

Supplementary materials

Climate warming may undermine sleep duration and quality in repeated-measure study of 23 million records

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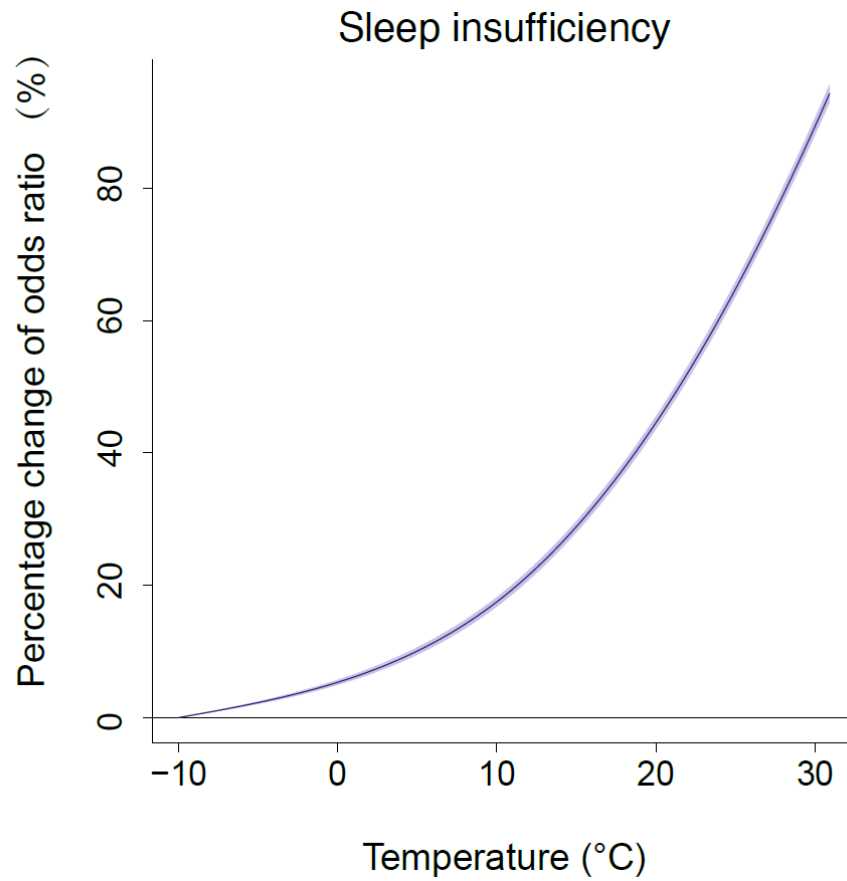


Figure S1. The exposure-response curves for the associations between daily mean temperature(°C) and sleep insufficiency at lag 0 day. Solid lines = mean percentage change of odds ratio; shaded areas = 95% confidence intervals. Sleep insufficiency was defined as total sleep duration less than 7 hours.

Note: Lag 0 d refers to 24 hours before waking.

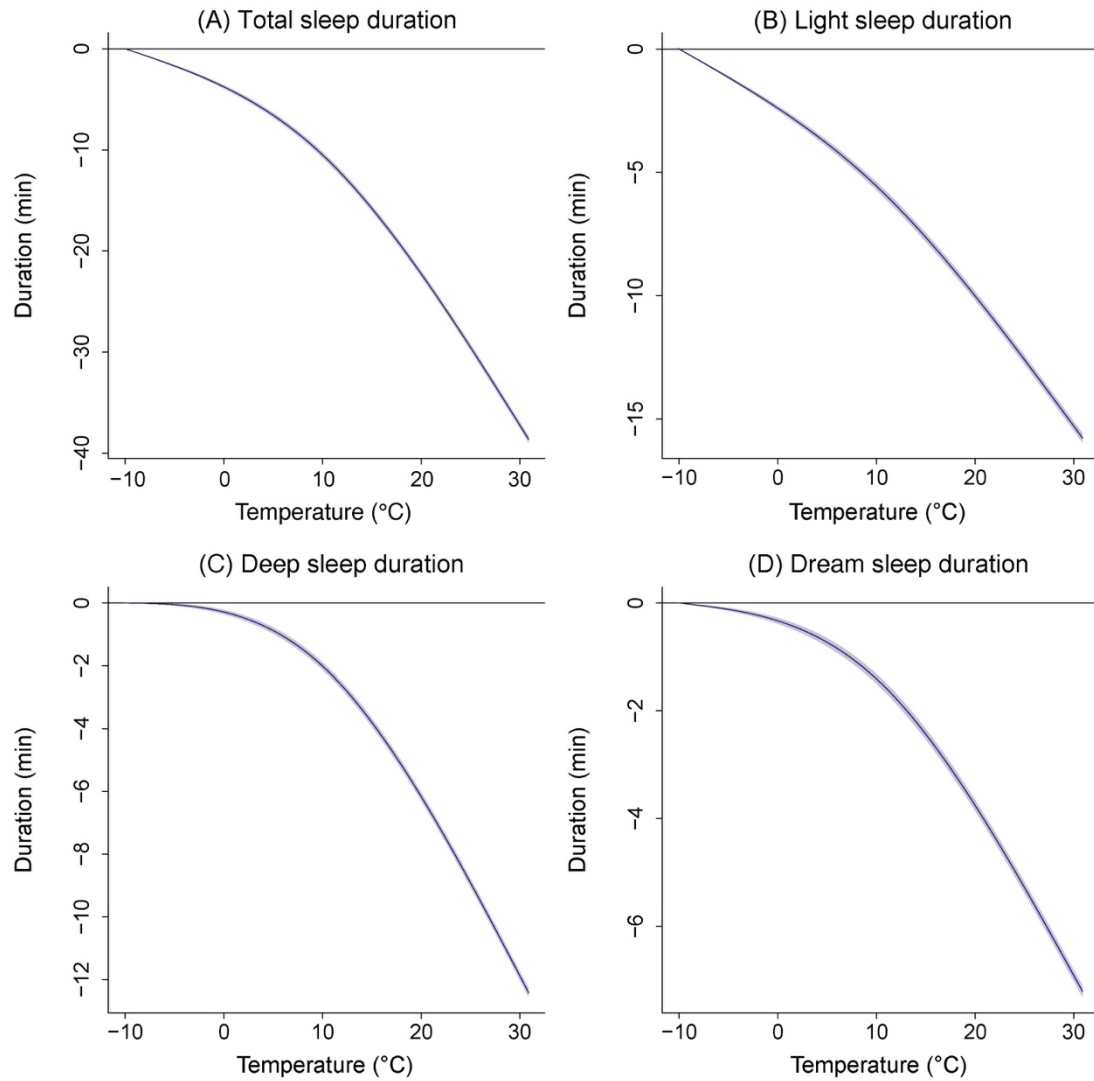


Figure S2. The exposure-response curves for the associations of daily mean temperature (°C, lag 0 d) with total sleep duration (A), light sleep duration (B), deep sleep duration (C) and dream sleep loss (D). Solid lines = mean change (min); shaded areas = 95% confidence intervals.

Note: Lag 0 d refers to 24 hours before waking.

