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# Thermospheric Temperatures Measured at the King Sejong Station, Antarctica

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**Abstract** : Previous measurements and associated theoretical studies indicated that the polar region has a critical role in the overall thermospheric dynamics. Recently, in order to investigate the neutral temperatures and winds in the Antarctic thermosphere, we installed a high-resolution Fabry-Perot interferometer at King Sejong Station, which is the Korean Antarctic Research Base, on King George Island, Antarctica. Interferometric measurements during March 1989 showed unusually elevated thermospheric temperatures. This elevation may be due partly to major solar events that occurred in March. Initial comparisons of the observed temperature data with the calculated values from the semi-empirical MSIS thermospheric models showed consistent and significant differences, both qualitatively and quantitatively, between the measured temperatures and the calculated values.

**Key words** : thermospheric temperatures, interferometer, Antarctica

## Introduction

The installation of a high-resolution Fabry-Perot interferometer at the King Sejong Station (geographic : 62.2° S, 301.3° E ; geomagnetic: 50.7° S, 7.5° E), on the King George Island, Antarctica, in January 1989 has since provided valuable information on the thermospheric neutral temperatures and winds in the Antarctic thermosphere. Of the several major events of solar activity that have been observed since October 1988, an event that occurred on March 13−14, 1989, is particularly significant, with solar effects and the associated geomagnetic storm comparable to the largest events in the solar cycle 19 (Hirman et al., 1989). Measures of geomagnetic activity showed that the storm was among the largest since 1868 and it caused extreme variations in magnetic field over the several days of the storm (McIntosh, 1989; Joselyn, 1989). The terrestrial effects of the storm were extraordinary in many respects. The sun's increased output in the form of UV radiation caused intense heat and expansion of the Earth's upper atmosphere. These events have far-reaching effects on satellite drag, which are particularly evident because the storm occurred during a time of extended high solar activity that had already inflated the atmosphere to unusual heights. Many communication and navigation systems were affected to the point that they were unusable during the storm. In addition aurora associated with this storm was seen to very low latitudes.

We report in this paper that interferometric measurements made at the King Sejong Station during March 1989 showed unusually elevated thermospheric temperatures. These large enhancements may be due partly to major solar events that occurred in March. Initial comparisons of the observed temperature data with predictions from the MSIS-83 and MSIS-86 thermospheric models showed consistent and significant differences, both qualitatively and quantitatively.

## 15-cm High-Resolution Fabry-Perot Interferometer System.

A Fabry-Perot interferometer system for observing the weak atmospheric emission line at 630.0 nm has been designed, constructed, and operated successfully by Okano, Kim, and Ichikawa (1980). This system has been further improved with funds provided by the DOD-University Research Instrumentation Program. We installed this improved system at the King Sejong Station, Antarctica, in January 1989, and its important features are summarized here.

The system uses Maksutov optics and a multiple annular slit system to achieve high optical throughput while maintaining high resolving power. Piezoelectric scanning is used, along with a computer-based data acquisition and reduction system incorporating the photon-counting method. The optical system design was optimized by ray tracing. A schematic diagram of the interferometer system is shown in Figure 1, and the operating parameters of the interferometer are summarized

