NOAA Technical Report OOE7

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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1. INTRODUCTION

This report summarizes the performance of the 64 U.S. drifting buoys deployed in the Southern Oceans during the First GARP (Global Atmospheric Research Program) Global Experiment, designated FGGE. Forty-six buoys were deployed by ship and 18 buoys were deployed by aircraft as part of the drifting buoy array established during the experiment, and results indicate that approximately 50 percent of the buoys should remain operational after one year of operation.

As part of the U.S. drifting buoy development program, extensive testing was performed to verify system performance prior to the start of the experiment. End-to-end systems tests were performed to establish compatibility among system interfaces and to determine if corrections to production buoys were needed prior to buoy deployment. Data quality analyses were performed on systems prior to and during buoy deployment periods.

An extensive test and evaluation program preceded the deployment of operational buoys. Pre-FGGE, end-to-end system testing was conducted to uncover system level problems before the shipment of production buoys from the manufacturer for deployment in the experiment. Predeployment and deployment testing was performed to evaluate the quality of the data from each of the buoys. A description of each test and the evaluation results follow. Finally, buoy performance during the First and Second Special Observing Periods (SOPs) is summarized.

2. PRE-FGGE TEST AND EVALUATION

The primary objective of pre-FGGE test and evaluation programs was to conduct end-to-end system tests prior to the shipment of production buoys from the manufacturer. The tests were performed on development/prototype buoys in an effort to identify problems attributable to buoy components/subsystems that could still be corrected on the production systems. The tests included system checkout of the buoys, satellite, communications links, data processing, and the training of personnel. Buoy sensor and position data were processed by Service ARGOS in Toulouse, France, and the results were compared with data from a ground-truth system developed by the NOAA Data Buoy Office (NDBO).

Three prototype buoys were evaluated during a six-week intensive test period. The following buoy performance characteristics were measured and evaluated:

- o Performance and accuracy of the two primary meteorological sensors (barometric pressure and sea-surface temperature)

- Performance and accuracy of the position location system

- Number of actual and good data transmissions per day

- Total elapsed time for various types of data received from Service ARGOS and processed or analyzed by NDBO.

2.1 Buoy Sensor Performance

Buoy data received through the TIROS-N satellite were compared with ground-truth data. The buoys under test were equipped with Paroscientific barometric pressure sensors with a specified accuracy of ± 1 mb and a range of 900 to 1050 mb. The digital resolution (one count) was 0.15 mb. The ground-truth pressure system included three Rosemount transducers with a specified accuracy of ± 0.6 mb over the range of 900 to 1050 mb. The ground-truth pressure sensors were averaged to provide a more accurate reference. The statistics on buoy pressure sensor performance are summarized in table I. All three buoys showed a positive mean difference when compared with the ground-truth reference standard. The pressures measured during the tests ranged from 1004.2 to 1032.2 mb.

The post-calibration check indicated that the ground-truth sensors averaged 0.8 mb low over the range of pressures measured. The test buoy pressures fell within the specified accuracy with the ground-truth correction taken into account.

The buoy water-temperature sensors were Yellow Springs Instruments thermistors with a specified accuracy of ± 1°C with a range of - 5° to + 35°C. The digital resolution (one count) was 0.16°C. The ground-truth temperature sensor system included several Action Instruments platinum-resistance transducers with a specified accuracy of ± 0.4°C over the range of 0° to 30°C. The ground-truth sensor readings were averaged to provide an accurate temperature reference. The buoy water temperature sensor statistics are summarized in table I. The data fell within the specified accuracy range.

2.2 Buoy Location System Performance

The buoy location system performance was evaluated in a controlled test. Five buoys were moored at fixed locations. Data were collected from the buoys starting two weeks after the launch of TIROS-N on October 13, 1978, and continuing through December 12, 1978. During this period, 224 position fixes were selected from the DISPOSE file obtained from Service ARGOS, the data processing service provided by France for the Experiment (1). The location data can be summarized as follows:

- The mean radial error for all fixes from the actual location was 0.26 km.

- The standard deviation of mean radial error was 0.16 km.

- The largest radial error was 2.15 km.

o More than 96 percent of all position fixes were within 0.72 km.

The results of the controlled tests indicated that the position-fixing system is accuracy, reliable, and virtually error-free. The accuracy and reliability of the ARGOS location system well exceeded all initial estimates. It proved to be reliable, accurate, and suitable for use whenever accuracy to within 1 km was required.

To effectively evaluate the overall system performance early in the Experiment, a large data set was collected and analyzed. Statistics on the number of position fixes were analyzed. Time delays in obtaining, transmitting, and processing buoy data were analyzed statistically to provide estimates of minimum and maximum delays for data to be updated on the computer files of Service ARGOS. Estimates of delays in accessing data from the files were also made using remote terminals.

2.3 Data and Buoy Location Passes

A simplified approximation of the average number of satellite passes per day in view of a buoy is shown in figure 1. The number of passes depends on the latitude of the buoy and the minimum elevation angle at which the satellite can receive the buoy data.

Using operational U.S. FGGE buoy data, the mean number and the standard deviation of both good data passes and buoy locations per day were calculated as a function of latitude over a one month period for buoys located from 20°S to 65°S latitude. These data are shown in figure 1. Curve A shows the increase in the average number of good data passes per day as the latitude increases. Comparison with the curves in figure 2 indicates that data receptions appear to be obtained for buoy elevation angles as low as zero degrees. Curve B in figure 1 shows the average number of good buoy locations per day as a function of buoy latitude. This curve follows curve A very closely. The buoys transmitted every 51.36 seconds and at least three good transmissions are required to calculate buoy location.

Figure 3 presents the same buoy location data in a different form. Curve C shows the percentage of data passes that resulted in a good buoy location. This percentage (70 percent) is independent of buoy latitude. Curve D shows the percentage of satellite orbits per day that resulted in a good buoy location. This curve is similar to curve B of figure 2.

2.4 Data Transmission Per Pass

Service ARGOS data from the DISPOSE file were analyzed to determine transmission statistics on all passes for which buoy data were obtained. The average number of transmissions per orbit for passes over five different buoys at various latitudes were calculated, and the results are summarized in table II. The overall average was calculated to be 13.43 transmissions per orbit. The maximum number of transmissions received on any sample orbit was 19.

2.5 Time Delays in Data Transmission and Processing

The U.S. buoy data transmissions stored in the Service ARGOS AJOUR file were analyzed to determine typical maximum and minimum delays in obtaining the most recent buoy data. The AJOUR file indicated the time of the last update, and that time was compared with the actual time that each buoy transmitted data. Also, the dead time in orbit from a particular location was calculated to estimate the average time required to transfer data from the satellite to Service ARGOS and to update the AJOUR file. Early results of this analysis for a one-satellite system were as follows:

- Maximum time delay - 10.35 hours
- Average of the maximum time delays - 8.46 hours
- Minimum time delay - 1.27 hours
- Average time for data to be transferred from the satellite to Service ARGOS and to update AJOUR file (no dead time in orbit) - 80 minutes.

2.6 Data Errors

The system was designed to utilize redundant data transmitted from the buoys. Data from slowly varying sensors are transmitted every 40 to 60 seconds during the satellite overflight, resulting in sensor values that typically vary no more than a few counts. An average of 13.4 transmissions for a 51-second repetition rate is received by the satellite. After the buoy data are processed by Service ARGOS and stored in the DISPOSE file, identical messages are compacted and only the most significant is stored in the AJOUR file. The selection criteria for U.S. buoy data are based on the maximum number of identical consecutive transmissions received; if several different messages each have the same number of identical transmissions, the last group is selected. The AJOUR file was accessed four times per day to provide a data base for periodic reports and analysis.

The information in the DRIBU and DISPOSE files recorded between December 1978 and March 1979 was analyzed to determine the types and the sources of errors encountered in the data. Each error was examined in detail and classified by type. The majority of errors fit into a few main categories, which are described in subsequent paragraphs.

The search for data errors began in the DRIBU files. This is the data the typical user would receive. The buoy data were scanned for obvious errors, such as sensor values out of limits or improbable daily changes in pressure or temperature. When an error was found, the appropriate records in the DISPOSE files were consulted. By comparing the two files, it was usually possible to determine the source of the error. Generally errors resulted from faulty transmission of data from the buoy to the satellite or from improper selection of records from the DISPOSE file.

The most frequent type of error occurred when the wrong record was selected from the DISPOSE file data. In accordance with Service ARGOS protocol, the record selected for the DRIBU files is the one having the most identical transmissions in a row. At times, the last record of a set was selected instead. (Occasionally, the last record contained errors resulting from the low elevation angle of the satellite.)

Another type of error occurred when either a single transmission or only a few transmissions, none of which were identical, were received from the buoy. Eight cases of this error were found. Another type of error occurred in the transmission of the DRIBU bulletins. In four instances, characters were dropped, perhaps due to a parity error. A similar transmission error also occurred between Service ARGOS and NDBO. In several instances, a spurious buoy transmission caused by a digit change in the buoy ID was received.

Thirty-one errors were found in over 5,000 DRIBU messages. Although this was significant in that the data were manually edited, the error rate was very small. An estimate of the order of magnitude of the bit error rate for the data prior to manual editing at NDBO was about 10^{-5}.