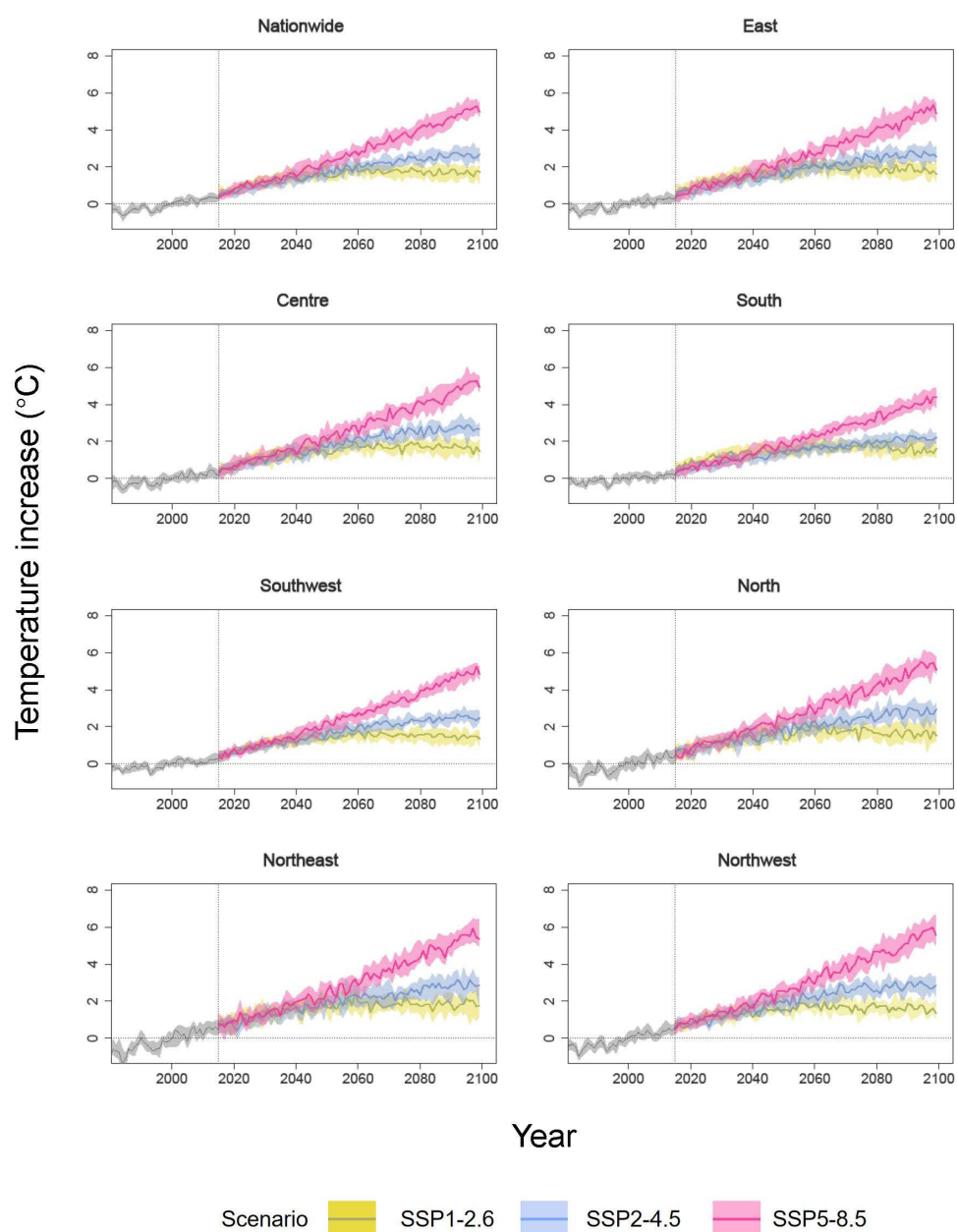


Figure S3. The annual trends for the projected temperature (annual means, °C) under historical (1985-2014) and future (2015-2099) climate scenarios in China, classified by region. The scenarios of shared socioeconomic pathway (SSP) include strict (SSP1-2.6), medium (SSP2-4.5), and unrestricted (SSP5-8.5) emissions of atmospheric greenhouse gas.

Note: Solid lines correspond to the mean annual temperatures estimated across the 15 GCMs specific modeled series. The shaded areas show their ranges for each year. Abbreviations: SSP, shared socioeconomic pathway, GCMs, general climate models.

