JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 85, NO. C12, PAGES 7285–7292, DECEMBER 20, 1980

Project Gametag: An Overview

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Presented in this first paper of the Gametag series is an overview of the Gametag program. This presentation is intended to provide the reader with background information about several of the important characteristics of the program. These include (1) the sampling strategy and general philosophy of the program; (2) the field-sampling track; (3) the nature of the sampling platform; (4) a listing of instruments and measurements recorded; (5) Gametag data-archiving procedures; and (6) a listing of participating institutions, scientific team members, and principal investigators.

Introduction

In this issue of the *Journal of Geophysical Research*, 12 papers are presented that reflect some of the important findings from the 2-year field-sampling program known by the acronym Gametag (Global Atmospheric Measurements Experiment on Tropospheric Aerosols and Gases). Several other Gametag papers have already been published before this issue [*Huebert and Lazrus*, 1978; *Danielsen*, 1980; *Danielsen and Hipskind*, 1980; *Schiff et al.*, 1979], and it is expected that several additional papers will follow in the coming months. In the text below, the author has attempted to describe the important characteristics of the Gametag program and thus render the sequence of papers that follows more meaningful.

Sampling Strategy and General Philosophy of Program

It is now generally recognized that the trace gas and aerosol species which collectively define the chemistry of the troposphere are coupled together with time constants ranging from seconds to years. Representative of those species involved in fast chemical coupling are the various nitrogen and oxygen species shown in Figures 1 and 2. These figures illustrate the importance of making simultaneous measurements of species during field sampling. This mode of sampling becomes of critical importance in the testing of chemical models that are designed to predict concentrations of short-lived photochemical species. For species having lifetimes of a few days or longer the impact of atmospheric transport must also be seriously considered. In this case simultaneous measurements can prove to be quite valuable but not necessarily definitive in model testing.

The Gametag program was designed to provide a limited but meaningful test of present models for short-lived photochemical species and also to provide survey data on these and numerous other longer-lived species over an extensive latitude range. Both before and during this field measurement program, numerous scientific questions have been raised, some of which follow: What is the relative importance of photochemical and transport processes in controlling the global distribution of O_3? What is the impact of pollution versus natural sources in dictating the tropospheric distribution of CO? What is the global distribution of methyl chloroform, and can this be systematically related to the global OH distribution? What evidence exists for gas to aerosol conversion in the clean troposphere? What is the relative importance of natural versus pollution sources in controlling global SO_2 levels? What is the role of the oceans in controlling boundary layer trace gas concentrations? What is the global distribution of NO_x species?

The above listing is not intended to imply that all or even most of these questions originated with the conception and deployment of Gametag; rather, it is an indication of the types of questions to which Gametag data are now believed to be directly applicable.

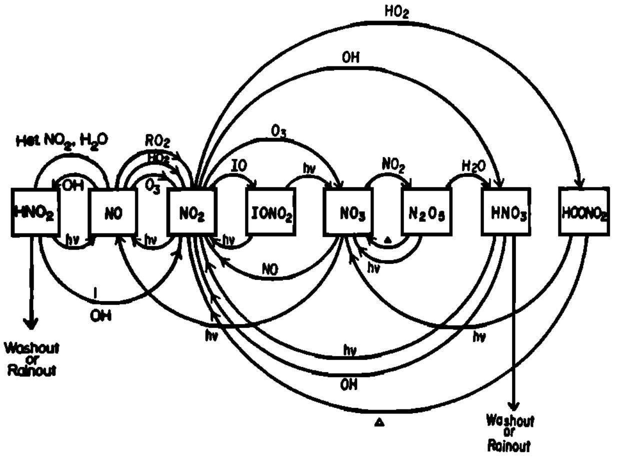

Fig. 1. A possible daytime tropospheric chemical scheme involving nitrogen oxide species (modified from *Levy* [1974]).

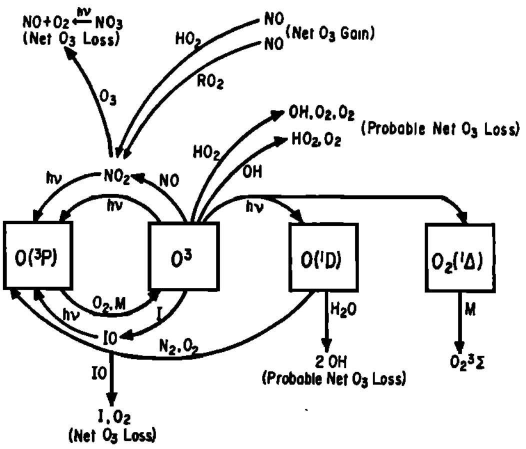

Fig. 2. A possible daytime tropospheric chemical scheme showing the key reactions of active oxygen (modified from *Levy* [1974]).

