Weather – March 2017, Vol. 72, No. 3

Pakistan Meteorological Department. 1993. *Climate Normals of Pakistan (1961–1990)*. CDPC: Karachi.

Palmer TN, Anderson DLT. 1994. The prospects for seasonal forecasting – a review paper. *Q. J. R. Meteorol. Soc.* **120**: 755–793.

Preisendorfer RW. 1988. *Principal Component Analysis in Meteorology and Oceanography*. Elsevier: Amsterdam.

Rasul GR, Chaudhry QZ, Zhao S *et al.* 2004. A diagnostic study of record heavy rain in twin cities Islamabad-Rawalpindi. *Adv. Atmos. Sci.* **21**: 976–988.

Renwick JA, Wallace JM. 1995. Predictable anomaly patterns and the forecast skill of Northern Hemisphere wintertime 500-mb height fields. *Mon. Weather Rev.* **123**: 2114–2131.

Sheikh MM. 2001. Drought management and prevention in Pakistan. *Sci. Vision Q.* **7**(3 & 4): 117–131.

Sheikh MM, Manzoor N, Adnan M *et al.* 2009. *Climate Profile and Past Climate Changes in Pakistan*, GCISC-RR-01. Global Change Impact Studies Centre (GCISC): Islamabad.

Shukla J. 1981. Dynamical predictability of monthly means. *J. Atmos. Sci.* **38**: 2547–2572.

Von Storch H, Zwiers FW. 1999. *Statistical Analysis in Climate Research*. Cambridge University Press: Cambridge, UK.

Tracton MS, Mo K, Chen W *et al.* 1989. Dynamical extended range forecasts (DERF) at the National Meteorological Center. *Mon. Weather Rev.* **117**: 1604–1635.

Van den Dool HM. 1994. Long-range weather forecasts through numerical and empirical methods. *Dyn. Atmos. Oceans* **20**: 247–270.

Vautard R, Plaut G, Wang R *et al.* 1999. Seasonal prediction of North American surface air temperatures using space–time principal components. *J. Clim.* **12**: 380–394.

Walker GT, Bliss EW. 1932. World weather V. *Mem. R. Meteorol. Soc.* **4**: 53–84.

Wallace JM, Gutzler DS. 1981. Teleconnection in the geopotential height field during the Northern Hemisphere winter. *Mon. Weather Rev.* **109**: 784–812.

Correspondence to: Muhammad Adnan.

scarpion982@gmail.com

doi:10.1002/wea.2784

The Newton linseed oil thermometer: an evaluation of its departure from linearity

Dario Camuffo and Antonio della Valle

National Research Council of Italy (CNR), Institute of Atmospheric Sciences and Climate (ISAC), Padua, Italy

Departures of early liquid-in-glass thermometers

In a recent paper we have discussed the error due to non-linearity of early thermometers calibrated at the freezing and boiling temperatures of water. Mercury thermometers have a very small departure from linearity of ±0.11 degC in the temperature range −20 to 100°C. Due to this small bias, mercury thermometers are usually used as a reference for weather purposes. The departure of an alcohol thermometer from a mercury thermometer is parabolic, and the maximum departure is reached at 50°C, with an underestimate of around −6 degC (Camuffo and della Valle, 2016). Alcohol thermometers, especially the famous Réaumur (1732) type, were popular in the eighteenth and nineteenth centuries, and may have caused a consistent underestimate of the summer temperatures, especially in central and southern Europe, where upper temperatures may reach 30–40°C.

In this paper we consider the potential error of linseed oil thermometers that were built in the UK under the authoritative influence of Isaac Newton. Although Newton did not write about thermometer technology, except for the choice of the reference points (Newton, 1701), we can benefit from comments left by Desaguliers (1744), who built a number of oil thermometers following Newton's directives. A strong advantage of linseed oil was its high boiling point (343°C) and the possibility of it being used at relatively high temperatures compared to alcohol (which boils at 80°C). The most negative factor was that the oil adhered to glass, making it difficult to take readings.

