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SUMMARY

Data from the Southeastern Virginia Urban Plume Study conducted by the National Aeronautics and Space Administration during July 1978 are presented. The overall purpose of the measurement program was to define the characteristics of the Southeastern Virginia urban plume with emphasis on the photo-oxidant species. The measurement area was a rectangle approximately 150 km by 100 km centered around Cape Charles, Virginia. Included in this area are the cities of Norfolk, Virginia Beach, Chesapeake, Newport News, and Hampton. The area is bounded on the north by Wallops Island, Virginia, and on the south by the Hampton Roads area of Tidewater Virginia. The major axis of the rectangle is oriented in the southwest-northeast direction. The data set includes aircraft measurements for carbon monoxide, methane, nonmethane hydrocarbons, and ozone. The urban plume program was a combined effort of NASA Langley Research Center, NASA Wallops Flight Center, Virginia State Air Pollution Control Board Region VI, and Old Dominion University.

CO can be successfully measured as a tracer gas and used as an index for determining localized and urban plumes. The 1978 data base provided sufficient data to assess an automated chromatograph with flame ionization detection used for measuring methane and nonmethane hydrocarbons in flight.

INTRODUCTION

The Southeastern Virginia Urban Plume Study (SEV-UPS, ref. 1) is an element in the long-term commitment of the National Aeronautics and Space Administration (NASA) to develop the necessary technology to monitor the Earth's environment and resources from space. A number of remote sensing systems currently under development (refs. 2 to 6) are being used both in airborne platforms and from surface sites to develop a basic understanding of the environmental problems associated with the troposphere. Solutions to these problems may be found through the use of remotely sensed data. Verification of the existence of the Southeastern Virginia urban plume and definition of its characteristics are prerequisites to the design of experiments using maturing NASA remote sensing capability. The measurement area for the study was a rectangle approximately 150 km by 100 km centered around Cape Charles, Virginia. Included in this area are the cities of Norfolk, Virginia Beach, Chesapeake, Newport News, and Hampton. The area is bounded on the north by Wallops Island, Virginia, and on the south by the Hampton Roads area of Tidewater Virginia. The major axis of the rectangle is oriented in the southwest-northeast direction so that for southwesterly winds, the air mass moves from the highly populated Tidewater area toward the NASA Wallops Flight Center.

The first phase of SEV-UPS was carried out in 1977 (ref. 7) when airborne and surface in situ instruments were used to characterize the production of the secondary pollutant ozone downwind of the urban complex. These measurements revealed the characteristic oxidation diurnal cycle at ground level. The oxi-

dant concentration in an air parcel nearly doubled as the parcel moved downwind of the populated areas and was advected over primarily rural agricultural areas. The second phase of SEV-UPS was conducted in the summer of 1978 when airborne and surface instruments were again used to characterize the production of the secondary pollutant ozone downwind of the urban complex. In addition, an airborne remote ozone sensor, the laser absorption spectrometer, was used.

Experimental objectives differed on various days of the study. These objectives ranged from correlative data missions for comparing in situ and remotely sensed ozone data to comprehensive urban plume studies to provide data for correlation with photochemical and pollutant transport models. Supporting measurements of meteorological parameters, mixing-layer height, and ozone precursors (nitrogen oxides and hydrocarbons) were also made, both on the surface and at altitude. Participating in the 1978 SEV-UPS field program were the NASA Langley Research Center (LaRC) and Wallops Flight Center (WFC), the Jet Propulsion Laboratory, the Virginia State Air Pollution Control Board, and Old Dominion University. Measurement systems included approximately 10 surface pollutant monitoring sites, 3 airborne platforms, and numerous sites for observing meteorological parameters. While all three aircraft monitored ozone, each was individually equipped to monitor additional parameters: one was equipped for nitrogen oxides, methane, dew point, and temperature; a second was equipped for carbon monoxide, methane, nonmethane hydrocarbons, and ozone; and a third was equipped for remotely sensing the total burden of ozone from the aircraft to the surface. Reference 8 presents the results of the aircraft data set for measurements of ozone, nitrogen oxides, and methane.

This report summarizes the data measured (July 21, 27, and 28, 1978) onboard a Douglas C-54 aircraft which was equipped to monitor carbon monoxide, methane, nonmethane hydrocarbons, and ozone. A brief description of each instrument used in the experiment is also presented. The C-54 aircraft was chosen as a platform for measuring carbon monoxide (CO), ozone (O_3), methane (CH_4) and nonmethane hydrocarbons (NMHC) because the test instruments are large. The data sets are therefore not intended to correlate, since no real scientific connection between the measurements exists. No attempt has been made in this report to correlate the data sets.

The expected sources for carbon monoxide in the region studied are documented by Brewer et. al (ref. 9). Methane and nonmethane hydrocarbons are produced as combustion products and also emanate from the swamp areas located around Tidewater Virginia.

Identification of commercial products in this paper is used to adequately describe the model. The identification of these commercial products does not constitute an official endorsement, expressed or implied, of such products or manufacturers by the National Aeronautics and Space Administration.

NOMENCLATURE

Values are given in SI units; measurements were made in U.S. Customary Units.

CH_{4o}	methane concentration at ground level
FID	flight ionization detector (detection)
LaRC	Langley Research Center
NMHC	nonmethane hydrocarbons
Norfolk Airport	Norfolk International Airport
ODU	Old Dominion University
ppb	parts per billion by volume
ppm	parts per million by volume
R	response at altitude
R_o	response at ground level
t	time
Tidewater College	Tidewater Community College
Va. School	Virginia School at Hampton
VIMS	Virginia Institute of Marine Science
VOR	VHF omnidirectional range
WFC	Wallops Flight Center
σ_{DIFF}	standard deviation of the difference in concentration
χ_{co}	carbon monoxide concentration

DESCRIPTION OF FLIGHT LEGS

A map of the southeastern region of Virginia is presented in figure 1. As the figure shows, the flight legs were set up to be transverse to the air-parcel flow from southwest to northeast. This procedure allowed the Hampton Roads urban plume, produced by automobile exhausts, power plants, industrial stacks, and so forth, to be monitored using CO as a tracer gas. The Hampton Roads area is comprised of five major cities: Norfolk, Virginia Beach, Portsmouth, Newport News, and Hampton. Data were collected on specific flight legs which are designated in the figures by straight lines connecting lettered points. All flight

legs except E'→F" (457 m) were flown at an altitude of 610 m. Aircraft speed was approximately 140 to 150 knots and was constant over each flight leg. The geographical position of any data point for CO concentrations is indicated by tick marks. For the CH_4/NMHC and O_3 data, the geographical position is determined by dividing the appropriate flight leg into equal divisions which correspond sequentially with time.

Ground station locations for other experiments conducted during the SEV-UPS program are indicated by the solid circles.

DACOM INSTRUMENT

The Differential Absorption Carbon Monoxide Monitor (DACOM) is an optical instrument developed at LaRC to make in situ ambient CO measurements from an aircraft platform. During the 1978 SEV-UPS flights, the CO measurement was made across a 10-meter-long absorption path located in the airstream along the fuselage of the C-54 aircraft (see fig. 2). The differential absorption measurement is accomplished by current sweeping the wavelength of a PbSSe diode laser across a single 4.7 μm CO absorption line. The resulting differential transmission of the laser beam at the end of the absorption path is detected by a PbSe detector and synchronous electronics. For typical ambient CO concentrations, this differential transmission signal is linearly related to the CO concentration. The proportionality constant or instrument gain is determined by inserting 2-cm-long cells containing accurately known CO mixing ratios into the absorption path.

DACOM is subject to systematic and random errors associated with three sources: The harsh aircraft environment, the ambient atmosphere, and the instrument itself. Several unique electronic/optical subsystems were incorporated in DACOM to minimize potential instrument-generated error sources, including laser frequency instability, laser power drift and oscillation, and detector and electronics gain variations. Fast automatic gain-control circuitry designed to compensate for instrument gain fluctuations also worked well in minimizing the effects of flight through clouds. Systematic errors arising from absorptions due to ambient levels of interfering gases such as water vapor (H_2O), nitrons oxide (N_2O), carbon dioxide (CO_2), and ozone (O_3) are minimized by optimally selecting the CO absorption line. A detailed study was undertaken to characterize the error sources associated with the aircraft, including turbulence noise, vibrational misalignments of the laser beam, and CO contamination from the aircraft engines. Through careful design of a vibration isolation system and by scanning the laser wavelength at a high frequency, these noise contributions were greatly reduced in comparison with the residual instrument-generated errors. The contamination question was investigated by taking simultaneous grab samples in front of the engines and at three locations along the absorption path for several flight configurations, including climbs, descents, turns, and several flap positions. Within the error range of the gas chromatograph measurements, no differences were found in the CO mixing ratios in front of the engines and along the absorption path. Detailed discussions of these errors and of optimization are found in references 10 to 11.

The DACOM performance (measurement and time response) is strongly coupled to several parameters of the tunable diode laser source, including the spectral tuning region of the laser and its output power, the power and spectral distribution of the laser modes, and the time stability of these parameters. With a sufficiently large inventory of diode lasers, a laser is generally available which will permit high performance CO measurements (±10 ppb at 1-sec time response). Reference 11 includes CO flight data which support this performance. Unfortunately, during the 1978 SEV-UPS flights, the best available laser had very low output power. To compensate for this low power laser, a considerably longer instrument time response (35 sec) was used to retain a measurement signal-to-noise ratio equivalent to a ±10 ppb CO uncertainty. The DACOM time resolution is defined as the full-width at half maximum (FWHM) time response of DACOM to a simulated impulse of CO. Typically, the C-54 aircraft speed was 140 to 150 knots, and the ascent and descent rate during spirals was 2.4 m/sec. Consequently, the horizontal resolution was about 2.4 km and the vertical resolution about 80 m.

PLUME AND SPIRAL MEASUREMENTS FOR CARBON MONOXIDE

Carbon monoxide data for the morning of July 27, 1978, are shown in figure 3. All the flight legs were flown at an altitude of 610 m except for the E'→F" leg, which was flown at 457 m. Flight directions are indicated with an arrow, and the time (eastern daylight time (EDT)) at each end of the legs is given for reference. Midpoint times can be calculated assuming a constant aircraft speed of 140 knots. Carbon monoxide concentrations are shown in units of parts per billion by volume mixing ratio. As shown in figure 3, the entire southeastern section of Virginia was mapped in 99 minutes and represents a reasonable picture of the overall CO concentration. However, this picture is somewhat modified because of a rapidly varying inversion layer height during the early morning hours. Surface winds for the morning of July 27 are shown in table I(a), and the winds aloft for the same morning, measured at WFC, are shown in table I(b). Tables II(a) and II(b) show the surface winds and winds aloft for the afternoon of July 27.

As shown in figure 3, the CO concentration over the area varied from 120 to 200 ppb. The lower concentration of 120 ppb was observed over the Chesapeake Bay near Cape Henry and the highest concentration of 200 ppb was recorded over the WFC area. The morning measurements did not indicate any well-defined plumes.

Several spirals were made during the morning flight on July 27 and are shown in figures 4 to 6. Figure 4 depicts a descent spiral from approximately 1400 m to 610 m taken over WFC (point B). The aircraft descent rate was approximately 122 m/min. During the descent, the CO concentration increased from a value of 155 ppb at 1400 m to approximately 210 ppb at 610 m.

An ascent spiral over point L (Deep Creek) was made from 152 m to 1524 m with CO concentrations ranging from 200 ppb to approximately 130 ppb. An ascent rate of 137 m/min was used for this spiral (see fig. 5).

Figure 6 shows both an ascent and a descent spiral for an afternoon flight taken over WFC (point B). These concentrations agree with those taken earlier

in the morning (fig. 4) above 1128 m but differ considerably below that altitude. Measurements taken during the morning spirals indicate considerably more CO than do measurements taken during the spirals 3 hours later over the same point B. Figure 6 shows excellent agreement in CO concentrations for ascent and descent between 914 m and 1524 m. Between 610 m and 914 m, the differences in ascent and descent CO concentrations are as much as 30 ppb. The differences in CO concentrations for the ascent and descent spirals are believed to be real and not due to contamination or instrument error. As mentioned earlier, a series of tests were performed with DACOM and CO grab-sample analysis using a gas chromatograph; these results were identical within the range of experimental accuracy (see ref. 11).

Figure 7 shows the results of the afternoon horizontal flights for July 27. Again, flight time, direction, and aircraft altitude are indicated on each leg. Well-defined urban plumes, some having strong horizontal CO mixing-ratio gradients, are evident in the afternoon data which are indicated in figure 7. One plume coincides well with the Norfolk area and the other with the Peninsula area, containing the NASA Langley Research Center. The advantage of using CO as a tracer of urban plumes is graphically illustrated in the data taken in flight leg G→H. Leg C"→D was traversed twice during a 2-hour period, and the urban plume is readily seen to have shifted eastward. This shift is apparently the result of a wind direction which was actually recorded in Norfolk for this time period. Also related to the plume shift is a possible interaction of sea breeze with the coastal environment. Several measurements are also indicated in the flights A→B→B'. Comparison of the morning and afternoon measurements of figures 3 and 7 indicates that the afternoon concentrations are generally larger than those in the morning.

The only flight leg flown for horizontal repeatability measurements was leg A→B. Figure 8 shows the concentration as a function of location along flight leg A→B and then along flight leg B→A. These data were taken with an integration time constant of 10 sec and an aircraft speed of 150 knots. Because the two legs were flown in opposite directions, a correction was made for spatial resolution, and the standard deviation of differences over this path was measured to be ±4 ppb.

Figures 9 and 10 both depict ascent and descent spirals taken over WFC (point B). Data were taken on the afternoon of July 27 at intervals approximately 2 hours and 20 minutes apart. The spirals in figure 9 indicate much more structure in CO concentration than do the spirals shown in figure 10, which were taken later in the day. Again, there are large differences in the mixing ratios for the ascent and descent spirals. With vertical structure in the CO concentration, the ascent and descent values show differences because of the relatively long integration times (10 sec). This phase shift and the spatial averages complicate the interpretation when a lot of vertical structures exist in the CO concentration. The ascent and descent spirals shown in figure 9 were taken just after take-off from WFC and just before flight leg B→A (fig. 7). Flight leg B→A showed the strongest horizontal gradient of all the flights (125 to 250 ppb). In addition, the next leg flown, C"→D, also exhibited a rather large horizontal gradient. With the turning radius of the aircraft during spirals of approximately 1.6 km and strong horizontal gradients in CO mixing ratios, one would expect to find sizable differences in ascent and descent measurements, as indi-

cated in figures 9 and 10. Figure 10 shows the ascent and descent spirals taken later in the day than those for figure 9 but does not show the structure indicated in figure 9. The horizontal flights (fig. 7) for the same time period as the spirals shown in figure 10 do not have strong horizontal gradients, and therefore, one would not expect a lot of structure in the vertical measurements.

AUTOMATED AIRBORNE METHANE/NONMETHANE HYDROCARBON ANALYZER

The hydrocarbon analyzer is basically an automated chromatograph equipped with flame ionization detection (FID). Electronically actuated switching valves form the heart of the analyzer. A schematic of the valve-switching train is shown in figure 11. The valve positions were electronically cycled so that samples were alternately loaded and swept into the detector. Valve 1 directed the pump-supplied air sample through either a 1/8- by 12-in. stainless steel column packed with 80 to 100 mesh Porapak[1] Q, or directly into one of two matched 0.50-millimeter-diameter sample holding loops connected to valve 2. Since the air sample flowed continuously through the packed column during the CH_4 loading cycle, CH_4 eluted as a frontal (wave) rather than as a peak, and after achieving steady-state concentration, was captured in one of the sample holding loops. Methane frontals from the selected column were determined to elute well ahead of ethylene when methane/ethylene mixtures were fed into the system. It was assumed that other nonmethane hydrocarbons would elute no earlier than ethylene.

The valve train and column were operated at ambient temperatures. Nitrogen carrier was used simultaneously for backflushing and sweeping the samples from the holding loops into the detection system. When the system was operated, alternate FID output signals were obtained corresponding to methane and total hydrocarbons (THC). The difference between the two is reported as nonmethane hydrocarbons.

A metal diaphragm pump was used to force air samples (drawn through a 1/4 in. by 12 ft-long stainless steel sampling line as shown in fig. 2) through the valve train. The sampling line was extended approximately 9 in. perpendicular to the aircraft fuselage and forward of the engines. The valves were set to cycle every 7 seconds, producing alternate CH_4/THC peaks.

Four calibration gases in hydrocarbon-free air (purchased with analysis ±1 percent) were used as standards for the analyzer. Respective methane/hydrocarbon concentrations (in ppm) were as follows: 2.04/2.01 ethylene, 10.3/4.83 ethane, 2.00/0.995 butane, and 5.11/0.00 hydrocarbon. A pressurized cylinder of the methane/butane calibration mixture was permanently attached at the calibration inlet for in-flight calibration. Calibration was accomplished by manually changing the three-way valve position to feed the methane/butane mixture into the valve train. Since operation of the three-way valve involved

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[1]Porapak: Registered trademark of Waters Associates, Inc.

only a simple manual switching operation, preset flows were not disturbed during calibration. Constant-altitude measurements were calibrated before, during, and after data acquisition. Atmospheric oxygen concentrations were assumed constant during the measurements and equal to that of the calibration mixture. No corrections for humidity were applied to detector response. Typically, CH_4/NMHC peaks varied less than 1 percent from their mean over 15-minute intervals during constant input of calibration gas.

Flying an FID in a nonpressurized aircraft presents the experimentor with several problems not typically encountered during laboratory or ground station measurements. Most of these problems result from barometric pressure changes experienced during the ascent or descent of an aircraft. In figure 12, the response of the FID to a continuous input of calibration mixture is shown for a typical spiral. The response of the FID can be seen to decrease as altitude increases. Figure 13 shows the relative response for methane on three calibration spirals; this curve was used to correct all spiral data. The response at ground level is denoted R_o.

PLUME AND SPIRAL MEASUREMENTS FOR METHANE/NONMETHANE HYDROCARBONS

One spiral and three flight legs at constant altitude were flown on the afternoon of July 21, 1978. Figure 14 depicts a spiral flown over WFC (point B) at approximately 1340 EDT. Methane concentrations appear almost invariant between 305 to 1524 m, although wind speed and direction over Wallops at 1400 EDT were variable. The wind direction varied progressively from southwest to northwest over the depicted altitude interval. A temperature profile taken at 1100 EDT revealed an inversion between 914 to 1128 m. This profile, however, was determined more than 2.5 hours before the measurements. Shifting winds, along with the inversion (if still persistent), do not appear to have affected the uniformity of the methane mix. NMHC concentrations appear relatively constant between 305 to 1067 m but increase between 1067 to 1524 m.

In figures 15 and 16, CH_4 and NMHC measured over the designated flight paths and under the influence of west to northwest winds can be seen to differ very little at 610 m over and/or between the rural Wallops Flight Center and the urbanized Hampton Roads region. Methane concentrations appear uniformly higher (approximately 1.8 ppm) than the concentrations typically cited for clean tropospheric air (refs. 6 and 7). Nonmethane hydrocarbons appear lowest over the Hampton Roads area.

Constant altitude data for the morning of July 27 under prevailing southwest winds are shown in figures 17 and 18 for CH_4 and NMHC, respectively. Figure 19 shows the CH_4 concentrations for the same morning flight for three connecting flight legs not covered in general during the SEV-UPS experiment. Morning CH_4 concentrations appear high upwind of the Hampton Roads area (leg K→L) and progressively decrease up the Eastern Shore of Virginia toward WFC. NMHC concentrations, although somewhat erratic, imply the same pattern. On the morning of July 27, two spirals were taken approximately an hour apart at both ends of the experimental sampling area. Figures 20 and 21 show the

spiral results taken over Deep Creek (point L) and WFC (point B). Significant increases in CH_4 and NMHC concentrations can be seen to occur from 915 to 1524 m. The curve shapes are noticeably similar. Concentrations of CH_4 appear almost uniformly higher over Deep Creek than over WFC at all corresponding altitudes. The large increases in CH_4 and NMHC concentrations which were observed to occur during the spirals on July 27 over the 915-m altitude, are difficult to interpret. Either advective transport aloft of a relatively large scale concentrated CH_4/NMHC air mass from distant sources, or the interaction of a sea breeze with an area plume of more local origin could have produced these results.