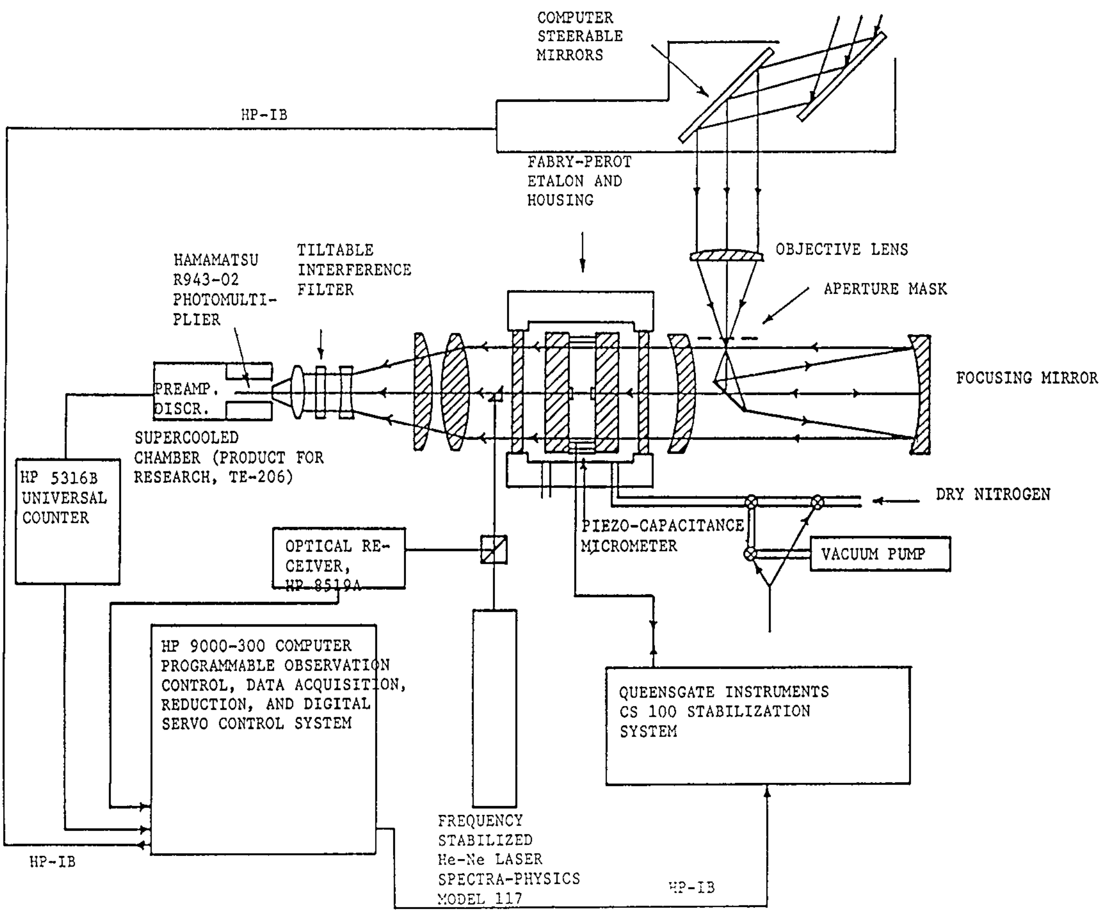


Fig. 1. Block diagram of the Fabry-Perot interferometer system.

in Table 1.

**Table 1.** Operating Parameters of the Fabry-perot Interferometer.

| | |
|---|---|
| effective diameter of etalon | 14.6 cm |
| flatness | $\lambda/120$ |
| reflectivity | 0.88 |
| spacing t | 1.054 cm |
| objective lens diameter | 10cm |
| objective lens focal length | 30cm |
| collimating focal length | 73.3cm |
| instrument field of view | 2.24° |
| interference order | 47, 700 |
| free spectral range | 0.131Å (0.333cm$^{-1}$) |
| scanning method | piezo scanning |
| overall instrument finesse | 5.7 |

The etalon plates are of fused quartz, having a diameter of 15.2 cm, surface flatness of $\lambda/120$, and reflectivity of 0.88 at 630.0 nm. The spacing of the etalon plates is 1.504 cm, giving a nominal free spectral range of 332 mK. This interferometer is characterized by its use of a multiple-zone aperture, which has openings for 10 consecutive interference fringes besides the central hole, and by the use of Maksutov optics, which compensates aberrations arising from the Newtonian type collimator. The view direction of the interferometer can be directed toward the desired portion of the sky by a computer-controlled plane mirror assembly mounted on the roof of a building in which the interferometer system is housed. The field of view of the interferometer is 2.24°. A secondary optical path is included, forming fringes that provide built-in calibration information in the light (632.8 nm) of a stabilized He-Ne laser (Spectra-Physics, 117). A small central portion of the etalon is modified for higher reflectance and used for this purpose. An HP 8519A optical receiver monitors this fringe system and is also interfaced to the computer.

