

## INTERANNUAL CHANGES OF UPPER STRATOSPHERIC TEMPERATURES BASED ON RECENT SATELLITE OBSERVATIONS

Toshihiko HIROOKA

*Meteorological College, 4-81, Asahi-cho 7-chome, Kashiwa 277*

**Abstract:** Interannual changes of zonal mean temperature in the upper stratosphere are investigated for the period from 1979 to 1986 with the aid of TIROS-N/NOAA satellite observations. It is found that a systematic interannual change of the temperature with a maximum in 1980 and a minimum in 1985 is predominant in the upper stratospheric summer of the Northern Hemisphere. The magnitude of the difference between the maximum and minimum temperature is about 2 K at the 1 mb level. This interannual change seems to be in phase with sunspot number index and may be caused by the 11-year solar cycle. In the Southern Hemisphere, however, such a systematic interannual change is unclear even in the summer season of the upper stratosphere, which is probably related to irregular occurrence of final warmings.

### 1. Introduction

Observations by the Stratospheric Sounding Unit (SSU) instruments, which are payloads of the TIROS-N/NOAA series of operational satellites, have provided a global view of stratospheric temperature fields, since TIROS-N, the first operational satellite of the series, was launched on 13 October 1978.

The SSU is a 3-channel infrared radiometer designed to measure the radiation emitted by stratospheric carbon dioxide. From the SSU measurements, along with those obtained by other instruments on the same satellite such as the Microwave Sounding Unit (MSU) and the High-Resolution Infrared Sounder (HRIS), vertical profiles of temperature fields are retrieved by the U. K. Meteorological Office using a multi-channel linear regression scheme. See MILLER *et al.* (1980) for details of the instruments and the analysis scheme.

Since the launch of TIROS-N, data have been continuously accumulated. Now, the data are available for the period from November 1978 to December 1986.

Hence, I investigate long-term variations of the global temperature field in the upper stratosphere using these data. The original data supplied from the U. K. Meteorological Office are geopotential height thicknesses between the 100 mb level and other 5 pressure levels, *i. e.*, 20, 10, 5, 2 and 1 mb. In the present analysis, the geopotential thickness fields were converted to mean temperature fields between the two neighboring levels, *i. e.*, 100 and 20, 20 and 10, 10 and 5, 5 and 2, and 2 and 1 mb. The data are at 1200 GMT and  $5^{\circ} \times 5^{\circ}$  latitude-longitude grid spacing.

## 2. Results

Figure 1 shows interannual changes of the zonal mean temperature in the layer between the 2 and 1 mb levels of the Northern Hemisphere (NH) for the period from 1979 to 1986. Note that the center of the time axis corresponds to summer. Comparing figures for eight years, the following interesting features can be seen: In winter, the interannual change is irregular due to stratospheric sudden warmings which are

