

Seasonal change of the troposphere in the early summer of 1993 over Central Tibet observed in the Tanggula mountains

Nobuhiko ENDO, Ken'ich UENO and Tetsuzo YASUNARI

Institute of Geoscience, University of Tsukuba, Tsukuba 305 Japan

(Received April 15, 1994 ; Revised manuscript received July 23, 1994)

Abstract

Aerological observations were carried out from May to July of 1993 to study the change in atmospheric conditions with the seasonal march in the Tanggula mountains (33.0°N, 92.0°E) in the central Tibetan Plateau.

During this period, increases in tropospheric temperature and specific humidity were about 5K and about 3 g kg⁻¹, respectively. Short-period fluctuations (with about 5 days period) in all upper-air meteorological elements were dominant in the pre-monsoon season, whereas large amplitude, low-frequency oscillations of about 15-day period were prominent during the monsoon season. Abrupt change of the variation pattern occurred around June 10.

The diurnal variation of the PBL (planetary boundary layer) was examined under fair weather condition during the pre-monsoon season. A mixed-layer with almost uniform potential temperature was observed with maximum height of around 7000–8000 m, and vertically uniform distribution of moisture is also noticeable in the afternoon.

1. Introduction

Many observational studies and numerical studies have suggested that the thermal effect of the Tibetan plateau plays an important role in the onset and the maintenance of Asian summer monsoon (Hahn and Manabe, 1975 ; Luo and Yanai, 1983, 1984 ; He *et al.*, 1987 ; Yanai *et al.*, 1992). Nitta (1983), using the First GARP (Global Atmospheric Research Program) Global Experiment (FGGE) level II-b data, found a large diurnal variation in tropospheric heating and moisture sink. Yanai *et al.* (1992), using FGGE and the Chinese Qinghai-Xizang Plateau Meteorology Experiment in 1979 (QXPME79) data, analyzed the large-scale field, vertical circulation. They found that the thermally induced vertical circulation has a pronounced diurnal component. They also noted that the Tibetan Plateau acts as a heat source in spring and summer.

The planetary boundary layer (PBL) with large-amplitude diurnal variation is suggested to play an important role in the heating mechanism over the

Plateau. Yeh and Gao (1979) first described that remarkable diurnal variation in various meteorological elements over the plateau and its vicinity. Yanai and Li (1994) studied the structure of the PBL over the plateau, relating to the atmospheric heating. They observed a deep and well mixed layer over the western and central plateau at 1200 UTC. They also noted that the moisture is not well mixed vertically.

However, the diurnal variation of the PBL described so far based on twice-daily data, including FGGE and QXPME79 data. There had been no upper-air observations to fully describe the diurnal variation of PBL over the Plateau. The relation between the changes in surface fluxes variation and time evolution of the troposphere is also a question to be solved.

Intensive aerological observations were conducted in early summer in the Tanggula Mountains in the central part of the Tibetan Plateau. The aims of the observations were 1) to investigate the diurnal variation and vertical structure of the PBL, 2) to describe the seasonal change of the PBL and the vertical struc-

ture of the troposphere relating to the onset of the monsoon, and 3) to clarify the characteristics of the disturbances which cause precipitation on the plateau.

In this report we present some preliminary results on the seasonal evolution and the diurnal variation of the vertical structure of the troposphere and the PBL from the dry pre-monsoon season to the wetter monsoon season in the Tanggula Mountains.

2. Observations

We used Beijing Standard Time (BST, UTC+8 hours) in this report. The local time of the observation area is approximately 2 hours behind BST. Aerological soundings were made in the Tanggula Mountains (33.0°N, 92.0°E, 5070 m a.s.l.) in the central Tibetan plateau totally 200 times from May 20 to Aug 1, 1993. The type of radiosonde is type RS80-15N of Vaisala Co. Ltd., which measures pressure, temperature and relative humidity with high vertical resolution (every 2 seconds), with the OMEGA navaid system for measuring wind speed and direction (see Table 1).

Table 1. List of instruments used for radiosonde observation.

