Upgraded Thermistor for Unbiased Mesurments –Evaluation of New GPS Radiosonde RS-06G –

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Abstract

The Final Report on 2005 WMO Intercomparison in Mauritius [1] indicated that the thermistor of Meisei RS-01G radiosonde showing a tendency of positive bias temperature at high altitude. It assumed that the phenomenon had been attributed to a difference in cloud albedo between Japan and Mauritius. However, on investigation of Meisei factory after comparison, influence of positive temperature bias in daytime caused by thermal flux from warmed balloon is greater than variation of cloud albedo. Also, the Final Report indicated the negative bias on humidity at low altitude in high humidity condition caused by storage environment and the negative bias on humidity at high altitude with incident solar radiation. To solve these biases, Meisei developed new GPS radiosonde RS-06G. RS-06G, the upgraded radiosonde with a new thermistor is a successor to RS-01G and its time constant is 2.4 seconds at the altitude of 30km. We evaluated the thermistor using JWA-01GH that was newly developed for GPS thermo radiosonde. 10μm of tungsten fine wire is adapted to a temperature sensor for JWA-01GH. Its time constant is less than 0.03 seconds at an altitude of 30km and it can obtain data in 0.5 second cycle. The test flight of JWA-01GH successfully resulted in observing the thermal flux from warmed balloon. For humidity mesurment, the humity sensor hood was changed, and packaging material was changed. The newly humidity sensor was evaluated with SRS Snow-White. On result of comparison with JWA-01GH and SRS Snow-White, RS-06G was proved satisfactory performance for operational sonde. Meisei Electric will supply RS-06G for regular product line. And, JWA-01GH is going to be refined for research-purpose product.

1 Introduction

In the final report on 2005 WMO Intercomparison[1], some improvement requirements of Meisei RS-01G were indicated as below;

- Positive bias on temperature at high altitude caused by difference of cloud albedo between Japan and Mauritius
- Negative bias on humidity at low altitude in high humidity condition caused by storage environment.
- Negative bias on humidity at high altitude with incident solar radiation.

We had developed RS-06G radiosonde with a new sensor for more precise measurement of temperature and humidity. RS-06G has the miniaturized thermistor and the humidity sensor hood made from polystyren with aluminum deposition. These are experimentally confirmed to decrease systematic error. And RS-06G is covered up with aluminized polyethylene package on shipment. This package replacement was confirmed to show negligible influences that would be subject tp some storage environment.

In this report, we describe improvement of RS-06G with RS-01G, development of JWA-01GH GPS thermo-radiosonde, experimental evaluation of RS-06G using with JWA-01GH for temperature and SRS Snow-white for humidity.

Table 1: Specification of RS-06G and RS-01G

	RS-06G	RS-01G
T sensor surface	Aluminized coating	Aluminized coating
T sensor volume	1.4×10^{-10} m^3	8.6×10^{-9} m^3
Response 1000hPa with no flow	1.3 s	6.7 s
Response 1000hPa with 5 m/s flow	0.4 s	1.8 s
Response 10hPa with 5 m/s flow	2.4 s	10.8 s
Solar error 10hPa	1.8 ℃	2.5 ℃
Humidity hood diameter	15 mm	10 mm
Humidity hood surface	Aluminized	-

2 Improvement of sensor

WMO/CIMO pointed out that RS-01G has three sensor biases as mentioned above. On Investigation of Meisei factory after comparison, influence of positive temperature bias in daytime caused by thermal flux from balloon heated by solar radiation is greater than variation of cloud albedo. Negative humidity bias at high altitude resulted from heated aluminum humidity sensor hood of RS-01G by solar radiation, although negative bias at low altitude in high humidity condition resulted from contamination due to outgas from the adhesive.

To solve these sensor biases, Meisei developed a new GPS radiosonde, RS-06G with improved temperature and humidity sensors. We changed packaging material for reduce environment contamination. Improvement of RS-06G in detail is described in followed sections.

2.1 Improvement of temperature sensor

To decrease positive temperature bias caused by thermal flux from balloon, the smaller sensor with high time constant is effective. New GPS radiosonde, RS-06G was selected the miniaturized bead thermistor for temperature measurement. The small thermistor is effective for time constant and reduction of solar radiation error known as theoretically and experimentally[2]. The volume of new thermistor for RS-06G is about 60 times smaller than that for RS-01G thermistor. New thermistor and previous one are shown in Figure 1. And specifications are shown in Table 1.

