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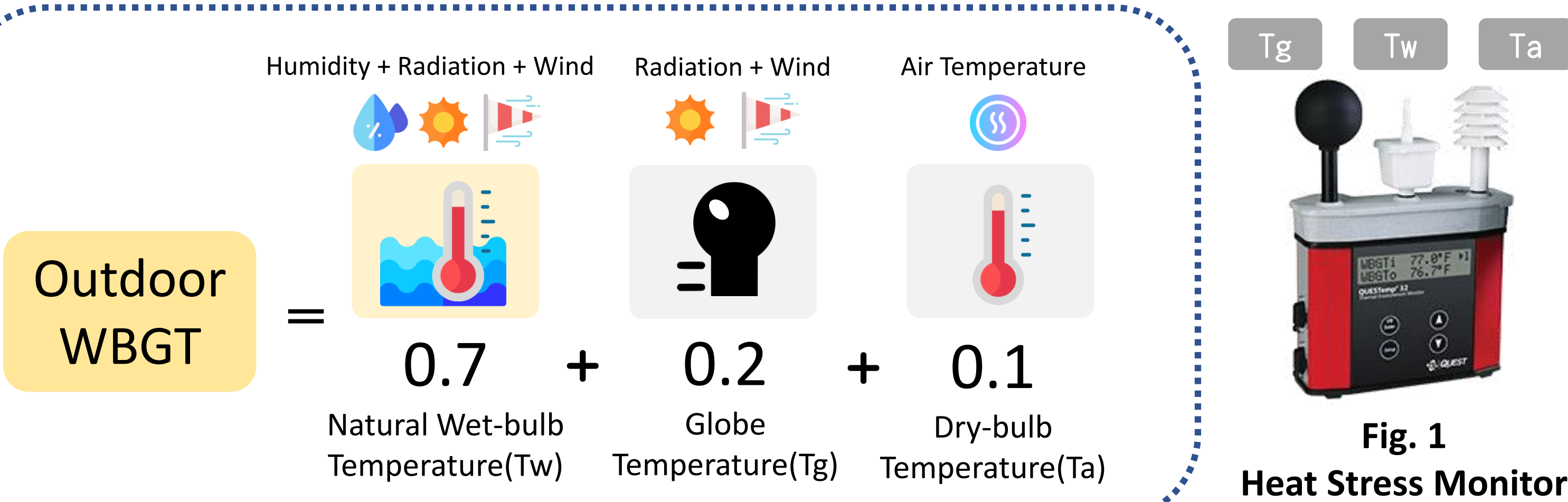
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Abstract

Wet-bulb globe temperature (WBGT) is the most widely used index of heat stress nowadays, used to estimate the effect of temperature, humidity, wind speed (wind chill), and solar radiation on humans. To begin with, this study estimates WBGT with four parameters mentioned above, based on the hourly historical data of Taiwan weather stations from the Central Weather Bureau (CWB). Then, the study attempts to visualize the change of WBGT in Taiwan among years, months, and hours. Finally, the study applies the calculated WBGT to two regulations, including Heat Flag Conditions use by the U.S. military and Work-rest Standards during High-temperature operation used by Taiwan government, to see the change of flag conditions and rest time per hour regulated in Taiwan.

Wet-bulb Globe Temperature (WBGT)



Estimation of WBGT

- Data Source: Central Weather Bureau
- Data Type: Hourly Data of Taiwan Weather Stations

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.

