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FINAL REPORT

A DEFINITION STUDY OF AN ADVANCED DATA COLLECTION AND LOCATION SYSTEM (ADCLS)

PREPARED FOR:

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1.0 EXECUTIVE SUMMARY

The purpose of this effort is to assess the technical and economic advantage of developing an Advanced Data Collection and Location System (ADCLS) to operate within the Earth observation System (EOS) planned for Polar Platform, as a replacement and/or augmentation of the existing ARGOS data coleection system. The cost/effectiveness of ADCLS with respect to ARGOS hinges on the trafffic and quality of service demand of the future user constituency.

The latter falls into four categories: 1) Conventional users, that are currently subscribing to ARGOS, and their expected future growth; 2) Latent users, that currently use data collection systems other than ARGOS, but that may become future subscribers to ADCLS for reasons of improved quality and lower costs; 3) Peak users, that conduct international experiments utilizing massive numbers of in-situ platforms for limited periods of time; 4) EOS users, i.e., scientists that will use EOS data and that need "surface" or "atmospheric" truth to calibrate their data sets.

A middle-of-the-road forecast of the aggregate number and traffic requirements of these user's platforms indicates the following world-wide totals as a function of time:

	1990	1995	2000
Number of platforms	7,860	15,800	18,500
Traffic demand, erlangs	61	94	107

These totals are distributed unevenly over the globe: in year 2000, for example, the densest satellite footprint (over Europe and the Mediterranean) will contain about 3,000 platforms and require about 20 erlangs in traffic demand. The least dense (over the south Indian Ocean) will contain less than 30 platforms, generating a traffic demand less than 0.2 erlangs.

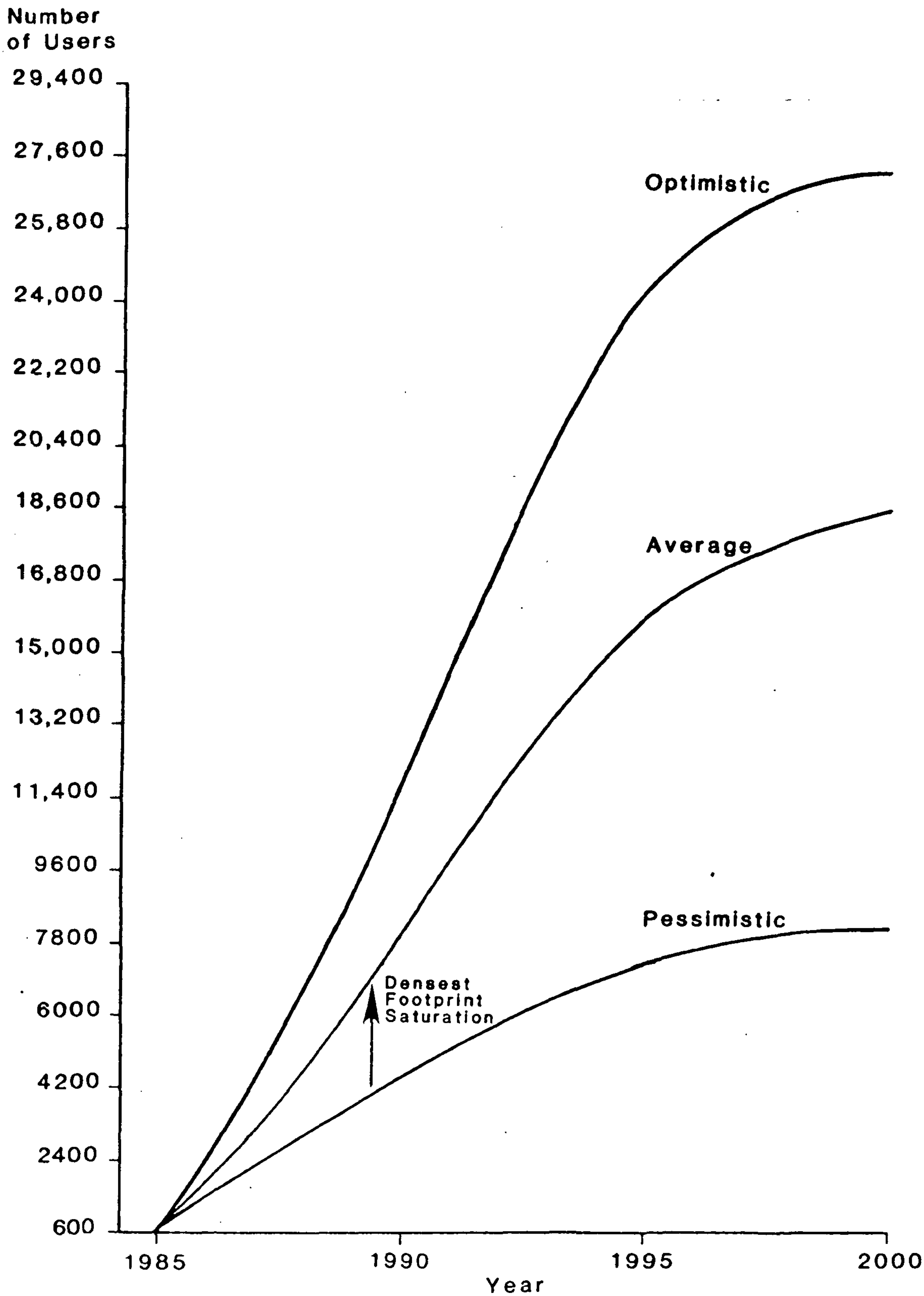

Exhibit A. Forcasted Growth of Insitu Platforms and Estimated ARGOS Saturation Levels

Current users are by and large satisfied with ARGOS performance. ARGOS's principal future drawback is that it will saturate, i.e., will not be able to meet the requirements of the platform's traffic demand. Exhibit A depicts the ARGOS saturation and estimated users by year 2000. The figure shows that ARGOS system may saturate by 1990 if the system is used for data or location only. For a fifty-fifty distribution of data and location platforms the ARGOS saturation will also be by year 1990.

This constraint will manifest itself in two ways: i) excessive loss of platform-derived data--users indicate that they will not tolerate more than 5%-10% loss; and ii) loss of position fixes--future users will require no more than 20% loss of fix data. Some alleviation of the saturation problem can be achieved if the proposed ARGOS II is deployed: however, this will extend the saturation date to no later than 1995.

The principal, optimal remedial measures to ARGOS saturation are: i) use of a broad-footprint interferometer, capable of providing a position fix with one platform message per satellite pass instead of the five messages currently required; ii) increase of the r.f. bandwidth to ~ 100 kHz from the current ~ 25 kHz. These measures will not require modifications to the current design of platform transmitters, thus will add no burden to the users. With these modifications the ADCLS will be able to accommodate up to 5,000-7,000 platforms per footprint, leaving margin for further growth in the number of platforms beyond year 2000.

2.0 FOREWORD

The purpose of this report is to provide the Goddard Space Flight Center with an assessment of the technical and economic desirability of developing an Advanced Data Collection and Location System (ADCLS), as part of the Earth Observation System (EOS) planned to be installed aboard the Polar Platform; to document tradeoffs between ADCLS and the existing ARGOS data collection system; to specify the characteristics and to structure a top-level configuration of an ADCLS.

3.0 PHILOSPHY OF THE APPROACH

The purpose of this effort is to assess the overall cost effectiveness of developing, implementing, and deploying an Advanced Data Collection and Location System (ADCLS) for use in relaying world-wide data from in-situ platforms to scientific users, either directly or through the intermediary of suitable ground stations and data dissemination networks.

NASA is currently in the process of defining an Earth Observation System (EOS) to be deployed on the Polar Platform (an element of the Space Station system) approximately in 1992, intended to provide the international scientific communities the opportunity to investigate global phenomena related to assessing and forecasting key environmental processes affecting life and well-being on earth.

The ADCLS is being considered by NASA as a potential addition to EOS, to supplement the data provided by EOS remote sensors through data gathered in-situ from land and oceanic surfaces and atmospheric platforms. Additionally, ADCLS could take over selected portions and the overflow of the traffic generated world-wide by fixed in-situ platforms that perform environmental measurements on a routine or ad-hoc basis.

Two systems for relaying in-situ data are currently operational. The GOES Data Collection System (DCS) relays data only, and is best suited to relaying information collected by fixed platforms of known position. The ARGOS system relays data and can provide position location, and is thus suitable for use with moving or drifting platforms, where the data need to be correlated with the location in which they are gathered.

The need for the service that ADCLS can provide depends upon two factors: a) will the growing user constituency eventually exceed the traffic handling capability offered by ARGOS and GOES, thus requiring a supplementary data throughput capacity; and b) will future users require a quality of service not currently supplied by ARGOS and/or GOES.

The cost effectiveness of ADCLS hinges upon what is the "value" of these added services with respect to its cost to the user community, and the cost of the ADCLS system to NASA.

Our approach proceeds along the following logical steps:

- Assess the future traffic demand and quality of service desired by users of in-situ data, up to year 2000.

- Assess the factors that drive the users' willingness to expand their in-situ data collection systems--assess how these factors evolve with time, and the consequent increase in user constituency.

- Assess whether ARGOS and/or GOES, or future improvements thereof, can meet the requirements of the future traffic demand.

- In the event that ARGOS and/or GOES should turn out to be deficient with respect to users' needs, assess the technical/operational improvements needed to meet the future users' demands.

- From these, develop and apply criteria to define an optimal configuration for the ADCLS instrument.

4.0 DATA AND DATA LIMITATIONS

Key to the technical choice of ADCLS versus ARGOS is the credible forecast of future traffic demand on the part of the users. To construct our forecast, we have sought the best and most reliable data that are available. This was done by three methods: i) by querying the users and the ARGOS systems' operator; ii) by analyzing historical data to uncover internal evidence of growth trends; and iii) by estimating the future evolution of the factors that govern the number of in-situ platforms, key among which is cost. Our forecast assumes conditions of continued steady state evolution of the U.S. and international situation, and continued interest in science on the part of the various governments involved. The forecast cannot and does not take into account the occurrence of "breakthroughs" or of a radically changed international situation--events that are not predictable.

The sources of data that we used, together with a value assessment for each, are as follows.

- The current constituency of ARGOS subscribers, and the forecast of future subscribers, were obtained from Service ARGOS. Since Service ARGOS is the "owner" of the system, and is supported by the system's revenue, the presumption is that their forecast represents a thoughtful, reliable source of data.

- To validate the forecasts supplied by Service ARGOS, the current consistency of subscribers, their characteristics, budgets, anticipated growth, degree of satisfaction with ARGOS, and future needs, were obtained by querying fourteen principal U.S. agencies and academic institutions currently availing themselves of the ARGOS service. The data collected offer a good assessment of current numbers, characteristics and desires of users of in-situ platforms. The forecasts by this community, however, are generally limited to the short range. Most of them do not extend beyond 5 years, a few go as far as 1995.

- The historical constituency and composition of subscribers of the GOES/DCS system was obtained from NESDIS. Our objective was to determine the saturation level of GOES/DCS, in order to assess whether the growing constituency of GOES/DCS users could and would eventually spill over onto other services, e.g. ADCLS. The NESDIS data are excellent, and sufficiently detailed to allow computing the "logistic growth" of GOES/DCS users.

- The historical cost reduction of platform systems were obtained from historical series (some dating back to the 1950's), and from detailed investigation of recent prices of platform components -- that, we found, substantially confirm the historical trends. This data serves to gage the additional number of platforms that users can be expected to procure as a result of lowered platform costs. These data appear to be highly reliable.

- The expected deployment of in-situ platforms on occasion of future major international scientific programs--primarily dealing with the oceans--was obtained from NOAA and NSF. Our objective was to assess the extra number of platforms--above and beyond conventional uses--that such major programs would generate. While the descriptions of the proposed experiments are excellent, their funding status and era of realization are in most cases not quantified precisely. The corresponding forecasts ought therefore to be viewed with a degree of reservation.

- The in-situ needs of prospective EOS experimenters were derived from queries to scientists making up the EOS steering committee. The responses were supplemented by discussions with NASA scientific investigators. In view of the fact that the EOS is still undergoing definition of its functional requirements, these data ought to be considered indicative rather than final.

In summary, we believe that the significant number of the data collected, their methodical crosschecking, and the fact that they were collected from numerous independent sources--thus overestimates and underestimates among sources tend to compensate statistically--supplies a reasonable estimate of the future constituency and traffic demand within which a potential future ADCLS will have to operate.

5.0 USER CONSTITUENCY

5.1 Approach

The purpose of this effort is to assess, up to year 2000, the volume of traffic, as a function of time and geographic location, expected to be generated by potential users of ARGOS and/or ADCLS.

The following user groups are considered as actual or potential candidates for ARGOS or ADCLS up to year 2000:

= **Conventional users**, i.e., the scientific user community that is currently utilizing ARGOS, and that plans to continue utilizing any future expansion thereof--and that may eventually "switch over" to ADCLS should the future ARGOS system be unable to meet their requirements--or offer substantially lower costs.

= **Latent users**, i.e., additional users that may subscribe to the system by virtue of quality advances or of reduced costs (either costs of the terrestrial equipment and/or service charges).
Latent users fall into the two subcategories of scientific and commercial applications.

= **Peak users**, representing unusually large deployment of surface sensors for limited time periods on special occasions, e.g. international cooperative scientific programs.

= **EOS users**, i.e., scientists planning to analyze data from the EOS polar platform and who require calibration of EOS sensors by means of "surface truth" or "atmospheric truth", as well as supplementary in-situ data that cannot be gathered remotely.

There is no single source of data that provides a completely reliable forecast of the numbers of these users and the traffic that they are likely to generate. We have gathered the best available forecast data, compared them, reconciled discrepancies and filled in the gaps by means of reasoned extrapolations, correlations and adjustments.

5.2 Consistency of Conventional Users of Service ARGOS

Forecasts produced by the system's operator and revenue-getter (Service ARGOS) ought to be regarded as a highly authoritative source of data.

The highlights of the **forecast** by **Service ARGOS** are as follows.

Table 5-1 depicts the August 1985 constituency of ARGOS subscribers, as supplied in personal communication to Mr. Lalit Wanchoo of ECOsystems by Mr. Michel Taillade, Director, Service ARGOS.

Table 5-2 shows these subscriber's total erlang traffic demand.[a,b]

(a) The erlang unit is the ratio between the length of the message and the time available for its transmission, both expressed in the same units. For example, a message lasting one minute, transmitted during one available hour, represents 1/60th of an erlang (16.6 millierlangs).