3. PREDEPLOYMENT AND DEPLOYMENT DATA QUALITY ANALYSIS

The objective of this effort was to evaluate the performance of each of the U.S. FGGE drifting buoys deployed in the Southern Pacific Ocean during the November 1978 to February 1979 time period, extending from buoy activation to just after launch. Forty-six buoys were deployed by five ships. Buoy data obtained from Service ARGOS were evaluated daily and compared with ground-truth data reported by each ship.(2)

The evaluation period started at the time each ship left port and continued until after the buoy had been launched and ground-truth data had been compared with buoy data received via the satellite. Shipboard ground-truth data received via radio communication links were compared and evaluated daily with buoy data obtained from Service ARGOS. If buoy sensor data were questionable or out of tolerance, NDBO management and the U.S. FGGE Project Office were notified immediately so that a decision could be made whether to deploy the buoy, substitute another buoy, or forego deploying a buoy at that location. Also, in certain instances, instructions concerning buoy operation or maintenance were sent to the ships.

Each ship was requested to activate its buoys and to provide an update of the launch schedule by buoy ID and location well in advance of the time that daily buoy checkout reports were required. There was some reluctance on the part of the ships to activate the buoys, because the buoy transmission frequency of 401.65 MHz is slightly above the frequency of some of the shipboard navigation equipment. However, tests conducted by NDBO did not show an interference problem. Typically, several messages were sent to and received from each ship before the message procedure became routine. Messages were transmitted and received over the AUTODIM circuits using the Naval Oceanographic Office (NAVOCEANO) Communications Center located at the National Space Technology Laboratories (NSTL) near Bay St. Louis, Mississippi.

Buoy data were obtained by accessing the computer at Service ARGOS. Calibration tables and other data had been previously sent to Service ARGOS. The system periodically received satellite data and updated the AJOUR file with the latest buoy data. The Telex system was used as the primary means of accessing the AJOUR file. In most instances, this file was accessed at least once daily.

The overall data flows are shown in figure 4. Note that there are two completely separate flows for the data. The ground-truth data from each of the ships go through radio and hardwire links to the U.S. FGGE Project Office with an information copy going to NDBO. The buoy data are stored in a tape recorder on the satellite, dumped to one of the satellite ground Control and Data Acquisition (CDA) stations, and transmitted first to the Data Processing and Services System (DPSS) at the National Environmental Satellite Service (NOAA/NESS) and then to Service ARGOS, where the data are processed. The latest data are stored in the AJOUR file, which is accessed by means of a dial-up terminal. In order to time-correlate the ground-truth and buoy data, ground-truth data were taken by the ships at the same time that buoy data were being received by the satellite. In addition, the AJOUR file was accessed and the buoy data obtained before the buoy data from the next satellite pass were used to update the file.

The mean and the standard deviation of the buoy-measured barometric pressures and sea surface temperatures were calculated daily for all buoys on board each ship. These statistics were compared with the ground-truth data. Typically, there was better correlation among the buoy sensors than between the buoy sensor mean and the ground truth. As greater numbers of buoys were launched, more emphasis had to be placed on the ground truth and analyzing the data. Daily verbal and weekly written reports were provided to NDBO and the U.S. FGGE Project Office.

Ground-truth pressure and temperature data were taken by ship personnel to coincide with the closest morning and afternoon local satellite passes. Equatorial crossing time and longitude were provided by NOAA/NESS for each satellite orbit. Planned and updated buoy launch location and time data were requested and obtained from each ship. Using the NOAA satellite and buoy launch data, equatorial crossing time and longitude for the morning (descending) and afternoon (ascending) orbits that passed closest to the ship were determined and the data sent to each ship. Each ship determined the time correction for its location. Ground-truth data were taken at this time and at 30 minutes prior to and after this time. Ground-truth data were also taken 3 hours prior to launch, at launch, and at 1-hour intervals for 9 hours after launch.

The procedures and steps required for the data analysis evolved during the program. The steps that were followed varied some from ship to ship, but in general followed the flow shown in figure 5. Procedures were followed for monitoring buoys on a daily basis and during the launch sequence. Each ship was requested to provide the buoy deployment schedules, which also indicated which buoy (by Service ARGOS ID) was to be deployed at each position. Each ship was also requested to activate all of its buoys shortly after the ship left port. The AJOUR file at Service ARGOS was accessed daily and all buoy data that had been updated (since the last update) were obtained. A detailed data report from each ship was prepared which evaluated sensor performance by calculating the mean and the standard deviation of all sensors that were within tolerance. Since the sensor data from each buoy on a ship were usually collected within minutes of each other, it was relatively easy to evaluate the data. These detailed data reports from each ship were compared with FGGE buoy checkout status reports which were received daily from each ship. If a problem was found, it was brought to the attention of NDBO and the U.S. FGGE Project Office and appropriate action taken. Similarly, FGGE buoy deployment status reports (prepared by each ship following the launch of each buoy) were compared with the appropriate data from the AJOUR file and the results analyzed. This analysis and the day-to-day tracking of the sensors were used to determine whether the buoy was operational at launch and whether to put the sensor messages in DRIBU code format on the Global Telecommunications System (GTS) for distribution.

The predeployment performance of FGGE buoy barometric pressure and sea surface temperature sensors were expected to meet or exceed the following standards during the predeployment analysis:

Physical parameter	Range	Resolution	Mean	Standard deviation
Barometric pressure	900 to 1050 mb	0.15 mb	$\pm$1 mb	0.6 mb
Water temperature	-5°C to +35°C	0.16°C	$\pm$1°C	0.5°C

Redundancy of the received data permitted the detection of most random and burst errors in the overall end-to-end system that included the satellite processing, communications links, and the ground-truth processing. Differences between the standard and the measured pressures were less than 1 mb and averaged 0.6 mb over the range of pressures tested. The sea-surface temperature data were checked while the buoys were on deck prior to deployment. Due to varying amounts of solar and other radiation and different physical locations on deck, the sea surface temperature sensor values varied as much as 2°C. Differences between sensor values and ground truth were as much as 3°C.

After the buoys on a ship had been activated for several days, the differences in pressure between the individual buoys and the average of three or more buoys sampled at the same time were determined. If this difference was greater than 1 mb for a particular buoy, the sensor data were considered out of limits. A similar procedure was followed for the temperature, except that a wider tolerance was used and the temperatures were monitored over a longer period of time.

The calculated averages of the deviation of the acceptable sensors from the mean of the sensor values for each satellite pass are listed below for each ship:

Ship	Average pressure standard deviation (mb)	Average temperature standard deviation (°C)
ORCADAS	0.5	1.3
POLAR STAR	0.3	0.7
ACUSHNET	0.5	1.1
MAUMEE	0.4	1.5
BLAND	0.4	0.4

There was good pressure correlation, but the temperature correlation was poor for the reasons described previously.

4. PERFORMANCE EVALUATION FOR FGGE FIRST AND SECOND SPECIAL OBSERVING PERIODS (SOP I AND SOP II)

As part of both SOP I and SOP II, 64 NDBO drifting buoys were deployed in the Southern Oceans. Forty-six were launched by ship and 18 were launched by aircraft. The purpose of the air-launched buoys was to reestablish the buoy network in preparation for SOP II. After launch, the buoys were monitored daily, using the World Meteorological Organization DRIBU messages and other available data. The DRIBU messages were processed at NDBO on a weekly basis to edit the data, calculate performance statistics, and provide a summary report on overall network performance. Buoy positions as shown in figure 6 were plotted weekly on a polar chart of the Southern Hemisphere. DISPOSE file listings for the U.S. FGGE buoys were obtained from Service ARGOS to provide additional data for buoy failure analysis. Additional information on buoy sensor performance was obtained by comparing buoy data with historical data and synoptic maps of pressure and sea surface temperature obtained from the Bureau of Meteorology, Melbourne, Australia, and from the National Weather Service, National Meteorological Center, Suitland, Maryland.

Weekly and monthly summary reports were prepared for engineering and management evaluation of buoy performance. A typical report is shown in figure 7 for the period January 5, 1979, to March 5, 1979. The mean, standard deviation, maximum and minimum values for the buoy daily drift velocity, barometric pressure, and sea-surface temperature are plotted. The last reported buoy position and battery voltage are also reported. Buoy sensor performance, position fix, and network performance are computed for all the operational buoys during the report period.

Historical global mean pressure and temperature charts were obtained for the months of January and February. The historical mean-sea-level barometric pressure and sea-surface temperature were determined for each buoy position reported on January 15, 1979. The monthly mean pressure and temperature values calculated for each operational buoy during January 1979 were compared with historical mean values for January. The data comparisons for January are tabulated in table III by Service ARGOS buoy ID. The last two columns in the table list the pressure and temperature differences between the buoy and historical mean values. The mean pressure difference is -1.2 mb and the standard deviation is 3.6 mb. The mean temperature difference is 0.41°C and the standard deviation is 1.3°C. In the vicinity of latitude

50°S to 56°S and longitude 90°W to 100°W, there was a large pressure anomaly or departure from normal of approximately -10 mb as reported by buoys 1604, 1605, and 1649. A pressure anomaly of 8 mb was also observed from buoy 1614, which had moved into the Atlantic.

