NOAA Technical Memorandum ERL ARL-101

DEMONSTRATION OF A LONG-RANGE ATMOSPHERIC TRACER SYSTEM USING PERFLUOROCARBONS

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / Environmental Research Laboratories

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
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Environmental Research Laboratories
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DEMONSTRATION OF A LONG-RANGE ATMOSPHERIC TRACER SYSTEM USING PERFLUOROCARBONS

Abstract. Regional-scale tracer experiments are needed to validate atmospheric dispersion aspects of air pollution models. The capability of a new system, using perfluorocarbon tracers (PFTs), for long-range dispersion experiments at reasonable cost was demonstrated in two experiments. Two PFTs (C_7F_{14} and C_8F_{16}) were released simultaneously with SF_6 and two heavy methanes.

The PFT system provides automatic sequential samplers and rapid, inexpensive analyses down to 2 parts per 10^{15} of air. PFT concentrations were measured 600 km away, up to three days after release. Performance of the PFT system was excellent and a consistent set of tracer data was obtained.

1. INTRODUCTION

Atmospheric transport and dispersion models are being used extensively to simulate the behavior of air pollutants and to estimate regional air concentrations. Increased concern over regional and international aspects of air pollution has created a need for reliable model calculations of concentrations as far as 1000 km from pollutant sources. Experimental verification of these calculations is essential to establish the credibility of the models and environmental assessments based on model simulations.

Attempts to verify model calculations with air quality data are complicated by the presence of multiple sources and imprecise knowledge of emission amounts. There is a need for nonreactive, nondepositing tracers that could be released at precisely controlled rates and measured accurately at very low concentrations. This would allow us to conduct tracer experiments which isolate atmospheric transport and dispersion from other variables and provide data for verification of this basic aspect of model calculations. Regional-scale experiments require tracers that can be unambiguously identified and measured as far as 1000 km from the release point. Sulfur hexafluoride, SF_6, has been used out to 100 km but its relatively high and variable background concentration militates against its use to much greater distances. Even at shorter distances, a tracer system is needed that would provide automatic sequential sampling and rapid, inexpensive sample analysis. A new atmospheric tracer system, using perfluorocarbons, has been developed to meet this need.

The capabilities of the perfluorocarbon tracer (PFT) system were successfully demonstrated in two long-range experiments described in this report. The experiments were designed to provide a proof-test of the perfluorocarbon tracer release, sampling, and analysis techniques and to demonstrate the feasibility of conducting long-range atmospheric dispersion experiments at reasonable cost. Each experiment involved simultaneous release of two PFT tracers along with SF_6 over a 3-hr period with concentrations measured 100 km downwind. In the primary experiment, two heavy methanes, new tracers being developed at the Los Alamos Scientific Laboratory (LASL) were also released and the perfluorocarbons and methanes were measured at a distance of 600 km as well as 100 km. Intercomparison of the PFT, SF_6, and heavy methane results has established the validity of the new tracer systems.

The perfluorocarbon tracer data on the 600 km sampling arc present an interesting case of very fast transport by a night-time low-level jet and the reappearance of tracer over the arc on the day following its first arrival. Tracer concentrations were still measurable three days after release. This experiment provides a useful case study for verification of long-range transport and dispersion models.

2. PERFLUOROCARBON TRACER SYSTEM

Investigations by Lovelock (1974) indicated that a perfluorocarbon tracer system could be developed that would be ideal for long-range dispersion studies. The NOAA Air Resources Laboratories (ARL) contracted with Lovelock to develop three different samplers as the first step in the development of the new tracer system. Prototype instruments were delivered by Lovelock in 1976. Since then ARL has been working closely with the Department of Energy's Environmental Measurements Laboratory (EML) and Brookhaven National Laboratory (BNL) in a cooperative effort to develop a practical perfluorocarbon system.

The perfluorocarbons are extremely stable non-toxic compounds, measurable at very low concentrations by gas chromatography and electron-capture detection. At present, we are working with two perfluorocarbons, perfluoromonomethylcyclohexane (PMCH; C_7F_{14}) and perfluorodimethylcyclohexane (PDCH; C_8F_{16}). Comparative data on SF_6, PMCH and PDCH are shown in Table 1. The atmospheric background concentration of PDCH is about 0.026 parts per trillion by volume ($26x10^{-15}$), about 1/25 of the SF_6 background. Background of PMCH is an order of magnitude lower than PDCH. The amount of tracer released in any experiment must be sufficient to distinguish the plume from background at the maximum sampling distance. The required release rate (by weight) for PDCH is about 10% that for SF_6; for PMCH it is about 1% of the SF_6 rate. Taking the higher price of the perfluorocarbons into account, the PDCH required for an experiment would cost about 20% more than SF_6; the cost of PMCH would be about 10% of the SF_6 cost.

Another factor in favor of the perfluorocarbons over SF_6 is their very uniform background concentration. SF_6 has a highly variable background because of many local sources throughout the country and the world.

Table 1. Comparative Data on SF_6 and Perfluorocarbons.

Tracer	Sulfur-Hexa-fluoride	Perfluoro-Dimethyl-cyclohexane (PDCH)	Perfluoro-Monomethyl-cyclohexane (PMCH)
Formula	SF_6	C_8F_{16}	C_7F_{14}
Mol. Wt.	146	400	350
Background (pptv)	0.6	0.026	0.0024
Cost/kg	$11	$110.	$110.
Relative Release Rate (by wt.)	100	12	1.0
Relative Cost/ Release	1.0	1.2	0.1

2.1 Tracer Release Mechanisms

The two perfluorocarbon tracers, which are liquids at ordinary temperatures, were released as aerosol sprays. Each tracer is held in a 210-liter tank on a trailer. Compressed nitrogen provides pressure to force the liquid out of the tracer tank.

The mechanics of the spray system are simple. The spray nozzle has two hoses, one from the tracer tank, and the other from a construction-type air compressor that delivers 100 psi at 100 cfm. The tracer is introduced into the fast-moving air stream, atomized through a small orifice, and released into the atmosphere. Tracer release rate is monitored with a calibrated rotometer.

A newly designed release system, which was not completed in time for these experiments, has since been tested and performed well in the DOE Atmospheric Studies in Complex Terrain (ASCOT) experiments in California in September 1980. This system, also trailer-mounted and designed to be completely self-contained (no air compressor required), vaporizes the tracer before release.

The tracer is mixed with a stream of N_2 gas to evaporate it and to carry the tracer through the system. This mixture of nitrogen and perfluorocarbon gas flows through a tube furnace. Temperature of the tube furnace is kept above the boiling point of PDCH, 105°C, to assure that the tracer is completely vaporized. From the tube furnace the mixture of N_2 and tracer gas passes through a mass flow meter where the volume is accurately metered. From there the tracer is released to the atmosphere.

The design of this system provides back-up measurements of the actual amount of released tracer. The mass flowmeter provides both instantaneous and total volumes, and also supplies a 0-5 volt dc output which is connected to a stripchart recorder. The recorded release rate shows the constancy of tracer release and provides a measurement of total output over the time of release. The system also has a large set of crane scales (0-450 kg) and a small balance (0-40 kg) to provide accurate weighings of the tracer tanks before and after release.

Both release systems were designed and built by the NOAA Air Resources Laboratories Field Research Office in Idaho Falls, Idaho.

2.2 Automatic Sequential Sampler

Based on Lovelock's prototype, R. Dietz at BNL, developed an improved sequential sampler dubbed the Brookhaven Atmospheric Tracer Sampler (BATS). The sampler consists of an Air Flow Module (lid) and a Power Control Module (base). The entire unit, shown in Figure 1, measures 36x25x20 cm and weighs 7 kg. The lid contains 23 sampling tubes filled with 150 mg of 20-50 mesh-type 347 *Ambersorb** which traps all the perfluorocarbons in the air flowing through the tube. The base contains a constant volume pump which draws air through each sampling tube in a sequence controlled by an internal digital clock. Flow rates, controlled by critical orifices, are selectable from 2 to 50 cc/min. The base also contains a digital printer that records the tube number, start time and number of pump strokes (which can be converted to air volume) for each sample. Controls in the base provide for automatic start at a preselected day and time for a preselected

*Trade name of Rohm and Hass Company.

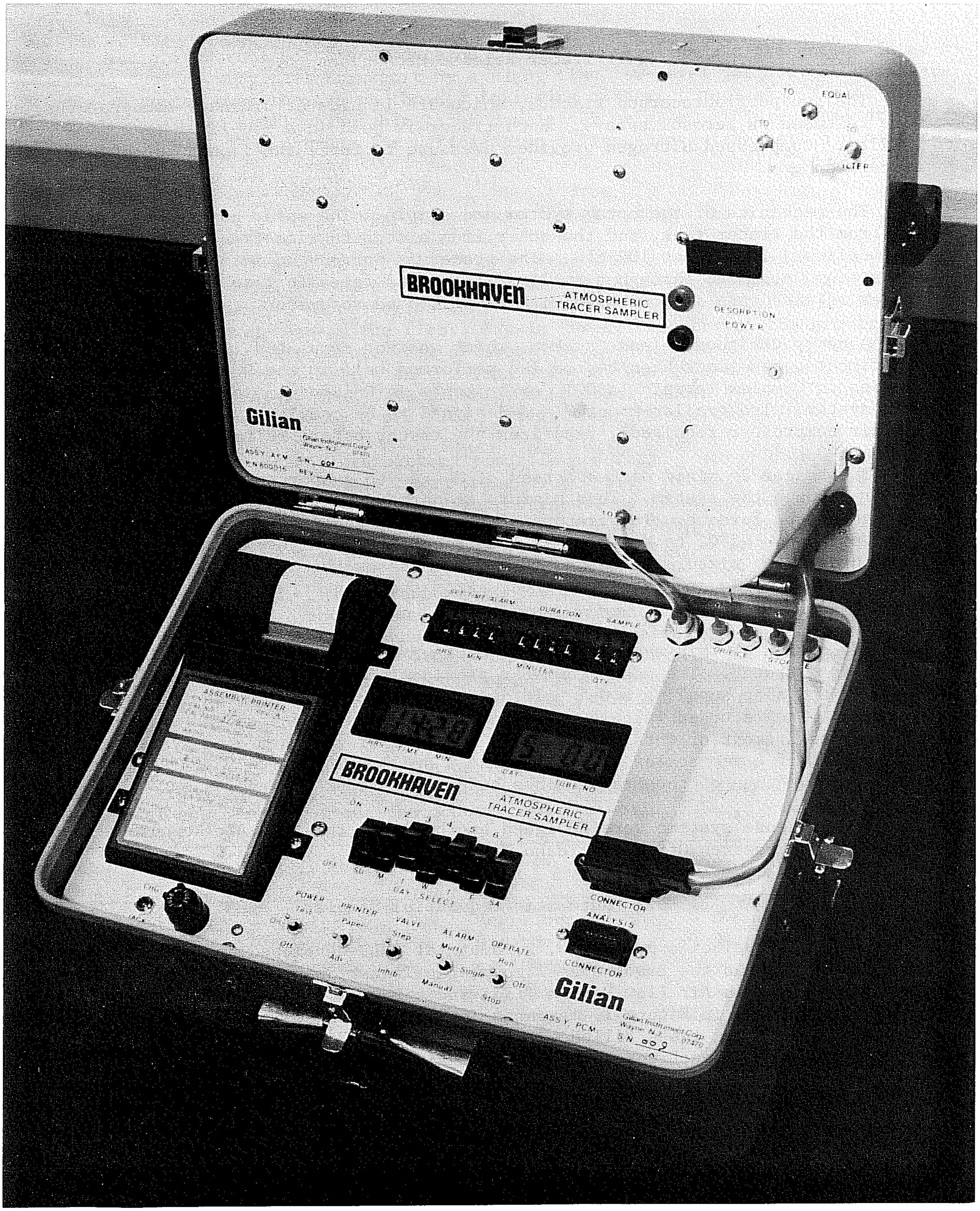

Figure 1. Automatic sequential sampler (BATS).

number of samples and duration of sampling (1 min to 1 week per tube), as well as for automatic analysis with a gas chromatograph. Internal rechargeable batteries provide sufficient power for unattended operation for up to a month. After 23 samples have been collected, the lid unit can be removed for sample analysis (in the laboratory) and a fresh lid attached in its place to continue the sampling program.

The Air Resources Laboratories contracted with Gilian Instrument Corp. for final design and production of 60 complete BATS samplers which were delivered in May 1980 for use in the July experiments. An operations manual was also prepared by Gilian (1980).

2.3 Sample Analysis System

The determination of perfluorocarbon tracer concentrations from the BATS samples is accomplished with an analysis apparatus designed, built and operated at BNL. The tracer is recovered by thermal desorption from the BATS tubes with subsequent gas chromatographic separation prior to electron capture detection. The scheme also includes chemical processing of the recovered constituents in order to destroy and remove interfering components, such as chlorofluorocarbons, which are present in the air at concentrations orders of magnitude higher than that of the PFTs.

Before the sample is thermally desorbed, the BATS tube is purged with carrier gas (5% H_2 in N_2) for a short period of time to remove any traces of oxygen which otherwise would react with the PFTs during the 400°C desorption recovery. Desorption is accomplished by direct ohmic heating of the thin stainless steel wall of the BATS tube. The sample is purged from the BATS tube through a Pd catalyst bed at 260°C and then through a 120 cm Porasil F pre-cut column. The 10-cm long catalyst bed reduces any chlorofluorocarbon compounds, as well as any remaining oxygen, to their hydrogenated form, thus rendering these interfering constituents non-electron-capturing. After the surviving PFTs elute from the pre-cut column, heavier molecular weight constituents, still within the column, are purged to the atmosphere by reversing the direction of flow. Meanwhile, the eluted PFTs are reconcentrated within a 10-cm long bed of Porapak QS adsorbent. The purpose of the bed is two-fold. First, only the PFTs are retained in the Porapak QS; any lighter constituents which might ultimately interfere are flushed away. Secondly, once the Porapak QS-trapped PFTs are released into the main analytical column, the next BATS tube recovery cycle can be initiated, thus halving the overall PFT recovery and analysis time by overlapping the stages.

When the Porapak QS trap has been heated to 200°C, the PFTs are released into a second catalyst bed (2.5 cm long) for a final clean-up and flushed through a Nafion permeation dryer to remove traces of moisture before entering the main column, 6 meters of Porasil F, which is at the same temperature as the pre-cut column, 90°C. The 22 mL/min flow of carrier gas at this column temperature provides good resolution of the two PFTs. Automation is accomplished by interfacing the timing capability of the BATS with the INJECT command of a Varian CDS-111 integrator-controller, which provides the control capability for the involved valving and heating sequences within a Varian 3700 series gas chromatograph. Analyses of the 23 tubes on a BATS unit can be completed in just under 3 hours.

The present system incorporates a ^{63}Ni electron-capture detector which provides a measurement accuracy within ±10% at concentrations as low as 2 parts per

10^{15} (approximate ambient concentration of PMCH) with a sampled volume of 8 liters of air. This is the approximate volume collected in the 600 km arc samples (3-hr duration). The uncertainty in measurements near the PMCH background level is somewhat greater (about ±25%) on the 100 km arc where the volume sampled was about 2 liters (45-minute duration).

2.4 Dual-Trap Sampler

Another prototype instrument, the Dual-Trap sampler, was designed by Lovelock to combine the sampling and analysis functions into a single unit. The unit contains two sampling tubes which are automatically cycled so that one tube samples while the other is being analyzed. This instrument provided readout of PDCH tracer concentrations (no PMCH) every five minutes at the sampling site.

The original prototype has been modified at EML and BNL to provide a more rugged instrument for field use, to collect and measure PMCH and PDCH simultaneously, and to improve its detection limit by more than two orders of magnitude.

Ambient PDCH (about .03 ppt) can be measured with ±15% precision and PMCH can be measured at concentrations slightly above its ambient level of about .003 ppt. The attainment of this degree of sensitivity in a real-time field instrument is a major advance which will add significantly to long-range tracer capability.

2.5 Continuous Tracer Monitor

The third prototype sampler developed by Lovelock is a real-time continuous monitor intended primarily for use in aircraft sampling. Ambient air is drawn through a catalytic reactor that reduces the O_2 and other electron-absorbers, leaving the perfluorocarbons and nitrogen. This is passed directly to an electron-capture detector providing continuous concentration readout with only a 3-second delay.

Many problems have been encountered in the operation of this instrument, but the concept appears to be sound and work is continuing on the development of this sampler. If successful, it should be able to provide a continuous in-flight record of tracer concentrations down to 0.1 ppt or better.

3. 600-KM TRACER EXPERIMENT

A long-range tracer experiment was conducted on July 8, 1980 with the simultaneous release of two perfluorocarbons, SF_6, and two heavy methane tracers at the NOAA National Severe Storms Laboratory (NSSL) at Norman, Oklahoma. Samplers were deployed to measure tracer concentrations along arcs at 100 km and 600 km north of the release point. The objectives of the experiment were:

1) to provide a proof-test of the perfluorocarbon release, sampling and analysis techniques,

2) to test the concept of using the National Weather Service substation network for cross-country sampling,

3) to compare measurements of five different tracers to establish the validity of the new tracer techniques, and

4) to demonstrate the capability to perform long-range atmospheric transport and dispersion experiments, at reasonable cost, for verification and improvement of air pollution models.

3.1 Tracer Release

The five tracers were released simultaneously over a 3-hr period from 1900 to 2200 GMT (1400-1700 CDT) from an open field at NSSL. Release nozzles were about a meter above ground level. Flowrates were carefully monitored to assure a nearly constant release rate for each tracer. Release amounts are shown in Table 2. The amounts of perfluorocarbon and heavy methane released were calculated to produce concentrations well above the detection limit at the 600 km sampling arc. The amount of SF_6 released was sufficient to be detected at the 100 km arc for comparison with the new tracers.

Table 2. Tracer Releases on July 8, 1980

Tracer	Formula	Molecular Wt.	Release Amount (kg)
PMCH	C_7F_{14}	350	192
PDCH	C_8F_{16}	400	186
SULFUR HEXAFLUORIDE	SF_6	146	273
METHANE-20	$^{12}CD_4$	20	0.153
METHANE-21	$^{13}CD_4$	21	0.084

Tracer Release Ratios (by Volume)

PMCH/PDCH:	1.18
SF_6/PMCH :	3.41
SF_6/PDCH :	4.02
PDCH/Me-21 :	116
PMCH/Me-21 :	137
SF_6/Me-21 :	467

It should be noted that although very small amounts of heavy methanes are required, they are relatively expensive to produce. When the costs of tracer materials and sample analysis are taken into account, the cost per experiment is comparable for perfluorocarbons and heavy methanes.

The two perfluorocarbons (PMCH and PDCH) were released as aerosol sprays from separate tanks mounted on trailers a few feet apart. The tanks were weighed immediately before and after the experiment to determine the amount released from each tank. Since the commercially available PDCH contains about 8% (by weight) PMCH and the commercial PMCH has about 2% impurities, samples of the purchased tracers were assayed at BNL prior to the experiment, and samples from the release tanks were assayed after the second experiment. The release tank weighings and the chemical assays were used to calculate the PMCH and PDCH release amounts shown in Table 2. These values are accurate within ±4%.

SF_6 was released as a gas from pressurized cylinders positioned between the perfluorocarbon trailers. The release amount was determined by weighing the cylinders before and after release and is accurate within ±2%.

The two heavy methane tracers were released as a calibrated mixture of gases from a single pressurized cylinder. The mixture was prepared at LASL and the ratio of the two methanes was determined by mass spectrometry. The total amount released was determined by weighings before and after release. Release amounts are accurate within ±1%.

The lower part of Table 2 gives the tracer release ratios, by volume, as calculated from the release amounts and molecular weights shown above. Ideally, if the tracer systems worked perfectly, these same ratios should be found in all air samples collected within the tracer plume (after ambient background concentrations are removed).

3.2 Sampling Array

Sampling arcs were established at 100 km and 600 km from the release point. Sites were selected in a sector to the north of the release site, based on a 5-year climatology of July trajectories.

3.2.1 100 km arc

Thirty sampling sites were selected at 4-5 km intervals along the roadway of HWY 51 and HWY 33 as shown in Figure 2. The latitude-longitude azimuth, and distance from the release site of each sampling site are listed in Table 3. The operations center for the 100 km arc was set up at the Agronomy Research Station, Oklahoma State University at Stillwater, OK. National Weather Service instrument shelters were set up at each location to house the BATS sequential sampler. Only seventeen samplers were available, so the sites to be instrumented had to be selected just prior to the start of the tracer release. Based on the latest trajectory forecast, two EML sampling teams deployed the BATS samplers to Sites 12-28. The tracer release began at 1900 GMT (1400 CDT) and the samplers were set to take ten 45-minute samples starting at 2100 GMT, before the tracer was expected to arrive.

A whole-air sampler (pump and plastic bag enclosed in a barrel) was co-located with each BATS sampler to collect a single sample starting when the BATS was placed at the site and ending when the BATS sampling was terminated. The purpose of the whole air samplers was to provide intercomparisons among the five tracers and aliquots were taken from each bag for perfluorocarbon, heavy methane, and SF_6 analyses.

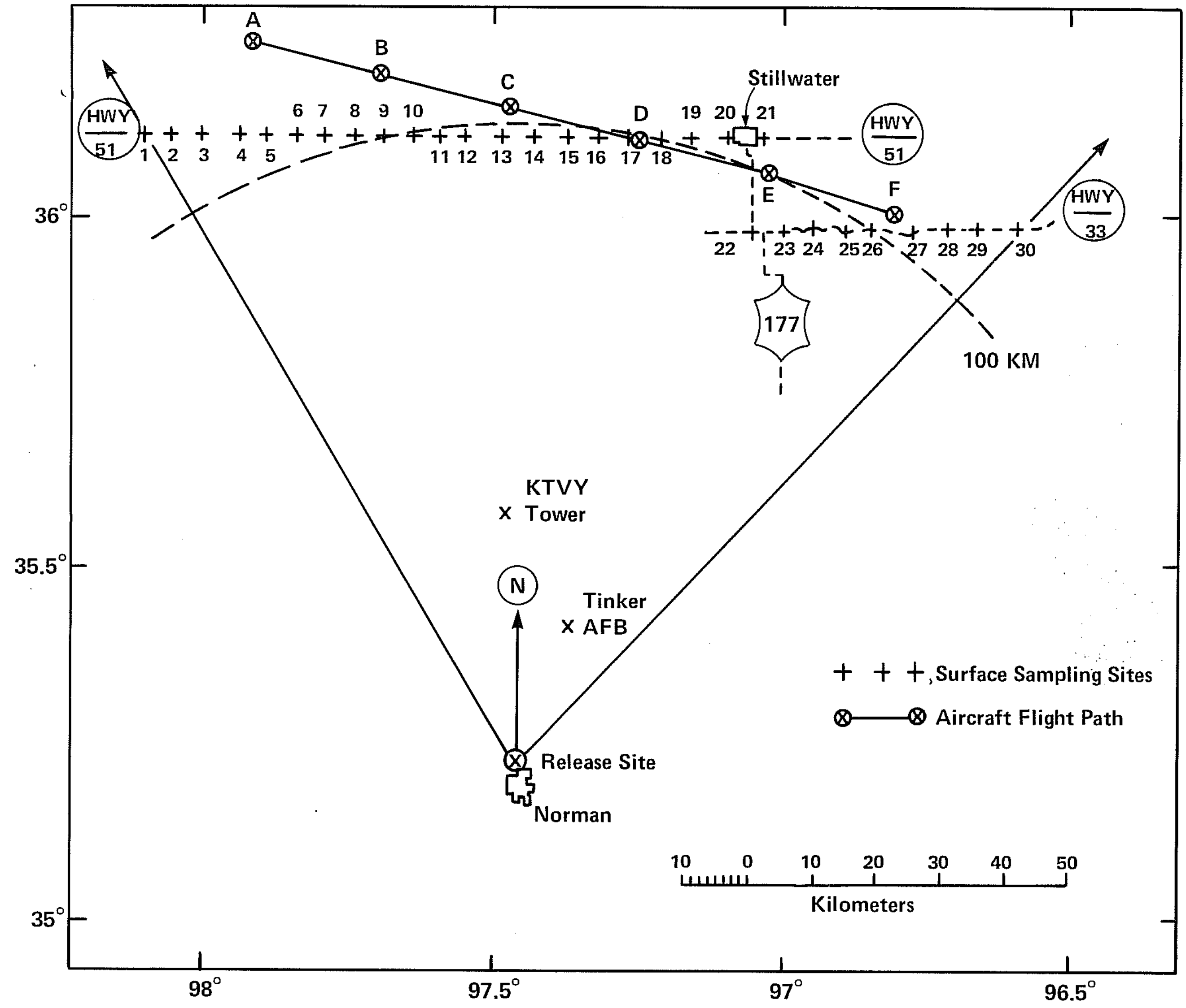

Figure 2. Location of the sequential air samplers (BATS) and aircraft sampling path at 100 km from the tracer release site.

Table 3. Location of sampling sites at the 100 Km arc.

Station No.	Latitude °N	Longitude °W	Distance[a] Km	Azimuth[a] deg
1	36.12	98.10	115	328
2	36.12	98.05	113	330
3	36.12	98.00	111	333
4	36.12	97.94	108	335
5	36.12	97.89	106	338
6	36.12	97.84	105	340
7	36.12	97.79	103	342
8	36.12	97.73	102	345
9	36.12	97.68	100	347
10	36.12	97.63	99	350
11	36.12	97.59	98	352
12	36.12	97.54	98	355
13	36.12	97.48	97	358
14	36.12	97.42	97	001
15	36.12	97.36	98	003
16	36.12	97.31	98	006
17	36.11	97.26	98	008
18	36.10	97.21	98	011
19	36.12	97.15	101	014
20	36.12	97.09	103	017
21	36.12	97.05	104	019
22	35.99	97.05	91	022
23	35.98	97.00	93	025
24	35.99	96.94	95	028
25	35.99	96.89	97	030
26	35.98	96.84	100	033
27	35.96	96.77	104	036
28	35.97	96.72	108	038
29	35.97	96.66	110	040
30	35.97	96.59	114	043
Tinker AFB	35.42	97.38		
Release Site	35.24	97.46		
KTVY Tower	35.58	97.48		

(a) Measured from Release Site.