Type of receiver	MW11 (Vaisala Co.,Ltd)
Type of sonde	RS80-15N (Vaisala Co.,Ltd)
Windfinding	OMEGA Navaid Windfinding
Measuring range/resolution	
Pressure	1060 to 3hPa/ 0.1hPa
Temperature	+60 to -90°C/ 0.1°C
Humidity	0 to 100%RH/ 1%RH
Wind Speed	0 to 180 ms ⁻¹ / 0.1ms ⁻¹
Wind Direction	1 to 360°/ 1°
Wave length	403 MHz
Weight of balloon	250g

The surface meteorological elements were observed to evaluate the surface fluxes at the launch site from May 21 to September 21, 1993. Table 2 shows the list of instruments.

Radiosonde was routinely launched at 0800BST (0000UTC) every day. Intensive observations were carried out for 32 days to observe the variation of the vertical structure of the PBL with launching every 6 hours from 0800BST (0000UTC) to 2000BST (1200UTC). Special observations were also taken for 3-days to intensively observe the diurnal variation of the vertical structure of the PBL with launching of radiosondes every 3 hours from 0800BST (0000UTC) to the next 0800BST (0000UTC).

3. Seasonal evolution of the vertical structure of the troposphere from the pre-monsoon season to the monsoon season

Figure 1a shows a time-height cross section of the zonal wind from the surface (5070 m a.s.l.) to 20 km at 0800 BST (0000 UTC). The strong westerlies (larger than 30 m s⁻¹) were observed in the upper troposphere (12–15 km) until the middle of June, while the westerlies were weakened after the middle of June (less than 20 m s⁻¹). A weak easterly wind appeared sometime in the lowest 1000 m layer. The large amplitude of the zonal wind fluctuation is observed with a period of around 5 days in the upper troposphere before June 15, while the fluctuation of this period range was not clear with relatively small amplitude after June 15.

Figure 1b shows a time-height cross section of the meridional wind. Northerly was dominant above 15 km during the observational period. It seems that southerly and northerly alternatively appeared with

Table 2. List of surface meteorological instruments at Base Camp.

Elements	Sensor	Accuracy	Manufacturer
Air Temperature	Platinum resistor (forced ventilated shelter)	0.1°C 0.2°C	Vaisala Co., Ltd. CHINO Co., Ltd.
Humidity	Hygroscopic macromolecular material	1%RH 2%RH	Vaisala Co., Ltd. CHINO Co., Ltd.
Wind speed	3-cup anemometer	0.1ms ⁻¹	Makino Co.
Wind direction	Potentiometer type	2°	Vector Instruments
Global solar radiation	Temperature difference type	3%	Eko Co., Ltd.
Reflective solar radiation	Temperature difference type	3%	Eko Co., Ltd.
Net radiation	Temperature difference type	3%	Campbell Scientific, Inc.
Ground surface temperature	Infrared radiometer (8μm~14μm)	0.5%	Everest Interscience Inc.
Ground temperature	Thermister	0.1°C	Grant
Ground heat flux	Temperature difference type	5%	Eko Co., Ltd.

