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We are pleased to forward five copies of the Semiannual Status Report on the above referenced grant.

This report covers the period ending 15 March 1973.

Sincerely,

John Vanderford

John Vanderford
Executive Officer
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JV:jm
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SEMIANNUAL STATUS REPORT

to

National Aeronautics and Space Administration

from

The University of Texas at Dallas
P. O. Box 30365
Dallas, Texas 75230
(214) 231-1471

on

"Investigations into the Mechanism and Rates of Atmospheric Mixing in the Lower Thermosphere"

NASA Grant NGL 44-004-026

For the Period Ending March 15, 1973

F. S. Johnson
Principal Investigator

Energy Input to the Lower Thermosphere*

by

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Abstract

The asymmetry in solar heat input to the upper atmosphere at the solstice, and the asymmetry in atomic oxygen production, are largely compensated by a large scale wind system towards the winter polar region. At magnetically disturbed times, atmospheric composition at high winter latitudes changes in such a way as to indicate that polar region heating by magnetic variations, energetic particle inputs, and current systems is more intense than solar heating at low latitudes, thus leading to a reversal of the normal pattern of atmospheric motion. Uncertainties in the intensity of solar radiation responsible for upper atmosphere heating and oxygen dissociation, and uncertainties in the degree of oxygen dissociation in the upper atmosphere, are such that the average rates of eddy mixing may be significantly lower than frequently assumed for the lower thermosphere.

*Presented at 2nd General Scientific Assembly of IAGA, Kyoto, Japan, September, 1973.
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10/5/73

A variety of heat inputs to the lower thermosphere have been recognized, mainly solar heating, energetic particles, electrical currents, dissipation of internal gravity waves, and viscous drag between ions and neutral winds. The most important of these, and the only one that is easily evaluated, is solar heating. While it is the more important single heat source, there are clearly important contributions from other sources, as the downward heat flow in the lower thermosphere clearly exceeds the solar input at higher levels.

The fact that atomic oxygen remains plentiful over the winter hemisphere and in particular over the winter polar region requires that there be a summer-to-winter wind system to carry atomic oxygen from the summer hemisphere to the winter polar region. This in turn established that polar heat sources - energetic particles and dissipation from electric currents - do not dominate over average solar heating even in the polar regions. At particularly disturbed times, the importance of polar heating may rival or exceed the solar heat input, but only for relatively short periods of time. It therefore seems likely that dissipation of internal gravity waves is probably the most important heat input after solar heating, and that this source is geographically widespread.

The nature of the solar heat input into the lower thermosphere is shown in Figure 1 for the equator at solstice (Johnson and Gottlieb, 1970).

The curve labelled O_2 indicates the total heat released above each altitude due to absorption of solar ultraviolet by molecular oxygen. The curve O + O indicates the heat released above each altitude by the recombination of atomic oxygen into molecules; the atomic oxygen is mainly produced by photodissociation of molecular oxygen above 90 km, and it diffuses downward to below 90 km to recombine. The curve O_3 indicates the heating due to absorption by ozone; any dissociation is followed by recombination very near the same altitude, so account need not be taken of the diffusion of chemical energy as in the case of dissociation of molecular oxygen above 90 km. The curve labelled IR represents the heat loss above each altitude by infrared radiation (Kuhn and London, 1969). The O curve shows the infrared loss above each altitude from atomic oxygen in the 62-micron line (Craig and Gille, 1969).

Figure 2 shows a family of curves for the total heat deposited above each altitude for various latitudes, the equatorial curve (O^o) being the total curve shown in Figure 1. The global average curve is also shown, and it should be valid for all seasons, although the curves for individual latitudes are for the summer solstice.

Although the solar ultraviolet heat input to the upper atmosphere at solstice is markedly asymmetric, the upper atmosphere is remarkably uniform in its composition and temperature. Other heat sources are not likely to compensate for the asymmetry in solar heat input, so Johnson and Gottlieb (1970 assumed that a meridional circulation compensated the asymmetry by producing adiabatic heating and cooling of such a magnitude as to correct the differences between the individual latitude curves and the average curve shown in Figure 2. The results for the required vertical velocities as a function of latitude are shown in Figure 3. Later Johnson and Gottlieb (1973) averaged these results over the summer and winter hemispheres to derive the average vertical motion in each hemisphere and the meridional horizontal wind across the equator required to maintain continuity, as shown in Figure 4.

The velocities shown in Figure 4 are substantiated by considerations of the world-wide atomic oxygen budget. The transport of atomic oxygen from the summer to the winter hemisphere produced by the wind system of Figure 4 is sufficient to compensate, and perhaps even over compensate, the asymmetry between the two hemispheres in photoproduction. Thus the wind system is a realistic one so far as the concept is concerned that the atomic oxygen concentrations over the winter hemisphere are maintained at the observed values by transport from the summer hemisphere. Figure 5 (Johnson and Gottlieb, 1973) compares the downward diffusive flux of atomic oxygen with the vertical transport associated with the hemispheric average vertical wind (up in summer hemisphere and down in winter). Also shown is the vertical flux associated with the vertical wind over the polar region as indicated in Figure 3. The atomic oxygen profile calculated by Colegrove et al. (1966), was used in determining the advective flux; the profile of Shimazaki and Laird (1970) is also shown for comparison. The downward diffusive flux near 90 km is almost an order of magnitude greater than the downward advective flux over the pole and over an order of magnitude greater than the hemispheric average downward advective flux.

It is interesting to note from Figure 1 that heating by recombination of atomic oxygen is so important near 85 km that the integrated heat release by atomic oxygen recombination above 80 km is about the same as the total of all of the local heating at all higher altitudes by ultraviolet absorption. However, that part of the heating over the winter polar region due to downward transport of atomic oxygen by vertical winds is very small compared to the adiabatic heating. This can be seen from Figure 5. The heating by recombination of downward advected atomic oxygen is small compared to that from diffusively transported oxygen, and the integrated heating above 80 km by diffusively transported oxygen is, according to Figure 1, approximately equivalent to the direct release of heat by ultraviolet absorption. The adiabatic heating takes the place of direct release of heat by ultraviolet absorption over the polar region, and hence is nearly an order of magnitude greater than the heat release by recombination of advected atomic oxygen.

