Geophysical Monitoring for Climatic Change

No. 5

Summary Report 1976

U.S DEPARTMENT OF COMMERCE

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

ENVIRONMENTAL RESEARCH LABORATORIES

Geophysical Monitoring for Climatic Change No. 5

Summary Report 1976

Kirby J. Hanson, Editor

November 1977
Boulder, Colorado

U. S. DEPARTMENT OF COMMERCE
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NOTICE

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Donald Pack served as the first Director of the Geophysical Monitoring for Climatic Change (GMCC) program from 1971 to 1975 and was instrumental in establishing monitoring programs at four remote locations to determine the global background levels of certain atmospheric trace constituents, sometimes called global "pollution". In the early 1970's, the need for this monitoring was pointed out by the Study of Critical Environmental Problems (1970), the Study of Man's Impact on Climate (1971), and the Stockholm Conference (1974). Mr. Pack's unique contribution was to develop within the National Oceanic and Atmospheric Administration (NOAA) a timely response to this need. Thanks to his foresight and hard work, the global background monitoring effort was established early, on firm ground. We are indebted to him for his leadership.

It is possible for the secrets of nature to be hidden in a flood of data as well as in nature. Clearly, we need information more than we need data.

Verner Suomi

FOREWORD

From Prof. Suomi have come many memorable quotations, but the one given above (Suomi, 1977) is particularly appropriate to our work.

Each year a number of important factors are considered in deciding on GMCC programs:

- The needs of climate modelers for GMCC information to develop and validate their models.
- The degree of accuracy and spatial resolution with which the technology must be applied to obtain data suitable to achieve understanding of the role of external causal factors in climatic change.
- The needs of the user community for the resultant data, and the most useful forms for the data.
- The periods of time over which monitoring of different variables should continue.
- The resources available for monitoring programs.

In the real world where we cannot monitor everything, everywhere, all of the time, we must depend on a clear definition of the needs of climate modelers. But as Prof. Suomi has pointed out (in the reference above) what the climate modelers need and what the technologists can provide may not be the same; each group must make the effort to understand the other's area. Only if effective dialog, debate, and negotiation go on between the two groups will there evolve a monitoring plan that meets the needs for climate prediction and yet is held within the bounds of available resources. This is the challenge that we recognize today, one that no doubt will remain until the climate prediction problem eventually is mastered. We are indebted to Prof. Suomi for illuminating this challenge.

Kirby J. Hanson
Boulder, Colorado
October 7, 1977

ACRONYMS AND ABBREVIATIONS

ARL	Air Resources Laboratories
BOSS	BASIC Operating Software System
CCN	cloud condensation nucleus
CPU	central processing unit
CSIRO	Commonwealth Scientific and Industrial Research Organization
DAS	data acquisiton system
DOY	day of year
ECC	electrochemical concentration cell
EPA	Environmental Protection Agency
ERDA	Energy Research and Development Administration
ERL	Environmental Research Laboratories
GATE	GARP Atlantic Tropical Experiment
G.E.	General Electric
GMCC	Geophysical Monitoring for Climatic Change
GMT	Greenwich Mean Time
GSA	General Services Administration
HASL	Health and Safety Laboratory
ICDAS	Instrument Controlled Data Acquisition System
INSTAAR	Institute of Arctic and Alpine Research
IPC IV	International Pyrheliometer Comparison IV
IPS	International Pyrheliometric Scale
LED	light-emitting diode
LST	Local Standard Time
MLO	Mauna Loa Observatory
NASA	National Aeronautics and Space Administration
NARL	Naval Artic Research Laboratory
NBS	National Bureau of Standards
NIP	normal incidence pyrheliometer
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
NWS	National Weather Service
PSRB	Physical Science Research Building (Boulder, Colo.)
UNOR	(a German-made infrared gas analyzer)
URAS	(a German-made infrared gas analyzer)
USGS	U.S. Geophysical Survey
WMO	World Meteorological Organization
WPL	Wave Propagation Laboratory

GEOPHYSICAL MONITORING FOR CLIMATIC CHANGE

NO. 5

SUMMARY REPORT - 1976

1. SUMMARY

A sampling program for carbon dioxide (CO_2) and Freon-11 was initiated at Niwot Ridge, Colorado, at an altitude of 3.6 km. This is regarded as representative of midcontinent, midlatitude clean air. The quality of data is comparable with that obtained at the baseline stations. The CO_2 sampling resumes at this location after a 23-month break.

A CO_2 sampling program was reinitiated at Key Biscayne, Florida, after a break of 20 months. Sampling is obtained by flasks only under well established trade wind conditions.

Increased control of parameters in chromatographic analysis has greatly reduced the scatter in the Freon-11 measurement at the baseline stations, beginning in May 1976. This will allow much greater confidence in determining zonal gradients, trends, and annual cycles.

A tropical disturbance passed over Samoa on December 11, 1976, causing the University of Rhode Island sampling tower to collapse. No other significant damage was sustained.

Use of the under-snow clean air sampling facility at the South Pole was discontinued in the austral summer of 1976-77, and the GMCC monitoring program was moved to a newly constructed building above the snow surface. The building was provided by the National Science Foundation (NSF).

An ion chromatograph was added to the GMCC program on the island of Hawaii for analysis of all major ions in precipitation chemistry samples. Sampling is limited to the island.

There was some evidence during 1976 that activities on Alaska's north slope have decreased the sector from which clean air measurements can be obtained at the Barrow Observatory. The evidence is from measurements of near-surface aerosols.

There have been some periods in 1976 at the Mauna Loa Observatory (MLO) when unusually high CO_2 concentrations have been observed with downslope winds--winds that usually provide stable background CO_2 concentrations. An effort is being made to determine the source of these anomalies.

A workshop held in Boulder is reviewed in Appendix A.

Figure 1. Aerial view of Mauna Loa Observatory in 1958.

2. OBSERVATORY FACILITIES

2.1 Mauna Loa

In August 1976, the Hilo offices of MLO were transferred from the University of Hawaii campus to the Federal Building, Rooms 202 and 203, in downtown Hilo (mailing address: Mauna Loa Observatory, P.O. Box 275, Hilo, HI 96720; phone: 808-961-3788).

The new facilities provide more office space, as well as separate electronics and chemistry laboratories in the basement of the building. Some remodeling of the laboratory areas was necessary to satisfy observatory requirements. The modifications, carried out by the General Services Administration (GSA), included installing extra outlets, air conditioning, laboratory benches, new lighting, a ventilation hood, and other equipment needed for electronic and chemistry work. All these changes should be completed by early 1977. The trailer at Cape Kumukahi, which was formerly used as a research facility, has been sold through the GSA.

In July 1976, MLO celebrated its twentieth year since opening the main building. Figure 1 shows the observatory in 1958. Contrast this picture with Figure 2, taken in 1976.

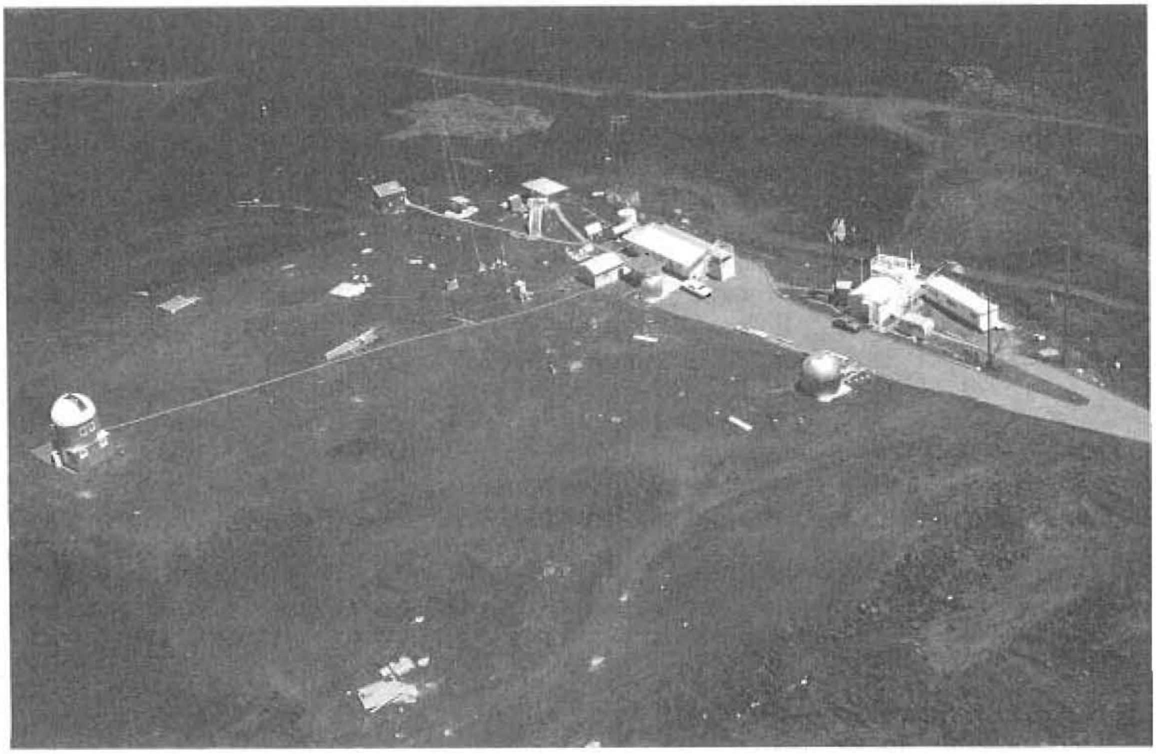

Figure 2. Aerial view of Mauna Loa Observatory in May 1976. (Photo by J. P. Lockwood, USGS Hawaii Volcanoes Observatory.)

2.2 Barrow

A six-pair shielded cable was installed from the observatory to the Air Force hangar at the Naval Arctic Research Laboratory (NARL) which houses the commercial telephone terminal for Barrow. The cable was laid on the ground parallel to the road and was marked with red flags along its length for access and protection during the winter months. Two telephones using this cable, a commercial phone and a local, three-digit phone, were installed at the station. In addition, one pair was made available to the U. S. Geological Survey (USGS) magnetic observatory to provide telephone service to their instruments, which are located near the Barrow station.

A glass still was installed in the observatory to provide pure water for the precipitation chemistry program.

The GMCC married quarters at NARL were improved by adding a 16' x 22' wanigan, which nearly doubled the living space. The interior of the existing quonset hut was remodeled, and new furniture was purchased.

The station was plagued by vehicle problems throughout 1976. The USGS vehicle at Barrow was borrowed in the fall to ensure continuous transportation through the winter months.

2.3 South Pole

The temporary under-snow clean air facility was used for its final year in 1976. Plans of GMCC and NSF were well underway for the 1976-77 austral summer construction of a more permanent elevated facility almost directly grid north of the temporary facility.

During the 1975-76 austral summer, a leaking roof and snow loading from local drifting continued to threaten the structural well-being of the facility. Two support beams were added, and a 1 m vertical extension was added to the main and emergency hatches. To help reduce melting from the ceiling, room temperature was reduced to approximately 15°C.

A 2-month surface ozone and aerosol sampling program was carried out on the top floor of the sky laboratory. This was intended to assess Skylab's suitability as a central monitoring location in the event that the GMCC program had to be moved, because of the deteriorating physical condition of the temporary clean air facility.

2.4 Samoa

There were no changes in the Samoa Observatory during 1976 except for the addition of a remote sampling building in November. This consisted of a prefabricated 8' x 16' building purchased from Elder International. It was erected at the east end of Lauagae Ridge and will be adjacent to the Samoa remote sampling tower, to be built in early 1977. The building is air conditioned and will be used to house the Samoa aerosol equipment consisting of the General Electric (G.E.) condensation nucleus counter and nephelometer, a Pollak counter and possibly a surface ozone counter. Air will be sampled at approximately the 50-ft level and brought to the instruments to a gas aerosol sampling stack designed by the GMCC Techniques and Standards Group.

2.5 Boulder

Two observatory facilities in Boulder and vicinity are available to the GMCC program. One consists of platform space on the roof of the University of Colorado Physical Science Research Building (PSRB) No. 3, headquarters of the GMCC program. This roof space is especially suited for exposure of solar radiation measuring instrumentation, and contains an Ash dome observation shelter housing a Carson Astronomical Instruments solar tracker. The second facility is located at NOAA's Fritz Peak Observatory which is operated by the Environmental Research Laboratories' (ERL) Aeronomy Laboratory. This observatory is about 40 km west of Boulder at an elevation of 2.4 km above mean sea level. (Fritz Peak rises to an altitude of 2.7 km.) The site is especially suited for testing and operating gas analysis instrumentation since clean air is predominantly available there, even in spite of heavy traffic passing near the observatory, especially on summertime weekends. Prevailing winds at the observatory are from the west, the direction of the Rocky Mountain Great Divide.

Niwot Ridge, at an elevation of 3.6 km near the Great Divide, is also a GMCC monitoring site. Air samples for CO_2 and Freon-11 analyses are collected once a week there under contractual arrangements with the University of Colorado Institute of Arctic and Alpine Research (INSTAAR). This high altitude location is regarded as a midcontinent clean air site. Data from here are often comparable in quality with data obtained at the GMCC baseline stations.

3. OBSERVATORY PROGRAMS

3.1 Mauna Loa

Two special short-term programs were carried out at MLO. Glenn Shaw, of the University of Alaska, installed his narrow-band sun photometer in March, and measurements were made through November (see Appendix for further description). A 2-month (June-July) intercalibration of Dobson spectrophotometers, using the world standard Dobson No. 83 and the MLO Dobson No. 63, was performed by student aides Steve Mina and Gary Brown, who took a series of concurrent total ozone measurements.

The program comparing the GMCC URAS-2/Scripps Applied Physics CO_2 analyzer systems is still in effect. In addition, weekly CO_2 flask samples have been taken through the URAS-2 since June, and the manually operated weekly CO_2 flask program was reinstated at Cape Kumukahi in March.

In accordance with the U.S.-U.S.S.R. bilateral program on the protection of the environment, Anatoli Yeliseyev and Vladimir Kovalov of the Geophysical Observatory of Leningrad visited MLO for about 3 weeks in October. The scientists brought with them the M83, the device used in the USSR to measure total ozone in the atmosphere. They spent more than 20 days at the observatory making total ozone measurements with the M83 and comparing their data with concurrent MLO Dobson spectrophotometer readings (Fig. 3). The results showed that the two instruments agreed within 5%. Drs. Yeliseyev and Kovalov also had the opportunity to observe all the other measurement programs at MLO.

During the latter part of the year, the data acquisition system (DAS) suffered a major outage, possibly due to hardware or environmental causes. Since December, measurements from all systems have been kept on backup recorders. Because of the outage, only the National Weather Service (NWS) normal incidence pyrheliometer (NIP), the quartz pyranometer, and the first quartz channel of the 13-channel radiometer could be

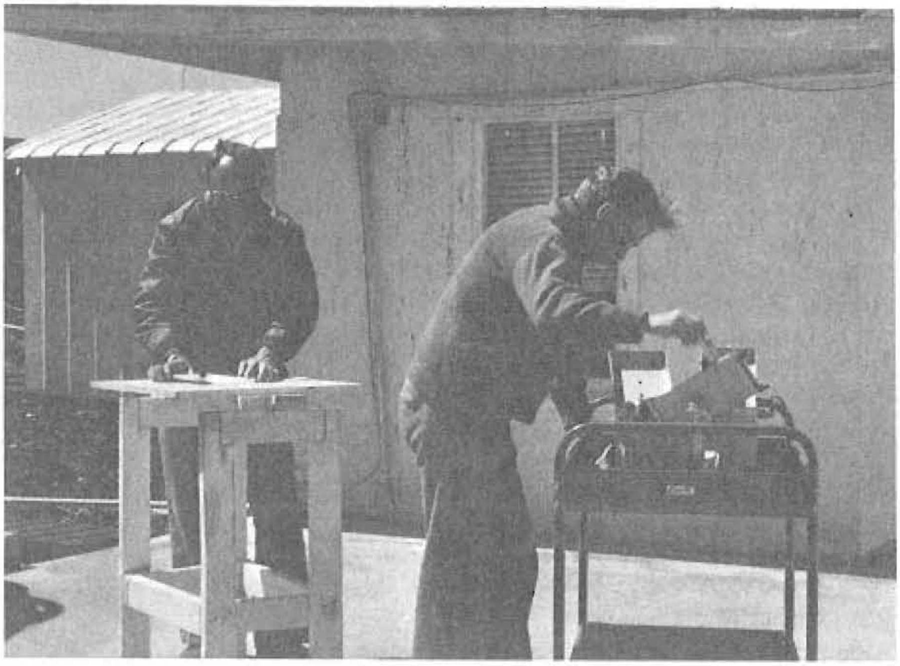

Figure 3. Drs. Yeliseyev and Kovalov, Geophysical Observatory of Leningrad, check ozone measurements on the M83 at Mauna Loa.

recorded continuously. In October, a filter wheel pyrheliometer was installed which requires manual measurement and recording of data. To prevent further interruptions due to DAS failure, a separate NOVA II computer is now being used for the lidar system.

An ion chromatograph, which allows measurement of all major ions in precipitation chemistry samples, was acquired for the new MLO chemistry laboratory in December.

The following programs were discontinued during 1976: solar aureole; rain Sr^{90}; and aerosol particles for analysis from the Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia.

Mauna Loa programs operated during 1976 are listed in Table 1.

3.2 Barrow

The Instrument Controlled Data Acquisition System (ICDAS) was inoperative during the first 2 months of 1976 becuase of problems with the Wangco magnetic tape drive alignment.

Table 1. Summary of Sampling Programs at Mauna Loa in 1976

Monitoring Programs	Instrument	Sampling Frequency	Data record
Gases			
Carbon dioxide	Evacuated glass flask (SIO)	2/month	Oct 1958 - present
	Applied physics infrared gas analyzer (SIO)	Continuous	Oct 1958 - present
	URAS-2 infrared gas analyzer	Continuous	Jun 1974 - present
	Evacuated glass flask (GMCC)	1/week	Jun 1976 - present
Surface ozone	Electrochemical concentration cell (ECC)	Continuous	Sep 1973 - present
	Dasibi ozone meter	Continuous	Jul 1975 - present
Total ozone	Dobson spectrophotometer	Discrete	Oct 1957 - present
Fluorocarbons	Evacuated flask	1/week	Sep 1973 - present
Aerosols			
Atmospheric particulates (height distribution)	Lidar	1/week	Apr 1973 - present
Condensation nuclei	Gardner counter	Discrete	Sep 1967 - present
	G. E. counter	Continuous	Sep 1973 - present
	Pollak counter	Discrete	Jul 1973 - present
Optical properties	Four-wavelength nephelometer	Continuous	Jan 1974 - present
Solar Radiation			
Global spectral irradiance	Ultraviolet radiometer	Continuous	Apr 1972 - present
	Four Eppley pyranometers	Continuous	May 1972 - present
	Eppley bulb-type pyranometer	Continuous	Jan 1958 - Sep 1975
Direct spectral irradiance	Eppley normal incidence pyrheliometer	Continuous	Jan 1958 - present
	Filter wheel pyrheliometer	Discrete	Nov 1976 - present
	Multi-channel pyrheliometer	Continuous	May 1972 - present
Water vapor	Foskett	Continuous	Jul 1967 - present
Solar aureole	Aureole camera	1/week	Jun 1974 - present
Meteorology			
Temperature/dewpoint	Hydrothermograph/thermistor	Continuous	1955 - present
Pressure	Barograph/pressure transducer	Continuous	1955 - present
Precipitation	8 inch rain gage	Daily	Dec 1956 - present
	Tipping bucket gage	Continuous	Dec 1956 - present
Precipitation chemistry--GMCC	pH meter, bridge, electrodes	Discrete	Oct 1974 - present
Winds	Anemometer	Continuous	Dec 1956 - present
Cirrus clouds	Lidar	1/week	Apr 1973 - present
Cooperative Programs			
Carbon monoxide--Max Planck Institute	Chemical reaction with HgO	Continuous	Aug 1973 - present
SO_2, NO_2--EPA	Chemical bubbler system	1/2 weeks	Aug 1971 - present
Total surface particulates--ERDA	Hi-volume filter	Intermittent	1970's - present
Turbidity--EPA	Dual wavelength sunphotometer	Discrete	1960's - present
Precipitation Chemistry--EPA	Misco collector	Discrete	Mar 1973 - present
Rain Sr^{90}--ERDA	Ion exchange column	1/month	Nov 1955 - Apr 1976
Aerosol particles for analysis--CSIRO	Impactor/precipitator	Discrete	Aug 1971 - Nov 1976
Surface Tritium--University of Miami	Molecular sieve	2-day averages	Aug 1971 - present
Solar Radiation	Ultraviolet meter	Continuous	Dec 1973 - present
Erythema Spectrum--Temple University			
Atmospheric electricity--APCL-ERL	Electrical sensors	Continuous	Oct 1975 - present
Precipitation chemistry--ERDA	HASL collectors	Discrete	Apr 1976 - present
Turbidity--AFGL	Volz twilight photometer	Discrete	Aug 1975 - present

A G.E. aerosol counter and a four-wavelength nephelometer were installed in May 1976. The nephelometer was inoperable from August 3 to the end of the year and had to be returned to the manufacturer for repair and modification of the cooling system. A Royco particle counter was put in operation in July.

The CO_2 UNOR analyzer was replaced on August 2 because of a "noise" problem with the old analyzer. The CO_2 system was modified to provide direct control by the ICDAS.

The relative humidity sensor was deactivated and replaced by the dew point temperature sensor in channel 5 of the ICDAS data array. A summary of the sampling programs is given in Table 2.

Several cooperative programs were supported during 1976. In September, Kenneth Rahn, University of Rhode Island, installed a wind controlled aerosol sampling system, under an Office of Naval Research contract to study the Arctic haze layer. A special SF_6 flask sampling program was conducted for the Energy Research and Development Administration. The 1976 National Aeronautics and Space Administration (NASA) Latitude Survey was supported by GMCC ground-based measurements. Station personnel assisted in erecting a "Wyoming shield" precipitation collector, approximately 200 m north-northwest of the station, for Carl Benson, University of Alaska. The collector is designed to minimize the effects of blowing snow on precipitation collection. The Smithsonian Radiation Biology Laboratory installed a new data acquisition system for its solar radiation instrumentation. Data are now digitized and stored on magnetic cassette tapes.

The University of Nevada Desert Research Institute high-volume sampling program was discontinued during 1976 because of equipment failure. The Environmental Protection Agency (EPA) "Misco" automatic precipitation collector was discontinued early in 1976 because of design problems.

3.3 South Pole

The new executive program, BASIC Operating Software System (BOSS) 75170, was installed and started operating in early January 1976. The system performed satisfactorily until September, when an integrated circuit on the central processing unit (CPU) board failed. As a result ICDAS was down until the arrival of a new CPU board on November 21, 1976.

A new meteorological system was added in January 1976. Measurements included air and snow surface temperature, barometric pressure, and wind speed and direction. The signals for these measurements were processed through individual translators and then were recorded by ICDAS.

Table 2. Summary of Sampling Programs at Barrow in 1976

Monitoring Programs	Instrument	Sampling Frequency	Data record
Gases			
Carbon dioxide	URAS infrared gas analyzer	Continuous	Mar 1973 - present
	Evacuated glass flask	1/week	Apr 1971 - present
Total ozone	Dobson spectrophotometer	Discrete	Aug 1973 - present
Surface ozone	ECC	Continuous	Mar 1973 - present
	Dasibi ozone meter	Continuous	Jul 1975 - present
Fluorocarbons	Evacuated flask	1/week	Sep 1973 - present
Aerosols			
Condensation nuclei	Gardner counter	Discrete	Sep 1971 - present
	G.E. condensation nucleus counter	Continuous	May 1973 - Nov 1974 and May 1976 - present
	Pollak counter	Discrete	Oct 1975 - present
	4-λ nephelometer	Continuous	May 1976 - Aug 1976
Solar Radiation			
Global spectral irradiance	Four Eppley pyranometers	Continuous	Jun 1974 - present
	Ultraviolet radiometer	Continuous	Jun 1974 - present
Meteorology			
Temperature	Hygrothermograph	Continuous	Feb 1973 - Jan 1976
Dewpoint temperature	Hygrothermograph	Continuous	Feb 1973 - present
Pressure	Microbarograph	Continuous	Feb 1973 - present
Precipitation	8-inch rain gage	Discrete	Feb 1973 - Jan 1976
Snow cover	Observer	Discrete	Oct 1974 - present
Wind speed/direction	Bendix aerovane	Continuous	Feb 1973 - present
Air and ground temperatures	Remote sensors (thermistors)	Continuous	Nov 1975 - present
Relative humidity	Remote sensor	Continuous	Nov 1975 - Dec 1976
Pressure	Transducer	Continuous	Nov 1975 - present
Cooperative Programs			
Turbidity--ERDA	Dual wavelength sun photometer	Discrete	Mar 1973 - present
Precipitation chemistry--EPA	Misco collector	Discrete	Sep 1973 - Sep 1975
Surface global radiation--SRBL	Eppley pyranometers	Continuous	Apr 1973 - present
	Scanning UV radiometer	Continuous	May 1975 - present
Total surface particulates--URI	Hi-volume sampler	Continuous	Oct 1973 - Aug 1976
CO_2 sampling--Scripps	Evacuated flask	2/month	Jan 1974 - present
Total surface particulates--ERDA	Hi-volume sampler	Continuous	Aug 1975 - present
Total NO_2--Aeronomy Lab., NOAA	NO_2 spectrometer	Discrete	Aug 1975 - present
Total surface particulates and elemental analysis--URI	Hi-volume sampler	Discrete	Sep 1976 - present

After only a year of use at the South Pole, the multichannel radiometer program was discontinued in February 1976 because the fogging window problem could not be corrected. The instrument was sent back to Boulder in November 1976.

Mr. Cobb's field mill and air-Earth current antenna were relocated in January 1976. The original site experienced extensive local drifting that bnried the sensors. The sensors were relocated about 60 m grid east of the clean air facility, and this new site proved to be free of excessive local drifting.

New cooperative programs for GMCC included a carbon-14 sampling program from NOAA/ARL (Air Resources Laboratories) and an acoustic echo sounder from NOAA/WPL (Wave Propagation Laboratory).

Table 3 summarizes sampling programs at South Pole Station.

3.4 Samoa

The active measurement programs at the Samoa observatory are summarized below. They are divided into the following areas: gases, both surface and total atmospheric column; aerosols, which include surface cloud condensation nucleus (CCN) measurements and turbidity monitoring; solar radiation; meteorology measurements; precipitation collection; and cooperative programs. Included are any changes, such as relocations, modifications, new installations, or special procedures.

3.4.1 Gases

The following were monitored: carbon dioxide; surface ozone; total ozone; and fluorocarbon-11 (surface). An NO_2 spectrometer is scheduled for installation in early 1977.

Carbon dioxide

Continuous CO_2 measurements were made with consistent sampling configuration during the entire year. A URAS-2T is used as the primary monitoring device and its output is continually recorded by the station ICDAS. In addition, weekly flask samples are obtained for shipment to Boulder where analyses for comparison purposes are done. During 1976 air was brought to the URAS analyzer from Cape Matatula by a 1100-ft sampling line composed of an internal gas line of 3/8-in polyethylene tubing (continuous length, no splices). It is protected by an outer line of 1-in diameter black polyvinylchloride, used primarily as a light barrier. The sample line inlet was attached to the University of Rhode Island sampling tower on the Cape. Early in 1976, the URAS analyzer floating-signal output was modified by using a preamplifier to reference one side of its floating signal to a system chassis ground. Prior to this, the high side of the output had been saturating the ICDAS digitizer.

Table 3. Summary of Sampling Programs at South Pole Station in 1976

Monitoring Programs	Instrument	Sampling Frequency	Data record
Gases			
Carbon dioxide	URAS infrared gas analyzer	Continuous	Jan 1975 - present
	Evacuated gas flask	2/month	Jan 1975 - present
Surface ozone	Electrochemical concentration cell	Continuous	Dec 1971 - present
	Dasibi ozone meter	Continuous	Jan 1976 - present
Total ozone	Dobson spectrophotometer	Discrete	Dec 1963 - present
Fluorocarbons	Stainless steel flask	2/week	Temporary Dec 1975 - Jan 1976
Aerosols			
Condensation nuclei	G. E. counter	Continuous	Jan 1974 - present
	Gardner counter	Discrete	Jan 1975 - present
	Pollak counter	Discrete	Jan 1974 - present
Solar Radiation			
Global spectral	Four Eppley pyranometers	Continuous during austral summer	Feb 1974 - present
	Ultraviolet radiometer	Continuous during austral summer	Feb 1974 - present
Direct spectral	NIP	Continuous during austral summer	Feb 1974 - present
	Multichannel radiometer	Continuous during austral summer	Jan 1975 - Feb 1976
Meteorology			
Air temperature	Thermistor	Continuous during austral summer	Dec 1975 - present
Snow surface temperature	Thermistor	Continuous during austral summer	Feb 1976 - present
Pressure	Transducer	Continuous	Dec 1975 - present
Wind speed and direction	Bendix aerovane	Continuous	Dec 1975 - present
Cooperative Programs			
CO_2 sampling--Scripps	Evacuated glass flask	2/month	1955 - present
Carbon-14--ARL	Steel flasks	1/week	Jan 1974 - present
Acoustic sounder--NOAA	Transmitter and receiver	Continuous	Temporarily discontinued-Jan 1976
Particulate sampling--ERDA	Hi-volume pump and filter assembly	1/week	1970 - present
Trace metal sampling--University of Maryland	Hi-volume pump and filter assembly	1/week	1974 - present
Atmospheric electricity--NOAA	Field mill and dipole antenna	Continuous	Jan 1975 - present
Ionospheric absorption--NOAA, UCSD	30 and 50 mHz radiometers	Continuous	1962 - present
Thermal radiation	Net IR radiometer	Continuous	Jan 1975 - present
Turbidity--EPA	Sun photometer	Discrete	1975 - present

Surface Ozone

Two methods of surface ozone monitoring were used: the electrochemical concentration cell (ECC) meter, and the Dasibi ozone analyzer. An ECC meter Model No. 005-8 was used to monitor air in the vicinity of the observatory roof. The sample inlet was located approximately 15 ft above the roof and a sample line of Teflon tubing was used to minimize ozone destruction. Total inlet line length was approximately 30 ft. The Dasibi ozone analyzer was equipped with the same inlet configuration as the ECC meter. In addition, both ozone instruments were calibrated on a weekly basis using a McMillan ozone generator, modified by the GMCC Techniques and Standards Group in Boulder, for greater long-term stability.

Total Ozone

Total atmospheric ozone was monitored during the entire year using Dobson ozone spectrophotometer No. 42. The instrument is housed in an Ash dome on the observatory roof. As part of a special program to develop correction factors for the instrument, quasi-simultaneous observations were conducted during April and May.

Fluorocarbon-11

Weekly flask samples were obtained throughout the year for shipment to Boulder and subsequent analysis. The sampling flasks consist of 300-ml evacuated stainless steel cylinders equipped with valves.

3.4.2 Aerosols

Surface aerosols (CCN) were monitored throughout 1976 using a modified Gardner counter equipped with a long tube and a light-emitting diode (LED) light source. Observations were made daily at Cape Matatula. Two other instruments were also used during 1976: a Volz sun photometer, and a Volz twilight photometer. The official observing site for the sun photometer has been moved from the NWS station at Pago Pago to the GMCC observatory site. The twilight photometer became operational in April 1976 and its data records are sent directly to Dr. Volz. Sun photometer data are sent to the National Climatic Center in Asheville, North Carolina. An additional aerosol sampling program has been conducted for the Health and Safety Laboratory (HASL). It involves operation of a high-volume air sampler installed in April, adjacent to the observatory. These sample filters are mailed weekly to HASL for radionuclide analysis.