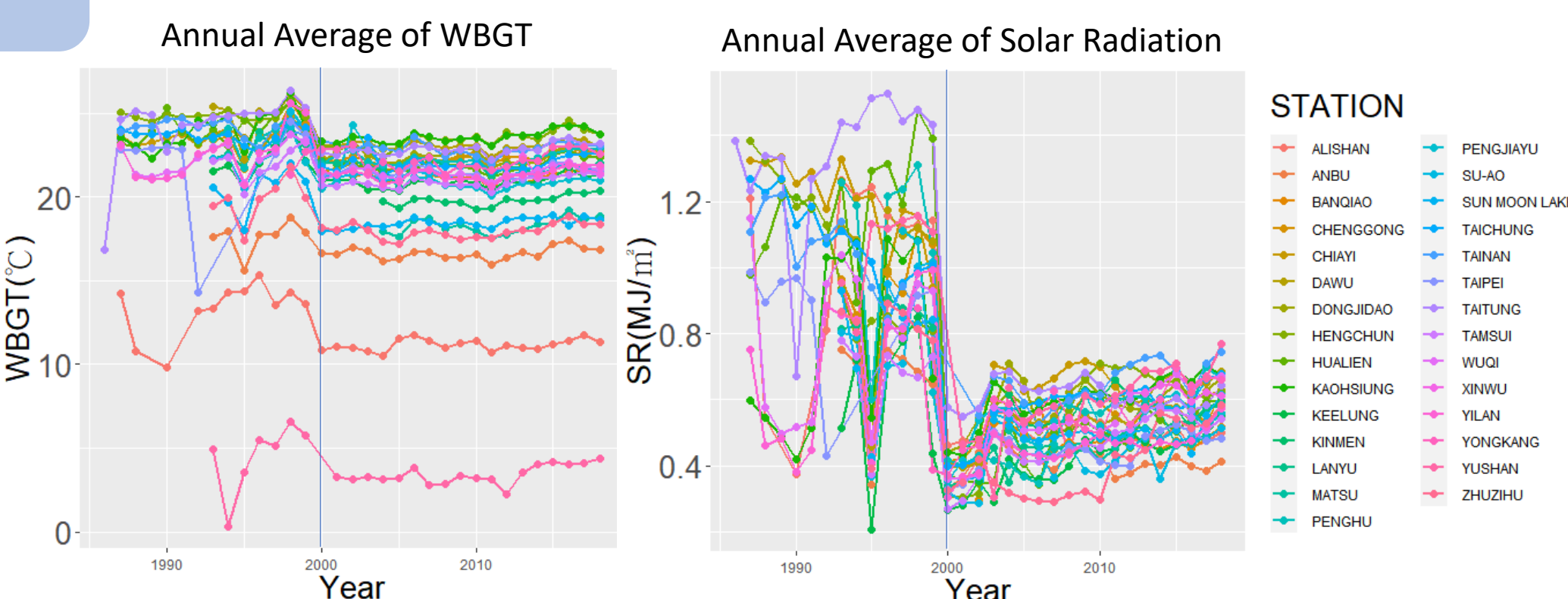


Fig. 2 Annual Average of WBGT & Global Solar Radiation

Monthly Average

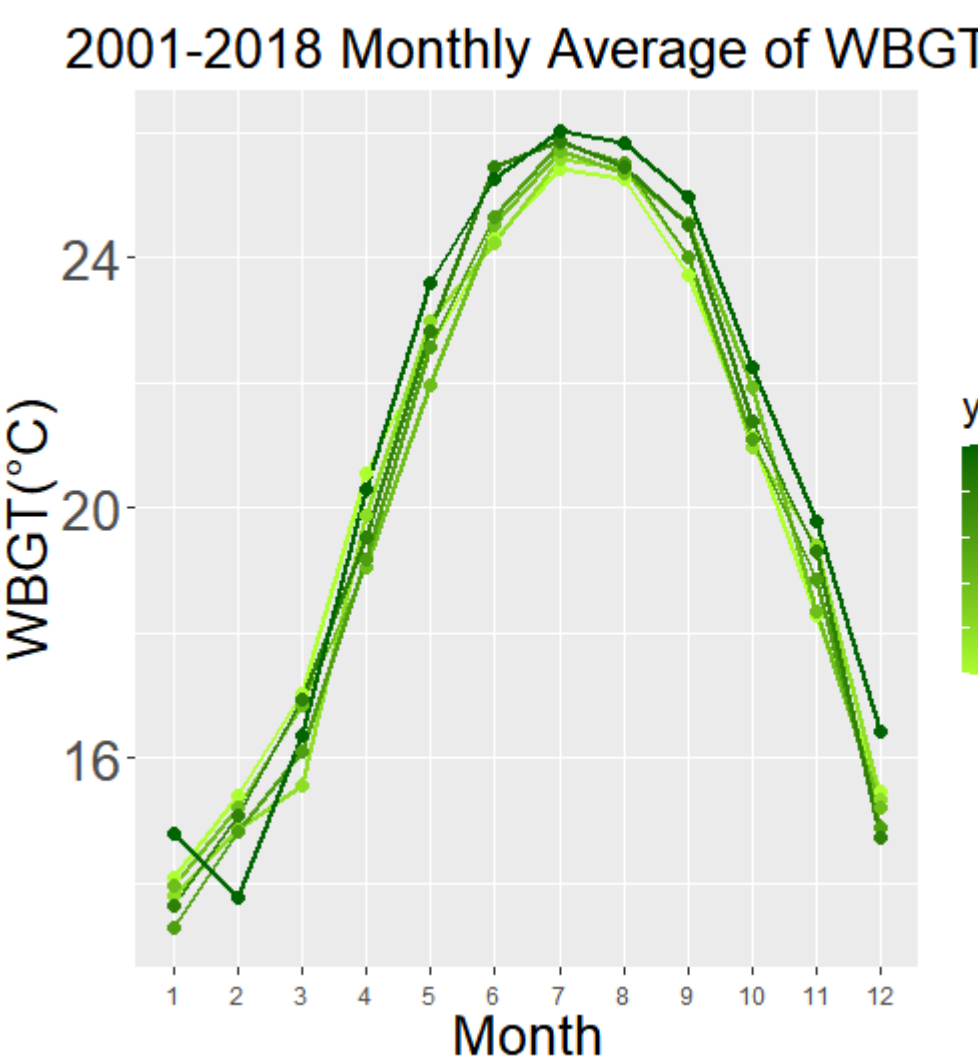