A quantitative evaluation of the non-linear behaviour of linseed oil was made by du Crest (1765). He put three thermometers, one each filled with alcohol, mercury, and linseed oil, in a pot of water at boiling temperature. He then made a complete temperature cycle by slowly cooling the pot to freezing temperature and returning it again to boiling point. He used the alcohol thermometer as a reference and noted the readings of each of the thermometers each time the reference column changed by 5 degC. He expressed readings in Celsius but in an unusual form, with the degrees and fractions given in sexagesimal parts (i.e. in minutes and seconds).

Looking at the du Crest (1765) results in Figure 1, we see that the cooling part of

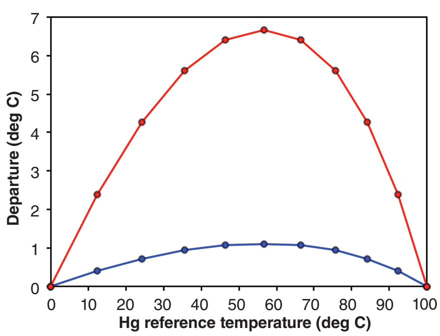


Figure 1. Departure of alcohol thermometers (red line) and linseed oil thermometers (blue line) from readings taken with mercury thermometers, according du Crest (1765).

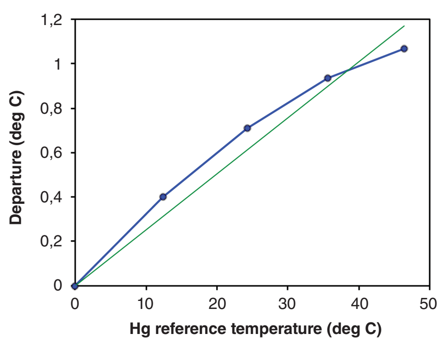


Figure 2. Departure of linseed oil thermometers from readings taken with mercury thermometers (blue line) in the meteorological range 0–50°C (test conducted by du Crest (1765)). Green line: linear interpolation.

the cycle was executed well, while the heating part of the cycle was performed with the mercury and linseed oil thermometer exposed to the warm air from the heater, resulting in inaccurate temperature readings (i.e. around 150°C in boiling water). For this reason De Luc (1772) and others repeated the test, but unfortunately only used mercury and alcohol, disregarding linseed oil thermometers.

As linseed oil thermometers are rare and the physical properties of the aged oil have changed, we are forced to rely on the du Crest experiment (Figure 1), where the vertical axis represents the difference between readings taken with a mercury thermometer, used as a reference, and the other two thermometers, which were filled with alcohol and linseed oil, respectively. The plot is not symmetrical, and this suggests that some of the heat from the experimental apparatus may have escaped, negatively affecting even the cooling phase, though in a limited way. However, the interval 0–50°C, which is the most relevant temperature range for meteorological purposes, seems to be unaffected by major errors, because the departures in this interval are consistent with similar experiments made by De Luc (1772) and Wildt (1825). In particular, De Luc compared 12 alcohol thermometers with a mercury reference (Camuffo and della Valle, 2016).

The result is that the linseed oil thermometer was less linear than mercury (whose departure lies within ±0.1 degC), but more linear than an alcohol thermometer. The departure of a linseed oil thermometer from a mercury thermometer accounts for a −1 degC underestimate at 40°C (Figure 2). In Figure 2 the best-fit interpolation indicates a −0.025 degC/°C mean rate. The bias of an alcohol thermometer was some 5 times greater.

