Estimation of DALY loss due to heat stroke and sleep disturbance caused by air temperature rise in Tokyo, Japan

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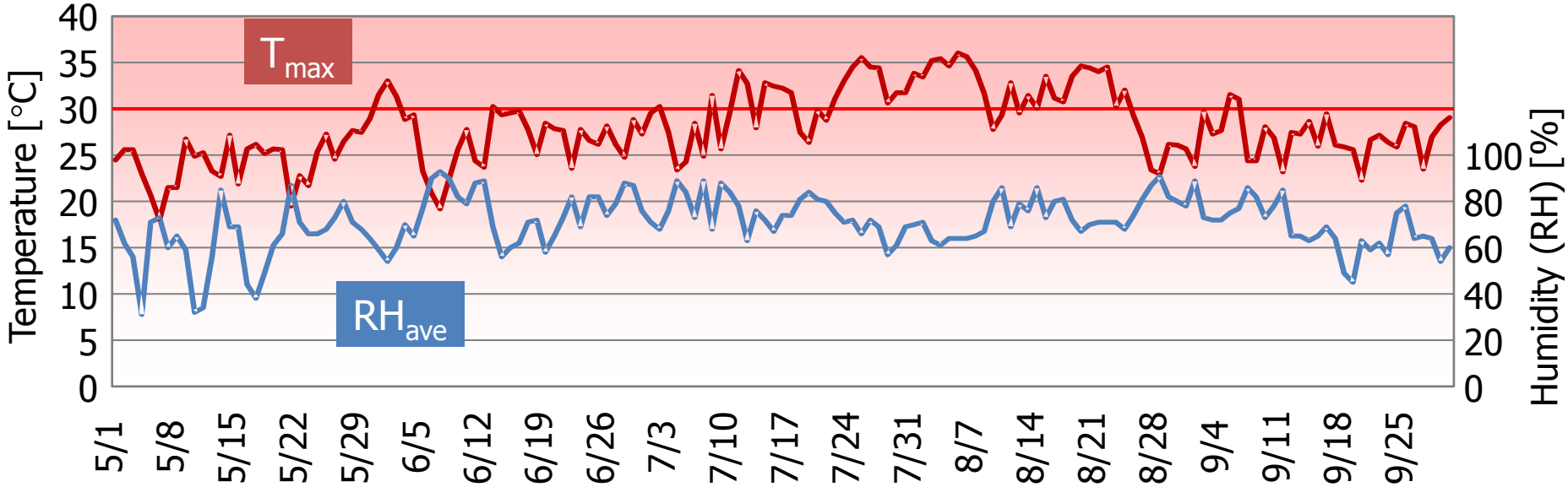
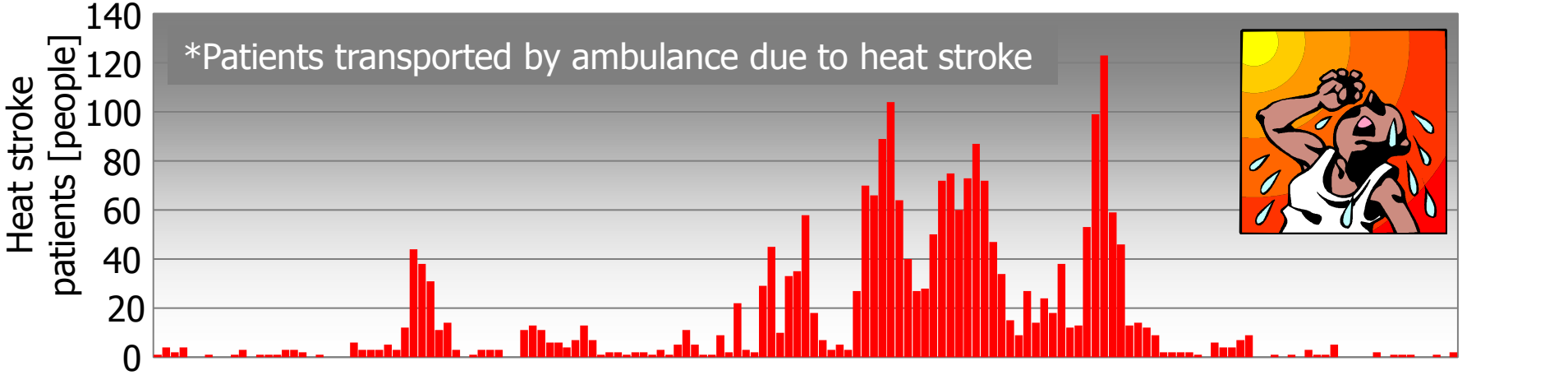
1 Introduction

◆Daytime air temperature in Tokyo

Hot & humid summer!



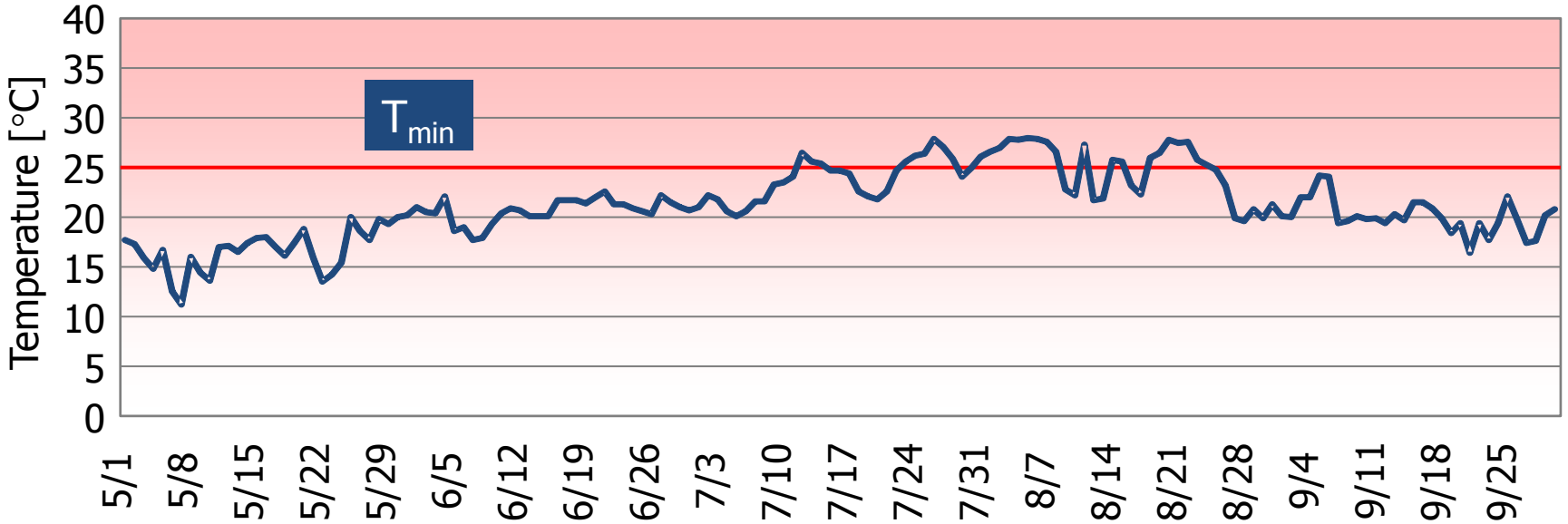


Many heat stroke patients.

1 Introduction

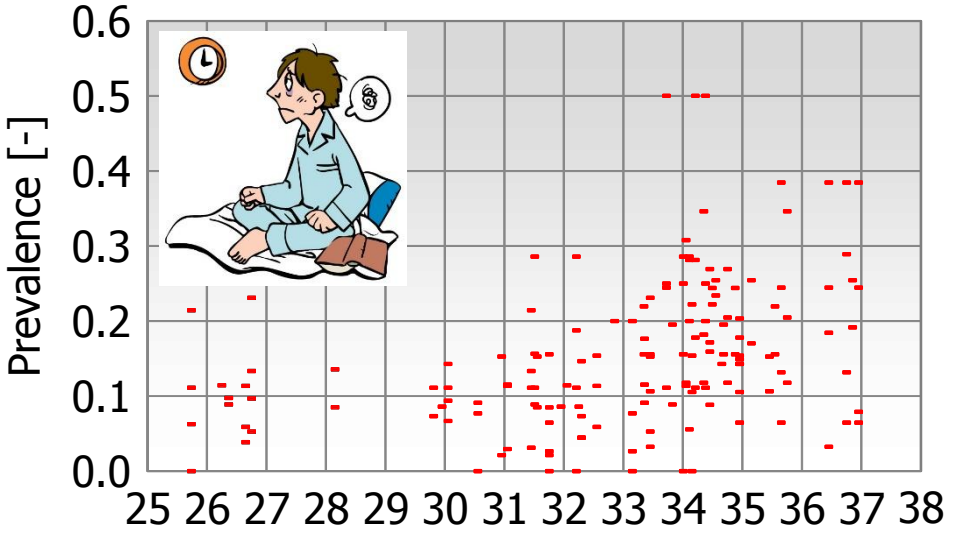
◆Nighttime air temperature in Tokyo

Hot & humid summer nights!



No statistics.

But, there would be many sleep disturbances.



Ihara T *et al.* The 8th International Conference on Urban Climate, 2012.

1 Introduction

◆Heat stroke & sleep disturbance

- Heat stroke is a large problem.

  ⇨ We need to decrease daytime air temperature.

  Reflective & green roof (control of solar radiation heat)

- If sleep disturbance is a large problem,

  ⇨ We may need to decrease nighttime air temperature.

  Reduction in anthropogenic heat

However, sleep disturbance is an important problem?

For answering this question,
quantification of damage of sleep disturbance is needed.

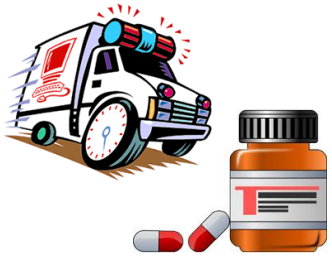
2 Metrics

◆Which metric should be used?