The computer (HP model 9000−300) fills a number of control and analysis functions. It scans the etalon by controlling the piezoelectric transducers, and processes the intensity data from both the main and the reference detectors. It is also connected to stepper-motor systems that can move the steerable sky mirrors so as to point the field of view in any desired direction. The received data are not only accumulated and stored, but also analyzed and plotted on command.

## Observation and Data Analysis

Neutral thermospheric winds and temperatures were derived from the parameters of the Doppler broadening, which are evaluated from the nonlinear, least squares application of the fitting function obtained from the analytic evaluation of the convolution of the instrumental function with the assumed Gaussian function for the 630.0 nm line of atomic oxygen. Fabry-Perot interferometric observations are made with an observing sequence that incorporates two directions in the north-south and the east-west at zenith angles of 45° and /or 70°, in addition to zenith measurements taken once in each direction. Good quality temperature (and neutral wind) data exit for 3 days in March (04, 14, and 15) 1989. While March 4th was a day with quiet geomagnetic conditions ($\Sigma Kp=20$ and $Ap=13$), the other two days, 14 and 15 March, were characterized as disturbed ($\Sigma Kp=55$, 38, and $Ap=158$, 49 respectively). The 10.7 cm solar flux was $164\times10^{-22}Wm^{-2}Hz^{-1}$ for 4 March, and 264 and $256\times10^{-22}Wm^{-2}Hz^{-1}$ for 14 and 15 March respectively.