(b) The traffic demand was derived from data supplied by Service ARGOS through personal communication and through the ARGOS User's Guide, as follows. The length of the fixed portion of the message is 160 msec. of unmodulated carrier (to allow the ARGOS onboard receiver to lock onto the carrier), plus 48 bits @ 2.5 msec. = 120 msec., for a total of 280 msec. The length of the variable portion of the message, that conveys sensor data, ranges from 32 bits = 80 msec. up to 256 bits = 640 msec. Thus the total message lengths vary from 280 msec. for "dumb" drifters without sensors (position location only) up to 920 msec. for sophisticated drifters or moored buoys. The repetition rates are comprised between 50 and 60 seconds: we assume 55 seconds in our computations.

TABLE 5-1

CONSISTENCY OF ARGOS SUBSCRIBERS AS OF AUGUST 1985[a]

TYPE OF PLATFORM	PLATFORM CONSTITUENCY	
	Number	Percent (rounded)
Drifter Buoys	384	51
Moored Buoys	72	10
Fixed Land Stations	241	32
Ships	14	2
Balloons	1	0
Service ARGOS (in-house test purposes)	7	1
Miscellaneous Data Relay (fisheries, wildlife,etc. mostly on land)	34	4
TOTAL	753	100
DISTRIBUTION		
BY OWNERSHIP		
GOVERNMENT	670	89
PRIVATE	83	11
	753	100
BY FUNCTION		
LOCATION	500	66
DATA COLLECTION	253	34
	753	100
BY NATIONAL APPURTENANCE		
U.S.	414	55
NON-U.S.	339	45
(France, Canada, FRG, South Africa, Australia, Norway, U.K., Denmark)	753	100

(a) The number of **users** active at any one time equals 80% of the number of subscribers.

SOURCE: Service ARGOS Data

TABLE 5-2

TRAFFIC REQUIREMENTS OF ARGOS SUBSCRIBERS AS OF AUGUST 1985[a]

TYPE OF PLATFORM	MILLIERLANGS PER PLATFORM	TOTAL ERLANGS
Drifter Buoys	6.5	2.496
Moored Buoys	17	1.224
Fixed Land Stations	6	1.446
Ships	17	0.238
Balloons	6.5	0.006
Service ARGOS in-house tests	17	0.119
Miscellaneous	6.5	0.221
Total		5.75

[a] The user traffic, i.e., the traffic active at any one time, equals 80% of the subscriber's traffic shown in the Table.

SOURCE: ECOsystems elaboration of Service ARGOS Data

We distinguish between "subscribers" and "users". The term **subscribers** connotes the total constituency of platforms that enlist into the ARGOS service. The term **users** connotes the number of platforms that are **active at any one time.** It is the latter that the ARGOS system must service in terms of traffic handling capability.

Service ARGOS estimates the average user-to-subscriber ratio to be 0.8. This means that if, say, ARGOS had 1,000 subscribers, its data relaying segment would need to accommodate 800 users. With reference to Table 5-2, these users would generate, in August 1985, world-wide, a total traffic demand of 5.75 x 0.8 = 4.6 erlangs, at any one time.

A curtailment of the ARGOS data handling requirement occurs because of the geographic spread of the platforms with respect to the ARGOS's footprint.

Figure 5-1 from Service ARGOS shows the platform's geographic distribution, in December 1983, by cells measuring 10^{o} Latitude by 10^{o} Longitude.

The area in Km^2 subtended by each cell is:

$$1{,}110 \times 1{,}110 \times \cos (lat)^{o} =$$

$$= 1{,}232{,}000 \times \cos (lat)^{o}$$

To evaluate the traffic within each footprint, the subscriber constituency occupying each $10^{0} \times 10^{0}$ cell needs to be integrated with that of neighboring cells aggregating the total area subtended by an ARGOS footprint. Assuming a minimum elevation of the DCP-to-satellite line of sight of 5^{0} (for adequate signal reception), simple trigonometric computations yield that the radius of the "footprint" subtends:

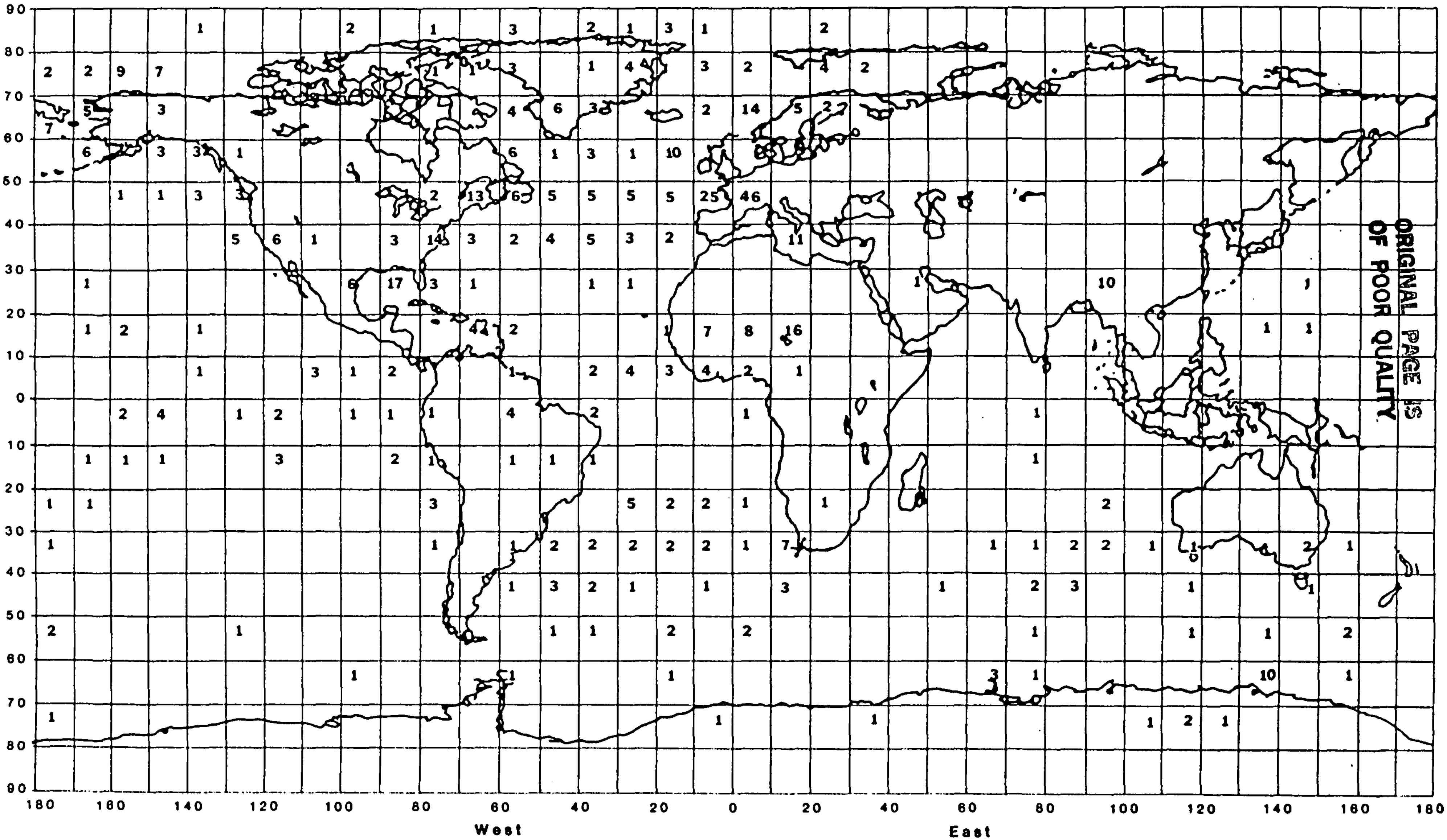

Figure 5-1. ARGOS Platform Geographic Distribution December 1983

22.5° in latitude
$22.5^{\circ} \times \cos(\text{lat})^{\circ}$ in longitude

A synthetic representation of the footprint can be obtained by replacing the ellipsoid with a rectangle having the same area. The synthetic footprint subtends 40° in latitude (in the north-south direction), 40° in longitude at the equator (in the east-west direction), and an increasing longitude arc at the higher latitudes. This is represented schematically in Figure 5-2 (for December, 1983).

The subscriber count per footprint was upgraded by the growth in the number of subscribers after December 1983, by using Table 5-3 which shows the Service ARGOS forecasts to year 2000. Assuming that the "mix" of platform traffic, Table 5-2, as well as the subscriber-to-user ratio, remain constant throughout geographic regions and with time, Table 5-4 shows the number of subscribers and their traffic demand per footprint as a function of time.

Figure 5-3 depicts the estimated number of ARGOS subscribers, and their traffic demand, in 2000, by geographic distribution.

5.3 Test of Service ARGOS Forecasts of Conventional Users - Major U.S. Agencies and Institutions

The intent here was to perform a "reasonableness test" of the service ARGOS forecasts. To this effect, we analyzed and compared the projections of major U.S. agencies that utilize ARGOS-addressable platforms.

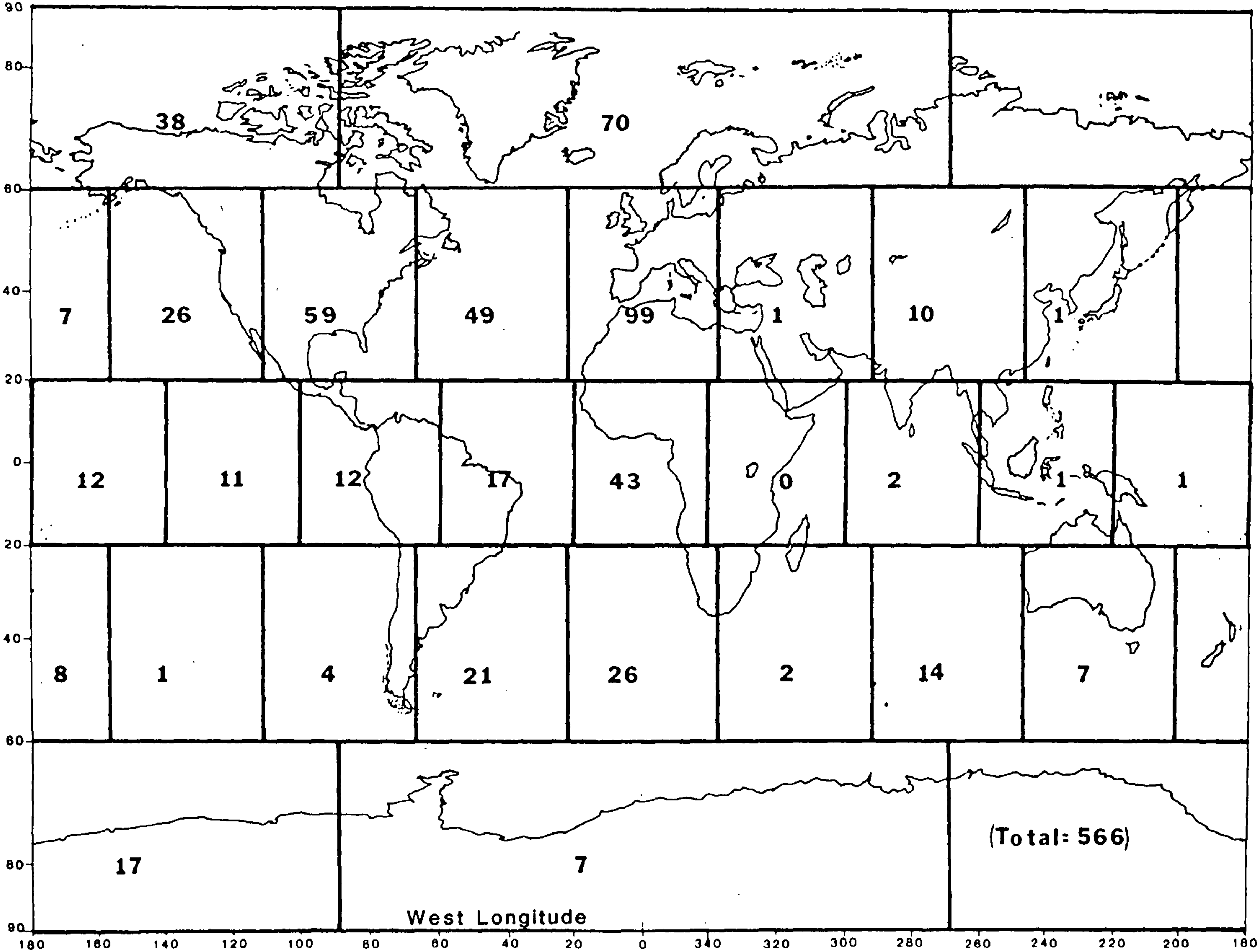

Figure 5-2. ARGOS Platform Population per Footprint
December 1983

TABLE 5-3

SERVICE ARGOS HISTORICAL STATISTICS AND FORECASTS

NUMBER OF SUBSCRIBERS

PLATFORM FUNCTION	Dec. 1983(a)	Dec. 1984(a)	Aug. 1985	1987	1990	1995	2000
LOCATION	376 (est)	413 (est)	500	660	850	1,650	2,900
DATA COLLECTION	190 (est)	209 (est)	253	320	450	750	1,300
	566	622	753	980	1,300	2,400	4,200

(a) For 1983 and 1984, Service ARGOS provided the total number of platforms, but not their subdivision by function.

