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NASA
Technical
Memorandum

NASA TM-86522

THE MSFC/J70 ORBITAL ATMOSPHERE MODEL AND THE DATA BASES FOR THE MSFC SOLAR ACTIVITY PREDICTION TECHNIQUE

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November 1985

(NASA-TM-86522) THE MSFC/J70 ORBITAL ATMOSPHERE MODEL AND THE DATA BASES FOR THE MSFC SOLAR ACTIVITY PREDICTION TECHNIQUE (NASA) 42 p HC A03/MF A01 CSCL 04A
N86-22023
Unclas
G3/46 05746

National Aeronautics and
Space Administration
George C. Marshall Space Flight Center

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.
NASA TM-86522

2. GOVERNMENT ACCESSION NO.

3. RECIPIENT'S CATALOG NO.

4. TITLE AND SUBTITLE
The MSFC/J70 Orbital Atmosphere Model and the Data Bases for the MSFC Solar Activity Prediction Technique

5. REPORT DATE
November 1985

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
Dale L. Johnson and Robert E. Smith

8. PERFORMING ORGANIZATION REPORT #

9. PERFORMING ORGANIZATION NAME AND ADDRESS
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

10. WORK UNIT NO.

11. CONTRACT OR GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS
National Aeronautics and Space Administration
Washington, D.C. 20546

13. TYPE OF REPORT & PERIOD COVERED
Technical Memorandum

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES
Prepared by Atmospheric Sciences Division, Systems Dynamics Laboratory.

16. ABSTRACT

This document contains a description of the MSFC/J70 Orbital Atmospheric Density Model, a modified version of the Smithsonian Astrophysical Observatory Jacchia 1970 model. The algorithms describing the MSFC/J70 model are included as well as a listing of the computer program. The 13-month smoothed values of solar flux ($F_{10.7}$) and geomagnetic index (A_p), which are required as inputs for the MSFC/J70 model, are also included and discussed.

17. KEY WORDS
Atmospheric Model
Atmospheric Density
Density Variability
Orbital Analyses
Solar Flux
Geomagnetic Index

18. DISTRIBUTION STATEMENT
Unclassified — Unlimited

19. SECURITY CLASSIF. (of this report)
Unclassified

20. SECURITY CLASSIF. (of this page)
Unclassified

21. NO. OF PAGES
41

22. PRICE
NTIS

MSFC - Form 3292 (May 1969)

For sale by National Technical Information Service, Springfield, Virginia 22151

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THE MSFC/J70 ORBITAL ATMOSPHERE MODEL AND THE DATA BASES FOR THE MSFC SOLAR ACTIVITY PREDICTION TECHNIQUE

1.0 PURPOSE AND SCOPE

The purpose and scope of this report is to document the MSFC/J70 Orbital Atmosphere Model (hereafter referred to as the MSFC/J70 model) and the 13-month smoothed values of the 10.7 cm solar radio flux, $\bar{F}_{10.7}$, and the geomagnetic index, A_p, used in the current solar activity prediction technique.

2.0 GENERAL

2.1 MSFC/J70 Orbital Atmosphere Model

The standard, neutral atmospheric density model used at NASA/MSFC for control and lifetime studies involving all orbital spacecraft projects, is the MSFC/J70 Model [1,2]. It is a semi-empirical model that requires values of the 10.7 cm solar radio flux and geomagnetic activity index as inputs.

The model is based on a static diffusion method which defines temperature and chemical composition and provides densities in agreement with satellite drag observations and, to a somewhat lesser degree, with rocket probe measurements from 90 to 2500 km altitude. Densities are derived from the empirically determined temperature profile and an assumed constant boundary condition at 90 km. Mixing is assumed to prevail to an altitude of 105 km and any change in the mean molecular mass below this level is assumed to result only from dissociation of oxygen.

The distribution of mean molecular mass between 90 and 105 km is determined empirically in such a way that it results in a ratio of atomic oxygen to molecular oxygen of 1.5 at 120 km. All of the recognized variations in the upper atmosphere which will be described in the next section, except the ones associated with tidal and gravity waves, are included in the model.

A plot of all the MSFC/J70 constituent concentrations is given in Figure 1, versus altitude, for minimum and maximum solar conditions.

A computational procedure/program listing for the MSFC/J70 Orbital Atmosphere Model prediction method is given in Appendix A. The output of the computer program gives temperature, mass density, number density of each constituent, and mean molecular weight as a function of altitude (90 to 2500 km), time and location. The MSFC/J70 Model evolved from the Smithsonian's Jacchia 1970 (3) model, along with two additions from the Jacchia 1971 (4) model. The seasonal-latitudinal variations in density below 170 km, and seasonal-latitudinal variations of helium above 500 km have been incorporated in the MSFC/J70 Model using equations developed by Jacchia for his 1971 Thermospheric model. The MSFC/J70 Model is also an integral part of the NASA/MSFC Global Reference Atmosphere Model (GRAM) as given in Reference 5.

2.2 Solar Activity Prediction Technique

Since the MSFC/J70 Model requires values of the 10.7 cm solar radio flux and the geomagnetic index as inputs, as well as the orbital parameters, a technique has been developed for predicting these values for the time period being considered in the various development efforts. This prediction technique is described in detail in NASA TM-82462 [6], entitled: "Lagrangian Least-Squares Prediction of Solar Flux ($\bar{F}_{10.7}$)," dated January 1984 by R. L. Holland and W. W. Vaughan.

3.0 DISCUSSION

3.1 Atmosphere Model

Analyses have shown that the following factors contribute to the observed variations in the thermospheric (atmosphere above approximately 80 km altitude) density, temperature and composition:

1) Solar activity

2) Rotation of Earth (diurnal)

3) Geomagnetic activity

4) Earth's rotation about Sun (semiannual)

5) Seasonal-latitudinal variations of the low thermosphere density

6) Seasonal-latitudinal variations of helium at all altitudes above 500 km

7) Rapid density fluctuations probably connected with tidal and gravity waves.

The first six have some regularity and can be modeled with relatively well understood degrees of accuracy. Each of these six variations have been taken into account in the MSFC/J70 Model. Studies are now underway to incorporate into the MSFC/J70 Model, representation of the rapid density fluctuations.

Since temperature plays a minor role in comparison with density, current orbital atmosphere models have been developed to represent, insofar as practical and possible, the variability of the ambient mass density rather than the temperature. The models are based on temperature profiles which have been adjusted so as to produce the density values derived from the analyses of satellite orbital decay data.

3.1.1 Variations with Solar Activity

In the thermosphere, or orbital atmosphere altitudes, the density is strongly influenced by the changing levels of solar activity. The resulting density variations, in turn, affect the frictional air drag on orbiting spacecraft. Studies of satellite drag data have verified a pronounced correlation between solar activity and density variations. However, the reaction of the atmosphere to variations of the Sun is not instantaneous. The atmospheric response time is on the order of one day.

The ultraviolet solar radiation that heats and causes compositional changes in the Earth's upper atmosphere consists of two components, one related to active regions on the solar disc and the other to the disc itself. The active-region component varies from day-to-day while the disc component varies more slowly, presumably with the longer periodicities in the solar activity; i.e., the approximately 11-year solar cycle. The atmosphere has been observed to react in a different manner to each of these two components. Jacchia and Slowey (private correspondence) have found that the disc component of the solar radiation is, for all practical purposes, linearly related to the 10.7 cm solar flux smoothed over six solar rotations (162 days). When the short-period oscillations which are caused by the diurnal variation are removed, there is essentially an approximate 11-year variation in density that parallels the smoothed 10.7 cm solar flux data.

The night time minimum global exospheric temperature resulting from the variation with solar activity can be computed from the following equation [for a geomagnetic index (A_p) of zero].

$$T_C(^\circ K) = 383 + 3.32\,\bar{F} + 1.8\,(F - \bar{F}) \tag{1}$$

where:

$\bar{F}$ = centered 162 day mean $F_{10.7}$ cm solar flux (watts/m^2/cycle/second)

F = daily mean $F_{10.7}$ cm solar flux (watts/m^2/cycle/second) .

3.1.2 The Diurnal Variation

Analyses of satellite orbital decay histories have shown that orbital altitude atmospheric densities reach a maximum around 2 p.m. local solar time at a latitude approximately equal to that of the subsolar point while the minimum occurs between 3 and 4 a.m. at about the same latitude in the opposite hemisphere. The effect is believed to be caused by the absorption of EUV radiation and by heat conduction of the neutral gas. The energy that is conducted downward into the lower thermosphere and upper mesosphere (altitude range of approximately 50 to 80 km) is mostly lost by radiation processes. At an altitude of about 120 km, the time constant for heat loss by conduction is on the order of one day or greater. Thus, the diurnal variation is not a predominant phenomenon at lower altitudes. Consistency between temperature and density cannot always be achieved on a diurnal basis in a quasi-static model; therefore, the temperature profile has been used as a parameter so that observed density values can be reproduced by the model. Even though the global temperature distribution is an artifact developed solely for use in the density and composition models, some experimental results are in good agreement. Thomson-scatter temperature measurements [7] generally show that the temperature maximum occurs between 3 and 5 p.m. rather than near 2 p.m. This controversy has not been resolved at this time; however, it appears as if there is a phase lag between the density maximum and the temperature maximum which cannot be included in the current atmospheric models.

The ratio of day-to-night exospheric (altitude region from 500 to 1000 km) temperature was also found not to depend completely upon solar activity although it tends to be higher during maximum solar activity and lower during minimum solar activity. This ratio has a fairly good correlation with the yearly running mean of the geomagnetic activity index A_p, but is independent of latitude. The numerical value of the ratio varies between 1.27 and 1.40 and has an average of 1.31.

The correction to be applied to the night time minimum temperature to account for the diurnal variation can be computed from the following equation:

$$T_L(^\circ K) = T_C \, (1 + R \sin^{2.5} \theta) \, (1 + A \cos^{3.0} \frac{TAU}{2}) \tag{2}$$

where:

T_C = night time minimum exospheric temperature (°K) from equation (1)

$R = 0.31$

$$A = R \left(\frac{\cos^{2.5}\eta - \sin^{2.5}\theta}{1 + R \sin^{2.5}\theta} \right)$$

$$\eta = \frac{1}{2} \left| LAT - DS \right|$$

$$\theta = \frac{1}{2} \left| LAT + DS \right|$$

TAU = HRA - 37 + 6 sin (HRA + 43)

HRA = hour angle, deg

LAT = latitude, deg

DS = declination of Sun, deg .

3.1.3 Variations with Geomagnetic Activity

Geomagnetic storms usually occur when clouds of charged particles collide with the Earth's magnetosphere. These charged particles are believed to be ejected from the Sun during the course of a solar flare which is generally a short-lived phenomenon. As a result, a large amount of solar radiation is emitted by the flare region which subsequently heats the Earth's atmosphere. The heating mechanism is not well-understood.

Analyses of orbital decay histories can give only a blurred picture of the complex reaction of the upper atmosphere to geomagnetic disturbances. It has been shown that the upper atmosphere first reacts in the northern and southern latitude polar auroral zones with the energy subsequently propagating toward the equator apparently in the form of wave-like perturbations. It appears as if the atmosphere reacts with a zero time delay in the auroral zones with the geomagnetic storm effects showing up in the equatorial zone about 6 to 9 hr later. An average time lag is presently taken as 6.7 hr in the MSFC/J70 Model.

It is very difficult to adequately include this effect in a quasi-static model. The current model calculates the density variations on the basis of a global increase in exospheric temperature. Observations have shown that this is not the case; however, for satellite lifetime prediction calculations, an assumed global temperature increase is acceptable. For some calculations, such as control dynamics analyses, control moment gyro analyses and aerodynamic torques, instantaneous temperature (and therefore density), increases for short time periods, and specific locations may be required. These studies may require special applications and interpretations of the model. Current research is directed toward improving this aspect of the model.

The geomagnetic activity temperature correction can be computed as follows:

$$T_G(°K) = 1.0\,A_p + 100\,[1 - \exp\,(-0.08\,A_p)] \qquad (3)$$

where

A_p = geomagnetic index value measured 6.7 hr before computation time .

3.1.4 The Semiannual Variation

No satisfactory explanation has been found for this variation. It was initially assumed that this density variation could be linked with a temperature variation; however, data from analyses of more recently orbited satellites showed that the original assumption was in error. The amplitude of this density variation is strongly height-dependent and variable from year-to-year, with a primary minimum in July and principal maximum in October, and a secondary minimum in January, followed by a secondary maximum in April. It does not appear to be related to solar activity. It has also been found that the semiannual effect varies considerably from solar cycle to solar cycle, both in magnitude and in altitude dependence. According to Jacchia [8], the amplitude of this variation is quite large at sunspot maximum but decreases toward sunspot minimum.