Deaths?

Sleep disturbance does NOT lead to death directly.

Patients?



Degree of severity is different!

DALY!

2 Metrics

◆Disability-adjusted life year (DALY)

- An index developed by WHO to measure damage on human health.

DALY = Years of Life lost (YLL) + Years Lost due to Disability (YLD)

YLL = Number of deaths × Life expectancy at age of death

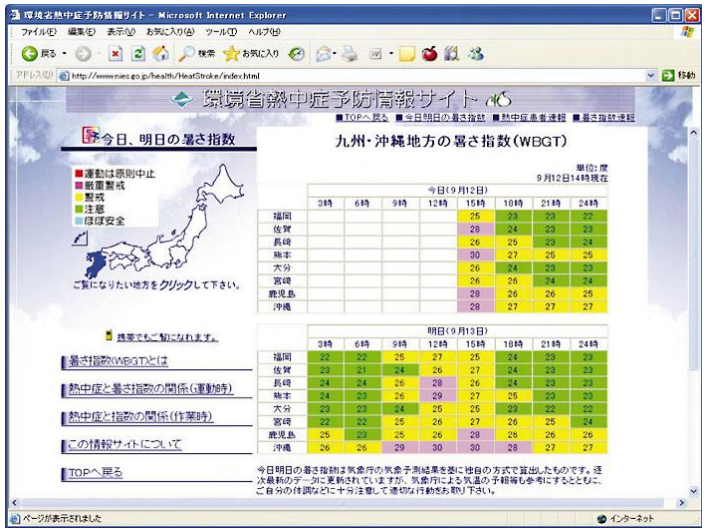
YLD = Number of subjects × Disability weight (0–1) × Duration

3 Heat stroke

◆YLL: Number of deaths

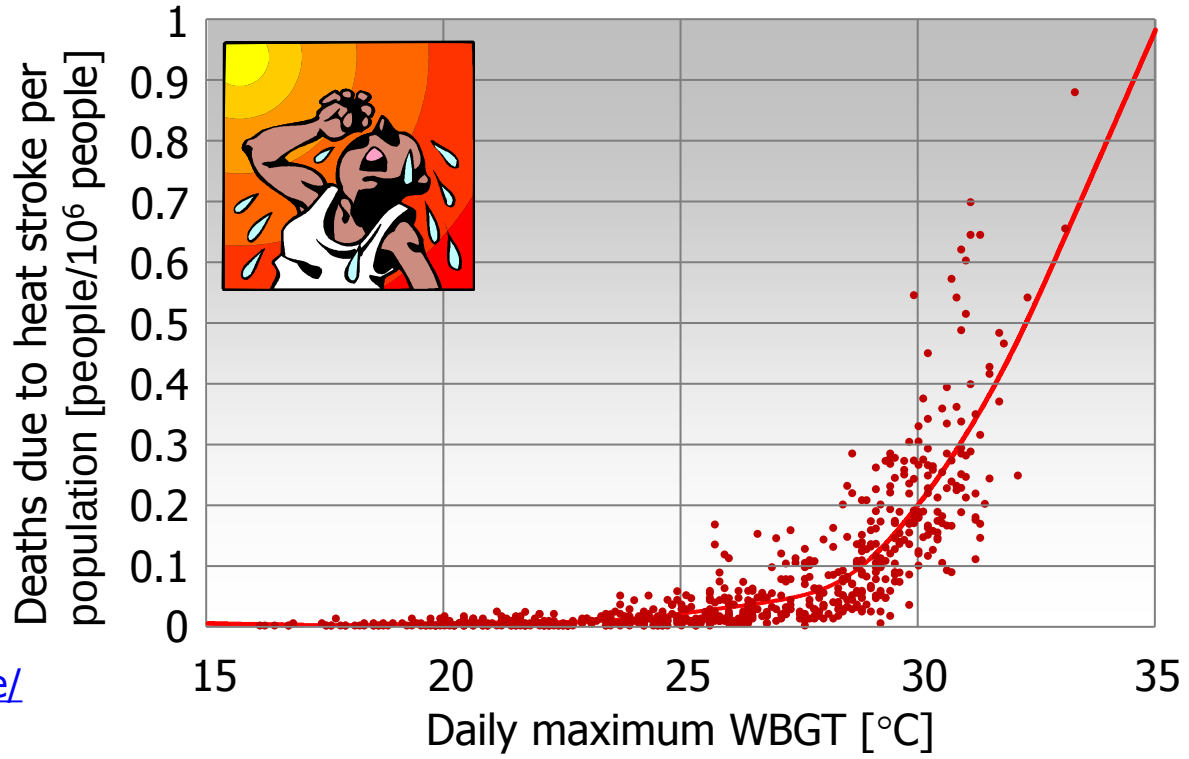
Daily max. WBGT vs. Daily transported patients

Yearly transported patients vs. Yearly deaths



"Today & Tomorrow's Hotness Indexes"

- Heat stroke prevention information site by Ministry of the Environment, Japan
  http://www.nies.go.jp/health/HeatStroke/

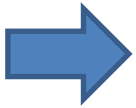


3 Heat stroke

◆YLL: Life expectancy at age of death

Yearly deaths　　Mortality table

Age	Death		Life expectancy [years]	
	Male	Female	Male	Female
20-29	3	0	57.33	64.15
30-39	6	1	47.37	54.06
40-49	14	1	37.53	44.07
50-59	20	9	28.32	34.76
60-64	43	9	22.50	28.20
65-69	33	16	18.60	23.80
70-79	84	60	13.03	16.83
80-89	55	96	7.24	9.41
90-	7	16	3.75	4.62



Average:
16.24 years

3 Heat stroke

◆DALY

- YLL
  - Number of deaths (3.4% of transported patients)
  - Life expectancy (16.24 years)

- YLD
  - Number of subjects (hundredfold of deaths)
  - Disability weight (0.01?, 0.1?, 1?)
  - Duration (16 years?, 1.6 years?, 2 months?)

YLD can be ignored because it is relatively small compared to YLL.

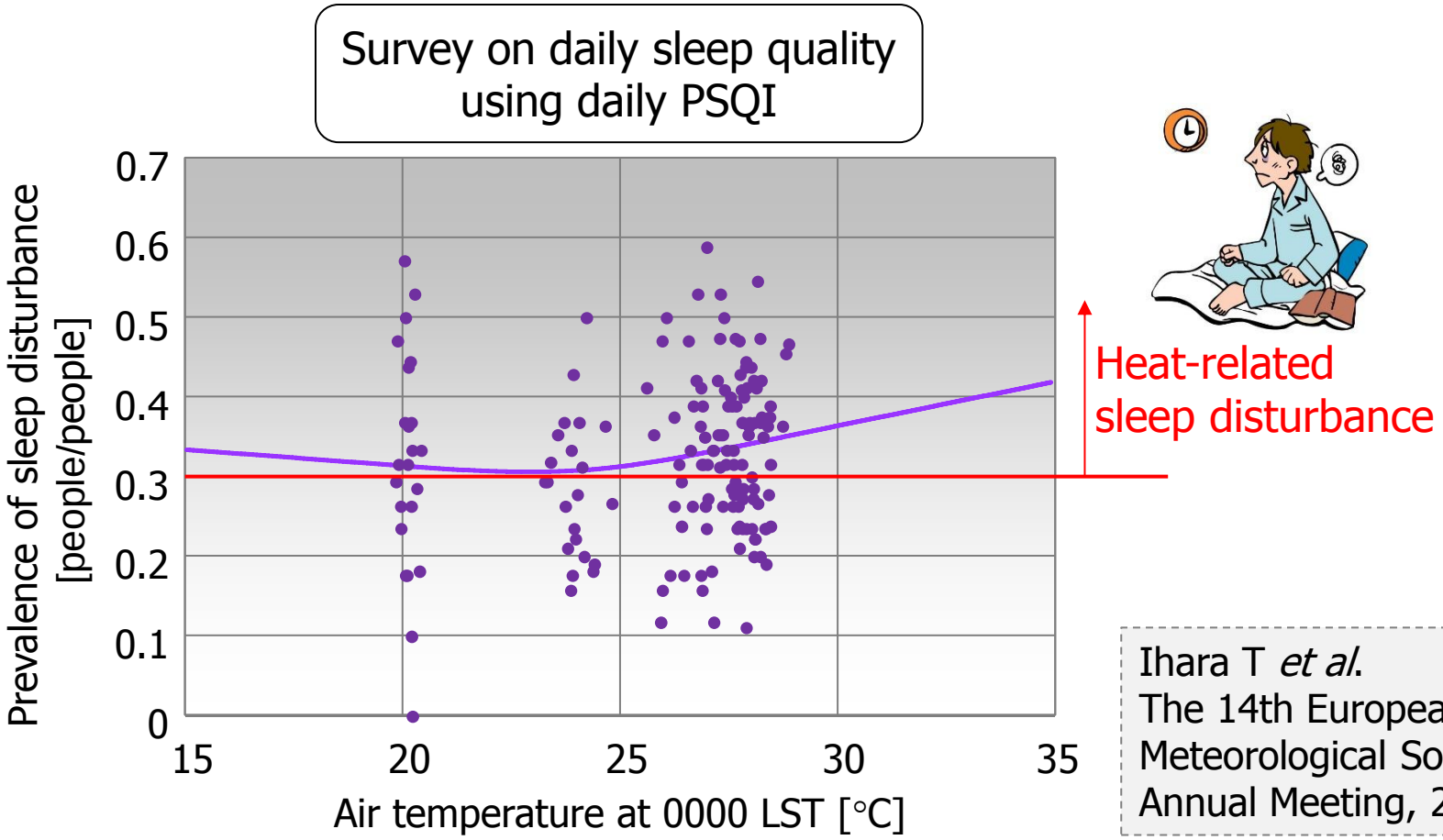
Then,
DALY ≈ YLL.

4 Sleep disturbance

◆Definition of sleep disturbance

Definition: PSQI > 5.5 (Pittsburg Sleep Quality Index)

◆YLD: Number of subjects



Ihara T *et al.*
The 14th European Meteorological Society Annual Meeting, 2014.

