Environmental Research 144 (2016) 106–116

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Review article

Humidity: A review and primer on atmospheric moisture and human health

Robert E. Davis [a,*], Glenn R. McGregor [b], Kyle B. Enfield [c]

[a] Department of Environmental Sciences, University of Virginia, P.O. Box 400123, 291 McCormick Road, Charlottesville, VA 22904-4123, USA
[b] Department of Geography, Durham University, Durham DH1 3LE, United Kingdom
[c] Division of Pulmonary and Critical Care, Department of Medicine, University of Virginia Health System, Charlottesville, VA 22908, USA

ARTICLE INFO

Article history:
Received 3 July 2015
Received in revised form
14 October 2015
Accepted 14 October 2015
Available online 21 November 2015

Keywords:
Atmospheric moisture
Biometeorology
Human health
Humidity
Water vapor

ABSTRACT

Research examining associations between weather and human health frequently includes the effects of atmospheric humidity. A large number of humidity variables have been developed for numerous purposes, but little guidance is available to health researchers regarding appropriate variable selection. We examine a suite of commonly used humidity variables and summarize both the medical and biometeorological literature on associations between humidity and human health. As an example of the importance of humidity variable selection, we correlate numerous hourly humidity variables to daily respiratory syncytial virus isolates in Singapore from 1992 to 1994. Most water-vapor mass based variables (specific humidity, absolute humidity, mixing ratio, dewpoint temperature, vapor pressure) exhibit comparable correlations. Variables that include a thermal component (relative humidity, dewpoint depression, saturation vapor pressure) exhibit strong diurnality and seasonality. Humidity variable selection must be dictated by the underlying research question. Despite being the most commonly used humidity variable, relative humidity should be used sparingly and avoided in cases when the proximity to saturation is not medically relevant. Care must be taken in averaging certain humidity variables daily or seasonally to avoid statistical biasing associated with variables that are inherently diurnal through their relationship to temperature.

1. Introduction

The health impacts of climate, particularly temperature and humidity, have been of interest for centuries. One area of growing concern is the health effects of heat waves, especially given the likely increased frequency and intensity of extreme temperature events under human-induced climate change (Perkins et al., 2012). The mechanism by which heat impacts humans is complex, and although it is often treated as a sole product of temperature, in reality it is a result of the interactions between temperature, radiation, wind, and humidity. Of these variables, the most debated (with respect to health outcomes) is humidity, as there is significant inconsistency in how humidity is incorporated and interpreted in human health studies.

Despite its physiological importance, humidity is rarely the explicit focus in health impact studies. Consequently, our goals are to review and summarize the recent literature on how humidity impacts human health, to define and compare a suite of commonly used humidity variables, and to provide guidance to researchers regarding humidity variable selection and implementation.

This paper is organized in the following manner. We begin by presenting an overview of how humidity is examined in the climate/environment and health literature. We then present a primer on atmospheric humidity, which is followed by a review of research that considers humidity either directly or indirectly in health outcomes. Finally, to demonstrate how humidity variable selection may influence the interpretation of the impacts of atmospheric moisture on health, we re-evaluate the analysis of a previously published study on the association between weather and respiratory syncytial virus (RSV) in Singapore. We conclude with recommendations concerning how to incorporate humidity in climate/environment and health studies.

Abbreviations and variable definitions: AT, apparent temperature; COPD, chronic obstructive pulmonary disease; DPD, dewpoint depression; e_s, saturation vapor pressure; hPa, hectopascals; *Hx*, humidex; LST, local standard time; q, specific humidity; q_s, saturation specific humidity; *RH*, relative humidity; T, air temperature; T_d, dewpoint temperature; *THI*, temperature–humidity index; T_w, wet bulb temperature; w, mixing ratio; w_s, saturation mixing ratio; UTC, Universal Time Coordinates; ρ_v, absolute humidity; ρ_{vs}, saturation absolute humidity

* Corresponding author.
E-mail addresses: red3u@virginia.edu (R.E. Davis), glenn.mcgregor@durham.ac.uk (G.R. McGregor), KE4Z@hscmail.mcc.virginia.edu (K.B. Enfield).

http://dx.doi.org/10.1016/j.envres.2015.10.014
0013-9351/

2. Overview of humidity and human health

That the role of humidity in human health outcomes has attracted increasing attention is apparent from a broad analysis of the number of health-related publications. A PubMed search (conducted in September 2015) conducted in English incorporating the terms "humidity," "human" or "humans," "epidemiology," "environment" or "environmental," produced over 1700 citations starting in 1965 (Derrick, 1965). Over the subsequent 50 years, the number of citations has grown exponentially, covering a diverse range of human conditions. Based on our search parameters, but limiting our analysis to the 260 publications since 2013, we examined the humidity variable(s) used in each publication (Table 1) and the primary research topic(s) of each paper (Table 2).

