Comment to Authors:

Although following comment can partially be an answer to the GRUAN's comments to our paper (amt-2021-246), the issue on the mechanism behind the temperature effect is also important to this paper (amt-2021-187).

We have consulted with an expert on heat transfer and found that the temperature effect is mainly because the thermal conductivity of air is decreased as the air temperature is lowered (**Fig. 1**). We have also learned that long-wave radiation from the sensor is negligible whether the sensor temperature is 20 °C or -70 °C as originally insisted by the authors.

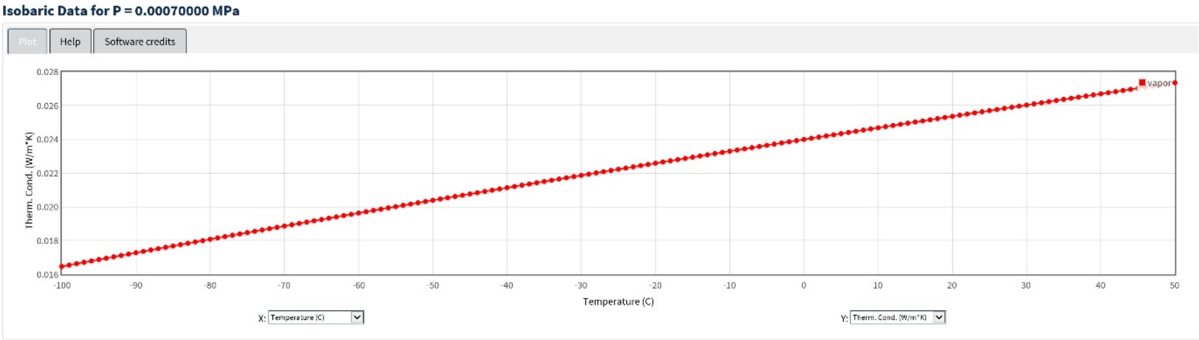

Figure 1. Thermal conductivity of N_2 gas at 7 hPa as a function of temperature.

To make this matter as simple as a textbook example, a metal sphere is considered to be a temperature sensor under solar irradiation with varied temperature as shown in Fig. 2.

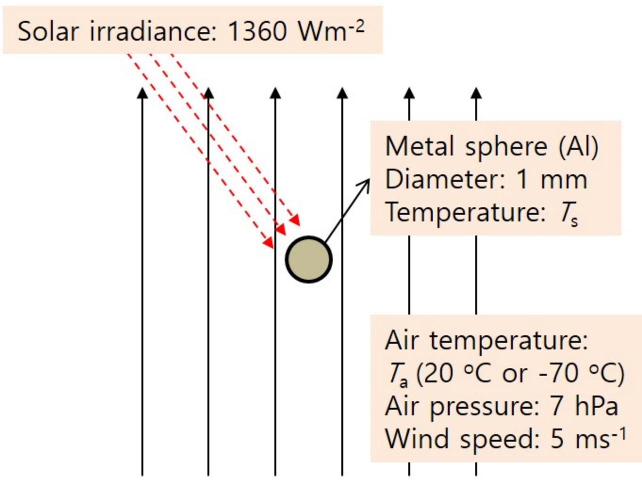

Figure 2. Simplified example to show the temperature effect on T_s - T_a.

Equation governing the heat transfer of the sphere is as follows:

$$q = h \cdot A(T_s - T_a) \tag{1}$$

, where q is heat flow (W) due to solar irradiation, h is heat transfer coefficient (W/(m^{2}K)), A is surface area (m^2), and T_s and T_a are the sensor and air temperature (K), respectively. Long-wave radiation from the sensor is not considered in Eq. (1) since it is negligible. Thus, the heat transfer from the sensor is governed by h which is a function of various properties of air including density ρ (**Fig. 3**), ventilation speed (fixed at $v = 5$ ms^{-1}), viscosity μ (**Fig. 4**), heat capacity C_p (**Fig. 5**), and thermal conductivity k (**Fig. 1**).