4 Sleep disturbance

◆YLD: Disability weight & Duration

Fukuda S *et al*. *International Journal of Life Cycle Assessment*, Vol.18, No.5, pp.1089-1097, 2013.

- Disability weight

	Environmental	PSQI > 5.5
Specialists	0.101±0.0004	0.069±0.053
Primary care physicians	0.114±0.095	0.140±0.165

⇨ DW = approximately 0.1

- Duration
  - One day (because of daily survey to the same subjects)
    = 0.0027 years

4 Sleep disturbance

◆DALY

- YLL = 0
  - Sleep disturbance does NOT directly lead to death.

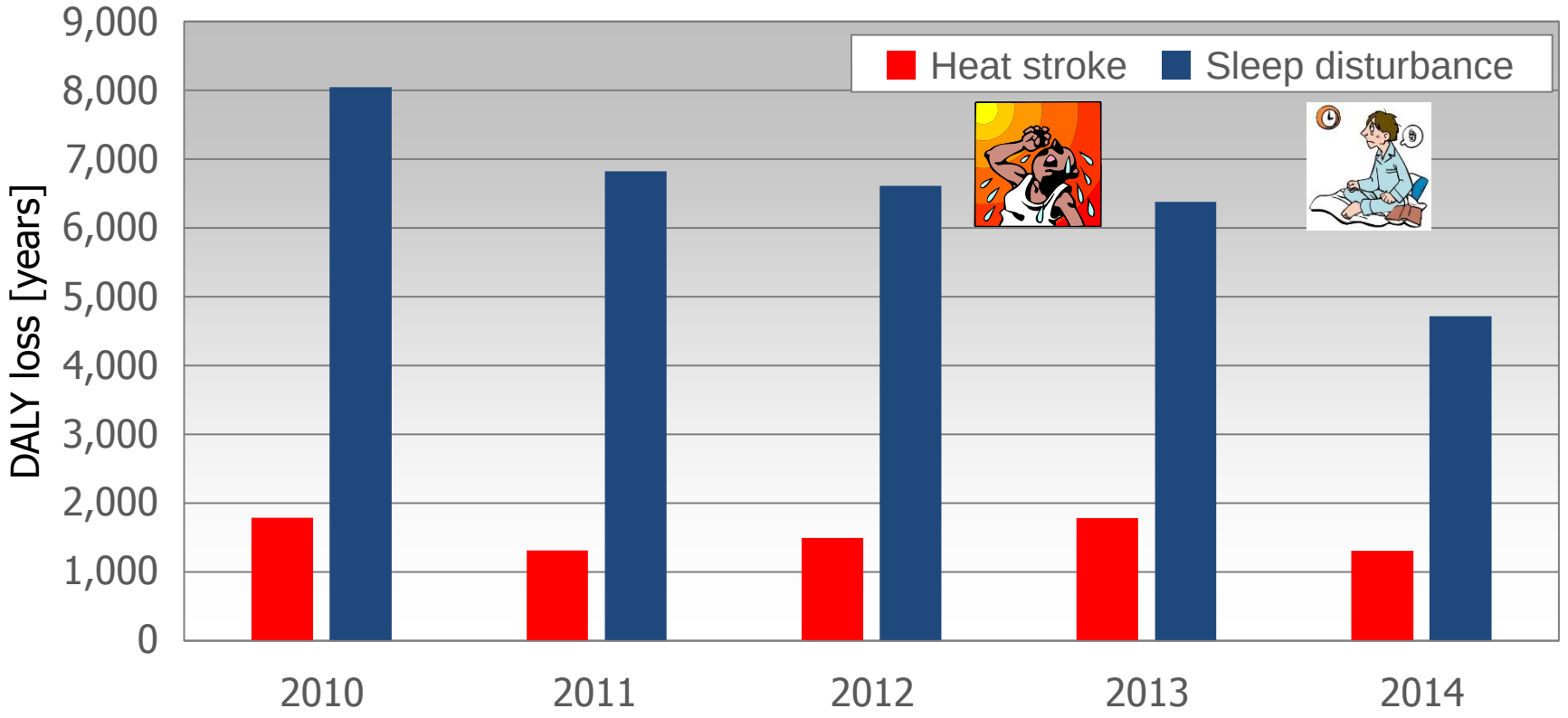
- YLD
  - Number of subjects (judged by daily PSQI > 5.5)
  - Disability weight (0.1, defined by PSQI > 5.5)
  - Duration (0.0027 years)

DALY = YLD.

5 Impact assessment of heat stroke & sleep disturbance

◆Damage from May to Sep of 2010 – 2014

- Damage functions using DALY was applied to past five years' temperature…



The orders of DALYs due to heat stroke and sleep disturbance are the same.

6 Conclusion

◆Results

- DALY can quantify various heat impact leading to death / not to death.
- Damage of sleep disturbance is not small compared to that of heat stroke.
- We may have to consider decrease in nighttime air temperature.

◆Acknowledgement

- This study was partly supported by the Environment Research and Technology Development Fund (S-14-4(3)) of the Ministry of the Environment, Japan.

Thank you for your kind attention.

1 Introduction

◆Disability-Adjusted Life Year (DALY)

- An index developed by WHO to measure damage on human health.
- DALY = Years of Life Lost (YLL) + Years Lost due to Disability (YLD)

How to calculate DALY?

- Heat stroke (death) → YLL

DALY (YLL) = Number of deaths × Life expectancy at age of death

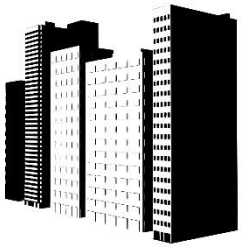
- Sleep disturbance (disease not resulting in death) → YLD

DALY (YLD) = Number of subjects × Disability weight (0–1) × Duration

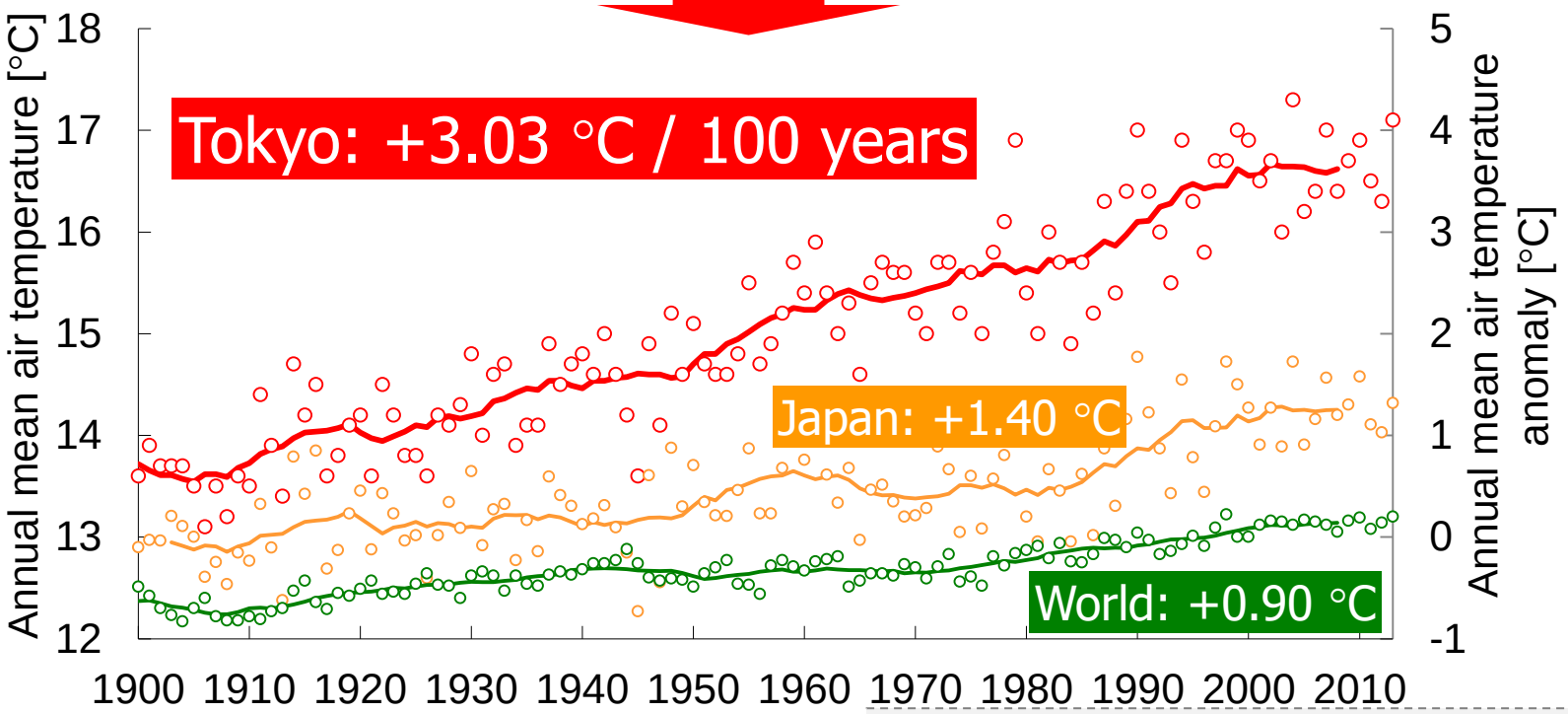
1 Introduction

◆Climate change in urban areas

Global climate change (global warming)



