

Seasonal Variations in Sleep Quality and Stability Among Patients with Chronic Insomnia: Real-World Evidence Across the 24 Solar Terms

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Background: The 24 Solar Terms of the traditional Chinese lunisolar calendar reflect seasonal and climatic changes that may influence sleep. Few large-scale studies have examined sleep quality and stability across these seasonal markers in chronic insomnia. **Methods:** This retrospective observational study analyzed anonymized data from 25,428 chronic insomnia patients using the “Good Sleep 365” platform at Zhejiang University’s Affiliated Mental Health Center (2018–2023). Sleep quality and stability were assessed via the Pittsburgh Sleep Quality Index (PSQI), incorporating the total score to reflect overall sleep quality, along with score reduction and reduction rate to capture changes and stability over time. Seasonal autoregressive integrated moving average (SARIMA) models were applied to time-series data; 2023 data validated the models, and 2024 predictions were generated.

Results: Sleep quality was poorer during Grain Rain (Guyu) and Cold Dew (Hanlu), with mean PSQI scores of 9.53 and 9.48, respectively, whereas it was better during Major Snow (Daxue) and Minor Snow (Xiaoxue), with mean PSQI scores of 8.91 and 8.96, respectively. Women were more sensitive to seasonal variations than men ($P < 0.05$), while patients aged 45–59 showed greater fluctuations ($P < 0.05$). No significant associations were found between sleep and key solar terms such as Beginning of Spring (Lichun), Beginning of Summer (Lixia), Beginning of Autumn (Liqiu), and Beginning of Winter (Lidong), etc. SARIMA(1,0,1)(0,1,1)[24] best modeled sleep quality and fluctuations, and SARIMA(1,0,1)(1,0,1)[24] for improvements; both models demonstrated good fit and predictions are mostly contained within the confidence intervals.

Conclusion: Sleep quality and stability vary across the 24 Solar Terms, with notable gender and age differences. SARIMA models are able to reflect these patterns to a certain extent, with the majority of predictions lying within the confidence intervals, which may contribute to personalized insomnia management. Cultural context of the 24 Solar Terms adds interpretive value. Limitations of this study include reliance on self-reported PSQI scores, lack of direct meteorological data, and other factors.

Plain Language Summary: Changes across the 24 Solar Terms, a key component of the traditional Chinese lunisolar calendar, may influence sleep patterns. The 24 Solar Terms divide the year into 24 segments based on seasonal and climatic changes, and are widely used in traditional Chinese culture to guide daily activities and health practices. For example, “Grain Rain” (around April 20) marks the period of increased rainfall and warming temperatures in spring, which may influence sleep patterns. This study investigated how these solar terms affect sleep quality and stability in over 25,000 patients with chronic insomnia in China. Sleep quality was generally lower during certain solar terms, and both age and gender influenced individuals’ sensitivity to these variations. Older adults and women showed greater fluctuations in sleep measures across the year. These findings suggest that considering variations across the 24 Solar Terms can help guide personalized insomnia management. The study relied on self-reported sleep questionnaires and did not include direct meteorological measurements, which should be considered when interpreting the results. Overall, the cultural context of the 24 Solar Terms provides additional insight into seasonal effects on sleep and highlights the potential for seasonally informed approaches to insomnia care.

Keywords: sleep quality, sleep stability, 24 solar terms, SARIMA, time series analysis, prediction

Introduction

Sleep is a fundamental physiological process essential for maintaining physical health, cognitive function, emotional regulation, and immune balance.¹ Among its key components, sleep quality reflects subjective satisfaction with sleep and its restorative function, while sleep stability refers to the regularity and resilience of sleep patterns over time, particularly in response to internal or external perturbations.² Insomnia disorder is one of the most prevalent sleep disorders worldwide.³ While its causes are multifactorial, emerging evidence highlights the significant role of external environmental conditions, particularly meteorological variables, in its onset and maintenance.⁴

The 24 Solar Terms (24 Jieqi), rooted in ancient Chinese astronomical observations, form a sophisticated lunisolar timekeeping system that reflects cyclical changes in solar position and their associated climatic transitions. Each term corresponds to approximately 15° movement of the sun along the ecliptic, resulting in 24 distinct intervals distributed throughout the year (see [Supplementary Table 1](#) for details and calendar dates).⁵ The system was first used in the Yellow River area (latitude and longitude), where the weather follows a continental monsoon pattern. But it also works well in other places, like the middle and lower parts of the Yangtze River (latitude and longitude), where the climate is a subtropical monsoon type.⁶ In 2016, the system was recognized by UNESCO as an Intangible Cultural Heritage,⁷ and its relevance to traditional Chinese medicine (TCM), health preservation, and seasonal disease management has since received growing attention.⁸ Compared with the traditional four-season division, the 24 solar terms provide a more refined representation of meteorological variations by delineating key climatic nodes and typical phenological phenomena during seasonal transitions, thereby exhibiting higher temporal resolution and ecological adaptability.

The 24 Solar Terms not only serve agronomic and cultural functions but also encapsulate predictable patterns of environmental changes, including shifts in temperature, humidity, light exposure, and atmospheric pressure.⁹ These environmental variations may influence physiological processes such as circadian rhythm,¹⁰ body temperature rhythm,¹¹ and melatonin secretion,¹² thereby disrupting sleep architecture and exerting an impact on both sleep quality and sleep stability. For example, exposure to sudden climatic changes or extreme weather conditions can lead to reduced total sleep time and increased wakefulness.⁴ Given that the 24 Solar Terms systematically represent meteorological cycles, they offer a culturally meaningful and temporally structured framework for examining seasonal patterns of sleep disturbances, yet their application in sleep epidemiology remains underexplored.

To our knowledge, this is the first large-scale, data-driven study to employ the 24 Solar Terms as a temporal framework for sleep epidemiology. Using a longitudinal dataset of chronic insomnia patients from 2018 to 2023, combined with modern time-series modeling (eg, SARIMA), this study aims to (1) characterize solar term-associated changes in insomnia symptoms, (2) identify potential high-risk periods for poor sleep, and (3) explore the feasibility of using solar term-based patterns to guide personalized, time-sensitive interventions for chronic insomnia. By integrating cultural timekeeping knowledge with predictive modeling and big data, this work offers novel insights into the intersection of climate-sensitive health management and sleep medicine.

Materials and Methods

Study Participants

This study encompassed 25,428 patients diagnosed with chronic insomnia at the Affiliated Mental Health Center, Zhejiang University School of Medicine, between January 1, 2018, and December 31, 2023. Prior to their clinic visits, all patients underwent systematic evaluations of sleep patterns and emotional states through the “Good Sleep 365” platform. The diagnosis of insomnia disorder was subsequently validated by a chief psychiatrist. Follow-up assessments utilizing the same sleep-related scales were conducted biweekly.

Inclusion and Exclusion Criteria

Inclusion criteria: (1) Diagnosis of non-organic insomnia in accordance with the ICD-10 criteria; (2) Educational attainment of primary school level or above, with the ability to comprehend the content of the assessment scales; (3) Completion of all required questionnaire items.

Exclusion criteria: (1) Presence of comorbid severe cardiovascular, cerebrovascular, or other organic diseases; (2) Pregnant or breastfeeding women; (3) Patients with comorbid mental disorders such as anxiety disorders, depressive disorders, and mood disorders.

Methods

This study primarily utilized data from Zhejiang Province, sourced from the ‘Good Sleep 365’ platform. The dataset comprised basic patient information, the dates of each sleep assessment, and the total Pittsburgh Sleep Quality Index (PSQI) scores. Each assessment date was aligned with one of the 24 Solar Terms, with assessments occurring between two consecutive solar terms being assigned to the preceding term to ensure temporal consistency. The change in total PSQI scores between two assessments was calculated to determine the PSQI score reduction (Δ PSQI). The PSQI reduction rate was computed as the score decrease divided by the initial (pre-treatment) PSQI score.

In this study, the total score of PSQI was utilized to assess the severity of insomnia in patients suffering from chronic insomnia. The reduction in PSQI scores (Δ PSQI) was employed to quantify the extent of changes in sleep patterns. Additionally, the PSQI reduction rate provided insight into the degree of improvement in sleep quality. These two metrics were analyzed together to enhance the understanding of changes in sleep stability.

This study examined the variations in the average PSQI total score, PSQI score reduction, and PSQI reduction rate across different solar terms over a six-year period. The objective was to identify patterns in the severity of insomnia, the extent of changes observed, and the degree of improvement over time. Additionally, the data were categorized by sex and age to investigate the relationships between these demographic factors, solar terms, insomnia severity, sleep changes, and the efficacy of patient recovery. Ultimately, a Seasonal Autoregressive Integrated Moving Average (SARIMA) model was employed to further analyze the temporal relationships between the characteristics of solar terms and changes in insomnia severity and sleep stability.

SARIMA Model Parameters

The Seasonal Autoregressive Integrated Moving Average (SARIMA) model is a way to predict future values by using patterns from long-term trends, seasonal changes, and random changes in time-series data. The model is written as SARIMA(p, d, q)(P, D, Q) s . Here, p is the number of non-seasonal autoregressive terms. d is the number of times the data is differenced to remove trends. q is the number of non-seasonal moving average terms. $P, D,$ and Q are the same types of terms but for seasonal parts. s is the length of the seasonal cycle. In this study, since the data was grouped by the 24 Solar Terms, s was set to 24.