The correction to be applied to the temperature to account for this semiannual variation can be computed as follows:

$$T_S(°K) = 2.41 + \bar{F}\,[0.349 + 0.206\,\sin\,(360\,\tau + 226.5)]\,\sin\,(720\,\tau + 247.6) \qquad (4)$$

where

$$\tau = \frac{DD}{y} + 0.1145\left(\left\{\frac{1 + \sin\left[360\left(\frac{DD}{y}\right) + 342.3\right]}{2}\right\} - \frac{1}{2}\right)$$

y = 365.2422 days

DD = day number after January 1 .

3.1.5 Seasonal-Latitudinal Variations of the Lower Thermosphere Density

Presently accepted models assume constant temperature and density values at 90 km altitude to prevent the models from becoming too complex even though large temperature and somewhat smaller density variations are known to exist there.

Current models therefore are constructed with a seasonal-latitudinal density variation which varies in the vertical from minimal at 90 km, to a maximum at ∿110 km, and then decreases with altitude to 170 km where no appreciable seasonal-latitudinal variation has been observed. In the horizontal, the maximum occurs on December 27 at the North Pole. These variations are included as additions to the mass densities calculated as a function of the exospheric temperature used in the model. These variations are small and because they occur solely below 170 km altitude they will have little effect on orbital lifetime prediction or control requirement calculations.

After exospheric temperature is computed from

$$T_E(^\circ K) = T_L + T_G + T_S \quad , \tag{5}$$

both local temperature (T_Z) and mean molecular mass (EM) at altitude, are calculated. Finally mass density can be calculated from the following equation:

$$\mathrm{DENS}\ (g/cm^3) = \mathrm{DENO}\left(\frac{TO}{TZ}\right)\left(\frac{EM}{MO}\right)\exp\int_{Z1}^{Z2}\left[-\frac{(EM)\ G}{(FK)\ TZ}\right]dz \tag{6}$$

where

DENO = assumed density at 90 km altitude (3.46×10^{-9} gm/cm^3)

TO = assumed temperature at 90 km altitude (183° K)

MO = mean molecular mass at 90 km altitude (28.878)

G = gravity ($980.665 \times [1 + Z/RE]^{-2}$) cm/sec^2

Z = altitude, km

RE = Earth radius (6.356766×10^3 km)

FK = Universal Gas Constant (8.31432 Joule/mole-°K)

TZ = local temperature at altitude Z, °K .

Now the seasonal-latitudinal correction for density can be computed from the following equation:

$$\mathrm{DENLG(I)} = 0.014\ (Z-90)\ \exp\ [-0.0013\ (Z-90)^2]\ \frac{LAT}{|LAT|}\ \sin\ (2\pi\Phi + 1.72) \times \sin^2\ (LAT) \tag{7}$$

where

LAT = geographic latitude, deg

Z = altitude (km)

Φ = semi-annual variation phase ([t - 36204]/365.2422)

t = Modified Julian Day .

3.1.6 Seasonal-Latitudinal Variations of Helium

Experimental results have shown a strong increase of helium above the winter pole. Through an analysis of the intensity of the 10830 Å emission line, Bitterberg et al. [9] deduced that helium varied seasonally in one year by a factor of 3 to 4 above 500 km. They pointed out that clear maxima in the helium concentration were observed repeatedly in the month of December and January and then were followed by a rather steep decline. Minima in the helium concentration were usually observed in April and May, but some early ones were observed in March.

The formation of this helium bulge over the winter pole has been explained by a seasonal subsidence of the level at which the diffusion of helium begins. It has been shown that a change of this level by 5 km could change the amount of helium in the thermosphere by a factor of 2. However, the mechanism of this winter helium bulge and its latitudinal dependence are still under investigation. Although the mechanism for this migration is unclear; empirical equations which describe the phenomenon are included in the model. These variations influence the computed densities only at heights above approximately 500 km.

The seasonal-latitudinal variation of helium correction can be computed from:

$$\mathrm{DLHe} = 0.65 \left|\frac{\mathrm{DS}}{23.44}\right| \left[\sin^3\left(\frac{\pi}{4} - \frac{\mathrm{LAT}}{2} * \frac{\mathrm{DS}}{|\mathrm{DS}|}\right) - \sin^3\frac{\pi}{4}\right] \tag{8}$$

where

DS = declination of Sun, deg

LAT = geographic latitude, deg .

3.1.7 Density Waves

Ambient density waves have been detected throughout the upper atmosphere in the height range from 120 to at least 510 km. These fluctuations are believed to be caused by tidal and gravity waves. In addition, traveling ionospheric disturbances (TIDs) have long been thought of as manifestations of internal gravity waves. Their vertical wavelengths apparently increase with altitude until they break down due to physical limitations. Density increases on the order of 100 percent have been observed to occur over short distances (∿10's of kms). The waves apparently propagate from either south to north, or north to south with maximum horizontal wavelengths on the order of 500 to 700 km. Although the current MSFC/J70 model and other models do not include variations associated with internally propagating waves, users should be cautioned that they have been observed.

3.1.8 Total Density Computation

Total neutral mass density (g/cm^3) is then computed as:

$$DL = DLHe + DENLG \tag{9}$$

where

DLHe = the log density term modified by Helium S-L variation if greater than 500 km altitude

DENLG = the log density S-L component added if less than 170 km alt .

Finally, the absolute value of density (g/cm^3) can be given as:

$$DENS = 10^{DL} \quad . \tag{10}$$

3.1.9 MSFC/J70 Model Program Listing and Test Case Example

The MSFC/J70 Model Fortran program is listed in its entirety in Table 1. It represents the current MSFC program running on the HP-1000. Table 2 contains a test case example of total density (kg/m^3) which can be used to compare outputs. This test case example was selected from the Space Station Natural Environment Design Criteria document, NASA TM-82585 [10]. It corresponds to the Reference 7 Table 1 guidance and control density design global mean value of 0.2522×10^{-11} kg/m^3 at 600 km altitude. Table 3 contains mean orbital total density design values for many altitudes from 400 to 1100 km, which can also be used to compare outputs. The required inputs for these test cases (Tables 2 and 3) include:

Date: March 21, 1970
Time: 1400 UT

F10 and $\overline{F10}$ = 230
A_p = 400
Latitudes = -30° to +30°
Longitudes = 0° to 350°
Latitude and longitude increment = 10° .

3.2 Solar Activity Data

The 13-month smoothed values of the 10.7 cm solar radio flux ($\overline{F}_{10.7}$) and the geomagnetic index, A_p, used as model inputs are listed in Table 4, where they are listed as they would be used in a maximum to maximum solar activity prediction. Figures 2 and 3 show the 10.7 cm flux and A_p values, respectively.

4.0 CONCLUSIONS

The MSFC/J70 Orbital atmosphere model provides continuous density, temperature, and composition data from 90 to 2500 km for analyses requiring these data. Copies of the computer program for this model are available upon request to Chief, Atmospheric Sciences Division, NASA, Marshall Space Flight Center, Huntsville, Alabama 35812.

Personnel performing analyses requiring knowledge of any small-scale, short time period fluctuations in atmospheric parameters such as those perturbations associated with internally propagating waves should contact the Chief, Atmospheric Sciences Division, NASA Marshall Space Flight Center, Huntsville, Alabama 35812, for the most current recommended inputs based on results of analyses and studies in progress at this time.

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TABLE 1. MSFC/J70 FORTRAN PROGRAM LISTING (HP-1000 VERSION)

```
&J70MM T=00004 IS ON CR00032 USING 00151 BLKS R=0000

FTN4X,L
$EMA(XDATA)
      PROGRAM J70MM(3),ACI-101281  JACCHIA '70 MODEL (REEDA SYSTEM)
C****************************************************************
C++                                                            **
C++ DESCRIPTION:    PROGRAM 'J70MM' IS THE JACCHIA '70 MODEL   **
C++                 WHICH WAS CONVERTED FROM THE UNIVAC 1108   **
C++                 TO THE REEDA SYSTEM.                       **
C++                                                            **
C++ INPUTS:         USER PROVIDES INPUT PARAMETERS VIA 'CRT'.  **
C++                                                            **
C++ OUTPUTS:        A MATRIX GRID OUTPUT IS GENERATED TO THE   **
C++                 HP-2608 PRINTER. A MEAN VALUE OF ALL GRID  **
C++                 VALUES IS ALSO GENERATED.                  **
C++                                                            **
C++ LATEST MODIFICATION:                                       **
C++                12 JUL 1985 (CSC)                           **
C++                                                            **
C++ WRITTEN BY:     JOHN S. HICKEY (ACI)  533-7590             **
C++                 MIKE DICKERSON (ACI)  533-7590             **
C++                 BILL JEFFRIES  (CSC)  830-1000 EXT 507     **
C++                                                            **
C****************************************************************
C
C++ COMMON STATEMENTS
C
      COMMON /EDATA/ IYR,IDA,MN,IHR,MIN,XMJD,F10,F10B,GI,ILAT,ILNG,
     .               XLAT,XLNG,I1
      COMMON/XDATA/AMAT(73,37),DENMAT(73,37),DENLOG(73,37),HEMAT(73,37)
     .               HMAT(73,37),O2MAT(73,37),OMAT(73,37),TEMP(73,37),
     .               XN2(73,37),WTMAT(73,37),EXTEM(73,37)
      COMMON /FDATA/ A(300,6),DENLG(300),DENS(300),DL(300),EM(300),
     .               TZZ(300),XLATT(300),XLONG(300),Z(300),XTEMP(300)
C
C++ DIMENSION STATEMENTS
C
      DIMENSION KBUF(15),JVARY(11),JV(11),ZALTS(10)
      DIMENSION IDCB(276),IBUF(40),NAME(3),IPAR(5)
C
C****************************************
C++ FETCH 'CRT' LOGICAL UNIT NUMBER.    **
C****************************************
C
      CALL RMPAR(IPAR)
      LU = IPAR(1)
C
C++ PRINT OUT BANNER PAGE INCLUDING PROGRAM NAME AND DATE
C
 777  CALL FTIME(KBUF)
      WRITE(6,107)
107   FORMAT("1")
      DO 7 K=1,10
      WRITE(6,108) (KBUF(I),I=1,15)
108   FORMAT(" *********** PROGRAM J70MM EXECUTED AT:  ",15A2,
     .       " NASA/MSFC REEDA SYSTEM ***********")
7     CONTINUE
C
C++ PRINT HEADER TO CRT
```

TABLE 1. (Continued)

```
CƐY
      WRITE(LU,398)
398   FORMAT("ƐHƐJ")
CƐZ
      WRITE(LU,399)
399   FORMAT("*********************************************************"/
     .       "** DESCRIPTION:  PROGRAM 'J70MM' IS THE JACCHIA '70    **"/
     .       "**               MODEL WHICH WAS CONVERTED FROM THE    **"/
     .       "**               UNIVAC 1108 TO THE REEDA SYSTEM.      **"/
     .       "**                                                     **"/
     .       "** INPUTS:       USER PROVIDES ALL INPUT PARAMETERS    **"/
     .       "**               VIA 'CRT-TERMINAL'.                   **"/
     .       "**                                                     **"/
     .       "** OUTPUTS:      A MATRIX GRID OUTPUT WITH MEAN VALUE **"/
     .       "**                IS GENERATED TO THE HP-2608 PRINTER. **"/
     .       "**                                                     **"/
     .       "** WRITTEN BY:   JOHN S. HICKEY (ACI) 533-7590         **"/
     .       "**                                                     **"/
     .       "** MODIFIED BY:  BILL JEFFRIES  (CSC) 830-1000 EXT 507**"/
     .       "*********************************************************"/
     .       //)
C
C**********************************************************
C** ASK FOR DATE & TIME:  YEAR,MONTH,DAY,HOUR,MINUTES    **
C**********************************************************
C
      WRITE(LU,400)
400   FORMAT("Ɛ&dBENTERƐ&d@ Date & Time of Data? (yy,mm,dd,hh,mm): _")
      READ(LU,*) IYR,MN,IDA,IHR,MIN
      IYR = IYR + 1900
C
C*****************************************
C** ASK FOR RANGE OF LATITUDE? (-90,90)**
C*****************************************
C
      WRITE(LU,401)
401   FORMAT("Ɛ&dBENTERƐ&d@ Range of Latitude? (-90,90):            _")
      READ(LU,*) ILAT1,ILAT2
C
C*****************************************
C** ASK FOR LATITUDE INCREMENT?(5 - 10)**
C*****************************************
C
      WRITE(LU,402)
402   FORMAT("Ɛ&dBENTERƐ&d@ Latitude Increment? (5 or 10):          _")
      READ(LU,*) LINC
C
C** COMPUTE NUMBER OF LATITUDE POINTS
C
      ILAT = ((ILAT2 - ILAT1)/LINC)+1
C
C** STORE LATITUDES INTO XLATT ARRAY
C
      XLATT(1) = ILAT1
      DO 450 I=2,ILAT
      XLATT(I) = XLATT(I-1) + LINC
450   CONTINUE
C
C*******************************************
C** ASK FOR RANGE OF LONGITUDE? (0,360)   **
```