2.2 Improvement of humidity sensor

In the WMO Intercomparison, humidity of RS-01G showed a negative bias at high altitude with incident solar radiation. Humidity sensor of RS-01G was shaded by aluminum sensor hood. When RS-01G's aluminum sensor with large thermal conductivity was heated by solar radiation, humidity value was found to become small. New RS-06G'S sensor hood is made by polystyrene with aluminized deposition. To increase ventilation effect, diameter of the hood has changed to 15 mm form 10mm. Polystyrene hood is smaller

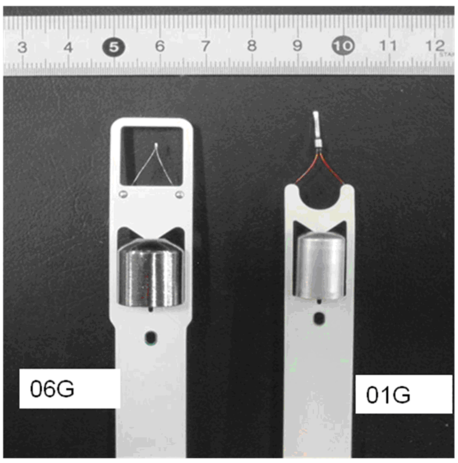

Figure 1: New TU board for RS-06G and previous TU board for RS-01G

thermal conductivity than RS-01G'S aluminum sensor hood and hood surface deposited by aluminum has larger reflectance, so thermal flow from hood to humidity sensor is reduced (See Figure 1).

2.3 Improvement of radiosonde packaging

In the WMO Intercomparison in 2005, RS-01G humidity sensor has a negative bias at low altitude due to high humidity condition. On the investigation after Intercomparison, the sensor was contaminated by outgas from adhesive of identification label for export to Mauritius. To prevent the sensor from any contamination, the packaging material was changed to aluminized polyethylene from polyvinyl. The RS-06G and packaging outlook are shown in Figure 2 To evaluate difference of packaging material, we had made accelerated aging test correspond in two years according to Japan Industrial Standard. The result of aging test is shown in Figure 3. From the result of aging test, previous packaged sensor was found negative bias, especially, it was -12%RH in high humidity. New packaged sensor is 2%RH or less bias.

Figure 2: RS-06G (left) and packed RS-06G on shipment (right)

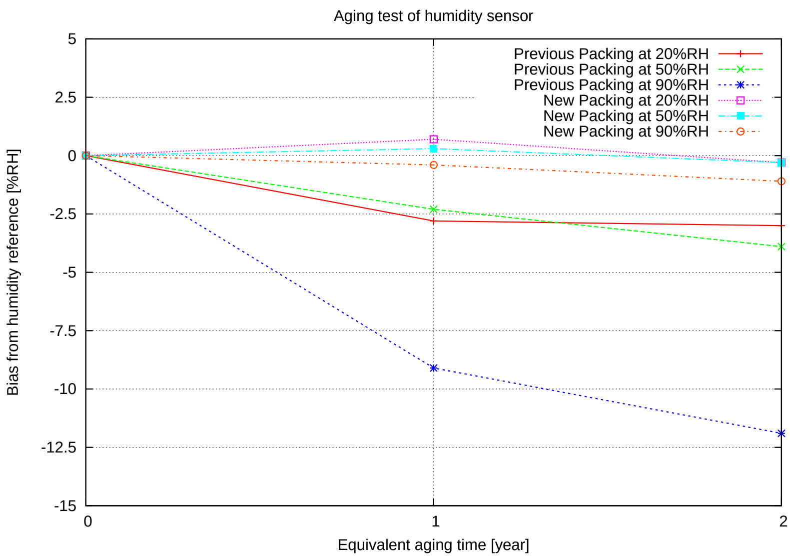

Figure 3: Humidity sensor bias with equivalent aging time. Red solid line , green dashed line and blue dashed lines are shown humidity bias of previous packing each environment parameter 20%RH, 50%RH, 90%RH. Pink dotted line, light blue dot dashed line and orange dot dashed line are shown humidity bias of aluminized new packing same environment.