SARIMA Model Construction

The SARIMA model was developed through the following five steps: (1) Stabilization of the time series: The original series was assessed for stationarity through visual inspection of the raw data plot and time-series decomposition, followed by unit root testing. If the series was found to be non-stationary, differencing or seasonal differencing was applied to achieve stationarity. (2) Model parameter estimation: Taking into account both trend and seasonality, the `pm.auto_arma()` function was used to automatically identify optimal SARIMA model parameters. (3) Selection of the optimal model: Candidate models were compared comprehensively based on the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC). The fit of the optimal model was further evaluated by inspecting the autocorrelation function (ACF) and partial autocorrelation function (PACF) plots of the residuals. (4) Model diagnostics: The residuals of the selected model were subjected to the Ljung–Box test to assess white noise characteristics, along with a normality test to evaluate the distribution of residuals. (5) Model forecasting: The optimal SARIMA model was then used to forecast future trends in the time series.

SARIMA Model Evaluation and Forecasting

In this study, optimal SARIMA models were constructed using the mean PSQI total scores, PSQI score reduction, and PSQI reduction rate across the 24 Solar Terms from 2018 to 2022 in patients with chronic insomnia. The predictive performance of these models was evaluated by comparing the forecasted values with the actual observed means for each metric during the 24 Solar Terms in 2023. Finally, the models were used to forecast the trends of these indicators across the 24 Solar Terms in 2024.

Statistics

In this study, data processing and statistical analysis were performed using SPSS version 26 and R version 4.3.2. Measurement data were expressed as mean \pm standard deviation ($x \pm s$), while categorical data were summarized as frequencies (n) or percentages (%). For measurement data, independent-sample t-tests or analysis of variance (ANOVA) were conducted according to the grouping. The fUnitRoots package in R was used for unit root testing, and functions from the forecast package were employed for time series forecasting. The significance level was set at $\alpha = 0.05$.

Effect sizes (eg, η^2 for ANOVA, Cohen's d for t-tests) were considered during the analysis. However, in this study, most effect size estimates were very small ($\eta^2 < 0.01$, $d < 0.2$), indicating that the proportion of variance explained by factors such as solar term or assessment timing is minimal. Therefore, effect sizes are not reported in the main text, as they do not meaningfully alter the interpretation of the findings.

Results

General Information

A total of 25,428 patients were included in the final analysis. Table 1 summarizes the demographic and clinical characteristics of the study population. Among them, 5921 (23.3%) were male and 19,507 (76.7%) were female. Participants spanned all age groups, with the largest proportion aged 45–59 years ($n = 13,143$, 51.7%) and the smallest aged ≥ 75 years ($n = 130$, 0.5%). The minimum education level required was primary school; the majority had a secondary

Table 1 Demographic and Clinical Characteristics of the Study Population (N = 25,428)

Demographic and Psychological Characteristics	Number (percentage)
Gender	
Male	5921 (23.3%)
Female	19,507 (76.7%)
Age (years)	
A. ≤ 18	248 (1.0%)
B. 19~44	8395 (33.0%)
C. 45~59	13,143 (51.7%)
D. 60~74	3512 (13.8%)
E. ≥ 75	130 (0.5%)
Educational level	
Primary school	3634 (14.3%)
Secondary school	12784 (50.3%)
Undergraduate	7759 (30.5%)
Postgraduate	821 (3.2%)
Other	430 (1.7%)
Family history	
Yes	7387 (29.0%)
No	12149 (47.8%)
Unknown	5892 (23.2%)
Disease duration	
1–3 months	5060 (19.9%)
3–12 months	4437 (17.4%)
1–3 years	4396 (17.3%)
3–5 years	3340 (13.1%)
5–10 years	8054 (31.7%)
Unknown	141 (0.6%)
Current medication use	
Yes	15197 (59.8%)
No	10231 (40.2%)

education ($n = 12,784$, 50.3%), followed by tertiary education ($n = 7759$, 30.5%). A family history of insomnia was reported in 7387 cases (29.0%), while 12,149 (47.8%) had no such history, and 5892 (23.2%) were uncertain. The most common disease duration was 5–10 years ($n = 8054$, 31.7%), followed by 1–3 months ($n = 5060$, 19.9%). At the time of assessment, 15,197 patients (59.8%) were currently using medication, while 10,231 (40.2%) were not.

Table 2 presents the distribution of patients across the 24 Solar Terms. The highest number of assessments occurred during the ‘End of Heat’ (Chushu; $n = 1250$, 4.92%), while the fewest occurred during the “Beginning of Spring” (Lichun; $n = 837$, 3.29%). A total of 8466 patients (33.29%) were assessed precisely on Solar Term points, and 16,962 (66.71%) on non-Solar Term points.

Overall Distribution Characteristics of Solar Terms in Chronic Insomnia Patients Comparison of PSQI Total Score, PSQI Reduction Score, and PSQI Reduction Rate at 24 Solar Terms in Insomnia Disorder Patients (2018–2023)

Statistical analysis suggests that the PSQI total score was highest during Grain Rain (Guyu), then Cold Dew (Hanlu). It was lowest during Minor Heat (Xiaoshu), then Heavy Snow (Daxue). The PSQI score reduction and PSQI reduction rate were both highest during Heavy Snow (Daxue), then Light Snow (Xiaoxue). They were lowest during Grain Rain (Guyu). The second lowest PSQI score reduction was during Rain Water (Yushui), and the second lowest PSQI reduction rate was during Major Cold (Dahan). There were clear differences in PSQI total score ($F = 2.017$, $P = 0.003$), PSQI score drop ($F = 3.501$, $P < 0.001$), and PSQI reduction rate ($F = 2.747$, $P < 0.05$) across different Solar Terms. These findings indicate potential seasonal variation in insomnia severity, sleep fluctuation, and improvement across the 24 Solar Terms (See Figure 1).

Table 2 Distribution Characteristics of Study Subjects by Solar Terms

Solar Term(s)	Number (percentage)
Beginning of Spring(Lichun)	837(3.29%)
Rain Water(Yushui)	937(3.68%)
Awakening of Insects(Jingzhe)	897(3.53%)
Spring Equinox(Chunfen)	1123(4.42%)
Pure Brightness(Qingming)	1015(3.99%)
Grain Rain(Guyu)	1063(4.18%)
Beginning of Summer(Lixia)	1085(4.27%)
Grain Full(Xiaoman)	1241(4.88%)
Grain in Ear(Mangzhong)	1019(4.01%)
Summer Solstice(Xiazhi)	1139(4.48%)
Minor Heat(Xiaoshu)	1188(4.67%)
Major Heat(Dashu)	1166(4.59%)
Beginning of Autumn(Liqiu)	1044(4.11%)
End of Heat(Chushu)	1250(4.92%)
White Dew(Bailu)	1043(4.10%)
Autumn Equinox(Qiufen)	1094(4.30%)
Cold Dew(Hanlu)	1025(4.03%)
Frost Descent(Shuangjiang)	1054(4.15%)
Beginning of Winter(Lidong)	1094(4.30%)
Minor Snow(Xiaoxue)	1118(4.40%)
Major Snow(Daxue)	1009(3.97%)
Winter Solstice(Dongzhi)	1050(4.13%)
Minor Cold(Xiaohan)	999(3.93%)
Major Cold(Dahan)	938(3.69%)
Solar Term Point	
Yes	8466(33.92%)
No	16962(66.71%)

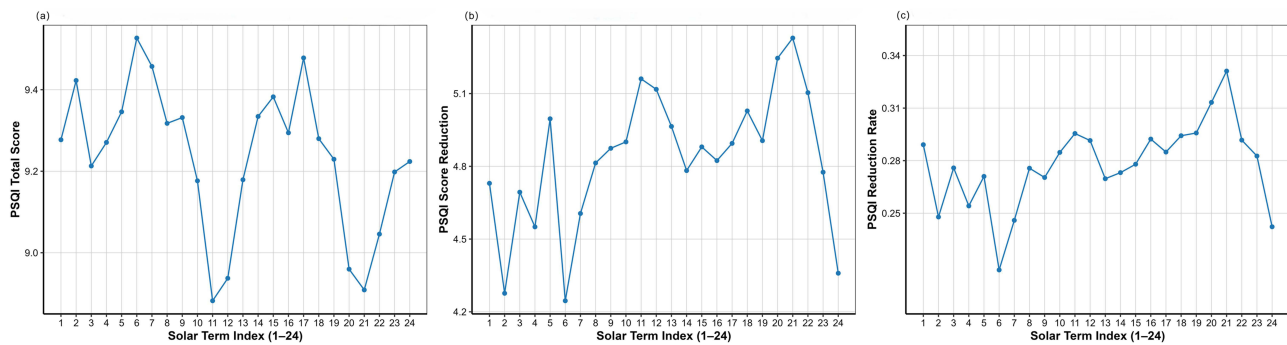


Figure 1 Comparison of (a) PSQI total score, (b) PSQI score reduction, and (c) PSQI reduction rate across the 24 solar terms in patients with insomnia disorder across solar terms (2018–2023). All three measures showed significant seasonal variation ($P < 0.05$), indicating fluctuations in insomnia severity, sleep fluctuation, and improvement throughout the year.