TABLE 1. (Continued)

```
C********************************************
C
      WRITE(LU,403)
  403 FORMAT("␛&dBENTER␛&d@ Range of Longitude? (0,360):            _")
      READ(LU,*) ILON1,ILON2
C
C********************************************
C** ASK FOR LONGITUDE INCREMENT? (5 - 10)**
C********************************************
C
      WRITE(LU,404)
  404 FORMAT("␛&dBENTER␛&d@ Longitude Increment? (5 or 10):         _")
      READ(LU,*) LLINC
C
C** COMPUTE THE NUMBER OF LONGITUDE POINTS
C
      ILNG = ((ILON2 - ILON1)/LLINC)+1
C
C** STORE LONGITUDES INTO XLONG ARRAY
C
      XLONG(1) = ILON1
      DO 451 I=2,ILNG
      XLONG(I) = XLONG(I-1) + LLINC
  451 CONTINUE
C
C**************************************************
C** ASK FOR USER INPUTS:                         **
C**   Z    --  ALTITUDE                          **
C**   F10  --  SOLAR RADIO NOISE FLUX            **
C**   F10B --  81-DAY AVERAGE F10                **
C**     GI --  GEOMAGNETIC ACTIVITY INDEX        **
C**************************************************
C
      WRITE(LU,605)
  605 FORMAT("␛&dBENTER␛&d@ Number of Altitude Cases? (1-10):      _")
      READ(LU,*) NALTS
      DO 606 KK=1,NALTS
      WRITE(LU,405) KK
  405 FORMAT("␛&dBENTER␛&d@ Altitude(km) # ",I2,
     1" (Z = 90 to 2500km):  _")
      READ(LU,*) ZALTS(KK)
  606 CONTINUE
C
C*****************************************
C** ASK USER FOR 'INDEX' VARIABLES     **
C**   I1 -- GEOMAGNETIC INDEX          **
C**   I2 -- DIURNAL EQUATION INDEX     **
C*****************************************
C
      WRITE(LU,409)
  409 FORMAT("␛&dBENTER␛&d@ Geomagnetic Index? (1-KP, 2-AP):        _")
      READ(LU,*) I1
      WRITE(LU,410)
  410 FORMAT("␛&dBENTER␛&d@ Diurnal Equ Index? (1-KP,2-F10B,3-AVG):_")
      READ(LU,*) I2
      WRITE(LU,406)
  406 FORMAT("␛&dBENTER␛&d@ Solar Radio Noise Flux? (F10= 0-460):  _")
      READ(LU,*) F10
      WRITE(LU,407)
  407 FORMAT("␛&dBENTER␛&d@ 81-Day Average F10? (F10B= 0-250):     _")
```

TABLE 1. (Continued)

```
      READ(LU,*) F10B
      IF(I1.EQ.2) WRITE(LU,408)
408   FORMAT("Ȩ&dBENTERȨ&d@ Geomagnetic Activity Index? (GI=0-400):_")
      IF(I1.EQ.1) WRITE(LU,412)
412   FORMAT("Ȩ&dBENTERȨ&d@ Geomagnetic Activity Index? (GI=0-9):  _")
      READ(LU,*) GI
C
C
C**********************************************
C** ASK FOR ELEMENTS TO PROCESS (1 - 12)     **
C**  1. ITEMP        7. IH                   **
C**  2. IXN2         8. IEM                  **
C**  3. IO2          9. IDEN                 **
C**  4. IO          10. IDLOG                **
C**  5. IA          11. IXTEM                **
C**  6. IHE         12. ALL OF THE ABOVE     **
C**********************************************
C
      WRITE(LU,411)
411   FORMAT(//,"***************************************************",/,
     .          "** SELECT DESIRED ELEMENTS TO PROCESS:           **",/,
     .          "**   1.  TEMPERATURE (K)   7.  HYDROGEN (H)      **",/,
     .          "**   2.  NITROGEN (N2)     8.  MEAN MOLE WT      **",/,
     .          "**   3.  OXYGEN (O2)       9.  DENSITY (KG/M3)   **",/,
     .          "**   4.  ATOM OXYGEN (O)  10.  LOG DEN (GM/CM3)  **",/,
     .          "**   5.  ARGON (A)        11.  EXO TEMP (K)      **",/,
     .          "**   6.  HELIUM (HE)      12.  ALL THE ABOVE     **",/,
     .          "***************************************************",/,
     .          "Ȩ&dBENTERȨ&d@ Selections? (1,3,7):   _")
      READ(LU,*) ( JV( J), J=1,11)
C
C** INITIALIZE VARIABLE ARRAY
C
      DO 453 I=1,11
      JVARY( I ) = 0
453   CONTINUE
      IF( JV( 1 ).NE.12) GO TO 456
      DO 457 I=1,11
      JVARY( I ) = 1
457   CONTINUE
      GO TO 458
456   DO 454 I=1,11
      IF( JV( I ).EQ.0) GO TO 454
      JVARY( JV( I )) = 1
454   CONTINUE
458   CONTINUE
C
C** PRINT HEADER AND TITLE INFORMATION
C
      DO 666 KL=1,NALTS
      Z( 1 )=ZALTS(KL)
      WRITE(6,109) IYR,MN,IDA,IHR,MIN,ILAT1,ILAT2,ILON1,ILON2,
     .             Z( 1 ),F10,F10B,GI,I1,I2
109   FORMAT("1",///," PROGRAM NAME:  J70MM",/,
     .               " -------------      ",//,
     .               " DATE & TIME:   "I4,1X,I2,1X,I2,1X,I2,1X,I2,/,
     .               " ------------   ",//,
     .               " LATITUDE RNG:  ",I4,",",I4,/,
     .               " ------------- ",//,
     .               " LONGITUDE RNG: ",I4,",",I4,/,
```

TABLE 1. (Continued)

```
     .                    " --------------- "//,
     .                    " ALTITUDE (KM): ",F5.1,/,
     .                    " --------------- ",//,
     .                    " F10:           ",F5.1,/,
     .                    " ----           ",//,
     .                    " F10B:          ",F5.1,/,
     .                    " -----          ",//,
     .                    " GI:            ",F5.1,/,
     .                    " ---            ",//,
     .                    " 1-KP,2-AP:     ",I2,/,
     .                    " ------------   ",//,
     .                    " 1-KP,2-F10B,3-AVG:  ",I2,/,
     .                    " -------------------  ",//)
C
C** INITIALIZE XMJD = 0.0 & IZ = 1
C
      XMJD = 0.0
      IZ = 1
C
C** INITIALIZE J COUNTER = 0
C
      J=0
C
C** LOOP TO PROCESS 'XLAT' DATA
C
      DO 202 III=1,ILAT
C
C** LOOP TO PROCESS 'XLONG' DATA
C
      DO 201 II=1,ILNG
      XLAT=XLATT(III)
      XLNG =XLONG(II)
C
C** LATITUDE -- LT,   LONGITUDE -- LD
C
      DO 200 I=1,IZ
      J=J+1
C
C** CHECK J COUNTER EXCEEDS 30 ?
C
      IF(J-30)52,52,51
C
C** RESET J COUNTER = 0
C
51    CONTINUE
      J=0
C
C** CALL 'TME' SUBROUTINE
C
   52 CONTINUE
      CALL TME(MN,IDA,IYR,IHR,MIN,XMJD,XLAT,XLNG,SDA,SHA,DD,DY)
C
C** CALL 'TINF' SUBROUTINE
C
C++++++++++++++++
C++ SET RE=0.31++
C++++++++++++++++
      RE = 0.31
      CALL TINF(F10,F10B,GI,XLAT,SDA,SHA,DY,RE,I1,I2,TE)
      T=TE
```

TABLE 1. (Continued)

```
      XTEMP(I) = TE
C
C** CALL 'JAC' SUBROUTINE
C
      CALL JAC(Z(I),T,TZZ(I),A(I,1),A(I,2),A(I,3),A(I,4),A(I,5),A(I,6),
     1EM(I),DENS(I),DL(I))
C
C** INITIALIZE VARIABLES
C
      ZZ=Z(I)
      DUMMY=0.
      DEN=0.
      DENLG(I)=0.
      DUMMY=DL(I)
      DEN=DL(I)
      YDAY=DD
      IF(ZZ-170.)20,20,50
C
C** CALL 'SLV' SUBROUTINE
C
   20 CALL SLV(DUMMY,ZZ,XLAT,YDAY)
      DENLG(I)=DUMMY
      GO TO 40
   50 IF(ZZ-500.)40,40,30
C
C** CALL 'SLVH' SUBROUTINE
C
   30 CALL SLVH(DEN,A(I,5),XLAT,SDA)
      DL(I)=DEN
   40 CONTINUE
      DL(I)=DL(I)+DENLG(I)
      DENS(I) = 10.**DL(I)
      XLAT=XLAT*(57.29577951)
C
C** COMPUTE DENMAT(II,III)
C
      DENMAT(II,III) = DENS(I) * 1000.
      TEMP(II,III) = TZZ(I)
      XN2(II,III) = A(I,1)
      O2MAT(II,III) = A(I,2)
      OMAT(II,III) = A(I,3)
      AMAT(II,III) = A(I,4)
      HEMAT(II,III) = A(I,5)
      HMAT(II,III) = A(I,6)
      WTMAT(II,III) = EM(I)
      DENLOG(II,III) = DL(I)
      EXTEM(II,III) = XTEMP(I)
  200 CONTINUE
  201 CONTINUE
  202 CONTINUE
C
C** PERFORM MATRIX PRINTOUT
C
      IF(JVARY(9).NE.0) CALL MATPR(1)
      IF(JVARY(1).NE.0) CALL MATPR(2)
      IF(JVARY(2).NE.0) CALL MATPR(3)
      IF(JVARY(3).NE.0) CALL MATPR(4)
      IF(JVARY(4).NE.0) CALL MATPR(5)
      IF(JVARY(5).NE.0) CALL MATPR(6)
      IF(JVARY(6).NE.0) CALL MATPR(7)
```

TABLE 1. (Continued)

```
      IF(JVARY(7).NE.0) CALL MATPR(8)
      IF(JVARY(8).NE.0) CALL MATPR(9)
      IF(JVARY(10).NE.0) CALL MATPR(10)
      IF(JVARY(11).NE.0) CALL MATPR(11)
  104 CONTINUE
 666  CONTINUE
C
C** ASK TO CONTINUE?
C
      WRITE(LU,888)
 888  FORMAT("Process Another Case? (Y or N): _")
      READ(LU,609) IPC
 609  FORMAT(A1)
      IF(IPC.EQ.1HY) GO TO 777
C
C** PROGRAM 'J70MM' COMPLETED
C
999   STOP
      END
$EMA(XDATA)
      SUBROUTINE MATPR(IP)
C***************************************************
C** SUBROUTINE 'MATPR' PERFORMS THE PRINTOUT OF    **
C** THE SPECIFIED MATRIX.                          **
C***************************************************
C
C** COMMON STATEMENTS
C
      COMMON /EDATA/ IYR,IDA,MN,IHR,MIN,XMJD,F10,F10B,GI,ILAT,ILNG,
     .               XLAT,XLNG,I1
      COMMON/XDATA/AMAT(73,37),DENMAT(73,37),DENLOG(73,37),HEMAT(73,37),
     .               HMAT(73,37),O2MAT(73,37),OMAT(73,37),TEMP(73,37),
     .               XN2(73,37),WTMAT(73,37),EXTEM(73,37)
      COMMON /FDATA/ A(300,6),DENLG(300),DENS(300),DL(300),EM(300),
     .               TZZ(300),XLATT(300),XLONG(300),Z(300),XTEMP(300)
C
C** DIMENSION STATEMENTS
C
      DIMENSION IHEAD(9,11),JMTH(24)
C
C** DATA STATEMENTS
C
      DATA JMTH/2HJA,2HN ,2HFE,2HB ,2HMA,2HR ,2HAP,2HR ,2HMA,2HY ,
     .          2HJU,2HN ,2HJU,2HL ,2HAU,2HG ,2HSE,2HP ,2HOC,2HT ,
     .          2HNO,2HV ,2HDE,2HC /
      DATA IHEAD/2HDE,2HNS,2HIT,2HIE,2HS ,2H(K,2HG/,2HM3,2H) ,
     .           2HTE,2HMP,2H. ,2HDE,2HG.,2H K,2H  ,2H  ,2H  ,
     .           2H(N,2H2),2H  ,2H  ,2H  ,2H  ,2H  ,2H  ,2H  ,
     .           2H(O,2H2),2H  ,2H  ,2H  ,2H  ,2H  ,2H  ,2H  ,
     .           2H(O,2H) ,2H  ,2H  ,2H  ,2H  ,2H  ,2H  ,2H  ,
     .           2H(A,2H) ,2H  ,2H  ,2H  ,2H  ,2H  ,2H  ,2H  ,
     .           2H(H,2HE),2H  ,2H  ,2H  ,2H  ,2H  ,2H  ,2H  ,
     .           2H(H,2H) ,2H  ,2H  ,2H  ,2H  ,2H  ,2H  ,2H  ,
     .           2HME,2HAN,2H M,2HOL,2H W,2HT ,2H  ,2H  ,2H  ;
     .           2HLO,2HG ,2HDE,2HN ,2H(G,2HM/,2HCM,2H3),2H  ,
     .           2HEX,2HOS,2HPH,2HER,2HIC,2H T,2HEM,2HP(,2HK)/
C
C** COMPUTE NGP
C
      NPG = ILAT / 7
```