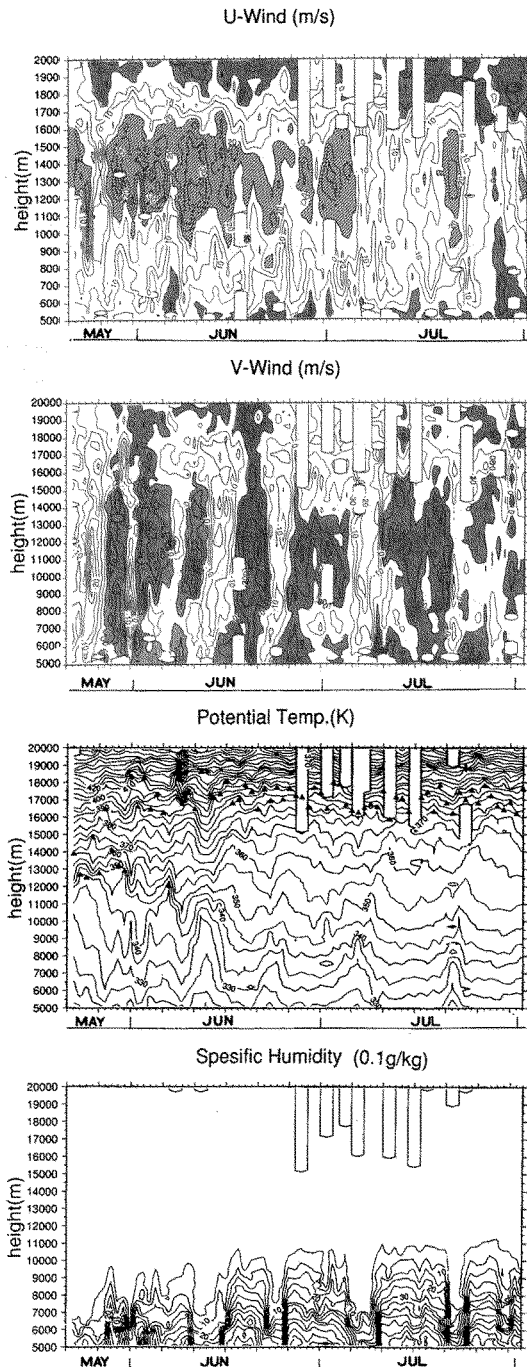


Fig. 1. (a) Time-height section at 00Z for zonal wind ($m s^{-1}$). Contour interval is $5m s^{-1}$. Values more than $20m s^{-1}$ are hatched; values less than $0m s^{-1}$ are shaded. (b) That for meridional wind ($m s^{-1}$). Contour interval is $5m s^{-1}$ and positive values are shaded. (c) That for potential temperature (K). Solid triangles are tropopause. (d) That for specific humidity ($10^{-1} g kg^{-1}$).

period of about 5 days through the troposphere under 15 km before June 21. After June 21, 5 northerly days and 10 southerly days seem to have appeared alternately in the layer between 8 and 15 km, while in the layer between the surface and 8 km northerly prevailed through the period. The amplitude of the meridional wind fluctuation before June 21 was larger than that after June 21.

The time-height cross section of the potential temperature is shown in Fig. 1c. The tropopause was located at around 13 km at the end of May. In June, the tropopause height was abruptly raised to around 17 km. This height continued until the end of July. This abrupt shift of the tropopause may be related to the migration of the South-Asian anticyclone (Tibetan high) from Indochina (Fig. 2).

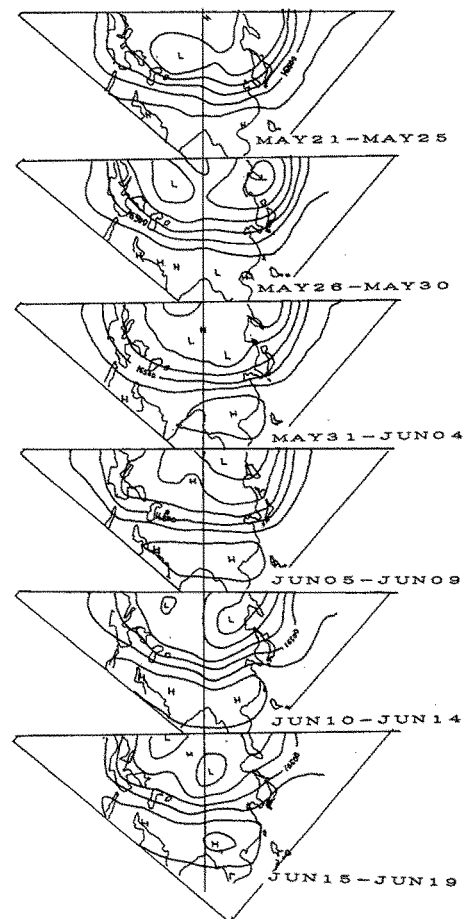


Fig. 2. 5-day mean geopotential height at 100hPa from May 21 to June 19, 1993, based on JMA (Japan Meteorological Agency).