TABLE 5-4

ARGOS SUBSCRIBER CONSTITUENCY VERSUS GEOGRAPHIC LOCATION AND VERSUS TIME

Footprint No.	Footprint Center Lat.	Footprint Center Long.	Footprint Dimensions	No. Subscribers Within Footprint 1985	1995	2000	Subscriber Traffic Demand Erlangs 1985	1995	2000
1	0°	0°	40° x 40°	57	182	318	0.35	1.11	1.94
2	0°	40°W	40° x 40°	23	73	128	0.14	0.45	0.78
3	0°	80°W	40° x 40°	16	51	89	0.10	0.31	0.54
4	0°	120°W	40° x 40°	15	48	84	0.09	0.29	0.51
5	0°	160°W	40° x 40°	16	50	89	0.10	0.30	0.54
6	0°	200°W	40° x 40°	1	3	6	0.01	0.02	0.04
7	0°	240°W	40° x 40°	1	3	6	0.01	0.02	0.04
8	0°	280°W	40° x 40°	3	10	16	0.02	0.06	0.10
9	0°	320°W	40° x 40°	0	1	3	0	0.01	0.02
10	40°N	0°	40° x 45°	132	421	736	0.81	2.57	4.50
11	40°N	45°W	40° x 45°	65	208	363	0.40	1.27	2.22
12	40°N	90°W	40° x 45°	78	249	435	0.48	1.52	2.66
13	40°N	135°W	40° x 45°	35	112	195	0.21	0.68	1.19
14	40°N	180°W	40° x 45°	9	30	50	0.06	0.18	0.30
15	40°N	225°W	40° x 45°	1	3	6	0.01	0.02	0.04
16	40°N	270°W	40° x 45°	13	42	73	0.08	0.26	0.45
17	40°N	315°W	40° x 45°	1	3	6	0.01	0.02	0.04
18	40°S	0°	40° x 45°	35	112	195	0.21	0.68	1.19
19	40°S	45°W	40° x 45°	28	89	156	0.17	0.54	0.95
20	40°S	90°W	40° x 45°	5	16	28	0.04	0.10	0.17
21	40°S	135°W	40° x 45°	1	3	6	0.01	0.02	0.04
22	40°S	180°W	40° x 45°	10	32	56	0.06	0.20	0.34
23	40°S	225°W	40° x 45°	9	30	50	0.05	0.18	0.30
24	40°S	270°W	40° x 45°	19	61	106	0.12	0.37	0.65
25	40°S	315°W	40° x 45°	3	10	16	0.02	0.06	0.10
26	80°N	0°	30° x 180°	93	297	519	0.57	1.81	3.17
27	80°N	180°W	30° x 180°	51	163	285	0.31	1.00	1.74
28	80°S	0°	30° x 180°	9	30	50	0.06	0.18	0.30
29	80°S	180°W	30° x 180°	23	73	128	0.14	0.44	0.78

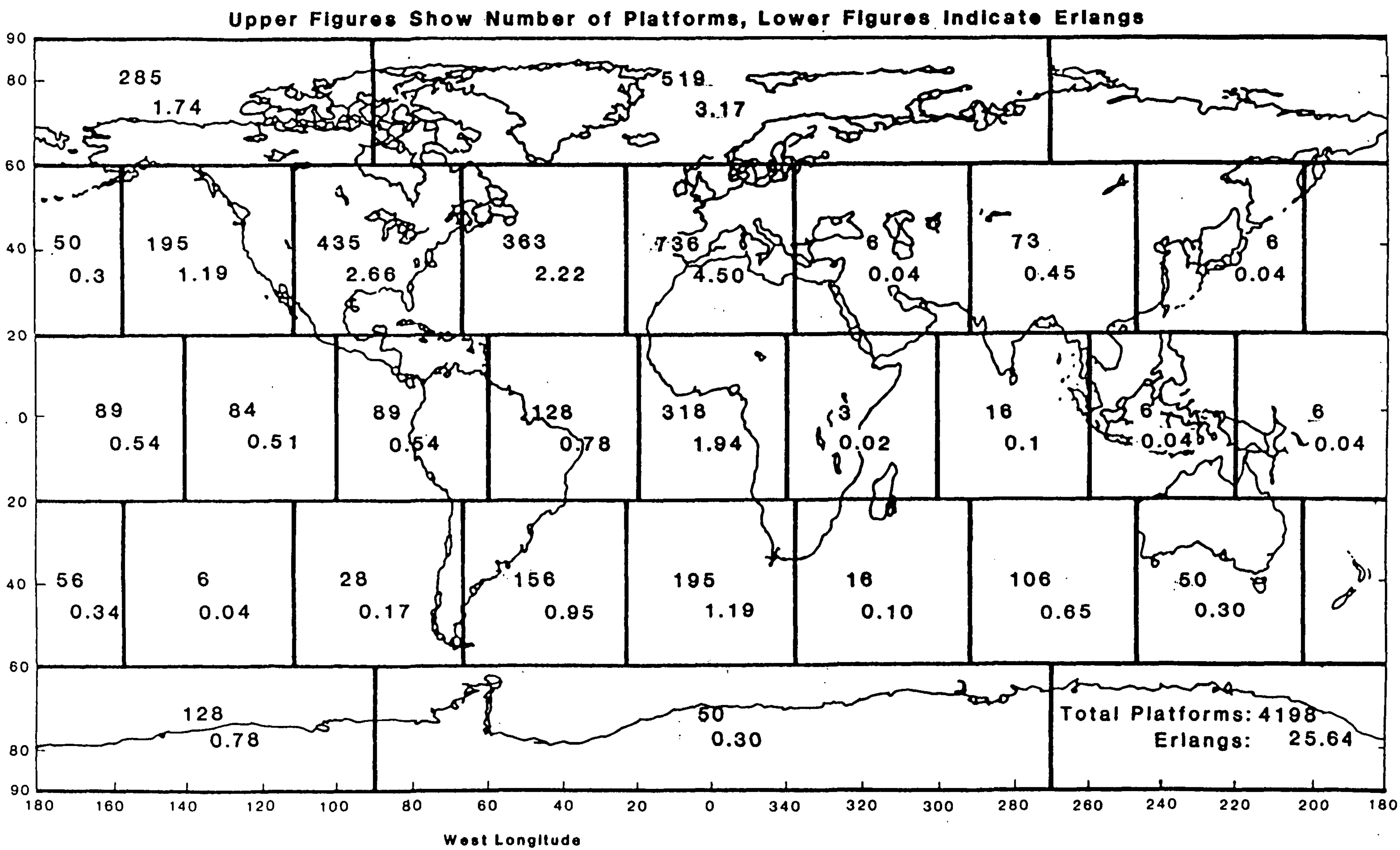

Figure 5-3. ARGOS Platform Population and Traffic Demand per Footprint Year 2000

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NDBC has experienced a growth in the number of **moored buoys** from 10 in 1976 to 59 in 1984 [(a)], equivalent to a yearly compound growth rate of 25%. Although the number of moored buoys is not large with respect to that of drifters, each moored buoy generates considerably more traffic than a drifter. Thus the moored buoy's "traffic weight" is higher than that of the drifters (by approximately three times).

According to NDBC, much of the reason for the growth experienced up to 1984 is that, in the 10 years elapsed from 1974 to 1984, costs of the electronics have dropped by a factor of 10, buoy system reliability has increased tenfold (thus further contributing to reducing overall costs), and the utility of moored buoys has been amply validated and recognized, so that increasing uses have been developed for their services. As an example, the Coast Guard has recently begun to implement its own moored buoy system, designated C-MAN (Coastal Marine Network), that is managed by NDBC.

As a "reasonableness test" on extrapolating the moored buoy population, we observe that the drop in electronic equipment costs reported by NDBC (factor of 10 in 10 years) parallels the historical cost decrease of sophisticated electronic equipment (e.g., computers), that since the 1950's has averaged approximately 0.8/year compound (that is, if the cost in the first year is 1, in the second it becomes 0.8, in the third 0.8 x 0.8 = 0.64, and so forth). The costs of the buoy's mechanical structure have dropped at a lesser rate, approximately a factor of 3 over the 1974-1984 time span (equivalent to a yearly decrease of 0.9).

(a) NDBC FY 1984 Annual Report, January 1985, U.S. DOC/NOAA National Data Buoy Center, NSTL, MS39529.

Currently, the respective cost ratios are of the order of 60-70% for the electronics, 30 to 40% for the structure. Assuming that the historical cost reduction will continue at the same rate experienced in the past (there appears to be no reason to the contrary), the year 2000 buoys ought to cost approximately one tenth of current costs. In theory then, and assuming constant NDBC budgets, the year 2000 NDBC moored buoy population ought to approximate ten times the 1985 population, (estimated at 59 x 1.25 = 73), or roughly 730: not counting additional "growth factors" such as increased budgets (as national wealth increases, and as more applications of greater utility are developed). This would represent a compound yearly growth rate of **17%**. We observe that the past growth rate has been **25%**. We thus extrapolate the moored buoy population at two compound growth rates: minimum of 17%; maximum of 25%. The extrapolation yields the following numbers:

	1985	1990	1995	2000
Minimum	73	150	330	730
Maximum	73	225	680	2000

We observe that a significant number of NDBC moored buoy transmissions are currently effected through the GOES DCS. However, as discussed later in this report, the GOES DCS system is now saturating, and the development of a more capacious system does not currently appear to be included in any future funding plans. If an improved GOES DCS is not funded, moored buoys could eventually become candidate subscribers for ARGOS and/or ADCLS.

As regards **drifters**, NDBC's primary responsibility is their technical improvement, and to act as a procuring agency for users that so request (several users procure directly from manufacturers, without passing through NDBC). NDBC buoy procurements are effected via RFP's to buoy and/or sensor manufacturers. To meet their statutory responsibility, NDBC is engaging in a thorough program of technical innovation, reliability improvement, and cost reduction of drifters and associated sensors and electronics.

Drifters are used in two major categories of applications:

- Measurement of ocean **currents**: this involves no sensors, only a transmitter to enable determining the buoy's location.

- Measurements of ocean **parameters** (in addition to location): sea surface temperature; atmospheric temperature; sea subsurface temperatures (100 to 150 meters, and down to 600 meters); atmospheric pressure at the ocean's surface; absolute wind speed; wind direction; subsurface currents (either by means of a drogue immersed at a desired depth, and that is entrained by the current at that depth, thus overcoming the entraining effect of surface currents on the buoy -- or via an immersed string of velocity meters, each of which conveys its own depth measurement to the buoy); solar irradiance.

Figure 5-4, courtesy of NDBC, depicts the drifter's mission spectrum. Drifters are designed to be as economical as possible: acquisition costs trade off against survival rates. Typical survival rates quoted by NDBC are: after 3 months-70%; after 6 months-56%; after 9 months-50%; after 12 months-40%; after 15 months-34%. A fairly novel technology is represented by aircraft-dropped drifters. NDBC delivered 90 drifter buoys for TOGA in 1985. Future plans for deliveries are: 150 drifters in spring of 1986 (for TOGA), followed by 75 to 100 TOGA drifters per year for the next 10 years.

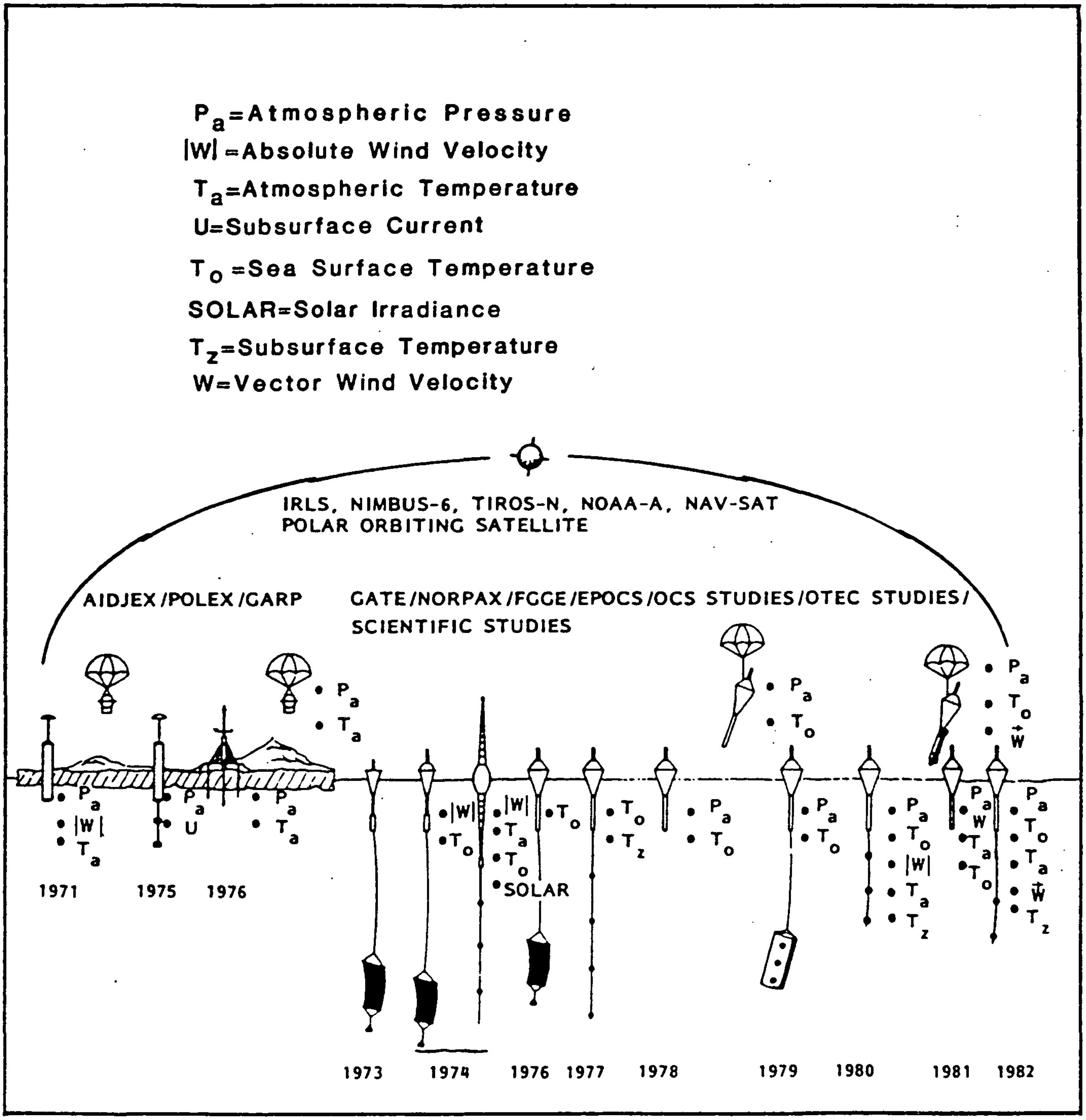

Figure 5-4. Drifting Buoy Mission Spectrum (Courtesy NDBC)

Other **principal U.S. institutions**, queried by telephone and personal contacts, supplied the current and future platform constituencies reported in Table 5-5.

Integration of the **projections** expressed by the "conventional" U.S. users yields the results shown in Table 5-6. Note that the projections do not extend much beyond 1990. This is due to the respondents' natural inability to perceive what will happen in the more distant future. Two key factors contained in the user's responses allow us to project the user constituency further into the future:

- most users assert that the number of platforms that they will procure and deploy is principally **conditioned** by their **budgets**. The effect is evidenced in Table 5-5, whence it can be seen that the number of platforms times their costs approximately equals the user's budget. Thus, a reduction in platform costs will result in increased platform numbers. To quantify the relationship, we observe that the increase is not strictly proportional to the cost reduction of the hardware, because some of the user's budget is spent in data analysis. From user responses, see Table 5-5, we see that approximately 0.11 data analysis persons are needed per sophisticated ($15,000) buoy. Assuming an hourly salary of $20 including benefits, this yields a yearly burden of $0.11 x 2,080 x $20 ≅ $4,600 per platform. An orientative ratio of data analysis labor to capital costs is thus (4,600) ÷ (15,000) = 0.30.