Neutral atmospheric composition measurements from OGO-6 have been illuminating with regard to heat input to the thermosphere. Figure 6 shows results of a spherical harmonic analysis of data reduced to a standard altitude of 450 km for nitrogen, helium, and atomic oxygen (Hedin et al., 1973). Reber et al. (1971), also using OGO-6 data, found the helium concentration in the winter hemisphere to fall by about a factor of two between about 55^{o} and 90^{o}; this secondary minimum over the winter polar region has been largely lost in the spherical harmonic analysis averaging process according to the results shown in Figure 6. Keating et al. (1972) compared the drag on Explorer satellites with helium observations from OGO-6 and deduced a secondary temperature maximum over the winter pole, a higher than subsolar latitude in the summer hemisphere for the primary temperature maximum, and a maximum oxygen concentration at 120 km at low latitude in the winter hemisphere. These conclusions agree rather well with the OGO data extrapolated down to 120 km, as shown in Figure 7 (Hedin et al., 1973). A constant nitrogen concentration has been assumed at 120 km, and the helium and oxygen measured concentrations have been extrapolated to 120 km using a mean temperature between 120 km and the altitude of observations as determined from the nitrogen concentrations. The exospheric temperature distribution is also shown in Figure 7 and a larger difference between poles was found than is normally inferred from satellite drag.

The maximum oxygen concentration shown in Figure 7 occurs at somewhat higher latitude than deduced by Keating et al. The decrease in atomic oxygen concentration over the winter polar region can be associated with a reduction in the poleward circulation, which also fits with the concept of a polar heat source producing a weak secondary temperature maximum over the winter pole. However, the required increase in temperature must be below 100 km to greatly affect the atomic oxygen transport, whereas Keating's inference of higher polar temperature was for exospheric altitudes; both are probably correct. The helium reduction over the winter pole also suggests an important polar heat source below 100 km. The entire winter hemisphere above about 15° latitude is deficient in heat input relative to the world wide average, but the deficit over the winter pole is apparently less than at middle latitudes. Thus polar heat source apparently produces significant heating, both below 100 km and above.

At times of severe magnetic disturbance, the polar heating apparently becomes much more prominent. Figure 8 shows nitrogen and atomic oxygen (and helium) concentrations at 500 km on two successive days, one only moderately disturbed and the other severely disturbed. For the severely disturbed day, concentrations over the equator increased slightly over the moderately disturbed day for all constituents. However, at high latitudes nitrogen showed a dramatic increase, while atomic oxygen did not. As the time of observation was near equinox, both polar zones should have been heat deficit regions with low geomagnetic activity, and the global circulation was presumably upward over the equator, poleward in both hemispheres, and downward over the polar regions. This circulation pattern was responsible for maintenance of atomic oxygen over the polar regions. With increased magnetic activity, the polar region was dramatically warmed above 100 km, as indicated by the increased nitrogen concentrations. In addition, significant warming below 100 km can be inferred from the lack of a corresponding increase in the atomic oxygen concentrations. Apparently the poleward circulation near 100 km that controls the transport of atomic oxygen and helium was slowed down or stopped, thus reducing or cutting off the supply of atomic oxygen to the polar regions. Even with a marked temperature rise above 100 km, the atomic oxygen concentrations at 500 km did not rise, thus indicating a marked decrease in atomic oxygen concentration near 100 km.

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CAPTIONS

Figure 1 — Heat input into the upper atmosphere above given altitudes evaluated over the equator at solstice, according to Johnson and Gottlieb (1970). O_2 indicates heat released due to absorption by molecular oxygen of solar radiation in the wavelength range below 1875 Å; O_3 that due to absorption of solar radiation by ozone: O + O the heat release due to recombination of atomic into molecular oxygen; O the heat loss by infrared emission by atomic oxygen according to Craig and Gille (1969); IR the infrared losses due to other constituents according to Kuhn and London (1969).

Figure 2 — Net heat input into the upper atmosphere above given altitudes during the solstice, according to Johnson and Gottlieb (1970). The curve labeled O is for the equator and is the same as the total curve shown in Figure 1. Curves are shown for various latitudes, with summer latitudes shown as positive.

Figure 3 — Vertical velocities calculated for various latitudes to compensate for unsymmetrical solar heating input into the upper atmosphere at the solstice, according to Johnson and Gottlieb (1970). Positive labels apply to the summer hemisphere, negative to the winter.

Captions (continued)

Figure 4 Vertical velocity averaged over hemisphere (upward in summer and downward in winter) and average horizontal velocity required at equator to provide continuity.

Figure 5 Atomic oxygen concentration profile, downward diffusion flux and advective flux (upward in summer and downward in winter) for hemispheric average and polar vertical motions required to compensate inequalities in solar heat input at solstice.

Figure 6 Concentrations at 450 km of O, N_2, and He relative to equatorial concentration, inferred from measurements on OGO-6 (Hedin et al., 1973).

Figure 7 The latitudinal variation in atomic oxygen and helium concentrations at 120 km as derived from OGO-6 observations by Hedin et al. (1973), assuming constant nitrogen concentrations, expressed as ratios relative to the equatorial concentrations. The exospheric temperature latitudinal variation is also shown as the difference from the equatorial value.

Figure 8 Concentrations at 500 km of O, N_2, and He, inferred from measurements on OGO-6 for a day of moderate magnetic disturbance (7 March 1970) and a highly disturbed day (8 March 1970).