Potential temperature gradually increased (-5K) below 13 km during the observational period. The potential temperature showed a fluctuation of period about 5 days before June 15 with large amplitude in the layer between 8 and 15 km. Although the amplitude of this period range was generally small after June 15, quasi-biweekly fluctuation was observed in this period with, its maximum amplitude in the lower troposphere.

Figure 1d shows a time-height cross-section of the specific humidity. Humidity increased gradually (by -3 g kg^{-1}) and the depth of the humid layer increased during the observational period. Specific humidity of about 6.5 g kg^{-1} was observed in the lowest 1000 m depth at the end of July. Associated with the northerly wind and fair weather, rapid decrease of humidity occurred periodically on June 10, June 22, July 6 and July 22. The abrupt moistening occurred at June 15, June 24, July 9 and July 24 when a southerly wind blew. The period of the fluctuation of the specific humidity before June 10 was shorter than that after June 10 (around 15 days).

As described above, the fluctuation with period about 5 days was prominent in each meteorological element before June 10. This fluctuation has the following characteristics: 1) southerly wind was coupled with strong westerly wind, temperature was high in the whole troposphere, specific humidity was high near the surface, 2) when northerly wind coupled with weak westerly wind blew, low temperature and humidity were observed.

This phase relationship seems to be related to the passage of the trough embedded in the mid-latitude westerlies over the Tanggula mountains. The fluctuation with a period of about 5 days seems, therefore, to correspond to the westerly disturbance in mid-latitudes.

After June 10, similar to before June 10, specific humidity increased (decreased) with increase in the southerly (northerly) component of wind in the lowest 2000 m of the troposphere. Lower-frequency fluctuation with a period of 15 days was prominent in the meridional wind during this period. The change in the periodic fluctuation suggests that the summer monsoon arrived in the middle of June in Tanggula, which is consistent with the definition of the onset of monsoon precipitation in this region (Ueno *et al.*, 1994).

Similar periodicity has been pointed out over the Asian summer monsoon region (Krishnamurti and

Bhalme, 1976; Murakami, 1976; Yasunari, 1979 *etc.*). Similar long period fluctuation was noted in the tropospheric heat source over the eastern Tibetan plateau (Nitta, 1983), though longer-period oscillation (*i.e.* intraseasonal variation) of about 30 to 40 days was stressed in this study.

4. Diurnal variation of the PBL in the pre-monsoon season

The diurnal variation of the vertical structure of the PBL was also prominent during fair weather in the pre-monsoon season.

Figure 3a shows the diurnal variation of the potential temperature profile from the surface (5700m a.s.l) to 8500m on May 24, 1993. A stable layer was observed near the surface at sunrise (0800 BST). The surface skin temperature strongly warmed up as the sun rose and the temperature difference between the surface and air became very large. This large difference suggested that a large sensible heat flux was provided from the surface. A mixed layer with nearly uniform potential temperature in the vertical developed, and its top level reached about 2000 m above the surface in the afternoon. The potential temperature difference between 0800 BST and 2000 BST was about 10K in the lowest 1000m. After sunset, the stable layer was formed near the surface and temperature dropped in the PBL.

Figure 3b shows the diurnal variation of the specific humidity profile. In the morning (0800 BST), the humid layer was observed only below the surface inversion level. With increase in the mixed layer depth, the moisture was also mixed vertically in daytime and became dryer. The difference of the specific humidity between 0800BST and 2000BST was about 1.7 g kg^{-1} in the lowest 1000 m. During the night moisture was confined to the nocturnal boundary layer, the lower layer became wet with increase of wind.

Figure 3c shows the diurnal variation of wind speed near the surface. Wind was weak in the surface inversion layer and strong above the layer in the morning. After the mixed layer developed, wind speed became almost uniform vertically in the mixed layer, which indicates that vertical mixing of momentum occurred in the mixed layer. During the night, wind was very weak near the surface and the vertical gradient of wind speed was large above the nocturnal boundary layer.

