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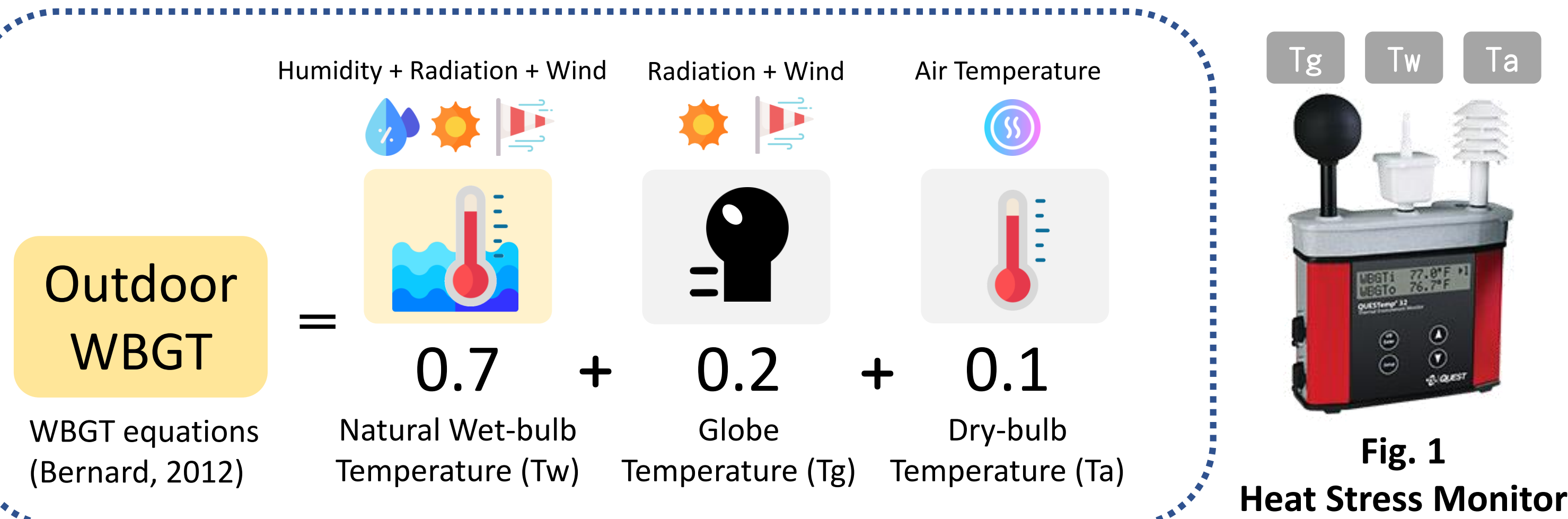
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Abstract

Wet-bulb globe temperature (WBGT), a weighted combination of natural wet-bulb temperature, globe temperature and dry-bulb temperature, is the most widely used index of heat stress nowadays. However, only dry-bulb temperature was provided by routine meteorological measurements, and monitors may be overheating when measuring outdoor WBGT under the sun. Therefore, this study estimates WBGT with four parameters including temperature, humidity, wind speed, and solar radiation, based on the hourly historical data from the CWB, Taiwan. To begin with, the study attempts to visualize the change of WBGT among years, months, and hours. Furthermore, the study applies the calculated WBGT to two standards, including Heat Flag Conditions use by the U.S. military and Rest-work Schedule during Operations with Heat Exposure used by Taiwan government, to see the change of flag conditions and rest time per hour regulated in Taiwan.

1. Wet-bulb Globe Temperature (WBGT)



Estimation of WBGT

- Data Source: Central Weather Bureau
- Data Type: Hourly Data of Taiwan Weather Stations
- References: Liljegren et al. 2008

Input

- TX01: Air Temperature (Ta / unit: °C)
- RH01: Relative Humidity (RH / unit: %)
- WD01: Average Wind Speed (WS / unit: m/s)
- SS02: Global Solar Radiation (SR / unit: MJ/m²)

Output

- Natural Wet-bulb Temperature (Tw / unit: °C)
- Globe Temperature (Tg / unit: °C)
- WBGT (unit: °C) = 0.7 x Tw + 0.2 x Tg + 0.1 x Ta

Annual Average

There is a rapid drop in solar radiation in 2000 at every station shown in Fig. 2, corresponding to the trend of WBGT. Before that, there are no consistent trends of SR across all stations probably due to the personal or instrumental error. Therefore, in the following analysis, this study only uses the data after 2000 to avoid errors.