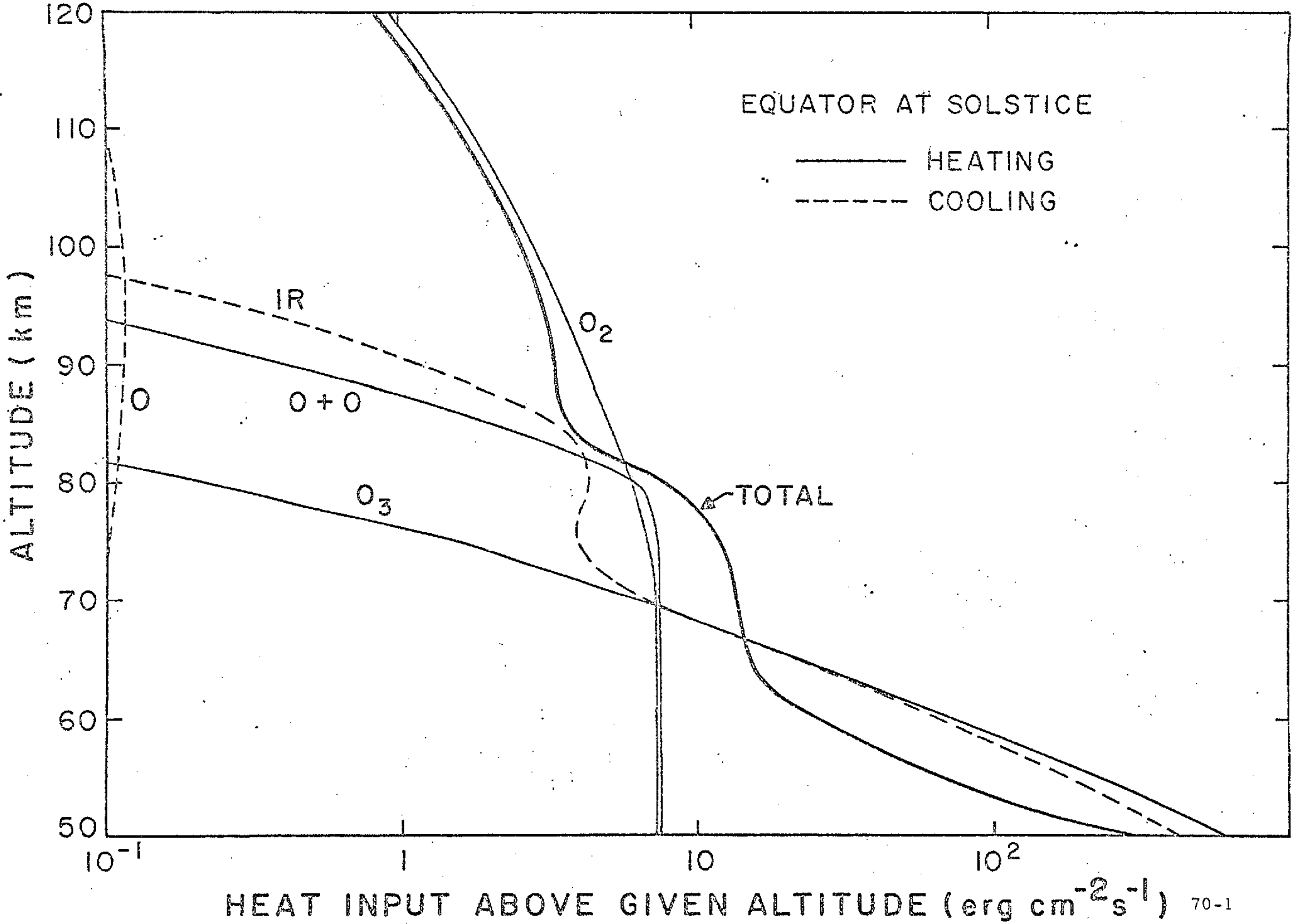
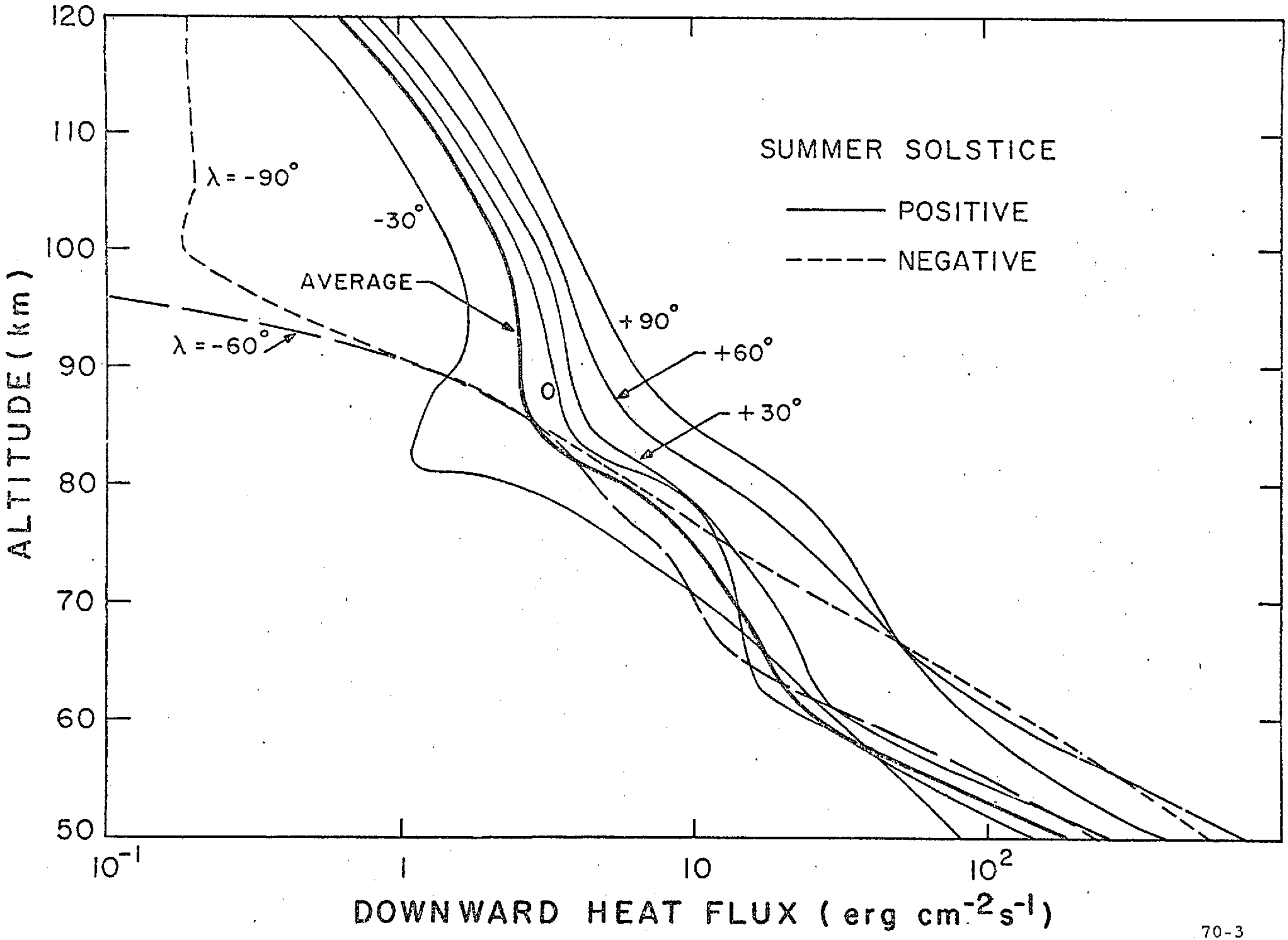