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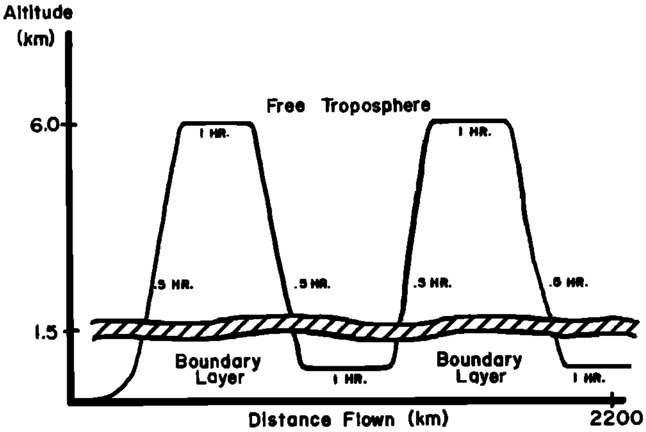

Fig. 3. Blueprint aircraft flight pattern used during the 1977 and 1978 Gametag flight operations.

In addition to 'simultaneous measurements' being a fundamental part of the sampling strategy in Project Gametag a second important aspect of the field-sampling scenario was that of making measurements both in and above the atmospheric boundary layer. The latter sampling approach was dictated by the fact that tropospheric trace gases can have both biospheric and atmospheric sources and sinks. Thus by measuring the concentration gradients of species between the boundary layer and the free troposphere it was believed that considerable insight could be gained into the relative importance of these different sink/source regimes. Based on this strategy, the 'blueprint' sampling profile that was to be flown during Gametag flights is that of Figure 3. Since the typical flight was limited to approximately 6½ hours, the profile in Figure 3 suggests that there normally would be two 1-hour boundary layer and two 1-hour free tropospheric flight legs during each flight operation. In operating between 1 and 6 km the two ascents and descents would also each take ~0.5 hour. In actual fact, it was rarely possible to execute the blueprint sampling profile given in Figure 3 for two reasons: First, the sampling strategy of covering a large latitude range, using a single aircraft, required that virtually every flight involve moving to a new geographical location some 1200–2000 miles away. Each move to a new location, however, was controlled by a 2- to 3-day logistics period, a period that frequently was not synchronized with the presence of good weather conditions between the point of initiation and the final destination. The second problem area, as will be discussed later in the pa-