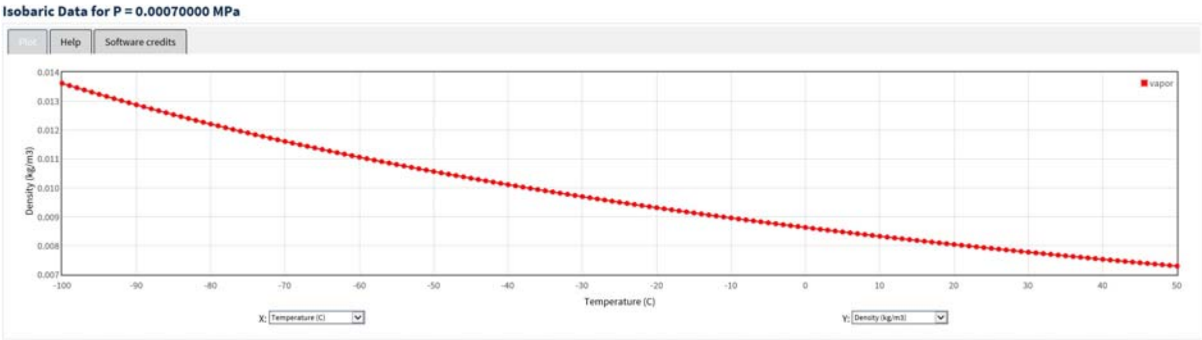

Figure 3. Density of N_2 gas at 7 hPa as a function of temperature.

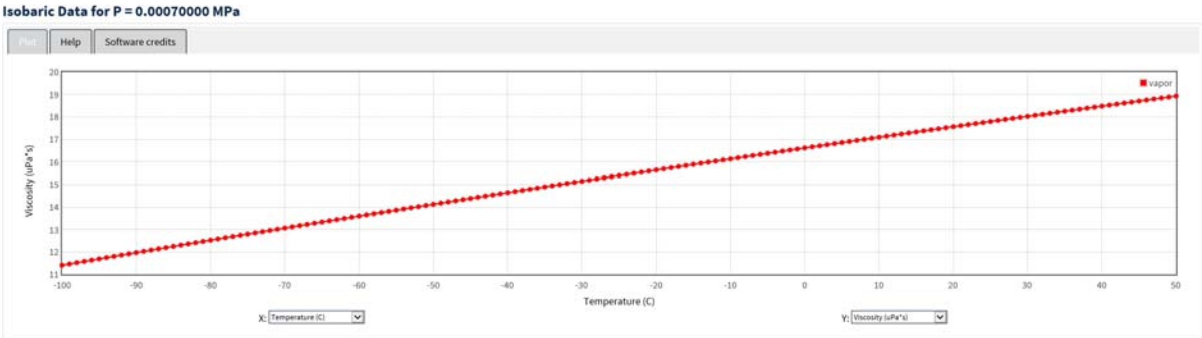

Figure 4. Viscosity of N_2 gas at 7 hPa as a function of temperature.

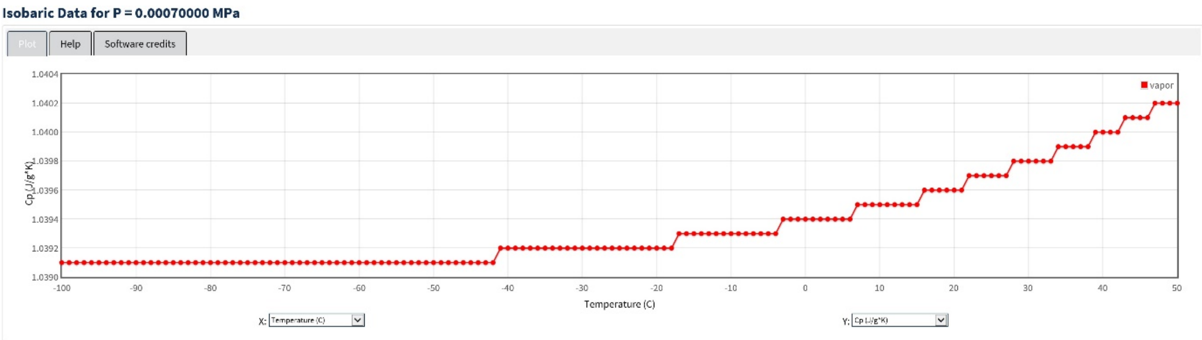

Figure 5. Heat capacity of N_2 gas at 7 hPa as a function of temperature.