Urban heat island

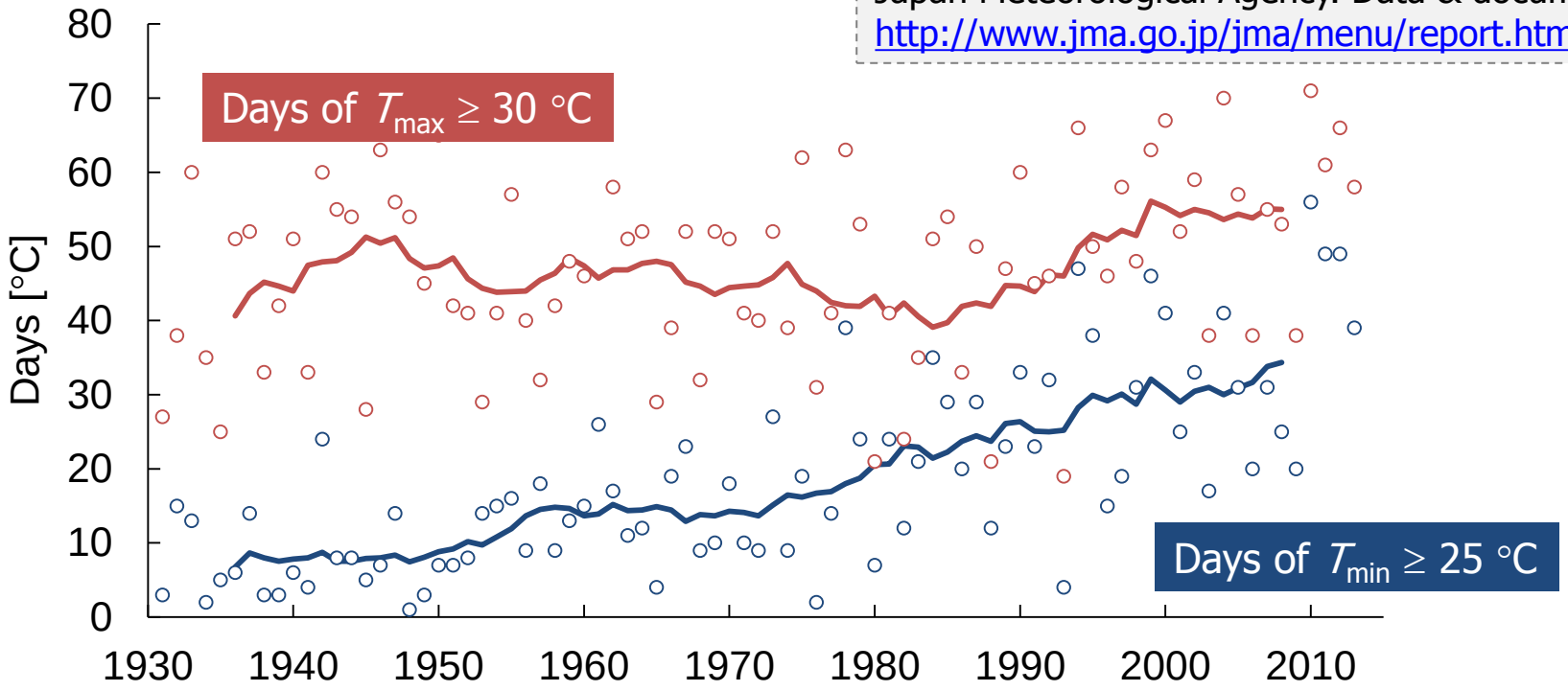


Japan Meteorological Agency. Data & documents.
http://www.jma.go.jp/jma/menu/report.html

1 Introduction

◆Change in daily max./min. air temperature in Tokyo

Japan Meteorological Agency. Data & documents.
http://www.jma.go.jp/jma/menu/report.html



Hot daytime

Hot nighttime

Heat stroke

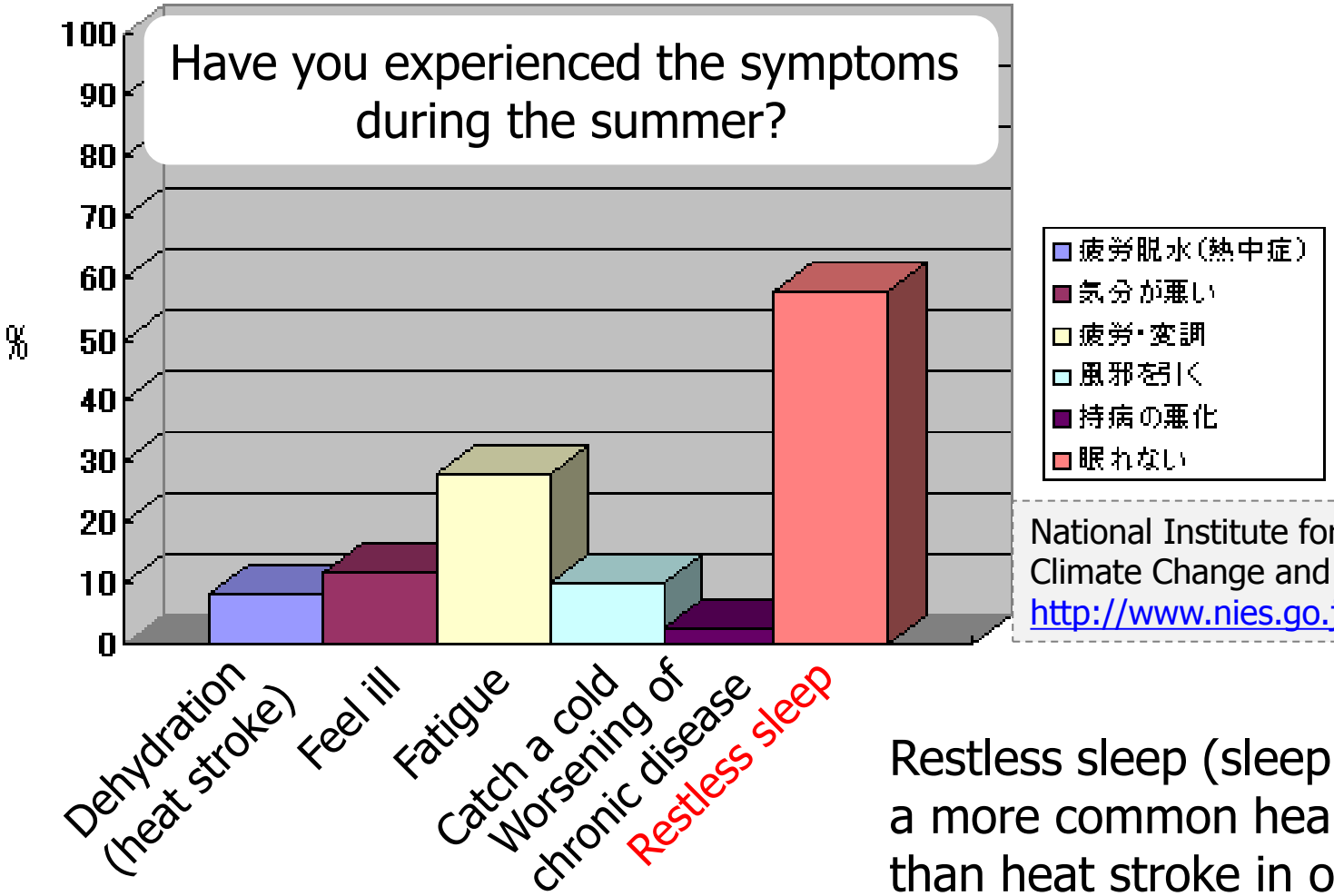
Sleep disorder

Hot summer might pose various human health damages in our society.

1 Introduction

◆Symptoms experienced in the middle of summer

- Results of questionnaire survey in Japan (2003 FY)



National Institute for Environmental Studies. Climate Change and Health. 2004. http://www.nies.go.jp/archiv-impact/

Restless sleep (sleep disorder?) is a more common health impact than heat stroke in our society.

1 Introduction

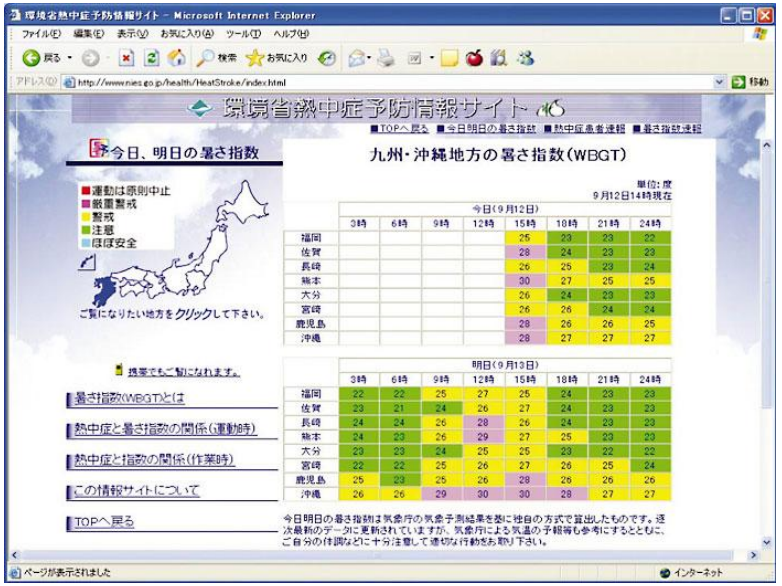
◆Is sleep disorder serious?

- Heat stroke

  - Medical-defined disorder
  - Quantitative damages
    - Deaths
    - Patients transported by ambulance

- Restless sleep

  - Subjective symptom
    - "insomnia" is medical disorder
  - No quantitative damages



"Today & Tomorrow's Hotness Indexes"

- Heat stroke prevention information site by Ministry of the Environment, Japan http://www.nies.go.jp/health/HeatStroke/

Medical definition of restless sleep & quantification of its damage based on the definition are needed.

1 Introduction

◆Disability weight (DW) of sleep disturbance

Fukuda S *et al*. *International Journal of Life Cycle Assessment*, Vol.18, No.5, pp.1089-1097, 2013.