Figures 22 to 25 show the results of constant-altitude flights taken during the afternoon of July 27, 1978. These measurements also show high CH_4 concentrations over Hampton Roads that progressively decrease toward Wallops Flight Center. NMHC, with the exception of leg A→B at 1626 EDT, seem to follow the CH_4 trend. Afternoon concentrations of CH_4 are lower than their morning counterparts. NMHC, however, do not reflect this behavior, but their daily input into the troposphere would be expected to be more variable.

Figures 26 and 27 show the results of afternoon spirals taken over WFC (point B) at intervals 2 hours and 20 minutes apart. Methane and NMHC concentrations increased considerably above 915 m, as they did in the morning measurements.

A significant urban CH_4 source does not appear to exist in the Hampton Roads area. It seems more reasonable that the elevated concentrations of CH_4 measured at 610 m on July 27, and progressively diminishing in a northeasterly direction towards WFC, may be the result of a large CH_4 plume emanating from the Dismal Swamp of Virginia and North Carolina. Significant concentrations of atmospheric CH_4 have been generated in areas of little anthropogenic activity (ref. 12). The progressive decrease in CH_4 concentrations up the Eastern Shore of Virginia could then be viewed as the result of dispersion-produced dilution. Wind direction on July 27 was favorable for this dispersion.

PLUME AND SPIRAL MEASUREMENTS FOR OZONE

A portable ozone analyzer was used for O_3 measurements, which were continuously recorded at 20-sec intervals. Air samples for the analyzer were collected from approximately the same location as the hydrocarbon samples. Internal instrument calibration was used exclusively during aircraft operations. No data were collected on July 21.

Morning O_3 data collected during constant-altitude flight legs on July 27 (figs. 28 to 31) suggest that O_3 concentrations varied from about 75 to 90 ppb in a relatively random fashion between Hampton Roads and WFC. Morning spiral data revealed very little information about vertical structure.

Constant-altitude data on the afternoon of July 27, particularly at times later than 1500 EDT, suggested a progressive buildup of O_3 from Hampton Roads to WFC (figs. 32 to 35). Individual traverses over the designated flight legs frequently revealed O_3 structure that could not be correlated with a

Hampton Roads plume. Only the 1635 EDT spiral over WFC suggested strong vertical structure with respect to O_3 (fig. 35).

CONCLUSIONS

Data for carbon monoxide, methane, nonmethane hydrocarbons, ozone, and flight parameters measured onboard the Douglas C-54 aircraft during the 1978 Southeastern Virginia Urban Plume Study field program are documented in the report. These data, combined with the data from two other aircraft, the surface effluent data, and the meteorological data, provide the inputs required for interpretation and analysis of the data set. Meteorological conditions were less than optimum during the 3-week field program and often resulted in frontal passage, overcast skies, and wind shifts during experiments designed for days of constant wind direction. However, the data for these experiments are included in the report, as they are believed to be useful for purposes other than those for which the experiments were designed. Concerning the 1978 Southeastern Virginia Urban Plume Study data base and in particular the objectives of the program, the following conclusions are appropriate:

1. Carbon monoxide can be successfully measured as a tracer gas and may thus serve as a means of determining both localized and urban plumes with sufficient accuracy and repeatability.

2. The 1978 data base has provided sufficient data to evaluate and assess the application of an automated chromatograph equipped with flame ionization detection for flight measurements of methane and nonmethane hydrocarbons.

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TABLE I.- WINDS FOR MORNING OF JULY 27, 1978

(a) Surface winds at Norfolk and Newport News, Va.

Airport	Time, EDT	Direction, deg	Speed, knots
Norfolk Int.	0800	220	10
	1000	220	9
	1200	220	11.5
Patrick Henry Int. (Newport News)	0800	190	6
	1000	210	9
	1200	210	7

(b) Winds aloft at Wallops Island

Time, EDT	Altitude, m	Direction, deg	Speed, knots
0800	500	230	16
	1000	255	15
	1500	260	12
	2000	250	13
0900	500	230	12
	1000	242	11
	1500	250	12
	2000	250	13
1100	500	205	12
	1000	220	15
	1500	230	17
	2000	240	17

TABLE II.- WINDS FOR AFTERNOON OF JULY 27, 1978

(a) Surface winds at Norfolk and Newport News, Va.

Airport	Time, EDT	Direction, deg	Speed, knots
Norfolk Int.	1300	200	12
	1400	220	10
	1500	215	14
Patrick Henry Int. (Newport News)	1300	180	10
	1400	190	10
	1500	190	8

(b) Winds aloft at Wallops Island

Time, EDT	Altitude, m	Direction, deg	Speed, knots
1400	500	230	19
	1000	233	17
	1500	250	19
	2000	250	14
1600	500	215	21
	1000	240	23
	1500	250	20
	2000	235	14
2000	500	225	25
	1000	240	28
	1500	240	25
	2000	240	22

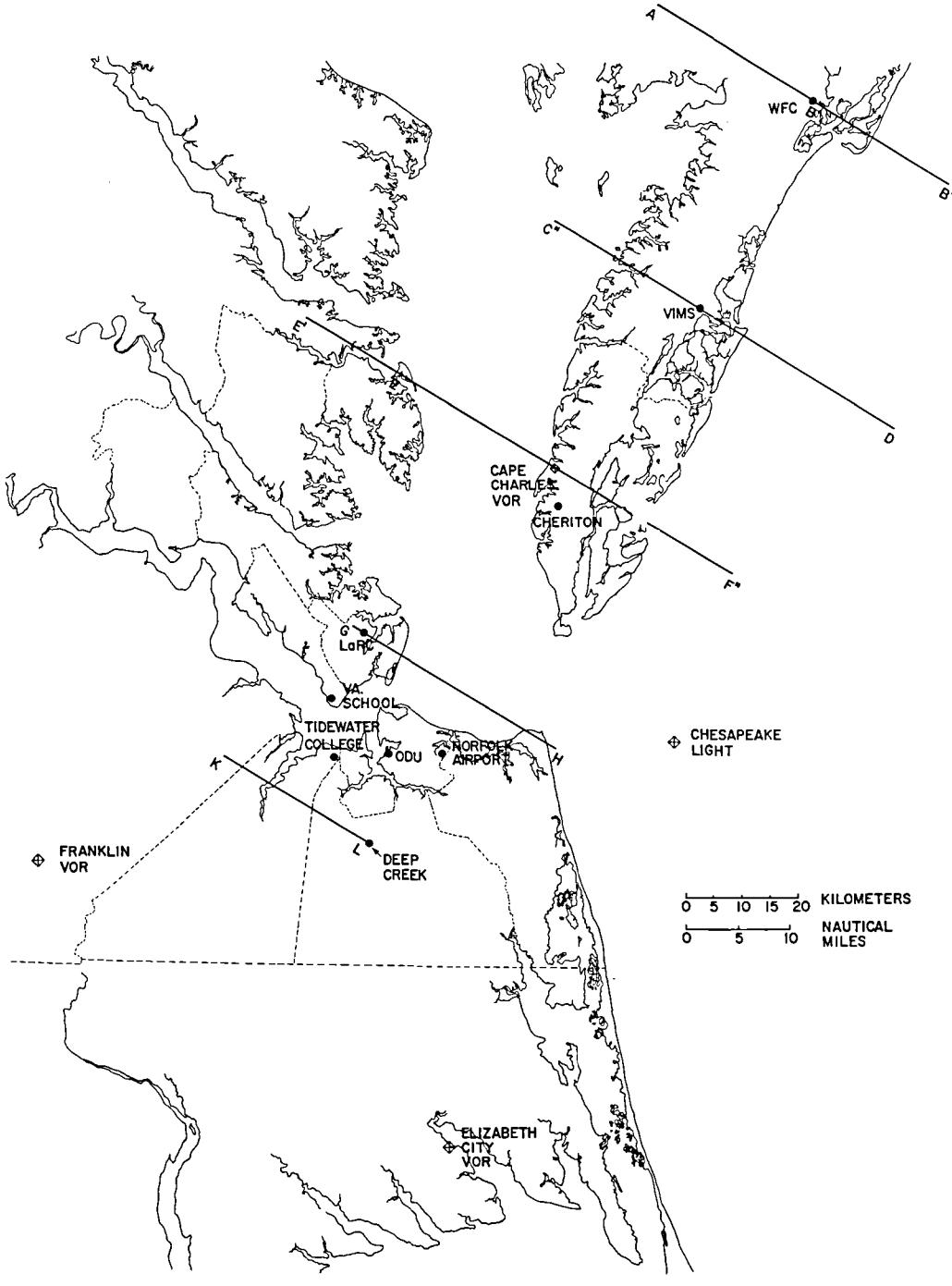

Figure 1.- Map showing flight paths and ground station locations.

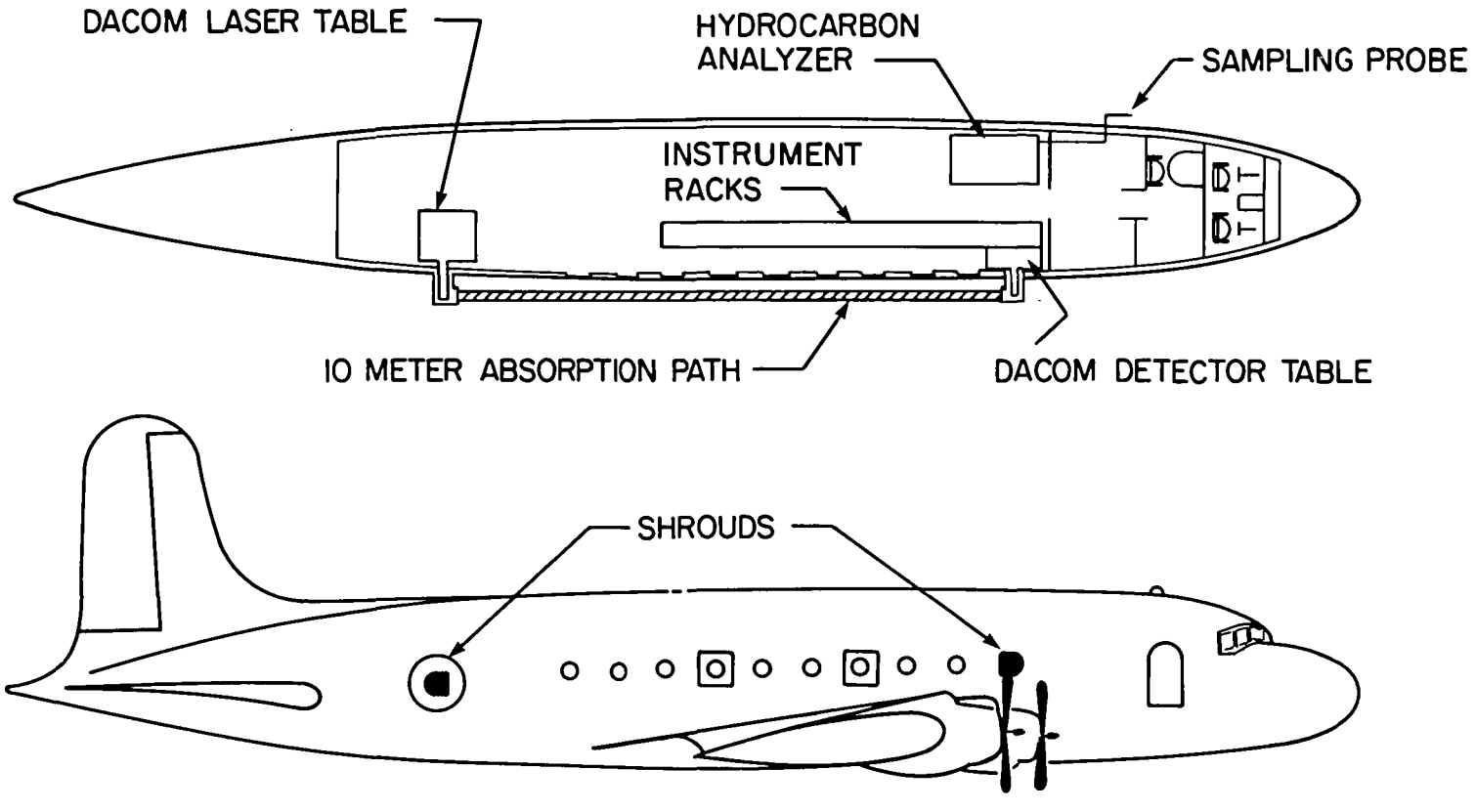

Figure 2.- Schematic of C-54 aircraft showing instrument and sampling locations.

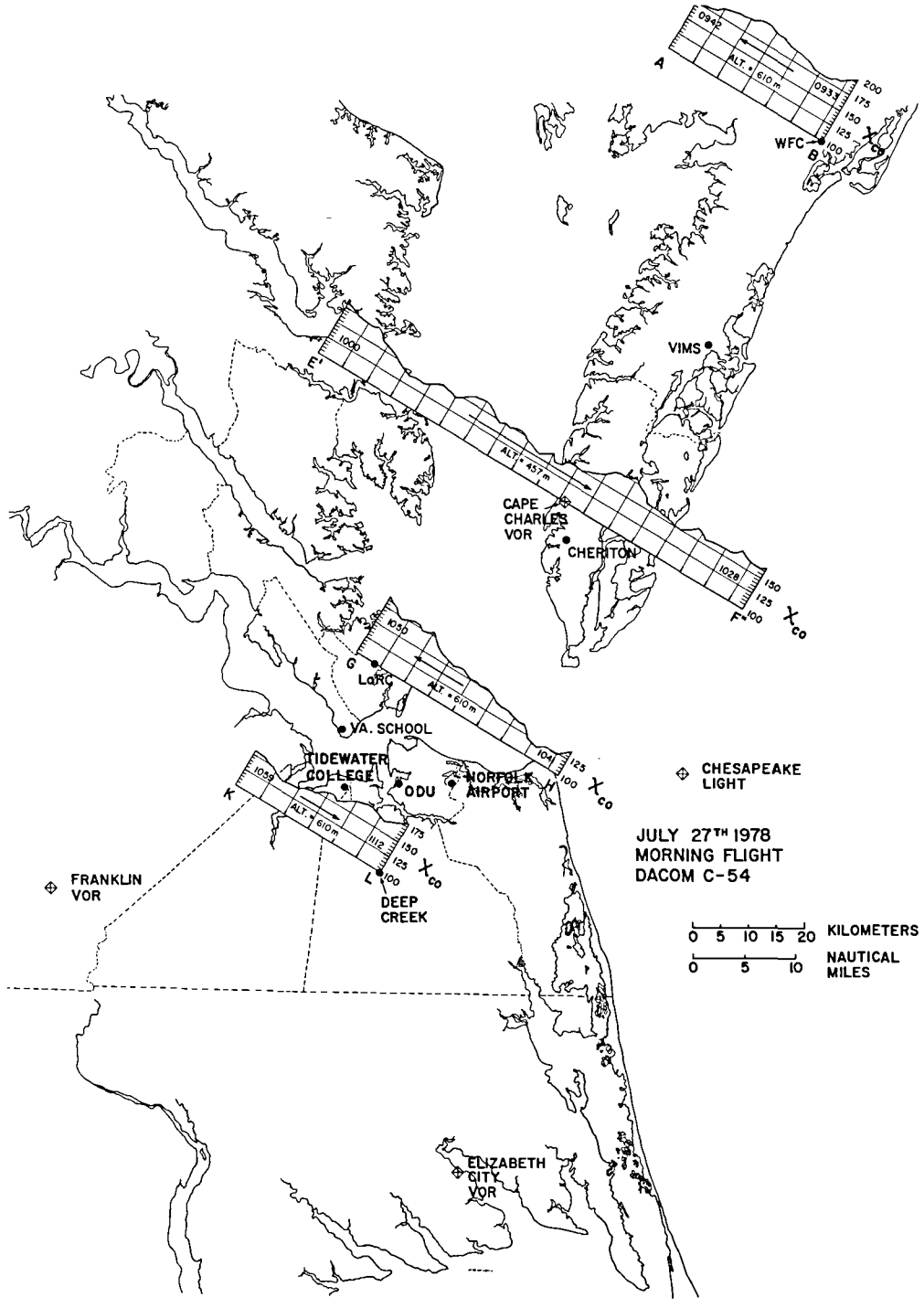

Figure 3.- CO concentration X_{CO} (in ppb) as a function of geographical location for morning flight, July 27, 1978. The starting and finishing times are indicated on each flight leg.

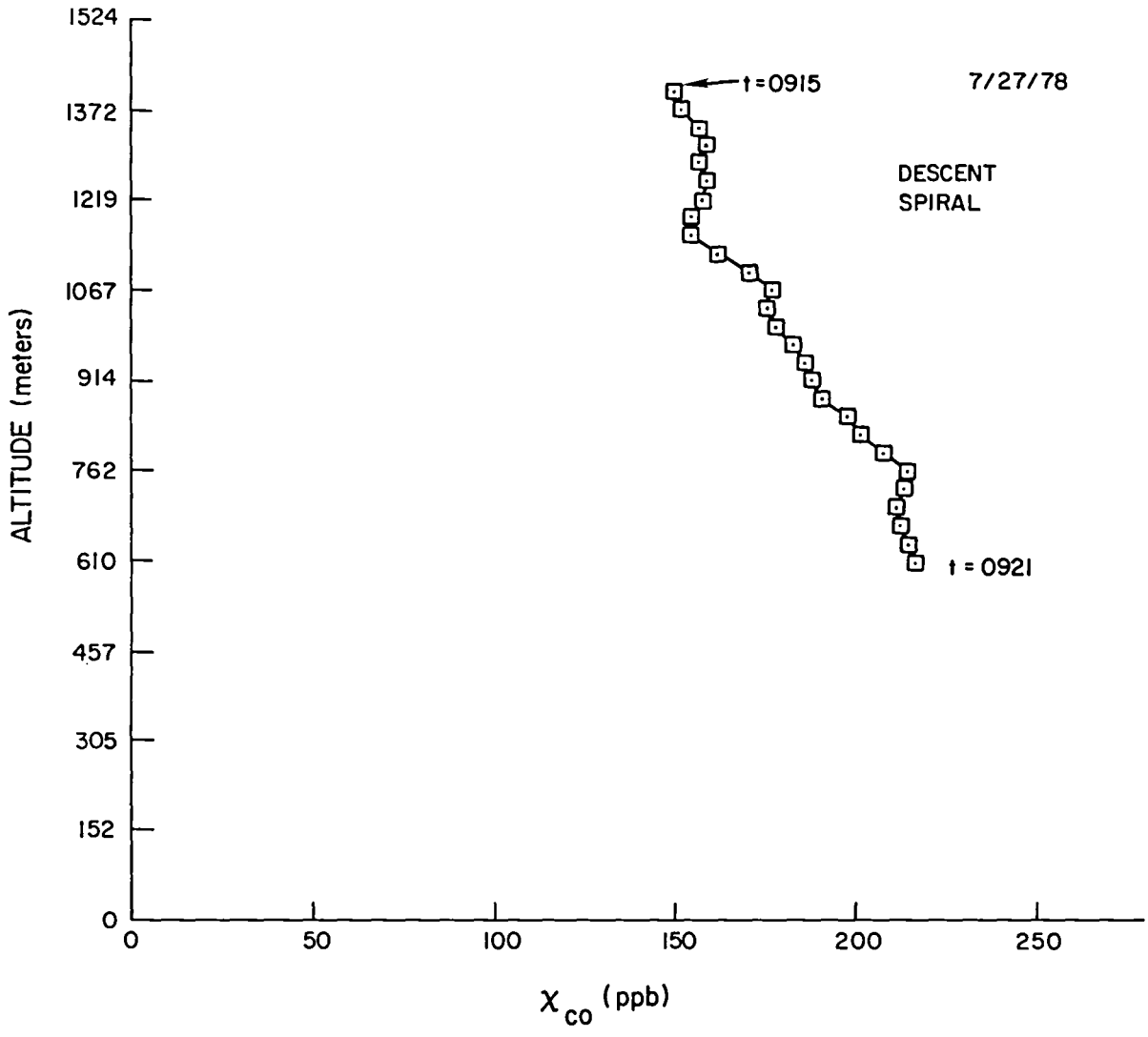

Figure 4.- CO concentration versus altitude over Wallops Flight Center (point B).

