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SOLAR CYCLE VARIATION OF UPPER THERMOSPHERIC TEMPERATURE OVER KING SEJONG STATION, ANTARCTICA

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ABSTRACT

A ground Fabry-Perot interferometer has been used to measure atomic oxygen nightglow (OI 630.0 nm) from the thermosphere (about 250 km) at King Sejong station (KSS, geographic: 62.22°S, 301.25°E; geomagnetic: 50.65°S, 7.51°E), Antarctica. While numerous studies of the thermosphere have been performed on high latitude using ground-based Fabry-Perot interferometers, the thermospheric measurements in the Southern Hemisphere are relatively new and sparse. Therefore, the nightglow measurements at KSS play an important role in extending the thermospheric studies to the Southern Hemisphere. In this study, we investigated the effects of the geomagnetic and solar activities on the thermospheric neutral temperatures that have been observed at KSS in 1989 and 1997. The measured average temperatures are 1400 K in 1989 and 800 K in 1997, reflecting the influence of the solar activity. The measurements were compared with empirical models, MSIS-86 and semi-empirical model, VSH.

Key words: thermosphere, Fabry-Perot, interferometer, Solar cycle

1. INTRODUCTION

There have been numerous investigations on the dynamic and thermodynamic state of the Earth's upper thermosphere in the high-latitude (McCormac & Smith 1984, Meriwether et al. 1988, Hernandez & Killeen 1989, Sica et al. 1989, Smith et al. 1989, Killeen et al. 1991, Killeen et al. 1995, Hernandez et al. 1991, Niciejewski et al. 1992, Niciejewski et al. 1994). Increases in the solar Ultra-Violet (UV) and Extreme Ultra-Violet (EUV) radiation have significant influence on the temperature, density and composition variations in the Earth's thermosphere. In addition, precipitating energetic particles from the magnetosphere and Joule heating due to different motion between ion and neutral particle contribute to the energy budget of the high-latitude thermosphere. The influence of high-latitude heat and momentum sources in thermosphere can extend to mid-latitude during geomagnetic disturbances.

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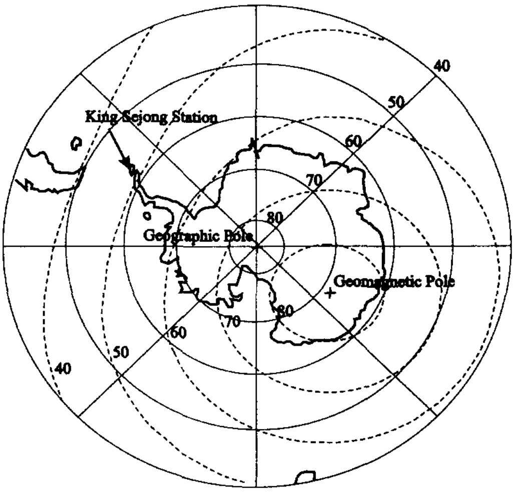

Figure 1. The location of King Sejong station in geographic and geomagnetic coordinates. The solid line is the geographic latitude and the dotted line is the invariant geomagnetic latitude.

Most experimental investigations on the high-latitude thermosphere have been performed in the Northern Hemisphere and there is still a significant limitation in the experimental coverage in the Southern Hemisphere. Those measurements of thermospheric properties in the Southern Hemisphere have been confined to limited ground-based station (Yagi & Dyson 1985, Smith et al. 1988, Kim et al. 1990, Hernandez et al. 1990, Smith et al. 1994, Smith & Hernandez 1995) and from Dynamic Explorer data (McCormac et al. 1991). The reported discrepancies between measurements and model predictions motivate further investigations on the physical processes responsible for controlling the variations of the upper thermospheric temperatures and winds in the Southern Hemisphere.

A 15-cm high resolution Fabry-Perot interferometer (FPI) was installed in January 1989 at King Sejong station (KSS), the Korean Antarctic research station in King George Island, Antarctica. The King Sejong station is located at high-latitude (62.22°S, 301.25°E) geographically but at mid-latitude (50.65°S, 7.51°E) geomagnetically (Figure 1). This discrepancy between geographic and geomagnetic latitudes is therefore subject to unusual combinations that are related to either solar radiation or geomagnetic disturbance in the upper thermosphere (Smith et al. 1988). For this reason, it is a unique station in evaluating the validity of model predictions of the temperatures and winds in the southern thermosphere.