## Results

### 1. Quiet Day

Temperature data (Fig. 2) show typical

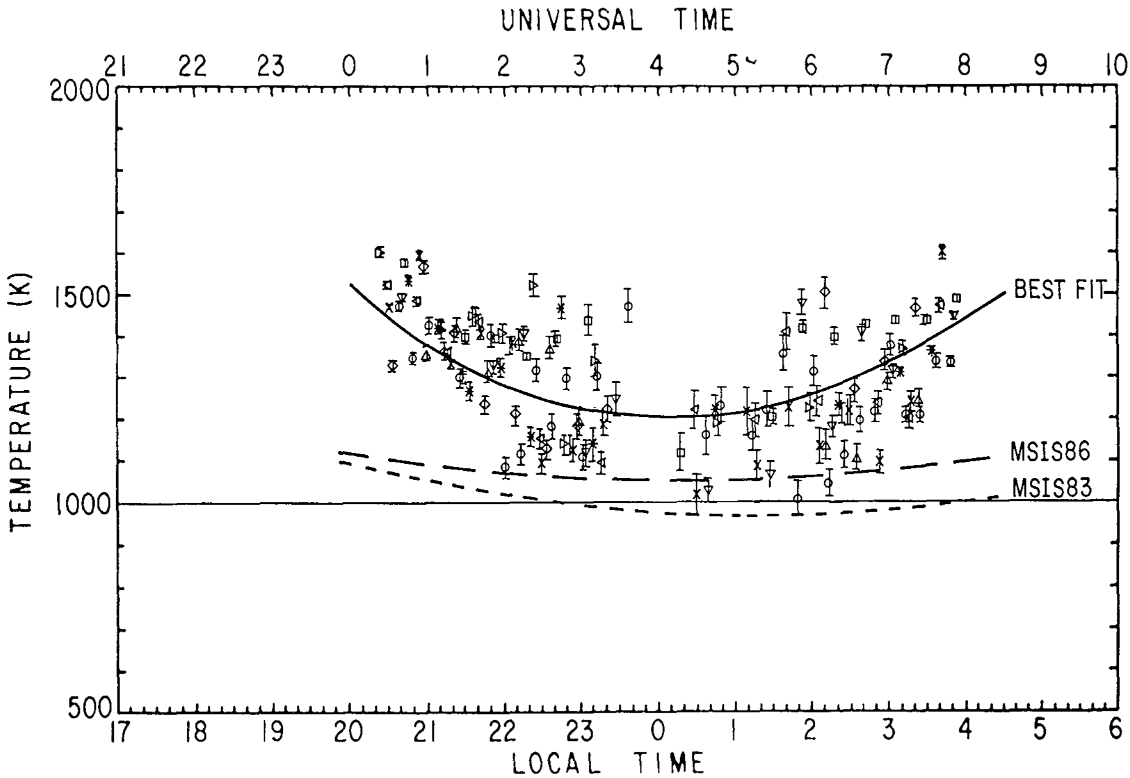


Fig. 2. Neutral temperatures measured at the King Sejong Station, King George Island, Antarctica on 4 March 1989. Observations made at zenith angle 70°N are denoted by ◇, 45°N by △, 45°S by ▽, 70°S by □, 70°E by *, 45°E by ▷, 45°W by ◁, 70° W by X, and zenith measurements at 0° by O. Smoothed solid curve re presents the best fitted curve drawn through the temperature data. Curve with short dashes represents the MSIS-83 model temperature predic tions, while the curve with long dashes is for the MSIS-86 values.

quiet time variation with values ranging between 1000°K and 1600°K, and minimum temperatures observed at around local midnight (04 : 00 UT). Average temperature is 1307±140°K during the period 00 : 00−08 : 00 UT. A dependence on observing direction seems to exist in the temperature data. In the meridional direction, for instance, temperatures in the north were usually smaller compared to those in the south. Similarly, in the zonal direction, temperatures in the east were generally higher than those measured to the west. However, quantitatively, the differences are not much and it is interesting to see that the trend in the temperature variations is similar in each case. Best fitted curve (smooth solid curve in Fig. 2) is drawn through the observed temperature data to show average quiet time variation.

Here, the MSIS-83 model (Hedin, 1983) is used to calculate the temperature for geophysical conditions on March 4, 1989, and to compare-knowing fully the shortcomings of this model-the calculated temperatures with the measurements made at the King Sejong Station, Antarctica, during that night. The appropriate geophysical parameters were taken from the Solar-Geophysical Data reports, compiled by the National Geophysical and Solar-Terresterial Data Center(NGSDC) in Boulder, Colorado. Model temperatures calculated at 15 min intervals are shown in Figure. 2 as a short-dashed curve. Temperature values ranged between ~975 and 1080°K for the time period 00:00-08:00 UT, with the minimum temperatures occurring approximately 75 min after the local midnight, i.e., at about 05:15 UT. It may be noted that the average of all the observed temperatures (1307±140°K) is 301 degrees higher than the mean (1006±32°K) of the MSIS-83 model temperatures.

Since the MSIS-86 model (Hedin, 1987) has been augmented over the basic expansion formula used in MSIS-83, with terms to express hemispherical and seasonal differences in the polar regions and local time variations in the magnetic activity effect, computations based on the revised model were carried out for the appropriate geophysical conditions on March 4, 1989, to see whether the agreement between the temperature measurements and the MSIS-86 model estimates has been improved. Temperature values derived using the revised model (long dashed curve in Fig. 2) varied between ~1055 and 1100°K during 00:00-08:00 UT, with the minimum temperatures occurring around local midnight (04:00 UT). It may be noted that the average measured temperature (1307±140°K) is still about 235°K higher than the mean (1072 ±14°K) of the model temperatures from the MSIS-86 for the same time period.

## 2. Disturbed Days

Following a severe geomagnetic storm that occurred on March 13, 1989 (Ap=246), with SC at ~01:28 UT and $D_{st}$ reaching a minimum of about-1838 nT (provisional), the magnetosphere continued to be in a disturbed state until 2 days later. Temperature measurements on March 14th (Fig. 3) show a disturbed day variation with values ranging between ~1200 and 1800°K. Average temperature is 1562±173°K during the period ~02:00-08:00 UT. There is a trend of increasing temperatures towards the local midnight (04:00 UT) and then a gradual decrease later on followed by a sudden decrease in temperature after 06:30 UT. Best fitted curve (smoothed solid curve in Fig. 3) is drawn through the observed temperature data to show typical disturbed time variation.