3.2.2 600 km arc

Sampling sites on the 600 km arc, in Nebraska and Missouri are shown in Figure 3. Deployment and operation of samplers over the long distances on this arc could have presented difficult logistic problems. Fortunately, we were able to secure the cooperation of the NOAA National Weather Service (NWS) to allow us to use their substation network as a fixed sampling array. This network is comprised of over 12,000 locations in the U.S. where cooperative observers, mostly volunteers, gather weather data for the NWS.

The BATS samplers were delivered, in advance of the experiment, by NWS substation specialists to the sites shown in Figure 3. At the time of delivery, the samplers were set to take 22 three-hour samples. On the day of the experiment, after the tracer release had begun, all observers were notified by telephone to set the samplers to start automatically at 0800 GMT (0300 CDT) on July 9. The station locations and cooperative observers are listed in Table 4.

The Los Alamos Scientific Laboratory had 6 cryogenic samplers available for deployment on the 600 km arc for the collection of heavy methanes. On the evening of July 8, based on the latest wind data and forecasts, they were advised by ARL to deploy the samplers to the sites indicated by double circles in Figure 3. Five sequential samples were taken at these locations at 3-hour intervals beginning at 1100 GMT (0600 CDT) on July 9.

3.3 Airborne Sampling

The Battelle Pacific Northwest Laboratory provided a DC-3 aircraft and crew for sampling missions over the 100 km and 600 km arcs. It was intended to obtain plume profiles aloft with the Lovelock real-time continuous perfluorocarbon monitor and a modified version of this instrument developed at BNL. However, neither instrument was operational on the day of the experiment. Whole-air samples were collected in plastic bags, and analyzed for all five tracers. Frequent wind measurements were also made aboard the aircraft during both sampling flights.

Three sampling passes were made at the 100 km arc along the flight path shown in Figure 2 at an altitude of 900 meters above the ground (1250 m MSL) between 2300 GMT and 0000 GMT (6-7 PM). On each pass, a plastic bag was filled with outside air along each segment of the flight path.

The aircraft returned to Wiley Post Field in Oklahoma City, refueled, and then took off for Kansas City in preparation for the 600 km sampling flight the next morning. The plume had been forecast to arrive about 1300 GMT (8 AM) but the 0600 GMT wind data indicated faster plume travel and the aircraft was rescheduled for take-off at 1230 GMT (7:30 AM) and a sampling flight path north of the 600 km arc, shown in Figure 3 was chosen to compensate for the stronger winds. Bag samples of about 12-minute duration were collected along each segment of the flight path from about 1240 to 1630 GMT at an altitude of 1200 meters above the ground (1525 meters MSL). Aliquots were transferred from each bag for later analysis by BNL and LASL.

3.4 Meteorology

On July 8-9 a broad area of high pressure dominated most of the U.S. A west-to-east oriented stationary front just north of the 600 km sampling arc was

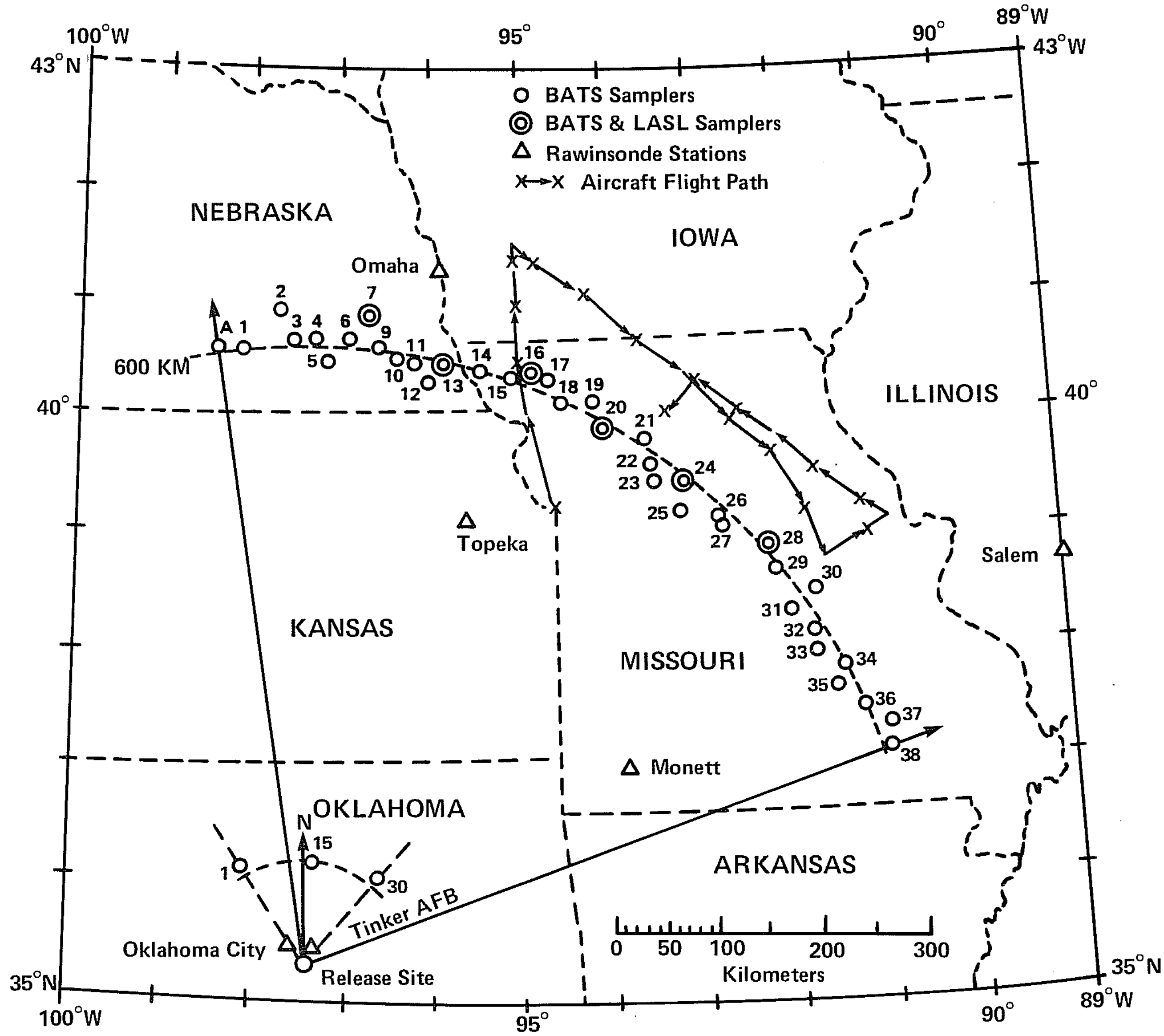

Figure 3. Location of sequential samplers (BATS), LASL samplers, and aircraft sampling flight path at 600 km from the tracer release site. The locations of rawinsonde stations are also shown.

Table 4. Sampling sites at the 600 Km arc

Station No.	Location	Observer	Latitude °N	Longitude °W	Azimuth[a] deg.
NEBRASKA					
A	Hastings	Ralph A. Powell	40.60	98.35	352
1	Clay Center 5W	Jim Chapman	40.53	98.15	354
2	Bradshaw	Jack Pugh	40.88	97.75	358
3	Fairmont	Andrew Anderson	40.63	97.58	000
4	Friend	Jim Hannon	40.65	97.28	001
5	Western	Kenneth Roesler	40.40	97.20	002
6	Crete	Dr. Delbert King	40.62	96.95	004
7	Lincoln (WSO)	Orval Jurgena	40.85	96.75	005
9	Firth	Roland Beach	40.53	96.60	007
10	Sterling	Raymond Zink	40.47	96.38	008
11	Tecumseh	Arthur Lempke	40.37	96.18	010
12	Table Rock 4N	Betty Vrtiska	40.23	96.08	011
13	Auburn 5NNE	Daryl Obermeyer	40.45	95.80	012
MISSOURI					
14	Fairfax	Dillard Price	40.33	95.40	015
15	Skidmore	Donald Brown	40.28	95.08	018
16	Maryville 2E	George Wolfe	40.35	94.83	020
17	Conception	Br. Damian Larson	40.25	94.68	022
18	King City	John Martin	40.05	94.52	023
19	Pattonsburg	Mrs. Kenneth Mason	40.05	94.13	026
20	Hamilton 2 W	William Kuhnert	39.75	94.03	028
21	Chillicothe	Sam Bowling	39.77	93.55	031
22	Coloma	Mrs. Freda Trussel	39.53	93.53	033
23	Carrollton	Harold Finley	30.37	93.50	034
24	Brunswick	John M. Smith	39.42	93.12	036
25	Marshall	Steve Hilton	39.12	93.18	038
26	New Franklin	Mrs. Ronda Thiessen	39.00	92.77	040
27	Boonville	Rolland Goode	38.97	92.75	041
28	Columbia (WSO)	Dave Horner	38.65	92.22	046
29	Jefferson City	Robert Block	38.58	92.15	048
30	Freedom	Mrs. Velma Niewald	38.47	91.70	052
31	Vienna	Henry Kaiser	38.20	91.98	053
32	Vichy (FAA)	Newton Lipplitt	38.12	91.77	055
33	Rolla	Dr. Al Spreng	37.95	91.77	057
34	Cook Station	Mrs. Ozella Brand	37.82	91.43	060
35	Salem	Warren Sellers	37.63	91.53	061
36	Bunker	Mrs. Grace Shaffer	37.45	91.22	064
37	Ellington	Billy Swyres	37.20	90.93	066
38	Van Buren	Gerry Whittle	36.98	91.02	068

(a) Measured from Release Site.

associated with a weak low pressure center moving slowly eastward (see Figures 4 and 5). The wind flow in the boundary layer (surface to about 2500 m) over the central U.S. was predominantly from the south-southwest around a strongly persistent high pressure system centered in the southeastern U.S. This weather pattern was associated with the severe "heat wave" in the central U.S. during July 1980. Afternoon surface temperatures in the experimental area generally rose above 38°C (100°F) during the entire period of the experiment.

3.4.1 Forecast tracer trajectories

In order to alert the sites in advance to prepare for sampling, forecast trajectories were prepared on a daily basis. Trajectories starting at 6-hour intervals were determined from a computer program using the NOAA National Meteorological Center forecast gridded wind fields. The forecast obtained the morning of July 8, based on 0000 GMT data, was for trajectories starting 18 to 24 hours later (for a planned tracer release time of 1900 GMT). The plume centerline was forecast to move to the northeast across the eastern part of the 100 km arc and then continue northeast-to-north crossing near the center of the 600 km arc. Based on the forecast, preparations continued for a 1900 GMT release. The last forecast before release was obtained at noon (based on 1200 GMT data) for a trajectory starting at 1800 GMT. The plume centerline was forecast to be in about the same position as before with a slight northeast shift at the 600 km arc. The tracer was released with the knowledge that backing (counter-clockwise shifting) of the local winds was forecast during the afternoon turbulent mixing. This insured that the plume would cross the 100 km arc shifting from east to west as time progressed.

3.4.2 Upper air observations

The wind direction and speed from the KTVY tower, about 40 km north of the release site, is given in Appendix A. The tower is instrumented at seven levels between the surface and 444 meters. The wind data at these levels were averaged over 15-minute periods.

Special rawinsonde observations were taken at Tinker AFB, about 20 km NNE of the release site, starting on the morning of July 8. These data (height, temperature, wind direction and speed) are given in Table 5. In addition, a transport layer height, TLH, computed from each temperature sounding (Heffter, 1980) is given at the bottom of the table together with the average wind speed and direction in the layer.

Rawinsonde data at selected stations, for the period July 8, 0000 GMT to July 12, 1200 GMT are given in Appendix B. These data, and the Tinker AFB soundings, have been included in the NAMER-WINDTEMP data tapes available at the National Climatic Center, Asheville, NC (see Appendix C, Heffter, 1980).

3.4.3 Aircraft winds

The PNL sampling aircraft took wind observations at the 100 km arc along the flight path shown in the lower part of Figure 6. The upper figure shows a plot of the winds by longitude (along the flight path) versus time. To locate the geographic position of any wind, read directly down (along a constant longitude) from the plotted wind position of the upper figure to the intersection along the flight path in the lower figure. The winds are tabulated in Table 6.

TUESDAY, JULY 8, 1980

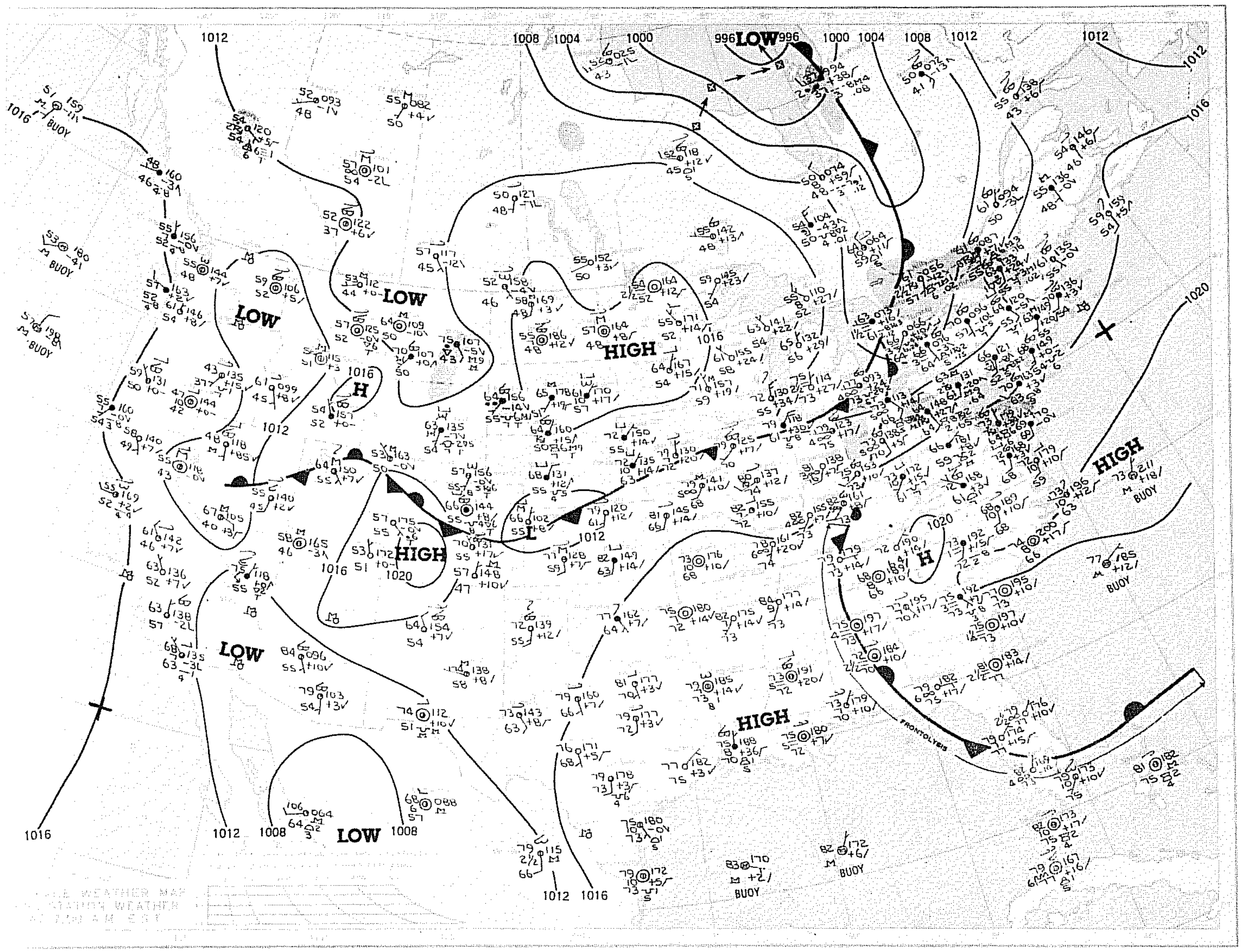

Figure 4. Surface weather map for 1200 GMT, Tuesday, July 8, 1980.

WEDNESDAY, JULY 9, 1980

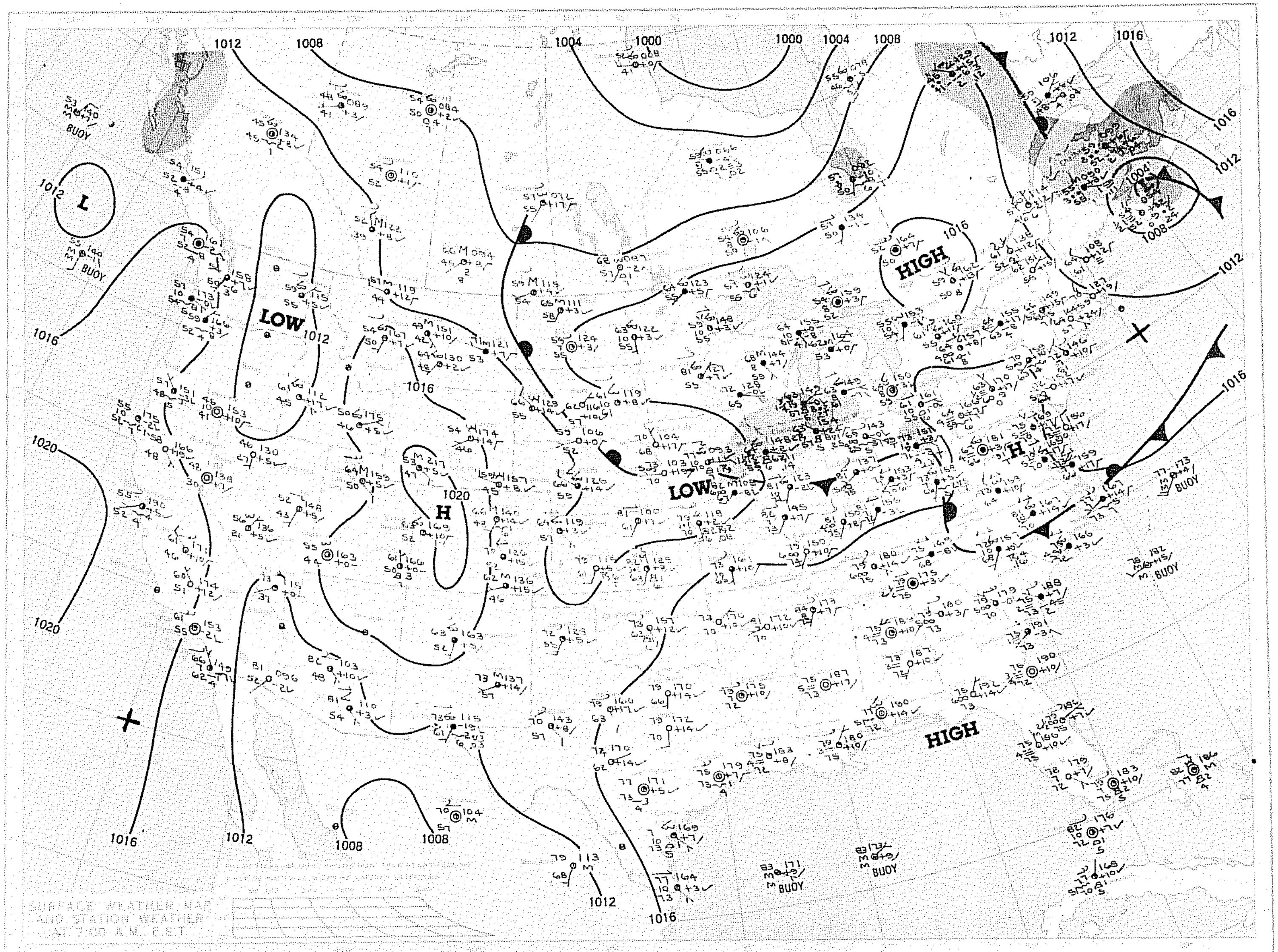

Figure 5. Surface weather map for 1200 GMT, Wednesday, July 9, 1980.

TABLE 5. TINKER AFB RAWINSONDE DATA FOR THE JULY 8 EXPERIMENT.

08 JUL 80 17GMT

HT M,MSL	DIR DEG	SPD M/SEC
387	190	2.0
610	210	7.7
915	205	7.2
1220	210	6.6
1551	210	6.6
1830	210	6.6
2135	215	7.7
2440	205	9.7
2745	195	11.2
3050	185	12.8
3215	185	14.4
3660	185	15.4
4270	185	9.2
4880	195	5.6
5490	190	8.2

HT M,MSL	PRES MB	TEMP DEG K
387	969	305
1551	850	295
3215	700	287
4351	609	278
5212	548	274
5960	500	271

TLH M,MSL	DIR DEG	SPD M/SEC
2270	209	7

08 JUL 80 19GMT

HT M,MSL	DIR DEG	SPD M/SEC
387	170	3.0
610	170	5.1
915	185	6.1
1220	200	5.6
1550	205	6.1
1830	210	6.1
2135	215	8.2
2440	210	9.7
2745	200	11.3
3211	195	15.4
3660	195	16.9
4270	210	10.2
4880	235	5.6
5795	210	6.1

HT M,MSL	PRES MB	TEMP DEG K
387	969	307
1550	850	295
1888	817	291
2004	806	292
2329	776	291
3211	700	286
4470	600	277
5960	500	271

TLH M,MSL	DIR DEG	SPD M/SEC
1990	196	5

08 JUL 80 21GMT

HT M,MSL	DIR DEG	SPD M/SEC
387	170	4.1
610	170	10.8
915	180	10.3
1220	190	9.8
1623	190	9.3
1830	195	8.8
2135	205	9.3
2440	200	12.9
2745	195	12.9
3288	205	16.0
3355	205	17.0
3660	215	13.9
3965	225	9.3
4270	220	7.2
4880	240	3.6
5795	235	4.6

HT M,MSL	PRES MB	TEMP DEG K
387	976	309
1623	850	296
2089	805	292
2294	786	292
3288	700	286
5297	547	273
6030	500	271

TLH M,MSL	DIR DEG	SPD M/SEC
2280	188	9

09 JUL 80 00GMT

HT M,MSL	DIR DEG	SPD M/SEC
387	180	5.1
610	175	9.2
915	175	9.7
1220	170	9.7
1525	175	10.2
1531	175	10.2
1830	180	10.8
2135	185	10.2
2440	195	11.3
2745	210	12.3
3194	220	13.3
3355	220	13.3
3660	230	9.2
4270	205	2.0
4880	260	3.6
5490	280	5.1

HT M,MSL	PRES MB	TEMP DEG K
387	966	309
516	952	307
1531	850	297
2256	781	290
2683	743	288
3194	700	286
5940	500	270

TLH M,MSL	DIR DEG	SPD M/SEC
2630	180	10

09 JUL 80 03GMT

HT M,MSL	DIR DEG	SPD M/SEC
387	170	2.6
610	170	16.0
915	175	15.4
1220	180	13.9
1526	190	12.4
1830	200	11.3
2135	205	11.3
2440	210	10.8
2745	220	9.8
3192	250	4.6
3660	210	2.6
4270	205	4.6
4880	285	1.5
5490	315	2.1

HT M,MSL	PRES MB	TEMP DEG K
387	966	304
500	952	304
550	945	306
1526	850	298
2530	755	288
2830	728	289
3192	700	287
3460	673	286
3960	628	281
5594	500	271

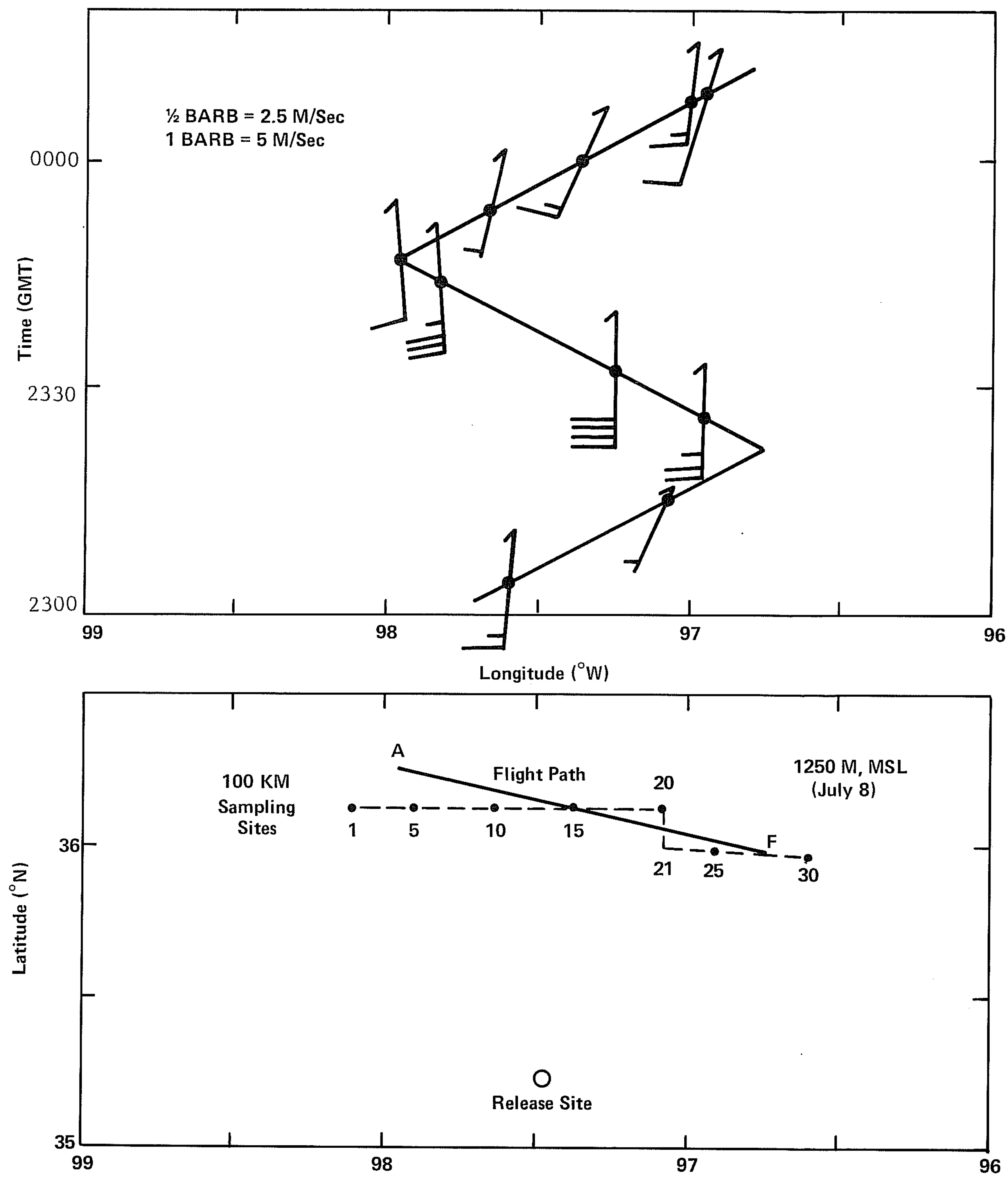

Figure 6. Wind observations at 1250 meters (MSL) along the 100 km arc aircraft sampling path.

