STRATOSPHERIC-MESOSPHERIC CIRCULATION PATTERNS AND D-REGION ABSORPTION

by

George Earl Chapman

B.S., Texas A&M University
(1965)

SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENT FOR THE
DEGREE OF MASTER OF
SCIENCE

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

July 17, 1969

Signature of Author ....
Department of Meteorology
17 July 1969

Certified by ....
Thesis Supervisor

Accepted by ....
Chairman, Departmental Committee
on Graduate Students

STRATOSPHERIC-MESOSPHERIC CIRCULATION PATTERNS AND D-REGION ABSORPTION

by

GEORGE EARL CHAPMAN

Submitted to the Department of Meteorology on July 17, 1969 in partial fulfillment of the requirements for the degree of Master of Science.

ABSTRACT

D-region absorption measurements have been collected for a network of stations during the IQSY. The data has been divided into quarters of the year and correlated with daily 5577A (OI) airglow measurements, Meteorological Rocket Network data, and daily grid-point values of geopotential height, temperature, and wind at the 10 mb level. A cross-correlation of the individual absorption stations has also been made. The correlation of parameters at the 10 mb level appears to be related to the position of the large-scale troughs during the winter quarters. MRN results are hampered by a paucity of data; however, a strong correlation is apparent between the zonal component of the wind and the variation in daily absorption in the Washington D.C. area. This was also the most persistent area of favorable correlations at the 10 mb level. It is suggested that the favorable correlations that have been found are due to a large-scale transfer of atomic oxygen into the affected region by the slow-moving long waves, with the associated vertical motion causing an increase in electron density within the D-region. There is additional evidence to support a planetary wave feature over the Northern Hemisphere at the 10 mb level with centers of oppositely directed vertical motions over North America and central to eastern Asia.

Thesis Supervisor: Reginald E. Newell
Title: Professor of Meteorology

ACKNOWLEDGEMENTS

The author is principally grateful to the United States Air Force who provided the opportunity for this course of study through the Air Force Institute of Technology. The subject for this investigation was offered by Professor Reginald E. Newell who is due considerable thanks for both this and the invaluable advice he offered throughout the course of the study. The weekly seminars that he encouraged among the students working on problems in the ionosphere were the source of many helpful points. Special thanks are due to Mr. Robert Crosby who provided the majority of the computer programming assistance for this study, and also to Miss Deborah Walther who wrote the program involving the rocket data. The airglow and absorption data was punched on to IBM cards by Mrs. Mary Bagarella. The excellent drawings and figures were accomplished by Miss Isabelle Kole, and the manuscript was type by Miss Diane Lippincott.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

The designation of the term ionosphere stems from the existence of free ions and electrons in sufficient quantities to affect the propagation of radio waves, according to the Institute of Radio Engineers.

The ionosphere is subdivided into three parts termed the D, E, and F regions. The lower D-region extends up through 90 km, the E-region from 90 to 160 km, and the F-region is found above 160 km. Appleton is responsible for this nomenclature and the specific designation of the D-region resulted from observations he made while experimenting with radio wave propagation in the ionosphere. He noticed that a reduction in intensity of the wave seemed to occur below the reflecting E-region and he reasoned that this was due to the absorbing effects of a highly ionized layer, which he termed the D-region (Appleton, 1930; Silberstein, 1959; Ratcliffe and Weekes, 1960). It is this portion of the ionosphere that will be the region of concern during the course of this study.

In 1931 Chapman put forth his theory of layer formation in which he assumed that the absorption of incident solar radiation was entirely responsible for the photoionization of a particular constituent of the atmosphere. His theory led him to the prediction of electron concentration as a function of sun angle due to the photoionization of the species as shown below:

$$n(e) = K \cos^{1/2} \chi \quad 1.1$$

$$\cos \chi = \sin \Phi \sin \delta + \cos \Phi \cos \lambda \cos \delta \quad 1.2$$

where

K = constant

Φ = latitude

λ = longitude

δ = solar declination.

This simple Chapman theory predicted a maximum electron concentration for a given layer during the summer season, with a minimum to be expected during the winter. Likewise, a strong diurnal variation would be predicted, especially in the lower ionosphere, although n(e) would be nearly constant at a given time on consecutive days.

In 1937 Appleton conducted a series of experiments which provided a test of the Chapman theory of layer formation. Rather than working directly with the limited information available on electron number density, Appleton utilized the factor of radio wave absorption as a measure of electron concentration. A radio wave penetrating the D-region will be reflected from either the E or F layer, but in the process a portion of the energy of the wave will be absorbed within the D-region; first as it penetrates the D-region and secondly as it is reflected and returns to the earth's surface. Appleton was able to show that when the collision frequency of the electrons is very small compared to the electric wave frequency, then $|\log \rho|$ should vary as $\text{Cos}^{3/2} \chi$, where ρ is the reflection coefficient of the wave. As seen in Figure 1, Appleton compared the results of his experiment to both a $\text{Cos}\,\chi$ and a $\text{Cos}^{3/2} \chi$ curve. His results were generally as expected during the summer months, but a significant disparity was found to exist during the winter months for both cosine curves in that more absorption was observed than was predicted. Based on the results of Appleton's work, and related tests which followed, the term D-region anomaly was introduced. It is an anomaly only with respect to Chapman's original theory. We actually find that the deviations from the Cos χ function are quite common at mid-latitude stations throughout the winter. Although the term is somewhat of a misnomer, the phrase is widely accepted in the literature today, and it will be referred to in this context throughout the remainder of the thesis.

There has been increasing speculation that the D-region anomaly may be linked to a meteorological factor and more will be said about this possibility in Chapter III. It is the purpose of this study to perform a thorough investigation of absorption in the D-region during the IQSY and to determine what meteorological factors, if any, play a role in the creation of the D-region winter anomaly.

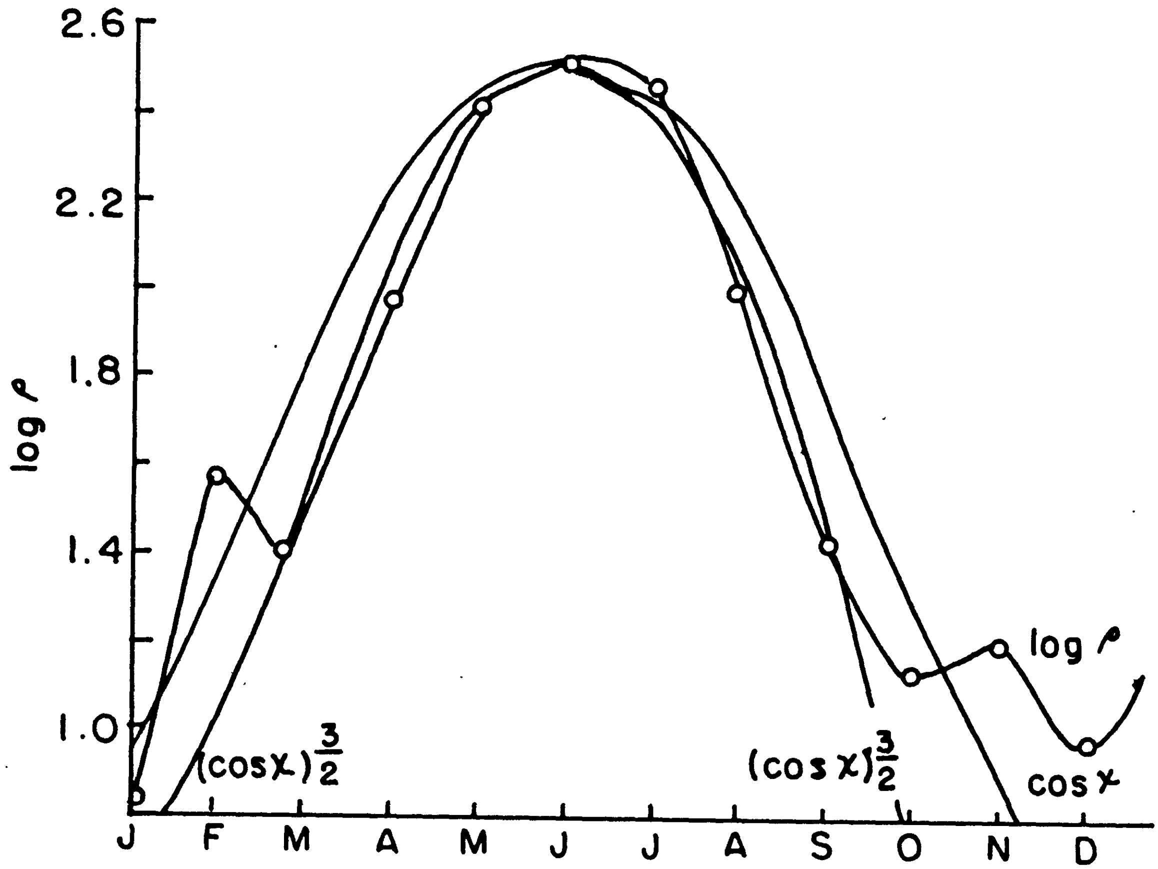

Figure 1. A comparison of log ρ and two Cos χ functions. (Appleton, 1937)

II. D-REGION MORPHOLOGY

Radiation incident on the upper atmosphere is still accepted as the principle means of ion formation and in the D-region three processes are thought to be of the greatest importance: solar X-radiation, Galactic Cosmic Radiation (GCR) and solar Lyman-α radiation (Whitten and Poppoff, 1965).

The relative importance of each of these processes varies considerably within the D-region and with the stage of the solar cycle. X-rays are quite capable of ionizing all of the atmospheric constituents, but in the D-region the abundant gases O_2 and N_2 are the most important. At solar maximum, X-rays with wavelengths less than 10Å will be the dominant ionizing process down to 70 km, but at solar minimum the process is only effective down to 85 km (Poppoff et al., 1964; Thrane, 1966). GCR in the form of energetic protons and α-particles is the dominant process in the lower D-region, generally from 50 through 70 km. Lyman-α is instrumental in the photoionization of nitric oxide (NO) through the reaction stipulated by Nicolet (1965).

$$NO + h\nu(\lambda = 1216\text{Å}) \longrightarrow NO^+ + e \qquad 2.1$$

Although the measurement of NO has varied considerably within the D-region (Nicolet and Aikin, 1960; Barth, 1964, 1966; Pearce, 1969), the concentration is deemed to be of sufficient magnitude to materially affect the electron concentration in the middle portion of the D-region. Lyman-α radiation is essentially constant over the sunspot cycle.

There are other processes which may play a significant role in the day to day variation of the electron density, and they will be referred to in a later section of the thesis; however, the net effect of these processes is an electron density profile which ranges from 10 electrons/cm^3 near the 50 km level to 10^3 electrons/cm^3 at the top of the D-region during the daytime period. Davies (1965) points out that the electron content is reduced by a factor of 10 during the nighttime period.

III. D-REGION ANOMALIES

A. Observational Evidence

In the thirty-two years that have elapsed since Appleton's discovery of the anomalous behavior of the D-region, a host of workers have confirmed his findings. At the same time many have added to the puzzle by pointing out that the disparity is observed in many different forms: there are seasonal, daily, longitudinal, and latitudinal anomalies.

1. Seasonal anomaly

Belrose et al. (1966) have performed considerable research to obtain various electron density profiles throughout Canada using the partial reflection technique. Because of the nature of the earth's atmosphere, any radio wave incident on the upper atmosphere will be separated into characteristics waves called the ordinary and extraordinary waves. Each characteristic wave will penetrate a layer of electrons, such as the D-region, with a different frequency. The waves will be partially reflected by the ionization irregularities in the 50 to 90 km region and ground receivers will ultimately record an amplitude for each of the waves that is weakly reflected (Ratcliffe and Weekes, loc. cit.; Belrose and Burke, 1964). The technique will be explained more fully in a later section of the thesis, but it suffices to say that a measure of the electron density can be obtained from the ratio of the amplitudes of the extraordinary and ordinary waves. The results that Belrose obtained at Resolute Bay during 1964 are shown in Figure 2.

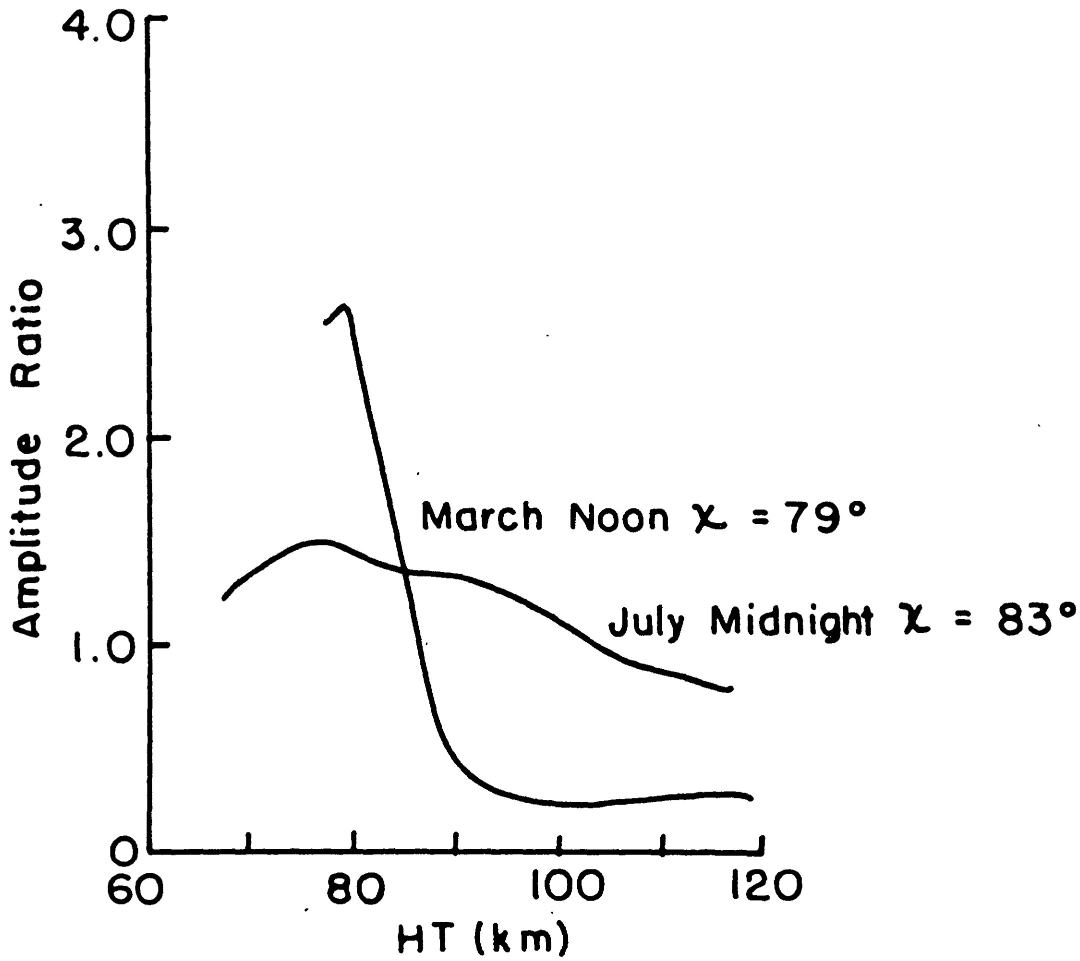

Figure 2. Seasonal variations in amplitude ration A_x/A_o against height. (Belrose et al, 1966)

Although the sun angle differed very little between midday in March and midnight in July, there was a marked difference in the inferred electron density profiles. According to equation 1.1, we should expect very little difference in these profiles with sun angles so nearly the same. This suggests that a seasonal anomaly in electron concentration may be observed in the D-region, and this feature has been confirmed by other workers. Gregory and Manson (1969) reported the same disparity during their work in the Southern Hemisphere near New Zealand. They found a variation at 80 kms from 700 electrons/cm^3 at a summer minimum to 1300 electrons/cm^3 during a winter peak.

2. Daily anomaly

The day to day fluctuation of electron number density has been observed many times, but primarily by Belrose and his group in Canada (Belrose and Burke, loc. cit.; Belrose et al., loc. cit.). One of the best examples was observed at Ottawa, Canada, during February, 1961, and is illustrated in Figure 3. The sun was quiet during the entire period; thus, the increased electron densities do not appear to be attributable to an enhancement of GCR, X-rays or Lyman-α. These day-to-day variations seem to exhibit a definite preference for middle to high latitudes during the winter season, and though a completely satisfactory explanation of the anomalous variation has not been advanced, the association with a meteorological factor seems quite possible (Diemenger, 1968).

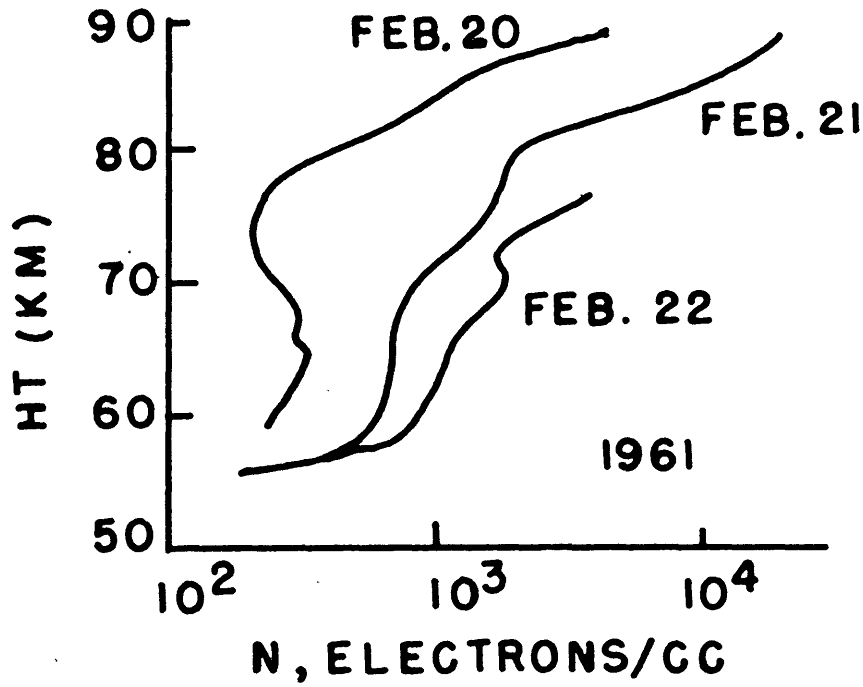

Figure 3. Daily changes in the winter electron densities at Ottawa, Canada. (Belrose, 1963)

3. Longitudinal anomaly

Thomas (1962) utilized data from a network of stations throughout North America and Europe during the years 1957 to 1959 and arrived at some interesting conclusions. In two different facets of his study he selected an American master station, Washington D.C., and compared it with the absorption stations in Europe; he also selected a European master station, Freiburg, Germany, and compared it with the absorption stations in North America. In both instances he found a good positive correlation existed between stations located in the same region, but a negative correlation was found between stations in North America and Europe. The specific period used in this portion of the study was only the three months of December 1958, through February 1959. Nevertheless, he also seemed to confirm the fact that there is little, if any, correlation between days of anomalous absorption and the daily variation in magnetic activity.

4. Latitudinal anomaly

Beynon and Jones (1965) discovered another aspect of anomalous behavior in the low-latitude regions. Using data from three stations located at 70°N and 19°S, they found that a significant departure from the Cos χ relationship occurred during the summer months at these stations, and thus they extended the terminology to include summer anomalies. However this particular phenomena is not germane to the objective of this thesis, and has only been included to complete the discussion of the D-region anomalies.

B. Suggested Causes

It was Dieminger (1952) who perhaps first inferred that there might be a meteorological basis for the D-region winter anomaly. His intent was to determine if the daily variation in absorption could be related to daily changes in the output of solar radiation. He found that there was no correlation and speculated that the cause of the anomaly might be of a terrestrial rather than extraterrestrial nature; however, at this time the paucity of upper-air data left little room for further investigation.

When a refined upper-air network operating on a global basis began to provide opportunities to examine the possible meteorological links with this anomaly, Bossalasco and Elena (1963) obtained the daily mean absorption values taken at Freiburg, Germany, during the winters of 1958-1959 and 1960-1961 and plotted them against the daily variation of temperature at the 10 mb level. The striking correlation that was achieved is shown in Figure 4. The fact that the temperature and absorption patterns were separated by a vertical distance of some 50 km gave rise to further speculation on stratospheric-mesospheric links, as well as inciting additional interest in the meteorological aspects of the problem.

Shapley and Beynon (1965) followed with a study which tended to confirm the findings of Bossalasco and Elena; however, in the former case 14 days were selected on which a significant stratospheric warming occurred. On these days they observed a

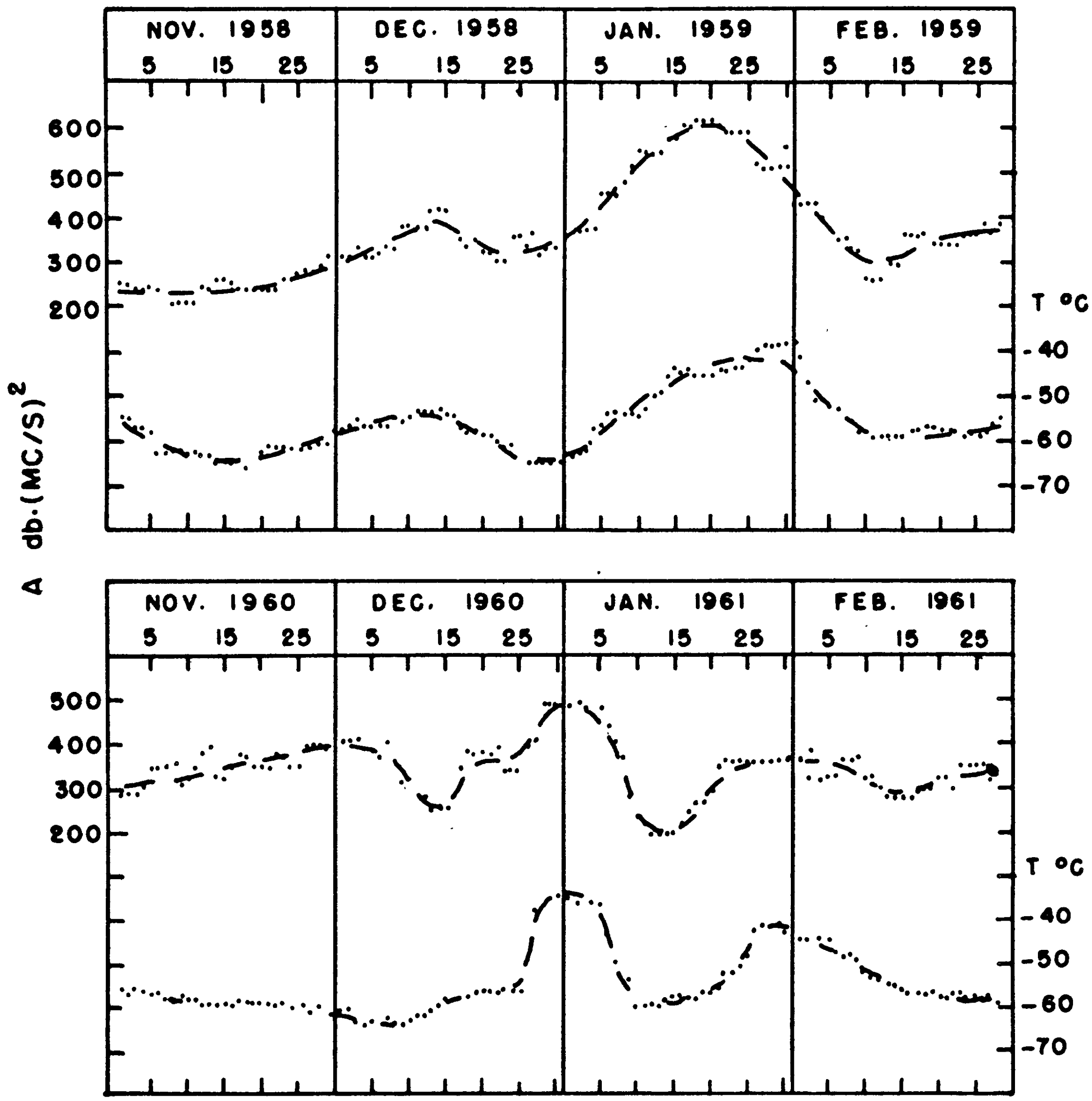

Figure 4. The variation of D-region absorption and 10 mb temperatures at Freiburg, Germany. (Bossolasco and Elena, 1963)

25% increase in ionospheric absorption, but there was no definite time correlation between the two events. In half of the cases the warmings and the increase in absorption were coincident, whereas in the remaining 14 days the warmings were observed to precede or follow the absorption anomaly by as much as three days.

Using the results of Nicolet's work (1965), in which he demonstrated that warmings can produce an enhancement of the nitric oxide content in the D-region, Sechrist (1967) sought to relate the winter anomaly to the increase in n(NO) within the D-region. He assumed photoequilibrium conditions and made steady-state computations of the nitric oxide content using the equation

$$n^*(NO) = 10^{-1} \exp[-3000/T]n(O_2) + 5x10^{-7}n(O) \qquad 3.1$$

where $n^*(NO)$ is the equilibrium value of nitric oxide and T is the absolute temperature within the mesosphere. He suggests that a warming of the D-region will enhance the nitric oxide concentration. This in turn will produce an increase in the electron density through the effects of Lyman-α radiation. Thus he feels that we might expect to find a correlation between mesospheric warmings and the anomalous absorption within the D-region. In a subsequent investigation (Sechrist et al., 1969), a rocket measurement of D-region temperatures was obtained on a day of anomalous radio wave absorption. Although the results indicated an increase of temperature with height between 70 and 76 km, this does not seem to be an absolute confirmation of his hypothesis.

The source of such a warming could be of the nature suggested by Kellogg (1951), in which he invoked a meridional circulation model to explain the warm winter mesopause near the pole. A northward flux of atomic oxygen into the high latitude regions would result in a subsidence of the airmass. Atomic oxygen would then be transported downward to the lower levels where a reaction such as 3.2 would be quite common. This would allow for heating by chemical conversion as well as that due to adiabatic compression.

$$O + O + M \longrightarrow O_2 + M + 5.1 \text{ ev} \qquad 3.2$$

The relevancy of Kellogg's suggestion has been examined in another light, but prior to considering these ideas we should briefly examine the concentration of atomic oxygen in the atmosphere. In Chapman's classic paper (1930) he observed that molecular oxygen was dissociated through the absorption of ultra-violet solar radiation, predominantly in the range from 2300-2900Å. In the process the molecular oxygen will be broken down into oxygen atoms. The recombination, if any, takes place through a three-body collision. In the atmosphere above 100 km, where the density of the constituents is greatly decreased, the recombination will be a very slow process allowing for a greater accumulation of atomic oxygen. Thus as Craig (1965) points out, the percentage concentration by volume of atomic oxygen begins to increase sharply above 85 km, and at 100 km it exceeds the concentration of molecular oxygen.