TABLE 5-5

BUOY PLATFORM CONSTITUENCY OF PRINCIPAL U.S. AGENCIES AND INSTITUTIONS

AGENCY/ INSTITUTION	1985 # OF BUOYS	TYPE	FUTURE PROJECTIONS	CURRENT UNIT COST	COMMENTS
POLAR SCIENCE CENTER	20-25	DRIFTER ON ICE FLOES, ARCTIC	• 30/YEAR THROUGH 1990 • $300,000/YEAR BUDGET FOR BUOYS THROUGH 1990	• $2K FOR PTT (DOWN FROM $3500 IN 1982) • $10K FOR COMPLETE UNIT, INCLUDING SENSORS	• WOULD LIKE MORE BUOYS, LIMITED BY FUNDING • SATISFIED WITH CURRENT ARGOS PERFORMANCE
U.S. COAST GUARD R&D CENTER	5-10	DRIFTER IN ARCTIC, PORTION GULF STREAM	• MAINTAIN 5-10 IN NEAR FUTURE, LIMITED BY FUNDING • BUDGET ABOUT $50K/YEAR	• $6-6.5K FOR FULLY ASSEMBLED BUOYS	• SATISFIED WITH ARGOS PERFORMANCE • DATA ANALYSIS CURRENTLY HANDLED BY 2 SCIENTISTS
NOAA/ATLANTIC OCEANIC MARINE LABORATORY	50	DRIFTERS, PACIFIC & INDIAN OCEAN	• 100/YEAR BY 1990 • BUDGET $1M/YEAR BY 1990 • LIKE TO HAVE MORE: FUNDING LIMITATIONS	• $10K FOR COMPLETE UNIT, INCLUDING SENSORS	• FUNDING LIMITATIONS • SOMETIMES EXPERIENCES DATA MIX-UP THROUGH GPS
USN OCEANOGRAPHIC OFFICE	3	DRIFTERS, NORTH ATLANTIC	• 1986-5 • 1987-15 • 1988-25, LEVEL OFF THERE • BUDGET $375K BY 1988	• $15K FOR COMPLETE UNIT (WITH THERMISTOR, IN AIR DROP CONFIGURATION)	• DATA ANALYSIS -- 9 BUOYS/PERSON • WOULD LIKE DATA DELAY <1 HOURS • MAY GO TO "LUT" SYSTEM TO REDUCE DATA DELAY
U.S. COAST GUARD INTERNATIONAL ICE PATROL	12	DRIFTERS, NORTH ATLANTIC	• MAINTAIN SCHEDULE OF 12/YEAR DUE TO FUNDING • BUDGET $120,000	• $10K PER BUOY, COMPLETE WITH SENSORS	• WOULD LIKE SHORTER DATA DELAY PERIOD • NUMBER OF PERSONS/BUOY VARIES WITH TYPE OF DATA COLLECTED • LIMITED BY FUNDING
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH	10	DRIFTERS	• 1986-70 • 1990-100 • 1990+ - 100+ • WOULD LIKE AS MANY BUOYS AS POSSIBLE		• ARGOS DATA RATE "TOO SLOW" • POSITIONING UNNECESSARILY ACCURATE • COLLECTS FULL METEO. AND OCEAN DATA PACKAGE

TABLE 5-5 (CONTINUED)

BUOY PLATFORM CONSTITUENCY OF PRINCIPAL U.S. AGENCIES AND INSTITUTIONS

AGENCY/ INSTITUTION	1985 # OF BUOYS	TYPE	FUTURE PROJECTIONS	CURRENT UNIT COST	COMMENTS
VIRGINA INSTITUTE FOR MARINE SCIENCE	3	ATTACHED TO SEA TURTLES	• 1986-20 • 1986 BUDGET $60K • NO MORE AFTER 1986	• $3K FOR PTT, INCLUDING ANTENNA	• DATA DELAY TOO LONG • OPERATES WHEREVER TURTLES GO
NOAA/PMEL	14	ICE PLATFORMS	• 1986-6 • 1988 TO 1995 - 15/YEAR • BUDGET ABOUT $60K/YEAR	• $4K FOR CHEAP ONES (INCLUDING TRANSMITTER, ANTENNA, THERMISTOR, BUILT TO COLD WEATHER SPECS.)	• DATA LOSS: >5% UNACCEPTABLE >2% UNDESIRABLE CURRENTLY EXPERIENCE 3-4% DATA LOSS USING ARGOS • SOMETIMES EXPERIENCE 8 TO 16 HOUR "DATA GAPS" FROM SOME PLATFORMS • WOULD LIKE TO SEE DATA DELAY <2 HOURS
NDBC	90	DRIFTERS, SOUTHERN OCEANS (TOGA PROGRAM)	• 150-SPRING 1986 • 75-100 TOGAS/YEAR FOR THE NEXT 10 YEARS • 20-30 OTHERS/YEAR • TOGA PROGRAM WILL RUN 10 YEARS	• $8.9K EACH FOR 1ST 200 (2 YEARS) • AVERAGE 1 YEAR LIFE PER BUOY	• OPERATE BUOYS MOSTLY FOR OTHER AGENCIES (CONTACT POINT FOR NAVY, FOREIGN GOVERNMENT, ETC.) • SOME USERS PROCURE DIRECTLY THROUGH MANUFACTURERS • NO INTEGRATED U.S. AVAILABLE
WOODS HOLE	50	DRIFTERS, MID ATLANTIC	• 30-50/YEAR FOR SEVERAL YEARS	• $1500 FOR TRANSMITTER, $1500-2000 FOR BUOY	• WOULD BUY MORE IF COSTS WERE LOWER, APPROXIMATELY IN PROPORTION • DATA LOSS: UP TO 10% WOULD BE ACCEPTABLE • PLANNING VERY SOPHISTICATED BUOYS COSTING UP TO $50,000

TABLE 5-5 (CONTINUED)

BUOY PLATFORM CONSTITUENCY OF PRINCIPAL U.S. AGENCIES AND INSTITUTIONS

AGENCY/ INSTITUTION	1985 # OF BUOYS	TYPE	FUTURE PROJECTIONS	CURRENT UNIT COST	COMMENTS
RHODE ISLAND UNIVERSITY	30	DRIFTERS, SUB-SURFACE, IN GULF STREAM-SUBMERGED, POP UP AT END OF CRUISE	• 30 FOR NEAR FUTURE • MORE IN PROPORTION TO COST REDUCTION	• $3000 FOR MATERIALS PLUS 1.5 DAYS LABOR • EQUIVALENT COMMERCIAL ACQUISITION COST $6K	• WOULD BUY MORE IF COSTS WERE LOWER, APPROXIMATELY IN PROPORTION--INCLUDE OVERHEAD COSTS IN COMPUTATION • VERY PLEASED WITH ARGOS • DATA RATE: 256 DATA BITS ~ EVERY 45 SEC FOR 2 TO 3 WEEKS TILL BATTERY WEARS • POSITION ACCURACY COULD BE RELAXED TO 3×10^{-7} STABILITY • ACCEPTABLE DATA LOSS: 5% TOTAL MAXIMUM; UP TO 25% ERROR IN MESSAGE OK, IF CORRECTED SUBSEQUENTLY • FORESEES SIGNIFICANT FUTURE INCREASE OF IN-SITU PLATFORMS

TABLE 5-6

SUMMARY OF PROJECTIONS OF PLATFORM CONSTITUENCIES BY U.S. AGENCIES AND INSTITUTIONS[a]

AGENCY/INSTITUTION	1985	1987	1990	1995	2000
POLAR SCIENCE CENTER	22	30	30		
U.S. COAST GUARD R&D CENTER	7	7	7		
NOAA/ATLANTIC OCEANIC MARINE LABORATORY	50	70	100		
USN OCEANOGRAPHIC OFFICE	3	15	25		
U.S. COAST GUARD INTERNATIONAL ICE PATROL	12	12			
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH	10	100	100+		
VIRGINIA INSTITUTE FOR MARINE SCIENCE	3	20			
NOAA/PMEL	14	15	15	15	
NDBC	90	110	110	110	
WOODS HOLE	50	40	40		
OTHER (@10%)	30	40			
TOTAL	291	459			

(a) UNFILLED SPACES INDICATE THAT RESPONDENT COULD NOT SUPPLY PROJECTIONS

Assuming this ratio to remain constant for the less sophisticated platforms, Figure 5-5 shows the effect on the number of platforms of reducing platform costs.

- platform **costs** can be confidently forecasted to **decrease** with **time.** Figure 5-6 portrays the trend of the cost reduction: it is consistent with the cost trends experienced by NDBC during the last 10 years, by the scientific community over the last 3 to 4 years, and by the electronic market since the 1950's.

Combining the factors of Figures 5-5 and 5-6 yields the upgraded forecast shown in Table 5-7. The Table also shows our forecast for foreign platforms, on the assumption that these will continue to maintain a 45% proportion of the total platform population.

Comparing Table 5-7 with the Service ARGOS forecast of Table 5-4 (repeated at the bottom of Table 5-7) shows that the two projections are within the same "ballpark"; they differ by only about ±13% from their common average, although they were derived by independent methods. We favor the higher forecast, because we do not believe that Service ARGOS has taken into complete account the effects of future price reductions.

5.4 Potential Constituency of Latent Users

These are Agencies, industrial concerns and private persons engaged in gathering in-situ data, on a routine and/or and ad-hoc basis, and who find it necessary, or convenient and cost-effective to have these data transmitted automatically to a central repository rather than gathered manually.

An example of "necessary" data transmission are the Corps of Engineers' (COE) rivergage levels in flash-flood-critical areas, where rapid data conveyance is of the essence. An example

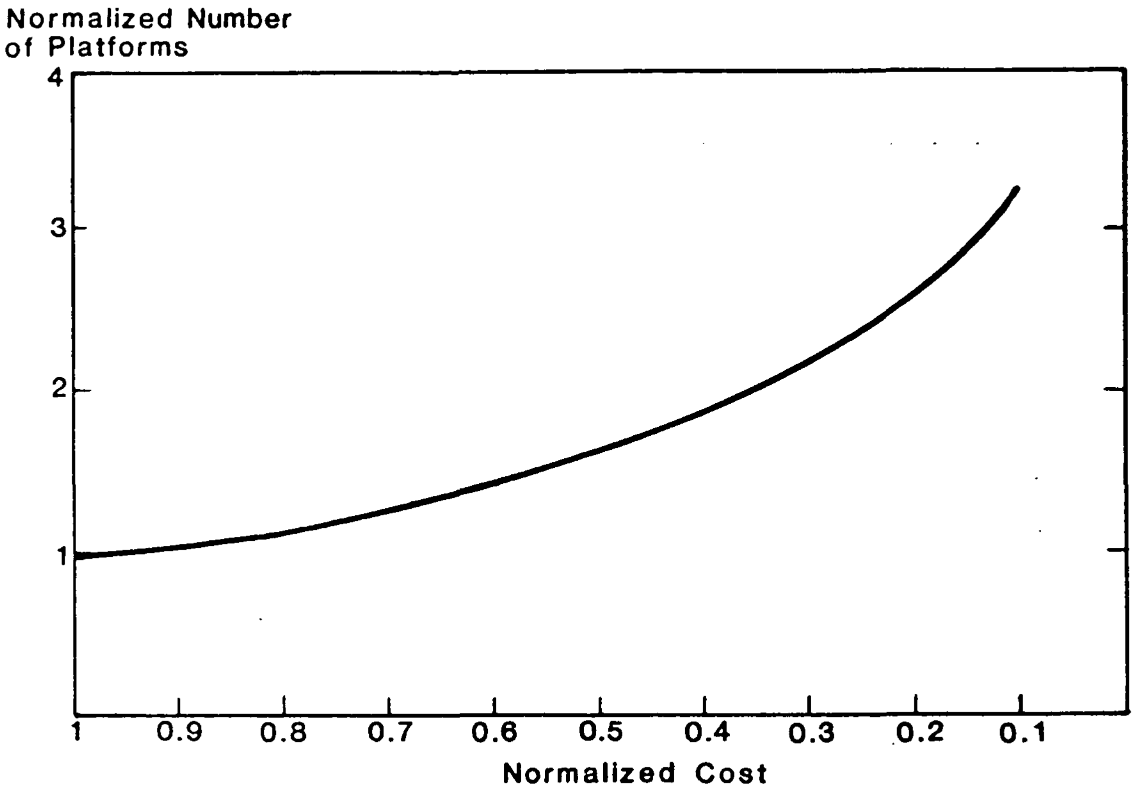

Figure 5-5. Effect of Cost Reduction on Number of Platforms

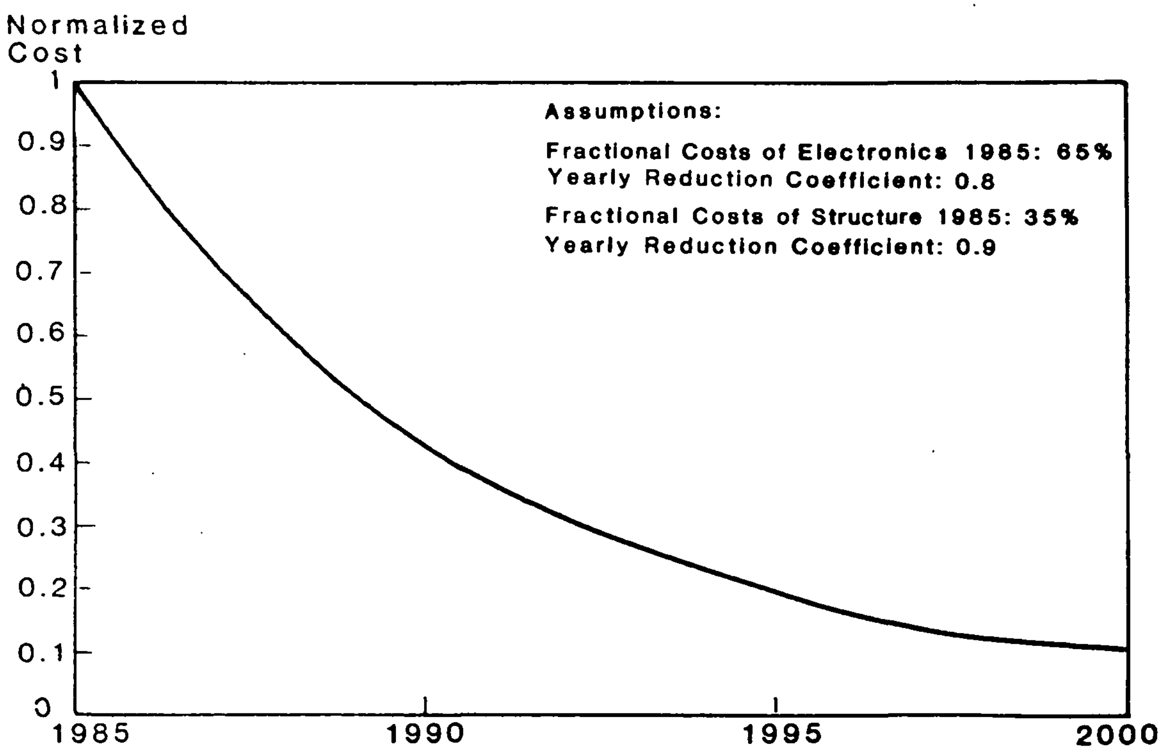

Figure 5-6. Expected Reduction of Platform Costs with Time

TABLE 5-7

PROJECTION OF PLATFORM CONSTITUENCIES BY U.S. AGENCIES AND INSTITUTIONS - UPGRADED TO REFLECT REDUCTION IN PLATFORM COSTS

	NUMBER OF SUBSCRIBERS [a]				
	1985	1987	1990	1995	2000
TOTAL U.S.	341	509	1,000	2,600	3,000
TOTAL FOREIGN	279	416	800	2,000	2,500
WORLD TOTAL	630	925	1,800	4,600	5,500
SERVICE ARGOS PROJECTION, WORLD TOTAL	753	980	1,300	2,400	4,200
AVERAGE	691	952	1,500	3,500	4,850
DEVIATION FROM AVERAGE, PERCENT ±	9	3	16	31	13

(a) Multiply by 0.8 to obtain number of users active at any one time.

of "convenient" data transmissions are the U.S. Geological Survey's (USGS) rivergage levels in non-critical sites. These data are needed for historical-statistical purposes with no particular urgency constraints: in hard-to-access sites, the cost of automatic data gathering is often less than that of manual retrieval.