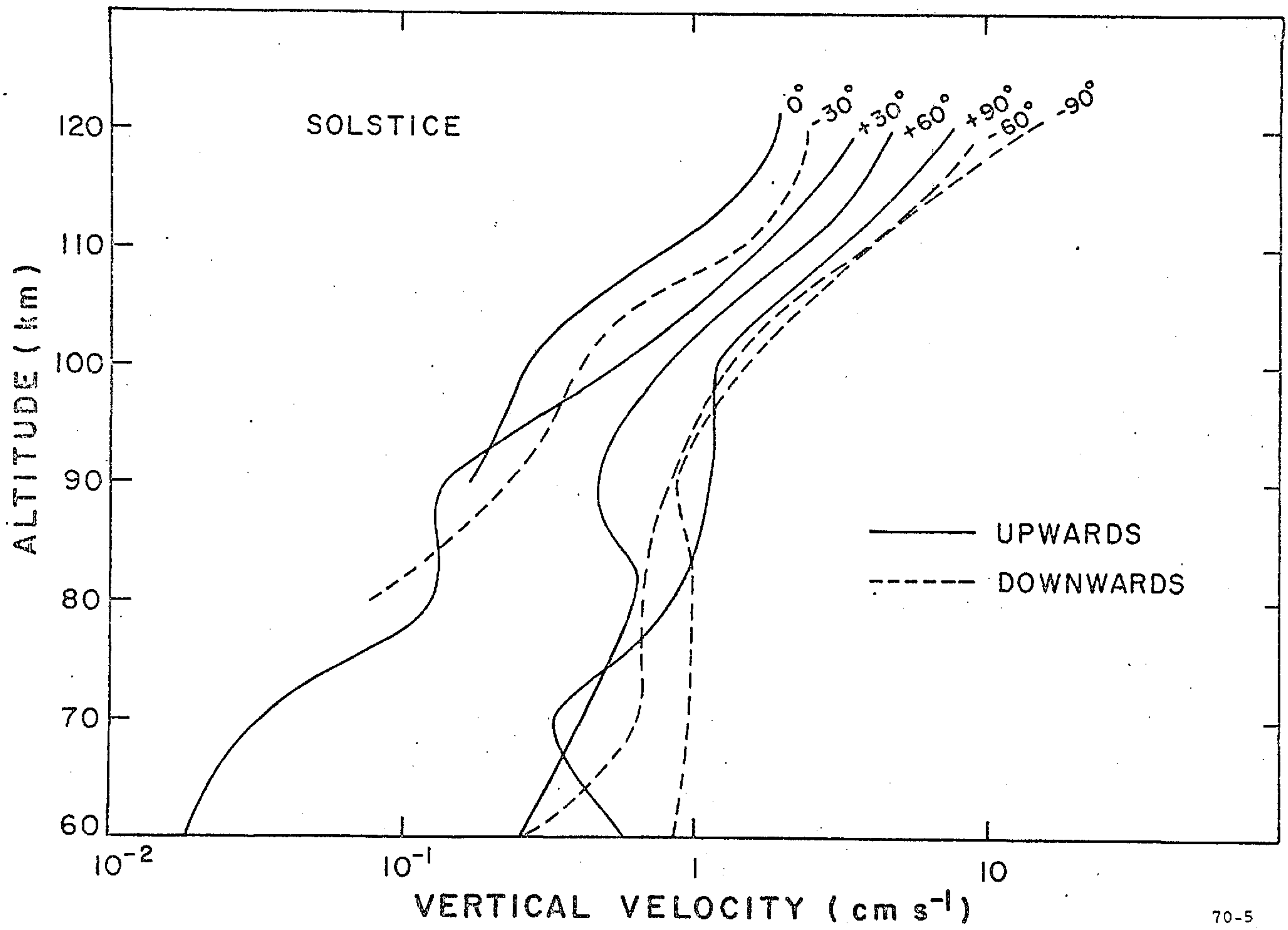

