COMPARISON OF THE ESRO 4 THERMOSPHERE MODEL WITH ESRO 4 DATA DURING MAGNETICALLY QUIET CONDITIONS

G.W. Prölss M. Roemer

Institut für Astrophysik
und Extraterrestrische Forschung
Universität Bonn
5300 Bonn, F.R. Germany

ABSTRACT

Using ESRO 4 data obtained during 10 geomagnetically quiet time intervals, the accuracy of the ESRO 4 model is tested. A graphical comparison and a statistical analysis indicate that the overall agreement is good and that mean deviations are of the order of 13% for O and 20% for N_2 and He. Larger differences are observed only locally, with maximum deviations typically of the order of 30%, 55%, and 40% for O, N_2, and He, respectively.

Keywords: Thermosphere Model, ESRO 4 Model,
ESRO 4 Data

1. INTRODUCTION

In recent years, numerous empirical models have been constructed which describe the temporal and spatial variation of the thermospheric temperature and density under various geophysical conditions (Refs. 1,2 and references therein). The general purpose of these models is two-fold: first, they represent a useful vehicle for summarizing and organizing the large amount of data provided by today's satellite missions. Second, they can be used to predict thermospheric conditions beyond the range of the data base employed in the model. It is this latter capability which makes them indispensable for satellite emphemeris predictions. This is especially true for the calculation of satellite lifetimes and for the prediction of the re-entry of space debris.

Important as they are, these models are far from perfect, and any potential user should be aware of their inherent limitations. First, the data base used for their construction may contain systematic errors. Second, the algorithms chosen may not reflect the physics of the processes to be modelled. And third, the relatively crude model structure does not allow the reproduction of smaller scale variations. Given these limitations, it is essential to have a general idea of the accuracy to be expected. Since a comprehensive evaluation is practically impossible, only rough error estimates can be given. One possible way is to compare model predictions among themselves, and this approach has been taken, for example, in the previous study (Ref. 2). Another way is to compare model predictions directly with measurements, and this method is employed in the present investigation. In particular, the following question is addressed: How well can a present-day model reproduce a given data set under the most favorable conditions? By most favorable conditions, we mean that a model is compared directly with the data set on which it is based, and also that this data set is uniform and derived from one and the same experiment. This way, any differences observed can be unambiguously attributed to the model algorithm. In addition, only geomagnetically quiet periods should be considered because it is during these times that current models are at their best (Refs. 3,4). In the present study, the ESRO 4 thermosphere model (Refs. 5,6) and the data set on which it is based, viz. the density measurements obtained by the mass spectrometer on board the ESRO 4 satellite (Refs. 7,8), are used for such a comparison. The following section gives some details of the analysis, and Section 3 discusses the results obtained.

2. ANALYSIS

The time intervals selected for the model-data comparison are listed in Table 1. As is evident, only magnetically very quiet days were considered. Also, all data refer to solar minimum conditions. For each time interval, density measurements from 11 to 15 satellite orbits were available. Only data obtained between perigee (ca. 230-260 km) and 320 km altitude were considered. This limits the latitudinal coverage to between 60 and 97 degrees. Since ESRO 4 was a polar orbiting satellite, each period refers to one or two fixed local time sectors.

To obtain a visual impression of the model accuracy, the following procedure was adopted. First, all density measurements (O, N_2, He) were adjusted to a common altitude of 280 km using standard hydrostatic techniques (Refs. 9,10,11,12). The exospheric temperature was thereby inferred from the molecular nitrogen density. Second, all density values were normalized using a reference value suitably chosen for each time interval. This way only relative density variations are considered. The height-adjusted and normalized density values and the derived exospheric temperature were subsequently smoothed using a 3-point running mean and plotted as a function of latitude. To suppress small scale fluctuations of

Proc. Workshop on Re-entry of Space Debris, Darmstadt, 24-25 Sept.1985 (ESA SP-246, Feb.1986)

Table 1. Time intervals selected for the model-data comparison. The date, the latitudinal coverage, the solar local time, and the season (W=winter, E=equinox, S=summer) are given for each period. The level of magnetic activity is indicated by both the average ap ($\overline{ap}$) and the average AE ($\overline{AE}$) indices and also by the peak Kp ($\hat{Kp}$) and peak AE ($\hat{AE}$) indices. The 10.7 cm solar radio flux F10.7 [10^{-22} Wm^{-2} Hz^{-1}] serves as a measure of solar activity.