There were, however, some interesting features when viewed individually in each of the separate directions. The sudden decrease in temperature after 06:30 UT was noticeable in all directions and temperatures seemed to reach a maximum in about 45 minutes after the local midnight (04:00 UT). Neither qualitative nor quantitative differences in the temperature can readily be seen in north and south points of observations in the meridional direction and also in east and west points of observations in the zonal direction.

Neutral temperatures were estimated for this night using the semiempirical thermospheric models MSIS-83 and MSIS-86 and the results are shown in Figure 3 as short and long dashed curves, respectively. MSIS-83 model predictions varied between 1203 and 1275°K, with the minimum temperatures occurring approx-imately 60 min after local midnight (i. e., at about 05:00 UT). The average of all the observed temperatures (1562±173°K) is 336°K higher than the mean (1226±21°K) of the MSIS-83 model values.

MSIS-86 model predictions showed an altogether different variation, starting with a minimum value of 1321°K at about 01:30 UT, they rose to 1494°K by 08:00 UT. However, the average measured temperature

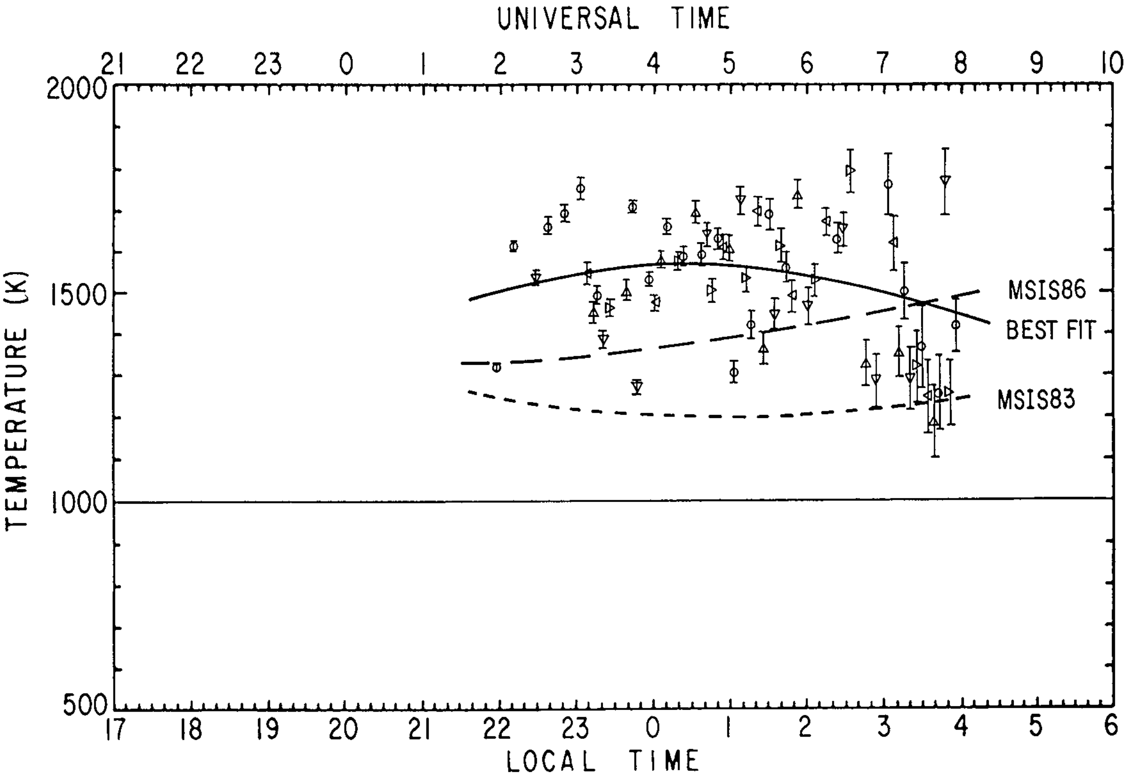


Fig. 3. Same as in Fig. 2 but for the day-14 March 1989.