EQUATOR AT SOLSTICE
HEATING
COOLING
ALTITUDE (km)
120
110
100
90
80
70
60
50
IR
O_2
O
O + O
O_3
TOTAL
10^{-1}
1
10
10^2
HEAT INPUT ABOVE GIVEN ALTITUDE (erg cm^{-2}s^{-1})
70-1

FIGURE 1


SUMMER SOLSTICE
POSITIVE
NEGATIVE
λ = -90°
λ = -60°
-30°
AVERAGE
0
+90°
+60°
+30°
ALTITUDE (km)
120
110
100
90
80
70
60
50
10^{-1}
1
10
10^2
DOWNWARD HEAT FLUX (erg $cm^{-2}s^{-1}$)

70-3

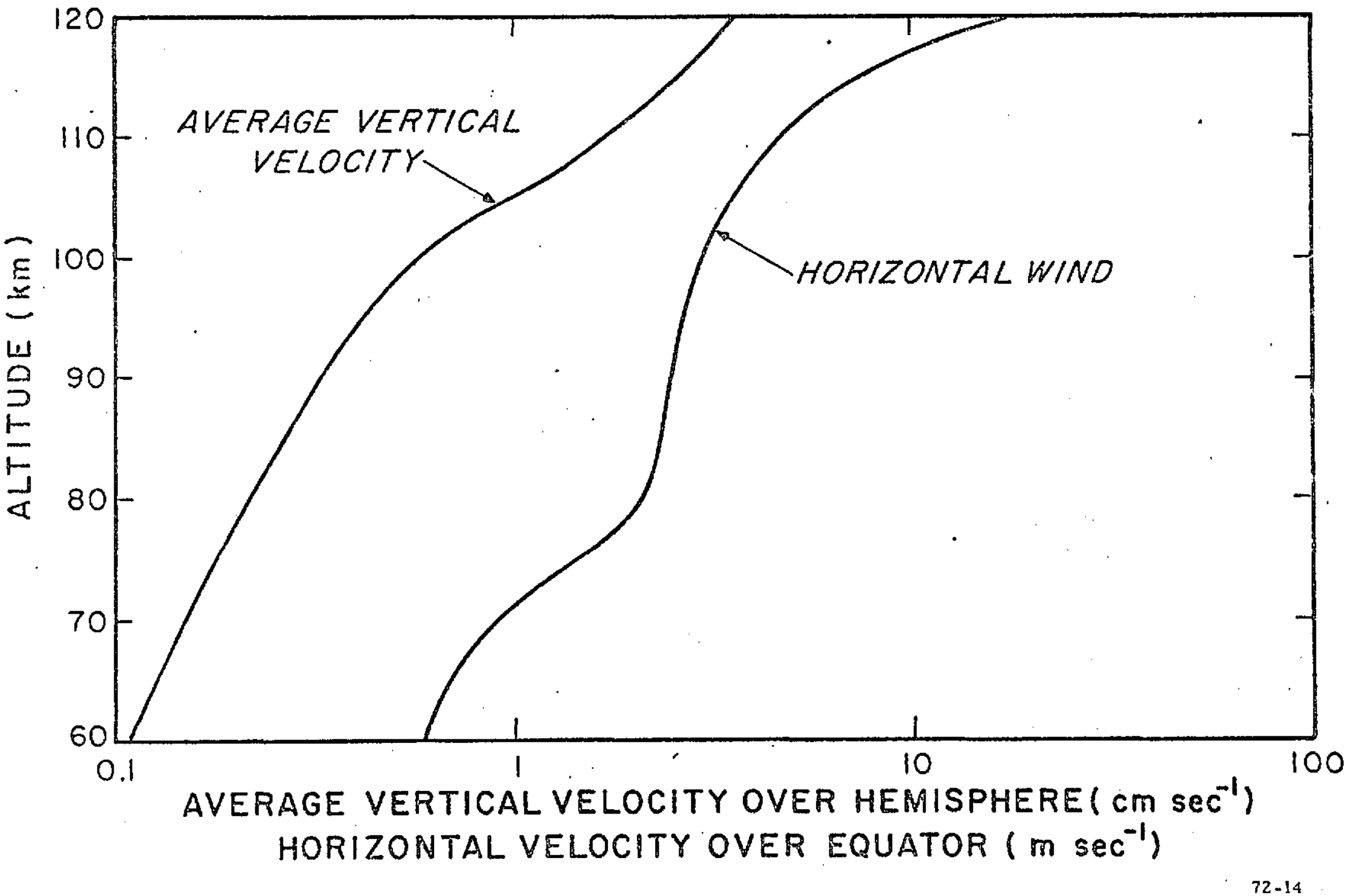
FIGURE 2



SOLSTICE
0°
-30°
+30°
+60°
+90°
-60°
-90°
UPWARDS
DOWNWARDS
ALTITUDE (km)
120
110
100
90
80
70
60
10^{-2}
10^{-1}
1
10
VERTICAL VELOCITY (cm s^{-1})

70-5

FIGURE 3



120
110
100
90
80
70
60
ALTITUDE (km)
AVERAGE VERTICAL VELOCITY
HORIZONTAL WIND
0.1
1
10
100
AVERAGE VERTICAL VELOCITY OVER HEMISPHERE(cm sec^{-1})
HORIZONTAL VELOCITY OVER EQUATOR (m sec^{-1})
72-14