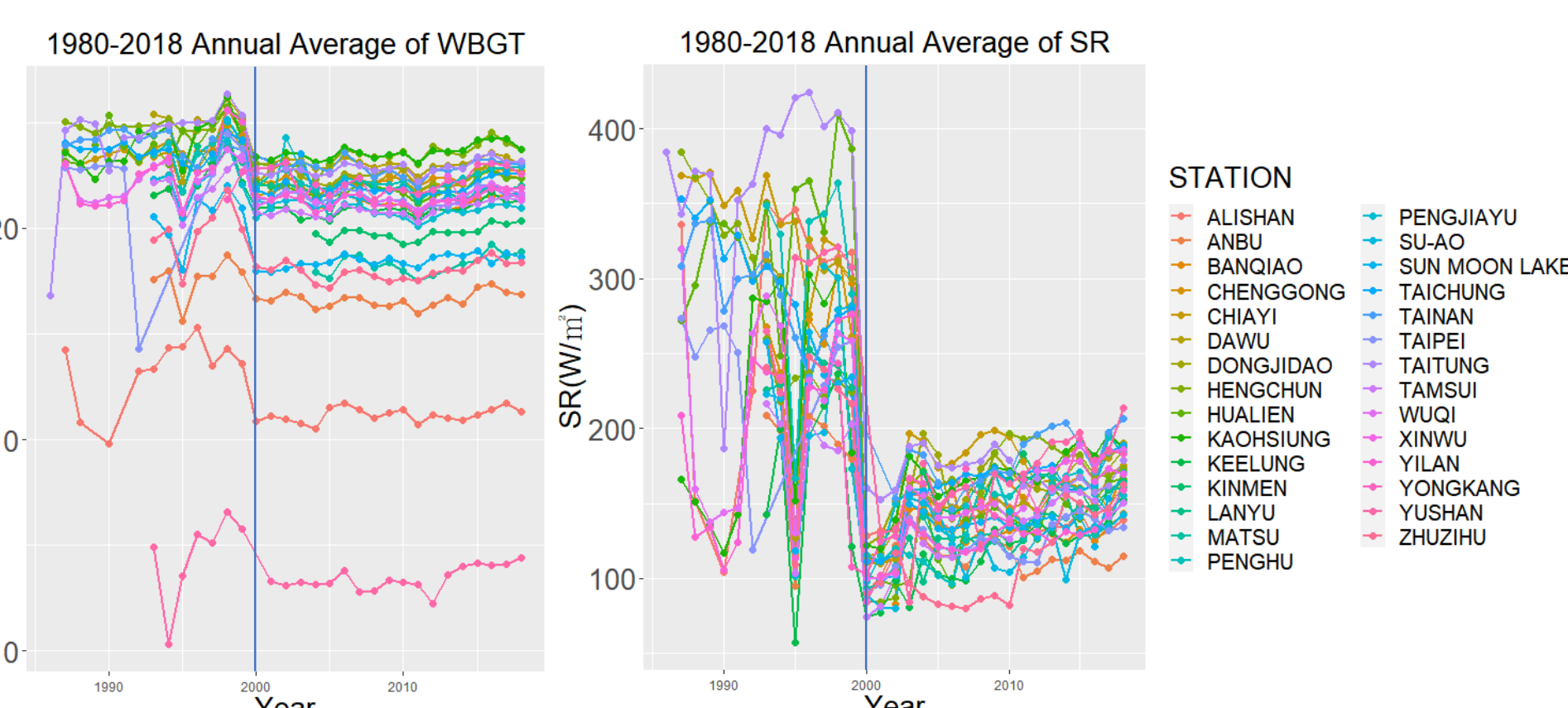


Fig. 2 Annual Average of WBGT & Global Solar Radiation

Monthly Average

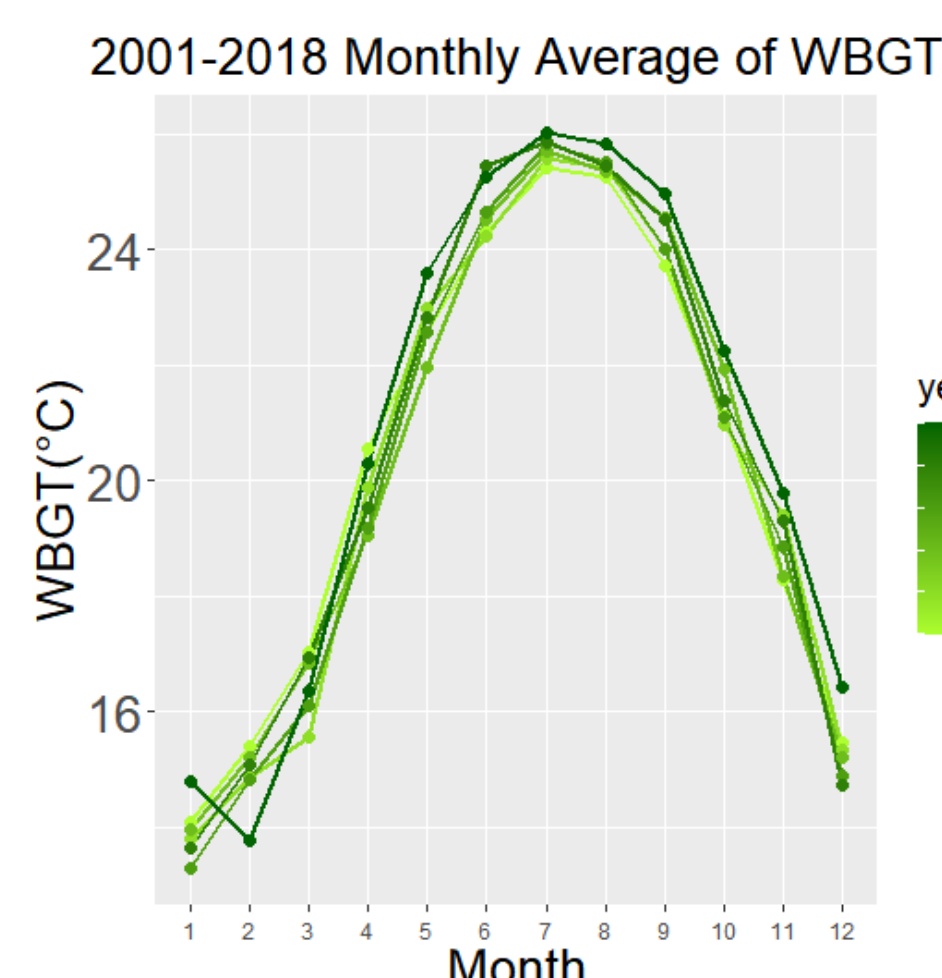


Fig. 3 2001-2018 Monthly Average of WBGT

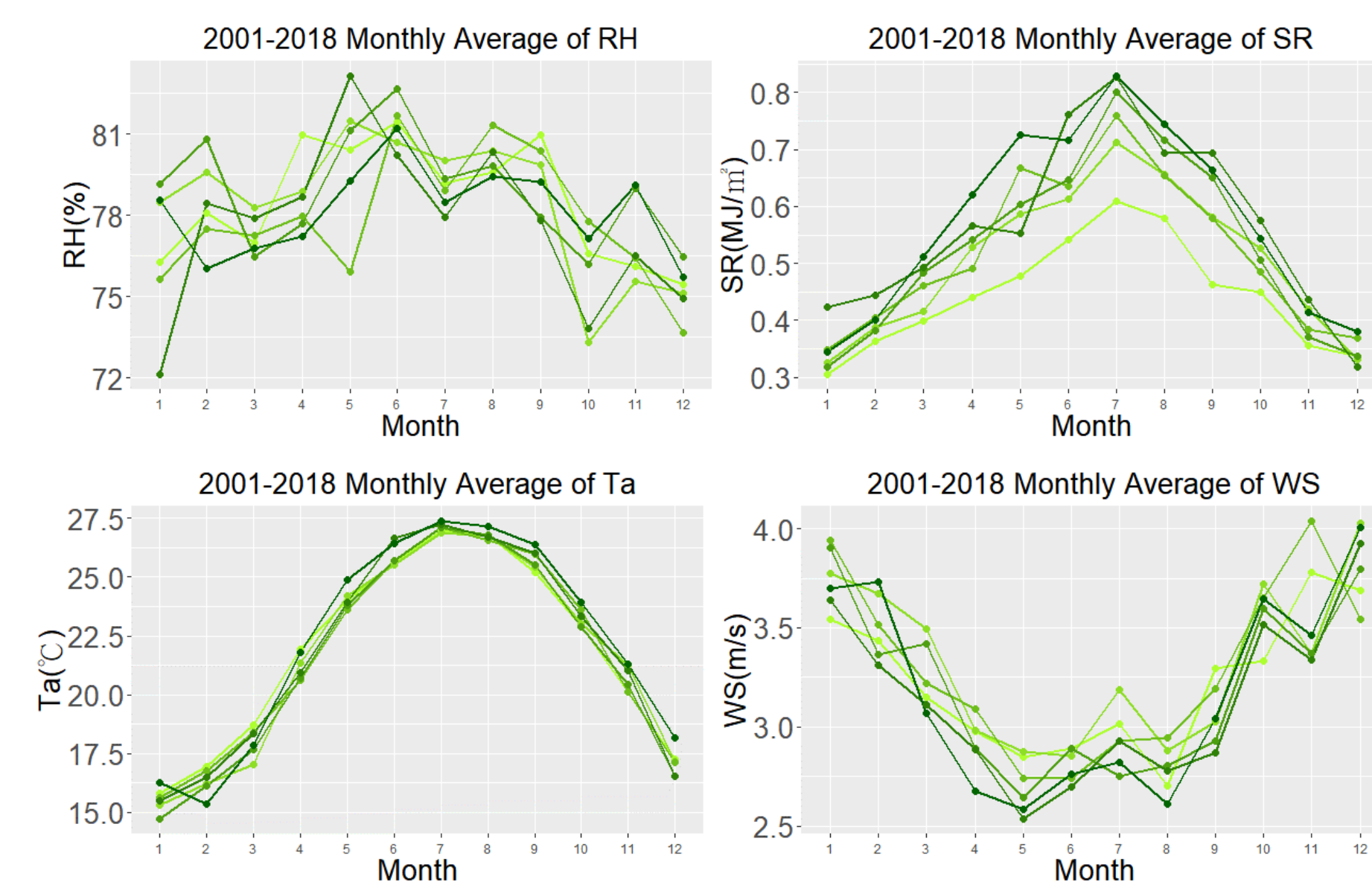


Fig. 4 2001-2018 Monthly Average of all Parameters of WBGT