TABLE 1. (Continued)

```
C
C** LOOP FOR NGP TIMES
C
      IF(MOD(ILAT,7) .NE. 0) NPG = NPG + 1
      DO 300 II=1,NPG
      ISTR = (II - 1) * 7 + 1
      ISTP = ISTR + 6
      IF(ISTP .GT. ILAT) ISTP = ILAT
C
C**WRITE HEADER
C
      INDX1 = (MN-1)*2 + 1
      JMON1 = JMTH(INDX1)
      JMON2 = JMTH(INDX1+1)
      IF(MIN.GT.10) WRITE(6,7000) (IHEAD(I,IP),I=1,9),II,JMON1,JMON2,
     1              IDA,IYR,XMJD,IHR,MIN,Z(1),F10,F10B,GI,I1
 7000 FORMAT(1H1,29X,9A2,51X,"PAGE ",I2,//
     11X,"DATE: ",2A2,I2," ",I4,"   JULIAN: ",F9.0,"   TIME: ",2I2,
     2"Z   ALTITUDE(KM): ",F7.1,/,1X,"F10:  ",F6.2,"   F10B: ",F6.2,
     3"   GI: ",F6.2,"   (1-KP OR 2-AP): ",I1)
      IF(MIN.LT.10) WRITE(6,8000) (IHEAD(I,IP),I=1,9),II,JMON1,JMON2,
     1              IDA,IYR,XMJD,IHR,MIN,Z(1),F10,F10B,GI,I1
 8000 FORMAT(1H1,29X,9A2,51X,"PAGE ",I2,//
     11X,"DATE: ",2A2,I2," ",I4,"   JULIAN: ",F9.0,"   TIME: ",I2,"0"I1,
     2"Z   ALTITUDE(KM): ",F7.1,/,1X,"F10:  ",F6.2,"   F10B: ",F6.2,
     3"   GI: ",F6.2,"   (1-KP OR 2-AP): ",I1)
C
C** PRINTOUT 'XLATT' ARRAY
C
      WRITE(6,7001) (XLATT(I),I=ISTR,ISTP)
 7001 FORMAT(1H0,30X,"(-SOUTH) LATITUDES (+NORTH)"/1X,"LON.",8X,
     17(F5.0,5X))
      WRITE(6,7003)
 7003 FORMAT(1H ,"(-WEST)"/1X,"(+EAST)"/)
C
C** PRINTOUT 'XLONG' ARRAY
C
      DO 250 J=1,ILNG
      IF(IP.EQ.1) WRITE(6,7002) XLONG(J),(DENMAT(J,I),I=ISTR,ISTP)
      IF(IP.EQ.2) WRITE(6,7002) XLONG(J),(  TEMP(J,I),I=ISTR,ISTP)
      IF(IP.EQ.3) WRITE(6,7002) XLONG(J),(   XN2(J,I),I=ISTR,ISTP)
      IF(IP.EQ.4) WRITE(6,7002) XLONG(J),( O2MAT(J,I),I=ISTR,ISTP)
      IF(IP.EQ.5) WRITE(6,7002) XLONG(J),(  OMAT(J,I),I=ISTR,ISTP)
      IF(IP.EQ.6) WRITE(6,7002) XLONG(J),(  AMAT(J,I),I=ISTR,ISTP)
      IF(IP.EQ.7) WRITE(6,7002) XLONG(J),( HEMAT(J,I),I=ISTR,ISTP)
      IF(IP.EQ.8) WRITE(6,7002) XLONG(J),(  HMAT(J,I),I=ISTR,ISTP)
      IF(IP.EQ.9) WRITE(6,7002) XLONG(J),( WTMAT(J,I),I=ISTR,ISTP)
      IF(IP.EQ.10) WRITE(6,7002) XLONG(J),(DENLOG(J,I),I=ISTR,ISTP)
      IF(IP.EQ.11) WRITE(6,7002) XLONG(J),( EXTEM(J,I),I=ISTR,ISTP)
 7002 FORMAT(1H ,F4.0,4X,7E10.4)
 250  CONTINUE
 300  CONTINUE
C
C** COMPUTE AND PRINT MEAN
C
      NPTS=ILNG*ILAT
      TOT=0.0
      DO 10 I=1,ILAT
      DO 20 J=1,ILNG
      IF(IP.EQ.1) TOT=DENMAT(J,I)+TOT
```

TABLE 1. (Continued)

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```
      IF(IP.EQ.2) TOT=  TEMP(J,I)+TOT
      IF(IP.EQ.3) TOT=   XN2(J,I)+TOT
      IF(IP.EQ.4) TOT= O2MAT(J,I)+TOT
      IF(IP.EQ.5) TOT=  OMAT(J,I)+TOT
      IF(IP.EQ.6) TOT=  AMAT(J,I)+TOT
      IF(IP.EQ.7) TOT= HEMAT(J,I)+TOT
      IF(IP.EQ.8) TOT=  HMAT(J,I)+TOT
      IF(IP.EQ.9) TOT= WTMAT(J,I)+TOT
      IF(IP.EQ.10)TOT=DENLOG(J,I)+TOT
      IF(IP.EQ.11)TOT= EXTEM(J,I)+TOT
20    CONTINUE
10    CONTINUE
      XMEAN=TOT/FLOAT(NPTS)
      WRITE(6,444) NPTS,XMEAN
 444  FORMAT(//,1X,"Number of Data Values:",I5,5X," Mean Value: ",
     *E10.4)
C
C** RETURN TO CALLING PROGRAM
C
      RETURN
      END
      SUBROUTINE TINF(F10,F10B,GI,XLAT,SDA,SHA,DY,RE,I1,I2,TE)
C*************************************************************
C** SUBROUTINE 'TINF' CALCULATES THE EXOSPHERIC TEMPERATURE **
C** ACCORDING TO JACCHIA SAO NO. 313, 1970.                 **
C**                                                         **
C**   F10 = SOLAR RADIO NOISE FLUX (XE-22 WATTS/M**2)       **
C**   F10B= 81-DAY AVERAGE F10                              **
C**   GI  = GEOMAGNETIC ACTIVITY INDEX                      **
C**   LAT = GEOGRAPHIC LATITUDE AT PERIGEE  (IN RAD)        **
C**   SDA = SOLAR DECLINATION ANGLE         (IN RAD)        **
C**   SHA = SOLAR HOUR ANGLE                                **
C**   DY  = D/Y (DAY NUMBER/TROPICAL YEAR); 1               **
C**   I1  = GEOMAGNETIC EQUATION INDEX(1--GI=KP, 2--GI=AP.  **
C**   I2  = DIURNAL EQU INDEX (1--R(KP),2--R(F10B),3-R(AVG).**
C**   RE  = DIURNAL FACTOR  KP,F10B,AVG.                    **
C**                                                         **
C** CONSTANTS -- C=SOLAR ACTIVITY VARIATION.                **
C**           -- BETA,ETC. = DIURNAL VARIATION.             **
C**           -- D=GEOMAGNETIC VARIATION.                   **
C**           -- E=SEMIANNUAL VARIATION.                    **
C**                                                         **
C*************************************************************
C
C** DATA STATEMENTS
C
      DATA C1/383.0/
      DATA C2/3.32/
      DATA C3/1.80/
      DATA PI/3.14159/
C
C** PERFORM CALCULATIONS
C
      CON = PI/180.
      BETA= -37.0*CON
      GAMMA= 43.0*CON
      P   =   6.0*CON
      XM  =   2.5
      XNN =   3.0
C
```

TABLE 1. (Continued)

```
C** INITIALIZE GEOMAGNETIC VARIATION VARIABLES
C
      D1 =  28.0
      D2 =   0.03
      D3 =   1.0
      D4 = 100.0
      D5 =  -0.08
C
C** INITIALIZE SEMIANNUAL VARIATION VARIABLES
C
      E1 =   2.41
      E2 =   0.349
      E3 =   0.206
      E4 = 360.*CON
      E5 = 226.5*CON
      E6 = 720.*CON
      E7 = 247.6*CON
      E8 =   0.1145
      E9 =   0.5
      E10= E4
      E11= 342.3*CON
      E12=  2.16
C
C** SOLAR ACTIVITY VARIATION
C
      TC = C1 + C2*F10B + C3*(F10 - F10B)
C
C** DIURNAL VARIATION
C
      ETA    = 0.5*ABS(XLAT - SDA)
      THETA  = 0.5*ABS(XLAT + SDA)
      TAU    = SHA + BETA + P*SIN(SHA + GAMMA)
      TPI=2*PI
      IF(TAU) 210,230,230
  210 IF(TAU+PI) 220,250,250
  220 TAU=TAU+TPI
      GO TO 210
  230 IF(TAU-PI) 250,250,240
  240 TAU=TAU-TPI
      GO TO 230
  250 CONTINUE
C
C********************************
C** SET R = RE  (RE = 0.31)    **
C********************************
C
      RE = 0.31
      R = RE
      A1 =(SIN(THETA))**XM
      A2 =(COS(ETA))**XM
      A3 =(COS(TAU/2.))**XNN
      B1 = 1.0 + R*A1
      B2 =(A2-A1)/(1. + R*A1)
      TV = B1*( 1. + R*B2*A3)
      TL = TC*TV
C
C** GEOMAGNETIC VARIATION
C
      IF (I1-1) 50,50,60
   50 TG = D1*GI + D2*EXP(GI)
```

TABLE 1. (Continued)

```
      GO TO 70
   60 TG = D3*GI + D4*(1-EXP(D5*GI))
   70 CONTINUE
C
C** SEMIANNUAL VARIATION
C
      G3 = 0.5*(1.0 + SIN(E10*DY +E11) )
      G3 = G3**E12
      TAU1 = DY + E8*(G3 - E9)
      G1 = E2 + E3*(SIN(E4*TAU1 + E5))
      G2 = SIN(E6*TAU1+ E7)
      TS = E1 + F10B*G1*G2
C
C** EXOSPHERIC TEMPERATURE
C
      TE = TL + TG + TS
C
C** RETURN TO CALLING PROGRAM
C
      RETURN
      END
      SUBROUTINE TME(MN,IDA,IYR,IHR,MIN,XMJD,XLAT,XLNG,SDA,SHA,DD,DY)
C*********************************************************************
C** SUBROUTINE 'TME' PERFORMS THE CALCULATIONS OF THE SOLAR DECLI- **
C** NATION ANGLE AND SOLAR HOUR ANGLE.                              **
C**                                                                 **
C** INPUTS:  MN  = MONTH                                            **
C**          IDA = DAY                                              **
C**          IYR = YEAR                                             **
C**          IHR = HOUR                                             **
C**          MIN = MINUTE                                           **
C**          XMJD= MEAN JULIAN DATE (IF=0 THEN XMJD IS CALCULATED) **
C**          XLAT= LATITUDE (INPUT-GEOCENTRIC LATITUDE)             **
C**          XLNG= LONGITUDE(INPUT-GEOCENTRIC LONGITUDE,-180,+180) **
C**                                                                 **
C** OUTPUTS: SDA = SOLAR DECLINATION ANGLE (RAD)                    **
C**          SHA = SOLAR HOUR ANGLE (RAD)                           **
C**          DD  = DAY NUMBER FROM 1 JAN.                           **
C**          DY  = DD/TROPICAL YEAR
C*********************************************************************
C
C** DIMENSION STATEMENTS
C
      DIMENSION IDAY(12)
C
C** DATA STATEMENTS
C
      DATA IDAY/31,28,31,30,31,30,31,31,30,31,30,31/
      DATA YEAR/365.2422/
C
C** SET CONTSTANTS
C
      XLAT=XLAT/57.29577951
      YR=IYR
      J=IYR-4*(IYR/4)
      IF(J)10,5,10
    5 IDAY(2)=29
   10 CONTINUE
      IF (MN-1) 3,3,4
    3 DD=IDA
```

TABLE 1. (Continued)

