Radiosonde observation from the ship in the tropical region

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The radiosonde is one of the most basic but still most popular atmospheric sounding systems. Several sensors which measure pressure, temperature, relative humidity, and wind speed/directions respectively are packed in one compact package and is launched with balloon filled with helium gases. Despite their popularity, recent studies have revealed that radiosonde data often contains serious errors especially for humidity. In addition, it is well known that surface meteorological observation on the ship should be carefully treated to avoid ship body structural influences. In the present paper, the procedure of radiosonde observation from the research vessel MIRAI is described to show how we obtain the accurate data. Besides, surface data correction scheme that has been developed based on the experimental results is also presented.

Keywords : radiosonde, humidity error, tropical region

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1. Introduction

Atmospheric sounding by radiosonde has been one of the most basic and inevitable components recognized world-widely for the understanding of the atmospheric phenomena and the weather forecast. In the international field experiment "Tropical Ocean and Global Atmosphere/ Coupled Ocean-Atmosphere Response Experiment" (TOGA COARE)[1], that was taken place in the tropical western Pacific region for four months period from November 1992 through February 1993, robust radiosonde observations were carried out intensively. While TOGA COARE brought a lot of new knowledge on the atmospheric/oceanic phenomena in the warm pool region[2], it also revealed the significant problem that radiosonde had dry bias and could not measure the atmospheric condition properly especially for Vaisala radiosonde sensors[3]. This feature has been recognized as not only for TOGA COARE data sets but also world-wide problem. Since this has a strong impact on analysis that may cause a significant change of results[4], it should be most carefully treated.

For the atmospheric sounding from the research vessel(R/V) MIRAI, Vaisala radiosonde system is adopted. This system consists of a) sensors (type : RS80-15G or RS80-15GH), b) receiver and processing unit (type : DigiCORA MW11), and c) balloon launcher that is stored in the 20ft sea container. Basic specifications of radiosonde sensor are listed in Table 1. Usually, radiosonde is launched with balloon filled with helium gases (Fig.1) and ascends to 20-24km at about 3.5m/sec ascending rate. Raw data are recorded every 2 seconds. After the sounding, obtained data are immediately sent to the global telecommunication system through the Japan Meteorological Agency for further use.

The study of the air-sea interaction focussing on the precipitation mechanism of the convections developed over the tropical western Pacific Ocean is one of the main research missions of the R/V MIRAI. Radiosonde observation is an important measurement for this mission, and is often conducted every three hours in order to resolve diurnal cycle of atmospheric phenomena over the tropical Oceans. In order to obtain accurate data as much as possible without errors that were found in TOGA COARE data sets, several techniques are adopted during this research mission.

In the following section, some known problems for radiosonde data are described first. Then, in the section 3, it shows how these possible errors are eliminated from MIRAI data. Finally, some recommendations for exact radiosonde observations from the ship in the Tropics are noted in the section 4 as concluding remarks.

Table 1 Specification of Vaisala RS80 GPS radiosonde.

Pressure		
	Sensor type	Capacitive aneroid
	Measuring range	1060 to 3 hPa
	Accuracy (repeatability)	0.5 hPa
Temperature		
	Sensor type	Capacitive bead
	Measuring range	＋60 to －90˚C
	Accuracy (repeatability)	0.2˚C
Humidity		
	Sensor type	Thin film capacitor
	Measuring range	0 to 100 % RH
	Accuracy (repeatability)	2 % RH
Wind speed/direction		
	Wind detection	Measuring Doppler shift of GPS carrier
	Accuracy	0.5 m/s RMS

Fig. 1 Launch the radiosonde from container.

2. Known problems

2.1. Sensor arm heating

When the humidity errors were found in TOGA COARE data sets at first, this problem was thought to be attributed mainly to a) sensor arm heating, and b) launch procedure from air-conditioned container. Sensor arm heating was caused by that sensors had been exposed before the launch under the tropical strong solar radiation for a long time. In such a situation, sensor becomes warm and results in making relative humidity low. So, this kind of error appears only in the daytime observations. As it takes several seconds to recover, near surface data just after the launch show low relative humidity for a while. On the other hand, some observational sites use the container, where air-conditioner is equipped. If sensors are stored in such an air-conditioned room for a long time, it keeps sensor in a cool and low relative humidity condition that is far from tropical warm and moist outside conditions. These errors usually appear in only lower troposphere (a few seconds after the launch, it depends on sensor response time and environmental condition). As for the TOGA COARE data sets, these were corrected in the earlier release of the data sets[5]. But it taught us that surface condition in the launch site is crucial to the exact upper sounding.