- Interviewee
  - Face-to-face survey to specialists (sleep medicine or psychiatry)
  - Internet survey to primary physicians
- Method
  - Text description of symptoms of 3 kinds of sleep disturbance
  - Showing of DW list of 33 mental diseases
    - Müller-Wenk (2002) + some mild mental diseases
  - Set of DWs by inserting to DW list

Description based on PSQI
Mild: PSQI = 5.5 – 7.4
Moderate: PSQI > 7.5

	Sleep disturbance		
	Environmental	Mild	Moderate
Specialists (n=6)	0.101±0.0004	0.069±0.053	0.086±0.067
Primary physicians (n=57)	0.114±0.095	0.140±0.165	0.126±0.132

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DALY (YLD) = Number of subjects × Disability weight (0-1) × Duration

Fukuda S *et al*. *International Journal of Life Cycle Assessment*, Vol.18, No.5, pp.1089-1097, 2013.

2 Survey on sleep

◆How to define sleep disturbance?

- Pittsburg Sleep Quality Index (PSQI)

Buysse DJ *et al*. *Psychiatry Research*, Vol.28, No.2, pp.193-213, 1989.

  - Questionnaire for subjective sleep quality over the past one month
  - Composed of 7 components (0-3 pt, global score: 0-21 pt)
    - (C1) subjective sleep, (C2) sleep latency, (C3) sleep duration, (C4) habitual sleep efficiency, (C5) sleep disturbance, (C6) use of sleeping medication, (C7) daytime dysfunction
  - Widely used in sleep medicine
  - Cut-off value: 5.5 pt

- Sleep Quality Index for Daily Sleep (SQIDS)

Okano Y *et al*. *Web Journal of Heat Island Institute International*, Vol.3, pp.22-33, 2008.

  - Questionnaire for subjective sleep quality over the past one day
  - Adopted the same items as PSQI

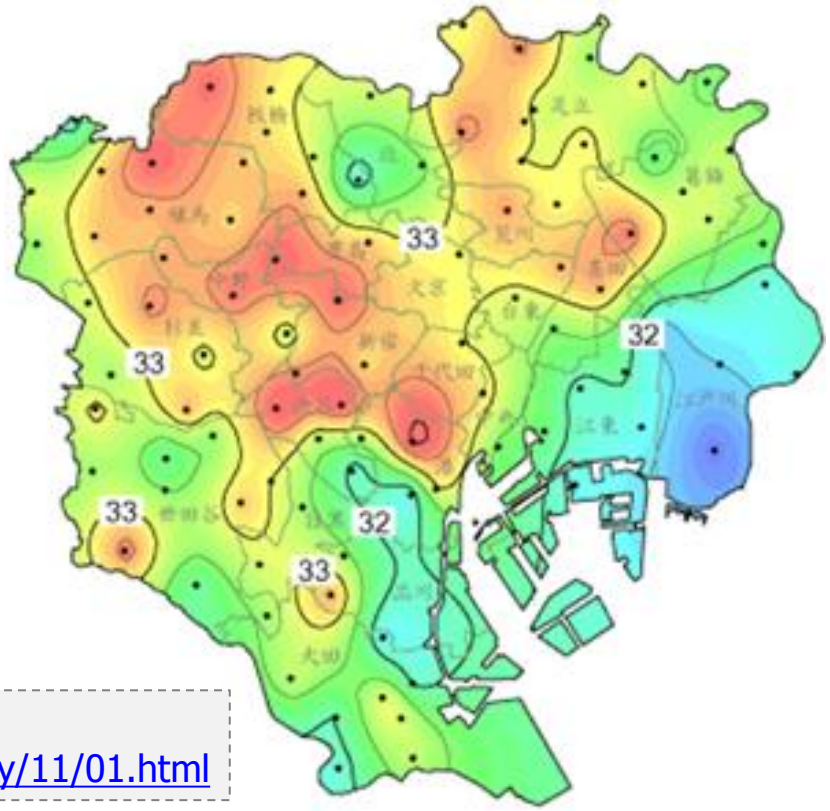
Cut-off value of SQIDS was deemed to 5.5 pt.

2 Survey on sleep

◆Epidemiological survey

- Epidemiological survey
  - Subject: 418 Internet survey company's monitors living in Tokyo
  - Period: July 31st – August 9th, 2006 (total 8 days excl. Sat & Sun)

- Outdoor air temperature data
  - METROS (Metropolitan Environmental Temperature and Rainfall Observation System) by Tokyo Metropolitan Government
  - High resolution observation network

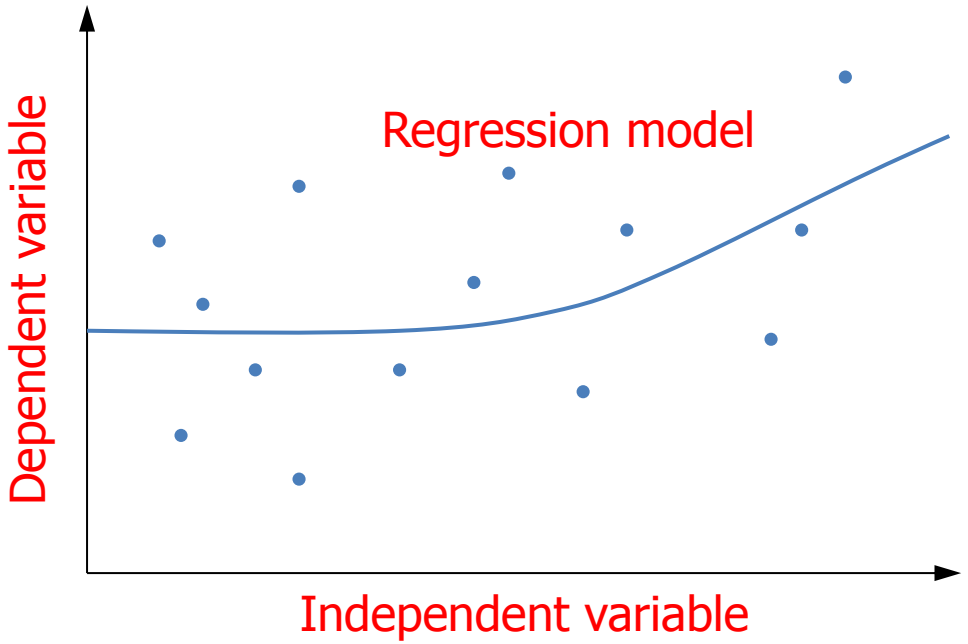


ECO Tokyo Net 62.
http://all62.jp/ecoacademy/11/01.html

3 Analysis

◆Regression analysis

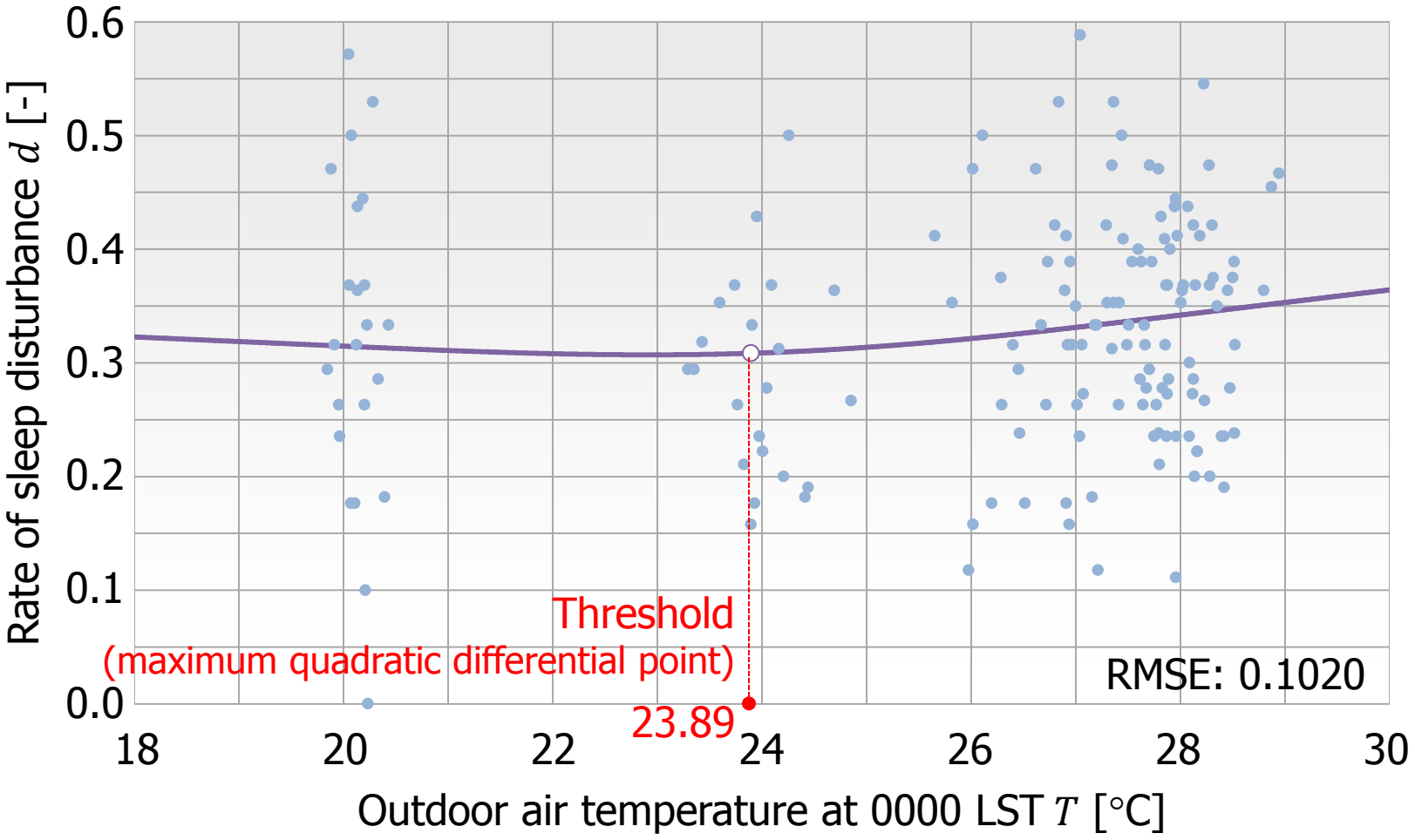
- Dependent variable
  - Rate of subjects whose SQIDS ≥ 5.5 pt d [-]
- Independent variable
  - Outdoor air temperature at 0000 LST T [°C]