Similar comparisons were made for the month of February. The mean pressure difference was 3.8 mb and the standard deviation was 3.6 mb. The mean temperature difference was 0.5°C and the standard deviation was 1.4°C. No pressure anomaly was reported by buoys 1604 and 1605 during February. In the vicinity of latitude 40°S to 46°S and longitude 150°W to 156°W, there was a pressure anomaly of about +8 mb as reported by buoys 1625, 1626, and 1627. In the vicinity of latitude 60°S to 65°S and longitude 111°W, as well as longitude 157°W, there were anomalies of about -7.5 mb as reported by buoys 1650 and 1651. These comparisons do not prove whether or not the buoys are reporting correctly. However, the means and the standard deviations of the buoy data and chart differences are small, indicating that the buoys were generally reporting pressures and temperatures near normal for that part of the ocean in the Southern Hemisphere.

Additional historical statistical data were obtained for various regions in the Southern Hemisphere and were used to determine the historical standard deviations of pressure and temperature for each region that included a buoy.

In a similar manner, synoptic pressure and temperature charts were used to tabulate pressures and temperatures for each buoy location and to compare these values with the edited DRIBU messages. Pressure charts for January 15 and February 15, 1979 (Bureau of Meteorology, Melbourne, Australia) and temperature charts for January 16 and February 13, 1979 (NWS, NMC) were compared with the detailed buoy listings.

Table IV indicates that, for January 15, the mean pressure difference between each buoy and the synoptic chart for all buoys is -0.8 mb with a standard deviation of 2.8 mb. The January 15-16 temperature differences are quite small with the mean difference of 0.16°C and a standard deviation of 0.44°C. Buoys 1602, 1621, 1623, 1649, 1651, and 1652 had pressure differences that varied more than 3 mb from the synoptic chart. Buoy 1649 and 1652 had differences greater than 5 mb.

The February 15 comparison showed that mean pressure difference between each buoy and the synoptic chart for all buoys is 2.1 mb, with a standard deviation of 5.2 mb. The February 13-15 temperature differences are quite small, with a mean of 0.34°C and a standard deviation of the differences of 0.83°C. Buoys 1602, 1605, 1607, 1615, 1624, 1626, 1627, 1648, and 1652 showed the largest pressure differences.

The pressure and temperature statistics are all larger for February. Even though all buoys were checked repeatedly against synoptic pressure charts, data for the buoys listed with the largest differences were checked for several days picked at random. The result in all cases indicated that the listed buoys were within 2 or 3 mb of the charted values. This tended to indicate that they were operating as well as the other buoys, even though the differences were large on February 15th. Statistical values for temperature were relatively small. This may reflect the fact that temperature charts were developed with drifting buoy data. Standard deviations of pressures and temperatures from each buoy for January and February, and for the two months combined, were compared with historical data.

The comparisons of the means and the standard deviations of pressure and temperature from the drifting buoys with the means and the standard deviations of pressure and temperature for comparable locations from climatic atlases indicated that the drifting buoys were performing well. Further, the comparisons of pressure and temperature data with synoptic charts of pressure and temperature for the same dates confirmed the overall excellent performance of the drifting buoys.

As of November 5, 1979, performance statistics (table V) were computed for the original 64-buoy network.

The buoys have logged over a total of 13,000 buoy-days of operation since the start of the Global Weather Experiment. Considering any failure mode (sensor failure, buoy aground, failure at deployment, low power) a buoy failure, the average time to failure of the deployed buoy network is 423 days. The average time to failure is defined as the total buoy network operating time divided by the number of failed buoys. The average lifetime of a failed buoy is defined as the total of all failed buoy operating times divided by the number of failed buoys.

Figure 8 shows a discrete failure density function (failure histogram) for the buoy network. Buoy failures should start increasing rapidly beyond the nominal 360-day buoy life as the batteries are depleted. A bimodal failure curve showing early random-type failures and buoy end-of-life battery depletion will result. Figure 9 shows the cumulative distribution of the buoy network failures for all failure modes through November 5, 1979.

5. CONCLUSIONS

The feasibility of economically and reliably deploying meteorological drifting buoys in the remote data-sparse areas of the world has been shown during FGGE. The performance of the U.S. drifting buoys during the experiment indicates that about 50 percent of the buoys can be expected to remain operational for at least one year.

Although the buoy-derived data will be used primarily for climate-related research studies, these data have also proved extremely valuable in overcoming weather forecasting problems arising from the deficiency of surface observations in the oceans of the Southern Hemisphere. The experiment has provided the operational experience and data network performance characteristics needed for the planning, design, and implementation of future drifting buoy monitoring systems.

An operational polar-orbiting satellite network, reliable data processing, and a data dissemination network have been established to provide a global environmental monitoring capability during the next several years. Planning is underway to continue this capability into the next decade.

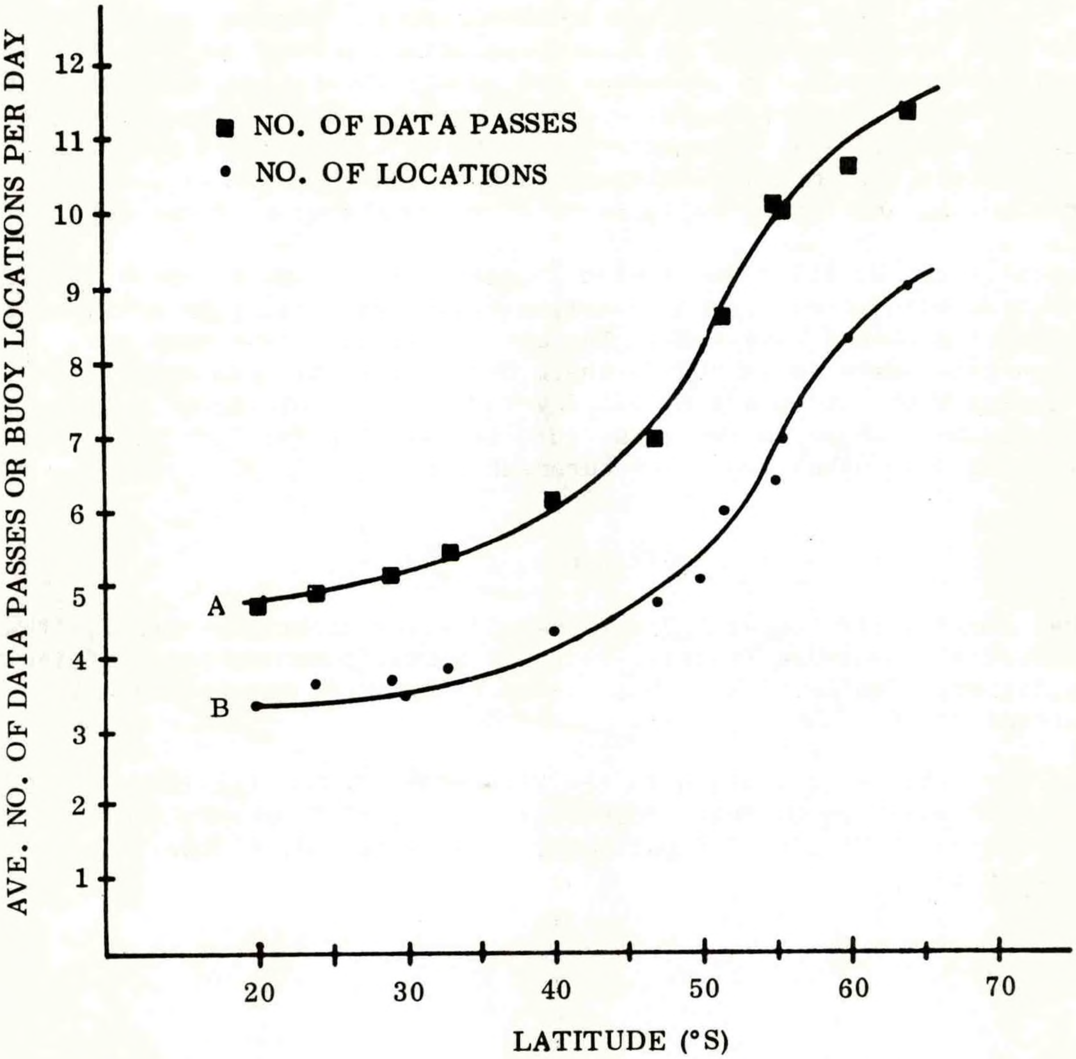
It is expected that drifting buoy technology will play an increasingly important role in climate-related research programs during the next decade. Climatically important ocean processes are poorly understood, due mainly to the relative lack of long-term, synoptic time-series data defining large-scale oceanic variability. Comprehensive data sets are needed for ocean climate diagnosis, for model development and validation, for process-oriented studies, and for investigations of ocean-atmospheric coupling.

Meteorological drifting buoys with increased measurement capabilities, in conjunction with other remote measurement systems, will play a key role in providing the needed data sets. The use of drifting buoy data for improved surface analysis in the Southern Hemisphere has been amply demonstrated during FGGE. Within the next several years, operational drifting buoys may become a major source of meteorological data for forecasting purposes along with other remote measurement systems.

REFERENCES

1. Global Atmospheric Research Programme, Global Weather Experiment, "The FGGE Special Observing Systems, Part D: Southern Hemisphere Drifting Buoy System," Implementation Operations Plan, World Meteorological Organization, Vol. 5, May 1978.

2. "Plan for U.S. Participation in the First GARP Global Experiment (FGGE) Southern Hemisphere Drifting Buoy System," United States Project Office for the First GARP Global Experiment, Annex 4 to Vol. 1 (Operations), September 1978.