Date	Lat. Coverage	Local Time	Season	$\overline{ap}$	$\overline{AE}$	$\hat{Kp}$	$\hat{AE}$	F10.7
5 Dec 72	82-15^{O}N	15:50	W	2.0	21	1_+	51	80
10 Dec 72	80-90-31^{O}N	2:50/15:30	W	2.1	31	1_+	100	97
27 Dec 72	20-80^{O}N	2:10	W	1.8	27	2_-	77	98
2 Jan 73	0-67^{O}N	1:50	W	1.9	33	1_+	53	98
18/19 Jan 73	55^{O}S-0-10^{O}N	0:50	(S)	2.5	37	1_o	105	95
30/31 May 73	0-75^{O}S	5:30	W	2.6	51	1_o	120	91
6/7 Jul 73	42-90-55^{O}N	15:15/3:30	S	3.0	86	1_+	255	99
17 Aug 73	89-27^{O}S	13:10	E	2.4	57	1_-	154	75
26/27 Oct 73	20^{O}S-0-72^{O}N	9:20	E	1.6	46	1_o	74	101
1/2 Dec 73	13-90-70^{O}S	19:15/7:40	S	3.0	84	1_+	170	87

instrumental origin, the helium data were in addition hand-smoothed. A somewhat different latitudinal profile was obtained for each orbit. To indicate the range of values, these profiles were superimposed and the envelopes were determined. It is these upper and lower envelopes which are depicted in Figs. 1 to 5. They are compared with ESRO 4 model predictions derived for the same geophysical conditions. Actually, these model predictions also show slight variations depending on changes in the geophysical conditions. However, this range is so small that it can be safely neglected in comparison with the actually observed variability.

Whereas Figs. 1 to 5 provide an excellent visual impression of the model accuracy, a more quantitative evaluation is desirable. Therefore the percentage deviation between measurement and model prediction was determined for each single data point. Considering only the absolute magnitude of these differences, averages were calculated for each time interval and are listed in Table 2.

Besides these mean deviations, maximum differences are also of interest. To lessen the influence of faulty measurements, the data were first smoothed using a 4-point running mean. Subsequently, the maximum deviation was determined for each orbit. Averaged over each time interval, these maximum differences are also listed in Table 2.

Note that all calculations were performed using both the basic and the longitudinally corrected version of the ESRO 4 model (Refs. 5,6). Very similar results were obtained in both cases. Whereas Figs. 1 to 5 refer to the basic model, Table 2 is based on the modified version.

3. RESULTS

An inspection of Figs. 1 to 5 and of Table 2 leads to the following conclusions:

(1) Good agreement is found between the ESRO 4 model and the ESRO 4 data during the magnetically quiet time intervals considered in this study. As indicated by the graphical comparison, model predictions are generally within or close to the range of values actually observed. Mean deviations are of the order of 13% for atomic oxygen (which incidently is the major gas in the height region considered) and 20% for molecular nitrogen and helium.

(2) Whereas good agreement is found in general, somewhat larger deviations may exist locally. As is indicated in the figures, model predictions are systematically too high or too low in certain latitudinal regions. Small-scale fluctuations add to these deviations. Maximum differences are typically of the order of 30% for atomic oxygen, 55% for molecular nitrogen, and 40% for helium.

If the ESRO 4 model is replaced by another model, differences increase. For example, standard deviations between the ESRO 4 data set and the MSIS-83 model are 0.24, 0.33, and 0.30 for O, N_2, and He, respectively (Ref. 13). This translates into mean deviations of 19% for O, 26% for N_2, and 24% for He for normally distributed differences. Considering that this comparison includes magnetically active periods, and furthermore, that the MSIS-83 model is based on many different data sets (16 altogether), the observed increase in the model-data differences is relatively small.