FIGURE 4

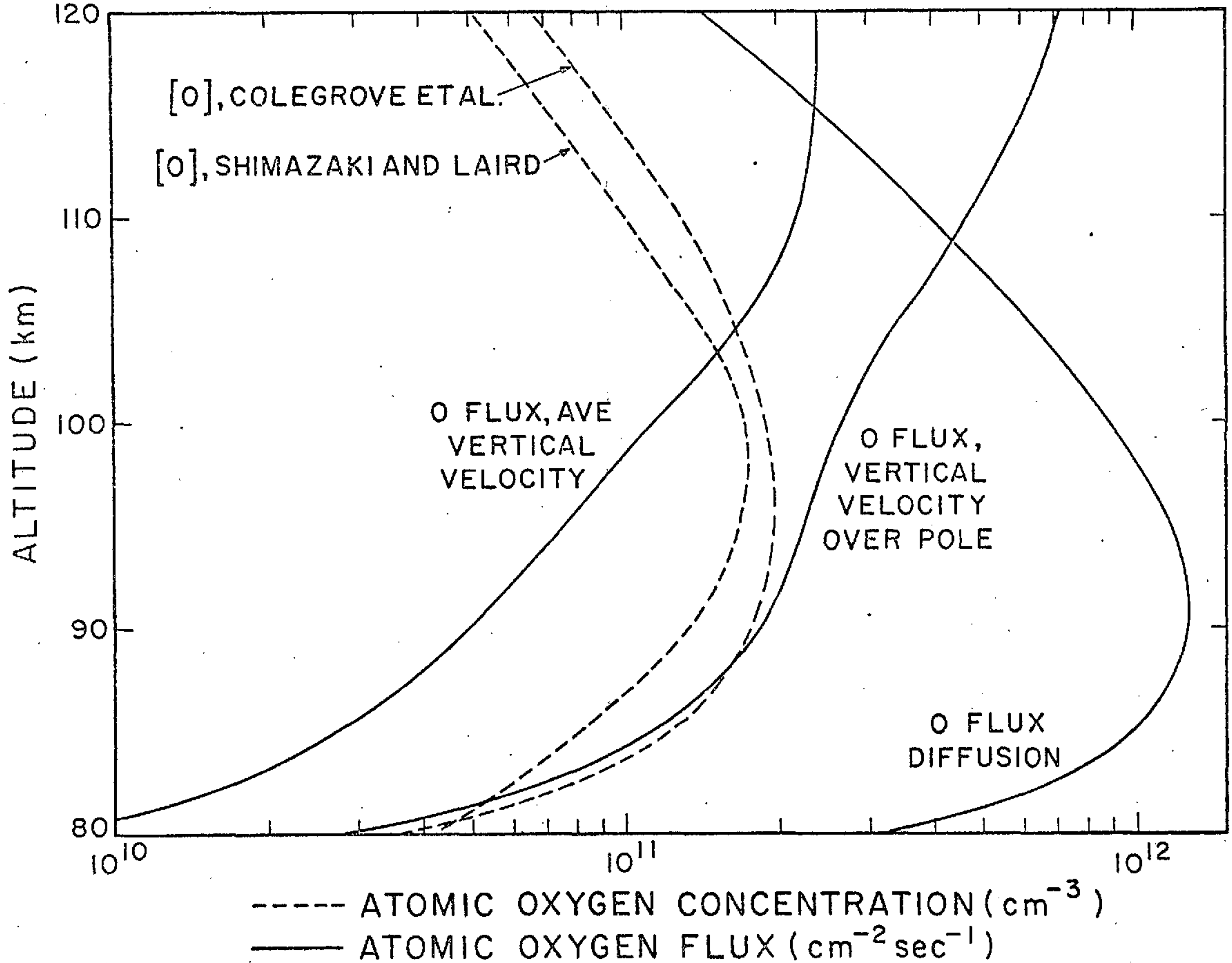
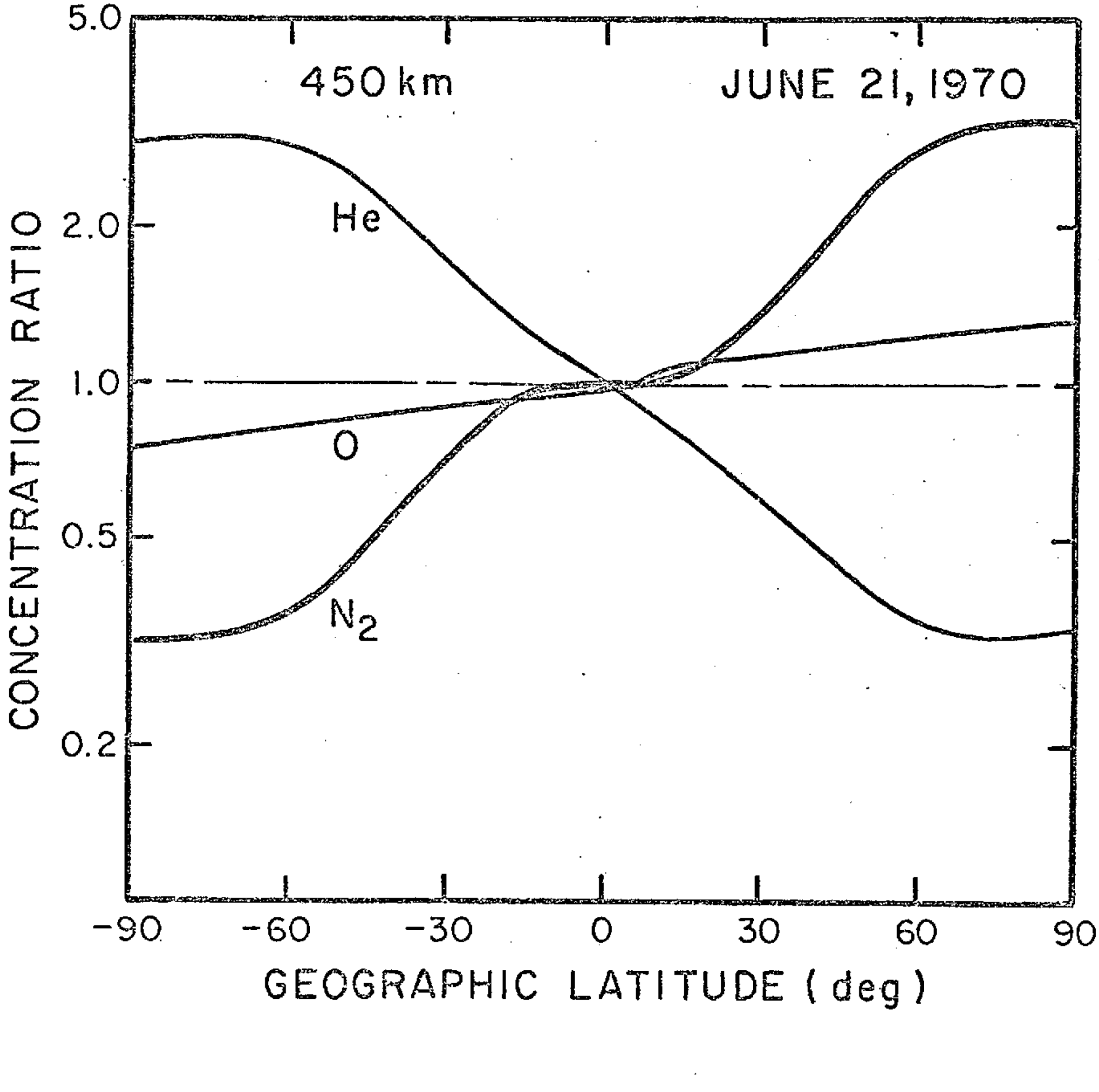