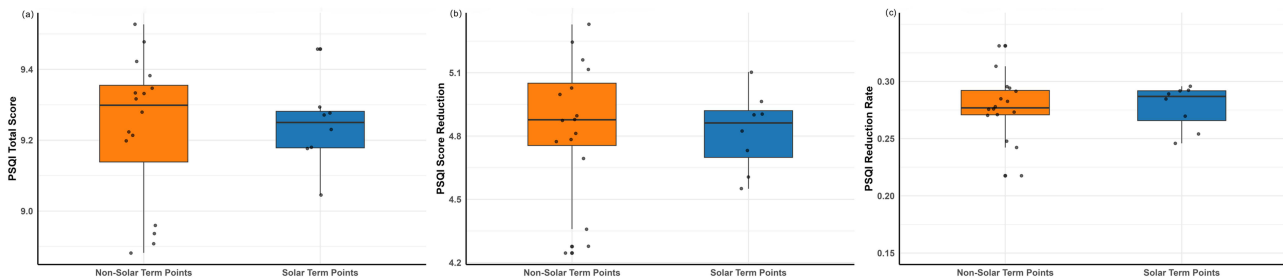


Figure 2 Comparison of (a) PSQI total score, (b) PSQI score reduction, and (c) PSQI reduction rate between solar term points and non - solar term points in patients with insomnia disorder (2018–2023). Each dot represents the mean at a given time point; boxes show interquartile ranges, and horizontal lines indicate medians. No significant differences were found between solar term points and non-solar term points in any measure (all $P > 0.05$).

Comparison of PSQI Total Score, PSQI Reduction Score, and PSQI Reduction Rate Between Solar Term Points and Non-Solar Term Points in Insomnia Disorder Patients (2018–2023)

To see if solar terms affect sleep, each “solar term point” was set as a 15-day period. This included the solar term day and the 7 days before and after. Eight main solar term points were chosen: Beginning of Winter (Lidong), Winter Solstice (Dongzhi), Beginning of Spring (Lichun), Spring Equinox (Chunfen), Beginning of Summer (Lixia), Summer Solstice (Xiazhi), Beginning of Autumn (Liqiu), and Autumn Equinox (Qiu fen). Comparisons revealed no statistically meaningful differences in PSQI total score ($t = -0.212, P = 0.832$), PSQI score reduction ($t = 0.470, P = 0.638$), or PSQI reduction rate ($t = -0.134, P = 0.893$) between the solar term points and the other times. This means how bad the insomnia was, how much it changed, and how much it got better had nothing to do with whether the test happened during a solar term point (See Figure 2).

Distribution of Solar Terms Among Patients of Different Genders

Comparison of PSQI Total Score, PSQI Score Reduction, and PSQI Reduction Rate at 24 Solar Terms Among Insomnia Patients of Different Genders (2018–2023)

There was no clear difference in PSQI total scores between male and female patients across different solar terms ($t = 1.223, P = 0.221$). But for PSQI score reduction ($t = -4.923, P < 0.001$) and PSQI reduction rate ($t = -2.068, P < 0.009$), the average values were higher in women than in men. This means that men and women had about the same level of insomnia during different solar terms, but women’s sleep variability and improvement are more easily influenced by changes in solar terms.

Further analysis showed that there were no clear differences in PSQI total scores ($F = 1.007, P = 0.451$) or PSQI reduction rate ($F = 1.436, P = 0.081$) among male patients with insomnia across the 24 solar terms. This means that changes between solar terms did not clearly affect how serious their insomnia was or how much it improved. But the PSQI score reduction showed a clear difference ($F = 1.904, P = 0.006$), which means that solar term transitions may have

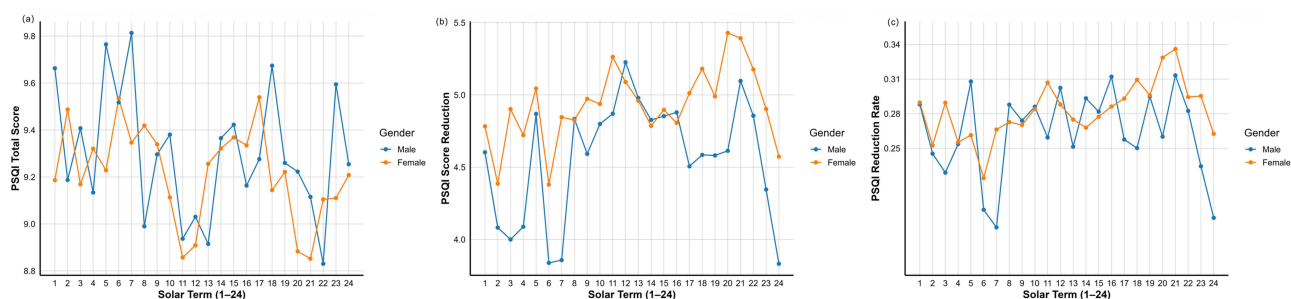


Figure 3 Comparison of (a) PSQI total scores, (b) PSQI score reduction, and (c) PSQI reduction rate between male and female patients with insomnia disorder across solar terms (2018–2023). No significant gender difference was found in total scores, but females showed greater score reduction and reduction rates ($P < 0.01$). Seasonal variation was significant in all three measures for females ($P < 0.01$), while only score reduction varied significantly in males ($P = 0.006$), suggesting stronger sensitivity to seasonal change in women.

some effect on sleep fluctuation in men. For female patients, there were clear differences in PSQI total score ($F = 1.949$, $P = 0.004$), PSQI score reduction ($F = 2.333$, $P < 0.001$), and PSQI reduction rate ($F = 2.238$, $P = 0.001$) across the solar terms. The follow-up analysis of PSQI score reduction showed a trend toward difference ($P = 0.063$). This suggests that solar term transitions had a stronger effect on women, leading to bigger changes in insomnia severity, sleep fluctuation, and improvement at different times of the year (See Figure 3).

Comparison of PSQI Total Score, PSQI Score Reduction, and PSQI Reduction Rate Between Solar Term Points and Non-Solar Term Points Among Insomnia Patients of Different Genders (2018–2023)

To better understand how solar term points affect sleep in men and women with insomnia, we compared PSQI-related data between solar term points and non-solar term points for both groups. The results showed no clear difference in PSQI total scores between men and women at either solar term points or non-solar term points ($t = 1.330$, $P = 0.184$). This means that being in a solar term point does not have a big effect on how serious insomnia is in men or women. But there was greater differences in PSQI score reduction between men and women, both at solar term points ($t = -4.129$, $P < 0.001$) and non-solar term points ($t = -2.687$, $P = 0.007$). This means that solar term points may have more of an effect on how much sleep changes in different genders. There was no clear difference in PSQI reduction rate between men and women at solar term points ($t = -1.039$, $P = 0.299$). But at non-solar term points, there was a clear difference ($t = -2.462$, $P = 0.014$), which means that sleep improvement was greater outside of solar term points. In short, whether or not a person is assessed during a solar term point does not seem to affect how bad their insomnia is, but it may be related to how much their sleep changes or improves (See Figure 4).

Comparison of PSQI Total Score, PSQI Score Reduction, and PSQI Reduction Rate Between Solar Term Points and Non-Solar Term Points in Male and Female Insomnia Patients (2018–2023)

Statistical analysis showed that for both men and women with insomnia, there was no clear difference in the average PSQI total score, PSQI score reduction, or PSQI reduction rate between solar term points and non-solar term points (all $P > 0.05$). This means that seasonal changes marked by solar term points did not have a big effect on how bad the insomnia was, how much sleep changed, or how much it improved within each group (See Figure 5–6).

Distribution of the 24 Solar Terms Among Insomnia Patients of Different Age Groups Comparison of PSQI Total Score, PSQI Score Reduction, and PSQI Reduction Rate Across Age Subgroups in Patients with Insomnia Disorder (2018–2023)

To better understand how solar terms affect sleep quality and stability, we looked at different age groups. Participants were divided into five age groups (see Table 1 for details). ANOVA showed clear differences between age groups in PSQI total score ($F = 35.278$, $P < 0.05$), PSQI score reduction ($F = 24.063$, $P < 0.05$), and PSQI reduction rate ($F = 21.717$, $P < 0.05$). This means that changes in insomnia severity, sleep fluctuation, and improvement with the solar termination are not the same for all ages.