- Regression model
  - Smoothing spline (basis: cubic function)
  - Degree of freedom: minimizing general cross validation (GCV)

4 Results

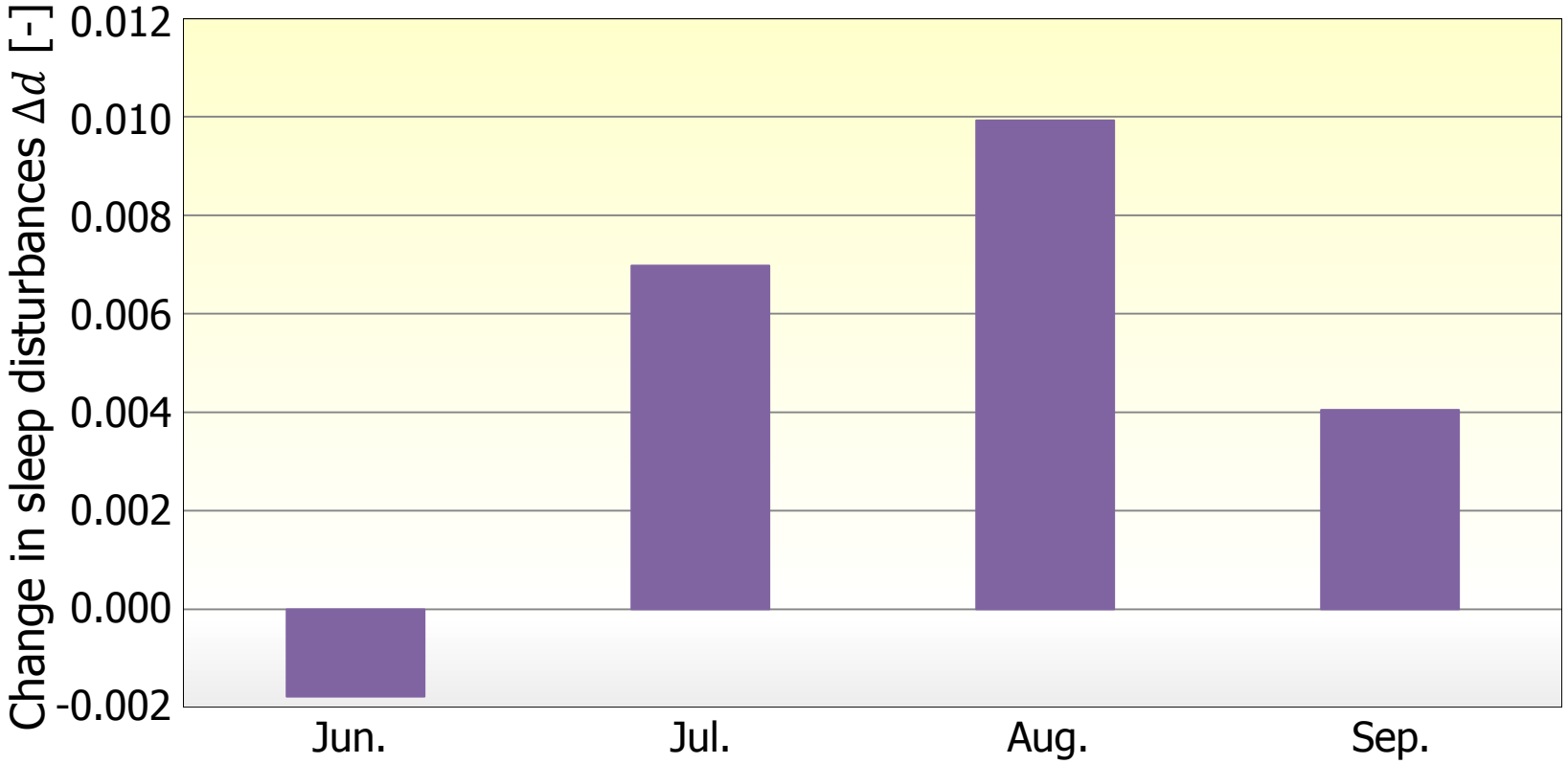
◆Outdoor air temperature vs. rate of sleep disturbance



Sleep disturbances increase by 1% per 1 °C air temperature rise.

4 Results

◆Change in sleep disturbances by 40-year air temp. rise



Change in the rate of sleep disturbance by outdoor air temperature rise from June to September over the past 40 years (1967 → 2007) in Tokyo is calculated. (min: 10.4 °C, max: 32.7 °C)。

0.48% of Tokyo residents became poor sleepers over the past 40 years.

5 Conclusion

◆Sleep disturbance vs. outdoor air temperature

- SQIDS based on PSQI was developed as a sleep quality index which can be assessed with DALY.
- The analysis of SQIDS global score and outdoor air temperature at 0000 LST showed that the threshold temperature, where poor sleepers begin to increase, was 23.9 °C. Sleep disturbances increase by 1% per 1 °C rise.

◆Sleep disturbances in Tokyo

- It is found that the ratio of poor sleepers was increased by 0.48% in the past 40 years in Tokyo, which has 9 million residents and 90 deaths due to heat stroke per year.
- DALY (approximate values)
  - Heat stroke: $90 \times 30 = 2{,}700$
  - Sleep disturbance: $9\text{M} \times 0.48\% \times 4/12 \times 0.1 = 1{,}440$

1 Introduction

◆Disability-Adjusted Life Year (DALY)

WHO. Metrics: Disability-Adjusted Life Year (DALY), http://www.who.int/healthinfo/global_burden_disease/metrics_daly/en/index.html

- Concept & definition
  - An index developed by WHO to measure damage on human health.
  - One DALY can be thought of as one lost year of "healthy" life.

- Calculation
  - $DALY = YLL + YLD$
  - $YLL = N \times L$
    - Years of Life Lost due to premature mortality in the population
    - N = numbers of deaths, L = standard life expectancy at age of death
  - $YLD = I \times DW \times L$
    - Years Lost due to Disability for incident cases of the health condition
    - I = number of incident cases, DW = disability weight, L = average duration of the case until remission or death

DALY can evaluate magnitude of diseases which does not reach to death.

1 Introduction

◆Disability weights

Fukuda S *et al*. *International Journal of Life Cycle Assessment*, Vol.18, No.5, pp.1089-1097, 2013.

Description of condition	Disability weight
Full health	0
Dental disease: periodontal disease (gingivitis)	0
Dental disease: periodontal disease (pockets >6 mm deep)	0.01
Mild vision disorder (some difficulty reading small print, no difficulty recognizing faces at 4 m)	0.02
Adult-onset mild hearing loss (25-34 dBHTL)	0.02
Mild to moderate asthma (symptom-free with or without maintenance therapy)	0.03
Adult-onset mild hearing loss (35-44 dBHTL): (some difficulty understanding or actively participating in a conversation with one or more persons)	0.04
Benign prostatic hypertrophy (symptomatic)	0.04
Chronic hepatitis B infection without active viral replication	0.06
Uncomplicated diabetes mellitus	0.07
Mild stable angina pectoris (NYHA 1-2)	0.08
Mental retardation (IQ 70-84)	0.09
Primary insomnia	0.1
Problem drinking (physical, psychological, or social problems caused by excessive alcohol intake)	0.11
Mild to moderate congenital or early acquired hearing disorder	0.11
Moderate hearing disorder in the elderly (some difficulty understanding or participating in a conversation with one person but great difficulties with conversations with more than one person)	0.12

Description of condition	Disability weight
Unipolar depressive disorders: mild depressive episode	0.14
Unipolar depressive disorders: dysthymia	0.14
Osteoarthritis (grade 2) of hip or knee	0.14
Diabetes mellitus with neuropathy	0.19
Diabetes mellitus with nephropathy	0.29
Mild mental handicap (IQ 50-69)	0.29
Unipolar depressive disorders: moderate depressive episode	0.35
Severe asthma (not symptom-free despite maintenance medication)	0.36
Severe hearing disorder acquired as an adult (great difficulty understanding or participating in a conversation with one person)	0.37
Chronic hepatitis B with active viral replication	0.36
Severe vision disorder (unable to read small newspaper print, great difficulty recognizing faces at 4 m)	0.43
Moderate mental handicap (IQ 35-49)	0.43
Schizophrenia	0.528
Severe stable angina pectoris (NYHA 3)	0.57
Paraplegia, stable stage	0.57
Unipolar depressive disorders: severe depressive episode	0.76
Extreme mental handicap (IQ < 20)	0.76
Tetraplegia, stable stage	0.84
Severe dementia (permanent supervision required)	0.95
Death	1