Newell et al. (1966) and Newell (1968) have suggested that the transfer of atomic oxygen by the motions of the large-scale waves in the upper atmosphere could be a partial explanation for the winter anomaly. The D-region is high in concentration of negative ions and as suggested by Fehsenfeld et al. (1967), any introduction of atomic oxygen into the region would give vent to reactions 3.3 or 3.4, thereby causing an increase in the electron concentration:

$$O^- + O \longrightarrow O_2 + e \qquad 3.3$$

$$O_2^- + O \longrightarrow O_3 + e \qquad 3.4$$

Newell (private communication) has further postulated an atomic oxygen mixing ratio gradient as illustrated in Figure 5. Any pole-ward motion between 85 and 100 km having a vertical component would clearly transfer atomic oxygen down the mixing ratio gradient and result in an increase of atomic oxygen within the aforementioned interval. The process which may facilitate this transfer may be the large-scale waves, and this is somewhat analogous to the ozone transport mechanism that is effective in the lower stratosphere (Newell, 1964).

Gregory (1965) has likewise suggested that the partial cause of the observed warmings accompanying the anomalous absorp-tion could be from the subsidence associated with the air mass and its excess atomic oxygen. The increased absorption would then follow from the reactions stipulated in 3.3 and 3.4.

Geisler and Dickinson (1968) have also suggested that enhancement of the nitric oxide content within the 70 to 85 km portion

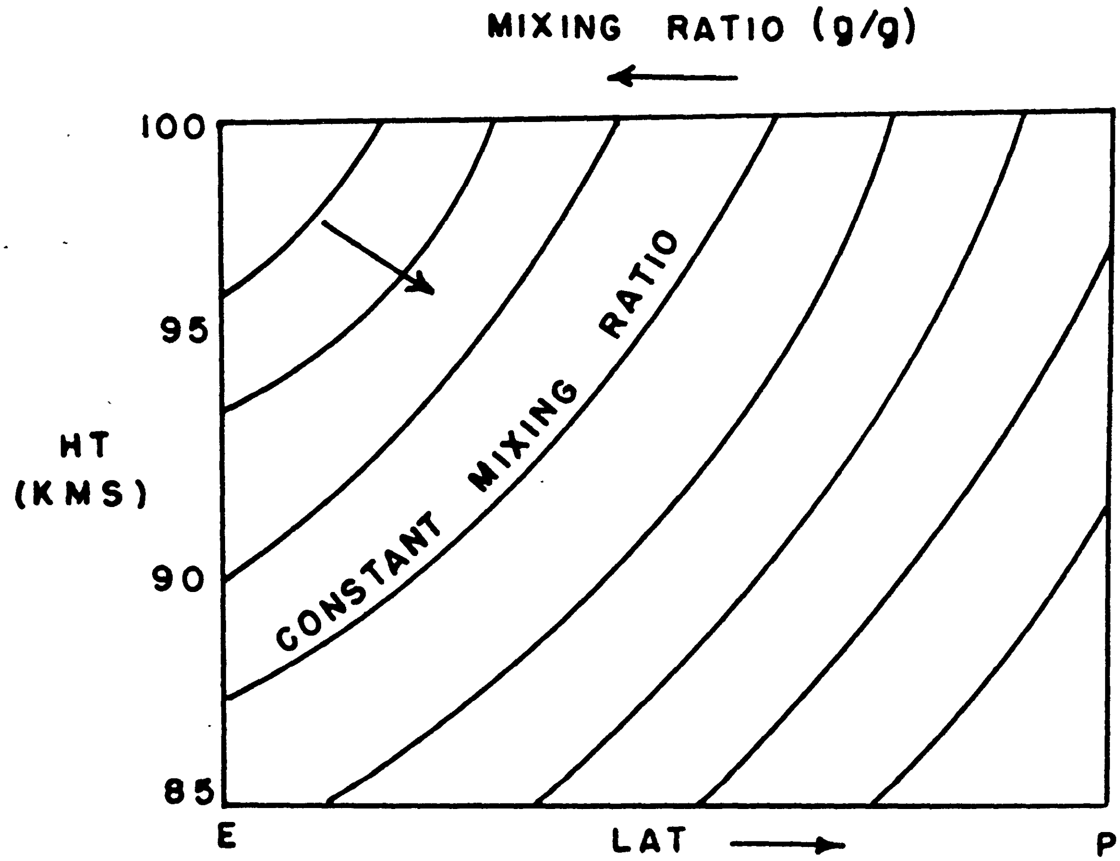

Figure 5. Schematic illustration of atomic oxygen mixing ratio gradient for the winter hemisphere. Arrow denotes motion down the gradient (after Newell).

of the D-region could serve as an explanation for the anomaly, but they differ from Sechrist (loc. cit.) in their explanation of the nitric oxide source. They reason that the vertical motion accompanying the large-scale planetary waves will provide a mechanism for increasing the nitric oxide content at the 85 km level in a manner similar to the atomic oxygen argument. A steady vertical motion will transport nitric oxide down the mixing ratio gradient from 70 to 85 km, which would maintain a concentration of the order required by Sechrist. The crucial point of this theory centers on the measurement of nitric oxide. The high values measured by Barth in 1966 were termed anomalous by Sechrist, but subsequent measurements by Pearce (loc. cit.) were even higher. Thus the normal state of nitric oxide in the D-region is now in some doubt and deserves further attention.

Maehlum (1967) has speculated that the precipitation of energetic charged particles may be the source of the anomaly. This seems rather doubtful as the anomalies are commonly observed in the middle-latitudes that are well removed from the auroral zones. The case observed by Belrose in 1961 serves as an excellent example (see Figure 3) as these days were marked by a magnetic quiet period.

The research connected with this thesis will seek to determine if there is a basis for assuming a correlation between the transport of atomic oxygen and the increase of ionospheric absorption, which to the author's understanding has not been previously examined.

IV. IONOSPHERIC MEASUREMENT TECHNIQUES

A. Electron Densities

Although the D-region is located closer to the earth's surface than either the E or the F regions, the former has been the most difficult to study. The atmospheric densities are too high to permit satellite observations, and thus we are restricted to either direct rocket measurements or the indirect method of radio wave propagation.

Rocket techniques are certainly the most desirable method of obtaining electron densities within the D-region, and attempts to date have been quite successful. Figure 6 shows two different profiles obtained during the IQSY by Mechtly and Smith (1968), and Hall and Fooks (1967). The principle argument against rocket measurements is the prohibitive cost required to obtain electron densities on a regular time and scale basis. Thus to obtain this information on a synoptic basis for a worldwide network of stations it is necessary to revert to the indirect method of radio wave propagation.

There are a number of different methods that are currently in use but the most popular are the pulse (A1), riometer (A2), and the partial reflection technique. Each of these methods enables one to obtain a measure of the electron density for the D-region, and the data subsequently used in this study was taken from the pulse and riometer techniques; however, many of the results referenced in this report have been derived from the partial reflection

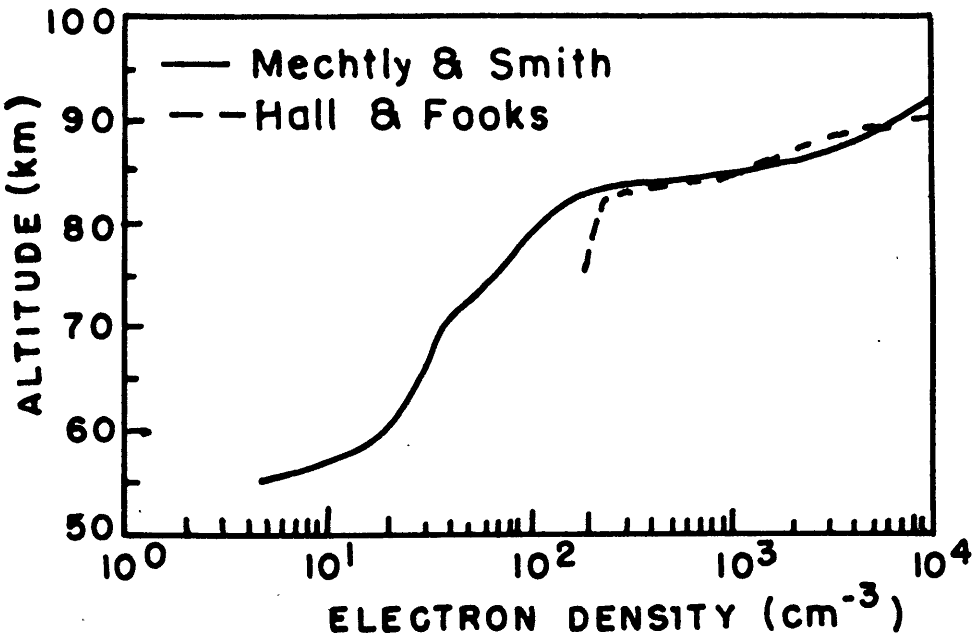

Figure 6. D-region electron densities from rocket techniques.

method. The manner of converting from the basic data to electron number densities has been fully described by Piggott et al. (1957), Belrose and Burke (loc. cit.) and Geiswald et al. (1968), and will be only outlined below.

1. Pulse (A1)

It has been pointed out earlier in this thesis that a radio wave reflected from the E-region will be partially absorbed before it is detected at the ground source. The absorption occurs within the D-region as the electrons therein interact with the vibrational modes of the wave and thus absorb a portion of the energy (Whitehead, 1955). There is a direct relationship between the electron content of the D-region and the absorption of radio waves penetrating this layer. We can then infer increases and decreases in the electron concentration through measurements of the loss of the wave due to absorption, as shown in 4.1.

$$L(db) = -20\log(E_d/E_n) \qquad 4.1$$

where L is given in decibels, E_d is the pulse-echo amplitude during the day, and E_n is the amplitude during the night when little or no absorption is expected.

2. Riometer (A2)

The riometer technique differs from the pulse method in that the wave suffers absorption only once as it enters the earth's atmosphere from outer space. The extra-terrestrial radio noise incident on the earth's upper atmosphere is generally assumed to be constant with time; thus any deviations can be attributed to absorption of the wave within the ionospheric D-region. Actually during unusual solar activity the value will not be constant, but during the IQSY this problem was of little concern. The non-deviative absorption of plane high-frequency waves traversing the D-region is given below:

$$A = C \int [n\nu/\nu^2 + \omega_e{}^2] dh \qquad 4.2$$

where

A = absorption in decibels

C = constant

n = electron density

ν = electron collision frequency

ω_e = effective angular frequency

= $\omega + \omega_L$ for the ordinary wave

= $\omega - \omega_L$ for the extraordinary wave

ω_L = gyro-frequency of the electron for a magnetic field strength equal to the longitudinal component of the earth's magnetic field

ω = angular frequency of the exploring radio wave

dh = height increment

3. Partial reflection technique

In Chapter IIIA1 the physics associated with this technique was briefly mentioned in conjunction with Figure 2. If the ratio of the amplitudes of the extraordinary (x) and ordinary (o) waves reflected from a scatterer at height h is known, then the integrated electron density profile can be computed from 4.3,

$$A_x/A_o = R_x/R_o \int_0^h \exp[-2(K_x-K_o)dh] \qquad 4.3$$

where $R_{x,o}$ is the effective reflection coefficient of the scatterer, and $K_{x,o}$ is the absorption coefficient integrated up to the scatterer and back. This method is in popular use by both Belrose and Gregory.

B. 5577Å Airglow

Photometric observations of the airglow were quite common during the IQSY and the methodology has been fully described by Roach (1968).

In the case of the green line of atomic oxygen the occurrence is marked by a transition from the excited ^1S state to the lower ground state. The radiant energy is then detected by photometers at the ground normally oriented in a fixed zenith position. The data used in this study was taken in this position. The brightness of the radiation, B, is measured in units of 10^6 quanta cm^{-2} sec^{-1} sterad^{-1}, and the actual intensity of the airglow is then given in Rayleighs, R, where R is equal to $4\pi B$.

V. DATA

A. Acquisition

The acquisition of data for this study was primarily dictated by the desire to study absorption patterns during the IQSY period, and determine how the circulation patterns at various altitudes related to the daily change in D-region absorption. The selection of data was designed to test the hypothesis cited in Chapter IIIB, whereby the transport of atomic oxygen by the large-scale waves would conceivably cause a change in electron density within the D-region.

1. Absorption stations

Data from 11 absorption stations were obtained through the World Data Center at Boulder, Colorado. The breakdown of this data appears in Table 1. The absorption values that were selected for this study were those taken at 1200 local standard time, or as close thereto as data permitted. The time difference was rarely more than one hour from the synoptic time.

2. 10 millibar data

Research previously cited in this report has referred to strong correlations between temperature patterns at the 10 millibar level and the variations in D-region absorption. Gregory (1963) has also indicated that variations in height of the pressure surface appear to be related at times. The 10 mb level was the highest level at which routine daily analyses were accomplished by the National Meteorological Center's Upper Air Branch. From

TABLE 1

Absorption stations with McIlwain's L - shell parameter shown adjacent to each station.

A(1) - Pulse	Lat.	Long.	L-Shell
1. DeBilt, Netherlands	52N	05E	2.5
2. Freiburg, Germany	48N	07E	2.0
3. Genova, Italy	44N	09E	1.8
4. Alma Ata, USSR	43N	76E	1.5
5. Ashkhabad, USSR	37N	58E	1.6
6. Tokyo, Japan	35N	139E	1.5
7. Taipei, Nat. China	25N	121E	1.2

A(2) - Riometer	Lat.	Long.	L-Shell
1. Great Whale, Quebec	55N	77W	7.0
2. Neustrelitz, E. Germany	53N	13E	2.4
3. Baie St. Paul, N.B.	47N	70W	3.9
4. Washington, D.C.	38N	77W	3.0

these analyses Richards (1967) was able to obtain daily values of the geopotential height (Z), temperature (T), and u and v geostrophic wind components on magnetic tape from the National Weather Records Center at Asheville, North Carolina. The values were obtained for each 5 degrees of latitude and 10 degrees of longitude in the Northern Hemisphere, beginning at 20 degrees north latitude. A complete description of the data reduction can be found in Richard's paper.

3. Meteorological Rocket Network

A growing network of meteorological rocket stations is presently in operation throughout North America, with a few stations scattered outside of this region. The Department of Meteorology, Massachusetts Institute of Technology, receives the monthly data prepared by the U.S. Army Electronics Research and Development Activity, White Sands Missile Range, New Mexico, and edited by the Meteorological Rocket Network Committee. For those stations listed in Table 2 the zonal and meridional wind components were obtained for the rocket launch closest to noon, GCT, on each day during the IQSY. The values received at each reportable level were linearly interpolated to provide routine wind readings at two km intervals above 20 km. Although the extreme limits of the data in the vertical is generally between 20 and 70 km, the greatest concentration of data occurred between 30 and 60 km. The number of launches also varied greatly from station to station.

TABLE 2

Meteorological Rocket Network Stations

		Lat.	Long.
1.	Wallops Island, Virginia	38N	75W
2.	Pt. Mugu, California	34N	119W
3.	Ft. Greely, Alaska	64N	146W
4.	White Sands, New Mexico	32N	106W
5.	Barking Sands, Hawaii	22N	160W
6.	Cape Kennedy, Florida	28N	81W

4. Airglow

The association of atomic oxygen and the 5577Å (OI) airglow emission is well known. Johnson (1964) has pointed out that enhancement of the green line emission is a result of downward mixing of atomic oxygen. This would fit in well with the theory of increased D-region absorption due to the transport of atomic oxygen, although the level for maximum emission of the 5577Å band is generally near 97 km. Data have been acquired for those stations listed in Table 3 through the World Data Center, Boulder, Colorado. Midnight values were used for each station. The number of days with reportable values varied greatly within this group of stations, thus limiting the effectiveness of this portion of the study.

TABLE 3

5577Å Airglow Stations

	Station	Lat.	Long.
1.	Haleakala, Hawaii	21N	156W
2.	Kitt Peak, Arizona	32N	112W
3.	Fritz Peak, Colorado	39N	105W
4.	Dodaira, Japan	36N	139E
5.	Gifu, Japan	35N	137E
6.	Poona, India	18N	73E
7.	Vannovskya, USSR	38N	58E
8.	Haute Provence, France	43N	05E

5. Synoptic analyses

In addition to those charts described in VA2, monthly mean analyses were also available at the 10 millibar level during the IQSY (see Staff, Upper Air Branch, NMC, 1967). Through the utilization of available data from the meteorological rocket network, weekly analyses were also performed at the 5, 2 and 0.4 millibar pressure surfaces. These analyses will serve as a basis for comments to be made later in the report. A geographical illustration

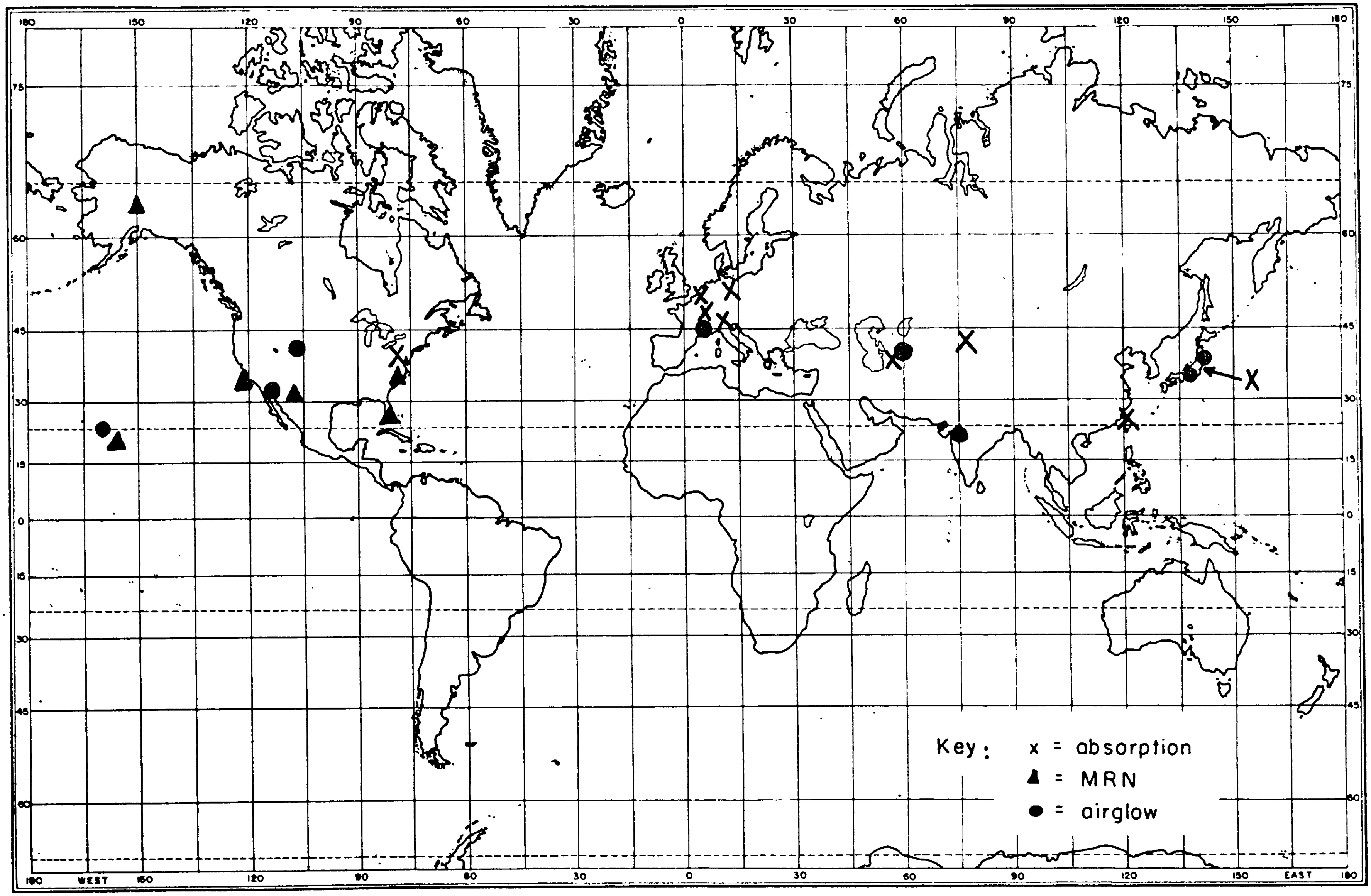

Figure 7. Geographical illustration of the complete data network used in the thesis.

of all data sources is indicated in Figure 7.

B. Utilization

With two years of data available it was decided to subdivide each of the data sets into three month groups, rather than treat monthly sets, as this would provide for a better data sample for the ensuing calculations. It has been noted by Diemenger (1968) that the period of anomalous winter absorption is observed between October and March, and for this reason the calendar quarters were utilized as the appropriate subdivisions.

The basic result that was derived from all of the programs that will be described was the standard correlation coefficient, which is defined in most textbooks dealing with statistics. The form of the two equations shown below was taken from Spiegel (1961). Using the correlation of u, the zonal wind component, and A, the absorption, as an example,

$$r_{uA} = \frac{N\Sigma uA - (\Sigma u)(\Sigma A)}{[(N\Sigma u^2 - (\Sigma u)^2)(N\Sigma A^2 - (\Sigma A)^2)]^{1/2}}$$

where N is the sample size. A correlation of 1.0 would be a perfect positive correlation, while a -1.0 would indicate a completely negative correlation, and 0 would mean the two parameters varied in a random manner.

In the case of small data samples, where the results may have been of dubious value, a confidence factor was calculated using Student's t test as shown below. Only those values which were determined to be significant at the 5% confidence level were considered in the results section.

$$t = \frac{r(N-2)^{1/2}}{(1-r^2)^{1/2}}$$

where N-2 represents the number of degrees of freedom, and r is the calculated correlation coefficient.

The data was then processed in the following manner:

1. 10 millibar grid data versus absorption data

Two different programs were used with these sets of data. In the first instance a grid point was picked as close to each absorption station as the grid network permitted. Using the daily values four correlation coefficients were computed for each quarter between the geopotential height (Z), temperature (T), zonal wind component (u), meridional wind component (v), and the absorption values. In the second program five absorption stations were picked that were representative of each of the areas in which data existed. The stations chosen were Washington D.C., DeBilt, Genova, Alma Ata, and Tokyo. A selection of grid points was chosen to compare against the absorption values for each station. The choice of grid points was primarily dictated by the circulation features that exist at the 10 mb level in each area; in the case of Washington D.C., the grid points were also chosen to coincide with certain meteorological rocket stations. The reason for this will be obvious in the next chapter. A correlation coefficient was again computed as before, but with one additional feature; a three day time lag was utilized. This permitted an examination of the variation in absorption on days one, two, three and four, with the 10 mb parameter on day one. Table 4 shows the match of grid points for each absorption station.

TABLE 4

The 10 millibar grid points used with each absorption station.

65N 150W *35N 120W 35N 100W 30N 130W 40N 80W	vs	Washington Absorption
50N 00E *35N 120W 40N 80W	vs	DeBilt Absorption
40N 80W 45N 10E *35N 120W	vs	Genova Absorption
40N 70E 35N 20E *35N 120W 55N 50E	vs	Alma Ata Absorption
35N 140E 55N 100E *35N 120W 30N 110E	vs	Tokyo Absorption

*Master station for this program

2. MRN data versus absorption data

The primary utilization of these data sets was limited to the principle North American station at Washington D.C., due to the geographical location of the useable rocket stations (see Table 2). However, attempts were also made to correlate the rocket winds on the eastern seaboard of the United States with absorption values in Europe. As indicated in an earlier section the rocket data was broken down into standard two km intervals, thus providing a correlation coefficient at each two km interval for which data existed. A three day time lag was also used in this program.

3. Airglow data versus absorption data

The airglow stations in Table 3 were correlated with a variety of absorption stations, as indicated in the results section. The three day time mechanism considered the variation of absorption on days one through four against the airglow value on day one. This would allow sufficient time for both horizontal and vertical transport of atomic oxygen, if such were a factor.

4. Absorption cross-correlations

In the manner of Thomas (loc. cit.), Washington D.C. was established as the master station, and it was then correlated with all of the other absorption stations on a longitudinal basis. The purpose here was twofold: one, to determine if the larger data sample and different time period (IQSY vs IGY) modified the original findings of Thomas; two, to see if a wavelength in the circulation pattern might become apparent if the correlations were extended far enough on a longitudinal basis. This could be manifest in the form of a strong negative correlation between distant stations, thus inferring large-scale rising motion at one longitude and sinking motion at the other. This is in consonance with an idea put forth by Newell et al. (loc. cit.), and later by Geisler and Dickinson (loc. cit.). Regional cross-correlations were also computed, and in all cases a three day time lag was again used.

VI. RESULTS AND DISCUSSIONS

The complete results of the programs referred to throughout the remainder of the thesis may be found in the tables and figures following Chapter VIII.

A. 10 mb Parameters Against Absorption Data, Program 1:

The initial results were extremely encouraging for Washington D.C. but generally inconclusive for the other stations. Figure 8 compares the results for both Washington D.C. and Tokyo. In the former case a persistently strong negative correlation was observed between the geopotential height, temperature, and the corresponding absorption values during those quarters in which the westerlies were still dominant at the 10 mb level. The results suggest that both a decrease in height and an influx of colder air at the 10 mb level relate very strongly to an increase in the daily absorption values at Washington D.C.

During the first and fourth quarters of the year the polar vortex and the associated trough over North America are the main circulation features over the Northern Hemisphere, along with the large Aleutian anticyclone. The second quarter is essentially a period of transition from the westerlies to the easterlies. A positive correlation between the zonal wind component and the change in absorption was very obvious during these three quarters, but the meridional wind component did not appear to be as well correlated.

During the third quarter the results are just reversed.

A strong positive correlation is found between the geopotential height, temperature, and the absorption changes, while a pronounced negative correlation is noted for the zonal wind relationship. Daily maps at the 10 mb level indicate that minor perturbations are observed in the easterly flow, and the greatest correlation with these features is found along the ridge line as shown in Figure 9. These perturbations may certainly be evident at the 85 km level and could be accompanied by increased atomic oxygen that exists over the cold polar mesopause in the summer. The excess atomic oxygen may subside as it extends equatorward along the ridge lines and thus explain the high summer correlations that are prevalent at nearly every station shown in the tables. Although this period of the year was not the original focal point of the study, the nature and magnitude of the results seem worthy of comment.

It is significant to note that none of the other 10 absorption stations exhibit the high correlations that are evident at Washington D.C., although in certain quarters some stations do show a very significant correlation. An example of this is the relationship between geopotential height and absorption changes during the fourth quarters of 1964 and 1965 at Tokyo. The respective correlation coefficients of .43 and .45 are significant at the 1% level and indicate that the absorption increase is related to an increase in height at the 10 mb surface. This is precisely the reverse of the results found at Washington D.C. during this particular period of time.

Warnecke and Nordberg (1965) have pointed out that both the Aleutian anticyclone and the polar vortex are identifiable features in the circulation up to at least 70 km, along with moving perturbations of a smaller scale. Theon et al. (1967) have shown good evidence of the latter at the 50 km level. Troughs of this intensity do not appear to be as common in the upper stratosphere and mesosphere over Europe and Asia where the flow is more zonal in nature. Thus it appears that the combination of the Aleutian high pressure cell and the persistent polar trough may be of possible significance in transporting atomic oxygen from the lower latitudes into the Washington D.C. area, and thereby effecting an increase in the electron density.

The ensuing programs will be discussed with these features in mind and then a more detailed picture connecting these factors will be presented in the concluding chapter.