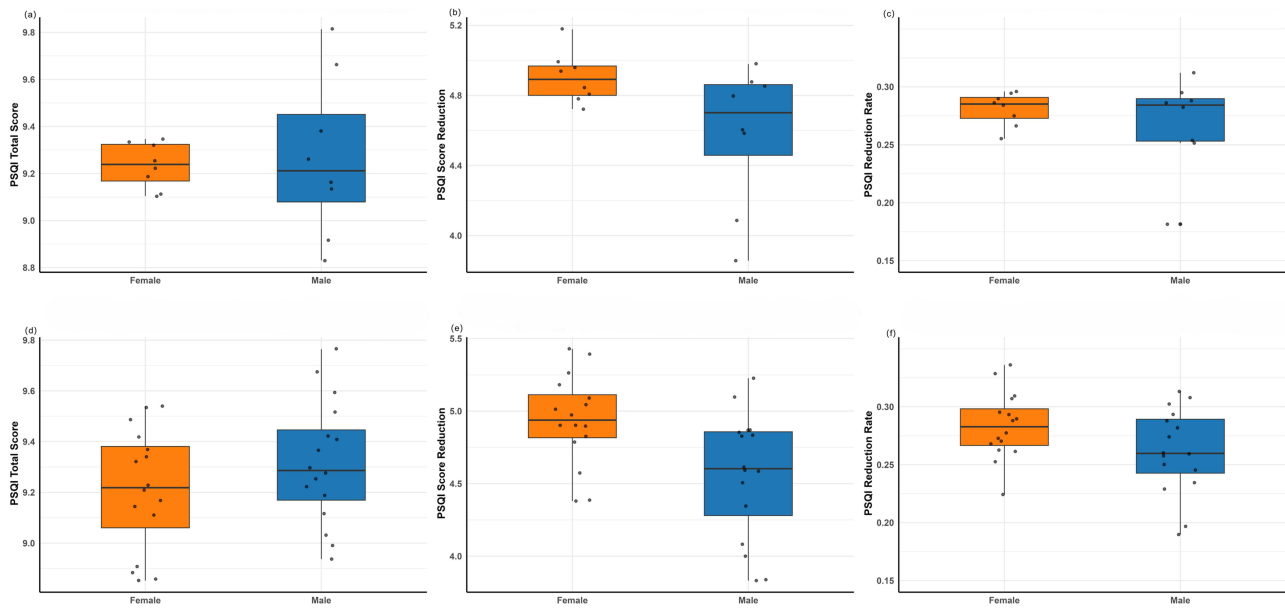


Figure 4 Comparison of PSQI indicators in male and female patients with insomnia disorder (2018–2023): (a) PSQI total scores, (b) PSQI score reduction, and (c) PSQI reduction rate across solar terms; (d) PSQI total scores, (e) PSQI score reduction, and (f) PSQI reduction rate across non-solar terms. No significant gender differences were found in PSQI total scores at either time point ($P > 0.05$). Significant differences between genders were observed in score reduction at both solar term points and non-solar term points ($P < 0.01$), and in reduction rate at non-solar term points ($P = 0.014$), indicating gender-related variation in sleep changes and improvement.

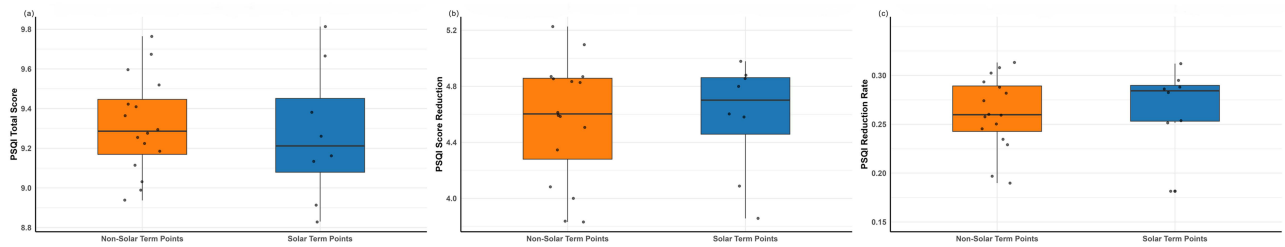


Figure 5 Comparison of (a) PSQI total score, (b) PSQI score reduction, and (c) PSQI reduction rate between solar term points and non-solar term points in male patients with insomnia disorder (2018–2023). No significant differences were found between solar term points and non-solar term points in any measure (all $P > 0.05$).

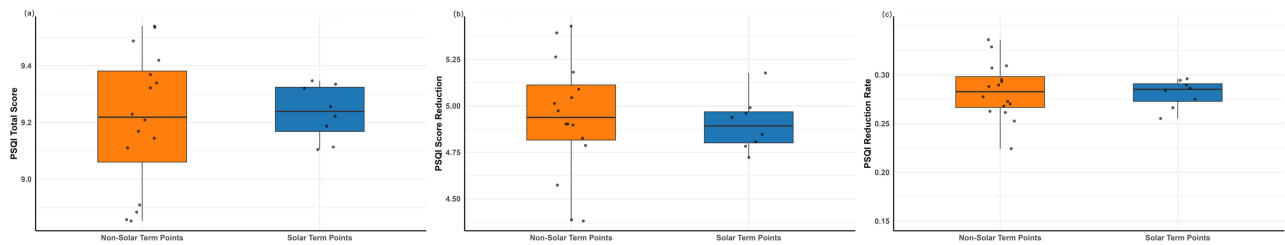


Figure 6 Comparison of (a) PSQI total score, (b) PSQI score reduction, and (c) PSQI reduction rate between solar term points and non-solar term points in female patients with insomnia disorder (2018–2023). Similar to men, no significant differences were observed between time points in any measure (all $P > 0.05$).

Among patients aged 45–59 years with chronic insomnia, there were clear differences in PSQI total scores ($F = 1.983$, $P = 0.003$), PSQI score reduction ($F = 1.812$, $P = 0.010$), and PSQI reduction rate ($F = 1.891$, $P = 0.006$) across different solar terms. All differences were statistically evident. In patients aged 60–74 years, PSQI score reduction also showed notable differences ($F = 1.812$, $P = 0.010$), but PSQI total scores ($F = 1.301$, $P = 0.153$) and PSQI reduction rate ($F = 1.294$, $P = 0.157$) did not. For the other three age groups, there were no significant differences in any of the PSQI-related

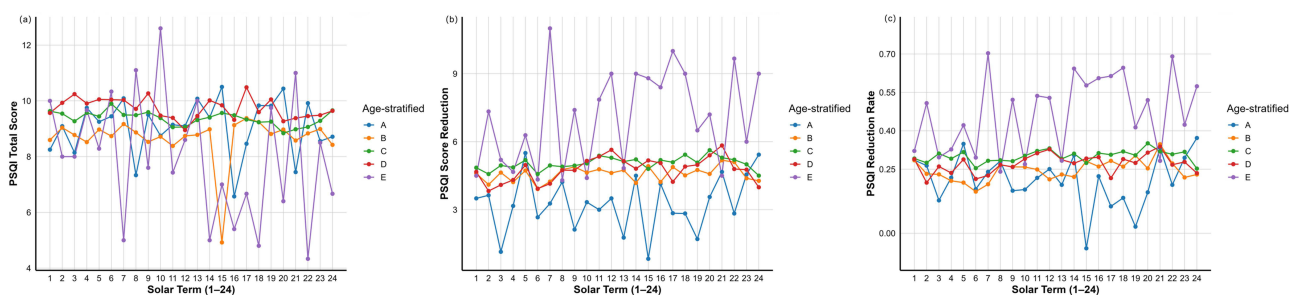


Figure 7 Comparison of (a) PSQI total score, (b) PSQI score reduction, and (c) PSQI reduction rate across solar terms among age - stratified patients with insomnia disorder (2018–2023). Age groups: A ≤ 18 years, B 19–44 years, C 45–59 years, D 60–74 years, E ≥ 75 years. All three measures showed significant age-related differences ($P < 0.05$). Seasonal variation was most pronounced in the 45–59 age group (all $P < 0.05$), while only score reduction varied in the 60–74 group ($P = 0.01$). No significant seasonal patterns were found in other age groups.

scores (all $P > 0.05$). These results suggest that solar term changes mostly affect sleep variability in people aged 45–74, and have a stronger link with insomnia severity and improvement in the 45–59 age group (See Figure 7).

Comparison of PSQI Total Score, PSQI Score Reduction, and PSQI Reduction Rate Between Solar Term Points and Non-Solar Term Periods Across Age Subgroups in Patients with Insomnia Disorder (2018–2023)
 Statistical analysis showed that in all age groups, there were no clear differences in average PSQI total scores, PSQI score reduction, or PSQI reduction rate between solar term points and non-solar term points (all $P > 0.05$). This means that the changes during solar terms were not clearly linked to how bad the insomnia was, how much sleep changed, or how much it got better in different age groups (see Figure 8).

ARIMA Time Series Analysis

Stationarization of the Time Series

Overview of PSQI Total Score, PSQI Score Reduction, and PSQI Reduction Rate

From 2018 to 2022, PSQI total scores across the 24 Solar Terms appeared to gradually decrease. In 2021 and 2022, the

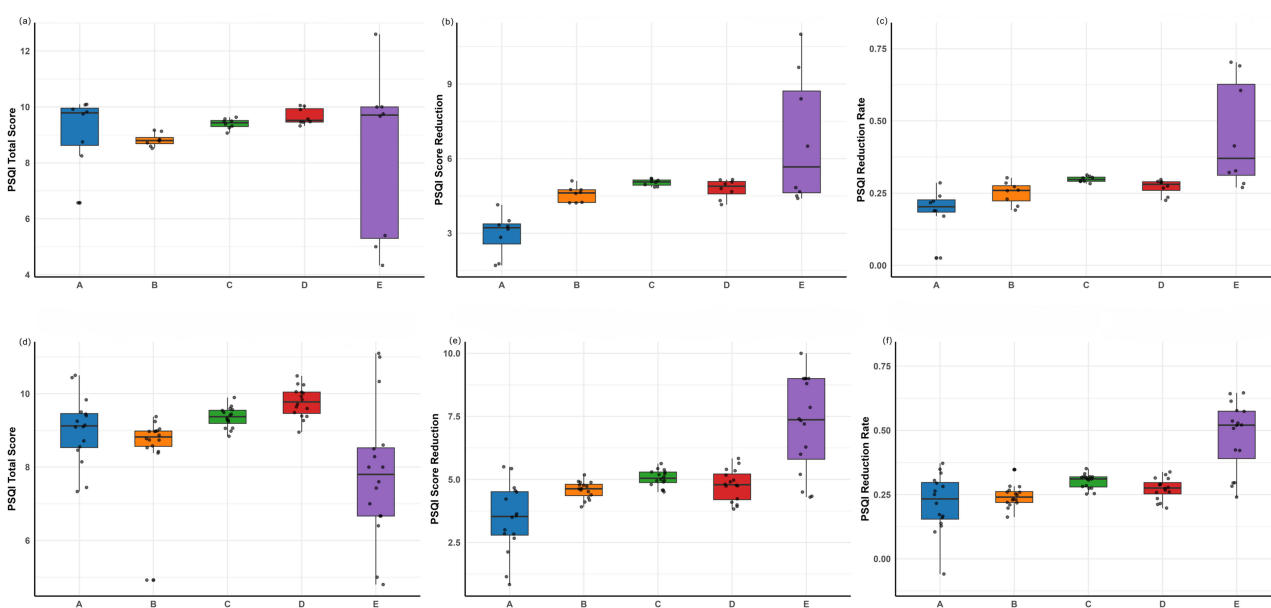


Figure 8 Comparison of PSQI indicators among age-stratified patients with insomnia disorder(2018–2023): (a) PSQI total scores, (b) PSQI score reduction, and (c) PSQI reduction rate across solar terms; (d) PSQI total scores, (e) PSQI score reduction, and (f) PSQI reduction rate across non-solar terms. Age groups: A ≤ 18 years, B 19–44 years, C 45–59 years, D 60–74 years, E ≥ 75 years. No significant differences were found between solar term and non-solar term points in any measure across all age groups (all $P > 0.05$).

