

Where air-conditioning is essential

- Raising a red flag ten times –**

Weather station analysis of limits for passive cooling

(paper 119)

Eric Laurentius Peterson, Visiting Research Fellow



**UNIVERSITY
OF LEEDS**

Themes

Global Heat Stress Context

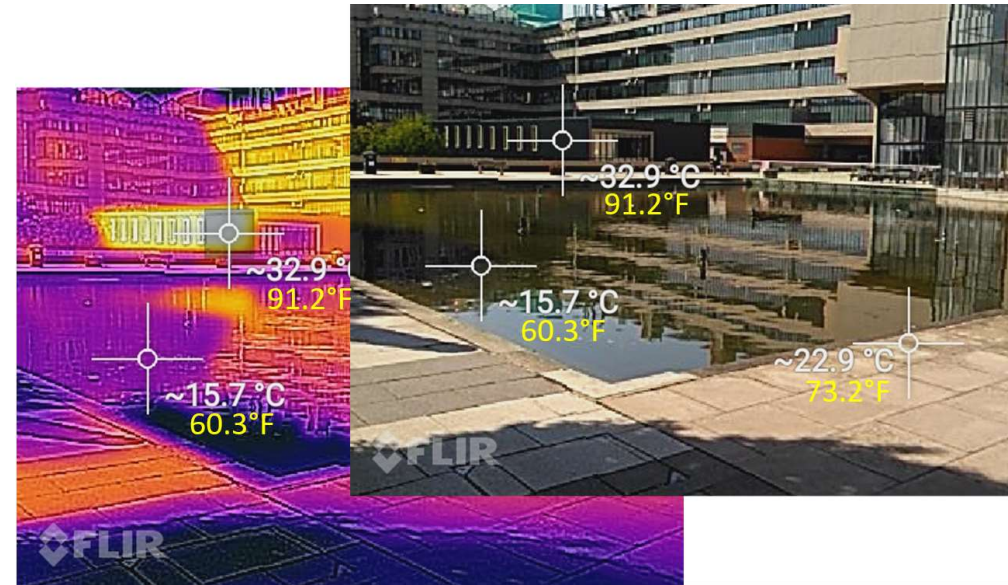
Understand how global heat stress impacts the effectiveness of passive cooling strategies in buildings.

WBGT Thresholds Impact

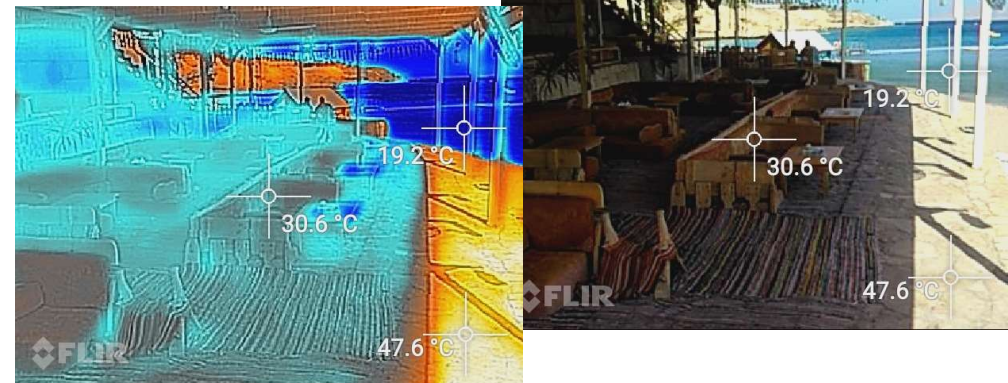
Learn about Wet Bulb Globe Temperature thresholds and their significance for design decisions in building cooling.

Weather Data and Risk

Explore how weather station data supports risk classification and adaptive planning for building resilience.



Infrared and Visible snapshot of Roger Stevens Cooling Pond at the University of Leeds



Sufficient alternative to air-conditioning provides shade, while open to views and provided with ceiling fans –Sharm el-Sheikh

Background and Motivation

Impact of Air-Conditioning

Air-conditioning boosts life expectancy and productivity but raises sustainability and power outage concerns.

Passive Cooling Strategies

Vernacular architecture and bioclimatic design offer passive cooling, yet effectiveness under extreme heat is uncertain.

Insulated Buildings Challenge

Insulated buildings can worsen summer overheating, highlighting the need for balanced adaptive solutions.

Adaptive Cooling Solutions

Balancing passive and active cooling is vital considering climate variability and urban heat island effects.



Elderly man sitting under a tree in Indonesia 26 October 2023
by Prandito Simanjuntak

Wet Bulb Globe Temperature (WBGT) –vs- Activity

<u>Occupational Class</u>	<u>Metabolic Watts</u>	<u>Acclimated WBGT_{eff}</u>	<u>Unacclimated WBGT_{eff}</u>
0 Resting	115	33 °C	32 °C
1 Low	180	30 °C	29 °C
2 Moderate	300	28 °C	26 °C
3 High	415	26 °C	23 °C
<u>4 Very high</u>	<u>520</u>	<u>25 °C</u>	<u>20 °C</u>