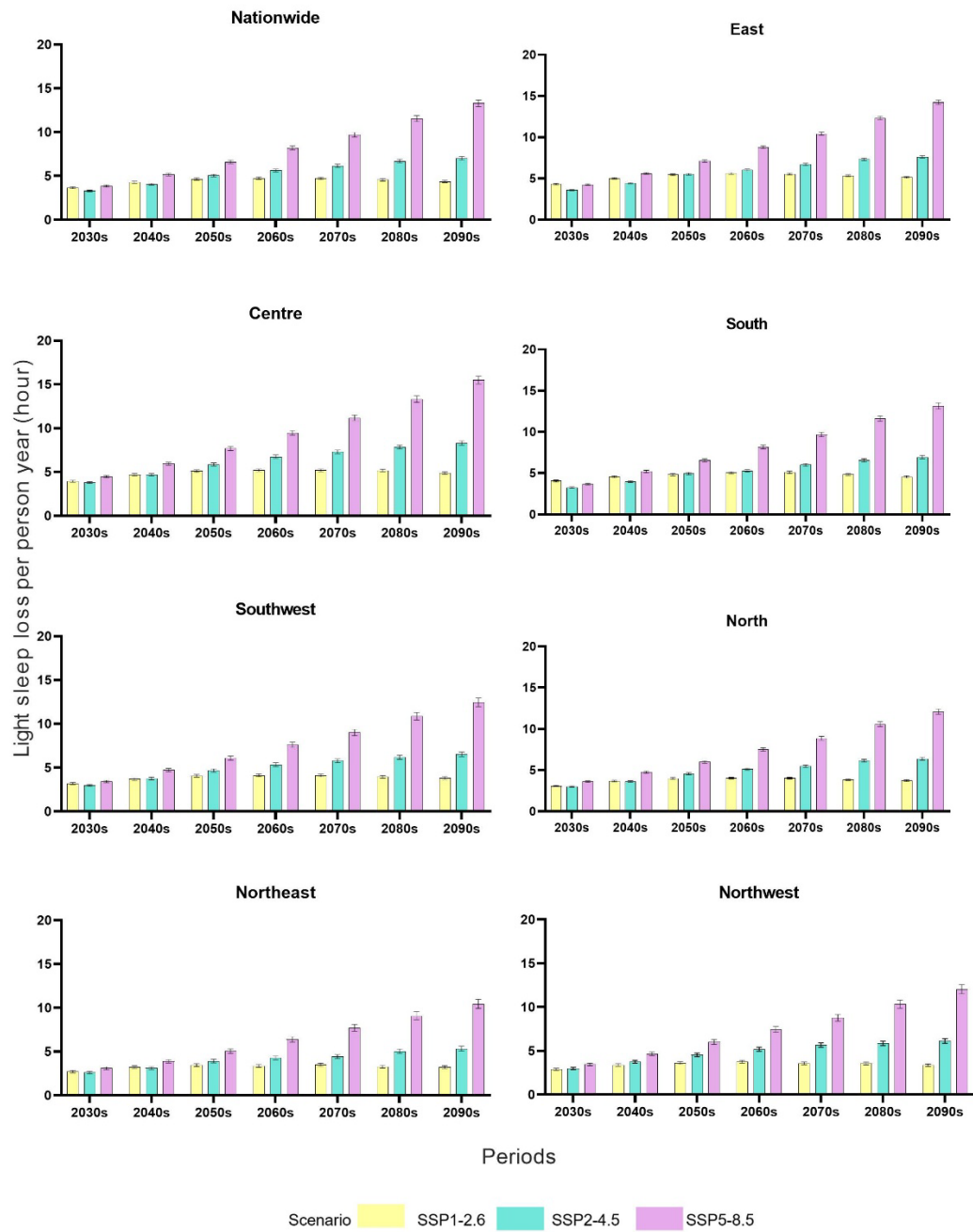


Figure S4. Projected light sleep loss (the decrement in light sleep hours) per person-year associate with climate warming under different climate scenarios compared with the historical period (1985-2014), classified by region and period.

The height of columns denotes the mean estimate and the vertical black lines represent their empirical 95% CIs computed from Monte Carlo simulations (1000 samples). Source data are provided as a Source Data file. Abbreviations: SSP, shared socioeconomic pathway, GCMs, general climate models.

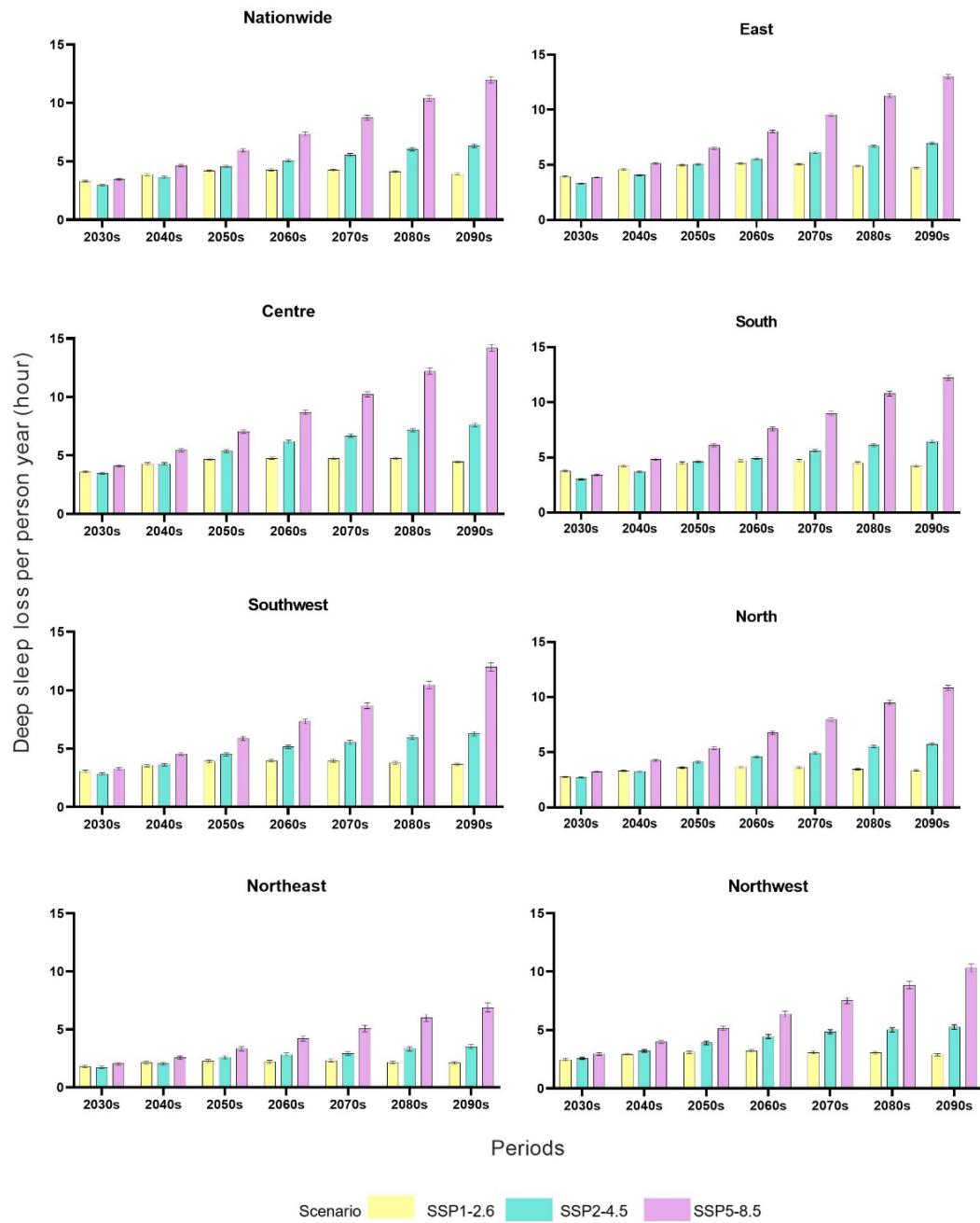


Figure S5. Projected deep sleep loss (the decrement in deep sleep hours) per person-year associate with climate warming under different climate scenarios compared with the historical period (1985-2014), classified by region and period.

The height of columns denotes the mean estimate and the vertical black lines represent their empirical 95% CIs computed from Monte Carlo simulations (1000 samples). Source data are provided as a Source Data file. Abbreviations: SSP, shared socioeconomic pathway, GCMs, general climate models.