In this paper, we report some of neutral temperatures derived from the neutral atomic oxygen emission, 630.0 nm with Fabry-Perot interferometer in 1989, near solar maximum, and in 1997, near solar minimum. The data set covers periods of quiet and enhanced geomagnetic activities. Therefore, our results provide some quantitative aspects of the variation of the high-latitude thermospheric temperatures in relation to both solar and geomagnetic activities.

2. INSTRUMENT

A FPI has been installed at the King Sejong station, Antarctica in January 1989. This optical sys-

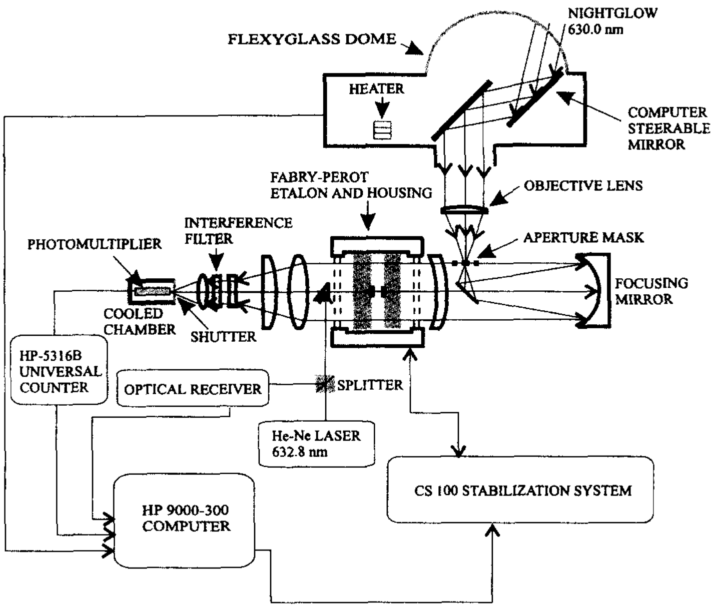

Figure 2. Block diagram of the Fabry-Perot Interferometer system for OI (630.0 nm) nightglow installed at King Sejong station, Antarctica.

tem was designed, constructed and operated by Okano et al. (1980) and further improved before the installation at the King Sejong station. Figure 2 displays a schematic diagram of the interferometer system.

The system uses Maksutov optics and a multiple annular slit system to achieve high optical throughput while maintaining high resolving power. One of main characteristic of this system is the use of a multiple-zone aperture, which has openings for 10 consecutive interference fringes beside the central hole to achieve high optical throughput (Okano et al. 1980). The fused-quartz etalon plates have a diameter of 15.2 cm with 1.504 cm gap spacing, giving a nominal free spectral range of 332 mK. The wavelength scanning is performed by controlling the piezoelectric transducers. A wavelength stabilized He-Ne laser at 632.8 nm is used to provide the free spectral range and overall built-in calibration information of the system. A small central portion of the etalon is modified for higher reflectance and used for instrument calibration. Measurements are usually taken along the cardinal azimuths at 45 elevation and in the zenith by a plane mirror assembly mounted on the roof of the building in which the interferometer is housed. The sky mirrors can steer to point the field of view in any direction by stepper-motor systems. Some of the operating parameters of the system are summarized in Table 1.

3. OBSERVATION AND DATA ANALYSIS

The 15 cm high-resolution FPI was used to measure the 630.0 nm emission lines of neutral atomic oxygen. The 630.0 nm emission is thought to come from about 250 km altitude, with about one local neutral scale height in thickness (Smith & Hernandez 1995). This assumption is valid if the vertical gradient of temperature is small. Because it is difficult to get the emission layer of 630.0

Table 1. Operating Parameters of the Fabry-Perot Interferometer.