2.2. Dry bias problem

Nevertheless, after the correction of radiosonde data for sensor arm heating and other sources of possible errors mentioned above, it was pointed out that the data obtained during TOGA COARE showed still dry bias and it was recognized that it was not only TOGA COARE data problem but also world-wide problem[3]. Especially, this phenomenon was found only in the Vaisala radiosonde sensors. After the careful examination on this issue, it was found that this was due to the contamination of the polymer used as the dielectric material in the capacitive relative humidity sensor[6]. This contamination came from the packaging material as well as the plastic and Styrofoam materials used in the construction of the radiosonde itself. Due to this reason, the older radiosonde is much worse than new one, and the grade of bias depends mainly on the radiosonde ages. This bias often reaches 8–10% at measured relative humidity values of 80% and above for over one year old radiosonde. If this dry bias exists in the sensors, for example, it does not show greater than 95% even when the sensor penetrates the wet clouds. Guichard et al.[4] showed that the impact of these errors onto the thermodynamic and radiative features was so huge and it might affect and/or even change the past analytical results. In their calculation of convective available potential energy (CAPE) for TOGA COARE data obtained aboard the R/V Moana Wave, corrected four-month mean CAPE lies between 1000–1500J/kg, while uncorrected lies between 500–800J/kg.

In order to elucidate this dry bias, several techniques have been proposed. Cole and Miller[6] with Vaisala technical team have developed the correction algorithm that uses radiosonde ages and surface calibration results that are usually conducted just prior to launch. Lucas and Zipser[7], on the other hand, have developed different scheme for TOGA COARE data. They first added constant amount of specific humidity from second sounding point to 700hPa, then its amount is linearly reduced to zero from 700hPa to 500hPa. A constant amount is chosen at each site separately, because different humidity offsets were found from observational site to site. Then, the differences of specific humidity between boundary layer data obtained by radiosonde (about 50hPa from surface) and independently measured surface data were taken account for correction. These correction schemes are widely recognized well as good performances. In addition, recent radiosondes have been much improved for this dry bias problem by Vaisala.

However, it seems that there still remains this problem especially for old radiosondes with over one year. Figure 2a and b show the radiosonde ages and the results of surface humidity calibration conducted in the R/V MIRAI MR99-K06 cruise[8] in the tropical western Pacific region. It is easily found that old radiosondes had large offsets. Namely, when old radiosondes were used, the differences of relative humidity between calibrator and sensors show large positive values (calibrator's is higher than that of radiosonde).

2.3. Ship's influences

Aforementioned are relatively well-known general problems for radiosonde observation. In addition, there is an another problem for radiosonde observation and its data, when we conduct on the R/V MIRAI. Since the R/V MIRAI is so huge (130m length, 8600tons), and