Hourly Average

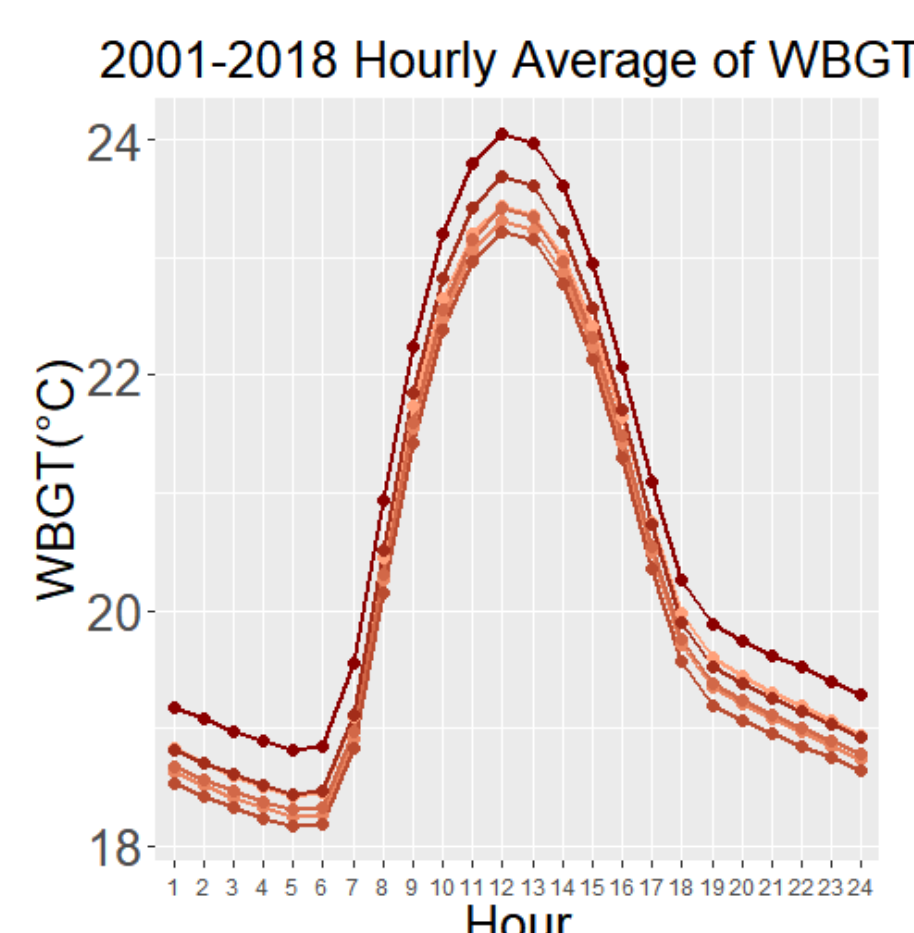


Fig. 5 2001-2018 Hourly Average of WBGT

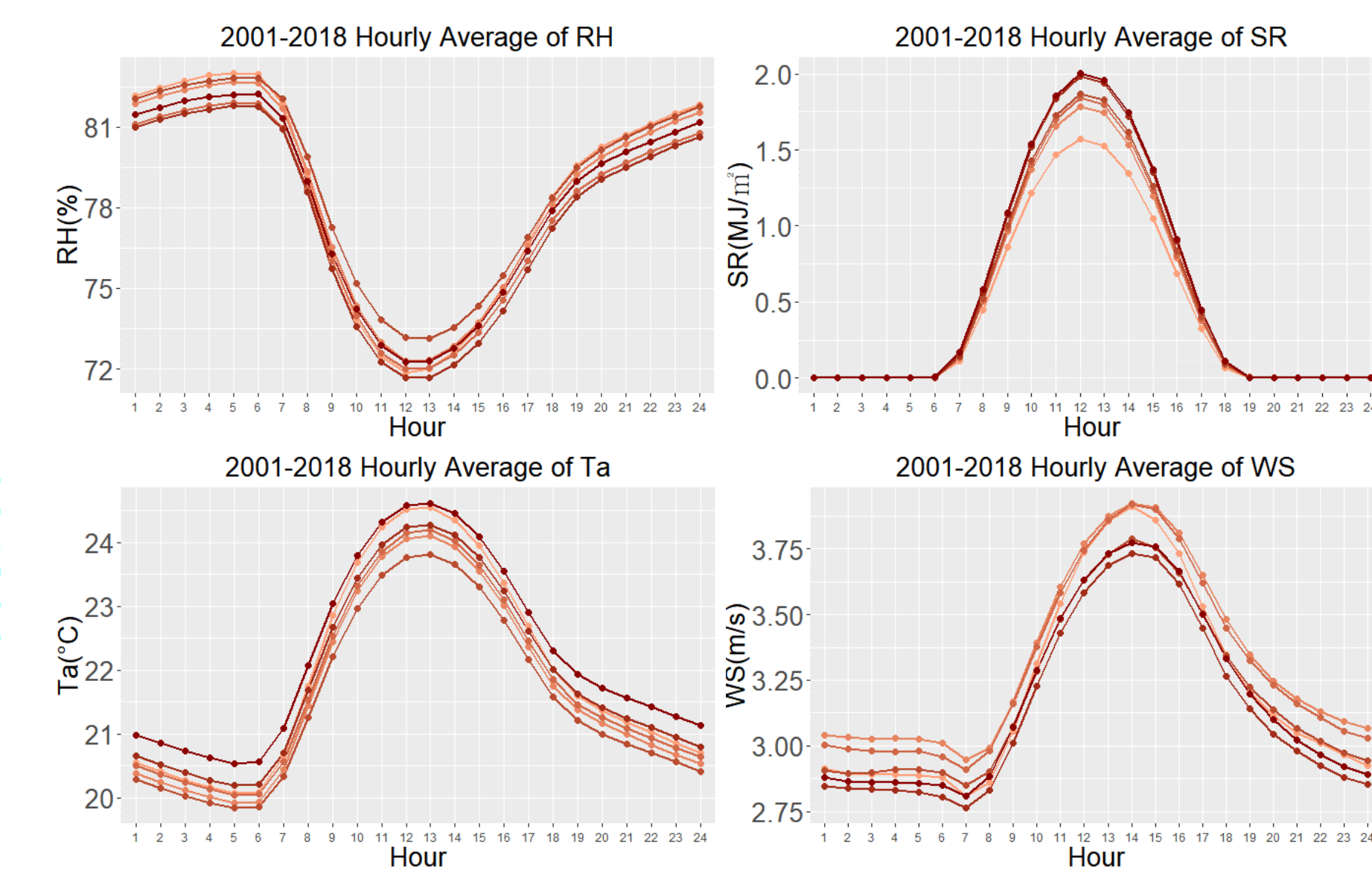


Fig. 6 2001-2018 08-17(UTC+8) Hourly Average of all Parameters of WBGT

2. Heat Flag Conditions

Heat flag conditions in the military describe the risk of suffering heat illness (heat cramps, heat exhaustion, heat injury, and heat stroke) during work or exercise outside in the heat, which are currently based on WBGT. Currently, there are 5 flag conditions in use by the U.S. military shown in Fig. 5. After no flag, each color corresponds with increasing restrictions to work or training based on personnel's heat acclimatization status and training intensity.

Source: Military heat flag conditions explained | HPRC

(<https://www.hprc-online.org/physical-fitness/environmental-extremes/military-heat-flag-conditions-explained>)

