Appendix 1: Example of standard operating procedure for outdoor environmental monitoring for heat stress

1. Introduction

Meteorological monitoring is a key component of a comprehensive heat stress management policy, where weather conditions can be used to adjust or modify activities to maximize safety.[176] Key meteorological factors associated with heat strain include air temperature, atmospheric moisture, wind flow, and radiative energy transfers (solar and longwave).[177] Various heat strain indices are available that combine multiple factors; these can range from simple combinations of weather variables (e.g. wet bulb globe temperature or WBGT) to complex energy balance models that link meteorological and physiological factors like clothing and activity levels.[177] Regardless of the particular index, all require inputs of accurate and representative weather information to adequately assess heat stress conditions.

Outdoor Olympic events occur in a wide variety of settings, including sporting venues, grass playing fields, roads, beaches, and bodies of water. Differences in surface type, sheltering, or shading can affect environmental conditions like air temperature, humidity, wind speed, and solar radiation between event locations and even along segments of a long racecourse.[16,17,178] In addition, apparent differences in on-site meteorological conditions may arise due to use of low-precision, low-accuracy, or uncalibrated instrumentation which can affect heat stress assessment,[179] (or even with correct instrumentation inappropriately used). Thus, proper maintenance/calibration, and siting/positioning of meteorological instrumentation are needed to obtain accurate and reliable measurements.

2. Purpose

The purpose of this document is to delineate the steps that should be taken to properly measure event meteorological conditions for use in decision making by event coordinators and medical staff.

3. Scope

The scope of this document is to provide policy and procedure for the event meteorological measurement for IOC sanctioned competitions.

4. Instrument Accuracy, Maintenance, and Calibration

Meteorological instruments for heat stress assessment should use well-established sensor technology[21] that provide accurate measurements with sufficient resolution (e.g., 0.1ºC for temperature) to meet decision making thresholds. Instruments should include documentation of accuracy as indicated by the uncertainty (see **Table A1**). All weather instruments should be maintained and calibrated according to manufacturer specifications, and regularly inspected.

5. Meteorological Measurements

There are a variety of different observations that can be collected for use in heat stress assessment. The measurements used will depend on the specific competition and guidelines of the International Sport Federation (IF) that governs the event. Meteorological values can be direct measurements of a variable or derived from other measurements to form a new value.

Direct Meteorological Measurements

- Air temperature
- Dewpoint temperature
- Relative humidity
- Wind Speed
- Black globe temperature
- Wet bulb temperature

Derived Meteorological Measurements

- Wet Bulb Globe Temperature (WBGT). WBGT is commonly used by many IFs for heat stress assessment. It is computed as a weighted average of the natural wet bulb temperature (NWB), the black globe (BG) temperature, and the dry bulb temperature (DB) as follows:

$$WBGT = 0.7\ NWB + 0.2\ BG + 0.1\ DB$$

  There are many commercially available portable WBGT sensors. Some instruments directly measure all three variables (BG, NWB, DB) while others determine the components from other meteorological measurements. The Japanese National Institute of Occupational Safety and Health (JNIOSH) categorizes the various WBGT sensors based on how they measure WBGT and Japanese Industrial Standards (JIS) has established classes for sensor accuracy (**Table A1**).[22,23] Devices should be JNIOSH category 1 or 2 and have accuracies comparable to JIS Class III or above.

Direct Environmental Measurements for Open Water Events

- Water Temperature. The water temperature should be measured on the day of the race prior to the start. Measurements should be taken in the middle of the racecourse at a depth of 40 cm. Temperatures should be monitored periodically during the race.[180]

6. Instrument siting and exposure

Weather observations should provide representative conditions (e.g., surface type, sheltering, sun exposure) to those of the particular activity (see **Table A2** for examples). Local environmental conditions such as a venue with an artificial surface (e.g., synthetic turf or hardcourt tennis) or events like road cycling or marathon on paved roadways may differ greatly from established weather stations that tend to be located on a natural surface like grass.[18] Thus, on-site "field of play" (FoP) measurements should be used in all cases to best capture athlete heat stress.

In identifying appropriate siting and exposure for on-site portable sensors, the following should be considered:

- For heat stress monitoring, measurements should be recorded at the average human gravity center, ranging from 0.9-1.2 m, or at a height that is recommended by the manufacturer.[20,181]

- The measurements should be taken over a location that is representative of the FOP.
    - In settings with multiple adjacent athletic fields with similar surface types and exposure conditions, a single monitoring site may be appropriate.[179]

- For long courses (e.g., marathon, mountain biking), significant microclimate differences may appear depending on the particular course route. For marathons, the amount of solar exposure is a key determinant in observed variations of heat stress and WBGT.[16,178,182,183] Therefore, measurements should be taken in the sun if any part of the FOP is in the sun and should represent the main surface and surrounding in case there are variations in these conditions along the racecourse.

7. Communication and Decision Making

Prior to the event, there should be coordination regarding who takes the environmental measurements, who makes the determination about activity modification, and who communicates this information to the event participants.

Table A1: JNIOSH Categories and Classes for WBGT Sensors

JNIOSH Category	JIS Class
Category 1: Natural wet bulb and black globe	Class I: able to measure/estimate WBGT within ±1℃ of "gold standard" measurement.
Category 2: Humidity sensor and black globe	Class II: able to measure/estimate WBGT within ±1.5℃ of "gold standard" measurement.
Category 3: No black globe	Class III: able to measure/estimate WBGT within ±2℃ of "gold standard" measurement.

Table A2: Sample measurement procedures for different competitions. Actual measurement protocols will be directed by the particular IF.

Event	Measurement Protocol
Beach Volleyball on sand	On-site WBGT on center court.
Football (soccer) on grass	On-site WBGT on the field in the sun.
Marathon/Race Walking on pavement	On-site WBGT collected over a paved surface in the sun.
Open Water Swimming	Water Temperatures at 40 cm depth in the middle of the course.