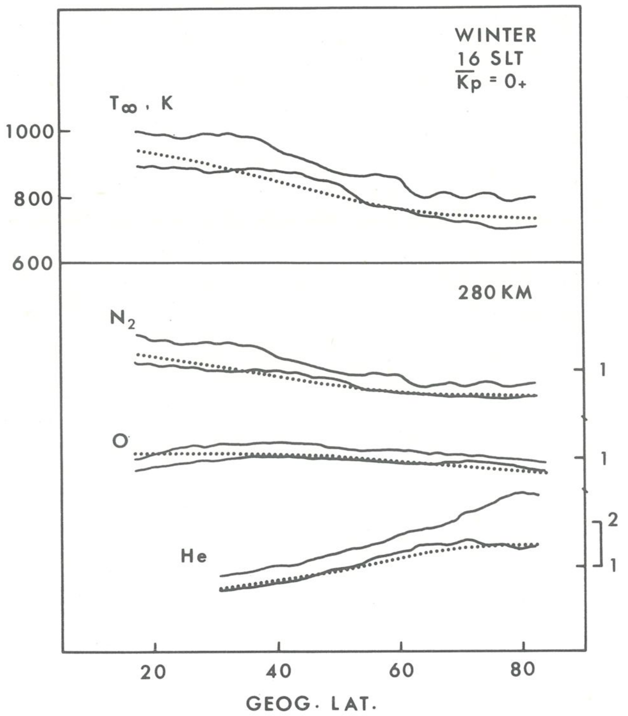

Figure 1. Comparison between the ESRO 4 model and ESRO 4 data during the 5 Dec 72 time interval. The upper panel presents the exospheric temperature and the lower panel the molecular nitrogen (N_2), the atomic oxygen (O), and the helium (He) densities as a function of geographic latitude. Whereas each pair of full lines limits the range of values actually observed, the dotted line indicates the associated model prediction. All density data have been normalized and refer to an altitude of 280 km. The common scale of the relative density variations is indicated by a bar on the right-hand side. Season, approximate local time, and average Kp index (derived from the average ap index) are given in the right-hand upper corner.

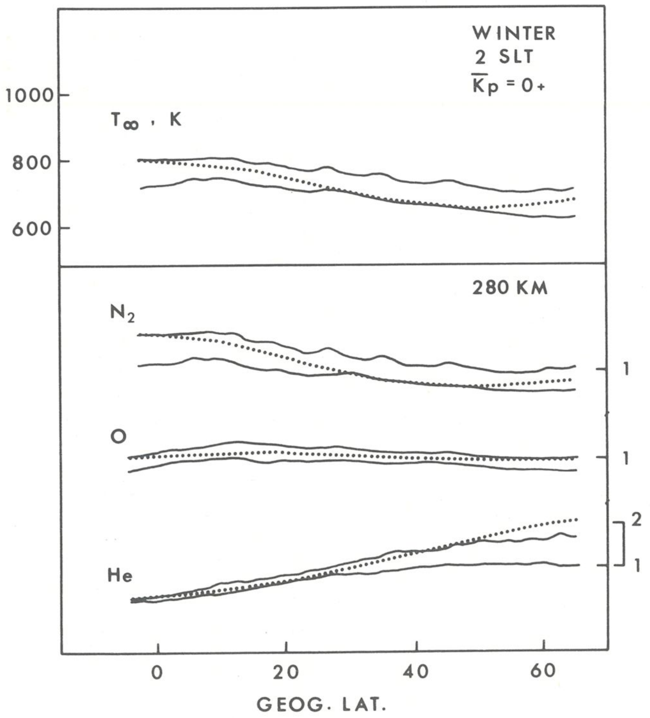

Figure 2. Comparison between the ESRO 4 model and ESRO 4 data during the 2 Jan 73 time interval. Same format as in Fig. 1.

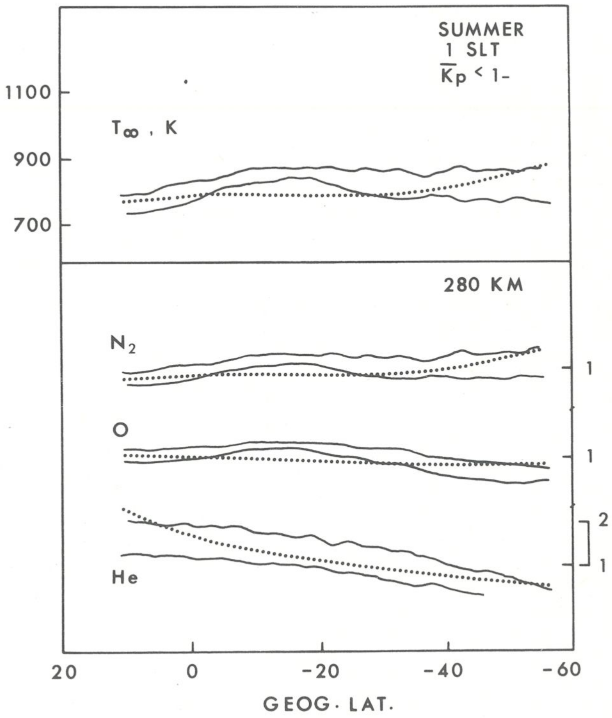

Figure 3. Comparison between the ESRO 4 model and ESRO 4 data during the 18/19 Jan 73 time interval. Same format as in Fig. 1.