scores changed more often, with a small increase overall. The short-term line often went up and down, which may mean the scores follow a regular or seasonal pattern. During the same time, the PSQI score reduction showed bigger changes, especially after 2021. The overall direction was upward. The many small peaks and dips also suggest a short-term pattern that may repeat over time. The PSQI reduction rate mostly went up from 2018 to 2022, but the line did not show a clear repeating pattern. This needs more study to understand better (see Figure 9).

Original Time Series

Time series decomposition plots for PSQI total scores, PSQI score reduction, and PSQI reduction rate from 2018 to 2022 were made using the decompose function in R. This was done to look at the long-term trend, seasonal changes, and random changes in the data.

The PSQI total score appeared to follow a generally stable trend, with a slight decrease around 2020 and relative stabilization after 2022. Seasonal variation was suggested, with higher scores tending to occur during summer solar terms and lower scores during winter ones, indicating a possible annual cycle. The random component remained within a relatively stable range. PSQI score reduction showed an overall upward tendency and appeared to exhibit seasonal variation, with higher values in winter and lower in summer. Some fluctuations in the random component were observed, potentially due to external factors. The PSQI reduction rate also tended to increase over time and displayed intermittent seasonal fluctuations, with occasional larger variations in 2019 and 2021, while remaining relatively small at other times. These patterns suggest possible seasonal influences on sleep quality and variability, though further investigation is needed (see Figure 10).

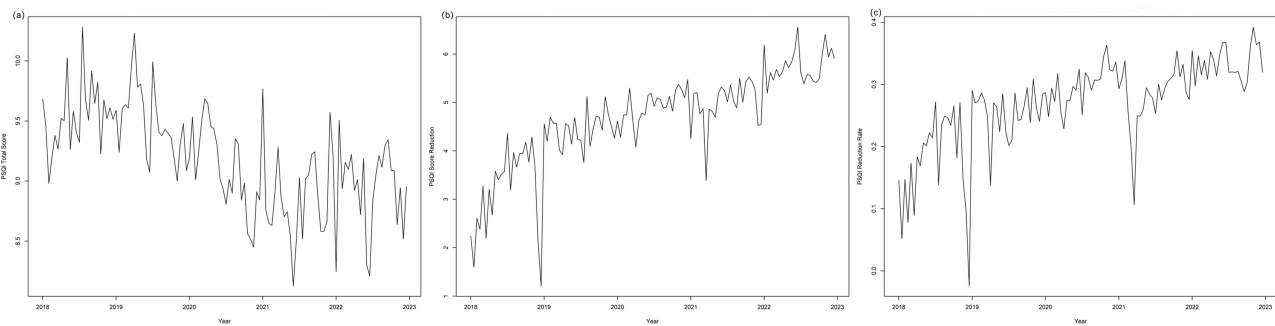


Figure 9 (a) PSQI total score, (b) PSQI score reduction, and (c) PSQI reduction rate, showing yearly trends across the 24 Solar Terms (2018–2022). PSQI total scores gradually declined from 2018 to 2020, with increased short-term fluctuations in 2021–2022. Score reduction showed greater variability and an overall upward trend, especially after 2021, suggesting possible seasonal patterns. Reduction rate also increased over time, though without a clearly repeating pattern.

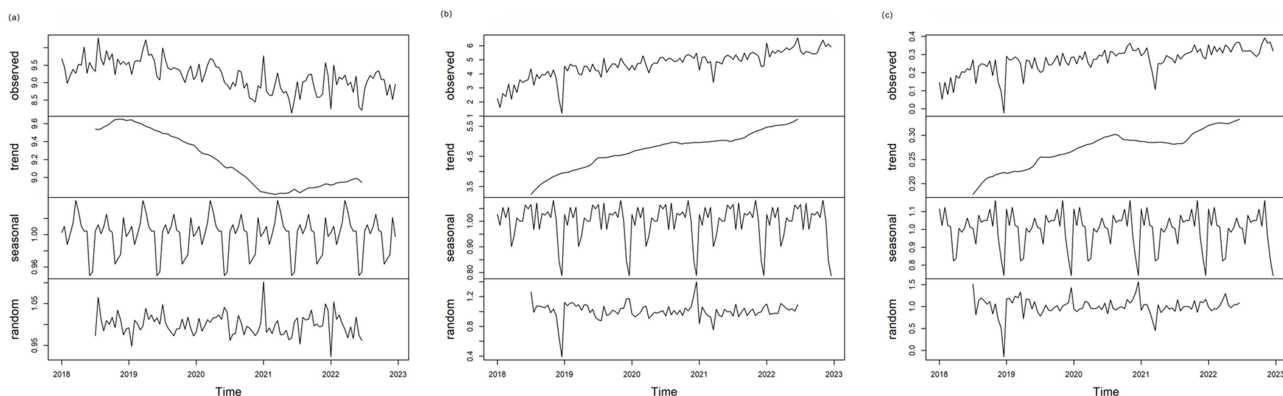


Figure 10 Time series decomposition of (a) PSQI total score, (b) PSQI score reduction, and (c) PSQI reduction rate (2018–2022). All three indicators showed clear seasonal patterns. PSQI total score peaked in summer and dropped in winter, while PSQI score reduction peaked in winter and dipped in summer. The PSQI reduction rate showed multiple seasonal fluctuations each year. Trends and random components remained generally stable, with occasional variability in specific years.

Model Parameter Estimation

Unit root tests were conducted on the PSQI total score time series, PSQI score reduction time series, and PSQI reduction rate time series for the period of 2018 to 2022 using the `adfTest` function from the `tseries` package in R. The results indicated that the PSQI total score time series had a unit root test statistic of $DF = -4.048$ with $P = 0.01$, the PSQI score reduction time series had $DF = -4.6277$ with $P = 0.01$, and the PSQI reduction rate time series had $DF = -4.8071$ with $P = 0.01$. All series were found to be stationary, and thus no differencing was required.

Selection of the Optimal Model

In time series analysis, to avoid overfitting from setting the model orders too high, the p , d , and q values are usually not set above 2. In R, AIC and BIC are often used to choose the best model. The smaller the AIC and BIC, the better the model fits the data.

The SARIMA models for PSQI total score and PSQI score reduction were chosen using the `pm.auto.arima()` function. Based on AIC and BIC, different candidate models were compared (see Tables 3–4). In the end, the SARIMA(1, 0, 1)(0, 1, 1)₂₄ model was picked as the best one. The ACF and PACF plots of the model's residuals showed that most values stayed within the confidence range. This means that the residuals had no clear patterns or correlations, and the model fit the data well.

The same method was used for the PSQI reduction rate. The `pm.auto.arima()` function picked a model, and AIC and BIC were used to compare different options (see Table 5). The SARIMA(1, 0, 1)(1, 0, 1)₂₄ model was finally selected.

The ACF and PACF plots showed that most values were inside the confidence limits. This means that the residuals had no obvious patterns or correlations, and the model fit well (see Figure 11).