Fig. 3 2001-2018 Monthly Average of WBGT

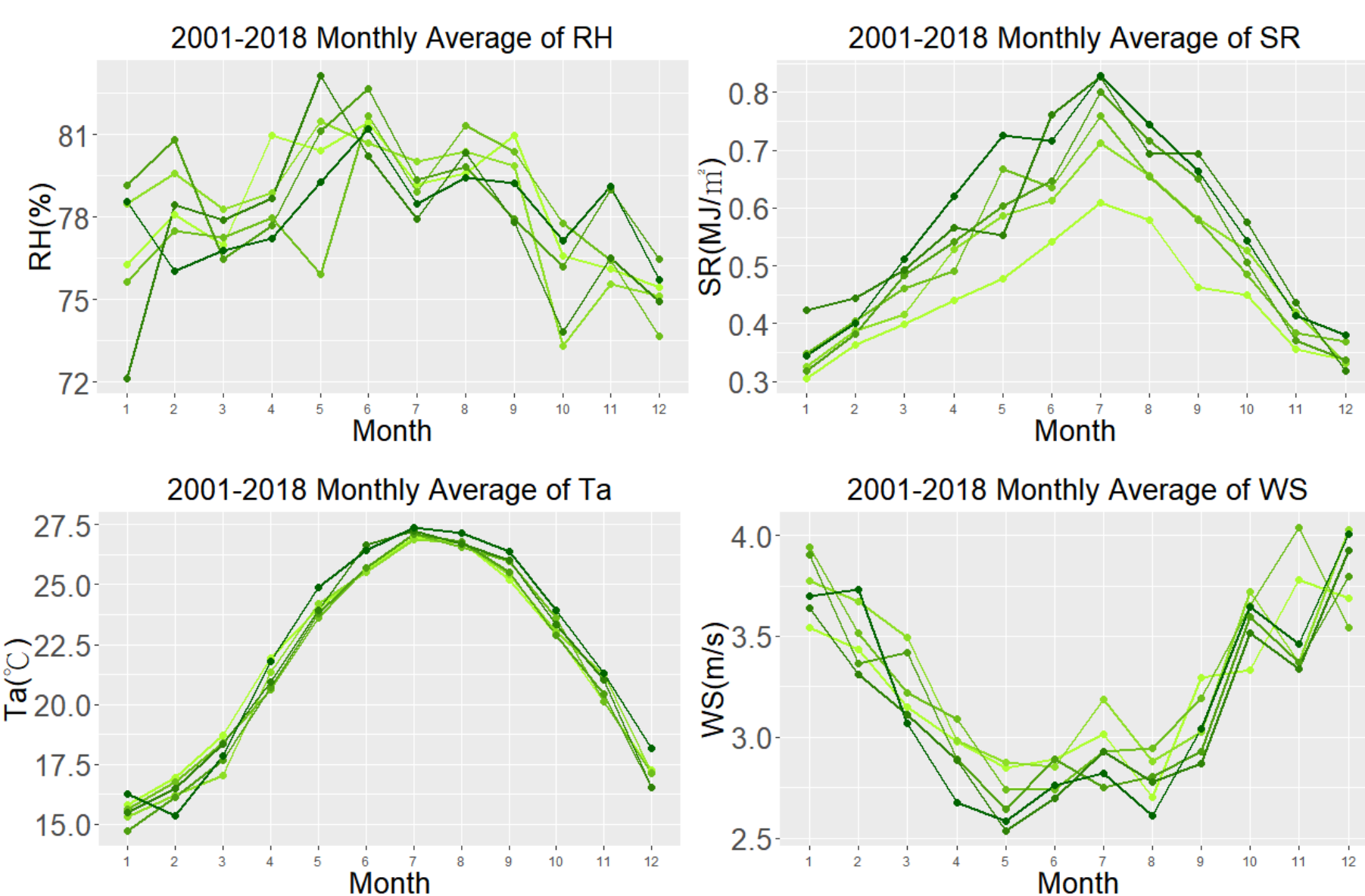


Fig. 4 2001-2018 Monthly Average of all Parameters of WBGT

