwane during years of high (2001) and low (2007) solar activity.

Based on these findings, continuous monitoring of POD in inhaled air is necessary to assess hypoxia/hyperoxia and should be included in weather forecasting systems.

CONCLUSION

In the subarctic region, high and extremely high values of POD are observed during years of low and high solar activity, respectively. In the North, the circannual variability in the hyperoxia/hypoxia state extends far beyond the range of favorable weather types. In the subtropical climate, a hypoxic pattern of POD fluctuations is recorded regardless of the level of solar activity. The indicator of POD polyrhythmicity in the ground-level air layer can be used as a criterion for diagnosing heliometeotropic responses to solar activity fluctuations. Continuous monitoring of POD is essential for predicting emergency medical conditions.

ADDITIONAL INFORMATION

Author contributions: O.N. Ragozin: conceptualization, study design, writing—review & editing; L. Muthelo: formal analysis; E.Yu. Shalamova: writing—original draft; A.B. Gudkov, I.V. Radysh: writing—review & editing; E.R. Ragozina: investigation; I.A. Pogonysheva: formal analysis. All authors confirm that their authorship meets the international ICMJE criteria (all authors made substantial contributions to the conceptualization, investigation, and manuscript preparation, and reviewed and approved the final version prior to publication).

Ethics approval: The study was approved by the Local Ethics Committee of the Budgetary Institution Khanty-Mansiysk State Medical Academy (Approval No. 214, dated October 15, 2024).

Funding sources: No funding.

Disclosure of interests: The authors have no relationships, activities, or interests for the last three years related to for-profit or not-for-profit third parties whose interests may be affected by the content of the article.

Statement of originality: No previously published material (text, images, or data) was used in this work.

Data availability statement: The editorial policy regarding data sharing does not apply to this work, as no new data was collected or created.

Generative AI: No generative artificial intelligence technologies were used to prepare this article.

Provenance and peer-review: This paper was submitted unsolicited and reviewed following the standard procedure. The peer review process involved two external reviewers, a member of the editorial board, and the in-house scientific editor.

ДОПОЛНИТЕЛЬНАЯ ИНФОРМАЦИЯ

Вклад авторов. О.Н. Рагозин — существенный вклад в концепцию и дизайн исследования, редактирование и окончательное утверждение рукописи; Л. Мутэло — анализ данных; Е.Ю. Шаламова — подготовка первого варианта статьи; А.Б. Гудков — редактирование и окончательное утверждение рукописи; И.В. Радыш — редактирование первого варианта статьи; Э.Р. Рагозина — набор первичного материала; И.А. Погонышева — анализ данных. Все авторы подтверждают соответствие своего авторства международным критериям ICMJE (все авторы внесли существенный вклад в разработку концепции, проведение исследования и подготовку статьи, прочли и одобрили финальную версию перед публикацией).

Этическая экспертиза. Проведение исследования одобрено локальным этическим комитетом БУ «Ханты-Мансийская государственная медицинская академия» (заключение № 214 от 15.10.2024).

Источники финансирования. Отсутствуют.

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Рассмотрение и рецензирование. Настоящая работа подана в журнал в инициативном порядке и рассмотрена по обычной процедуре. В рецензировании участвовали два внешних рецензента, член редакционной коллегии и научный редактор издания.

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