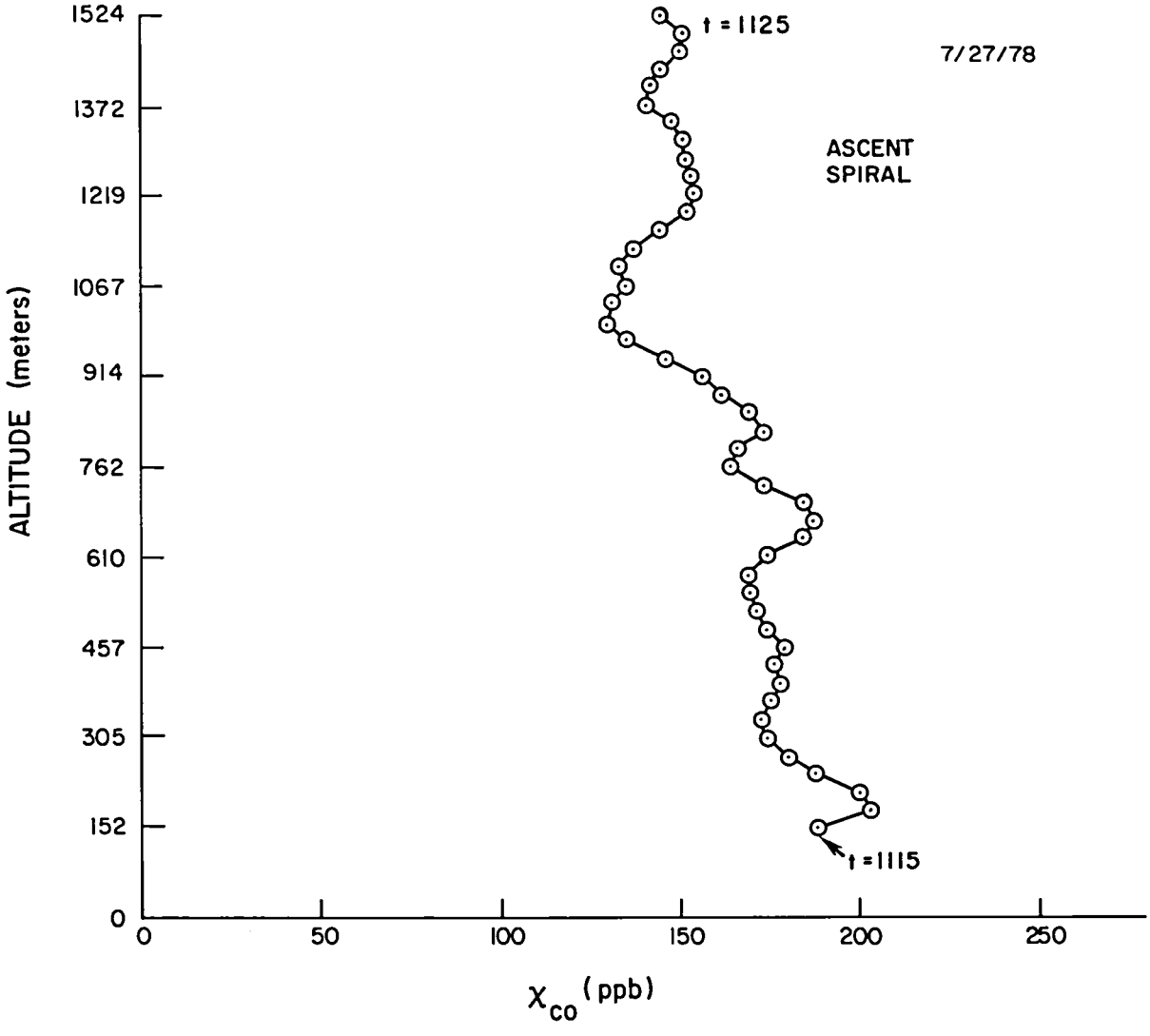

Figure 5.- CO concentration versus altitude over Deep Creek (point L).

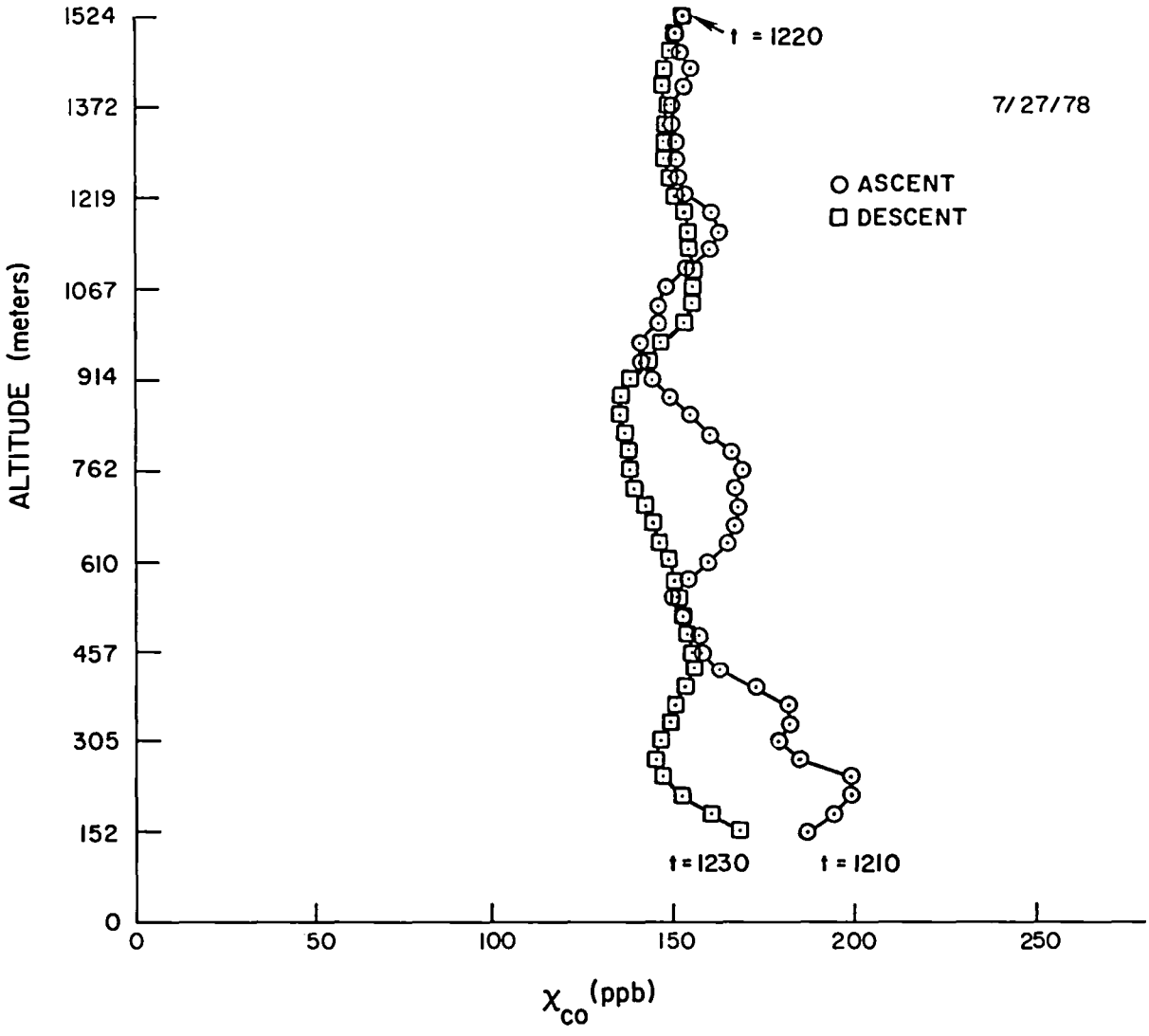

Figure 6.- CO concentration versus altitude over Wallops Flight Center (ascent and descent spirals) - early afternoon.

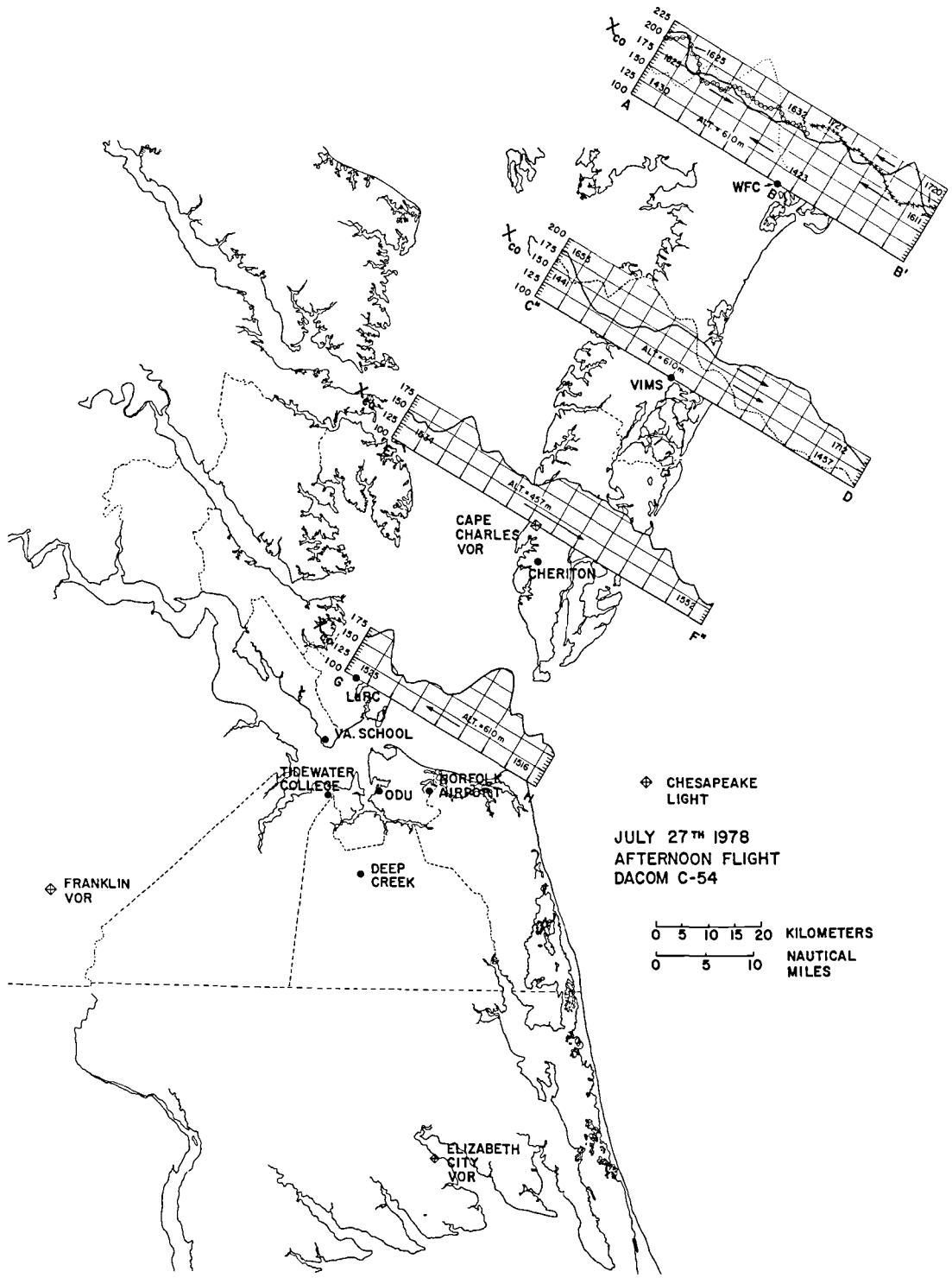

Figure 7.- CO concentration X_{CO} (in ppb) as a function of geographical location for afternoon flight, July 27, 1978. The starting and finishing times are indicated on each flight leg.

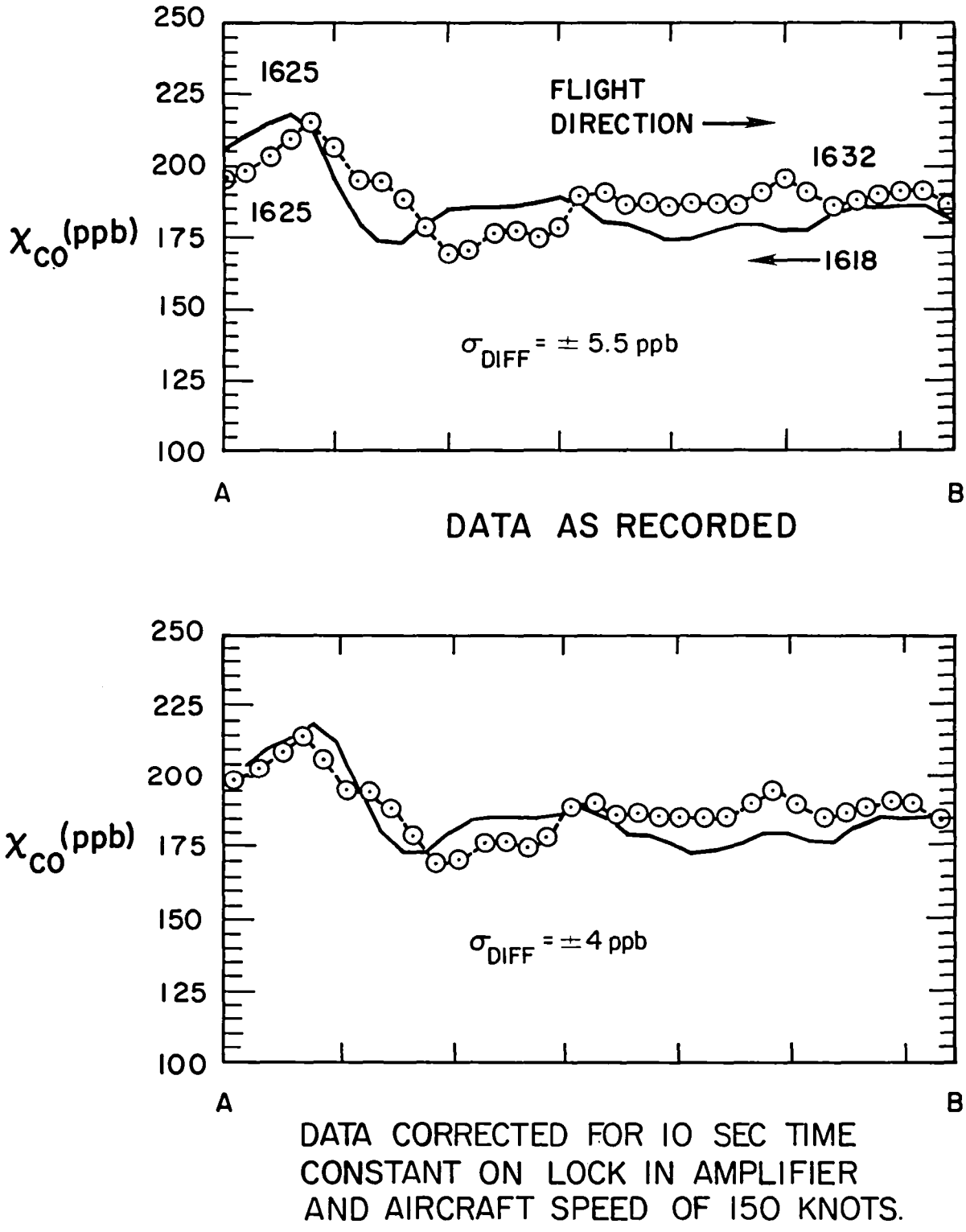

Figure 8.- CO-concentration repeatability measurements for flights between points A and B.

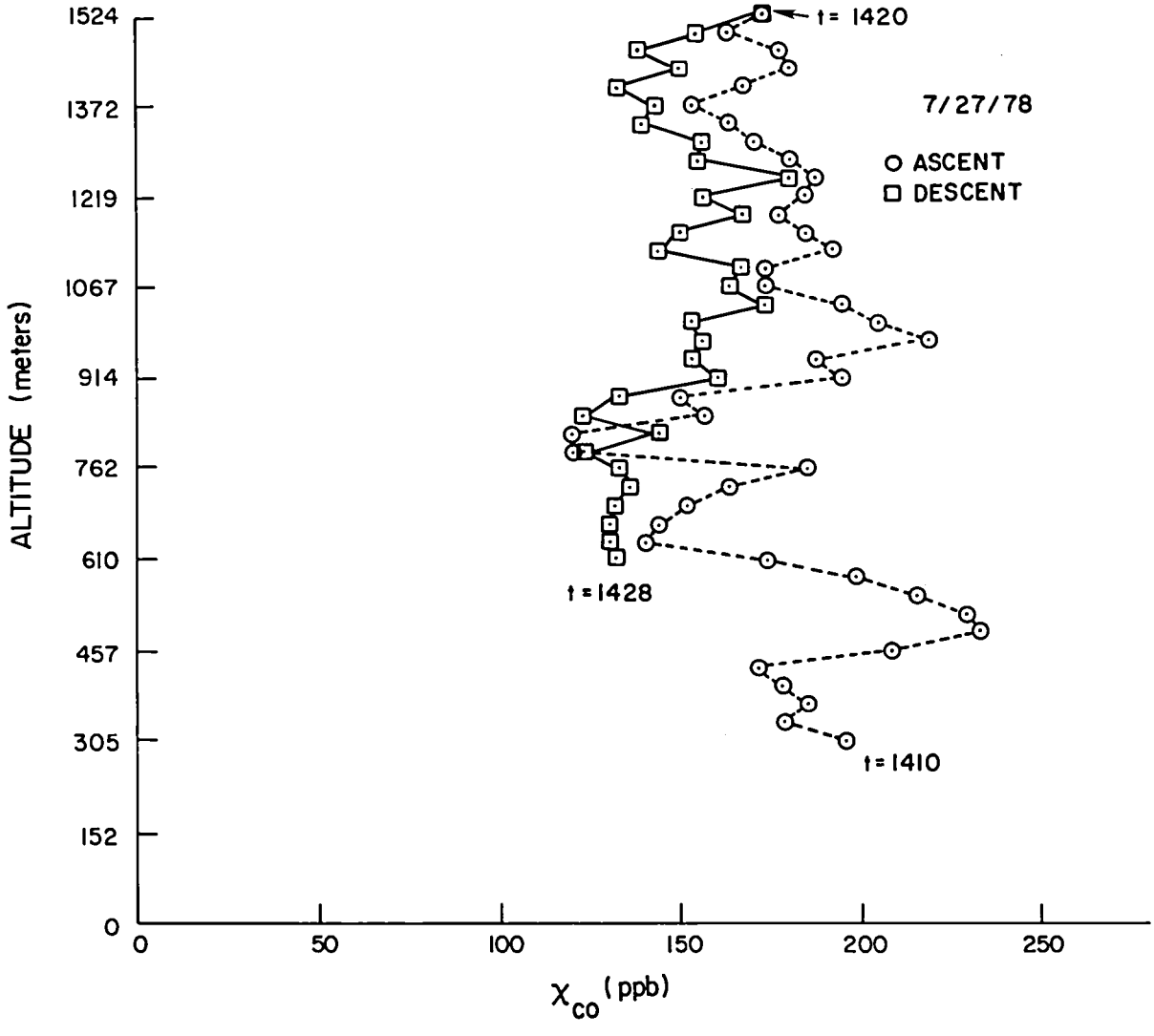

Figure 9.- CO concentration versus altitude over Wallops Flight Center (ascent and descent spirals) - midafternoon.