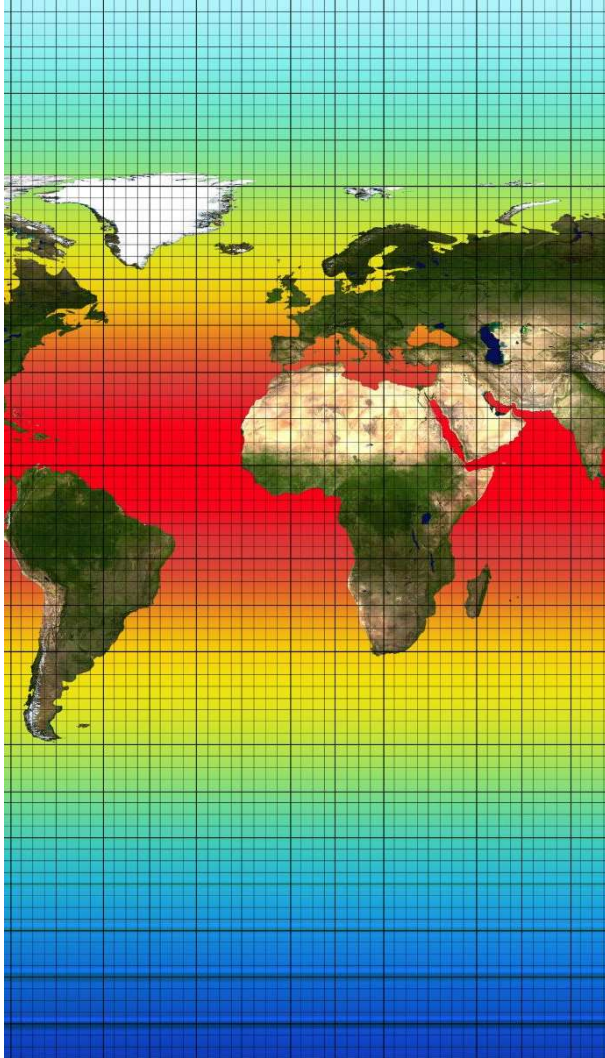
Adapted from informative Annex A, ISO 7243:2017 Table A.1

$WBGT = 0.7 \times \text{natural wet bulb} + 0.2 \times \text{globe temperature} + 0.1 \times \text{dry bulb}$

$WBGT_{\text{shade}} = 0.7 \times \text{psychrometric wet bulb} + 0.3 \times \text{dry bulb air temperature}$

WBGT warning Flags

FLAG	WBGT (°C)	RISK LEVEL	Annex A, ISO 7243:2017 Activity level	Metabolic <u>Watts</u>	Acclimated WBGT _{eff}	Unacclimated WBGT _{eff}
White ≥ 78°F	25.6–27.7°C	Very Low	4 Very high	520	25 °C	20 °C
Green ≥ 82°F	27.8–29.4°C	Low	3 High	415	26 °C	23 °C
Yellow ≥ 85°F	29.5–31.1°C	Moderate	2 Moderate	300	28 °C	26 °C
Red ≥ 88°F	31.2–32.1°C	High	1 Low	180	30 °C	29 °C
Black ≥ 90°F	≥32.2°C	Extreme	0 Resting	115	33 °C	32 °C



Data Sources and Analytical Approach

Comprehensive Weather Data

16,582 global weather stations data reanalyzed from NOAA's GSOD dataset spanning 1988–2020.

Population-Weighted Analysis

Stations weighted by population density to democratically represent human exposure to heat stress. Columbia University GPWv4 (2000-2020)

Heat Risk Classification

Locations classified into risk zones based on days exceeding WBGT heat thresholds in hotter than normal years.