B. MRN Winds Against Washington Absorption Data

The four rocket stations at Wallops Island, White Sands, Pt. Mugu, and Ft. Greely provided a good test of the importance of these synoptic features as related to the Washington D.C. absorption, as the vertical wind profiles at each of the stations are a reflection of the movement and intensification of either the polar vortex or the Aleutian anticyclone. The shading in figures 10 through 13 has been provided as a visual aid to show where the absolute value of the correlation exceeded 0.5. It is quite obvious that there is a strong relationship between the absorption changes at Washington D.C. and the variation in wind t the four stations, although the nature of the correlation varies from station-to-station.

1. Figure 10, Wallops Island and Washington D.C.

For the second and fourth quarters of 1964 there was an insufficient amount of rocket data to obtain valid results; however, during the first quarter of both 1964 and 1965 a pronounced correlation existed between the increase of absorption and the increase of southwesterly winds over Washington D.C., predominantly from the 40 to 50 km level. r_{ua} and r_{va} were both decidedly positive in the upper stratosphere with a correlation coefficient as high as 0.9. During the third quarter of 1964 there was a pronounced negative correlation involving the zonal wind component, while the relationship involving the meridional wind component varied in a random manner. The nature of these correlations fits quite well with the comment made previously on the perturbations in the easterlies.

2. Figure 11, White Sands and Washington D.C.

From September 1964 through March 1965 a high positive correlation was determined for both the zonal and meridional components of the wind and the mean flow was southwesterly at all levels in the White Sands area. By contrast the first quarter of 1964 revealed a different flow pattern over the area with north to northeast winds dominating to well above 40 km, and a relatively low correlation was observed between the two stations. This also suggests that the preferred supply of air should be from the southwest to cause an increase in absorption at Washington D.C.

3. Figure 12, Pt. Mugu and Washington D.C.

During the first quarter of 1964 the average winds between 30 and 40 km varied from north-northwest to north-northeast and the correlations obtained were relatively small for this height interval; however, a significant correlation was observed during this period between the zonal wind component and the absorption at 46 to 52 km and it was noted that the wind had returned to an average west-southwesterly flow over this interval. There were insufficient observations above this height to permit further examination of the data. Over the last three months of 1964 a very strong positive correlation was also noted for r_{ua} between 30 and 50 km and the mean wind direction throughout this height interval was again from the southwest. During the first quarter of 1965 a pronounced negative correlation existed for both r_{ua} and r_{va} from 26 to 30 km and an inspection of the winds over this interval revealed that they were predominantly from the northwest. The explanation of the correlations is not as straightforward as it is for the other two rocket stations. It appears that a strong surge of northerly winds into the Pt. Mugu area might be indicative of a southward displacement of the main trough over most of the United States, to include Washington D.C. This would mean a decrease in the advection of atomic oxygen, which would yield a negative correlation between the zonal component of the wind at Pt. Mugu and the absorption at Washington D.C. By contrast southwesterly winds at Pt. Mugu would mean that the trough was still north of Washington, and thus the southwesterly winds would carry more atomic oxygen into the area, increasing the absorption and causing a positive correlation for r_{ua}.

4. Figure 13, Ft. Greely and Washington D.C.

Throughout the first and fourth quarters of 1964 and the first quarter of 1965 the average winds varied between northwesterly and north-northeasterly at all of the levels for which a correlation is shown. The correlation patterns during the first quarter of both 1964 and 1965 were quite similar if one examined the time lag feature. A marked positive correlation was noted for both r_{ua} and r_{va} during the first quarter of 1964, and a similar trend was evident at a one to three day time lag in 1965, although at a lower height interval. The inference here is similar to that made for Pt. Mugu. It appears that an increase in northerly winds over Ft. Greely results in both a re-positioning and a sharpening of the main trough feature, such that the return flow on the east or southeast side of the trough is from a more southerly direction into the Washington D.C. area, which favors the transport of more atomic oxygen. The negative r_{va} correlation that is evident at the end of the third day during the last quarter of 1964 is not explicable in this light, and is an anomaly in itself.

On the basis of the correlations that have been discussed thus far, one might speculate on a synoptic pattern such as that indicated in Figure 14. On the first day the Aleutian anticyclone dominates the flow over Ft. Greely, but on the second day the ridge retrogresses to the west as the vortex increases in intensity. The winds back at Ft. Greely, the pressure drops, and the trough moves southward over the western part of the United States. This results in a more northeast-southwest orientation of the main trough feature, with southerly flow moving into the Washington D.C. area. A more complete example of the flow pattern which would facilitate the transport of atomic oxygen will be presented in the conclusions.

C. 10 mb Parameters Against Absorption Data, Program 2

The results for Washington D.C. and Tokyo have been selected from the tables and plotted in Figures 15 through 23. The shading in the drawings depicts the general spread of the correlation coefficient over the three day time lag.

1. Washington D.C. absorption

As noted in Chapter VB, four of the grid points chosen coincided as closely as possible to the four rocket stations described in the previous section. This facilitated a comparison of the previous results using a larger and more uniform data sample. The outcome was a strong confirmation of the results described in the foregoing sections, particularly with respect to those points located near Wallops Island (40N 80W) and Ft. Greely (65N 150W).

(a) Figure 15: During the first quarter of 1964 it is implied that an increase in the northerly wind and a decrease in the geopotential height at Ft. Greely will be accompanied by an increase in the absorption values at Washington D.C., with the u vs A correlation reaching a peak of 0.88. As suggested earlier this seems to imply that a minor perturbation moving southward past Ft. Greely effects a more northeast-southwest orientation of the major trough which increases the flow from the lower latitude regions into the Washington D.C. area. This is also evident by the negative correlation between temperature and absorption which corresponds to an influx of colder air from the polar region as the minor feature passes southward.

(b) Figure 16: The results for the grid point near Wallops Island are also explicable in this light. The trough at the 10 mb level frequently moves east of the Washington D.C. area, as will be shown in a later diagram. However, the slope of the trough usually carries it to the west of the area above the 40 km level. Thus the eastward movement of the trough into the coastal area would bring a decrease in the geopotential height and temperature, and a veering of the wind to north of west. The net results at the higher levels would be a strong southerly flow of air into Washington D.C. along the east side of the trough, which may explain the increase in absorption that is observed.

(c) Figures 17, 18 and 19: The trends at the intermediate grid points are displayed in these three diagrams, and are related to the picture just described.

2. Tokyo absorption

The grid points that were matched with the Tokyo absorption data suggest that a different feature of the circulation may be hinged to the variation of absorption in this area. This is particularly true for the grid point at 35N 140E shown in Figure 20, which is the point nearest to the location of Tokyo. The southwest corner of the huge Aleutian anticyclone seems to dominate the flow over Tokyo at the 10 mb level during certain periods of the winter. This is evident in Figure 24 taken from the NMC series for the IQSY. The persistent positive correlations for r_{za} may be linked to strong subsidence at the higher levels as the anticyclone increases in intensity, as this would result in a downward mixing of the atomic oxygen supply above 85 km. Likewise the positive correlation between temperature and absorption could be partially explained by adiabatic warming, but the effects of advection would have to be considered and this may explain the weaker correlations that are observed. The predominant negative correlation for the zonal wind component would appear to be attributable to a simultaneous increase in the easterly circulation as the high pressure cell intensifies. Unlike the North American continent where the rocket network provides a clue as to the nature of the mesospheric circulation, there are insufficient observations over eastern Asia on a synoptic scale to permit more than mere speculation.

3. Genova, DeBilt and Alma Ata absorption

In an indirect manner the explanation advanced for the high correlation at Washington D.C. seems to be supported by the results obtained for these three stations. The final computations over Europe do not exhibit the regular pattern that is evident in the Washington D.C. area and the correlations are not nearly as high. The lack of irregularities in the flow pattern over this area seems to afford very little opportunity for the transport of atomic oxygen from the lower to middle latitudes as it does in the area near Washington D.C.

D. Relationship of Pressure Levels and Absorption Variation

An intriguing aspect of the dynamics of the upper atmosphere may have been confirmed with this particular program. Newell (1966, 1968) has argued that the mesosphere must have an external energy supply to maintain the circulation and he has postulated that the source is the upper stratosphere between 30 and 55 km. This would be analogous to the relationship between the upper troposphere and the lower stratosphere.

The absorption data was compared with the geopotential height and temperature at both Washington D.C. and Tokyo for eight different pressure levels ranging from 1000 mb (100 cbs) to 10 mb (1 cb), and the results are shown in Figures 25 and 26.

1. Figure 25, Washington D.C.

It is interesting to note that at Washington D.C. there is virtually no correlation at or below the 10 cb level, but a sharp increase in the correlation to a very significant figure is witnessed at the one cb level. This may be indicative of a phase relationship in the circulation patterns between the 30 km level and the mesopause. The results are shown only for the winter quarters during which the large-scale eddies are apparent in the circulation, as the results were quite random during the summer quarter.

2. Figure 26, Tokyo

Tokyo revealed a significant trend for only one of the winter quarters, and this occurred during the last three months of 1964. During this period of time a significant positive correlation for r_{za} was noted over the entire interval from 85 cb to one cb. At the same time a strong positive correlation was noted with the temperature in the lower troposphere, but it reversed and became a significant negative correlation in the lower stratosphere. This again infers a strong link between the intensification of the Aleutian anticyclone and the increase of absorption at Tokyo, but this time the temperature effects seem strongly related to the advection of air from the warm equator in the lower troposphere and from the cold equator in the lower stratosphere. The correlations during the first quarter of 1964 were completely random, whereas the first and fourth quarters of 1965 exhibited significant correlations at three different pressure levels. They did not follow the same pattern as observed during the fourth quarter of 1964, and this could be due to the variation in the intensity of the circulation features from quarter to quarter.

E. Absorption Cross-Correlations

One of the more interesting aspects of this study involved the comparison of the absorption change at Washington D.C. with each of the other absorption stations.

Washington D.C. and Baie St. Paul are located at nearly the same meridian, but Baie St. Paul is nearly 600 miles north of Washington and at a higher L-shell. The results in Table 12 clearly indicate that the two stations do not follow the same pattern of absorption changes; furthermore, during the fourth quarter of 1964 there was a significant negative correlation between the two stations. Whereas the correlations at the noise level could be attributed to some form of particle precipitation at the higher L-shell, the strong negative correlation would not be achieved in this manner. It is conceivable that a significant change in the vertical motion field occurred across this latitudinal distance during the last three months of 1964, and thus affected the distribution of atomic oxygen at 85 km over the two stations.

In comparing Washington D.C. with the other stations in Europe and Asia the number of the L-shell should not have been a factor as it never exceeds 3.0 for any of the stations. From the results in Table 12 one can say that there appears to be a negative correlation between Washington and the European-Asiatic complex of stations, although there are departures from this rule. The relationship between Tokyo and Washington is the most emphatic. A strong negative correlation was evident in all but the single summer quarter of 1964. The most impressive results were during the two consecutive winter quarters of 1964-1965 when the correlation factor reached -.607 and -.740 respectively.

The results for all of the stations are plotted in Figure 27 according to their longitudinal location. Although it was quite tempting to sketch in a best-fit curve, the density of the plotted values was too small to permit this liberty. Nevertheless, there is a strong indication of a planetary wave feature by virtue of the persistently strong negative correlations between Tokyo and Washington. This might be of the nature to give descending motion at the 85 km level over Washington D.C. and rising motion over eastern Asia at the same level. Young and Epstein (1962) have shown that the effects of downward vertical motion would greatly enhance the atomic oxygen content at 80 to 85 km, and this could be an explanation for the negative absorption correlations between the two stations.

The sense of the regional correlations was generally the same as those determined by Thomas (loc. cit.) but the values were not nearly as significant. Using the 20 days of highest absorption values in each month of the three month period December 1958 to February 1959, Thomas found a correlation of 0.95 between DeBilt and Freiburg. The results obtained for the IQSY data were also positive, but the highest correlation was 0.63 during the second quarter of 1965 (Reference Table 15).

During the course of the comparison of absorption stations in Europe and Asia it became apparent that the Genova data did not mesh well with that from the other stations. This is apparent in Figure 28, as well as Table 13. However, the results in the figure depict the use of Genova and Neustrelitz as master stations matched against four other stations from the same region. The correlations with Genova seemed to vary in a random manner from positive to negative even though all of these stations recorded their observations in the Al (pulse) manner. The results between Neustrelitz and the other stations were decidedly better, especially during the four winter quarters. The reason for this disparity is not immediately obvious as all of these stations are in the L-shell range of 1.6 to 2.4.

F. Airglow-Absorption Correlations

The association between the enhancement of the 5577Å airglow and the vertical transport of atomic oxygen has been described by Tohmatsu and Nagata (1963) and Johnson (loc. cit.). If the increase in the intensity of the airglow is caused by the downward mixing of atomic oxygen, then it is feasible that a connection could be found between the airglow and radio wave absorption.

The results between the airglow at Dodaira, Japan, and the absorption at Tokyo, Japan, are quite impressive in this regard, especially during the fourth quarter of 1964 and the first quarter of 1965. As seen in Figure 29 there is a significant positive correlation between these two stations during the two quarters cited, and to a lesser extent during the final quarter of 1965.

This suggests that the mixing may extend downward to the 80 or 85 km level where the atomic oxygen would be a factor in the increased absorption at the lower levels.

The airglow data at Haleakala, Hawaii, seems reasonably well correlated with the absorption data at Tokyo even though they are separated by nearly 3,000 miles. Particular reference is made to the period extending from October 1964 through March 1965 shown in Figure 30. This would suggest that the stations were connected by the same flow pattern during this period with similar vertical motion fields in both areas.

The same might be said for the comparison of airglow at Haute Provence, France, and the absorption values at Alma Ata, USSR, as shown in Figure 31. A positive correlation is essentially present at all times despite the distance that separates the two stations. However, both locations are connected by the strong westerlies that prevail around the polar vortex in this region. In the same diagram it is interesting to note the dominant negative correlation found between Haute Provence and Genova even though they are located within 200 miles of each other. Whether this is a further reflection on the absorption data at Genova, as mentioned earlier, or whether it infers that there was little mutual relationship between the 85 and 95 km level in this area is open to speculation.

The data samples for the Fritz Peak, Colorado, and Kitt Peak, Arizona, were relatively small and thus there were insufficient results to produce a meaningful graph; however, a very high correlation of 0.792 was noted between Fritz Peak and Washington D.C. during the fourth quarter of 1964, and this was significant at the 1% level (Reference Table 16).

G. 5577Å Airglow Cross-Correlations

Although only three of the quarters contained enough observations from which to draw valid results, the relationship between the two airglow stations at Haute Provence and Dodaira was very strong (Reference Figure 32). Correlation coefficients of .406, .632, and .692 were respectively found during the fourth quarter of 1964 and the first and fourth quarters of 1965. This would seem to infer that the source of the increased airglow was the same in these two regions, which means that the sense of the vertical motion at 95 km was identical over Europe and Asia. This would again infer a wave of planetary dimensions with vertical motion fields in the same direction over Europe and Asia. Unfortunately the data samples were so low for the other stations that no further evaluations could be made.

VII. CONCLUSIONS

This study has not attempted to completely resolve the answer to the D-region winter anomaly, but rather to determine the significance of the meteorological process related to this problem. In this regard the study seems to have met with success.

The convincing correlations that have been found between the absorption data at Washington D.C. and the wind profiles in the upper stratosphere suggest that the main polar trough that extends southwestward over North America into the lower latitudes of the Pacific Ocean is a very efficient mechanism for increasing the electron density at Washington D.C. Nordberg (1966) pointed out that the average wind direction in the winter between 70 and 80 km was northerly at Ft. Churchill, Canada, but southerly at Wallops Island. Thus the circulation feature still seems to be evident at this altitude.

The situation favorable to an increase in absorption at Washington D.C. is shown in Figure 33. The trough configuration is shown at three different altitudes. The influx of air into Washington D.C. at the 85 km level would be from a region where relatively cold air prevails and also where a surplus of atomic oxygen exists. The oblique motion would carry atomic oxygen down its mixing ratio gradient as it moves poleward at and above the 85 km level. This would provide for an increase of atomic oxygen at the 80 to 85 km level and thus facilitate an increase in the electron density. If the trough were located east of the Washington

D.C. area at all levels, northerly winds would prevail, and this would decrease the amount of atomic oxygen that would be transported into this area.

The persistently strong negative correlations between Washington and Tokyo during the winter period infers that as the electron density increases over Washington D.C. it decreases over Tokyo, or vice-versa. This fits quite well with the picture just presented. Downward vertical motion in the Washington area in conjunction with the trough would be countered by net upward motion in the regions of central and eastern Asia. Considered in terms of the vertical mixing of atomic oxygen this would mean an increase in the absorption over Washington but a decrease in the Tokyo area; thus the negative correlation between the two regions.

The strong correlation between airglow observation over France and Japan further suggest that the direction of the vertical motion field is the same in these two regions.

Finally the positive correlations obtained between the airglow and absorption stations certainly adds to the conviction that the vertical mixing responsible for the increased airglow at 95 km may extend down to the 85 km level.

VIII. RECOMMENDATIONS

There is evidence that a relationship exists between the increase of atomic oxygen at 95 km and the increase of radio wave absorption between 80 and 85 km. An effort should be made to test this hypothesis with large data samples from airglow and absorption stations located in the same area. This could be accomplished at Vannovskaya and Alma Ata in the USSR or at Fritz Peak and Washington D.C. in America.

A large scattering of points on a cross-correlation diagram such as Figure 27 would certainly aid in distinguishing the wavelength in the hemispheric circulation patterns. This would require an increase in useable absorption data over both North America and Europe. According to the catalogue supplied by the World Data Center the facilities are in place in numerous locations, but a relatively small amount of observations are made. It would seem that a concerted effort should be made to maintain a large network of facilities over a six month winter period. The cost would not be prohibitive over such a short period in terms of the scientific enlightenment that might be realized.

TABLE 5. 10 mb Grid Values vs Absorption Data, Program 1

Washington - 40°N 80°W

YR/QTR	Z	T	u	v
64-1	-.60	-.37	.61	-.34
64-2	-.80	-.79	.29	-.03
64-3	.74	.76	-.74	-.06
64-4	-.59	-.14	.30	-.02
65-1	-.63	-.66	.35	-.14
65-2				
65-3				
65-4				

DeBilt - 50°N 00°E

YR/QTR	Z	T	u	v
64-1	.03	.19	-.21	-.03
64-2	.33	.23	.01	.13
64-3	.53	.47	-.52	.03
64-4	.36	.29	-.31	-.14
65-1	.27	.18	-.29	.01
65-2	.61	.61	-.43	-.06
65-3	.49	.44	-.40	.09
65-4	.01	-.01	-.04	.05

Neustrelitz - 50°N 10°E

YR/QTR	Z	T	u	v
64-1	.17	.15	-.18	-.23
64-2	-.08	-.06	.27	.08
64-3	-.48	-.39	.47	-.23
64-4	.47	.33	-.32	-.06
65-1	.18	-.02	-.22	.05
65-2	.33	.34	-.35	-.12
65-3	.09	.05	-.10	-.09
65-4	.35	.34	-.25	-.02

Genova - 45°N 10°E

YR/QTR	Z	T	u	v
64-1	.12	.19	-.02	.07
64-2	.06	.20	-.24	.10
64-3	.21	.27	-.20	-.11
64-4	-.15	.01	.32	.16
65-1	-.13	-.07	.19	.09
65-2	-	-	-	-
65-3	-.18	-.22	.26	.01
65-4	.56	.48	-.26	.04

Frieburg - 50°N 00°E

YR/QTR	Z	T	u	v
64-1	-.15	-.04	.03	-.05
64-2	-.12	-.23	-.26	-.17
64-3	.53	.47	-.41	-.18
64-4	.10	.10	-.14	-.08
65-1	.05	-.19	-.10	-.13
65-2	.57	.52	-.43	-.10
65-3	.34	.21	-.39	-.11
65-4	-.13	-.14	-.17	-.18

Alma Ata - 40°N - 70°E

YR/QTR	Z	T	u	v
64-1	-.20	-.16	.12	.02
64-2	.64	.35	-.59	-.17
64-3	.13	.14	-.20	.13
64-4	.25	.08	-.26	.24
65-1	-.16	-.13	.15	.03
65-2	.41	.27	-.15	.04
65-3	.53	.25	-.47	-.12
65-4	.21	.30	-.34	.12

Table 5 (continued)

Ashkhabad - 35°N 60°E

YR/QTR	Z	T	u	v
64-1	-.25	.14	.38	.14
64-2	.33	.12	-.37	.09
64-3	.44	.33	-.51	.16
64-4	.12	.00	-.27	-.16
65-1	-.34	-.10	.32	.31
65-2	-.55	-.40	.54	-.07
65-3	.26	.17	-.22	-.16
65-4	.32	.32	-.34	-.11

Tokyo - 35°N 140°E

YR/QTR	Z	T	u	v
64-1	.05	-.00	-.30	-.02
64-2	.29	.10	-.15	-.12
64-3	.29	.03	-.31	-.13
64-4	.43	-.03	.23	-.34
65-1	-.20	-.04	-.31	-.17
65-2	.39	.30	-.18	-.04
65-3	.44	.32	-.50	.50
65-4	.45	.24	-.24	-.40

Baie St. Paul - 45°N 70°W

64-1	.03	.10	.12	.10
64-2	-.03	-.03	-.09	.07
64-3	.31	.32	-.31	.06
64-4	.24	.01	-.29	-.25
65-1				
65-2				
65-3				
65-4				

Great Whale - 55°N 80°W

64-1	.03	.08	.06	-.06
64-2	-.44	.52	.30	-.17
64-3	.08	-.07	-.09	.17
64-4	.06	-.05	-.17	.03
65-1				
65-2				
65-3				
65-4				

Taipei - 25°N 120°E

64-1				
64-2				
64-3				
64-4				
65-1	-.05	-.11	.14	-.18
65-2	-.05	.06	.02	.15
65-3	-	-	-	-
65-4	.56	-.09	-.41	-.36

TABLE 6. WASHINGTON ABSORPTION CORRELATIONS

10 MB STN	1-3, 1964					4-6, 1964				
	LAG	Z	T	u	v	LAG	Z	T	u	v
	0	-.60	-.37	.61	-.34	0	-.80	-.79	.29	-.03
40°N 80°W	1	-.64	-.45	.68	-.35	1	-.52	-.54	.11	.00
	2	-.64	-.44	.69	-.34	2	-.51	-.56	.10	-.10
	3	-.64	-.39	.72	-.34	3	-.49	-.53	.07	-.19
	0	-.59	-.21	.81	-.47	0	-.65	-.66	.58	.19
65°N 150°W	1	-.64	-.21	.85	-.48	1	-.39	-.41	.39	.19
	2	-.65	-.23	.86	-.48	2	-.37	-.39	.36	.07
	3	-.66	-.26	.88	-.50	3	-.33	-.35	.31	.08
	0	.23	-.02	.21	-.24	0	-.83	-.47	.51	-.46
35°N 120°W	1	.24	.03	.29	-.23	1	-.54	-.35	.26	-.36
	2	.26	.08	.31	-.29	2	-.53	-.37	.28	-.32
	3	.24	.09	.33	-.22	3	-.49	-.32	.22	-.25
	0	-.24	-.26	.46	-.53	0	-.85	-.58	.38	-.18
35°N 100°W	1	-.25	-.27	.53	-.54	1	-.58	-.46	.12	-.27
	2	-.25	-.25	.54	-.55	2	-.55	-.39	.17	-.17
	3	-.18	-.18	.56	-.51	3	-.51	-.36	.18	-.18
	0	.27	.03	-.20	.31	0	-.83	-.13	.74	-.39
30°N 130°W	1	.27	.06	-.20	.41	1	-.54	-.10	.47	-.35
	2	.31	.10	-.23	.49	2	-.53	-.11	.46	-.31
	3	.26	.14	-.18	.47	3	-.49	-.11	.43	-.38

	7-9, 1964					10-12, 1964				
	0	.74	.76	-.74	-.06	0	-.59	-.14	.30	-.02
40°N 80°W	1	.78	.78	-.77	-.08	1	-.57	-.12	.28	.01
	2	.78	.77	-.77	-.07	2	-.55	-.11	.28	.04
	3	.79	.77	-.77	-.10	3	-.53	-.07	.26	.09
	0	.80	.84	-.74	.41	0	-.08	.21	.57	-.35
65°N 150°W	1	.85	.88	-.78	.42	1	-.05	.24	.59	-.33
	2	.85	.87	-.76	.44	2	-.02	.28	.58	-.33
	3	.84	.87	-.76	.45	3	-.01	.29	.57	-.34
	0	.73	.64	-.67	.07	0	-.69	-.23	-.11	-.35
35°N 120°W	1	.77	.64	-.72	.07	1	-.66	-.21	-.15	-.41
	2	.78	.66	-.70	.11	2	-.66	-.20	-.16	-.44
	3	.77	.65	-.70	.06	3	-.62	-.22	-.15	-.44

Table 6 (continued)

10 MB STN	7-9, 1964 (continued)					10-12, 1964 (continued)				
	LAG	Z	T	u	v	LAG	Z	T	u	v
	0	.71	.61	-.61	-.03	0	-.66	-.19	.27	.18
35°N 100°W	1	.76	.61	-.65	-.01	1	-.67	-.20	.22	.18
	2	.77	.60	-.64	.01	2	-.67	-.19	.22	.26
	3	.76	.60	-.65	.02	3	-.65	-.16	.21	.23
	0	.71	.71	-.68	-.03	0	-.74	-.24	.15	-.46
30°N 130°W	1	.75	.70	-.72	-.05	1	-.72	-.22	.09	-.49

10 MB STN	1-3, 1965				
	LAG	Z	T	u	v
	0	-.63	-.66	.35	-.14
40°N 80°W	1	-.60	-.64	.35	-.14
	2	-.59	-.60	.33	-.11
	3	-.58	-.56	.34	-.14
	0	.23	-.02	.50	.27
65°N 150°W	1	.16	-.06	.52	.25
	2	.08	-.13	.54	.22
	3	.00	-.17	.56	.21
	0	-.02	-.61	-.50	-.61
35°N 120°W	1	-.00	-.64	-.48	-.60
	2	.03	-.63	-.49	-.59
	3	.06	-.64	-.48	-.61
	0	-.53	-.74	-.07	-.38
35°N 100°W	1	-.55	-.71	-.09	-.40
	2	-.53	-.70	-.11	-.38
	3	-.52	-.71	-.14	-.39
	0	.12	-.59	-.25	-.47
30°N 130°W	1	.13	-.61	-.25	-.43
	2	.15	-.57	-.27	-.39
	3	.16	-.57	-.28	-.34