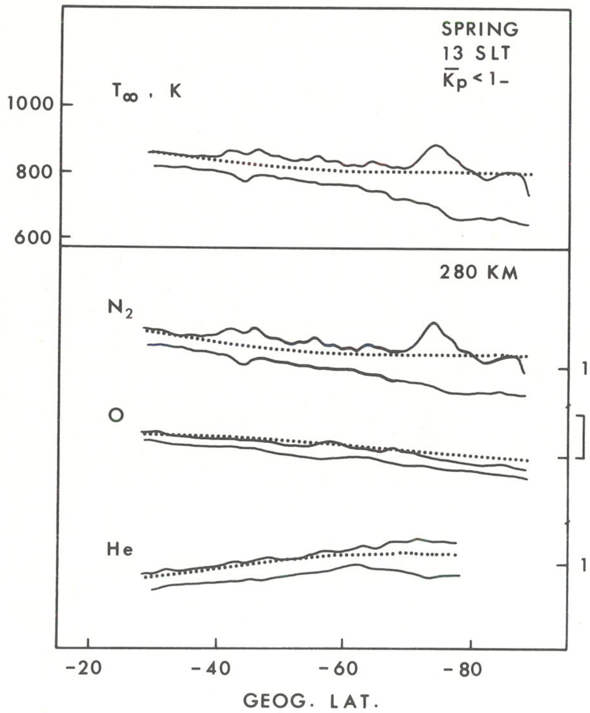

Figure 4. Comparison between the ESRO 4 model and ESRO 4 data during the 17 Aug 73 time interval. Same format as in Fig. 1.

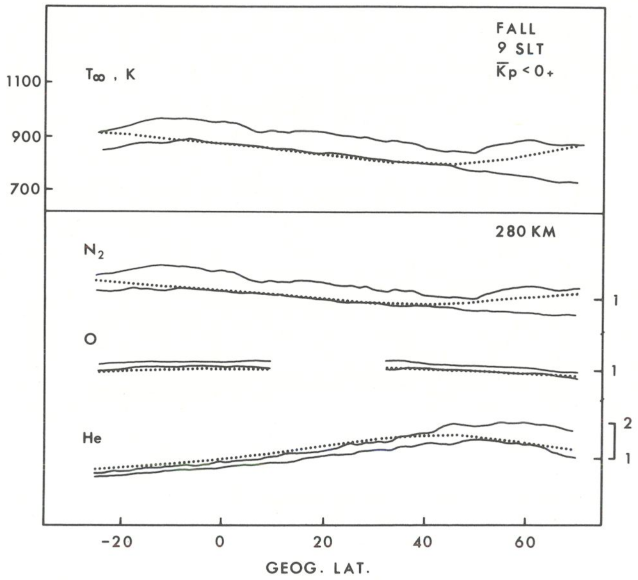

Figure 5. Comparison between the ESRO 4 model and ESRO 4 data during the 26/27 Oct 73 time interval. Same format as in Fig. 1.

Table 2. Mean deviations and average maximum differences between (longitudinally corrected) ESRO 4 model and ESRO 4 measurements (in percent)

Period	T_∞		O		N_2		He	
	Mean	Max	Mean	Max	Mean	Max	Mean	Max
5 Dec 72	5	12	13	27	17	34	21	37
10 Dec 72	5	13	13	26	21	62	21	37
27 Dec 72	5	12	10	23	23	58	12	31
2 Jan 73	4	10	10	27	15	35	23	69
18/19 Jan 73	5	12	19	54	18	55	23	61
30/31 May 73	6	14	9	21	17	39	16	29
6/7 Jul 73	6	16	12	34	18	52	19	45
17 Aug 73	9	19	22	60	36	142	20	38
26/27 Oct 73	5	11	9	17	18	43	17	35
1/2 Dec 73	6	14	12	27	16	32	17	32
Average	6	13	13	32	20	55	19	41

Related information on the model accuracy is derived from model comparisons. For example, maximum differences of 12% to 33% between the C and MSIS-83 model predictions were found for N_2 in the previous study (Ref. 2). These estimates, however, refer only to specific Fourier components, and effective deviations may be larger and comparable to those obtained in the present study. Also on the basis of a model comparison, Köhnlein (Ref. 14) estimates model predictions for O, N_2, and He to be accurate, in general, to within ±20%. Taking all evidence together, these numbers may well characterize the present state of the art.

Acknowledgments

We are very grateful to U. von Zahn and W. Köhnlein, who kindly provided the ESRO 4 data and the ESRO 4 model used in the present study.

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