(1562±173°K) is still about 155°K higher than the mean (1407±57°K) of the model temperatures from the MSIS-86.

March 15, 1989 gives another example of disturbed condition. An intense geomagnetic storm that commenced at 01 : 28 UT on March 13, 1989 continued to recover, but a minor magnetic storm suddenly commenced at 05 : 32 UT with a $D_{st}$ minimum of about-160 nT (provisional).

Temperature measurements indicate a moderately disturbed time variation (Fig. 4) with values ranging from 1200 to 1700°K during the period ~00 : 30–08 : 00 UT. The mean of the observed temperatures is about 1479±122°K. On this day also, temperatures tended to increase slightly until approximately 60 min after the local midnight and then they decreased gradually after 05 : 00 UT. Best fitted curve (smoothed solid curve in Fig. 4) is drawn through the measured temperatures to show typical variation of thermospheric temperature on this night. Temperature data in both meridional and zonal scans showed, however, some interesting features. In the meridional direction, for example, temperatures in the north were unusually large by approximately 150–200°K compared to those measured in the south during the first half of the night. At around local midnight (04:00 UT), there appeared to be a transition, and temperatures in the south enhanced while those measured to the north decreased by nearly 250–300°K. This trend continued through the rest of the night with temperatures in the north smaller than those observed to the south. Overall, there seemed to be a maximum temperature occurring around

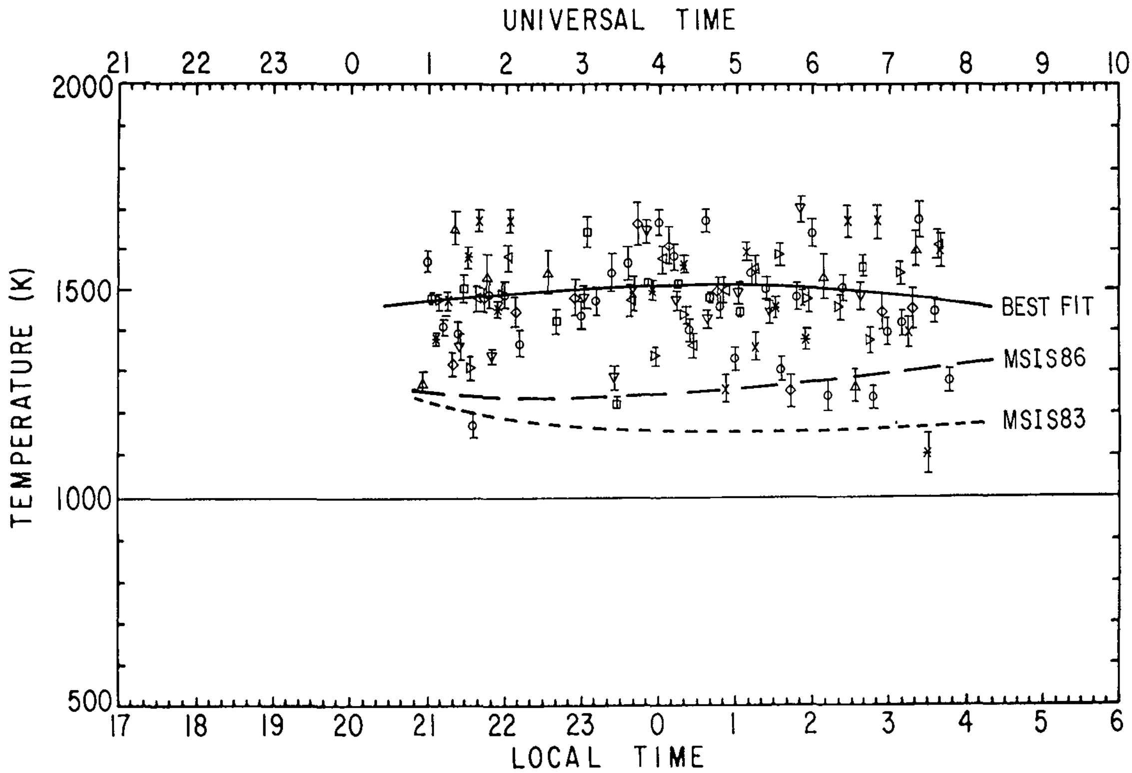


Fig. 4. Same as in Fig. 2 but for the day-15 March 1989.

the local midnight in the meridional direction. On the other hand, temperature data in the zonal direction do not show any such clear-cut picture in terms of qualitative differences in the measurements made to the east or west of the observing station. Temperature values appear to decrease until about 60 to 90 minutes after the local midnight (04:00 UT), and then they start to enhance again, due probably to the commencement of a magnetic storm.