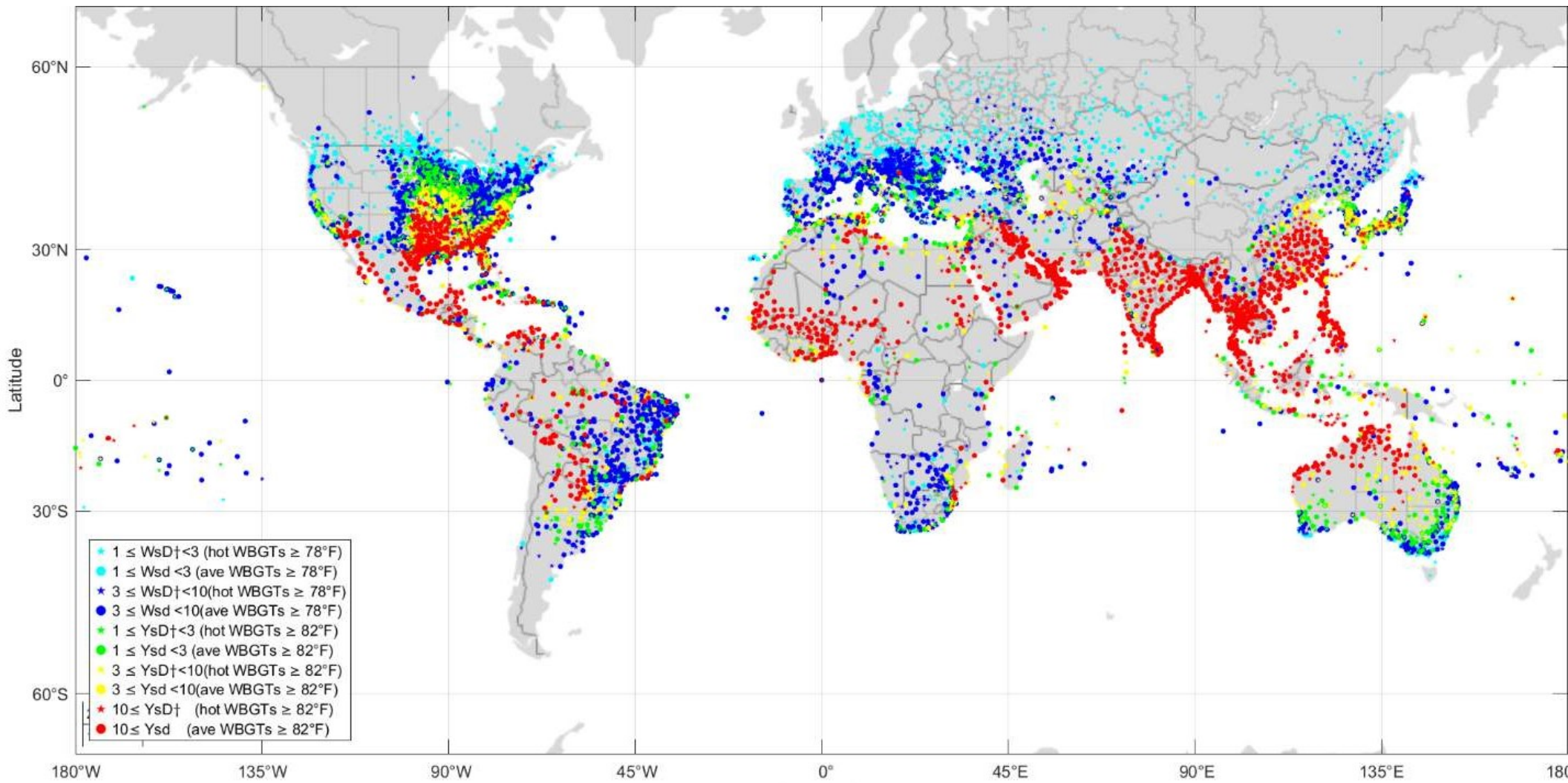
Cooling Design Trigger

Analysis aligns with ASHRAE standards, guiding practical cooling strategy designs using unmet-hour allowances.