TABLE 7. TOKYO ABSORPTION CORRELATIONS

10 MB STN	1-3, 1964					4-6, 1964				
	LAG	Z	T	u	v	LAG	Z	T	u	v
35°N 120°W	0	-.34	-.23	.04	.24	0	.28	.15	-.20	.14
	1	-.37	-.09	.02	.11	1	.29	.25	-.22	.01
	2	-.39	-.17	-.01	.18	2	.27	.23	-.12	.02
	3	-.32	-.09	-.08	.11	3	.24	.12	-.11	.23
35°N 140°E	0	.05	-.00	-.30	-.02	0	.29	.10	-.15	-.12
	1	-.01	-.01	-.26	.22	1	.33	.18	-.10	-.20
	2	.00	-.18	-.18	.19	2	.32	.11	-.16	-.28
	3	.02	-.20	-.23	.18	3	.28	.13	-.23	-.08
55°N 100°E	0	.39	.41	-.41	-.13	0	.28	.28	-.13	-.00
	1	.40	.37	-.45	-.13	1	.28	.32	-.17	-.00
	2	.44	.40	-.44	-.09	2	.28	.34	-.20	.01
	3	.44	.36	-.45	-.02	3	.26	.24	-.24	.04
30°N 110°E	0	.22	.36	-.10	-.26	0	.27	-.19	-.26	.23
	1	.22	.35	-.04	-.41	1	.28	-.23	-.30	.43
	2	.32	.37	-.04	-.42	2	.27	-.17	-.31	.42
	3	.38	.42	-.06	-.42	3	.25	-.06	-.27	.34
	7-9, 1964					10-12, 1964				
35°N 120°W	0	.43	.35	-.33	.02	0	.61	.22	-.32	.02
	1	.39	.27	-.30	.05	1	.62	.15	-.35	.02
	2	.44	.43	-.34	.12	2	.59	.08	-.36	.05
	3	.49	.41	-.40	.16	3	.61	.13	-.37	.04
35°N 140°E	0	.29	.03	-.31	-.13	0	.43	-.03	.23	-.34
	1	.42	.32	-.39	-.19	1	.51	.05	.29	-.41
	2	.38	.11	-.41	-.05	2	.41	-.03	.39	-.38
	3	.42	.21	-.30	-.03	3	.39	-.15	.40	-.29
55°N 100°E	0	.43	.26	-.32	-.10	0	.52	.46	-.45	-.11
	1	.42	.42	-.42	.04	1	.53	.46	-.44	-.13
	2	.43	.50	-.42	-.23	2	.53	.46	-.45	-.20
	3	.41	.42	-.42	-.07	3	.55	.47	-.50	-.22
30°N 110°E	0	.39	.45	-.47	.02	0	.65	.46	-.47	-.17
	1	.43	.45	-.53	.09	1	.67	.53	-.45	-.14
	2	.40	.47	-.45	.04	2	.65	.47	-.43	-.19
	3	.38	.49	-.45	.05	3	.62	.35	-.34	-.23

Table 7 (continued)

10 MB STN	1-3, 1965					4-6, 1965				
	LAG	Z	T	u	v	LAG	Z	T	u	v
	0	-.07	.38	.47	.50	0	.42	-.12	-.46	-.08
35°N 120°W	1	-.06	.42	.47	.50	1	.36	-.14	-.46	-.23
	2	-.06	.42	.45	.42	2	.35	-.14	-.38	-.32
	3	-.10	.39	.41	.32	3	.37	.04	-.37	-.10
	0	.20	-.04	-.31	-.17	0	.39	.30	-.18	-.04
35°N 140°E	1	.28	.07	-.33	-.18	1	.36	.30	-.17	-.00
	2	.31	.12	-.35	-.22	2	.29	.21	-.15	-.09
	3	.29	.10	-.32	-.20	3	.30	.29	-.18	-.08
	0	.49	.33	-.55	-.09	0	.34	.18	-.03	.18
55°N 100°E	1	.49	.29	-.53	-.02	1	.25	.24	.06	.27
	2	.48	.32	-.50	.02	2	.20	.07	.09	.20
	3	.47	.36	-.50	.03	3	.16	.18	.10	.22
	0	.31	-.00	-.64	-.10	0	.46	.35	-.35	-.09
30°N 110°E	1	.37	-.01	-.67	-.04	1	.41	.35	-.28	-.08
	2	.41	-.01	-.67	-.04	2	.36	.35	-.27	-.05
	3	.45	-.04	-.67	-.01	3	.32	.31	-.24	-.04

	7-9, 1965					10-12, 1965				
	0	.40	.16	-.55	-.21	0	.54	.38	-.22	.27
35°N 120°W	1	.44	.22	-.55	-.10	1	.51	.34	-.23	.21
	2	.39	.18	-.50	.11	2	.49	.31	-.21	.22
	3	.36	.19	-.45	.17	3	.44	.27	-.20	.16
	0	.44	.32	-.50	.00	0	.45	.24	-.24	-.40
35°N 140°E	1	.39	.26	-.44	.06	1	.53	.29	-.26	-.37
	2	.31	.33	-.41	.02	2	.54	.35	-.26	-.28
	3	.31	.44	-.38	-.05	3	.51	.35	-.26	-.21
	0	.40	.17	-.49	.06	0	.39	.37	-.15	-.08
55°N 100°E	1	.42	.24	-.48	.03	1	.36	.37	-.13	-.15
	2	.44	.28	-.46	.07	2	.31	.34	-.09	-.18
	3	.40	.23	-.43	.06	3	.26	.26	-.07	-.25
	0	.27	.34	-.44	-.01	0	.47	.44	-.38	.21
30°N 110°E	1	.23	.39	-.44	-.13	1	.46	.46	-.38	.29
	2	.23	.37	-.36	-.20	2	.44	.51	-.32	.26
	3	.26	.38	-.34	-.07	3	.42	.48	-.27	.21

TABLE 8. GENOVA ABSORPTION CORRELATIONS

10 MB STN	1-3, 1964					4-6, 1964				
	LAG	Z	T	u	v	LAG	Z	T	u	v
	0	-.25	-.11	.14	.09	0	.06	.04	-.13	.14
40°N 80°W	1	-.17	-.05	.09	.15	1	.09	.08	-.14	.11
	2	-.10	.00	.02	.24	2	.07	.00	-.16	-.00
	3	.12	.19	-.02	.07	3	.10	.07	-.13	-.03
	0	.12	.19	-.02	.07	0	.06	.20	-.24	.10
45°N 10°E	1	.11	.25	-.09	.09	1	.13	.29	-.14	.03
	2	.04	.22	-.12	.03	2	.12	.17	-.06	.03
	3	-.04	.17	-.13	-.20	3	.10	.15	-.15	.08
	0	-.35	-.34	.37	.22	0	.02	-.08	-.11	-.18
35°N 120°W	1	-.34	-.32	.21	.08	1	.09	-.03	-.14	.00
	2	-.39	-.32	.18	.04	2	.09	.06	-.13	-.10
	3	-.30	-.22	.15	.05	3	.08	.08	-.22	-.07

	7-9, 1964					10-12, 1964				
	0	.22	.22	-.26	-.11	0	-.23	.07	.24	.05
40°N 80°W	1	.21	.20	-.24	-.11	1	-.18	.16	.22	.08
	2	.21	.24	-.24	-.09	2	-.22	.17	.26	.10
	3	.18	.17	-.20	-.09	3	-.18	.17	.35	.21
	0	.21	.27	-.20	-.11	0	-.15	.01	.32	.16
45°N 10°E	1	.19	.27	-.16	-.10	1	-.15	.03	.28	.19
	2	.16	.16	-.20	-.02	2	-.22	-.06	.22	.09
	3	.15	.13	-.22	-.12	3	-.32	-.28	.12	-.06
	0	.22	.26	-.19	.02	0	-.28	.10	.06	-.00
35°N 120°W	1	.17	.11	-.21	-.01	1	-.25	.17	.07	-.00
	2	.16	.06	-.16	.19	2	-.29	.07	.08	.06
	3	.24	.13	-.17	.17	3	-.38	-.07	.23	-.00

Table 8 (continued)

10 MB STN	1-3, 1965					4-6, 1965 missing				
	LAG	Z	T	u	v	LAG	Z	T	u	v
	0	.08	-.15	-.24	-.18					
40°N 80°W	1	.04	-.22	-.19	-.13					
	2	.06	-.13	-.23	-.25					
	3	.12	.03	-.23	-.23					
	0	-.13	-.07	.19	.09					
45°N 10°E	1	-.15	-.02	.22	.13					
	2	-.16	.01	.11	.15					
	3	-.03	.00	.10	.02					
	0	.15	-.07	-.13	-.03					
35°N 120°W	1	.18	.01	-.18	-.12					
	2	.27	.07	-.19	-.00					
	3	.33	.21	-.28	.17					

	7-9, 1965					10-12, 1965				
	0	-.14	-.21	.19	-.01	0	.36	.47	.15	.20
40°N 80°W	1	-.17	-.21	.16	-.03	1	.36	.47	.15	.25
	2	-.16	-.18	.11	.10	2	.39	.54	.09	.20
	3	-.20	-.25	.08	-.09	3	.36	.47	.04	.16
	0	-.18	-.22	.26	.01	0	.36	.48	-.26	.04
45°N 10°E	1	-.16	-.19	.25	-.06	1	.49	.44	-.28	-.04
	2	-.13	-.12	.23	-.06	2	.45	.44	-.32	-.01
	3	-.20	-.17	.25	-.04	3	.43	.40	-.32	-.23
	0	-.11	-.11	.24	.07	0	.36	.29	.06	.06
35°N 120°W	1	-.17	-.03	.25	-.12	1	.32	.29	.05	.09
	2	-.18	-.03	.20	-.14	2	.32	.34	.04	.20
	3	-.21	-.18	.16	-.18	3	.29	.20	.05	.18

TABLE 9. DeBILT ABSORPTION CORRELATIONS

10 MB STN	1-3, 1964					4-6, 1964				
	LAG	Z	T	u	v	LAG	Z	T	u	v
	0	.03	.19	-.21	-.03	0	.33	.23	.01	.13
50°N 00°E	1	-.05	.01	-.17	.07	1	.35	.27	-.31	.25
	2	-.12	-.11	-.13	-.10	2	.35	.18	.07	.18
	3	-.17	-.12	-.08	-.17	3	.35	.26	.11	.07
	0	.11	-.16	-.15	.19	0	.38	.27	-.24	.02
40°N 80°W	1	.19	-.09	-.17	.20	1	.34	.34	-.23	.25
	2	.26	.10	-.28	.27	2	.36	.32	-.24	.14
	3	.34	.26	-.35	.15	3	.36	.29	-.20	-.04
	0	-.14	-.31	-.15	-.02	0	.36	.24	-.27	.04
35°N 120°W	1	-.03	-.16	-.15	-.05	1	.33	.31	-.24	.02
	2	.08	.01	-.16	-.08	2	.37	.20	-.26	.04
	3	.13	.14	-.21	-.05	3	.39	.49	-.28	.05
	7-9, 1964					10-12, 1964				
	0	.53	.47	-.52	.03	0	.36	.29	-.31	-.14
50°N 00°E	1	.51	.42	-.48	.11	1	.34	.22	-.32	-.29
	2	.51	.35	-.51	.23	2	.32	.14	-.35	-.24
	3	.52	.38	-.56	.25	3	.37	.23	-.38	-.13
	0	.54	.56	-.51	-.21	0	.38	.28	-.32	.07
40°N 80°W	1	.54	.61	-.52	-.11	1	.33	.26	-.25	.10
	2	.50	.54	-.50	.11	2	.27	.20	-.27	-.04
	3	.49	.47	-.45	-.00	3	.27	.09	-.25	.00
	0	.57	.47	-.48	.09	0	.25	.14	-.04	.07
35°N 120°W	1	.51	.51	-.47	.04	1	.22	.11	-.03	-.01
	2	.44	.29	-.43	.05	2	.26	.03	-.10	-.08

Table 9. (continued)

10 MB STN	1-3, 1965					4-6, 1965				
	LAG	Z	T	u	v	LAG	Z	T	u	v
	0	.27	.18	-.29	.01	0	.61	.61	-.43	-.06
50°N 00°E	1	.29	.21	-.36	.04	1	.63	.52	-.43	.01
	2	.28	.16	-.34	-.01	2	.63	.56	-.39	.08
	3	.23	.06	-.32	-.08	3	.62	.53	-.38	.12
	0	.25	.21	-.09	-.06	0	.68	.33	-.59	-.10
40°N 80°W	1	.29	.20	-.15	-.09	1	.72	.37	-.62	-.13
	2	.29	.21	-.22	-.16	2	.73	.34	-.64	-.09
	3	.26	.23	-.23	-.22	3	.71	.32	-.60	-.04
	0	.10	.36	.07	.19	0	.67	-.00	-.57	-.19
35°N 120°W	1	.11	.34	.10	.29	1	.71	-.02	-.62	-.09
	2	.08	.46	.14	.29	2	.72	.61	-.62	.05
	3	.01	.48	.20	.43	3	.70	.02	-.58	-.07

	7-9, 1965					10-12, 1965				
	0	.49	.44	-.40	.09	0	.01	-.01	-.04	.05
50°N 00°E	1	.49	.40	-.39	.02	1	.02	.12	-.05	.24
	2	.48	.42	-.42	.10	2	.04	.14	-.03	.32
	3	.48	.44	-.45	.03	3	.05	.12	-.03	.10
	0	.45	.43	-.45	-.06	0	.05	.08	.07	.19
40°N 80°W	1	.42	.30	-.46	-.08	1	.00	.06	.04	.13
	2	.47	.41	-.47	-.00	2	-.04	-.02	.04	.08
	3	.50	.43	-.48	.07	3	-.06	-.09	.02	.03
	0	.39	.35	-.47	-.02	0	-.02	.08	.08	-.04
35°N 120°W	1	.39	.23	-.45	-.03	1	-.06	.09	.11	-.06
	2	.44	.29	-.46	-.12	2	-.06	-.03	.15	.01
	3	.40	.27	-.49	.02	3	-.05	-.05	.11	.00

TABLE 10. ALMA ATA ABSORPTION CORRELATIONS

10 MB STN	1-3, 1964					4-6, 1964				
	LAG	Z	T	u	v	LAG	Z	T	u	v
	0	-.20	-.16	.12	.02	0	.64	.35	-.39	-.17
40°N 70°E	1	-.25	-.01	.24	.09	1	.59	.40	-.57	-.20
	2	-.23	.05	.32	.13	2	.60	.44	-.45	-.28
	3	-.16	.06	.39	.33	3	.54	.38	-.43	-.20
	0	-.21	-.03	.15	.08	0	.62	.37	-.52	-.18
35°N 20°E	1	-.31	-.12	.23	-.03	1	.61	.41	-.48	.02
	2	-.25	-.14	.18	-.02	2	.60	.34	-.50	.10
	3	-.21	-.13	.15	.04	3	.53	.30	-.46	-.01
	0	.01	.02	-.11	-.09	0	.59	.54	.00	.36
55°N 50°E	1	-.09	-.13	-.07	-.19	1	.56	.53	.04	.24
	2	-.16	-.15	-.00	-.22	2	.55	.49	-.01	.24
	3	-.22	-.15	.03	-.22	3	.50	.43	-.05	.10
	0	-.01	-.02	-.27	-.07	0	.62	.34	-.39	.32
35°N 120°W	1	-.05	-.03	-.25	-.10	1	.56	.26	-.40	.24
	2	-.05	.02	-.15	-.16	2	.53	.22	-.34	.06
	3	.05	.10	-.14	-.16	3	.51	.34	-.37	.07

10 MB STN	7-9, 1964					10-12, 1964				
	0	.13	.14	-.20	.13	0	.25	.08	-.26	.24
40°N 70°E	1	.12	.15	-.18	-.01	1	.19	.05	-.19	.24
	2	.16	.13	-.17	.04	2	.14	.17	-.09	.19
	3	.16	.14	-.20	-.06	3	.13	.17	-.04	.17
	0	.07	.03	-.18	-.18	0	.08	-.09	-.28	.09
35°N 20°E	1	.11	.22	-.11	-.05	1	.10	-.01	-.26	-.05
	2	.14	.12	-.11	.00	2	.14	.03	-.22	-.09
	3	.18	.19	-.16	.08	3	.15	.18	-.17	-.06
	0	.17	.22	-.17	.18	0	.36	.28	-.37	-.12
55°N 50°E	1	.17	.20	-.21	-.04	1	.30	.25	-.30	-.17
	2	.7	.22	-.15	.00	2	.19	.21	-.17	-.11
	3	.19	.20	-.17	.09	3	.12	.19	-.08	-.07
	0	.17	.21	-.08	-.04	0	.24	-.01	-.09	-.10
35°N 120°W	1	.18	.17	-.06	.04	1	.22	-.10	-.17	-.21
	2	.13	.18	-.11	.16	2	.24	-.13	-.28	-.24
	3	.22	.28	-.10	.08	3	.25	-.13	-.41	-.29

Table 10 (continued)

10 MB STN	1-3, 1965					4-6, 1965				
	LAG	Z	T	u	v	LAG	Z	T	u	v
	0	-.16	-.13	.15	.03	0	.41	.27	-.15	.04
40°N 70°E	1	-.12	.02	.14	.03	1	.38	.22	-.12	-.06
	2	-.15	-.03	.13	-.02	2	.37	.32	-.16	-.03
	3	-.18	.12	.16	.01	3	.37	.12	-.25	.19
	0	-.04	-.08	.11	.05	0	.35	.43	-.27	.08
35°N 20°E	1	-.05	-.10	.14	.26	1	.35	.36	-.38	.03
	2	-.05	.03	.11	.16	2	.33	.38	-.31	.09
	3	-.02	-.04	.13	.11	3	.36	.34	-.27	.01
	0	-.24	-.16	.24	-.01	0	.33	.38	-.16	.15
55°N 50°E	1	-.24	-.17	.23	.03	1	.32	.33	-.16	.06
	2	-.22	-.20	.25	.03	2	.33	.31	-.21	.02
	3	-.21	-.25	.16	.01	3	.32	.30	-.24	-.02
	0	-.21	-.17	.00	-.12	0	.46	-.19	-.57	-.32
35°N 120°W	1	-.20	-.11	.02	-.15	1	.47	-.09	-.56	-.12
	2	-.18	-.08	.05	-.08	2	.42	-.13	-.47	.13
	3	-.16	.00	.02	-.11	3	.39	.02	-.46	.05

	7-9, 1965					10-12, 1965				
	0	.53	.25	-.47	-.12	0	.21	.30	-.34	.12
40°N 70°E	1	.56	.44	-.45	-.24	1	.18	.21	-.36	.07
	2	.46	.23	-.53	-.11	2	.13	.24	-.27	.05
	3	.46	.01	-.47	.16	3	.11	.18	-.21	-.06
	0	.56	.36	-.50	-.16	0	.19	.23	-.35	-.01
35°N 20°E	1	.48	.25	-.42	-.22	1	.19	.21	-.40	-.08
	2	.36	.07	-.46	-.21	2	.16	.13	-.38	-.03
	3	.40	.21	-.50	-.11	3	.12	.11	-.40	-.01
	0	.55	.48	-.50	.22	0	.36	.33	-.23	-.17
55°N 50°E	1	.55	.49	-.46	.23	1	.40	.33	-.27	-.23
	2	.50	.48	-.46	.14	2	.39	.30	-.33	-.26
	3	.50	.43	-.50	.02	3	.37	.32	-.36	-.29
	0	.44	.26	-.48	-.10	0	.22	.15	-.14	-.03
35°N 120°W	1	.43	.24	-.49	-.17	1	.22	.10	-.15	-.08
	2	.45	.16	-.47	-.06	2	.19	.12	-.15	-.09
	3	.48	.29	-.50	-.14	3	.20	.06	-.15	-.09

TABLE 11A. Geopotential Height and Temperature Values at various Pressure Levels versus Washington, D. C. Absorption Data (40°N 80°W)

Pressure level(cbs)	r_{ZA}	r_{TA}	r_{ZA}	r_{TA}	r_{ZA}	r_{TA}
100	-.05	-.29	.04	-.14	.06	-
85	-.10	-.13	-.12	-.06	-.03	-.18
70	-.13	-.11	-.12	-.14	-.09	-.14
50	-.12	-.03	-.19	-.34	-.11	-.11
30	-.11	-.10	-.27	-.42	-.11	-.00
20	-.13	.05	-.36	-.25	-.08	.22
10	-.20	-.21	-.46	-.07	-.06	.07
1	-.60	-.37	-.59	-.14	-.63	-.66
	64-1		64-4		65-1	

TABLE 11B. Geopotential Height and Temperature Values at Various Pressure Levels versus Tokyo Absorption Data (35°N 140°E)

Pressure level(cbs)	r_{ZA}	r_{TA}	r_{ZA}	r_{TA}	r_{ZA}	r_{TA}	r_{ZA}	r_{TA}
100	.00	.02	.09	.63	-.12	-	-.14	-.00
85	.04	.18	.38	.60	-.17	-.05	-.05	.14
70	.10	.13	.56	.63	-.19	-.14	.00	.12
50	.11	.04	.67	.69	-.20	-.17	.06	.14
30	.06	.00	.73	.48	-.29	-.21	.14	.33
20	.08	-.02	.74	-.11	-.36	.05	.22	.37
10	.10	.01	.77	-.60	-.21	.41	.35	-.01
1	.05	.00	.43	-.03	.20	-.04	.45	.24
	64-1		64-4		65-1		65-4	

TABLE 12. Absorption Cross-Correlations Using Washington, D.C. as the Master Station

YEAR-QTR	LAG	1	2	3	4	5	6	7	8	9
	0	-.123	-.091	-.431	.096	.012	-.518	-.066	-.323	-
	1	-.112	-.172	-.328	-.059	.060	-.581	-.105	-.395	-
1964-1	2	-.105	-.207	-.419	-.202	-.029	-.382	-.110	-.421	-
	3	-.167	-.285	-.378	-.274	-.026	-.231	-.006	-.416	-
	0	.183	-.277	-.051	.337	.071	-.265	-.565	-.259	-
	1	.198	-.236	.039	.288	-.007	-.292	-.557	-.288	-
1964-2	2	.106	-.307	.080	.298	-.003	-.453	-.497	-.384	-
	3	.085	-.384	.116	.185	-.046	-.322	-.408	-.326	-
	0	.316	.558	-.337	.482	.420	.623	.267	.467	-
	1	.333	.546	-.340	.529	.319	.600	.344	.426	-
1964-3	2	.316	.529	-.295	.490	.314	.584	.206	.441	-
	3	.255	.526	-.378	.433	.323	.542	.239	.447	-
	0	-.345	-.306	-.511	-.091	.451	-.017	-.275	-.589	-
	1	-.258	-.289	-.521	-.093	.364	.108	-.210	-.607	-
1964-4	2	-.413	-.309	-.510	-.017	.463	-.253	-.096	-.506	
	3	-.222	-.313	-.512	-.042	.299	-.176	-.071	-.474	-
	0	-	-.273	-.253	-.069	.105	.242	.222	-.688	.037
	1	-	-.294	-.320	-.043	.136	.155	.267	-.740	.053
1965-1	2	-	-.312	-.251	-.092	.141	.193	.277	-.716	.001
	3	-	-.243	-.325	-.101	.177	.228	.227	-.697	-.139

1 - Baie St. Paul   4 - Frieburg   7 - Alma Ata
2 - DeBilt   5 - Genova   8 - Tokyo
3 - Neustrelitz   6 - Ashkhabad   9 - Taipei

TABLE 13. Absorption Corss-Correlations Using Genova, Italy as the Master Station
(Data for second quarter 1965 was missing)

YEAR-QTR	LAG	DeBILT	FREIBURG	ALMA ATA	TOKYO
	0	.029	.334	-.179	.214
	1	.013	.318	-.307	.106
1964-1	2	-.047	.181	-.171	-.050
	3	-.055	.036	-.164	.030
	0	-.028	-.056	.199	.303
	1	.044	.052	.074	.124
1964-2	2	.121	.066	.178	.129
	3	.019	-.179	.163	.029
	0	.096	.332	.032	.138
	1	.126	.282	-.095	.101
1964-3	2	.120	.109	.090	.225
	3	.100	.258	-.046	.046
	0	-.182	.270	-.004	-.421
	1	-.196	.211	-.093	-.495
1964-4	2	-.045	.082	-.019	-.427
	3	-.113	.221	-.023	-.350
	0	.089	-.022	.067	-.075
	1	.055	.078	-.254	.011
1965-1	2	.205	-.157	-.064	-.049
	3	.223	-.088	-.088	-.061
	0	-.073	-.073	-.199	-.119
	1	-.106	-.140	-.087	-.132
1965-3	2	-.165	-.190	.119	-.162
	3	-.000	-.195	.016	-.088
	0	.107	-.282	.067	.290
	1	-.150	-.140	.124	.190
1965-4	2	-.068	-.215	.071	.135
	3	.035	-.146	.067	.212

TABLE 14. Absorption Cross-Correlations using Neustrelitz, Germany, as the Master Station

YEAR-QTR	LAG	DeBILT	FREIBURG	ALMA ATA	TOKYO
	0	.186	.179	-.025	.349
	1	.220	-.014	.037	.036
1964-1	2	.005	.346	-.000	.232
	3	.306	.356	-.107	.481
	0	.093	-.215	.124	.043
	1	.044	-.064	-.002	.075
1964-2	2	-.137	-.042	.032	.150
	3	-.040	.037	-.078	-.072
	0	-.253	.045	-.004	.023
	1	-.223	-.137	-.257	-.125
1964-3	2	-.273	-.149	.044	.072
	3	-.159	.009	-.008	.058
	0	.054	-.012	.219	.356
	1	.177	-.025	.127	.377
1964-4	2	.181	-.100	.067	.291
	3	.214	-.210	-.003	.387
	0	.016	.169	.073	.084
	1	.107	.174	.179	.173
1965-1	2	.090	.339	.041	.130
	3	.003	.281	.098	.148
	0	.425	.247	.100	.161
	1	.280	.283	.147	.150
1965-2	2	.254	.292	.196	.076
	3	.297	.245	.118	.093
	0	-.081	-.166	.102	.094
	1	-.047	-.045	.050	.102
1965-3	2	-.170	-.167	.079	-.083
	3	-.074	-.057	.129	.034
	0	-.002	.004	.050	.359
	1	.058	-.080	.146	.299
1965-4	2	.014	-.038	-.018	.341
	3	-.201	-.192	.000	.310

TABLE 15. Absorption Correlations Between DeBilt, Netherlands, and Freiburg, Germany

YEAR-QTR	LAG	r	YEAR-QTR	LAG	r
	0	.114		0	.051
	1	.233		1	.022
1964-1	2	.220	1965-1	2	.083
	3	.095		3	.182
	0	.097		0	.629
	1	-.020		1	.547
1964-2	2	.077	1965-2	2	.630
	3	.101		3	.486
	0	.282		0	.249
	1	.170		1	.071
1964-3	2	.275	1965-3	2	.167
	3	.219		3	.030
	0	.214		0	.125
	1	.213		1	.125
1964-4	2	.161	1965-4	2	.121
	3	.081		3	.172

TABLE 16. The Correlation of 5577Å Airglow at various Stations with Washington, D. C. Absorption Data

YEAR-QTR	STATION	LAG 0	1	2	3
1964-1	Haleakala	-.361	-.142	-.157	-.440
	Kitt Peak	-	-	-	-
	Fritz Peak	-	-	-	-
1964-2	Haleakala	-.180	.081	.054	.070
	Kitt Peak	-.097	-.374	.018	.015
	Fritz Peak	-	-	-	-
1964-3	Haleakala	.020	.339	.311	.261
	Kitt Peak	-.090	-.298	-.343	-.581
	Fritz Peak	-	-	-	-
1964-4	Haleakala	-.519	-.418	-.429	-.374
	Kitt Peak	-.214	-.200	.108	-.108
	Fritz Peak	.547	.768	.747	.792
1965-1	Haleakala	-.191	-.080	-.223	-.026
	Kitt Peak	-.658	-.586	-.484	-.292
	Fritz Peak	-	-	-	-