3.4.3 Solar Radiation

Four horizontal incidence Eppley pyranometers with quartz, green, orange, and red filter domes compose the present GMCC radiation sensor array in Samoa. A normal incidence pyrheliometer (NIP) is scheduled for installation in early 1977. The four Eppley sensors were operational from January 11 through December. In April, Bernard Mendonca conducted a special project to intercompare the Eppley sensors with the GMCC traveling standard.

3.4.4 Meteorology Measurements

GMCC meteorology sensors consist of the following pieces of equipment: Bendix aerovane, Model No. 120; surface and ground temperature sensors (thermistor sensing element); humidity sensors; and surface pressure sensors.

Wind

Wind and wind speed were continuously recorded using both the Bendix chart recorder and the GMCC ICDAS system. The instrument is located on the remote sampling tower on Cape Matatula.

Temperature

Ground and surface air temperatures were continuously monitored using linearized thermistors. The surface air temperature sensor is mounted in an aspirated radiation shield which is attached to the remote sampling tower located on Cape Matatula.

Humidity

Attempts at continuously recording humidity with the ICDAS and a solid state sensor failed. As an interim solution, a hygrothermograph, located at Cape Matatula, was used during most of 1976. Installation of a dew cell is scheduled for 1977.

Surface Pressure

By use of a pressure transducer as a sensor, station pressure is continuously recorded. In addition, a microbarograph provides a chart record of pressure. Records from both the transducer and the microbarograph are compared with those from the station standard, a wall-mounted mercurial barometer.

3.4.5 Precipitation Collection

Two types of precipitation collectors were operational during 1976: the HASL wet/dry collector, and the EPA Misco collector.

HASL Wet/Dry Collector

Two collectors of this type were installed during April 1976 by Herbert Volchok. They are located on the instrument platforms on the observatory roof, and their sample containers are mailed to HASL each month. In addition, two bulk collectors are also exposed continuously for HASL and returned monthly.

EPA Misco Collector

Previously located at the NWS station near the Pago Pago International Airport, this collector was moved to the Samoa Observatory roof in January 1976. The original collector developed irreparable mechanical problems and was replaced in July. All mechanical and electrical components in the replacement were coated to prevent corrosion, a primary cause of the original collector's failure. Samples are mailed back to the United States monthly.

3.4.6 Cooperative Programs

Active cooperative programs during 1976 are sampling for environmental lead, sampling for trace inorganic constituents in maritime air, and operating a twilight photometer.

Environmental Lead Sampling

Clair Patterson, California Institute of Technology, collected environmental samples for lead analysis at extremely low levels. Sampling methods were dry deposition, air sampling and subsequent analysis of collection filter, precipitation collection, and plant tissue collection. The two samplings were conducted during August, November, and December 1976.

Trace Inorganic Constituents

R. A. Duce, University of Rhode Island, is the principal investigator for this program. The facility on Cape Matatula includes a small prefabricated building that houses a clean bench, supplies, and a 60-ft walkup tower manufactured by Upright Scaffold Co. Primary activities during 1976 involved high-volume air sampling using the tower as a sampling platform. Preliminary sampling, which began in January 1976, terminated in February. Sampling resumed in July and continued through September. The program suffered a major loss during December, when a tropical storm destroyed the sampling tower. At the time of the tower's destruction, winds were over 100 mph. Resumption of the program is now scheduled for 1980.

Twilight Photometer

This monitoring program was begun in April for Frederick Volz, and involves collection of data concerning spectral characteristics of the twilight sky. Chart recorder records are mailed directly to Dr. Volz.

3.5 Boulder

3.5.1 Total Ozone

This continuing program started iu Boulder in 1966. Measurements are made on the roof of PSRB-3 with Dobson ozone spectrophotometer No. 82. Observational data are routinely processed and results are sent to the Atmospheric Environment Service, Department of the Environment, Toronto, Ontario, Canada, for publication in Ozone Data for the World.

3.5.2 Erythemal Irradiance

This program was initiated in Boulder in May 1975 after similar observations, under sponsorship of the Climatic Impact Assessment Program, U. S. Department of Transportation, were terminated at Bismarck, North Dakota, and Tallahassee, Florida. Results of the Bismarck and Tallahassee measurements have been summarized in a report submitted to the Department of Transportation. The purpose of the Boulder program is to continue investigations, at a moderately high altitude station, of the relationship between near ground level variations in solar ultraviolet radiation and changes in the total amount of atmospheric ozone. An additional goal is to compare observed erythemal ultraviolet irradiance values with results deduced theoretically for the Boulder location.

3.5.3 Solar Radiation

Solar radiation observations were made primarily to calibrate pyranometers and pyrheliometers for use at the GMCC baseline stations. Pyranometers and pyrheliometer intercomparisons were also conducted with instruments used in the 1974 GARP Atlantic Tropical Experiment (GATE) project, as well as with pyranometer and pyrheliometer standards maintained by the NOAA/ARL Solar Research Facility.

The Solar Research Facility is in the University of Colorado PSRB-3. Its primary responsibility is to maintain calibration standards and to calibrate pyranometers and pyrheliometers used at 35 stations throughout the United States. Toward the end of 1976, the Solar Research Facility began a routine monitoring program to measure total global radiation, global radiation in broad wavelength bands (greater than 295, 395, 530 and 695 nm), and diffuse and direct radiation. This program is expected to continue indefinitely.

3.5.4 Atmospheric Turbidity

Measurements of atmospheric turbidity were made throughout 1976. A dual wavelength (380 and 500 nm) sun photometer was employed for the measurements, which were taken from PSRB-3 in Boulder.

3.5.5 Surface Ozone

The program to measure surface ozone, initiated at Fritz Peak Observatory in the mountains west of Boulder in 1975, continued throughout 1976. Data obtained at this relatively clean air midlatitude site are compared with data gathered at the GMCC stations. The ozone data are furthermore used by the NOAA/ERL Aeronomy Laboratory staff in their interpretation of NO_2 measurements taken at the observatory. An ECC and a Dasibi ozone meter are used to measure the surface ozone.

Ozone measurements with an ECC meter also are made routinely at PSRB-3. Although the primary purpose of this instrument setup is observer training, the demand by various Boulder researchers for the data obtained has been relatively high.

3.5.6 Carbon Dioxide

In January 1976, a flask CO_2 sampling program was resumed near Boulder at Niwot Ridge, under contractual arrangements with INSTAAR. This cooperative monitoring effort began in June 1969, but was interrupted from May 1973 to December 1975. Pair flask air samples are collected on a weekly basis at Niwot Ridge, and delivered to the GMCC Laboratory for CO_2 analysis by infrared analyzer instrumentation.

3.5.7 Freon-11

Under contractual arrangements with INSTAAR, a program to monitor Freon-11 (CCl_3F) commenced at Niwot Ridge, Colorado, in January 1976. Pair air samples are collected in stainless steel cylinders at weekly intervals, and delivered to Boulder for CCl_3F analysis by chromatographic means.

4. GMCC MEASUREMENT PROGRAMS

4.1 Measurement of Gases

4.1.1 Carbon Dioxide

Continuous measurements of atmospheric carbon dioxide were made throughout the year at all GMCC stations.

Point Barrow, Alaska, is the only observatory continuing the use of the UNOR, a nondispersive infrared gas analyzer manufactured by H. Maihak, A. G., in Germany. The UNOR has been used at the Barrow station since the start of the program in July 1973; the remaining observatories have the URAS analyzer made in Germany by Hartmann and Braun, A. G.

During the year, an exchange of analyzers was required at Barrow because of a failing UNOR. An URAS has been purchased for Barrow and is scheduled for installation in 1977. All the URAS instruments operating at the other stations ran throughout the year without major difficulties. Table 4 lists the provisional monthly mean carbon dioxide concentrations determined at four GMCC stations for portions of 1976. Figure 4 is a graphic presentation of these data. Mauna Loa data are available for the entire year. Barrow data for January, February, March, and April are questionable, because the analyzer air intake system had a leak.

Table 4. Provisional Monthly Mean CO_2 Concentrations

1976	South Pole	Samoa	Mauna Loa	Barrow
Jan	322.04 ppm	324.12 ppm	324.78 ppm	(329.97) ppm
Feb	321.82	324.28	325.56	(331.72)
Mar	321.67	323.89	326.15	(333.12)
Apr	321.67		327.00	(336.17)
May	321.70		327.18	330.63
Jun	321.86		326.83	329.24*
Jul			325.62	
Aug			323.99	
Sep			322.84	
Oct			322.67	
Nov			323.79	
Dec			325.13	

*First 16 days only.
Note: Data in parentheses were affected by leak in air intake line.

The frequency at which reference gases are used to calibrate the continuous analyzer was changed late in the year to economize in use of reference gases. Previously, the two working reference gases had been run for 5 minutes on the hour and the half hour. At present, they are run once an hour on the half hour for 5 minutes. The change was initiated only after a study proved that no adverse effect on the data quality would result.

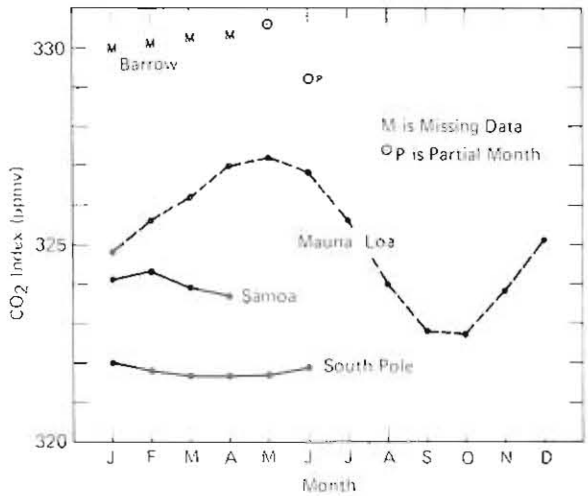

Figure 4. Provisional monthly mean CO_2 concentrations, 1976.

The carbon dioxide flask sampling program was enlarged during 1976. Flask sampling is performed at all the GMCC observatories by using an apparatus built into the rack of the continuous analyzer. By activation of a solenoid valve, air that normally passes through the air intake line into the analyzer is diverted into the paired glass flasks for simultaneous flushing and filling to an overpressure of 1 or 2 p.s.i. MLO, the last of the stations to implement this technique, commenced sampling in July. All flask sampling is done weekly, except at the South Pole where samples are taken only on the first and fifteenth of each month. Three additional flask sampling programs were started during the year: the program at Niwot Ridge, Colorado, was restarted after being inactive for 23 months; the Key Biscayne, Florida, program was also resumed after a 20-month break; and a program was initiated at Cape Kumukahi to provide sea level samples on the island of Hawaii. The 1976 provisional data for the seven flask sampling programs are given in Tables 5 and 6 for hand-aspirated samples and through-the-analyzer samples. Figures 5 and 6 graph these data for the Southern and Northern Hemispheres.

4.1.2 Total Ozone

Observations of total ozone are currently made with Dobson ozone spectrophotometers at the 12 stations listed in Table 7. During 1976, a number of possible field sites were surveyed for a West Coast Dobson spectrophotometer observatory. The list of candidate sites has been narrowed to three stations: Fresno, Bishop, and White Mountain Peak, all in California. Final site selection and implementation of station facilities are expected in 1977.

Calibrations

Recalibrations of three Dobson instruments (No. 63 at Mauna Loa, Hawaii; No. 72 at Wallops Island, Virginia; and No. 33 at Bismarck,

Table 5. Provisional Mean Monthly CO_2 Index Values Determined From Flask Sampling Taken by Aspirator Bulb in 1976

	Cape Kumukahi			Key Biscayne			Niwot Ridge		
Month	# of Samples	Mean Conc. Index	σ	# of Samples	Mean Conc. Index	σ	# of Samples	Mean Conc. Index	σ
Jan	-			-			4	326.84	0.55
Feb	-			-			4	327.76	0.59
Mar	4	327.69	0.56	4	328.14	0.48	4	328.73	0.58
Apr	4	329.04	0.52	2	328.74	0.25	5	329.71	1.93
May	4	329.69	0.67	4	329.23	0.61	3	327.88	0.66
Jun	4	327.96	0.96	3	327.84	0.35	5	326.84	1.45
Jul	4	325.53	1.06	5	327.00	1.45	4	323.92	2.43
Aug	4	323.80	0.85	2	324.97	0.48	4	323.68	0.88
Sep	5	323.84	0.74	3	324.19	0.31	5	323.41	1.57
Oct	4	323.98	1.01	2	324.60	1.37	4	324.72	0.46
Nov	4	326.80	0.93	2	325.89	0.29	4	326.03	0.62
Dec	4	326.25	0.47	2	326.15	1.24	4	327.24	0.76

Table 6. Provisional Mean Monthly CO_2 Index Values Determined From Through-the-Analyzer Flask Sampling in 1976

	South Pole			Samoa			Mauna Loa			Barrow		
Month	# of Samples	Mean Conc. Index	σ	# of Samples	Mean Conc. Index	σ	# of Samples	Mean Conc. Index	σ	# of Samples	Mean Conc. Index	σ
Jan	2	324.14	0.09	-			-			4	(331.28)	1.70
Feb	-			-			-			2	(337.42)	1.28
Mar	2	324.23	0.31	2	325.60	0.85	-			5	(338.68)	3.36
Apr	2	323.93	0.07	5	325.64	0.97	-			3	(341.19)	5.81
May	2	324.21	0.04	4	325.73	1.09	-			3	330.85	0.58
Jun	2	324.30	0.12	4	325.72	0.35	-			3	324.59	0.50
Jul	2	324.54	0.18	5	325.29	1.45	2	326.26	0.16	5	325.10	1.86
Aug	2	324.95	0.16	2	325.70	0.18	4	325.20	0.50	2	318.80	1.64
Sep	2	325.29	0.10	5	325.98	0.45	5	324.34	0.32	4	322.79	2.37
Oct	2	325.62	0.14	5	326.50	0.77	4	323.64	1.06	5	325.14	1.92
Nov	2	325.70	0.22	3	326.59	0.33	5	325.18	0.50	2	327.76	1.30
Dec	2	325.53	0.09	1	326.74	--	4	326.13	0.60	5	329.22	0.58

Note: Data in parentheses were affected by leak in air intake line.

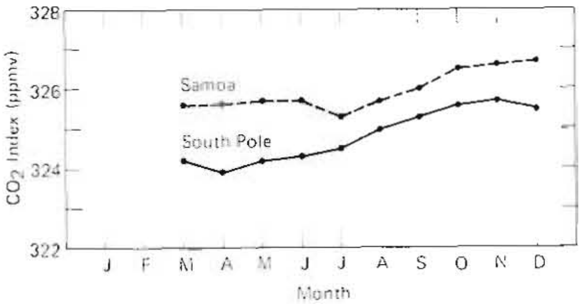

Figure 5. Flask sampling data for the Southern Hemisphere, 1976.

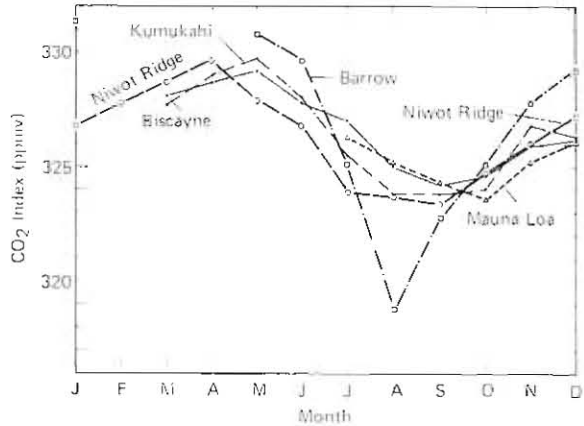

Figure 6. Flask sampling data for the Northern Hemisphere, 1976.

North Dakota) were conducted during the summer of 1976. In addition, extensive observations were made at Mauna Loa from June to August 1976 with Dobson spectrophotometer No. 83. This was done to calibrate the NOAA standard on an absolute scale. During 1976, the International Ozone Commission recommended to the World Meteorological Organization (WMO) that U.S. Dobson instrument No. 83 be established as a World Primary Standard instrument for total ozone measurements.

Observations were also made at Bismarck and Mauna Loa observatories (with instruments No. 33 and No. 63, respectively) during the summer of 1976 in a program designed to improve the quality of zenith sky type observations. Analysis of the data has not yet been completed.

Table 7. The U.S. Dobson Spectrophotometer Network

Station	Period of Record	Instrument Serial No.	Agency
Bismarck, N.Dak.	010163-Present	33	NOAA
Caribou, Maine	010163-Present	34	NOAA
Tutuila Island, Samoa	121975-Present	42	NOAA
Tallahassee, Fla.	060273-Present	58	NOAA/Florida State University
Mauna Loa, Hawaii	010264-Present	63	NOAA
Wallops Island, Va.	070167-Present	72	NOAA
Barrow, Alaska	080273-Present	76	NOAA
Nashville, Tenn.	010163-Present	79	NOAA
Amundsen-Scott, South Pole	120563-Present	80	NOAA
Boulder, Colo.	090166-Present	82	NOAA
White Sands, N.Mex.	010572-Present	86	NOAA/Department of Army
Huancayo, Peru	021464-Present	87	NOAA/Huancayo Observatory

Data

Daily 1976 total ozone data (applicable to local apparent noon) for all stations except Amundsen-Scott are available now in Ozone Data for the World. Mean monthly total ozone values for the NOAA observatories and cooperative stations are presented in Table 8.

Table 8. Provisional Mean Monthly Total Ozone Amounts (milli-atmo-cm), 1976

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bismarck, N.Dak	352	371	389	364	357	337	314	308	294	301	334	334
Caribou, Maine	406	408	382	362	393	348	349	321	321	317	349	357
Tutuila Is., Samoa	263	262	261	255	264	266	262	268	267	276	273	264
Tallahassee, Fla.	313	299	298	328	336	334	327	319	308	294	293	294
Mauna Loa, Hawaii	269	270	294	289	298	287	276	278	267	264	264	255
Wallops Island, Va.	333	312	331	345	353	338	333	324	311	309	314	313
Barrow, Alaska	---	---	463	443	422	355	332	292	319	308	---	---
Nashville, Tenn.	334	323	337	330	350	348	334	320	312	311	318	314
Boulder, Colo.	314	333	368	353	348	327	307	306	302	304	295	299
White Sands, N.Mex	315	296	330	329	341	309	312	312	290	295	297	295
Huancayo, Peru	273	279	275	269	270	274	272	278	283	280	278	271

4.1.3 Surface Ozone

There is now a complete year of data from Samoa, so many basic features of surface ozone distribution at all GMCC baseline stations can be described. There has been renewed interest in tropospheric ozone, and there are claims that tropospheric photochemical processes play a large role in determining the ozone distribution of the troposphere (Crutzen, 1974). GMCC clean air measurements can shed some light on the processes involved.

Program Changes

To standardize surface ozone measurements, all observatories have been equipped with nearly identical sets of monitoring equipment. Each observatory has an ECC Model No. 005 oxidant meter (see Summary Report No. 1 for a description of the ECC meter), a Dasibi ozone photometer (see Summary Report No. 4), and a modified McMillan ozone generator (see Summary Report No. 4) for calibration. In addition, the ECC and Dasibi instruments have been run almost continuously at the Fritz Peak Observatory in Colorado, and an ECC meter is operated at Boulder.

An improved calibration procedure which allows for better utilization of the ICDAS was implemented. This procedure ensures that calibration information is properly recorded for easier access when the data are processed. A reversed calibration schedule calls for once-a-week calibration checks of both the ECC and Dasibi ozone meters.

Data Summary

The basic features of the surface ozone distribution at Barrow, Mauna Loa, and South Pole were described in Summary Report No. 3. Two features of the surface ozone distribution at Samoa stand out. As at the other GMCC observatories, surface ozone at Samoa shows a strong annual variation with a maximum in August and a minimum in April. As can be seen in Figure 7 this variation is in phase with that at South Pole, but out of phase with the annual variation at Mauna Loa. In the Southern Hemisphere tropics the total ozone maximum occurs later (about October) than the surface ozone. This suggests weak coupling between stratospheric and near-surface ozone at these latitudes.

Another prominent characteristic of the surface ozone behavior at Samoa is the generally lower absolute amount of surface ozone. This is brought out in Figure 8 where the surface ozone mixing ratio is plotted as a function of latitude for the GMCC stations and Fritz Peak. The large summertime values at Fritz Peak probably are partly due to local photochemical production. This limited latitudinal profile suggests a midlatitude maximum in the Northern Hemisphere.

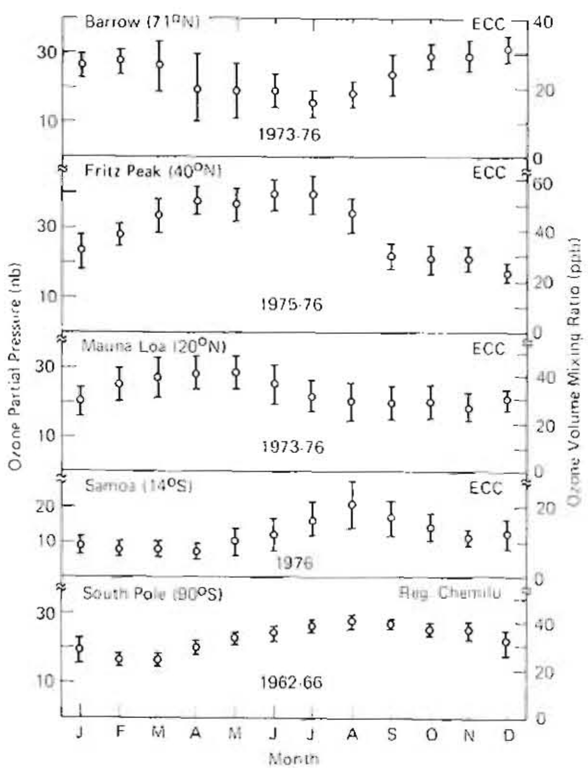

Figure 7. Mean monthly surface ozone. Standard deviations represent variability within the month.

At Samoa there is a greater diurnal variation in surface ozone during the austral winter and spring seasons than in the other two seasons. This is shown in Figure 9. Whether or not such a variation is a real feature of the surface ozone distribution is questionable. It may be an artifact of the sampling location above the main observatory building since some diurnal variation in the air ventilation at this site has been noticed. By the middle of 1977, a new sampling location with a much better exposure will be in operation. This should answer the question of the reality of the diurnal variation.

During 1976, the ECC and Dasibi ozone meters were operated simultaneously at the GMCC stations and at Fritz Peak. The monthly mean values for the period of comparison from each instrument are shown in Figure 10. The Dasibi values for each station have been adjusted by a constant factor to bring them into agreement with the standard ECC scale represented by ECC Meter No. 001-1. In general, the month-to-month variations are reproduced well. On a shorter time scale, the agreement is also good between the two different types of instruments. On an absolute scale, the Dasibi ozone meter does not give good agreement with the ECC meter. All the ECC meters give comparable results on an absolute scale, but the Dasibi meters do not. It is for this reason that the Dasibi values are adjusted to a common scale based on the ECC meter.

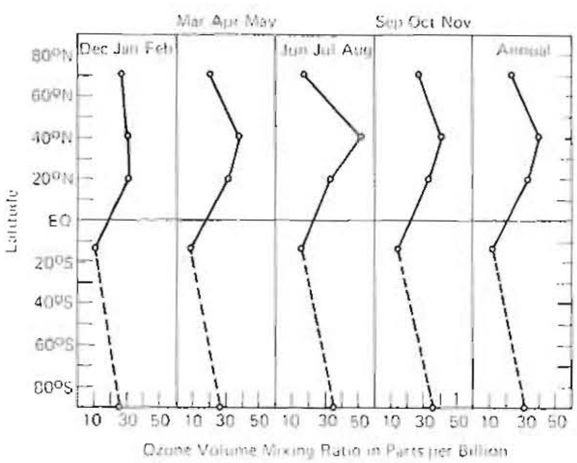

Figure 8. Surface ozone plotted by latitude--seasonal and annual averages.

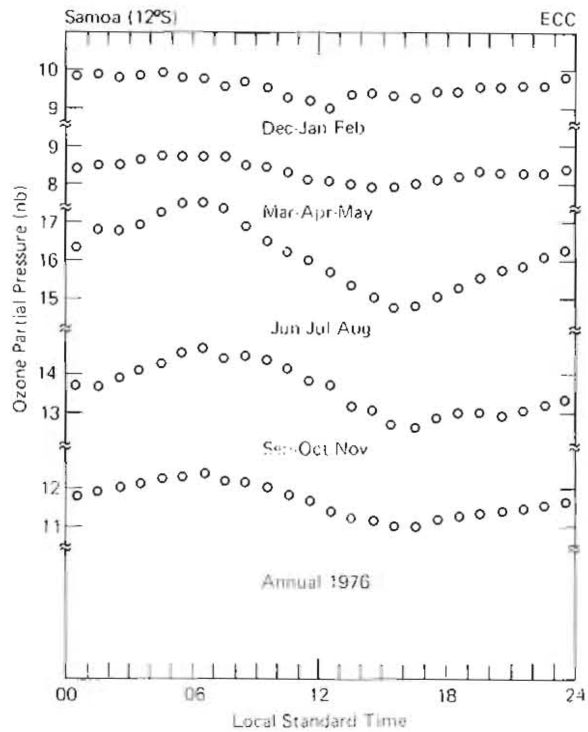

Figure 9. Diurnal surface ozone at Samoa--seasonal and annual averages.

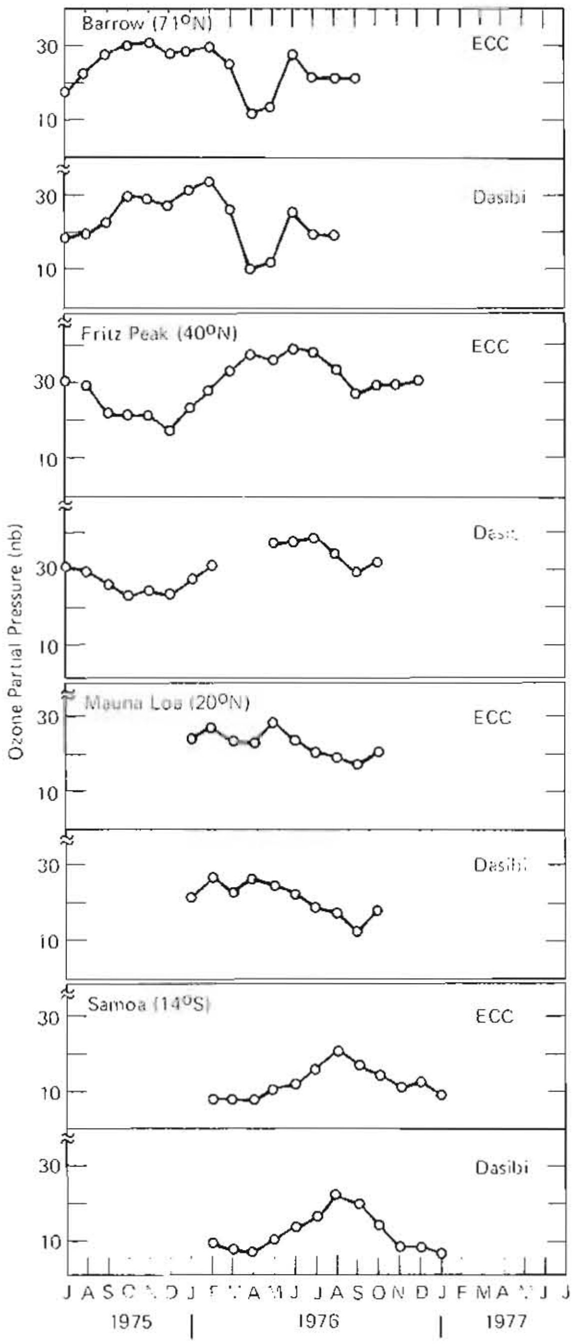

Figure 10. Monthly surface ozone measured by ECC and Dasibi ozone meters.

Calibrations

During 1976 an ECC meter was compared with the ozone standard instrument maintained by the National Bureau of Standards (NBS). Preliminary results indicate that the ECC meter reads higher than the

NBS standard by about 5% over a wide range of ozone values, and higher by about 2% over the range from an ozone partial pressure of about 20 to 70 nanobars, which includes almost all the data from the GMCC observatories.

4.1.4 Halocarbons

The weekly exposure of an evacuated stainless steel cylinder has continued at Barrow, Mauna Loa, and Samoa throughout 1976. In addition, a set of special flask samples was taken at these stations during late October and early November in cooperation with the NASA Latitude Survey.

A dual evacuated cylinder program was instituted at Niwot Ridge, Colorado, in January and continued through the year. INSTAAR, which has facilities on Niwot Ridge, was under contract to expose the pair of flasks each week.

A dual cylinder pump-up system was tested during January at the South Pole station.

Instrumentation

A number of changes and additions helped improve the quality of the data. During March 1976, the Hewlett-Packard chromatograph was electronically modified according to the manufacturer's recommendations. This permitted the variable frequency mode of operation to be used with ultrapure nitrogen carrier gas. The change brought about a sensitivity increase of 2.5. The Idaho Falls detector and fixed-pulse electronics were no longer used. A mass flow controller was installed in the carrier gas line in April to reduce flow fluctuations and their effect on detector response. Negative chromatogram peaks were observed and found to be caused by halocarbons in the carrier gas despite the ultrapure (99.999%) nitrogen used. In August, a Supelco Gas Purifier was installed in the carrier gas line which reduced halocarbon impurities to an amount below their detectable limit.

The cylinder pump-up tests run in January at South Pole showed unfavorable results. Following a critical review of the flasks and pump system, changes are being made to improve the sampling system. Our stainless steel cylinders are being passivated by the SUMMA electropolishing process developed by Molectrics, Inc., of Englewood, California. It is believed this will minimize cylinder wall effects that cause modification, adsorption or desorption of collected trace halogens. The cylinders are being equipped on both ends with all stainless steel Nupro type SS-4H bellows valves. These valves contain no elastomers or polymers that could serve as halocarbon sources or sinks. After chemical cleaning, the cylinders are evacuated while heating, then filled with zero air. Chromatographic purity checks are made a day and at least a month later by sampling the zero air.

The dual cylinder pump-up system has been simplified. The pump system contains a 7-micron all stainless steel filter at the inlet to the stainless steel bellows pump. At the outlet of the pump, the gas flows through a relief valve, then through both cylinders which are parallel. The inlet of the pump system is connected through a short section of stainless steel tubing to the gas stack manifold at each station.

Future Program Developments

The dual cylinder pump-up system described in the previous section will be tested at the South Pole facilities during 1977. Samples taken in January and February will be used to assess the quality of the system and the value of deploying similar systems to all of the baseline stations. Cylinder pairs will also be pumped up monthly through the rest of 1977 to test for long-term sample stability.

A major emphasis during the coming year will be developing reference gases for chromatograph calibration. Large cylinders will be pressurized with background air, and reference values of halocarbons will be determined through interlaboratory and standard gas comparisons.

Analysis for other halocarbons, such as dichlorodifluoromethane (F-12) and nitrous oxide (N_2O), will be possible when reference gases become available.

Data

Our complete 1976 data base for trichlorofluoromethane (F-11) is presented in Table 9. These data are graphically presented with earlier data in Figure 11. The scatter in the data and the standard deviations have decreased. This is partly due to increased control of parameters in the chromatographic analysis. Also, the evacuation of sampling flasks has been monitored more closely.