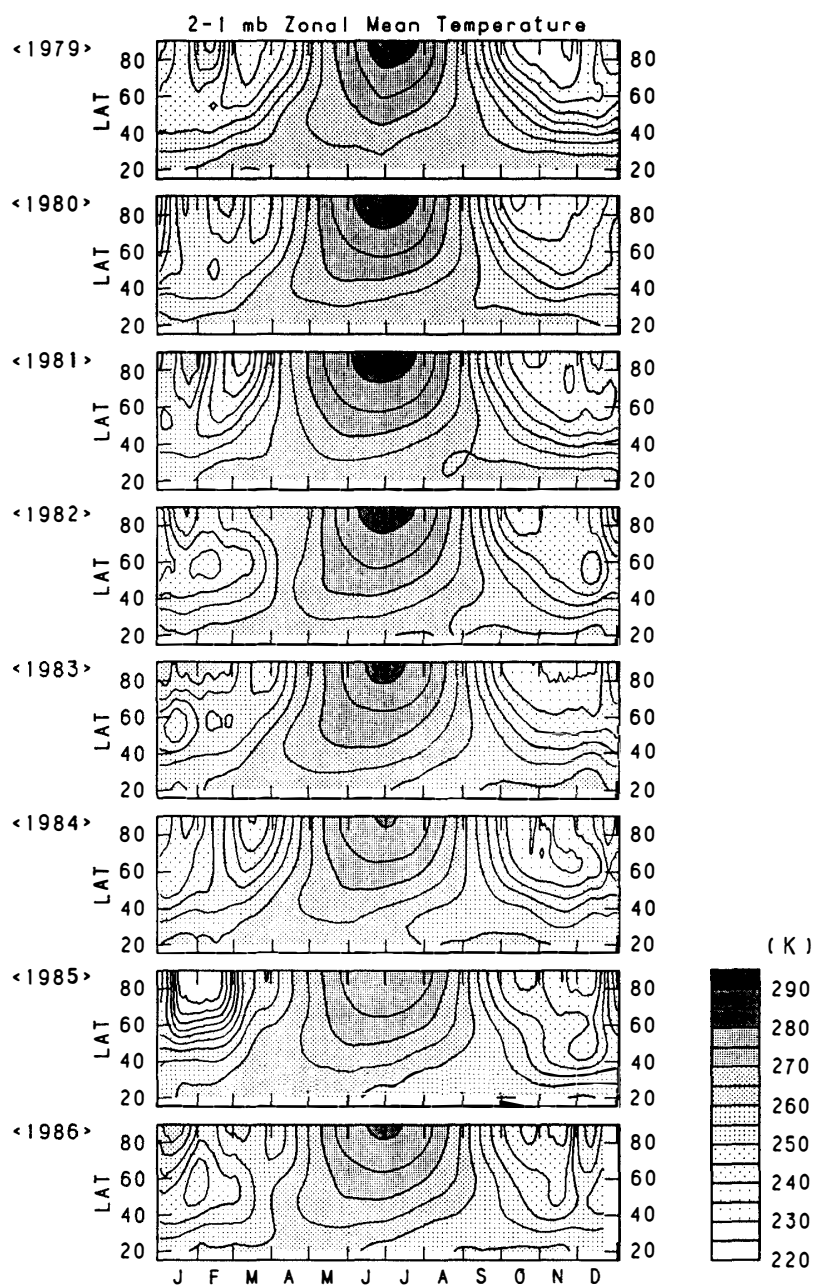
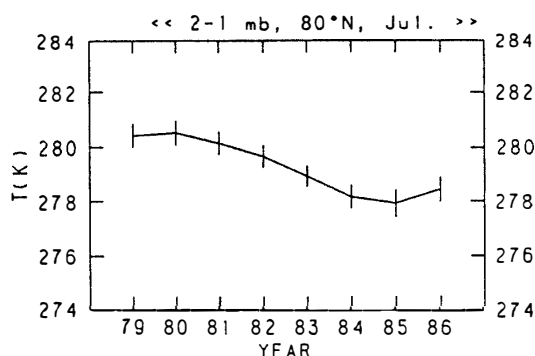


Fig. 1. Interannual changes of the zonal mean temperature in the layer between the 2 and 1 mb levels in the Northern Hemisphere (north of  $20^{\circ}\text{N}$ ) from 1979 to 1986. In order to remove short-term changes, 21-day running averaging is done on the original data. The contour interval is 5 K. For the shading, see the tone bar.

Fig. 2. Interannual change of the July monthly averaged zonal mean temperature in the layer between 2 and 1 mb at 80°N. See text for the meaning of the vertical bars.



irregular, as well known, in terms of their occurrence times and magnitudes. On the other hand, in summer, the seasonal progression is almost invariable every year, while the maximum temperature near the summer solstice changes systematically with a long period; the maximum occurred approximately in 1980 and the minimum approximately in 1985.

The instruments were renewed several times during the analysis period. Hence, it is difficult to attribute the systematic interannual temperature change in the summer stratosphere to changes of sensitivity of the instruments, if any. Moreover, ANGELL (1987) also found a similar interannual temperature change based on rocketsonde analyses, as described in the following section.

In order to estimate the magnitude of the temperature change, I calculated monthly averaged temperature for the summer season. Figure 2 shows the interannual change of the July monthly averaged zonal mean temperature in the layer between 2 and 1 mb at 80°N. The vertical bars denote ranges of root-mean-square values of daily temperature deviations from 31-day moving averages. So, these bars indicate the magnitude of day-to-day temperature variations during the month. As seen from the figure, the maximum temperature occurred in 1980 and the minimum in 1985, and the magnitude of the difference between the maximum and minimum temperatures is about 2 K. For the high- and mid-latitudes of the NH, the magnitude is almost the same as this value. Near the equator, a semiannual temperature oscillation is predominant, which changes interannually, probably being controlled by some dynamical effects, *e. g.*, equatorial waves and/or extratropical planetary waves. Thus, the systematic interannual change, if any, is unclear (not illustrated). As for the semiannual oscillation, see the review of HIROTA (1980), for example.