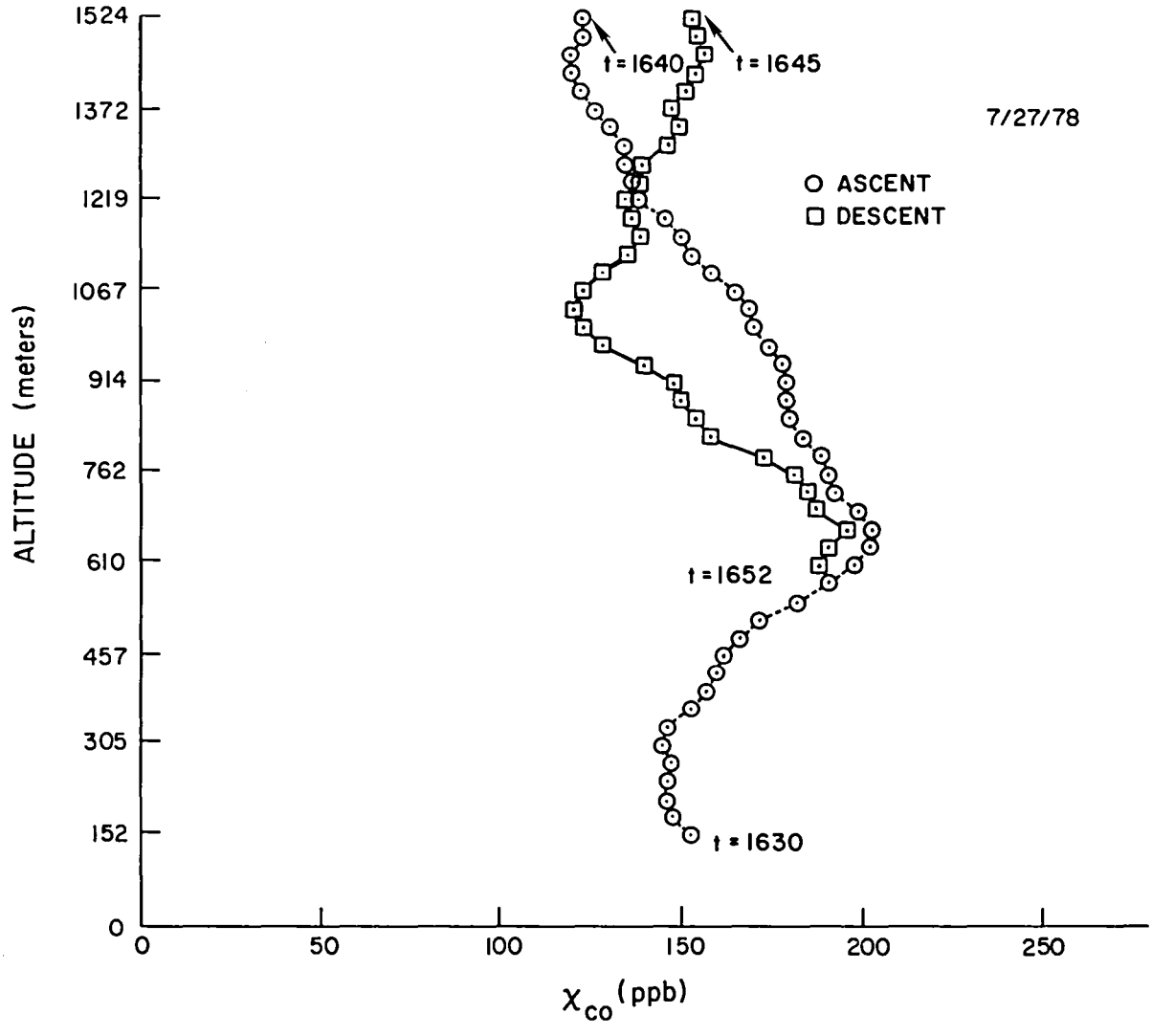

Figure 10.- CO concentration versus altitude over Wallops Flight Center (ascent and descent spirals) - late afternoon.

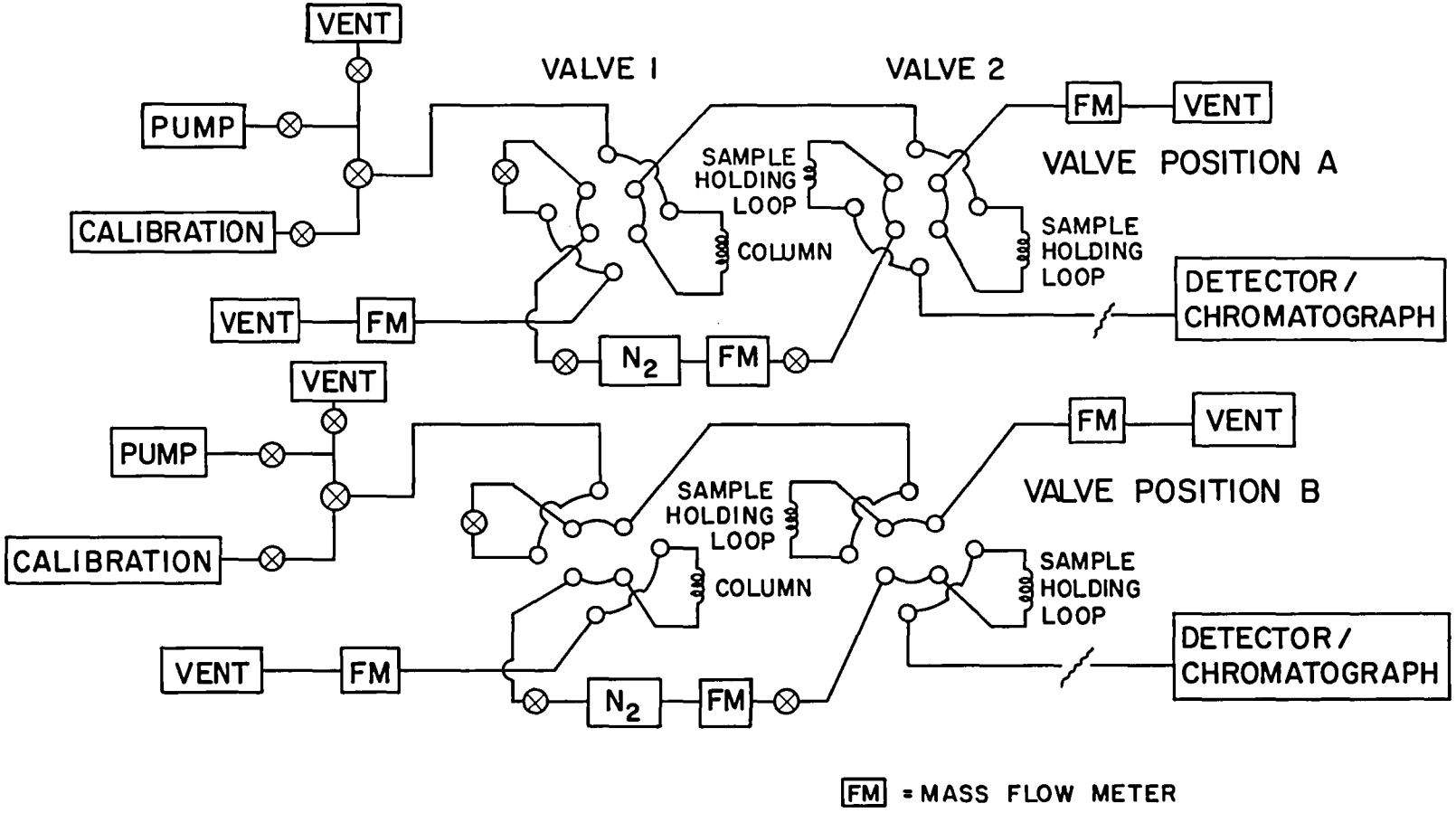

Figure 11.- Schematic of the valve-switching train for the hydrocarbon analyzer.

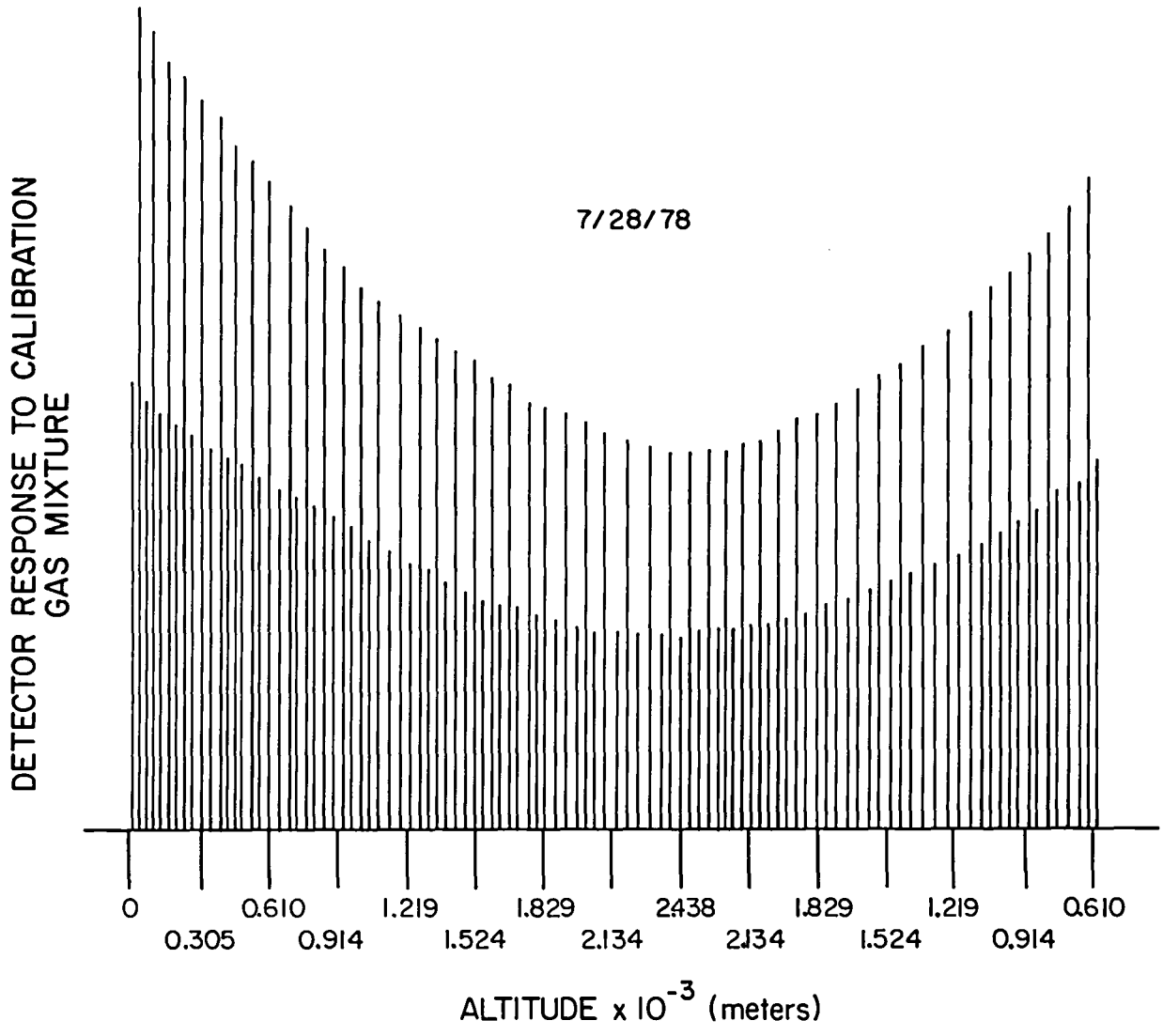

Figure 12.- Detector response for calibration gas versus altitude.

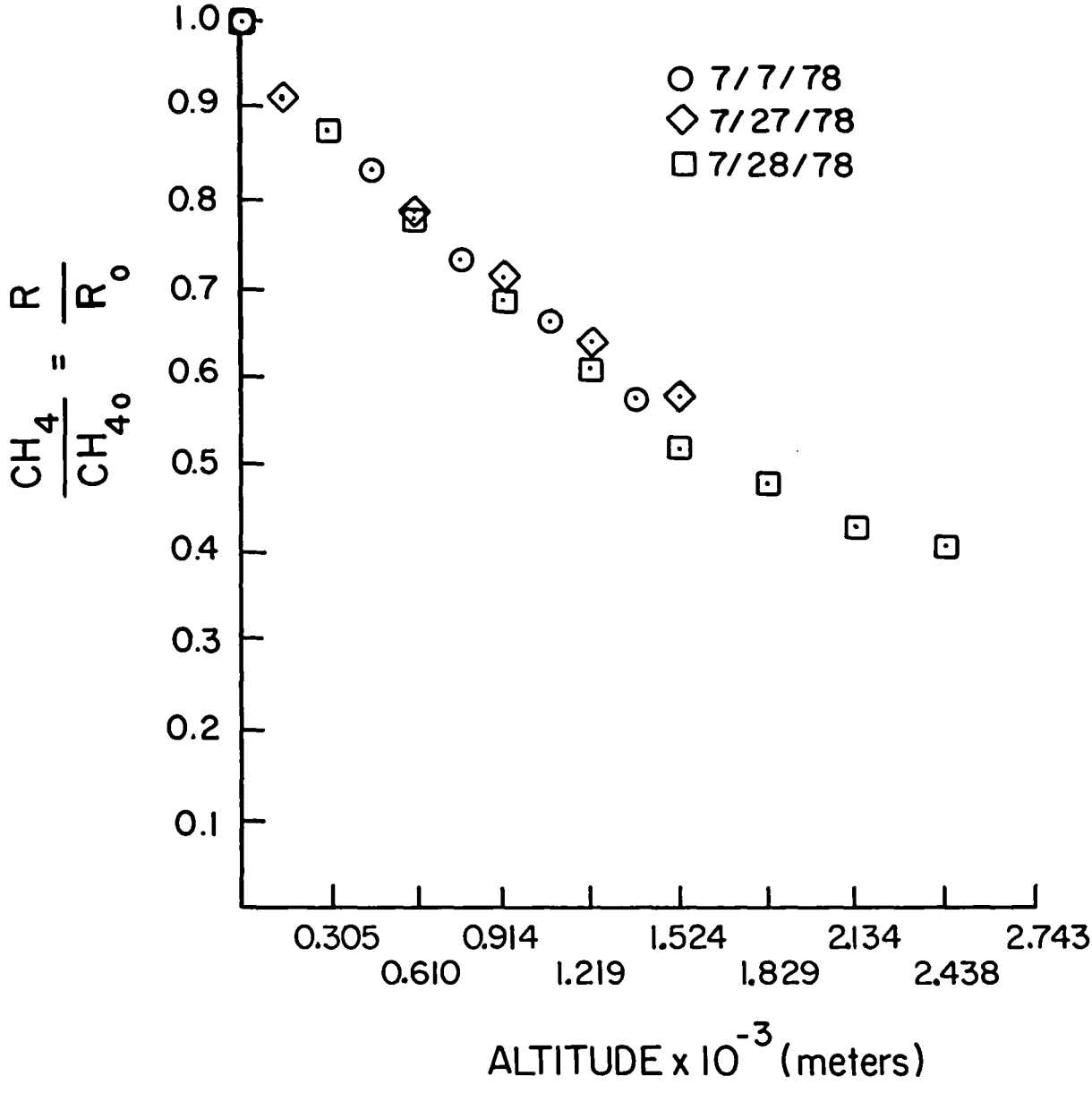

Figure 13.- Relative response versus altitude for three independent measurements.

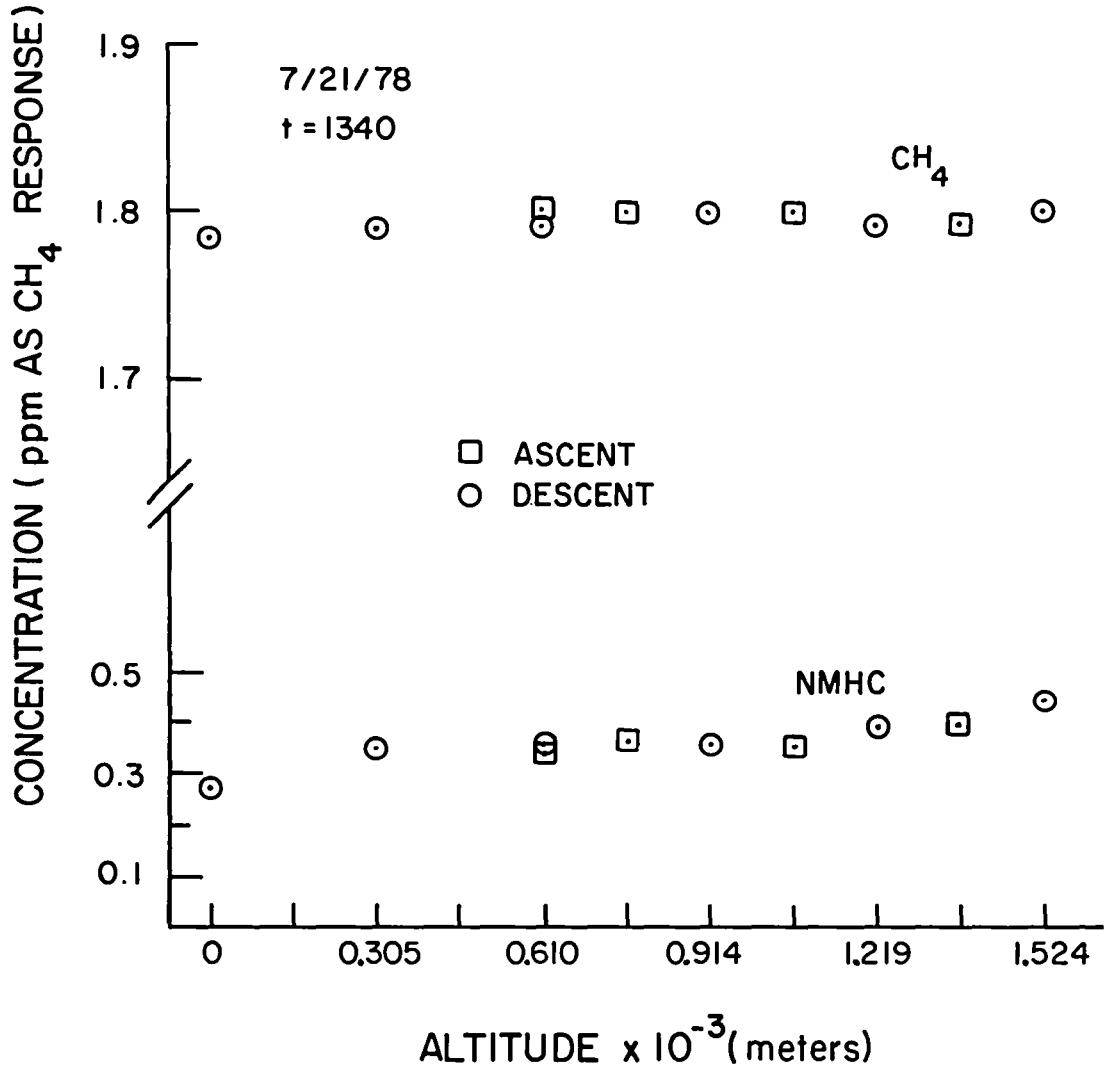

Figure 14.- Hydrocarbon concentration versus altitude over Wallops Flight Center at t = 1340.