LATITUDE	MEAN NO. OF DATA PASSES/DAY	STANDARD DEVIATION	MEAN NO. OF BUOY LOCATIONS/DAY	STANDARD DEVIATION
20°	4.74	0.94	3.37	0.97
24° S	4.89	0.97	3.63	0.49
29° S	5.11	0.89	3.67	0.68
30° S	5.14	0.79	3.52	0.70
33° S	5.48	0.70	3.85	0.82
40° S	6.19	0.56	4.37	0.84
47° S	7.00	1.00	4.74	0.71
50° S	8.22	0.58	5.07	1.04
51.5° S	8.62	0.79	6.00	1.07
55° S	10.11	0.32	6.41	1.34
55.5° S	10.07	0.47	7.00	1.07
60° S	10.63	0.56	8.30	1.49
64° S	11.37	0.63	9.00	1.07

Figure 1. AVERAGE NUMBER OF DATA PASSES AND BUOY LOCATIONS PER DAY AS A FUNCTION OF LATITUDE

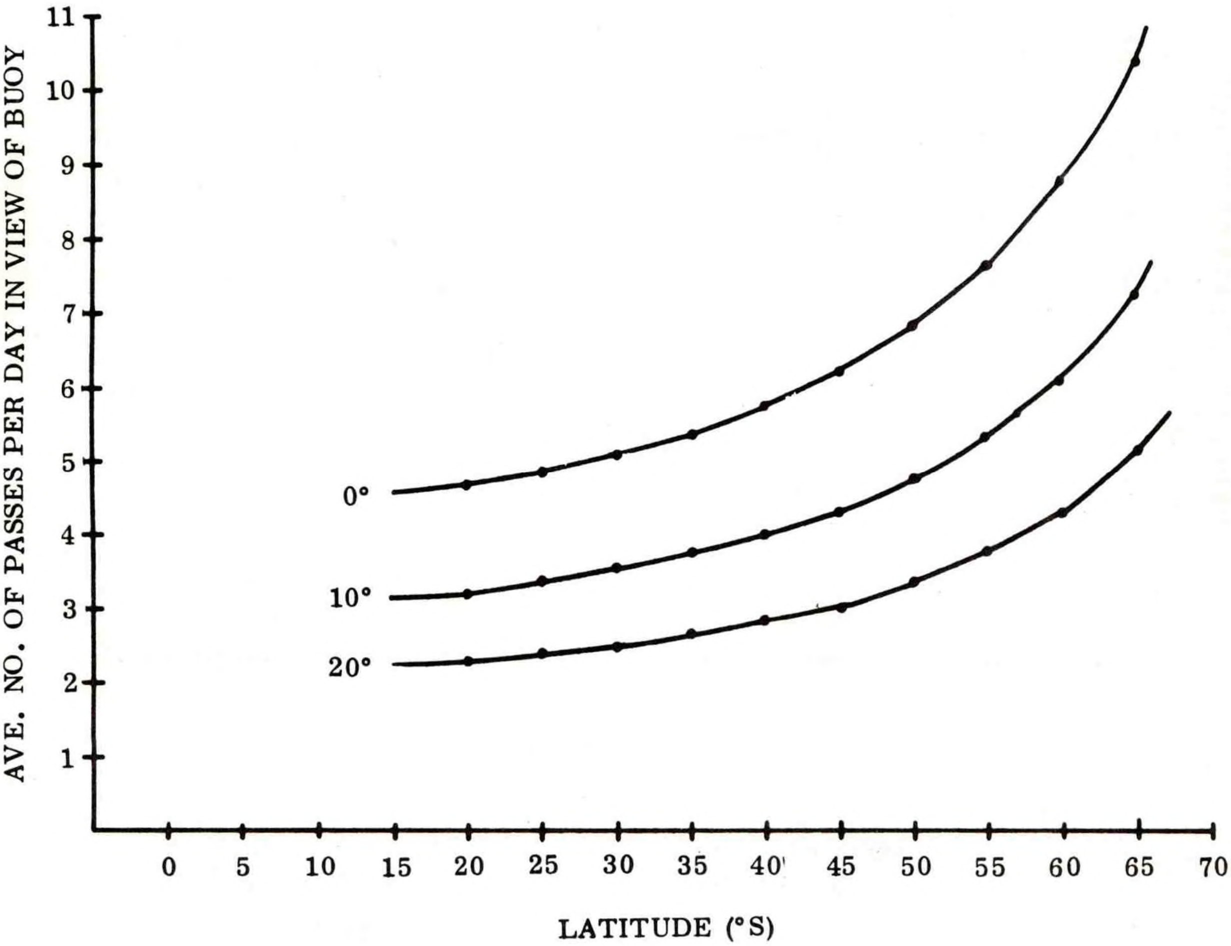
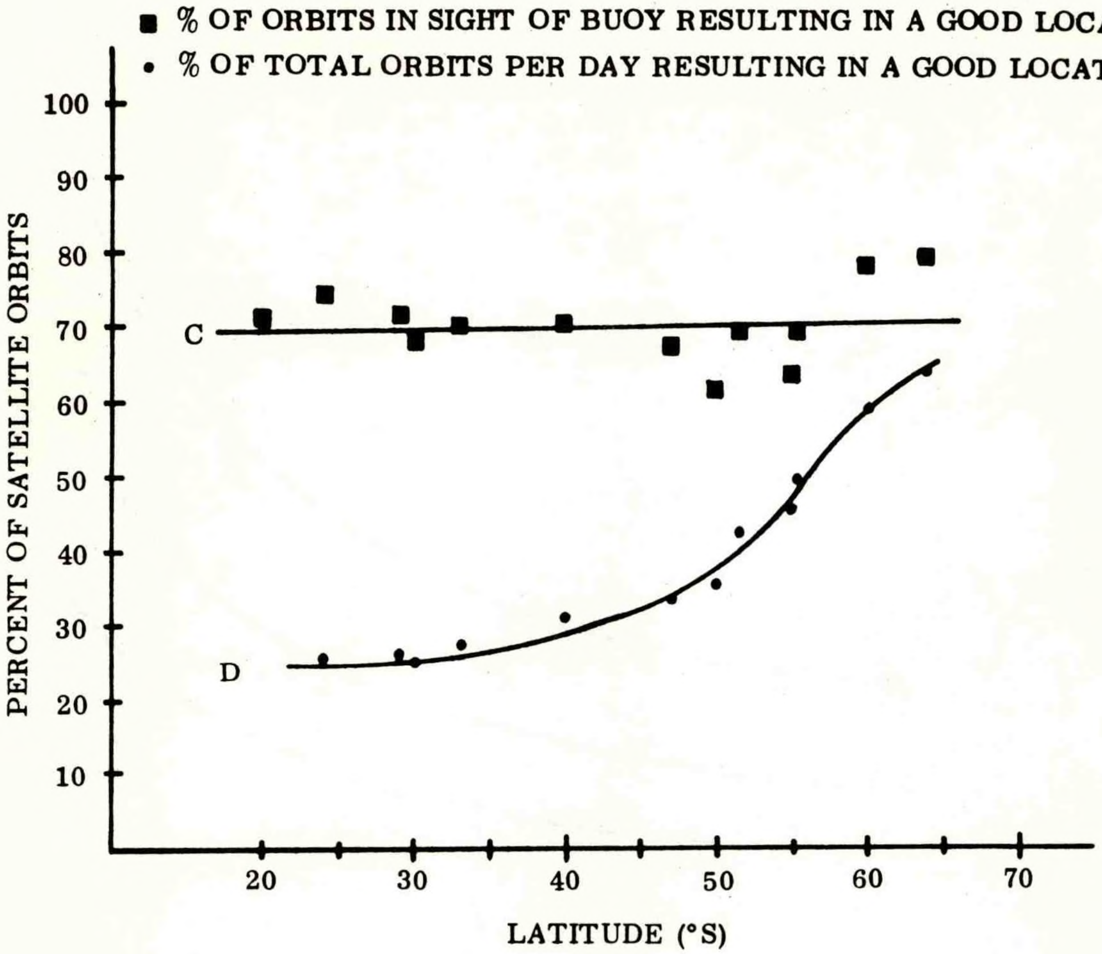


Figure 2. AVERAGE NUMBER OF SATELLITE PASSES PER DAY IN VIEW OF A BUOY AT A GIVEN LATITUDE FOR VARIOUS ANGLES ABOVE THE HORIZON



LATITUDE	PERCENT OF TOTAL DAILY ORBITS	PERCENT OF ORBITS IN SIGHT OF TRANSMITTER
20° S	24.0	71.1
24° S	25.8	74.2
29° S	26.1	71.8
30° S	25.0	68.4
33° S	27.4	70.3
40° S	31.1	70.6
47° S	33.7	67.7
50° S	36.0	61.7
51.5° S	42.6	69.6
55° S	45.6	63.4
55.5° S	49.8	69.5
60° S	59.0	78.1
64° S	64.0	79.2