For the vertical extent of this systematic interannual change seen in the upper stratosphere, similar changes are found at lower levels but the magnitude becomes weaker with decreasing height; such a systematic change cannot be detected in regions lower than 10 mb (not illustrated).

In the Southern Hemisphere (SH), however, interannual changes are not so simple, as seen in Fig. 3. In this figure, the time axis starts in July and ends in June of the next year so that the center corresponds to summer. Note that the upside of each figure is the South Pole. In the austral winter, sudden warmings occur irregularly although they are not major warmings different from those in the NH. It is also noteworthy that temperature minima exist in mid-latitudes every year, as was

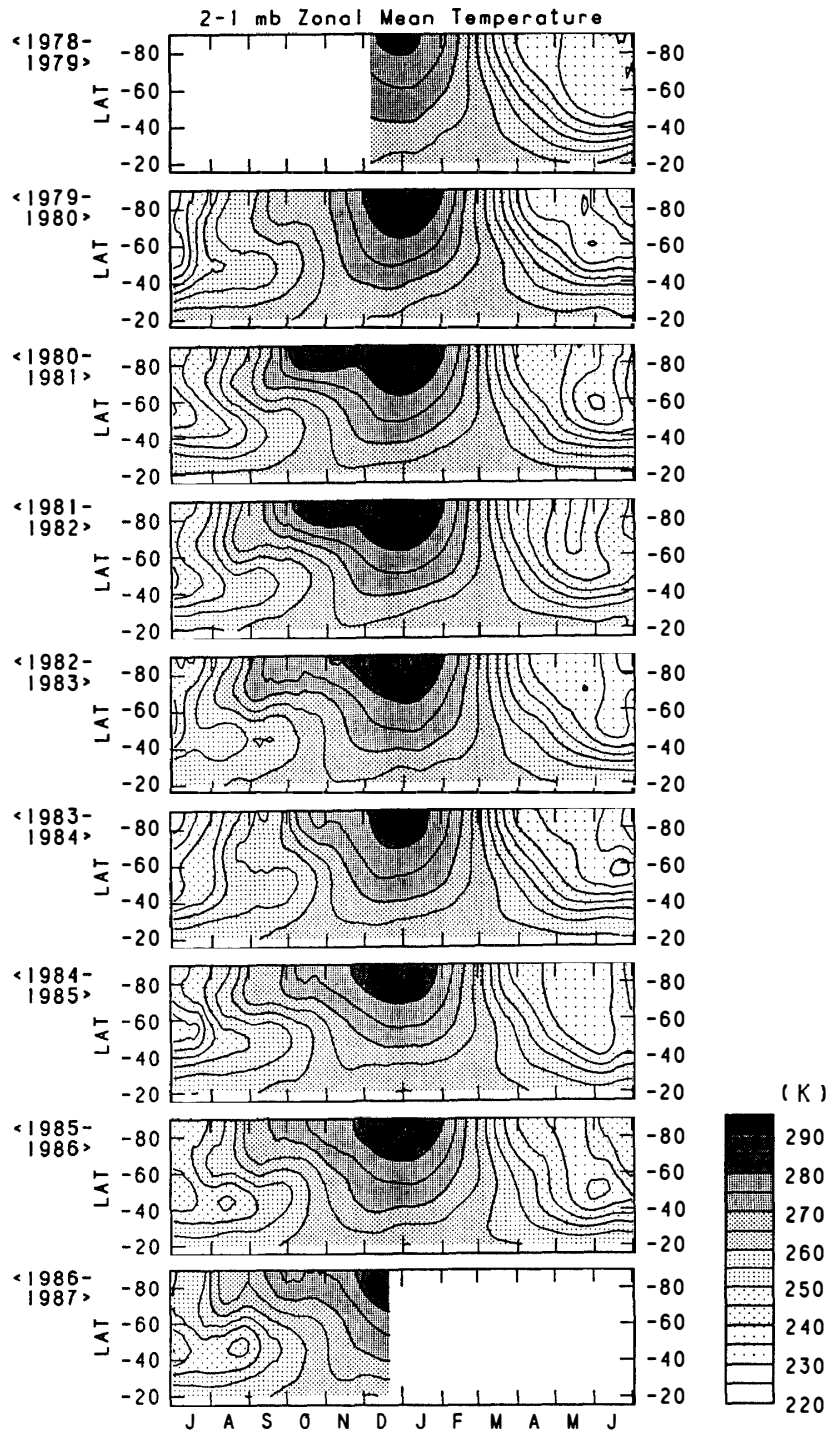


Fig. 3. As in Fig. 1 except in the Southern Hemisphere (south of  $20^{\circ}\text{S}$ ). The time axis starts in July and ends in June of the next year so that the center corresponds to summer. The top of each figure is the South Pole.

already reported by HIROTA *et al.* (1983). On the other hand, in summer, two temperature maxima are seen: One is in early spring and the other nearly at the summer solstice. The interannual change of temperature values of the solstice maxima is relatively systematic compared to that of the early spring maxima, but it is not so

systematic as that in the NH.