Table 5-8 lists the numbers of such data stations currently in existence in the U.S., and estimates their total number world-wide.

Most of these users currently employ semi-manual data retrieval. An example are the USGS river stage gages. Most of these are instrumented with an automatic recorder, that punches the river's stage (in feet and fractions thereof) on paper tape. Approximately half the automated U.S. rivergages effect this measurement at quarter-hour intervals: one quarter, at hourly, and another quarter at semihourly intervals. The punched paper tape is retrieved periodically (typically at one to two month intervals) by technicians, that also, on that occasion, perform preventive and/or corrective maintenance.

About 7% of the USGS rivergages are instrumented with data telemetry over telephone lines. USGS's tradeoff between manual retrieval and telemetry (other than in cases where real-time data retrieval is necessary) is based strictly on cost considerations: i.e., does the actuarial cost of capital telemetry equipment and telephone service offer savings versus the cost (salary, travel) of periodic visits to the measurement station by technicians.

A fraction of the data produced by the sensors enumerated in Table 5-8 is currently telemetered via the GOES DCP system. Tables 5-9 and 5-10 show the distribution of the GOES DCP users by Agency and by application.[a] Two elements affect the question of whether these users are potential future candidates for ARGOS and/or ADCLS: a) what is the expected growth rate of

TABLE 5-8

ENVIRONMENTAL MONITORING ACTIVITIES AS OF 1979 BY FIXED SURFACE STATIONS

UNITED STATES

MEASUREMENT PARAMETERS	APPROXIMATE NUMBER OF MEASUREMENT STATIONS	APPROXIMATE NUMBER OF INSTRUMENTS (SENSORS)
Surface Water	24,800	59,600
Surface Water Quality	16,200	162,000
Groundwater and Groundwater Quality	51,200	51,200
Snowmelt/Soil Moisture	2,000	4,000
Meteorology	21,700	65,200
Air Quality	9,500	38,000
Seismic	2,200	4,400
Total United States	127,600	384,400
REST OF THE WORLD	125,000 (Est.)	360,000 (Est.)
WORLD	253,000	745,000

SOURCE: Adapted from Report "Modular In-Situ Environmental Sensor System" by ECOsystems International, Inc., contract NAS5-0-25441.

TABLE 5-9

DISTRIBUTION OF GOES DCS DATA COLLECTION PLATFORMS BY USING AGENCY AUGUST 1985

AGENCY	PERCENT
CORPS OF ENGINEERS (MOSTLY REAL-TIME NEEDS)..........	46.00
USGS..	18.00
BUREAU OF RECLAMATION.................................	11.00
USDA - FOREST SERVICE.................................	7.00
STATE GOVERNMENTS.....................................	6.50
NATIONAL WEATHER SERVICE..............................	3.50
BUREAU OF LAND MANAGEMENT.............................	2.50
UNIVERSITIES..	2.00
OTHERS..	2.90
NATIONAL PARK SERVICE.................................	0.60
TOTAL	100.00

TABLE 5-10

DISTRIBUTION OF GOES DATA COLLECTION PLATFORMS BY APPLICATION AUGUST 1985

APPLICATION	PERCENT
HYDROLOGY (MOSTLY RIVERSTAGE, REAL TIME NEEDS)	77
METEOROLOGY (MOSTLY REAL TIME NEEDS)	18
SEISMIC	2
OCEANIC	2
MISCELLANEOUS	1
	100

GOES DCS users; b) to what extent can the GOES DCS system meet the requirements of the user's demand. A reasonable answer to the first question can be sought by analyzing the historical pattern of growth of GOES DCS users. Figure 5-7 [a] depicts this historical growth.

We note firstly that the curve is "flattening". The reason is that GOES DCS, as currently configured, saturates at a level of utilization of approximately 5,000 users. In fact, between October 1984 and April 1985, over 900 users were withdrawn or rejected from the system by NOAA. According to NOAA, the current saturation is due not to DCS channel availability, but to insufficiency of the ground processing system. With the currently planned update of the ground system, NOAA expects the saturation level to increase to 10,000 users, i.e., the saturation level of the DCS itself. Thus the saturation trend indicated in Figure 5-7 is apparent and not real: it is due to system saturation rather than to "market saturation".

Secondly, we note that the growth trend has been significant: between 1980 and 1983 (when incipient saturation set in), it averaged 45% compound per year.

Thirdly, we note that the historical growth curve exhibits the behavior typical of a "logistic" curve. Logistic behavior characterizes most growth phenomena, e.g., from automobiles to radios to passenger-miles of travel. A relatively slow initial growth is followed by a faster, sustained increase, and ends finally by flattening out at a certain level known as "market saturation". The above holds true if there are no constraints to growth--e.g., the inability of the supply to meet the requirements of the demand (for example, because of system saturation). The "market saturation" connotes the maximum number of

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(a) Courtesy of NESDIS

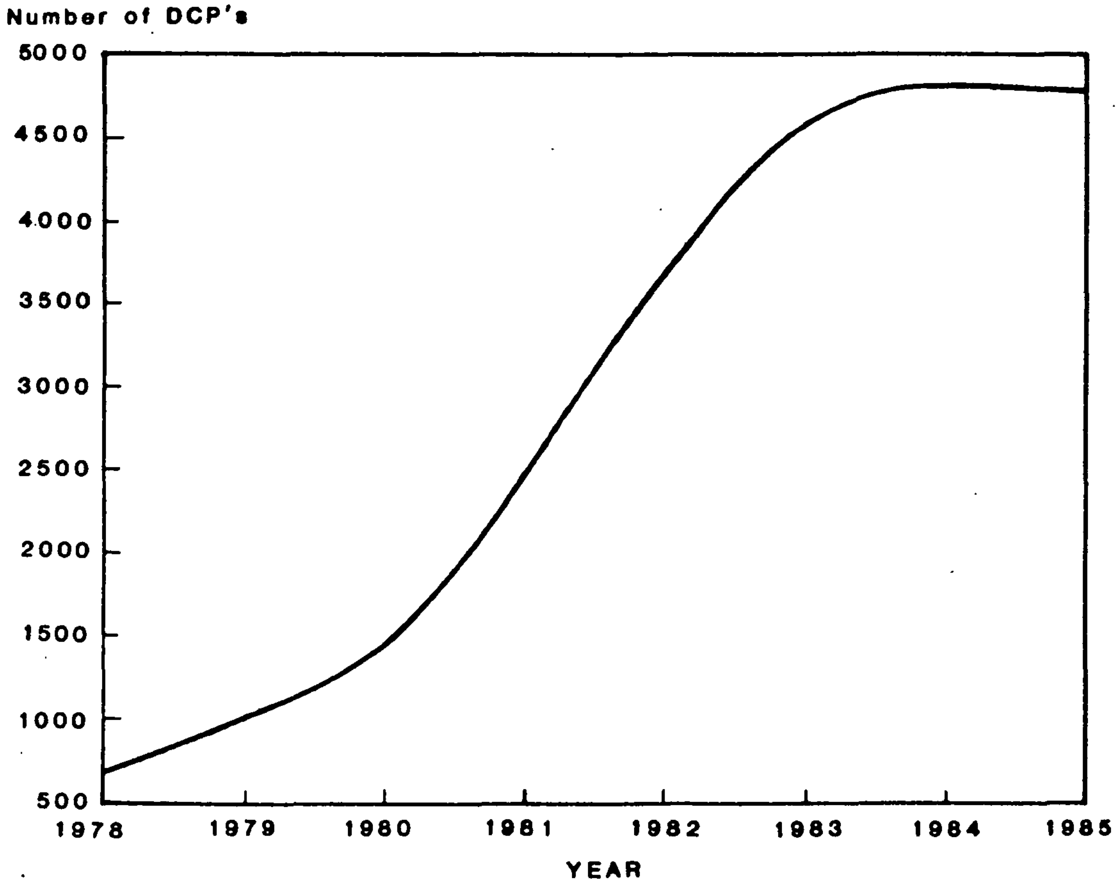

Figure 5-7. Historical Growth of GOES/DCS Data Collection Platforms (DCP)[(a)]

(a) Current GOES/DCS saturates at 5,000 users because of ground system limitations. Ultimate saturation level with unconstrained ground system is ~10,000 users.

users that will acquire the product or service, almost regardless of price. Above the market saturation level, users essentially say "we do not need any more, even if offered free (or almost free)". The market saturation level for any commodity is assessed by means of the "logistic growth curve":

$$N = \frac{Ns}{1 + ae^{-bT}}$$

where:

N	=	number of units at time T
Ns	=	saturation number of units
a,b	=	coefficients
T	=	future time (years)

The parameters a, b, Ns are computed from historical data such as are shown in Figure 5-7. The computation excludes any portion of the curve that is "flattening" due to system saturation. It is clear that the accuracy of the computation is affected by the consistency of the available data. Logistic growth curves exhibiting good accuracy are typically constructed from historical series of 20 years or more. With five years of available data, the expected accuracy, estimated to be of order ± 30%, is however still adequate for the purposes of this study, i.e., a 15-year forecast.

The logistic parameters derived from the internal evidence of the data of Figure 5-8 are approximately:

Ns	=	25,000
T_{90}	=	1992 (year of 90% saturation)
a	=	50
b	=	0.45

Figure 5-8 depicts the expected logistic growth in the absence of constraining factors. It indicates that approximately 25,000 US

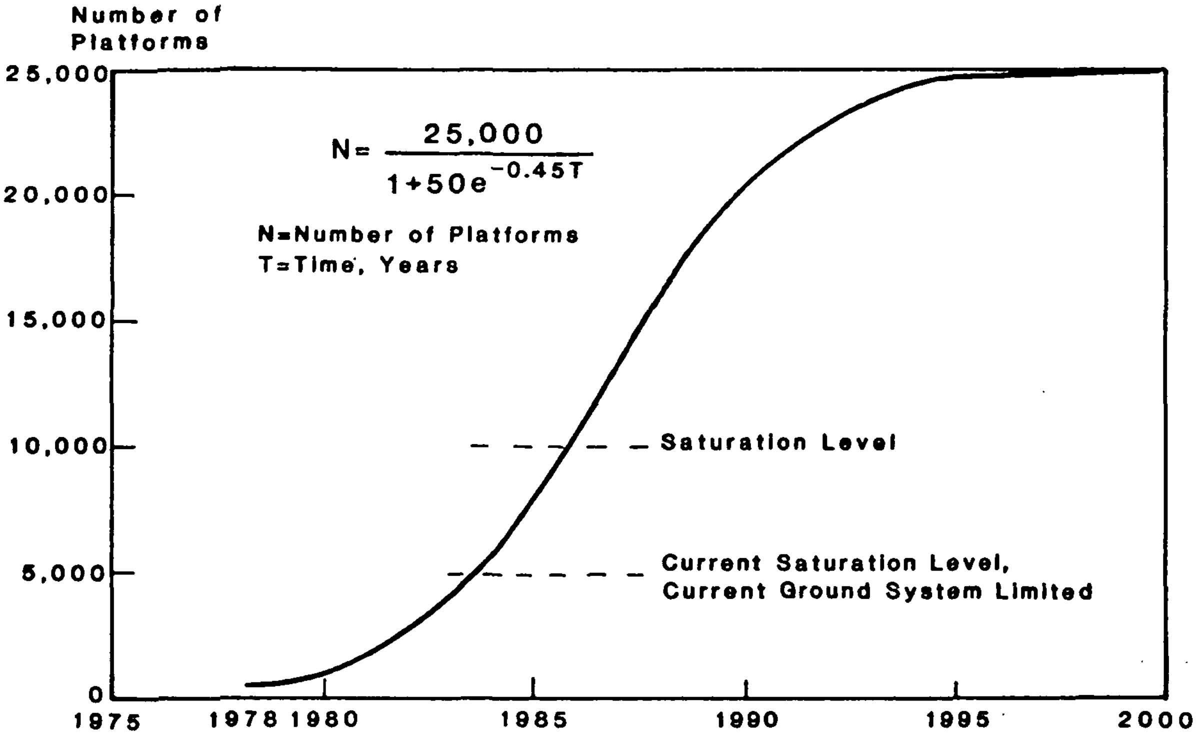

Figure 5-8. Estimated Logistic Growth of GOES DCS Platforms

users can be expected to wish to access the GOES DCS system by year 1995. For the rest of the world, a conservative estimate is an additional number of users equaling the US users, i.e., a total of 50,000 users. It is worth repeating that, because of the shortness of the available historical series, these data are not more accurate than ±30%.

Three questions are key in assessing the possible role of ARGOS/ADCLS in this "market":

- Firstly, will GOES/DCS (and its foreign counterparts) be able to meet the requirements of the anticipated user demand for service

- Secondly, can the discontinuous temporal coverage provided by ARGOS or ADCLS satisfy the user's requirements

- Thirdly, what would be the effect on the user's constituency caused by the fact that the GOES/DCS service is free, while ARGOS charges a fee

The outlook for the first question is that a more capacious GOES/DCS system does not currently appear to be included in any US or European funding plan. The prognosis for the realization of such a system is at present uncertain. If it is not realized, a significantly improved ARGOS or a timely ADCLS could address and aspire to capture a major portion of the GOES/DCS user "overflow".

As regards the second question, most candidate users do not require real-time data. For example, most USGS streamgage records are retrieved once every month or two. Timeliness of retrieval, i.e. in a matter of hours, is important to certain users--this can be provided by an improved ARGOS or an ADCLS. If no advanced GOES/DCS is in the cards, an obvious split would be for the GOES/DCS to accommodate the users requiring real-time data (minutes to fractional hours), while a polar low earth orbit (LEO) system such as ARGOS or ADCLS would address the other users.