Effective diameter of etalon	14.6 cm
Flatness	l/120
Reflectivity	0.88
Space of etalon plates	1.504 cm
Objective lens diameter	10 cm
Objective lens focal length	30 cm
Collimating focal length	73.3 cm
Instrument field of view	2.24o
Interference order	47,700
Free spectral range	0.131 A
Scanning method	Piezo scanning
Overall instrument finesse	5.7

nm emission from the ground, the assumption of the peak height as 250 km is generally assumed and used for the interpretation of the observed data as well as for the model calculations. Measurements of Doppler shifts and line width of OI (630.0 nm) by a FPI have become an established means of remote sensing of the neutral winds and temperatures at F-region altitudes. Although the FPI at King Sejong Station has produced its high quality data, observations have only been made in irregular base because the instrument is operated manually and have been further limited by weather condition, moon phase and the electric noise as well. The long-term program for monitoring the thermospheric properties was recently initiated at the King Sejong station and we expect comprehensive data sets to be built in the near future. An observing sequence of FPI consists of two measurements at zenith and each at four cardinal directions with a zenith angle of 45°. The time for a complete cycle of the sequence takes about 30 minutes, but it varies depending on the brightness of the emission. The main part of the retrieval procedures is the use of the instrumental profile for deconvolution and the application of non-linear least-squares technique to the observed profile. In the procedures, a set of parameters is assumed and the iteration is continued until the best fitting is achieved. The detailed data reduction procedures are described in Okano et al. (1980).

4. RESULTS

Figure 3 displays the variation of solar radio flux at 10.7 cm from 1986 to 1997 that encompasses almost one solar cycle. As seen in the figure, the solar activity was at its maximum during 1989-1991 and remained almost at minimum in 1997. Table 2 is the solar activity, F10.7 index and geomagnetic activity, Kp and Ap indices for the observing period. In this study, total four nights of observations in 1989 and in 1997 were used to examine the variation of upper thermospheric temperatures over King Sejong station in relation to solar activities. We had difficulty finding old mesurements taken in 1989 because those data were limited and available only through a published report. For this reason we have chosen only four nights measurements in 1989 and in 1997 that were taken at similar date of the year in order to avoid any seasonal variation.

4.1 Solar Maximum

Two nights of observation in 1989 were chosen in our study for solar maximum case. Even though the solar flux at 10.7 cm wavelength remained near 200 ($\times 10^{-22}$ $Wm^{-2}Hz^{-1}$) in February 19 and March 2, 1989, those two days could be regarded as solar maximum period as viewed from

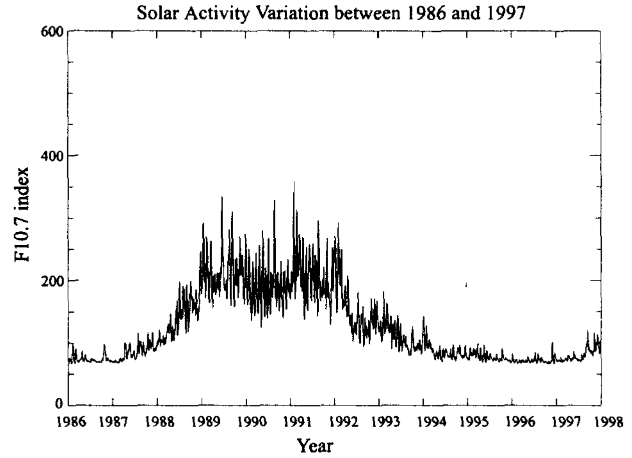

Figure 3. The solar EUV flux activity index F10.7 variations from 1986 to 1997.

the solar cycle variation in Figure 3. As indicated in Table 2, geomagnetic activities are quiet on February 19 and disturbed on March 2, 1989.

The measured neutral temperatures on both days are displayed in Figure 4a and 4b. The data are plotted according to the UT of the measurement (LT=UT-4 hours). The error bars indicated the calculated uncertainty of each measurement and no error bars are available for measurements on February 19, 1989.

The observation started at 01:00 UT and continued for about six hours on February 19 (Figure 4a). The observations were made only in zenith direction on this night. The measured nighttime thermospheric temperatures are in the range between 1127 K and 1610 K with an averaged value of 1394 ± 87 K. For the comparison purposes, our results are compared to the predictions of the MSIS-86 (Mass Spectrometer Incoherent Scatter; Hedin 1987) and VSH (Vector Spherical Harmonics; Killeen et al. 1987) models at a height of 250 km. The input parameters for model calculations closely followed the geophysical conditions during the observing period.