Of the three baseline stations Barrow has the highest concentrations, Samoa the lowest, and Mauna Loa is in between. This is what is expected. However, a phase difference is also likely but is not readily apparent from the graphs. In fact, the concentrations appear to have risen and peaked together. Whether the rise and fall is a true annual cycle will need at least another year's data to determine.

Niwot Ridge samples were taken in pairs of flasks. Most of these pairs showed coincidence. Early in the sampling, one pair consistently was not coincident and had F-11 concentrations higher than expected. That pair was considered contaminated and was withdrawn from the sampling rotation scheme in early June.

A plot of the Niwot Ridge data indicates close agreement with the Mauna Loa data.

Table 9. 1976 Data Base for CCl_3F

	Barrow			Mauna Loa			Niwot Ridge					Samoa		
Month	Day	Conc. (pptv)	σ	Day	Conc. (pptv)	σ	Day	Conc. (pptv)	σ	Conc. (pptv)	σ	Day	Conc. (pptv)	σ
Jan	6	361	2	9	1878	3	16	152	2	153	2	25	218	3
	19	241	6	17	216	2	23	144	1	146	2			
				25	171	2								
Feb	17	274	6	13	117	2	7	131	1	145	4	19	167	1
	25	169	5				24	460	-	778	-			
Mar	13	130	2	11	136	2	7	900	-	723	-	9	263	1
	19	139	4	23	189	2	10	137	3	168	4	18	622	13
	23	130	1	30	121	1	18	108	1	117	1	26	102	1
							24	118	2					
Apr	2	138	2	16	250	3	2	122	1	122	1	2	118	2
	19	120	2	24	38000	-	8	131	2	129	1	7	256	5
	28	161	2				15	115	2	123	2	15	131	1
							30	150	1	138	1	24	123	2
May	6	630	14	5	123	2	5	119	1	122	3	9	459	6
	12	195	1	14	113	2	14	118	1	118	2	15	101	2
	21	127	2	26	104	2	24	119	3	121	2	29	108	1
	25	125	1											
Jun	3	143	6	3	122	5	2	194	1	174	1	6	122	3
	9	135	1	10	121	3	8	120	1	120	1	10	106	1
	19	124	1	17	113	3	16	118	3	117	1	19	113	3
							24	118	2	123	1	24	112	3
							30	1434	19	1672	13			
Jul	3	143	2	1	124	5	7	131	1	130	2	3	111	1
	7	365	-	9	125	1	22	125	4	125	1	8	113	1
	13	139	2	22	126	4	30	122	2	123	1	15	117	2
	21	141	1	29	126	2						22	116	2
	27	187	3									29	119	3
Aug	12	127	2	3	119	1	4	117	2	120	4	5	117	1
	25	157	1	12	120	1	12	119	3	119	1	12	124	1
				18	302	5	20	127	1	132	1	19	121	2
				25	571	4	26	133	2	132	1	26	133	3
				30	143	2								
Sep	7	165	4	10	143	1	5	146	2	145	1	2	129	1
	15	434	3	16	149	1	10	151	1	151	2	8	132	2
	22	159	2	21	145	2	24	142	1	142	2	23	136	1
	29	173	1	28	155	2						30	131	1
Oct	5	235	1	6	154	1	5	152	1	153	1	7	144	1
	15	188	1	12	162	1	14	175	2	174	1	13	153	1
	19	205	2	20	179	2	23	186	1	184	2	21	155	1
	27	247	3	29	183	2	28	186	1	185	1	27	172	1
	29	204	2											
		204	2											
		205	2											
Nov	2	202	1	1	192	2	4	178	1	177	1	4	175	2
	16	265	3	5	188	2	12	185	1	---	-	8	165	1
				10	207	1	19	173	2	171	1		174	1
				16	172	1	24	174	2	175	1		165	1
				22	177	2						11	156	1
				29	177	2						18	162	1
												25	176	3
Dec	3	205	2	9	172	2	3	183	1	182	5	1	158	1
	8	196	2	15	177	3	9	169	1	168	1	16	160	2
	15	256	2	22	170	2	22	171	1	171	1	30	154	1
	20	193	1	29	170	2	29	171	1	172	1			
	28	193	2											

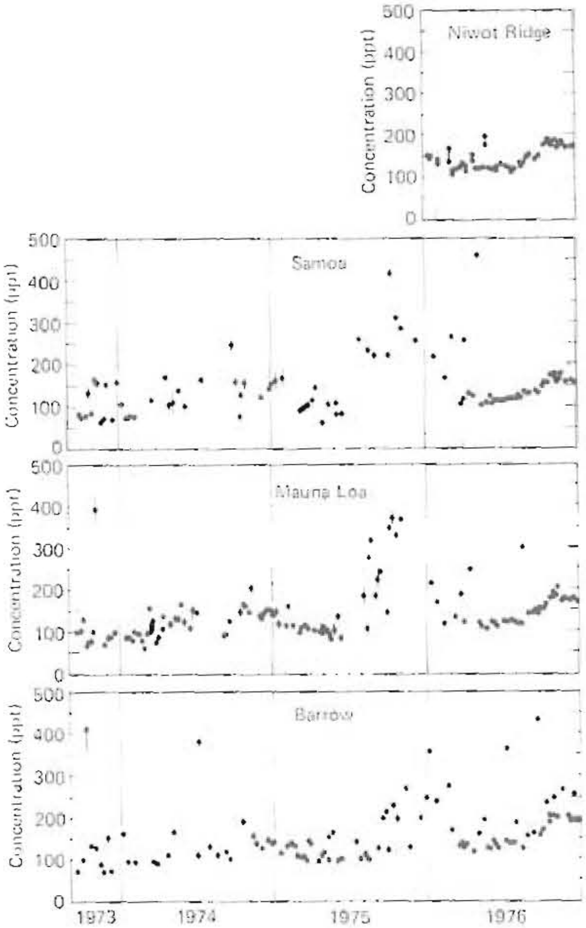

Figure 11. CCl_3F *concentrations at four GMCC observatories.*

4.2 Stratospheric Aerosol Measurements Using Lidar

Since the last report, monitoring of stratospheric aerosols over Mauna Loa has remained the major activity. Data were taken at Mauna Loa 20 times during 1976. In general, the trend during this period was a return to a clean stratosphere after the volcanic injection by the de Fuego volcano in Guatemala during October 1974 (Fegley and Ellis, 1975 a,b; Russell and Hake, 1977). However, on January 24, 1977, a new, intense volcanic-like cloud was detected at the tropopause above Mauna Loa. To our knowledge, as of the date of this writing (3/77) the cloud has not been detected at other locations. It seems to have density comparable with that of the de Fuego cloud, but it is more patchy, disappearing and reappearing every few days.

Hardware Development

During the fall, a NOVA minicomputer system was installed in the lidar dome. This change was made because it was previously necessary to interrupt the ICDAS during lidar operation. The lidar program now remains in the computer at all times, so lidar operation is quicker and simpler. Minor modifications of the lidar analysis program were made, resulting in more complete documentation, greater mathematical accuracy, and greater ease of use.

Additionally, a diagnostic routine was incorporated to test the Biomation digitizer unit at operator request. This particular unit has been the least reliable link in the total system. It is subject to electronic drift and requires realignment at least yearly. It is also affected by room temperature fluctuations. It is hoped that lidar room improvements planned for 1977 will regulate the temperature and reduce problems with this unit.

The next step in the MLO lidar development will be incorporating the CAMAC interface system and then partially automating the lidar system. More shots will then be possible with greater statistical accuracy at higher altitudes (25-35 km region). Photon counting will also be used at the longer ranges to provide greater accuracy.

During 1976, the remaining hardware for the Barrow lidar was procured. A new dye laser with a pulse energy of 1½ joules (J) was purchased. This unit will be operated in the region of 6300 A* where new, high efficiency red dyes are available. This region is optimal for aerosol detection and simultaneous high efficiency photomultiplier detection. Following are the operational parameters of this system:

Pulse energy - 1½ joules
Wavelength - 6300 A
Receiver aperture - 40 cm diameter
Fresnel lens
Maximum repetition rate - 10 shots/minute
Detector - RCA 7265
Pulse length - 0.5 microseconds
Signal processor - Biomation model 805 digitizer,
  Camac interface, NOVA minicomputer.

The Barrow system will be designed to operate through a window in the roof of a small building. This is in contrast to MLO where the system is located in an astronomical dome without a window. The dye laser is also capable of being operated at different wavelengths.

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*A is used for Angstrom throughout this report.

Operating Difficulties

Three months of data (October-December 1976) were lost because of an unrecognized problem with the Biomation digitizer. The unit was returned to the factory for alignment in December. A Biomation diagnostic routine, which places portions of the output onto the teletype for operator examination and archiving at Boulder, was incorporated into the lidar program. Now, an experienced operator can spot defective operation. When the lidar is automated, it will be possible to build in this diagnostic routine so that the computer can continuously check the Biomation. The Biomation Co. has provided instructions on how to align the unit.

The flashlamp failed two days after the new dust cloud was detected. Upon replacement, an explosion blew up the lamp-rod cavity. The unit was sent to the factory for rejuvenation. The high voltage system would not charge when the unit was returned. After unsuccessful attempts to repair the circuitry, this unit was also returned to the factory where new diodes were installed. We have never been able to use a flashlamp longer than 1 year. This amounts to only about 1000 shots, which is much less than the manufactnrer claims. We have always had to run higher voltages on the lamp than the manufacturer recommends, and this may explain our difficulties. Our Pockels cell appears optically distorted, and perhaps this necessitates our higher voltages.

Data were not collected during August and September because the station minicomputer was not functioning. The computer system for the lidar being developed for Barrow also has had several difficulties. The memory failed soon after delivery, the teletype had problems, and the NOVA software had some errors in it. This has slowed program development for both MLO and Barrow.

Data

The stratospheric data are summarized in Figure 12. The enhanced backscatter layer generally extended from 17 to about 23 km msl. The maximum backscatter coefficient average declined somewhat throughout the period January 8, 1976, to January 19, 1977. As stated before, on January 24, 1977, a new layer was sighted visually; on January 26, the lidar was used to establish the height at 16.2 km msl, slightly below the tropopause, as determined by Hilo upper air data. The maximum backscatter coefficient is approximately 50 times greater than that of the previous week. In fact, it is comparable with that of the de Fuego dust cloud.

The enhanced backscatter layer is not continuous horizontally. As seen in Figure 12, on January 26 it covers the sky, but on January 27 the cloud seems to be gone, although the dust concentration at higher altitudes appears to be enhanced. Additional analysis of the data will be described in forthcoming publications.

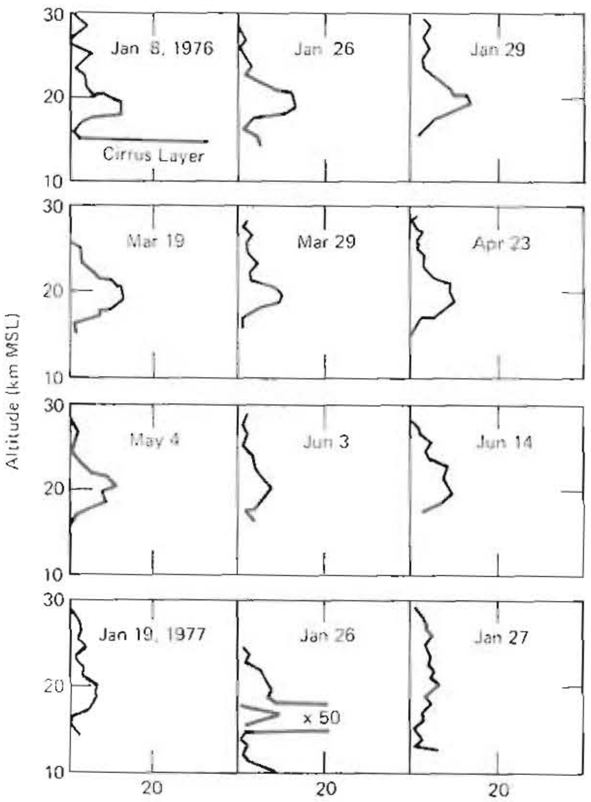

Figure 12. Non-Rayleigh backscatter coefficient (10^{-9} m^{-1} Steradians^{-1}) in Mauna Loa.

It is important to emphasize that the data displayed are not raw data. Some assumptions have been made in analyzing the results. For instance, we assume that a clean layer (i.e. any Raleigh scattering) of the atmosphere exists in the region 15-16 km msl. This produces the relative minimum shown on the graphs. Our assumption has been experimentally tested on several occasions by other workers and generally seems to be borne out (See Rosen, Hofmann, and Laby, 1975). A second assumption is that there is no aerosol at the longest range, in this case about 35 km msl. This also has been tested experimentally by others and has been found to be generally true. But there were several occasions when others found significant aerosol at 35 km, and we could not detect this in our analysis. It is unfortunate but necessary that we make this assumption.

The data displayed are typical of our stratospheric results. Also, some returns from the middle troposphere have not been shown. During October to December 1976, some useful tropospheric returns were available, even though the Biomation difficulties prevented retrieving useful stratospheric results.

4.3 Surface Aerosol Measurements

The GMCC surface aerosol program for 1976 included the measurement of condensation (or Aitken) nuclei at all sites, and integrated light scattering (by a 4-wavelength nephelometer) at Mauna Loa. A second four-wavelength nephelometer was operated at Barrow during May and June 1976. Instruments in the field during 1976 are summarized in Table 10.

Table 10. Instruments for Surface Aerosol Measurements at Field Stations

	Mauna Loa	Barrow	Samoa	South Pole
Standard Gardner	X	X	X	
Long-tube Gardner	X	X	X	X
G. E. counter	X	X		X
Pollak counter	X	X		X
4-λ nephelometer	X	X		

Aitken Nuclei

Maintaining a stable calibration base is fundamental to successful long-term Aitken nucleus monitoring. The routine Aitken nucleus monitoring instrument at each site is a G.E. condensation nucleus counter with modifications incorporated at the University of Washington. Briefly, the modified G.E. counter uses electronic techniques that give greatly improved stability and increased sensitivity. The proven cloud chamber, using a low forward-scattering angle detection scheme, and the rotary valve providing five measurement cycles per second remain the same. However, the improved electronic processing gives a lower limit of sensitivity below 10 nuclei cm^{-3}. This sensitivity is necessary at South Pole, our cleanest site. Figure 13 is a simplified block diagram of G.E. counter electronics, Figure 14 shows the air flow and valve scheme, and Figure 15 gives the geometry of the expansion chamber.

A long-tube Gardner counter is located at each site as a backup monitoring instrument and is especially useful at remote sites because of its portability. The long-tube Gardner counter has a fog tube twice as long as the standard Gardner counter. The fog tube provides about twice the sensitivity, and measurement capability to below 100 nuclei cm^{-3}. The long-tube Gardner is used to provide routine calibration checks on the G.E. counter.

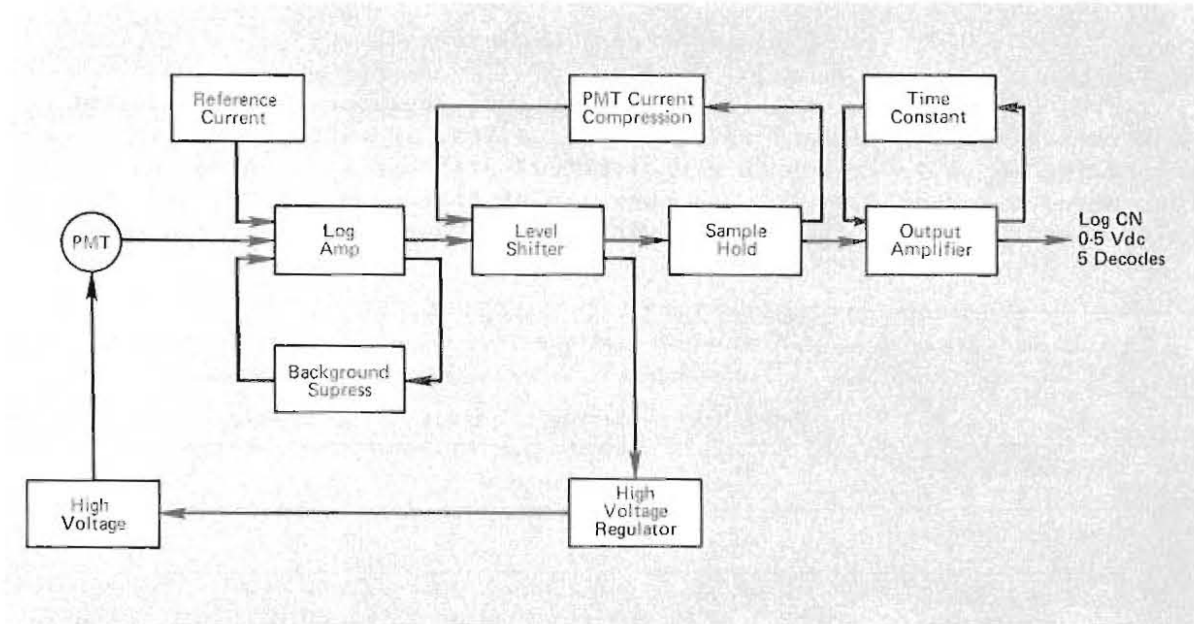

Figure 13. Electronic scheme of the modified G.E. condensation nucleus counter.

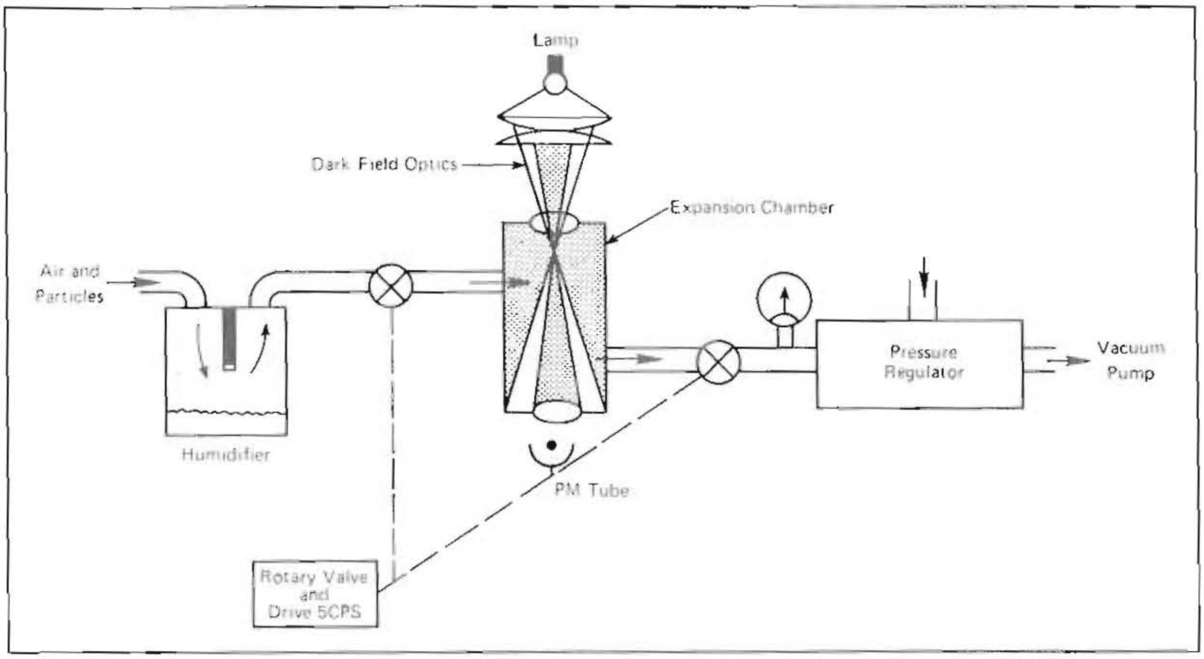

Figure 14. Diagram of air flow in the G.E. condensation nucleus counter.

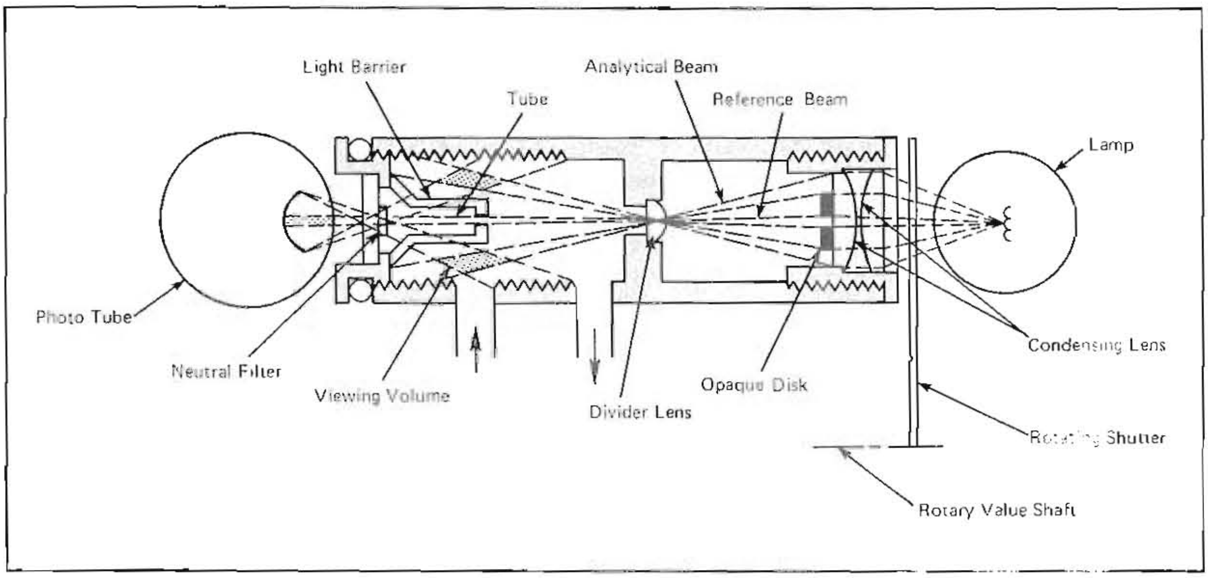

Figure 15. Expansion chamber and optics for the G.E. condensation nucleus counter.

A Pollak condensation nucleus counter is located at each site as a secondary standard to provide accurate calibration points for the G.E. counter, and to provide an on-site comparison to establish the calibration of a long-tube Gardner counter. The Pollak counter has proved a very stable instrument over the long term and is probably the best choice as an on-site standard.

Absolute calibration for the Aitken nucleus program will be provided by a photographic Aitken nucleus counter to be acquired in 1977. This instrument will be transported to the field sites for comparison with the on-site standards. In addition, a monodisperse aerosol generator, providing a controlled aerosol source, will be located in the Boulder Laboratories to provide a calibration of all instruments sent into the field.

Light Scattering

Calibration of the four-wavelength nephelometers requires only one point to establish the scale. This calibration point is provided by filling the instrument with Freon-12, measuring the integrated light scattering, and setting the scale of the nephelometer to the known scattering coefficients of Freon-12. In addition, the calibration depends on the linearity of the instrument electronics which can be checked by inserting simulated scattering signals in place of the photomultiplier signals.

The operation of the Mauna Loa nephelometer has been described in the GMCC summary report for 1974. The operation of the Barrow nephelometer and of those to be installed at Samoa and South Pole has been significantly improved throngh a sophisticated internal calibration scheme which essentially eliminates electronic drift and simplifies the operation of the instruments. Briefly, the instrument accumulates data for a given time interval in three independent memories while the instrument is filled with clean air, with clean air plus a white calibration object, and with ambient air. Next, the instrument performs the snbtractions

ambient - clean

and calibrate - clean

to eliminate the effects of molecular scatter and instrument backgronnd. These two valnes are proportional to the scattering signal dne to aerosols alone, and to the white calibration object alone. The instrument then calibrates

log (ambient - clean) - log (calibrate - clean)

to give an output voltage. This voltage is proportional to the logarithm of the ratio of aerosol scatter to white calibration object scatter. This stabilizes the instrument against drifts in lamp color and brightness, filter transmission, and photomultiplier tube sensitivity. Instrument output is 0-10 volts spanning 5 decades at 2 volts per decade.

The calibration schedule for the four-wavelength nephelometer includes an absolute calibration using Freon-12 gas at 2-month intervals and a weekly internal check of the relative calibration object.

4.3.1 Mauna Loa

Pollak counter SN13 and long-tube Gardner counter SN1185 were operated regularly throughout 1976. Observations were obtained hourly during the normal working day. Figure 16 shows monthly geometric means of Pollak counter observations taken at 1000, 1100, 1200, 1300, and 1400 hr local standard time (LST). The 1000 hr observations (shaded data) show a general tendency toward low values of about 200 nuclei cm^{-3} during the winter, and higher values of about 300 nuclei cm^{-3} during the summer. Vertical bars give standard errors of the mean. The site cleanliness deteriorates with the afternoon upslope wind each month and this is shown clearly in the annual means given in Figure 17. Gardner counter SN1185 (long-tube) was calibrated by means of a 6-month comparison with Pollak SN13 on Mauna Loa ambient aerosol. Figure 18 gives the results of this comparison along with a least squares fit of Hoerl's equation. A calibration table for Gardner SN1185 was then made to convert the Gardner scale readings to nucleus concentrations.

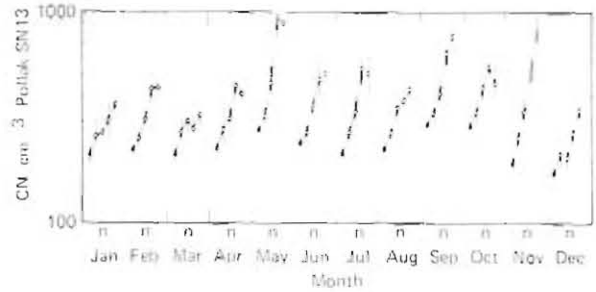

Figure 16. Monthly geometric means of condensation nuclei (MLO, 1976) for 1000, 1100, 1200, 1300, and 1400 LST. The shaded dots indicate the 1000 LST values; n indicates the 1200 LST values; the vertical bars give standard errors about the mean (SE = $\sigma/\sqrt{n}$).

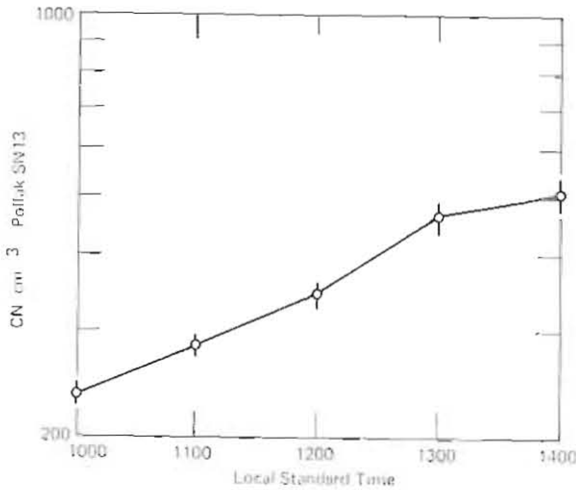

Figure 17. Annual geometric means of condensation nuclei (MLO, 1976). Vertical bars give standard errors about the mean (SE = $\sigma/\sqrt{n}$).

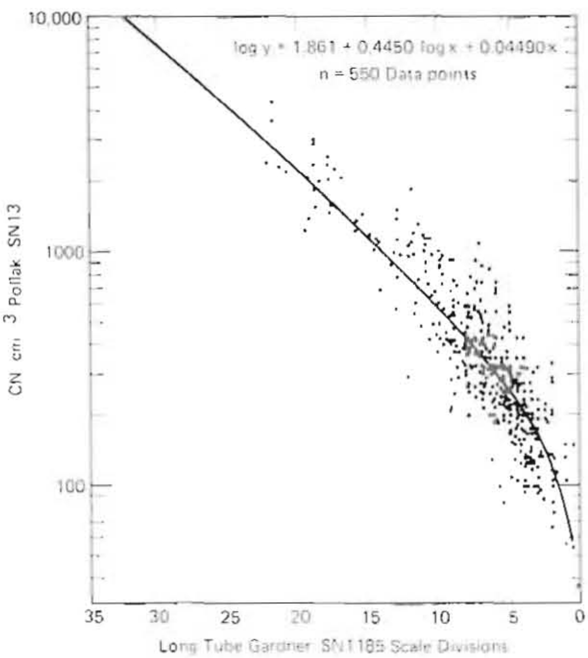

Figure 18. Comparison between long-tube Gardner counter SN1185 and Pollak counter SN13 on ambient aerosol at MLO during December 1975 and January to May 1976. The curve is a least squares fit of Hoerl's equation.

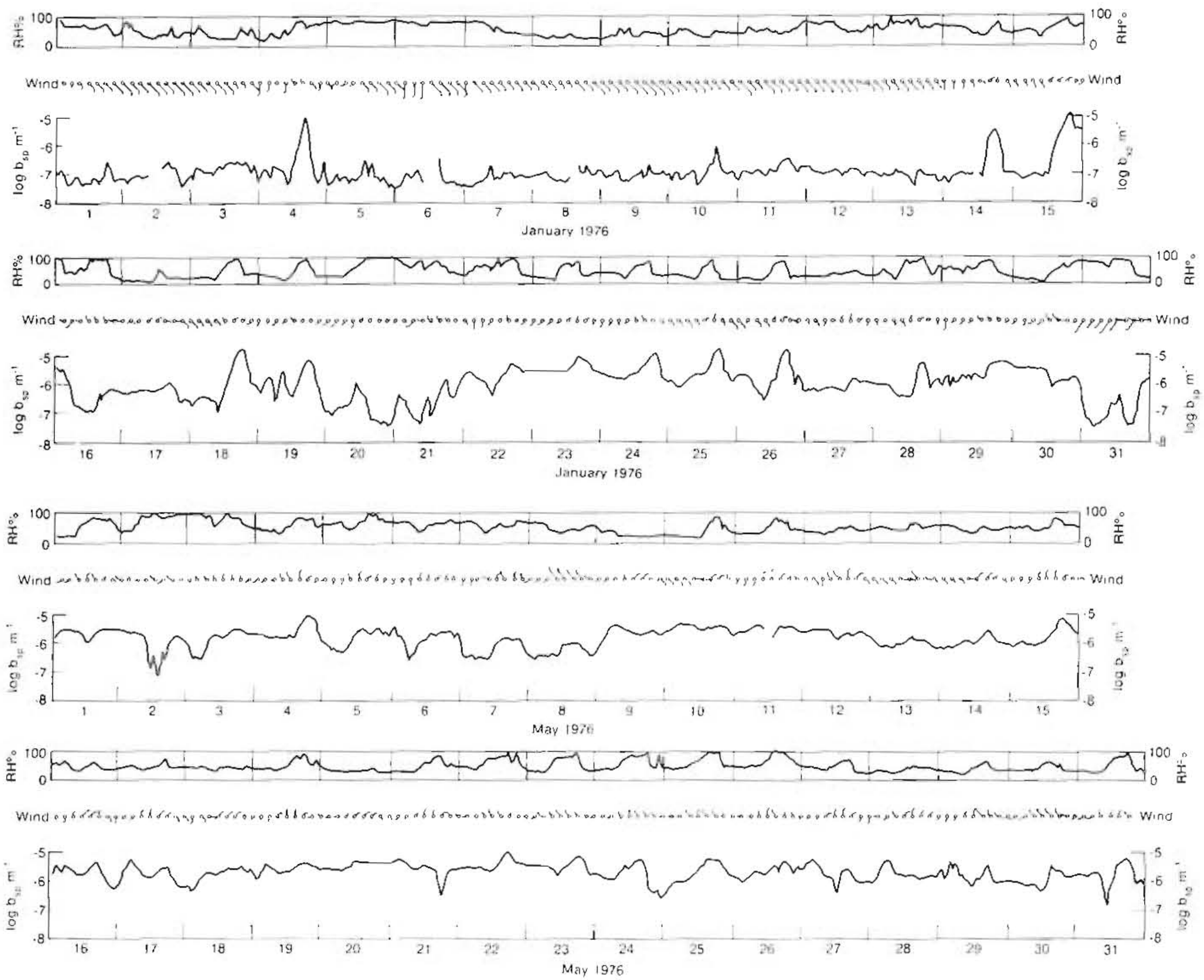

Figure 19. Hourly averages of 550 nm light scattering and relative humidity at MLO for January and May 1976. Wind speed and direction are given at 3-hour intervals. Speed is shown as the length of the vector where the barb length is equivalent to 5 kurts (2.6 m s^{-1}).