With respect to the third question related to the price of service, we note that currently, the ARGOS service prices are modest with respect to the capital cost of the telemetry data formatter, transmitter, and related elements such as power supply. Table 5-11 compares these costs and indicates that, while the "free" price of GOES DCS is attractive, it is not an overwhelming economic determinant. The major determinant for using GOES DCS appears to be either the real-time need for the data, or the fact that automatic data retrieval is less costly than manual collection.

5.5 **Constituency of Peak Users**

These represent unusually large deployments of surface sensors, occurring upon occasion of major national and international cooperative programs.

The principal such programs, planned for the time era up to year 2000, are:

TOGA (Tropical Ocean Global Atmosphere) will run from 1986 to 1996 in the Southern hemisphere. Principal measurements will be sea surface temperature, subsurface temperature profile, air temperature. The International TOGA Project Office in Boulder, CO. estimates the number of TOGA drifters at 150 per year through 1996, of which 80 to 100 will be U.S. - owned: 60 of these will be procured through NDBC. NDBC expects that TOGA will experience a major increase in 1993, with from 300 to 400 new drifting buoys deployed by several U.S. agencies.

TABLE 5-11

TYPICAL COSTS OF DATA RELAY SYSTEMS FOR IN-SITU PLATFORMS--GROUND PORTION

1985 DOLLARS	TYPE OF PLATFORM	
	SIMPLE	SOPHISTICATED
CAPITAL COST OF DCP (Signal Conditioner, Logic Circuits, Modulator, Transmitter, Antenna)	$2,500	$4,000
YEARLY COST OF DCP (Interest, depreciation, maintenance)	$700	$1,350
COST OF DATA LINK, YEARLY		
GOES/DCS	0	0
ARGOS @ 10% DUTY CYCLE	$250	$360

Source: Adapted from Report "Modular In-Situ Environmental Sensor System" by ECOsystem International, Inc., contract NAS5-0-25441.

OHTSE (Ocean Heat Transport and Storage Experiment) is being run by NOAA's Environmental Research Laboratory, Miami, Florida. NOAA estimates about 50 drifters per year from 1987 to 1989, possibly 100 per year by 1990. Budget for buoys is $1 million.

STORM EAST is expected to operate off the U.S. East Coast beginning circa 1993, using approximately 100 drifters.

STORM WEST is planned to operate off the U.S. West Coast beginning circa 1996, using between 100 and 200 drifters.

WOCE (World Ocean Circulation Experiment). Still in the planning stage by the WOCE Planning Office, with NSF the lead agency, NOAA and NASA contributing, this major experiment's budget is proposed at $55 million. Current plans are for a 1990-1994 yearly deployment of:

- 2,000 current-measuring drifters
- 1,800 pop-up drifters
- 150 temperature-profile drifters
- 350 flux drifters
- 600 acoustically tracked drifters

The program plans to use four satellites, none of which are as yet launched: N-ROSS, TOPEX, OCI, GRN.

Table 5-12 summarizes these program's data pertinent to ARGOS and/or ADCLS, based on current plans by the various Experiment Program and Planning Offices. We note that the WOCE program dominates the scenario in terms of number of drifters, but is currently planned to last only 4 years, from 1990 through 1994. Historically, large experiments have been launched at intervals of 6 to 10 years. Further, the anticipated reduction in drifter costs will act to encourage additional programs as time progresses. It is thus reasonable to assume that the number

TABLE 5-12

NUMBER OF PLATFORMS FORECASTED TO BE DEPLOYED BY PEAK USERS (a)

EXPERIMENT/PROJECT	PREDOMINANT LOCATION	PREDOMINANT TYPE OF PLATFORM AND DATA LOAD	NUMBER DEPLOYED IN YEAR 1990	1993	1995	2000
TOGA	SOUTHERN HEMISPHERE	MEDIUM DRIFTERS				
WORLD TOTAL			150	500	500	
OF WHICH U.S.			90	300	300	
OHTSE	WORLD	MEDIUM DRIFTERS				
WORLD TOTAL			150	150	150	
OF WHICH U.S.			100	100	100	
STORM EAST	U.S. EAST COAST	MEDIUM DRIFTERS				
WORLD TOTAL				120	120	
OF WHICH U.S.				100	100	
STORM WEST	U.S. WEST COAST	MEDIUM DRIFTERS				
WORLD TOTAL					200	200
OF WHICH U.S.					150	150
WOCE	WORLD	MEDIUM DRIFTERS				
WORLD TOTAL			4,000	4,000		
OF WHICH U.S.			2,500	2,500		

(a) As stated by the Experiment Planning Offices of platforms will not drop suddenly beyond 1994, as Table 5-12 indicates, but will continue at relatively sustained levels. Table 5-13 aggregates the data and includes a reasonable estimate for programs, not yet identified, but likely to be implemented in the 1995-plus time frame.

5.6 **Constituency of EOS Users**

These are scientists that are planning to analyze data from the Earth Observing System to be located on Polar Platform--an element of NASA's Space Station System.

The Working Group Report TM 86129 on Science and Mission requirements of August 1984, updated by the Report "Earth Observing System: Implementation Strategy", slated for publication in February 1986, set forth requirements of the scientific community for observations from EOS.

We expect that these requirements are subject to change, as the thinking of the Working Groups and Steering Committee continues to evolve, and as requirements from the International Scientific Community are gradually integrated with U.S. requirements. Nevertheless, the information supplied by the Working Group can be used as a preliminary "benchmark" to assess ADCLS requirements.

These requirements stem primarily from the need to **calibrate** the earth-observing sensors with in-situ **reference** data, in order to enhance the space sensor's **absolute** and/or **relative accuracy.** By absolute accuracy is meant the actual value of the parameter measured, e.g., ocean surface temperature in degrees Kelvin; by relative accuracy is meant the differential between parameters, either as a function of time or between different geographic locations. Examples of the latter are the difference in the surface temperature of a given location between noon and midnight, or between different locations at the same time.

TABLE 5-13

ESTIMATED NUMBER OF PLATFORMS THAT WILL BE DEPLOYED BY PEAK SUBSCRIBERS, INCLUDING ADDITIONS FOR PROGRAMS NOT YET IDENTIFIED

	1990	1993	1995	2000
TOTAL NUMBERS DEPLOYED	4,300	4,500	3,500	4,000
OF WHICH , U.S.	2,700	3,000	2,500	2,500
TOTAL TRAFFIC DEMAND, ERLANGS [(a)]	47	49.5	38.5	44
TRAFFIC DEMAND PER AVERAGE FOOTPRINT[(b)]	1.6	1.8	1.3	1.5

(a) Medium length data message of 128 bits assumed (see footnote [(b)], page 10), 55 sec. repetition rate, equivalent to $\frac{0.32 + 0.28}{55} = \frac{0.6}{55} = 11$ mE per platform.

(b) Assuming 29 equivalent footprints, see Figure 5-3 and Table 5-3.

The residual inaccuracies of remote sensors, hence the desirability of their calibration, derives from two major causes: i) the fact that the radiation entering most remote sensors is a combination of desired and extraneous elements, whose mix varies with location and time. Appropriate calibrators (e.g., reference electromagnetic generators) are provided on-board earth observing spacecraft to compensate for sensor drift: however, these calibrators in most cases cannot separate the desired from extraneous signals, nor can they correct for measurement **biases.** Moreover, even the best calibrators are themselves subject to some drift; ii) the radiation received by the sensor often is a function of certain target parameters that are only poorly known, e.g., surface emissivity. Imperfect knowledge can and frequently does give rises to **biases** that can only be eliminated by in-situ calibrations.

The need for calibration varies as a function of the particular sensor. Let us illustrate the calibration needs of typical sensors, then recapitulate the various requirements.

5.6.1 Illustration: Calibration of Microwave Radiometers by In-Situ Data

According to the Working Group reports, References 9, 10, use of microwave radiometers is planned primarily to measure surface temperature (ocean and land), soil moisture, the extent and thickness of sea and land ice, snow depth. For certain measurements, especially ocean temperature, the data from microwave radiometers are generally complemented by data from thermal IR sensors (TIR).

Microwave radiometers operate by sensing the "tail" of the emission spectrum radiated in the microwave range from the "gray" body representing the surface.

A major advantage of microwave radiometry is its ability to "penetrate" clouds--because the microwave absorption of water vapor, as well as of other atmospheric constituents, is relatively small, especially at the longer wavelength below approximately 3 centimeters.

A disadvantage of microwave radiometers is that their accuracy is affected by: a) the apparent emissivity of the surface, which varies significantly as a function of surface objects' dielectric constant (for land sensing) and as a function of sea state, winds, foam cover (for ocean sensing), b) the radiation scattered from the atmosphere; c) the residual absorption by the atmosphere and clouds, especially at the higher frequencies. As such, there is no "best band" for microwave radiometry. Advanced systems seeking good accuracies employ several, strategically located microwave bands, typically lying in the range between approximately 24 centimeters and 6 millimeters (some advanced experiments operate at frequencies as high as 180 GHZ). Each of these bands suffers from its own limitations which induce inaccuracies; the idea is to combine the "limitations" in such as way that they serve to "calibrate" each other.

For example, a highly variable influence on microwave sensing of ocean surface temperature is sea state. If the ocean surface is smooth, it acts as a reflecting mirror and thus appears relatively "cool". If the surface is rough, it acts as a diffused emitter and thus will appear warmer. In the latter case, an error of measurement will result. Experimental data show that significant levels of dispersion, thus of apparent "warming", begin to occur when the wave height approaches one quarter wavelength of the microwave radiation. Thus sea surfaces which appear smooth, thus cooler, at one wavelength can look rough and thus "warmer" at another. Well designed microwave radiometers tend to reduce these errors by utilizing the slope functions occurring at different microwave bands--for example, 6.6, 10.7, 18, 21, 37 GHZ. To achieve high accuracies, the residual bias error can be corrected from knowledge of sea state, or actual sea surface temperature, from an in-situ sensor.

State-of-the-art Microwave Radiometers operating in a single band experience errors in ocean surface temperature of order 10^{o} to $14^{o}K$. Multi-band microwave radiometers typically can reduce this error to the order of 1^{o} to $2^{o}K$.

5.6.2 Illustration: Calibration of Thermal Infrared Radiometers by In-Situ Data

This category of instrumentation is used primarily for measuring the temperature of the ocean and land surfaces.

Thermal Infrared (TIR) Radiometry is in principle more accurate than microwave radiometry because it operates at or near the peak of the black or gray body radiation of the earth's surface. Another advantage is that by virtue of the much smaller wavelength, in contrast with microwaves, TIR can provide much higher surface resolutions. TIR measurements are much less sensitive to sea state than measurements from passive microwave radiometry. Errors are induced by atmospheric absorption, principally water vapor. A major impediment is that TIR radiation is opaque to clouds, thus a TIR sensor will not operate over cloud cover. Statistical data indicate that, on the average, world-wide, one might expect approximately 50% cloud cover. For this reason, TIR sensors operate in conjunction with microwave radiometers: where the TIR is "blind", the microwave sensor will provide data, albeit at somewhat lower accuracy.

5.6.3 Desirability of Calibration

Quite apart from sensor drift, we see that environmental conditions induce inaccuracies. Strategically located, accurate in-situ sensors can provide data to "calibrate out" the errors. It is clear that, in non-real time scientific applications, these "calibration" data need not be supplied very rapidly: they should be available to the scientific investigator as a data set, adjunct to the main sensor data set, when the investigator is performing his analyses.

5.6.4 Assessment of the EOS User Requirements for In-Situ Data

The assessment of the requirements for in-situ measurements was accomplished in two ways: a) by discussions with knowledgeable scientist/users; and b) by computation based on accuracies desired and achievable from remote sensing and scale factors of the phenomena involded.

Discussions with involved scientists indicate certain approximate requirements for in-situ sensors for various elements of the EOS program. The requirements are intended to be for world-wide coverage.

The summary results are shown in Table 5-14. The following summarizes the philosphy underlying the values shown in the table.

From an EOS standpoint, the most important measurements are those conducive to improve our understanding of the hydrologic cycle--i.e., how water moves around the world.

From the scientific standpoint, a major reason for seeking this knowledge is to assess whether man-made activities (e.g., generation of CO_2) will affect the climate and the sea level. For example, if we knew that the increasing content of atmospheric CO_2 would eventually raise the sea-level with deleterious consequences for coastal areas and ports, we could begin planning modifications of our energy generation pattern in such directions as to ward off major deleterious effects. For

TABLE 5-14

IN-SITU CALIBRATION REQUIREMENTS OF EOS SCIENTIFIC USERS

Measurement	Scale Dimension, Km	Cell Size Km x Km	Location	Area of Coverage Km^2	Number of Cells	In-situ Measurements Per Cell	Total Number of In-situ Measurements
Soil Mositure	1,000	1,000 x 1,000	Land Mass	1.25×10^8	125	5	650
Sea Surface Temperature	5,000-10,000	5,000 x 5,000	Oceans & Major Lakes	3.8×10^8	15	25	375
Land Surface Temperature	1,000	1,000 x 1,000	Land Mass	1.25×10^8	125	5	650
Precipitation	1,000	1,00 x 1,000	Oceans	3.8×10^8	380	3	1,140
Antarctic Ice	1,000	1,000 x 1,000	Antarctica	2.7×10^7	27	5	135
Arctic & Sea Ice	500	500 x 500	Arctic & Subarctic Oceans	3×10^7	120	2	240
Ocean Measurements (Phytoplankton, Biolumineseense, Color)	500	500 x 500	Selected Ocean Areas	3×10^7	120	2	240
Atmospheric Measurements (Water Vapor, Winds)	1,000	1,000 x 1,000	World	5.1×10^8	510	8	4,180

instance, we could use more nuclear fission energy in place of coal; accelerate R&D in nuclear fusion; minimize the processes of coal gasification; accelerate R&D in electric automotive transportation. The hydrologic cycle, moreover, is key to agricultural production, the availability of water resources, etc. The principal measurements of interest to track the hydrologic cycle are:

- Soil moisture--key to estimating evaporation from water surfaces and evapotranspiration (ET). These estimates are in turn important to determine how much moisture will be evaporated into the atmosphere, hence how much precipitation to expect.

- Water vapor content of the atmosphere. Important to compute the evaporation from the oceans.

- Measurement of precipitation. On land, this is accomplished by rain gage networks, on the oceans, what needs to be perfected are good unattended, oceanic, precipitation gages.

- Determination and measurement of soil cover, principally to assess runoff from snow and ice. With current and foreseeable microwave techniques, this measurement is qualitative and needs to be integrated with empirical, in-situ measurements.

- Sea surface temperature (SST). Somewhat secondary to the hydrologic cycle, it is key to climate measurements.

- Ice measurements. The degree of net ice accumulation or disappearance is an indicator of future sea level rise and fall, and an important parameter in climate assessment.

Other important scientific measurements are included in Table 5-14.