3 Development of tungsten fine wire sensor

To evaluate new temperature sensor of RS-06G, we developed JWA-01GH with tungsten fine wire sensor[3] for temperature comparison. Time response of tungsten fine wire sensor is so small that the sensor could accurately observe the influence of thermal flux from balloon. Solar radiation errors were less than those of RS-06G and RS-01G. In this section, we described the experimental results and specification of tungsten fine wire sensor. The outlook of tungsten fine wire is shown Figure 4. The tungsten fine wire is strained in "V" shape, and diameter of wire is about 10 μm.

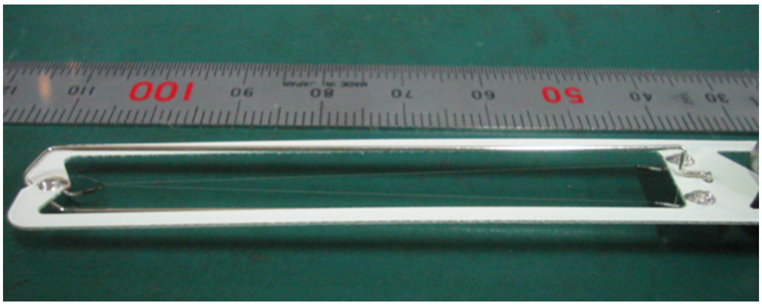

Figure 4: Outlook of tungsten fine wire. The wire is strained in "V " shape in sensor frame.

3.1 Evaluation of time constant

Time response of temperature sensor is important in detecting thermal flux from balloon. The influence of thermal flux appears by the frequency of the pendulum. The pendulum frequency is about 10 seconds in case of 30m suspension line. At least 2.5 seconds of time constant are necessary for detecting thermal flux. We evaluated time constant on experiment. The time constant is shown in Table 2

Table 2: Time constants and solar radiation errors of tungsten fine wire sensor of JWA-01GH

	time constant (second)	solar radiation error (K)
1000 hPa with no flow	0.041 s	1.39 K
1000 hPa with 5 m/s flow	0.005 s	0.16 K
300 hPa with 5 m/s flow	0.008 s	0.28 K
100 hPa with 5 m/s flow	0.013 s	0.43 K
30 hPa with 5 m/s flow	0.019 s	0.65 K
10 hPa with 5 m/s flow	0.026 s	0.88 K
5 hPa with 5 m/s flow	0.034 s	1.14 K

3.2 Evaluation of solar radiation error

The relationship between temperature and solar radiation error [4] is given by

$$HA(T_s - T_a) = \epsilon R + \alpha S - \epsilon A \sigma T_s^4$$

H is the heat-transfer coefficient (including convection and diffusion). A is surface area of sensor. ϵ is sensor coefficient of emissivity for infrared radiation. α is sensor coefficient of absorption for solar radiation. σ is Stefan-Boltzman constant. It is necessary to obtain the heat-transfer coefficient for sloving this equation. Heat-transfer coefficient is given by [5]

$$H = \frac{m_t C}{\tau A}$$

m_t is mass of sensor. C is specific heat of sensor. τ is time constant of sensor. Heat transfer coefficient was obtained from experiment of time constant. We assumed that the temperature error by the term of ϵR and term of $\epsilon A \sigma T_s^4$ were smaller than solar radiation term of αS. We had set the intensity of solar radiation error experiment with a solar simulator was $1350 W/m^2$ + 40% that include effect of albedo. Theorical and experimental result of the solar radiation error was shown in Figure 5. The solar radiation error on Standard Atomosphere is shown in Table 2.