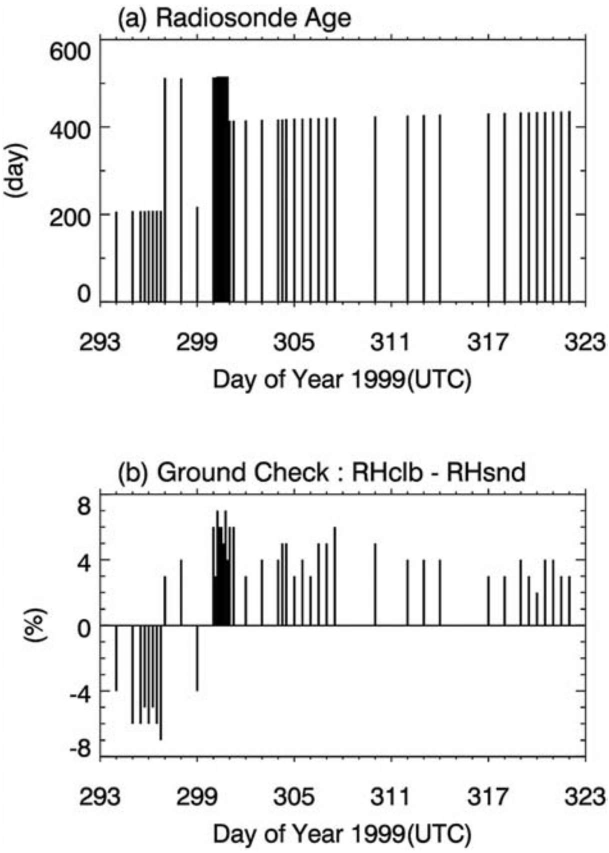

Fig. 2 (a) Radiosonde ages and (b) calibration results of relative humidity during MR99-K06 cruise. Positive in (b) indicates that calibration humidity set at 70% is higher than that of radiosonde sensor.

radiosonde container is located on the iron deck at the center of the ship (Fig. 3), surface sensors are easily affected by ship body heating and turbulence. Figure 4a and b show the examples of the temperature and dew point profiles near the surface obtained at 165E on the equator at (a) 0000LST and (b) 1200LST, in June 23, 1999 during the R/V MIRAI MR99-K03 cruise[9]. At that time, it corresponded to the convectively suppressed period of the equatorial intraseasonal oscillation and wind was weak[10]. It is evident that temperatures near the surface were strongly affected and became too high (low) at daytime (nighttime). Of course, this high (low) temperature profile was reflected onto low (high) relative humidity. This means that, strangely speaking, if the radiosonde sensors measure the ambient temperature and humidity correctly, the results become unreliable. The affected range is determined mainly by environmental conditions such as wind speed, temperature, and sensor's response and sampling time. So, these surface values should be corrected.

Fig. 3 R/V MIRAI from starboard side.

3. Procedures of radiosonde observations on the R/V MIRAI

In order to avoid temperature and humidity errors mentioned above as much as possible, careful treatments are poured onto the observations on the R/V MIRAI. In this section, how we try to obtain the reliable sounding data is described.

3.1. Pre-launch procedures

Radiosonde container on the R/V MIRAI consists of two spaces ; one is for launch and the other is for data processing. Data processor including personal computer should be kept dry for good performance, while the launch space is better to be ventilated and same as outside conditions to reduce the drastic change of circumstances before and after the launch. For this reason, ten small windows are equipped on the launch space side (cf. Fig. 1) and fan is also attached inside to aid the ventilation, while the air-conditioner is equipped in the processing room where is separated from launch space by door inside. Usually, launcher room is ventilated by opening windows and air conditioner in the processing room is turned off about 20 minutes prior to launch.

The simplest way to avoid the influence of dry bias problem is to use new sensors. Since Vaisala radiosonde series has a rule of their nine digits serial number indicate manufactured date, we can know radiosonde age. Basically we do not use radiosondes aged over one year. (One exception was at MR99-K06 as shown in Fig. 2.) Besides, we confirm that some data when we launch in the rainy days show the relative humidity of higher than 95% (or sometimes equal to 100%). Furthermore, we conduct a ground check of humidity sensor prior to launch using not a Vaisala's standard ground check kit, but an another humidity calibrator (Digilog Instruments, Inc. Vaporpak H-31 shown in Fig. 5). The former uses desiccant to set calibration environment 0%, while the latter can create desirable humidity with accuracy of 1%. Usually, we set humidity at 70%, as this is much closer to outside tropical moist condition. This humidity calibrator itself is maintained every year by manufacturer. Radiosonde sensors are kept dry (close to 0%) with desiccant in the package before use for quality assurance. If the calibration is done at 0% criteria, it is hard to notice that sensor has dry bias, as sensor is packed in a stable condition with very low humidity and such dry biased sensors often show crucial errors at high humidity range. So, surface calibration should be done at higher humidity values.

Just before the launch, we again confirm that calibrated sensors represent environmental surface conditions by comparing to that measured by portable temperature and humidity sensor independently.

Finally, it is noted that since the weather Doppler radar is located next to launch site as shown in Fig. 3, the radar operation is completely stopped when radiosonde is launched.