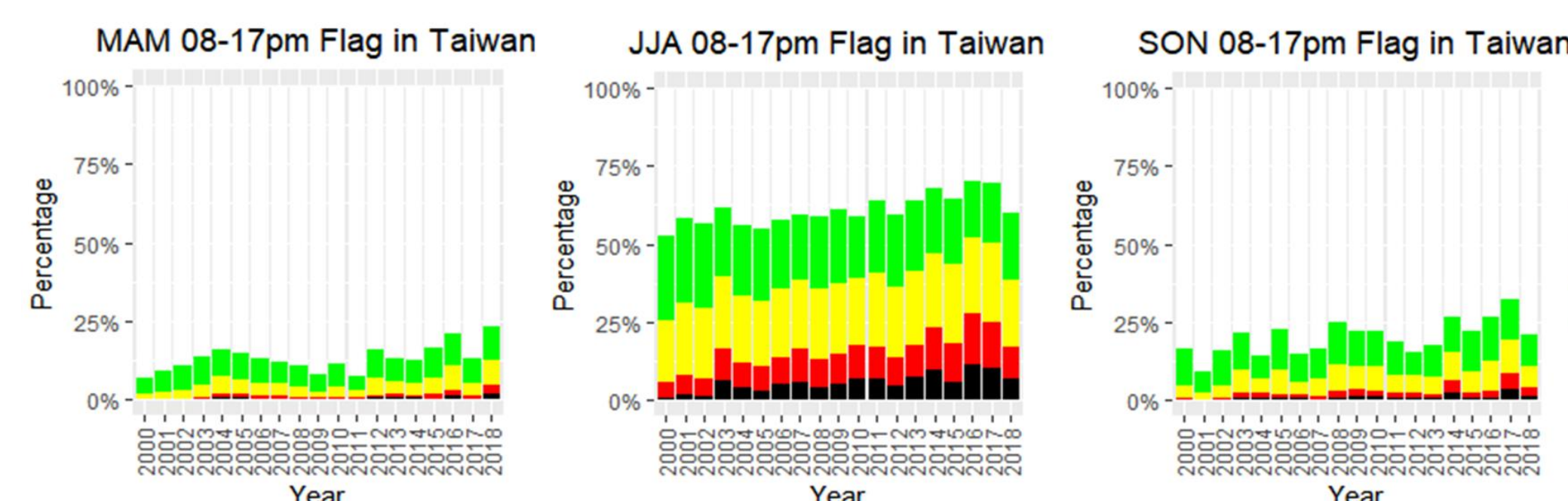


Fig. 7 2000-2018 Annual proportion of 5 flag conditions in each season

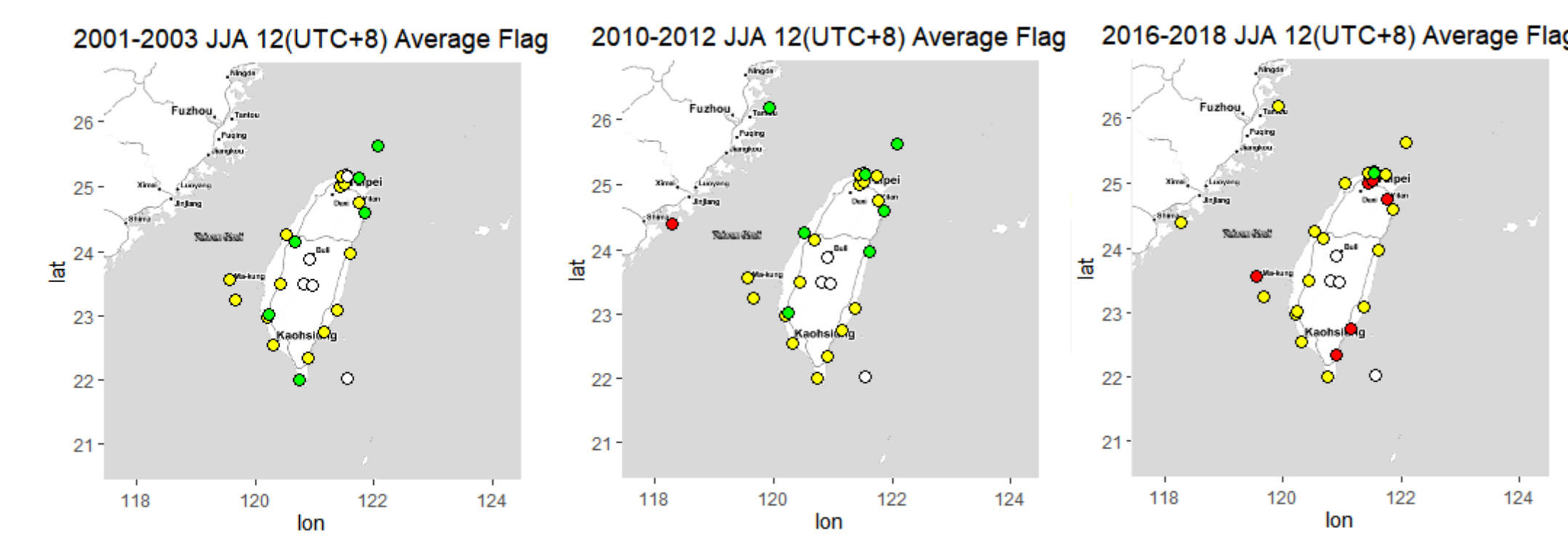


Fig. 8 JJA 12(UTC+8) Triennial average flag conditions at each station in Taiwan

3. Rest-work Schedule during Operations with Heat Exposure

Workload	WBGT(°C)			
Light Work Only performing arm movements in sitting or standing positions to operate machines	30.6	31.4	32.2	33.0
Moderate Work Lifting or pushing objects of general weight while walking	28.0	29.4	31.1	32.6
Heavy Work Full-body exercises such as shoveling, digging and pushing	25.9	27.9	30.0	32.1
Rest time per hour(Unit: Minutes)	Continuous work	Rest 15 Work 45	Rest 30 Work 30	Rest 45 Work 15