Table 3 AIC and BIC Values of Different Models for the PSQI Total Score Time Series

Fitted model	AIC	BIC
SARIMA(1,0,1) (0,1,1) ₂₄	85.18836	95.44575
SARIMA(1,0,1) (1,1,1) ₂₄	84.53788	97.35962
SARIMA(1,0,1) (2,1,1) ₂₄	86.41958	101.8057

Table 4 AIC and BIC Values of Different Models for the PSQI Score Reduction Time Series

Fitted model	AIC	BIC
SARIMA(1,0,1) (0,1,1) ₂₄	182.4082	192.6656
SARIMA(1,0,1) (0,1,0) ₂₄	196.057	203.7501
SARIMA(1,0,1) (1,1,0) ₂₄	190.7503	201.0077

Table 5 AIC and BIC Values of Different Models for the PSQI Reduction Rate Time Series

Fitted model	AIC	BIC
SARIMA(1,0,1) (0,1,1) ₂₄	-268.2668	-258.0094
SARIMA(1,0,1) (0,1,0) ₂₄	-260.5799	-252.8869
SARIMA(1,0,1) (1,0,1) ₂₄	-369.045	-352.3201
SARIMA(2,1,0) (1,0,0) ₂₄	-360.64	-346.75

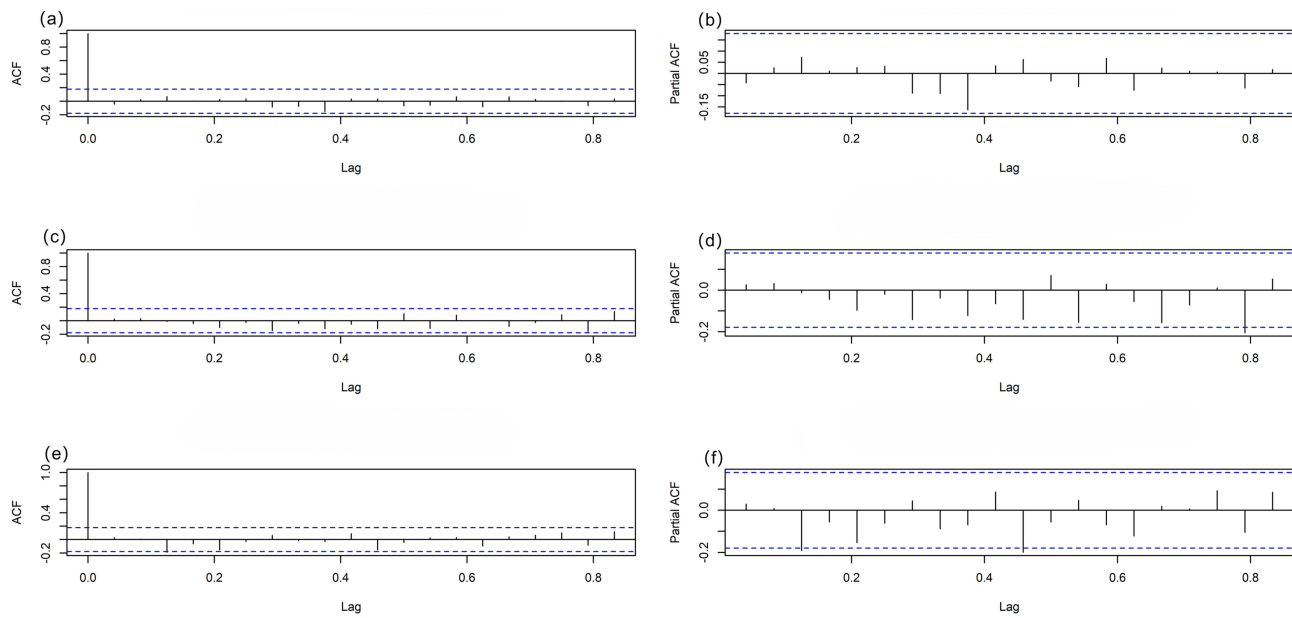


Figure 11 ACF (Autocorrelation Function) and PACF (Partial Autocorrelation Function) plots of residuals for the selected SARIMA models: (a and b) PSQI total score residuals of SARIMA(1,0,1)(0,1,1)_[24] ((a) ACF, (b) PACF); (c and d) PSQI score reduction residuals of SARIMA(1,0,1)(0,1,1)_[24] ((c) ACF, (d) PACF); (e and f) PSQI reduction rate residuals of SARIMA(1,0,1)(1,0,1)_[24] ((e) ACF, (f) PACF). In all three models, most ACF and PACF values remained within confidence intervals, indicating no significant autocorrelation and a good model fit.

Model Validation

Model Diagnostics

Ljung–Box tests were used on the residuals of the SARIMA(1, 0, 1)(0, 1, 1)_[24] model for the PSQI total score sequence ($\chi^2 = 18.679$, $P = 0.7689$), the same model for the PSQI score reduction sequence ($\chi^2 = 27.86$, $P = 0.266$), and the SARIMA(1, 0, 1)(1, 0, 1)_[24] model for the PSQI reduction rate sequence ($\chi^2 = 10.05$, $P = 0.4361$). All results showed that the residuals were white noise.

The residuals of all three models were also checked for normality using density plots and Q–Q plots. The density plots looked like normal distributions centered around zero. The Q–Q plots showed that most points were close to the line. These results mean that the residuals were mostly independent and normally distributed (See Figure 12).

Model Performance Evaluation

The fitted models were checked using the 2023 data for PSQI total score, PSQI score reduction, and PSQI reduction rate. The fitted curves for all three indicators were very close to the actual curves. Most of the actual values during the 24 solar terms in 2023 were inside the confidence intervals of the predicted values. These findings suggest that the models reasonably capture short-term patterns in PSQI outcomes, although predictions should be interpreted with caution given potential influences from unmeasured factors (See Figure 13).

Prediction of PSQI Total Score, PSQI Score Reduction, and PSQI Reduction Rate for 2024

The forecast function was used to predict the 2024 values based on the SARIMA (1,0,1)(0,1,1)_[24] model for PSQI total score and PSQI score reduction. The highest predicted PSQI total scores were at Grain Rain (Guyu) and Cold Dew (Hanlu), both at 9.26. The lowest score was at Great Heat (Dashu), at 8.60. The average score across all solar terms was 8.99. The PSQI total score curve had a small peak between Winter Solstice (Dongzhi) and Greater Cold (Dahan), and two larger peaks between Spring Equinox (Chunfen) and Grain Full (Xiaoman), and between White Dew (Bailu) and Beginning of Winter (Lidong) (see Table 6).

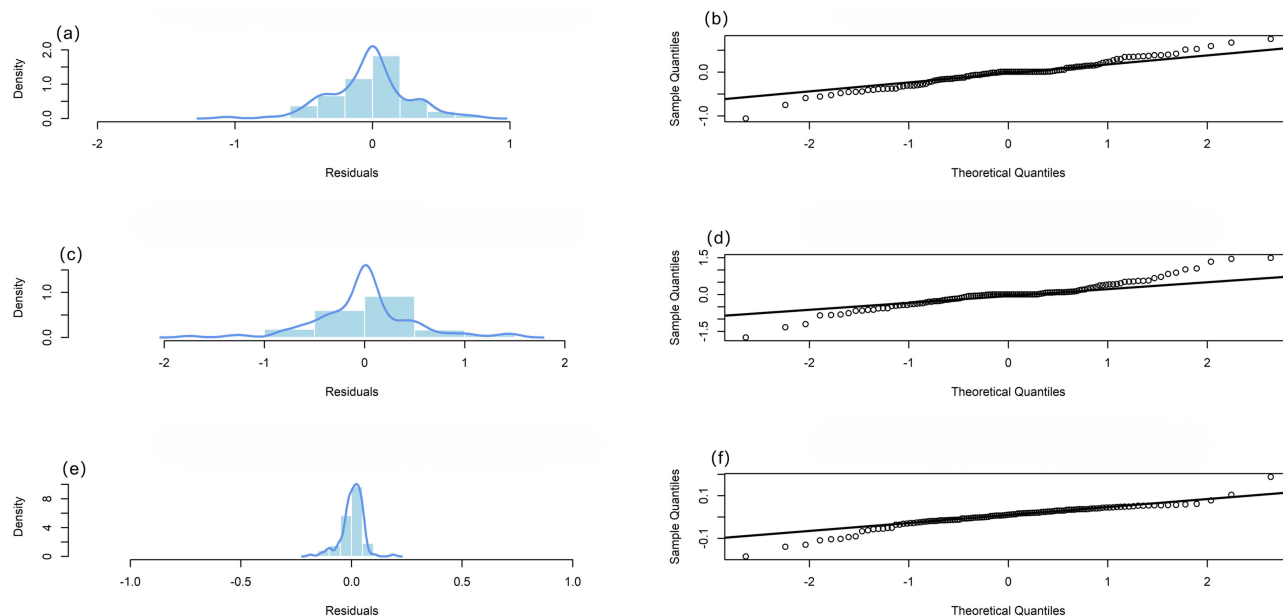


Figure 12 Diagnostic plots of residuals for the selected SARIMA models (Density plots showed near-normal distributions centered around zero. Q-Q plots indicated most residuals followed the reference line): (a and b) PSQI total score residuals of SARIMA(1,0,1)(0,1,1)[24] ((a) density plot, (b) Q-Q plot); (c and d) PSQI score reduction residuals of SARIMA(1,0,1)(0,1,1)[24] ((c) density plot, (d) Q-Q plot); (e and f) PSQI reduction rate residuals of SARIMA(1,0,1)(1,0,1)[24] ((e) density plot, (f) Q-Q plot). Together, these results suggest the residuals were independent and approximately normally distributed, supporting good model fit.