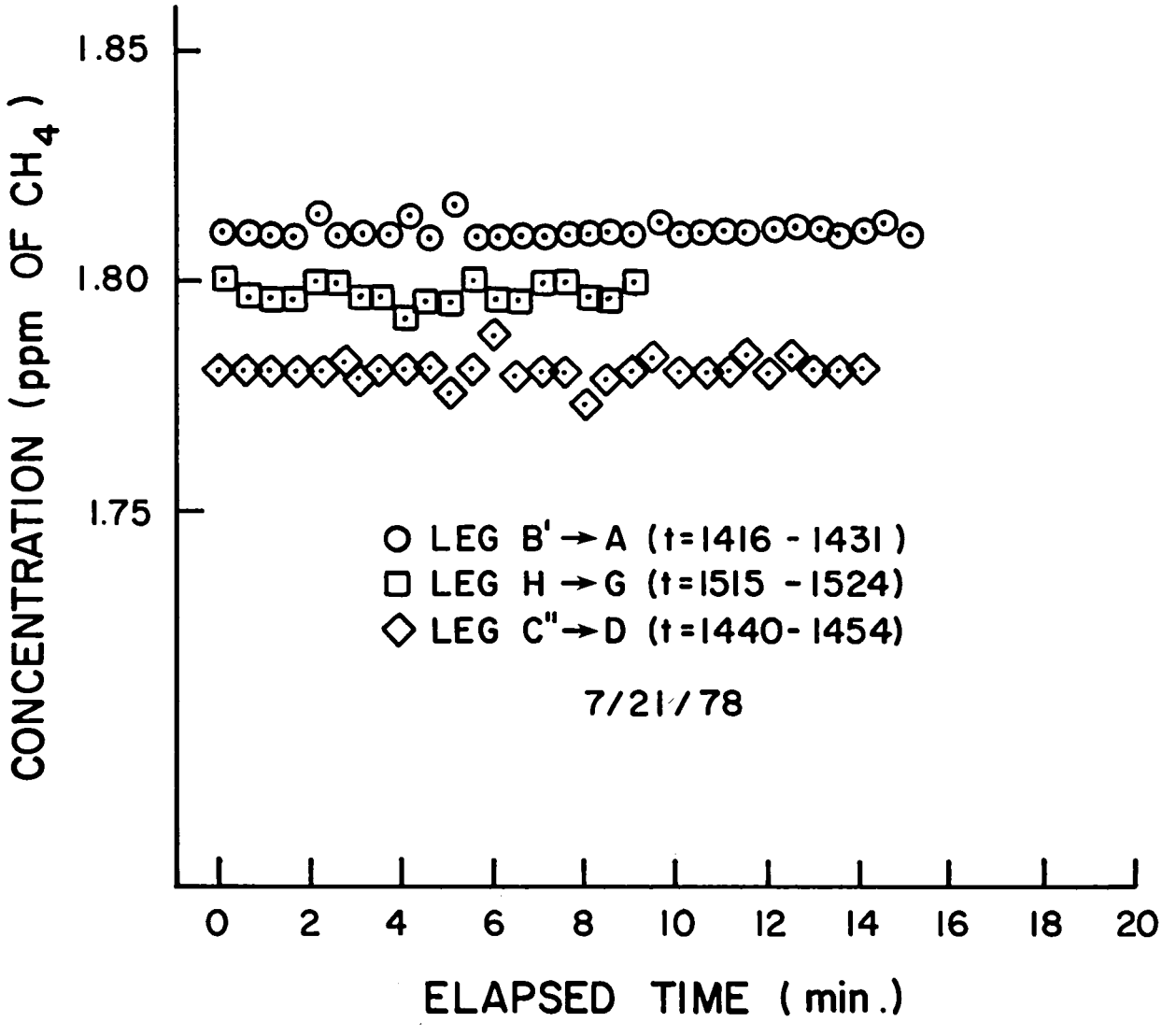

Figure 15.- Methane concentration versus relative location along flight path for afternoon flight for legs B'→A, H→G, and C"→D. (All legs flown at altitude of 610 m.)

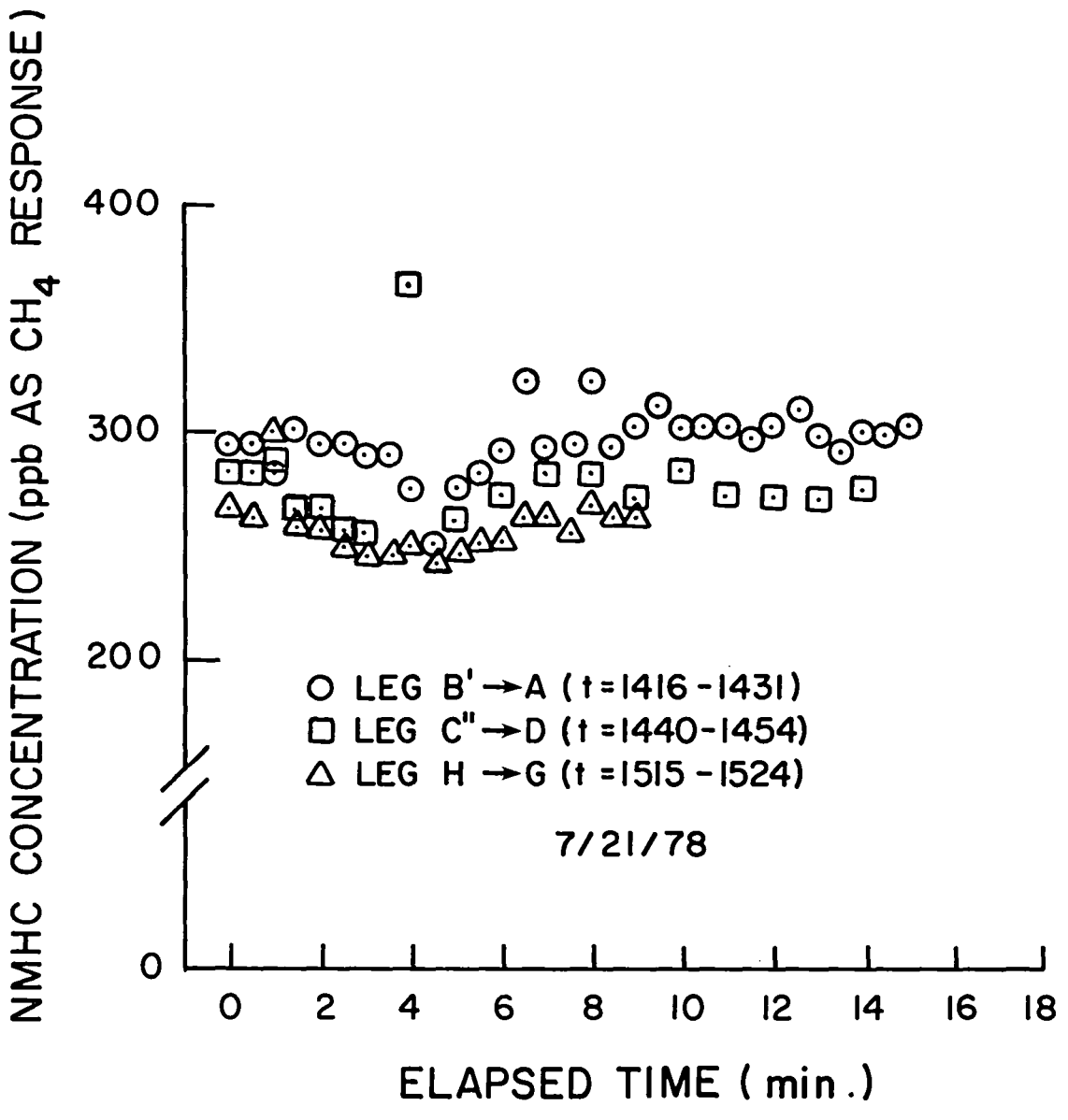

Figure 16.- Nonmethane hydrocarbon concentration versus relative location along flight path for afternoon flight for legs B'→A, C"→D, and H→G. (All legs flown at altitude of 610 m.)

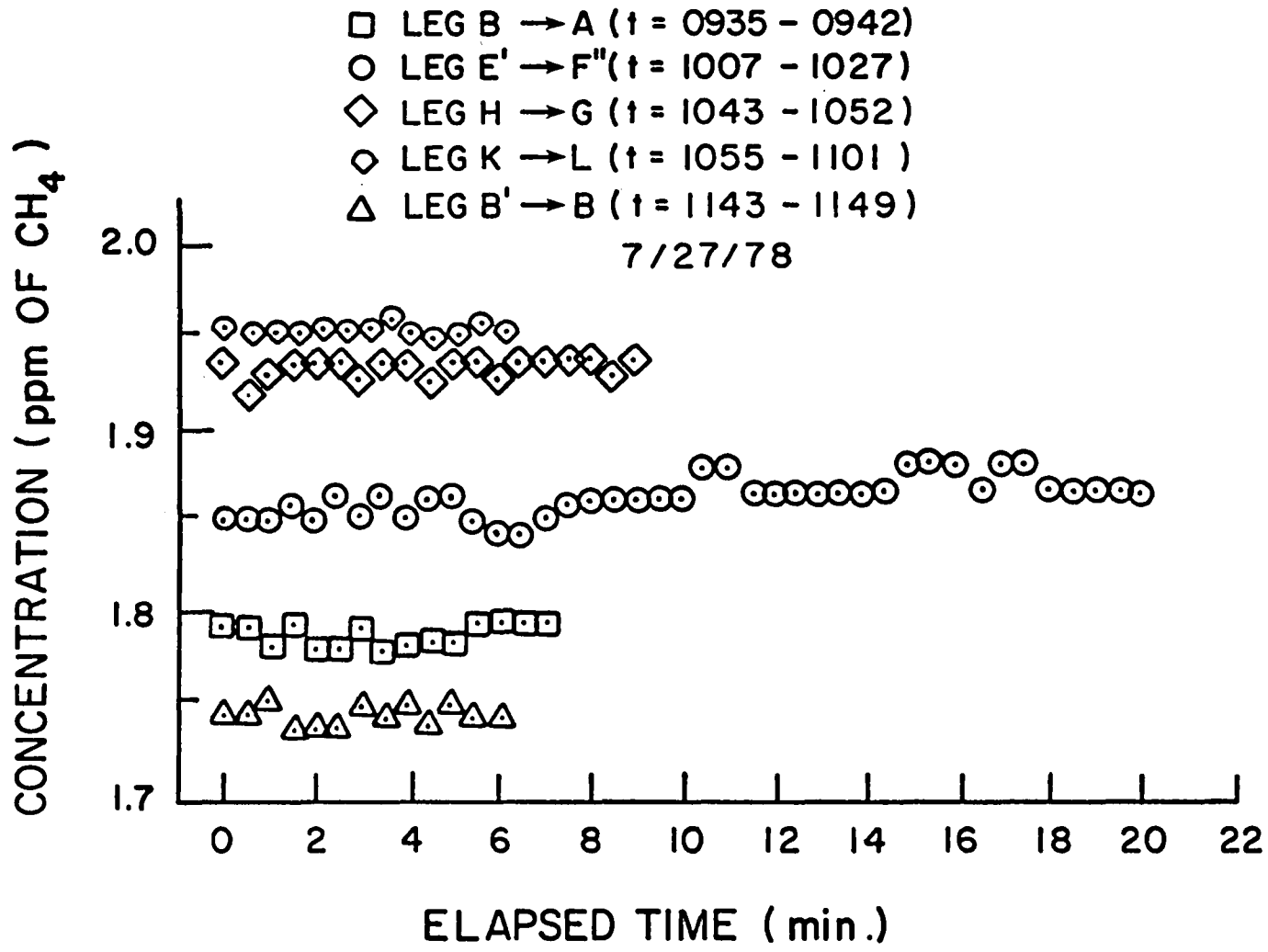

Figure 17.- Methane concentration versus relative location along flight path for morning flight. (Leg E'→F" flown at altitude of 457 m; all others flown at 610 m.)

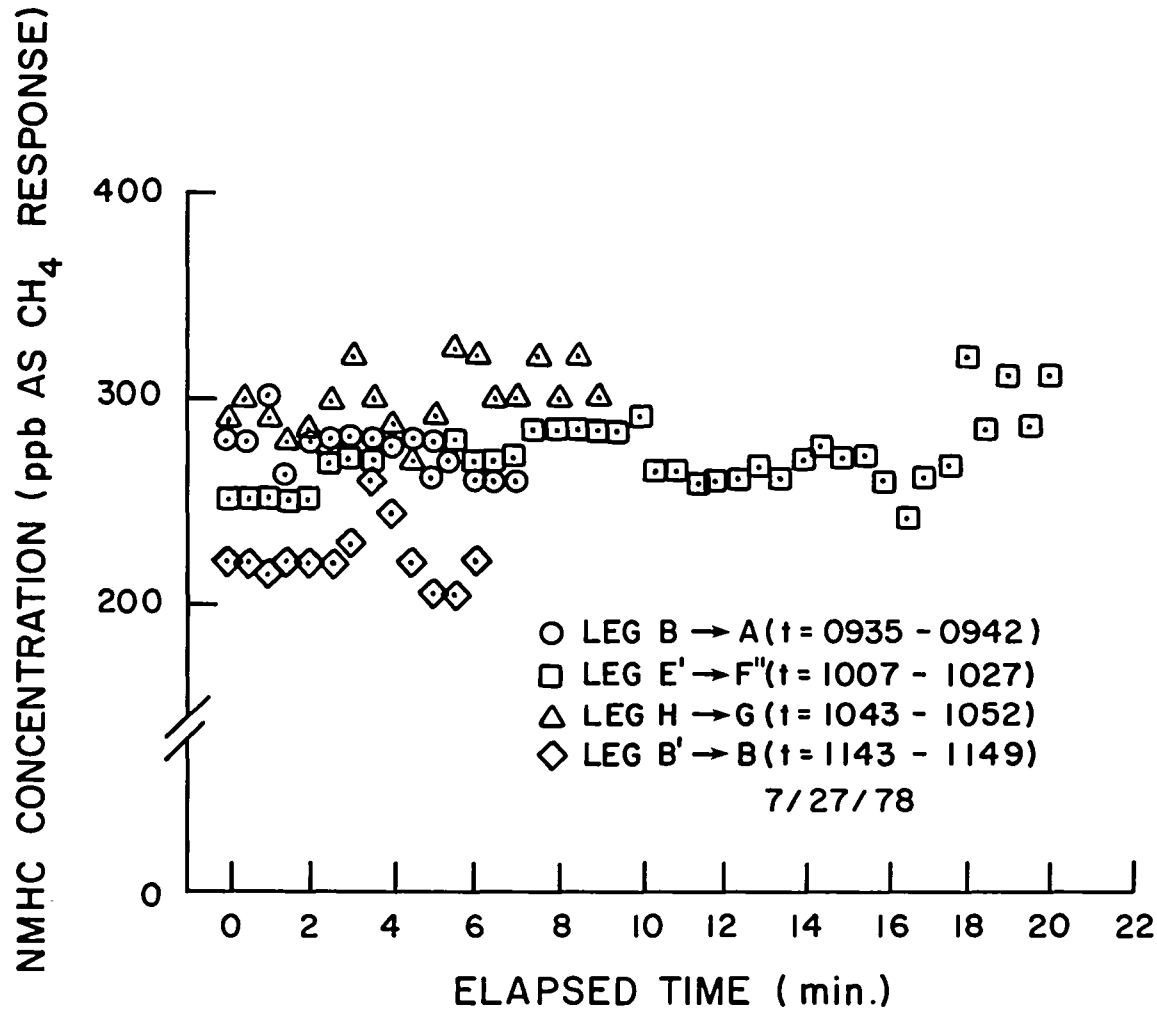

Figure 18.- Nonmethane hydrocarbon concentration versus relative location along flight path for morning flight. (Leg E'→F" flown at altitude of 457 m; all others flown at 610 m.)

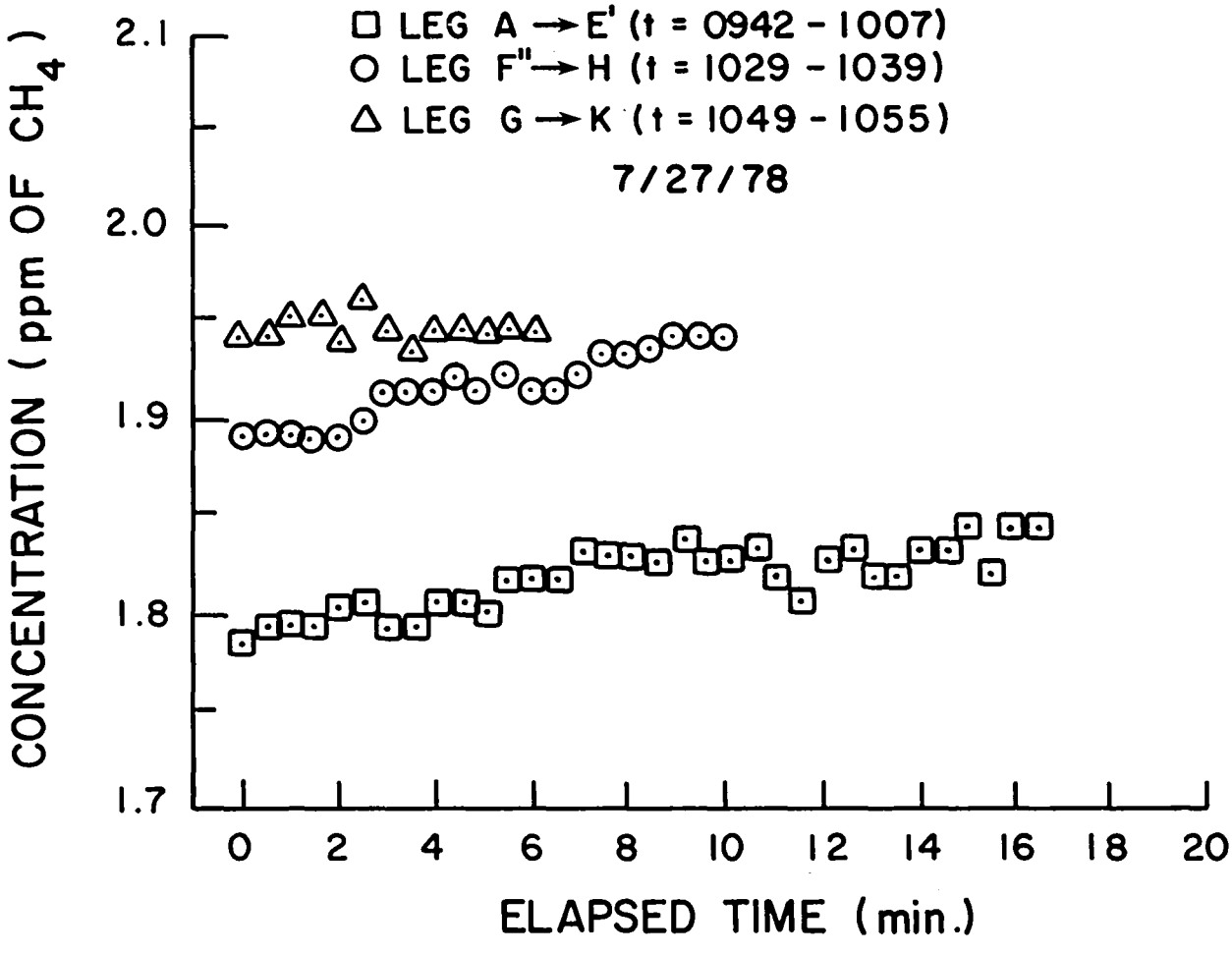

Figure 19.- Methane concentration versus relative location along flight path for morning flight. (All legs flown at altitude of 610 m.)