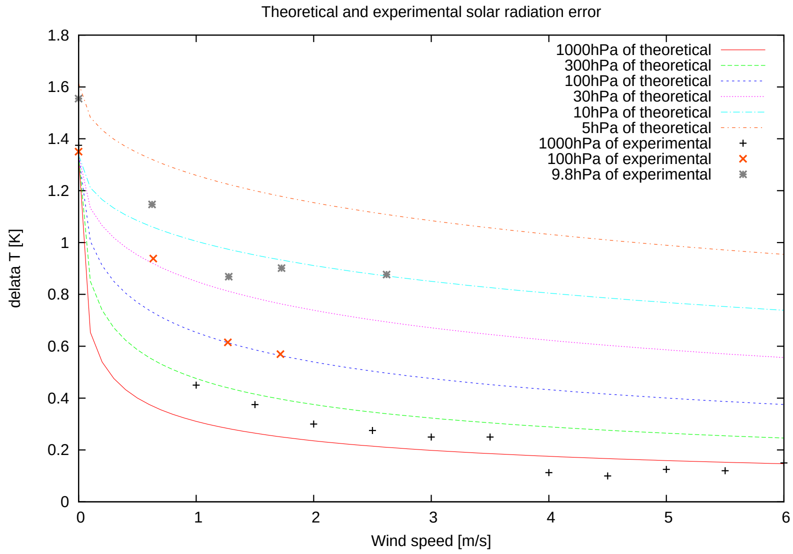

Figure 5: Solar radiation error with wind speed. Estimation value of solar radiation error from the result of theoretical are shown as lines. The result of experiment are shown as dots.

4 Evaluation of RS-06G

In this section, field evaluation of RS-06G is described. Comparison was made between temperature sensor of RS-06G and tungsten fine wire sensor of JWA-01GH. SRS Snow-White was used for comparison of humidity sensors.

4.1 Evaluation of RS-06G for temperature validated with JWA-01GH

In the WMO Intercomparison in 2005, daytime RS-01G has positive bias on temperature measurements. The result of Intercomparison is shown in Figure 6. To evaluate RS-06G, RS-01G and JWA-01GH were launched with one balloon that is Totex 2000g and 30 m suspension line. Raw level temperature data of RS-06G, RS-01G and JWA-01GH and filtered temperature data of RS-06G and JWA-01GH in high altitude (30km) is shown Figure 7. RS-06G has enough time response and JWA-01GH has best time response, so both data were detected thermal flux from balloon, however RS-01G was not detected it because of its large time constant. Temperature data obtained by RS-06G, RS-01G and JWA-01GH, and temperature difference to JWA-01GH are shown in Figure 8. Temperature diffrence between RS-01G and JWA-01GH showed the same tendency as WMO Intercomparison result. However, from ground to balloon burst, temperature difference between RS-06G and JWA-01GH was less than 0.5 ℃.

4.2 Evaluation of RS-06G for humidity validated with SRS(Snow-White)

Humidity sensor of RS-06G was experimentally evaluated with SRS Snow-White as a reference. Vaisala RS80 H-humicap and Tmax Board were used as a telemeter of Snow-White data. Configuration of experiment is shown in Figure 9. The humidity of RS-06G, RS80H-humicap and Snow-White, and difference between RS-06G and SnowWhite are shown in Figure 10. From ground to 10km, the humidity differences between RS-06G and Snow-White is less than 5%RH. From 10km to 12km, RS-06G humidity data was lost caused by human error. Above 12km, Snow-White detected some stratus, however RS-06G and RS80 H-humicap could not detect it due to large time constant of capacitive type humidity sensor in cold level.

5 Conclusion

RS-06G is a new development based on the indications as in the Final Report by the WMO/CIMO. RS-06G is improved than RS-01G in the following points.

- Positive temperature bias at high altitude in daytime.

  The Final report shows that the positive bias of temperature at high altitude resulted in diffrences in cloud albedo of Japan and Mauritius. From in-house experiment and field comparison, we found the thermal flux from balloon heated by solar radiation was larger than the said differences. The miniaturized bead thermistor was adopted in RS-06G for detection of thermal flux. The positive influences of thermal flux have been removed from RS-06G. Temperature error of RS-06G was reduced by 0.5K or less though RS-01G showed 1.5K at 30km when compared with tungsten fine wire sensor of JWA-01GH.

- Negative humidity bias at high altitude in daytime.

  Negative humidity bias at high altitude in daytime was caused by solar radiation to result in heat of humidity sensor with aluminum hood. Humidity sensor hood of RS-06G was changed from aluminum to polystyrene with aluminized deposition. In the comparison with Snow White, altitude range in 0 $\sim$ 10 km, negative humidity bias was't confirmed.

- Negative humidity bias at low altitude in high humidity condition.

  The negative humidity bias occured at 2005 Intercomparison was resulted in contamination of the humidity sensor. To decrease the influence of contamination, RS-06G packaging has been changed from polyvinyl to aluminized polyethylene. Our accelerated aging test proved that new packing had performance to keep the quality of the humidity sensor during the storage time of 2 years.