Figure 3. PERCENTAGE OF SATELLITE ORBITS RESULTING IN A GOOD BUOY LOCATION AS A FUNCTION OF LATITUDE

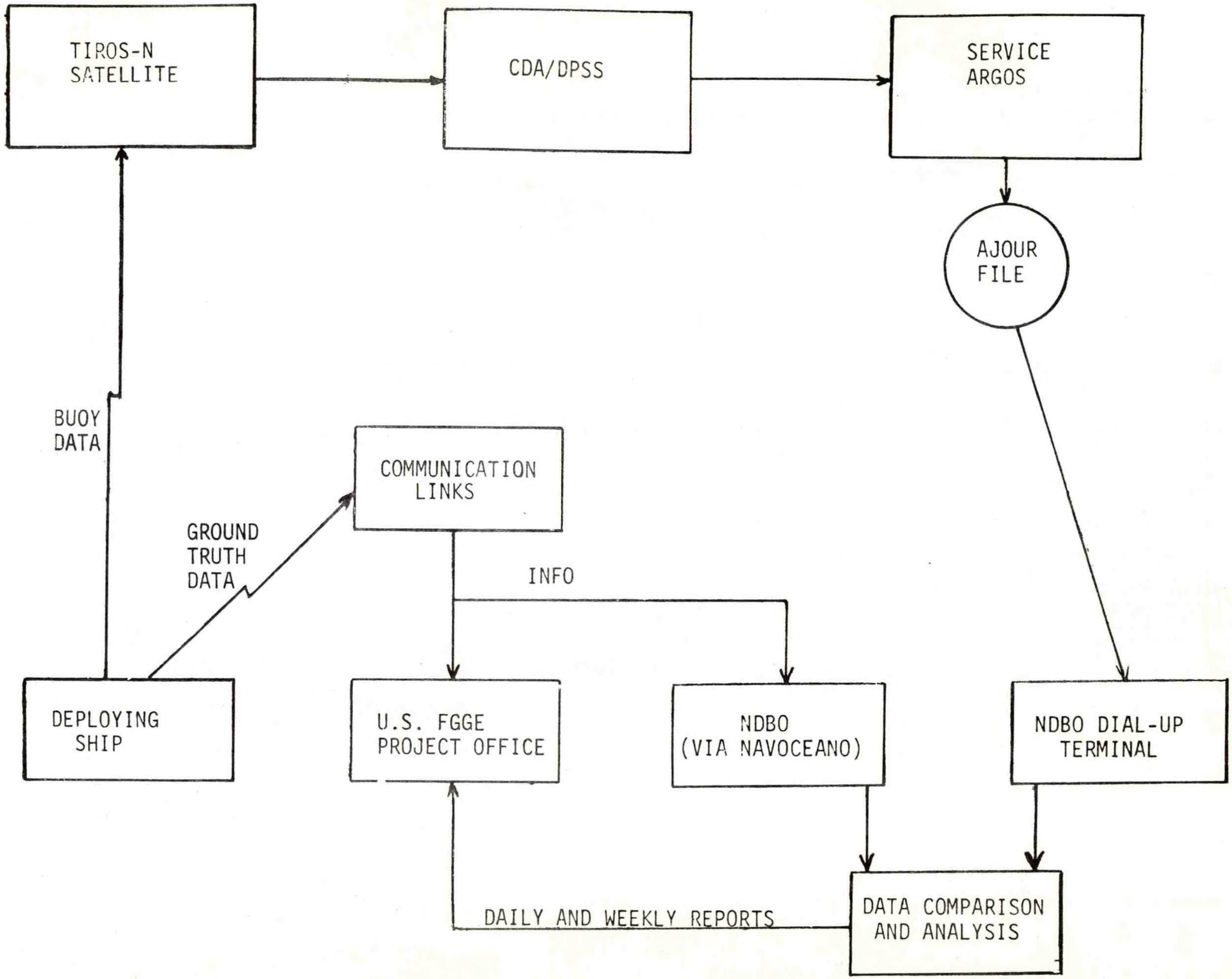


Figure 4. PRE-DEPLOYMENT - PRIMARY DATA FLOWS

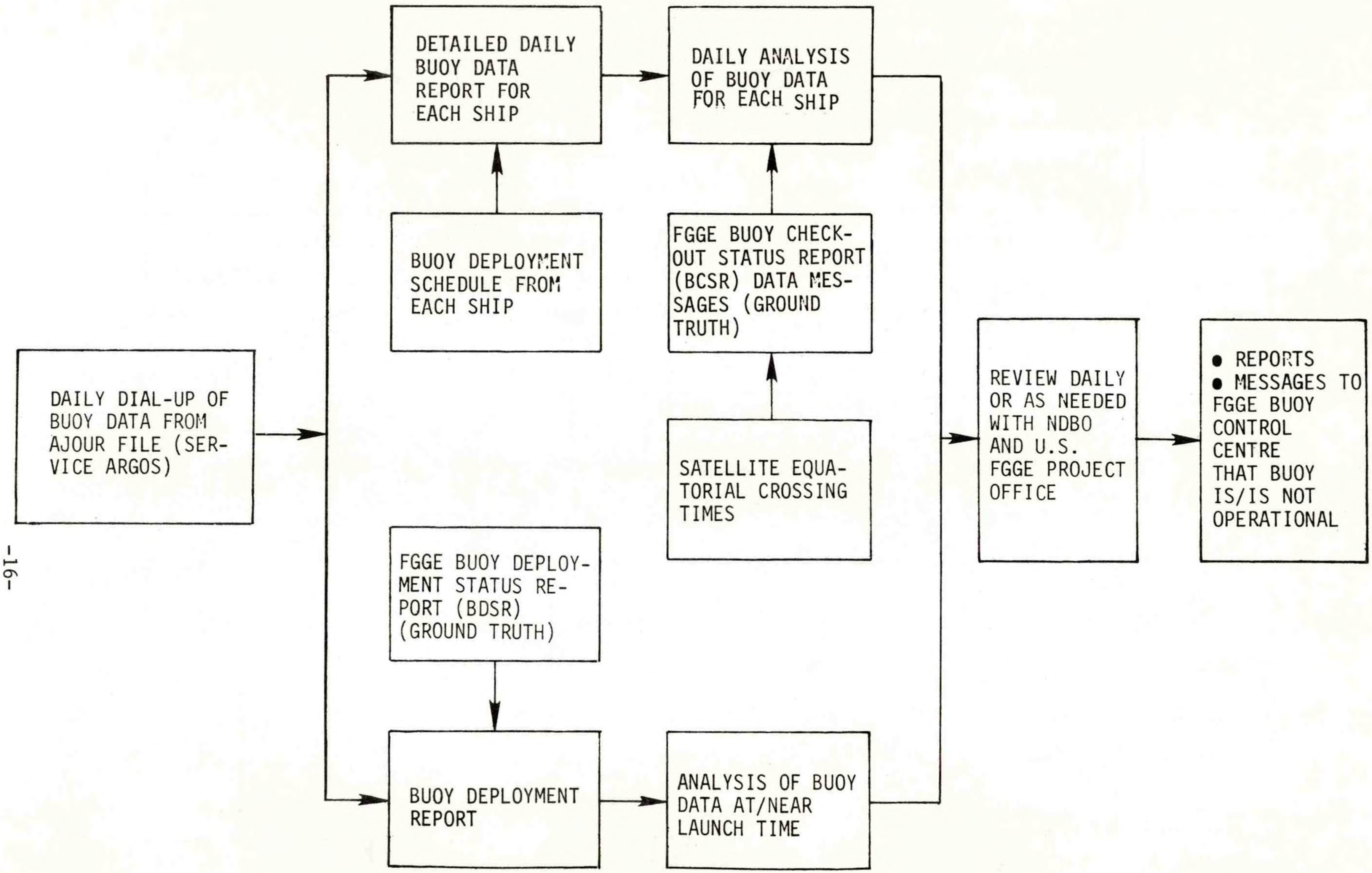


Figure 5. PROCEDURE AND STEPS - DATA ANALYSIS

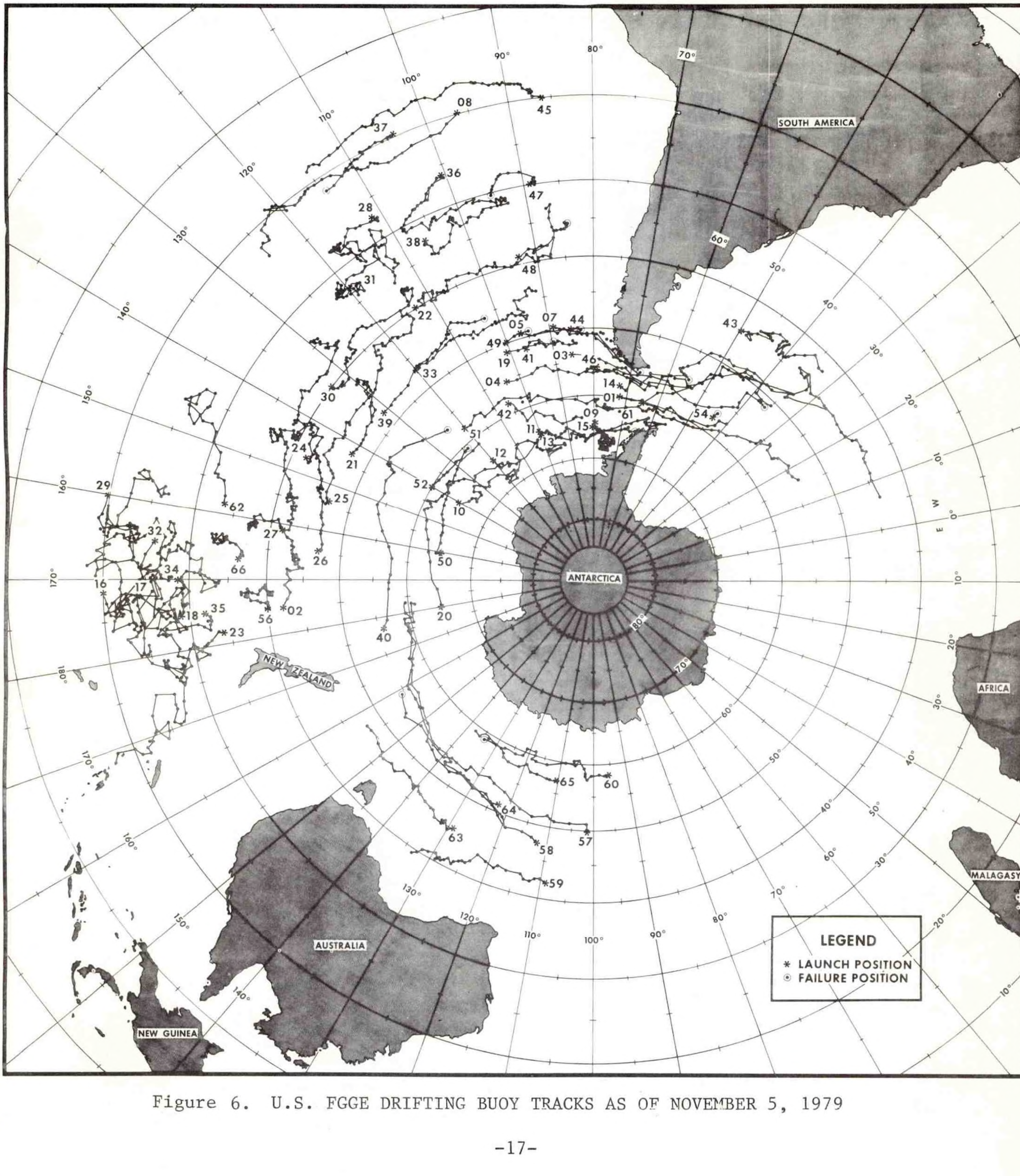


Figure 6. U.S. FGGE DRIFTING BUOY TRACKS AS OF NOVEMBER 5, 1979

OPERATIONAL FGGE DRIFTING BUOY SUMMARY
PERIOD: JAN. 5, 1979 - MAR. 5, 1979

BUOY ID DRIBU/SA	DEPLOYED MODYYR	FAILED MODYYR	POSITION LAT(S)	POSITION LONG(W)	DAILY DRIFT-KNOTS MEAN	STD.	MAX.	MIN	BATT VOLT	BAROMETRIC PRESSURE - MBAR MEAN	STD.	MAX.	MIN	SEA SURF TEMP - DEG MEAN	STD.	MAX.	MIN	NO OBS
54601/1601	121178		60.7	50.1	.44	.27	1.32	.03	16.2	F	F	F	F	.7	.42	1.5	-.1	94
54602/1602	121878		44.1	166.9	.49	.25	1.25	.06	17.4	1013.0	6.8	1028.1	994.9	16.8	.77	18.1	15.1	163
54603/1603	112878		53.8	57.4	.85	.64	4.19	.05	15.3	995.4	8.9	1012.6	977.7	7.0	.77	8.7	5.0	168
54604/1604	120478		56.3	75.3	.57	.34	2.76	.08	16.0	991.0	9.2	1013.1	972.2	7.4	.27	8.0	6.8	169
54605/1605	120178		55.9	67.3	.66	.51	3.31	.03	15.9	995.9	6.3	1011.8	978.2	9.7	.85	11.7	7.0	161
54607/1607	112278		54.8	71.4	.75	.33	1.46	.02	15.9	999.4	9.0	1015.6	975.1	8.2	1.65	11.5	3.0	142
54608/1608	011379		22.2	105.0	.45	.17	1.02	.12	16.9	1016.1	2.5	1022.1	1010.6	25.8	.33	27.2	24.9	67
54609/1609	120978		67.2	77.4	.41	.21	1.03	.06	16.2	984.8	9.9	1006.6	963.0	.6	.47	1.8	-.1	172
54610/1610	020279		66.4	135.5	.38	.19	.81	.02	16.8	981.1	9.6	996.3	952.7	.7	.22	1.1	.3	67
54611/1611	120678		64.9	89.6	.43	.25	1.74	.06	16.0	981.8	10.5	1001.0	952.5	.6	.35	1.2	-.3	169
54612/1612	020379		66.5	116.5	.17	.00	.17	.17	17.1	993.9	2.0	995.3	992.5	2.0	.00	2.0	2.0	2
54613/1613	020479		64.7	97.8	.41	.00	.41	.41	16.8	996.2	4.5	999.4	993.0	2.1	.00	2.1	2.1	3
54614/1614	112478		50.1	43.8	.59	.42	3.02	.04	15.7	1004.5	8.4	1023.6	977.7	6.6	.58	8.0	5.5	168
54615/1615	020679		65.1	78.1	.53	.24	1.16	.13	17.4	982.6	11.8	1008.6	964.8	1.8	.33	2.3	1.2	65
54616/1616	121478		26.0	170.1	.67	.40	2.28	.05	16.3	1009.6	3.8	1017.3	1000.1	26.7	.78	28.4	25.6	145
54617/1617	121478		26.9	-170.4	.65	.35	1.63	.05	16.2	1012.3	4.4	1019.6	997.5	24.8	.48	25.9	23.6	123
54618/1618	121578		28.8	175.7	.52	.29	2.45	.03	16.6	1013.1	4.1	1021.1	1004.8	23.9	.87	25.8	22.5	142
54619/1619	120278	011379	51.6	90.4	.52	.20	1.03	.22	16.3	988.3	9.4	1004.6	977.9	7.8	.13	8.0	7.5	22
54620/1620	020379		63.9	170.1	.59	.29	1.27	.03	16.5	982.1	11.5	1002.1	966.5	1.6	.10	1.7	1.5	65