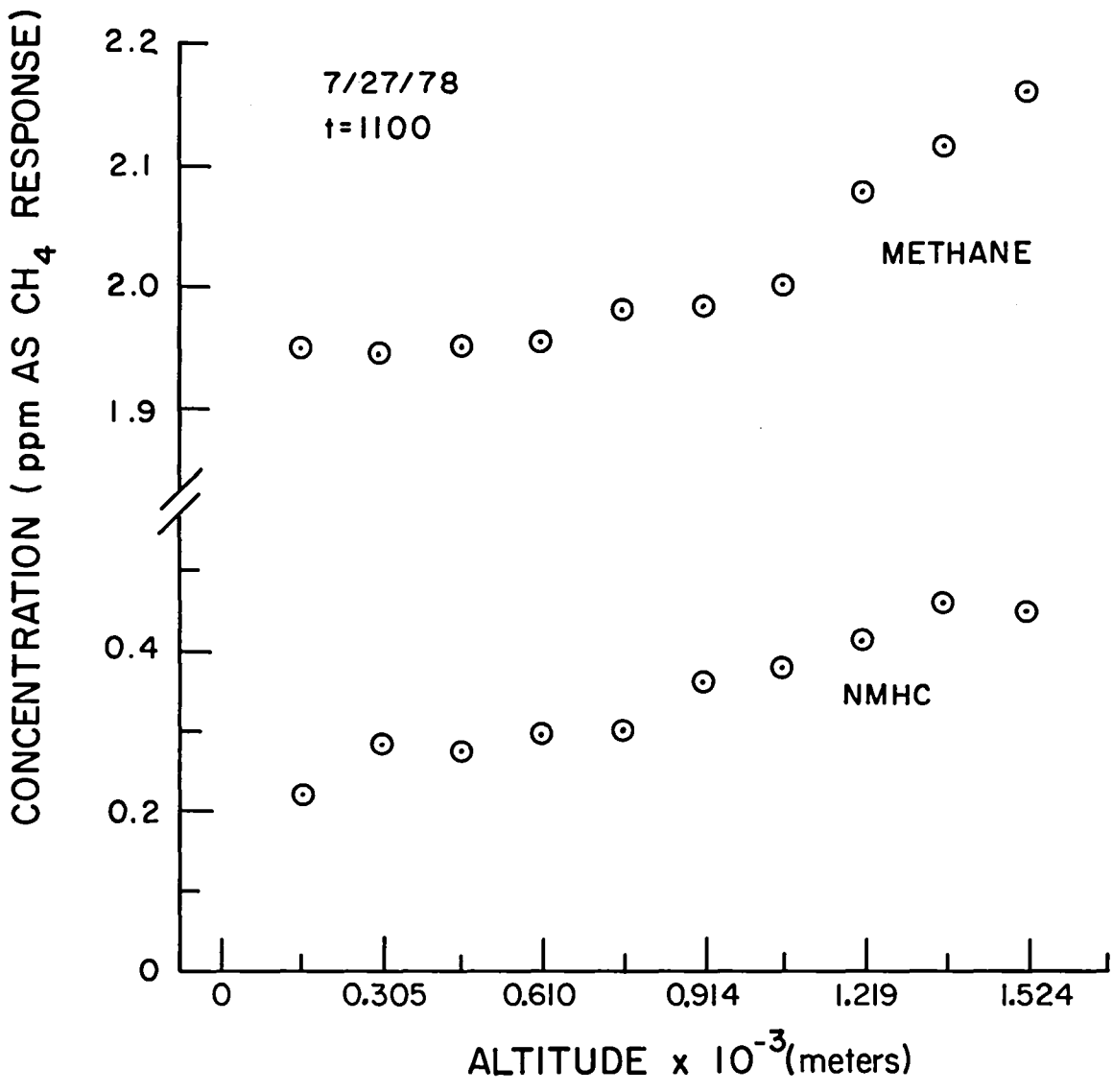

Figure 20.- Hydrocarbon concentration versus altitude over Deep Creek (point L).

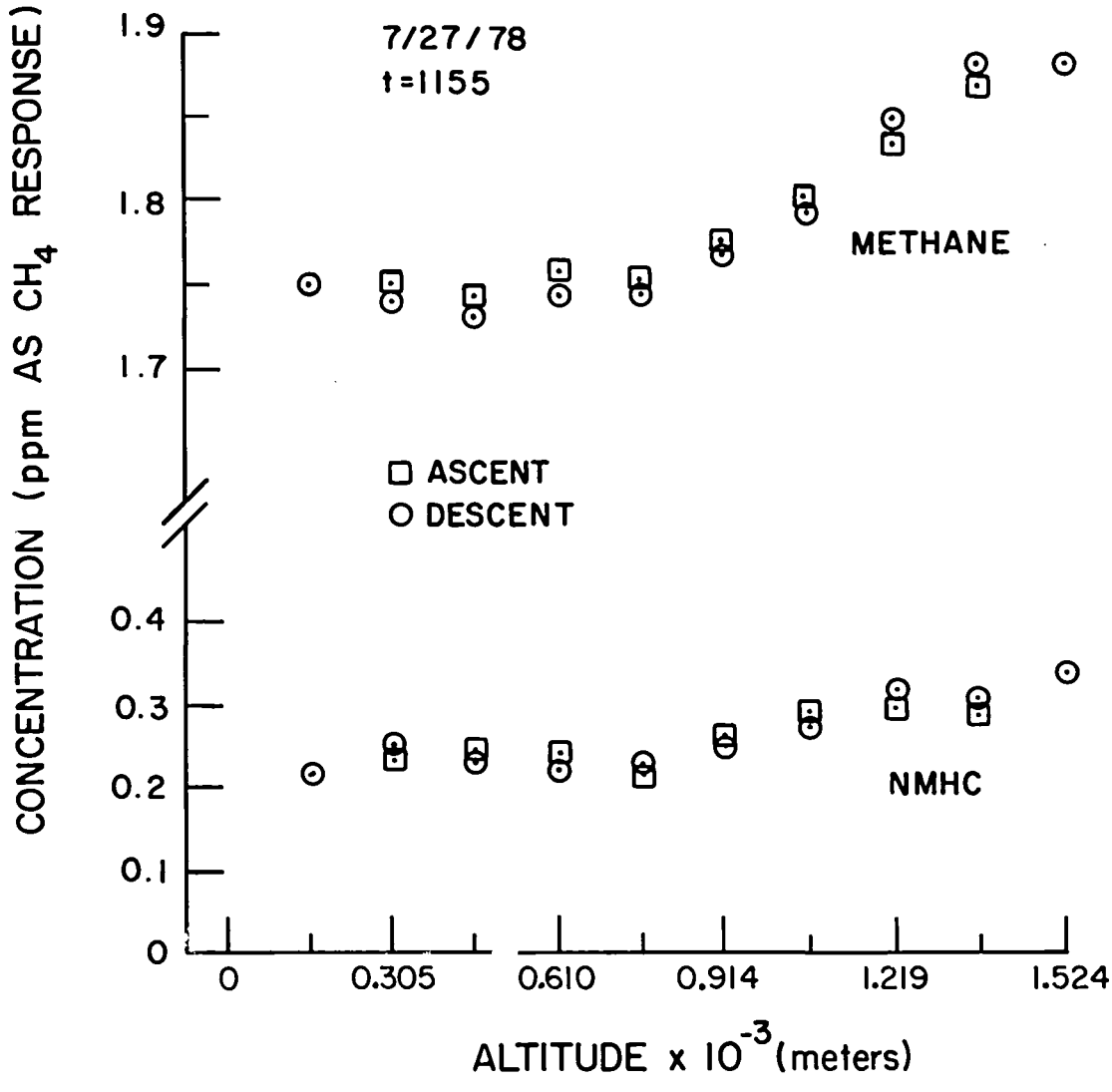

Figure 21.- Hydrocarbon concentration versus altitude over Wallops Flight Center at t = 1155.

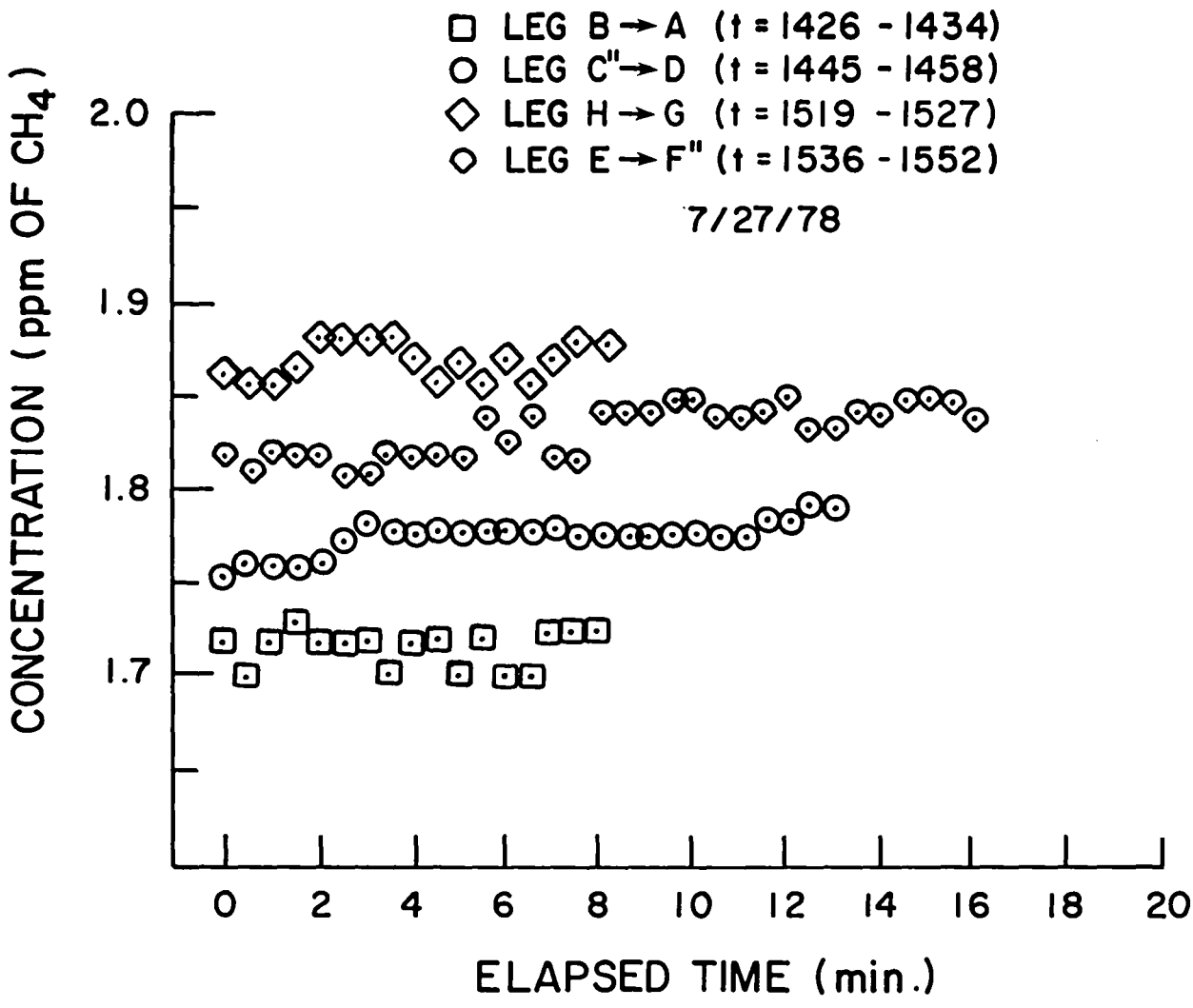

Figure 22.- Methane concentration versus relative location along flight path for afternoon flight for legs B→A, C"→D, H→G, and E→F". (Leg E→F" flown at altitude of 457 m; all others flown at 610 m.)

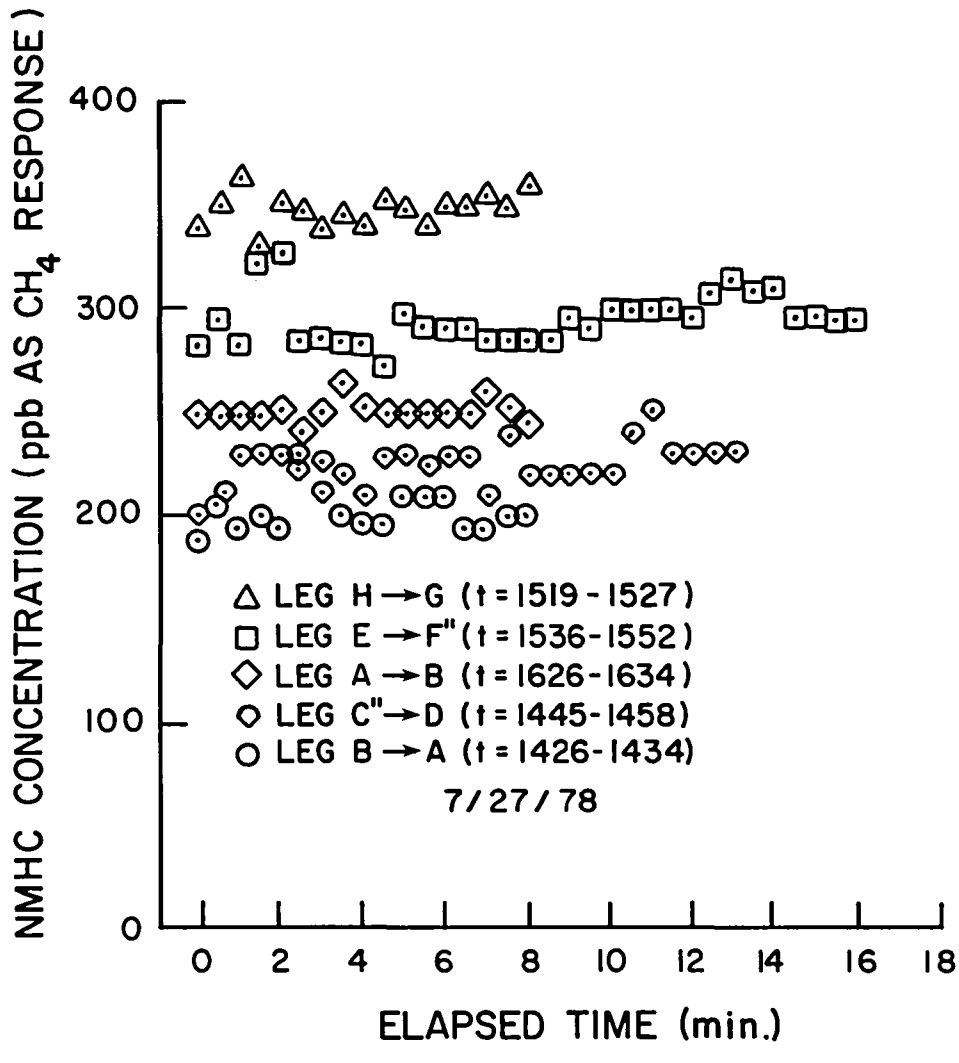

Figure 23.- Nonmethane hydrocarbon concentration versus relative location along flight path for afternoon flight for legs H→G, E→F", A→B, C"→D, and B→A. (Leg E→F" flown at altitude of 457 m; all others flown at 610 m.)

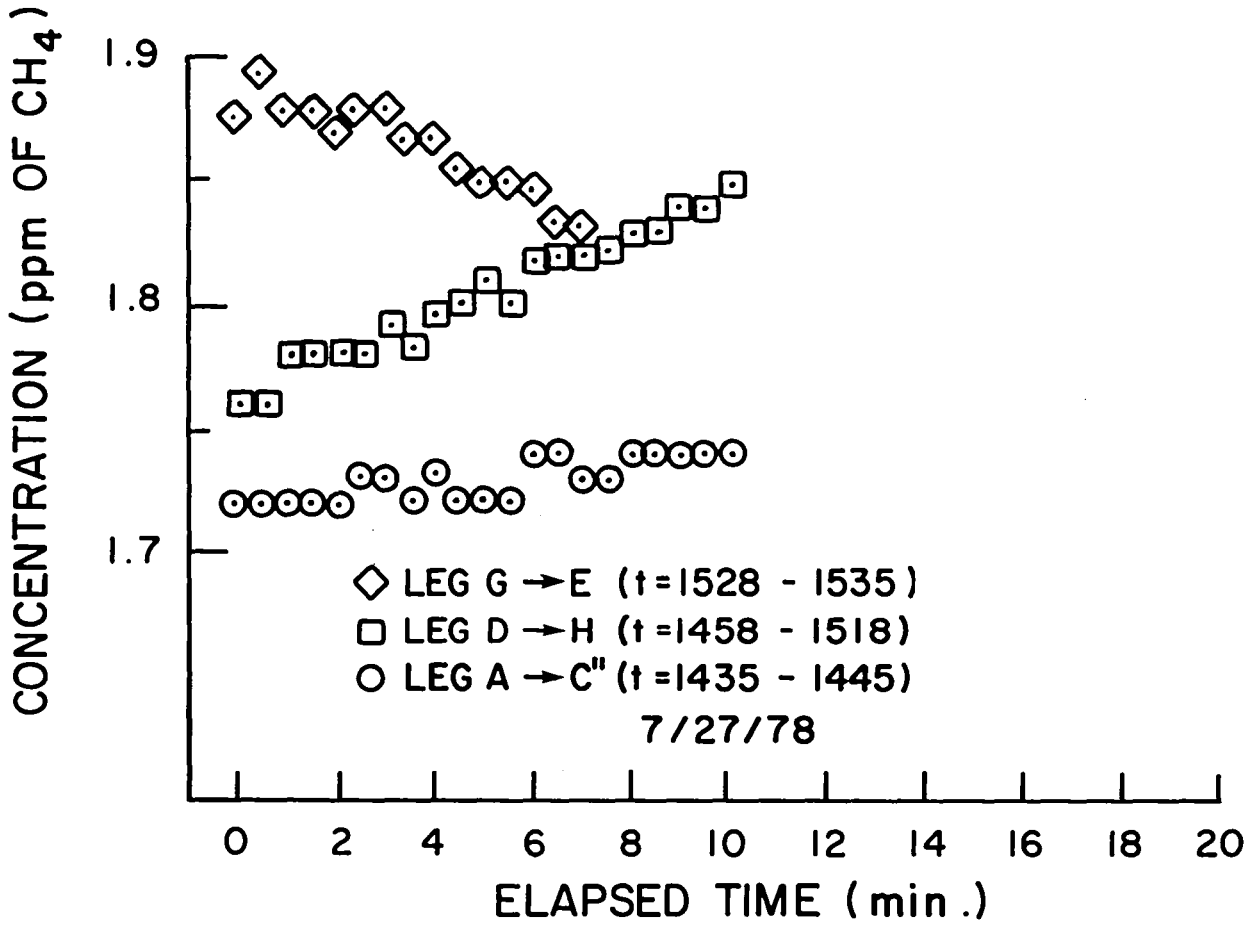

Figure 24.- Methane concentration versus relative location along flight path for afternoon flight for legs G→E, D→H, and A→C". (Leg G→E flown at altitude of 457 m; all others flown at 610 m.)

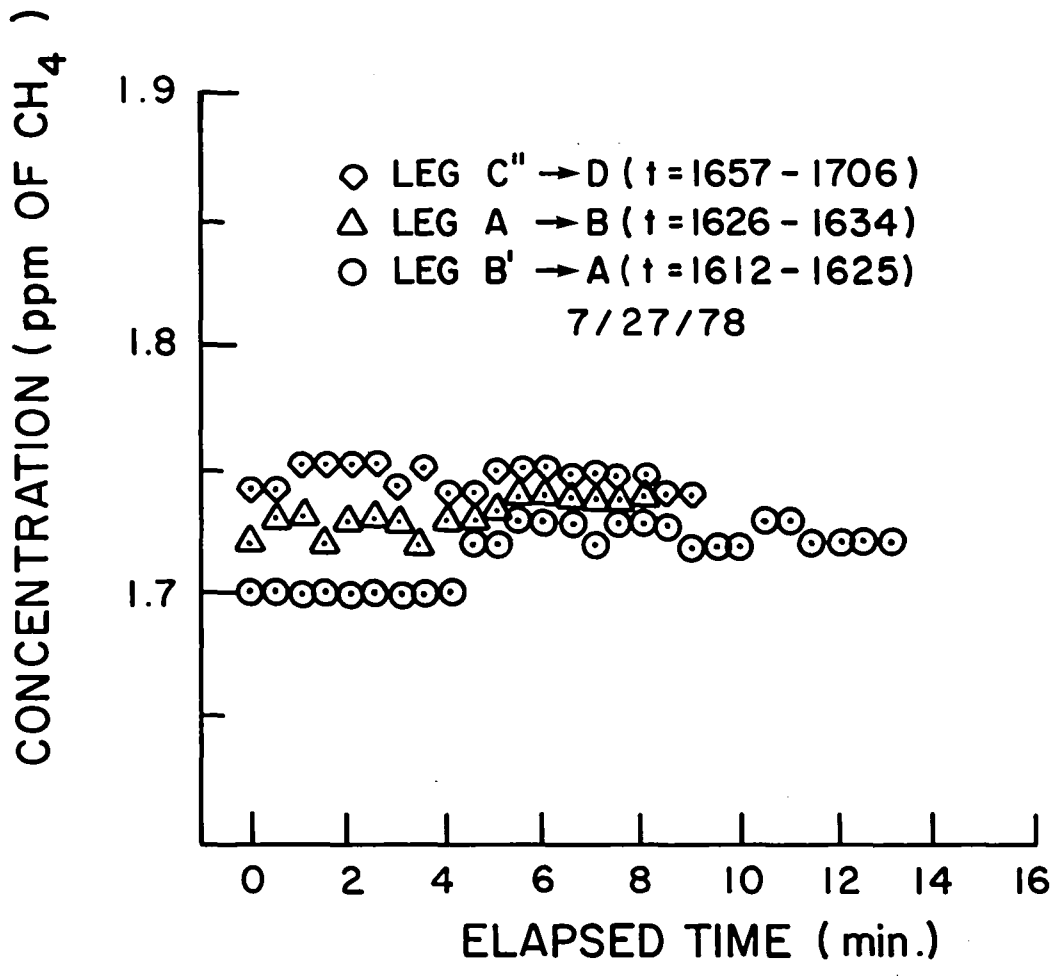

Figure 25.- Methane concentration versus relative location along flight path for afternoon flight for legs C"→D, A→B, and B'→A. (All legs flown at altitude of 610 m.)