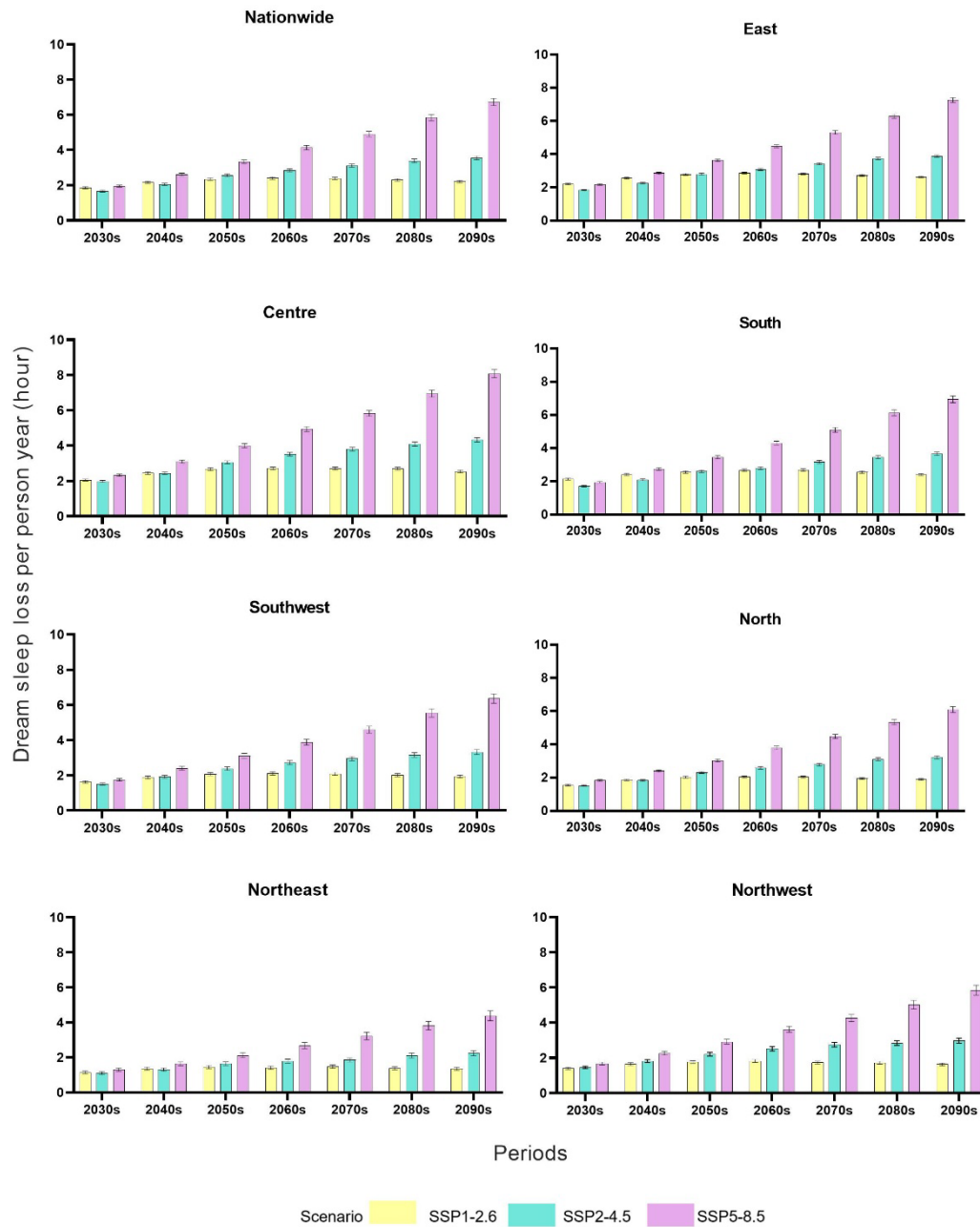
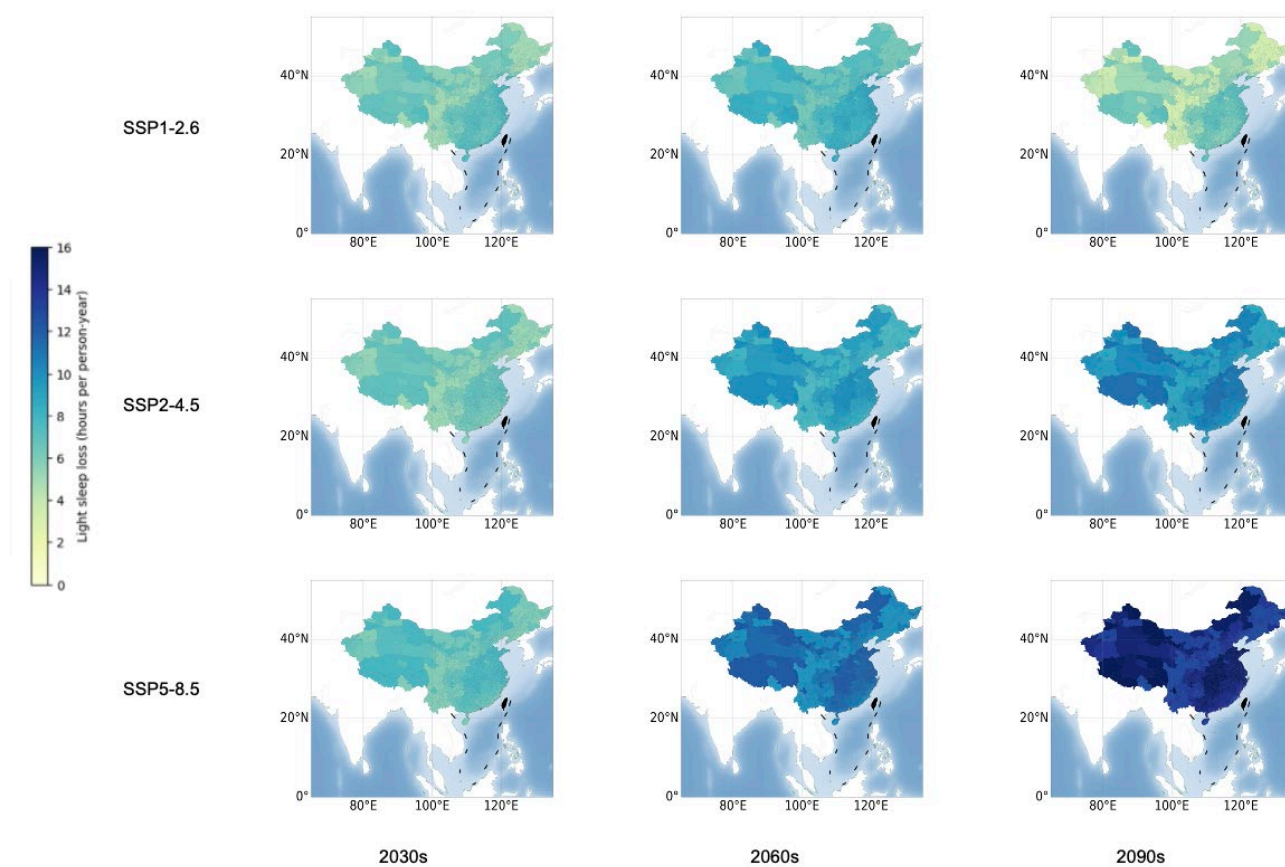
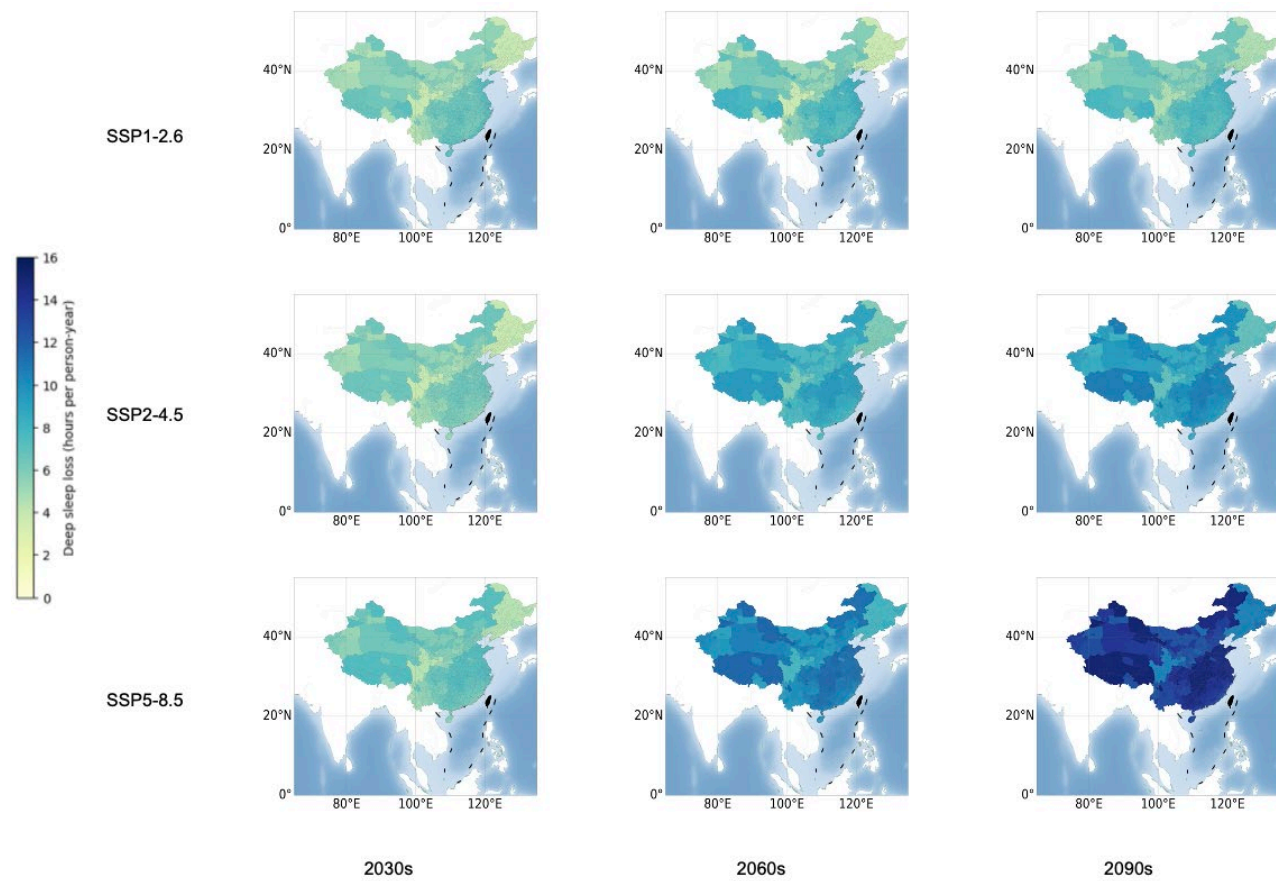