The Mauna Loa G.E. nucleus counter operated reliably for most of the year, producing a continuous record of nucleus concentrations. These data were recorded on magnetic tape and a strip chart recorder by the Mauna Loa data acquisition system.

The Mauna Loa four-wavelength nephelometer operated reliably throughout 1976 with total downtime of only about 17%. Part of this downtime can be attributed to recording system failure. Figure 19 gives hourly means of light scattering or bsp (550 nm) along with hourly means of relative humidity of RH(%) and wind at 3-hour intervals for January and May 1976. The first two weeks of January show some of the lowest light scattering data ever recorded at Mauna Loa; May shows the higher light scattering values typical of the summer months. It is evident that the very clean conditions in January are associated with persistent, strong southeasterly winds, and the winds in May are relatively light with a strong diurnal (upslope-downslope) influence. Note that wind speed is given by the length of the vector and that the length of the barb is equivalent to 5 knots (2.6 m s^{-1}).

Figure 20 shows monthly means for each hour of the day for selected months of 1976. These data show the same general tendencies discussed for similar data in the GMCC Summary Report for 1975.

Figure 21 shows the annual trend in light scattering data at Mauna Loa for 1974-76. Each point is the geometric mean of the 0100 to 0700 LST data for all days of each month. It was found that the early morning data (just before sunrise) are probably most representative of background tropospheric conditions at Mauna Loa. The seasonal trend is evident (as discussed in the two previous GMCC summary reports) with minimum light scattering in the winter and maximum light scattering during the early summer. It was also found that solar radiation turbidity data are correlated with the data in Figure 21 (Bodhaine, 1977). This suggests that surface aerosol measurements under the right meteorological conditions are representative of the upper troposphere, and that the tropospheric aerosol is partially responsible for turbidity variations above Mauna Loa. Similarly, the Angstrom exponent data show an annual variation suggesting that the smallest aerosols are present in late autumn and early winter, and that the larger aerosols are present during late spring. The annual trend in light scattering is shown most clearly in Figure 22 which gives the 3-year means, by months, of all 0200-0700 hr light scattering and Angstrom exponent data. Note the order-of-magnitude difference between light scattering in May and December.

At 2330 LST on July 5, 1975, Mauna Loa erupted, actively fountaining for about 24 hours. It continued fuming for several days. Figure 23 shows hourly means of light scattering, condensation nuclei, surface ozone, relative humidity, and wind speed and direction at 3-hour intervals. Occasional nucleus observations by a Pollak counter are also shown. These data clearly show the volcanic effects on the condensation

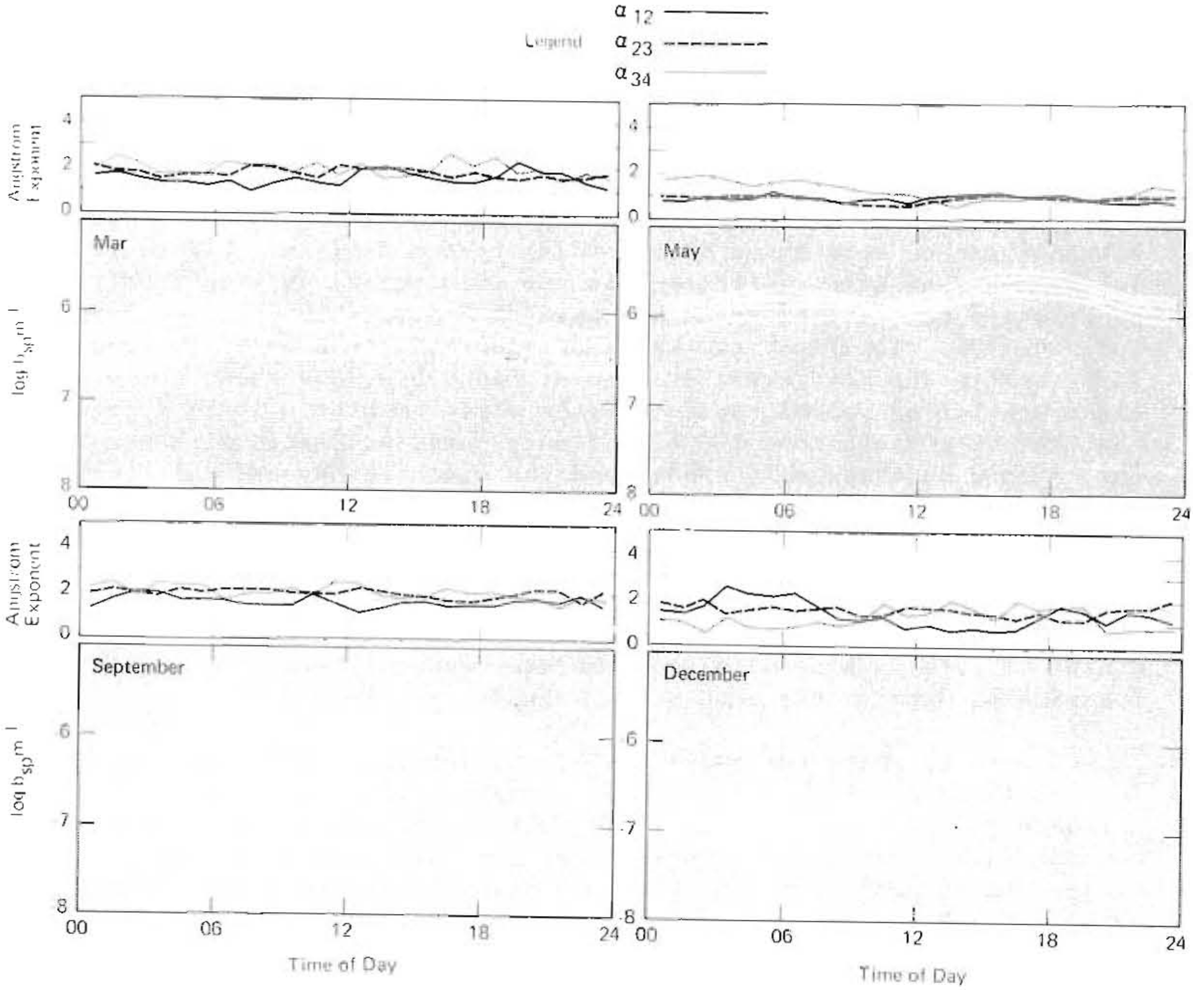

Figure 20. Monthly geometric means for each hour of the day from the Mauna Loa four-wavelength nephelometer for selected months of 1976. The Angstrom exponent α_{12} is derived from 450 and 500 nm, α_{23} from 500 and 700 nm, and α_{34} from 700 and 850 nm.

nucleus concentration at MLO. During the 5 days before the eruption, condensation nucleus concentrations were about 200-300 cm^{-3} with higher values during daytime upslope wind conditions. This is typical of Mauna Loa aerosol values. For the week following the eruption, condensation nucleus values were as much as two orders of magnitude higher than usual, and exhibited a reverse upslope-downslope effect as well. However, light scattering values are not obviously higher than usual after the eruption, suggesting that the volcanic aerosol particles are small sized and probably the result of combustion or gas-to-particle conversion processes.

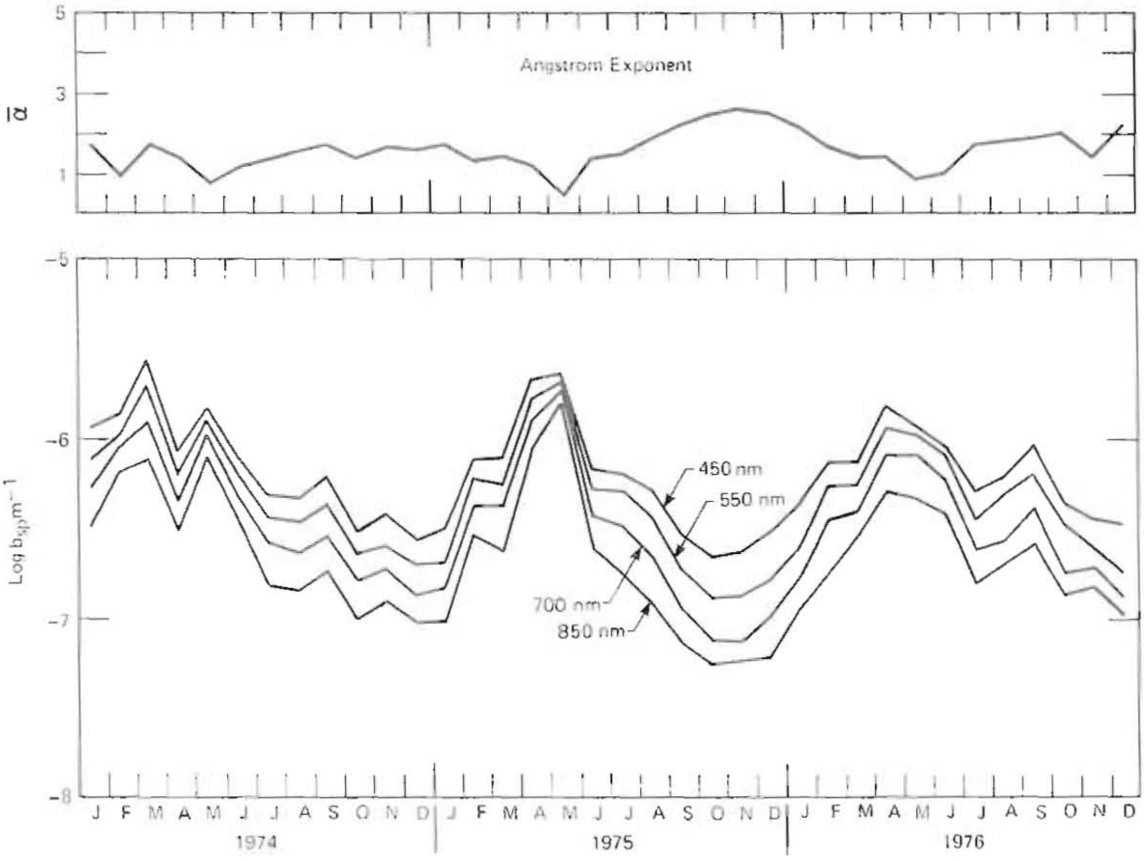

Figure 21. Monthly geometric means of light scattering (b_{sp}) and Angstrom exponent for all 0500-0700 LST data at MLO, 1974-76. $\bar{\alpha}$ is the average of α_{12} (450, 550 nm) and α_{23} (550, 700 nm).

Figure 22. Three-year monthly geometric means of light scattering (b_{sp}) and Angstrom exponent for all 0300-0400 LST data at MLO, 1974-76. $\bar{\alpha}$ is the average of α_{12} (450, 550 nm) and α_{23} (550, 700 nm).

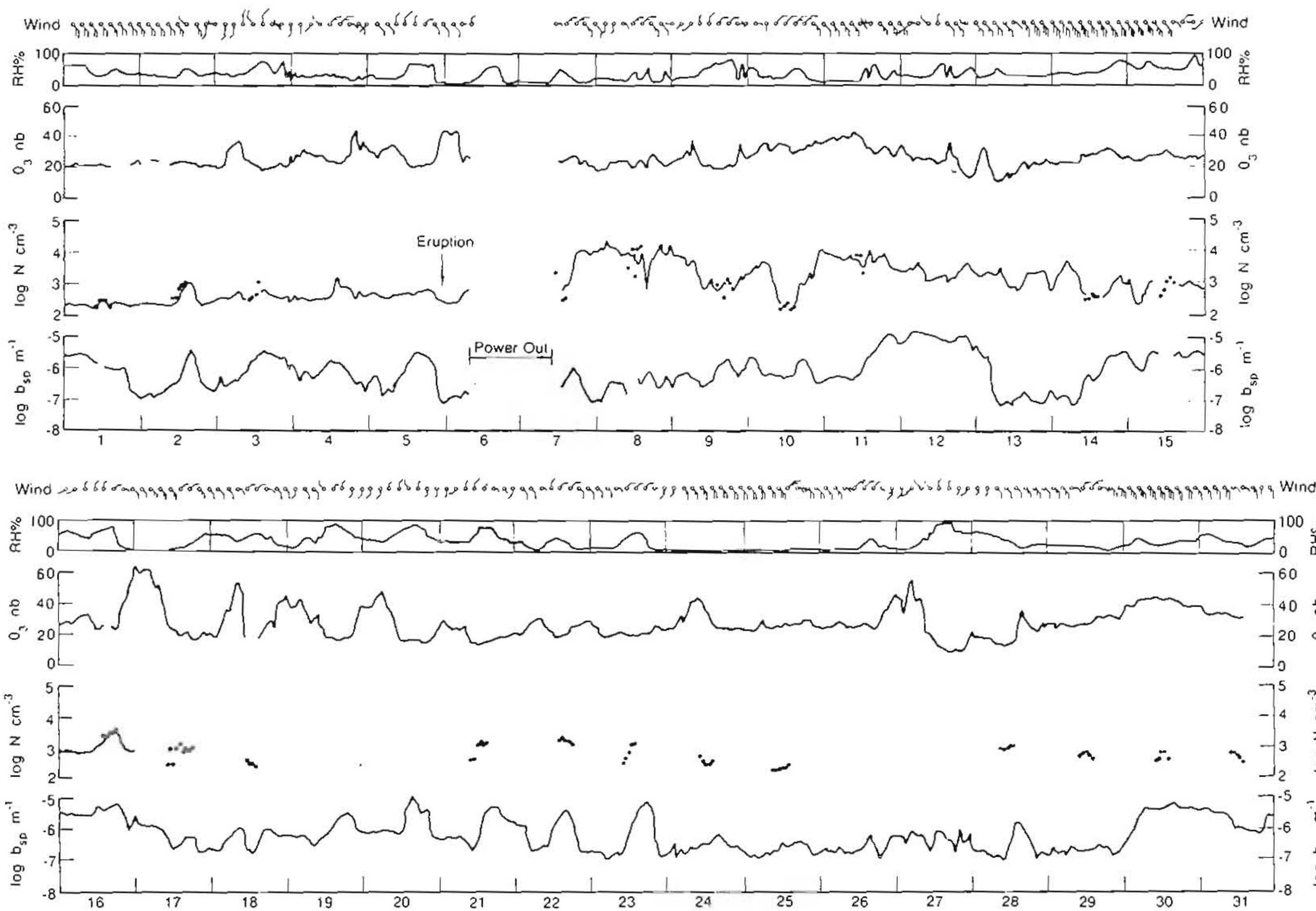

Figure 23. Hourly means of 550 nm light scattering (b_{sp}), condensation nuclei, surface ozone, relative humidity, wind speed and direction at 3-hour intervals, and occasional Pollak nucleus observations at MLO during July 1975.

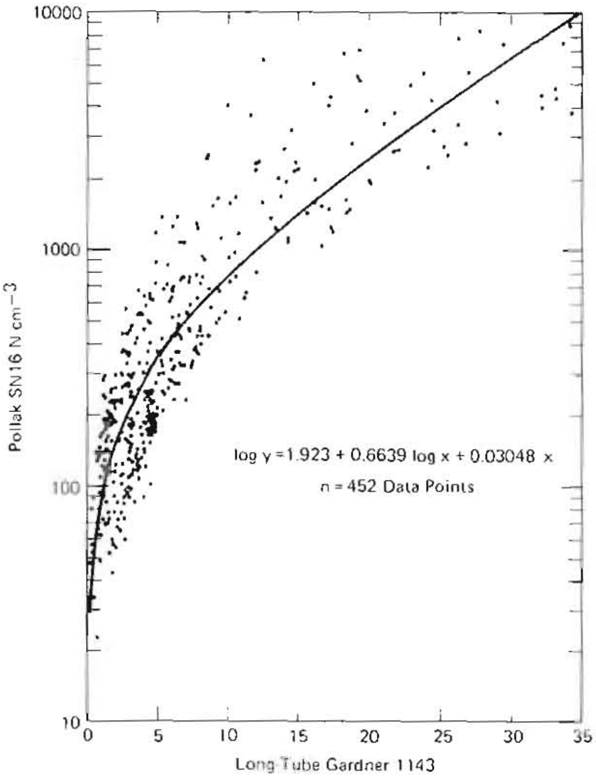

Figure 24. Comparison between long-tube Gardner counter SN1143 and Pollak counter SN16 on ambient aerosol at Barrow from January to April and June to November 1976.

4.3.2 Barrow

Long-tube counter SN1143 and Pollak counter SN16 were operated routinely throughout 1976. The Gardner counter was operated hourly during the normal working day until December 14 when the lamp failed. The Pollak counter was operated hourly during the normal working day until May 5, at which time it was changed to a once-per-day schedule for the remainder of the year. On December 15, the Pollak counter resumed an hourly observational schedule. During May, the Pollak counter was down for repair of the expansion valve.

A comparison between Pollak SN16 and Gardner SN1143 for all simultaneous observations of ambient aerosol in 1976 is shown in Figure 24 along with a least squares fit of Hoerl's equation. A calibration table was made for Gardner SN1143 to convert scale readings to nucleus concentrations. It is interesting to compare this calibration curve (Fig. 24) with a similar curve derived for Gardner SN1143 in the 1975 GMCC Summary Report (Fig. 36). Figure 25 gives the ratio of nucleus values calculated from the 1975 and 1976 Hoerl's equations as a function of scale reading. The two calibration curves differ by about 25% to 10% for scale readings from 2 to 15, the range of interest at a background site such as Barrow. This suggests that the calibration of Gardner SN1143 has probably not changed significantly over the 2 years.

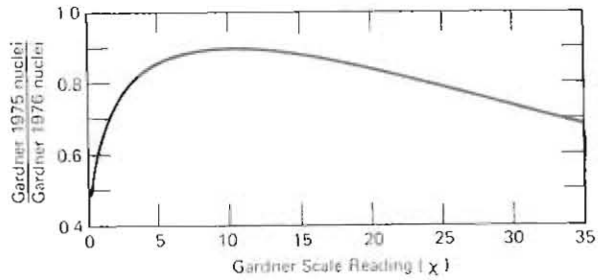

Figure 25. Ratio of 1975 calibration to 1976 calibration for long-tube Gardner counter SN1143 as a function of scale reading. The ordinate value was calculated from the ratio of the Hoerl's equations for 1975 and 1976.

In an effort to define a clean air direction for Barrow in 1976, monthly and annual means of Aitken nuclei measured with the Pollak counter were calculated as a function of wind direction. It was found that the northerly direction was significantly contaminated, and that the clean air sector probably should be redefined to include only winds from the northeast, east, and southeast. This was suggested by Emerson Wood, Barrow Station Chief in 1976. The recommendation was based on his own observations of activity upwind of the observatory and is confirmed by the data given in the wind rose of Figure 26 and the monthly means for the clean air sector shown in Figure 27.

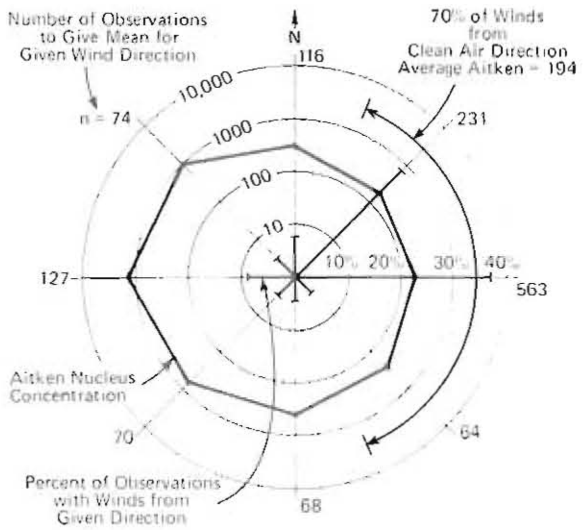

Figure 26. Barrow wind rose and geometric means of condensation nuclei measured with Pollak counter SN16 for 1976.

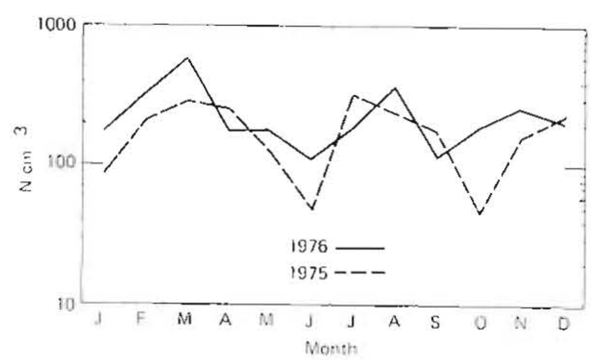

Figure 27. Monthly geometric means of condensation nuclei measured during clean air conditions (NE, E, SE) at Barrow during 1975 and 1976. These means were calculated from Pollak and Gardner counter observations.

Figure 26 gives wind rose and condensation nucleus means as a function of direction for all of 1976. Many of the observations taken during northerly winds were labeled contaminated and were not included in the means. Figure 27 shows monthly geometric means for 1975 and 1976 including only data taken during winds from the northeast, east, or southeast. For most of 1976, condensation nucleus means are as much as 100% higher than those of 1975. However, perhaps a careful screening of the data can eliminate the possible local effects.

Highly variable nucleus concentrations, even under clean conditions, are highest during March, July, and August, and lowest during June, September, and October of each year. Although a number of possible natural and manmade aerosol sources have been identified for the Barrow site, it is often difficult to identify the specific source. One possible source is the Arctic haze which is known to occur in early spring. However, human activity also increases upwind from the station during this period because of sunup and warmer temperatures. (Note that large concentrations occurred in March for both years.) Human activity east of the station decreases markedly in June because of the melting ocean ice and then picks up again sharply in July and August when the coastal waters are open for barge traffic. At the same time, there are many documented measurements of large aerosol concentrations ($\sim 3000^{-3}$) during apparently uncontaminated offshore winds and clear sunny conditions in March. These events are apparently associated with clear, sunny conditions following fog, or with an unusual upper level wind flow.

A G.E. condensation nucleus counter was installed at Barrow in May 1976 and produced reliable data for the remainder of the year. All data were recorded by the Barrow data acquisition system and are available on magnetic tape.

A four-wavelength nephelometer was installed at Barrow in May 1976, but there were problems with its thermoelectric cooler. However, approximately 5 weeks of data were obtained in May and June. The data suggest that very low values ($\sim 10^{-7} m^{-1}$) were sometimes obtained in Barrow but that most of the time the light scattering was between 10^{-6} and 10^{-5} m^{-1}. It should be mentioned that the ocean was opening up during this time and many of these data may have been taken on a marine aerosol.

4.3.3 Samoa

Long-tube Gardner counter SN912 was operated twice daily during uncontaminated conditions throughout 1976. Observations were taken from the 15 m level of the University of Rhode Island tower on Cape Matatula. Figure 28 gives a wind rose for the annual geometric means of condensation nucleus concentrations. Figure 29 gives monthly geometric means of all uncontaminated (no obvious local source) observations. Although the wind rose shows slightly higher concentrations when the wind is over land from the west or southwest, these observations are few and do not bias the monthly means given in Figure 29. All monthly means were also calculated as a function of wind direction, and in all cases the same annual trend of slightly higher concentrations in the austral summer was observed. Nucleus values in Figure 29 are tabulated in Table 11.

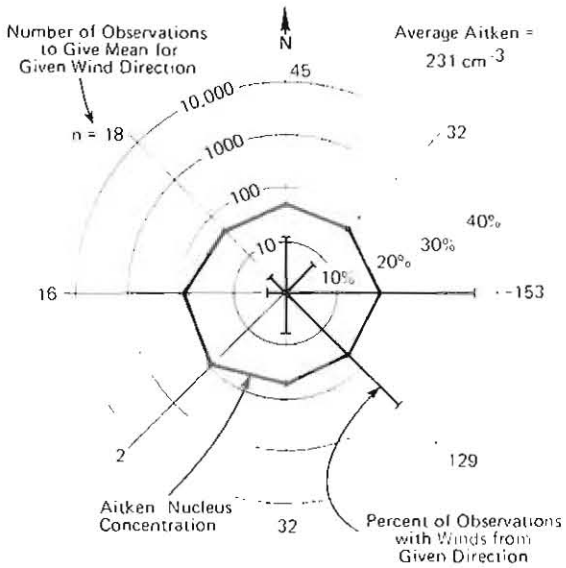

Figure 28. Samoa wind rose and geometric means of condensation nuclei measured with Gardner counter SN912 for 1976.

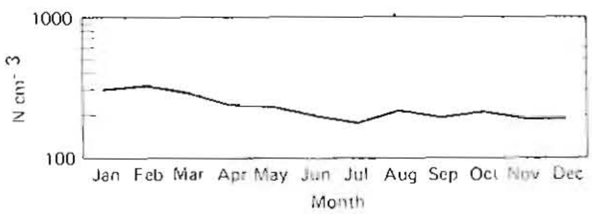

Figure 29. Monthly geometric means of condensation nuclei at Samoa during 1976, measured with long-tube Gardner counter SN912.

Table 11. Condensation Nucleus Concentrations at Samoa 1976

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$\bar{\chi}^*$	314	332	299	250	239	205	180	221	198	218	193	195
$\log \bar{\chi}$	2.50	2.52	2.48	2.39	2.38	2.31	2.25	2.34	2.30	2.34	2.29	2.29
$\log \sigma$	.17	.10	.14	.14	.13	.15	.17	.19	.15	.15	.20	.16
n	20	22	35	31	33	49	41	40	33	40	38	24

* in nuclei cm^{-3}

During 1977 a Pollak nucleus counter, a G.E. automatic nucleus counter, and a four-wavelength nephelometer will be installed in Samoa. Long-tube Gardner counter SN912 and the Samoa Pollak counter will be compared to establish the calibration of the Samoa long-tube Gardner counter.

4.3.4 South Pole

Pollak counter SN15 and the G.E. automatic nucleus counter continued to operate at South Pole station throughout 1976. During June and July 1976, the South Pole observers discovered a contamination problem with the Pollak counter which was repaired on July 28. In an attempt to understand the problem and recover the data, simultaneous readings of the G.E. counter and the Pollak counter were plotted as a ratio for all of 1976 as shown in Figure 30. If both instruments were operating perfectly, this diagram would show a horizontal line at a ratio of 1 for the entire year. However, assuming that the Pollak counter is correct and that the G.E. counter may exhibit some offset with reduced sensitivity at the low end of the scale, we would expect the ratio of Figure 30 to be near 1 at the beginning of the year, increase in value during midyear, and return to near 1 at the end of the year (nucleus concentrations are very low during June and July). It is apparent from Figure 30 that the Pollak counter probably began deteriorating sometime in April.

Therefore, it was assumed that the Pollak counter was operating properly during January to March and August to December. A comparison and a linear regression were run on the simultaneous G.E. and Pollak counter observations for these months (Fig. 31). Several equations were tried in the linear regression, and

$$\log y = 0.9000 + 0.3914 \log \chi + 0.08515 (\log \chi)^2$$

was the best fit, where y is the G.E. counter reading and χ is the Pollak counter reading. This equation was inverted and applied to the G.E. counter data for April to July, to recover midyear nucleus values. The results of this correction procedure, along with 1975 Pollak counter data, are shown in Figure 32, where data for January-March and August-December 1976 are from the Pollak counter, and data for April-July 1976

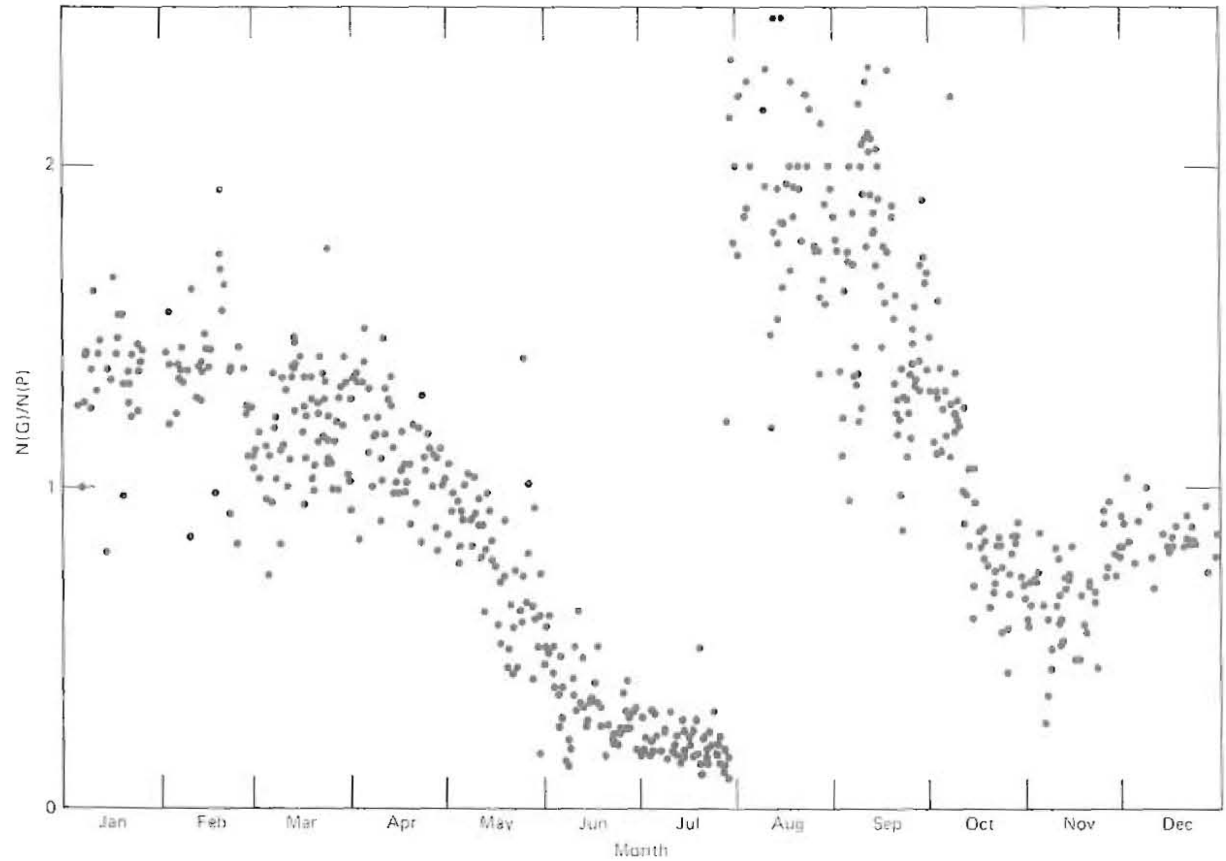

Figure 30. Ratios of all simultaneous G.E. counter and Pollak counter observations at South Pole. Two observations per day during all of 1976.