Table 6. Aircraft wind observations at 1250 meters (MSL) along the 100 km arc.

Time (GMT)	Direction (deg.)	Speed (m/sec)
2304	186	6.7
2315	205	2.6
2326	182	13.9
2332	181	19.6
2344	178	17.5
2347	176	6.2
2353	194	3.1
0000	205	7.2
0008	188	6.7
0009	198	5.7

The sampling aircraft also took wind observations at the 600 km arc along the flight path shown in Figure 7 (plotted similar to Figure 6). These winds are also tabulated in Table 7.

Table 7. Aircraft wind observations at 1525 meters (MSL) along the 600 km arc.

Time (GMT)	Direction (deg.)	Speed (m/sec)	Time (GMT)	Direction (deg.)	Speed (m/sec)
1304	267	20.1	1504	265	13.9
1313	271	19.0	1511	263	16.0
1316	271	19.0	1516	262	17.0
1327	272	19.0	1526	265	14.4
1328	272	19.0	1528	269	13.4
1340	327	10.3	1533	265	12.9
1346	332	13.4	1540	259	10.3
1352	318	12.9	1544	261	8.8
1358	312	12.4	1550	256	12.4
1404	309	15.4	1554	262	14.4
1416	279	11.8	1556	263	15.4
1427	254	18.0	1604	255	18.5
1440	277	12.4	1607	258	16.0
1449	267	13.4	1617	260	8.8
1452	255	17.0	1622	244	8.8

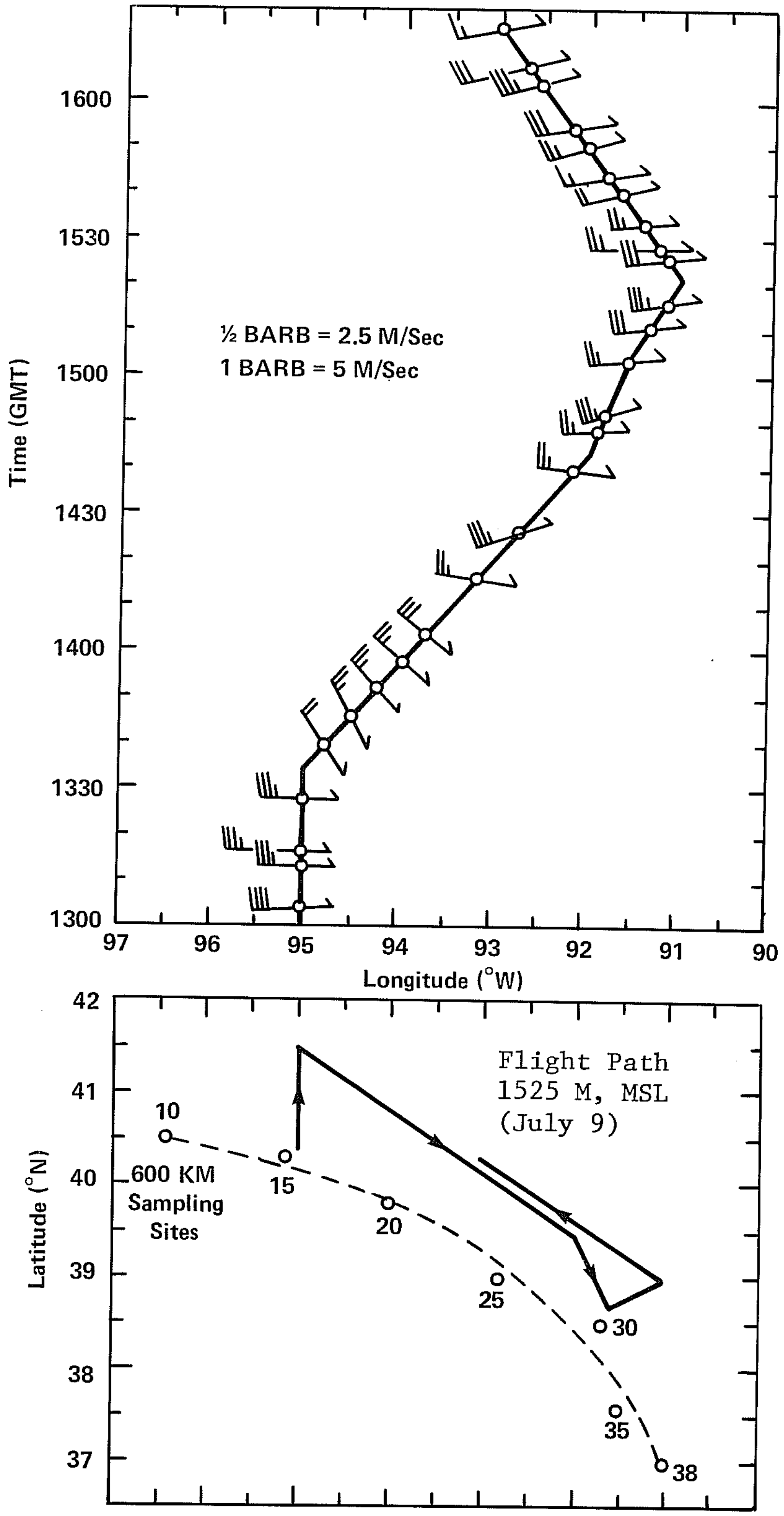

Figure 7. Wind observations at 1525 meters (MSL) along the 600 km aircraft sampling path.

3.4.3 Post-facto tracer trajectories

Tracer trajectories to the 100 km arc were hand-calculated using average winds in the computed transport layer as determined from the Tinker AFB soundings. Trajectories for the start and end of the tracer release are shown in Figure 8 with times (GMT) indicated along each trajectory. Also shown is the expected plume width. The calculated plume position and arrival time at the 100 km arc agreed well with the tracer data although the actual plume extended further to the west (see Section 3.5.1).

Tracer trajectories to the 600 km arc were computed using the ARL-ATAD model (Heffter, 1980). Meteorological input data were obtained from the NAMER-WINDTEMP data base. The computed trajectories are shown in Figure 9. The solid trajectory is determined from winds averaged in a computed variable transport layer; the dashed trajectory is from winds averaged in a constant layer 150 to 600 m above terrain. The calculated plume centerline at the 600 km arc using the variable transport layer was about 200 km east of the measured peak concentration; the calculated position using the 150-600 m layer was in better agreement, about 100 km east of the actual position.

3.5 Sampling Results

3.5.1 100 km sampling results

The BATS sequential samplers and whole air samplers were installed at Sites 12 through 28. The 45-minute sequential sample concentrations are given in Table 8. Due to analysis problems, no data are available for Site 17.

The PMCH sampling results on the 100 km arc are shown graphically in Figure 10. The sampling sites are plotted as a function of the azimuth from the release site. The scale gives the distance in kilometers between sampling sites projected onto the 100 km arc.

During the initial sampling period (2100-2145 GMT), the PMCH concentrations at all sampling sites are at or slightly above the background concentration of about 2.4 parts per 10^{15}. During the second sampling period (2145 to 2230 GMT), approximately 3 hours after the start of tracer release, concentrations had increased by three orders of magnitude with the plume centered between Sites 12 and 16. The backing of the winds with time carried the tracer plume further west than expected and the portion of the plume west of Site 12 was not sampled.

The next samples (2230 to 2315 GMT) show the peak PMCH concentrations. Later samples show decreasing concentration with the plume centerline shifting toward the west. As will be seen later, aircraft sampling data indicated that plume concentrations west of Site 12 probably decreased very rapidly.

During the sampling period 0130-0215 GMT (July 9), about 4 hours after the end of the release, concentrations along the 100 km arc had returned to near-background levels. Sites 23 through 28 had background concentrations during the entire sampling period.

The Dual-Trap sampler, described in Section 2.4, was operated along the 100 km arc but the only non-background data obtained was at Site 20 from 2227 to 2314 GMT as shown in Table 9. The average PDCH concentration for this period was 228 parts

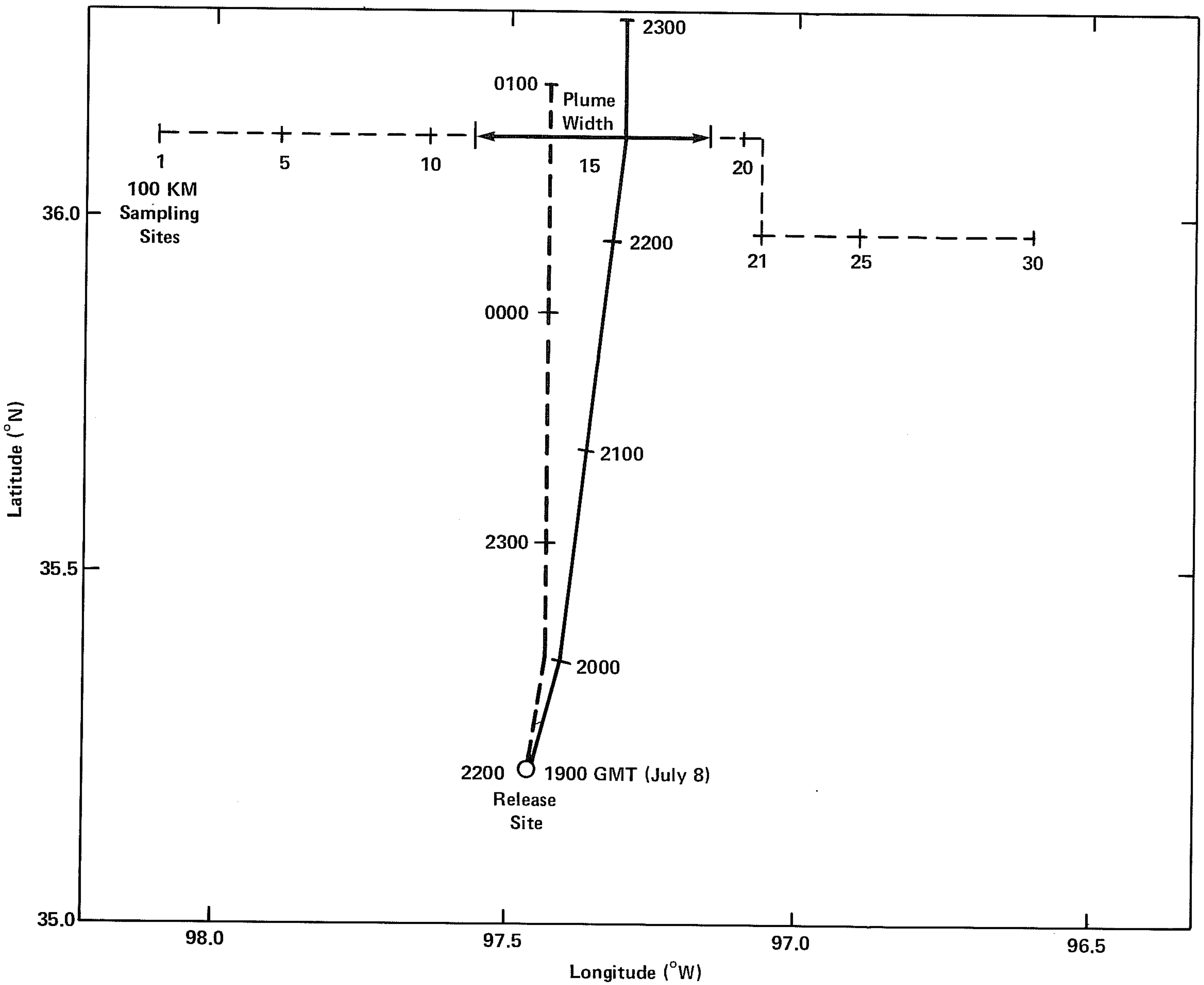

Figure 8. Calculated transport layer trajectories to the 100 km arc for the 3-hour tracer release on July 8.

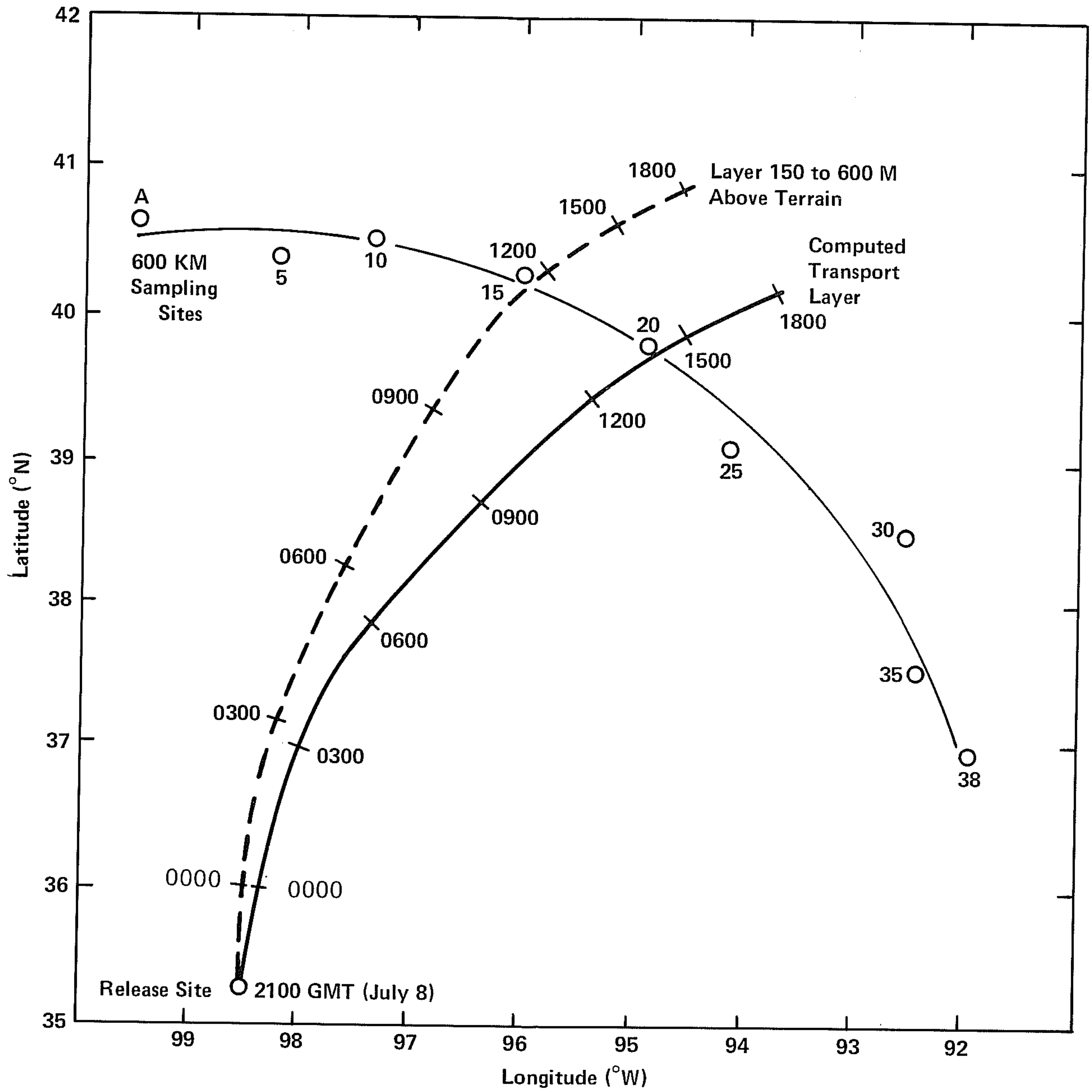

Figure 9. Comparison of the transport layer trajectory with the trajectory in a layer 150 to 600 meters above terrain.

TABLE 8

100 KM ARC

TRACER CONCENTRATIONS (PARTS PER 10^{15})

STATION	12		13		14		15	
START TIME(GMT)	PMCH	PDCH	PMCH**	PDCH**	PMCH	PDCH	PMCH	PDCH
JULY 08								
2100	3.1	25	4.	28	4.7	26	4.9	25
2145	650.	580	1300.	890	1010.	920	860.	760
2230	4000.	2980	5900.	3900	4670.	3500	2730.	2380
2315	2840.	2160	2700.	2000	1650.	1370	1260.	1110
JULY 09								
0000	2170.	1700	500.	390	182.	182	88.	96
0045	43.	67	4.	32	4.5	28	4.0	25
0130	4.6	32	-	32	5.0	28	4.8	23
0215	4.1	30	4.	31	4.4	27	5.*	28
0300	3.6	26	4.	31	4.6	27	5.*	28
0345	3.1	26	4.	26	4.4	28	10.*	25

STATION	16		18		19		20	
START TIME(GMT)	PMCH	PDCH	PMCH	PDCH	PMCH	PDCH	PMCH	PDCH
JULY 08								
2100	3.0	26	3.0	31	3.0	27	3.7	28
2145	1110.	980	290.	270	130.	150	16.	40
2230	2810.	2440	2100.	1780	560.	480	215.	238
2315	1000.	920	340.	310	50.	66	14.	41
JULY 09								
0000	90.	101	3.*	23	3.*	25	3.8	30
0045	9.*	28	3.*	23	1.*	26	4.5	29
0130	3.*	27	3.*	24	3.*	26	4.1	31
0215	4.*	27	4.*	26	3.*	26	4.2	31
0300	6.*	27	3.*	24	2.*	27	4.2	31
0345	10.*	28	-	-	1.*	26	4.1	31

STATION	21	
START TIME(GMT)	PMCH	PDCH
JULY 08		
2205	27.1	44
2250	3.6	24
2335	2.8	23
JULY 09		
0020	2.7	25
0105	3.1	25
0150	2.9	24
0235	2.8	25
0320	3.4	25
0405	2.8	25
0450	2.5	25

STATION	22	
START TIME(GMT)	PMCH	PDCH
JULY 08		
2130	5.7	37
2215	4.1	24
2300	3.4	25
2345	3.8	27
JULY 09		
0030	3.7	26
0115	5.5	27
0200	3.5	25
0245	4.2	29
0330	4.3	26
0315	3.9	27

STATION	23-28	
	PMCH	PDCH
	SEE FOOT NOTE A	

- NO DATA

* VALUE UNCERTAIN DUE PRIMARILY TO CONTAMINATION IN LAB ANALYZER.

** POOR DESORPTION POWER, CORRECTION ESTIMATED.

A SAMPLING SITES 23-28 HAD BACKGROUND PMCH AND PDCH CONCENTRATIONS IN ALL SAMPLES.

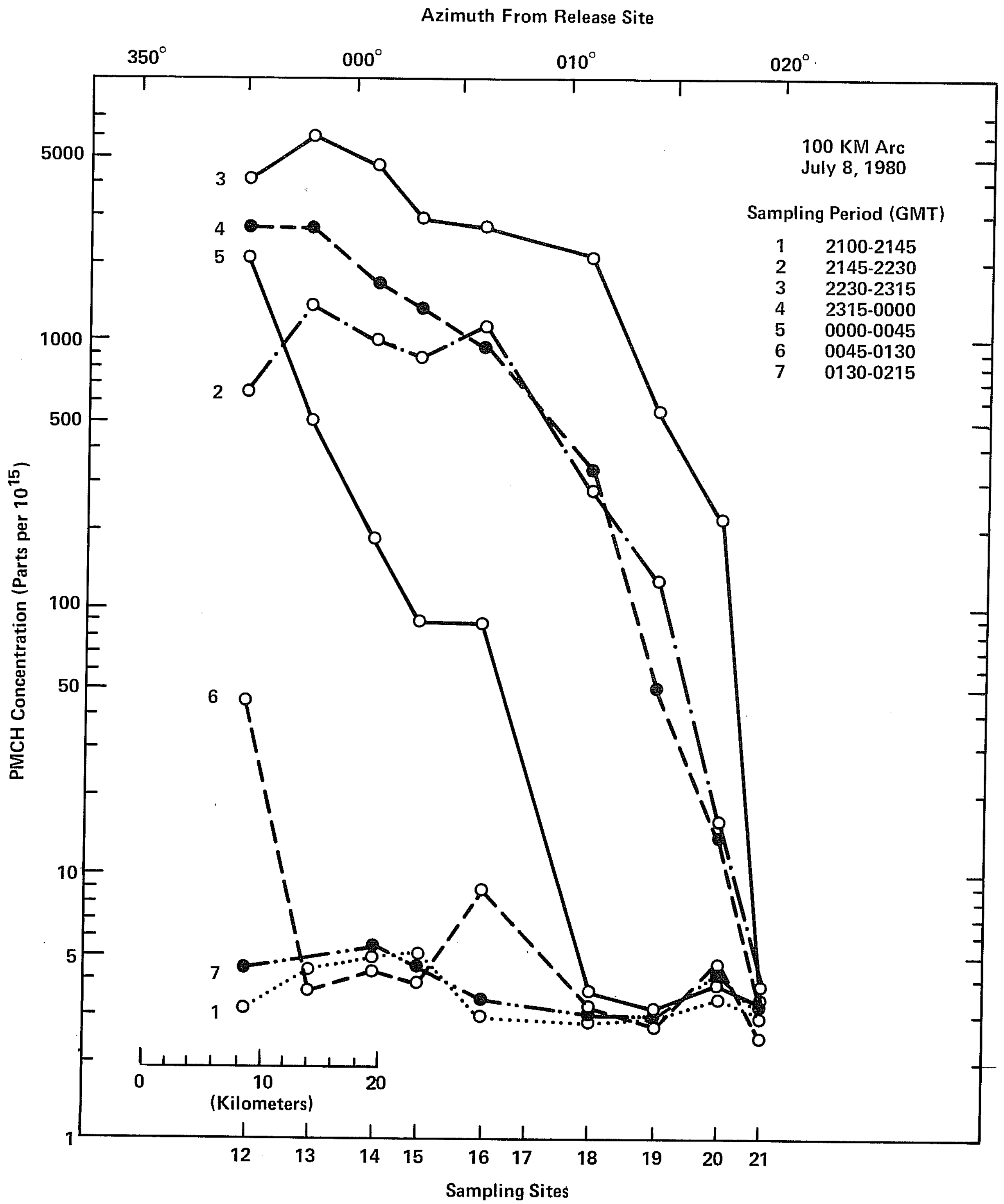

Figure 10. Average 45-min PMCH concentrations along the 100 km arc from the July 8 experiment.

per 10^{15}. The PDCH results from the BATS sequential sampler at Site 20 for the 2230 to 2315 GMT sampling period (see Table 8) show an average PDCH concentration of 238 parts per 10^{15}, in very good agreement with the Dual-Trap sampler.

Table 9. Dual-Trap Sampler Results at Site 20 (100 km Arc), July 8, 1980.

Sample Mid-Time (GMT)	PDCH Parts per 10^{15}
2227	60
2231	--
2236	180
2241	250
2246	660
2251	320
2255	400
2300	280
2304	160
2309	45
2314	35

A single whole-air bag sample for the entire sampling period was collected at each BATS sampling site. Laboratory analysis of aliquots from these samples, performed at BNL, indicated nearly all were severely contaminated and could not be used. It appears that the contamination (concentrations of SF_6, PMCH, and PDCH all were too high) most likely occurred while the aliquots (in small plastic bags) were stored at the BNL laboratory. Pin-hole leaks in the bags could have allowed a slow penetration of laboratory air which often has very high concentrations of all three tracers. Fortunately, aliquots from some of the same whole-air samples, taken by LASL for analysis, showed no evidence of contamination. Comparison of their results with the BATS data at the same sites is shown in Section 5.4.

3.5.2 Aircraft samples

Tracer concentrations measured on three passes over the flight path shown in Figure 2 are given in Table 10. Figure 11 shows the average PMCH concentrations on each segment of the flight path (solid bars) along with the average PMCH measurements obtained at the ground with the BATS samplers at about the same time (2230-0000 GMT). Concentrations aloft are quite comparable to those at the ground.

None of the PMCH data along segments A-B and E-F were usable because of sample contamination. However, the Methane-21 analyses (Table 10) showed background concentrations along these segments. The reported SF_6 concentrations are probably very close to background as well. Other analyses done at LASL suggest that

Table 10. Airborne Whole-Air Sample Concentrations (parts per 10^{15}).