The maxima in the early spring are most conspicuous nearly at the 10 mb level and occur there relatively later by a couple of weeks (not illustrated). These maxima correspond to final warmings by which winter circulation changes to summer circulation. These final warmings are clearer and occur later than those of the NH and it seems that these influence the solstice temperature maxima. Hence, the clear systematic interannual change as seen in the NH cannot be seen here. Such a feature of the SH final warming has never been reported and we must clarify the phenomenon in detail.

### 3. Speculation

In the previous section, I noted that there is a systematic interannual change of the temperature in the upper stratosphere during the boreal summer. A similar change was reported by ANGELL (1987) on the basis of rocketsonde analyses. He investigated temperature variations during 1973–1985 and noted that the change in the 46–55 km layer has a tendency to vary in phase with sunspot number although the short record makes the relation uncertain. Since rocketsonde stations are mostly located in the western hemisphere, he made a supplemental analysis of radiosonde data dividing them into the western and eastern hemispheres. As a consequence, temperature trends in the eastern hemisphere were different from those in the western hemisphere; overall trends in this height region were small. He noted that satellite data should be used for better determination of temperature changes of the western and eastern hemispheres in the upper stratosphere.

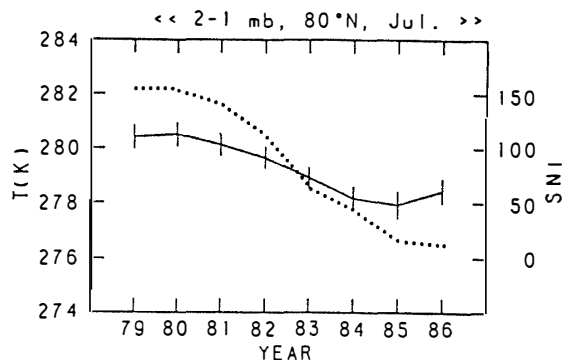
Thus, also in this study, an additional analysis was made in order to clarify this point. Figure 4 shows interannual temperature changes of the longitudinal mean over the eastern hemisphere. Apart from the winter season in which temperature fields strongly depend on longitude, the interannual temperature change of the summer season is much the same as that of the entire zonal mean (Fig. 1). Hence, it is confirmed that the systematic interannual temperature change in the upper stratospheric summer does not have longitudinal dependence, being different from the results for radiosonde levels of ANGELL (1987).

Next, also following ANGELL (1987), the relation to sunspot number was investigated. Figure 5 shows the interannual changes of zonal mean temperature in July (Fig. 2) and those of year-average sunspot number index (SNI) cited from the Chronological Scientific Tables (Rika Nenpyô). From this, significant positive correlation between the two is seen, although the relation cannot be considered certain because of the short data record.

Sunspot number is an index of the long-term solar activity such as 11-year solar cycle, as well as solar luminosity and 10.7 cm solar radio flux; when the value of sunspot number is large, the solar activity is in high level. See WILLSON and HUDSON (1988) for the relationship among the three indices. A probable mechanism of the temperature response to the solar activity is as follows: The UV flux changes following the solar activity. Such a solar irradiance variation brings about a variation in the concentration of ozone in the middle atmosphere. The variation of ozone causes



Fig. 5. Comparison of the interannual change in the July monthly averaged zonal mean temperature (same as in Fig. 2) with that in year-average sunspot number index (SNI) cited from the *Chronological Scientific Tables* (dotted line).



change in the upper stratosphere is less than 5% and the temperature change is at most 2 K. These values are close to the present result of 2 K. However, on the basis of a recent trend analysis of long record data, REINSEL *et al.* (1987) reported that the ozone change related to the 11-year solar cycle is much smaller than those obtained by the above numerical calculations.