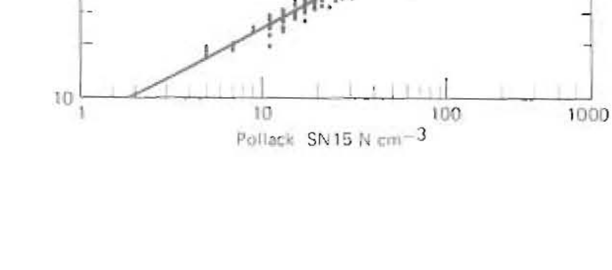

Figure 31. Comparison between Pollak counter SN15 and G.E. counter at South Pole for January to March and August to December 1976. Solid curve shows linear regression curve used to calibrate the G.E. counter.

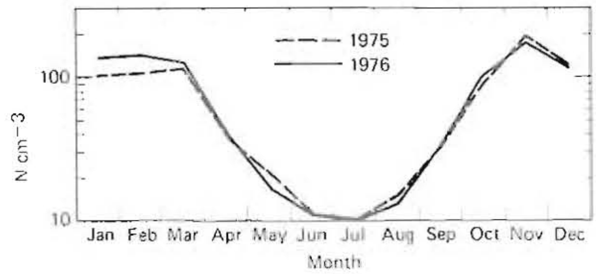

Figure 32. Monthly geometric means of condensation nuclei at South Pole during 1975 and 1976. 1975 data are all from Pollak counter SN15. 1976 data are from the Pollak counter for January to March and August to December and from corrected G.E. data for April to July.

are corrected G.E. counter data. Monthly nucleus data for 1976 are nearly the same as 1975 nucleus data.

G.E. counter data were recorded for the entire year by the South Pole data acquisition system and are stored on magnetic tape. These data have been corrected using a comparison of the G.E. counter and Pollak counter on a monthly basis according to the regression equations given in Table 12.

Daily aerosol observations along with temperature and wind data are shown in Figure 33 for August-October 1976. This is an interesting time period since it spans some of the very clean periods through sunup to the higher nucleus concentrations at year's end.

Table 12. Corrections to G.E. Counter Data at South Pole, 1976

Month	Equation for Correcting Data
Jan	$\log P = 0.0314D + 0.9289 \log G$
Feb	$\log P = 0.4468 + 0.7448 \log G$
Mar	$\log P = 0.1592 + 0.8956 \log G$
Apr, May, Jun, Jul	$\log P = \dfrac{-B + \sqrt{B^2 - 4A(C - \log G)}}{2A}$ where $A = 0.08515$, $B = 0.3914$, $C = 0.9000$
Aug	$\log P = -0.9523 + 1.443 \log G$
Sep	$\log P = -0.8375 + 1.378 \log G$
Oct	$\log p = -0.5274 + 1.287 \log G$
Nov	$\log P = -0.4203 + 0.8931 \log G$
Dec	$\log P = -0.07720 + 1.070 \log G$

G = G.E. data point in nuclei
P = Corrected data scaled to Pollak counter calibrations

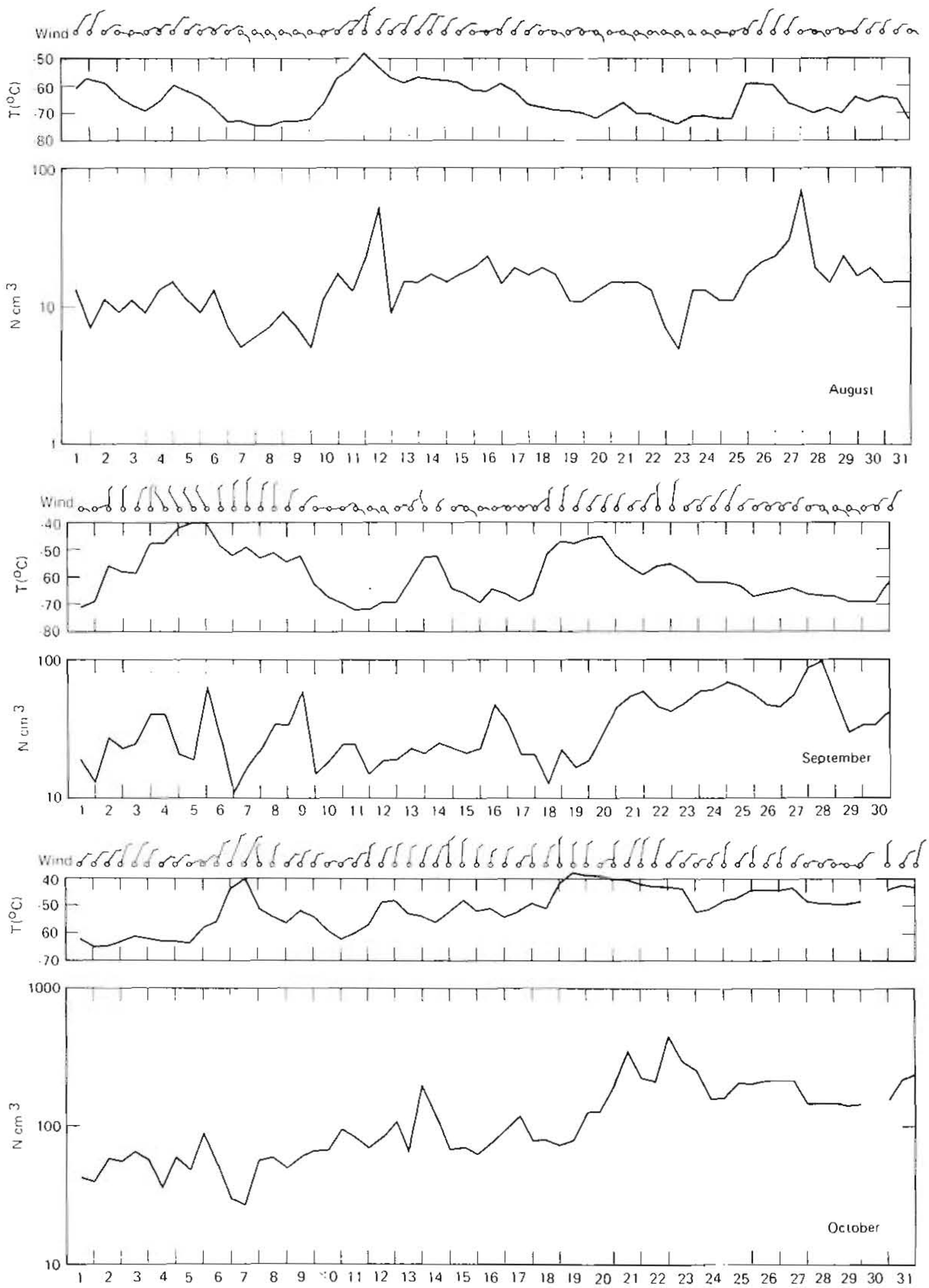

Figure 33. Condensation nucleus concentration at South Pole for selected months of 1976, with outside temperature and wind for each observation. All observations were taken with the Pollak counter at about 0700 or 2330 GMT.

4.3.5 Cooperative Programs

In cooperation with the Canadian Department of the Environment, long-tube Gardner counter SN1176 was placed aboard the Canadian Coast Guard Ship Vancouver at ocean station "Papa" in the northern Pacific at 50°N, 145°W. Nucleus observations were taken four times daily at 0300, 0900, 1500, and 2100 Greenwich Mean Time (GMT) for the periods December 8, 1975, to January 8, 1976; February 16 to March 28, 1976; May 10 to June 20, 1976; August 7 to September 12, 1976; and October 20 to December 5, 1976. This program was conducted at the request of William Elliot of NOAA/ARL and should provide an excellent time series of data at a single ocean based point. Most ocean aerosol studies previously have been conducted from moving ships.

Also during 1976, an experiment was conducted in cooperation with Keith Bigg of CSIRO to sample the Barrow aerosol. This sampler consists of an impactor-electrostatic precipitator arrangement to capture particles directly on electron microscope grids for chemical analysis. Dr. Bigg's technique is especially sensitive to sulfate and sulfuric acid aerosol. The results of this experiment should be available sometime in 1977.

4.4 Meteorological Measurements

4.4.1 Meteorological Sensors

In January, the standard meteorological sensors were installed on Cape Matatula, Samoa. These included an aerovane to measure wind direction and speed, a static pressure transducer, a mercurial barometer for pressure, and linearized thermistors to measure air and soil temperatures. Within a month of installation, the relative humidity sensor (humidicap) failed because of salt-spray corrosion. Attempts to clean the sensor also failed. The replacement sensor lasted only a few weeks, so the operation of this humidity sensor was discontinued. Until a new sensor is installed, the humidity will be reported from a hygrothermograph.

The failure of the relative humidity sensor at Samoa was followed by the failure of the unit in use at MLO. These elements will be replaced in 1977 with linearized thermistors inclosed in a lithium chloride-coated bobbin. Although the sensor has some drawbacks, it does have a ±1° accuracy from 0° to 25°C. The accuracy decreases markedly below 5°C, rendering the sensor useless in the Arctic. The dew point thermometer (Cambridge Systems) will continue to be used at the Barrow station to measure the moisture content of the air. Other methods will eventually be used at South Pole.

The voltage amplification of the wind speed translator was found to be in error, partly because of design errors and a poor choice of calibration voltage. The errors were small at wind speeds less than 20 m s^{-1} A new calibration voltage was imposed, and the performance of the unit was linearized to about ±1% for wind speeds from 0 to 40 m s^{-1}. The circuit was found to saturate at about 45 m s^{-1}. A new card, linear to 60 m s^{-1}, will be supplied in 1977.

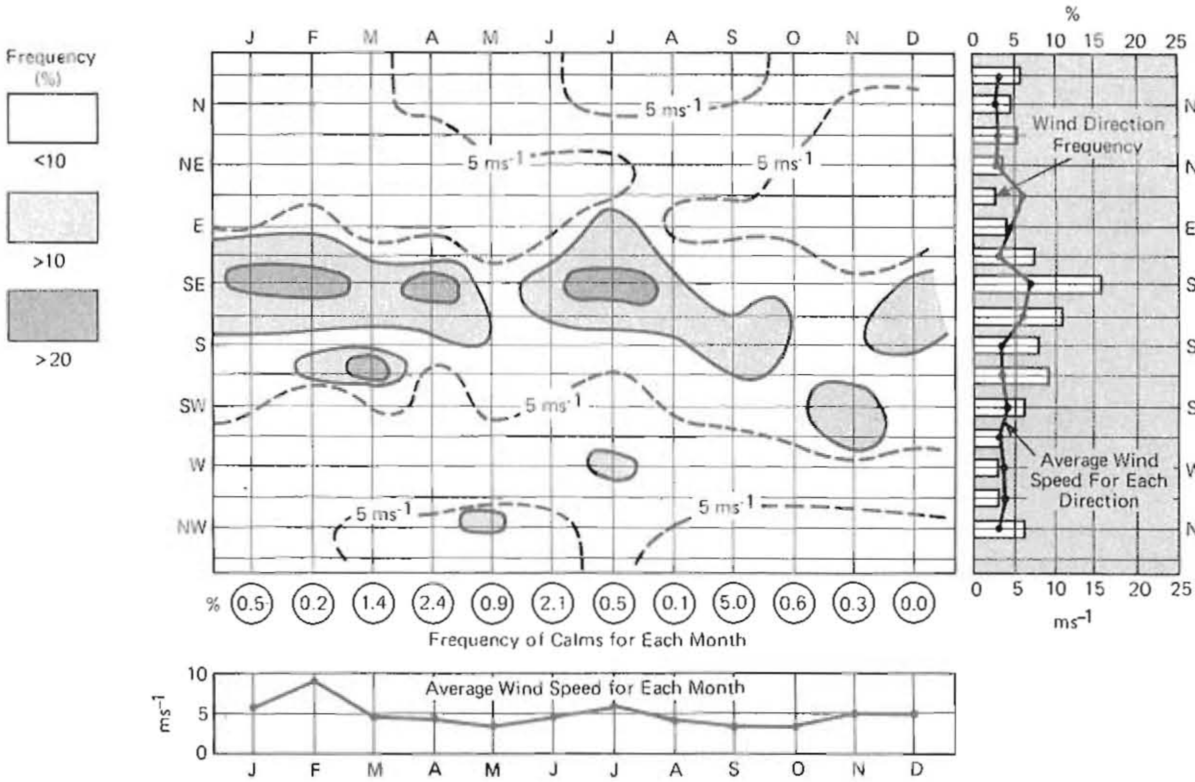

Figure 34. Surface wind climatology for Mauna Loa, 1976. Contours represent frequency of occurrence of wind direction in each month. Bar graph shows frequency of occurrence in the whole year.

4.4.2 Mauna Loa Meteorology

Figure 34 summarizes the surface wind data for each month of 1976. Although there is clearly a prevailing wind from a southeasterly direction, it does not occur as frequently as does the prevailing direction at other stations. There is also more variation in the wind direction climatology on a month-to-month basis at Mauna Loa than at other observatories. In the fall, for example, the most frequent wind direction is southwesterly. A similar shift occurs in March. The highest wind speed coincides with the southeasterly winds, and the average speed for the year was 4.7 m s^{-1}. The windiest months were January and February. The annual average of calm conditions was slightly more than 1% of the time. Pronounced variation in the meteorological parameters occurs on a diurnal basis. In future reports the statistical nature of these variations will be shown as a function of season.

On an average of 10 soundings per month, the planetary boundary layer extends above the level of MLO (see Fig. 35). The layer is deeper in the winter and spring than in the summer and fall. The wind direction within the layer is predominantly from the east, 26% of the time in 1976 (see Fig 36). The flow is seldom from the west. The trade wind is steadiest during the summer months. The average vector wind speed for the layer was 4.8 m s^{-1}

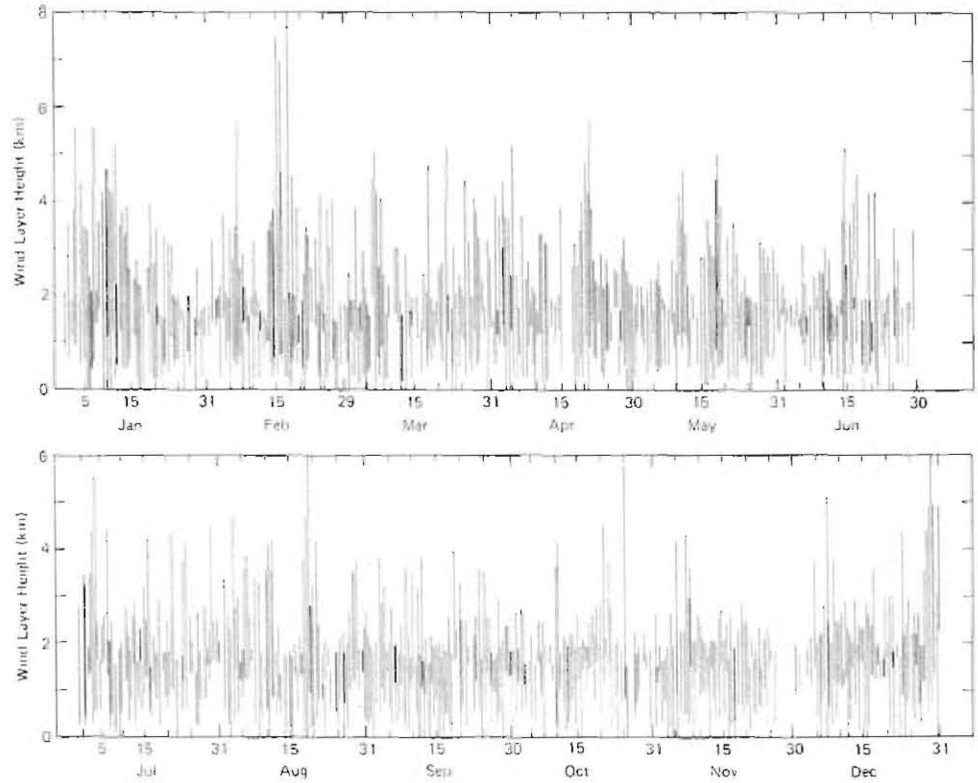

Figure 35. The gradient wind layer (850 mb) as plotted from the 1976 NWS Hilo rawinsonde data. The vertical bars show the height and thickness of the layer.

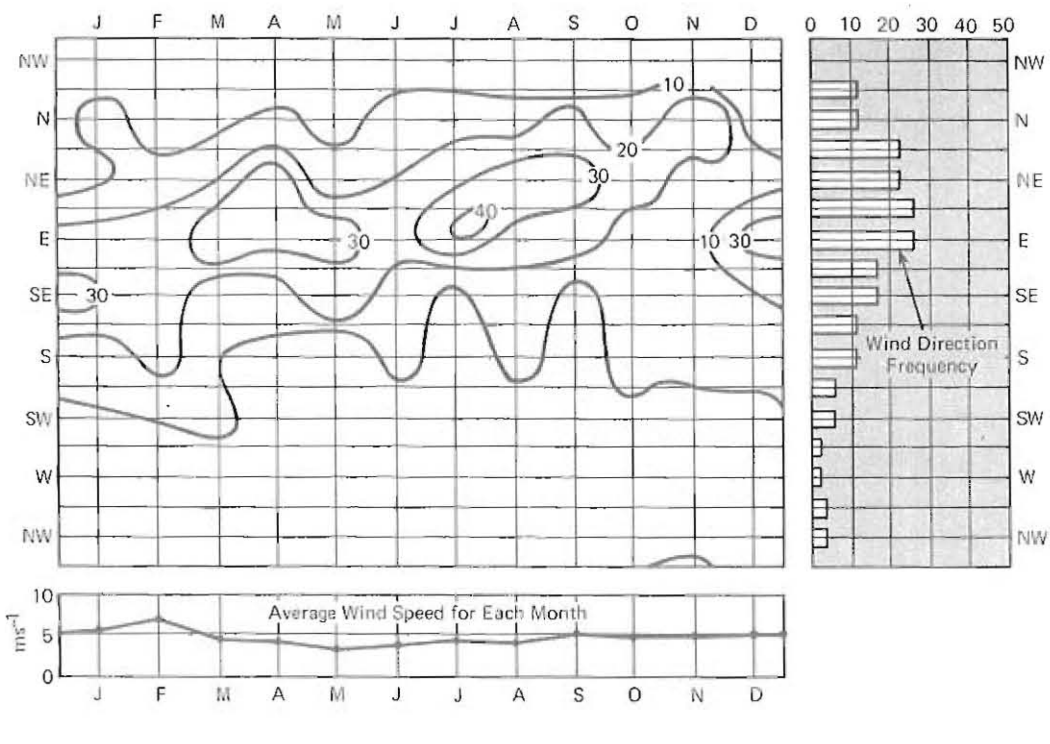

Figure 36. Climatology of the planetary boundary layer as determined from the NWS rawinsonde data from Hilo, Hawaii, in 1976. The Hilo station is 55 km northeast of MLO. Contours represent frequency of occurrence of wind direction in percents. (See legend, Fig. 34.)

Jet Stream Wind Observations

On many occasions the air reaching the Mauna Loa Observatory during the night and early morning hours comes from the upper troposphere. Figure 37 depicts the variation in height and thickness of the jet stream layer in the vicinity of the observatory. Although the bottom of the layer extends below 6 km ~28% of the time, it seldom reaches the observatory at 3.4 km or the top of the Mauna Loa volcano at 4.2 km. The most frequent wind direction in this layer, west, occurs 46% of the time (see Fig. 38). East and southeasterly winds occur infrequently. The average vector wind speed for the layer is 19.2 m s^{-1}, with the maximum speeds occurring in the spring and the minimum in the fall.

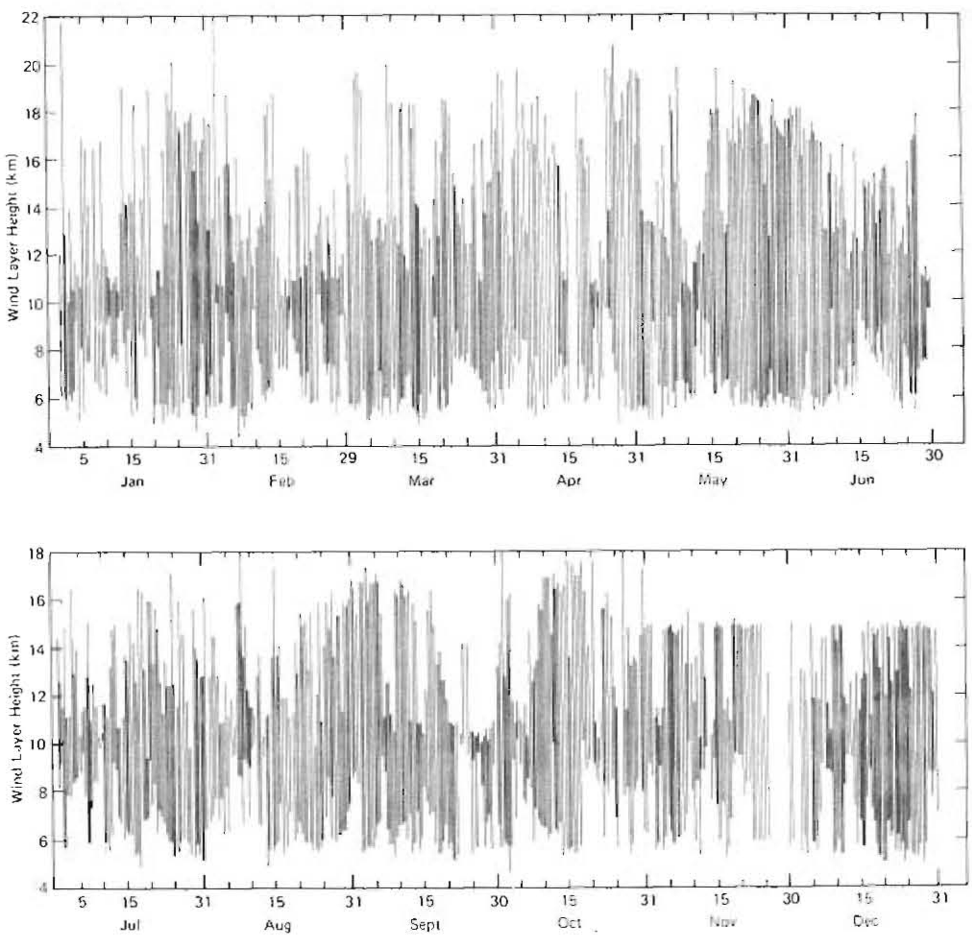

Figure 37. The jet stream wind layer as plotted from the NWS Hilo rawinsonde observations during 1976. The vertical bars depict the layer through which the wind direction changes less than 22° from the direction at 250 mb.

4.4.3 Barrow Meteorology

The GMCC observatory at Barrow is about 9 km from the "point", the northernmost extension of the Alaskan north slope. For 300 km the north slope is void of topographic barriers that could influence the local wind flow. For most of the year the winds are the result of synoptic scale weather systems. Between stormy periods, when the wind can blow from any direction, the local winds are controlled by the outflow from the polar anticyclone. This situation results in a persistent easterly wind at the surface. The most significant local phenomenon is the onset of the stratus cloud layer along the coast in the spring. The time of onset corresponds with the time the sun is up for most of the day, when extensive leads open along the Arctic coast.

The seasonal variations of wind speed and direction are displayed in Figure 39. Although easterly winds are those most commonly observed all year, they are most prevalent in the spring and summer. In the stormy spring and fall months, the prevailing wind is more northerly. Southerly winds are relatively uncommon, occurring less than 10% of the time. The seasonal variation in wind speed, although not too pronounced, shows a slight increase in the spring and fall compared with the summer and winter. The average wind speed for the year was 5.2 m s^{-1}. The maximum wind is easterly.

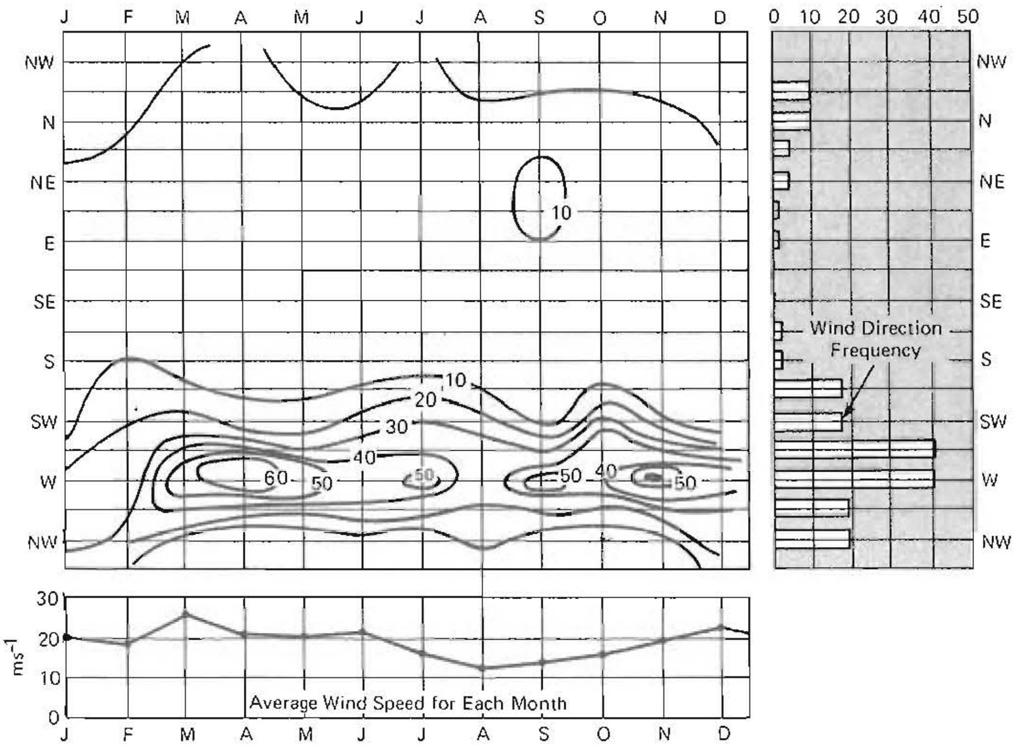

Figure 38. Climatology of the jet stream wind layer as determined from NWS Hilo 1976 rawinsonde data. Contours represent frequency of occurrence of wind direction in percents. (See legend, Fig.34.)

In 1976 the NWS office at Barrow reported a maximum temperature of 17°C on July 29 and a minimum of -41°C on February 26. They also reported 188 cloudy days (8/10 and greater cloud cover), 65 partly cloudy days (2/10 to 8/10 cloud cover), and 47 clear days (less than 2/10 cloud cover). After leads open in the Arctic ocean in the spring, a persistent stratus deck covers the coast. In the 6-month period May-October, only eight clear days were observed--141 were cloudy. Thus, 77% of the time the cloud cover exceeds 8/10. Although these observations are made at the Barrow airport 7 km southeast of the GMCC station, they are generally representative of the Point Barrow region because of the uniform nature of the surrounding terrain.

4.4.4 Samoa Meteorology

The GMCC observatory is on Cape Matatula, the most northeasterly extension of the island of Tutuila. The station is at long. 170° W., lat. 14° S., and 80 m above mean sea level. Tutuila is a long, narrow island of volcanic origin, with its major axis lying in a southwest-northeast direction. Its greatest length is 32 km, and its width ranges from 1 to 8 km. The highest peak is 0.65 km.

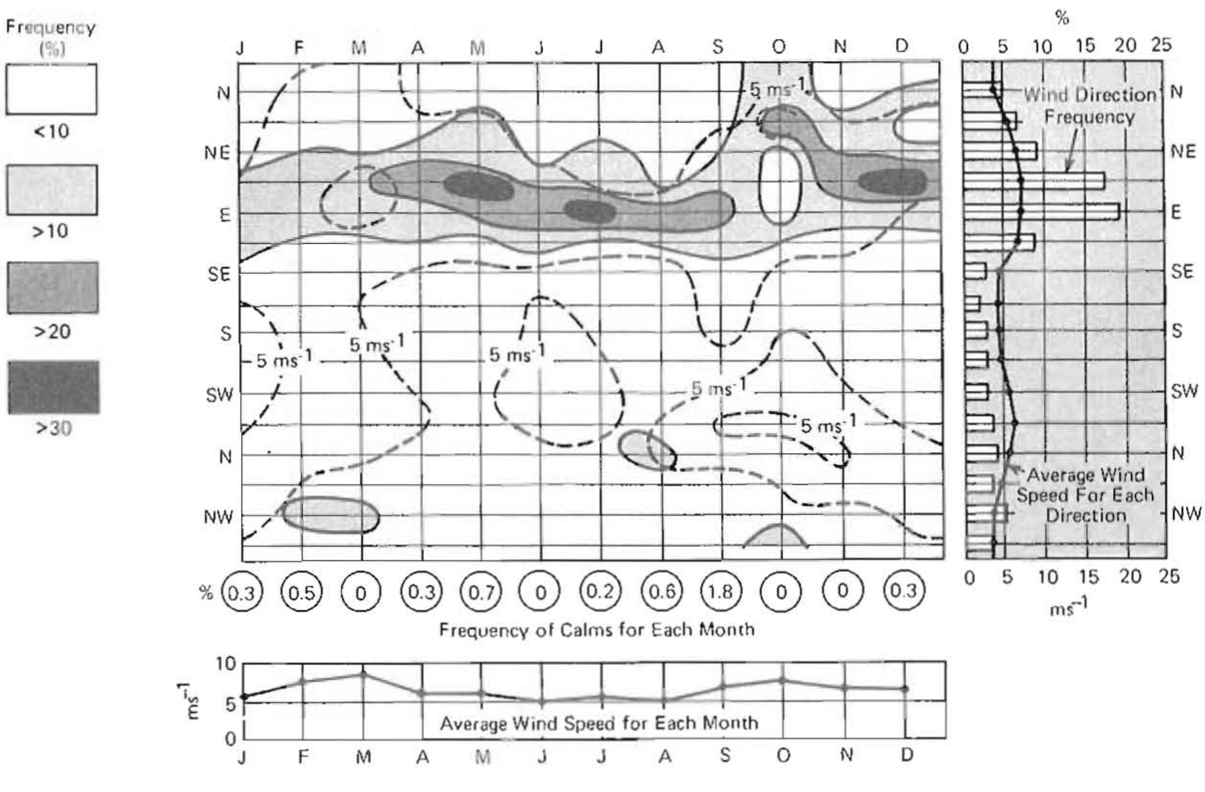

Figure 39. Surface wind climatology for Barrow, 1976. (See legend, Fig. 34.)

The regularity of the trade wind at Cape Matatula in 1976 is clearly shown in Figure 40. The wind blows from the east-southeast direction almost 25% of the time throughout the year. There is a slight shift to a more northerly direction in the austral summer months. The stronger winds are also associated with the trade winds. The wind speed is recorded as calm about 0.3% of a given month. The average wind speed for 1977 was 6.5 m s^{-1}. The maximum wind speed in 1976 was well in excess of 40 m s^{-1} and was associated with a passing tropical disturbance.

The tropical disturbance that passed Cape Matatula on December 11 was the outstanding meteorological event of the year. The wind did considerable damage, causing the sampling tower that supported the station anemometer to collapse. As a result, a record of peak gust during this storm is missing. Within 3 hours the pressure dropped 20 mb to a minimum value of 973 mb.