Sampling Time (GMT) (July 8, 1980)	PMCH(1)	PDCH(1)	SF_6(2)	Me-21(2)
		Path A to B		
2342-2346	?	?	1200	B
2348-2353	?	?	1300	B
		Path B to C		
2302-2305	990	835	3600	8.87
2337-2342	930	985	3100	6.21
2353-2357	880	810	3900	6.87
		Path C to D		
2306-2311	3200	3300	12700	36.6
2332-2337	2800	2400	8500	21.8
2357-0002	5400	4600	14500	29.6
		Path D to E		
2311-2316	1300	1400	4300	9.92
2327-2332	?	?	2100	3.65
0002-0007	?	?	1600	1.14
		Path E to F		
2316-2321	?	?	1200	B
2324-2327	?	?	1300	B
0007-0012	?	?	1300	B

(1) BNL analysis.

(2) LASL analysis.

? Bad data (contamination).

B Background concentration.

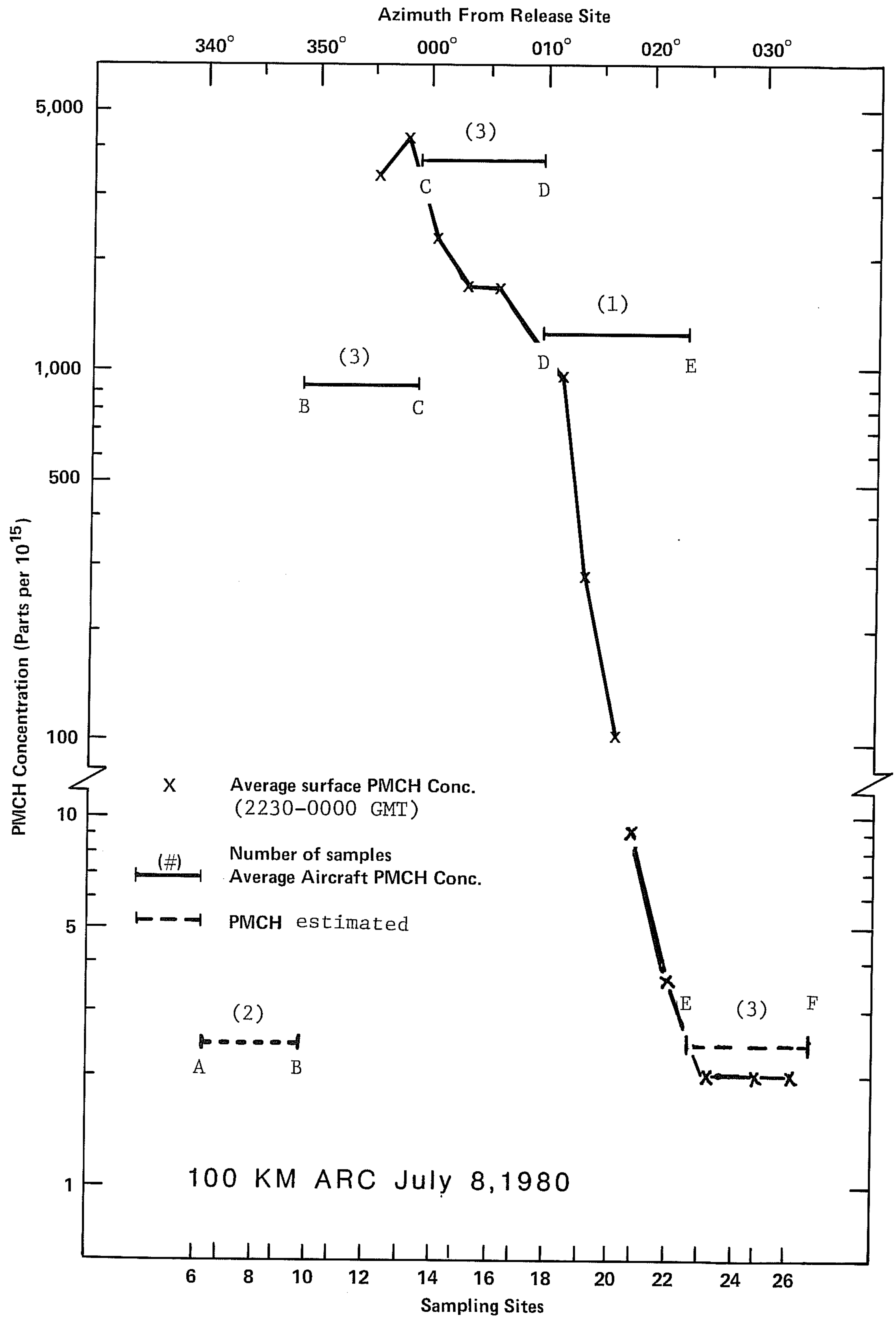

Figure 11. Comparison of PMCH concentrations aloft with surface concentrations.

SF_6 values on the order of 1100×10^{-15} obtained with their analyzer, are actually background values. Therefore, PMCH is estimated to be close to background (2.5 parts per 10^{15}) along segments A-B and E-F (dashed bars). The aircraft samples suggest that only a small portion of the plume extended west of Site 12, where no surface samplers were deployed.

The whole-air samples obtained on this flight also provided critical data for intercomparison of PFT's, heavy methanes and SF_6 measurements (see Section 5.4).

About half of the 600 km aircraft samples have been analyzed to date and all show only background levels.

3.5.3 600 km surface samples

Forecast trajectories based on 1200 GMT (July 8) wind data indicated that a tracer release starting at 1900 GMT would arrive at the 600 km arc at about 1300 GMT (July 9) with the centerline of the plume crossing over Site 20 (Hamilton, MO). All sampling sites (note that Site 8 had been eliminated) along the 600 km arc (Figure 3) were alerted to start sampling at 0800 GMT (July 9), five hours before the expected arrival time. A low level wind jet developed during the night transporting the tracer material faster than expected and further to the west.

The 3-hour sample concentrations along the 600 km arc are given in Table 11. Sites that are not listed (14, 21, 22) failed to obtain samples.

The PMCH concentrations for the first 6 sampling periods are shown in Figure 12. The peak plume concentrations arrived at about the time sampling commenced. The plume centered between Site 9 (Firth, NE) and Site 15 (Skidmore, MO). By 2300 GMT (sampling period 6) the PMCH at all sites was near the background level of about 2 parts per 10^{15}. Sampling sites east of Site 19 are not included in this figure since all samples at those sites showed background levels during the first 6 sampling periods.

The entire record of PMCH concentrations at all sites between July 9 (0800 GMT) and July 11 (2000 GMT) along the 600 km arc is shown in Figure 13. The ordinate shows the sampling sites plotted as a function of azimuth from the release site.

Solid dots indicate a measured PMCH concentration less than 3 parts per 10^{15} (for all practical purposes they can be assumed to be background concentrations) while crosses indicate concentrations at or above 3 parts per 10^{15}.

The initial plume probably arrived at the 600 km arc just before sampling began at 0800 GMT on July 9 with a duration of about 15 hours (2300 GMT, July 9) before background levels are seen at all locations. Background concentrations are seen for the next 15 hours, whereupon the July 11, 1400 to 1700 GMT samples (about 40 hours after release) show a secondary plume arriving at the 600 km arc.

The maximum concentrations of this secondary plume are about two orders of magnitude lower than the initial plume but they cover a much larger area. Although PDCH concentrations are close to background (26×10^{-15}) they confirm the presence of the secondary plume. The duration of this plume on the arc was about 30 hours. At present we are not sure whether this is a return of the initial plume or, possibly, tracer material that lagged behind the main plume. These data provide an interesting meteorological case study and will be investigated further.

TABLE 11

600 KM ARC

TRACER CONCENTRATIONS (PARTS PER 10^{15})

STATION	A		01		02		03	
START TIME(GMT)	PMCH	PDCH	PMCH*	PDCH*	PMCH	PDCH	PMCH	PDCH
JULY 09								
0800	2.8	29	2.0	21	3.6	28	3.7	26
1100	2.7	27	2.0	19	3.5	29	2.3	25
1400	2.7	27	1.7	18	3.1	27	2.3	26
1700	2.4	26	1.7	17	2.8	22	2.2	24
2000	2.5	23	1.7	17	2.4	21	3.1	28
2300	-	-	1.5	15	2.4	21	-	-
JULY 10								
0200	-	-	1.7	16	2.3	22	-	-
0500	-	-	1.7	16	2.3	24	2.8	29
0800	-	-	1.6	17	2.3	20	-	-
1100	-	-	1.5	16	2.6	24	-	-
1400	-	-	1.6	14	2.4	23	-	-
1700	-	-	1.8	15	2.1	21	-	-
2000	-	-	1.4	15	2.5	23	-	-
2300	-	-	1.6	16	2.3	19	-	-
JULY 11								
0200	-	-	2.2	16	5.0	23	-	-
0500	-	-	2.6	13	5.4	22	-	-
0800	-	-	2.0	17	3.2	25	-	-
1100	-	-	1.8	15	2.6	24	-	-
1400	-	-	1.8	17	2.2	20	-	-
1700	-	-	1.6	16	2.2	21	-	-

STATION	04		05		06		07	
START TIME(GMT)	PMCH	PDCH	PMCH	PDCH	PMCH	PDCH	PMCH	PDCH
JULY 09								
0800	2.6	30	-	-	17.2	37	3.2	30
1100	2.6	30	-	-	10.5	70**	2.8	32
1400	2.7	30	-	-	2.6	28	-	-
1700	2.6	28	2.3	22	2.6	27	2.8	27
2000	2.5	27	2.9	29	2.9	26	2.4	28
2300	2.3	28	2.9	29	3.0	26	3.2	27
JULY 10								
0200	2.5	28	2.8	31	2.4	27	2.3	27
0500	2.5	29	2.7	32	2.6	27	2.4	28
0800	2.5	28	2.8	33	-	-	2.3	28
1100	2.4	28	2.7	31	3.1	28	2.5	28
1400	2.4	28	2.7	32	2.6	27	3.3	29
1700	-	-	2.4	31	3.5	27	8.2	31
2000	2.4	27	2.9	30	3.8	27	10.1	34
2300	3.4	29	3.4	30	6.0	29	9.8	34
JULY 11								
0200	8.6	33	6.4	34	9.0	32	4.0	29
0500	5.0	31	3.9	32	6.6	30	5.6	30
0800	3.2	30	2.5	30	4.0	29	4.8	30
1100	2.5	29	2.9	30	3.2	28	2.7	28
1400	2.4	30	2.4	30	2.7	28	2.4	26
1700	2.5	30	2.4	30	2.5	27	2.3	26

\- NO DATA

* CONCENTRATIONS TOO LOW (DESORPTION PROBLEM).

** CONCENTRATION TOO HIGH.

TABLE 11 (CON'T)

600 KM ARC

TRACER CONCENTRATIONS (PARTS PER 10^{15})

STATION	09		10		11		12	
START TIME(GMT)	PMCH	PDCH	PMCH	PDCH	PMCH	PDCH	PMCH	PDCH
JULY 09								
0800	627.	598	1280.	970	1010.	710	900.	700
1100	63.	82	820.	600	530.	340	186.	182
1400	3.9	26	26.	44	164.	106	99.	108
1700	3.2	24	2.7	25	28.	34	32.	54
2000	2.6	22	3.6	25	5.3	18*	4.1	29
2300	2.7	25	2.8	24	2.4	13*	2.6	27
JULY 10								
0200	2.2	25	2.8	25	2.5	19*	2.6	28
0500	2.3	25	2.8	25	2.4	11*	2.6	28
0800	2.3	25	2.8	26	2.2	9*	2.6	28
1100	2.4	25	2.7	27	2.2	9*	2.6	28
1400	2.6	25	2.6	26	2.4	12*	-	-
1700	3.2	26	4.3	26	3.8	9*	3.3	28
2000	-	-	4.5	26	3.0	6*	2.8	27
2300	4.1	25	5.1	28	3.4	9*	2.9	27
JULY 11								
0200	6.2	27	5.7	29	-	-	-	-
0500	5.0	26	5.3	29	-	-	6.5	31
0800	-	-	4.2	29	-	-	3.4	29
1100	2.3	25	2.5	26	-	-	2.7	29
1400	2.2	24	2.3	26	-	-	2.6	28
1700	2.1	23	2.4	25	-	-	2.4	27

STATION	13		15		16		17	
START TIME(GMT)	PMCH	PDCH	PMCH	PDCH	PMCH	PDCH	PMCH	PDCH
JULY 09								
0800	980.	790	16.	37	4.8	29	2.5	25
1100	500.	420	2.6	26	2.5	26	2.4	25
1400	350.	310	4.5	26	4.3	27	2.9	25
1700	66.	83	11.	31	6.4	29	3.0	25
2000	-	-	6.4	27	5.7	28	3.2	24
2300	-	-	2.5	24	2.7	24	2.5	24
JULY 10								
0200	-	-	2.5	25	2.6	24	2.4	25
0500	2.9	28	-	-	2.3	24	2.4	24
0800	2.2	27	2.4	25	2.3	24	2.5	25
1100	2.4	28	-	-	2.2	24	2.5	27
1400	7.9	32	5.5	27	13.	33	10.	34
1700	16.	39	11.	31	10.	32	12.	35
2000	6.8	31	7.2	28	8.1	30	9.3	33
2300	7.0	31	7.2	28	7.0	21*	7.5	31
JULY 11								
0200	7.9	33	7.5	29	7.3	29	8.8	33
0500	10.	35	8.1	29	7.6	29	9.1	33
0800	8.4	35	7.9	30	8.1	29	8.5	33
1100	7.3	34	5.9	28	7.6	29	8.2	33
1400	6.3	33	2.8	24	3.4	25	3.3	27
1700	-	-	2.4	23	6.2	28	-	-

- NO DATA

* VALUES UNCERTAIN DUE TO LAB ANALYZER PROBLEMS.

TABLE 11 (CON'T)

600 KM ARC

TRACER CONCENTRATIONS (PARTS PER 10^{15})

STATION	18		19		20		23	
START TIME (GMT)	PMCH	PDCH	PMCH	PDCH	PMCH*	PDCH*	PMCH	PDCH
JULY 09								
0800	2.4	27	2.6	28	1.8	18	2.6	28
1100	2.3	26	2.6	28	1.7	18	2.5	23
1400	2.5	27	2.5	27	2.4	22	2.4	27
1700	-	-	2.5	27	2.9	24	2.5	26
2000	-	-	2.4	26	2.4	23	2.3	26
2300	-	-	2.4	27	2.3	22	2.3	25
JULY 10								
0200	-	-	2.4	27	2.2	22	2.4	26
0500	-	-	2.4	28	2.0	20	2.4	27
0800	-	-	2.4	28	2.1	22	2.4	27
1100	-	-	2.5	28	2.1	22	2.4	27
1400	-	-	5.1	29	2.3	21	2.4	27
1700	-	-	10.	33	2.4	22	2.3	26
2000	-	-	6.7	30	1.6	14	2.3	26
2300	-	-	7.4	31	2.4	23	2.3	26
JULY 11								
0200	-	-	10.	35	8.7	29	2.5	27
0500	-	-	9.2	35	9.3	31	5.4	30
0800	-	-	9.7	34	7.6	27	5.7	30
1100	-	-	8.7	33	5.3	26	2.9	27
1400	-	-	3.1	27	3.1	22	2.4	26
1700	-	-	2.6	27	2.4	20	2.4	26

STATION	24		25		26		27	
START TIME (GMT)	PMCH	PDCH	PMCH	PDCH	PMCH	PDCH	PMCH	PDCH
JULY 09								
0800	2.0	27	2.5	27	2.2	-	-	-
1100	2.0	27	2.7	28	2.2	-	2.6	26
1400	2.0	28	2.6	28	2.2	-	2.6	27
1700	2.0	28	2.5	25	-	-	2.4	26
2000	2.1	28	2.4	25	2.1	-	2.4	27
2300	2.1	27	2.4	26	-	-	2.4	26
JULY 10								
0200	2.0	26	2.5	27	1.9	-	2.5	27
0500	2.0	25	2.5	28	2.1	-	2.5	27
0800	2.1	26	2.6	28	2.1	-	2.5	27
1100	2.1	27	2.6	29	2.2	-	-	-
1400	2.1	27	2.4	28	2.0	-	-	-
1700	2.1	27	2.5	27	1.9	-	-	-
2000	2.1	27	2.4	27	1.9	-	-	-
2300	1.9	26	2.4	28	1.9	-	-	-
JULY 11								
0200	1.8	24	2.7	29	3.0	-	-	-
0500	2.0	25	4.1	30	5.7	-	-	-
0800	2.1	26	2.6	29	-	-	-	-
1100	4.4	29	2.5	29	-	-	-	-
1400	7.9	33	2.4	28	2.4	-	-	-
1700	9.3	34	2.4	28	2.2	-	-	-

\- NO DATA

* VALUES UNCERTAIN, SAMPLE VOLUMES HAD TO BE ESTIMATED.

TABLE 11 (CON'T)

600 KM ARC

TRACER CONCENTRATIONS (PARTS PER 10^{15})

STATION	28 PMCH	28 PDCH	29 PMCH	29 PDCH	30 PMCH	30 PDCH	31 PMCH	31 PDCH
START TIME(GMT)								
JULY 09								
0800	2.3	27	2.5	28	2.0	27	2.9	25
1100	2.7	29	2.5	29	2.4	29	3.3	26
1400	2.0	25	2.4	29	-	-	2.8	26
1700	2.2	25	2.3	28	1.9	26	2.9	22
2000	2.1	25	2.5	28	1.9	25	3.1	25
2300	2.1	25	2.5	29	1.9	26	2.8	27
JULY 10								
0200	2.3	28	2.5	29	2.0	27	2.5	28
0500	2.3	28	2.4	29	-	-	2.7	28
0800	2.3	28	2.5	30	2.0	27	2.6	27
1100	2.2	26	2.5	30	2.1	27	3.3	27
1400	2.2	26	2.6	29	2.0	27	2.6	27
1700	2.0	25	2.8	29	2.0	26	2.6	27
2000	2.0	23	2.4	29	2.0	26	2.6	27
2300	1.9	22	2.5	28	2.0	26	2.6	27
JULY 11								
0200	3.1	24	2.6	29	2.0	26	2.7	28
0500	4.6	24	2.7	30	2.2	27	2.8	28
0800	3.3	22	3.0	31	2.3	28	2.8	29
1100	1.9	23	2.8	30	2.2	27	2.8	29
1400	1.7	21	2.5	29	2.1	27	2.7	27
1700	1.7	21	2.7	30	2.1	26	2.7	27

STATION	32 PMCH	32 PDCH	33 PMCH	33 PDCH	34 PMCH	34 PDCH	35 PMCH	35 PDCH
START TIME(GMT)								
JULY 09								
0800	2.8	30	2.6	27	3.4	27	2.3	30
1100	2.8	30	2.6	28	2.9	27	2.4	30
1400	2.7	30	2.6	26	2.6	26	2.5	29
1700	2.3	29	2.4	26	2.6	25	-	-
2000	2.6	29	2.5	26	2.5	25	2.3	29
2300	2.6	29	2.5	26	2.6	25	2.3	30
JULY 10								
0200	2.9	29	2.4	25	2.7	27	2.4	30
0500	2.7	30	2.6	27	2.7	26	2.4	30
0800	2.7	30	2.5	28	2.9	26	2.3	30
1100	2.8	31	2.6	28	2.8	27	2.5	30
1400	2.7	30	2.7	28	2.7	26	2.5	30
1700	2.7	30	3.3	33	2.6	26	-	-
2000	2.6	29	2.6	27	2.3	23	-	-
2300	2.6	29	2.5	27	2.6	25	-	-
JULY 11								
0200	2.7	30	2.5	28	2.6	25	-	-
0500.	2.8	30	2.6	28	2.7	26	-	-
0800	2.6	30	2.6	29	2.6	24	-	-
1100	2.7	30	2.7	29	-	-	-	-
1400	2.7	30	3.1	29	2.7	26	-	-
1700	2.6	29	2.5	28	2.5	24	-	-

- NO DATA

TABLE 11 (CON'T)

600 KM ARC

TRACER CONCENTRATIONS (PARTS PER 10^{15})

STATION	36		37		38	
START TIME(GMT)	PMCH	PDCH	PMCH	PDCH	PMCH	PDCH
JULY 09						
0800	2.1	26	2.6	27	-	-
1100	2.0	26	2.3	27	2.1	27
1400	2.0	25	2.3	26	2.0	26
1700	2.0	26	2.5	27	1.8	26
2000	2.0	26	2.1	28	1.7	24
2300	2.0	26	2.6	27	1.8	24
JULY 10						
0200	2.2	25	2.0	26	1.9	25
0500	2.1	26	2.3	26	2.0	25
0800	2.1	26	2.0	28	2.4	31
1100	2.2	26	2.6	26	2.0	25
1400	2.2	26	2.8	26	2.0	24
1700	2.0	26	2.5	26	1.9	24
2000	1.9	26	2.7	28	1.8	25
2300	1.8	23	2.7	27	1.9	25
JULY 11						
0200	2.1	24	2.6	30	2.0	26
0500	2.0	24	2.2	27	2.0	26
0800	1.9	23	2.6	34	2.2	27
1100	2.0	25	2.8	30	2.1	26
1400	2.0	24	-	-	2.0	25
1700	1.9	24	-	-	1.9	25

- NO DATA

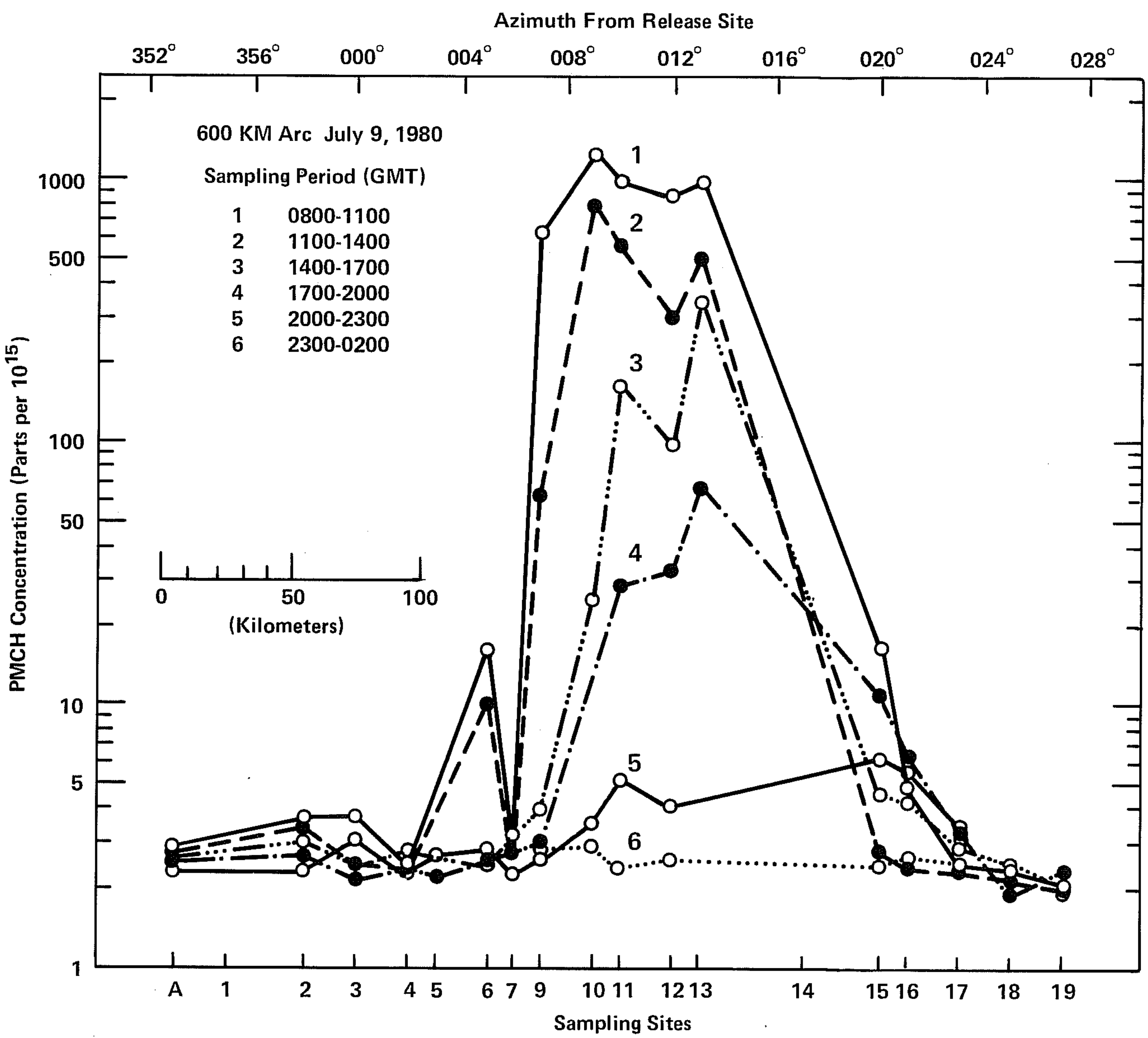

Figure 12. Average 3-hour PMCH concentrations along the 600 km arc.