3.2. Surface data correction

Despite the careful operation of radiosonde launch, surface data should be corrected if ambient temperature and humidity around launch site are affected to be distorted by ship body warming/cooling as shown in Fig. 4. From Fig. 4, it can be expected that discontinuity of temperature is about around 30m height from ship deck. To confirm this, tethered radiosonde was carried out during MR99-K03 and MR01-K05[11] cruises. We used same Vaisala radiosonde and lifted it from ship deck up to about 150m height. The results are shown in Fig. 6 and surface conditions at each time are listed in Table 2. Apparently, near surface values of temperature (humidity) are distorted to be high (low) at daytime and low (high) at nighttime. For comparison, we also conducted same procedures at upwind far from ship (about 150m) using small boat during the MR01-K05 cruise. Although this trial was done at only daytime due to difficulty of operation, the results shown in Fig. 7 confirm that surface values measured from ship are certainly affected. Important results inferred from the comparison between Fig. 6 and Fig. 7 is that these affected layers are limited within about 40m from deck and these values seem to be

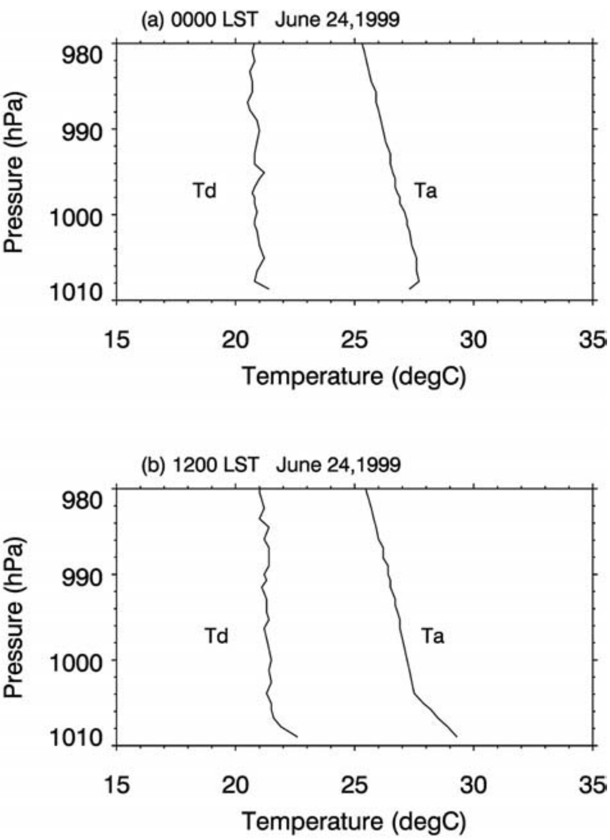

Fig. 4 Temperature and dew point profiles obtained at (0,165E) at (a) 0000LST and (b) 1200LST on June 24, 1999.

Fig. 5 Sensor calibration prior to launch. Reference barometer (left) and humidity calibrator (center).