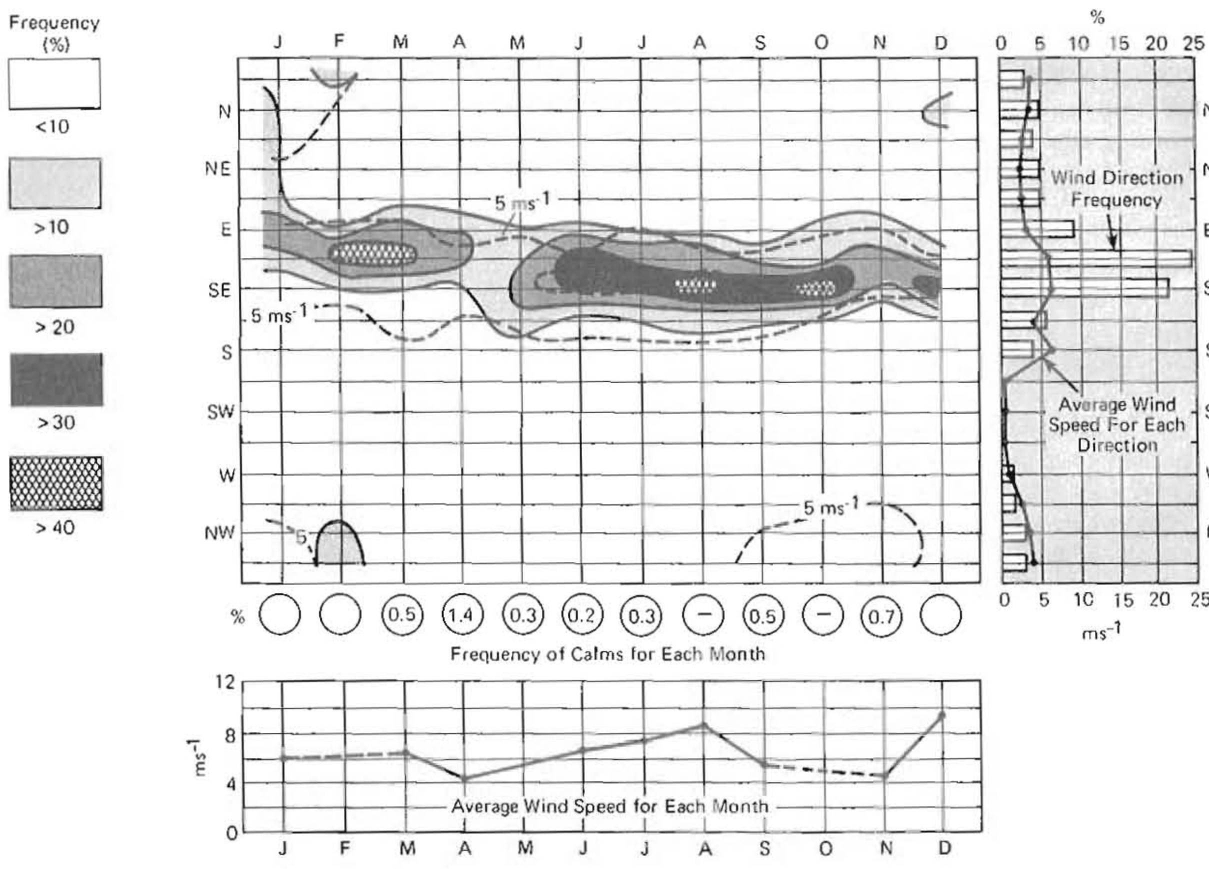

Figure 40. Surface wind climatology for Cape Matatula, American Samoa. (See legend, Fig. 34.)

4.4.5 South Pole Meteorology

The local meteorology at the South Pole is strongly controlled by persistent radiation inversions and katabatic winds. The inversions, which can be extremely strong, especially in the winter, effectively separate the surface layer from conditions aloft. Only during the middle of the summer season and during brief stormy periods does the inversion weaken, and at best an isothermal surface layer exists.

The station is on the high, locally flat Antarctic Plateau at an elevation of approximately 2800 m. The katabatic winds flow from the east (i.e., long. 90° E.) off the ridge of the plateau, which is located in east Antarctica. However, during stormy periods with wind speeds above 10 m s^{-1} the wind direction is predominantly from the north (long. 0°) or within 20° of either side of north. Thus, it is these high-speed winds from grid north that are responsible for most of the local drifting.

During the austral fall and spring of 1976 a few new temperature and pressure records were set. However, the monthly average temperature closely followed the climatological average of the past 20 years. One marked exception was August, which was the coldest month. The average temperature was about 5°C colder than the climatological average (see Fig. 41). The coldest recorded temperature, -76°C, was also in August.

The wind and temperature sensors were in the same location throughout 1976 as they were in 1975. That location was about 100 m grid northeast of the eastern edge of the main station. The anemometer is about 10 m above the snow surface. The thermometer is only 1.5 m off the surface.

Changes in the wind climatology for 1975 and 1976 were small. The relative distribution of wind direction was less concentrated in the grid easterly components in 1976 (see Fig. 41). The most common wind direction was from grid north-northeast. Westerly winds were observed about 20% of the time. This contrasts with only 11% the previous year. The average wind speed for the year was 5.2 m s^{-1}. Calm winds were reported only 2.5% of the time.

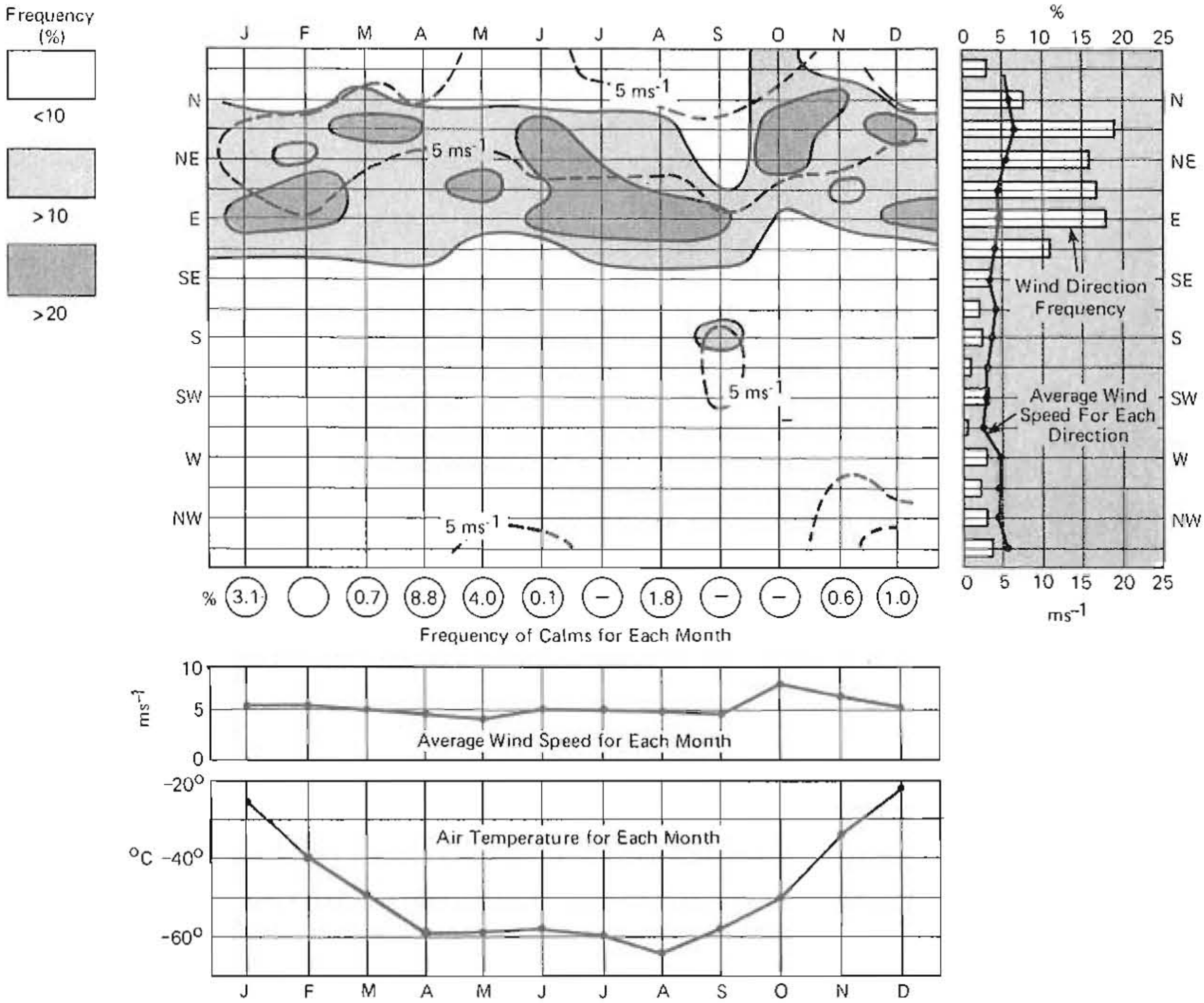

Figure 41. Surface wind climatology for Amundsen-Scott station, South Pole, 1976. (See legend, Fig. 34.)

4.4.6 GMCC Trajectory Program

The GMCC air parcel trajectory program became fully operational during 1976 for stations in the Northern Hemisphere. The wind data, which constitute the basic input to the computer program, are derived from two sources: observed winds (available every 6 or 12 hours) from the global upper air station network, and analyzed winds (available every 12 hours) from the National Meteorological Center in Suitland, Md., 65 x 65 Northern Hemisphere grid. Backward trajectories are computed routinely every 6 hours for the following stations. (They now have been generated through December 1976):

Station	Trajectory Type
Mauna Loa Observatory, Hawaii	10-day backward trajectory Analyzed wind only 3000-5000 m above terrain (msl)
Barrow, Alaska	10-day backward trajectory; Observed and analyzed winds 300-2000 m above terrain (msl)
Adrigole, Ireland	10-day backward trajectory Observed and analyzed winds 300-2000 m above terrain
Bermuda	10-day backward trajectory Observed and analyzed winds 300-2000 m above terrain
Ithaca, N.Y.; White Face Mountain, N.Y.; Charlottesville, Va.; State College, Pa.	5-day backward trajectory Observed winds only 300-1500 m above terrain

There is generally a 1½- to 2½-month lag in real time, mostly because of the complexity of assembling the observed winds. In practice, trajectories of any length, averaging layer and time period, can be computed for any location in the Northern Hemisphere. The validity of the trajectories is limited only by the quality of the wind data. That is, winds observed every 6 hours usually provide more realistic trajectories than do winds analyzed every 12 hours. The data base has not yet been extended to the Southern Hemisphere, so similar computations for Samoa and the South Pole GMCC stations have been deferred.

4.5 Solar Radiation

Solar irradiance is measured routinely at all four GMCC observatories as an integral part of the long-range monitoring of benchmark parameters. Eppley pyranometers and pyrheliometers are the principal instrumentation used for monitoring. Solar irradiances are measured over broad spectral bands as well as through narrow band-pass interference filters. The broad-band measurements are made through quartz and Schott glass cutoff filters where the mean wavelength windows measured are quartz, 2000A $\gtrsim \lambda \gtrsim$ 30000A; GG22, 3900A $\gtrsim \lambda \gtrsim$ 30000A; OG1, 5300A $\gtrsim \lambda \gtrsim$ 30000A; RG2, 6300A $\gtrsim \lambda \gtrsim$ 30000A; and RG8, 6950A $\gtrsim \lambda \gtrsim$ 30000A. The transmittance varies slightly with ambient temperature of field observation conditions and with different filter production melts. The ultraviolet global pyranometers used in the network incorporate a diffusing disk as well as a filter with a window of 2950A $\gtrsim \lambda \gtrsim$ 3850A. The narrow-band pass interference filters are used in the Eppley 13-channel normal incidence pyrheliometers (NIP).

4.5.1 Measurement Program

Table 13 lists the solar radiation measurement programs in GMCC through December, 1976. The Eppley filter wheel NIPs started a new normal incident solar irradiance measurement at all the observatories. Broad-band measurements are made during clear sky conditions and the instrument is manually aligned and pointed to obtain true values. Eventual automation of these instruments is planned.

The Volz-type sun photometers are part of the EPA Atmospheric Turbidity Network. Measurements through narrow-band pass interference filters of $\simeq$10 nm width at 3800A and 5000A are made to monitor dust loading (turbidity coefficients).

Table 14 lists all the GMCC solar radiation instruments with calibration constants that were used to obtain measurements at the observatories during 1976.

4.5.2 Data Acquisition

Data are acquired by two methods. First line data acquisition is by a NOVA computer. Second line (backup) acquisition is by a strip chart analog recorder. Both methods record signal voltages produced by the radiation instruments after they are amplified through a preamp bank.

The NOVA computer provides processing of data, magnetic tape data storage, and "D" array data conversion (see 4.5.3). The strip chart recorder produces a continuous trace of the signal voltage. To convert this record into engineering units, an average over a time span and corrections for the zero offset and preamp gain are first made. To convert these corrected signal voltages into engineering units, the calibration constant is then applied. Figure 42 shows the schematic flow of measurement recording systems.

Table 13. Solar Radiation Measurements up to January 1977

Instrument	Stations					Remarks
	MLO	Barrow	Samoa	South Pole	Boulder	
Eppley pyranometers						
Q global	X	X	X	X	*	
GG22 global	X	X	X	X	*	
OG1 global	X	X	X	X	*	
RG8 global	X	X	X	X	*	
UV global	X	X		X	*	
Eppley filter wheel NIP's						
Q NIP	X	pro.	X	X		Just begun this year, hand operated.
OG1 NIP	X		X	X		"
RG2 NIP	X		X	X		"
RG8 NIP	X		X	X		"
Eppley narrow- and broad-band NIP 13 Channels	X					Did not operate well at South Pole.
Eppley NWS NIP	X	proposed		X		On equatorial tracker.
Volz Sun photometers	X	X	X	X		Hand operated.
Diffuse (shader)	X					Occulting disk tracking sun and shading pyranometer.

*Nothing on regular basis.

4.5.3 Quality Control

Table 15 lists our quality control procedures. The NOVA data acquisition system temporarily records instantaneous signal voltages in a "V" array at 1-second intervals. These voltages are passed on to an "M" array where they are stored in 1-minute voltage total blocks on magnetic tape with observational scan tallies at 10-minute intervals. These same voltage totals and tallies are also stored in a "D" array. The voltage totals are converted into hourly integrals of solar irradiance values in engineering units. These hourly integrals are also stored on magnetic tape along with all other components of the "D" array. A calibration scheme and algorithm constants are maintained and used in the "D" array to convert the signal voltage into solar irradiances. This is done by substituting test voltages instead of signal voltages at timely intervals into the NOVA data acquisition system. The data generated in the "D" array are those used in Boulder to monitor instrument performance as well as those used for distribution.

Table 14. Solar Radiation Instruments On Line During 1976

Instruments	Station					NOVA Channel
	Mauna Loa	Barrow	Samoa	South Pole	Boulder	
Eppley Pyranometers						
Global Quartz						
Serial number	12616	12263	12273	12271	12276	16
Cal. constant†	.0794	.0956	.0927	.1072	.10204	
Global GG22						
Serial number	10151	12265	12274	12268	12622	17
Cal. constant	.0695	.0983	.0963	.10277	.09398	
Global OG1						
Serial number	10152	12264	12277	12269	12618	18
Cal. constant	.0735	.1051	.0962	.1036	.0769	
Global RG8						
Serial number	10153	12267	12275	12270	12619	19
Cal. constant	.0767	.0965	.0910	.0978	.0791	
Global UV						
Serial number	10232	12348	-	12349	-	20
Cal. constant	1.9084	1.869	-	2.278	-	
Eppley Pyrheliometers						
Eppley NIP Q, Filter Wheel OG1, RG2, RG8						
Serial number	13910	13913*	13914*	13912*	13909	None
Cal. constant	.0825	.0826	.0829	.0815	.0774	
Eppley Broad-Band and Narrow-Band NIP 13 Channels B8 Q, GG22, OG1, RG8						
Serial number	4758	-	-	4757+	-	MLO Ch 21, 22, 26-31 to Oct 76 MLO Ch 23-35 to Dec 76 South Pole Ch 21, 22, 26-28
Eppley NIP Quartz						
Serial number	2119	-	-	2968	-	MLO Ch 23 to Oct 76 Ch 21 to Dec 76 South Pole Ch 29
Cal. constant	.0295	-	-	.0259	-	
Volz Sun photometers						
Serial number	DA038	DAD49	DA116	E4640	DA115	None

†Calibration constants are in $mV/mW\ cm^{-2}$
* On line early 1977
+ Terminated Oct 1976

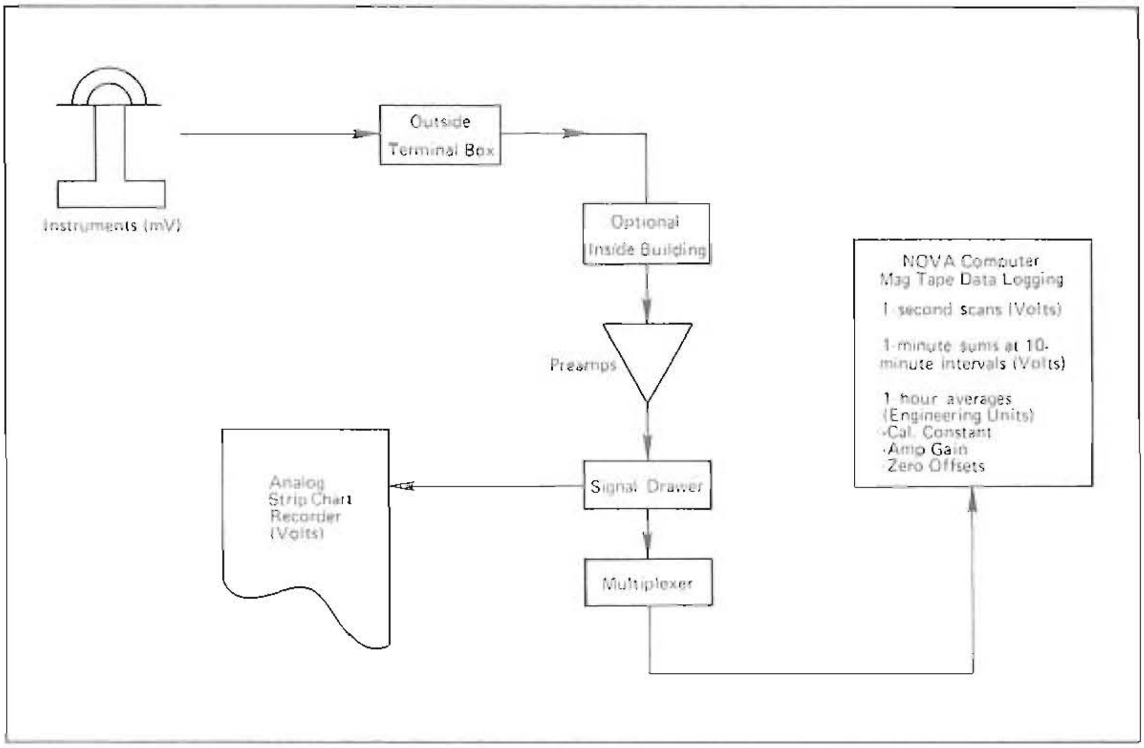

Figure 42. Schematic flow of measurement and recording systems for GMCC solar radiation instruments.

Table 15. Procedures for Quality Control of Solar Radiation Data

1. NOVA calibration system

2. Nighttime zero offsets

3. Daily documentation sheets
   a. Instrument malfunctions
   b. Obstructions on instruments
   c. Sky conditions
   d. Instrument orientation

4. Data examination
   a. NOVA computer plots
   b. Statistical analysis

5. Instrument comparisons
   a. Boulder Laboratory intercomparisons
   b. Field intercomparisons with traveling standards
   c. Instrument history files

6. Observatory feedback

In addition to the NOVA calibration procedures, an instrument zero (recorded dark voltages) is applied to the hourly averages of solar irradiance. This procedure is used to subtract out all internal noise, data acquisition, and instrument offsets that can become significant for low signal voltages at low solar angles. Typical values of the dark voltages can range from 0.0 to ±0.5 mW cm^{-2}.

Another quality control measure is a solar radiation daily documentation sheet. An example of the sheet is shown in Table 16. A checklist documentation is made by the observer in the field to record instrument performance, orientation, and repairs, as well as sky conditions and obstructions on the domes. A tabulation of two of the entries is given in Table 17. Note that all observatories averaged clear sky periods (sky clear from horizon to horizon for 2 hours or more) at least on 33% of the days.

Table 16. Example of Daily Check List Documentation Sheet for Solar Radiation Measurements at Amundsen-Scott Station

<table>
<tr><td>Date Dec 1976</td><td></td><td colspan="4">15</td><td colspan="4">16</td><td colspan="4">17</td><td colspan="4">18</td><td colspan="4">19</td></tr>
<tr><td>INSTRUMENTATION</td><td></td><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td></tr>
<tr><td rowspan="4">Orientation of Pyrheliometers (Time)</td><td>1</td><td colspan="4">00Z ok</td><td colspan="4">0130Z</td><td colspan="4">00Z</td><td colspan="4">0600Z</td><td colspan="4">2130Z cloudy</td></tr>
<tr><td>2</td><td colspan="4"></td><td colspan="4">0500Z ok</td><td colspan="4">0445Z</td><td colspan="4">2030Z</td><td colspan="4"></td></tr>
<tr><td>3</td><td colspan="4"></td><td colspan="4">2030Z</td><td colspan="4">21000Z</td><td colspan="4"></td><td colspan="4"></td></tr>
<tr><td>4</td><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td></tr>
<tr><td>Signal Cable Leads</td><td></td><td colspan="4">ok</td><td colspan="4">ok</td><td colspan="4">ok</td><td colspan="4">ok</td><td colspan="4">ok</td></tr>
<tr><td>Obstructions on Filter Domes</td><td></td><td colspan="4">*00Z
2030Z*</td><td colspan="4">*0130Z
*0500Z
*0815Z</td><td colspan="4">ok</td><td colspan="4">*0800Z
*2030Z</td><td colspan="4"></td></tr>
<tr><td>Dessicant</td><td></td><td colspan="4">ok</td><td colspan="4">ok</td><td colspan="4">ok</td><td colspan="4">ok</td><td colspan="4">ok</td></tr>
<tr><td>Level Pyranometers</td><td></td><td colspan="4">ok</td><td colspan="4">ok</td><td colspan="4">ok</td><td colspan="4">ok</td><td colspan="4">ok</td></tr>
<tr><td>Blower Operation</td><td></td><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td></tr>
<tr><td>Heater</td><td></td><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td></tr>
<tr><td>BOSS - ICDAS</td><td></td><td colspan="4">ok</td><td colspan="4">ok</td><td colspan="4">ok</td><td colspan="4">ok</td><td colspan="4">ok</td></tr>
<tr><td>Data Scan</td><td></td><td colspan="4">ok</td><td colspan="4">ok</td><td colspan="4">ok</td><td colspan="4">ok</td><td colspan="4">ok</td></tr>
<tr><td>Teletype Printout</td><td></td><td colspan="4">ok</td><td colspan="4">Δ</td><td colspan="4">Δ</td><td colspan="4">ok</td><td colspan="4">ok</td></tr>
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<tr><td>Clear Skies</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>√</td><td>√</td><td>√</td><td></td><td>√</td><td>√</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>REMARKS</td><td></td><td colspan="4">*00Z ice collecting on domes
*2030Z ice collecting on domes</td><td colspan="4">*0130Z-cleaned ice off domes
*0500Z ice on domes
*0815Z cleaned ice off domes
Δ investigating GG/Q ratio & QG vs. QG std. discrepancy</td><td colspan="4">Δ reset F=4 to correct values</td><td colspan="4">*0800Z ice collecting on domes
*2030Z ice cleaned off domes</td><td colspan="4">cloudy - snow all day</td></tr>
</table>

Table 17. Incidence in 1976 of Obstructions on Pyranometer Domes and Clear Sky Periods, From Data on Solar Radiation Daily Documentation Sheets

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Annual Avg.
Barrow														
No. of days checked	4	12	21	26	26	29	15	8	16	21	4	-	182	
Avg. % of days obstructed	0	0	0	27	4	3	0	0	25	5	50			9%
Avg. % of days w/clear periods	25	42	33	50	15	28	80	75	31	9	50			36%
Mauna Loa														
No. of days checked	29	11	13	15	15	13	6	10	13	13	19	14	171	
Avg. % of days obstructed	0	0	8	0	7	0	0	0	0	0	0	0		1%
Avg. % of days w/clear periods	76	45	15	47	87	54	83	70	54	38	53	57		57%
Samoa														
No. of days checked	24	14	26	20	22	22	17	20	24	26	23	24	262	
Avg. % of days obstructed	0	14	4	10	0	9	6	0	4	0	0	0		3%
Avg. % of days w/clear periods	29	21	23	25	32	41	35	50	63	35	26	25		34%
South Pole														
No. of days checked	15	6	18	--	--	--	--	--	4	31	30	31	135	
Avg. % of days obstructed	87	17	94	--	--	--	--	--	100	84	50	87		76%
Avg. % of days w/clear periods	67	0	6						50	16	47	48		33%

4.5.4 Quality Control Through Instrument Intercomparisons - 1976

Like instruments were intercompared to detect any abrupt changes or long-term drift in instrument sensitivities. Several instruments were designated control instruments (standards) and were used as the base for comparison. Intercomparisons were made at the Boulder office as well as at observatories in the field. In all comparisons the instruments were exposed to the sun under clear sky conditions and ambient temperature. Some data from cloudy sky conditions were incorporated into the comparisons at field sites only when not enough clear sky data could be obtained. All comparison results are determined from daily totals of irradiance. Comparisons for shorter time intervals are monitored and documented but are not listed in the tables of this report. Differences in response between instruments show a dependence on solar elevation. Any analysis of comparison data for time intervals shorter than one day should take this into consideration.

With the exception of the spectrolab global pyranometer standard maintained by the NOAA/ARL calibration facility in Boulder, all GMCC solar radiation intercomparison measurements in 1976 were made with Eppley pyranometers and pyrheliometers. The calibration scale used for the pyranometer is based on the International Pyrheliometric Scale. A multiplying factor of 1.026 is required to convert the data to the absolute radiation scale as determined by the World Meteorological Organization (WMO), and measurements based on a Kendall PACRAD radiometer, serial no. III. The pyrheliometer calibration scale is based on the transfers from an Angstrom No. 2274 pyrheliometer, a Kendal TMI absolute pyrheliometer (No. 67504) standard of NOAA, and a silver disk (No. 5178) pyrheliometer at the Davos, Switzerland, comparisons of 1975. The GMCC also maintains two standard pyrheliometers (an Angstrom No. 10180 and a Kendall No. P12843) that were intercompared at Davos. For the intercomparisons with the GMCC working pyrheliometer in 1976, the NOAA/ARL working NIP standard No. 1330 was used. It produces irradiance values that are 0.975 ±0.002 of the Kendall TMI No. 67502 irradiance values. To convert the data to the absolute radiation scale, a multiplying factor of 1.026 is required.

Data for the calibrations at the field observatories were processed with the NOVA minicomputer and the BOSS 176 ICDAS software. The signal from each instrument was amplified before being processed by the computer, and hourly integrals of solar irradiance were determined and used to obtain daily totals of solar irradiance.

Data for the calibrations at the Boulder GMCC office were processed by a Hewlett-Packard 2010 L data acquisition system and stored on Kennedy Model-1600H 7-track tape recorder. The magnetic tapes were processed through a CDC 6600 computer at NBS, Boulder, Colorado. Two-minute averages of solar irradiance were used to obtain the daily totals used for the comparisons.

Table 18 shows the results of the pyranometer comparisons at the GMCC observatories in 1976. The traveling standard No. 12617 was used as the base instrument. The entry in the fifth column is the multiplying factor that can be applied to the data to normalize all the measurements to instrument No. 12617. The 2.3% difference observed at the South Pole is questionable because noise was detected on the NOVA channel recording data from instrument No. 12617.

Table 19 lists the results of pyrheliometer comparisons at MLO. No standard instrument was used, but pyrheliometers at the observatory were intercompared. Instrument No. 3287 is retired and instrument No. 2119 is still on line at MLO. Quartz channel 12 of the 13-channel radiometer in operation at MLO was also compared.

Results of the quartz pyranometer intercomparisons at Boulder for 1976 are presented in Table 20. Both GMCC and GATE instruments were compared. Listed are the calibration constants used with each intrument for the intercomparisons.

Table 21 compares pyrheliometers at Boulder including the Eppley filter wheel NIP instruments that were incorporated into the GMCC program this year. The base instrument is the NOAA standard used by the ARL calibration facility in Boulder.

Table 22 lists the results of the Eppley pyrheliometer intercomparisons at Boulder for the quartz channel as well as for the filters. Instrument No. 13909 was used as the base instrument. In the intercomparisons of each filter, the original quartz difference between the base instrument and each other instrument was subtracted from the differences observed with the filters.

Table 23 summarizes the results of the intercomparisons between the standard (base) instruments made at Boulder for 1976. The difference between the Spectrolab and Eppley pyranometers may be mostly due to differences in instrument response at different solar angles rather than to a drift in instrument sensitivities with age. More checking will be done.