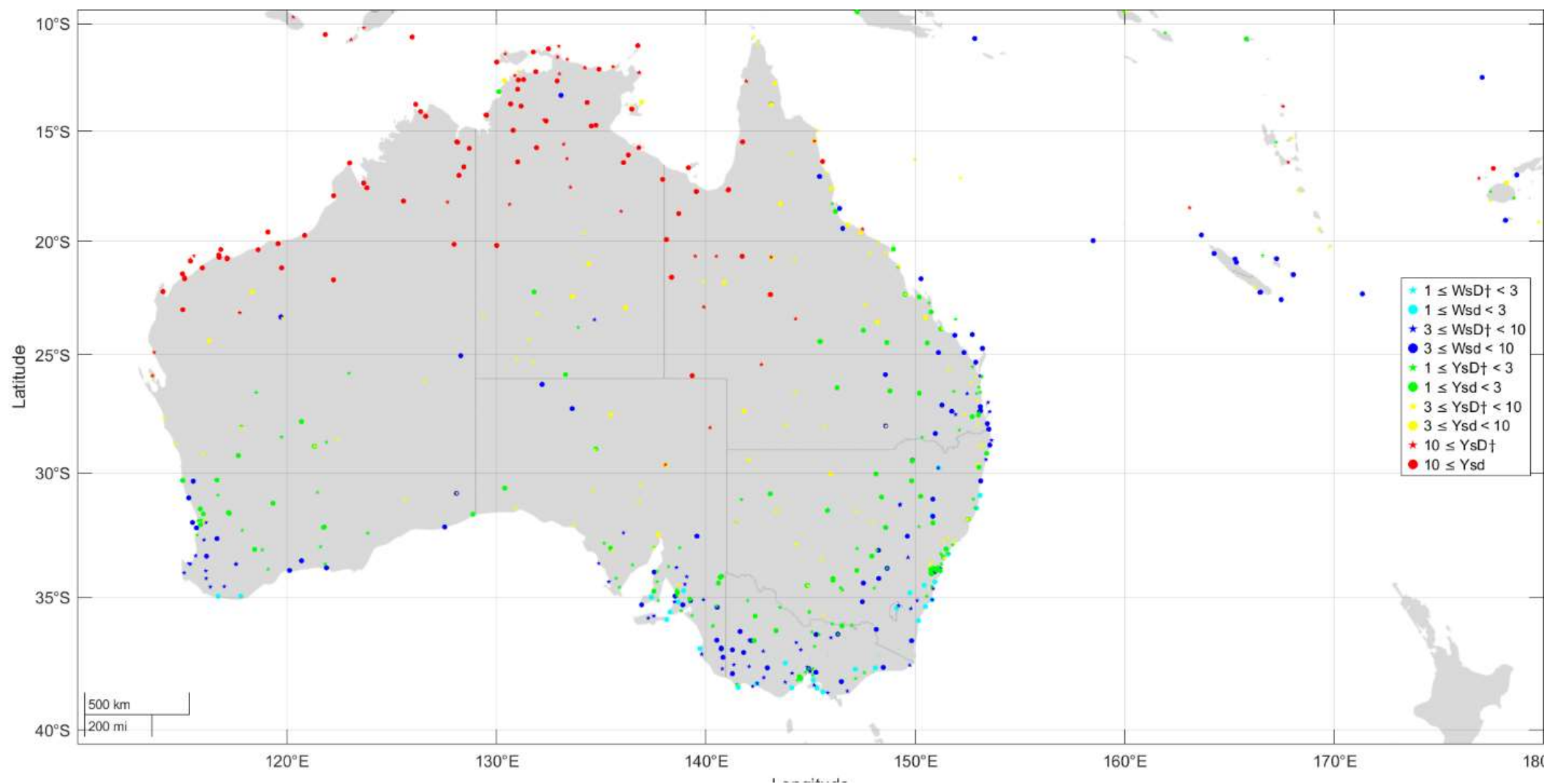
Global Exposure and Population Impact

Table 3: Exposure Risk Categories 1987-2020	stations	gpw_v4_pop	vote
average years' Ysd $\geq$ 10 (highest risk "5")	n=1,323	1,867,276 p	20 %
“red zone” hot year's YsD $\uparrow$ $\geq$ 10 (highest risk 5)	n=2,078	2,491,040 p	27%
average years' Ysd $\geq$ 3 (higher risk "4")	n=1,167	950,994 p	10%
“yellow zone” hot year's YsD $\uparrow$ $\geq$ 3 (higher risk 4)	n=1,368	950,994 p	10%
average years' Wsd $\geq$ 10 (medium risks "3 & 3½")	n=2,740	1,977,525 p	22%
“green zone” hot year's WsD $\uparrow$ $\geq$ 10 (medium risks)	n=2,713	1,748,335 p	19%
average years' Wsd $\geq$ 3 (lower risk "2")	n=1,436	784,210	9%
“blue zone” hot year's WsD $\uparrow$ $\geq$ 3 (lower risk 2)	n=1,590	807,224 p	9%
average years' Wsd $\geq$ 1 (lowest risk "1")	n=1,537	873,174	10%
“cyan zone” hot year's WsD $\uparrow$ $\geq$ 1 (lowest risk 1)	n=1,353	695,259 p	8%
average years' Wsd $<$ 1 (lowest risk "0")	n=7,949	2,588,218 p	28%
hot year's WsD $\uparrow$ $<$ 1 (lowest risk 0)	n=7,050	2,151,368 p	24%
stations NOT reporting 2020 WsD $\uparrow$'s/YsD $\uparrow$'s	n=430	83,586 p	0.9%
totals	n=16,582	9,124,984 p	100%

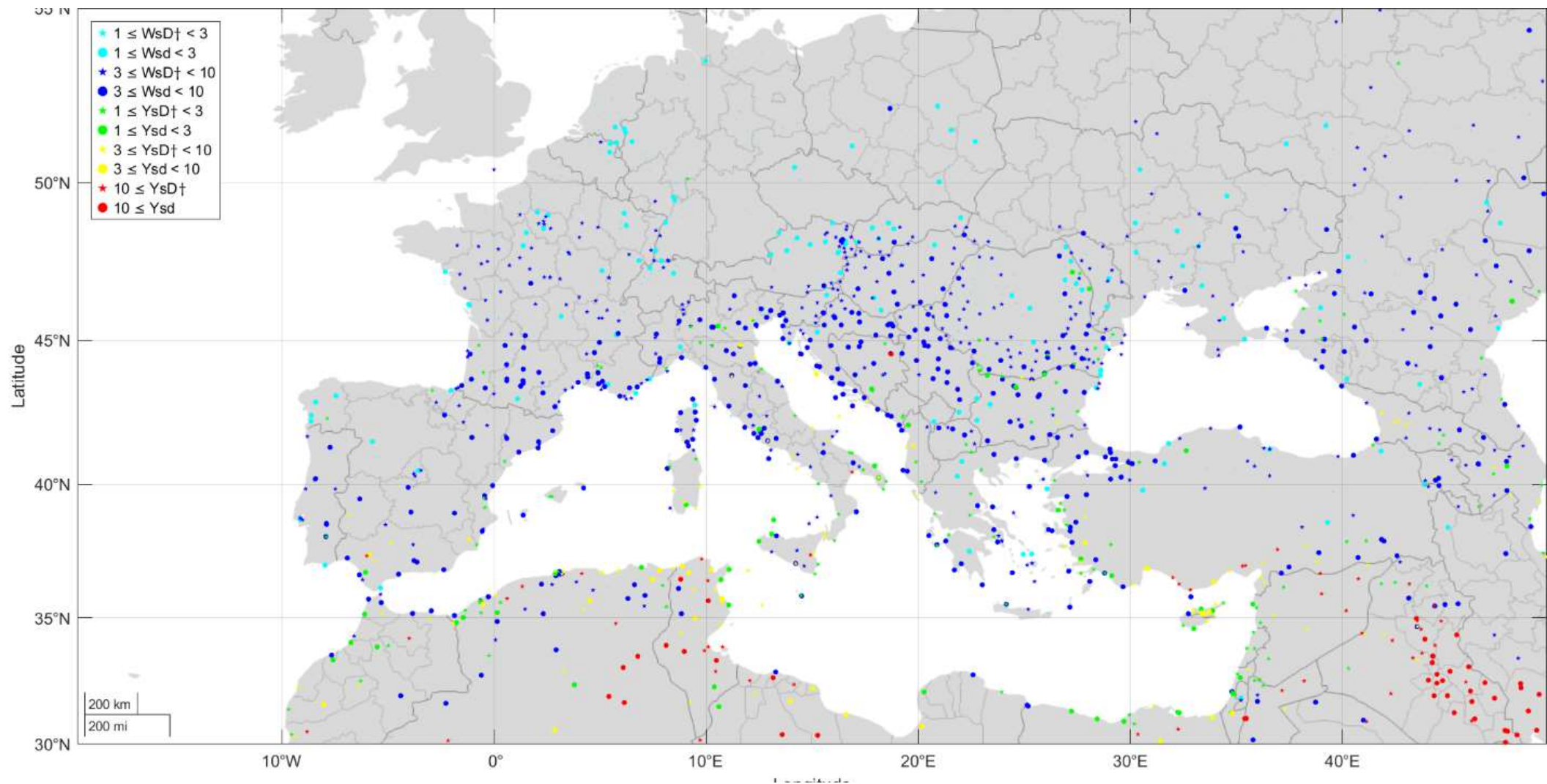
Figure 1: Global map based on 1987-2020 annals