TABLE 17. The Correlation of 5577Å Airglow and Absorption Values at Selected Stations

Dodaira vs Tokyo YEAR-QTR	LAG	r	Haleakala vs Tokyo YEAR-QTR	LAG	r
	0	-		0	.403
	1	-		1	-.075
1964-1	2	-	1964-1	2	.124
	3	-		3	.387
	0	-		0	-.174
	1	-		1	.452
1964-2	2	-	1964-2	2	-.018
	3	-		3	-.311
	0	-		0	.444
	1	-		1	.191
1964-3	2	-	1964-3	2	.142
	3	-		3	.311
	0	.516		0	.530
	1	.335		1	.565
1964-4	2	.214		2	.399
	3	.263		3	.449
	0	.395		0	.412
	1	.472		1	-.023
1965-1	2	.532	1965-1	2	.052
	3	.517		3	-.017
	0	.336		0	.123
	1	-.176		1	-.288
1965-2	2	.038	1965-2	2	-.515
	3	-.051		3	.256
	0	-.292		0	.002
	1	-.212		1	.137
1965-3	2	-.012	1965-3	2	.118
	3	-.033		3	.226
	0	.323		0	.115
	1	-.085		1	-.002
1965-4	2	.016	1965-4	2	-.061
	3	.209		3	.025

Table 17 (continued)

Haule Provence vs Alma Ata

YEAR-QTR	LAG	r
	0	.356
	1	.306
1964-1	2	.198
	3	.294
	0	.316
	1	.205
1964-2	2	.375
	3	.201
	0	.370
	1	.386
1964-3	2	.301
	3	.007
	0	.332
	1	.321
1964-4	2	.275
	3	.109
	0	.014
	1	-.110
1965-1	2	-.360
	3	-.190
	0	.387
	1	.219
1965-2	2	.416
	3	.479
	0	-.015
	1	.087
1965-3	2	-.271
	3	.217
	0	.063
	1	-.061
1965-4	2	.219
	3	.076

Haute Provence vs Genova

YEAR-QTR	LAG	r
	0	-.038
	1	-.055
1964-1	2	-.207
	3	-.325
	0	.489
	1	.158
1964-2	2	.436
	3	.457
	0	.152
	1	.313
1964-3	2	.262
	3	.187
	0	-.507
	1	-.397
1964-4	2	-.388
	3	-.574
	0	.135
	1	-.083
1965-1	2	.326
	3	.209
	0	-
	1	-
1965-2	2	-
	3	-
	0	-.196
	1	.193
1965-3	2	.144
	3	.143
	0	-.205
	1	-.014
1965-4	2	.226
	3	.005

TABLE 18. The Correlation of 5577Å Airglow Values at Haute Provence, France, and Dodaira, Japan
(January-September 1964 missing due to insufficient data)

YEAR-QTR	LAG	r
1964-4	0	.376
	1	.406
	2	.208
	3	.246
1965-1	0	.632
	1	.590
	2	.552
	3	.420
1965-2	0	-
	1	-
	2	-
	3	-
1965-3	0	.237
	1	-.385
	2	-.413
	3	.123
1965-4	0	.504
	1	.650
	2	.363
	3	.690

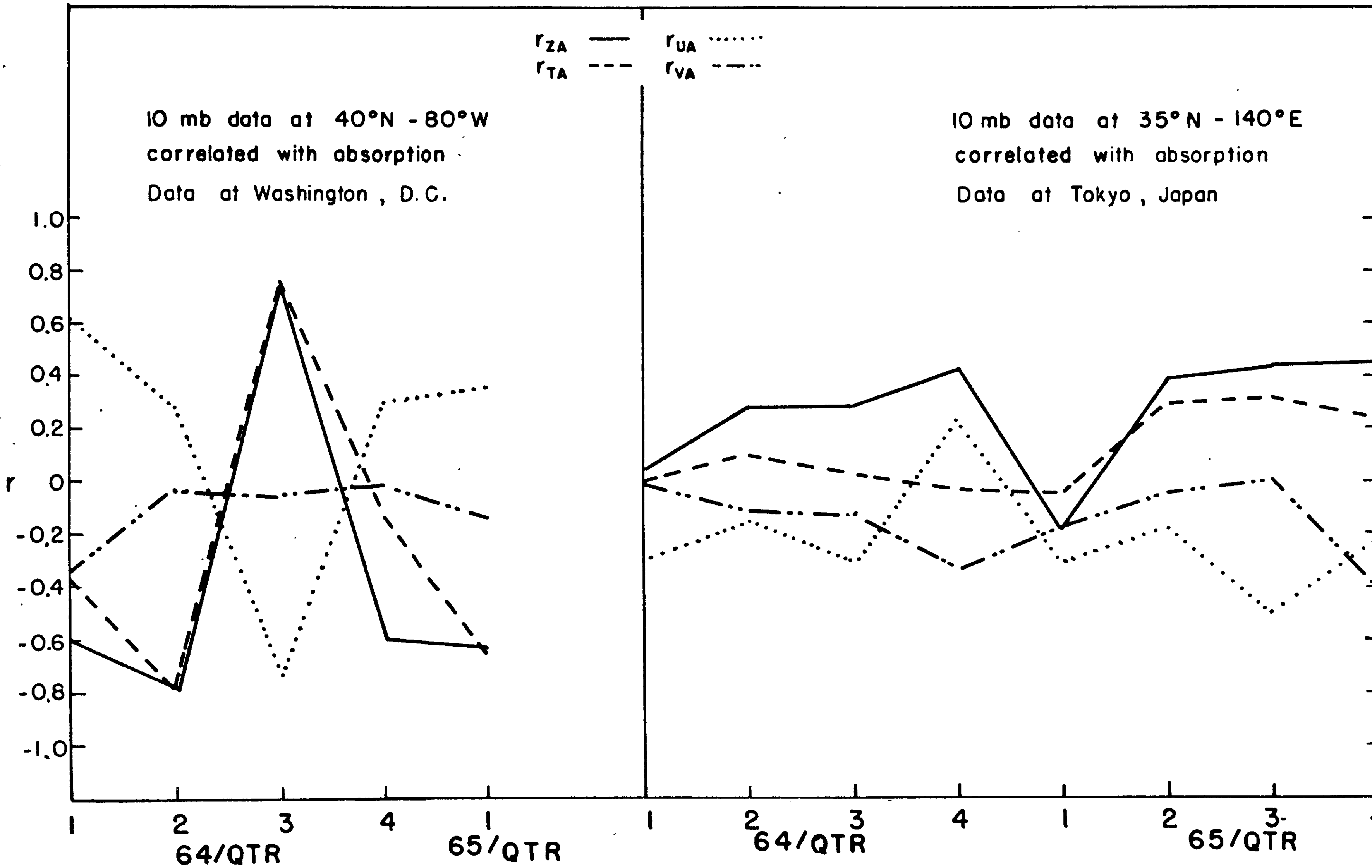

Figure 8. The correlation of 10 mb grid values and absorption data.

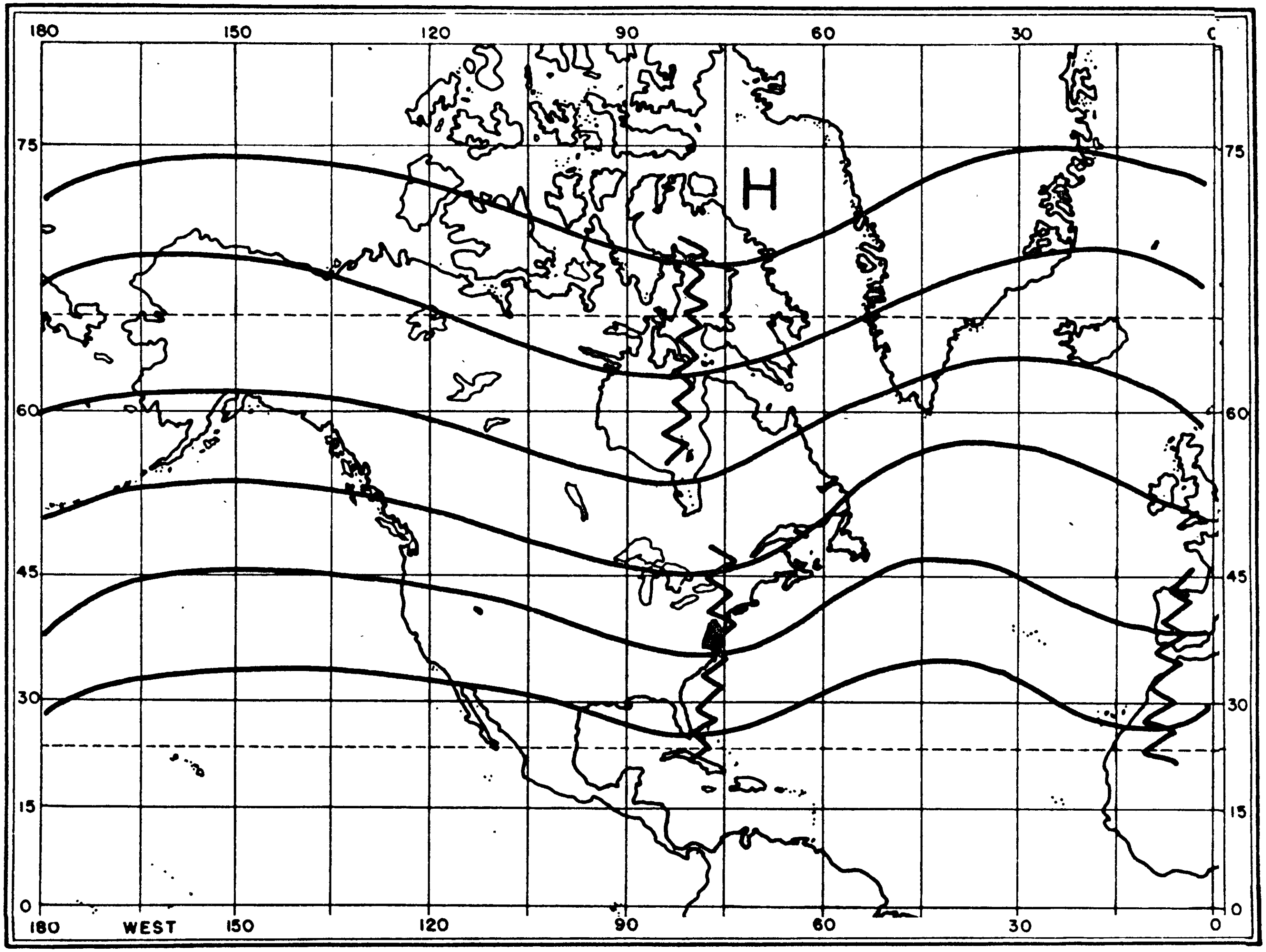

Figure 9. Typical 10 mb map for North America during the summer months.

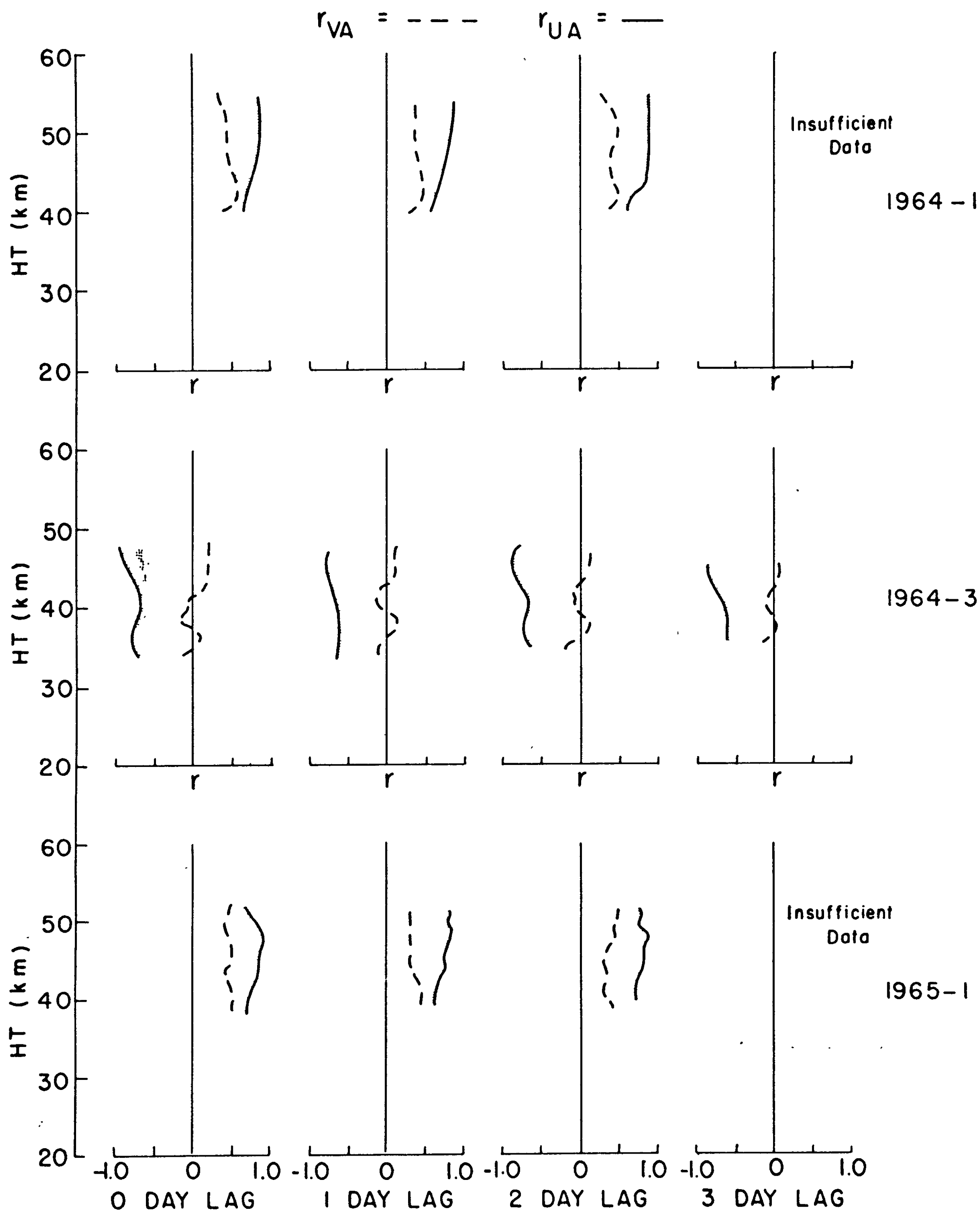

Figure 10. Wallops Island rocket winds correlated with Washington, D. C. absorption.

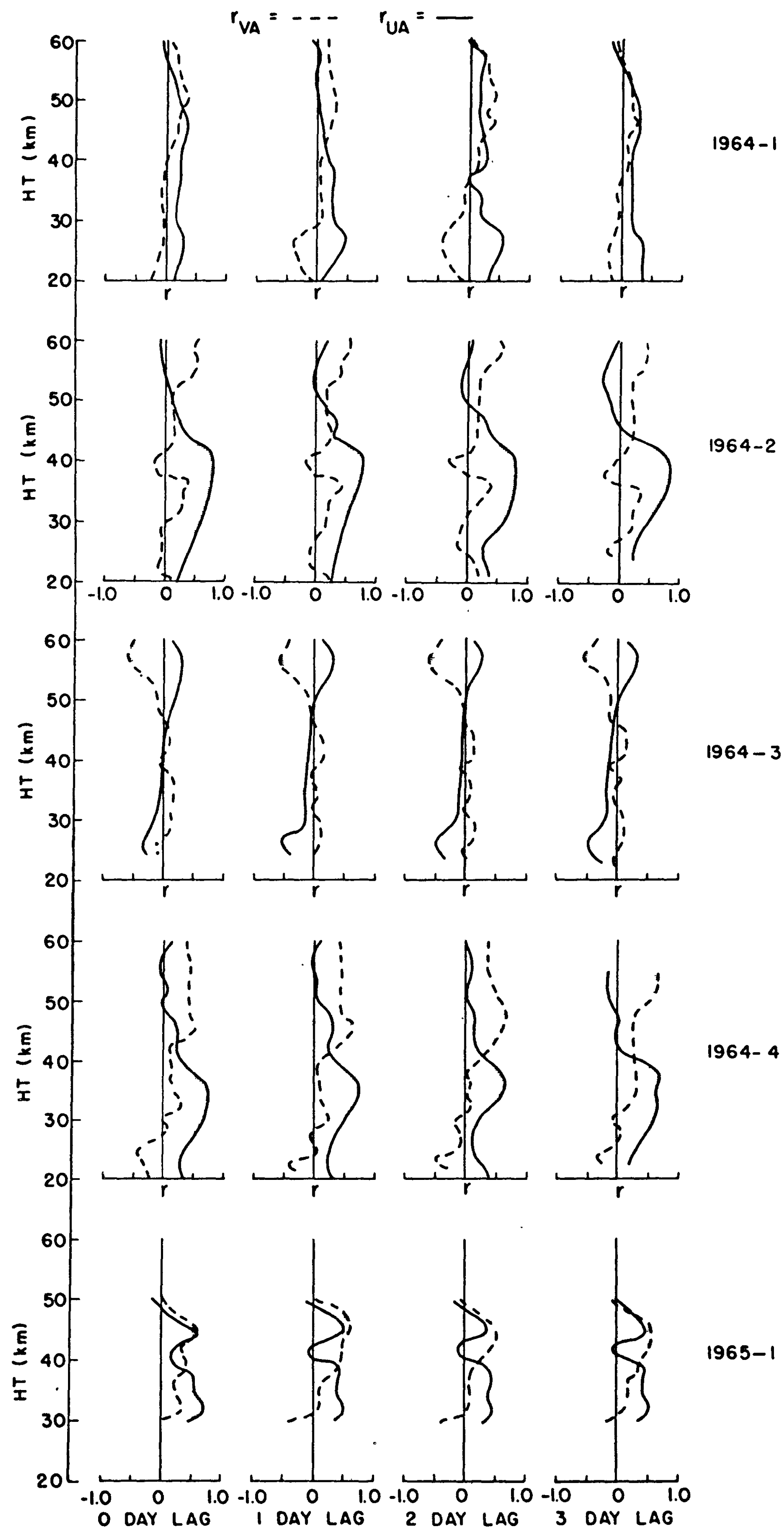

Fig. 11. White Sands rocket winds correlated with Washington absorption.

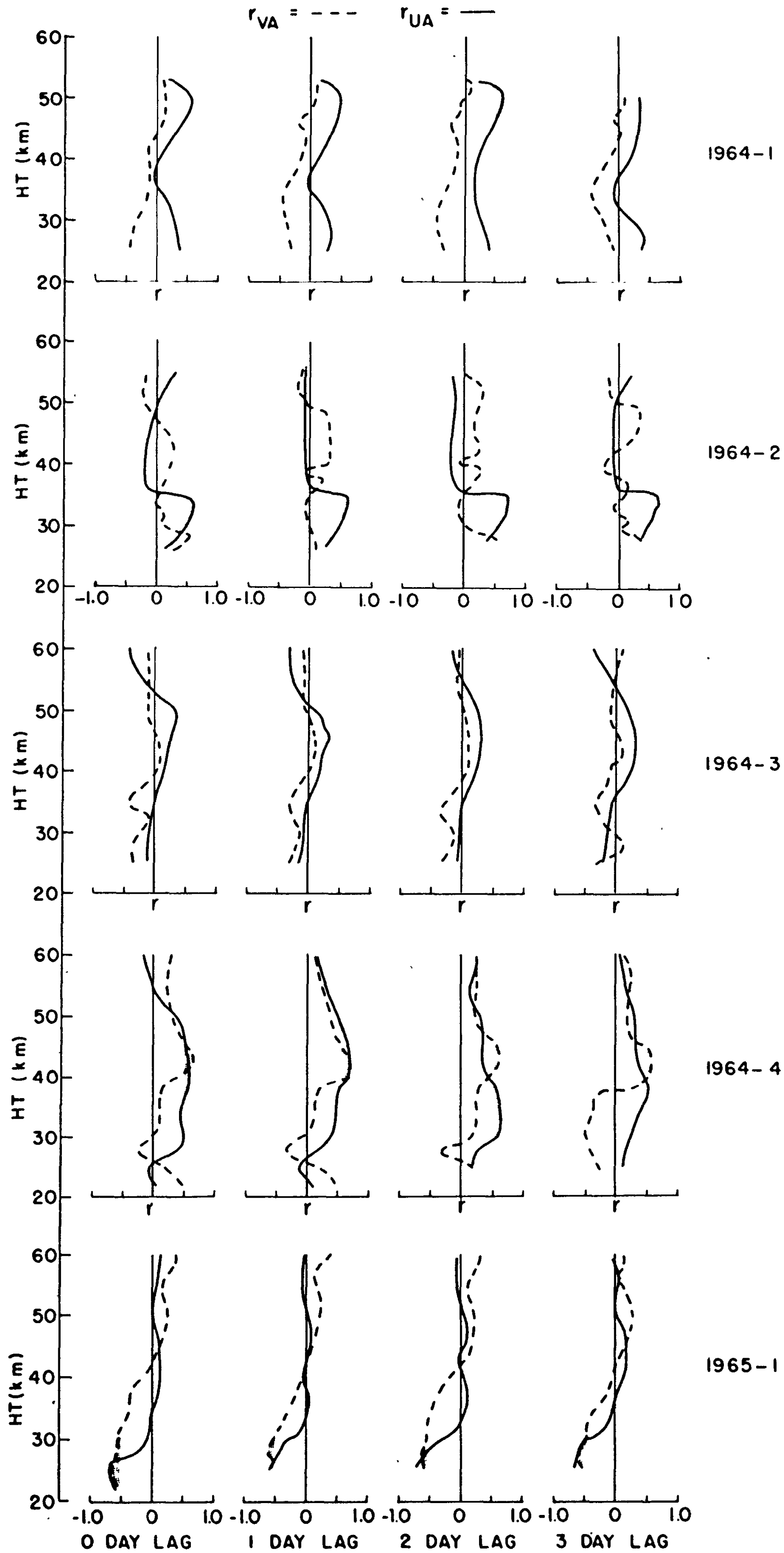

Fig. 12. Pt. Mugu rocket winds correlated with Washington absorption.

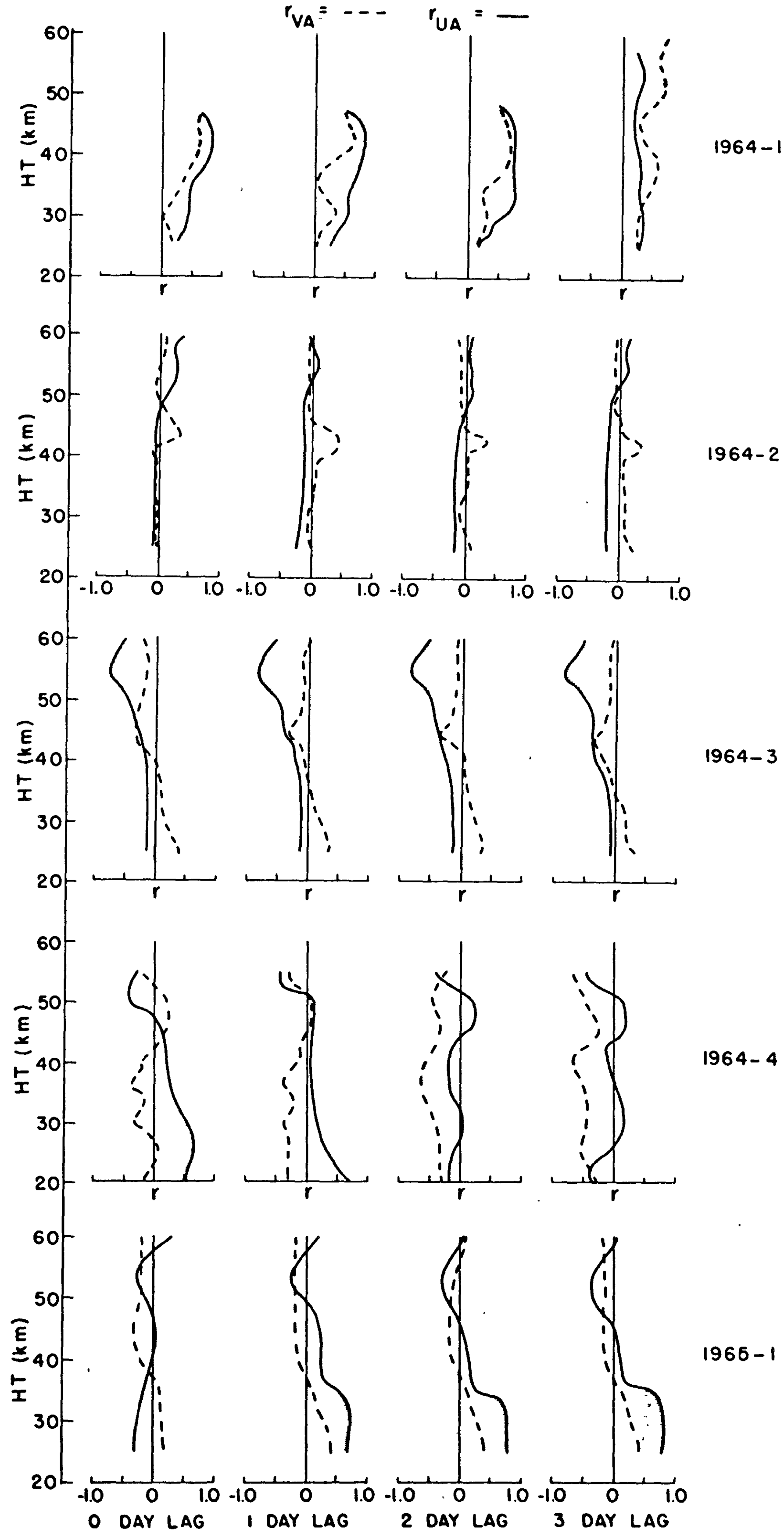

Fig. 13. Ft Greely rocket winds correlated with Washington absorption.