Hourly Average

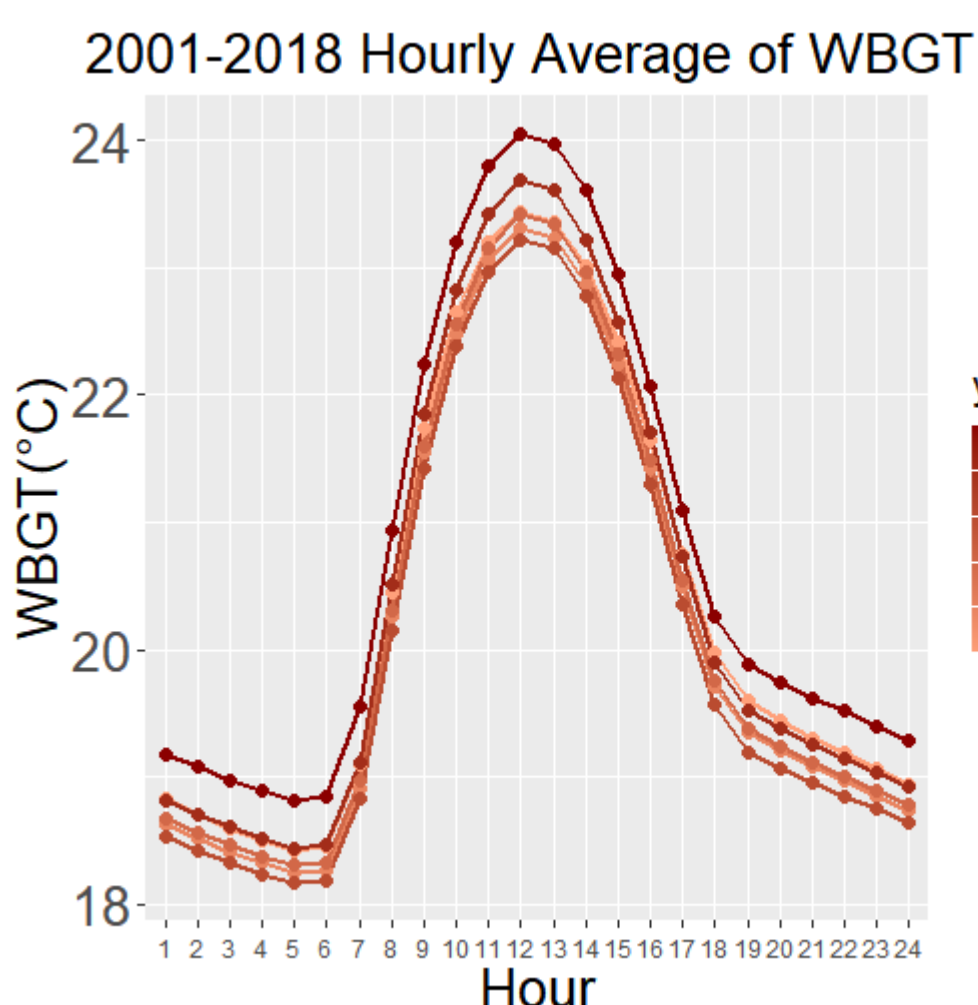


Fig. 5 2001-2018 Hourly Average of WBGT

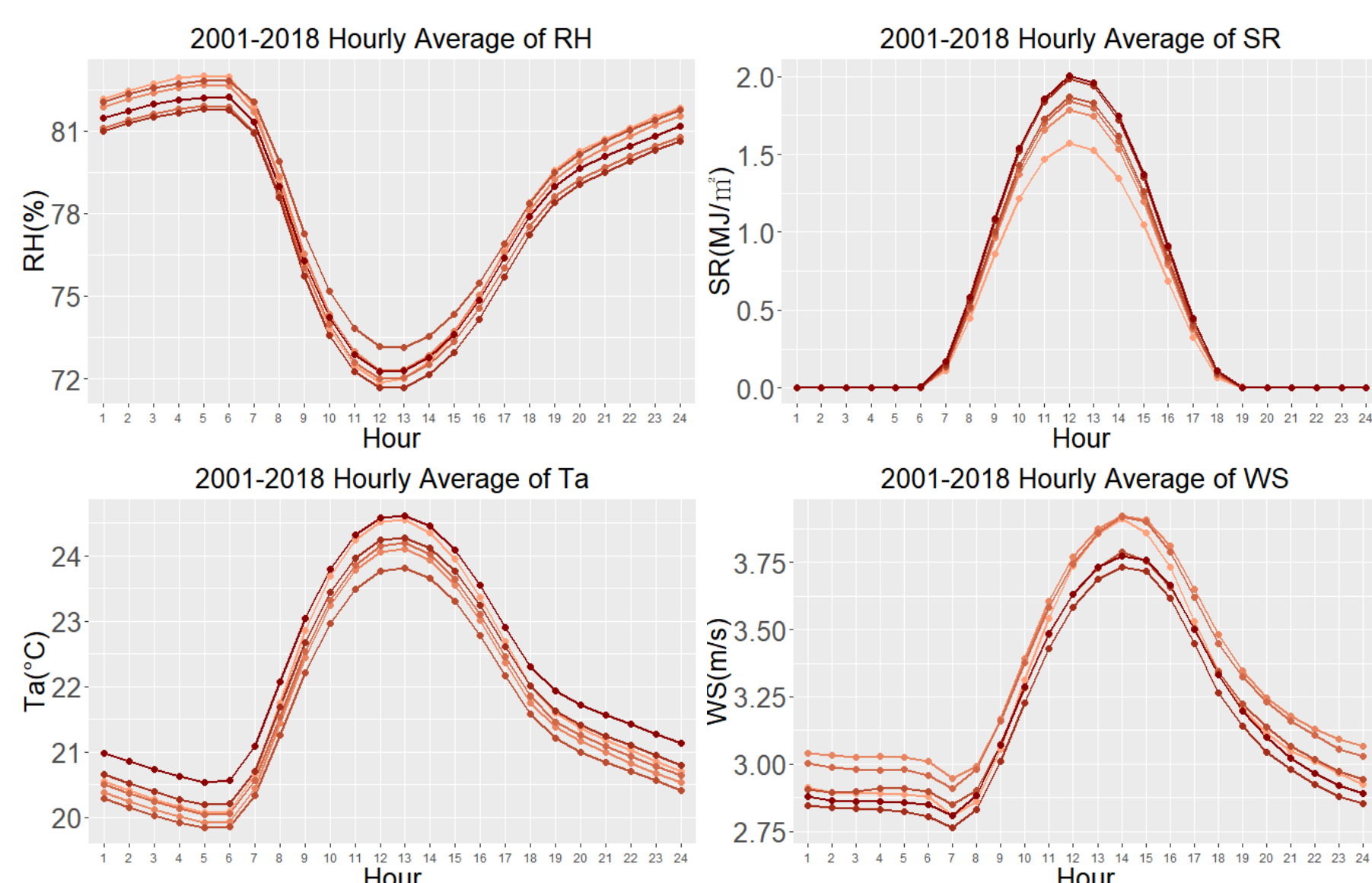


Fig. 6 2001-2018 08-17(UTC+8) Hourly Average of all Parameters of WBGT

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>)