Conclusions

Linseed oil was soon abandoned as a thermometric liquid for practical reasons, especially because it stuck to the sides of the glass tubes in cold weather and moved too slowly under sudden changes of temperature (Stewart, 1837). Although its departure from linearity was larger than that of mercury, it could have reached a −0.5 degC maximum underestimate of the UK summer temperature, considering that the July/August average is 16.2°C (Met Office, 2012). This bias was much smaller than in the case of Réaumur alcohol thermometers. The expansion of linseed oil was tested in the eighteenth century using known mixtures of boiling and cold water in various proportions (Taylor, 1724); once the accuracy of this instrument was established, it was used for laboratory experiments, in particular.

References

Camuffo D, della Valle A. 2016. A summer temperature bias in early alcohol thermometers. *Climatic Change* **138**: 633–640.

du Crest M. 1765. *Kleine Schriften von den Thermometern und Barometern*. Klett: Augsburg, Germany.

De Luc JA. 1772. *Recherches sur les modifications de l'atmosphère contenant l'histoire critique du baromètre et du thermomètre* Printed by the author: Geneva, Switzerland.

Desaguliers JT. 1744. *A Course of Experimental Philosophy*, Volume 2 Innys and Longman: London.

Met Office. 2012. England 1981–2010 averages. https://data.gov.uk/dataset/uk-climate-averages (accessed 21 September 2016).

Newton I. 1701. Scala graduum caloris: calorum descriptiones et signa. *Philos. Trans.* **22**: 824–829.

Réaumur RA. 1732. Règles pour construire des thermomètres dont les degrés soient comparables et qui donnent des idées d'un chaud et d'un froid qui puissent être rapportés à des mesures connues *Hist. Acad. R. Sci.* **MCCCXXX**: 452–507.

Stewart CS. 1837. Thermometers. *The Naval Magazine* **2**: 186–188.

Taylor B. 1724. An account of an experiment made to ascertain the proportion of the expansion of the liquor in the thermometers with regard to the degrees of heat. *Phil. Trans.* **32**: 291.

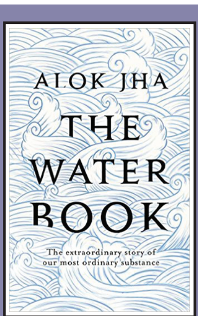
Wildt JCD. 1825. Neue vergleichung des quecksilber- und weingeist thermometers, nach beobachtungen und berechnungen. *Archiv. für die Gesammte Naturlehre* **6**: 299–301

Correspondence to: Dario Camuffo

d.camuffo@isac.cnr.it

doi:10.1002/wea.2909

Book review



The Water Book: The Extraordinary Story of Our Most Ordinary Substance

Alok Jha

Headline

Hardback (2015), £20.00;

Paperback (2016), £9.99

376 pp

ISBN 978-1472209542 (Hardback); 978-1472209535 (Paperback)

Water seems ordinary when pouring from our taps and falling from the sky, but in reality it is a profoundly strange substance, crucial to our survival and to life on Earth, shaping the world we live in.

In *The Water Book*, Alok Jha takes the reader on a double journey. First, we join him on his 2013 Antarctic adventure aboard the scientific research vessel *Akademik Shokalskiy*. He tells us of the importance of water in the ice fields, icebergs and weather systems of the Southern Ocean. The parallel voyage is scientific, beginning with the creation of water in the Big Bang and the beginning of life on Earth, examining how irrigation helped to shape human civilisations, and finally jetting off into space in search of water as the key to possible life elsewhere in our solar system and beyond.

The book alternates between these two journeys, returning time and again to Jha's Antarctic voyage. Sometimes this works, sometimes not, but overall the book is well-structured, in four parts. In Part I, *The Hydrosphere*, Jha looks in detail at the origins of water and clearly explains the hydrological cycle, global weather systems, ocean currents and the thermohaline circulation. In Part II, *The Biosphere*, he examines the chemistry and biology of water and life. This section is the least successful, since the attempt to explain different molecular structures without the aid of diagrams becomes confusing. I feel the book comes to life best in Part III, *The Cryosphere*, when Jha steps out onto the ice-floes and visits the huts left by Douglas Mawson's 1912 scientific expedition. Here we learn of the