Table 18. Field Intercomparisons of Eppley Model II Pyranometers With Quartz Window in 1976

Observatory	Serial No.	Calibration Constant (mV Ly^{-1*} min^{-1})	Calibration Constant (mV $mW^{-1}cm^{-2}$)	Ratio of Daily Totals: Instrument/Compared 12617/Instrument	Deviation From Standard (%)	Dates
GMCC Standard	12617	5.65	.0810	1.000		
Mauna Loa	12616	5.54	.0794	0.9938	0.6	Apr 3-16; Apr 28-30, May 26-Jun 8
Samoa	12273	6.47	.0927	0.9887	1.1	Apr 20-24
Barrow	12263	6.67	.0956	0.9936	0.6	May 5-18
South Pole	12271	7.48	.1072	0.9769**	2.3	Nov 23-Dec 30

* Ly = Langley = calorie cm^{-2}
** GATE Instrument

Table 19. Intercomparisons of Eppley Pyrheliometers With Quartz Window and 13-Channel Radiometer at Mauna Loa, June 8-24, 1976

Serial No.	Calibration Constant (mV $Ly^{-1}min^{-1}$)	Calibration Constant (mV $mW^{-1}cm^{-2}$)	Ratio of Daily Totals: Instrument/Compared 2119/Instrument	Deviation From Standard (%)
2119	2.06	.0295	1.000	
3287	2.09	.0300	1.029	2.9
13-Channel Radiometer 4758-12	4.48	.0642	1.033	3.3

Table 20. Boulder Laboratory Intercomparisons of Eppley Pyranometers (Model II With Quartz Window) on Cloud-Free Days, March 6-10, 1976

Instrument No.		Calibration Constant		Ratio of Daily Totals: Instrument/Compared 10155/Instrument	Deviation From Standard (%)
		(mV Ly^{-1}min^{-1})	(mV mW^{-1}cm^{-2})		
10155	GMCC Standard	5.06	.0725	1.000	
9876*	GATE Standard	4.31	.0618	0.9386	1.6
12617	GMCC Standard	5.65	.0810	1.0116	1.2
12276		7.12	.1021	0.9703	3.0
4361		5.14	.0737	0.9835	1.7
10154		4.03	.0578	0.9701	3.0
4364*		4.75	.0681	0.9888	1.1
4363*		4.97	.0712	0.9867	1.3
12502*		6.64	.0952	0.9895	1.0
12159*		6.91	.0990	0.9792	2.1
12560*		6.77	.0970	0.9756	2.4
12562*		7.00	.1003	0.9811	1.9
11538*		7.26	.1041	0.9956	0.4

* GATE Instrument

Table 21. Boulder Laboratory Intercomparisons of Eppley Pyrheliometers (NIP) With Quartz Window on September 1, 16, and 26, 1976

Instrument No.	Calibration Constant ($mV\ Ly^{-1} min^{-1}$)	Calibration Constant ($mV\ mW^{-1} cm^{-2}$)	Ratio of Daily Totals: Instrument/Compared 1330/Instrument	Deviation From Standard (%)
ARL-NWS Standard 1330	1.915	.0274	1.000	
ARL-NWS Standard 50098	2.42	.0347	1.018	1.8
GMCC Filter Wheel NIP Standard 13909	5.40	.0774	0.9964	0.4
GMCC Eppley Filter Wheel NIP 13910	5.76	.0825	0.9996	0.0
GMCC Eppley Filter Wheel NIP 13911	5.97	.0856	1.0056	0.6
GMCC Eppley Filter Wheel NIP 13912	5.69	.0815	1.0007	0.1
GMCC Eppley Filter Wheel NIP 13913	5.76	.0826	1.0037	0.4
GMCC Eppley Filter Wheel NIP 13914	5.78	.0829	1.0037	0.4
MLO Eppley NIP (retired) 3287	2.09	.0299	1.0114	1.1
MLO Eppley NIP (Temp. Comp.) 11372	5.22	.0748	0.9986	0.1
GATE Eppley NIP (Standard) 11755	5.50	.0788	0.9924	0.8
GATE Eppley NIP 11946	5.62	.0810	0.9998	0.0
GATE Eppley NIP 11947	5.55	.0796	1.0039	0.4
GATE Eppley NIP 11948	4.80	.0688	1.0029	0.3

Table 22. Boulder Laboratory Intercomparisons of Eppley Pyrheliometers with Filter Wheels Against the Standard on October 7-8, 1976

Instrument No. & Location	Calibration Constant		Ratio of Daily Totals: Instrument/Compared 13909/Instrument and (Deviation From Standard)			
	($mV\ Ly^{-1} min^{-1}$)	($mV\ mW^{-1} cm^{-2}$)	with Quartz	with OGI Filter	with RG2 Filter	with RG8 Filter
13909 Boulder (Standard)	5.40	.0774	1.000			
13910 Mauna Loa	5.76	.0825	.9917(0.8%)	.9923(0.8%)	.9913(0.9%)	1.0174(1.7%)
13911 Boulder	5.97	.0856	.9855(1.5%)	.9904(1.0%)	.9949(0.5%)	1.0240(2.4%)
13912 South Pole	5.69	.0815	.9985(0.2%)	.9983(0.2%)	1.0022(0.2%)	1.0039(0.4%)
13913 Barrow	5.76	.0826	.9914(0.8%)	.9933(0.7%)	.9885(1.1%)	1.029 (2.9%)
13914 Samoa	5.78	.0829	.9920(0.8%)	.9957(0.4%)	.9871(1.3%)	.9980(0.2%)

Table 23. Boulder Laboratory Intercomparisons of Standard Pyranometers and Pyrheliometers in 1976

Pyranometer Comparisons, Dec 6-28

Instrument No.	Calibration Constant		Ratio (1000-1400 MST): Instrument/Compared 73-1/Instrument	Deviation From Standard (%)
	($mV\ Ly^{-1} min^{-1}$)	($mV\ mW^{-1} cm^{-2}$)		
ARL-NWS Spectrolab 73-1	5.72	.0820		
GMCC-Eppley Model II 10155	5.06	.0725	.9852	1.5
GATE-Eppley Model II 9876	4.31	.0618	.9779	2.2

Pyrheliometer Comparisons, Sep 1, 16, 26

Instrument No.	Calibration Constant		Ratio of Daily Totals: Instrument/Compared 1330/Instrument	Deviation From Standard (%)
	($mV\ Ly^{-1} cm^{-2}$)	($mV\ mW^{-1} cm^{-2}$)		
ARL-NWS 1330	1.915	.0274	1.000	
GMCC Eppley Filter Wheel NIP 13909	5.40	.0774	0.9964	0.4
GATE Eppley NIP 11755	5.50	.0788	0.9924	0.8

Changes in the ratios with solar elevation between the pyranometers being intercompared are shown in Figures 43-45. The global pyranometers are more susceptible (between like instruments) to variances with solar elevation. These variances are the result of different cosine responses in the detectors at different solar elevation angles as well as to different instrument zeros (recorded dark voltages) for like instruments. At low solar angles, irradiance signals are small, and small differences in cosine response and instrument zeros can contribute to large variances in measured irradiance between like instruments. A program to subtract out the instrument zeros from the measured irradiances will be applied to the data and should lessen the variances observed between instruments.

Generally the pyrheliometers showed a better agreement between instruments than the pyranometers did. There will be a requirement to continue intercomparisons yearly in order to continue tracing solar radiation data in the GMCC program and to detect any change in instrument sensitivity over the years.

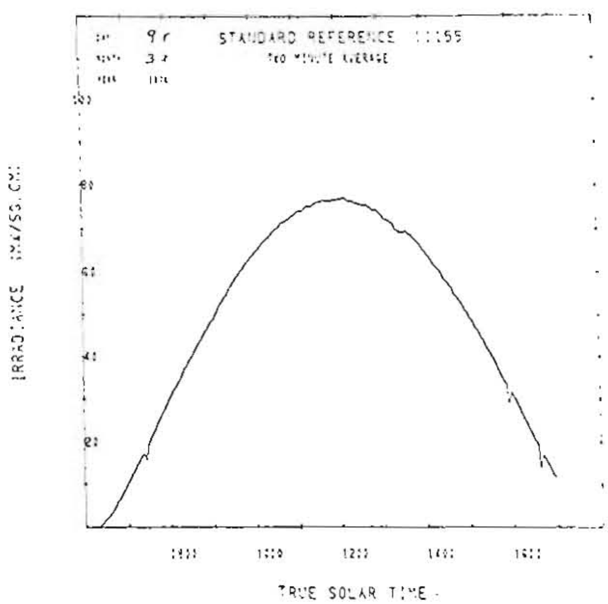

Figure 43. Two-minute averages of solar irradiance measured by the GMCC standard Eppley Model II pyranometer on a typical intercomparison day at Boulder Laboratory.

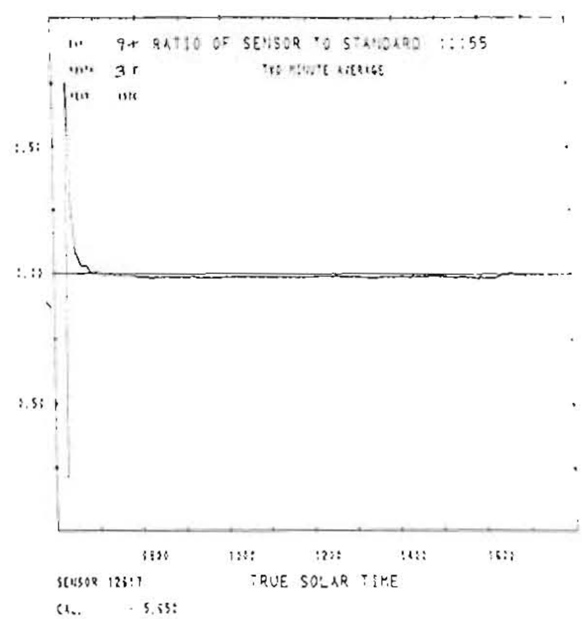

Figure 44. Two-minute averages of the ratios between the traveling standard Eppley Model II No. 12617 pyranometer and the GMCC standard Eppley Model II pyranometer No. 10155 for a typical intercomparison day at GMCC Boulder Laboratory.

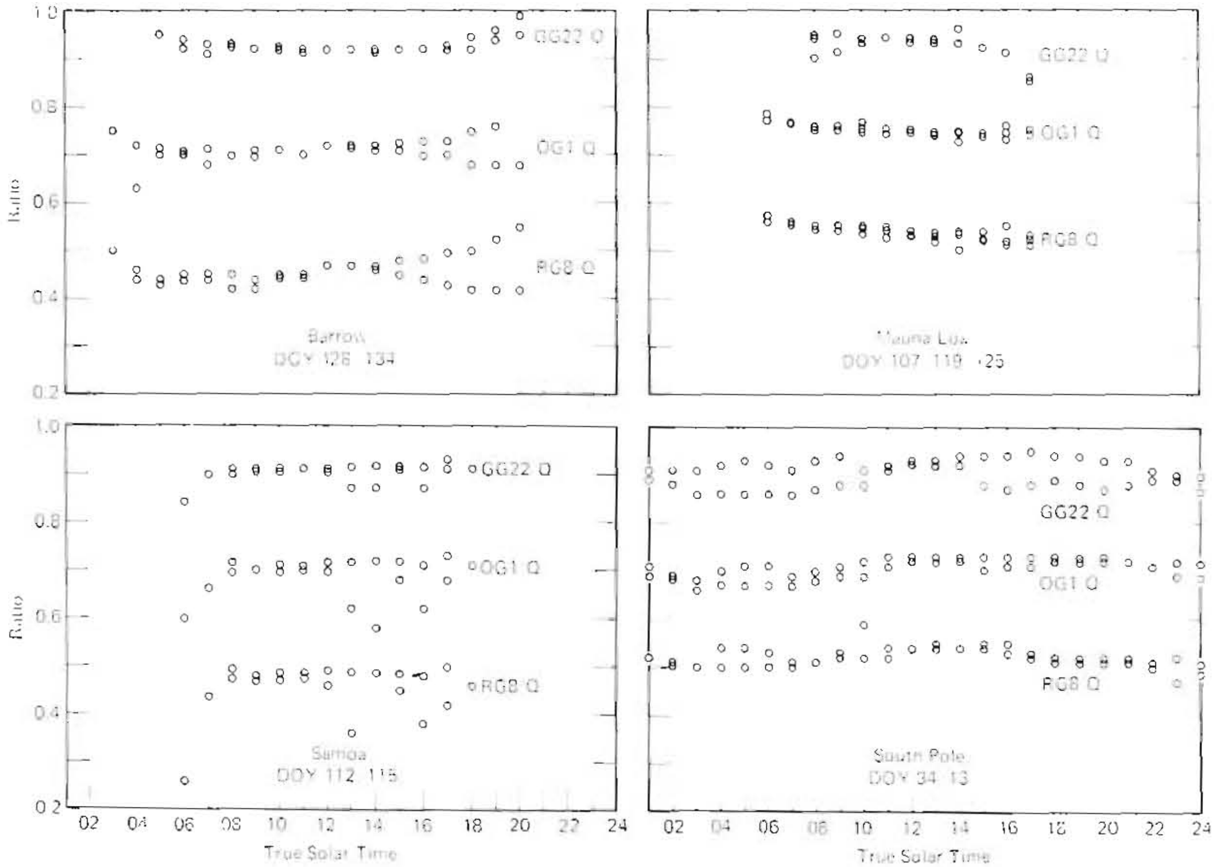

Figure 47. Ratios of solar irradiance measured through broad-band filters to total irradiance (quartz) for selected clear days. The difference between ratios is the contribution of solar irradiance between the spectral bands to the total solar irradiance measured, expressed as a percentage.

and the South Pole. Figure 49 presents the historical plot of MLO normal incidence transmission values for clear sky conditions. The transmission values are determined by the method of Ellis and Pueschel (1971) where

$q = In/In-1$

and q = average transmission factor;

I = solar irradiance at normal incidences;

n = secant of zenith angle where $2 \leq n \leq 5$.

Two sets of data are used in the plot. Data prior to 1968 are from clear days selected by Ellis and Pueschel's criteria. After 1968, data are from all clear days. The sudden decrease in "q", after stratospheric aerosol loading attributed to the Agung volcanic eruption, is

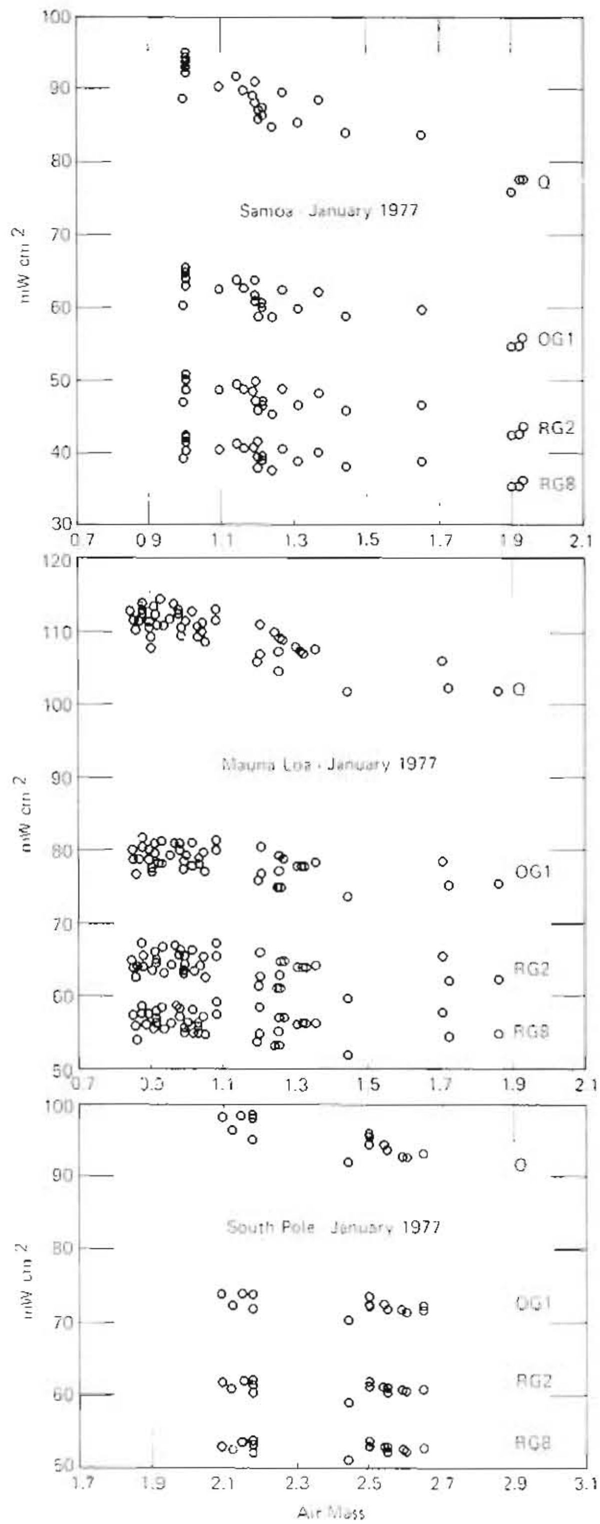

Figure 48. Normal incidence solar irradiances measured through broad-band filters, plotted against air mass. Air masses are corrected for station pressure and are equal to the cosecant of the solar elevation angle (P_{sta}/ 1013 mb).

Mauna Loa

As of the end of this year, Mauna Loa Observatory has its own fully equipped chemistry laboratory. The installation of an ion chromatograph in December will enable the MLO staff to do wide-range chemical analyses on precipitation samples from this observatory and from the Samoa, South Pole, and Barrow stations.

By use of a recently developed technique that greatly simplifies the analysis of water samples, the ion chromatograph is capable of measuring Ca, Na, K, NH_3, Mg, F, NO_3, SO_4, and other possible ions at detection limits one to two orders of magnitude lower than those obtained by wet chemistry techniques. The instrument is based on three principles: ion exchange, effluent suppression, and conductometric detection. Ions can be separated by their affinity for an ion exchange resin. The technique evolved in the early 1940's when ion exchange resins became commercially available, but was not developed because universal detectors based on conductivity were hampered by background interference from the effluent moving phase. Breakthrough occurred with the technique called effluent suppression, which makes possible removal of unwanted ions from the effluent stream by a second ion exchange column. In ion chromatography, the element is removed or modified to permit direct detection of sample ions at extremely low background levels. Conductivity can then be used as a means of detection.

The pH data taken on the island of Hawaii during 1976 are summarized in Figure 51. Most noteworthy is the separation of the data by

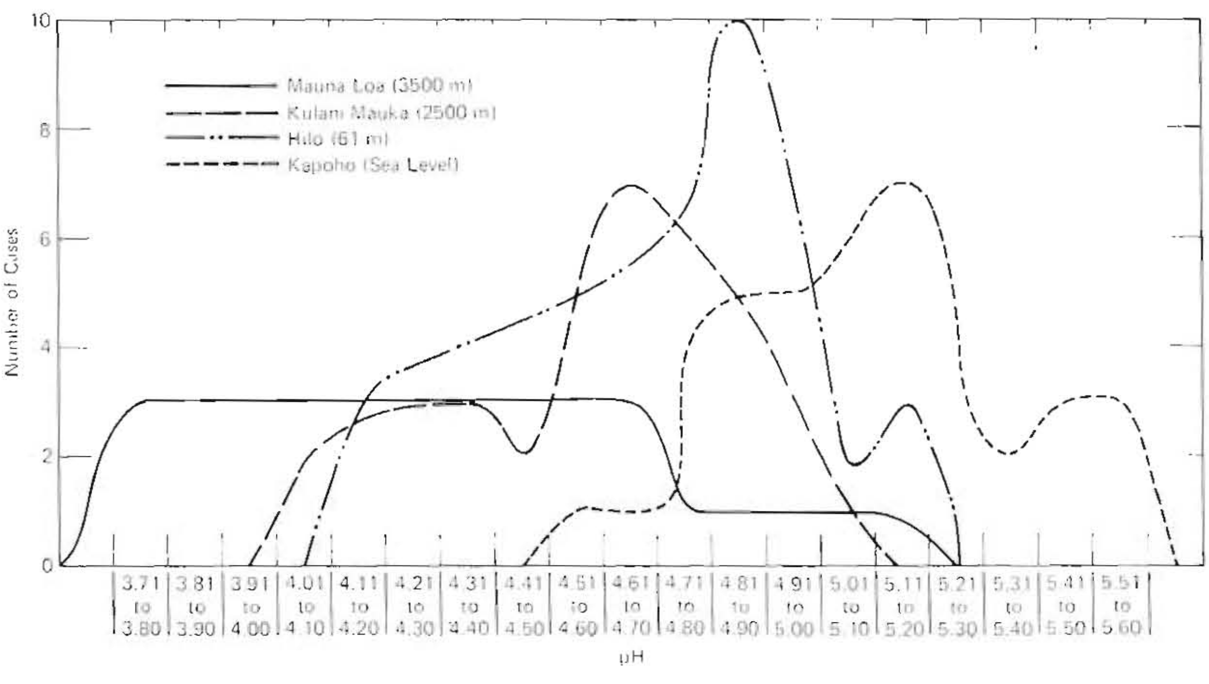

Figure 51. Histogram of pH values in Hawaii.

elevation. The lowest pH values are at MLO, whereas the highest are at the sea level site, Kapoho. One could postulate that the sea salt aerosols have a neutralizing effect on the sea level rainfall and that in higher regions most of these aerosols are washed out.

Also characteristic of these data are the generally low values. For an area far from either manmade or natural pollution sources, the precipitation is more acidic than was expected. With the new laboratory facilities at our disposal in the coming year, we will investigate this problem extensively. MLO staff chemist Alan Yoshinaga visited several laboratories in 1976 to observe laboratory techniques such as analysis, washing procedures, and storage. From his observations, he has established standards of cleanliness and analysis that have reduced contamination to a minimum.

Controversy still exists regarding the length of time between samples. Usually practices (i.e., monthly, weekly, daily, or event-by-event samplings) have varied depending on the resources a laboratory has to analyze a given number of samples. Theoretically, all sampling practices should yield the same results. However, a plot of monthly and weekly samples (see Fig. 52) shows that the values of the weekly samples averaged over a month are lower than the averaged values for the monthly samples. More tests will be made to determine the cause of this variation.

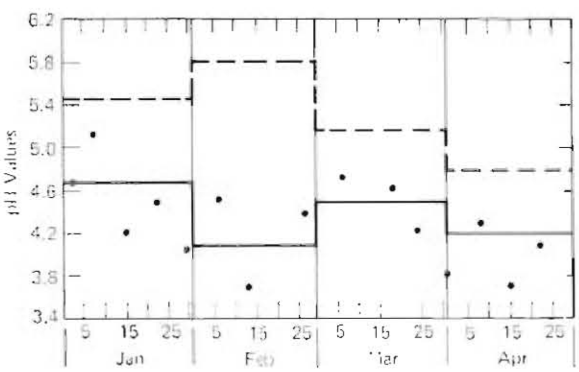

Figure 52. Monthly pH values measured in Misco collector versus weekly pH averaged over the given month. Weekly values are also plotted (1976). Monthly ph (----), weekly average pH (——), individual weekly pH values (·).

Barrow

After a testing period of several winter seasons, the open-close precipitation collector (Misco) program was discontinued in Barrow for two reasons: the collector efficiency was severely affected by the extreme temperature and icing conditions, and the amount of yearly precipitation in northern Alaska (114 mm/yr) is small.

The local program of snow collection for pH measurements was continued during the winter season. From October 1975 to May 1976, snow was collected on a weekly basis at four sites situated north, east, south, and west of the observatory. Samples were taken from newly fallen snow and from the old snow underneath when possible. By standard procedures, the pH values were determined on eight samples. Table 26 shows the values for the 1976 winter season, and the combined values for 1975 and 1976 which indicate that surface snow pH averages about 4.85. Under normal conditions of carbon dioxide equilibrium, values of snow pH should range from 5.2 to 5.7. We must conclude that either local or regional acidic materials are being scavenged by the snow. Plans are being made to evaluate this phenomenon further by using the ion chromatograph.

Table 26. pH Values of Snow at Barrow from October 1975 to May 1976

Average	North	South	East	West
New Snow	4.73	4.94	4.67	4.78
Old Snow	4.86	4.91	4.88	4.90
Total	4.79	4.92	4.76	4.83
1975 + 1976	4.84	4.80	4.87	4.92

Samoa

Because of the extreme difficnlties in shipping chemical supplies to Samoa, only a preliminary program of pH measurements could be established during 1976. Collections were made from April through July, the average pH value being about 5.0 for 27 separate determinations. By the end of the year, the supply problem had been solved (some orders took more than a year), and a comprehensive pH and conductivity program was started.

In March, the EPA collector was removed from the NWS office near the Pago Pago International Airport, refurbished, and placed on the roof of the Samoa Observatory building (Fig. 53). Data from this collector have been published in Atmospheric Turbidity and Precipitation Chemistry Data for the World.

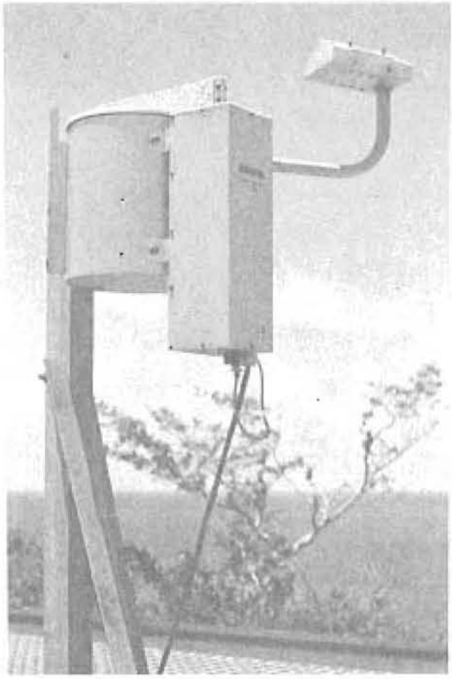

Figure 53. Misco collector mounted on roof of Samoa Observatory.

4.6.2 Regional Precipitation Chemistry

The programs at the ten WMO regional sites have continued under joint NOAA-EPA sponsorship. Monthly samples are sent from the collection sites to the Environmental Monitoring and Support Laboratories of EPA in Research Triangle Park, North Carolina. These data are published annually in Atmospheric Turbidity and Precipitation Chemistry Data for the World. For further details on this network see Miller and Highsmith (1977).

4.6.3 Special Study

The Washington, D. C., volunteer program, begun in 1974 to establish typical pH values in an eastern urban area, has continued. Figure 54 shows that the median value for the D.C. network is 4.0, whereas the median value for the island of Hawaii is 4.8. A report on the data taken through 1975 is presented by Miller et al. (1976).

4.6.4 Program Plans

Plans for the precipitation program within GMCC are as follows: (1) With the Mauna Loa laboratory fully equipped, samples will be sent on a regular basis from the Barrow and Samoa observatories for full chemical analysis using the ion chromatograph. (2) A special study of precipitation chemistry on the island of Hawaii will begin at the end of 1977. Besides analysis of precipitation samples, concurrent cloud water analysis, aerosol chemistry, and other parameters will be measured. (3) A study of snow collection and analysis will be undertaken at the Barrow observatory for the 1977 winter season.

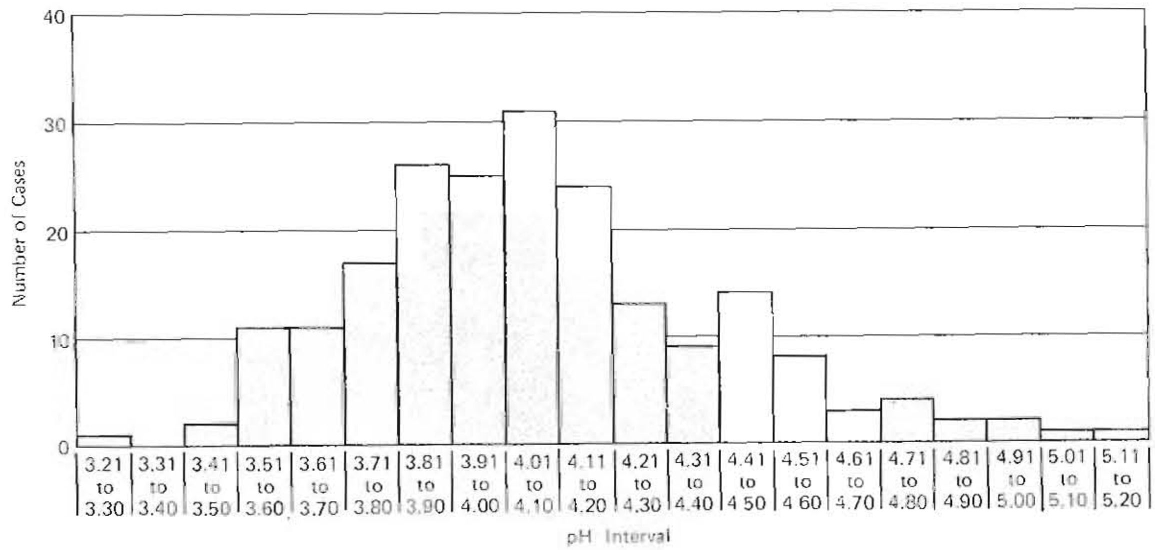

Figure 54. Histogram of pH values in Washington, D.C., 1976.

5. COOPERATIVE PROGRAM

During 1976, GMCC conducted a study of the marine aerosol in cooperation with the Canadian Government. This project was requested by William Elliot of ARL, and all data were forwarded to him.

We installed a Gardner counter on the Canadian Weathership Papa and four routine observations per day were performed by the meteorological crew for the entire year. Most previous oceanic aerosol studies had been made from moving ships. Consensus was that a 1-year study from Papa would give useful data on possible annual trends in aerosol concentration at a stationary ocean site. At the end of 1976, all equipment was returned to GMCC and the study was terminated. Dr. Elliot is currently studying the data in detail; a preliminary examination indicates that they are of high quality.

We had understood that the Canadians were considering establishing Papa as a baseline geophysical monitoring site (and that aerosol particle observations might continue after our study). However, this apparently has not been done.

The Papa data we used in our study were the meteorological and wave height data. However, it is conceivable that the other oceanographic data could be important in continued stndy of aerosols. We have no definite plans for subsequent aerosol studies; however, it would be desirable to repeat such work at least every 5 years and to expand the program to include other aerosol parameters such as size distribution and chemistry. In general, Papa should be considered a valuable measurement platform since it is the only ocean station entirely free of continental or island effects.

6. DATA MANAGEMENT

This section documents changes in the hardware and software configurations used to record and process data from the principal monitoring systems in GMCC. A catalog of the data published during the year is also included.

6.1 Data Acquisition

6.1.1 Hardware Considerations

In January 1976, the ICDAS was installed at the new observatory on Cape Matatula. The startup of this central recording system went very well, and data recording began on the 15th of the month. With the exception of an uninterruptable power supply, this installation is identical to those at the other three observatories. Noise tests run at the time of installation yielded very good results, partly because of the excellent earth ground available.

Voltage offset errors, resulting from excessive noise pickup in the ICDAS, were a continuing problem at MLO and Barrow. To isolate the signal return and thus to break ground loops, isolation amplifiers were prepared for all signal lines entering the ICDAS. Although this procedure decreased the noise level on specific channels, it did little to reduce the pickup of high frequency noise from the minicomputer in the ICDAS. Tests will continue.

During January, two separate events caused extensive data losses at the observatories in the Northern Hemisphere. In August 1975, a severe power transient took out part of the ICDAS at Barrow. At Mauna Loa, a lightning strike in December caused extensive damage to the multiplexer-digitizer and minicomputer in the ICDAS. Both events caused intermittent failures that resulted in loss of data recording capability during the first months of the year. Eventually, the faulty equipment had to be replaced.

6.1.2 Software Modifications

As new stations were activated a new edition of the executive software (BOSS) was issued. The structure of the recorded data did not change, but much of the content of the code did. This complicated software maintenance, and the discrepancy, along with some operational difficulties, made it necessary to produce a new, standardized BOSS for all stations. BOSS 76186 was issued in the fall. It included an updated version of BASIC with stringed "if" statements and ANSI Standard Code II input-output capability, two features useful in BOSS. A new CALL subroutine was added that writes the core-image records onto tape. In this way a copy of the operating system can be made each time the data tapes are changed. BOSS 76186 contains data records of fixed size and a subroutine to control the weekly CO_2 calibration. The time

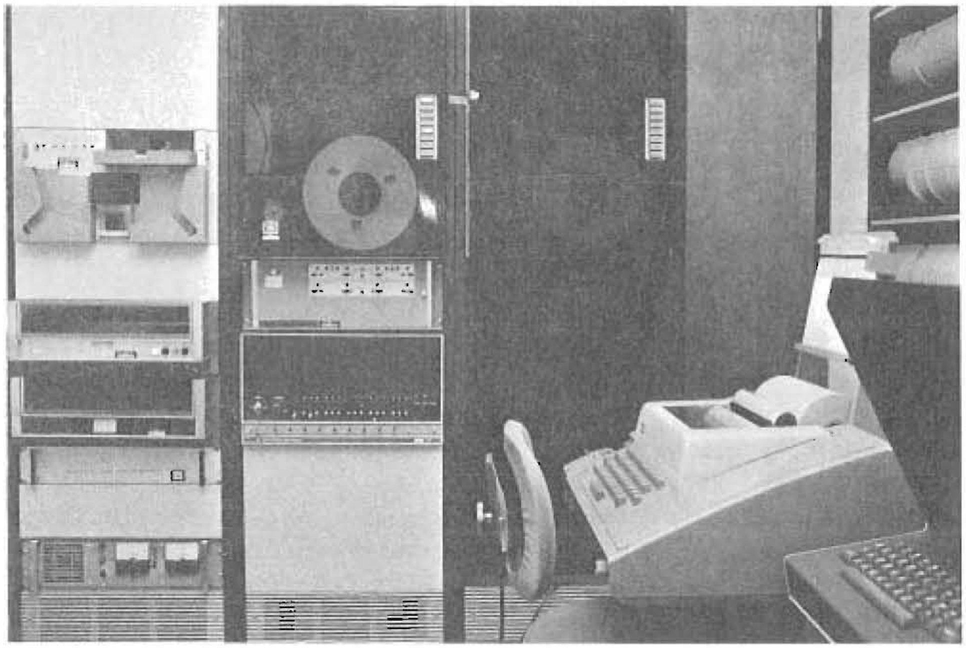

Figure 55. Data reduction facility.

required to print the daily log was reduced by a factor of five and the method used to place comments on the data tapes was streamlined. Although the codes are not identical at each station, the discrepancies are limited to a few modules. The software is not complete by any means, but future changes will not affect the structure of the data arrays or the operation.