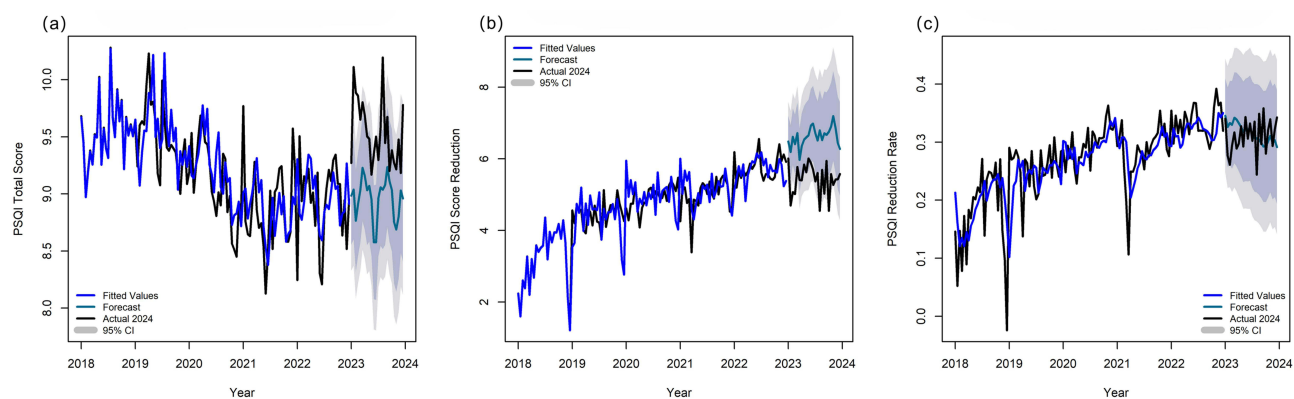


Figure 13 Model predictions for (a) PSQI total score, (b) PSQI score reduction, and (c) PSQI reduction rate in 2023. The predicted curves closely matched the actual values across the 24 solar terms, with most observed points falling within the confidence intervals, indicating good model accuracy and short-term predictive validity.

For PSQI score reduction, the highest predicted value was at Heavy Snow (Daxue) with 7.79, and the lowest was at Grain Rain (Guyu) with 6.58. The average across all solar terms was 7.22. The score reduction curve showed a small peak between Summer Solstice (Xiazhi) and Limit of Heat (Chushu), and a bigger peak between Beginning of Winter (Lidong) and Lesser Cold (Xiaohan) (see Table 7).

The PSQI reduction rate for 2024 was predicted using the SARIMA (1,0,1)(1,0,1)₂₄ model. The highest predicted rate was at Rain Water (Yushui) at 0.2931. The lowest was at Heavy Snow (Daxue) at 0.2621. The average rate was 0.2746. The reduction rate curve had two small peaks, one from Beginning of Spring (Lichun) to Awakening of Insects (Jingzhe), and another from Grain Full (Xiaoman) to Summer Solstice (Xiazhi) (see Table 8).

Table 6 Predicted PSQI Total Score for Each Solar Term in 2024

Solar Term(s)	Forecasted Value(s)	Lower 95% Confidence Limit	Upper 95% Confidence Limit
Beginning of Spring(Lichun)	9.02	8.14	9.89
Rain Water(Yushui)	9.07	8.19	9.96
Awakening of Insects(Jingzhe)	8.80	7.91	9.69
Spring Equinox(Chunfen)	8.94	8.04	9.84
Pure Brightness(Qingming)	9.07	8.16	9.97
Grain Rain(Guyu)	9.26	8.35	10.17
Beginning of Summer(Lixia)	9.19	8.27	10.11
Grain Full(Xiaoman)	9.06	8.14	9.99
Grain in Ear(Mangzhong)	9.10	8.17	10.03
Summer Solstice(Xiazhi)	8.98	8.04	9.92
Minor Heat(Xiaoshu)	8.61	7.66	9.55
Major Heat(Dashu)	8.60	7.66	9.55
Beginning of Autumn(Liqiu)	8.99	8.04	9.95
End of Heat(Chushu)	9.09	8.13	10.04
White Dew(Bailu)	9.06	8.10	10.03
Autumn Equinox(Qiufen)	9.10	8.14	10.07
Cold Dew(Hanlu)	9.26	8.29	10.23
Frost Descent(Shuangjiang)	9.14	8.16	10.11
Beginning of Winter(Lidong)	9.06	8.08	10.04
Minor Snow(Xiaoxue)	8.78	7.79	9.76
Major Snow(Daxue)	8.71	7.72	9.70
Winter Solstice(Dongzhi)	8.82	7.83	9.82
Minor Cold(Xiaohan)	9.05	8.06	10.05
Major Cold(Dahan)	8.98	7.99	9.98

Table 7 Predicted PSQI Score Reduction for Each Solar Term in 2024

Solar Term(s)	Forecasted Value(s)	Lower 95% Confidence Limit	Upper 95% Confidence Limit
Beginning of Spring(Lichun)	7.10	4.99	9.21
Rain Water(Yushui)	6.81	4.65	8.96
Awakening of Insects(Jingzhe)	7.23	5.03	9.43
Spring Equinox(Chunfen)	7.03	4.78	9.27
Pure Brightness(Qingming)	7.34	5.05	9.62
Grain Rain(Guyu)	6.58	4.26	8.91
Beginning of Summer(Lixia)	6.97	4.61	9.33
Grain Full(Xiaoman)	7.15	4.74	9.55
Grain in Ear(Mangzhong)	7.21	4.77	9.66
Summer Solstice(Xiazhi)	7.26	4.78	9.74
Minor Heat(Xiaoshu)	7.53	5.01	10.05
Major Heat(Dashu)	7.59	5.04	10.15
Beginning of Autumn(Liqiu)	7.31	4.72	9.90
End of Heat(Chushu)	7.11	4.49	9.74
White Dew(Bailu)	7.40	4.74	10.06
Autumn Equinox(Qiufen)	7.12	4.43	9.82
Cold Dew(Hanlu)	7.32	4.59	10.04
Frost Descent(Shuangjiang)	7.27	4.51	10.03

(Continued)

**Table 7** (Continued).

Solar Term(s)	Forecasted Value(s)	Lower 95% Confidence Limit	Upper 95% Confidence Limit
Beginning of Winter(Lidong)	7.36	4.56	10.15
Minor Snow(Xiaoxue)	7.50	4.67	10.32
Major Snow(Daxue)	7.79	4.94	10.65
Winter Solstice(Dongzhi)	7.45	4.56	10.34
Minor Cold(Xiaohan)	7.03	4.12	9.95
Major Cold(Dahan)	6.87	3.92	9.82

Table 8 Predicted PSQI Reduction Rate for Each Solar Term in 2024

Solar Term(s)	Forecasted Value(s)	Lower 95% Confidence Limit	Upper 95% Confidence Limit
Beginning of Spring(Lichun)	0.2891	0.1357	0.4427
Rain Water(Yushui)	0.2931	0.1385	0.4476
Awakening of Insects(Jingzhe)	0.2877	0.1321	0.4432
Spring Equinox(Chunfen)	0.2861	0.1296	0.4425
Pure Brightness(Qingming)	0.2791	0.1218	0.4363
Grain Rain(Guyu)	0.2777	0.1197	0.4357
Beginning of Summer(Lixia)	0.2775	0.1189	0.4361
Grain Full(Xiaoman)	0.2777	0.1185	0.4368
Grain in Ear(Mangzhong)	0.2784	0.1187	0.4381
Summer Solstice(Xiazhi)	0.2752	0.1151	0.4354
Minor Heat(Xiaoshu)	0.2730	0.1124	0.4336
Major Heat(Dashu)	0.2704	0.1094	0.4313
Beginning of Autumn(Liqiu)	0.2727	0.1113	0.4340
End of Heat(Chushu)	0.2729	0.1112	0.4345
White Dew(Bailu)	0.2715	0.1096	0.4334
Autumn Equinox(Qiufen)	0.2711	0.1089	0.4332
Cold Dew(Hanlu)	0.2714	0.1090	0.4338
Frost Descent(Shuangjiang)	0.2723	0.1097	0.4349
Beginning of Winter(Lidong)	0.2709	0.1081	0.4337
Minor Snow(Xiaoxue)	0.2668	0.1038	0.4297
Major Snow(Daxue)	0.2621	0.0990	0.4252
Winter Solstice(Dongzhi)	0.2652	0.1020	0.4285
Minor Cold(Xiaohan)	0.2626	0.0992	0.4260
Major Cold(Dahan)	0.2658	0.1023	0.4293

Discussion

This study analyzed data collected between January 1, 2018, and December 31, 2023, to examine the association between the 24 Solar Terms and sleep quality and stability in patients with chronic insomnia. The findings indicated that variations across the Solar Terms were associated to some extent with changes in both sleep quality and sleep stability. Moreover, similar associations between seasonal or climatic factors and sleep have been reported in international studies,¹³ suggesting that our findings are consistent with broader evidence rather than representing a unique phenomenon.

Looking at sleep quality, the highest PSQI total scores were observed during the Grain Rain (Guyu) and Cold Dew (Hanlu), suggesting a tendency toward poorer sleep in these periods. Conversely, the lowest PSQI scores occurred during Minor Heat (Xiaoshu) and Major Snow (Daxue), suggesting relatively improved sleep quality during these intervals.

For sleep improvement and stability, the PSQI score reduction and reduction rate reached their highest levels during Major Snow (Daxue), followed by Minor Snow (Xiaoxue), suggesting relatively greater improvements and stability in

sleep during these periods. In contrast, the lowest PSQI reduction values were observed during Grain Rain (Guyu) and Rain Water (Yushui), while the lowest reduction rates occurred during Grain Rain (Guyu) and Major Cold (Dahan), indicating limited improvement and less stable sleep at these times.