Figure S6. Projected dream sleep loss (the decrement in dream sleep hours) per person-year associate with climate warming under different climate scenarios compared with the historical period (1985-2014), classified by region and period.

The height of columns denotes the mean estimate and the vertical black lines represent their empirical 95% CIs computed from Monte Carlo simulations (1000 samples). Source data are provided as a Source Data file. Abbreviations: SSP, shared socioeconomic pathway, GCMs, general climate models.



- 1
- 2 **Figure S7. Projected light sleep loss (the decrement in light sleep hours) per person-year associate with climate warming under different climate scenarios in 2030s,**
- 3 **2060s and 2090s.**
- 4 Note: Climate scenarios were defined as in Figure S3.

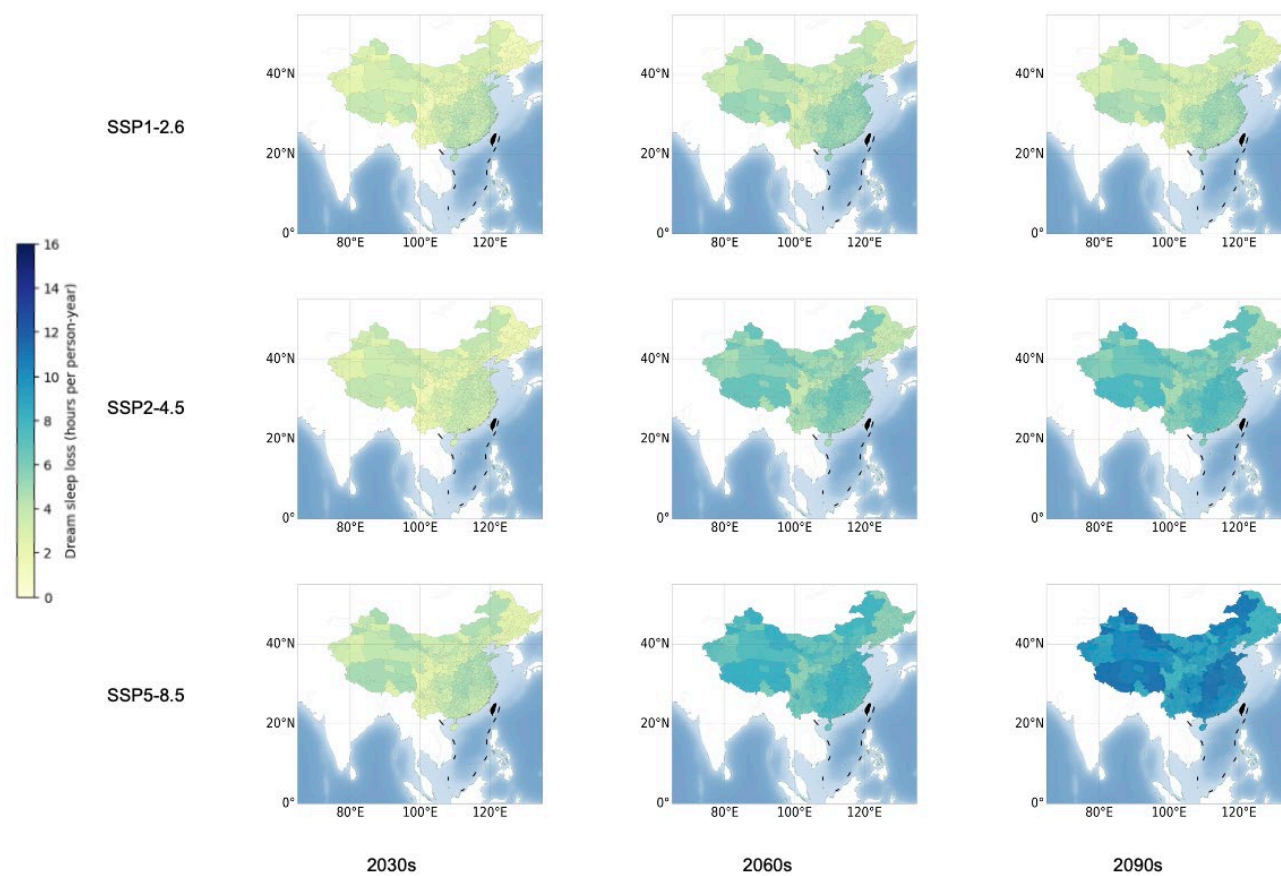


5

6 **Figure S8. Projected deep sleep loss (the decrement in deep sleep hours) per person-year associate with climate warming under different climate scenarios in 2030s,**

7 **2060s and 2090s.**

8 Note: Climate scenarios were defined as in Figure S3.



9

10 **Figure S9. Projected dream sleep loss (the decrement in dream sleep hours) per person-year associate with climate warming under different climate scenarios in**

11 **2030s, 2060s and 2090s.**

12 **Note: Climate scenarios were defined as in Figure S3.**

13 **Table S1. The percentage change in odds of sleep insufficiency and the changes of sleep duration (min) associated with each 10°C temperature increase at lag 0 d,**
14 **classified by potential effect modifiers.**