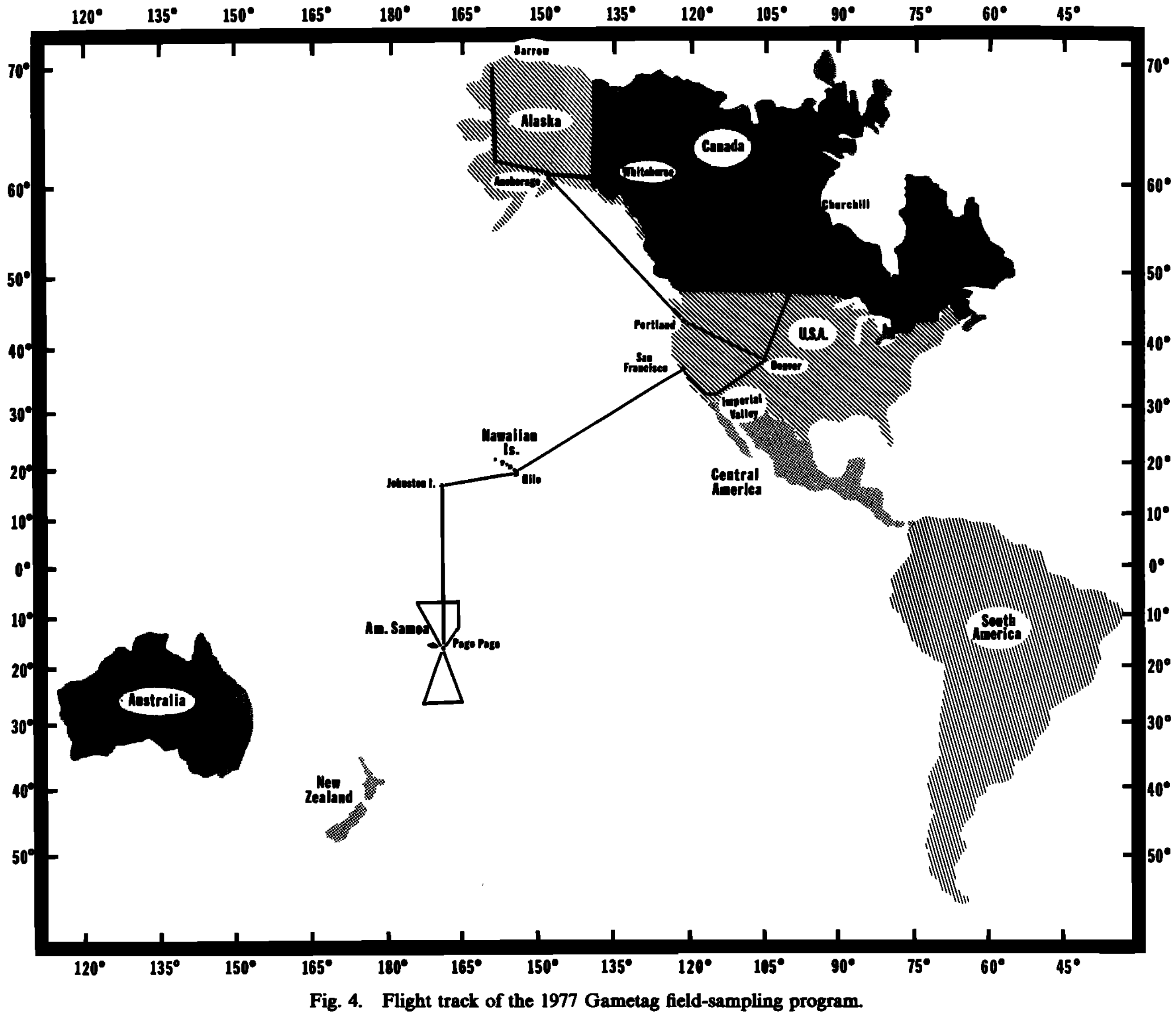

Fig. 4. Flight track of the 1977 Gametag field-sampling program.