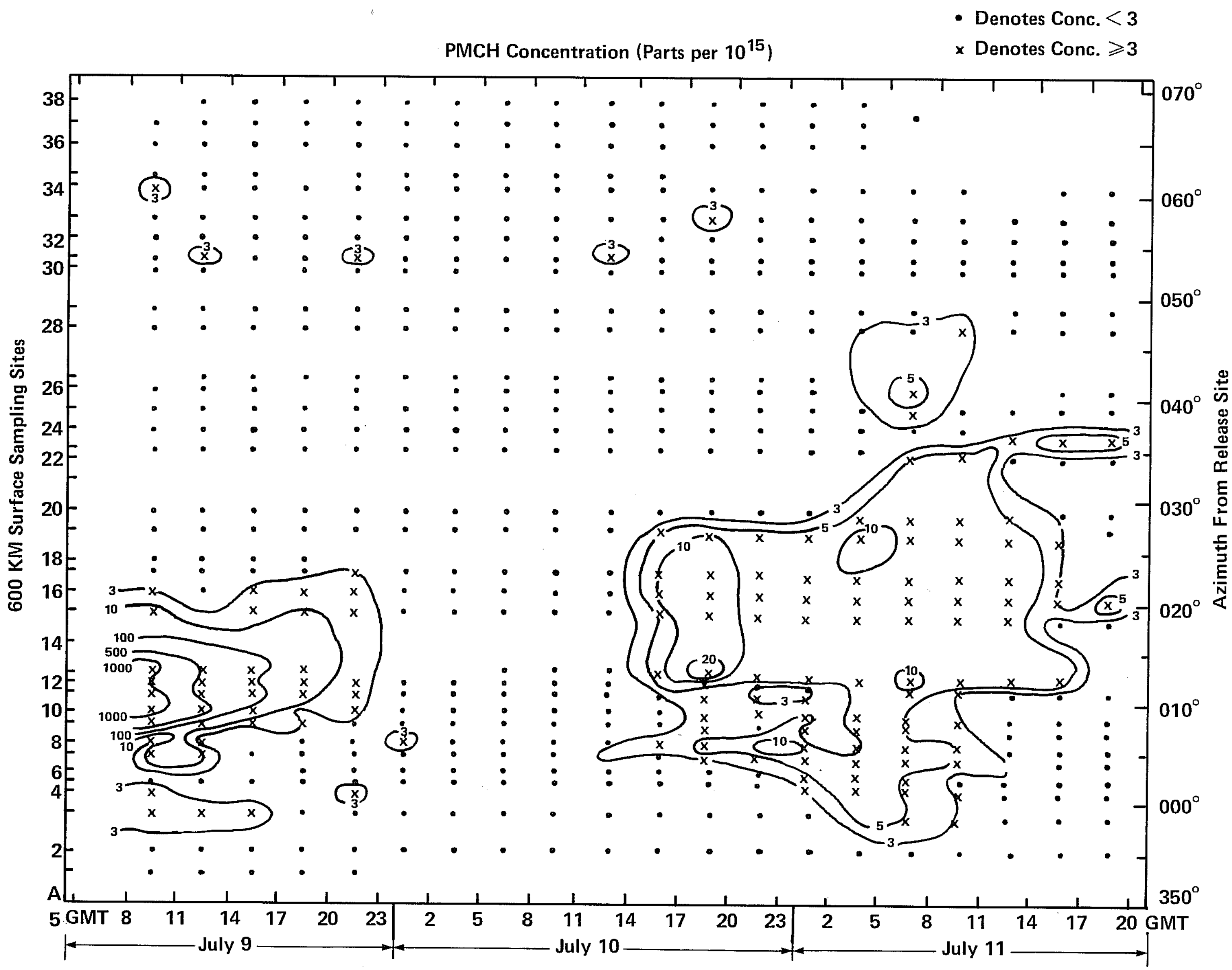

Figure 13. Average 3-hour PMCH concentrations along the 600 km arc for the period July 9, 0800 GMT to July 11, 2000 GMT.

4. 100 KM EXPERIMENT

A second, more limited, tracer experiment was conducted on July 11, 1980 to provide another test of the perfluorocarbon system.

4.1 Tracer Release

The two perfluorocarbons and SF_6 were released over a 3-hour period (1900-2200 GMT) using the same release systems at the same site in the first experiment. Release amounts, shown in Table 12, were calculated to produce concentrations well above the detection limits at the 100 km arc. Also shown are the tracer release ratios (by volume).

Table 12. Tracer Releases on July 11, 1980.

Tracer	Release Amount (kg)
PMCH	21
PDCH	26
SULFUR HEXAFLUORIDE	283

Tracer Release Ratios (by Volume)

PMCH/PDCH:	0.91
SF_6/PMCH:	33
SF_6/PDCH:	30

4.2 Sampling Array

In this experiment, sampling was done only at 100 km downwind of the release site, using the same array as in the first experiment. Based on the latest trajectory forecast, three EML sampling teams deployed the BATS sequential samplers to Sites 13-30. The tracer release began at 1900 GMT (2 PM) and the samplers were set to start at 2200 GMT (5 PM) and take nine 45-minute samples. The same samplers were used in both experiments with sampling tubes 1-10 being exposed in the July 8 experiment and tubes 12-20 exposed on July 11. As in the first experiment, a whole-air sampler was co-located with each sequential sampler to collect a single sample over the entire period for comparison of SF_6 and perfluorocarbon concentrations.

4.3 Meteorology

As shown in Figure 14, on July 11 the broad area of high pressure continued to dominate most of the U.S. The wind flow in the boundary layer over the 100 km experimental area remained from the south-southwest.

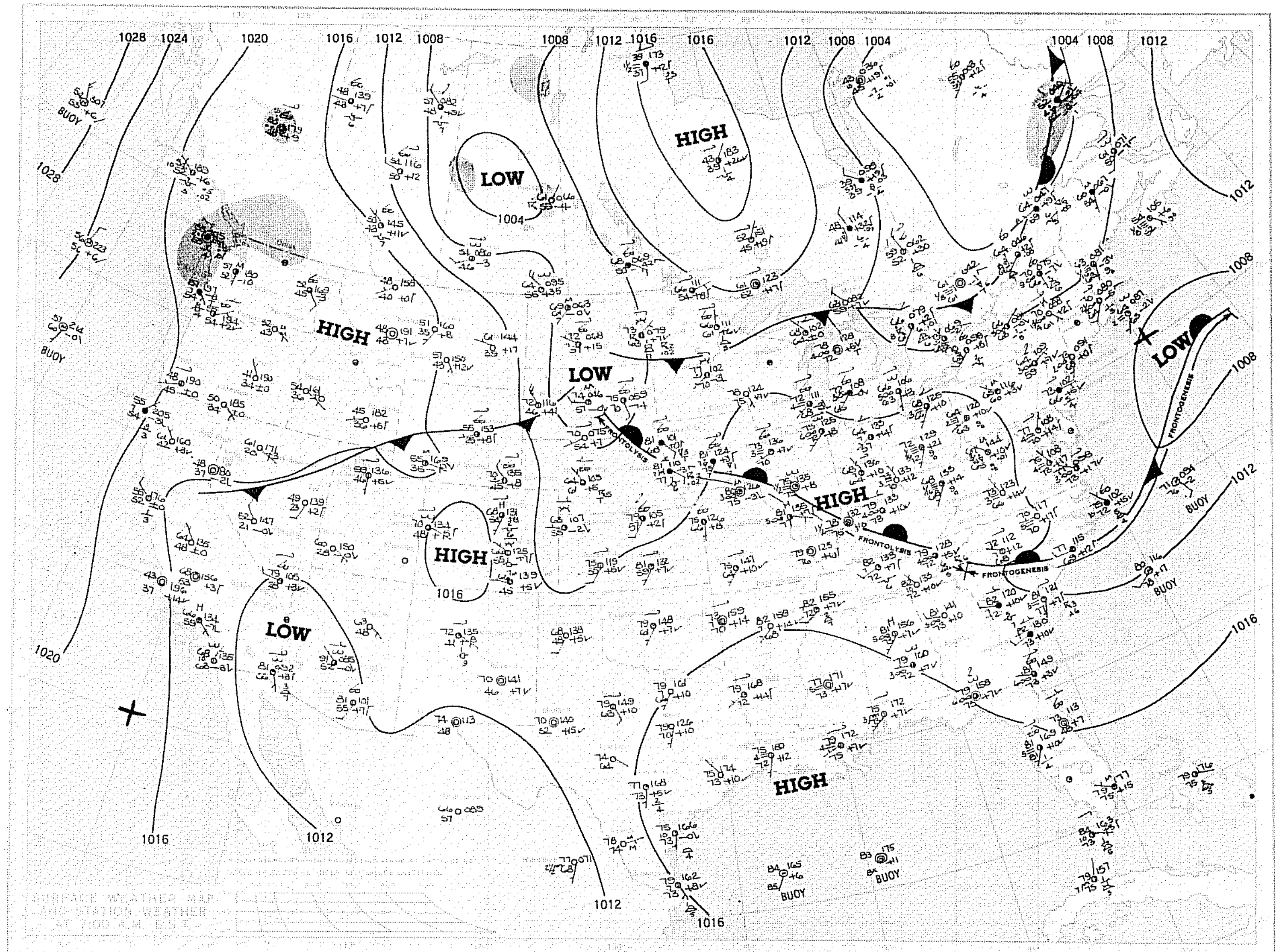

Figure 14. Surface weather map for 1200 GMT, Friday, July 11, 1980.

4.3.1 Special rawinsonde observations

Special rawinsonde observations up to 500 mb were again taken at Tinker AFB starting on the morning of July 11. Data are given in Table 13 for observations from July 11, 1800 GMT to July 12, 0000 GMT. The calculated transport layer height (TLH) and average wind speed and direction in the layer are given for each sounding.

4.3.2 Post-facto tracer trajectories

Tracer trajectories shown in Figure 15 were calculated for the start and end of the release period using the Tinker AFB soundings. Since the plume was still passing over the 100 km arc at the time of the last Tinker sounding, an average wind of 180 deg and 6 m/sec was estimated to complete the 2200 GMT trajectory. The estimated plume width is shown in the figure. The calculated plume position and arrival time at the 100 km arc agree well with the measured tracer data (see Figure 16).

4.4 Sampling Results

The BATS sequential samplers were installed at Sites 13 through 30. The 45-minute tracer concentrations are given in Table 14. Data for sites not listed were lost due to sampler malfunction (Site 13) or analysis problems (Site 25).

The PMCH results are plotted in Figure 16. The initial sampling period (2200-2245 GMT) showed concentrations near background at all sampling locations. The next sampling period (2245-2330 GMT) shows concentrations at Sites 14 through 24 at about 50 times background levels. During the third sampling period (2330-0015 GMT) peak plume concentrations are reached at Sites 14 through 21 with decreasing concentrations to the east.

During subsequent sampling periods, an orderly decrease in the PMCH concentration occurs at all sampling sites and by the eighth sampling period (0315-0400 GMT) the concentrations are approaching background levels again.

Since there was no sampling west of Site 14, the plume width could not be determined but the trajectories (Figure 15) suggest that the plume did not extend much beyond Site 14.

Whole-air samples again were unusable due to contamination which apparently occurred in the BNL Laboratory.

5. EVALUATION OF PERFLUOROCARBON TRACER SYSTEM

These experiments were designed primarily as a proof-test of the perfluorocarbon tracer system. Our evaluation will focus on the performance of the release, sampling, and analysis systems, and the reliability of the tracer concentration measurements.

5.1 Tracer Release

The two perfluorocarbons were released via separate, but identical, aerosol spray mechanisms. In both experiments, 3-hour releases were accomplished without any problem and the actual release amounts were within 10% of the intended amounts.

TABLE 13. TINKER AFB RAWINSONDE DATA FOR THE JULY 11 EXPERIMENT.

11 JUL 80 18GMT

HT M,MSL	DIR DEG	SPD M/SEC
387	200	2.0
610	200	4.1
915	200	6.6
1220	205	7.7
1542	215	6.6
1830	225	6.1
2135	225	5.1
2440	215	4.6
2745	210	5.1
3203	185	6.1
3355	180	6.6
3660	190	5.6
4270	205	3.6

HT M,MSL	PRES MB	TEMP DEG K
387	967	309
1322	871	299
1524	850	296
2343	774	288
2454	764	290
3203	700	286
3848	647	284
5960	500	270

TLH M,MSL	DIR DEG	SPD M/SEC
2410	211	5

11 JUL 80 20GMT

HT M,MSL	DIR DEG	SPD M/SEC
387	240	4.1
610	190	6.1
915	195	6.6
1220	200	6.1
1531	195	6.1
1830	200	7.2
2135	195	5.6
2440	200	5.6
2745	210	5.6
3050	215	5.1
3193	200	5.6
3355	200	5.6
3660	210	5.1

HT M,MSL	PRES MB	TEMP DEG K
387	966	310
1531	850	297
2534	756	288
2648	746	288
3193	700	286
3323	689	286
3553	670	286
5960	500	271

TLH M,MSL	DIR DEG	SPD M/SEC
2770	197	6

11 JUL 80 22GMT

HT M,MSL	DIR DEG	SPD M/SEC
387	240	3.0
610	205	6.1
915	205	7.2
1220	210	7.7
1524	215	6.1
1830	210	6.1
2135	205	6.1
2440	210	7.2
2745	215	6.6
3186	215	6.6
3355	210	5.6
3660	220	4.4
4270	220	5.1
4880	235	3.6
5795	285	5.6

HT M,MSL	PRES MB	TEMP DEG K
387	965	311
524	950	308
1524	850	298
2664	744	287
2944	720	287
3186	700	286
3719	656	286
5950	500	270

TLH M,MSL	DIR DEG	SPD M/SEC
2850	209	6

12 JUL 80 00GMT

HT M,MSL	DIR DEG	SPD M/SEC
387	210	3.0
610	190	5.6
915	180	6.6
1220	180	6.6
1518	190	6.6
1830	195	6.6
2135	200	6.6
2440	210	7.2
2745	225	7.6
3050	235	6.6
3185	245	5.6
3660	290	4.1
4270	270	3.0
4880	240	3.6
5185	265	3.0

HT M,MSL	PRES MB	TEMP DEG K
387	964	310
1518	850	299
2581	751	288
3002	715	287
3185	700	287
3532	671	287
5950	500	271

TLH M,MSL	DIR DEG	SPD M/SEC
2830	196	6

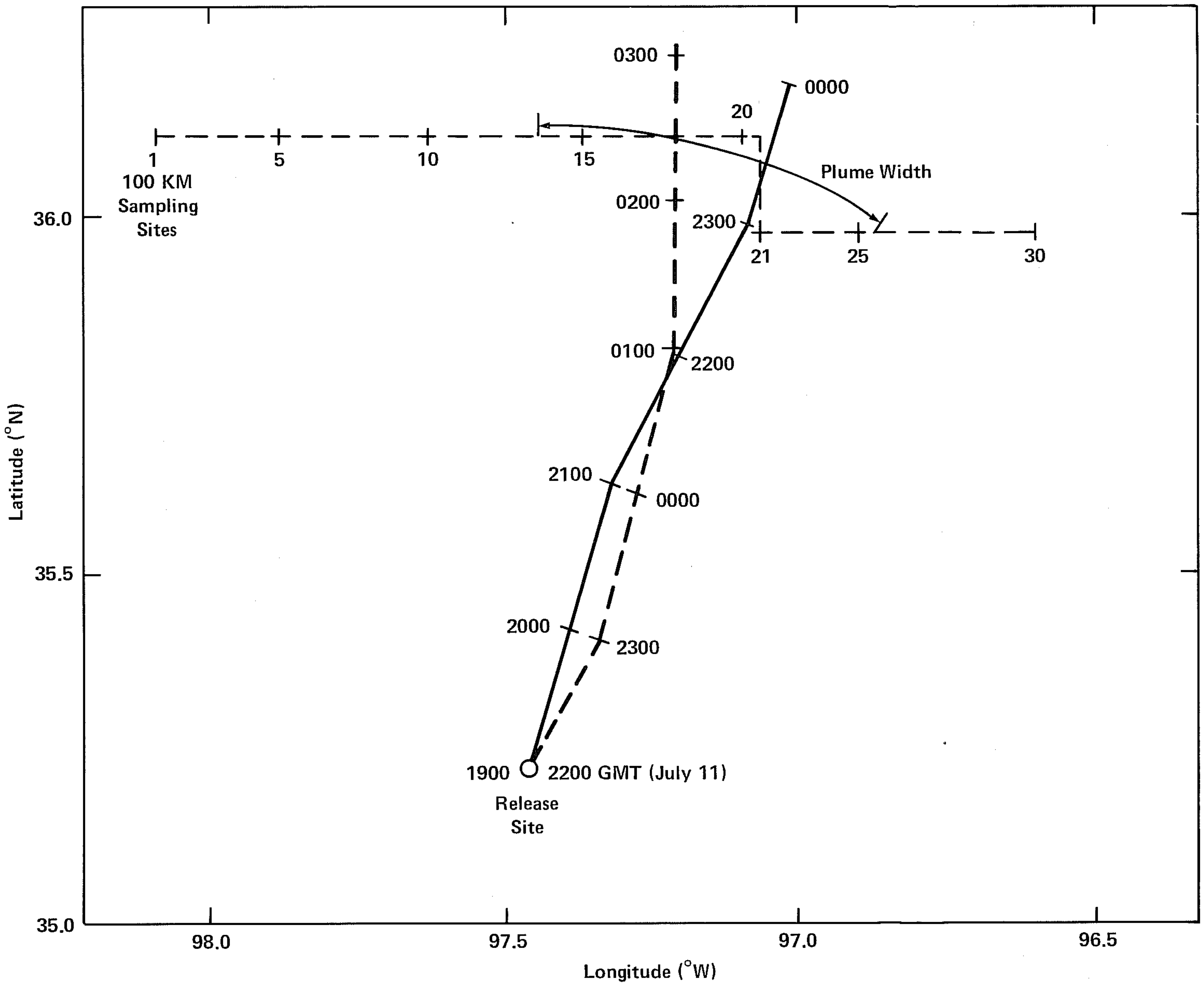

Figure 15. Calculated transport layer trajectories to the 100 km arc for the 3-hour tracer release on July 11.

TABLE 14

100 KM ARC

TRACER CONCENTRATIONS (PARTS PER 10^{15})

STATION	14		15		16		17	
START TIME(GMT)	PMCH	PDCH	PMCH	PDCH	PMCH	PDCH	PMCH**	PDCH**
JULY 11								
2200	3.6	27	3.*	26	3.8	26	2.	23
2245	38.	61	50.*	87	110.	157	12.	9
2330	270.	337	280.	337	241.	323	180.	150
JULY 12								
0015	178.	221	190.	235	142.	207	90.	70
0100	65.	97	-	-	68.	117	50.	50
0145	37.	70	1.*	70	25.	54	28.	24
0230	13.	44	2.*	38	9.5	35	12.	13
0315	5.4	34	2.*	26	5.3	30	-	-
0400	-	-	3.*	25	4.7	30	-	-

STATION	18		19		20		21	
START TIME(GMT)	PMCH	PDCH	PMCH	PDCH	PMCH	PDCH	PMCH	PDCH
JULY 11								
2200	4.5	33	2.*	36	4.2	27	3.5	28
2245	75.	111	40.*	74	38.	60	127.	186
2330	259.	349	330.	400	302.	357	360.	430
0015	216.	299	-	-	236.	288	126.	164
JULY 12								
0100	99.	149	-	-	66.	95	42.	71
0145	49.	87	-	-	30.	55	21.	45
0230	24.	57	-	-	23.	47	11.*	33
0315	10.	40	-	-	7.7	30	1.*	27
0400	7.1	36	-	-	-	-	11.*	25

STATION	22		23		24		26	
START TIME(GMT)	PMCH*	PDCH	PMCH	PDCH	PMCH	PDCH	PMCH	PDCH
JULY 11								
2200	10.	34	4.0	28	8.2	28	3.5	25
2245	300.	400	219.	263	56.	84	3.9	26
2330	200.	240	145.	175	76.	109	14.	37
JULY 12								
0015	100.	84	46.	67	33.	60	7.9	31
0100	40.	65	20.	40	25.	51	3.5	25
0145	20.	39	-	-	9.3	31	3.1	25
0230	-	30	6.*	25	5.5	30	3.1	24
0315	5.	30	3.*	22	5.4	28	3.3	24
0400	2.	28	9.*	24	5.2	28	3.1	24

SEE FOOT NOTE A

- NO DATA

* VALUE UNCERTAIN DUE TO CONTAMINATION IN LAB ANALYZER.

** POOR DESORPTION, CORRECTION ESTIMATED.

A SAMPLING SITES 27-30 HAD BACKGROUND PMCH AND PDCH CONCENTRATIONS IN ALL SAMPLES.

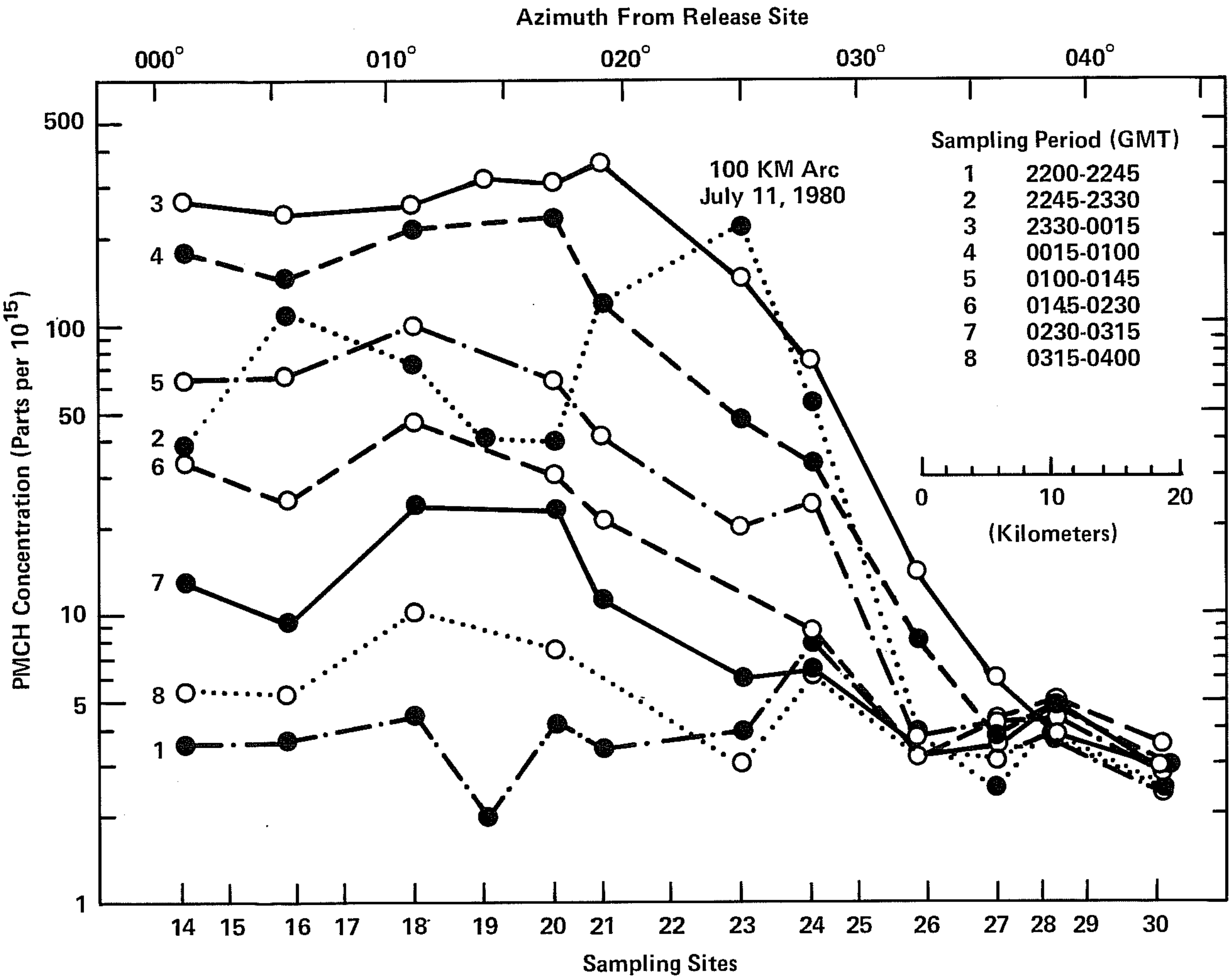

Figure 16. Average 45-min PMCH concentrations along the 100 km arc from the July 11 experiment.

A newly designed release mechanism, in which the tracers are vaporized, was not ready in time for these experiments but it was tested and used successfully in September, 1980. The new system provides more precise control and continuous recording of release rates.

5.2 BATS Sampling and Analysis System

The heart of the perfluorocarbon tracer system is the BATS automatic sequential sampler and the associated analysis apparatus.

The over-all performance of the BATS system was excellent in this first field trial. As shown in Table 15, 72% of the 1121 scheduled samples provided good tracer concentration data. Of the 28% lost, or poor data, 5% was due to human error (e.g., failure to turn on the sampler) and the remainder was about equally divided between sampler malfunctions and sample analysis problems. Sampler malfunctions were due most often to pump failures. Some units developed problems in the electronic control circuitry. Modifications to the design of the BATS sampler are under consideration to alleviate these problems.

Table 15. Performance of BATS Sampling-Analysis System.

	Number	Percent
Scheduled Samples	1121	100
Good Data	810	72
Sampling Failures	134	12
Analysis Failures	123	11
Human Error	54	5
Total Lost or Poor Data	311	28

Several problems in the analysis apparatus and procedures became evident during analysis of the large number of samples. The most troublesome was the presence of a contaminant that interferred with the PMCH chromatograph peak in many analyses. Eventually, it was discovered that the contamination was coming from a screen used in the Porapak QS trap in the analysis apparatus. The resolution of this, and other minor problems, should reduce the amount of data lost in analysis to well below the 10% level experienced in this experiment.

Another problem that complicates the determination of tracer concentrations is the non-linear response of the present electron-capture detector. Various attempts to reduce this non-linearity, which shows a change in response factor as much as 2-fold, depending on the size of the sample being analyzed, have not succeeded. Evidence in the literature suggests that the strength of the 8 mCi ^{63}Ni foil in the electron capture detector is about an order of magnitude too intense for the strongly electronegative PFTs. Lower activity foils will be substituted in an attempt to correct this problem.

5.3 Reliability of BATS Concentration Measurements

The reliability of tracer concentrations obtained with the BATS sequential samplers can be checked by comparing the PMCH and PDCH measurements. If the tracers behave identically in the atmosphere and the tracer release, sampling, and analysis systems function perfectly, the measured PMCH/PDCH concentration ratio in every sample (after backgrounds are subtracted) would be the same as the ratio of the release amounts of the two tracers. Comparison of the measured tracer ratios with the release ratio therefore provides a good test of the entire tracer system.