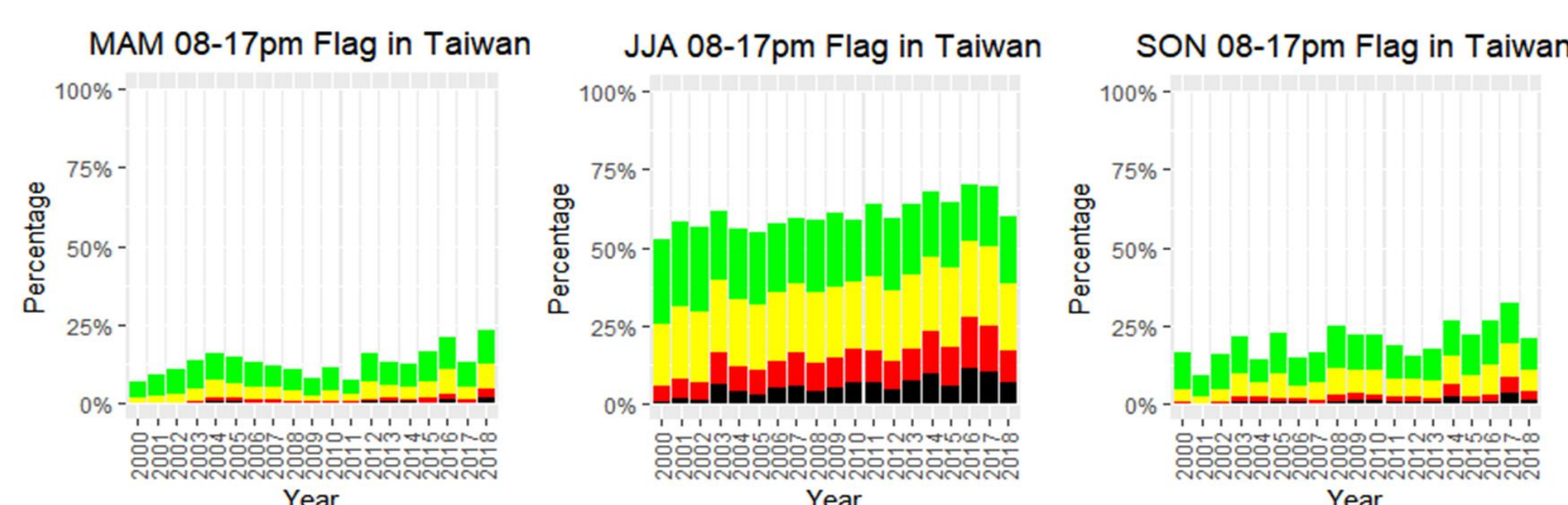


Fig. 7 2000-2018 Annual proportion of 5 flag conditions in each season

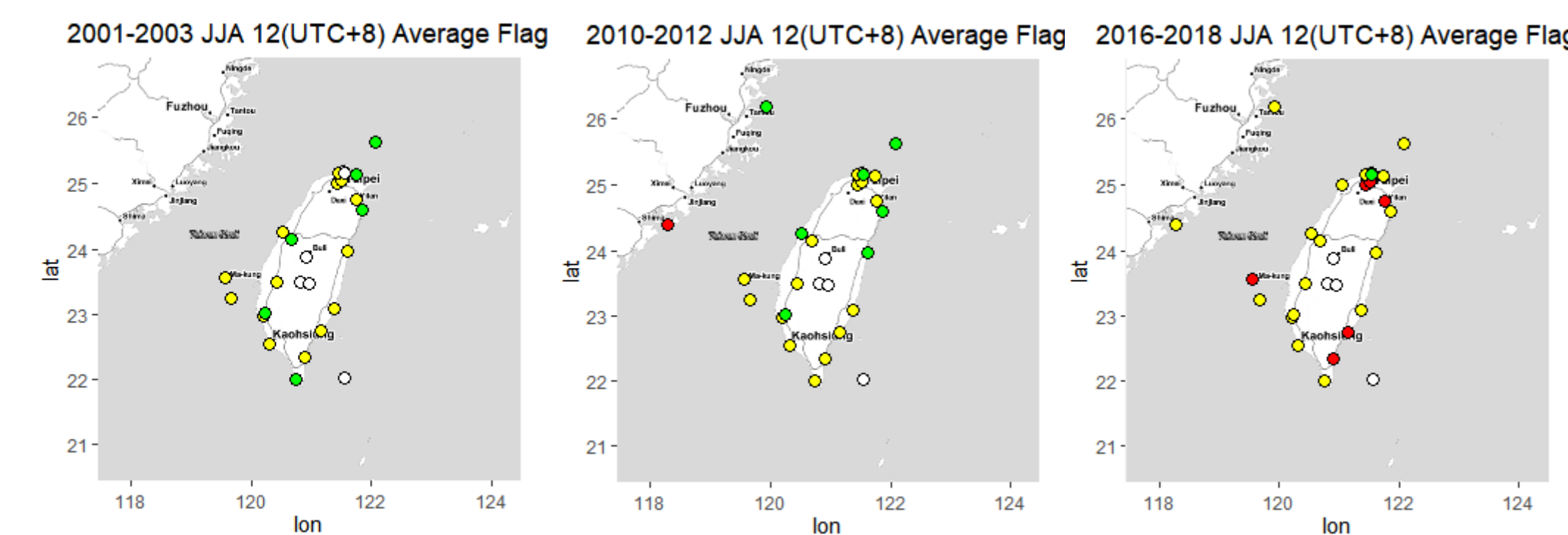


Fig. 8 JJA 12(UTC+8) Triennial average flag conditions at each station in Taiwan