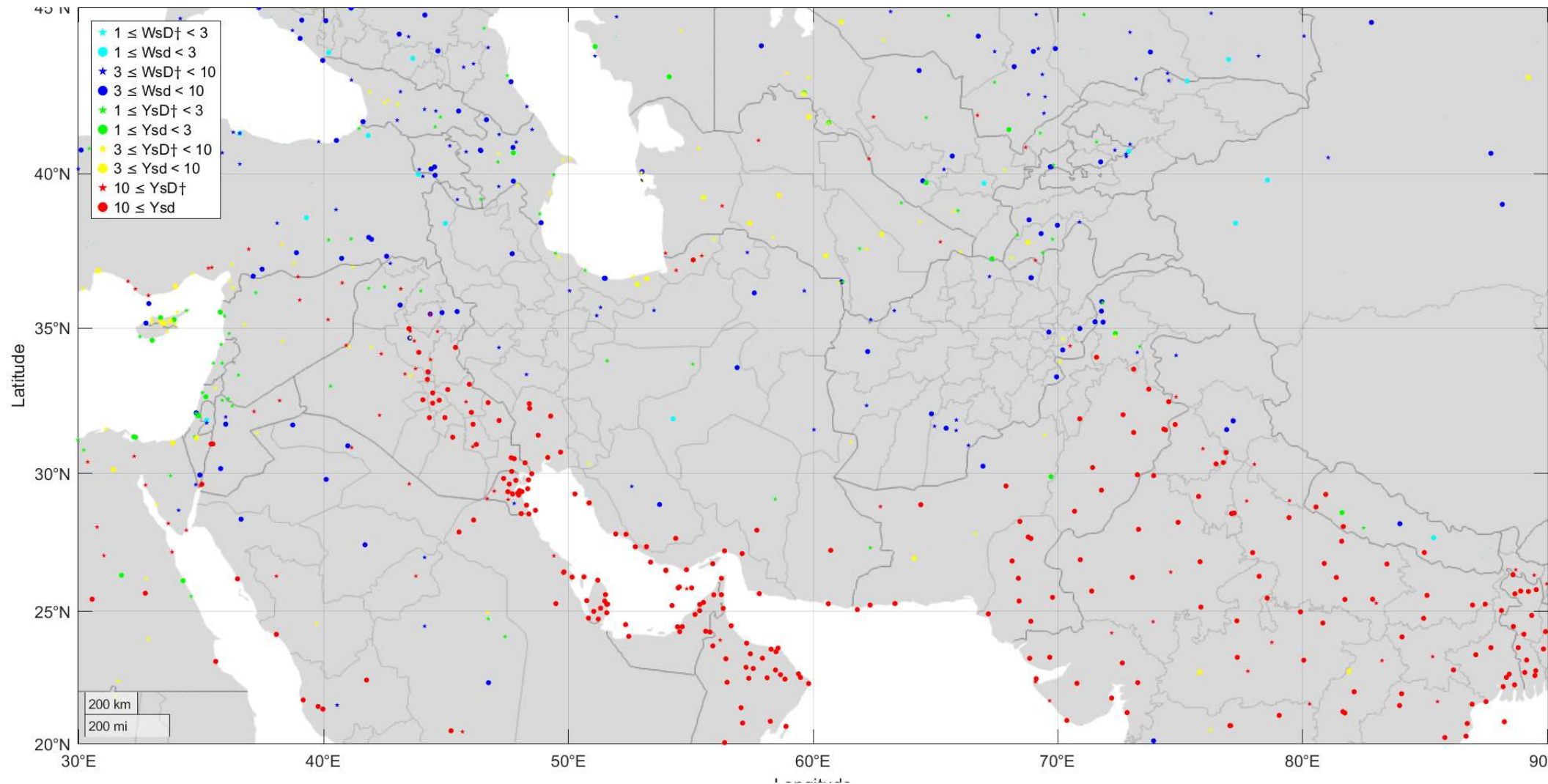
Australia & NZ based on 1987-2020 annals