```
      GO TO 6
    4 KE=MN-1
      ID=0
      DO 20 I=1,KE
      ID = ID + IDAY(I)
   20 CONTINUE
      ID = ID + IDA
      DD = ID
    6 DY = DD/YEAR
C
C** COMPUTE MEAN JULIAN DATE IF XMJD = 0
C
      IF(XMJD) 30,25,30
   25 XMJD = 2439856. + 365.*(YR-1968.) + DD
      LDD = (IYR-1965)/4
      XMJD = XMJD + LDD
   30 FMJD = XMJD - 2435839.
C
C** COMPUTE GREENWICH MEAN TIME IN MINUTES GMT
C
      XHR = IHR
      XMIN = MIN
      GMT = 60*XHR + XMIN
C
C** COMPUTE GREENWICH MEAN POSITION - GP (IN DEG)
C
      XJ = (XMJD - 2415020.0)/(36525.0)
      A1=99.6909833
      A2 = 36000.76854
      A3 = 0.00038708
      A4 = 0.25068447
      GP = A1 + A2*XJ + A3*XJ*XJ + A4*GMT
      N = GP/360.
      XN = N
      GP = GP - XN*360.
C
C** COMPUTE RIGHT ASCENSION POINT - RAP (IN DEG)
C
C** 1ST CONVERT GEOCENTRIC LONGITUDE TO DEG LONGITUDE - WEST NEG + EAST
C
      IFACT = XLNG/180.
      XFACT = IFACT
      XLNG=XLNG-360.*XFACT
C
      RAP = GP + XLNG
      N = RAP/360.
      XN = N
      RAP = RAP - XN*360.
C
C** COMPUTE CELESTIAL LONGITUDE - XLS (IN RAD) - -ZERO TO 2PI
C
      B1 = 0.017203
      B2 = 0.0335
      B3 = 1.410
      Y1 = B1*FMJD
      XLS = Y1 + B2*SIN(Y1) - B3
      TPI = 6.28318
      N = XLS/TPI
      XN = N
      XLS = XLS - XN*TPI
```

TABLE 1. (Continued)

```
C
C** COMPUTE SOLAR DECLINATION ANGLE - SDA (IN RAD)
C
      B4 = (TPI/360.)*23.45
      SDA = ASIN(SIN(XLS)*SIN(B4))
C
C** COMPUTE RIGHT ASCENSION OF SUN - RAS (IN RAD) - -ZERO TO 2PI
C
      RAS = ASIN(TAN(SDA)/TAN(B4))
C
C** PUT RAS IN SAME QUADRANT AS XLS
C
      PI = 3.14159
      PI2 = PI/2.
      PI32= 3.*PI2
      RAS = ABS(RAS)
      TEMP = ABS(XLS)
      IF(TEMP - PI2) 130,130,100
  100 IF(TEMP - PI) 105,105,110
  105 RAS = PI - RAS
      GO TO 130
  110 IF(TEMP - PI32) 115,115,120
  115 RAS = PI + RAS
      GO TO 130
  120 RAS = TPI - RAS
  130 IF (XLS) 135,140,140
  135 RAS = -RAS
  140 CONTINUE
C
C** COMPUTE SOLAR HOUR ANGLE - SHA (IN DEG) - -
C
      SHA = RAP*(PI/180.) - RAS
      IF(SHA) 210,230,230
  210 IF(SHA+PI) 220,250,250
  220 SHA=SHA+TPI
      GO TO 210
  230 IF(SHA-PI) 250,250,240
  240 SHA=SHA-TPI
      GO TO 230
  250 CONTINUE
C
C** RETURN TO CALLING PROGRAM
C
      IDAY(2)=28
      RETURN
      END
      SUBROUTINE JAC(Z,T,TZ,AN,AO2,AO,AA,AHE,AH,EM,DENS,DL)
C*********************************************************
C** SUBROUTINE 'JAC' PERFORMS THE SIMPSONS RULE QUADRA- **
C** TURE (SRQ4) IMPLEMENTED BY G. F. KUNCIR.            **
C**                                                     **
C**  A    = LOWER LIMIT OF INTEGRATION                  **
C**  D    = UPPER LIMIT OF INTEGRATION                  **
C**  FUNC = INTEGRAND FUNCTION SUBPROGRAM               **
C**  EPS  = RELATIVE ERROR CONVERGENCE CRITERION        **
C**  M    = MAXIMUM NUMBER OF INTEGRATIONS              **
C**  R    = RESULT OF INTEGRATION                       **
C**  N    = NUMBER OF INTEGRATIONS REQUIRED TO FIND R   **
C**                                                     **
C*********************************************************
```

TABLE 1. (Continued)

```
C
C** DIMENSION STATEMENTS
C
      DIMENSION ALPHA(6),EI(6),DI(6),B(7),DIT(6)
C
C** DATA STATEMENTS
C
      DATA QQ/100./
      DATA ALPHA/0.0,0.0,0.0,0.0,-.380,0.0/
      DATA AV/6.02257E23/
      DATA EI/28.0134,31.9988,15.9994,39.948,4.0026,1.00797/
      DATA B/28.15204,-0.085586,1.2840E-04,-1.0056E-05,-1.0210E-05,
           1.5044E-06,9.9826E-08/
      DATA QN/.78110/
      DATA QO2/.20955/
      DATA QA/.009343/
      DATA QHE/1.289E-05/
      DATA FK/8.31432/
C++
C++ SET VARIABLES
C++
      ALPHA( 1 ) = 0.0
      ALPHA( 2 ) = 0.0
      ALPHA( 3 ) = 0.0
      ALPHA( 4 ) = 0.0
      ALPHA( 5 ) = -.38
      ALPHA( 6 ) = 0.0
      AV = 6.02257E23
      EI( 1 ) = 28.0134
      EI( 2 ) = 31.9988
      EI( 3 ) = 15.9994
      EI( 4 ) = 39.948
      EI( 5 ) = 4.0026
      EI( 6 ) = 1.00797
      B( 1 ) = 28.15204
      B( 2 ) = -0.085586
      B( 3 ) = 1.2840E-04
      B( 4 ) = -1.0056E-05
      B( 5 ) = -1.0210E-05
      B( 6 ) = 1.5044E-06
      B( 7 ) = 9.9826E-08
      QN = .78110
      QO2 = .20955
      QA = .009343
      QHE = 1.289E-05
      FK = 8.31432
C
C** PERFORM CALCULATIONS
C
      TI = T
      TX=444.3807+.02385*TI-392.8292*EXP(-.0021357*TI)
      A2=2.*(T-TX)/3.14159265
      DIT(6)=0.
      M=10
      EPS=.0001
      T1=1.9*(TX-183.)/35.
      T4=3.*(TX-183.-2.*T1*35./3.)/(35.**4)
      T3=-T1/(3.*35.**2)+4.*T4*35./3.
      TZ=TX+T1*(Z-125.)+T3*(Z-125.)**3+T4*(Z-125.)**4
      IF (Z-105.) 43,43,40
```

TABLE 1. (Continued)

```
   43 Z2 = Z - QQ
      EM=B(1)+B(2)*Z22+B(3)*Z22**2+B(4)*Z22**3+B(5)*Z22**4+B(6)*Z22**5
     1+B(7)*Z22**6
      D=Z
70    CONTINUE
      A=90.
      FA=B(1)+B(2)*(A-QQ)+B(3)*(A-QQ)**2+B(4)*(A-QQ)**3+B(5)*(A-QQ)**4
     1+B(6)*(A-QQ)**5 +B(7)*(A-QQ)**6
      FA=FA*9.80655/((1.+A/6.356766E+3)**2)
      FA=FA/(TX+T1*(A-125.)+T3*(A-125.)**3 +T4*(A-125.)**4)
      FD=B(1)+B(2)*(D-QQ)+B(3)*(D-QQ)**2+B(4)*(D-QQ)**3+B(5)*(D-QQ)**4
     1+B(6)*(D-QQ)**5 +B(7)*(D-QQ)**6
      FD=FD*9.80665/((1.+D/6.356766E+3)**2)
      FD=FD/(TX+T1*(D-125.)+T3*(D-125.)**3 +T4*(D-125.)**4)
C
C** INITIALIZE COUNTERS
C
      N=0
      PREV=0.
      SONE=(D-A)*(FA+FD)/2.
71    N=N+1
      IF (N-M) 72,72,75
72    NINT=2**N
      STWO=0.
      DEL=(D-A)/FLOAT(NINT)
      DO 73 I=1,NINT,2
      X=A+DEL*FLOAT(I)
      FX=B(1)+B(2)*(X-QQ)+B(3)*(X-QQ)**2+B(4)*(X-QQ)**3+B(5)*(X-QQ)**4
     1+B(6)*(X-QQ)**5 +B(7)*(X-QQ)**6
      FX=FX*9.80665/((1.+X/6.356766E+3)**2)
      FX=FX/(TX+T1*(X-125.)+T3*(X-125.)**3 +T4*(X-125.)**4)
73    STWO=STWO+FX
      CUR=SONE+4.*DEL*STWO
      IF (EPS*ABS(CUR)-ABS(CUR-PREV)) 74,75,75
74    PREV=CUR
      SONE=(SONE+CUR)/4.
      GO TO 71
75    R=CUR/3
      IF (Z-105.) 44,76,44
  44  IF (D-105.) 76,55,76
76    DENS=3.46E-9*183.*EM*EXP(-R/FK)/(TZ*28.878)
      DL=ALOGT(DENS)
      PAR=AV*DENS/EM
      AN=ALOGT(QN*EM*PAR/28.96)
      AA=ALOGT(QA*EM*PAR/28.96)
      AHE=ALOGT(QHE*EM*PAR/28.96)
      AO=ALOGT(2.*PAR*(1.-EM/28.96))
      AO2=ALOGT(PAR*(EM*(1.+QO2)/28.96-1.))
      AH=-0.
C
C** RETURN TO CALLING PROGRAM
C
      RETURN
C
C** CONTINUE CALCULATIONS
C
   40 Z3=105.
      TZ3=TX+T1*(Z3-125.)+T3*(Z3-125)**3+T4*(Z3-125)**4
      ZM3=B(1)+B(2)* 5.+B(3)* 25.+B(4)* 125.+B(5)* 5.**4.+B(6)* 5.**5.
     1+B(7)* 5.**6.
```

TABLE 1. (Continued)