It is clear from Table 5-14 that many of the required measurements can be accomplished by using multiple sensors located in the same in-situ platform. Table 5-15 coalesces these multiple requirements into non-redundant requirements, i.e. the number of individual in-situ platforms needed to accomplish the EOS program.

5.7 Integration of User Constituency

We have thus far assessed separately and independently the expected future data traffic for ARGOS and/or ADCLS, for the following categories of users: Conventional, Latent, Peak, and EOS users.

We now proceed to aggregate the traffic requirements of the users, employing the following criteria:

- Our **pessimistic** approach assumes that 1) the GOES DCS system will be upgraded, thus none of the forecasted "latent" GOES DCS users will seek ARGOS data relay services; 2) in view of the projected high costs of space station, the EOS funding will not include as many in-situ platforms as the EOS users desire--thus we have reduced the EOS requirements by a factor of two; 3) the lower, service ARGOS forecast is correct, rather than our higher forecast based upon discussions with the U.S. user community, and extrapolation of the community's traffic demand.

- Our **optimistic** approach assumes that 1) an improved GOES DCS will not be implemented by year 2000 (but the ground segment will be upgraded), thus the traffic

TABLE 5-15

NON-REDUNDANT IN-SITU PLATFORM REQUIREMENTS OF EOS SCIENTIFIC USERS

Category of Measurment	Total Number of In-situ Platforms	Type of Measurement	Type of Platform	Millierlangs Per Platform[(a)]	Total Erlangs
Land	650	Soil moisture, Land surface temperature	Fixed	4.7	3
Ocean and water surfaces	1,140	Precipitation, sea surface temperature Other ocean measurements	Drifting	9.4	10.7
Arctic and Subarctic sea	240	Temperature, height, age	Drifting & fixed	7	1.6
Antartic ice	135	Snow depth, and seasonal variation thereof, temper-ature	Fixed	7	0.9
Atmosphere	4,180	Water, vapor, winds, temperature	Balloon	4.7	19.6
Total	6,345				36

(a) Based on 280 msec fixed transmission, plus 120 msec sensor data (48 bits @ 2.5 msec), repetition rate 85 sec, which is the average of the 55 sec rate for drifters and the 120 sec rate for fixed platforms.

spillover above the saturation limit of 10,000 users will be captured by ARGOS and/or ADCLS; 2) that such a spillover will occur for U.S users only; and 3) that all users will deploy their maximum forecasted number of platforms (equal to 0.8 x number of subscribers).

Tables 5-16 and 5-17 synthesize the two approaches. From these tables, the following conclusions can be drawn:

- With reference to Table 5-3 and Figure 5-2, that show that there are 29 equivalent footprints, the **average** user constituency, and corresponding average erlang traffic demand **per footprint** are:

	1990	1995	2000
Pessimistic Case - per footprint			
Average Number of Platforms	154	251	314
Average Erlangs	1.6	2	2.5
Optimistic Case - per footprint			
Average Number of Platforms	388	840	960
Average Erlangs	2.6	4.5	4.9
Mean Case (average between	271	545	637
optimistic and pessimistic)	2.1	3.25	3.7

- Our analysis and discussions with users counsel the adoption of the **Mean Case** for our "best" forecast. This is because: 1) the "optimistic" assumption that NOAA will not upgrade its GOES DCS spaceborne data relay segment by year 1995 or so is somewhat unrealistic; 2) the "optimistic" assumption that the EOS users will be

TABLE 5-16

INTEGRATED USER FORECAST - PESSIMISTIC APPROACH [(a)]

User Category	Number of Platforms-Total Erlangs 1985	1987	1990	1995	2000
Conventional (Service ARGOS forecast)	602-4.6	784-6.0	1,040-7.9	1,920-14.7	3,360-25.7
Latent	---	---	---	---	---
Peak	---	---	3,440-37.6	2,800-30.8	3,200-35.2
EOS	---	---	---	2,560-12	2,560-12
TOTAL	602-4.6	784-6.0	4,480-45.5	7,280-57.5	9,120-72.9

(a) Assumes that 80% of the subscribers are users, i.e., are active at any one time.

TABLE 5-17

INTEGRATED USER FORECAST - OPTIMISTIC APPROACH [a]

	Number of Platforms-Total Erlangs				
User Category	1985	1987	1990	1995	2000
Conventional [a] (U.S. user forecast)	602-4.6	784-6.0	1,440-11	3,680-28	4,400-34
Latent (U.S. users alone @ 3.7 mE) [b]	---	---	6,400-24	12,000-44	12,000-44
Peak	---	---	3,440-40	3,600-31	3,200-35
EOS	---	---	---	5,080-29	5,080-29
TOTAL	602-4.6	784-6.0	11,280-75	24,360-132	27,880-142

(a) Assumes that 80% of the subscribers (platforms) are active at any one time.

(b) The millierlang rate per platform is computed, from Service ARGOS data, based on an average of two sensor words (160 msec.) plus fixed time (280 msec), every 120 sec. This equals (0.44 sec) ÷ (120 sec) = 3.7 mE.

granted all their wishes for in-situ data also appears somewhat extreme; 3) the full realization of the "optimistic" forecast implies a growth by a factor of 40 in the number of platforms in the decade 1985 to 1995. This is equivalent to a yearly compound growth rate of 45%, thus departing markedly from the best historical growth rate (NDBC's moored buoys) of 25% per year--factor of 9 in ten years).

- With reference to Figures 5-2 and 5-3, we readily see that the world distribution of platforms is far from uniform. Platforms are highly concentrated in certain footprints, e.g. footprint Nos. 1, 10, 11, 12, 26, see Table 5-3. These "dense" areas correspond to Europe and its coastal areas, the U.S. and its coastal areas, the Arctic region, and the South Atlantic. Our analysis thus far shows no overwhelming reason why this pattern of concentration ought to change drastically, especially under the "optimistic" assumption of capture of the latent GOES DCS users, that are essentially contained within the U.S. (already a "dense" area). Under the reasonable assumption that the concentration pattern will remain approximately similar to the current user pattern shown in Figures 5-2 and 5-3, Figure 5-9 shows the distribution by footprint estimated for year 2000 for the **mean** case.

The preceding provides the traffic forecast. In the next section, we address ARGOS' capability to meet the requirements of the forecasted traffic.

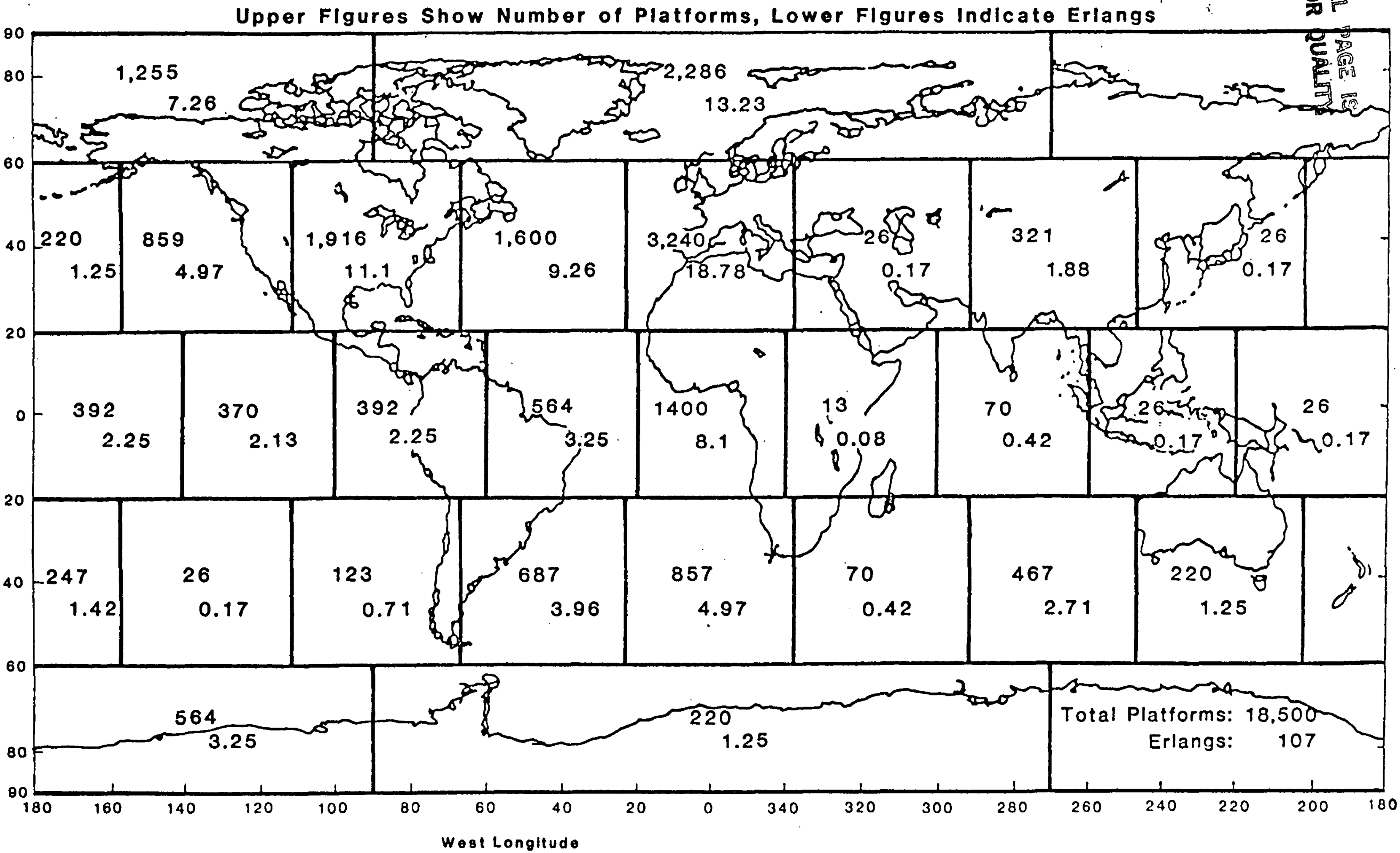

Figure 5-9. Total User Platform Population and Traffic Demand per Footprint Year 2000 - Mean Forecast

6.0 THE CAPABILITY OF ARGOS TO SERVE THE USER CONSTITUENCY

6.1 Approach

The ARGOS system provides two types of services; i) **data relay**; ii) **position fixing.**

In what follows, we treat first the capability of ARGOS to meet the requirements of the user's demand for data (Sections 6-2 through 6-6); next we address ARGOS' capability to deal with the user's demand for position fixing (Section 6-7).

In common with any communications service, two principal parameters affect the performance of the ARGOS data relay system:

- Loss of data from system **"line blockage"** (in radio systems also known as **"interference"**): this occurs when the demand for service exceeds the system's capability.

- **Delay** in data **delivery**, above and beyond what the subscribers are willing to tolerate. This can be caused, in part by the effects of line blockage (requests for free channels are not honored right away, the messages must be repeated till the next satellite pass, with consequent time delays); and, in part, by insufficient data processing capability of the ground segment.

As regards the **line blockage**, the factor that expresses the level of the system's saturation is the "grade of service".

By this is meant the fraction of attempted messages that is able to "get through" (in the first attempt). For example, a grade of service of one in ten (1:10) means that, out of ten attempted calls, one will not get through in the first attempt. Repeated messages will eventually "get through" -- the "price" is longer access time. An example of the grades of service customary in telecommunications is offered by the U.S. telephone service (including satellite relays), where the standard is 1:200 (one call out of 200 is blocked); the "threshold of discomfort" (at which users begin to feel uneasy) is approximately 1:50; and the "threshold of disservice" (at which complaints begin arriving at the telephone company) lies between 1:20 and 1:10. In the case of data transmission, some services "hold" the outgoing data until a transmission channel becomes free. The corresponding grade of service can be expressed as the average delay between the transmitting user's forwarding the data and the receiving user's obtaining them. In the case of U.S. radio paging systems, for example, this delay is typically on the order of 10 minutes. The "hold" feature is not used in the current ARGOS system.

The grade of service experienced by any multi-user communication system is a function of: the **number** of available channels; the traffic **demand**, conventionally expressed in erlangs[a]; the **way** in which the channels are made available to the incoming message traffic[b]; and the **manner** in which "competing" messages are handled. In hardwire and radio cellular systems, the first message finding a free channel is accepted, subsequent messages are rejected until the first message is completely delivered. In radio systems, this message exclusion

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(a) The erlang unit is the ratio between the length of the message or messages and the time available for their transmission, both expressed in the same units. For example, a message lasting one minute, transmitted during one available hour, represents 1/60th of an erlang (16.6 millierlangs).

(b) If the interconnection is such that any one of the available channels can be made available, on a "first come first served" basis, to any one of the incoming messages, the system is known as "trunked". This is the case with ARGOS.

policy is "softer", because "hard" switches are absent. In most well-designed radio receivers, once a signal is acquired and locked on, interference by subsequent competing signals is reduced--typically from 6 to 12 db. The reason is that the signal acquisition process generally involves uncertainty as to the signal's exact characteristics--thus a certain bandwidth is needed, encompassing the region of uncertainty. Upon reception and lock, the uncertainty is reduced, thus a narrower bandwidth is sufficient. If competing signals are not overpowering, this results in a degree of **immunity** against interference. In the ARGOS system, all platform transmitters emit approximately the same peak power. As shown in Figure 6-1, the relative signal strengths arriving at the satellite from platforms lying along the footprint's diameter will differ in power by no more than 10db. We can therefore assume that the ARGOS receiver is (or can be made) to a significant extent "immune" to interference by signals competing with the "first come, first served" signal. We note that the assumption of complete immunity is "optimistic", meaning that the resulting ARGOS performance estimates are the best achievable or **upper limits** dictated by the laws of nature. We note that the "ideal" case can be closely approximated in a "perfect" polling system, where each platform is queried separately by the satellite, and transmits only in response to the query.

We will later compare this "optimistic", ideal performance with the assumption of "zero immunity", i.e. where any signal overlap causes interference, hence loss of both signals; and with the assumption of "partial immunity", i.e., where interference is reduced by realistic factors.