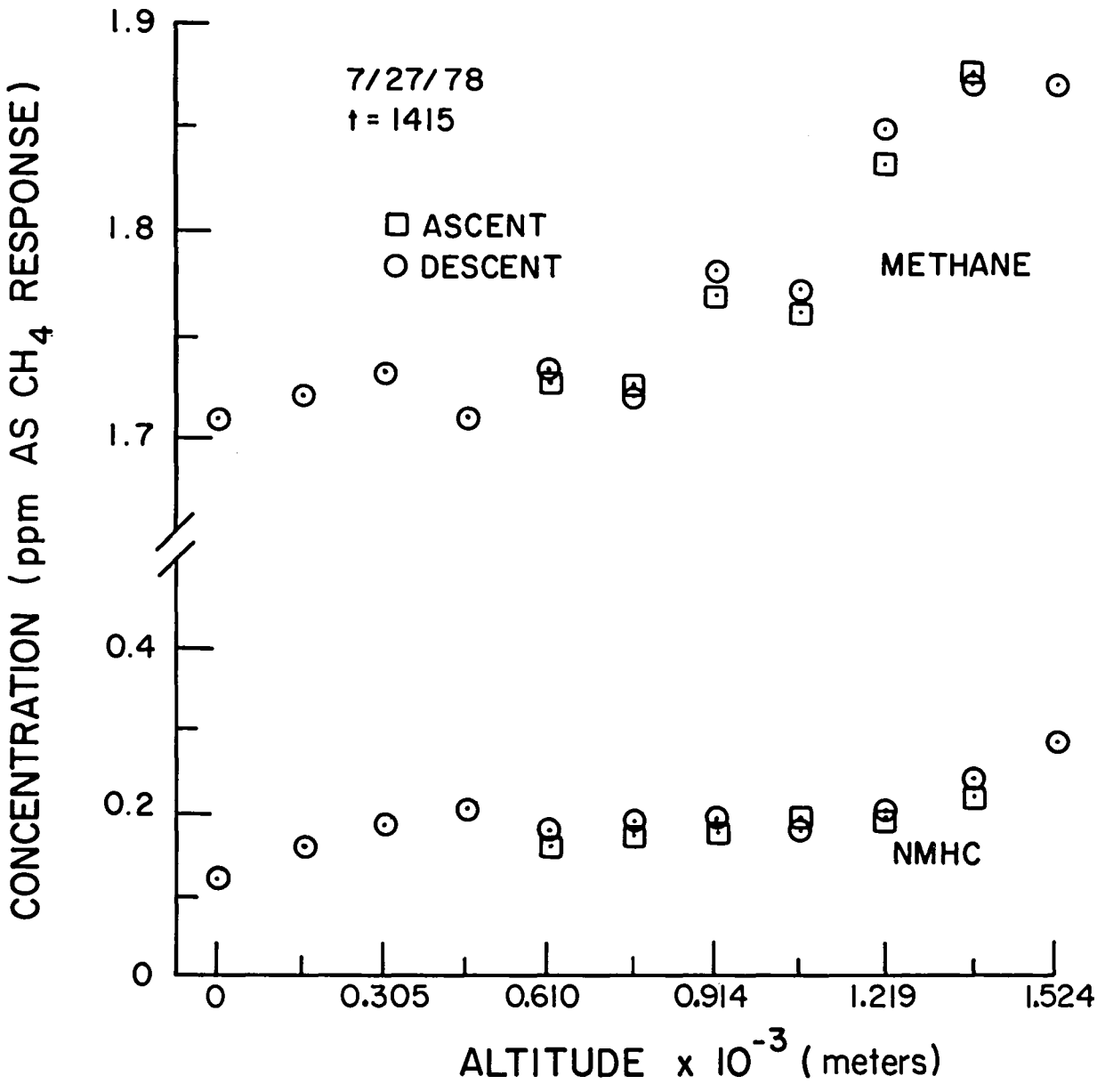

Figure 26.- Hydrocarbon concentration versus altitude over Wallops Flight Center at t = 1415.

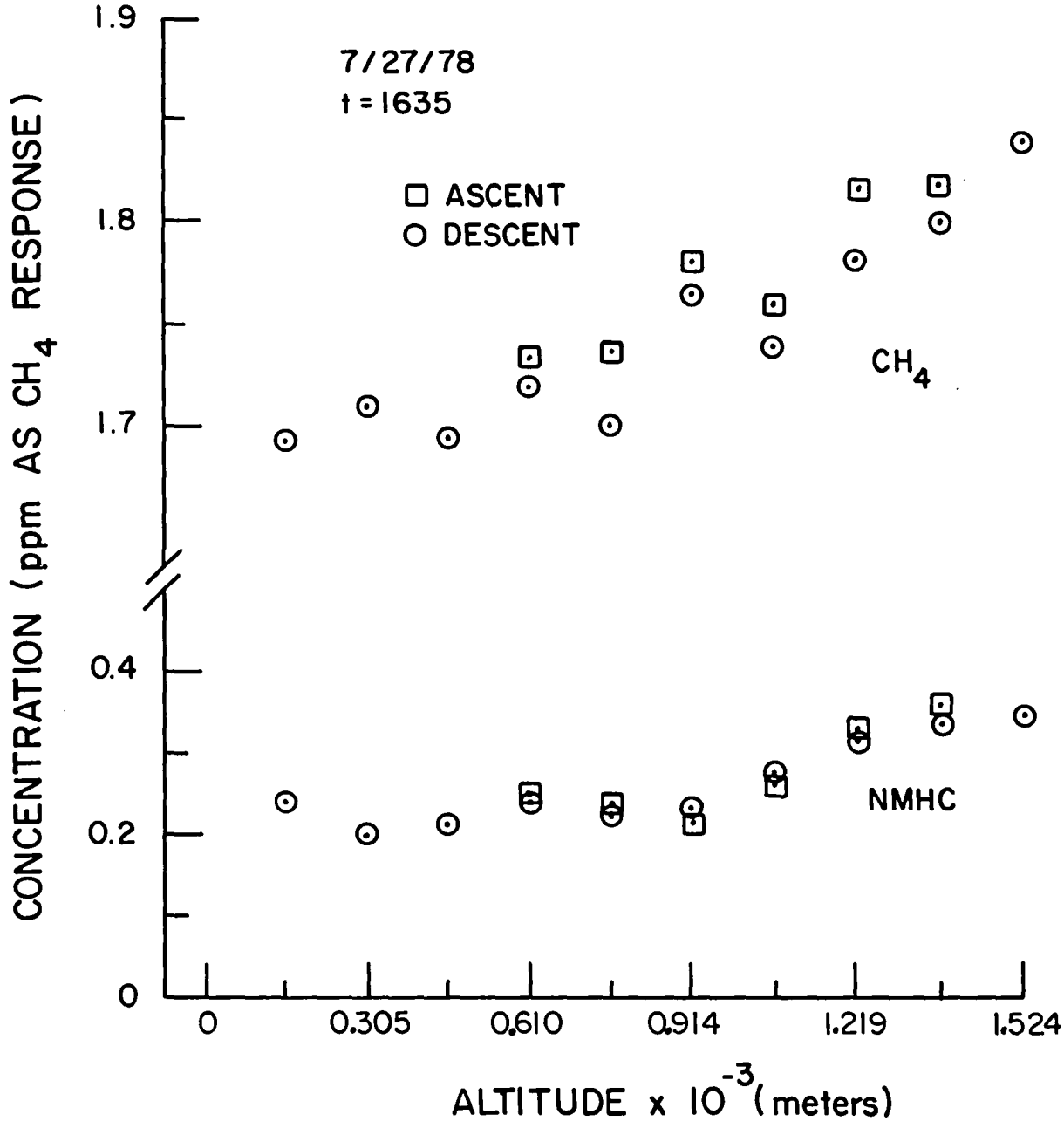

Figure 27.- Hydrocarbon concentration versus altitude over Wallops Flight Center at t = 1635.

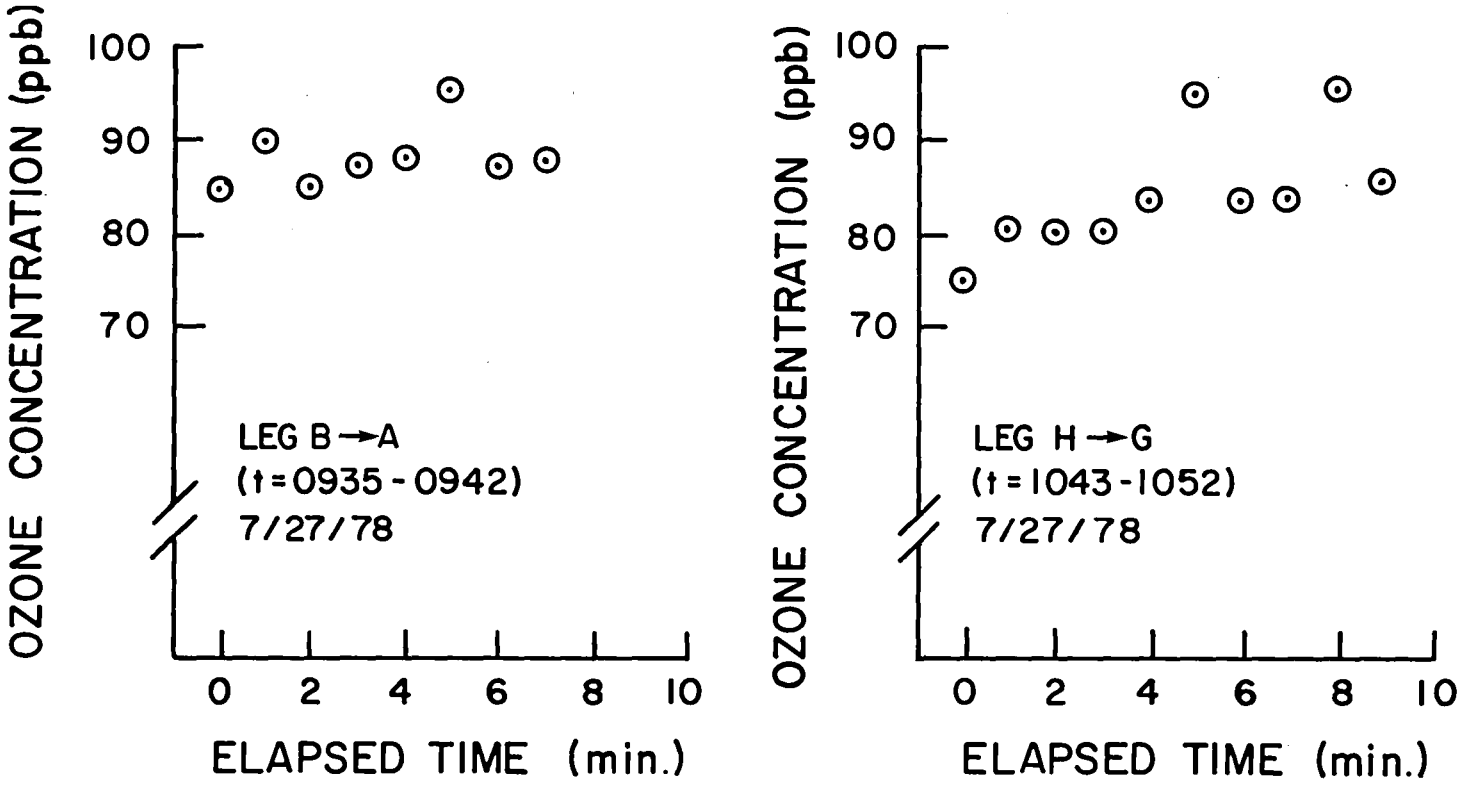

Figure 28.- Ozone concentration versus relative location along flight path for morning flight for legs B→A and H→G. (Altitude, 610 m.)

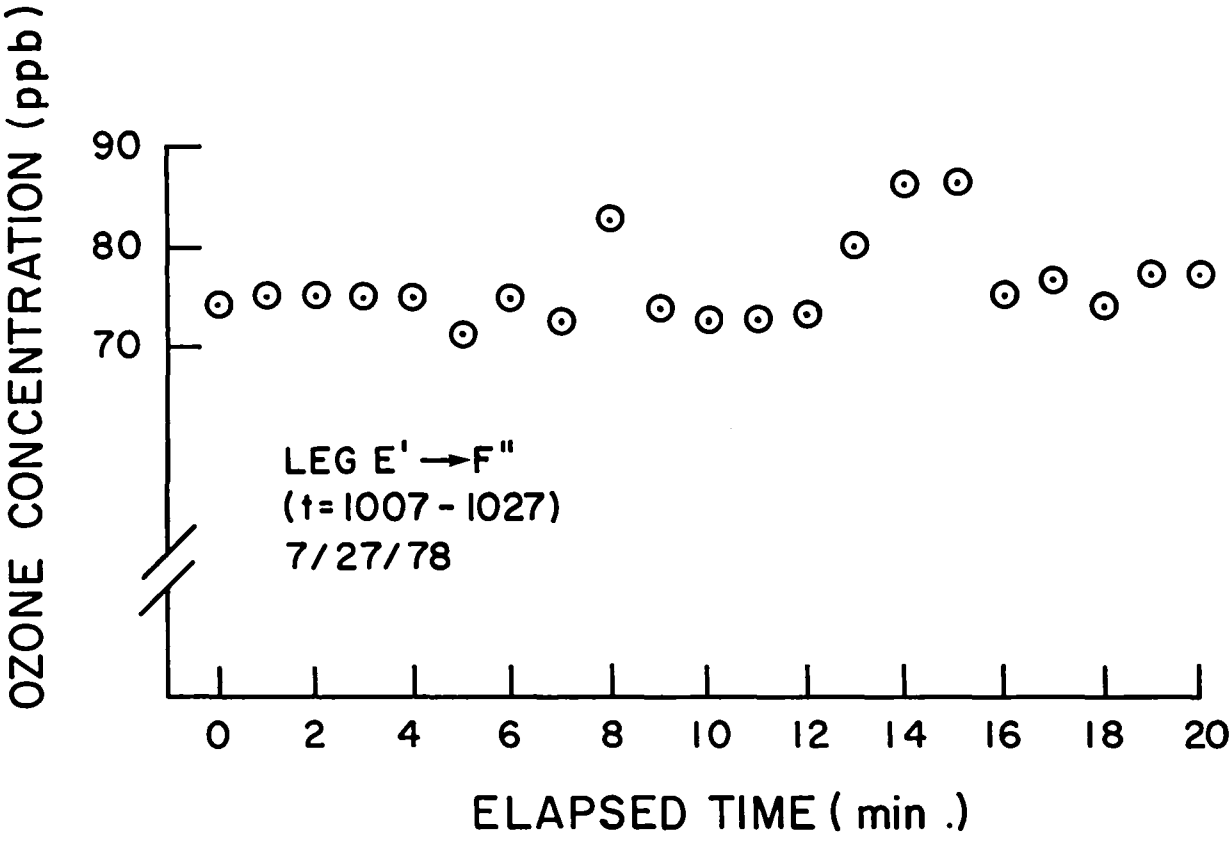

Figure 29.- Ozone concentration versus relative location along flight path for morning flight for leg E'→F". (Altitude, 457 m.)

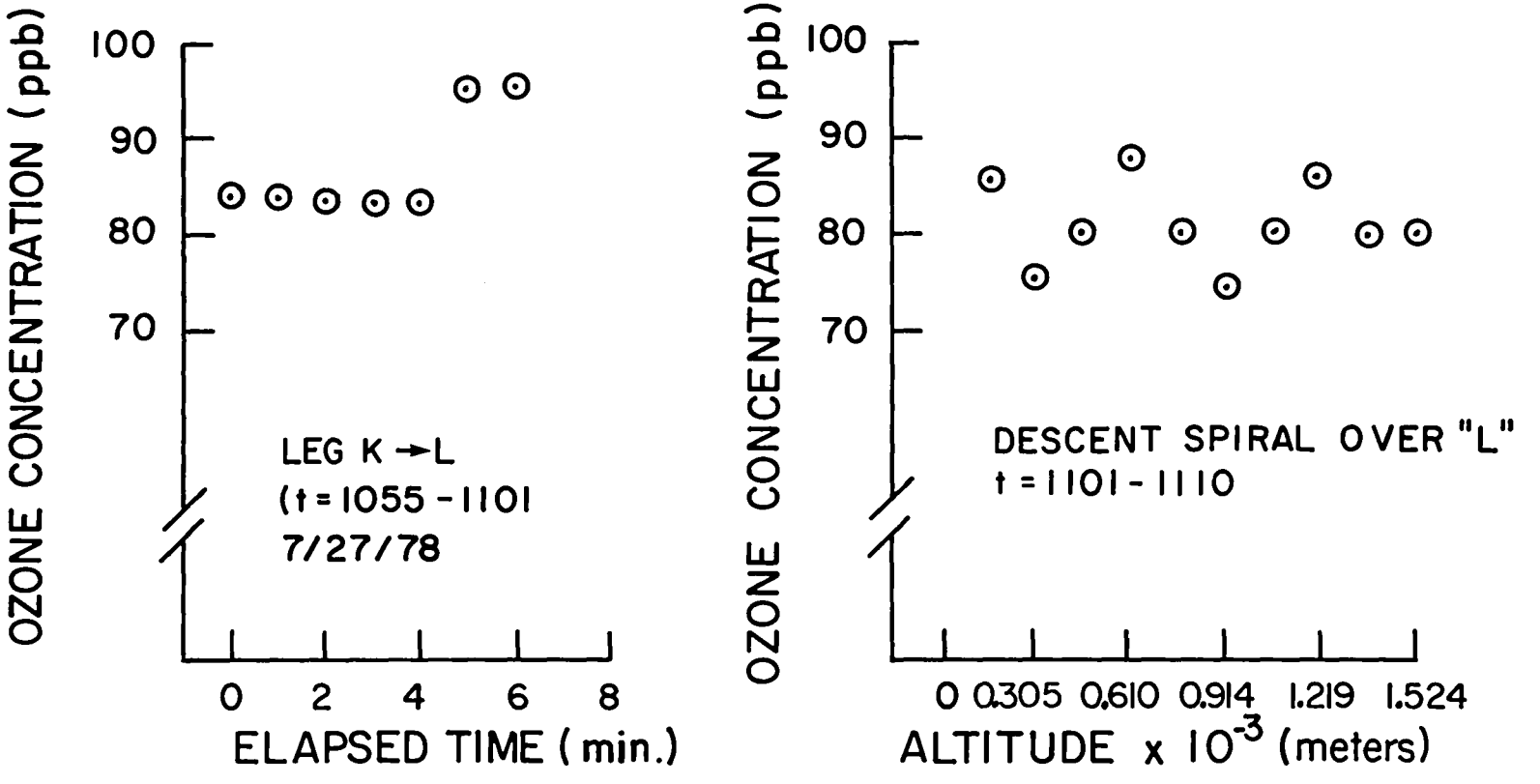

Figure 30.- Ozone concentration versus relative location along flight path K-L and versus altitude over Deep Creek (point L). (Altitude, 610 m.)