6.2 Data Reduction

The tapes from the observatories, containing the data for a 10-day period, are checked for quality immediately upon receipt. The data reduction facility is used for this purpose (see Fig. 55). A report is prepared on each tape delineating periods of missing data and excessive system noise. The calibration factors stored in the data array are also checked. Following this initial checkout, the calibration records for each sensor are tested for accuracy. To increase the flexibility of this facility a high-speed paper tape reader and punch, and a high-speed printer were added to the system. A second tape drive will be added soon.

During the year, a set of programs was written to print and graph data from the stations' data tapes. In particular, a routine was written to compute the hourly integral values of solar radiation and to plot the data from the five pyranometers and the pyrheliometers, in 1-minute increments.

6.3 Processing

Processing is the intermediate step where the data are prepared for special publications and archiving. This data manipulation is performed on the computer in ERL. The data have been assembled on tape in 1-month blocks.

6.4 Archiving

Extensive discussions with individuals responsible for data exchange at the National Center for Atmospheric Research and National Climatic Center, produced guidelines for archiving GMCC data. For example, it was suggested that data from discrete monitoring programs not be mixed with data from continuous programs (Jenne and Josephy, 1974). Also, for ease of access the continuous data should be in an integer format like the surface weather observations of NWS. The structure and format displayed in Table 27 will be used for the continuous data. No preamble or identifier records will be included so that a number of tapes can be combined without any discontinuities. The discontinuous data from monitoring programs will be grouped into files. Each file will contain a preamble record to define the data set written in the plain language format, Fortran "A".

For both sets of data the medium will be the same: computer-compatible magnetic tape recorded on nine tracks, at a density of 1600 bytes per inch (phase-encoded). For maximum exchange, the EBCDIC (Extended Binary-Coded Decimal Interchange Code) internal character code will be used.

The records containing continuous measurements will begin with the character count preceded by 99. The station number, date, and time of the observation follow, completing the identification block. The measurements are grouped into four sections: aerosol population, gas concentrations, weather measurements, and solar radiation. These parameters (T.6.4A) constitute the primary measurements. The secondary or calibration measurements will be appended to the record as they are available.

Table 27. Structure of Data on the Archive Tapes of Continuous Observation

Character Count	Station No.	Date YR MO DY	Hour (Cut)	
9 9 X X X X	0 1 X X X X X	1 0 X X X X X X	1 1 X X X X	
001	002	003	004	Field No.

Data Field Condensation Nuclei	Tally	Data Field Integrated Aerosol Scattering	Tally	Data Field Integrated Aerosol Scattering	Tally	
2 0 X X X X X X	X X	2 4 X X X X X X	X X	2 5 X X X X X X	X X	26
	005		006		007	

Data Field Horizontal Incidence	Tally	Data Field Oxidant	Tally	Data Field Ground Temperature	Tally	R M
6 0 X X X X X X	X X	4 4 X X X X X X	X X	5 7 X X X X X X	X X	
	017		018		019	

Tape Field Number	Tape Position	Element
001	001 - 006	Character Count
002	007 - 013	Station Number
003	014 - 021	Year - Mo - Day
004	022 - 027	Hour - Min
005	028 - 037	Condensation Nuclei
006	038 - 047	Integrated Aerosol Scatt. - 1
007	048 - 057	Integrated Aerosol Scatt. - 2
008	058 - 067	Integrated Aerosol Scatt. - 3
009	068 - 077	Integrated Aerosol Scatt. - 4
010	078 - 087	Carbon Dioxide
011	088 - 097	Ozone (Surface)
012	098 - 107	Wind Direction
013	108 - 117	Wind Speed
014	118 - 127	Station Pressure
015	128 - 137	Air Temperature
016	138 - 147	Dew-Point Temperature
017	148 - 157	Horizontal Incidence Irradiance
018	158 - 167	Oxidant (Surface)
019	168 - 177	Ground Temperature

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APPENDIX A

Workshop Review

In February the GMCC program held at Boulder a workshop concerned with an assessment of current progress in radiation and aerosol measurements and their applications to problems in atmospheric science. A total of 41 specialists from universities, government agencies, and private industry attended the workshop and provided valuable information for the direction of future research. This review of the deliberations of the workshop was made available for distribution.

WORKSHOP REVIEW

Working Group on Geophysical Monitoring for Climatic Change (GMCC)
Radiation and Aerosol Measurements and their Applications.

Boulder, Colorado, February 4-5, 1976

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1. Introduction and background

The Geophysical Monitoring for Climatic Change (GMCC) Program of the National Oceanic and Atmospheric Administration was organized to provide a part of the United States' contribution to the international need for a better understanding of the global environment.

The objectives of the GMCC program are:

- To monitor trace atmospheric gases and aerosol constituents for baseline value determination;
- To determine rates of change of these atmospheric constituents and to examine sources, sinks, and budgets;
- To determine possible effects on climate of these rates of change in collaboration with modelers and diagnosticians.

Accomplishment of these objectives on a global basis requires continuous observations at "clean air" locations in parallel with precision observing techniques and rigid quality control, all for an extended period of at least several decades. The GMCC program has four fully operational baseline observatories: Mauna Loa, Hawaii; Barrow, Alaska; Cape Matatula, American Samoa; and South Pole, Antarctica. Basic research and development activities including development of measurement technology are being conducted at some of these stations and at the Boulder, Colorado, headquarters.

Progress in the atmospheric sciences often invokes changes in observational requirements, techniques, and specifications. Consequently, continual assessment of such changes is vital to the establishment of priorities for GMCC in order to properly supplement the needs of the scientific community. In view of the forward progress that has been made in aerosal research related to climate variations it appeared timely to convene a working group of specialists for a current assessment of experimental data needs, with particular concern for modeling of climate.

2. Synopsis of Workshop Activities

A workshop was conducted on 4-5 February 1976 at Boulder, Colo. on the subject of aerosols in connection with climate variations. The workshop program was liberally structured in order to allow the participants to express opinions on other physical quantities that GMCC was already monitoring or might consider for monitoring in the future. The participants are listed in Appendix I.

The schedule of activities was divided into two parts.

Part I, consisted of brief presentations of GMCC's present scientific activities by its personnel and external collaborators.

Part II consisted of three open discussion sessions on the following principal topics: effects of aerosols on the general circulation and climate, ground truth data for satellite research programs, and solar irradiance research.

Because material presented in the first part is described in GMCC's annual reports, (see references) technical reports, and formal publications, it need not be included in this review. This review will cover only the second part of the working group's activities.

3. Activities in Part II

Section 1: Effect of Aerosols on General Circulation and Climate

A methodology, suggested by Junge (1975) was presented. It consists of a series of research efforts aimed at understanding the influence of aerosols on the general circulation and climate. Three basic steps are involved, as indicated in Fig. 1. The first step is to understand the non-uniform quasi-steady state distribution of aerosols in the troposphere on a global scale, and their changes as a function of production, modification and removal processes. The second step deals with understanding the optical properties of aerosols so that both direct and indirect effects on the short and long-wave radiation budget and the indirect effect of aerosols on clouds can be determined. The final step requires an understanding of the direct and indirect effect of aerosols on three dimensional circulation and climate, including all feedback processes by proper inclusion of aerosols in atmospheric simulation models.

Extensive discussions followed on the feasibility of carrying out this ambitious research effort, and on the philosophy of this proposed methodology. It was pointed out that a limitation of this method is that the proposed radiation calculations in general circulation models would depend on the assumptions inherent in Mie theory (such as spherical particles). To the extent these assumptions are invalid representations of the real atmospheric aerosol, the resulting radiation flux calculations will also be invalid. It was concluded that although good progress has been made in the chemistry of atmospheric aerosols, much more must be known about aerosol processes before the second step in Junge's approach could be reached. It is not likely that a sufficient understanding of aerosol processes required in step two will be achieved in the near future. In addition, step one is a formidable task which no single nation could achieve by itself (without a massive commitment of resources) if the parameterization of aerosols, globally, as a function of sources, modification, and removal is the final goal.

It was concurred, generally, that we should look for alternate approaches that would offer the possibility of immediate application to modelers needs and would not require the massive effort which appears to be required if Junge's approach were adopted.

One alternate approach was discussed whereby aerosol optical properties are obtained directly from radiation observations rather than through a knowledge of their chemical composition (fig.1). In this way, two purposes are served: 1) Initial basic information on aerosol optical properties will become available almost immediately for modeling needs; and 2) the radiation measurements of optical properties can be used as an ultimate validation of the more fundamental calculations of optical properties (through theory) based on chemical measurements of the aerosols. In order to apply the aerosol optical properties to circulation models, some statistics on their variability as a function of geographical area must be available.

a. Aerosol Models

Because of the highly variable chemical composition and physical properties (such as shape and size distribution) of aerosols, there was some doubt expressed as to whether a typical or average aerosol could actually be identified. It was concluded that existing knowledge of aerosol properties is insufficient to answer the question at present.

It was stated that regional aerosol characteristics reflect the local source characteristics (natural and anthropogenic) and subsequent time-dependent transformations that occur. Diffusion by turbulent mixing and advection dictate the bounds (or domain) of the associated aerosol. A model was described in which the gross national products of geographic regions determined the relative abundance of aerosol sources. The mean circulation patterns and aerosol residence times determined the approximate geographic boundaries of aerosols generated in highly industrialized locations such as these found in Europe and the United States.

b. Background aerosols and expeditionary measurements

The existence of a typical background aerosol in the middle and upper troposphere was debated. Such a background aerosol can only be postulated since there is but limited information on the chemistry and size distribution properties of aerosols in the upper altitudes. There was a strong recommendation to expand the frequency, geographical range and scientific scope of expeditionary (short-term) measurements in order to gain basic and preliminary understanding of the chemical and physical properties of aerosols in the high troposphere. This would assist in providing direction for defining necessary long-term monitoring on a global scale for application to climatic modeling. An example of an expeditionary aerosol research program of this type is the Soviet Union's CAENEX (Complex Atmospheric Energetics Experiment, Kondratyev, 1973).

c. Cloud nucleation and modification

A recommendation was made for improving the quality of physical and radiative measurements of clouds, such as cirrus, cumulus and contrails. Possible anomalies in radiative absorption properties due to natural and pollutant aerosols were considered.

Also recommended was increased investigative effort aimed at the effect of aerosols in modifying cloud properties (droplet size and concentration) which in turn, alter the radiative properties of the clouds. Cloud condensation nuclei measurements were said to be vitally important because of their ability to control cloud development. The importance of measurement specificity such as size distribution and chemical composition was stressed.

d. Aerosol optical properties

The aerosol optical properties needed for climate modeling were stated as:

(1) optical depth
(2) albedo of single scattering
(3) phase function
(4) absorption to backscatter ratio
(5) refractive index,

In addition, such properties as

(6) size distribution
(7) differential scattering coefficient

were thought to be useful as an aid for a more complete understanding of the optical effects. Optical properties 1-5 and 7 would also be specified as a function of wavelength.

e. Radioactivity in the atmosphere

It was remarked that in the near future a byproduct Kr^{85} of nuclear power generating plants was expected to exist in concentrations that will significantly increase the conductivity of the atmosphere on a global basis. Monitoring Kr^{85} at background stations may become necessary if the number of nuclear power plants increases according to present expectations.

Section 2: Ground Truth

A very important use of the GMCC baseline monitoring stations is providing ground truth for satellite measurements. One example is total ozone measurements. The total ozone data from baseline and regional stations were used by the NUMBUS-D BUV experiment team to qualify results produced by their total ozone retrieval technique.

a. Long-term observation continuity

Although the GMCC program attempts to maintain time continuity in the measurements at baseline observatories, such continuity is more difficult to achieve in satellite programs because of the limited lifetime of space hardware. It was pointed out that GMCC can provide continuity in many important long-term measurements of atmospheric variables where there will be time gaps in satellite data.

b. Recommendation for improvement of the U.S. total ozone measurement program

It was recommended that the U.S. total ozone network be upgraded to improve the quality and internal consistency of the data. Also, there should be an effort to obtain more uniform spacing of observation sites within the network. In connection with the upgrading process, an exploration of new superior instrumentation and methods of measurement should be undertaken within the next few years.

c. Remote sensing of aerosol optical properties

Methods for determining optical properties of aerosols such as phase function and refractive index were discussed. Measurement of tropospheric aerosols by satellite for global coverage poses a difficult problem because of the unknown reflectance of the underlying surface. On the other hand, some practical methods have been devised for interpreting specialized radiation measurements at the earth's surface. Diffuse skylight, polarization, and transmission of the direct solar beam are some of the specialized measurements. Interpretations are often accomplished though the use of Mie theory for spherical particles and radiative transfer calculations whereby variables such as size distribution and refractive index are deduced by virtue of agreement between theoretical calculations and measurements. For example (and without going into detail), aerosol size distributions (needed for deduction of optical properties) have been estimated from solar aureole measurements, and spectral measurements for the extinction of the direct solar radiation by aerosols. Also, absorption of solar radiation has been estimated from diffuse sky radiation data. The various methods seem to yield reasonable results. Nevertheless, most of them are quite complicated and employ assumptions such as spherical particles, assumed real term for the complex refractive index, and analytical expressions that constrain the form of an aerosol size distribution.

Since many of the methods have evolved from rather recent research and therefore are relatively new, there has not been much opportunity for organized intercomparison for verifying results.* Such intercomparisons would undoubtedly be useful for guiding atmospheric aerosol measurement programs in their selection of methods and instrumentation.

Section 3: Irradiance Determination

Following a short talk on measurement criteria, there evolved discussion on methods of determining atmospheric turbidity using the familiar Langley method, and the less familiar solar aureole method which is sensitive to low levels of turbidity. The Smithsonian Astrophysical Observatory solar irradiance data obtained by Abbot (1908, 1913) served as a special example of the available information on radiative properties of atmospheric substances, such as aerosols and ozone. The Smithsonian data are noteworthy for the great care exercised by the experimenters.

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* Authors' note: In view of this, it may be worthwhile to poll the opinions of investigators who would be interested in an intercomparison experiment. Direct sampling methods could be included in the intercomparison as well. We offer to assist with making such a poll and organizing a forum on the subject if the poll shows a preference to do so.

a. <u>Surface measurements of solar radiance</u>

The feasibility (and practicality) of continuing the Smithsonian solar irradiance measurements was discussed, particularly in regard to measurement of time variations in the solar flux. It was remarked that Abbot's data showed no discernible time variation in the solar constant. However, more recent investigations revealing periodicities in the far uv solar emission and long term anomalies in sunspot activity such as the Maunder Minimum were cited as examples of the variable nature of the sun. The little ice age of the 1700's was thought to be possibly caused by a variation in the solar constant. A consensus of opinions, indicated that significant short-term variations in the solar constant were unlikely to occur on a time scale of the 11 and 22 year cycles. There was uncertainty whether the Zurich sunspot number could be meaningfully correlated with small fluctuations in the solar constant.

It was proposed that GMCC monitor the solar radiance over at least a solar cycle and possibly longer. Some items to consider for such a measurement program were noted as:

1) wavelength range, bandwidth and frequency of observations
2) location and number of sites (other countries involved in an international program)
3) monitoring of local atmospheric conditions during periods of measurements (which would include measurements of O_3, H_2O, turbidity and thin innocuous cirrus)
4) special emphasis in the 3000-4000Å band

b. <u>Accuracy of surface solar irradiance measurements</u>

An opinion stated in regard to the measurement of the solar constant implied that the accuracy of broad-band pyrheliometric observations (for example) could be achieved to within 0.1% if aerosol scattering could be specified to within 10%. An ideal location for a solar observatory such as Mauna Loa (or possibly southwestern U.S.) would also be required.

It was suggested that satellite observation of the solar constant could be checked against the surface observations within the limits given above.

c. Stratospheric aerosols

Volcanically produced stratosopheric aerosols can cause a change in the earth's radiation balance. Severe volcanic activity was considered as a highly probable mechanism for inducing changes in climate.

Monitoring of stratospheric aerosols was recommended. Suggested methods for monitoring were by direct measurements using balloon platforms and indirect measurements using surface-based optical techniques such as twilight and lidar observations.

d. Monitoring the terrestrial infrared

There emerged the question of whether GMCC should measure downward broadband infrared flux. These data could be utilized to verify climate models that incorporate radiation balance calculations. There was some reservation concerning whether infrared measurements alone were practical. Rather, infrared measurements might be interpreted more meaningfully if specific measurement episodes were undertaken, such as an experiment on cirrus cloud effects on outgoing infrared flux.

4. A note of appreciation

The personnel of the GMCC are deeply indebted to the working group participants. The devotion of their time and energy, and the display of willingness to assist with the missions of GMCC are warmly appreciated.

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APPENDIX I

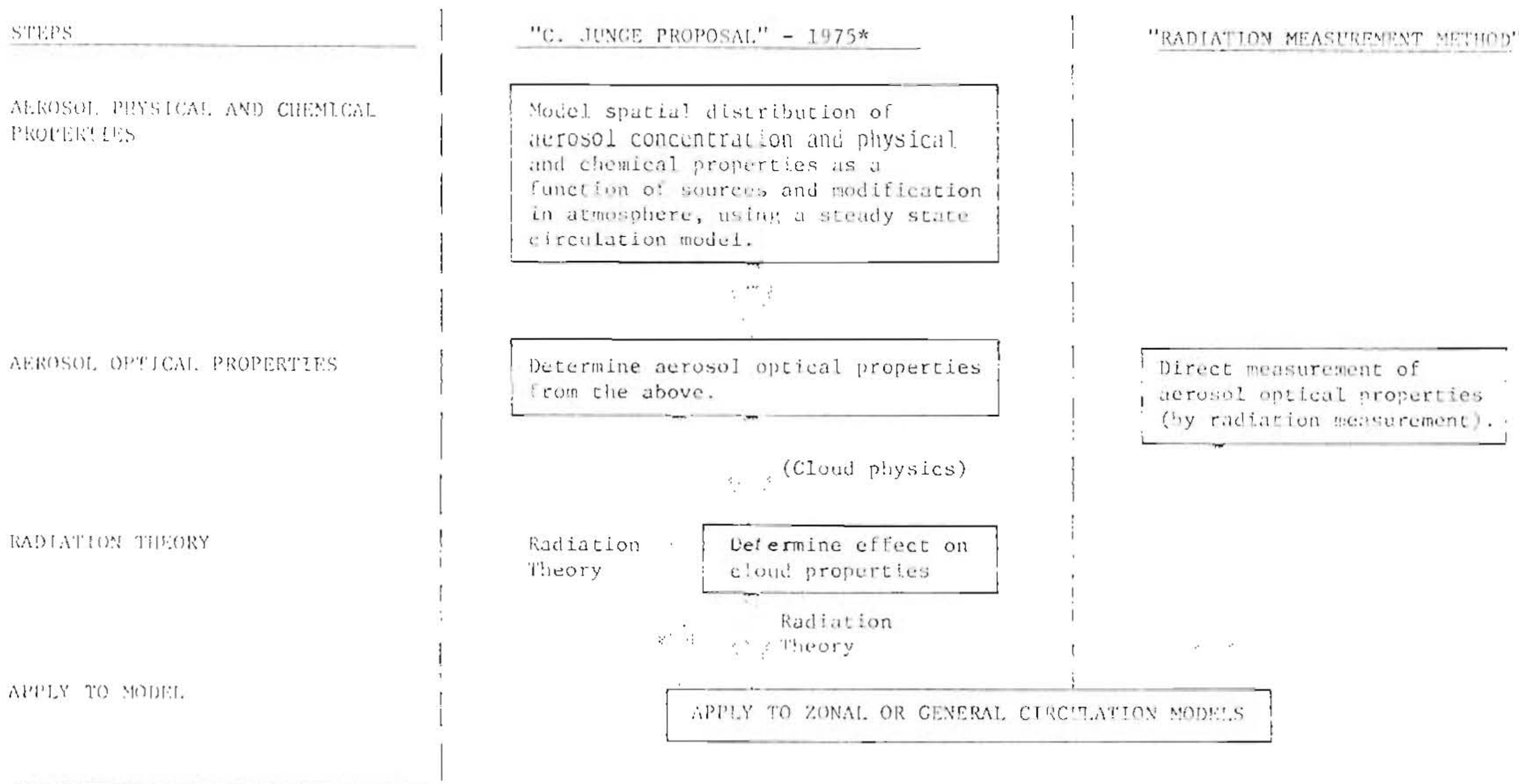
Working Group on GMCC Radiation and Aerosol Measurements and their Applications

February 4-5, 1976

Attendees

R. ANGIONE
E. BARRETT
F. BEALE
B. BODHAINE
R. CHARLSON
P. CHYLEK
J. COAKLEY (Chairman, Section III)
W. COBB
S. COX
R. CRAM
R. CULNAN
J. DE LUISI
J. EDDY
R. FEGLEY
E. FLOWERS
J. GILLE
K. HANSON (Coveneur)
R. HANSEN
D. HEATH
D. HOYT
W. KELLOGG (Chairman, Section II)
W. KOMHYR
J. LONDON
B. MENDONCA
A. MILLER
J. MILLER
G. NORTH
S. OLTMANS
J. PETERSON
R. PUESCHEL
E. ROBINSON
G. ROBINSON (Chairman, Section I)
C. RODGERS
R. ROOSEN
H. SCHIFF
D. SCHUERMAN
G. SHAW
W. SPRIGG
A. WAGGONER
H. WEICKMANN
J. WEINBERG

EFFECT OF AEROSOLS IN MODELS



*Junge, C., 1975, Aerosol Processes in the Physical Basis of Climate and Climate Modeling, pp 244-251

FIGURE 1

APPENDIX B

Spectral Turbidity Studies at Mauna Loa

Suspended particulates, or aerosols, in the atmosphere scatter and absorb sunlight; they play an important role in climate because they cause localized heating or cooling within the atmosphere and at the Earth's surface. Since the industrial revolution, the concentration of smoke and pollution aerosols has risen dramatically and spread over large areas, perhaps even crossing oceans or penetrating to the polar regions.

The University of Alaska Geophysical Institute in Fairbanks has conducted a 1-year study for GMCC to explore the possibility of using multiwavelength narrow-band sun photometry to monitor and quantify suspended aerosols. The advantage of the method is that it would measure aerosol properties through the whole atmosphere, and not just at or near the Earth's surface.

The aerosol load (the total number or mass of aerosol in a vertical column) is very small at locations such as Mauna Loa, and the extinction of sunlight caused by the aerosol is, of course, also small. But it is measurable, provided care is taken. One may be able to appreciate the difficulties involved by realizing that aerosols above Mauna Loa block out only about 1% of the direct solar beam, so the measures of sun intensity must be made to an accuracy of better than 1%, in fact, to about 0.1% accuracy. No commercial instruments were available that had the desired high accuracy and spectral resolution, so it was necessary to construct and characterize a stable multiwavelength photometer. Measurements of atmospheric transmission were made with this photometer every clear day from March to August 1976, and during an exceptionally clear and dry period in January 1977.

The measures of atmospheric extinction were made in the visible and near-ultraviolet spectral region at 12 individual narrow wavelength bands about 100A wide in the spectral region 400 to 1000 nm. Narrow wavelength bands permit use of the classic Langley technique to derive atmospheric extinction. This is an advantage that older broadband turbidity instruments do not have. Use of the Langley method on a day-by-day basis provided an independent instrument calibration for each observation period, and allowed the special photometer to demonstrate its extreme stability; it changed in sensitivity by only one or two-tenths of 1% during almost a full year of field activities.

Results of the experimental study for nearly 100 clear days indicate that there is always some slight amount of haze present, even above Mauna Loa in the central Pacific. An interesting and important finding is that there tended to be almost no connection between surface aerosol concentration at the observatory, and variation in total aerosol optical extinction through the whole atmosphere above the observatory. Nor was there any particular correlation between the observatory's local meteorological parameters and the optical aerosol extinction. This finding suggests that the aerosols above Mauna Loa have formed in situ or were brought in by winds from distant sources--that is, the optical extinction measurements are probably representative of the entire middle Pacific area, and can be described as "background aerosols". Obviously it is important to determine what these background aerosols are, where they came from and how they arrived in the air over such a distant observatory. By looking at air trajectories going back about 1000 km, and classifying the trajectories according to azimuth, it was learned that the optical extinction was somewhat larger during times when the wind had blown from the North American continent. The cleanest sector was air that had come from south of Hawaii. The increase and decrease of turbidity associated with specific air masses seemed to be superimposed on a fairly constant curve of optical extinction. That can he surmised to result from the stratospheric sulfate layer that is almost perpetually present everywhere on Earth.

Figure A.1 shows the average values of aerosol optical thickness (base e) at 11 wavelengths above the observatory during the period March to August 1976. There is reason to believe that the optical thickness at the two longest wavelengths in Figure A.1 are somewhat over-estimated because of a slightly absorbing water vapor continuum that affects the entire red and near-infrared portion of the spectrum. The aerosols prevent about 2% of blue light and less than 1% of red light in the direct solar beam from reaching the summit of the observatory. When the average aerosol extinction spectrum is weighted by the solar intensity

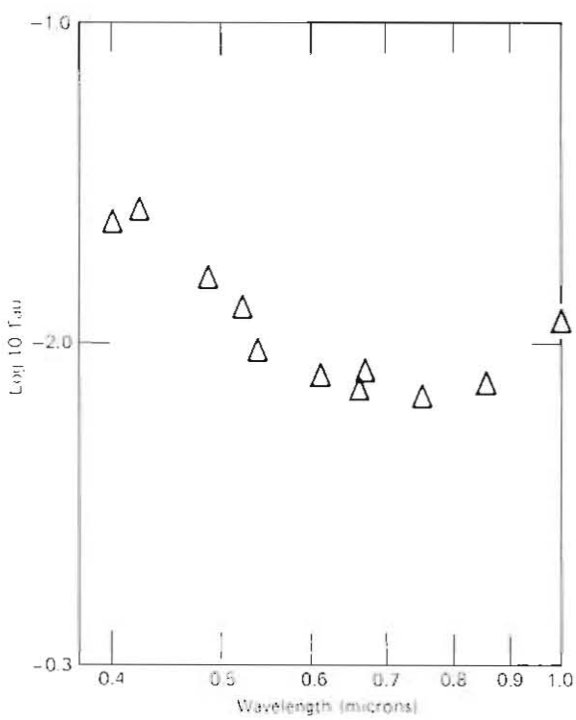


Figure A.1. Mean aerosol optical thickness at Mauna Loa for March-August 1976.

and integrated over wavelength, one finds that aerosols in the central Pacific block 1% of the total radiant energy in direct sunlight when the sun is at the zenith.

In Figure A.2 the frequency distribution of aerosol-plus-ozone optical thicknesses are shown for 12 identical sampled wavelengths. Filter 11, at 950 nm, is in the center of the strongly absorbing ρστ water vapor bands, and filter 6 is in the center of the Chappuis ozone bands.

The studies on sun photometry have led to several areas of investigation additional to aerosol physics. For example, the amount of water vapor dissolved in the air within a vertical column has been inferred from optical absorption in the near-infrared water vapor bands to be typically about 0.1 g cm^{-2}.

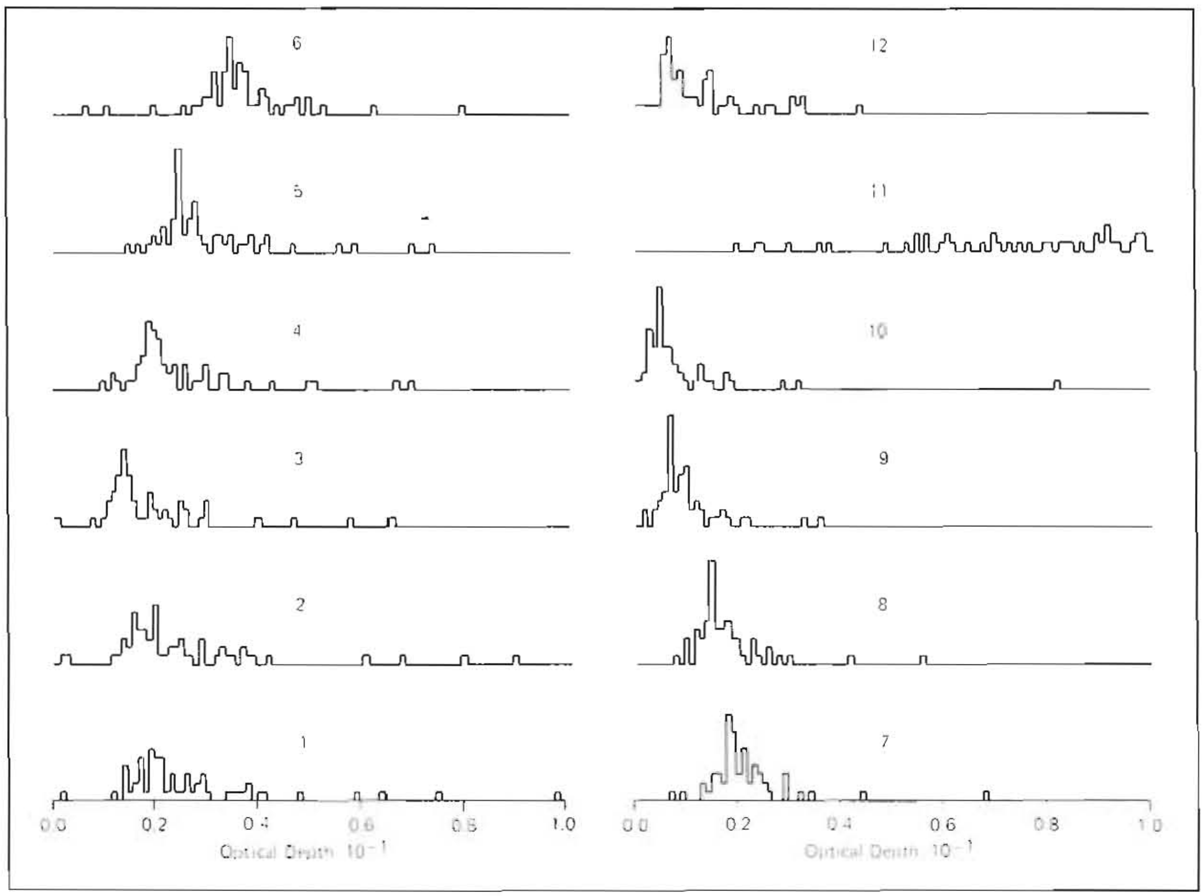


Figure A.2. Frequency distribution for ozone-plus-aerosol optical thickness at MLO for 85 days from March to August 1977. The numbers are sampled wavelengths numbered sequentially from blue to red: No. 1, 401 nm; No. 2, 422 nm; No. 3, 486 nm; No. 4, 521 nm; No. 5, 537 nm; No. 6, 611 nm; No. 7, 659 nm; No. 8, 669 nm; No. 9, 750 nm; No. 10, 860 nm; No. 11, 947 nm; No. 12, 1010 nm.

Atmospheric ozone has also been measured by sun photometry with accuracies comparable with those obtained by measuring absorption of yellow light in the Chappuis bands with a Dobson spectrophotometer. Our preliminary findings show good correlation with Dobson-derived ozone amounts, but there is an unexplained systematic difference between ozone amounts inferred by the two independent techniques. The Chappuis band determination gives larger values for atmospheric ozone than do the Dobson values.

Perhaps the most important result of this research concerns the sun's spectral irradiance. The study has shown that the sun's spectral irradiance (extrapolated through the atmosphere by using the Langley method) was constant to an accuracy better than 0.3% over 9 months; the extremely clear and stable observing conditions at Mauna Loa, as documented by this program, show that it would be a superb location for making solar spectral irradiance measurements.

*U.S. GOVERNMENT PRINTING OFFICE:1994-673-018/00048