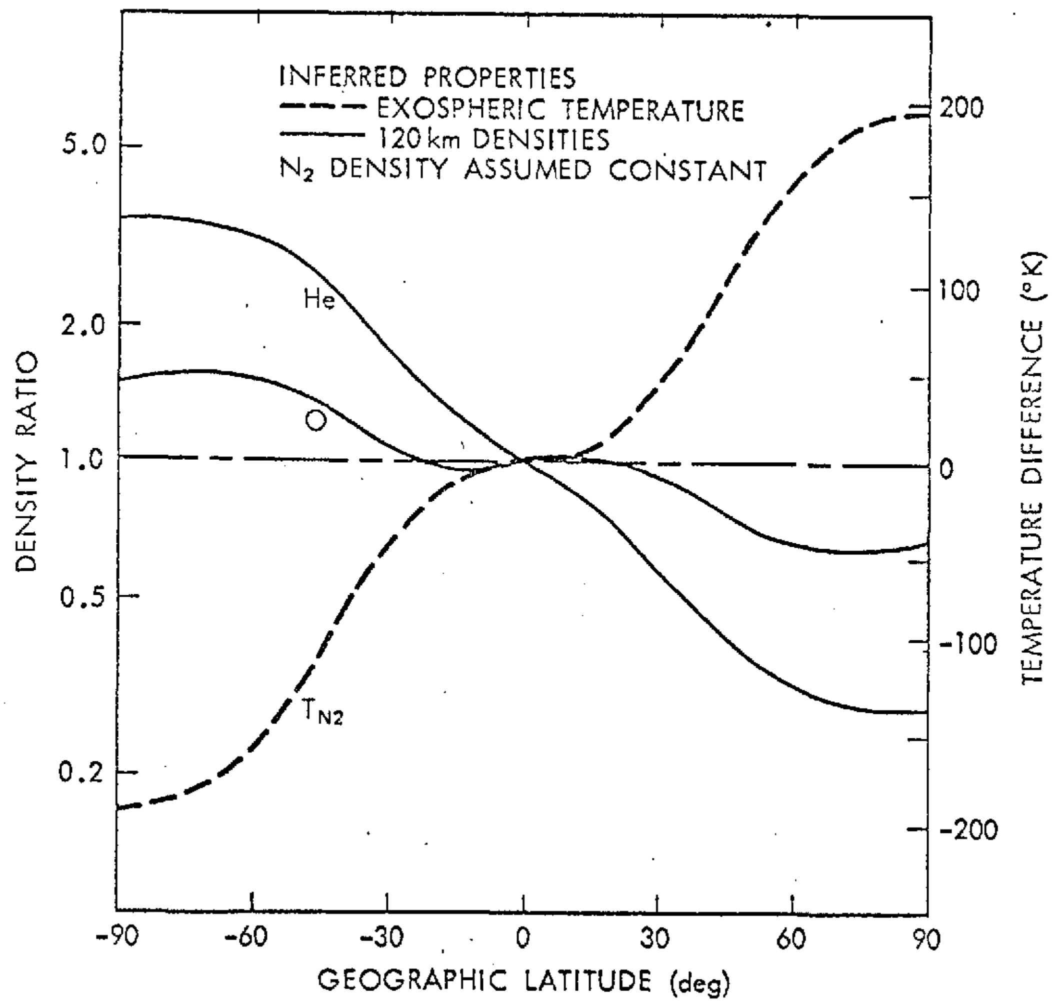
FIGURE 5

72-15a



5.0
2.0
1.0
0.5
0.2
450 km
JUNE 21, 1970
He
O
N_2
CONCENTRATION RATIO
-90
-60
-30
0
30
60
90
GEOGRAPHIC LATITUDE (deg)

FIGURE 6


INFERRED PROPERTIES
EXOSPHERIC TEMPERATURE
120 km DENSITIES
N2 DENSITY ASSUMED CONSTANT
He
O
TN2
DENSITY RATIO
5.0
2.0
1.0
0.5
0.2
TEMPERATURE DIFFERENCE (°K)
200
100
0
-100
-200
-90
-60
-30
0
30
60
90
GEOGRAPHIC LATITUDE (deg)