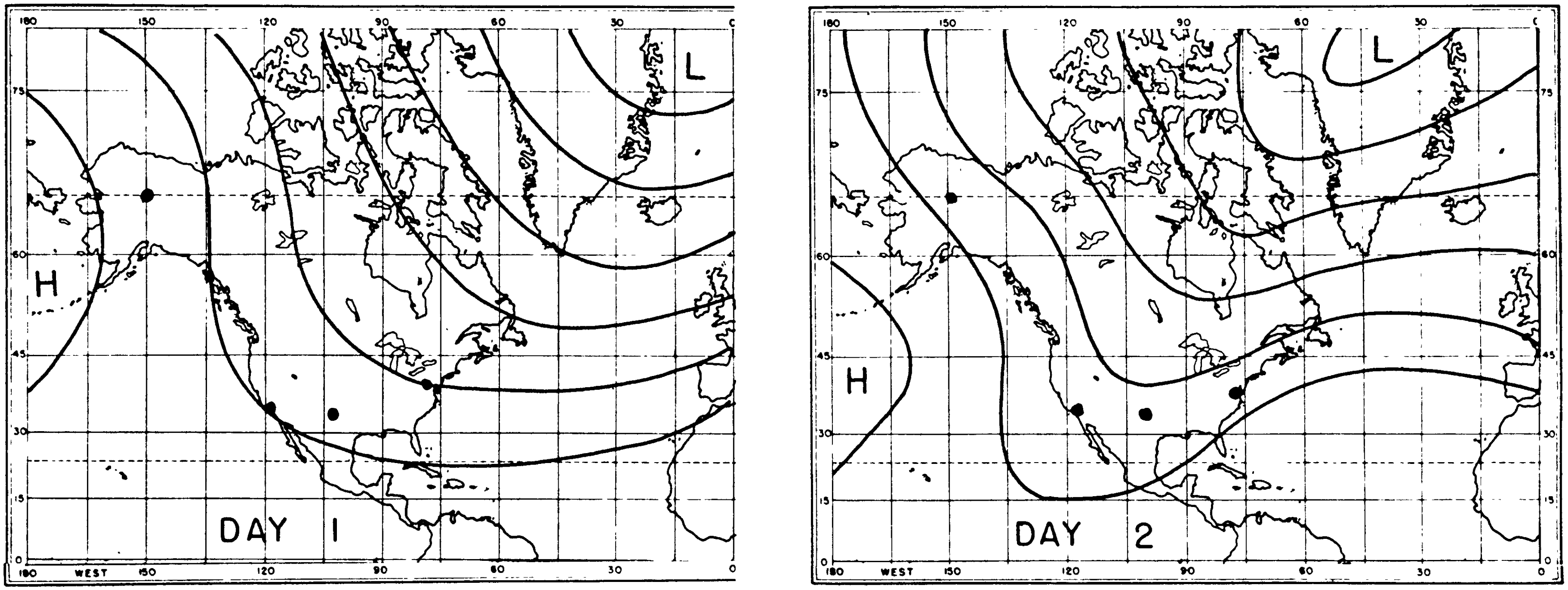

Figure 14. The configuration of synoptic features in the upper stratosphere that relates to an increase or decrease of absorption at Washington, D. C.

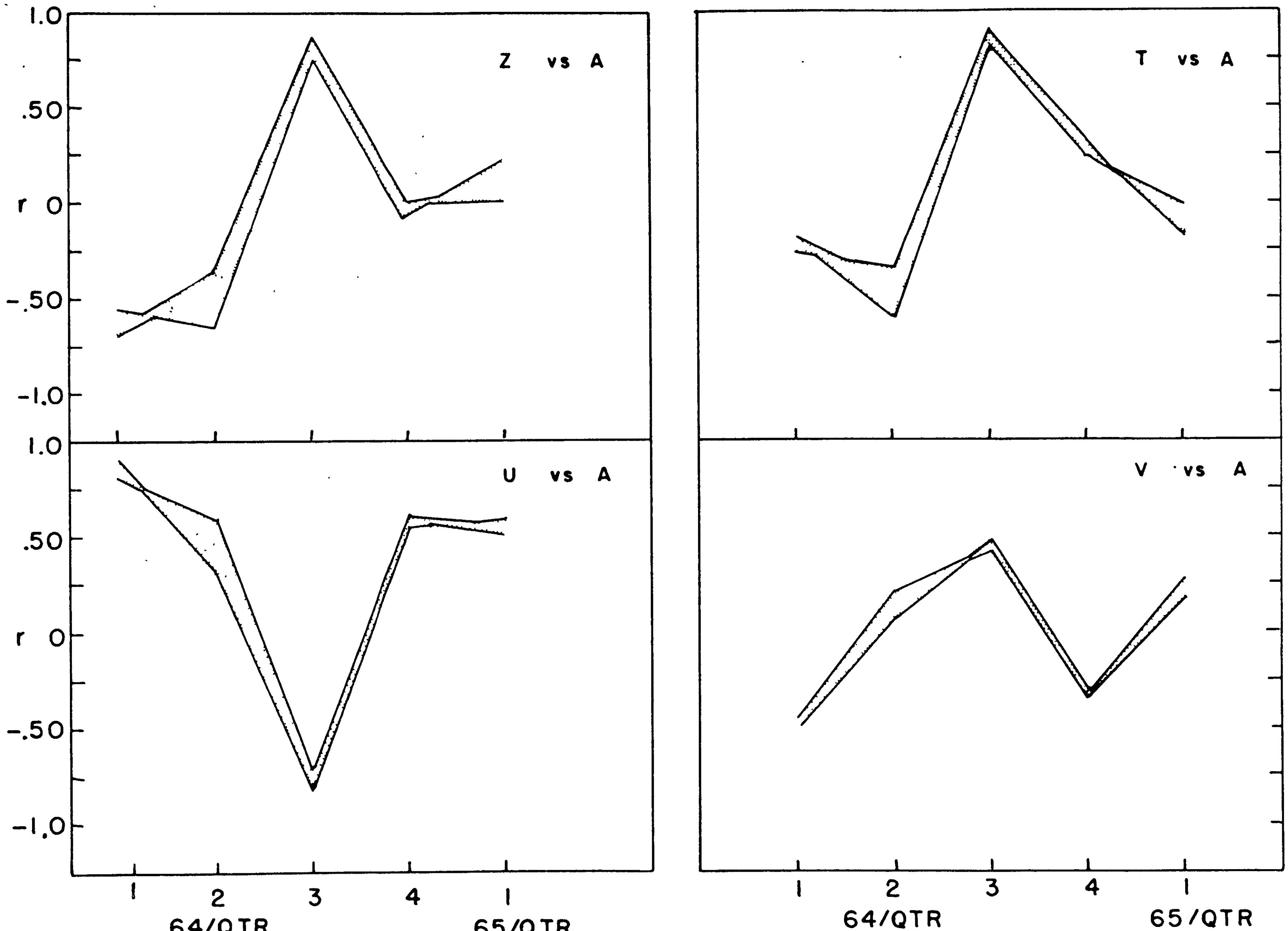

Fig. 15. The correlation of 10 mb grid values at 65N 150W with Washington absorption data.

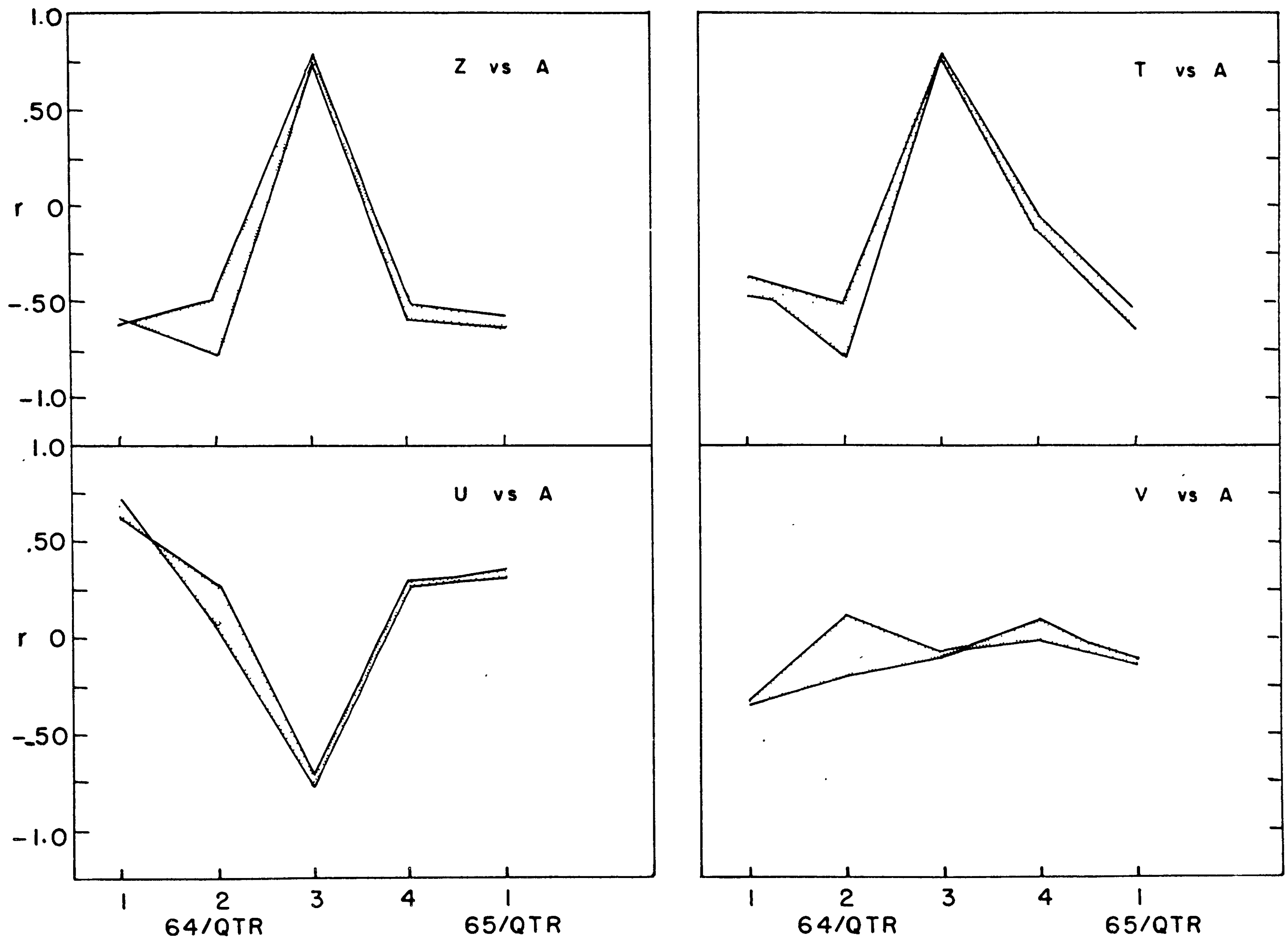

Fig. 16. The correlation of 10 mb grid values at 40N 80W with Washington absorption data.

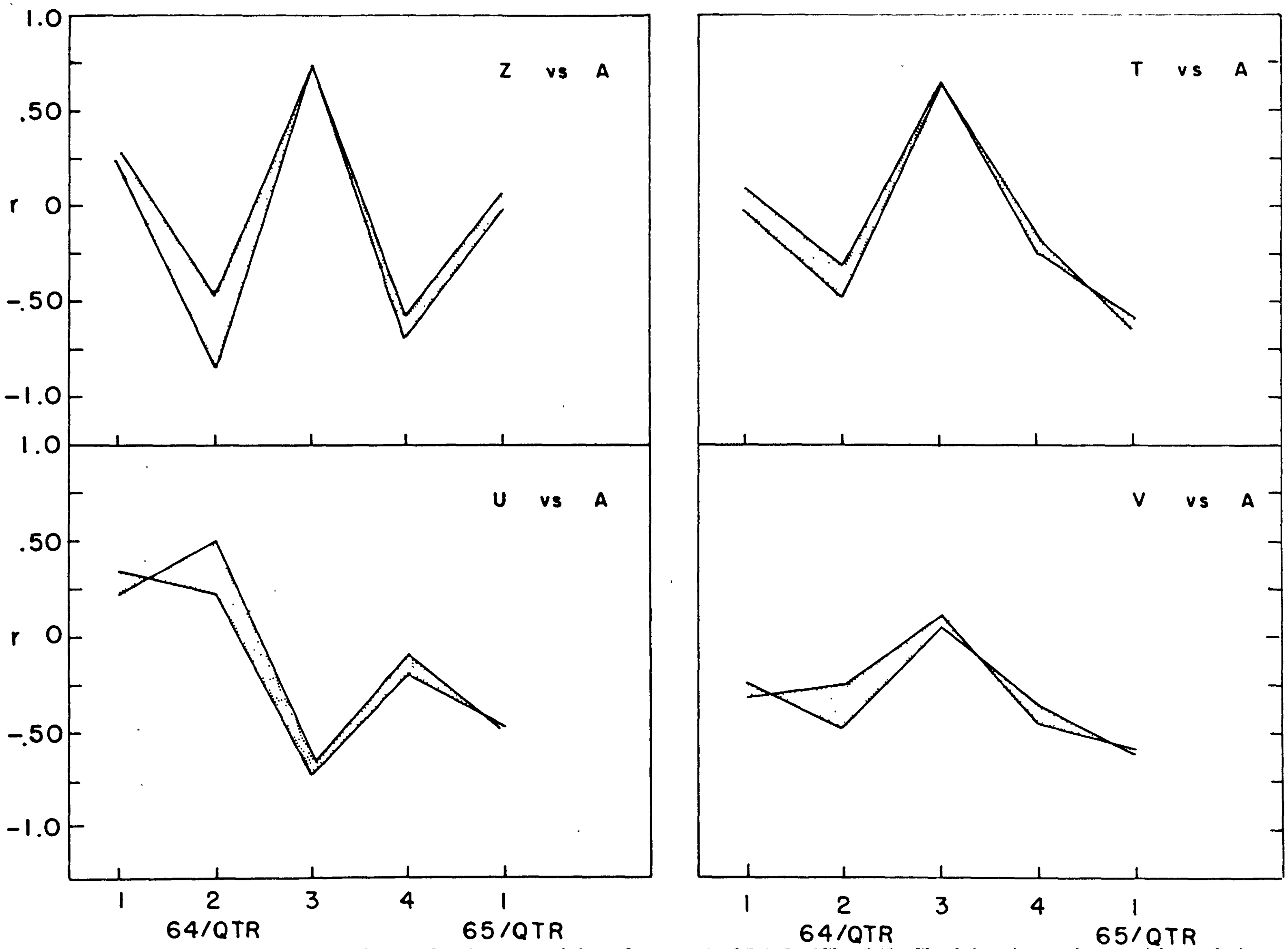

Fig. 17. The correlation of 10 mb grid values at 35N 120W with Washington absorption data.

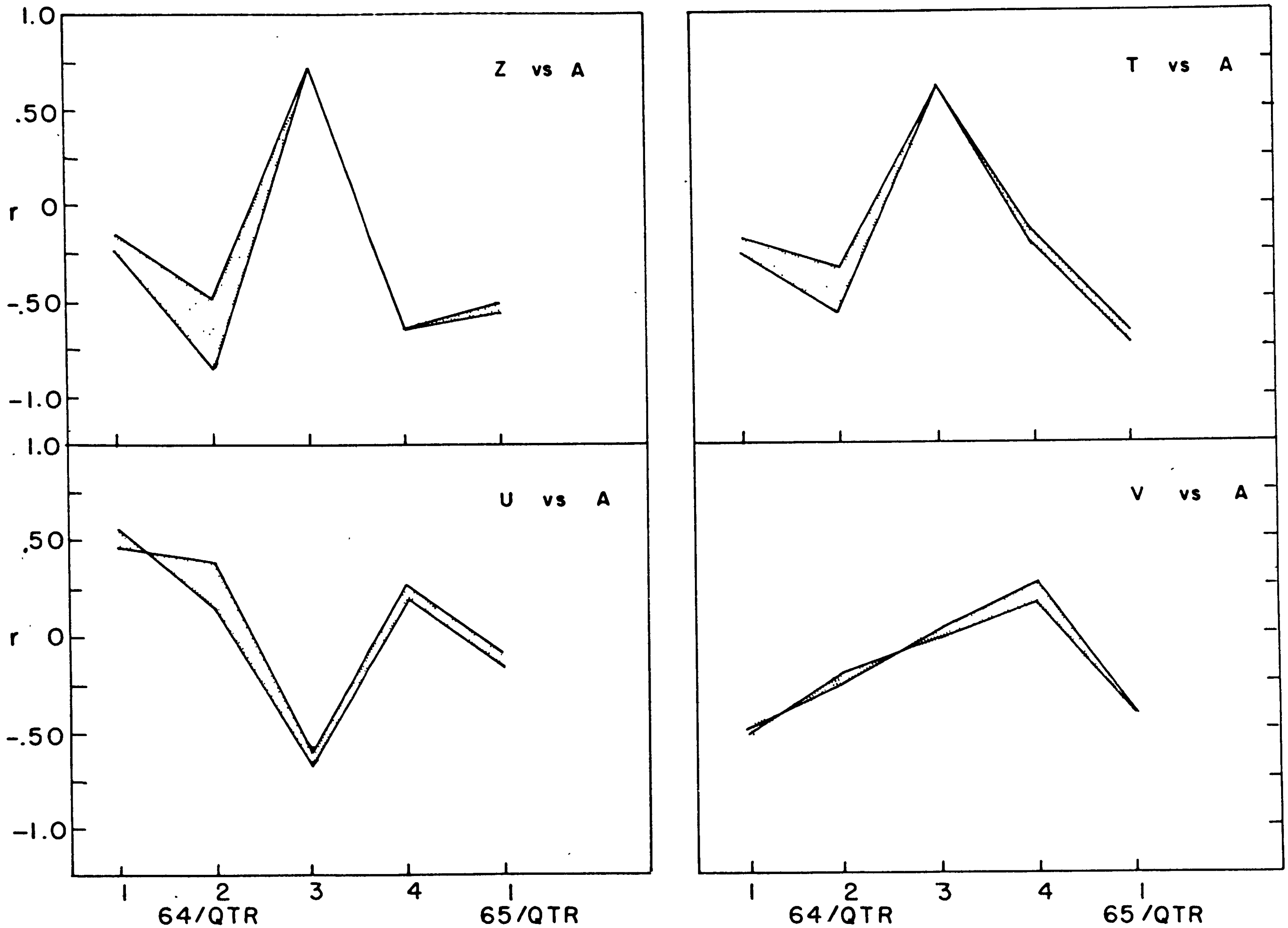

Fig. 18. The correlation of 10 mb grid values at 35N 100W with Washington absorption data.

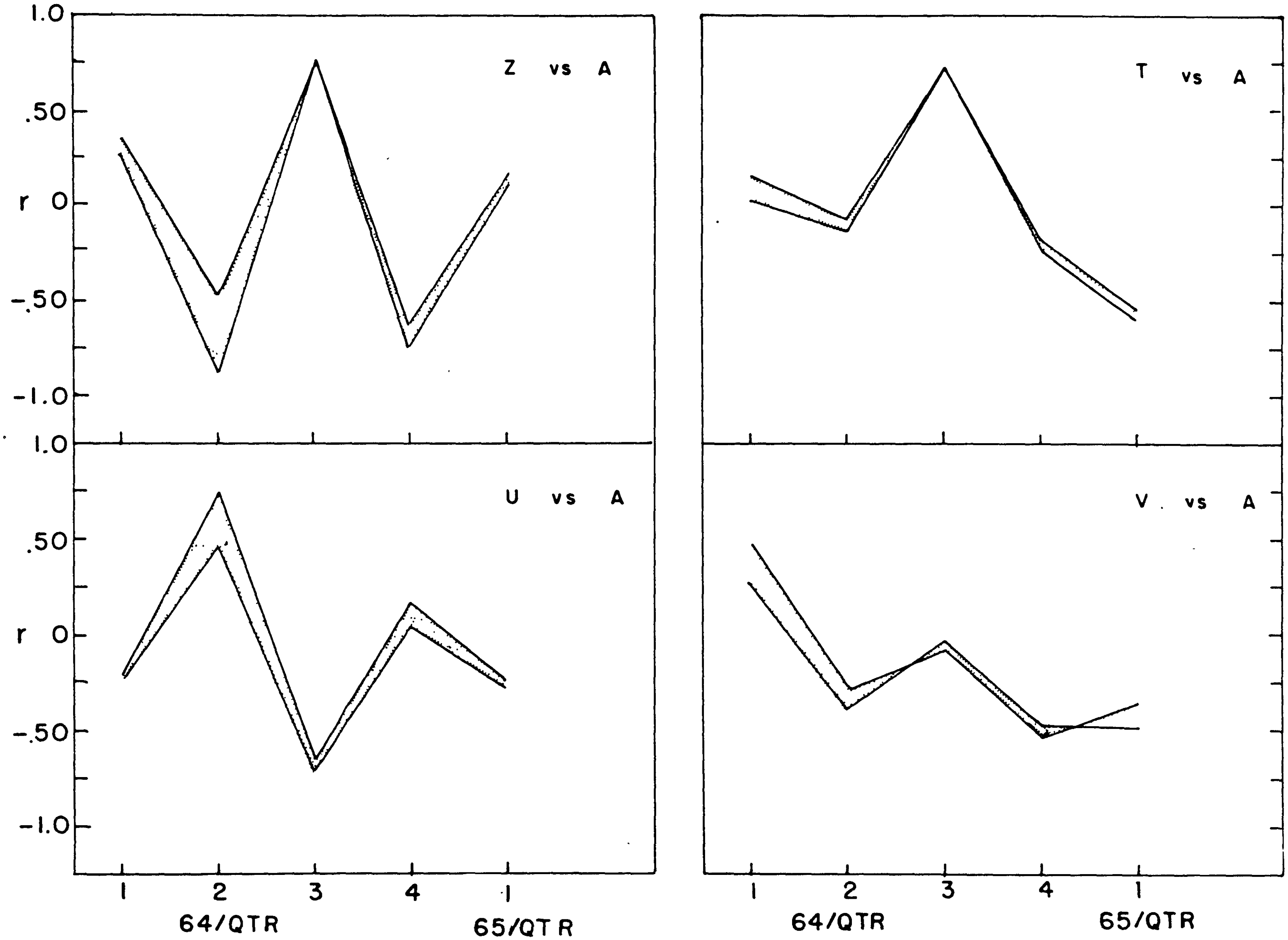

Fig. 19. The correlation of 10 mb grid values at 35N 130W with Washington absorption data.

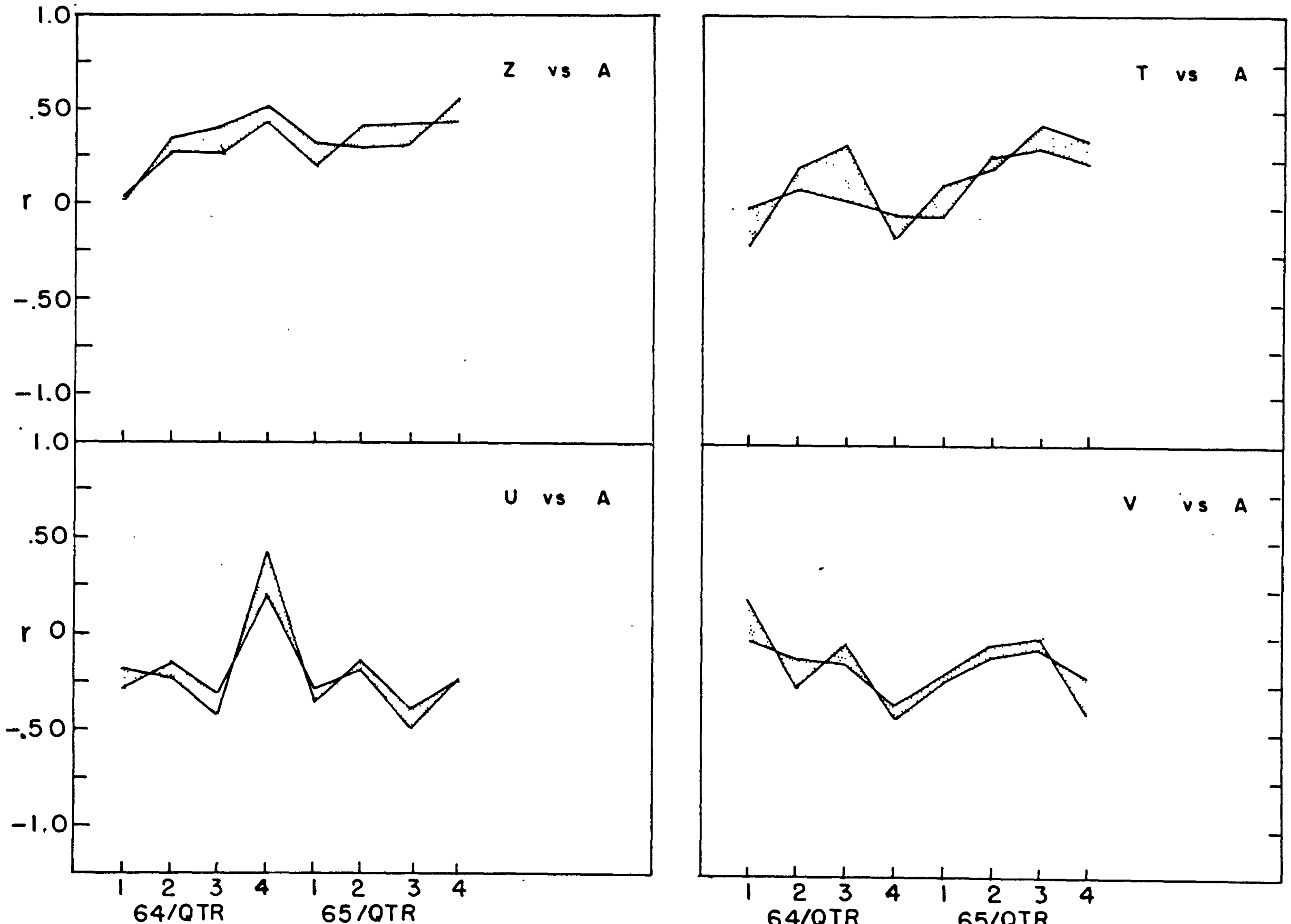

Fig. 20. The correlation of 10 mb grid values at 35N 140E with Tokyo absorption data.

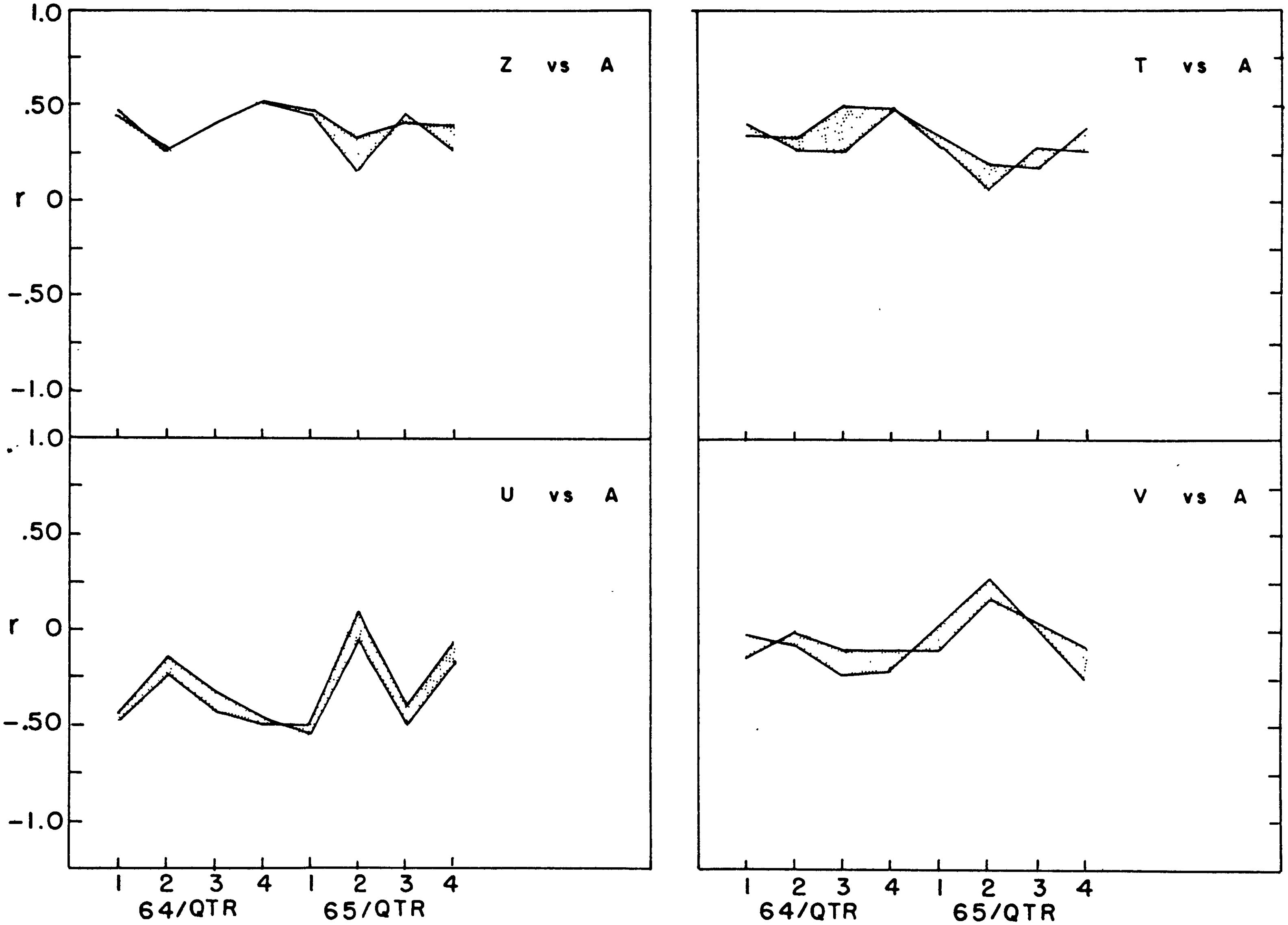

Fig. 21. The correlation of 10 mb grid values at 55N 100E with Tokyo absorption data.