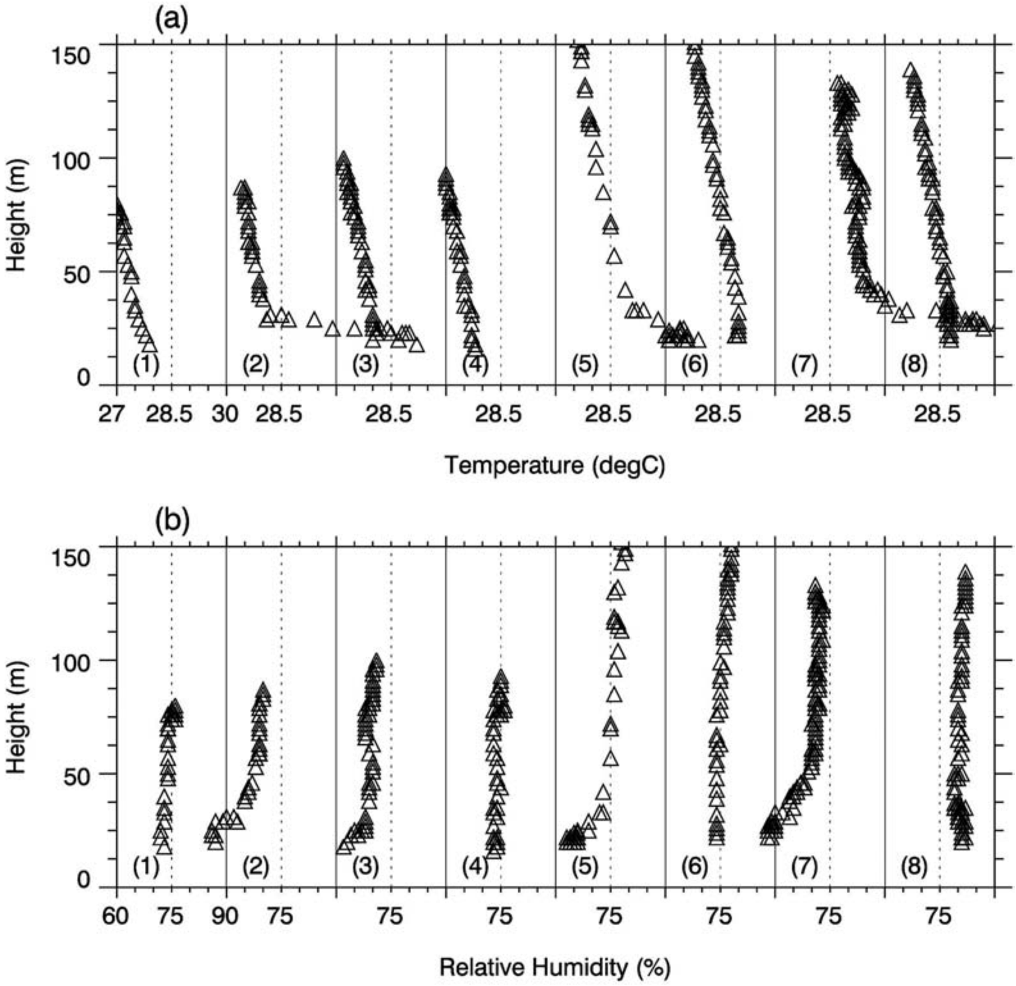

Fig. 6 (a) Temperature and (b) relative humidity profiles obtained by tethered radiosonde conducted from the R/V MIRAI deck on various time listed in Table 2.

Table 2 Time and surface wind conditions in tethered radiosonde observations.

No.	Time (LST)		Position	Relative wind	
1	Jun.25, 1999	10:45-11:05	0.01S, 165.00E	132 deg	3.2 m/s
2	Jun.25, 1999	13:46-14:04	0.02S, 165.00E	148 deg	2.8 m/s
3	Jun.25, 1999	16:45-16:53	0.02S, 165.01E	119 deg	2.8 m/s
4	Jun.25, 1999	19:41-19:48	0.01S, 165.00E	188 deg	3.1 m/s
5	Nov.13, 2001	16:50-17:03	1.78N, 138.07E	9 deg	4.0 m/s
6	Nov.14, 2001	22:54-23:08	1.92N, 137.98E	349 deg	2.5 m/s
7	Nov.26, 2001	13:52-14:07	1.90N, 138.10E	308 deg	2.3 m/s
8	Nov.26, 2001	22:50-23:04	1.93N, 138.06E	323 deg	3.3 m/s

able to be corrected using above surface layer's data that are not influenced. Based on these results, raw (2 seconds interval) data are corrected onto new data sets in order to remove the surface influenced data.

The simplest method is to interpolate near surface several values using independently measured surface values and 40m height data. However, even surface temperature and dew point sensors of the R/V MIRAI, that are mounted at 3m height from deck at both side masts, may have a chance to be influenced in a situation when ship keeps the stationary position and relative wind is weak or comes from backward. Besides, for the first two years of the R/V MIRAI operation (1998–1999), these surface sensors were located not at side masts but just only 1.5m above the deck. We judge that these surface temperature and humidity values are hard to be considered as reliable data. Instead, another simple scheme is developed based on the results of Fig. 6 and 7 ; (1) ship's influences reach