54621/1621	010379		45.0	129.9	.52	.41	3.79	.07	16.3	1013.8	10.1	1031.3	985.9	13.2	.42	14.0	12.2	138
54622/1622	010879		40.2	179.9	.42	.23	1.37	.06	16.8	1018.6	7.1	1029.8	994.2	17.1	.72	18.6	15.6	109
54623/1623	121678		30.2	179.8	.48	.35	2.46	.05	16.8	1015.3	4.1	1022.8	1000.6	23.1	.99	24.7	20.5	137
54624/1624	121378		41.2	142.0	.47	.31	2.02	.06	16.3	1015.9	9.8	1032.1	986.7	17.6	.45	19.1	16.6	153
54625/1625	010179		45.7	147.3	.48	.30	2.47	.04	16.9	1012.8	9.1	1032.8	994.9	14.8	.41	16.6	14.1	161
54626/1626	123178		46.4	153.8	.52	.38	3.56	.09	16.8	1012.3	8.8	1031.3	994.6	14.9	.56	16.1	13.8	163
54627/1627	121578		42.3	156.3	.39	.28	2.63	.07	16.3	1016.6	8.2	1031.8	996.8	17.4	.53	19.7	16.1	161
54628/1628	120678		30.5	116.1	.46	.19	.95	.09	16.5	1016.7	2.8	1021.8	1010.3	24.8	.50	26.0	23.6	97
54629/1629	012279	012979	19.9	160.0	M	M	M	M	17.5	1012.3	.0	1012.3	1012.3	28.9	.00	28.9	28.9	2
54630/1630	121178		39.2	128.1	.44	.26	1.53	.08	16.5	1018.0	8.2	1034.3	987.3	17.7	.39	18.7	16.8	140
54631/1631	120878		33.1	119.4	.58	.22	1.49	.10	16.0	1019.3	4.8	1026.8	1007.0	22.3	.62	23.5	20.7	123
54632/1632	012379		24.9	168.7	.64	.39	2.73	.06	16.8	1013.2	3.6	1017.1	992.8	26.2	1.03	28.1	23.9	87
54633/1633	010679		46.2	109.9	.38	.19	.77	.05	16.5	1010.9	10.1	1028.3	983.3	11.4	.37	12.3	10.5	125
54634/1634	012479		31.7	159.3	.43	.19	1.01	.08	16.9	1015.3	4.3	1023.3	1002.1	24.0	.50	25.2	22.9	87
54635/1635	012479		32.6	1.6.9	.43	.26	1.39	.06	16.9	1016.6	4.2	1023.8	1006.3	22.6	.56	24.4	21.7	82
54636/1636	011279		28.6	105.0	.37	.19	.97	.07	16.8	1019.0	2.8	1023.1	1010.8	25.5	.38	26.6	24.8	90
54637/1637	120278	030579	21.9	115.0	.37	.16	1.09	.10	16.5	1014.9	2.4	1019.3	1004.6	26.3	.56	28.0	24.8	115
54638/1638	011079		34.8	103.9	.37	.22	1.17	.06	16.8	1020.2	5.3	1027.1	1002.3	21.4	.29	22.0	20.9	98
54640/1640	020279		57.5	168.6	.59	.26	1.38	.12	16.8	996.1	11.1	1011.8	961.6	7.0	.51	9.6	6.3	65
54645/1645	010279		18.2	86.6	.20	.15	.86	.05	16.3	1014.5	1.2	1016.8	1011.6	23.2	.23	23.9	22.8	110
54647/1647	010479		28.1	92.7	.41	.40	2.80	.04	13.[illegible]	1017.4	3.0	1023.3	1010.6	22.3	.59	23.7	20.9	115
54648/1648	010579		36.2	86.2	.54	.30	1.81	.07	12.9	1019.0	7.1	1035.8	997.9	17.5	.92	19.5	15.9	119
54649/1649	010779	013079	49.3	94.6	.50	.21	.98	.10	13.1	998.8	12.7	1027.8	982.7	8.7	.43	9.5	7.9	48
54650/1650	011479		64.5	152.9	.44	.22	1.29	.04	12.9	980.6	13.3	1004.5	935.6	.1	.19	.6	-.3	147
54651/1651	011079		57.5	105.8	.61	.31	1.76	.08	12.9	990.0	8.9	1009.5	975.7	5.3	.68	8.5	4.3	139
54652/1652	011279		61.2	127.2	.52	.24	1.21	.12	12.4	988.3	9.7	1011.8	963.2	1.7	.78	3.1	.6	115