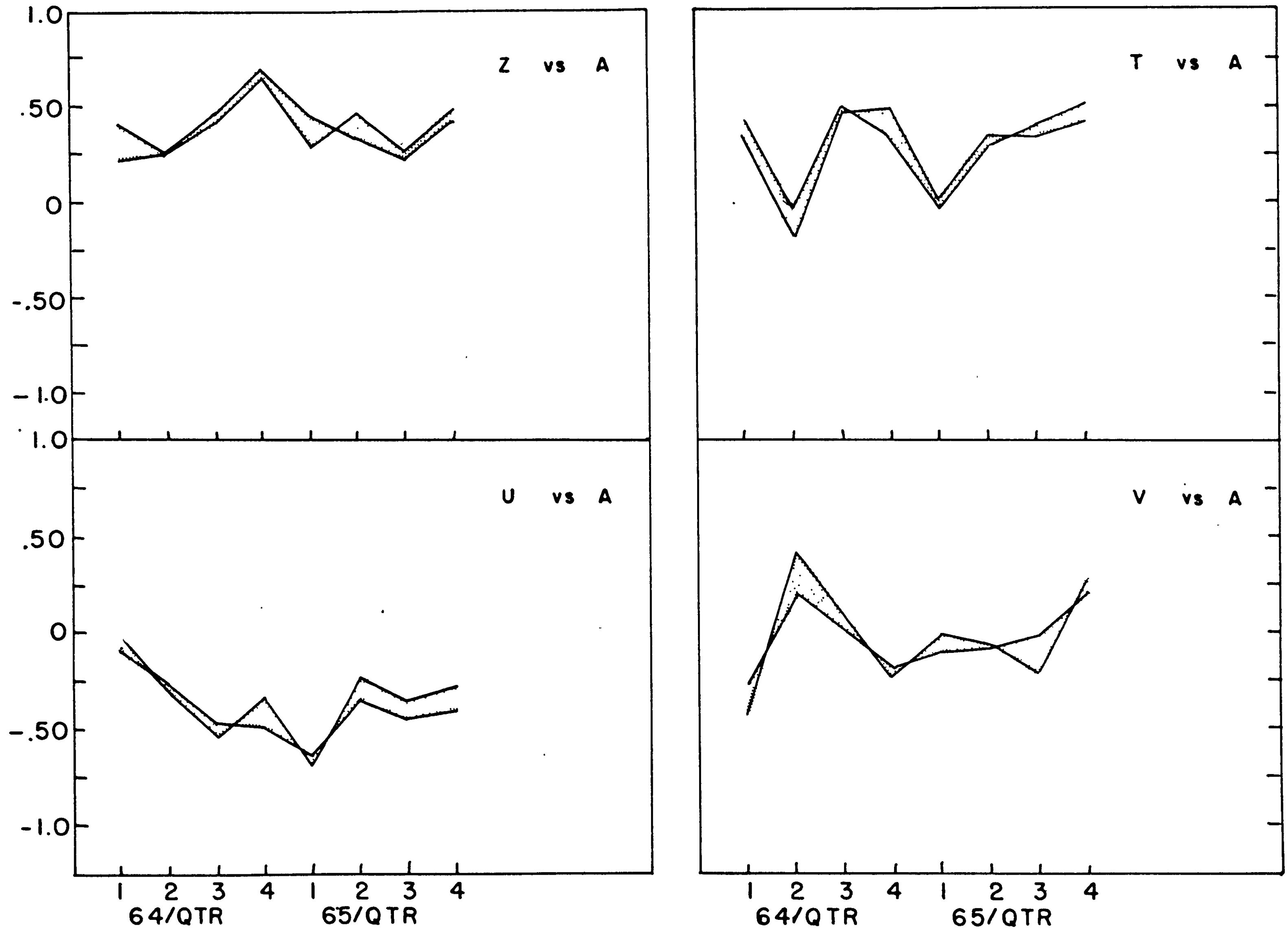

Fig. 22. The correlation of 10 mb grid values at 30N 110E with Tokyo absorption data.

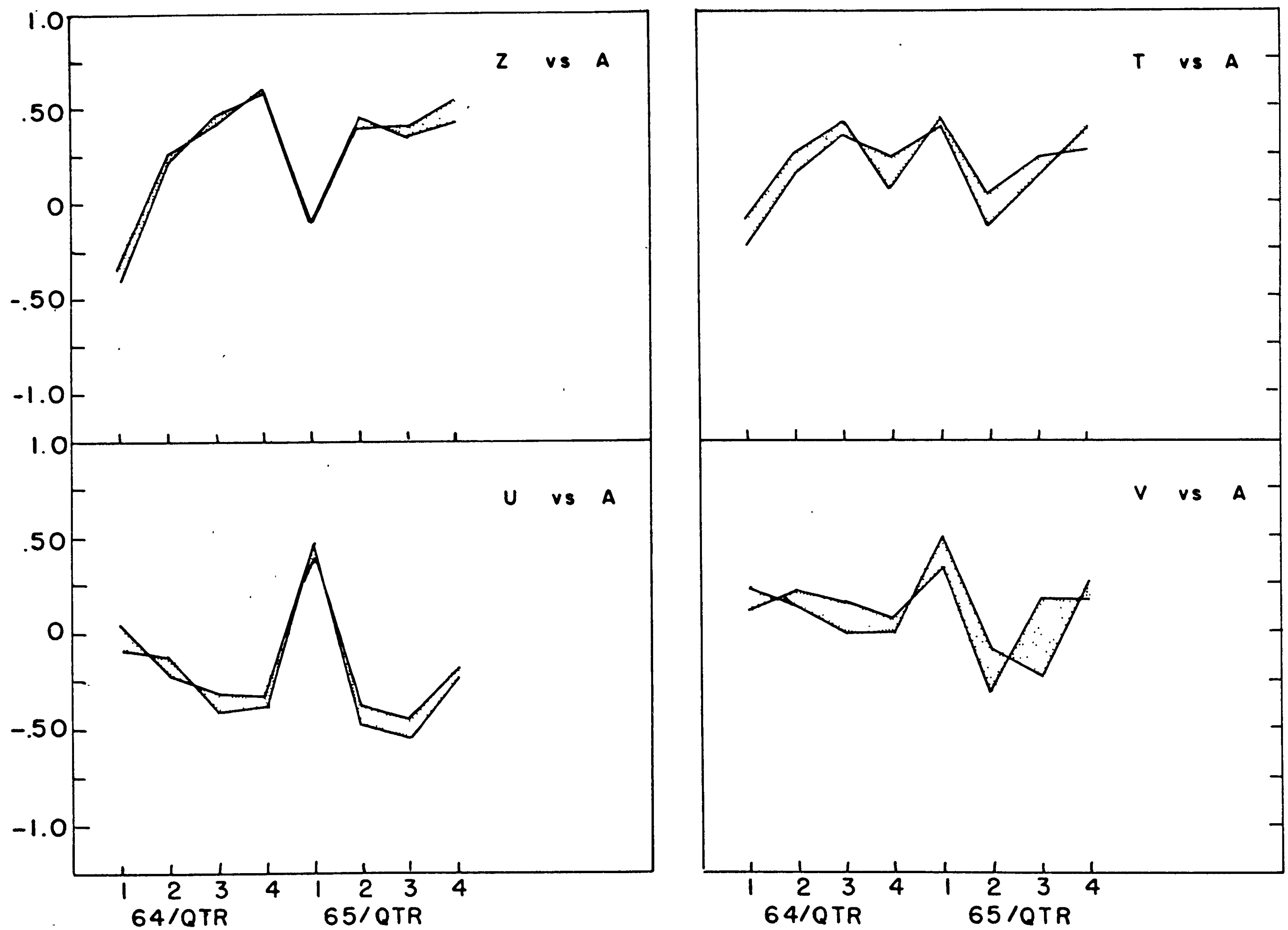

Fig. 23. The correlation of 10 mb grid values at 35N 120W with Tokyo absorption data.

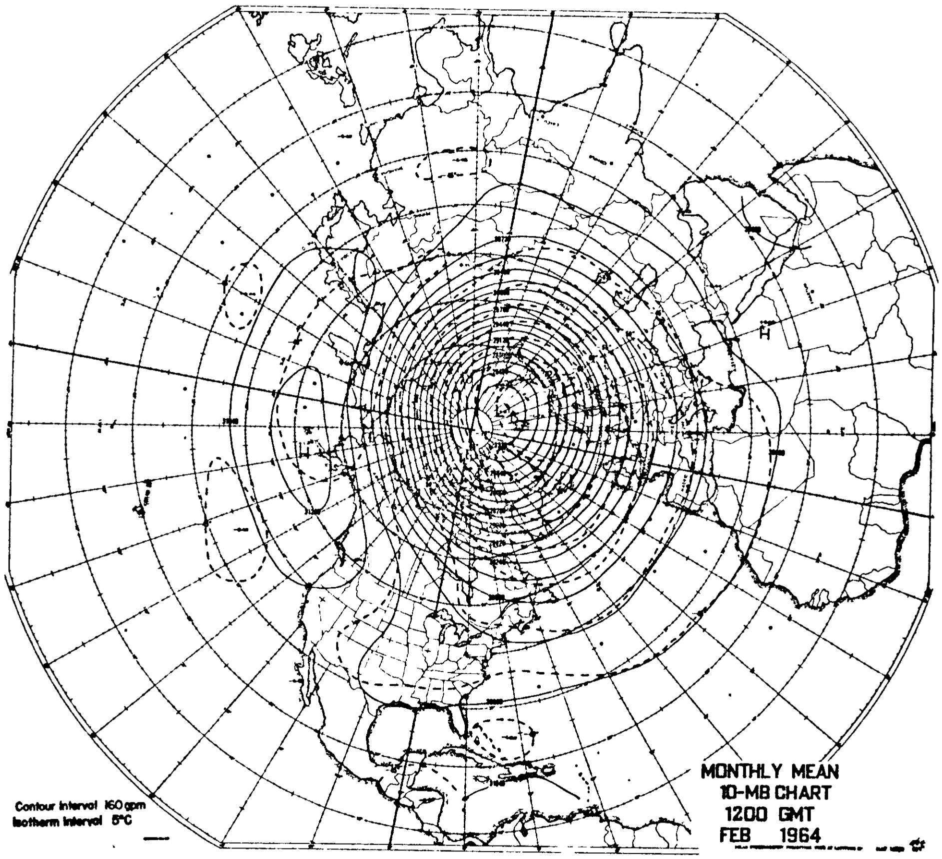

Figure 24. Monthly mean 10 mb chart for 1200 GMT, February 1964. (Staff, Upper Air Branch, NMC, 1967)

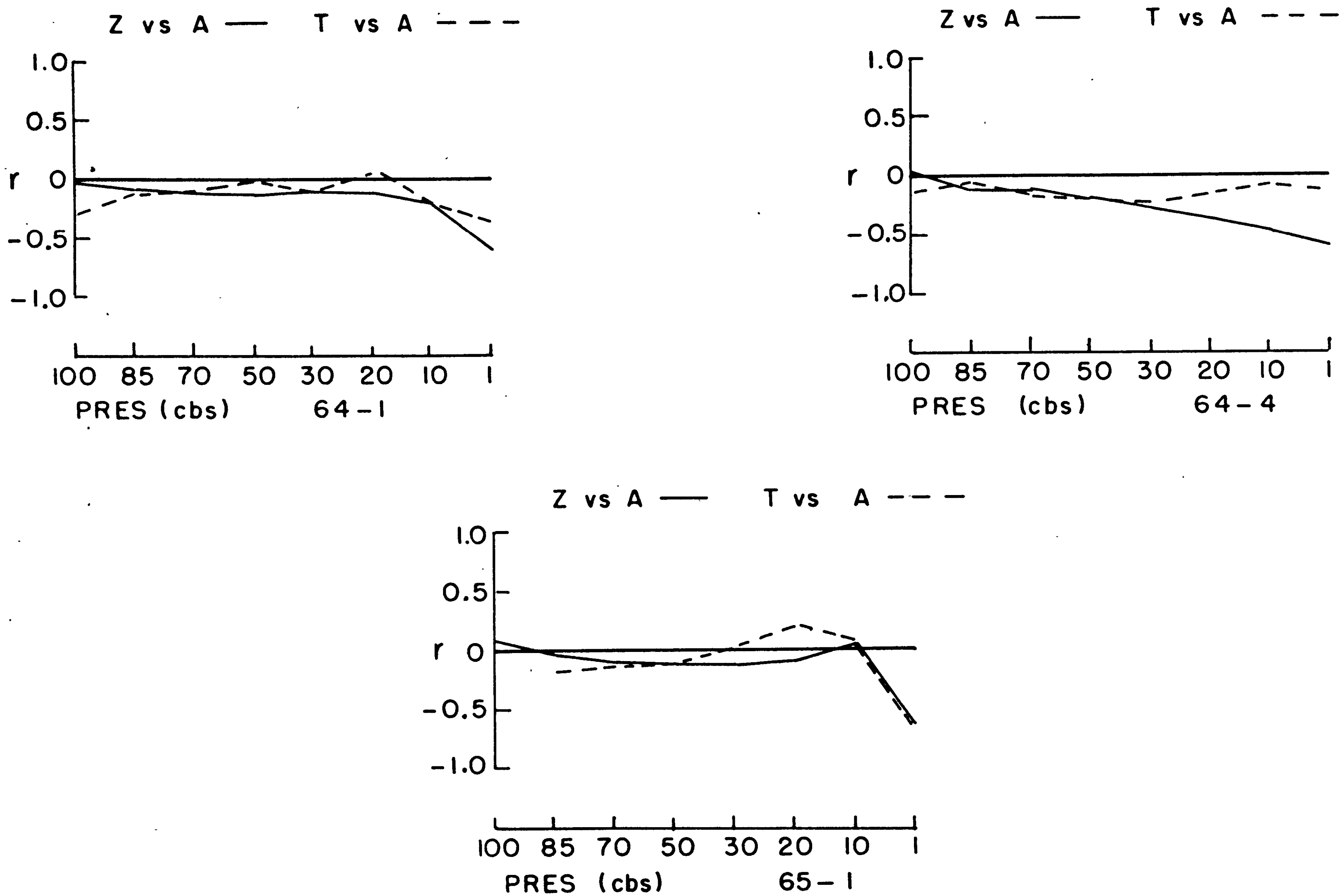

Fig. 25. The correlation of Z and T values for various pressure levels at 40N 80W with Washington absorption.

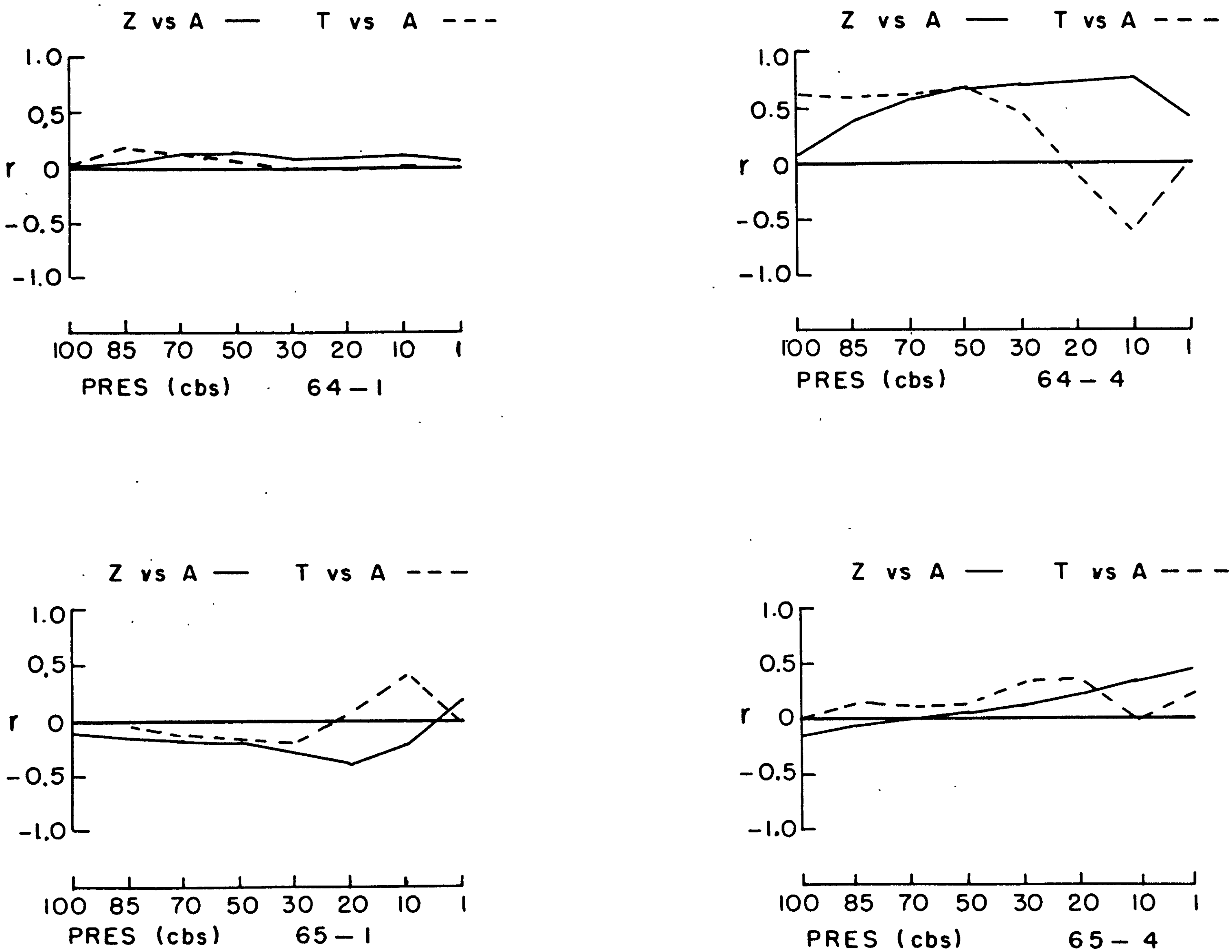

Fig. 26. The correlation of Z and T values for various pressure levels at 35N 140E with Tokyo absorption.

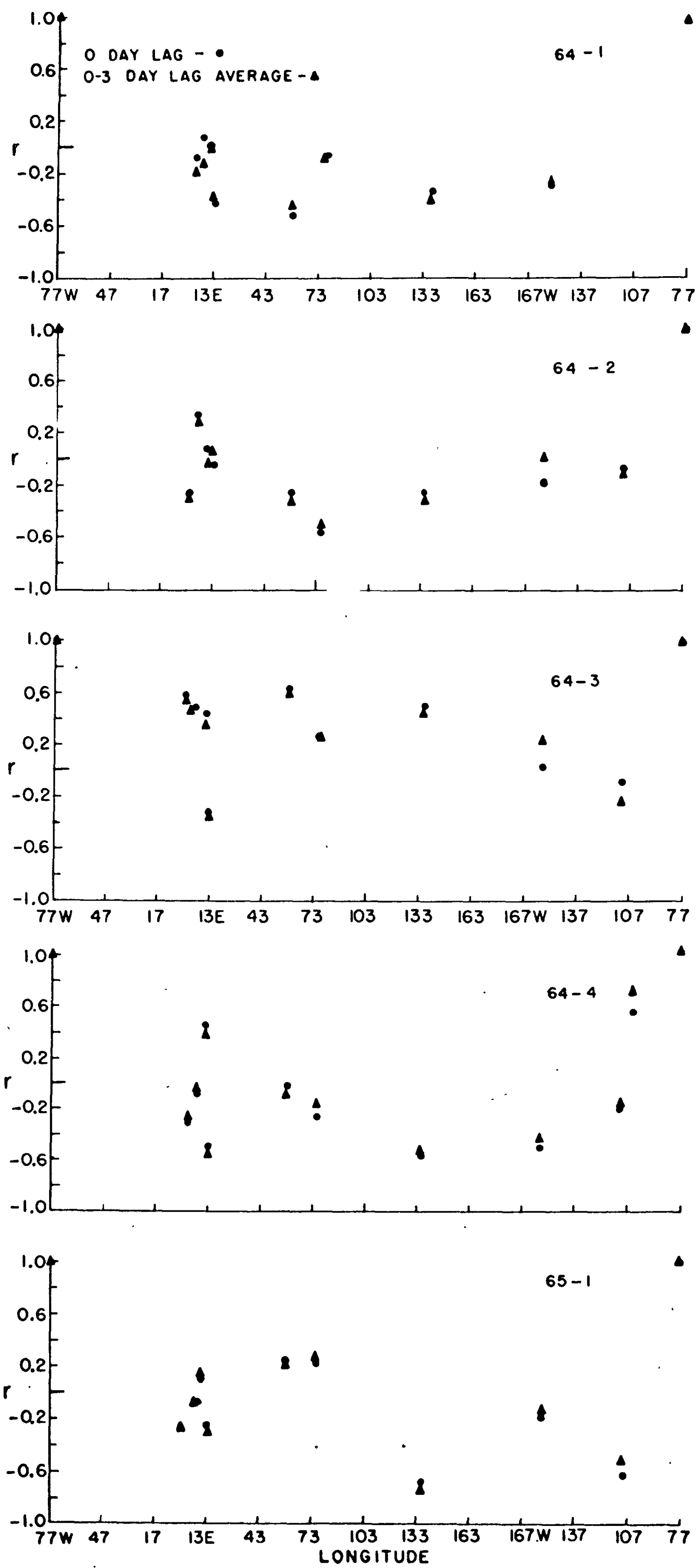

Fig. 27. Absorption cross correlations with Washington as master.

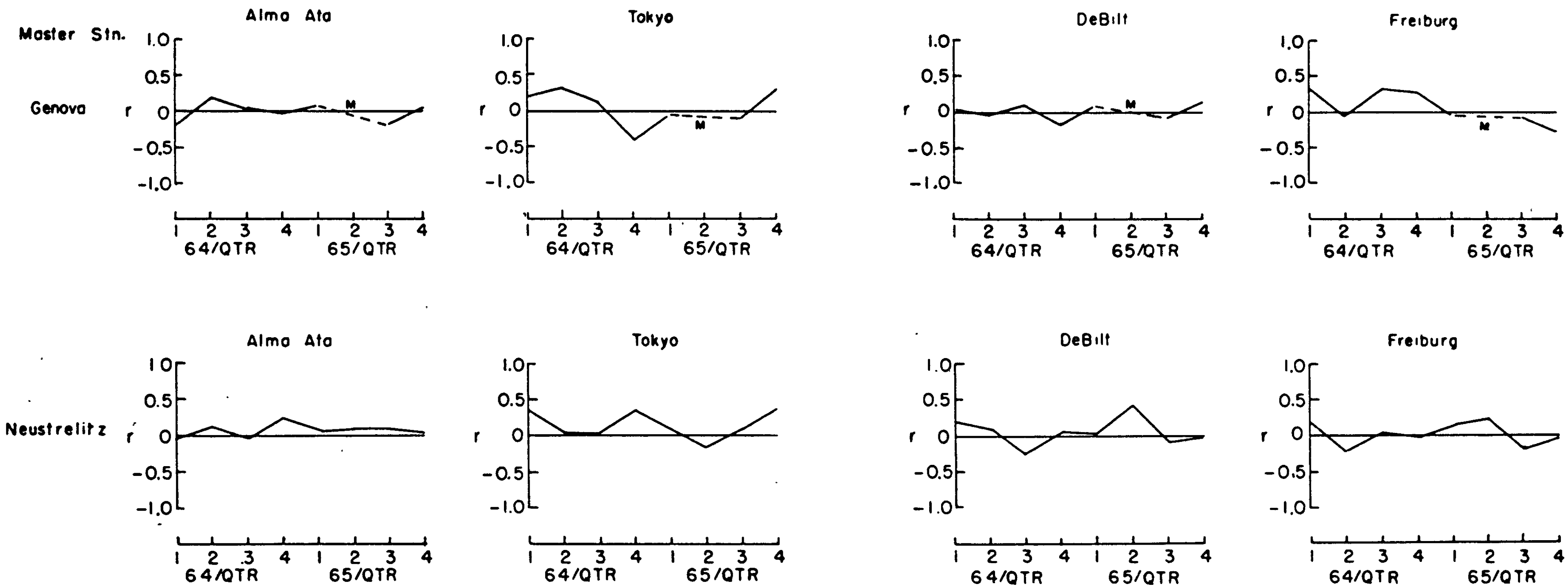

Figure 28. The cross correlation of absorption data in Europe and Asia using Genova, Italy, and Neustrelitz, E. Germany as the master stations.