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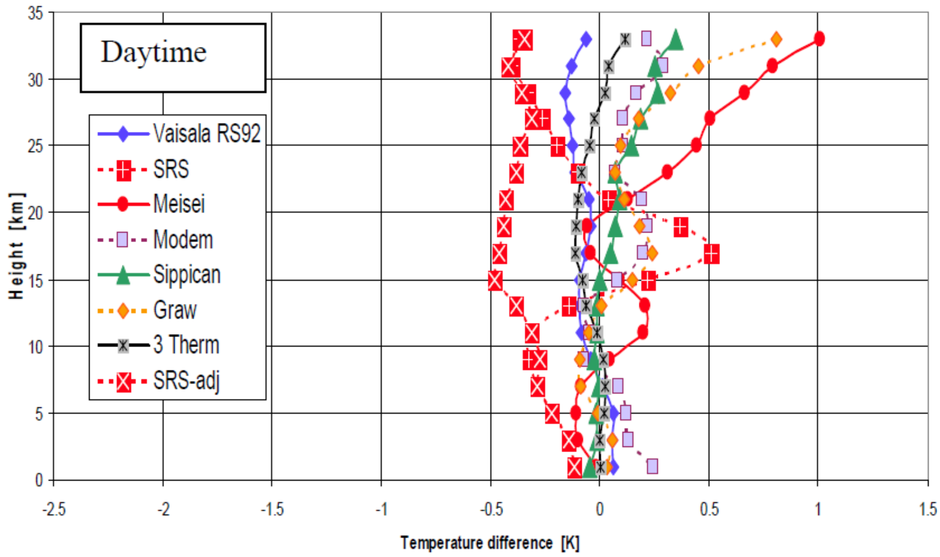

Figure 6: Systematic difference between simultaneous daytime temperatures (K) referenced to the nighttime reference, using multi-thermistor measurements as a link. [1]

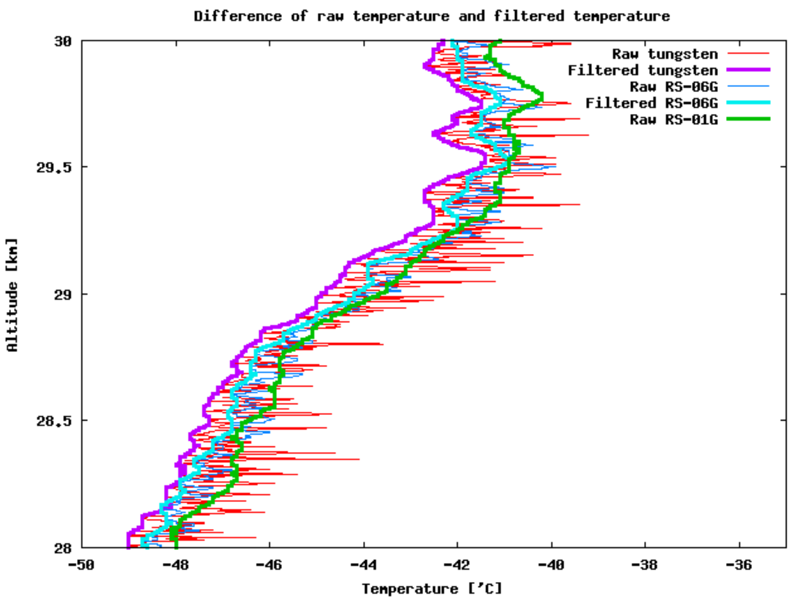

Figure 7: Temperature of raw data and filtered data. Red solid line is temperature of raw tungsten and purple solid line is temperature of filtered tungsten. blue solid line is temperature of raw RS-06G and light blue solid line is temperature of filtered RS-06G. Grean solid line is temperature of RS-01G.