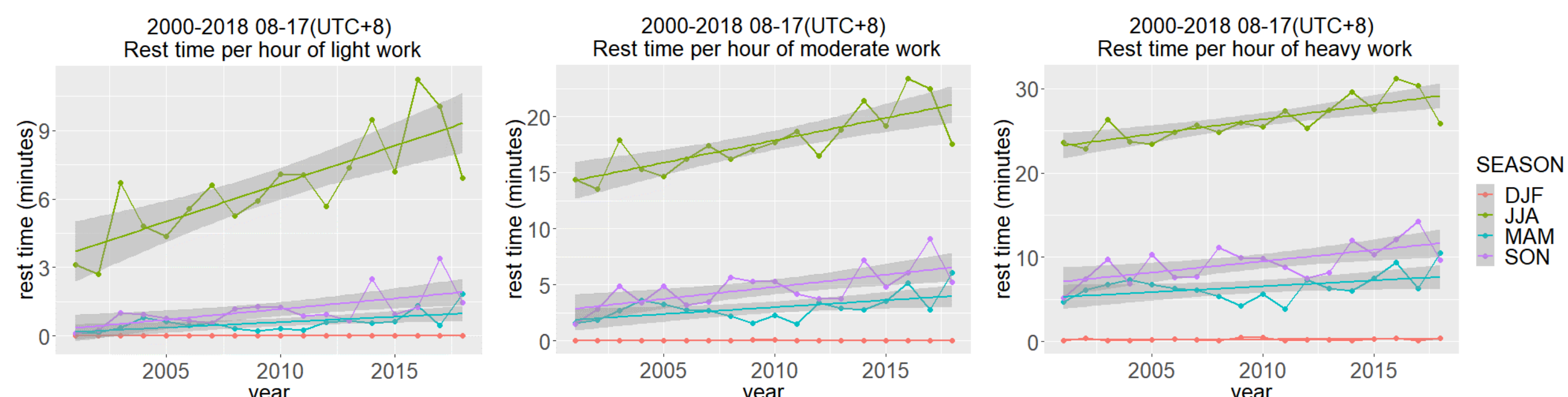


Fig. 9 2001-2018 08-17(UTC+8) Annual average of rest time per hour for each season

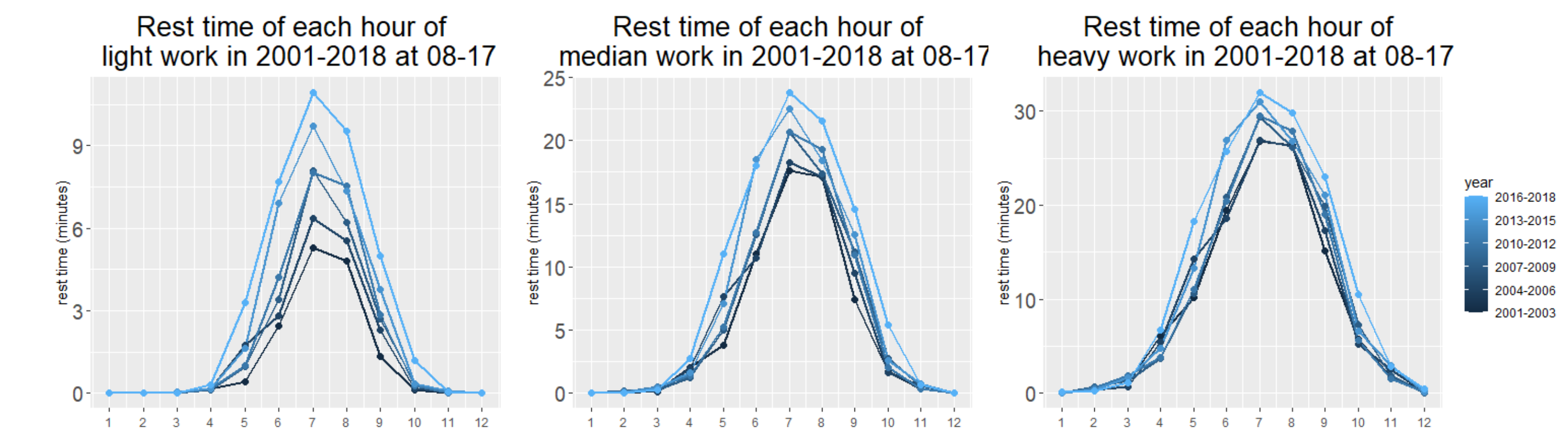


Fig. 10 2001-2018 08-17(UTC+8) Three-year average of rest time per hour

4. Summary

- Annual Monthly Hourly **WBGT** increases since 2000. Especially hourly average in 2016-2018. (Fig. 2 & 3 & 5)
- Hourly **Relative Humidity** decreases year by year. (Fig. 6)
- Monthly Hourly **Global Solar Radiation** sharply increases in MAM, JJA, SON. (Fig. 4) sharply increases in the daytime. (Fig. 6)
- Monthly Hourly **Air Temperature** increases year by year. (Fig. 4 & 6)
- Monthly Hourly **Wind Speed** decreases year by year. (Fig. 4 & 6)

- Heat Flag Conditions** used in the U.S.
 - "No flag" hours declines year by year. (Fig. 7)
 - Extreme conditions such as red & black flag increases from 0 to 5 stations. (Fig. 8)

- Rest-work Schedule during Operations with Heat Exposure** used in Taiwan
 - From May to October, annual average of rest time increases since 2000. (Fig. 10)

JJA 08-17 Rest-work Schedule (Fig. 9)	Light Work	Moderate Work	Heavy Work
2000	3 mins	15 mins	24 mins
2017	10 mins	22.5 mins	30 mins