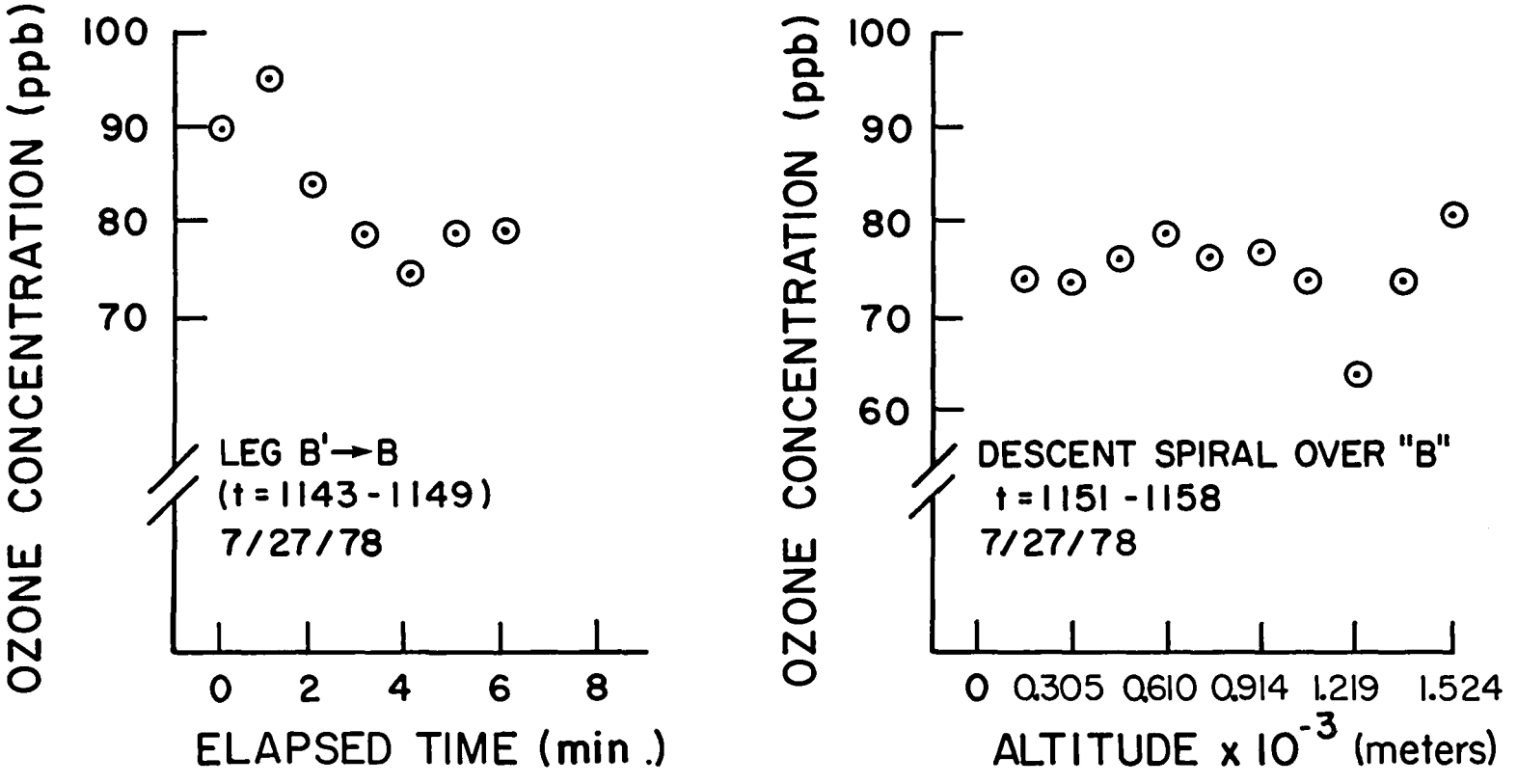

Figure 31.- Ozone concentration versus relative location along flight path (leg B'→B) and versus altitude over Wallops Flight Center. (Altitude, 610 m.)

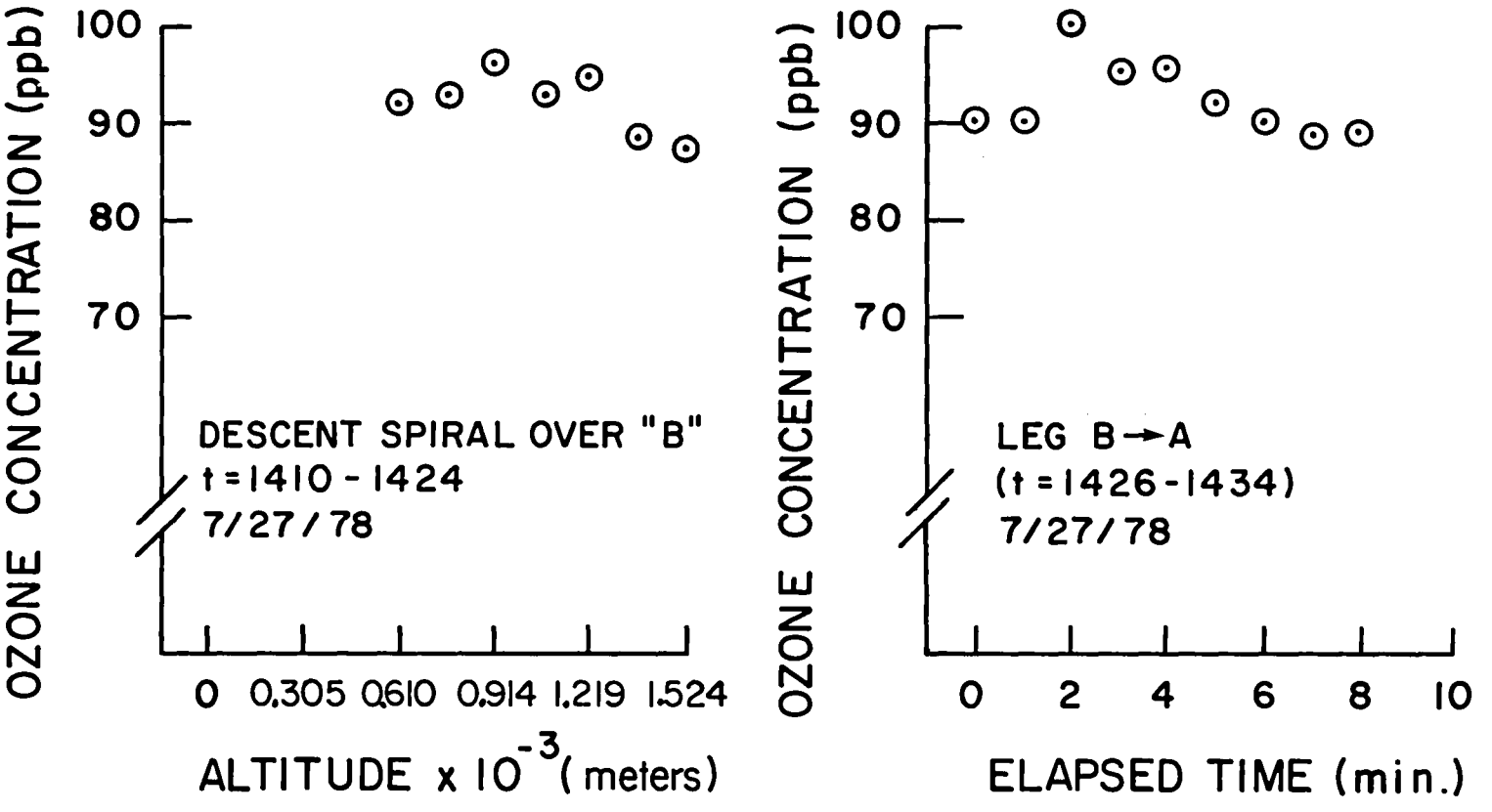

Figure 32.- Ozone concentration versus altitude over Wallops Flight Center and versus relative location along flight path (leg B→A). (Altitude, 610 m.)

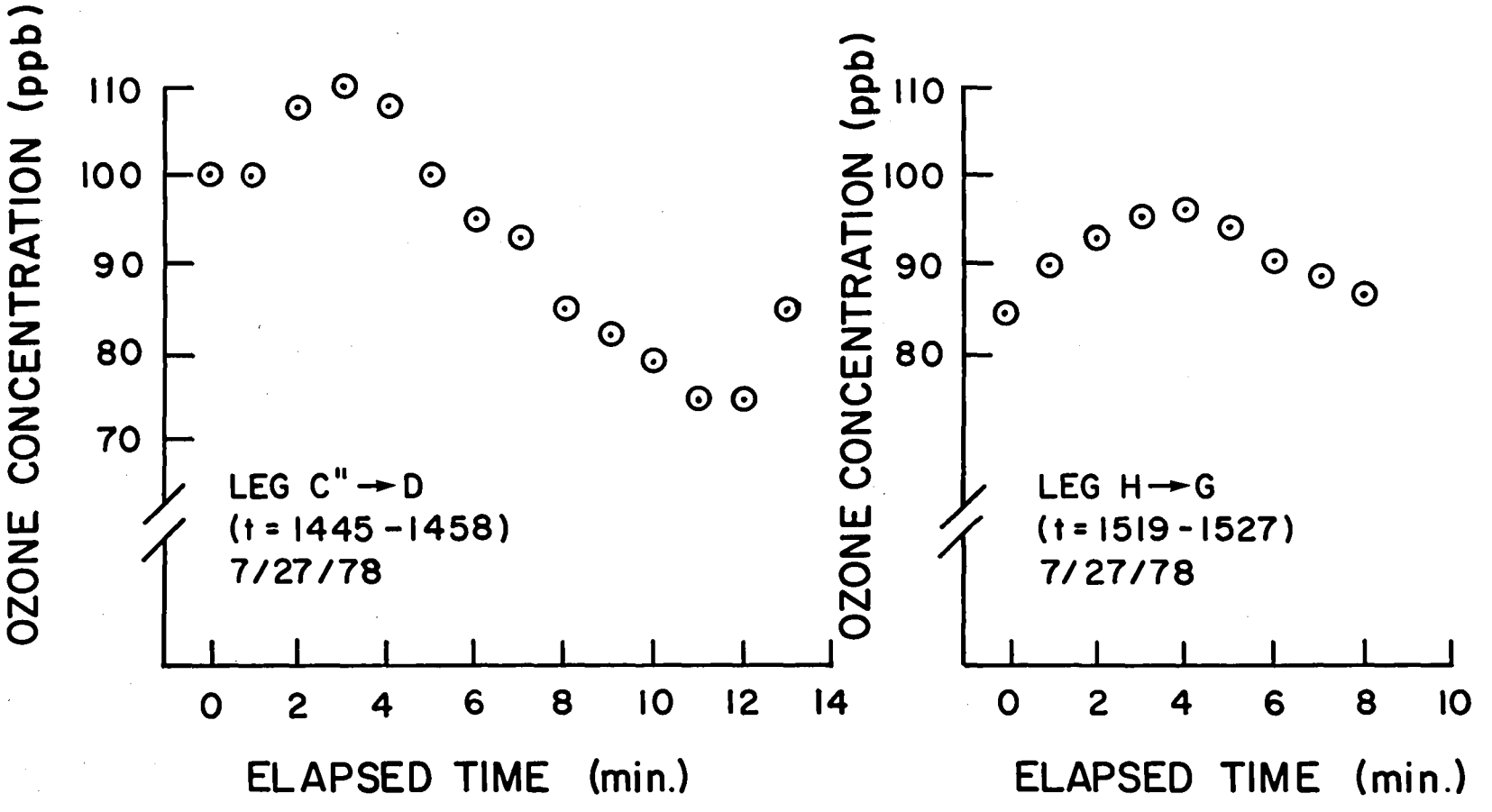

Figure 33.- Ozone concentration versus relative location along flight path for afternoon flight for legs C"→D and H→G. (Altitude, 610 m.)

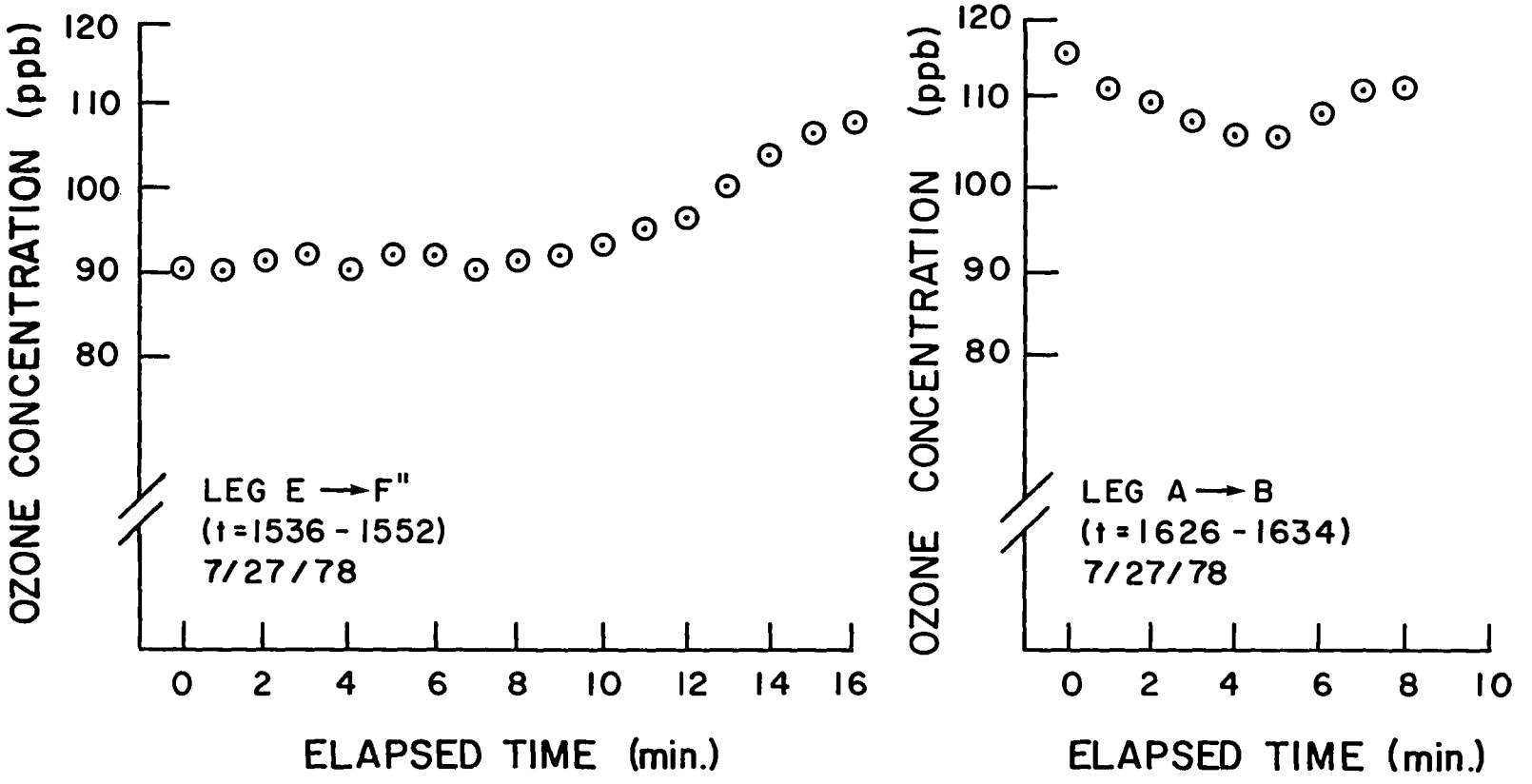

Figure 34.- Ozone concentration versus relative location along flight path for afternoon flight for legs E→F" and A→B. (Altitude for leg E→F", 457 m; for leg A→B, 610 m.)

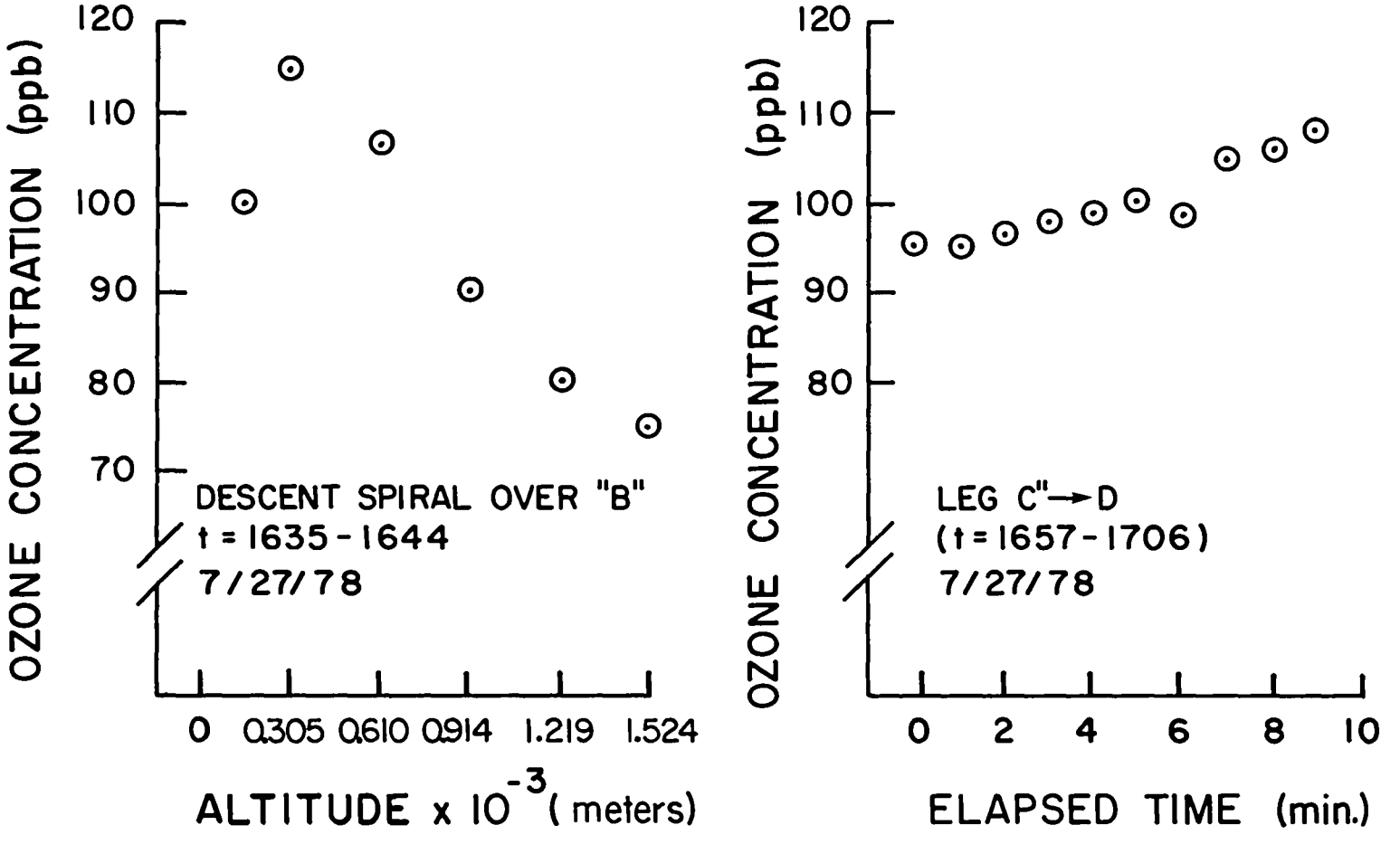

Figure 35.- Ozone concentration versus altitude over Wallops Flight Center and versus relative location along flight path (leg C"→D) for afternoon flight. (Altitude, 610 m.)

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16. Abstract

Data from the Southeastern Virginia Urban Plume Study conducted by NASA during July 1978 are presented. The overall purpose of the measurement program was to define the characteristics of the Southeastern Virginia urban plume with emphasis on the photo-oxidant species. The measurement area was a rectangle, approximately 150 km by 100 km centered around Cape Charles, Virginia. Included in this area are the cities of Norfolk, Virginia Beach, Chesapeake, Newport News, and Hampton. The area is bounded on the north by Wallops Island, Virginia, and on the south by the Hampton Roads area of Tidewater Virginia. The major axis of the rectangle is oriented in the southwest-northeast direction. The data set includes aircraft measurements for carbon monoxide, methane, nonmethane hydrocarbons, and ozone. The urban plume program was a combined effort of NASA Langley Research Center, NASA Wallops Flight Center, Virginia State Air Pollution Control Board Region VI, and Old Dominion University. CO can be successfully measured as a tracer gas and used as an index for determining localized and urban plumes. The 1978 data base provided sufficient data to assess an automated chromatograph with flame ionization detection used for measuring methane and nonmethane hydrocarbons in flight.

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