The outputs from MSIS-86 and VSH models are superposed as dashed and dotted lines, respectively. As shown in the Figure 4a, the predictions from both models underestimate the measured values in most observing period and even 500 K difference is observed between observations and model calculations. Unlike the wave-like character displayed in the measured temperatures, the model predicted values change rather smoothly with time and its variation during the observing period is smaller than 100 K. This is expected to a certain degree because the models are based on averaged conditions and cannot predict in detail the response of the thermosphere to high-latitude heating sources. The MSIS-86 output shows a minimum temperature near local midnight (04 UT) while VSH displays a less distinct minimum near 06 UT. The mean temperature of MSIS-86 during the observing period is 1199 ± 20 K, which is 195 K degree lower than the average of observed temperatures on February 19, 1989 (Table 3). The VSH model output starts with higher values than the MSIS-86 prediction in the early evening, but stays lower than MSIS-86 during the rest of the night. The calculated mean value of VSH prediction during observing period is 1131 ± 17 K, which is 68 and 263 K lower than MSIS-86 and measurement outputs, respectively.

Figure 4b shows a plot of temperature variation for March 2, 1989. The magnetic activity index indicates there was a magnetic storm on this day. The measurement was interrupted for about one

Table 2. F10.7, Kp and Ap indices of the observed nights.

Date	Kp	Ap	F10.7 (10^{-22} Wm^{-2}Hz^{-1})
February 19, 1989	1 1 2+ 2 2+ 3 2 3	9	214.0
March 2, 1989	3+ 6- 4- 3+ 4 3+ 3 3+	25	173.7
March 10, 1997	0 0 0 1- 1- 1- 1- 1+	2	73.8
April 4, 1997	4 3+ 3- 2 2 2- 2+ 3	13	78.6

Table 3. Daily averaged temperatures of atomic oxygen near 250 km altitude measured with FPI at King Sejong station, Antarctica at solar maximum in 1989 and minimum in 1997. The observed temperatures are compared with the results from MSIS-86 and VSH models.

Date	FPI (K)	MSIS-86 (K)	VSH (K)
February 19, 1989	1394 ± 87	1199 ± 20	1131 ± 17
March 2, 1989	1309 ± 113	1140 ± 29	1093 ± 5
March 10, 1997	820 ± 101	736 ± 4	683 ± 5
April 4, 1997	953 ± 128	785 ± 25	738 ± 8

hour near local midnight due to the bad weather condition. Again, the measurements were made only in the zenith on this night. The observed temperature decreases toward local midnight and then shows a trend of a gradual increase with time. The measured nighttime temperature varied between 1067 K and 1513 K with a average value of 1309 ± 113 K. The model prediction tends to underestimate the measured temperatures in most observing period, as was the case for February 19. The average values of MSIS-86 and VSH are 1140 ± 29 K and 1093 ± 5 K, respectively, which are 169 K and 216 K lower than that of the measurements. The averaged nighttime temperature of March 2 is slightly lower (85 K) than that on February 19. There is no significant difference on the average nighttime temperature between the two observing days in 1989.

4.2 Solar Minimum

Figure 4c displays the observed temperatures on March 10, 1997 with MSIS-86 and VSH model outputs superimposed. Measurements were interrupted due to cloudy conditions after 01:30 UT. The error bars, the calculated uncertainty of each measurement, gets larger at the end of observing period, indicating the extent of cloud cover. It is noted that the geomagnetic condition was very quiet on this day. The measured temperature on March 10, 1997 remains near 900 K at the beginning, then tends to decrease with some fluctuation after about 00:30 UT. The measured thermospheric temperatures never exceed 1000 K and the average temperature is 820 ± 101 K on this night. The mean values from MSIS-86 and VSH models during the observing period are 736 ± 4 K and 683 ± 5 K, respectively. The mean value from MSIS-86 is only 84 K degrees lower than the measurements and this discrepancy is much smaller compared with solar maximum case.

More scattered feature is observed in the nighttime temperature measurements on April 4, 1997. The measured temperatures are in the range between 700 K and 1200 K, and the minimum value is observed at around local midnight (03:30 UT). The average value of nighttime temperatures on April 4 is 953 ± 124 K, which is 160 K higher than that of March 10. The model prediction consistently underestimates the measured values. As is indicated in Table 2, it is magnetically disturbed on April 4. Meanwhile the solar activity index remained nearly same for both days, suggesting the geomagnetic influence for the increased thermospheric temperature on April 4, 1997.