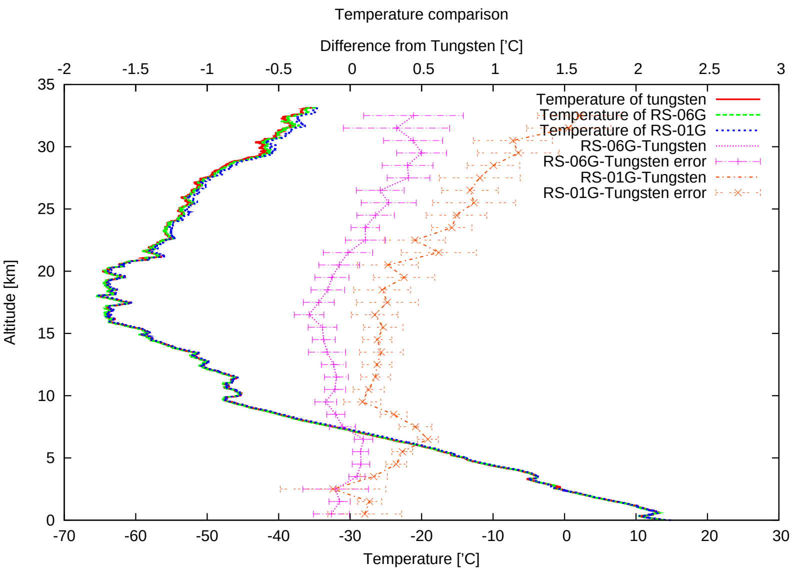

Figure 8: Comparison of RS-06G, RS-01G and tungsten temperature sensor. Red solid line is temperature of tungsten, grean dashed line is temperature of RS-06G and blue dashed line is tempetature of RS-01G (see lower x axis). Pink dotted line is difference bewteen RS-06G and tungsten,and orange dot-dot dashed line is difference between RS-01G and tungsten. (see upper x axis)

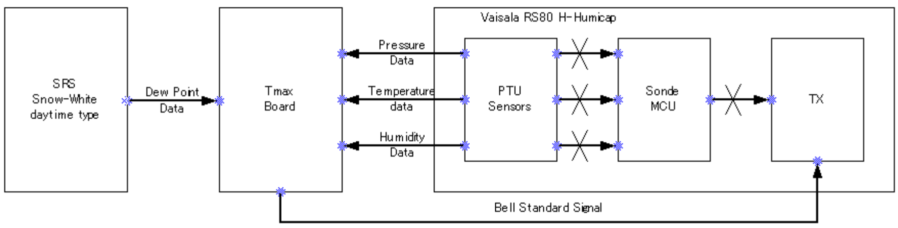

Figure 9: Configuration of SRS Snow-White

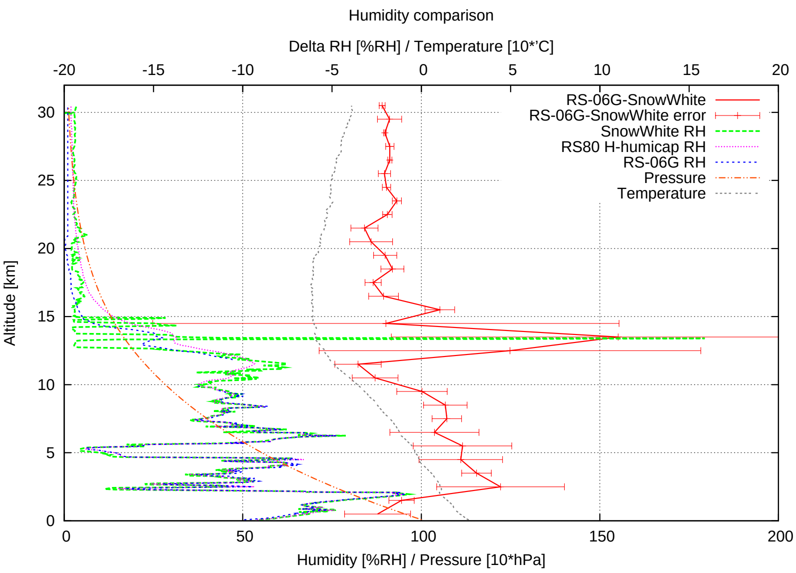

Figure 10: Comparison of RS-06G and SRS Snow-White. Difference between RS-06G and Sno-White is red solid line (see upper x axis). Grean dashed line is humidity of Snow-White, pink dotted line is humidity of RS80 H-humicap and blue dashed line is humidity of RS-06G(see lower x axis). Pressure is red dot-dot dashed line (lower x axis) and temperature is gray dotted line.(upper x axis)