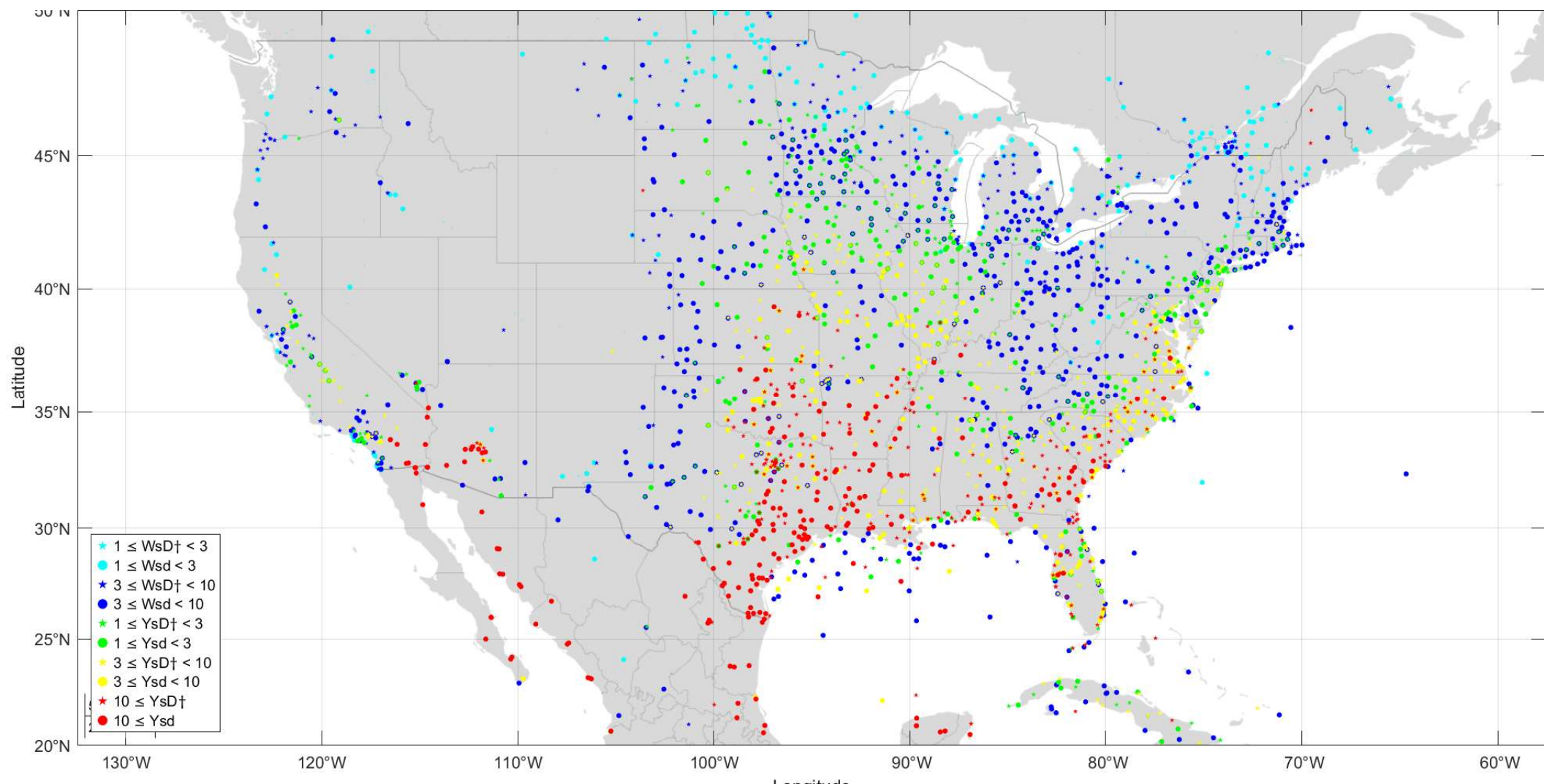
Mediterranean based on 1987-2020 annals



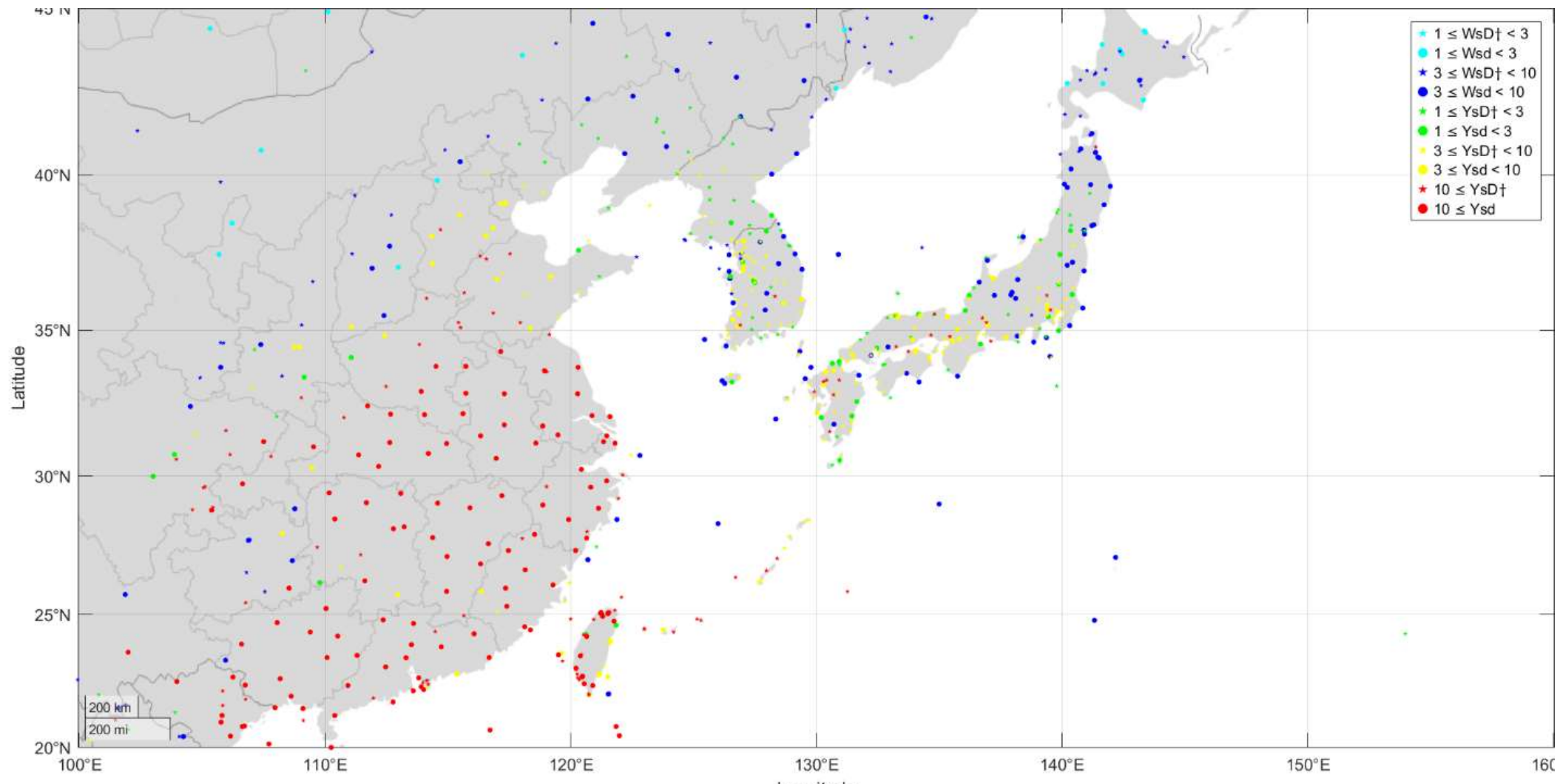
Middle East based on 1987 – 2020 annals



USA based on 1987 – 2020 annals



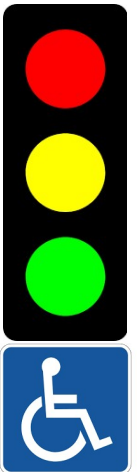
East Asia based on 1987-2020 annals



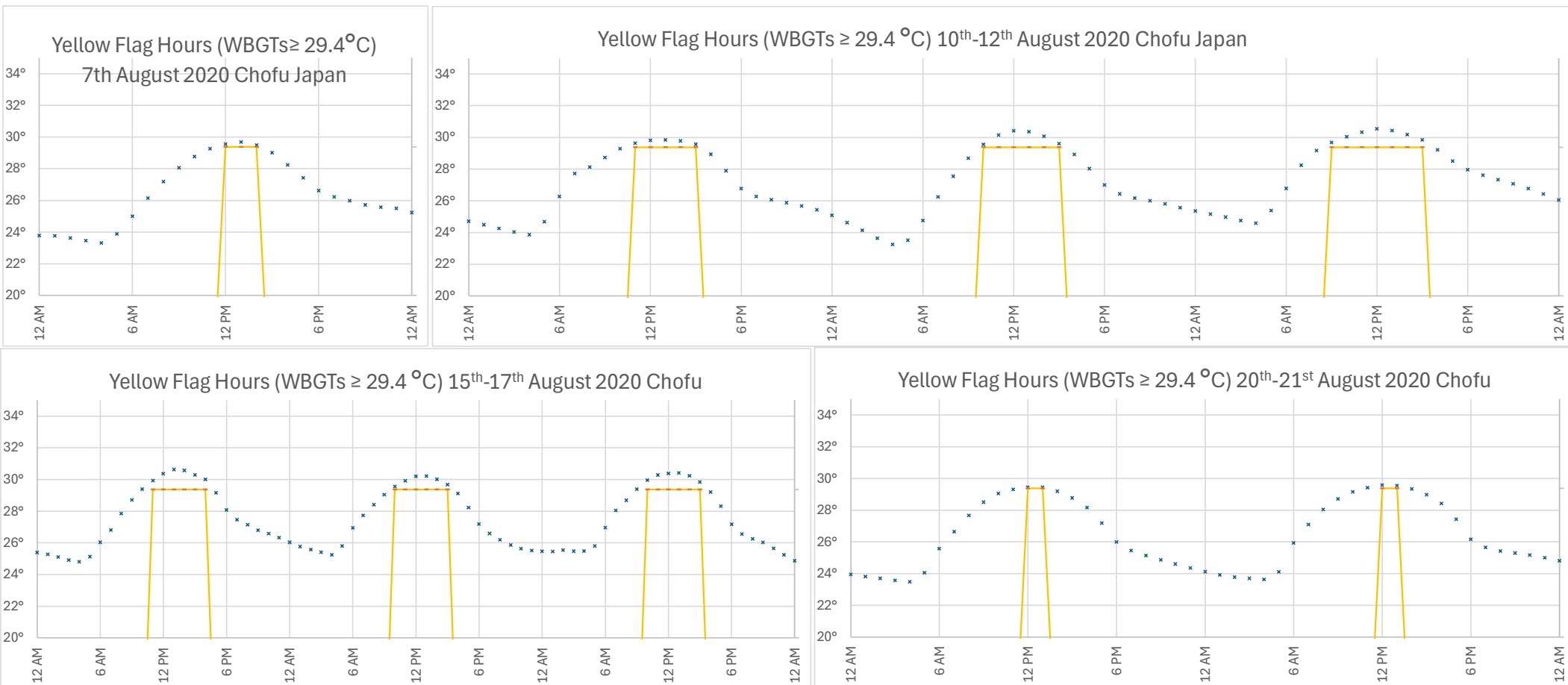
Discussion

Interpretations reflect the author's view of resilience and sustainable design rather than a public policy. The intention is to suggest an internationally understandable screening criteria for risk assessment of environments. The author is not aware of any standard defining which environments require that active cooling need be made accessible to all individuals. For example, as a Registered Professional Engineer of Queensland, the author asserts that there is no obligation to provide air-conditioning under the building and development codes of that quarter of Australia. But author acknowledges that there are critical process applications, poorly designed existing buildings that overheated, and also well-designed buildings where the occupants happen to be particularly vulnerable individuals who personally need air-conditioning in the same localities where passively cooled buildings have proven to be sufficient for other members of their local community.