Relative humidity was used in a significant majority (62%) of studies surveyed (Table 1). Only a small percentage of studies selected humidity variables commonly utilized by atmospheric scientists (e.g., specific humidity) or indices designed to measure heat stress that incorporate humidity (e.g., apparent temperature or energy balance models) (Jendritzky et al., 2012; Steadman, 1979) (Table 1).

Humidity is included as an environmental factor in a wide range of human health topics. The results shown in Table 2 include all topics that were cited at least twice in our search. After air quality (indoor and outdoor), there are similar frequencies across the broad groupings of thermal stress, respiratory diseases, strokes and heart attacks, vector-borne diseases, and gastro-intestinal and urinary disease.

3. Humidity variables

Atmospheric scientists use many variables to characterize atmospheric moisture based on the specific research goals and objectives. Selection of the correct variable is essential because some humidity measures can be highly correlated with other atmospheric variables, particularly temperature, making it difficult to identify the unique contribution of any single variable. The measures discussed here do not represent the full suite of atmospheric humidity variables, but rather serve to represent a subset of those commonly used in epidemiological or environmental health research.

Table 1
Frequency of citations of humidity variables from a PubMed search, 2013–present.

Humidity variable	Frequency	Relative frequency (%)
Relative humidity	163	62.0
Term not use (often "dampness" or "moisture")	28	10.6
"Humidity"—type not specified	26	9.9
Absolute humidity	14	5.3
Humidifier (interior use)	5	1.9
Apparent temperature	5	1.9
Specific humidity	4	1.5
Heat Index	3	1.1
Dew point temperature	3	1.1
"Saturation deficit"	2	0.8
Energy balance models	2	0.8
Vegetation index	2	0.8
"Humidity index"	1	0.4
Temperature–humidity index	1	0.4
"Humidity sensation"	1	0.4
Vapor pressure	1	0.4
Wet bulb globe temperature	1	0.4
Humidex	1	0.4
	263[a]	

[a] Sample size is 260, but some studies included more than one humidity variable.

Table 2
Frequency of citations of various research topics that included humidity based on abstract information from a PubMed search, 2013–present.

Research Topic	Frequency	Relative frequency (%)
Heat-related mortality	4	1.5
Heat stress, morbidity	8	3.0
Exercise-induced stress	3	1.1
Cold-related mortality	3	1.1
ER visits	6	2.2
Hospitalizations	6	2.2
Air quality (outdoor)	21	7.8
Air quality (interior, indoors)	23	8.6
Respiratory, RSV	15	5.6
Asthma	11	4.8
Myocardial infarction, cardio-pulmonary mortality	7	2.6
Aneurysm	5	1.9
Stroke	7	2.6
Influenza	12	4.5
Pneumonia	4	1.5
Legionnaire's disease	2	0.7
Skin, ulcers	9	3.3
Malaria	12	4.5
Dengue	13	4.8
West Nile virus	4	1.5
Leishmaniosis	6	2.2
Tick-borne disease	2	0.7
"Infectious disease"	2	0.7
Gastro-intestinal, diarrhea	9	3.3
Urinary and renal, nephritis	9	3.3
Hand–foot–mouth disease	5	1.9
Ebola	3	1.2
Hemorrhagic fever	4	1.5
Typhus	3	1.1
Epitaxis	2	0.7
Suicide	3	1.2
Testicular torsion	2	0.7
All others	42	15.6
	269[a]	

[a] Sample size is 260, but some studies were tallied in more than one category.

In the atmosphere's gaseous mixture, the amount of water vapor is small and variable. With respect to the atmospheric pressure at sea level (mean = 1013 hectopascals [hPa]), the water vapor component varies from almost zero (in extremely cold, dry climates) to 40 hPa (in some tropical locales). The *vapor pressure* (e [hPa]) is the partial pressure exerted by water vapor in this mixture.

Pressure-based units like vapor pressure are much less commonly used than mass-based measurements so several humidity variables incorporate the actual mass of moisture in the air. The density of water vapor, or *absolute humidity* (ρ_v [g m^{-3}]), is the mass of moisture per total volume of air. It is related to vapor pressure via the ideal gas law for the moist portion of the air:

$$e = \rho_v R_v T \quad (1)$$

where T is the air temperature [K] and R_v is the specific gas constant for moist air [487 J kg^{-1} K^{-1}]. Although the numerator of ρ_v is the mass of moisture, the denominator (volume) varies as a function of pressure and temperature according to the ideal gas law. For example, at sea level, an absolute humidity of 15 g m^{-3} measured at 10 °C would increase to 16 g m^{-3} if the air is cooled to 0 °C, thereby reducing its volume, despite a constant humidity level (i.e., no change in the actual mass of moisture). Thus, absolute humidity will exhibit some diurnal variation that is inverse with temperature.