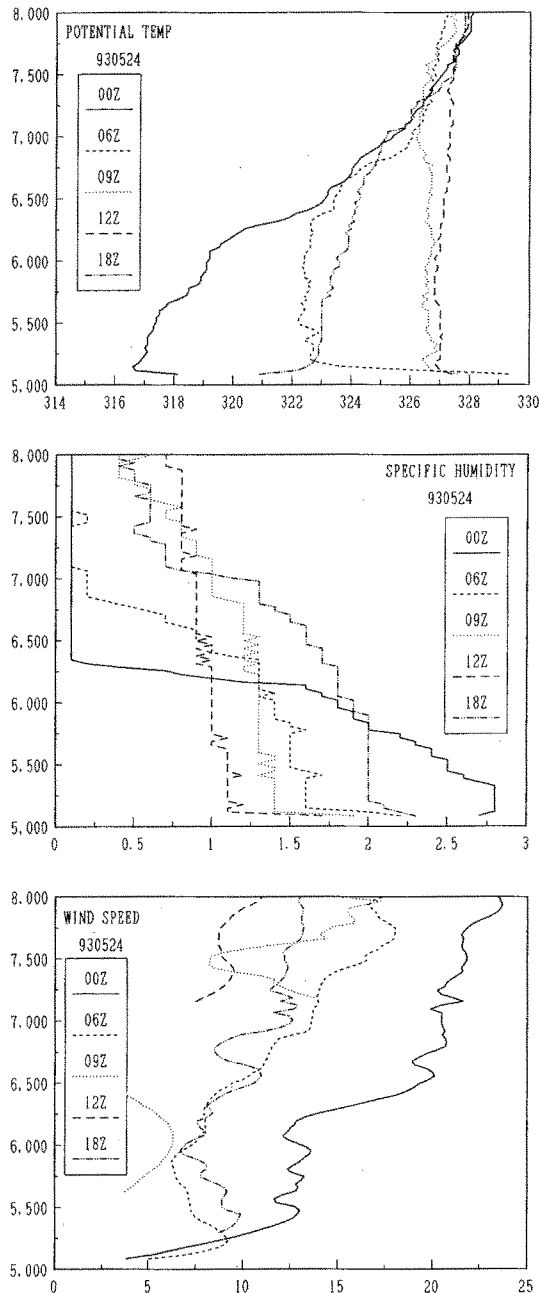


Fig. 3. (a) Vertical profile of potential temperature (K), (b) specific humidity (g kg^{-1}), and (c) wind speed (m s^{-1}) on May 24.

In the pre-monsoon season, a well-mixed vertical structure of uniform potential temperature and moisture was observed on fair weather days, though Yanai and Li (1994) reported that moisture was not mixed vertically in the evening. Further studies on the vertical structure of humidity would be needed.

In general, the depth of the mixed layer may correspond to the intensity of the sensible heat flux from the surface. Seasonal as well as diurnal variations of the mixed layer depth and associated regional surface heat fluxes should be examined as a next step.

5. Concluding remarks

Aerological observations were made from the pre-monsoon season to the monsoon season in the Tanggula mountains in the central part of the Tibetan Plateau. Preliminary results are summarized as follows:

- 1) Warming and moistening of the troposphere were observed from May to August. The tropopause abruptly rose at the beginning of June, which may be associated with the migration and the development of the South-Asian anticyclone.
- 2) Increase of moisture was observed in the southerly wind. When northerly wind was predominant, the atmosphere was dry and cold.
- 3) Short period fluctuations (~ 5 days) were prominent; They seem to be associated with the passage of westerly disturbances in the pre-monsoon season. These fluctuations suddenly changed in the middle of June to longer period (~ 15 days) fluctuations, which correspond to the onset of the monsoon season.
- 4) well-developed mixed layer was observed on pre-monsoon fair weather days; its top level reached about 7000–8000 m. The moisture was also well mixed vertically, and the layer became dry.

Acknowledgments

This study was supported by the Ministry of Education, Science and Culture International Scientific Research Program (No. 01041043). This research was partly supported by the Special Research Project on Global Environmental Change at the University of Tsukuba.

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