Partially answering the question implied by the title of this paper, accessibility to air-conditioning during heat events may be a necessity for most members of the population inhabiting the highest risk area (denoted by red symbols). Meanwhile increasing proportions of population could have tolerated heat where risk was lower (decreasing risk from yellow, green, and blue, to cyan in reference to the colour-coded symbols on the presented maps).



Hours / days exceeding 29.4°C WBGTs (yellow flag threshold) Chofu Japan year 2020



Discussion

Exceedance of a threshold 10 days per year is comparable to $\frac{1}{2}$ % of the hours in one year

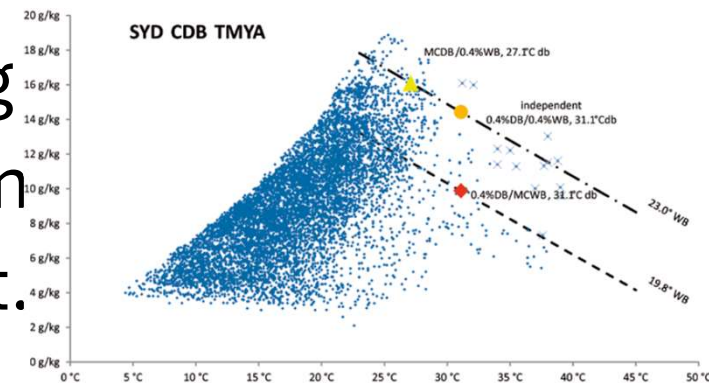
Previous research (Peterson 2022) argued that public access to air-conditioned shelter is essential in places where the daily maximum wet bulb globe temperature outdoors under shade (WBGTs) exceeds 29.4°C (the lower threshold of yellow-flag conditions) no more than ten days per year. Now the current discussion reconsiders if this measure of duration is comparable to building simulation and design practice for indoor temperatures to be allowed to float above an air-conditioning control setpoint 50 hours per year. The ten days per year allowance was inspired by the 20th century Australian method of design of air-conditioning based on whatever maximum daily outdoor temperature is not exceeded more than 10 days per year (Peterson, et al. 2006) under the condition that air-conditioning design thresholds should be “inclusive of one standard deviation”. Assuming a normal distribution of year-to-year variability, such thresholds tend to cover 84% of the annals of meteorological observations. And so, it turns out that Australian outdoor air temperatures were exceeded only about 5 days per year on average over the years of observations so that there were very few years when that design temperature would exceed more than 10 days in any particular “hot” year. This is similar to the threshold of five days of indoor dry bulb exceeding setpoint before people tend to install air-conditioning (Mastrucci, et al. 2019).

Ten exceedances of the daily maximum are comparable to 50 unmet hours per year

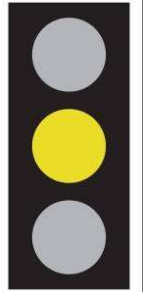
The tenth hottest day in a hotter-than-average year exceeding a threshold aligns with indoor unmet hour allowances (ASHRAE 90.1's 50 hours/year).

Also similar to ASHRAE's 0.4% of 8760 hours pa.

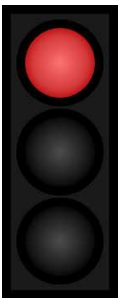
This supports the validity of expecting a series of ten or more daily maximum exceedances as a design trigger point.

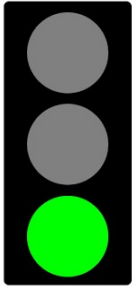


Passive and low-energy cooling strategies are limited by their local environment

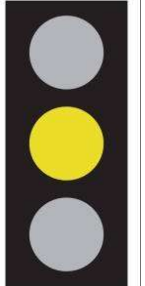


While passive building designs and shaded outdoor living areas can mitigate heat stress under green- and yellow-flag conditions ($27.8^{\circ}\text{C} < \text{WBGTs} \leq 31.1^{\circ}\text{C}$), such shelters may be insufficient under an extended series of yellow-flag events. Passive survivability without air-conditioning is feasible for most of the population dwelling outside of the “red-zone” or urban heat islands, while vulnerable individuals may need cooling.





The “green-amber” subset should be monitored for local climate change



30% of the global sample population dwell at 4,081 “green-amber” locations—where white-flag conditions were breached at least 10 days in a hotter-than-average year – while there were less than 10 yellow-flag days. These areas may not yet require universal air-conditioning, but monitoring and forecasting is warranted to check if some of these places join the “red zone”.



Reference and Acknowledgements

Reference

Global and local bioclimatic predilections for rebalancing the heating and cooling of buildings
[Dataset] <https://doi.org/10.5518/967>

Acknowledgements

Recognize NOAA NCEI, NASA POWER, and supporting institutions for their valuable data and resources.

Contact

E.Peterson@Leeds.ac.uk
<https://BioClimatic.GitHub.io/ELPeterson/>