NUMBER OF OBSERVATIONS = 5053. BUOY SENSOR PERFORMANCE = 97.32% POSITION FIX PERFORMANCE = 99.13%

F - SENSOR DATA INVALID BUOY 1607 IN COASTAL WATERS BUOY 1639 NOT YET ON GTS

NETWORK PERFORMANCE - 92.34%

Figure 7. OPERATIONAL SUMMARY - JANUARY 5, 1979 - MARCH 5, 1979

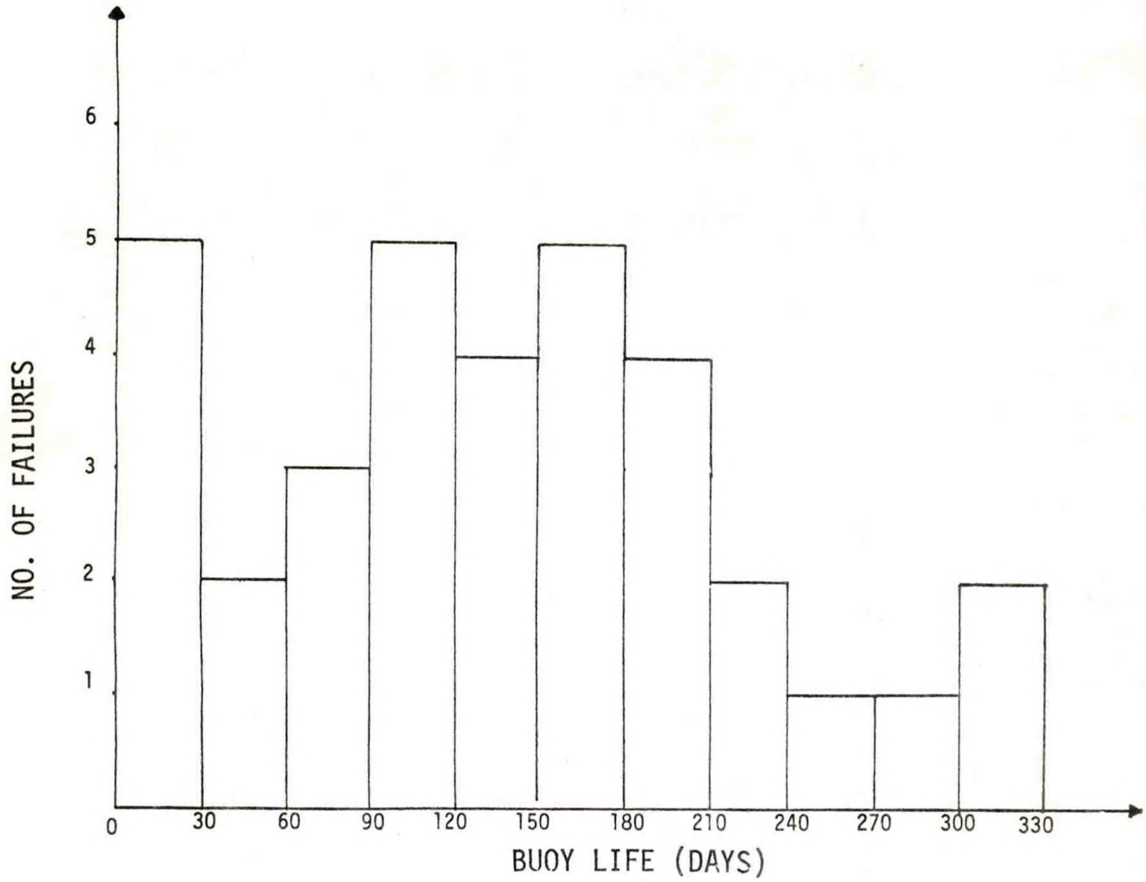


Figure 8. DISCRETE FAILURE DENSITY FUNCTION FOR U.S. FGGE DRIFTING BUOYS THROUGH NOVEMBER 5, 1979

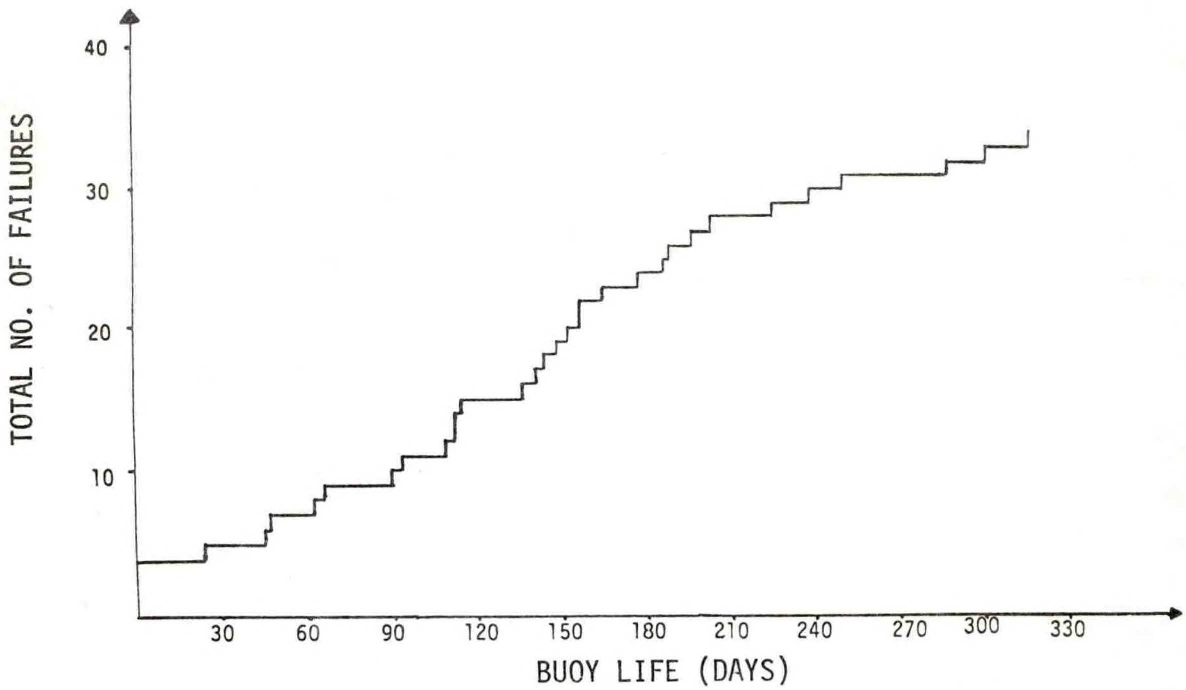


Figure 9. CUMULATIVE DISTRIBUTION OF U.S. FGGE DRIFTING BUOY FAILURES (ALL BUOYS) THROUGH NOVEMBER 5, 1979

TABLE I

STATISTICS ON BUOY SENSOR PERFORMANCE
FOR BAROMETRIC PRESSURE
AND WATER TEMPERATURE

	BUOY 1641	BUOY 1642	BUOY 1643	OVERALL
Barometric Pressure (mb)				
Mean Difference Between Buoy and Ground Truth	0.34	0.87	0.83	0.73
Standard Deviation	0.48	0.43	0.46	0.46
No. Observations	66	107	115	288
Water Temperature (°C)				
Mean Difference Between Buoy and Ground Truth	0.15	0.15	0.40	0.25
Standard Deviation	0.32	0.17	0.17	0.21
No. Observations	49	106	107	262

TABLE II

AVERAGE NUMBER OF TRANSMISSIONS PER ORBIT FOR DATA PASSES
OVER BUOYS AT VARIOUS LOCATIONS

BUOY ID	LATITUDE	AVERAGE NUMBER OF TRANSMISSIONS PER ORBIT	STANDARD DEVIATION	NUMBER OF ORBITS SAMPLED
1602	44°S	13.07	4.19	100
1608	22°S	13.76	3.97	50
1611	66°S	14.24	4.08	102
1621	45°S	12.93	4.58	60
1634	32°S	13.07	4.30	96
Overall		13.43	4.36	403

TABLE III

COMPARISON OF JANUARY HISTORICAL MEAN PRESSURE AND TEMPERATURE WITH BUOY MEAN PRESSURE AND TEMPERATURE FOR JANUARY 1979.