Figure 17 shows a plot of PMCH versus PDCH concentrations measured with the sequential samplers on the 100 km arc in the July 8 experiment. Background concentrations (2.4 parts per 10^{15} for PMCH and 26 parts per 10^{15} for PDCH) have been subtracted out. Only those 22 samples where both tracers had concentrations at least twice background were used for this comparison. When the concentrations are near background, uncertainties in the background value can have a large effect on the tracer ratio. The straight line in Figure 17 represents the tracer release ratio of 1.18. The measured mean ratio in the 22 samples is exactly what it should be and there is remarkably little scatter about the true ratio.

Very similar results were obtained at the 600 km arc (Figure 18). There are 13 samples with concentrations at least twice background and the mean measured PMCH/PDCH ratio is 1.19, again with very little deviation from the release ratio of 1.18. The inset shows a plot of PMCH versus PDCH for the highest concentrations observed during the second appearance of tracer on the 600 km arc on July 10. The PDCH concentrations were less than twice background in all of these samples. It is, therefore, not surprising that the data show more scatter. The mean ratio of 1.09 is still quite close to the 1.18 release ratio.

Many samples obtained at the 600 km arc over the 3-day period showed background concentrations. The background to be subtracted from each concentration was estimated separately from each sampler. Estimated background values varied from 2.2 to 2.5×10^{-15} for PMCH and from 24 to 28×10^{-15} for PDCH. The consistency of the background measurements attests to the good precision of tracer measurements at these levels.

Figure 19 shows a plot of PMCH against PDCH concentrations on the 100 km arc for the July 11 experiment. In this experiment there were 31 samples with concentrations at least twice background. The mean measured PMCH/PDCH ratio was 0.88, with very little scatter about the release ratio of 0.91.

In the two experiments there were a total of 66 BATS sequential samples with concentrations at least twice background. Most of the measured PMCH/PDCH ratios are within ±5% of the release ratio, all are within ±20%, over a concentration range from 20 to 5000 parts per 10^{15}. These results are excellent but they do not constitute a complete test of the BATS samplers. Any inaccuracies in sample volume or mechanical problems (e.g., timing errors) would have the same effect on both tracers. Therefore, as a further test, duplicate BATS samplers were set up at three of the sampling sites. As luck would have it, data from one sampler in each pair, were lost due to failure of the sampler or analysis problems. Some degree of independent verification of the BATS result was achieved by comparison with whole-air samples (Section 5.5).

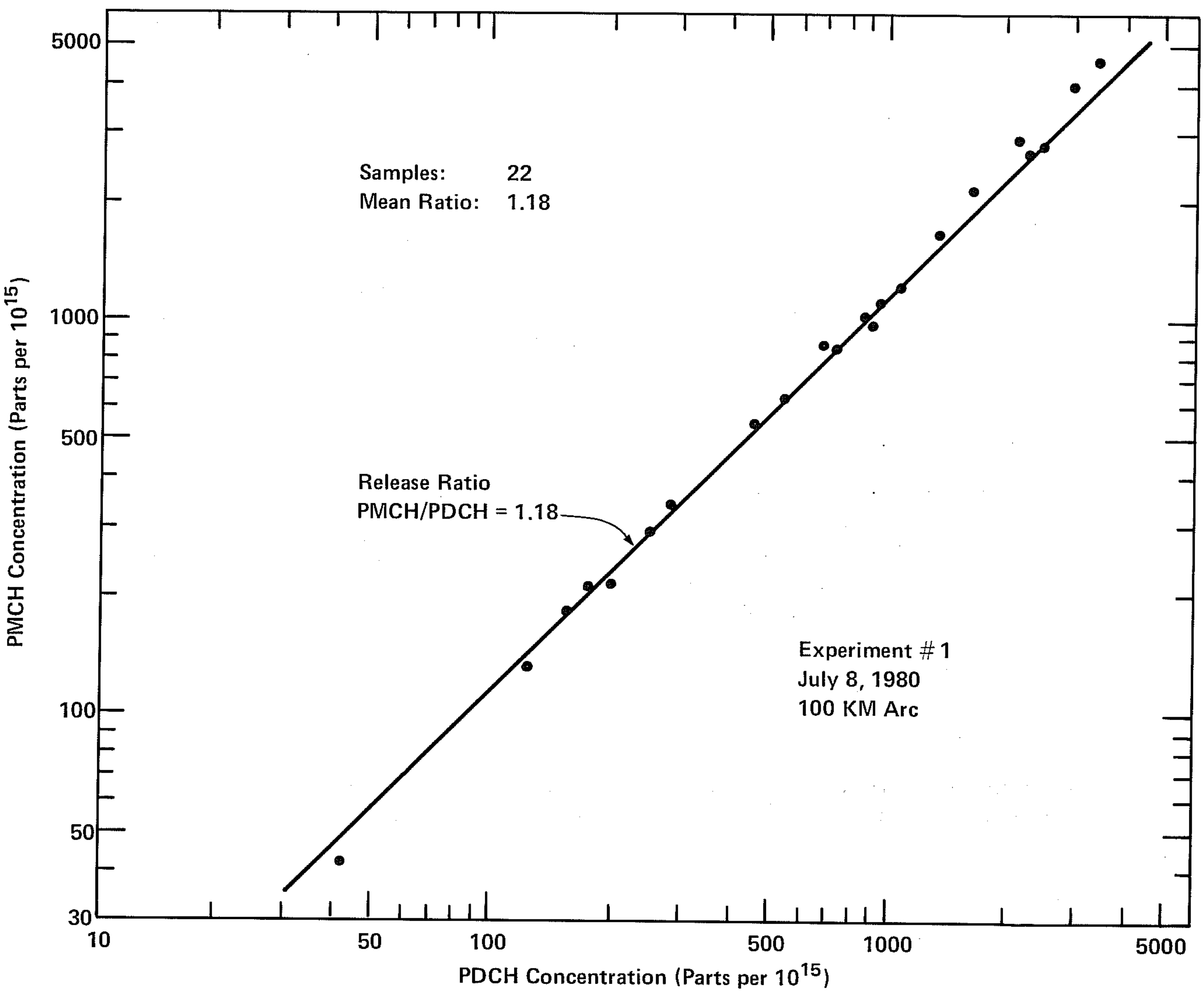

Figure 17. Comparison of PMCH and PDCH concentrations from the 100 km BATS samples on July 8.

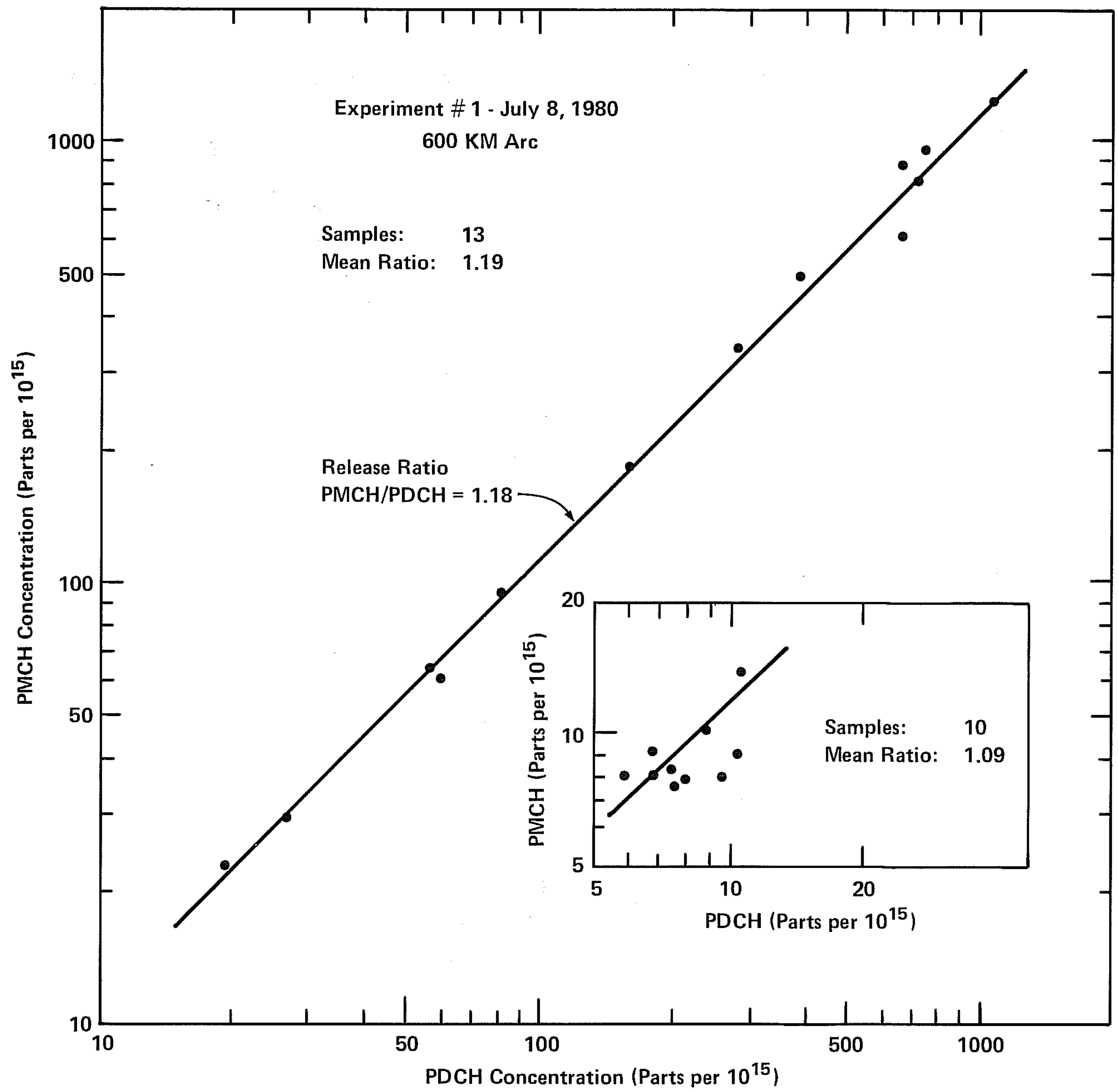

Figure 18. Comparison of PMCH and PDCH concentrations from the 600 km BATS samples.

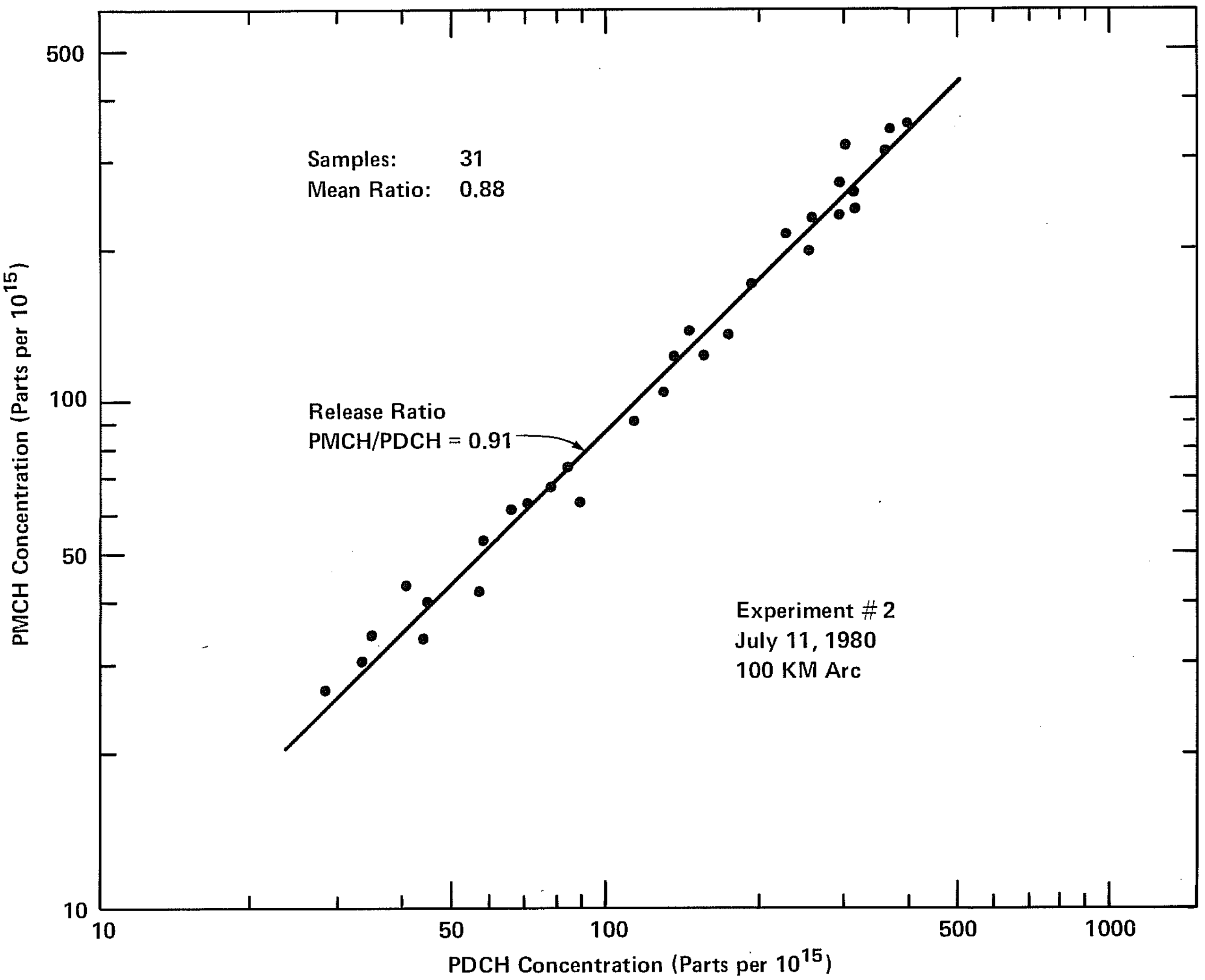

Figure 19. Comparison of PMCH and PDCH concentrations from the 100 km BATS samples on July 11.

5.4 Comparison with Other Tracers

In the July 8 experiment whole-air samples were collected in plastic bags at the 100 km sequential sampling sites, at the 600 km cryogenic sampling sites, and on the sampling flights over both arcs; in order to compare PFT, SF_6, and heavy methane tracer measurements. Unfortunately, most of the whole-air sample aliquots sent to BNL for analysis became contaminated with PFTs and SF_6 (apparently at BNL) to an extent that made them useless for tracer intercomparisons. It should be noted that the BATS sequential samplers were designed to avoid the contamination problems that had been encountered previously in handling whole-air samples.

In spite of the contamination problem, some good data have been salvaged for intercomparisons. Whole-air bag samples, analyzed for SF_6 and methane at LASL, are available for five of the BATS sampling locations on the 100 km arc. The PMCH and PDCH concentrations from the 45-minute BATS sequential samples were averaged over the time interval that the whole-air sample was collected at each location. The concentration of each tracer is shown in the upper part of Table 16. Background concentrations were subtracted from each value and tracer ratios were determined as shown in the lower portion of the table. The mean PMCH/PDCH ratio from the BATS samplers is very close to the release ratio and the individual values are within ±10% of the mean. The SF_6/Me-21 ratios from the whole-air samples are consistent though they are about 20% lower than the release ratio. The mean ratio between SF_6 from the whole-air samples and PMCH from the BATS samplers is 3.31, very close to the release ratio of 3.41 although the scatter of individual ratios is relatively large. The mean ratio between PMCH (BATS) and Me-21 (whole-air) is 115, about 15% lower than the release ratio. One reason for the discrepancy between the BATS results and the whole-air sampler results may be the failure of the whole-air sampler to pump air at a constant rate. It was discovered during the experiment that the bag sampler pumping rate was erratic, probably because it was not designed for the extreme heat encountered in this experiment. In spite of this problem, the correspondence between the BATS and whole-air sampler results is good; all measured tracer ratios are well within a factor of two of the release ratios.

Seven of the samples collected in the aircraft flight over the 100 km arc, analyzed for heavy methanes and SF_6 at LASL, were free of contamination when analyzed for PFTs at BNL. After subtraction of background values: 2.4×10^{-15} for PMCH, 26×10^{-15} for PDCH and 600×10^{-15} for SF_6 (Me-21 background is nil), the tracer concentrations were plotted in Figure 20. On the upper left, PMCH is plotted against PDCH. The PMCH/PDCH ratios are quite good in these samples with a mean value of 1.08 and little scatter about the line representing the release ratio of 1.18. On the upper right, PMCH concentrations determined at BNL are plotted against SF_6 concentrations determined at LASL. The mean SF_6/PMCH ratio in these samples is 3.08 compared to the release ratio of 3.41 and the individual sample ratios show only slightly more scatter than the PMCH/PDCH ratios. The lower graph in Figure 20 shows PMCH concentrations plotted against Me-21. The mean PMCH/Me-21 ratio is 131, very close to the release ratio of 137 and again the scatter is small. In all three comparisons shown in Figure 20, the mean of the measured tracer ratios is within 10% of the release ratio and all individual sample ratios are well within a factor of two of the release ratio.

Whole-air bag samples collected at the LASL cryogenic sampling site at Brownville, Nebraska, provide a comparison of PFT and methane tracer concentrations

Table 16. Comparison of BATS sequential samples with whole-air samples at the 100 km arc (July 8, 1980).

Site	Whole Air Bag Sampling Period (GMT)	Tracer Concentrations (parts per 10^{15}) PMCH(1)	PDCH(1)	SF_6 (2)	Me-21(2)
12	2130-0435	1030	810	3250	7.93
13	2121-0427	1090	950	3530	8.10
14	2012-0418	700	570	4030	9.37
16	2032-0401	450	410	2060	3.92
17	2001-0357	700	600	2720	5.50

(1) BATS (sequential air sampler) concentration averaged over the period of the whole air bag sample (analysis by BNL).

(2) Whole air sample (analysis by LASL).

Tracer Ratios

Site	PMCH/PDCH	SF_6/Me-21	SF_6/PMCH	PMCH/Me-21
12	1.31	332	2.58	129
13	1.17	362	2.69	134
14	1.28	366	4.93	74
16	1.15	372	3.29	113
17	1.21	385	3.04	127
Mean Ratio	1.22	363	3.31	115
Release Ratio	1.18	467	3.41	137

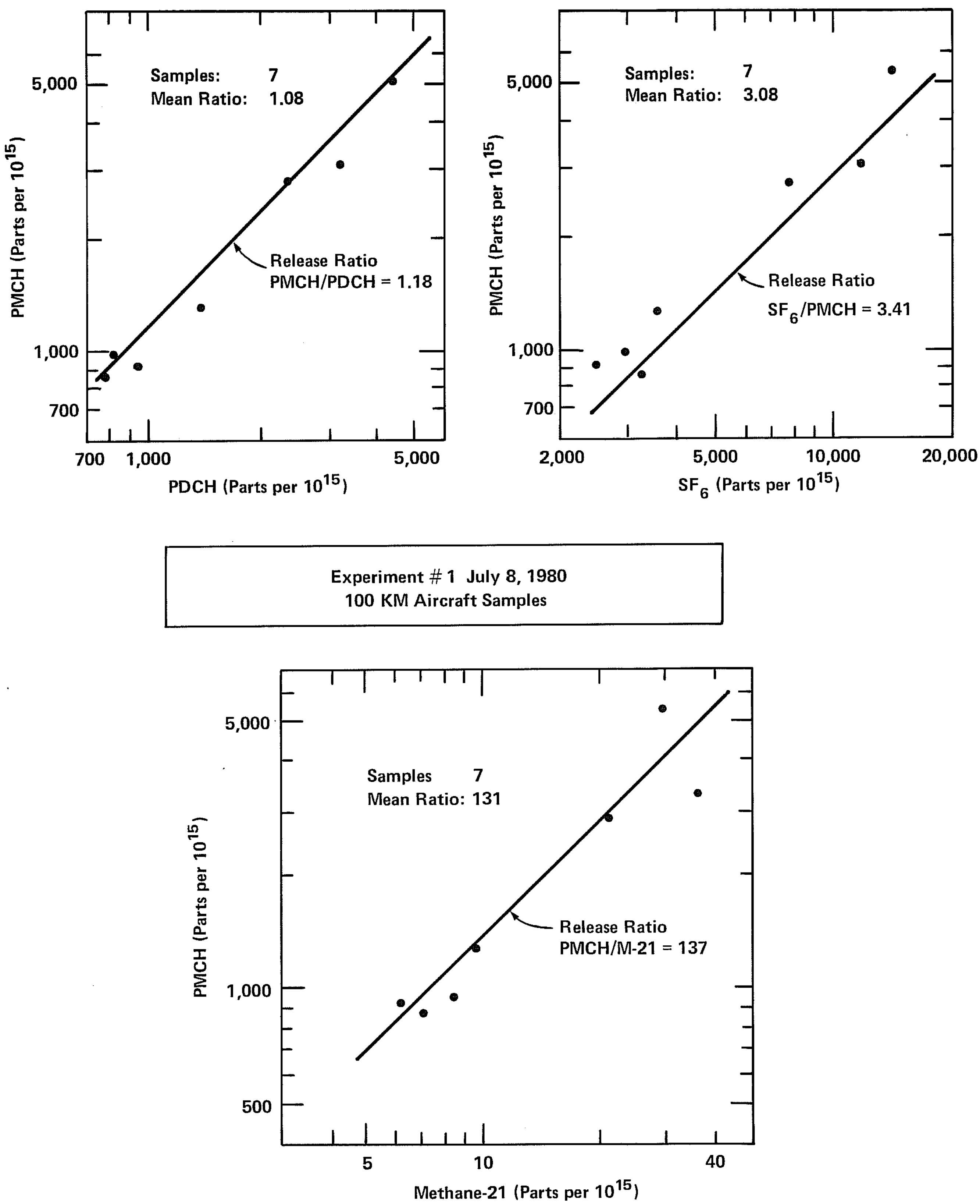

Figure 20. Comparisons of tracer concentrations in whole-air samples collected in the flight over the 100 km arc on July 8.

on the 600 km arc. The bag samples were transferred to aluminum cylinders for storage at LASL and later shipped to BNL for PFT analyses. Methane concentrations determined at LASL from the cryogenic samples and PFT concentrations determined at BNL are shown in Table 17.

The PFT/Me-21 ratios are shown in the lower part of the table along with the percent deviation of the measured ratio from the release ratio. The worst PMCH/Me-21 ratio shows a deviation of 34% and the worst PDCH/Me-21 ratio shows a deviation of 22% from the release ratio. For the four samples, the average PMCH/Me-21 ratio is 113, a deviation of 18% from the release ratio of 137. The average PDCH/Me-21 ratio is 108, a deviation of only 7% from the release ratio of 116. These results are quite good considering that the PFT samples were collected in bags and stored in cylinders for 6 months prior to analysis.

We conclude from these data that the perfluorocarbon and methane tracers behaved the same in the atmosphere, faithfully following the air motions with no significant depletion mechanism out to 600 km from the source. Considering that the heavy methane and perfluorocarbon determinations are made by totally different analysis techniques (mass spectrometry for the methane, gas chromatography followed by electron-capture detection for the PFTs) these results inspire confidence in both tracer systems.

5.5 Performance of Real-Time Samplers

The real-time continuous PFT monitor, intended for use in the sampling aircraft, was not available because of various malfunctions. Efforts to repair the instrument in the field were unsuccessful. The difficulties appear to be correctable and efforts are continuing to develop this instrument into a reliable continuous airborne monitor.

The Dual-Trap sampler functioned well and was used to provide field analyses of some of the whole-air bag samples as well as real-time tracer concentration measurements on the 100 km arc. Some difficulty was experienced in positioning the Dual-Trap sampler within the tracer plume because of shifting wind conditions at the arc. However, an excellent set of 5-min plume concentrations was obtained alongside of a BATS sampler (see Table 9). Concentrations obtained with these two samplers show very good agreement. The Dual-Trap sampler was later used extensively in the ASCOT drainage wind experiments and provided hundreds of 5-minute samples with real-time readout of PMCH and PDCH concentrations.

6. SUMMARY

These experiments have successfully demonstrated the capabilities of the perfluorocarbon tracer system and the feasibility of carrying out atmospheric transport and dispersion experiments over distances of 1000 km or more. A release of 65 kg/hr of PMCH produced concentrations at the 600 km arc almost three orders of magnitude above the background value of 2.4 parts per 10^{15}. This suggests that a PMCH release rate of about 10 kg/hr should be sufficient to provide plume measurements out to 1000 km from the release point.

Reliability of the BATS sequential samplers is judged to be very good for the first trial of a completely new system. About 12% of the 1121 scheduled samples were lost because of sampler malfunctions. Another 11% were lost in analysis.

Table 17. Sampling results and tracer comparisons at Brownville, NE (16 km east of site 13 on the 600 km arc).

Sampling Results

Sample	Cryogenic Samples: Sampling Time (GMT)	Concentrations (pp 10^{15}) Me-21	Concentrations (pp 10^{15}) Me-20	Whole-Air Bag Samples: Sampling Time (GMT)	*Concentrations (pp 10^{15}) PMCH	*Concentrations (pp 10^{15}) PDCH
13-1	1100-1320	1.39	2.45	1100-1320	208	172
13-2	1400-1620	1.58	2.92	1406-1620	142	142
13-3	1700-1920	0.92	1.69	1700-1920	89	93
13-4	2000-2235	0.40	0.72	2000-2220	47	47
13-5	2300-0120	0.04 (1)	0.07 (1)	2300-0120	0.3 (1)	5 (1)

*Background has been subtracted from the measured PMCH and PDCH concentrations.

(1) Concentrations are at or very near background.