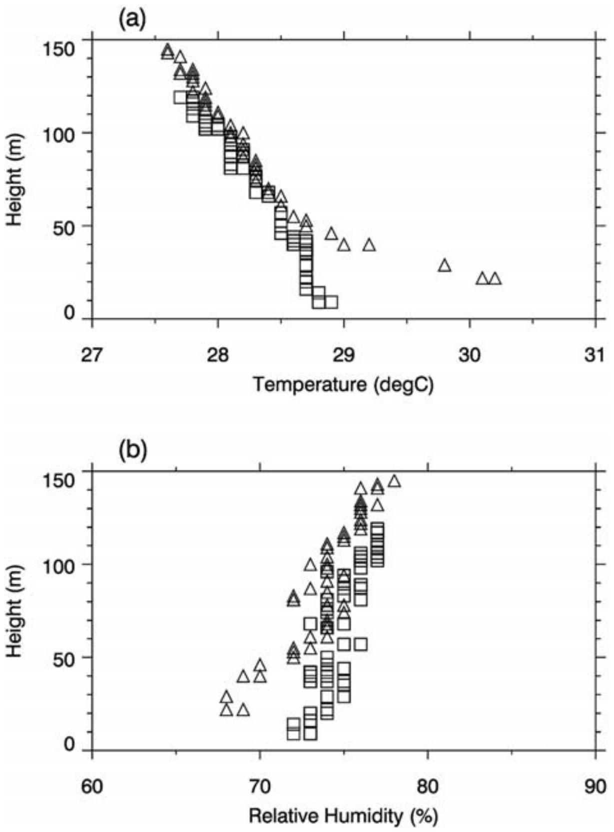

Fig. 7 Comparison of (a) temperature and (b) relative humidity obtained by tethered radiosonde conducted at (2N, 138E) from the R/V MIRAI deck (triangle) at 1330LST, and from small boat (square) at upwind far from ship at 1400LST on December 1, 2001.

to about 40m from the deck at worst, and (2) linearity of temperature lapse rate may give first order of approximation for real surface condition. The step is very simple as that first several data within 6hPa from surface point (about 50m and/or 5-8 data points) are replaced with ones that are calculated from linear extrapolation using above layers data within 6.0hPa and 18.0hPa higher from first point (usually it is equal to about 50-150m layer and/or 15–20 data points).

This method is applied to data shown in Fig. 7 to confirm the assumption (2) above mentioned. The difference of temperature and relative humidity between calculated values and independently measured surface values are 0.0℃ and −1%, respectively, that are acceptable as first order approximation. In addition, the same results calculated for 241 sounding data obtained during MR01-K05 cruise are 0.14℃ and 0.09% with root mean square of 0.36℃ and 3.56%, respectively. In Fig. 8, the case of June 23, 1999 is shown as an example for raw (thin line) and corrected (thick line) temperature and dew point data. It is worth to note that surface raw data were strongly affected and showed diurnal cycle in correspondence with daytime warming and nighttime cooling. These influences are fairly well removed by above calculation.

4. Concluding remarks

In this paper, we mainly described the procedures of radiosonde observation on the R/V MIRAI, focussing on how to obtain reliable data especially in the tropical region, where surface temperature and humidity are easily affected and changed due to strong solar radiation and ship's structure. Some basic but important recommendations to accomplish this can be summarized as follows.

First, use new radiosondes as much as possible. At least, over one year aged radiosondes should not be used. Second, keep radiosondes in good conditions and acclimate them outside conditions before the launch. Third, ground check just prior to launch should be conducted by not 0% desiccant, but suitable calibrators that can be set at higher humidity that are almost same as outside normal conditions. It helps not only to acclimate outside soon but also to find humidity bias at high humidity range. These surface calibration results are also useful in case that there exists dry bias and adopt Cole and Miller[6] scheme that uses this information. Forth, check obtained data for their reliability especially near the surface. Finally, if possible, it is recommended to survey the atmospheric conditions around the ship, for instance, by tethered radiosondes to evaluate the impact of ship's influences in various conditions. If necessary, surface data correction should be done using above layers data and/or surface data independently measured. For radiosonde data sets obtained aboard the R/V MIRAI, these influences have been removed and they are remade onto every 5hPa interval for convenience to use.

In the present paper, we did not argue the wind data. From year 1998, wind detection system has been changed from using Omega navigation signals to using a Doppler shift of carrier signals of Global Positioning Satellite (GPS). In spite of several improvements by Vaisala[12], GPS radiosonde observations from the R/V MIRAI still sometimes miss to measure wind data. So, another detailed examination should be carried out as very near future work.