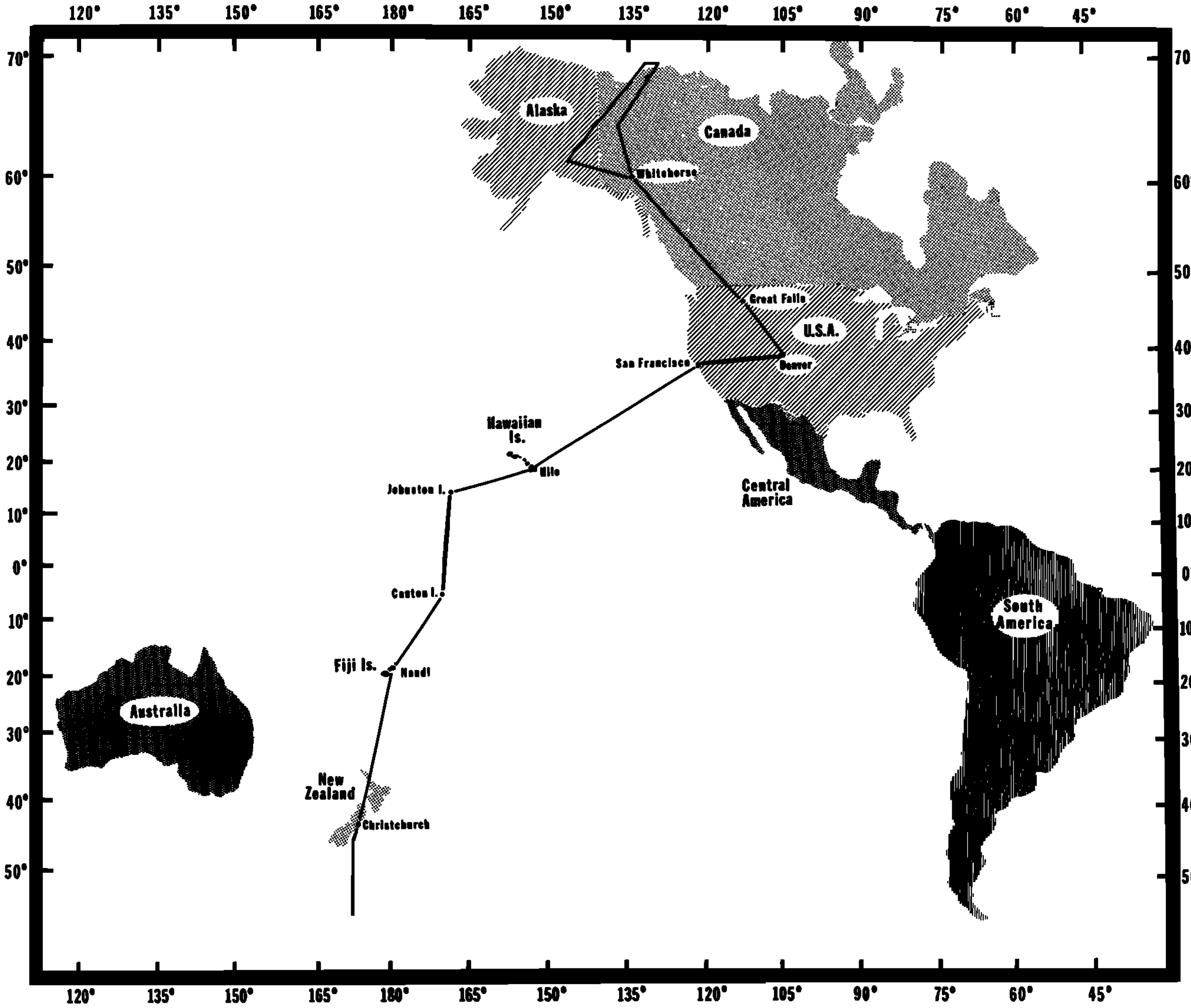

Fig. 5. Flight track of the 1978 Gametag field-sampling program.

per, involved the fact that flight profiles in the Pacific had to be tuned to take into account the low density of landing sites equipped to handle large aircraft. Flying extra long distances, for example, required stretching aircraft fuel, which, in turn, meant flying at high altitudes where engine efficiency was higher. Thus high-altitude flying dictated by condition 2 together with the high-altitude flying requirements to avoid harsh weather as defined by condition 1 resulted in nearly 3 times more flight hours logged in the free troposphere than in the boundary layer. Even so, it will be seen that the limited boundary layer sampling did produce some very significant results.

FIELD-SAMPLING TRACK

It should be noted that the word 'global' in the title of the Gametag program is being used here in a limited context. Actual sampling of the entire global troposphere was not achieved in the 2 years of field operations of Project Gametag; instead, a 'select' global sampling strategy was carried out. The major emphasis of this program was placed on covering the maximum possible latitude range in both the northern and the southern hemisphere (see Figures 4 and 5) and of carrying out sampling over both ocean and land areas. A detailed listing of the exact date and location of each flight during the 1977 and 1978 field experiments has been provided in Table 1. It will be noticed from Figures 4 and 5 that the northward and southward flight tracks in the South Pacific operation and in the Canadian-Alaska flights were in most cases largely redundant. In these instances, data were obtained from the same geographical area over time periods ranging from 2 days up to 2 weeks. Thus one might characterize this type of data collection as a 'long time exposure' rather than a quick 'snapshot' of the atmosphere. The effects of this extended sampling time are most clearly seen in the ozone and H_2O data for the northward and southward flight tracks in the South Pacific [see *Routhier et al.*, this issue; *Routhier and Davis*, this issue].

The selection of the Pacific Ocean and Canada/Alaska as the major regions over which sampling was carried out was dictated by a combination of factors, some of which were scientific, others logistical. In the case of Canada and the many islands in the Pacific Ocean, diplomatic permission for overflying and/or landing in their territories was relatively easy to