In order to compare the experimental temperature data with the semiempirical thermospheric model predictions, computations based on the MSIS-83 and MSIS-86 were carried out for the appropriate geophysical conditions on this night. MSIS-83 model calculations of the temperature (short dashed curve in Fig. 4) gave values between 1143 and 1245°K, with minimum temperatures occurring approximately 75 min after local midnight, i.e., around 05:15 UT. The average of the observed temperatures (1479±122°K) is 306°K higher than the mean (1173±30°K) of the MSIS-83 model values. On the other hand, MSIS-86 model computations revealed somewhat different variations in temperature (long dashed curve in Fig. 4) during the period 00:30–08:00 UT. The predictions showed a decreasing trend until about 02:30 UT and then they increased for the rest of the night. The values ranged between 1245 and 1313°K and the average measured temperature (1479 ±122°K) was still 213°K higher than the mean (1266±22°K) of the model values obtained from the MSIS-86.

## Discussion

The results presented thus far, provide a new set of observational temperature data obtained by the ground-based Fabry-Perot interferometer based at the King Sejong Station, King George Island in Antarctica. The King Sejong Station, with a geomagnetic latitude of 50.7°S, though normally lying in the sub-auroral zone, is a high-latitude station geographically in the Southern Hemisphere. Since the southern auroral zone is displaced from the rotation pole by about twice as much as its northern counterpart, it is subjected to an unusual blend of driving forces and a different combination of geographically and geomagnetically related dynamic and thermodynamic elements(Smith, et al., 1988). A further, more systematic, complication occurs since the geomagnetic poles migrate in and out of sunlight with the Earth's rotation. As the offsets between geomagnetic and geographic poles are about 9° and 15° in the north and south, respectively, the magnitude of effects due to this migration will thus be greater in the southern auroral zone. A comprehensive study of such contrasts in polar thermospheric behavior from observations will be a key test of our current understanding of thermospheric dynamics. Data sets obtained from the ground-based observations at King George Island will, therefore, make a significant contribution in that direction.

The particular data sets discussed here address three distinct temporal variations of the high-latitude thermosphere in the Southern Hemisphere. These are the detailed surveys of the variations of the thermospheric neutral temperatures during geomagnetically quiet and disturbed periods. Based on these data sets, a primary conclusion is that above 60 degrees of latitude in the Southern Hemisphere the observed neutral temperature variations are larger than the semi-empirical thermospheric model predictions. The MSIS-83 model estimates differed considerably by more than 300°K for all geomagnetic conditions. The MSIS-86 model, which is augmented with terms to express hemispherical and seasonal differences in the polar regions and local time variations in the magnetic activity effect, gave slightly better estimates of the neutral temperatures. Quantitatively, while the difference is about 235°K during quiet times, it decreases to approximately 155°K as the geomagnetic activity is increased. Thus, both models fail to exhibit the increase in the high-latitude temperature observed in the southern autumn. There is the fact, though, that the interferometer is observing a dynamic process that is responding to temporally varying energy inputs. Auroral substorms and large-scale variations associated with the magnetic storms are being mixed in our observed thermospheric temperatures, while the theories are treating the processes as steady state. It should also be noted that the solar cycle 22, which began in September 1986, continues to rise and that several major events of solar activity have occurred since October 1988. The Sun's increased output under such conditions has some benign effects on the Earth, such as heating and expanding its upper atmosphere. These solar activity related changes in the neutral temperature are expected to increase with increasing solar activity.

## Acknowledgements

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