Work-rest Standards during High-temperature Operation

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

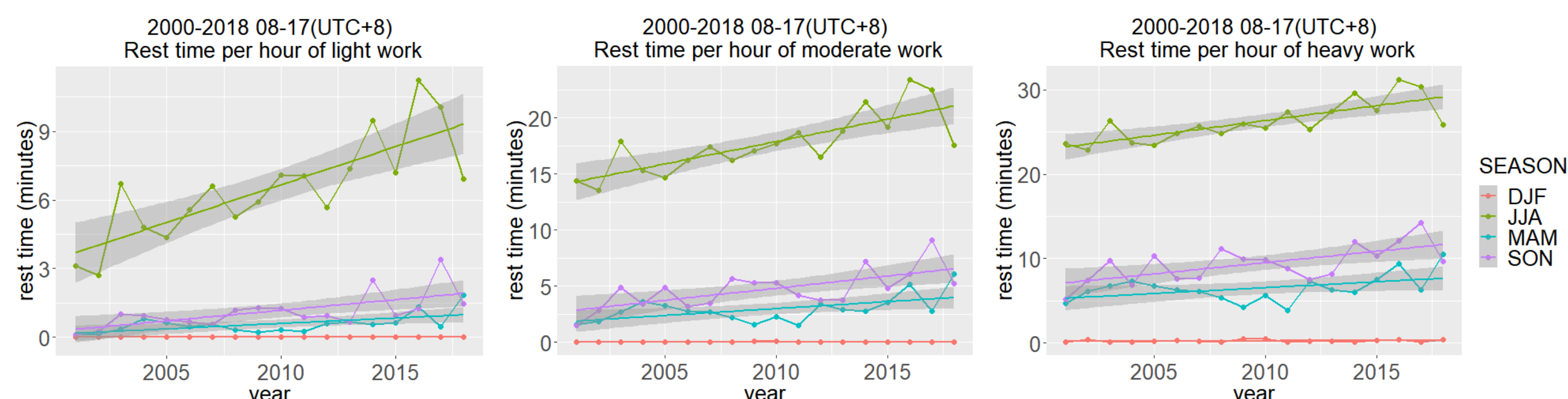


Fig. 4 2001-2018 08-17(UTC+8) Annual average of rest time per hour for each season