TABLE 1. Detailed Flight Track During the 1977 and 1978 Gametag Field Program

Date	Initiation	Destination	Significant Turning Points
		1977	
Aug. 7	Denver 39.6°N, 104.5°W	Portland 46.8°N, 122.7°W	
Aug. 8	Portland 46.8°N, 122.7°W	Anchorage 61.2°N, 150°W	50°N, 144.6°W
Aug. 9	Anchorage 61.2°N, 150°W	Anchorage 61.2°N, 150°W	64°N, 157.5°W 70.7°N, 159°W
Aug. 11	Anchorage 61.2°N, 150°W	Churchill 58.8°N, 94.2°W	stop at Whitehorse 60.2°N, 134.8°W
Aug. 12	Churchill 58.8°N, 94.2°W	Denver 39.6°N, 104.5°W	
Aug. 22	Denver 39.6°N, 104.5°W	San Francisco 37.5°N, 122.1°W	33°N, 115°W
Aug. 23	San Francisco 37.5°N, 122.1°W	Hilo, Hawaii 20°N, 155°W	
Aug. 25	Hilo, Hawaii 20°N, 155°W	Johnston Island 16.8°N, 169.5°W	19.5°N, 169.5°W
Aug. 26	Johnston Island 16.8°N, 169.5°W	Pago Pago 14.3°N, 170.8°W	
Aug. 28	Pago Pago 14.3°N, 170.8°W	Pago Pago 14.3°N, 170.8°W	8°S, 171°W 8°S, 168°W
Aug. 31	Pago Pago 14.3°N, 170.8°W	Pago Pago 14.3°N, 170.8°W	25.5°S, 170°W 25.5°S, 174°W
Sept. 1	Pago Pago 14.3°N, 170.8°W	Johnston Island 16.8°N, 169.5°W	
Sept. 2	Johnston Island 16.8°N, 169.5°W	Hilo, Hawaii 20°N, 155°W	13.0°N, 160.5°W
Sept. 5	Hilo, Hawaii 20°N, 155°W	San Francisco 37.5°N, 122.1°W	
Sept. 6	San Francisco 37.5°N, 122.1°W	Denver 39.6°N, 104.5°W	33°N, 155°W
		1978	
April 27	Denver 39.6°N, 104.5°W	San Francisco 37.5°N, 122.1°W	33°N, 115°W
April 28	San Francisco 37.5°N, 122.1°W	Hilo, Hawaii 20°N, 155°W	
May 2	Hilo, Hawaii 20°N, 155°W	Johnston Island 16.8°N, 169.5°W	
May 3	Johnston Island 16.8°N, 169.5°W	Canton Island 2.5°S, 171.1°W	
May 4	Canton Island 2.5°S, 171.1°W	Fiji Islands 17.7°S, 177.4°E	
May 6	Fiji Islands 17.7°S, 177.4°E	Christchurch, N.Z. 43.8°S, 172.6°E	
May 10	Christchurch, N.Z. 43.8°S, 172.6°E	Christchurch, N.Z 43.8°S, 172.6°E	58°S, 172.0°E
May 11	Christchurch, N.Z. 43.8°S, 172.6°E	Fiji Islands 17.7°S, 177.4°E	
May 12	Fiji Islands 17.7°S, 177.4°E	Canton Island 2.5°S, 171.1°W	
May 13	Canton Island 2.5°S, 171.1°W	Johnston Island 16.8°N, 169.5°W	
May 14	Johnston Island 16.8°N, 169.5°W	Hilo, Hawaii 20°N, 155°W	
May 17	Hilo, Hawaii 20°N, 155°W	San Francisco 37.5°N, 122.1°W	
May 18	San Francisco 37.5°N, 122.1°W	Denver 39.6°N, 104.5°W	33°N, 115°W
May 27	Denver 39.6°N, 104.5°W	Great Falls 47.0°N, 113.0°W	
May 28	Great Falls 47.0°N, 113.0°W	Whitehorse 60.2°N, 134.8°W	
May 30	Whitehorse 60.2°N, 134.8°W	Whitehorse 60.2°N, 134.8°W	62.9°N, 144.5°W 70.0°N, 132.5°W
May 31	Whitehorse 60.2°N, 134.8°W	Great Falls 47.0°N, 113.0°W	
June 1	Great Falls 47.0°N, 113.0°W	Denver 39.6°N, 104.5°W	