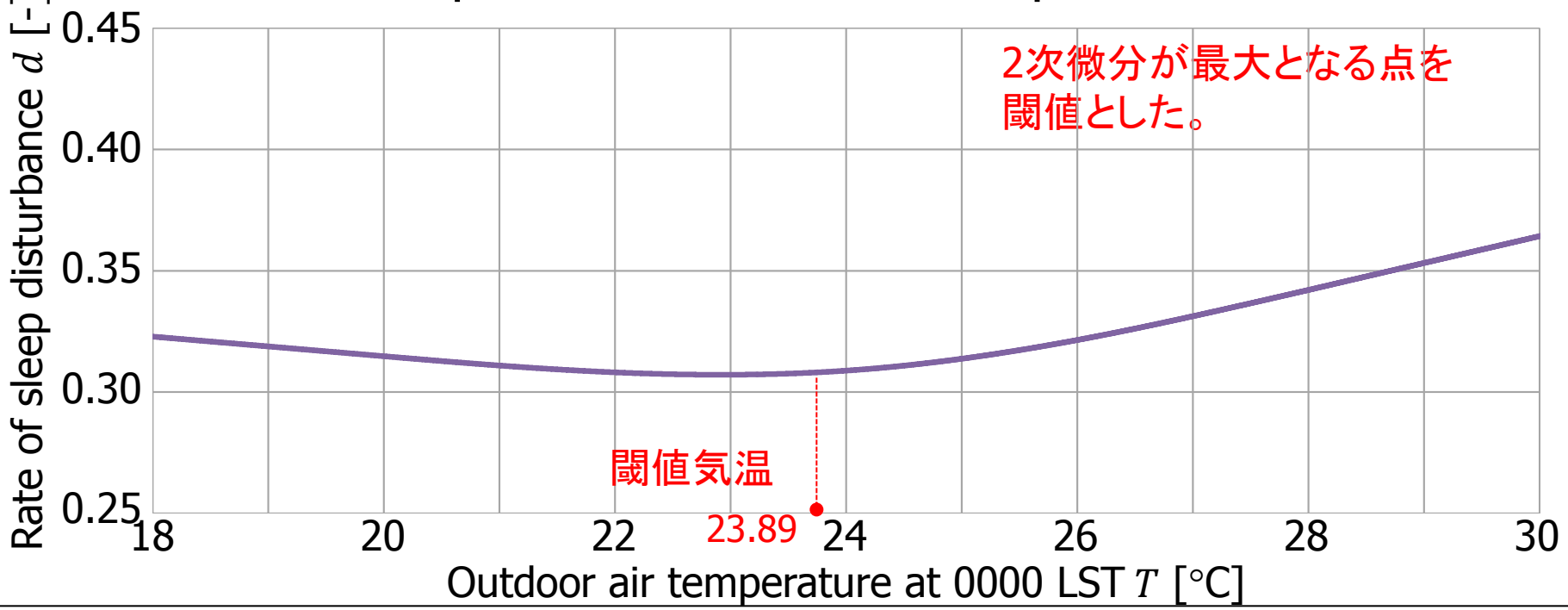
4 Results

- Damage function
  - Rate of sleep disturbance (SQIDS ≤ 5.5 pt) d [-]

$$d = k_i T^3 + l_i T^2 + m_i T + n_i \quad (T_i \leq T < T_{i+1})$$

$$(0 \leq i \leq 98)$$

- Outdoor air temperature vs. rate of sleep disturbance

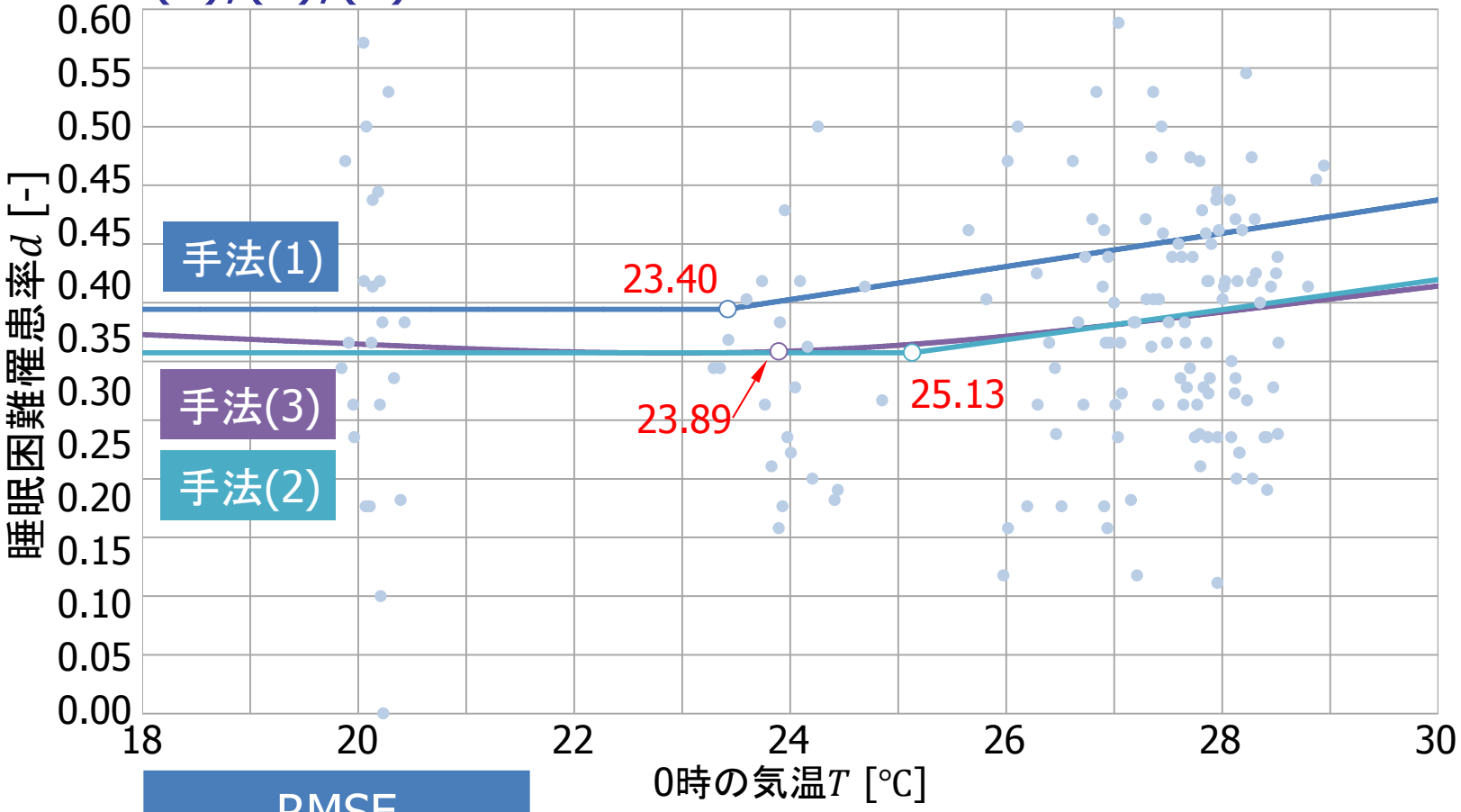


i	T_i	k_i	l_i	m_i	n_i
0	10.000	0.000	0.000	-0.004	0.396
1	19.848	0.000	0.000	0.002	0.354
2	19.883	0.000	-0.003	0.058	-0.018
3	19.913	0.000	-0.005	0.100	-0.291
4	19.958	0.000	-0.006	0.108	-0.347
5	20.048	0.000	0.000	-0.004	0.395
6	20.055	0.000	-0.017	0.343	-1.921
7	20.076	0.000	-0.015	0.290	-1.564
8	20.125	0.000	-0.007	0.138	-0.550
9	20.135	0.000	-0.019	0.381	-2.176
10	20.202	0.001	-0.034	0.686	-4.235
11	20.211	0.000	-0.005	0.103	-0.302
12	20.233	0.000	-0.013	0.249	-1.291
13	20.332	0.000	-0.011	0.214	-1.051
14	20.432	0.000	-0.008	0.155	-0.652
15	23.351	0.000	-0.007	0.125	-0.415
16	23.597	0.000	-0.010	0.210	-1.081
17	23.768	0.000	-0.008	0.160	-0.692
18	23.895	0.000	0.005	-0.160	1.861
19	23.931	0.000	0.000	-0.038	0.889
20	23.976	0.000	0.006	-0.177	1.995
21	24.048	0.000	0.006	-0.184	2.054
22	24.161	0.000	0.007	-0.209	2.255
23	24.257	0.000	0.003	-0.115	1.491
24	24.442	0.000	0.012	-0.316	3.135
25	24.852	0.000	0.011	-0.297	2.975
26	25.819	0.000	0.003	-0.107	1.340
27	26.016	0.000	0.020	-0.529	5.000
28	26.110	0.000	0.009	-0.241	2.490
29	26.286	0.000	0.015	-0.421	4.071
30	26.399	0.000	0.011	-0.313	3.116
31	26.464	0.000	0.027	-0.726	6.767
32	26.617	0.000	0.022	-0.601	5.656
33	26.716	0.000	0.023	-0.624	5.858
34	26.800	0.000	0.010	-0.285	2.828
35	26.896	0.000	-0.005	0.140	-0.984
36	26.909	0.000	0.009	-0.258	2.588
37	26.938	0.000	0.016	-0.443	4.249
38	26.963	0.000	0.016	-0.430	4.131
39	27.011	0.000	0.020	-0.536	5.092
40	27.043	0.000	0.011	-0.288	2.851
41	27.071	0.000	0.017	-0.449	4.307
42	27.181	0.000	0.023	-0.624	5.887
43	27.212	0.000	0.032	-0.857	8.003
44	27.301	0.000	0.025	-0.686	6.448
45	27.347	0.000	0.016	-0.433	4.142
46	27.364	0.000	0.009	-0.236	2.343
47	27.416	0.000	0.007	-0.196	1.980
48	27.452	0.000	-0.004	0.129	-0.994
49	27.505	0.000	-0.005	0.148	-1.170
50	27.596	0.000	-0.011	0.295	-2.522
51	27.627	0.000	-0.007	0.193	-1.585
52	27.656	0.000	-0.004	0.119	-0.902
53	27.675	0.000	0.001	-0.013	0.316
54	27.707	0.000	-0.008	0.215	-1.791
55	27.749	0.000	-0.002	0.050	-0.258
56	27.792	0.000	0.005	-0.134	1.444
57	27.800	0.000	0.006	-0.168	1.754
58	27.828	0.000	0.005	-0.143	1.530
59	27.855	0.000	0.002	-0.058	0.741
60	27.868	0.000	0.005	-0.145	1.543
61	27.876	0.000	0.010	-0.284	2.842
62	27.901	0.000	0.007	-0.203	2.085
63	27.953	0.000	-0.006	0.177	-1.459
64	27.960	0.000	0.007	-0.184	1.909
65	28.004	0.000	0.007	-0.204	2.095
66	28.019	0.000	0.009	-0.234	2.375
67	28.069	0.000	0.005	-0.147	1.565
68	28.086	0.000	0.013	-0.357	3.526
69	28.105	0.000	0.016	-0.431	4.221
70	28.117	0.000	0.020	-0.568	5.504
71	28.126	0.000	0.023	-0.637	6.151
72	28.144	0.000	0.029	-0.823	7.895
73	28.163	0.000	0.037	-1.039	9.927
74	28.223	0.000	0.024	-0.665	6.403
75	28.245	0.000	0.021	-0.576	5.569
76	28.273	0.000	0.007	-0.177	1.806
77	28.283	0.000	0.015	-0.419	4.085
78	28.313	0.000	0.003	-0.063	0.728
79	28.352	0.000	-0.009	0.279	-2.505
80	28.393	0.000	-0.005	0.148	-1.263
81	28.418	0.000	0.012	-0.319	3.159
82	28.473	0.000	0.011	-0.291	2.893
83	28.499	0.000	0.004	-0.100	1.081
84	28.518	0.000	0.009	-0.249	2.492
85	28.531	0.000	0.005	-0.123	1.299
86	28.594	0.000	0.016	-0.441	4.326
87	28.652	0.000	0.019	-0.545	5.321
88	28.682	0.000	0.019	-0.545	5.322
89	28.684	0.000	0.011	-0.298	2.963
90	28.697	0.000	0.006	-0.160	1.636
91	28.740	0.000	0.006	-0.160	1.639
92	28.748	0.000	-0.003	0.098	-0.831
93	28.798	0.000	-0.003	0.098	-0.829
94	28.871	0.000	-0.012	0.371	-3.459
95	28.944	0.000	-0.012	0.355	-3.308
96	28.967	0.000	-0.010	0.303	-2.799
97	29.110	0.000	-0.005	0.161	-1.425
98	29.153	0.000	0.000	0.011	0.033