Subgroup	Sleep insufficiency	Total sleep duration	Light sleep duration	Deep sleep duration	Dream sleep duration
Age (year)					
<45	18.4 (18.1,18.6)	-8.75 (-8.84,-8.66)	-3.33 (-3.39,-3.28)	-3.51 (-3.55,-3.47)	-1.80 (-1.83,-1.77)
≥45	23.0 (22.6,23.3)	-10.92 (-11.03,-10.81)	-5.04 (-5.11,-4.96)	-3.61 (-3.66,-3.56)	-2.31 (-2.35,-2.27)
Sex					
Male	19.9 (19.7,20.1)	-9.63 (-9.70,-9.56)	-4.04 (-4.09, -3.99)	-3.58 (-3.62,-3.55)	-1.98 (-2.01,-1.96))
Female	20.0 (19.6,20.4)	-9.90 (-10.08,-9.72)	-4.07 (-4.19,-3.95)	-3.59 (-3.67,-3.50)	-2.18 (-2.24,-2.12)
BMI (kg/m²)					
<25	19.4 (19.1,19.6)	-9.50 (-9.59,-9.41)	-3.86 (-3.92,-3.79)	-3.47 (-3.51,-3.42)	-1.97 (-2.01,-1.94)
≥25	20.7 (20.4,21.0)	-9.60 (-9.71,-9.49)	-4.10 (-4.17,-4.02)	-3.65 (-3.69,-3.59)	-1.98 (-2.02,-1.94)
RH					
Low	18.3 (18.0,18.5)	-8.77 (-8.86,-8.68)	-3.51 (-3.57,-3.46)	-3.25 (-3.29,-3.21)	-1.91 (-1.94,-1.88)
High	23.4 (23.1,23.8)	-12.02 (-12.14,-11.91)	-5.26 (-5.33,-5.18)	-4.46 (-4.52,-4.41)	-2.35 (-2.40,-2.31)

15 Abbreviations: BMI, body mass index; RH, relative humidity.

16

17 **Table S2. The percentage change in odds of sleep insufficiency and the changes of sleep duration (min) associated with each 10°C temperature increase at lag 0 d,**
18 **classified by regions of China.**

Region	Sleep insufficiency	Total sleep duration	Light sleep duration	Deep sleep duration	Dream sleep duration
East	27.3 (26.9, 27.7)	-11.31 (-11.44, -11.18)	-4.65 (-4.74,-4.56)	-4.25 (-4.32,-4.19)	-2.37 (-2.42,-2.32)
Centre	28.5 (27.8, 29.1)	-12.21 (-12.42, -12.00)	-5.01 (-5.15,-4.87)	-4.59 (-4.69,-4.50)	-2.61 (-2.69,-2.54)
South	33.7 (32.6, 34.7)	-16.03 (-16.34, -15.73)	-5.01 (-5.15,-4.87)	-4.66 (-4.76,-4.56)	-2.64 (-2.72,-2.57)
Southwest	17.5 (16.8, 18.2)	-10.23 (-10.48, -9.99)	-4.10 (-4.26,-3.94)	-3.95 (-4.07,-3.84)	-2.10 (-2.18,-2.01)
North	17.1 (16.7, 17.5)	-9.16 (-9.30, -9.01)	-3.78 (-3.88,-3.68)	-3.39 (-3.46,-3.32)	-1.91 (-1.96,-1.85)
Northeast	10.4 (9.8, 11.0)	-6.26 (-6.49, -6.04)	-3.00 (-3.16,-2.85)	-1.98 (-2.09,-1.87)	-1.26 (-1.34,-1.18)
Northwest	15.2 (14.6, 15.8)	-8.80 (-9.05, -8.55)	-3.68 (-3.84,-3.52)	-3.15 (-3.27,-3.04)	-1.79 (-1.88,-1.70)

19 Note: Lag 0 d refers to 24 hours before waking.

20

21 **Table S3. The percentage change in odds of sleep insufficiency and the changes of sleep duration (min) associated with each 10°C temperature increase at lag 0 d in**
 22 **sensitive analyses.**

Model	Sleep insufficiency	Total sleep duration	Light sleep duration	Deep sleep duration	Dream sleep duration
Sensitivity analysis 1	19.6 (19.4, 19.8)	-9.38 (-9.44, -9.31)	-3.92 (-3.96, -3.88)	-3.40 (-3.43, -3.37)	-1.92 (-1.95, -1.90)
Sensitivity analysis 2	18.5 (18.3, 18.7)	-8.78 (-8.86, -8.70)	-3.86 (-3.91, -3.80)	-3.11 (-3.14, -3.07)	-1.80 (-1.83, -1.77)
Sensitivity analysis 3	19.1 (18.9, 19.3)	-9.33 (-9.39, -9.26)	-3.94 (-3.98, -3.90)	-3.42 (-3.45, -3.39)	-1.94 (-1.96, -1.91)
Sensitivity analysis 4	18.5 (18.2, 18.7)	-9.16 (-9.24, -9.08)	-3.92 (-3.97, -3.87)	-3.36 (-3.40, -3.32)	-1.87 (-1.90, -1.84)
Sensitivity analysis 5	31.9 (31.3, 32.5)	-6.88 (-6.98, -6.79)	-2.86 (-2.93, -2.80)	-2.94 (-2.98, -2.89)	-1.17 (-1.20, -1.13)

23 Note: Sensitivity analysis 1 denotes the main analysis after excluding daytime sleep (4.9%);
 24 Sensitivity analysis 2 means the main analysis after additionally controlling for air pollutants;
 25 Sensitivity analysis 3 represents the main analysis after additionally controlling for napping;
 26 Sensitivity analysis 4 corresponds to the main analysis after additionally controlling for exercise.
 27 Sensitivity analysis 5 employed a person-level multivariate flexible fixed effects panel regression model for analyses.

Table S4. Projected percentage increments of sleep insufficiency associated with temperatures under different climate scenarios compared to the historical period (1985 to 2014), Classified by region and period