APPROXIMATE LOCATION AS OF JAN. 15 (1200 GMT)			CHART		BUOY		BUOY-CHART	
BUOY ID	LAT (S)	LONG (W)	PRESS (mb)	TEMP (°C)	PRESS (mb)	TEMP (°C)	DP (mb)	DT(°C)
1601	ON GTS	JAN 30, 79						
1602	43.42	170.12	1012.0	15.6	1012.0	17.2	0	1.6
1603	56.87	69.05	997.0	7.7	998.1	7.2	1.1	-0.5
1604	55.68	89.13	1001.0	7.5	992.2	7.2	-8.8	-0.3
1605	50.73	83.52	1010.0	9.0	996.8	9.1	-13.2	0.1
1607	52.55	76.92	1005.0	9.0	1003.9	9.1	-1.1	0.1
1608	20.47	97.27	1017.0	23.5	1014.9	25.6	-2.1	2.1
1609	66.52	76.70	989.0	0.0	987.5	0.5	-1.5	0.5
1610	DEPLOYED DURING FEB							
1611	66.03	94.75	987.0	1.0	983.1	0.3	-3.9	-0.7
1612	DEPLOYED DURING FEB							
1613	DEPLOYED DURING FEB							
1614	52.53	49.85	997.0	7.5	1005.0	6.3	8.0	-1.2
1615	DEPLOYED DURING FEB							
1616	22.10	174.25	1009.0	26.7	1007.6	26.1	-1.4	-0.6
1617	24.90	-179.08	1009.5	25.6	1010.9	25.0	1.4	-0.6
1618	28.02	172.58	1010.5	23.6	1013.0	23.2	2.5	-0.4
1619	FAILED	JAN 13, 79						
1620	ON GTS	FEB 9, 79						
1621	47.75	139.28	1007.5	12.5	1010.5	13.2	3.0	0.7
1622	40.23	111.23	1019.0	15.6	1015.8	16.4	-3.2	0.8
1623	31.75	179.72	1012.0	22.0	1014.6	22.2	2.6	0.2
1624	42.38	145.42	1011.0	15.0	1013.0	17.6	2.0	2.6
1625	46.72	153.53	1010.0	12.5	1008.9	14.9	-1.1	2.4
1626	46.90	160.67	1010.0	12.5	1008.8	14.8	-1.2	2.3

TABLE III (CONT'D)

COMPARISON OF JANUARY HISTORICAL MEAN PRESSURE AND TEMPERATURE WITH BUOY MEAN PRESSURE AND TEMPERATURE FOR JANUARY 1979.

APPROXIMATE LOCATION AS OF JAN. 15 (1200 GMT)			CHART		BUOY		BUOY-CHART	
BUOY ID	LAT(S)	LONG (W)	PRESS (mb)	TEMP (°C)	PRESS (mb)	TEMP (°C)	DP (mb)	DT(°C)
1627	42.67	158.30	1012.0	15.6	1014.0	17.3	2.0	1.7
1628	27.30	114.02	1018.0	23.8	1015.0	24.7	-3.0	0.9
1629	DEPLOYED JAN. 22, 79							
1630	40.80	131.67	1014.0	15.6	1016.2	17.6	2.2	2.0
1631	33.52	118.95	1017.0	21.0	1018.9	21.7	1.9	0.7
1632	DEPLOYED JAN. 23, 79							
1633	47.02	118.97	1011.0	12.0	1010.9	11.3	-0.1	-0.7
1634	ON GTS JAN. 26, 79							
1635	ON GTS JAN. 26, 79							
1636	ON GTS JAN. 19, 79							
1637	20.45	109.08	1015.0	23.6	1013.7	25.9	-1.3	1.3
1638	33.28	106.42	1019.0	20.0	1015.9	21.3	-3.1	1.3
1639	NOT YET ON GTS							
1640	DEPLOYED DURING FEB.							
1645	10.08	87.27	1016.0	22.5	1014.5	23.1	-1.5	0.6
1647	29.53	88.57	1020.0	21.1	1017.3	21.9	-2.7	0.8
1648	38.18	91.02	1021.0	16.5	1017.6	16.7	-3.4	0.2
1649	49.47	97.87	1010.0	9.0	998.8	8.7	-11.2	-0.3
1650	64.88	160.43	988.0	1.0	981.7	0.0	-6.3	-1.0
1651	58.25	118.00	992.0	5.0	990.1	4.7	-1.9	-0.3
1652	60.20	139.50	990.0	4.4	987.9	1.1	-2.1	-3.3
					MEAN		-1.2	0.41
				STANDARD DEVIATION			3.6	1.3

TABLE IV

PRESSURE AND TEMPERATURE FROM BUOYS AND SYNOPTIC CHARTS

JANUARY 15, 16, 1979

APPROXIMATE LOCATION AS OF JAN. 15 (00 GMT)			CHART		BUOY		BUOY-CHART	
BUOY ID	LAT (S)	LONG (W)	(Jan 15) PRESS (mb)	(Jan 16) TEMP (°C)	(Jan 15) PRESS (mb)	(Jan 15) TEMP (°C)	DP (mb)	DT (°C)
1601	ON GTS	JAN. 30, 79						
1602	43.32	170.08	1017.0	17.0	1014.1	17.9	-3.9	0.9
1603	56.88	69.55	984.5	7.0	982.7	7.7	-1.8	0.7
1604	55.68	89.32	985.0	6.9	984.3	6.8	-1.7	-0.1
1605	50.73	83.62	994.0	9.0	994.4	9.4	0.4	0.4
1607	52.53	77.20	993.0	8.6	995.3	8.6	2.3	0.0
1608	ON GTS	JAN. 19, 79						
1609	66.58	76.75	979.0	1.0	979.3	1.0	0.3	0.0
1610	ON GTS	FEB. 9, 79						
1611	66.03	94.78	980.0	0.5	980.7	0.4	0.7	-0.1
1612	ON GTS	MAR. 5, 79						
1613	ON GTS	MAR. 5, 79						
1614	52.63	49.88	1002.0	7.0	1004.5	6.6	2.5	-0.4
1615	ON GTS	FEB. 9, 79						
1616	22.10	174.25	1006.0	26.0	1005.6	25.7	-0.4	-0.3
1617	24.85	-179.13	1008.0	24.5	1006.0	25.3	-2.0	-0.2
1618	28.07	172.48	1010.0	22.5	1010.6	23.0	0.6	0.5
1619	FAILED	JAN. 13, 79						
1620	ON GTS	FEB. 9, 79						
1621	47.70	139.45	1017.0	14.0	1020.5	13.5	3.5	-0.5
1622	40.27	111.35	1020.0	17.0	1019.6	16.8	-0.4	-0.2
1623	31.72	179.62	1011.0	22.3	1007.3	22.7	-3.7	0.4
1624	42.38	145.35	1018.0	16.5	1019.6	17.2	1.6	0.7
1625	46.83	153.52	1016.0	14.5	1013.3	15.0	-2.7	0.5
1626	46.88	160.72	1014.0	15.0	1013.5	14.7	-0.5	-0.3

TABLE IV (CONT'D)

PRESSURE AND TEMPERATURE
FROM BUOYS AND SYNOPTIC CHARTS

JANUARY 15, 16, 1979

APPROXIMATE LOCATION AS OF JAN. 15 (00 GMT)			CHART		BUOY		BUOY-CHART	
BUOY ID	LAT (S)	LONG (W)	(Jan 15) PRESS (mb)	(Jan 16) TEMP (°C)	(Jan 15) PRESS (mb)	(Jan 15) TEMP (°C)	DP (mb)	DT(°C)
1627	42.65	158.32	1017.0	18.0	1018.0	17.5	1.0	-0.5
1628	27.30	114.02	1020.0	24.0	1019.0	24.6	-1.0	0.6
1629	FAILED JAN. 29, 79							
1630	40.80	131.45	1012.0	17.0	1011.3	17.6	-0.7	0.6
1631	33.48	119.03	1020.0	22.0	1020.8	22.4	0.8	0.4
1632	ON GTS JAN. 26, 79							
1633	47.03	118.97	1020.0	11.0	1017.8	10.8	-2.2	-0.2
1634	ON GTS JAN. 26, 79							
1635	ON GTS JAN. 26, 79							
1636	ON GTS JAN. 19, 79							
1637	20.43	109.05	1018.0	25.0	1016.1	25.9	-1.9	0.9
1638	33.28	106.42	1023.0	21.0	1021.6	21.1	-1.4	0.1
1639	NOT YET ON GTS							
1640	ON GTS FEB. 9, 79							
1645	19.10	87.27	1016.0	22.0	1015.3	22.9	-0.7	0.9
1647	29.55	88.53	1021.0	21.5	1021.3	21.2	0.3	-0.3
1648	38.18	91.18	1024.0	16.0	1022.3	16.6	-1.7	0.6
1649	49.43	98.07	998.0	8.0	988.4	8.2	-9.6	0.2
1650	64.88	160.43	986.0	0.0	986.2	-0.3	0.2	-0.3
1651	58.30	118.12	989.0	4.5	993.5	4.6	4.5	0.1
1652	60.18	139.63	994.0	1.5	987.4	1.5	-6.6	0.0
					MEAN		-0.8	0.16
				STANDARD DEVIATION			2.8	0.44

TABLE V

BUOY PERFORMANCE STATISTICS AS OF NOVEMBER 5, 1979

Performance Criteria	Average Life (Days)	Standard Deviation (Days)	Number of Buoys
Buoy still operational (pressure and temperature sensors operational)	266	63	30
Buoy life with pressure sensor failure	169	28	6*
Buoy life with temperature sensor failure	133	57	5
Buoy life with transmission failure	152	84	16
Buoy life with low voltage failure	179	80	11
Buoy still operational (pressure and temperature sensor operational) and (temperature sensor failure)	266	63	30
Buoy still operational (pressure and temperature sensor operational) and (pressure sensor failure)	269	61	33

*Statistics based on four buoys; two buoys failed on deployment.

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