4. 解析結果

◆手法(1),(2),(3)の結果・精度の比較

プロットは毎日の個人値ではなく、
毎日の地域平均値。

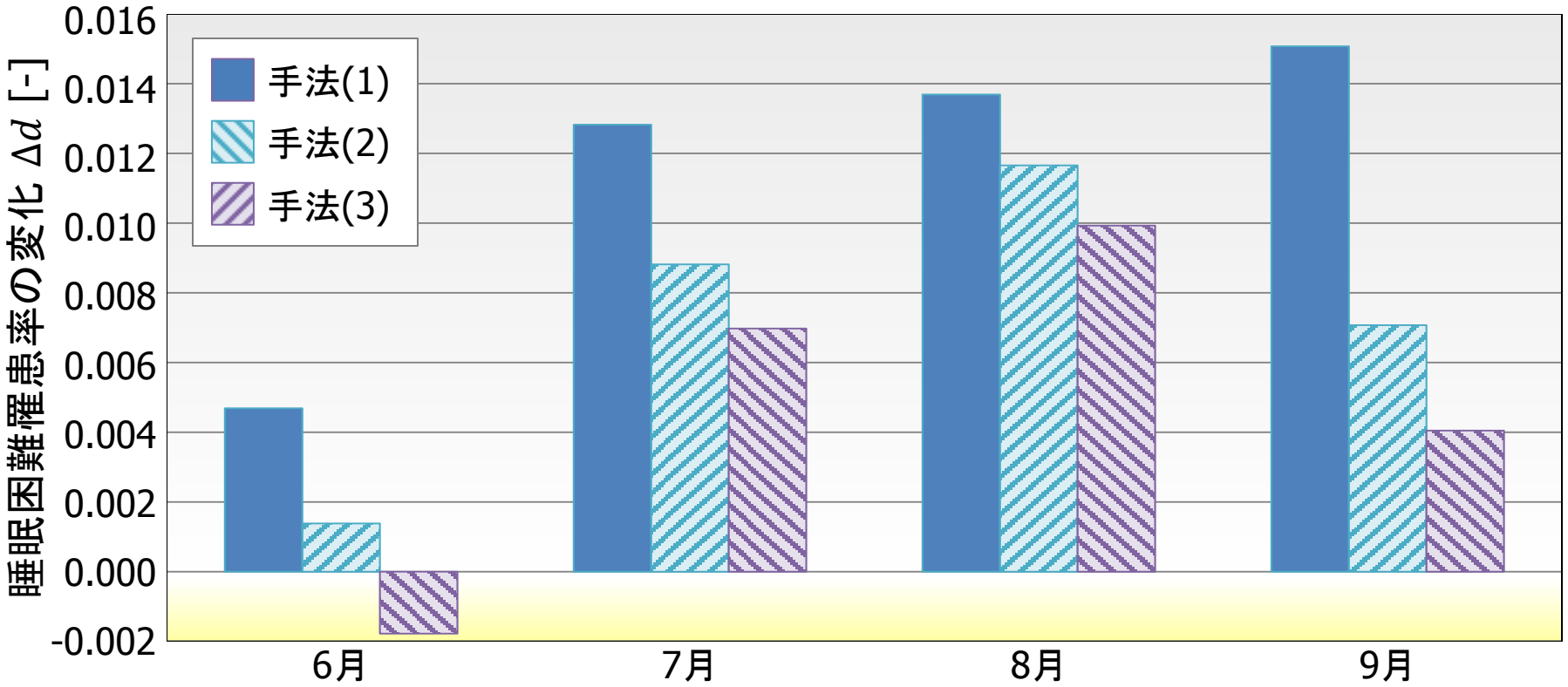


RMSE	
手法(1)	0.1190
手法(2)	0.1021
手法(3)	0.1020

手法(1)は、正規分布を仮定したことにより
罹患率の最小値・閾値ともに過大に評価している。
回帰誤差も大きい。

4 Results

◆各手法による睡眠困難罹患率の40年間の変化の予測（月平均）

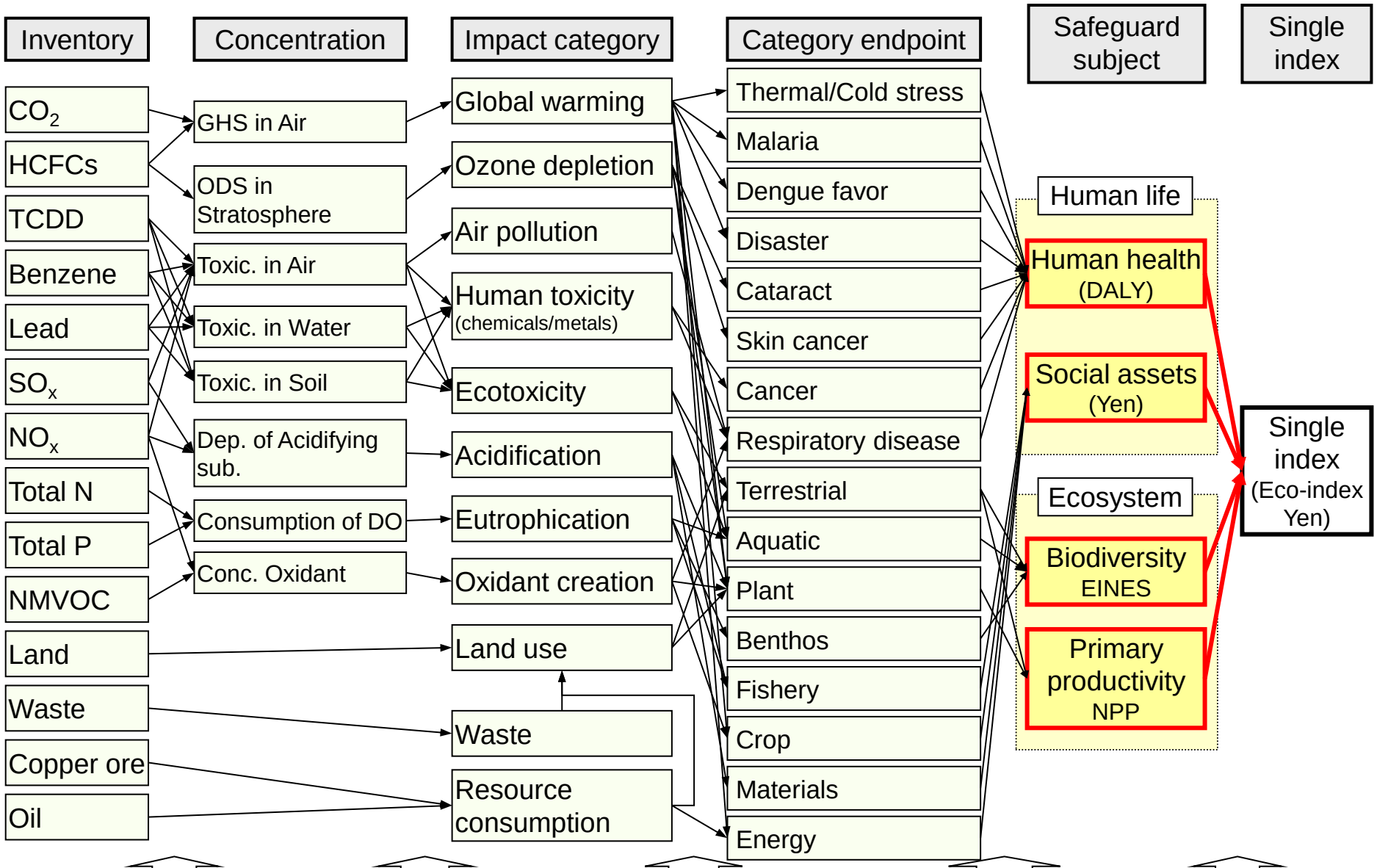


東京の過去40年間（1967年→2007年）の6-9月の気温上昇に伴う睡眠困難罹患率の変化を評価した（最低10.4℃・最高32.7℃）。

手法(1)は平均1.16%睡眠困難率が上昇したのに対し、手法(2)は0.72%、手法(3)は0.48%にとどまり、手法(1)は他の手法より大きい。

◆Endpoint-type LCIA Methodology for Japan (LIME)

Itsubo N & Inaba A (eds). Lifecycle Impact Assessment Method – LIME-LCA. 2005. [in Japanese]



Methodology: LCIA

Ihara T, et al. *Trans. AIJ*, 73(634), 1407-1415, 2008. [in Japanese]

◆LCIA method for air temperature rise (based on LIME)