```
      D=105.
      GO TO 70
55    DEN1=3.46E-9*183.*ZM3*EXP(-R/FK)/(TZ3*28.878)
      PAR=AV*DEN1/ZM3
      DI(1)=QN*ZM3*PAR/28.96
      DI(2)=PAR*(ZM3*(1.+QO2)/28.96-1.)
      DI(3)=2.*PAR*(1.-ZM3/28.96)
      DI(4)=QA*ZM3*PAR/28.96
      DI(5)=QHE*ZM3*PAR/28.96
      IF(Z-125.) 56,56,90
56    CONTINUE
      A1=105.
      FA1=9.80665/((1.+A1/6.356766E+3)**2)
      FA1=FA1/(TX+T1*(A1-125.)+T3*(A1-125.)**3+T4*(A1-125.)**4)
      D1=Z
      FD1=9.80665/((1.+D1/6.356766E+3)**2)
      IF(D1-125.) 45,45,50
   45 FD1=FD1/(TX+T1*(D1-125.)+T3*(D1-125.)**3+T4*(D1-125.)**4)
      GO TO 51
50    FD1=FD1/(TX+A2*ATAN(T1*(D1-125.)*(1.+4.5E-6*(D1-125.)**2.5)/A2))
      TZ=TX+A2*ATAN(T1*(Z-125.)*(1.+4.5E-6*(Z-125.)**2.5)/A2)
51    N=0
      PREV=0
      SONE=(D1-A1)*(FA1+FD1)/2.
81    N=N+1
      IF (N-M) 82,82,85
82    NINT=2**N
      STWO=0.
      DEL=(D1-A1)/FLOAT(NINT)
      DO 83 I=1,NINT,2
      X1=A1+DEL*FLOAT(I)
      FX1=9.80665/((1.+X1/6.356766E+3)**2)
      IF(X1-125.) 46,46,52
   46 FX1=FX1/(TX+T1*(X1-125.)+T3*(X1-125.)**3+T4*(X1-125.)**4)
      GO TO 83
52    FX1=FX1/(TX+A2*ATAN(T1*(X1-125.)*(1.+4.5E-6*(X1-125.)**2.5)/A2))
83    STWO=STWO+FX1
      CUR=SONE+4.*DEL*STWO
      IF (EPS*ABS(CUR)-ABS(CUR-PREV)) 84,85,85
84    PREV=CUR
      SONE=(SONE+CUR)/4.
      GO TO 81
85    R=CUR/3.
      DO 41  I=1,5
      DIT(I)=DI(I)*(TZ3/TZ)**(1.+ALPHA(I))*EXP(-EI(I)*R/FK)
   41 CONTINUE
      DENS=0
      DO 42 I=1,6
      DENS=DENS+EI(I)*DIT(I)/AV
42    CONTINUE
      EM=DENS*AV/(DIT(1)+DIT(2)+DIT(3)+DIT(4)+DIT(5)+DIT(6))
      DL=ALOGT(DENS)
      AN =ALOGT(DIT(1))
      AO2=ALOGT(DIT(2))
      AO =ALOGT(DIT(3))
      AA =ALOGT(DIT(4))
      AHE=ALOGT(DIT(5))
      IF(Z-500.) 47,48,48
   47 DIT(6)=10.**(-6)
   48 AH=ALOGT(DIT(6))
```

TABLE 1. (Continued)

```
      AN =AMAX1(-0., AN)
      AO2=AMAX1(-0.,AO2)
      AO =AMAX1(-0., AO)
      AA =AMAX1(-0., AA)
      AHE=AMAX1(-0.,AHE)
      AH =AMAX1(-0., AH)
C
C** RETURN TO CALLING PROGRAM
C
      RETURN
C
C** CONTINUE CALCULATIONS
C
90    S=TX+A2*ATAN(T1*375.*(1.+4.5E-6*375.**2.5)/A2)
      DI(6)=10.**(73.13-39.4*ALOGT(S)+5.5*ALOGT(S)*ALOGT(S))
      A1=500.
      IF(Z-500.) 49,60,60
   49 A1=Z
   60 FA1=9.80665/((1.+A1/6.356766E+3)**2)
      FA1=FA1/(TX+A2*ATAN(T1*(A1-125.)*(1.+4.5E-6*(A1-125.)**2.5)/A2))
      D1=Z
      IF(Z-500.) 61,62,62
   61 D1=500.
   62 FD1=9.80665/((1.+D1/6.356766E+3)**2)
      FD1=FD1/(TX+A2*ATAN(T1*(D1-125.)*(1.+4.5E-6*(D1-125.)**2.5)/A2))
      N=0
      PREV=0
      SONE=(D1-A1)*(FA1+FD1)/2.
91    N=N+1
      IF (N-M) 92,92,95
92    NINT=2**N
      STWO=0.
      DEL=(D1-A1)/FLOAT(NINT)
      DO 93 I=1,NINT,2
      X1=A1+DEL*FLOAT(I)
      FX1=9.80665/((1.+X1/6.356766E+3)**2)
      FX1=FX1/(TX+A2*ATAN(T1*(X1-125.)*(1.+4.5E-6*(X1-125.)**2.5)/A2))
93    STWO=STWO+FX1
      CUR=SONE+4.*DEL*STWO
      IF (EPS*ABS(CUR)-ABS(CUR-PREV)) 94,95,95
94    PREV=CUR
      SONE=(SONE+CUR)/4.
      GO TO 91
95    R=CUR/3.
      TZ=TX+A2*ATAN(T1*(Z-125.)*(1.+4.5E-6*(Z-125.)**2.5)/A2)
      IF(Z-500.) 63,64,64
   63 R=-R
   64 DIT(6)=DI(6)*(S/TZ)*EXP(-EI(6)*R/FK)
C
C** LOOP BACK FOR ADDITIONAL CALCULATIONS
C
      GO TO 56
C
C** RETURN TO CALLING PROGRAM
C
999   RETURN
      END
      SUBROUTINE SLV(DEN,ALT,XLAT,DAY)
C***********************************************************************
C** SUBROUTINE 'SLV' COMPUTES THE SEASONAL-LATITUDINAL    **
```

TABLE 1. (Continued)

```
C** VARIATION OF DENSITY IN THE LOWER THERMOSPHERE (IN   **
C** ACCORDANCE TO L. JACCHIA IN SAO 332, 1971.  THIS AF- **
C** FECTS THE DENSITIES BETWEEN 90 AND 160KM.  THIS SUB- **
C** ROUTINE NEED NOT BE CALLED FOR DENSITIES ABOVE 160KM,**
C** BECAUSE NO EFFECT IS OBSERVED.                       **
C**                                                      **
C** THE VARIATION SHOULD BE COMPUTED AFTER THE CALCULA-  **
C** TION OF DENSITY DUE TO TEMPERATURE VARIATIONS AND THE**
C** DENSITY (DEN) MUST BE IN THE FORM OF A BASE 10 LOG.  **
C** NO ADJUSTMENTS ARE MADE TO THE TEMPERATURE OR CONSTI-**
C** TUENT NUMBER DENSITIES IN THE REGION AFFECTED BY THIS**
C** VARIATION.                                           **
C**                                                      **
C**  DEN    = DENSITY (LOG10)                            **
C**  ALT    = ALTITUDE (KM)                              **
C**  XLAT   = LATITUDE (RAD)                             **
C**  DAY    = DAY NUMBER                                 **
C**                                                      **
C**********************************************************
C
C** INITIALIZE DENSITY (DEN) = 0.0
C
      DEN =0.0
C
C** CHECK IF ALTITUDE EXCEEDS 160KM?
C
      IF (160 - ALT) 999,5,5
C
C** COMPUTE DENSITY CHANGE IN LOWER THERMOSPHERE
C
    5 Z = ALT - 90.
      X = -0.0013*Z*Z
      Y = 0.0172*DAY + 1.72
      P = SIN(Y)
      SP = SIN(XLAT)
      SP = SP*SP
      S = 0.014*Z*EXP(X)
      D = S*P*SP
C
C** CHECK TO COMPUTE ABSOLUTE VALUE OF 'XLAT'
C
      IF (XLAT) 10,15,15
   10 D = -D
   15 DEN = D
C
C** RETURN TO CALLING PROGRAM
C
999   RETURN
      END
      SUBROUTINE SLVH(DEN,DENHE,XLAT,SDA)
C*********************************************************
C** SUBROUTINE 'SLVH' COMPUTES THE SEASONAL-LATITUDINAL **
C** VARIATION OF THE HELIUM NUMBER DENSITY (ACCORDING   **
C** TO L. JACCHIA IN SAO 332, 1971).  THIS CORRECTION   **
C** IS NOT IMPORTANT BELOW ABOUT 500KM.                 **
C**                                                     **
C**  DEN   = DENSITY (LOG10)                            **
C**  DENHE = HELIUM NUMBER DENSITY (LOG10)              **
C**  XLAT  = LATITUDE (RAD)                             **
C**  SDA   = SOLAR DECLINATION ANGLE (RAD)              **
```

TABLE 1. (Concluded)

```
C*********************************************************
C
C** PERFORM CALCULATIONS
C
      D0 = 10.**DENHE
      A = 0.65*(SDA/0.40909079)
C
C** CHECK TO COMPUTE ABSOLUTE VALUE OF 'A'
C
      IF(A) 5,10,10
    5 A   = -A
   10 B   = 0.5*XLAT
C
C** CHECK TO COMPUTE ABSOLUTE VALUE OF 'B'
C
      IF(SDA) 15,20,20
   15 B   = -B
C
C** COMPUTE X,Y,DHE, AND DENHE
C
   20 X   = 0.7854 - B
      Y   = SIN(X)
      Y   = Y*Y*Y
      DHE= A*(Y - 0.35356)
      DENHE = DENHE + DHE
C
C** COMPUTE HELIUM NUMBER DENSITY CHANGE
C
      D1 = 10.**DENHE
      DEL= D1 - D0
      RHO= 10.**DEN
      DRHO = (6.646E-24)*DEL
      RHO  = RHO + DRHO
      DEN  = ALOGT(RHO)
C
C** RETURN TO CALLING PROGRAM
C
      RETURN
      END
      BLOCK DATA
C*************************************
C** THIS IS THE BLOCK DATA FOR THE  **
C** 'J70MM' PROGRAM.                **
C*************************************
C
C** COMMON BLOCK DATA
C
      COMMON /EDATA/ IYR,IDA,MN,IHR,MIN,XMJD,F10,F10B,GI,ILAT,ILNG,
     .               XLAT,XLNG,I1
      COMMON /FDATA/ A(300,6),DENLG(300),DENS(300),DL(300),EM(300),
     .               TZZ(300),XLATT(300),XLONG(300),Z(300),XTEMP(300)
      END
      END$
```

TABLE 2. MSFC/J70 TEST CASE EXAMPLE RUN FOR TOTAL DENSITY COMPUTATION AT 600 km

```
                              DENSITIES (KG/M3)

DATE: MAR 21 1970   JULIAN:   2440667.   TIME: 1400Z   ALTITUDE(KM):   600.0
F10:  230.00   F10B: 230.00   GI: 400.00   (1-KP OR 2-AP): 2

                              (-SOUTH) LATITUDES (+NORTH)
LON.       -30.        -20.        -10.         0.         10.         20.         30.
(-WEST)
(+EAST)

  0.     .3399E-11  .3486E-11  .3540E-11  .3558E-11  .3539E-11  .3485E-11  .3398E-11
 10.     .3387E-11  .3473E-11  .3526E-11  .3544E-11  .3525E-11  .3472E-11  .3386E-11
 20.     .3337E-11  .3418E-11  .3469E-11  .3486E-11  .3469E-11  .3418E-11  .3336E-11
 30.     .3254E-11  .3329E-11  .3375E-11  .3391E-11  .3375E-11  .3328E-11  .3253E-11
 40.     .3146E-11  .3211E-11  .3252E-11  .3267E-11  .3252E-11  .3210E-11  .3145E-11
 50.     .3019E-11  .3074E-11  .3109E-11  .3121E-11  .3108E-11  .3073E-11  .3018E-11
 60.     .2882E-11  .2925E-11  .2953E-11  .2963E-11  .2953E-11  .2924E-11  .2881E-11
 70.     .2740E-11  .2771E-11  .2793E-11  .2801E-11  .2792E-11  .2771E-11  .2739E-11
 80.     .2600E-11  .2620E-11  .2635E-11  .2641E-11  .2635E-11  .2619E-11  .2599E-11
 90.     .2466E-11  .2476E-11  .2485E-11  .2489E-11  .2485E-11  .2476E-11  .2466E-11
100.     .2344E-11  .2344E-11  .2348E-11  .2350E-11  .2347E-11  .2344E-11  .2343E-11
110.     .2235E-11  .2227E-11  .2225E-11  .2226E-11  .2225E-11  .2226E-11  .2234E-11
120.     .2140E-11  .2126E-11  .2120E-11  .2120E-11  .2120E-11  .2125E-11  .2140E-11
130.     .2062E-11  .2042E-11  .2033E-11  .2032E-11  .2033E-11  .2042E-11  .2062E-11
140.     .2001E-11  .1976E-11  .1965E-11  .1963E-11  .1965E-11  .1976E-11  .2000E-11
150.     .1955E-11  .1927E-11  .1914E-11  .1911E-11  .1914E-11  .1927E-11  .1954E-11
160.     .1924E-11  .1894E-11  .1880E-11  .1877E-11  .1879E-11  .1893E-11  .1923E-11
170.     .1905E-11  .1874E-11  .1859E-11  .1856E-11  .1859E-11  .1874E-11  .1905E-11
180.     .1897E-11  .1865E-11  .1850E-11  .1847E-11  .1850E-11  .1865E-11  .1897E-11
190.     .1895E-11  .1863E-11  .1848E-11  .1844E-11  .1848E-11  .1863E-11  .1895E-11
200.     .1895E-11  .1863E-11  .1848E-11  .1845E-11  .1848E-11  .1863E-11  .1895E-11
210.     .1899E-11  .1867E-11  .1852E-11  .1849E-11  .1852E-11  .1867E-11  .1898E-11
220.     .1911E-11  .1880E-11  .1866E-11  .1863E-11  .1866E-11  .1880E-11  .1911E-11
230.     .1938E-11  .1909E-11  .1895E-11  .1892E-11  .1895E-11  .1909E-11  .1937E-11
240.     .1983E-11  .1958E-11  .1946E-11  .1944E-11  .1946E-11  .1957E-11  .1983E-11
250.     .2052E-11  .2031E-11  .2022E-11  .2020E-11  .2022E-11  .2030E-11  .2051E-11
260.     .2145E-11  .2131E-11  .2126E-11  .2126E-11  .2126E-11  .2131E-11  .2145E-11
270.     .2264E-11  .2258E-11  .2258E-11  .2259E-11  .2258E-11  .2258E-11  .2263E-11
280.     .2405E-11  .2410E-11  .2416E-11  .2419E-11  .2416E-11  .2409E-11  .2404E-11
290.     .2564E-11  .2581E-11  .2594E-11  .2600E-11  .2594E-11  .2581E-11  .2563E-11
300.     .2732E-11  .2763E-11  .2784E-11  .2792E-11  .2784E-11  .2763E-11  .2732E-11
310.     .2901E-11  .2946E-11  .2975E-11  .2985E-11  .2975E-11  .2945E-11  .2900E-11
320.     .3059E-11  .3117E-11  .3154E-11  .3166E-11  .3153E-11  .3116E-11  .3058E-11
330.     .3196E-11  .3265E-11  .3308E-11  .3323E-11  .3308E-11  .3264E-11  .3195E-11
340.     .3302E-11  .3380E-11  .3429E-11  .3445E-11  .3428E-11  .3379E-11  .3301E-11
350.     .3371E-11  .3455E-11  .3507E-11  .3525E-11  .3507E-11  .3454E-11  .3370E-11