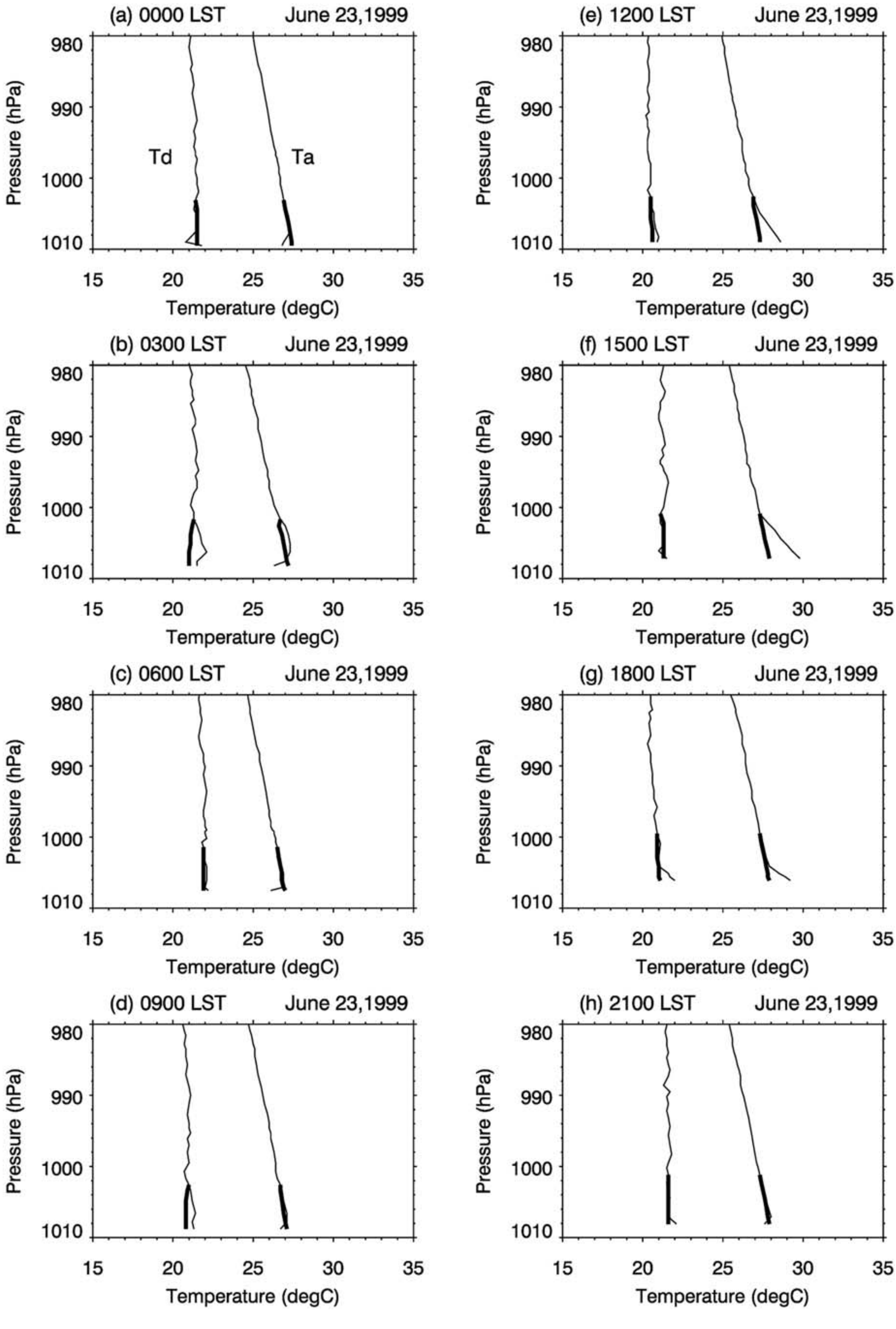

Fig. 8 Temperature and dew point profiles of raw (thin line) and corrected (thick line) values obtained at (0,165E) at (a)0000LST, (b)0300LST, (c)0600LST, (d)0900LST, (e)1200LST, (f)1500LST, (g)1800LST, and (h)2100LST on June 23, 1999.

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