Region	Time period	SSP1-2.6	SSP2-4.5	SSP5-5.8
Nationwide	2030s	2.93(2.86,3.00)	2.60(2.54,2.66)	3.05(2.97,3.12)
	2060s	3.79(3.70,3.87)	4.44(4.34,4.55)	6.47(6.32,6.62)
	2090s	3.48(3.40,3.56)	5.56(5.43,5.69)	10.50(10.25,10.75)
East	2030s	3.72(3.67,3.77)	3.11(3.06,3.15)	3.67(3.62,3.72)
	2060s	4.85(4.78,4.91)	5.22(5.15,5.29)	7.58(7.48,7.69)
	2090s	4.45(4.39,4.50)	6.57(6.48,6.65)	12.29(12.12,12.45)
Centre	2030s	3.28(3.21,3.35)	3.15(3.09,3.22)	3.71(3.63,3.79)
	2060s	4.33(4.24,4.42)	5.61(5.50,5.73)	7.88(7.71,8.04)
	2090s	4.05(3.96,4.13)	6.90(6.76,7.05)	12.89(12.62,13.16)
South	2030s	3.92(3.81,4.02)	3.14(3.05,3.22)	3.56(3.46,3.66)
	2060s	4.89(4.76,5.03)	5.13(4.99,5.27)	7.91(7.69,8.12)
	2090s	4.41(4.28,4.53)	6.72(6.54,6.91)	12.73(12.38,13.08)
Southwest	2030s	2.07(2.00,2.15)	1.92(1.85,1.99)	2.22(2.14,2.30)
	2060s	2.68(2.59,2.78)	3.47(3.35,3.59)	4.94(4.77,5.12)
	2090s	2.47(2.38,2.56)	4.23(4.08,4.39)	8.09(7.80,8.38)
North	2030s	2.12(2.07,2.17)	2.09(2.04,2.14)	2.50(2.45,2.56)
	2060s	2.79(2.73,2.86)	3.55(3.46,3.63)	5.21(5.08,5.33)
	2090s	2.59(2.53,2.65)	4.42(4.31,4.52)	8.37(8.17,8.56)
Northeast	2030s	1.48(1.40,1.56)	1.43(1.35,1.51)	1.69(1.60,1.78)
	2060s	1.83(1.73,1.93)	2.33(2.20,2.46)	3.48(3.29,3.67)
	2090s	1.75(1.66,1.85)	2.91(2.75,3.07)	5.69(5.38,6.00)
Northwest	2030s	1.84(1.77,1.91)	1.91(1.83,1.98)	2.20(2.12,2.29)
	2060s	2.39(2.30,2.49)	3.31(3.18,3.44)	4.75(4.57,4.94)
	2090s	2.15(2.06,2.23)	3.91(3.76,4.07)	7.68(7.38,7.97)

Note: Climate scenarios were defined as in Figure S3.

Table S5. Projected total sleep loss (the decrement in total sleep hours) per person-year associate with climate warming under different climate scenarios compared with the historical period (1985-2014), classified by region and period.

Region	Time period	SSP1-2.6	SSP2-4.5	SSP5-5.8
Nationwide	2030s	9.21 (9.05,9.38)	8.24 (8.10,8.39)	9.65 (9.48,9.83)
	2060s	11.91 (11.70,12.12)	14.09 (13.84,14.35)	20.51 (20.14,20.88)
	2090s	10.96 (10.76,11.15)	17.60 (17.28,17.91)	33.28 (32.67,33.88)
East	2030s	10.50 (10.39,10.62)	8.76 (8.66,8.86)	10.37 (10.25,10.48)
	2060s	13.67 (13.52,13.83)	14.72 (14.55,14.88)	21.38 (21.14,21.62)
	2090s	12.54 (12.40,12.68)	18.52 (18.31,18.72)	34.64 (34.26,35.03)
Centre	2030s	9.59 (9.43,9.76)	9.23 (9.08,9.39)	10.86 (10.68,11.05)
	2060s	12.66 (12.44,12.87)	16.44 (16.16,16.72)	23.06 (22.66,23.45)
	2090s	11.84 (11.64,12.05)	20.21 (19.86,20.55)	37.72 (37.08,38.36)
South	2030s	12.97 (12.73,13.22)	10.38 (10.18,10.57)	11.77 (11.55,11.99)
	2060s	16.22 (15.91,16.53)	16.95 (16.63,17.27)	26.15 (25.66,26.65)
	2090s	14.60 (14.32,14.87)	22.23 (21.81,22.66)	42.09 (41.29,42.88)
Southwest	2030s	7.96 (7.77,8.15)	7.39 (7.22,7.57)	8.52 (8.32,8.73)
	2060s	10.29 (10.05,10.54)	13.34 (13.02,13.66)	18.98 (18.53,19.43)
	2090s	9.48 (9.25,9.71)	16.26 (15.87,16.65)	31.05 (30.31,31.80)
North	2030s	7.42 (7.31,7.54)	7.30 (7.18,7.42)	8.77 (8.63,8.91)
	2060s	9.78 (9.63,9.94)	12.41 (12.21,12.61)	18.22 (17.92,18.51)
	2090s	9.07 (8.92,9.21)	15.46 (15.21,15.71)	29.28 (28.81,29.75)
Northeast	2030s	5.68 (5.48,5.89)	5.49 (5.29,5.69)	6.47 (6.23,6.70)
	2060s	7.04 (6.78,7.29)	8.92 (8.60,9.24)	13.34 (12.86,13.82)
	2090s	6.73 (6.49,6.97)	11.16 (10.76,11.56)	21.80 (21.02,22.58)
Northwest	2030s	6.90 (6.71,7.09)	7.14 (6.94,7.34)	8.25 (8.02,8.48)
	2060s	8.96 (8.71,9.21)	12.39 (12.04,12.73)	17.80 (17.30,18.29)
	2090s	8.04 (7.82,8.26)	14.66 (14.25,15.06)	28.74 (27.94,29.54)

Note: Climate scenarios were defined as in Figure S3.

Table S6. Projected light sleep loss (the decrement in light sleep hours) per person-year associate with climate warming under different climate scenarios compared with the historical period (1985-2014), classified by region and period.

Region	Time period	SSP1-2.6	SSP2-4.5	SSP5-5.8
Nationwide	2030s	3.66 (3.56,3.77)	3.29 (3.20,3.39)	3.86 (3.75,3.97)
	2060s	4.74 (4.61,4.87)	5.64 (5.47,5.80)	8.19 (7.95,8.42)
	2090s	4.37 (4.24,4.49)	7.02 (6.82,7.23)	13.29 (12.90,13.67)
East	2030s	4.32 (4.24,4.40)	3.60 (3.53,3.67)	4.26 (4.18,4.34)
	2060s	5.62 (5.52,5.72)	6.05 (5.94,6.16)	8.79 (8.63,8.95)
	2090s	5.15 (5.06,5.25)	7.61 (7.47,7.75)	14.24 (13.98,14.50)
Centre	2030s	3.94 (3.83,4.05)	3.79 (3.68,3.90)	4.46 (4.33,4.59)
	2060s	5.20 (5.05,5.34)	6.75 (6.56,6.94)	9.47 (9.20,9.73)
	2090s	4.86 (4.73,5.00)	8.29 (8.06,8.53)	15.49 (15.05,15.92)
South	2030s	4.05 (3.94,4.17)	3.24 (3.15,3.34)	3.68 (3.57,3.78)
	2060s	5.07 (4.92,5.21)	5.30 (5.15,5.45)	8.17 (7.94,8.41)
	2090s	4.56 (4.43,4.69)	6.95 (6.75,7.15)	13.15 (12.78,13.53)
Southwest	2030s	3.19 (3.07,3.32)	2.96 (2.85,3.08)	3.42 (3.28,3.55)
	2060s	4.13 (3.97,4.29)	5.35 (5.14,5.56)	7.61 (7.31,7.91)
	2090s	3.80 (3.65,3.95)	6.52 (6.26,6.77)	12.45 (11.97,12.94)
North	2030s	3.07 (2.98,3.15)	3.02 (2.94,3.10)	3.62 (3.52,3.72)
	2060s	4.04 (3.93,4.15)	5.12 (4.99,5.26)	7.52 (7.32,7.72)
	2090s	3.74 (3.65,3.84)	6.39 (6.22,6.55)	12.09 (11.77,12.41)
Northeast	2030s	2.72 (2.59,2.86)	2.63 (2.50,2.77)	3.10 (2.94,3.26)
	2060s	3.37 (3.20,3.54)	4.28 (4.06,4.49)	6.40 (6.07,6.72)
	2090s	3.23 (3.06,3.39)	5.35 (5.08,5.62)	10.45 (9.92,10.98)
Northwest	2030s	2.89 (2.76,3.01)	2.99 (2.86,3.12)	3.45 (3.30,3.60)
	2060s	3.75 (3.59,3.91)	5.18 (4.96,5.41)	7.45 (7.12,7.77)
	2090s	3.36 (3.22,3.51)	6.13 (5.87,6.40)	12.03 (11.50,12.55)

Note: Climate scenarios were defined as in Figure S3.