73-3

FIGURE 7

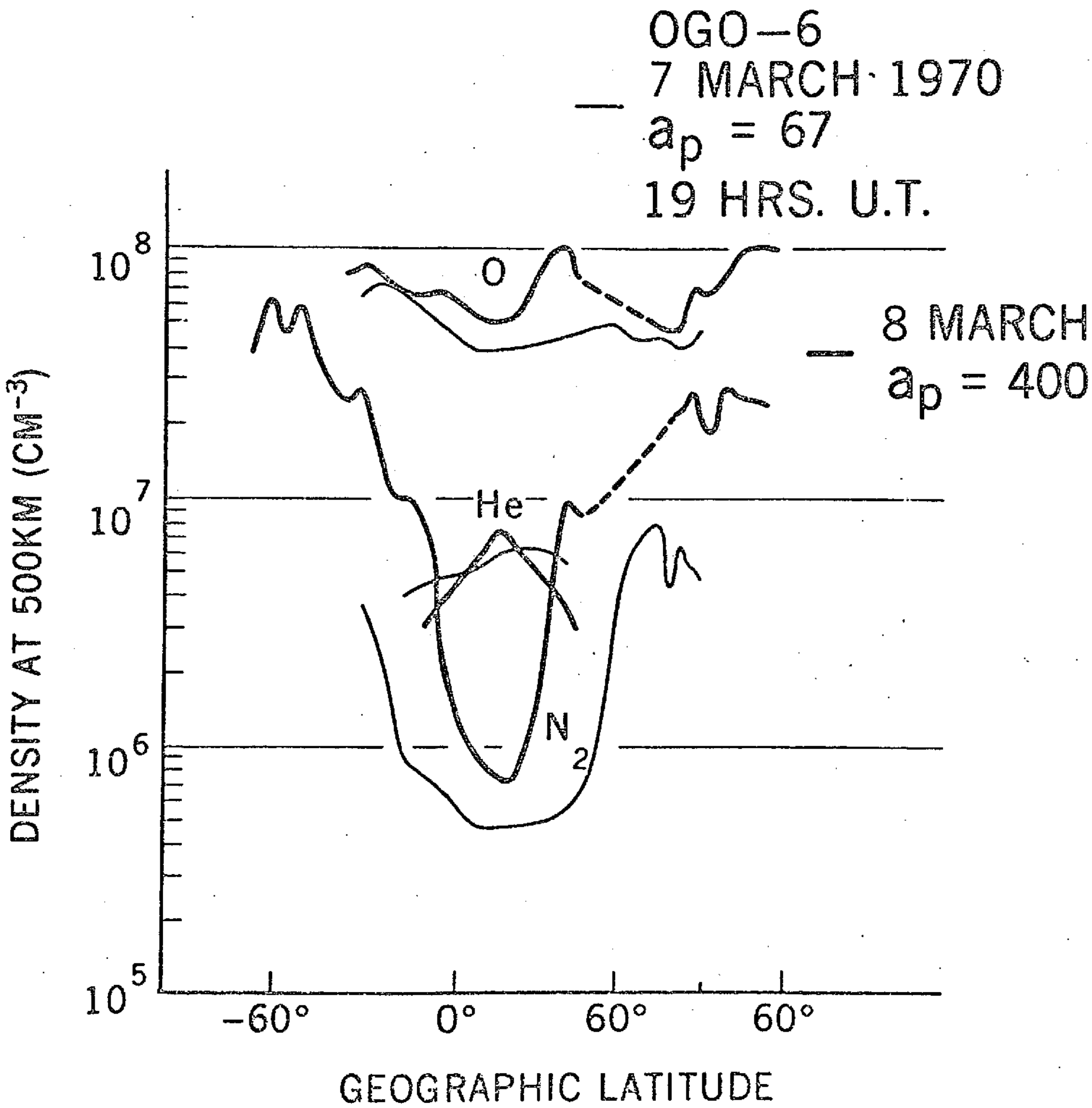

OGO—6
7 MARCH 1970
a_p = 67
19 HRS. U.T.
8 MARCH
a_p = 400
10^8
10^7
10^6
10^5
O
He
N_2
DENSITY AT 500KM (CM^{-3})
−60°
0°
60°
60°
GEOGRAPHIC LATITUDE

FIGURE 8

OGO Data Analysis Study

E. L. Breig

The retarding potential analyzer onboard OGO-6 satellite has provided comprehensive global measurements of the nighttime ion temperatures in the altitude region between 400 and 1100 km. The current phase of data analyses and theoretical study relates to the altitude profiles of such ion temperatures and their variation with latitude, longitude, and season.

The magnitudes and variabilities of the temperature of the ion species in the thermosphere provide information on transport, storage and the ultimate partitioning of short wavelength solar energy among the various atmospheric constituents. Additional information on basic physical processes of energy transfer can be derived from knowledge of the altitude levels at which the various neutral and ionic species become thermally decoupled; e.g. where the ions have characteristic temperature that are in excess of the ambient neutral temperature. Principal information on ion temperatues below 1000 km has been derived from remote sensing techniques such as ground-based radar. However, in situ satellite measurements at low altitudes in the thermosphere are capable of providing more extensive global and temporal coverage and better altitude resolution.

Theoretical studies are in progress of the altitude variations of the ion temperature for the basic time period between late December, 1969 and early February, 1970. During this period, satellite perigee moved from latitudes in the southern to the northern hemisphere, providing excellent coverage of the altitude range between 400 and 900 km over the mid-latitudes below the trough region; however, additional interest does exist in trough phenomena and the effects of photoelectrons that have been observed from the conjugate sun-lit hemisphere. Concurrent studies also concern variations with altitude and latitude of the atmospheric light ion concentrations, the purpose being to search for possible correlations between such behaviors and that noted for the ion temperatures. Theoretical interpretation of the ion temperature data requires numerical solution of the appropriate time-dependent thermal conduction equation, coupled with differential equations relating such atmospheric parameters as concentrations and temperatures of the various neutral and ionic species.

Progress with the OGO-6 data has been sufficient to suggest significant differences with latitude in the altitude profiles of the nighttime ion temperatures. Near 30° dip latitude, the ion temperatures remain low with no apparent increase over the altitude range between 400 and 700 km; there are in fact appearances of a possible decrease in temperature with altitude between 400 and 500 km. This behavior is followed by a sharp increase in ion temperature of over 5° per km above 700 km. In contrast, data near 50 degrees dip latitude indicate a more gradual temperature increase with altitude, commencing as low as 500 km. There does not appear to be any significant dependence of these profiles on longitude over the altitude range considered.

Additional data are being examined in order to increase the reliability of the statistics; this task has been greatly simplified by concurrent progress in the basic data reduction process for orbital plots of the satellite RPA data. Specific correlations also need to be made with the light ion concentrations. Computer programs describing the atmospheric modelling of the ion temperatures are being modified for utilization with the local computers. Formal conclusions and technical publications await further progress in these specific areas.

Induced Magnetosphere of Venus

J. E. Midgley

Ever since Mariner 5 observed a sharp cutoff in the ionospheric plasma density at about 400 km altitude on Venus there has been controversy about the nature of the Venus ionosphere and the physical mechanisms which might lead to such a cutoff. Dessler's original suggestion that interplanetary field lines pile up in front of a conducting ionopshere, such as we have on Venus, and lead to an induced magnetospheric cushion was endorsed and further amplified by Johnson and Midgley (1969). Other models, however, in which there is no magnetic field buildup have been pushed very hard in the literature. So far only one-dimensional calculations of any of the models have been carried out and these all suffer from some rather serious approximations and assumptions. The controversy can be resolved only by further experimental tests, or by detailed multidimensional calculations of the implications of the proposed models. We are now in process of carrying out a two-dimensional, self-consistent calculation of the induced magnetosphere model. Those arguing against such a model claim that it is not self-consistent, so the main objective is to see if a complete self-consistent solution can be obtained. The process is a difficult one involving many levels of interaction and the solution of two-dimensional elliptic partial differential equations at each level, utilizing boundary conditions which are not well defined except as the iterative process itself beings to converge. Early results were discouraging, but some new computational techniques have been developed during the progress of the work, which now seem to be leading toward consistent convergent solutions.

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