On the other hand, the impact of increasing carbon dioxide could be considered as a cause of the systematic temperature change, but it seems that this effect is not primary because the maximum and minimum are observed in the interannual change of the temperature. Recently, it has also been proposed that the increase of synthetic chlorofluorocarbons might cause a decrease of stratospheric ozone through chlorine chemistry to bring about a fair temperature decrease (*e. g.*, RAMANATHAN *et al.*, 1985). Hence, the present result of the temperature change of 2 K might include these effects.

In order to confirm the relationship to solar activity and to detect the impact of the above gases, data must be accumulated over a longer period, and further investigation is needed of both observational and theoretical aspects.

#### 4. Concluding Remarks

In this study, I have shown the systematic interannual temperature change in the upper stratosphere of the NH summer, which is considered to be related to the 11-year solar cycle.

Quite recently, other interesting observational reports have been presented on the relationship between long-term solar activity and general circulation of the middle atmosphere. LABITZKE and VAN LOON (1988) have reported that the occurrence of major mid-winter warmings is controlled not only by wind regimes of the quasi-biennial oscillation (QBO) in the equatorial stratosphere but also by the 11-year solar cycle: In their analysis, no major warming occurred in the westerly phase of the QBO during minimum solar activity periods, while major warmings tended to take place in the easterly phase during minimum solar activity periods. KODERA and YAMAZAKI (1988) have shown that there is a surprisingly clear positive correlation between strength of the polar night jet of December and sunspot number. However, the mechanism is not clear.

I hope that we can thoroughly understand effects of the solar cycle on climate in the near future.

### Acknowledgments

I would like to thank Dr. Hiroshi KANZAWA and an anonymous reviewer for a number of helpful comments on the original manuscript. The computations and drawing the figures were carried out on the HITAC M680H computer at the Numerical Prediction Division of the Japan Meteorological Agency.

### References

- ANGELL, J. K. (1987): Rocketsonde evidence for a stratospheric temperature decrease in the western hemisphere during 1973–85. *Mon. Weather Rev.*, **115**, 2569–2577.
- BRASSEUR, G. and SIMON, P. C. (1981): Stratospheric chemical and thermal response to long-term variability in solar UV irradiance. *J. Geophys. Res.*, **86**, 7343–7362.
- GARCIA, R. R., SOLOMON, S., ROBLE, R. G. and RUSCH, D. W. (1984): A numerical response of the middle atmosphere to the 11-year solar cycle. *Planet. Space Sci.*, **32**, 411–423.
- HIROTA, I. (1980): Observational evidence of the semiannual oscillation in the tropical middle atmosphere; A review. *Pure Appl. Geophys.*, **118**, 217–238.
- HIROTA, I., HIROOKA, T. and SHIOTANI, M. (1983): Upper stratospheric circulations in the two hemispheres observed by satellites. *Quart. J. R. Meteorol. Soc.*, **109**, 443–454.
- KODERA, K. and YAMAZAKI, K. (1988): Seisouken junkan no chōki hendō; Kita-hankyū 12 gatsu no baai (Long-term variations of stratospheric circulation; Northern Hemisphere of December). *Nihon Kishō Gakkai Shūki Taikai Kōen Yokōshū* (Paper presented to Fall Meet. Meteorol. Soc. Jpn.), **54**, 214.
- LABITZKE, K. and VAN LOON, H. (1988): Association between the 11-year solar cycle, the QBO and the atmosphere. Part I; The troposphere and stratosphere in the northern hemisphere in winter. *J. Atmos. Terr. Phys.*, **50**, 197–206.
- MILLER, D. E., BROWNSCOMBE, J. L., CARRUTHERS, G. P., PICK, D. R. and STEWART, K. H. (1980): Operational temperature sounding of the stratosphere. *Philos. Trans. R. Soc. Lond.*, **A296**, 65–71.
- RAMANATHAN, V., CICERONE, R. J., SINGH, H. B. and KIEHL, J. T. (1985): Trace gas trends and their potential role in climate change. *J. Geophys. Res.*, **90**, 5547–5566.
- REINSEL, G. C., TIAO, G. C., MILLER, A. J., WUEBBLES, D. L., CONNELL, P. S., MATEER, C. L. and DELUISI, J. J. (1987): Statistical analysis of total ozone and stratospheric Umkehr data for trends and solar cycle relationship. *J. Geophys. Res.*, **92**, 2201–2209.
- WILLSON, R. C. and HUDSON, H. S. (1988): Solar luminosity variations in solar cycle 21. *Nature*, **332**, 810–812.

*(Received January 19, 1989; Revised manuscript received April 27, 1989)*