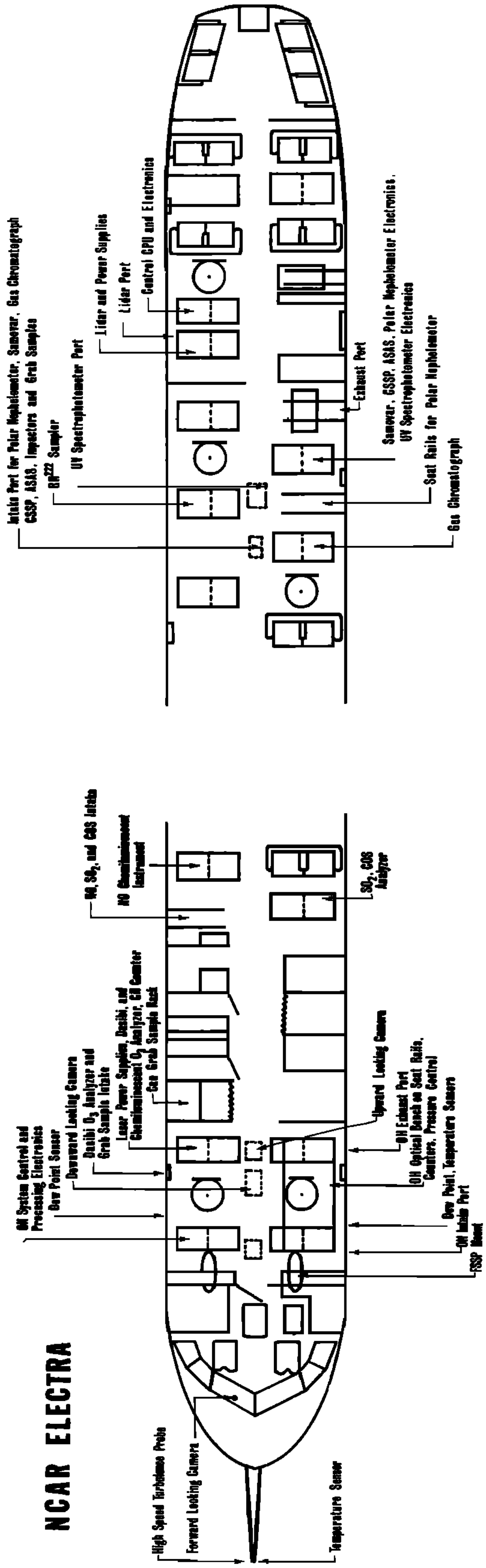

Fig. 6. Gametag instrumentation layout aboard the NCAR L-188C Electra (the forward section of the aircraft is shown on the left).

obtain. For many other areas also of great scientific interest to us, 1–2 years would have been required to obtain the same diplomatic clearance.

A major consideration in defining the detailed flight track over the Pacific Ocean was the rather limited range of the aircraft versus the density of islands with large enough runways to handle four-engine aircraft, appropriate aircraft fuel, and food and lodging facilities for the crew and scientific team members.

SAMPLING PLATFORM

The sampling platform used throughout the Gametag program was the L-188C turboprop Electra owned and operated by the National Center for Atmospheric Research (NCAR). This aircraft, when fully outfitted with Gametag instrumentation plus spare parts and personal baggage, had a nominal operating ceiling of 6.4 km and a range, at that altitude, of ~3200 km. For the flights between the U.S. mainland and Hawaii the weight of the aircraft was further reduced, thereby increasing the range by ~500 km. In the latter case, all spare parts and several flight crew and scientific personnel were shipped to the next stopping point via commercial jets. As was noted earlier, when following the blueprint Gametag sampling scenario, involving both boundary layer and free tropospheric sampling, the effective range of the Electra was reduced to ~2200 km.

The field operations team consisted of six to seven aircraft personnel (pilot, copilot, flight engineer, aircraft mechanic, and two or more electronic computer technicians) and 13–14 scientific crew members.

The instrumentation aboard the Electra consisted of instruments operated by both university and NCAR scientists as well as those maintained by NCAR aircraft personnel. Instruments in the latter category were primarily meteorological sensors such as those used to measure temperature, dew point, and horizontal and vertical winds. In addition to maintaining the meteorological sensors, NCAR flight technicians also maintained a Nova 1200 computer system. This data management system was used to store position and time information, all meteorological data, and real-time data from several instruments collecting chemical information.

The location of each instrument on the Electra aircraft is shown in Figure 6. Although some of the chemical sensors were relatively insensitive to location, others were not. In the case of the OH detector a primary concern was the need to sample air well outside the aircraft skin boundary layer. To ensure that this was the case and that relatively nonturbulent air entered the air scoop, the OH detection system was placed in the forward cabin of the aircraft. The exhaust port for this instrument was approximately 4 in. in diameter and was located on the port side of the Electra. To minimize any possible contamination from the exhaust of this system, all other chemical sensors had their intake ports either on the top center line of the aircraft or on the starboard side. In a further effort to minimize the possibility that the exhaust from one instrument might contaminate the intake of a second instrument behind it, the exhausts from all other real-time sampling instruments were dumped into a common large-diameter 'garbage' line. This garbage line exhausted near the rear of the aircraft on the port side. A final consideration on the location of several instruments was that of contamination from the aircraft engines. Tests were performed a year before the first