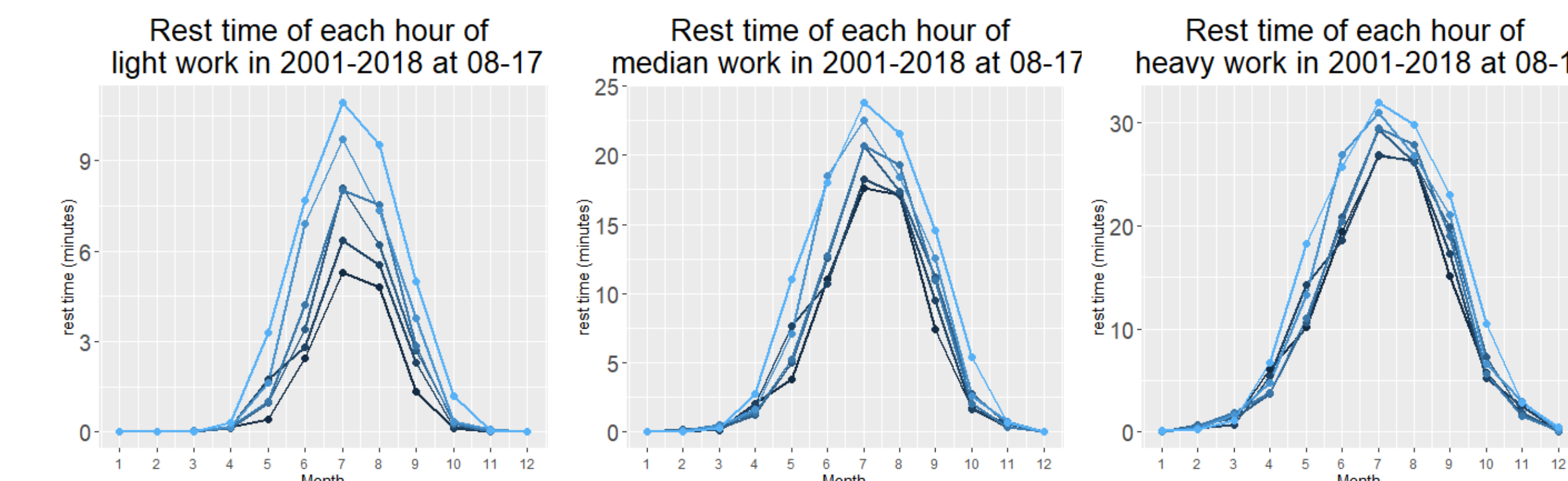


Fig. 4 2001-2018 08-17(UTC+8) Triennial average of rest time per hour

Summary

- After 2000, the annual, monthly, and hourly average of WBGT has increased at all stations in Taiwan year by year. There is a noticeable growth in hourly average in WBGT in 2016-2018.
- Hourly average of relative humidity decreases year by year.
- The monthly average of global solar radiation sharply inclines in MAM, JJA, and SON. Hourly average of solar radiation progressively increases in the daytime. The extent of its growth gradually declines from noon per day.
- The monthly and hourly average of air temperature both stably increases year after year.
- The monthly and hourly average of wind speed both gradually declines year after year.
- According to Heat Flag Conditions used by the U.S., the proportion of no flag hours has declined year by year, and the number of extreme conditions such as red and black flag increased at all stations in Taiwan since 2000.
- According to Work-rest Standards during High-temperature Operation used by Taiwan, the annual average of regulated rest time per hour has continuously increased in MAM, JJA, and SON since 2000. It's worth noting that the rest time dramatically increased in JJA year after year.