Number of Data Values:  252        Mean Value:   .2522E-11
```

TABLE 3. DESIGN SPACE STATION G&C SYSTEM MEAN TOTAL DENSITY FOR A LOW INCLINATION ORBIT

Orbital Altitude*	Total Density (kg/m^3)**
1100 km (594 n.mi.)	0.5189×10^{-13}
1000 km (540 n.mi.)	0.1018×10^{-12}
900 km (486 n.mi.)	0.2105×10^{-12}
800 km (432 n.mi.)	0.4567×10^{-12}
700 km (378 n.mi.)	0.1042×10^{-11}
600 km (324 n.mi.)	0.2522×10^{-11}
555 km (300 n.mi.)	0.3847×10^{-11}
500 km (270 n.mi.)	0.6617×10^{-11}
463 km (250 n.mi.)	0.9719×10^{-11}
400 km (216 n.mi.)	0.1958×10^{-10}

Ref: $\bar{F}_{10.7}(230)$, A_p (400), March 21, 1400 UT

*The values of total density pertain to the kilometer altitude levels given. Nautical mile altitudes are approximated.

**Design density values obtained from Reference 10.

TABLE 4. PERCENTILES OF 13-MONTH SMOOTHED VALUES OF $F_{10.7}$ cm SOLAR RADIO FLUX AND A_p GEOMAGNETIC INDEX OVER THE MEAN SOLAR CYCLE

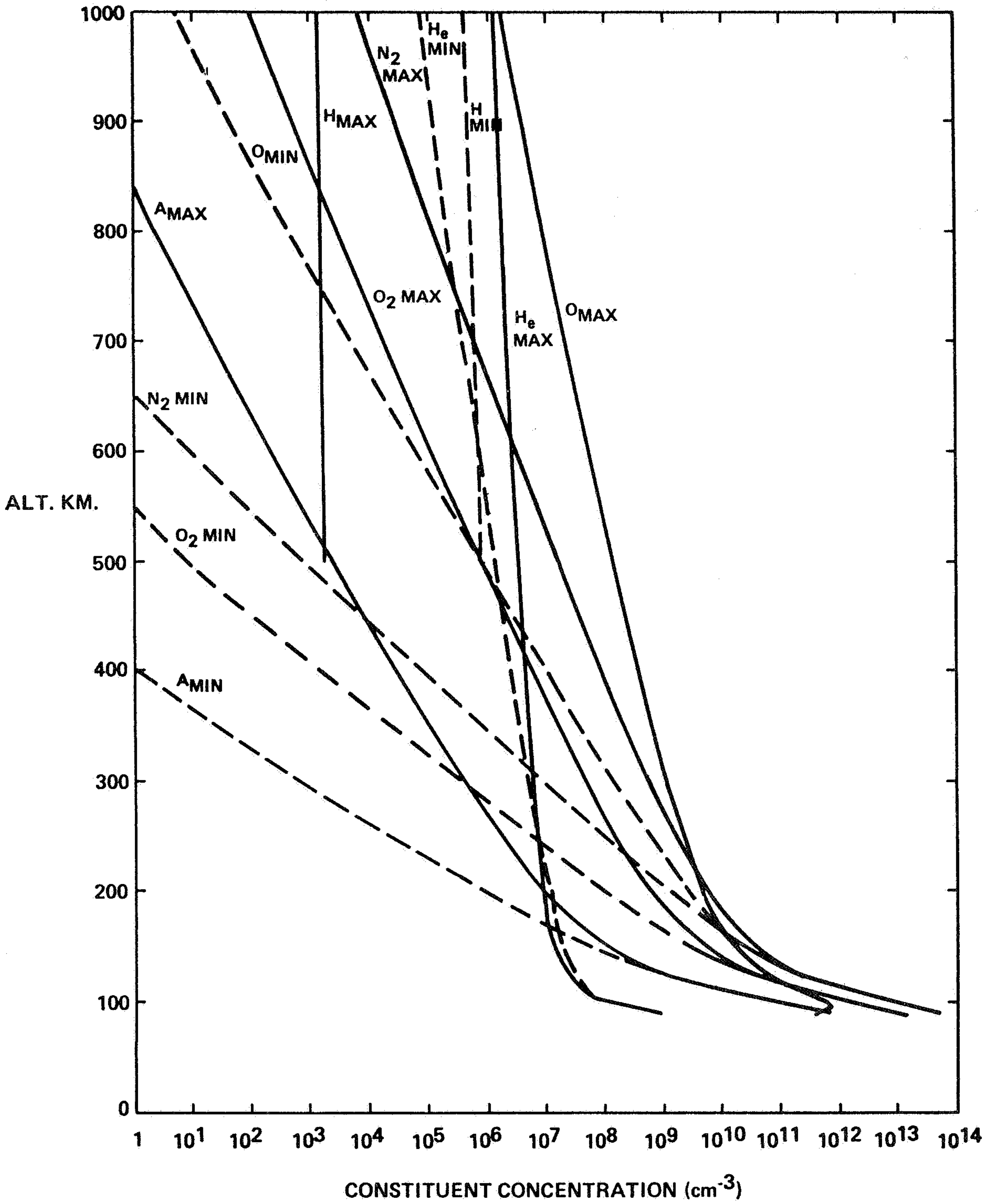
		F10.7			A_p		
YR	MO	97.5%	50%	2.5%	97.5%	50%	2.5%
1992,	05	242.9	154.0	100.6	18.1	12.6	10.5
	06	239.0	152.5	96.2	18.6	12.7	11.2
	07	234.2	150.5	96.1	19.1	12.6	11.3
	08	230.8	148.8	95.6	19.5	12.9	11.2
	09	231.2	143.3	93.1	20.1	13.2	11.4
	10	230.7	141.7	90.9	20.8	13.3	11.6
	11	228.2	140.2	89.8	21.2	13.4	11.7
	12	226.2	138.3	92.2	21.0	13.9	11.6
1993,	01	225.7	136.4	89.7	20.3	13.8	11.8
	02	224.5	134.5	87.4	20.5	14.1	12.0
	03	223.2	132.9	89.9	21.7	14.3	12.1
	04	219.9	126.9	88.8	22.5	13.9	12.0
	05	215.0	125.6	84.9	22.5	14.2	11.5
	06	211.4	124.5	85.0	22.1	14.2	11.2
	07	205.9	124.1	83.2	21.5	13.9	11.1
	08	200.8	123.5	84.8	21.3	13.7	11.3
	09	195.4	125.9	82.8	21.9	13.3	11.1
	10	189.9	124.9	81.6	22.9	13.5	11.4
	11	185.5	123.8	79.7	23.3	13.5	11.4
	12	180.8	122.7	78.3	23.2	13.5	11.4
1994,	01	176.4	121.5	77.0	23.1	13.5	11.0
	02	176.7	117.2	76.6	22.9	13.1	10.7
	03	178.1	118.2	75.5	21.6	13.0	10.9
	04	177.6	116.7	76.0	20.1	13.8	11.1
	05	175.5	115.4	75.3	19.5	14.0	11.6
	06	171.4	116.8	73.1	19.6	13.7	11.6
	07	165.8	114.7	73.8	19.9	13.4	11.4
	08	161.9	112.7	70.8	20.3	13.5	11.3
	09	160.8	113.4	71.1	20.5	13.6	11.4
	10	159.9	109.5	71.7	20.8	13.6	11.4
	11	158.1	108.1	70.5	20.9	13.5	11.2
	12	155.6	104.2	70.0	21.4	14.2	11.1
1995,	01	151.4	100.7	70.7	22.0	14.0	11.5
	02	145.9	99.7	70.4	21.8	13.3	11.5
	03	139.8	96.8	68.8	21.8	13.2	11.4
	04	133.8	97.8	69.9	22.0	13.0	11.4
	05	128.6	98.4	72.5	22.3	12.3	11.1
	06	126.3	98.7	72.5	22.6	12.1	11.3
	07	124.7	96.1	71.6	23.3	12.3	11.0
	08	122.2	93.6	71.5	24.0	12.2	11.2
	09	119.9	91.4	71.6	24.4	11.7	11.2
	10	118.4	90.7	71.4	24.7	11.7	11.2
	11	117.5	88.6	70.5	24.6	11.7	11.2
	12	117.5	87.5	70.0	24.2	12.2	11.2

TABLE 4. (Continued)

			F10.7			A_p	
YR	MO	97.5%	50%	2.5%	97.5%	50%	2.5%
1996,	01	116.3	86.3	70.1	23.4	12.2	11.8
	02	116.5	86.3	70.5	22.6	12.7	11.4
	03	117.5	86.6	69.8	21.9	12.8	11.2
	04	117.9	87.2	69.7	21.6	12.2	11.1
	05	118.0	86.3	68.2	21.2	11.9	11.2
	06	117.7	85.4	68.5	20.9	12.0	11.3
	07	116.8	83.0	67.6	20.3	12.1	10.5
	08	115.5	82.1	68.4	19.6	12.4	9.8
	09	113.5	82.6	67.9	19.6	12.5	9.6
	10	109.2	81.8	67.4	19.6	12.7	9.1
	11	103.5	81.2	67.3	19.4	12.9	9.1
	12	98.2	79.9	67.4	19.0	12.8	8.8
1997,	01	98.1	79.9	67.0	18.5	12.6	8.7
	02	98.8	78.3	67.1	17.8	12.6	9.3
	03	100.0	77.4	67.1	16.9	12.6	10.1
	04	100.4	76.9	67.3	16.4	12.5	10.5
	05	98.3	76.6	66.7	16.6	12.6	10.1
	06	95.2	76.3	66.9	16.8	12.7	9.8