TABLE 2. Gametag Measurements

Variable Measured	Technique	Time Resolution	Principal Investigator
O_3	UV absorption chemiluminescence	10 s 3–4 s	D. D. Davis and T. Delany
OH	laser-induced fluorescence	3–15 min	D. D. Davis
H_2O	two-stage thermoelectric hygrometer	2–3 s	NCAR RAF and D. D. Davis
UV flux	ultraviolet spectroirradiometer	2 min	B. Sellers
NO	chemiluminescence	1–2 min	H. Schiff
HNO_3	filter matte collection—wet laboratory chemical analysis	45–60 min	B. Huebert and A. Lazrus
NO_3^- SO_4^{-2} Cl^- NH_4^+	filter matte collection—wet laboratory chemical analysis	45–60 min	B. Huebert and A Lazrus
^{222}Rn	filter matte collection with on-board β counting	20–60 min	B. Huebert
SO_2 COS	cryo trapping with on-board GLC flame photometric analysis	4–7 min	A. Bandy
N_2O CO CH_3CCl_3 CCl_4 F-11 F-12 CO	air stream aliquot sampling with on-board GC flame ionization and/or electron capture analysis	5–15 min	L. Heidt
N_2O CCl_4 CH_3CCl_3 F-11 F-12 CH_4	grab sampling laboratory GC or GLC/flame ionization and/or electron capture analysis	not relevant	L. Heidt R. Rasmussen
CO_2 CH_3Cl C_2H_2 C_2H_4 C_2H_6 Intermediate molecular weight hydrocarbons	grab sampling laboratory GC or GLC/flame ionization and/or electron capture analysis	not relevant	R. Rasmussen
Intermediate molecular weight hydrocarbons	absorption on Tenax, GC/mass spectrometer analysis	not relevant	R. Seivers and T. Delany
Aerosol optical properties	polar nephelometer	10–15 min	G. Grams and E. Patterson
Aerosol size/number distributon	Knollenberg spectrometers	2 s	T. Delany and E. Patterson
Dew Point	two-stage thermoelectric hygrometer	2–3 s	NCAR RAF and D. D. Davis
Air temperature	platinum resistance thermometer		NCAR RAF
IR ground emissions	bolometric radiometer		NCAR RAF
Broadband upward and downward UV flux	broadband pyranometer	1–2 s	NCAR RAF and B. Sellers
True air speed	aircraft computed		
Horizontal winds	aircraft computed		
Vertical gust velocities	aircraft computed		
Geographical Position	aircraft computed		
Potential temperature	aircraft computed		
Vertical acceleration	aircraft computed		

NCAR RAF is the National Center for Atmosphere Research, Research Aviation Facility.

Gametag flights to determine the magnitude of this problem. In these tests, CO samples were collected from several locations along the port side of the Electra, some being in front of the prop line, others even with the prop line, and still several others at different positions behind the prop line. The results from these experiments indicated that the CO levels at the several different positions agreed with each other to within the experimental random error (±3%) for the measurements. Even so, it was recognized that some measurements (i.e., NO) could be influenced very significantly by even low levels of contamination, and thus the intakes for these systems were either even with the prop line, in front of it, or located overhead on the aircraft center line. To minimize contamination of the intakes while the aircraft was on the ground, all intake ports were routinely capped off upon landing.

MEASUREMENTS

Table 2 lists the variables that were measured during the Gametag field operation. Also listed in this table are the technique(s) that were employed in measuring a specific variable together with the time resolution of the instrument and the principal investigator(s) (PI) with major responsibility for the equipment and/or analyzing the data.

It will be noticed that the time resolution for the Gametag instrument array varied from a relatively short response time of 1 s to a very low resolution sampling time of ~60 min. Most of the real-time measurements, however, had a time resolution of 15 min or shorter and thus provided a reasonable basis for the testing of photochemical models. In the case of the grab samples, which were collected in the field and later ana-