Environmental and seasonal dynamics may partly explain the observed variations across solar terms. For example, Grain Rain (Guyu) and Rain Water (Yushui) often have large temperature swings, high humidity, and unstable sunlight, which may impair thermoregulation, alter airway lining tension, and activate wakefulness-related neurons, contributing to poorer sleep quality.^{14–17} Cold Dew (Hanlu) and Great Cold (Dahan) bring sudden cold, lower serotonin, higher norepinephrine, changes in sleep/wake-related gene activity, and sympathetic activation, which may increase nighttime awakenings and reduce sleep stability.¹⁸ Light exposure variations during these solar terms can further affect melatonin and cortisol rhythms, compounding the impact on circadian alignment.^{19,20} In contrast, Slight Heat (Xiaoshu) presents relatively steady temperatures and daylight,^{21,22} while Light Snow (Xiaoxue) and Heavy Snow (Daxue) offer longer nights and moderate cold,^{23,24} conditions that favor melatonin secretion and more consolidated sleep. These results are consistent with other studies showing that both excessive heat and extreme cold may impair sleep, while moderate and predictable environmental conditions tend to promote stability.⁴ Beyond meteorological conditions, psychosocial and behavioral factors also play an important role in seasonal variations in sleep. In spring, the solar terms of Rain Water (Yushui) and Grain Rain (Guyu) are often accompanied by unstable weather, large day–night temperature differences, and increased humidity. These environmental changes can directly disrupt circadian rhythms and impair thermoregulation. At the same time, seasonal transitions bring adjustments in daily schedules, changes in dietary habits, and variations in exposure to natural light, which may further exacerbate psychological stress or irritability, forming a chain reaction of “environmental changes → psychological stress → sleep disruption”.²⁵ This mechanism is consistent with clinical findings showing that cortisol levels in depressed patients are generally higher in spring and autumn than in summer and winter, indicating a seasonal association between mood and physiological markers.²⁶ In late autumn, during the Cold Dew (Hanlu) solar term, widened day–night temperature differences, shorter daylight hours, and sudden drops in temperature can trigger mood fluctuations, often referred to as “autumn melancholy”. Surveys have shown that adolescents exhibit higher rates of depression and anxiety symptoms in autumn compared with other seasons, and such mood disturbances can, in turn, disrupt sleep cycles by affecting neurotransmitter secretion, such as serotonin and melatonin.²⁷ Similarly, in late winter, the Great Cold (Dahan) solar term, characterized by cold, dark, and short days, may impair sleep through dual pathways: first, low temperatures enhance physiological stress responses and reduce sleep depth; second, prolonged lack of sunlight increases the risk of seasonal affective disorder.²⁸ These findings align with international studies reporting that autumn and winter are peak periods for seasonal affective disorder recurrence, ultimately creating a vicious cycle between mood and sleep quality.²⁹

From a cultural and medical perspective, these results resonate with traditional Chinese medicine (TCM) principles. TCM emphasizes “adapting to seasonal qi”, recommending heart-nourishing practices during the “Long Summer” (Slight Heat(Xiaoshu)) to maintain calmness,³⁰ and energy preservation during winter (Light Snow(Xiaoxue); Heavy Snow(Daxue)) to support recovery and restorative sleep.³¹

Further analysis indicated that while the overall severity of insomnia showed similar seasonal patterns in both men and women, women appeared to experience slightly greater fluctuations in sleep stability across the solar terms. This matches earlier international studies that found insomnia is more common in women.³² Possible contributing factors include hormonal fluctuations (eg, estrogen and progesterone), higher rates of anxiety and depression, and greater psychosocial stress related to balancing work and domestic responsibilities.^{33–35} However, these factors likely interact in complex ways, and the present study cannot establish causality.

Age-based analysis suggested that individuals aged 45 to 59 showed relatively greater sensitivity to seasonal changes in sleep, including variations in insomnia severity and sleep improvement, whereas those aged 60 to 74 primarily exhibited fluctuations in sleep stability. No clear patterns were observed in younger or older age groups. These findings are broadly consistent with a Japanese study reporting seasonal variations in sleep duration and disturbances among middle-aged and older adults.³⁶ The observed age differences may reflect age-related changes in physiological adaptability, such as altered circadian regulation and hormonal fluctuations.^{37,38}

To further explore potential short-term effects of solar terms on sleep, eight key solar terms (Lichun, Chunfen, Lixia, Xiazhi, Liqiu, Qiufen, Lidong, and Dongzhi) were analyzed using a 15-day window around each term (7 days before and after). Overall, no strong or consistent associations were observed between these solar terms and changes in insomnia severity or sleep stability, either in the entire cohort or when stratified by sex. This lack of clear effects may reflect mitigating influences of modern living conditions, such as climate-controlled environments and artificial lighting.^{39,40} Some minor differences in sleep patterns between men and women were noted, which could be influenced by sex-related physiological or behavioral factors.^{41,42}

This study used R software to build the models. The data included 144 solar terms, covering six full cycles, which met the needs for model building. Because insomnia severity, sleep changes, and improvement follow seasonal patterns, different models were tested and compared. The SARIMA(1,0,1)(0,1,1)₂₄ model was chosen for insomnia severity and sleep changes. The SARIMA(1,0,1)(1,0,1)₂₄ model was used for sleep improvement. After checking the models, the errors (residuals) looked like white noise and followed a normal pattern.

In 2024, most observed values for PSQI total score, PSQI score reduction, and PSQI reduction rate fell within the predicted confidence intervals. The PSQI total score was slightly higher than predicted ($RMSE = 0.65$, $MAPE = 6.00\%$), while the PSQI score reduction was slightly lower than expected ($RMSE = 1.28$, $MAPE = 22.48\%$). The PSQI reduction rate showed greater variability than anticipated ($RMSE = 0.09$, $MAPE = 46.19\%$). These results indicate that the SARIMA models provided a reasonable fit to the data though prediction errors were present. Such discrepancies likely reflect the preliminary nature of this study, in which numerous potential confounding factors—such as comorbid health conditions,⁴³ lifestyle habits,⁴⁴ and living environment⁴⁵—were not controlled for. In further research, we will incorporate additional variables and test alternative modeling approaches to improve predictive accuracy and better capture the complexity of insomnia dynamics.

This study looked at the link between the 24 solar terms and sleep quality and stability in people with chronic insomnia, and it also included short-term predictions. The results show that the rhythms of the traditional solar terms may help with modern sleep care. Based on these findings, sleep treatment could use ideas from Traditional Chinese Medicine's time-based methods together with modern timing treatments. This may help make personal care more accurate and timely.

This study has some limits that need to be improved in future work. First, the PSQI tool looks at sleep over a two-week period. This may smooth out short-term effects of solar-term changes and hide their real impact. Second, the PSQI is based on self-reports. Even though it is reliable, people's answers can still be affected by memory mistakes or personal thinking habits, which may lower the accuracy of the data. Third, most of the people in this study came from Jiangsu and Zhejiang. This means the results may not apply well to people in other areas. In addition, environmental factors closely related to solar terms, such as light exposure, temperature, and humidity, were not directly measured; instead, each solar term was treated as a single unit. Finally, other potential confounders, such as sleep hygiene and lifestyle habits, were not controlled, which may have affected the observed associations.

Based on the limits found in this study, future research will make several improvements. First, a group sample library for insomnia will be built. It will include tools like wearable devices to get more exact and objective data. Second, later studies will add weather data to better understand how sleep stability is linked to outside factors like light, temperature, and humidity. Also, to fix the narrow location range, data will be collected from more places to make the results more widely useful. Last but not least, potential confounders, such as sleep hygiene and lifestyle habits, will be carefully controlled to better isolate the effects of solar term changes. It should be noted that the present study represents a preliminary investigation; the next phase of research will adopt these enhanced methods to provide a more detailed and robust understanding of how solar term dynamics affect sleep in people with chronic insomnia. These efforts aim to establish a stronger foundation for the prevention and treatment of chronic insomnia in the future.

Conclusion

This study explored the association between the 24 Solar Terms and sleep quality and stability in patients with chronic insomnia, providing novel evidence that symptom fluctuations may follow predictable temporal patterns. These findings highlight the potential value of incorporating seasonal rhythms into clinical decision-making, such as optimizing the

timing of interventions and tailoring individualized sleep management strategies. Rather than replacing existing approaches, the results offer an additional perspective that may complement both conventional therapies and time-based strategies in Traditional Chinese Medicine. Nonetheless, the present work should be regarded as preliminary due to its limited geographic scope. Future research with larger, more diverse populations, objective sleep measures, and environmental variables will be essential to validate these observations and account for potential confounding factors. If confirmed, these insights may have broad clinical implications by helping to refine prevention, monitoring, and treatment of chronic insomnia in a more precise and timely manner.

Data Sharing Statement

The study data are available from the corresponding author upon request and without restriction.

Ethics Approval and Informed Consent

This study was conducted in accordance with the principles of the Declaration of Helsinki. The study protocol was reviewed and approved by the Ethics Committee of Hangzhou Seventh People's Hospital (Approval Number: Research Ethics [2024] No. 044). Given the retrospective design and use of anonymized data, the requirement for written informed consent was waived by the committee.

Author Contributions

Linlin Hu and Jiabin Wang contributed equally to this work and share first authorship. Xin Zhang and Hongjing Mao contributed equally as corresponding authors. Conceptualization: Linlin Hu, Xin Zhang, Hongjing Mao; Data Curation: Mingfen Song; Formal Analysis: Mingfen Song; Funding Acquisition: Hongjing Mao; Investigation: Hanxi Fu, Lili Yang; Methodology: Linlin Hu, Xin Zhang; Supervision: Xin Zhang, Hongjing Mao; Validation: Hongjing Mao; Visualization: Jiabin Wang; Writing – Original Draft: Linlin Hu, Jiabin Wang; Writing – Review & Editing: All authors. All authors have agreed on the journal to which the article has been submitted; have reviewed and approved the final version of the paper; and agree to be accountable for all aspects of the work.

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Disclosure

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