	07	92.3	76.0	67.1	17.0	12.5	9.4
	08	91.0	75.6	67.2	17.3	12.4	8.9
	09	91.4	75.1	66.9	17.6	12.1	9.1
	10	91.6	73.8	66.8	17.5	12.0	9.3
	11	91.2	73.2	66.9	17.3	11.7	9.3
	12	90.8	72.6	67.1	16.8	11.6	9.3
1998,	01	90.2	72.9	66.7	16.0	11.5	9.1
	02	89.4	71.8	67.2	14.6	11.3	9.1
	03	88.5	71.6	67.2	13.5	11.0	9.1
	04	87.5	71.3	67.1	13.6	10.6	8.9
	05	86.3	70.5	67.2	13.3	10.4	8.5
	06	84.7	70.4	67.4	12.8	10.0	8.1
	07	82.6	70.4	67.8	12.6	9.5	7.9
	08	80.0	70.1	67.7	12.3	9.6	7.6
	09	77.6	70.3	68.0	11.7	9.6	7.6
	10	76.7	70.8	67.8	11.2	9.6	7.6
	11	76.4	71.7	67.7	11.0	9.6	7.7
	12	77.0	71.0	67.6	11.0	9.7	7.7
1999,	01	78.0	70.8	67.8	11.1	9.7	7.9
	02	79.5	70.4	67.5	11.1	9.8	8.1
	03	81.6	70.8	67.7	11.1	9.9	8.1
	04	83.4	70.9	67.4	11.4	10.0	8.1
	05	85.8	70.5	67.7	12.0	10.2	8.0
	06	88.7	70.5	68.0	12.9	9.9	7.8
	07	91.7	70.7	67.8	13.5	10.2	8.0
	08	94.6	70.9	68.7	14.1	10.4	8.1
	09	99.1	69.8	68.6	14.8	10.5	8.4
	10	104.6	71.5	68.5	15.6	10.9	8.3
	11	110.0	72.1	68.7	16.3	10.6	8.4
	12	114.5	72.9	69.2	17.3	11.4	8.4

TABLE 4. (Concluded)

			F10.7			A_p	
YR	MO	97.5%	50%	2.5%	97.5%	50%	2.5%
2000,	01	118.5	73.9	67.8	18.2	11.5	8.4
	02	122.0	74.9	68.5	18.5	11.4	8.6
	03	125.3	76.1	69.3	18.6	11.6	8.8
	04	130.2	77.3	70.1	18.5	11.8	8.9
	05	135.0	81.4	71.1	18.2	11.8	9.3
	06	140.5	83.0	72.0	18.0	11.8	9.7
	07	147.3	81.8	72.9	18.3	11.7	9.5
	08	153.2	83.6	70.9	18.3	11.9	9.2
	09	157.1	85.6	72.6	17.5	12.1	9.0
	10	159.7	91.0	74.6	17.0	12.8	9.5
	11	161.4	93.1	73.6	17.3	12.8	9.3
	12	163.8	95.2	75.6	17.3	12.4	9.5
2001,	01	166.8	97.3	74.1	18.4	12.5	9.8
	02	170.6	99.0	75.2	19.7	12.8	10.1
	03	174.7	100.9	72.7	19.8	12.9	9.9
	04	178.9	99.5	74.2	19.8	12.9	10.0
	05	184.5	101.5	75.1	19.9	13.0	10.3
	06	188.9	103.6	72.6	20.2	13.1	10.2
	07	190.2	106.1	75.5	20.6	12.7	10.4
	08	190.2	108.8	75.5	20.7	12.7	10.7
	09	189.4	111.4	75.9	20.8	12.6	10.6
	10	190.5	113.4	74.8	21.0	13.4	10.7
	11	193.6	111.5	75.8	21.4	13.5	10.3
	12	196.7	116.6	76.5	21.9	13.5	10.8
2002,	01	198.4	118.0	77.8	22.0	12.9	11.0
	02	203.4	119.2	81.0	20.8	12.9	10.8
	03	209.8	120.7	84.2	19.9	12.7	10.8
	04	213.2	122.4	85.2	19.6	12.3	10.7
	05	216.0	128.4	86.7	19.2	12.0	10.6
	06	220.0	130.8	88.4	19.1	12.1	10.7
	07	225.5	133.1	89.1	18.9	12.2	11.1
	08	228.3	135.4	91.1	18.7	12.4	10.8
	09	229.8	137.9	94.1	18.5	12.5	10.7
	10	231.9	140.2	96.5	18.5	12.4	10.6
	11	233.9	142.5	99.0	18.2	12.5	10.3
	12	237.3	149.1	100.7	18.1	12.6	10.5
2003,	01	241.1	151.3	97.4	18.6	12.7	11.2
	02	243.0	153.0	99.0	19.1	12.6	11.3
	03	242.1	154.6	97.8	19.5	12.9	11.2
	04	241.2	156.0	100.7	20.1	13.2	11.4



USING MSFC—J70—3

FOR: MIN SOLAR CONDITIONS: 0400 hrs. USING $F_{10.7} = 70$ & $Ap = 0$
MAX SOLAR CONDITIONS: 1400 hrs. USING $F_{10.7} = 230$ & $Ap = 35$

Figure 1. MSFC/J70 constituent number density for low and high solar conditions.

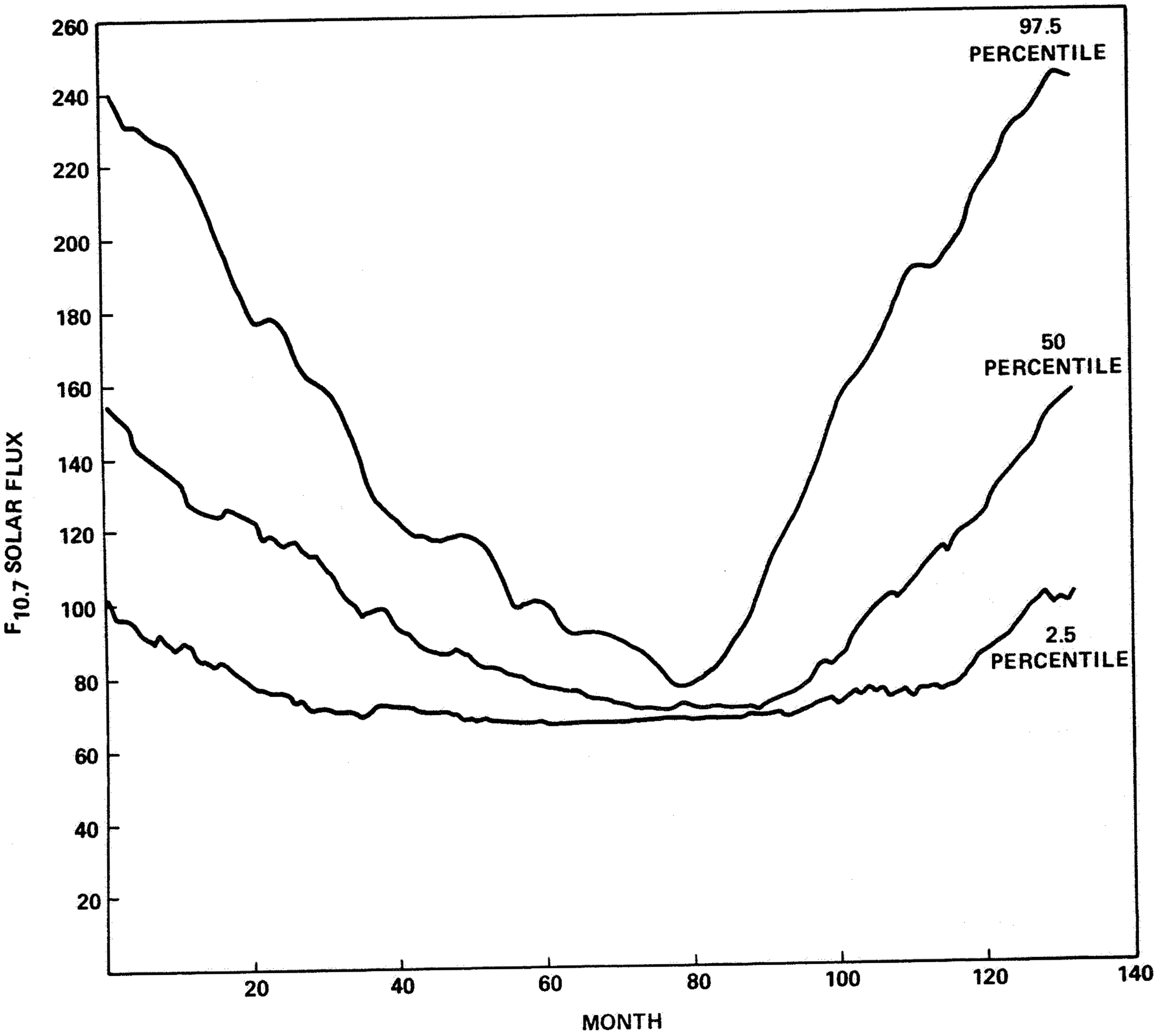


Figure 2. Percentiles of 13-month smoothed values of F10.7 cm solar radio flux over the mean solar cycle.

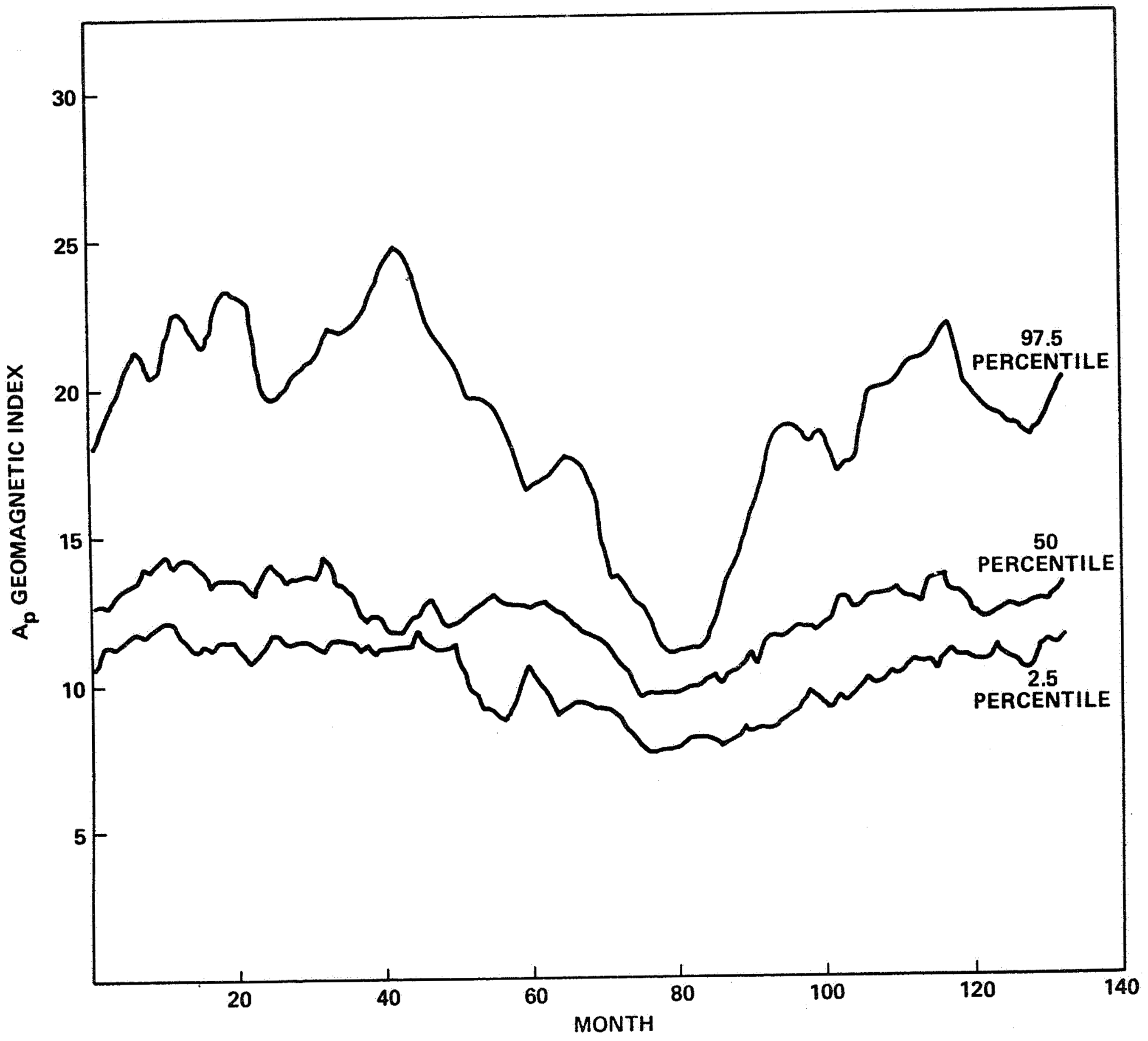


Figure 3. Percentiles of 13-month smoothed values of A_p geomagnetic index over the mean solar cycle.

APPROVAL

THE MSFC/J70 ORBITAL ATMOSPHERE MODEL AND THE DATA BASES FOR THE MSFC SOLAR ACTIVITY PREDICTION TECHNIQUE

By Dale L. Johnson and Robert E. Smith

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

G F McDonough

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