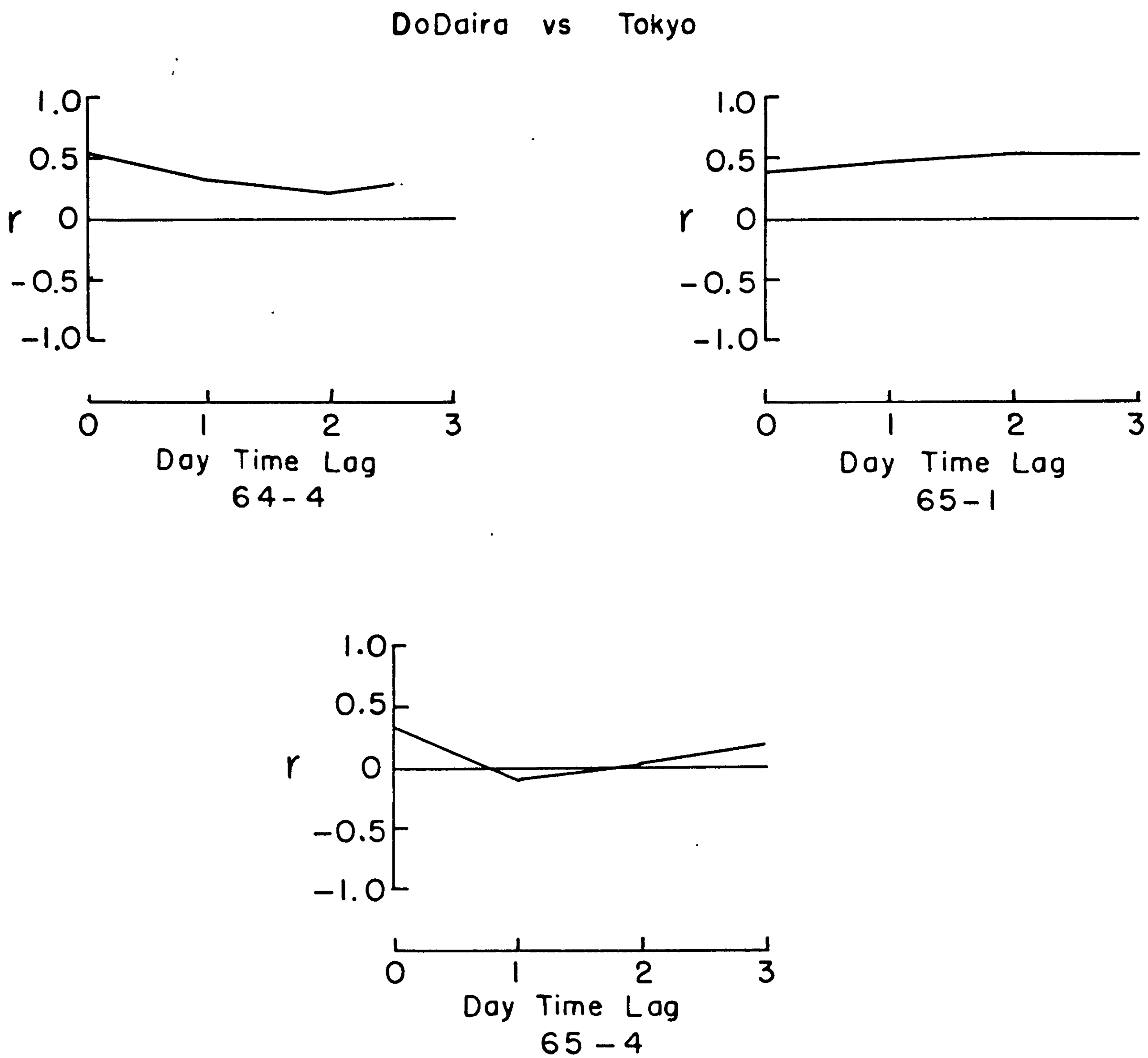

Fig. 29. The correlation of 5577 airglow at Dodaira with the corresponding absorption at Tokyo.

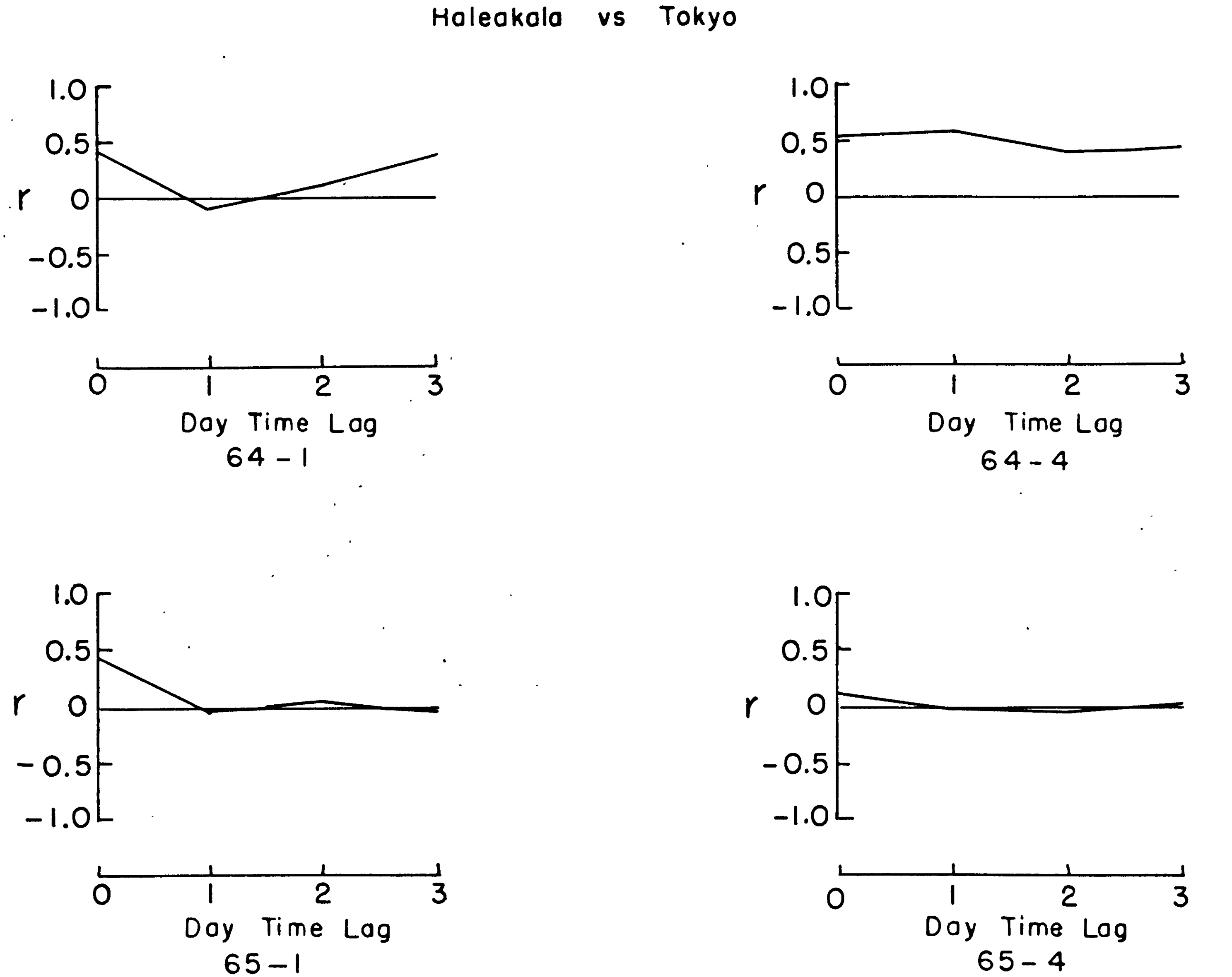

Fig. 30. The correlation of 5577 airglow at Haleakala with the corresponding absorption at Tokyo

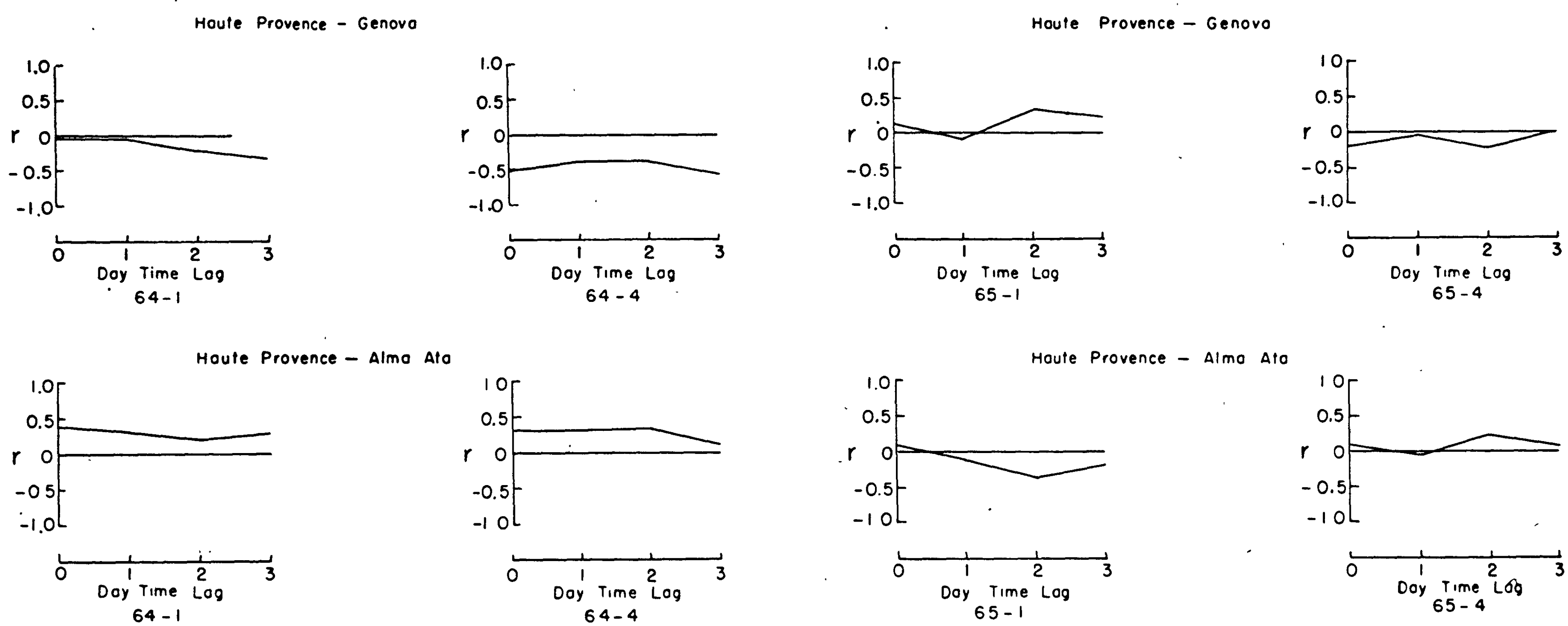

Figure 31. The correlation of the 5577 airglow values at Haute Provence, France, with the corresponding absorption values at both Genova, Italy and Alma Ata, USSR.

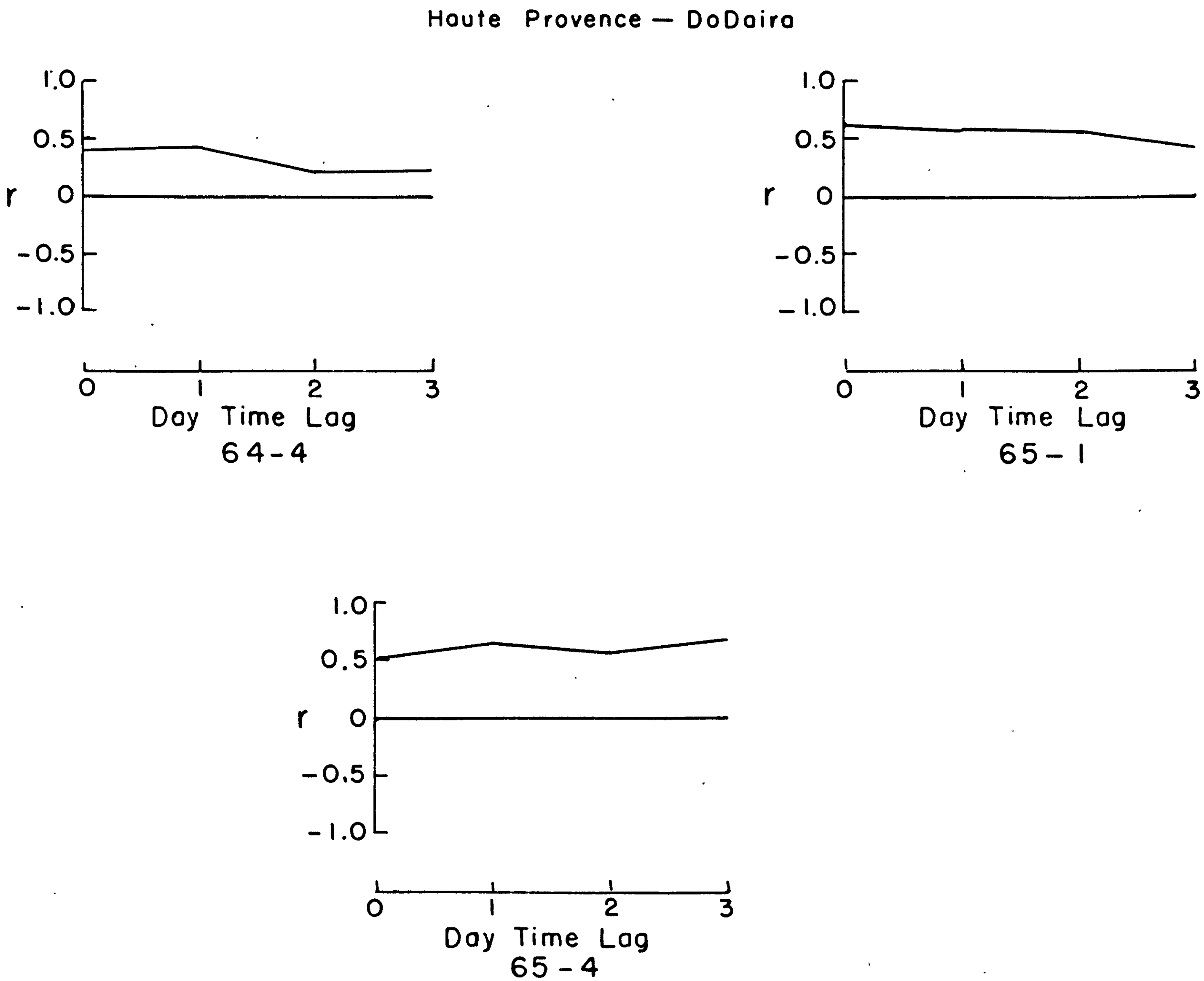

Fig. 32. The cross correlation of 5577 airglow values at Haute Provence, France and Dodaira, Japan.

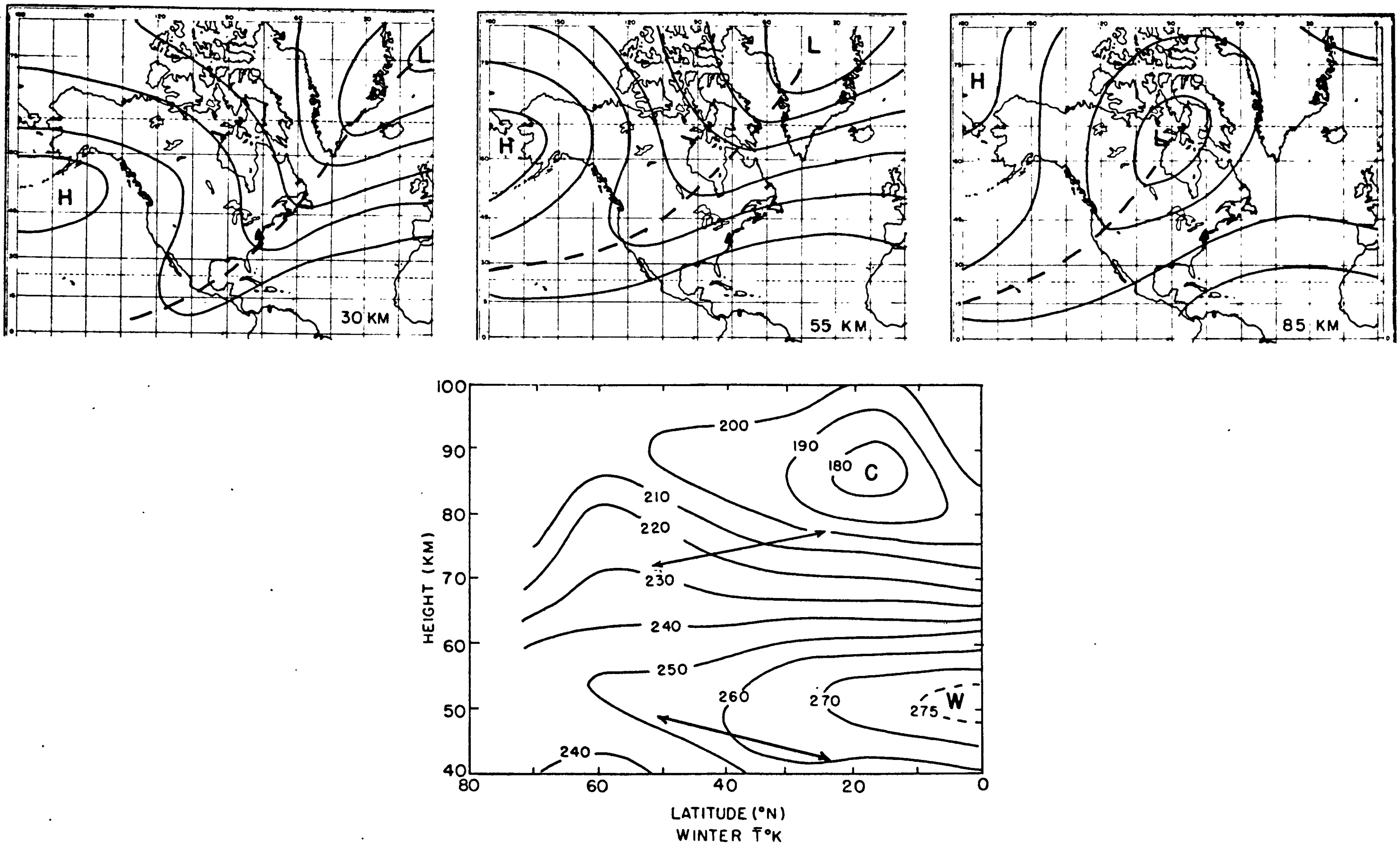

Fig. 33. A suggested synoptic picture which would facilitate the transfer of atomic oxygen into the Washington, D.C. area during the winter months.

BIBLIOGRAPHY

Appleton, E. V., 1930: On some measurements of the equivalent height of the atmospheric ionized layer. Proc. Roy. Soc., London, (A), 126, p. 542.

Appleton, E. V., 1937: Regularities and irregularities in the ionosphere. Proc. Roy. Soc., London, (A), 162, p. 451.

Barth, C. A., 1964: Rocket measurements of nitric oxide dayglow. J. Geophys. Res., 69, p. 3301.

Barth, C. A., 1966: Nitric oxide in the upper atmosphere. Ann. Geophys., 22, p. 198.

Belrose, J. S., 1963: Electron density measurements in the D-region by the method of partial reflection. Electron Density Distribution in Ionosphere and Exosphere, E. Thrane, Editor, North-Holland Pub. Co., Amsterdam.

Belrose, J. S., and M. J. Burke, 1964: Study of the lower ionosphere using partial reflection. 1. Experimental techniques and methods of analysis. J. Geophys. Res., 69, p. 2279.

Belrose, J. S., I. A. Bourne, and L. W. Hewitt, 1966: The winter variability of electron number density in the lower ionosphere over Ottawa. A discussion of results and possible causes. Electron Density Profiles in the Ionosphere and Exosphere, J. Frihagen, editor, North-Holland Pub. Co., Amsterdam.

Beynon, W. J. G., and E. S. O. Jones, 1965: Meteorological influences in ionospheric absorption measurements. Proc. Roy. Soc., London, (A), 288, p. 558.

Bossolasco, M., and A. Elena, 1963: Absorption de la couche D et temperature de la mesosphere. Comptes Rendus, 256, p. 4491.

Chapman, S., 1930: On ozone and atomic oxygen in the upper atmosphere. Phil. Magaz., London, 10, p. 369.

Chapman, S., 1931: The absorption and dissociative or ionizing effect of monochromatic radiation in an atmosphere on a rotating earth. Proc. Phys. Soc., London, 43, p. 26.

Craig, R. A., 1965: The Upper Atmosphere: Meteorology and Physics, Academic Press, New York and London.

Davies, K. R., 1965: Ionospheric Radio Propagation, U.S. Dept. of Commerce, National Bureau of Standards.

Dieminger, W., 1952: On the causes of excessive absorption in the ionosphere on winter days. J. Atmos. Terr. Phys., 2, p. 340.

Dieminger, W., 1968: D-region phenomena. Winds and turbulence in stratosphere, mesosphere and ionosphere, K. Rawer, editor, North-Holland Pub. Co., Amsterdam.

Fehsenfeld, F. C., A. L. Schmeltekopf, I. Shiff, and E. E. Ferguson, 1967: Laboratory measurements of negative ion reactions of atmospheric interest. Planet. Space Sci., 15, p. 373.

Geisler, J. E., and R. E. Dickinson, 1968: Vertical motions and nitric oxide in the upper mesosphere. J. Atmos. Terr. Phys., 30, p. 1505.

Geiswald, K. H., C. G. Little, K. Oberlander, H. Schwentek, and G. Umlauft, 1968: Ionosphere: absorption measurements, Annals of the IQSY,1, edited by C. M. Minnis and A. C. Strickland. M.I.T. Press, Cambridge, Mass., London, England.

Gregory, J. B., 1963: Particle influx at high latitudes. J. Geophys. Res., 68, p. 3097.

Gregory, J. B., 1965: The influence of atmospheric circulation on mesospheric electron densities in winter. J. Atmos. Sci., 22, p. 18.

Gregory, J. B., and A. H. Manson, 1969: Seasonal variations of electron densities below 100 km at mid-latitudes. II. Electron Densities and Atmospheric Circulation. J. Atmos. Terr. Phys., 31, p. 703.

Hall, J. E., and J. Fooks, 1967: D-region electron distributions from further rocket measurements of low frequency propagation. Planet. Space Sci., 15, 1967.

Johnson, W. F., 1964: Relations between the airglow and mesospheric circulation. M.S. thesis, Dept. Meteor., M.I.T., 151 pp.

Kellogg, W. W., 1961: Chemical heating above the polar mesopause in winter. J. Meteor., 18, p. 373.

Maehlum, B., 1967: On the winter anomaly in the midlatitude D region. J. Geophys. Res., 72, p. 2287.

Mechtly, E. A., and L. G. Smith, 1968: Seasonal variation of the lower ionosphere at Wallops Island during the IQSY. J. Atmos. Terr. Phys., 30, p. 1555.

Newell, R. E., 1964: Further ozone transport calculations and the spring maximum in ozone amount. Pure and Applied Geophysics, 59, p. 191.

Newell, R. E., 1966: The energy and momentum budget of the atmosphere above the tropopause. Problems of Atmospheric Circulation, edited by R. V. Garcia and T. F. Malone, Spartan Books, Washington.

Newell, R. E., J. M. Wallace and J. R. Mahoney, 1966: The general circulation of the atmosphere and its effect on the movement of trace substances. Tellus, 18, p. 363.

Newell, R. E., 1968: The general circulation of the atmosphere above 60 km. Meteorological Monographs, vol. 9, no. 31, American Meteorological Society, 98-113.

Nicolet, M., and A. C. Aiken, 1960: The formation of the D-region of the ionosphere. J. Geophys. Res., 65, p. 1469.

Nicolet, M., 1965: Nitrogen oxides in the chemosphere. J. Geophys. Res., 70, p. 679.

Nordberg, W., 1966: Recent observations of the structure of the upper stratosphere and mesosphere. Sci. Report No. 2, 66-369, AFCRL, Cambridge, Mass.

Pearce, J. B., 1969: Rocket measurement of nitric oxide between 60 and 96 km. J. Geophys. Res., 74, p. 853.

Piggott, R. W., W. J. G. Beynon, G. M. Brown and C. G. Little, 1957: Measurement of ionospheric absorption. Annals of the IGY, W. J. G. Beynon, editor, Pergamon Press, London, New York and Paris.

Poppoff, I. G., R. C. Whitten and R. S. Edmonds, 1964: The role of non-flare x radiation in the D-region. J. Geophys. Res., 69, p. 4081.

Ratcliffe, J. A., and K. Weekes, 1960: The Ionosphere. Physics of the Upper Atmosphere, J. A. Ratcliffe, editor, Academic Press, New York and London.

Richards, M. E., 1967: The energy budget of the stratosphere during 1965. Report No. 21, Planetary Circulations Project, Dept. of Meteor., M.I.T., 170 pp.

Roach, F. E., 1968: Photometric observations of the airglow during the IQSY. Annals of the IQSY, edited by C. M. Minnis and A. C. Strickland, The M.I.T. Press, Cambridge, Mass. and London, England.

Sechrist, C. F., Jr., 1967: A theory of the winter anomaly at middle latitudes. J. Atmos. Terr. Phys., 29, p. 113.

Sechrist, C. F., Jr., E. A. Mechtly, J. S. Shirke and J. S. Theon, 1969: Coordinated rocket measurements on the D-region winter anomaly - I. Experimental results. J. Atmos. Terr. Phys., 31, p. 145.

Shapley, A. H., and W. J. G. Beynon, 1965: Winter anomaly in ionospheric absorption and stratospheric warmings. Nature, 206, p. 1242.

Silberstein, R., 1959: The origin of the current nomenclature for the ionospheric layers. J. Atmos. Terr. Phys., 13, p. 382.

Spiegel, M. R., 1961: Theory and Problems of Statistics. Schaum Publ. Co., New York, 359 pp.

Staff, Upper Air Branch, NMC, 1967: Monthly mean 100, 50, 30 and 10 millibar charts, January 1964 through December 1965 of the IQSY period. ESSA Tech. Report WB1, U.S. Dept. of Commerce, Silver Spring, Md.

Staff, Upper Air Branch, NMC, 1967: Weekly synoptic analyses, 5, 2 and 0.4 Mb. surfaces for 1964. ESSA Tech. Report WB2, U. S. Dept. of Commerce, Silver Spring, Md.

Staff, Upper Air Branch, NMC, 1967: Weekly synoptic analyses, 5, 2 and 0.4 Mb. surfaces for 1965. ESSA Tech Report WB3, U. S. Dept. of Commerce, Silver Spring, Md.

Standards on wave-propagation. Definition of terms, 1950: Proc. IRE, 38, p. 1264.

Theon, J. S., W. Nordberg, L. B. Katchen, and J. J. Horvath, 1967: Some observations of the thermal behavior of the mesosphere. J. Atmos. Sci., 24, p. 438.

Thomas, L., 1962: The winter anomaly in ionospheric absorption. J. Atmos. Terr. Phys., 23, p. 301.

Thrane, E. V., 1966: Experimental studies of the structure of the ionospheric D-region. NDRE Report No. 54, Norwegian Defence Research Establishment, 95 pp.

Tohmatsu, T., and T. Nagata, 1963: Dynamical studies of the oxygen green line in the airglow. Planet. Space Sci., 10, p. 105.

Warnecke, G., and W. Nordberg, 1965: Inferences of stratospheric and mesospheric circulation systems from rocket experiments. Space Research V. North-Holland Publ. Co., Amsterdam, p. 1026.

Whitehead, J. D., 1955: The absorption of short radio waves in the D, E and F-regions of the ionosphere. J. Atmos. Terr. Phys., 16, p. 283.

Whitten, R. C., and I. G. Poppoff, 1965: Physics of the Lower ionosphere, Prentice-Hall, N. J., 232 pp.

Young, C., and E. S. Epstein, 1962: Atomic oxygen in the polar winter atmosphere. J. Atmos. Sci., 19, p. 435.