Tracer Comparisons

Sample	Tracer Ratio PMCH/Me-21	Deviation (%)	Tracer Ratio PDCH/Me-21	Deviation (%)
13-1	150	10	124	7
13-2	90	34	90	22
13-3	97	29	101	13
13-4	117	15	117	1
Avg. Ratio	113	18	108	7
Release Ratio	137		116	

Modification of the BATS pump and relatively minor changes in the analysis apparatus should significantly improve the reliability of the BATS system.

Simultaneous measurements of PMCH and PDCH concentrations with the BATS system were remarkably consistent. The PMCH/PDCH ratios in all samples were very close to the tracer release ratio; most measured ratios were within ±5% of the release ratio.

Most of the whole-air samples, intended for comparison of PFT measurements with SF_6 and heavy methane tracers, were of no use because of contamination of the bag samples. However, a small number of samples, that could be analyzed for all five tracers, showed generally good agreement, sufficient to establish that all tracers behaved the same in the atmosphere out to 600 km.

Deployment of many samplers over the large area involved in a long-range experiment can be very costly and present difficult logistics problems. One of the objectives of this experiment was to test the feasibility of using the National Weather Service sub-station network of over 12,000 sites to deploy the BATS sequential samplers. Sub-station specialists delivered the samplers to 38 selected sites on the 600 km arc where cooperative observers, who take routine temperature and precipitation measurements for the NWS, operated the samplers. The 600 km sampling program was very successful as the cooperative observers carried out their assigned role with competence and enthusiasm. Future long-range tracer experiments should take advantage of the capability inherent in the NWS sub-station network.

7. ACKNOWLEDGMENTS

This work was supported by the Office of Health and Environmental Research, Department of Energy and the Environmental Protection Agency.

Development of the perfluorocarbon tracer system has been carried out by the Air Resources Laboratories, NOAA, in collaboration with the Dept. of Energy's Environmental Measurements Laboratory and Brookhaven National Laboratory.

We wish to acknowledge our debt to Dr. James E. Lovelock who first conceived the perfluorocarbon tracer system and designed the prototype samplers and analyzer.

The success of this experiment would not have been possible without the cooperation of the many individuals, from the different agencies and laboratories, listed at the beginning of this report.

To Dr. Edwin Kessler, Director, National Severe Storms Laboratory, we owe a debt of gratitude not only for the support he and his staff provided but also for the hospitality extended to the experimenters stationed at Norman, OK and the spirit of cooperation that prevailed.

To Dr. Harold Myers, Superintendent of the Agronomy Research Station, Oklahoma State University, we wish to express our appreciation for the assistance he and the OSU students provided in shipping, storing, and operating sampling equipment along the 100 km arc and also for providing work space at considerable personal inconvenience.

Without the excellent cooperation and dedication of the National Weather Service, and the cooperative observers listed in Table 4, this experiment would not have been possible. We extend our thanks to Bernard Spittler, Chief Substation Management Branch, NWS, and his associates who were instrumental in setting up the 600 km sampling program and instructing the cooperative observers in the operation of the sequential samplers.

We wish to express our appreciation to Dr. Jeremy Hales, Battelle Pacific Northwest Laboratories, for his cooperation in providing a DC-3 aircraft and knowledgeable crew for airborne tracer sampling missions.

We wish to thank Paul Guthals and his colleagues at the Los Alamos Scientific Laboratory for participating in our 600 km experiment and providing heavy methane and SF_6 analyses for comparison with perfluorocarbon measurements.

Special thanks are extended to Col. Van Louven, Chief M/Sgt. Greening and the members of the 6th Air Weather Squadron, USAF, for taking special rawinsondes that provided data vital to the experiments.

8. REFERENCES

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APPENDIX A

15-MINUTE AVERAGE WINDS FROM KTVY TOWER - JULY 8, 1980

The base of the KTVY Tower is at an elevation of 350 meters above mean sea level (MSL) located at 35.58°N, 97.48°W.

The average weighted wind velocity from the surface to 530 meters assume that the wind velocity at the 444 meter altitude is representative of a layer from 355 meters to 530 meters.

NO TOWER DATA AVAILABLE FOR THE JULY 11, 1980 EXPERIMENT.

APPENDIX A 15 MINUTE AVERAGE WINDS FROM KTVY TOWER
JULY 8 1980

TIME ENDING (GMT)	SFC DD	SFC VV	24 METERS DD	24 METERS VV	45 METERS DD	45 METERS VV	89 METERS DD	89 METERS VV	177 METERS DD	177 METERS VV	266 METERS DD	266 METERS VV	444 METERS DD	444 METERS VV	AVERAGE (A) DD	AVERAGE (A) VV
1815	179	46	171	52	177	53	176	61	171	62	176	64	193	56	180	58
1830	191	42	187	44	187	50	186	60	186	56	188	59	198	57	191	56
1845	185	45	179	56	182	62	181	66	180	60	187	59	193	58	186	59
1900	191	47	187	55	190	55	192	65	186	62	191	66	199	58	193	61
1915	201	41	190	40	193	41	194	52	184	52	186	61	191	52	189	53
1930	192	45	187	57	189	59	189	68	187	61	191	65	193	59	190	61
1945	195	39	188	44	190	51	184	55	178	57	185	64	192	57	187	57
2000	191	45	187	54	187	55	188	64	183	67	184	70	191	67	187	65
2015	178	49	174	60	172	62	176	68	171	71	175	79	186	71	178	71
2030	167	40	162	50	165	56	170	66	164	64	172	72	177	65	171	65
2045	159	38	156	46	160	51	163	65	157	65	165	75	175	71	166	67
2100	170	43	164	55	163	56	162	62	160	61	167	68	173	64	167	63
2115	166	40	160	49	166	60	164	71	159	72	165	76	174	75	167	71
2130	171	49	172	53	176	58	173	72	166	73	170	79	180	73	173	72
2145	167	46	162	58	165	65	164	79	161	78	169	86	181	77	171	77
2200	176	43	178	50	177	54	178	68	166	64	174	82	183	68	177	68
2215	180	42	175	59	176	61	180	69	173	73	179	76	187	73	181	71
2230	177	48	178	47	178	50	179	64	174	67	183	78	189	77	183	70
2245	189	57	185	65	187	71	186	89	182	87	185	94	192	86	187	86
2300	178	36	175	43	176	49	180	62	175	64	181	72	187	70	182	65
2315	167	23	164	38	165	38	166	60	161	69	168	78	176	72	169	67
2330	171	26	162	28	168	38	172	52	162	59	172	71	179	70	173	61
2345	162	21	160	28	168	38	168	57	162	58	169	68	176	68	170	60
0000	159	17	161	29	164	40	171	54	166	70	172	83	180	88	174	72
0015	151	15	153	29	158	39	164	59	162	71	169	83	181	83	171	71
0030	143	11	147	33	148	46	155	70	154	79	162	91	174	83	163	76
0045	151	15	146	32	152	47	157	71	155	85	162	103	177	105	166	87
0100	151	15	146	33	151	50	156	75	153	95	163	113	176	111	165	94
0115	148	21	148	41	153	53	157	82	154	101	163	129	175	120	165	103
0130	150	22	151	44	152	54	159	82	157	109	166	141	177	127	167	110
0145	149	23	153	45	156	50	158	80	156	113	166	145	179	133	168	113
0200	157	33	155	48	161	58	161	88	160	115	170	153	180	140	171	120

DD: DIRECTION IN DEGREES

VV: SPEED (METERS PER SECOND)X10

(A) AVERAGE WEIGHTED WIND VELOCITY FROM SURFACE TO 530 METERS

APPENDIX B

RAWINSONDE OBSERVATIONS FROM JULY 8, 0000 GMT TO JULY 12, 1200 GMT

	Location	Lat. (°N)	Long. (°W)	Elevation (m-MSL)
OKC:	Oklahoma City, OK	35.40	97.60	392
UMN:	Monett, MO	36.88	93.90	438
TOP:	Topeka, KS	39.07	95.63	268
OMA:	Omaha, NE	41.37	96.02	400

Explanation of Appendix

PPPP: Pressure in millibars.
HHHH: Altitude in meters above mean sea level (MSL).
TT: Air temperature in °C.
DP: Dew-point depression (°C): the difference in degrees between the air temperature and dew point.

NOTE: A DP code of 30.0 signifies a relative humidity of less than 20%.

DD: Wind direction in degrees.
VV: Wind speeds in meters per second.

APPENDIX B

OKC JUL 08 00Z

PPPP	HHHH	TT	DP
969	392	37.2	20.5
962	460	33.5	17.0
904	1018	28.7	14.7
850	1561	23.2	10.7
777	2337	16.9	8.2
767	2448	16.5	15.0
753	2604	16.9	20.9
700	3222	13.0	22.0
500	5961	-3.9	30.0

HHHH	DDD	VV
392	170	5.1
612	170	9.8
866	172	9.8
1132	173	9.3
1418	185	9.3
1705	194	8.8
1992	198	9.3
2280	201	10.3
2552	198	12.9
2829	193	14.4
3109	195	12.4
3395	200	8.8
3683	212	6.2
3971	218	5.7
4260	219	4.1
4548	206	3.6
4837	191	3.6
5125	176	3.6
5413	171	4.1
5702	176	5.1
5990	173	5.1

OKC JUL 08 12Z

PPPP	HHHH	TT	DP
971	392	25.6	8.2
953	556	26.0	6.3
929	782	26.3	7.5
850	1561	20.9	6.4
784	2255	15.1	3.5
774	2364	16.3	16.8
756	2564	16.5	22.4
700	3212	11.2	20.3
628	4109	6.3	30.0
582	4727	1.4	30.0
556	5094	0.4	30.0
500	5937	-5.1	30.0

HHHH	DDD	VV
392	180	3.6
669	201	17.0
919	202	19.0
1148	202	16.0
1377	214	12.9
1610	221	10.8
1858	225	7.7
2133	221	6.7
2342	198	11.8
2618	194	15.4
2888	191	12.9
3158	187	8.8
3423	175	7.7
3687	169	9.3
3951	169	7.7
4217	174	4.1
4485	195	3.1
4753	198	3.6
5016	202	4.1
5285	201	3.6
5556	187	2.6
5828	195	3.6
6091	195	3.6

OKC JUL 09 12Z

PPPP	HHHH	TT	DP
970	392	23.9	7.9
959	492	26.4	6.7
935	716	27.9	9.5
850	1556	22.8	9.7
802	2060	19.6	9.8
770	2410	17.1	15.2
700	3216	12.6	19.4
658	3732	10.1	21.9
608	4382	4.4	19.7
500	5946	-5.3	30.0

HHHH	DDD	VV
392	150	3.1
684	203	17.5
968	212	18.5
1248	216	14.4
1528	213	9.3
1808	217	5.7
2089	229	5.1
2381	218	7.7
2660	204	8.8
2938	197	7.7
3206	204	3.6
3488	144	1.5
3760	106	3.1
4030	100	4.1
4301	127	3.6
4585	171	3.1
4875	184	3.1
5164	193	4.6
5454	206	5.1
5743	221	4.6
6029	215	3.6

APPENDIX B

OKC JUL 10 00Z

PPPP	HHHH	TT	DP
969	392	38.9	22.4
961	463	36.1	19.8
850	1563	25.3	12.7
749	2656	14.6	5.7
742	2735	16.0	30.0
733	2839	16.6	30.0
700	3229	14.0	22.1
677	3510	13.4	30.0
551	5208	2.4	30.0
500	5983	-3.8	30.0

HHHH	DDD	VV
392	180	5.7
657	186	8.2
981	184	3.6
1304	183	4.1
1624	184	6.2
1927	186	6.2
2231	191	7.7
2534	198	7.7
2813	201	6.2
3131	192	4.6
3426	170	3.1
3722	162	1.5
4025	109	0.5
4329	142	0.0
4632	255	0.5
4935	265	1.5
5237	293	2.1
5536	307	1.5
5834	314	1.0
6131	44	0.5

OKC JUL 10 12Z

PPPP	HHHH	TT	DP
971	392	25.0	8.2
949	590	27.4	9.5
933	741	27.9	11.1
850	1561	22.4	11.3
775	2356	16.0	7.9
764	2478	16.6	16.6
770	3217	13.0	22.3
650	3834	8.2	21.4
622	4197	7.3	30.0
543	5299	-0.4	30.0
500	5952	-5.1	19.4

HHHH	DDD	VV
392	150	3.1
665	207	14.4
905	213	14.9
1139	210	11.3
1373	209	8.8
1612	208	6.7
1868	207	4.1
2125	216	2.6
2386	218	3.1
2669	220	3.6
2943	177	3.1
3217	137	4.6
3486	135	5.7
3754	129	6.7
4030	121	6.7
4299	117	6.7
4556	107	6.2
4812	105	6.2
5068	104	5.7
5330	96	5.1
5641	87	4.6
5952	70	4.1

OKC JUL 11 00Z

PPPP	HHHH	TT	DP
969	392	38.3	23.5
953	539	34.5	19.6
850	1560	24.7	14.5
774	2370	16.4	8.5
764	2481	17.2	19.8
757	2560	17.6	21.3
700	3223	13.7	30.0
636	4025	10.1	30.0
557	5111	2.1	20.1
508	5846	-4.1	15.6
500	5971	-4.0	30.0

HHHH	DDD	VV
392	120	6.2
675	0	0.0
1016	0	0.0
1356	0	0.0
1695	0	0.0
2033	0	0.0
2370	0	0.0
2583	0	0.0
2811	0	0.0
3040	0	0.0
3277	0	0.0
3544	0	0.0
3811	0	0.0
4080	282	0.0
4351	38	0.5
4623	182	0.0
4894	39	0.5
5160	39	2.6
5405	45	3.1
5650	43	2.1
5896	339	2.1
6150	285	3.1

APPENDIX B

OKC JUL 11 12Z

PPPP	HHHH	TT	DP
969	392	23.3	7.8
955	516	26.9	8.7
941	647	28.1	11.3
932	732	28.4	12.3
925	799	28.1	12.2
850	1544	22.8	9.9
825	1804	21.0	9.7
806	2005	19.7	12.2
787	2210	18.5	12.9
781	2276	18.7	18.2
751	2611	17.1	21.4
707	3121	12.6	15.1
700	3205	12.4	17.0
674	3521	11.3	22.1
671	3558	11.6	21.3
598	4501	5.2	18.3
547	5230	-0.3	15.9
539	5348	0.3	30.0
500	5947	-3.3	30.0

HHHH	DDD	VV
392	170	3.1
668	212	14.9
928	228	16.0
1184	215	12.9
1441	222	10.3
1717	219	5.7
2005	174	2.1
2332	153	2.1
2611	169	2.6
2894	152	4.6
3205	140	6.2
3468	133	6.2
3726	137	7.2
4006	145	7.2
4286	150	5.1
4565	144	3.1
4842	117	1.5
5120	163	1.5
5377	206	3.6
5662	214	4.6
5947	212	4.1

OKC JUL 12 00Z

PPPP	HHHH	TT	DP
967	392	39.4	23.7
956	495	36.1	19.3
850	1549	26.0	14.9
729	2873	13.0	7.2
718	3000	12.6	13.2
711	3083	15.0	30.0
700	3215	14.4	30.0
660	3710	13.0	30.0
557	5109	3.1	30.0
500	5973	-3.3	30.0

HHHH	DDD	VV
392	160	5.1
630	185	9.8
854	186	8.2
1078	186	8.8
1303	188	8.2
1527	194	6.7
1766	199	6.7
2006	213	7.2
2247	221	8.8
2488	224	9.8
2728	229	10.8
2958	232	10.3
3193	232	7.2
3427	240	4.1
3663	280	3.6
3885	292	4.6
4104	285	4.1
4322	273	3.6
4541	244	3.6
4759	226	4.1
4978	225	3.1
5205	241	2.6
5445	263	2.6
5685	286	1.5
5925	270	1.5
6174	201	2.1

OKC JUL 12 12Z

PPPP	HHHH	TT	DP
969	392	25.6	10.5
956	507	27.2	9.9
921	838	28.9	13.7
873	1313	26.5	13.0
850	1548	23.8	11.9
734	2810	14.3	10.0
715	3032	12.7	11.1
700	3209	11.6	14.1
686	3378	11.2	30.0
671	3562	11.0	30.0
645	3891	9.7	30.0
594	4569	5.1	30.0
577	4805	4.7	30.0
500	5954	-4.1	30.0

HHHH	DDD	VV
392	170	2.6
673	221	16.0
957	226	18.0
1254	227	13.9
1522	226	10.3
1825	219	8.8
2133	225	5.7
2441	261	3.1
2749	328	1.5
3057	50	3.1
3344	101	4.1
3622	130	4.6
3920	123	5.1
4215	117	4.6
4510	132	4.1
4836	164	5.1
5147	183	6.7
5457	194	7.7
5768	208	7.7
6073	218	7.7

APPENDIX B

UMN JUL 08 00Z			
PPPP	HHHH	TT	DP
967	438	35.3	16.1
963	471	33.9	14.5
850	1584	23.4	6.6
834	1750	21.8	6.5
795	2166	21.8	18.9
775	2387	21.2	19.0
700	3256	13.7	16.4
660	3747	8.9	14.1
642	3976	8.2	19.4
573	4900	-0.2	14.0
554	5171	1.1	20.5
500	5988	-4.0	19.5

HHHH	DDD	VV
438	230	3.6
758	222	6.7
1117	226	7.7
1476	232	7.2
1802	248	8.2
2062	256	10.8
2332	253	10.3
2626	245	9.3
2926	233	8.8
3226	225	8.2
3516	224	7.7
3798	226	6.7
4060	235	6.7
4340	237	7.2
4620	232	6.7
4900	226	4.1
5200	239	2.1
5492	227	0.5
5783	64	0.5
6075	83	1.0

UMN JUL 08 12Z			
PPPP	HHHH	TT	DP
967	438	23.6	3.4
942	671	27.0	6.9
882	1253	25.3	12.0
868	1393	23.3	8.4
850	1576	23.5	16.5
829	1794	23.7	21.1
700	3242	12.4	14.4
645	3920	6.0	13.0
627	4151	4.4	15.3
567	4960	-2.8	11.7
565	4988	-1.2	30.0
562	5030	0.4	30.0
540	5351	0.5	30.0
500	5964	-3.1	30.0

HHHH	DDD	VV
438	210	3.1
722	245	14.9
974	247	13.9
1227	235	12.9
1515	235	13.4
1794	241	11.8
2078	244	10.8
2362	239	9.3
2641	224	8.8
2930	218	8.8
3213	218	8.2
3468	212	8.2
3719	209	9.3
3972	213	8.8
4232	214	6.2
4502	211	3.6
4771	210	5.1
5057	191	6.7
5324	183	6.2
5614	194	5.1
5906	219	3.6
6185	262	3.1

UMN JUL 08 18Z			
PPPP	HHHH	TT	DP
968	438	33.6	13.2
955	558	29.7	11.0
903	1055	25.0	7.7
867	1411	21.3	4.5
850	1584	25.2	19.5
758	2578	17.4	17.7
700	3248	11.5	16.1
667	3649	8.2	14.8
648	3887	6.8	16.5
581	4770	-1.2	13.1
580	4784	-0.9	30.0
569	4938	1.5	30.0
500	5968	-3.9	30.0

HHHH	DDD	VV
438	240	6.2
806	257	8.8
1144	246	8.2
1440	242	8.8
1718	241	10.3
1986	239	9.8
2254	235	9.3
2522	218	8.8
2809	206	9.3
3102	205	9.3
3382	209	8.8
3649	205	8.8
3942	191	9.3
4218	187	9.8
4494	192	11.3
4770	203	10.8
5015	228	8.2
5273	245	7.2
5530	241	7.2
5788	236	6.7
6056	227	6.2

APPENDIX B

UMN	JUL	09	00Z
PPPP	HHHH	TT	DP
966	438	35.6	16.1
952	569	33.5	13.7
850	1580	23.9	7.9
832	1767	22.5	8.7
825	1840	21.8	13.4
813	1967	21.6	16.8
725	2949	15.3	17.0
700	3245	13.3	20.0
620	4251	4.9	14.8
589	4667	2.2	16.7
566	4989	2.5	30.0
500	5982	-2.5	30.0

HHHH	DDD	VV
438	200	4.1
747	216	7.2
1045	202	7.2
1342	195	8.2
1626	198	8.2
1872	205	8.8
2158	211	9.8
2431	217	9.8
2704	224	9.8
2979	232	9.3
3274	220	9.3
3561	218	9.3
3849	215	8.8
4134	231	8.8
4443	262	8.8
4741	272	8.8
4989	269	7.2
5290	273	6.7
5590	265	6.7
5891	268	7.7
6183	266	7.7

UMN	JUL	09	06Z
PPPP	HHHH	TT	DP
966	438	25.4	6.0
958	510	29.8	7.7
942	661	29.6	11.9
887	1195	25.9	10.5
869	1376	25.6	13.7
850	1570	23.0	7.5
845	1621	22.4	7.0
825	1830	21.7	14.9
768	2448	18.9	17.0
729	2892	15.2	16.6
700	3234	11.9	12.0
670	3598	8.5	12.1
655	3786	7.8	14.6
610	4367	2.5	15.3
602	4474	2.7	20.0
598	4528	5.7	30.0
542	5327	2.2	30.0
500	5971	-3.4	19.7

HHHH	DDD	VV
438	190	2.6
661	223	11.8
904	226	12.9
1147	223	12.4
1400	216	11.8
1621	214	11.8
1879	219	11.3
2126	232	9.3
2373	236	7.7
2611	229	6.7
2845	233	8.8
3087	242	10.8
3331	244	11.3
3574	244	11.3
3836	250	10.3
4089	259	8.8
4341	250	5.7
4608	235	3.6
4874	219	3.6
5140	237	5.1
5411	241	5.1
5691	232	4.6
5971	241	4.6

UMN	JUL	09	12Z
PPPP	HHHH	TT	DP
967	438	25.1	6.9
941	675	27.9	10.0
866	1407	23.5	11.3
850	1570	23.5	18.0
794	2159	18.3	13.7
757	2567	17.1	16.1
700	3228	11.5	15.6
587	4672	1.5	30.0
500	5940	-5.1	30.0

HHHH	DDD	VV
438	230	3.1
675	235	14.9
956	242	15.4
1238	245	11.8
1500	243	10.3
1757	237	11.8
2025	232	13.4
2305	229	13.4
2595	229	11.8
2870	231	9.8
3145	237	8.2
3443	237	7.2
3750	223	3.1
4058	268	1.0
4365	307	2.6
4672	285	3.6
4976	269	5.7
5280	268	7.2
5584	266	8.8
5888	263	8.8
6182	264	9.3

APPENDIX B

UMN JUL 09 18Z

PPPP	HHHH	TT	DP
968	438	34.2	13.6
951	593	29.6	10.3
881	1269	22.6	5.7
872	1359	22.9	7.5
869	1389	23.3	9.8
850	1582	22.6	13.4
841	1674	21.5	12.3
834	1747	22.6	17.4
804	2064	20.2	15.4
700	3243	12.7	19.5
626	4168	5.3	18.4
589	4664	3.1	18.9
571	4915	2.1	30.0
500	5973	-4.8	18.1

HHHH	DDD	VV
438	220	5.1
735	243	8.2
1091	251	9.3
1359	248	9.8
1605	243	10.8
1832	242	11.8
2043	241	12.4
2305	235	12.4
2573	233	10.3
2841	236	9.3
3109	238	9.3
3372	245	8.8
3628	246	7.7
3885	232	6.7
4142	241	5.7
4416	270	5.1
4689	296	5.7
4943	312	7.7
5221	310	8.8
5499	308	8.8
5778	305	8.2
6057	297	8.8

UMN JUL 10 00Z

PPPP	HHHH	TT	DP
965	438	36.5	16.2
955	534	33.8	15.6
890	1166	27.4	11.6
850	1571	23.0	7.9
824	1841	20.5	6.2
814	1947	20.1	7.1
797	2129	20.8	19.1
744	2721	18.6	30.0
700	3239	14.2	30.0
631	4104	7.2	20.4
605	4448	3.8	5.1
598	4542	3.4	1.4
590	4652	2.1	1.7
581	4776	2.3	11.3
578	4818	1.9	6.8
561	5058	0.3	6.5
553	5174	0.2	14.6
519	5680	-1.9	15.2
500	5976	-4.2	17.9

HHHH	DDD	VV
438	200	5.1
794	214	8.8
1166	221	7.7
1436	232	8.2
1706	243	8.8
1973	258	9.3
2224	272	8.8
2461	287	6.2
2698	302	4.1
2967	300	4.1
3239	291	4.6
3518	291	5.1
3797	308	5.1
4076	328	4.6
4342	334	4.1
4608	336	5.1
4862	330	6.7
5081	319	7.7
5326	310	8.2
5579	307	8.8
5858	308	7.7
6151	302	7.2

UMN JUL 10 12Z

PPPP	HHHH	TT	DP
967	438	25.1	5.5
924	839	27.8	9.2
903	1043	27.3	12.0
850	1576	23.6	10.2
817	1921	21.4	9.9
787	2245	20.7	19.1
738	2797	17.4	20.6
719	3018	15.2	10.1
700	3245	13.5	12.8
661	3725	10.3	14.8
594	4603	2.9	4.9
569	4950	0.3	4.9
537	5413	-2.2	8.8
527	5562	-2.4	8.5
510	5822	-5.0	8.7
500	5977	-5.7	17.9

HHHH	DDD	VV
438	240	2.1
802	240	18.0
1106	248	16.5
1419	254	12.9
1719	276	8.2
2018	298	5.1
2337	293	3.6
2643	280	2.1
2981	135	1.0
3279	161	3.1
3622	131	3.1
3953	101	3.1
4278	60	3.6
4603	43	5.1
4919	41	5.1
5248	33	4.6
5562	25	5.7
5899	21	5.1
6232	17	5.1