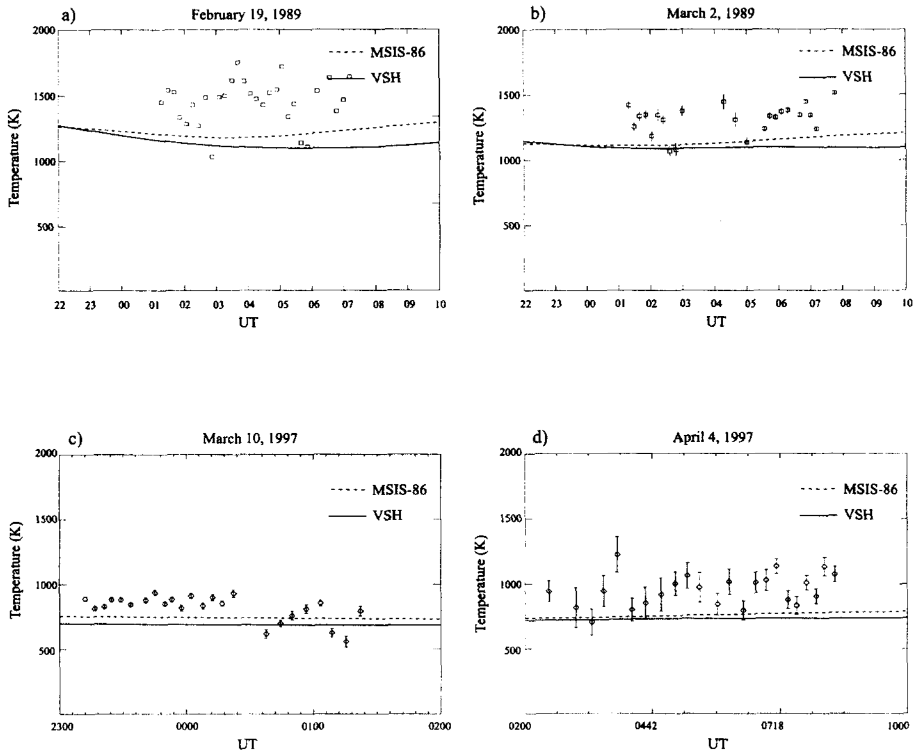

Figure 4. The neutral temperatures in the upper thermosphere (250 km altitude) measured with FPI at King Sejong station in 1989 and 1997 and derived from MSIS-86 and VSH models. The four panels depict under the geophysical conditions of (a) F10.7 = 214.0 and Ap = 9 in 1989 (b) F10.7 = 173.7 and Ap = 25 in 1989 (c) F10.7 = 73.8 and Ap = 2 in 1997 (d) F10.7 = 78.6 and Ap = 13 in 1997. Dashed and solid line are from MSIS-86 and VSH models, respectively. The error bars represent the calculated uncertainty.

5. SUMMARY

The OI 630.0 nm nightglow measurements from a ground-based Fabry-Perot interferometer at the King Sejong station, Antarctic were used to investigate the upper thermospheric (~250 km) behavior in relation to solar and geomagnetic activities. Two nights of measurements were chosen each in 1989 and in 1997, respectively for solar maximum and minimum cases in this work. The data sets presented here are also representative of varying levels of geomagnetic activities, which range between quiet to disturbed conditions.

The average nighttime upper thermospheric temperature was 1394 ± 87 K on February 19, and 1309 ± 113 K on March 2, 1989. As is indicated by Kp index in Table 2, it was magnetically moderate on February 19 and was disturbed on March 2, 1989. On the other hand, the solar flux measurement (F10.7 index) was 214.0 on February 19 and 173.7 on March 2. Therefore it is likely that the different levels of geomagnetic and solar activities are combined to result in similar nighttime temperatures on both days.

The average upper thermospheric temperatures are 820 ± 101 K on March 10 and 953 ± 128 K on April 4, 1997. These values are at least 356 K lower than the solar maximum cases. The average nighttime temperature on April 4 is obviously higher than that of March 10. The diurnal variation is not appearant from model outputs (Figure 4c and 4d) and the F10.7 index remains near same for both days. Therefore, the measured temperature difference could be attributed to the varying levels of magnetic activities.

For a qualitative measure, MSIS-86 and VSH models were used for comparison with our measurements. The calculations from both models tend to underestimate experimental observations for both solar maximum and minimum conditions. Because the empirical and the semi-empirical models were nearly weighted to limited time of observations (especially during solar minimum conditions) the discrepancy between measurements and model predictions are greater during periods of solar maximum condition and geomagnetic disturbances, common in most high-latitude observations (McCormac et al. 1989, Killeen et al. 1995).

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