TABLE 3. Participating Institutions

Institution	Scientific Team Members	Principal Investigator
Colorado College	B. J. Huebert	B. J. Huebert
Drexel University	A. R. Bandy	A. R. Bandy
	P. J. Maroulis	
	A. L. Torres	
	A. B. Goldberg	
Georgia Institute of Technology	D. D. Davis	D. D. Davis
	D. Philen	
	W. Heaps	
	M. Rodgers	
	R. Dennett	
	D. Putman	
	F. Routhier	
Georgia Institute of Technology	G. W. Grams	G. W. Grams and E. Patterson
	E. Patterson	
	C. Wyman	
	C. S. Kiang	
National Center for Atmospheric Research	L. Heidt	L. Heidt
	J. Krasnec	
	W. H. Pollock	
National Center for Atmospheric Research	T. Delany	T. Delany
	A. Wartburg	
National Center for Atmospheric Research	A. L. Lazrus	A. L. Lazrus
National Center for Atmospheric Research	P. Haagenson	flight meteorologist
Oregon State University	E. Danielsen	E. Danielsen
	R. S. Hipskind	
Oregon Graduate Center	R. A. Rasmussen	R. A. Rasmussen
	L. E. Rasmussen	
	M. A. K. Khalil	
	R. W. Dalluge	
Panametrics	B. Sellers	B. Sellers
	F. A. Hanser	
	J. Hunerwadel	
York University	H. Schiff	H. Schiff
	D. Pepper	
	B. Ridley	
University of Colorado	R. Sievers	R. Sievers
	D. W. Denney	
	R. M. Barkley	
Florida State University	A. C. D. Leslie	A. C. D. Leslie

lyzed in the laboratory, the results must be viewed in terms of a set of unconnected snapshots of the atmosphere.

A final point concerning Table 2 is that not in all cases were quantitative data collected for all variables in both 1977 and 1978. The 1977 flights, in particular, resulted in the identification of calibration problems in several instruments, problems which had not appeared in any of the advance test flights. The respective PI's for these instruments have therefore looked upon their 1977 data as being qualitative in nature.

In contrast to the 1977 flights, ~90% of all instrumentation aboard the Electra in 1978 produced quantitative data. For this reason the reader will generally see a heavier emphasis on 1978 results than on those from 1977. Also reflecting the larger abundance of quantitative data in 1978 has been the decision by the Gametag executive committee to archive the 1978 data first with a later follow-up on the smaller data base from 1977.

ARCHIVING OF DATA

One of the major considerations involved in defining the archiving scheme for Gametag data was selection of a format that would be relatively easy to use. Details on this procedure have been provided by R. Dennett et al. (unpublished manuscript, 1980). A brief summary of the latter document is provided below.

Because of the large amounts of data collected for several of the variables, magnetic tapes were chosen as the principal storage medium. Data are placed on these tapes in the form of card images, each card image representing one update interval. Although it is recognized that this is not the most concise form of storage, it is nevertheless a widely recognized form of information interchange. In an effort to reduce the amount of data that has to be stored on a data tape, only updates in the value of each variable are stored. This approach has greatly reduced the amount of computer memory required for data playback. The organizational scheme for archived Gametag data is as follows:

1. Each data tape contains data from a single flight day.
2. The first file on the tape contains information about the flight track and general comments regarding the data or the instruments used to record it.
3. Each of the remaining files on the tape represents 1 hour of data from a given flight day.
4. The first record within each of these data files initializes the data table in the computer memory. Each successive record then updates the values of all variables.

PARTICIPATION IN PROGRAM

Listed in Table 3 are the several organizations which played the major roles in defining the 1977/1978 Gametag program. In all, seven universities, one private research institute, the NSF-supported National Center for Atmospheric Research, and one private company were actively involved. The scientific team members from each participating organization have been listed in Table 3 along with the senior scientist who served as principal investigator on each project. The executive committee during the program consisted of C. S. Kiang (Georgia Institute of Technology), R. Duce (University of Rhode Island), P. Crutzen (National Center for Atmospheric Research), and this author (Georgia Institute of Technology). Not listed are the names of the many people at the NCAR Research Aviation Facility who spent numerous hours working with the executive committee and individual Gametag scientists to help make this project a success. Most notable among these were the pilots, L. Newcomer, G. Summers, W. Zinser, and J. Covington; the flight engineer, J. Lundahl; the flight mechanic, H. Barber; the electronic and computer technicians, R. Taylor and M. Reynolds; and the interface/structural engineer, N. Zrubek.

The program is also greatly indebted to the members of the NCAR Aviation Panel, who provided for the necessary flight hours on the Electra, and to the National Science Foundation, which provided all the financial support for the project.

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(Received January 28, 1980;
revised June 2, 1980;
accepted June 4, 1980.)