APPENDIX B

UMN JUL 11 00Z

PPPP	HHHH	TT	DP
965	438	36.7	18.9
957	515	35.0	15.8
876	1308	26.5	12.2
850	1574	24.5	9.9
817	1920	22.7	18.4
801	2092	22.4	20.7
725	2948	16.1	17.8
700	3245	13.7	12.6
676	3538	11.6	14.9
652	3840	9.3	11.6
607	4429	4.9	4.5
572	4911	1.3	6.6
555	5154	0.2	6.4
546	5285	0.2	14.0
535	5448	0.5	20.2
500	5988	-2.5	19.9

HHHH	DDD	VV
438	260	5.1
683	231	6.2
924	226	6.2
1164	231	5.1
1415	242	4.6
1680	244	4.1
1944	235	4.6
2196	238	4.6
2455	260	3.6
2715	291	3.1
2975	294	3.6
3245	294	2.1
3490	229	1.5
3739	217	3.1
3993	239	1.5
4249	330	1.5
4505	9	2.6
4759	25	3.6
5008	45	3.6
5259	67	4.6
5499	69	5.7
5756	61	4.6
6014	54	3.6

UMN JUL 11 12Z

PPPP	HHHH	TT	DP
966	438	23.4	4.8
952	565	26.8	7.8
915	916	27.5	11.4
850	1566	24.0	11.5
839	1997	22.1	20.9
745	2707	18.0	20.6
700	3236	13.6	15.1
680	3479	11.7	15.1
652	3829	8.6	8.7
608	4403	4.7	11.3
590	4648	2.7	7.1
578	4814	1.7	11.0
565	4997	0.4	12.8
537	5402	-3.1	11.9
523	5611	-3.1	19.4
500	5966	-4.6	18.3

HHHH	DDD	VV
438	250	2.1
700	253	13.4
973	257	12.4
1255	257	9.8
1538	252	9.8
1843	247	9.8
2134	239	6.7
2407	218	4.1
2680	191	2.6
2945	178	3.6
3209	176	4.1
3435	174	3.1
3712	186	3.1
3986	163	2.6
4248	138	1.5
4512	171	2.1
4814	211	3.1
5055	240	4.1
5344	245	5.1
5666	239	5.7
5939	235	6.7
6197	230	5.1

UMN JUL 12 00Z

PPPP	HHHH	TT	DP
964	438	36.6	21.0
959	484	35.0	19.1
850	1560	23.8	11.8
793	2162	18.9	10.1
783	2271	19.3	22.2
757	2561	19.1	30.0
700	3228	14.9	14.6
576	4842	2.6	19.1
500	5974	-3.3	18.8

HHHH	DDD	VV
438	210	5.1
659	218	6.2
909	221	6.2
1159	218	6.2
1410	211	6.2
1665	204	6.2
1926	201	6.7
2189	205	7.7
2474	211	10.3
2734	206	11.8
2981	197	11.3
3228	193	10.3
3488	197	8.8
3749	213	6.7
4009	235	3.6
4269	263	1.5
4530	36	0.5
4790	204	1.5
5074	231	5.1
5364	250	5.7
5654	273	6.7
5945	277	9.3
6217	281	10.3

APPENDIX B

UMN JUL 12 12Z

PPPP	HHHH	TT	DP
965	438	24.4	6.9
933	734	27.4	10.5
850	1553	22.2	10.5
776	2338	17.1	8.3
763	2482	16.5	16.8
744	2697	15.6	20.6
700	3211	13.7	30.0
500	5950	-4.8	18.3

HHHH	DDD	VV
438	220	3.1
734	238	17.0
998	241	16.0
1262	236	12.4
1526	238	10.3
1814	259	9.3
2105	286	7.7
2410	298	5.7
2673	288	3.6
2940	236	1.5
3211	194	2.1
3500	198	3.1
3788	204	3.6
4076	232	4.1
4365	255	3.1
4653	278	0.5
4941	78	1.0
5230	204	0.5
5518	275	3.6
5806	273	5.7
6101	255	6.7

TOP JUL 08 00Z

PPPP	HHHH	TT	DP
980	268	37.2	18.0
976	305	37.8	23.9
945	600	35.5	23.3
850	1549	26.5	17.0
776	2342	18.6	11.9
758	2543	16.6	16.6
735	2805	16.8	30.0
700	3218	13.8	30.0
610	4357	4.4	19.6
595	4560	5.1	30.0
500	5955	-4.2	30.0

HHHH	DDD	VV
268	210	8.8
541	211	8.2
871	211	11.3
1210	212	12.9
1549	216	10.8
1894	221	12.4
2239	224	14.4
2543	233	16.5
2805	239	18.0
3080	244	17.0
3376	248	16.5
3693	251	13.9
4009	255	11.3
4326	263	10.8
4621	270	8.2
4924	265	5.7
5227	249	6.2
5531	243	7.2
5834	242	7.7
6139	237	9.3

TOP JUL 08 12Z

PPPP	HHHH	TT	DP
983	268	27.2	7.5
930	761	29.3	12.1
850	1557	24.6	14.7
746	2684	15.7	10.6
726	2915	15.5	20.1
700	3223	13.7	21.0
590	4633	2.6	19.3
581	4758	2.9	30.0
535	5421	-0.5	30.0
500	5958	-4.3	30.0

HHHH	DDD	VV
268	200	5.1
576	223	19.0
889	229	22.7
1207	231	19.0
1525	236	14.4
1817	240	10.3
2106	235	6.7
2395	216	4.1
2684	193	4.6
3007	208	7.2
3319	217	8.8
3639	216	8.8
3960	222	8.2
4281	231	6.2
4601	237	5.7
4902	246	5.7
5190	262	4.6
5484	254	4.1
5800	241	5.1
6123	234	5.1

APPENDIX B

TOP JUL 08 18Z

PPPP	HHHH	TT	DP
983	268	33.9	10.2
972	372	32.2	11.8
954	540	31.1	14.3
850	1560	21.2	6.5
836	1704	19.7	5.7
820	1870	19.7	12.6
771	2397	15.6	12.5
749	2643	15.8	21.8
700	3213	11.7	21.3
668	3601	8.1	20.9
597	4521	3.7	30.0
544	5270	0.2	30.0
500	5939	-5.3	30.0

HHHH	DDD	VV
268	210	6.7
540	226	10.8
783	226	11.3
1026	223	11.3
1268	218	10.3
1511	217	8.8
1770	220	8.8
2065	215	8.8
2342	213	9.3
2643	222	8.8
2914	227	8.2
3186	219	8.2
3504	210	8.2
3796	214	7.2
4075	226	7.7
4354	231	8.2
4636	234	7.2
4924	229	7.2
5213	221	8.2
5514	216	9.8
5818	211	10.3
6109	209	9.8

TOP JUL 09 00Z

PPPP	HHHH	TT	DP
980	268	36.1	16.1
966	396	37.6	20.1
850	1548	26.8	14.0
803	2047	21.5	9.7
726	2912	13.9	3.2
700	3219	12.8	19.7
690	3340	12.8	30.0
567	4952	0.9	18.3
542	5314	0.5	30.0
500	5957	-3.0	30.0

HHHH	DDD	VV
268	190	7.7
521	213	8.8
772	212	8.8
1022	210	9.3
1273	208	9.8
1523	209	10.3
1744	211	10.8
1960	212	11.3
2200	211	11.8
2454	213	12.9
2708	217	12.9
2959	222	12.4
3195	235	11.3
3449	247	11.3
3722	251	11.3
3996	253	9.3
4269	258	8.2
4542	256	8.8
4816	256	8.8
5091	250	8.8
5366	241	9.8
5623	240	11.3
5880	246	12.4
6147	251	12.9

TOP JUL 09 06Z

PPPP	HHHH	TT	DP
980	268	32.2	13.8
850	1538	25.5	11.6
700	3213	13.8	11.5
641	3948	8.8	16.2
615	4289	5.5	5.5
581	4753	3.8	17.9
577	4809	4.1	20.7
500	5957	-4.0	19.0

HHHH	DDD	VV
268	190	5.1
602	204	19.0
937	213	22.7
1271	223	21.1
1600	232	16.5
1910	242	11.3
2220	255	7.7
2530	282	6.7
2841	300	6.2
3151	307	6.2
3469	307	6.2
3788	305	7.7
4103	310	9.3
4413	311	8.2
4722	297	7.7
5039	283	8.2
5367	276	9.3
5694	272	10.3
6018	268	12.4

APPENDIX B

TOP JUL 09 12Z

PPPP	HHHH	TT	DP
981	268	27.2	7.0
965	410	27.6	8.6
850	1532	25.4	13.8
700	3205	13.0	5.7
685	3387	12.6	7.0
645	3888	7.0	3.2
613	4306	5.2	6.1
561	5024	-0.5	2.4
541	5313	-2.9	2.1
500	5935	-5.8	11.8

HHHH	DDD	VV
268	170	4.6
608	204	12.9
938	234	19.6
1268	246	23.7
1591	254	21.1
1884	264	20.6
2178	272	20.6
2471	276	19.0
2765	273	15.4
3058	266	12.4
3357	262	10.3
3652	260	9.8
3944	257	9.8
4222	253	10.3
4534	254	12.4
4861	262	13.9
5185	267	12.9
5483	269	9.8
5766	269	9.3
6055	270	10.3

TOP JUL 09 18Z

PPPP	HHHH	TT	DP
982	268	35.6	11.6
965	422	33.6	13.9
954	526	32.8	17.5
850	1551	23.0	10.5
801	2067	21.6	14.7
762	2498	18.6	12.8
700	3220	13.4	16.0
630	4096	6.6	14.3
616	4279	4.7	10.8
598	4520	2.7	13.7
590	4629	1.5	14.9
564	4990	-1.3	10.0
556	5104	-1.7	11.1
529	5499	-4.6	12.6
500	5940	-7.7	12.0

HHHH	DDD	VV
268	230	6.2
579	240	7.7
841	246	9.8
1104	253	10.3
1367	259	10.3
1642	276	10.3
1946	291	11.3
2252	285	12.4
2556	274	13.4
2844	269	12.4
3133	271	10.3
3424	278	9.8
3716	290	8.8
4008	300	8.2
4279	306	7.7
4575	318	10.3
4892	326	11.3
5195	318	9.3
5499	297	9.8
5838	294	11.8
6132	298	12.9

TOP JUL 10 00Z

PPPP	HHHH	TT	DP
978	268	37.8	15.5
966	385	41.1	23.5
850	1548	29.0	16.1
801	2073	24.4	12.6
743	2725	18.0	7.2
700	3233	13.0	2.6
687	3391	11.5	1.5
648	3878	8.8	9.4
632	4084	6.7	9.5
589	4659	2.5	3.7
556	5124	-0.7	3.8

HHHH	DDD	VV
268	200	6.2
517	212	7.7
781	212	7.7
1046	218	7.7
1310	224	8.2
1576	229	8.2
1852	237	7.7
2135	243	7.7
2446	248	8.8
2754	252	8.8
3035	254	8.2
3327	257	8.8
3634	272	8.8
3924	296	7.7
4180	301	7.7
4500	299	8.8
4814	313	10.3
5124	319	10.8

APPENDIX B

TOP	JUL	10	12Z
PPPP	HHHH	TT	DP
982	268	28.3	9.8
971	366	30.7	12.7
935	904	29.7	15.4
909	956	31.0	19.0
850	1554	27.5	17.6
700	3235	14.0	5.9
645	3920	8.1	3.9
601	4500	3.4	0.0
550	5215	-1.7	1.7
542	5332	-2.5	4.4
534	5450	-2.0	17.5
523	5615	-1.4	30.0
500	5972	-4.2	30.0

HHHH	DDD	VV
268	240	3.6
581	248	16.0
893	255	22.1
1196	265	20.1
1494	277	15.4
1813	283	11.8
2136	280	10.3
2459	276	9.3
2783	277	7.7
3106	280	8.2
3441	280	9.3
3783	282	8.8
4113	281	8.8
4436	284	8.8
4772	289	8.2
5113	296	7.2
5450	326	8.8
5777	338	11.8
6106	330	11.3

TOP	JUL	11	00Z
PPPP	HHHH	TT	DP
979	268	38.3	15.5
964	414	39.9	23.9
850	1557	29.9	19.3
700	3241	12.8	6.5
682	3460	10.7	3.7
673	3571	12.6	11.9
627	4160	6.9	8.1
595	4588	4.1	14.8
541	5353	-2.8	3.9
519	5682	-2.6	30.0
500	5977	-4.8	30.0

HHHH	DDD	VV
268	280	5.1
659	205	6.2
1067	232	6.2
1475	235	6.2
1844	240	5.1
2202	240	5.1
2560	242	7.2
2919	241	7.7
3272	241	6.2
3571	260	4.6
3881	280	4.6
4186	282	5.1
4454	280	6.7
4725	282	8.8
4998	290	9.8
5271	299	9.3
5545	290	6.2
5816	258	4.6
6086	252	3.6

TOP	JUL	11	12Z
PPPP	HHHH	TT	DP
981	268	23.9	5.9
972	349	27.1	7.8
910	937	30.9	17.1
850	1544	26.9	16.8
700	3222	14.3	17.7
602	4473	4.5	9.8
560	5058	-0.1	6.8
536	5407	-2.9	10.4
500	5955	-6.6	8.1

HHHH	DDD	VV
268	130	1.0
584	229	8.8
878	245	7.7
1158	262	6.7
1434	262	6.2
1718	218	5.7
2007	237	5.7
2296	302	5.7
2586	349	5.1
2875	296	3.6
3164	250	5.1
3460	253	5.1
3758	256	4.1
4056	260	3.6
4354	260	4.6
4649	0	0.0
4941	0	0.0
5208	0	0.0
5462	0	0.0
5736	0	0.0
6008	0	0.0

APPENDIX B

TOP JUL 12 12Z

PPPP	HHHH	TT	DP
980	268	24.4	5.5
906	968	31.2	16.8
850	1538	28.1	18.2
726	2910	16.8	11.6
700	3220	14.1	8.1
631	4086	6.9	5.2
594	4580	2.7	0.0
560	5055	-1.0	0.1
550	5199	-1.3	2.8
527	5538	-4.0	0.0
500	5953	-6.1	0.0

HHHH	DDD	VV
268	360	2.1
524	270	4.1
782	250	9.3
1053	250	9.3
1356	274	7.7
1652	291	7.7
1938	283	6.2
2224	253	4.6
2510	263	6.2
2795	274	8.2
3079	275	8.2
3355	276	8.8
3626	271	4.6
3896	212	1.5
4173	217	2.1
4464	227	3.1
4758	262	3.1
5055	295	3.6
5312	296	3.1
5598	287	2.6
5894	254	2.1
6187	257	2.1

OMA JUL 08 00Z

PPPP	HHHH	TT	DP
963	400	35.8	13.0
953	497	35.9	18.8
850	1524	26.7	15.2
765	2444	20.3	15.5
700	3202	14.3	20.5
669	3583	12.7	30.0
500	5948	-5.0	30.0

HHHH	DDD	VV
400	209	5.7
725	217	12.9
1011	222	13.9
1296	226	13.9
1584	233	14.9
1880	242	15.4
2177	258	15.4
2476	273	15.4
2792	285	12.9
3107	293	9.8
3424	281	5.7
3739	254	3.6
4050	263	3.1
4361	271	3.6
4672	264	5.1
4984	258	7.2
5295	261	8.2
5606	270	8.8
5917	275	10.3
6211	274	10.3

OMA JUL 08 12Z

PPPP	HHHH	TT	DP
967	400	22.3	5.0
943	616	24.5	3.1
926	776	26.4	7.5
850	1532	25.0	14.0
785	2226	21.8	14.0
700	3202	13.3	8.3
655	3762	8.3	7.1
633	3979	6.4	8.3
627	4122	5.9	11.0
613	4307	6.0	30.0
573	4855	1.2	7.5
557	5082	-0.1	17.4
518	5659	-4.5	18.5
510	5781	-5.2	30.0
500	5937	-5.7	30.0

HHHH	DDD	VV
400	60	4.1
696	113	3.1
997	224	5.7
1311	248	10.3
1622	254	22.7
1924	255	22.7
2226	257	12.4
2533	252	9.8
2839	241	8.2
3146	230	6.7
3441	228	6.2
3733	236	4.1
4036	250	2.6
4337	233	3.1
4642	209	2.6
4952	218	3.1
5264	226	4.6
5568	234	4.6
5885	250	6.7
6205	262	9.8

APPENDIX B

OMA	JUL	08	18Z
PPPP	HHHH	TT	DP
967	400	29.9	8.2
960	463	28.3	6.9
903	1015	25.2	11.5
850	1538	26.1	16.2
765	2456	19.2	12.9
700	3210	12.0	7.3
661	3688	7.9	5.4
644	3902	6.3	10.8
636	4005	6.5	30.0
620	4214	6.3	30.0
569	4996	0.8	30.0
532	5450	0.1	19.7
500	5943	-4.1	19.3

HHHH	DDD	VV
400	120	2.1
705	215	3.1
1043	248	5.1
1375	265	8.2
1691	251	9.3
1997	227	8.8
2303	215	10.3
2606	210	10.3
2908	208	9.8
3210	212	8.8
3509	214	8.2
3810	217	9.3
4094	227	9.3
4409	234	7.2
4735	224	7.2
5056	232	8.8
5359	228	8.8
5680	229	9.3
6009	231	10.8

OMA	JUL	09	00Z
PPPP	HHHH	TT	DP
964	400	33.1	8.6
937	661	31.4	12.2
850	1528	24.9	8.0
814	1907	22.3	7.5
766	2434	19.0	11.7
738	2758	16.5	8.8
715	3022	15.3	15.1
700	3202	13.7	10.0
618	4237	5.1	3.3
577	4794	0.9	3.0
556	5092	0.1	30.0
500	5936	-4.0	30.0

HHHH	DDD	VV
400	80	3.6
688	115	6.2
959	143	6.7
1230	170	8.2
1501	190	10.8
1772	198	12.9
2046	209	14.4
2323	225	14.9
2608	237	16.0
2921	244	16.0
3202	256	14.9
3481	266	15.4
3761	272	13.9
4041	272	12.4
4317	272	11.3
4582	269	11.8
4849	262	12.9
5120	254	13.4
5402	248	13.9
5683	244	15.4
5965	247	16.5

OMA	JUL	09	06Z
PPPP	HHHH	TT	DP
962	400	30.7	8.5
902	975	30.9	17.2
850	1505	27.6	15.6
700	3187	14.3	7.6
582	4714	1.6	0.5
563	4982	1.0	1.9
549	5185	0.5	7.4
531	5452	-1.4	13.4
513	5725	-3.6	7.5
500	5928	-4.1	19.1

HHHH	DDD	VV
400	180	5.7
720	208	20.6
1031	221	23.7
1310	223	22.7
1585	223	21.6
1852	227	21.6
2119	227	22.1
2386	227	21.1
2653	231	17.0
2920	236	14.9
3187	247	14.4
3465	256	15.4
3742	256	16.5
4020	257	16.5
4298	254	16.5
4575	249	16.0
4836	249	13.4
5098	251	13.4
5392	251	13.9
5671	255	13.9
5962	262	13.9

APPENDIX B

OMA JUL 09 12Z

PPPP	HHHH	TT	DP
963	400	22.7	1.4
927	738	28.0	6.2
850	1505	23.7	9.5
700	3172	13.5	15.3
645	3856	9.0	12.4
599	4464	4.4	14.7
572	4839	4.1	20.3
500	5919	-2.7	30.0

HHHH	DDD	VV
400	240	2.1
682	305	9.8
984	313	10.8
1290	310	9.8
1592	316	10.8
1885	309	12.4
2177	301	12.9
2470	296	13.4
2763	294	14.4
3055	295	15.4
3343	290	15.4
3628	289	14.9
3917	283	14.9
4230	285	15.4
4532	277	15.4
4868	258	15.4
5160	250	16.0
5452	254	16.0
5744	261	16.5
6038	266	14.9

OMA JUL 09 18Z

PPPP	HHHH	TT	DP
966	400	30.6	6.7
946	586	28.0	5.8
924	795	27.5	11.2
850	1531	24.4	14.7
814	1909	23.0	15.1
700	3202	12.6	7.4
677	3481	10.8	12.4
565	4962	0.7	19.8
529	5487	-3.4	12.5
520	5622	-3.4	30.0
500	5931	-5.7	30.0

HHHH	DDD	VV
400	230	3.1
705	256	3.1
1010	277	4.1
1316	296	6.2
1626	296	7.7
1939	288	8.8
2232	288	9.8
2526	291	12.4
2820	290	12.9
3114	284	12.9
3398	282	13.4
3685	290	14.9
3975	296	16.0
4265	298	17.5
4555	298	17.5
4846	297	17.0
5172	298	19.0
5514	299	18.5
5808	291	17.0
6124	283	19.0

OMA JUL 10 00Z

PPPP	HHHH	TT	DP
964	400	36.6	11.3
850	1531	26.8	14.1
788	2194	21.1	10.1
761	2496	20.3	22.0
700	3209	14.0	10.3
673	3539	11.2	11.3
614	4299	5.5	3.6
556	5102	-1.0	4.1
527	5528	-3.9	10.1
519	5648	-4.2	30.0
500	5942	-4.2	30.0

HHHH	DDD	VV
400	170	1.5
714	175	3.6
1028	197	4.1
1312	229	7.2
1646	246	9.3
1935	253	10.3
2217	261	11.3
2449	273	13.9
2699	279	15.4
2954	278	15.4
3209	276	15.4
3463	274	15.4
3729	273	17.0
4000	278	18.5
4271	278	19.0
4511	284	19.6
4748	285	21.1
4984	286	21.6
5235	286	20.1
5501	287	18.0
5746	292	17.5
5995	295	20.6

APPENDIX B

OMA JUL 10 12Z

PPPP	HHHH	TT	DP
966	400	24.4	0.7
937	670	25.3	0.1
924	795	29.0	8.2
908	950	27.5	9.8
877	1259	29.3	20.4
850	1537	26.8	12.5
797	2102	23.2	19.2
700	3213	13.1	17.0
633	4049	6.9	15.0
582	4731	-0.1	3.8
577	4800	-0.1	11.4
559	5055	1.8	30.0
545	5260	2.1	30.0
500	5948	-3.5	30.0

HHHH	DDD	VV
400	60	1.5
701	60	2.1
981	319	4.1
1290	325	6.7
1599	330	8.2
1914	321	10.3
2225	313	14.4
2534	310	15.4
2842	308	12.4
3151	304	12.9
3452	296	13.4
3750	287	15.4
4049	282	19.0
4359	283	20.6
4669	288	19.6
4960	303	18.0
5291	316	19.0
5604	315	20.1
5917	311	20.1
6220	308	19.0

OMA JUL 11 00Z

PPPP	HHHH	TT	DP
966	400	33.4	8.7
941	641	31.9	14.7
873	1310	25.9	8.6
850	1545	25.2	13.2
834	1712	24.5	19.6
744	2702	19.4	30.0
700	3221	14.7	30.0
644	3917	8.0	15.2
630	4098	7.2	30.0
602	4471	5.3	30.0
530	5496	-2.9	30.0
500	5955	-5.5	30.0

HHHH	DDD	VV
400	40	2.1
697	97	4.1
975	141	4.6
1254	145	3.6
1601	143	0.5
1877	321	4.1
2152	313	6.2
2437	308	7.7
2702	310	10.3
2991	309	11.8
3275	301	11.8
3543	292	12.4
3810	291	12.9
4098	290	10.8
4385	285	9.3
4670	277	8.8
4955	270	8.2
5239	271	8.2
5524	278	8.8
5811	277	9.3
6095	265	9.3

OMA JUL 11 12Z

PPPP	HHHH	TT	DP
965	400	27.2	2.9
906	963	30.3	15.3
850	1530	25.9	14.5
762	2484	20.2	13.3
700	3209	13.9	8.5
614	4297	4.2	1.2
500	5949	-3.5	0.0

HHHH	DDD	VV
400	120	3.6
696	159	8.8
995	186	7.7
1310	228	6.2
1632	251	10.3
1973	253	13.9
2331	249	13.4
2648	246	12.4
2978	244	12.4
3311	243	11.8
3651	243	11.8
3991	238	12.9
4332	238	13.9
4684	238	14.4
5035	239	13.4
5387	252	12.4
5738	264	11.8
6115	266	13.9

APPENDIX B

OMA	JUL	12	00Z	OMA	JUL	12	12Z
PPPP	HHHH	TT	DP	PPPP	HHHH	TT	DP
962	400	36.2	14.5	965	400	33.6	8.1
955	468	35.4	18.9	936	674	28.9	30.0
905	954	32.2	19.0	850	1527	26.7	30.0
850	1514	27.4	16.5	819	1853	24.1	30.0
779	2280	23.4	21.4	807	1981	24.3	30.0
700	3201	15.8	14.6	718	2987	15.4	30.0
640	3953	8.8	8.8	700	3201	14.1	18.5
604	4403	4.8	5.8	677	3483	12.9	19.7
540	5332	-2.3	2.3	627	4120	7.9	15.0
534	5421	-1.7	30.0	576	4811	1.1	2.5
519	5647	-2.1	30.0	545	5254	-2.3	1.1
500	5948	-4.6	15.1	500	5934	-6.9	3.4

HHHH	DDD	VV	HHHH	DDD	VV
400	250	2.6	400	360	5.1
695	255	8.8	705	26	12.4
1013	251	9.8	1009	17	9.3
1303	239	10.8	1314	4	7.7
1603	236	12.9	1616	3	9.3
1897	245	16.5	1917	2	11.3
2193	253	16.5	2218	354	9.8
2476	262	13.4	2514	340	7.2
2754	274	10.3	2809	316	6.7
3033	283	9.3	3109	295	8.8
3321	287	9.3	3398	294	10.8
3622	293	8.8	3695	300	11.8
3922	297	9.3	3999	304	11.3
4205	297	9.3	4293	302	10.8
4495	295	8.8	4581	295	9.3
4805	293	9.8	4866	281	8.2
5115	298	12.9	5143	268	9.3
5449	305	12.4	5417	268	9.8
5736	306	10.8	5689	260	9.3
6038	296	11.3	5962	253	9.3

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