Figure 1, 3, 4, and 5 are adopted from NIST Chemistry WebBook in the following address:

https://webbook.nist.gov/cgi/fluid.cgi?P=0.0007&TLow=-100&THigh=50&TInc=1&Applet=on&Digits=5&ID=C7727379&Action=Load&Type=IsoBar&TUnit=C&PUnit=MPa&DUnit=kg%2Fm3&HUnit=kJ%2Fkg&WUnit=m%2Fs&VisUnit=uPa*s&STUnit=N%2Fm&RefState=DEF

Using these properties of air (all known), the heat transfer coefficient h in this spherical geometry is calculated based on a textbook equation as follows:

$$h = \frac{k}{D} \times [2 + \left(0.4Re^{\frac{1}{2}} + 0.06Re^{\frac{2}{3}}\right) \cdot \left(\frac{\mu C_p}{k}\right)^{\frac{2}{5}}] \quad (2)$$

, where D is diameter of the sphere and Re is the Reynolds number calculated by $\rho v D/\mu$. Eq. (2) is adopted from "Introduction to Heat Transfer" by F. P. Incropera & D. P. DeWitt, Fourth Ed. Chapter 7.5.

Parameters and their values used for the calculation of Eq. (2) is summarized in **Table 1**.

The heat transfer coefficient h is reduced by about 20% when air temperature (T_a) is varied from 20 °C to −70 °C at a fixed pressure of 7 hPa and ventilation speed of 5 m·s^{-1}. Consequently, the radiation correction value (T_s - T_a) at T_a = −70 °C is increased by about 20%. This number is surprisingly in good agreement with the experimental result by the upper air simulator (UAS).

Table 1. Parameters and values for calculation of h and (T_s - T_a).

Parameter	**Symbol (Unit)**	**Value (T_a = 20 °C)**	**Value (T_a = −70 °C)**
Diameter	D (m)	0.001	0.001
Air pressure	P_a (Pa)	700	700
Ventilation speed	v (ms^{-1})	5	5
Air viscosity	μ (Pa·s)	0.00001756	0.00001307
Air density	ρ (kg·m^{-3})	0.00804	0.01161
Thermal conductivity	k (W·m^{-1}·K^{-1})	0.025367	0.018869
Heat capacity	C_p (J·kg^{-1}·K^{-1})	1039.6	1039.1
Reynolds number	Re	2.29	4.44
Heat transfer coefficient	h (W·m^{-2}·K^{-1})	66.5	54.4
Solar irradiance	S (W·m^{-2})	1360	1360
Absorptivity	α	0.2	0.2
Radiation correction	**T_s - T_a (K)**	**1.02**	**1.25**

Although there are many parameters in Eq. (2), the decrease of thermal conductivity (k) of air dominantly causes the decrease of h at low temperature. The thermal conductivity of air plays a main role in the heat transfer from sensor to air at the very boundary between them.

Since low temperature effect on radiation correction is due to a temperature-dependent change of material properties of air, the use of a low temperature chamber such as UAS is not the issue here. In this regard, the experimental observation of the low-temperature effect by the UAS is highly likely to be experienced by radiosondes during sounding.

In my opinion, the GRUAN data processing (GDP) of Vaisala RS41 should incorporate the effect of low temperature on the radiation correction because it is explained by both theoretical and experimental works.

The UAS paper (amt-2021-246) will be revised in the context of this comment soon. One simple way to include the low temperature effect is to use the Eq. (6) in the UAS paper. This may be possible when the GRUAN and the UAS papers are published back to back in the same Issue of the Journal with the help from the Editor.