Table S7. Projected deep sleep loss (the decrement in deep sleep hours) per person-year associate with climate warming under different climate scenarios compared with the historical period (1985-2014), classified by region and period.

Region	Time period	SSP1-2.6	SSP2-4.5	SSP5-5.8
Nationwide	2030s	3.30 (3.23,3.38)	2.96 (2.90,3.03)	3.47 (3.39,3.55)
	2060s	4.28 (4.18,4.37)	5.08 (4.96,5.19)	7.37 (7.20,7.54)
	2090s	3.94 (3.85,4.02)	6.33 (6.19,6.47)	11.97 (11.69,12.24)
East	2030s	3.95 (3.89,4.01)	3.30 (3.25,3.34)	3.90 (3.84,3.96)
	2060s	5.14 (5.07,5.22)	5.54 (5.46,5.62)	8.04 (7.93,8.16)
	2090s	4.72 (4.65,4.79)	6.97 (6.87,7.07)	13.03 (12.85,13.22)
Centre	2030s	3.61 (3.53,3.69)	3.48 (3.40,3.55)	4.09 (4.00,4.18)
	2060s	4.77 (4.66,4.87)	6.19 (6.06,6.32)	8.68 (8.49,8.86)
	2090s	4.46 (4.36,4.55)	7.61 (7.44,7.77)	14.20 (13.90,14.50)
South	2030s	3.77 (3.69,3.85)	3.01 (2.95,3.08)	3.42 (3.35,3.49)
	2060s	4.71 (4.61,4.81)	4.92 (4.82,5.03)	7.60 (7.43,7.76)
	2090s	4.24 (4.15,4.33)	6.46 (6.32,6.60)	12.22 (11.96,12.48)
Southwest	2030s	3.07 (2.98,3.17)	2.86 (2.77,2.94)	3.29 (3.20,3.39)
	2060s	3.98 (3.86,4.10)	5.15 (5.00,5.31)	7.33 (7.12,7.55)
	2090s	3.66 (3.56,3.77)	6.28 (6.10,6.47)	12.00 (11.64,12.35)
North	2030s	2.75 (2.69,2.81)	2.71 (2.65,2.76)	3.25 (3.18,3.32)
	2060s	3.63 (3.55,3.70)	4.60 (4.50,4.70)	6.75 (6.61,6.89)
	2090s	3.36 (3.29,3.43)	5.73 (5.61,5.85)	10.85 (10.63,11.08)
Northeast	2030s	1.80 (1.70,1.90)	1.74 (1.64,1.83)	2.05 (1.93,2.16)
	2060s	2.23 (2.10,2.35)	2.82 (2.67,2.98)	4.22 (3.99,4.45)
	2090s	2.13 (2.01,2.25)	3.53 (3.34,3.72)	6.90 (6.52,7.28)
Northwest	2030s	2.47 (2.38,2.56)	2.56 (2.47,2.65)	2.96 (2.85,3.06)
	2060s	3.21 (3.10,3.33)	4.44 (4.28,4.60)	6.38 (6.15,6.61)
	2090s	2.88 (2.78,2.99)	5.25 (5.06,5.44)	10.30 (9.92,10.67)

Note: Climate scenarios were defined as in Figure S3.

Table S8. Projected dream sleep loss (the decrement in dream sleep hours) per person-year associate with climate warming under different climate scenarios compared with the historical period (1985-2014), classified by region and period.

Region	Time period	SSP1-2.6	SSP2-4.5	SSP5-5.8
Nationwide	2030s	1.86 (1.80,1.91)	1.67 (1.61,1.72)	1.95 (1.89,2.01)
	2060s	2.40 (2.33,2.47)	2.85 (2.76,2.94)	4.14 (4.02,4.27)
	2090s	2.21 (2.15,2.28)	3.56 (3.45,3.67)	6.72 (6.52,6.93)
East	2030s	2.20 (2.16,2.24)	1.84 (1.80,1.87)	2.17 (2.13,2.22)
	2060s	2.87 (2.81,2.92)	3.08 (3.02,3.15)	4.48 (4.39,4.57)
	2090s	2.63 (2.58,2.68)	3.88 (3.81,3.96)	7.26 (7.12,7.40)
Centre	2030s	2.05 (2.00,2.11)	1.98 (1.92,2.03)	2.33 (2.26,2.39)
	2060s	2.71 (2.63,2.79)	3.52 (3.42,3.62)	4.94 (4.80,5.08)
	2090s	2.54 (2.46,2.61)	4.33 (4.20,4.45)	8.08 (7.85,8.31)
South	2030s	2.14 (2.08,2.20)	1.71 (1.66,1.76)	1.94 (1.88,1.99)
	2060s	2.67 (2.60,2.75)	2.79 (2.71,2.87)	4.31 (4.19,4.43)
	2090s	2.41 (2.34,2.47)	3.66 (3.56,3.77)	6.93 (6.74,7.13)
Southwest	2030s	1.63 (1.56,1.70)	1.51 (1.45,1.58)	1.75 (1.67,1.82)
	2060s	2.11 (2.02,2.20)	2.73 (2.62,2.85)	3.89 (3.72,4.05)
	2090s	1.94 (1.86,2.02)	3.33 (3.19,3.47)	6.36 (6.09,6.63)
North	2030s	1.55 (1.50,1.59)	1.52 (1.48,1.56)	1.83 (1.78,1.88)
	2060s	2.04 (1.98,2.10)	2.59 (2.51,2.66)	3.80 (3.69,3.90)
	2090s	1.89 (1.84,1.94)	3.22 (3.13,3.31)	6.10 (5.93,6.27)
Northeast	2030s	1.14 (1.07,1.22)	1.10 (1.03,1.18)	1.30 (1.22,1.39)
	2060s	1.41 (1.32,1.51)	1.79 (1.68,1.91)	2.68 (2.51,2.86)
	2090s	1.35 (1.26,1.44)	2.24 (2.10,2.39)	4.38 (4.10,4.67)
Northwest	2030s	1.40 (1.34,1.47)	1.45 (1.38,1.52)	1.68 (1.60,1.76)
	2060s	1.82 (1.74,1.91)	2.52 (2.40,2.64)	3.62 (3.45,3.80)
	2090s	1.64 (1.56,1.72)	2.98 (2.84,3.13)	5.85 (5.57,6.13)

Note: Climate scenarios were defined as in Figure S3.