6.2 The Total Immunity (Optimistic) Assumption

From the aforegoing, the "best possible" or "ideal" or "limiting" grade of service for ARGOS can be expressed by means of the Erlang B formula:

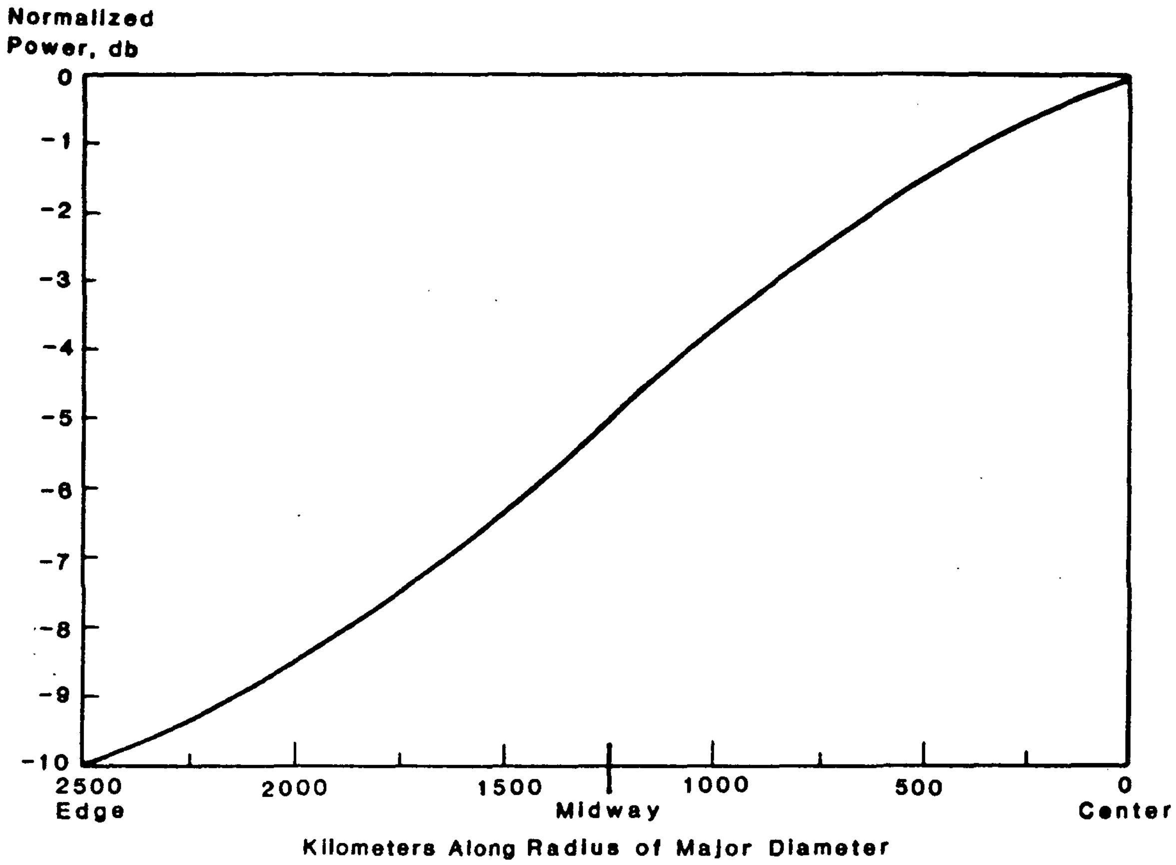

Figure 6-1. Power Level Along Radius of Major Diameter of ARGOS Footprint

$$P_b = \frac{E^n}{n!} \frac{1}{\sum_{o}^{n} E^n / n!} \quad (6\text{-}1)$$

where:

P_b = probability of line blockage (on first attempt)

E = traffic demand, Erlangs

n = number of trunked channels

The Erlang B formula applies to the case in which a given request for access to a channel is "cleared" (not held) should the channel turn out to be unavailable (if it reappears later, it is considered as a "new" call). This is the case with ARGOS under the postulated assumption of no interference with the first accepted signal by subsequent messages.

Strictly speaking, 6-1 is valid for the case of a large number of message sources (theoretically infinite). In practice, the departures are quite small down to ten or so sources. Since, moreover, we are interested in the ARGOS performance near saturation, i.e., in the presence of numerous sources, we can disregard the cases of very few sources.

In the ARGOS system, the number of channels, n, equals 4 per satellite [(a)]. There are 8 channels for both satellites: however, the 8 channels are not trunked, because they are not available simultaneously within the same footprint. We treat the case of a single 4-channel system first.

(a) The single 401 MHz channel, approximately 24 kHz wide, is actually "split" into 4 "pseudochannels" (data recovery units) by ARGOS' spaceborne receiver. These are available on a first come, first serve basis. To the user, this arrangement looks like 4 trunked channels.

Figure 6-2 shows the grade of service versus traffic demand for a "single" attempt at communicating. The significance of "single" attempt can be visualized in two ways: 1) imagining that each transmitter signals but once during the satellite's passage; or, equivalently, 2) as the probability of any one transmitter finding a free channel on the first try.

It can be seen, for example, that if we wished to maintain the signal loss at a low level, say 2% (signal throughput 98%), no more than 1 Erlang ought to be processed by the system (on a one-query basis). We note in passing that the one-query case is of interest for very sophisticated platforms transmitting very long messages, for example some of the oceanic platforms currently being planned by Woods Hole.

Conventional platforms repeat their message during the ARGOS satellite's passage, with typical repetition rates of the order of 50 to 60 seconds.

Each attempt at transmission represents an "independent experiment". Thus if the traffic statistics remain the same between attempts, the probability of any one transmitter "getting through" in k attempts is:

$$P_k = 1 - P_b^k \qquad (6\text{-}2)$$

and

$$P_{bk} = 1 - (1 - P_b^k) = P_b^k \qquad (6\text{-}3)$$

where:

- P_k = probability of successful message conveyance in k repeated attempts
- P_b = probability of channel blockage (one-shot)
- k = number of attempts

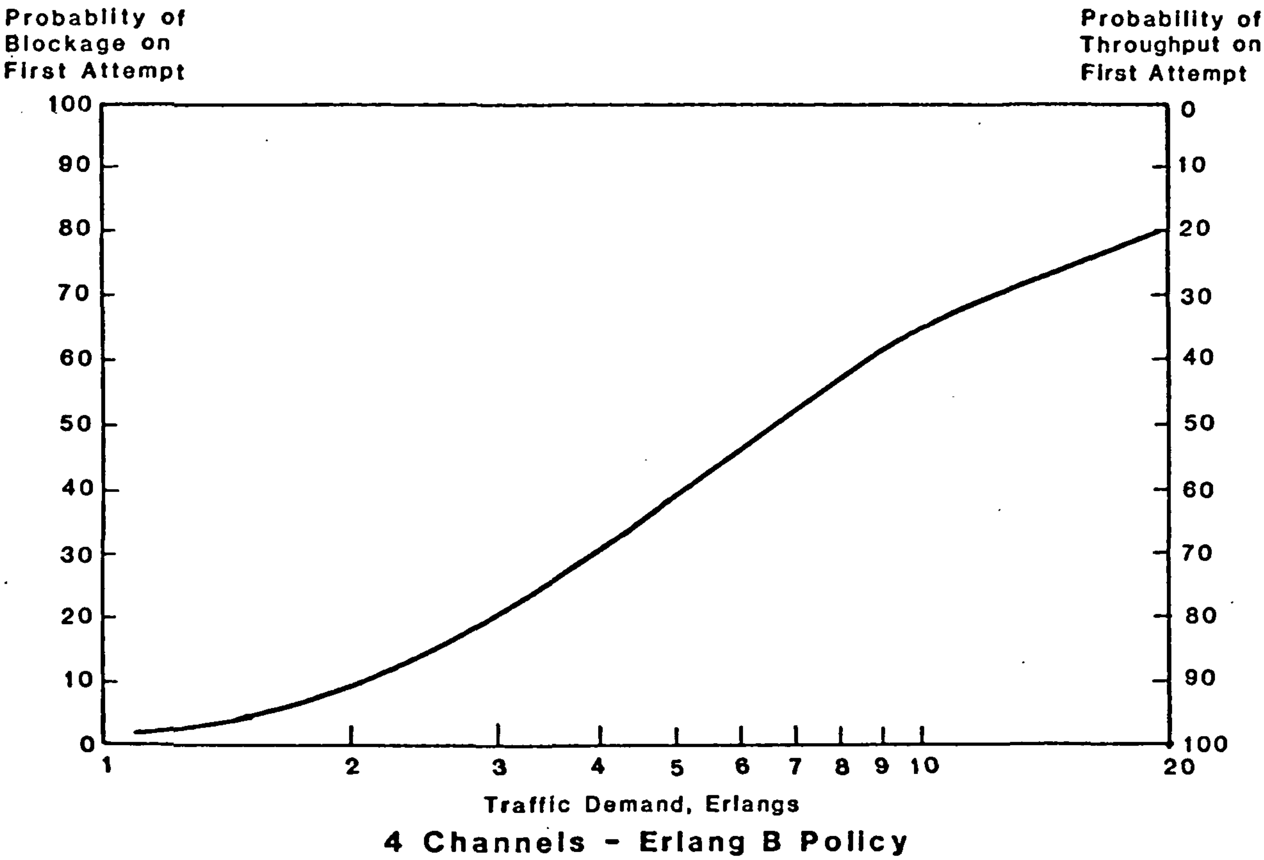

Figure 6-2. Channel Blockage Versus Traffic Demand - First Attempt
Total Immunity, Optimistic Assumption

P_{bk} = cumulative probability of channel blockage in k attempts

The diameter of the ARGOS footprint at 5^0 elevation, is 5,000 Km; the satellite's orbital speed at 800 Km altitude is such that **on the average** a footprint passage lasts approximately 600 seconds. We use the term "on the average" to mean that, although platforms lying towards the edges of the footprint will dwell less time within the ARGOS field of view in that particular pass, they will experience full or close to full dwell time during a subsequent pass.

The repetition rate of the drifter platform is of order 50 to 60 seconds. Hence, the maximum number of attempts possible during a satellite overpass is 10 to 12, thus k equals 10 to 12.

For fixed land platforms, that have average repetition rates of the order of 150 seconds, k $\approx$ 4.

Inverting 6-3, the required one-attempt probability of channel blockage turns out to be:

$$P_b = (P_{bk})^{\frac{1}{k}} \qquad (6\text{-}4)$$

Knowing the number of attempts at communicating, k, and the "grade of service" (in terms of allowable data loss rate) desired by the user, P_{bk}, expression 6-4 in conjunction with expression 6-1 allows computing the ARGOS saturation level, i.e., the value of P_b at which the traffic demand will begin to exceed the system's capability to handle it (loss of data becomes excessive). Discussions with users indicate that an acceptable value of sensor and/or positional data loss from drifters and fixed platforms lies between 1% and 10% during any one pass.

This yields the figures shown in Table 6-1, where we have assumed, for an advanced ARGOS system, a degradation of 30% from

TABLE 6-1

ARGOS SYSTEM SATURATION THRESHOLD
IDEAL CASE - 4 CHANNELS

Maximum Allowable Data Loss in Any One Pass	Number of Attempts		Probability of Channel Blockage Degradation in the number of attempted accesses		Allowable one-shot Number of Erlangs
	Maximum	Degraded	None	Degraded	Per Footprint degraded
1%	11	8 (Drifter)	0.66	0.56	7
1%	4	3 (Fixed)	0.32	0.21	3
3%	11	8 (Drifter)	0.73	0.65	11
3%	4	3 (Fixed)	0.42	0.31	4
5%	11	8 (Drifter)	0.76	0.68	12
5%	4	3 (Fixed)	0.47	0.37	4.3
10%	11	8 (Drifter)	0.81	0.74	15
10%	4	3 (Fixed)	0.56	0.46	5

"perfect" operation: i.e., 8 and 3 attempts at communicating instead of 11 and 4, for drifters and fixed buoys respectively. The 30% degradation is based on current statistics of ARGOS message losses (positional) published by the World Meteorological Organization (WMO). These report that 24% of attempted position locations are dropped due to inadequate satellite-platform geometry; 13% are eliminated due to excessive short and medium-term frequency deviation (if greater than 2.10^{-7} or 4 Hz/minute over 10 minutes, or greater than 10^{-8} over 0.1 seconds, the computation aborts); and 58% are lost from other reasons due mostly to deficiencies of the ground processing segment.

Thus, according to WMO, approximately only 21% of the possible positional fixes per pass are achieved by the current ARGOS system, representing a degradation of order 80%.

In our analysis, we assume that an improved ARGOS system operating in conjunction with more stable platform transmitters would obviate most of these difficulties, except possibly those connected with satellite-platform geometry. Hence our choice of 30% degradation.

Let us now compare the results derived above for the ideal case of "complete immunity" with the results obtained by using the standard assumption that any two signals, overlapping in time and frequency, do interfere, with consequent loss of both.

6.3 The Zero Immunity (Pessimistic) Assumption

This "worst case" assumes that any two signals received by ARGOS, that overlap in whole or in part, either in time or frequency, interfere with each other and therefore are lost.

The expression for interference without any immunity is[a]:

$$P_i = 1 - \left(1 - \frac{2t}{T} \frac{2\Delta f}{F}\right)^{N-1} \qquad (6\text{-}5)$$

where:

P_i	=	probability of mutual interference (on first attempt)
t	=	duration of signal transmission
T	=	time between successive transmissions
Δf	=	bandwidth of the receiving channel
F	=	total available reception bandwidth
N	=	number of platforms transmitting within footprint

We note that, in the hypothesis that any interference means loss of data, $P_i = P_b$. In highly sophisticated systems (not in ARGOS), some data can still be extracted despite mutual interference. Hence, we prefer to keep the two notations P_i and P_b separate: where P_b connotes the channel blockage in a system operating in the Erlang B mode, P_i the mutual signal interference in a system operating with a radio link.

Expression 6-5 assumes implicitly that all platforms transmit identical message lengths and repetition frequencies. If this is not the case, 6-5 needs to be corrected to reflect the non-uniform transmission patterns. For values typical of the ARGOS platforms, and under conditions of high traffic (approaching saturation) that we are concerned with, the differences are not great and can be neglected.

From (6-5), $\frac{t}{T}$ is clearly the erlang traffic demand for transmitting platforms, see Table 5-2 for representative values. $\frac{\Delta f}{F}$ is the inverse of the number of available channels (4 in ARGOS). Thus for ARGOS, $\frac{\Delta f}{F} \cong 0.25$.

(a) See also James L. Coates, "The Nimbus F Random Access Measurement System (RAMS)", IEEE Transactions on Geoscience Electronics, Vol. GE-13, No. 1, January 1975.

Substituting these values, (6-5) becomes:

$$P_i = 1 - (1 - E)^{N-1} \qquad (6\text{-}6)$$

Where E is the traffic demand **per platform** in erlangs.

Let us illustrate by example, for a case of low erlang demand. Say we had 10 platforms each requesting 17 millierlangs. Expression 6-6 yields:

$$P_i = 1-(1-0.017)^9 = 0.14$$

This means a 14% chance of interference on the first attempt. On the other hand, expression 6-1 ("ideal system") with n=4, E = 0.017 x 10 = 0.17 erlangs yields:

$$P_b = \frac{E^n}{n!} \frac{1}{\sum_o^n E^n/n!} = \frac{(0.17)^4}{24} \frac{1}{\sum_o^n (0.17)^n/n!} =$$

$$= 3 \times 10^{-5} = 0.003\%$$

As an example for a case of high erlang demand, say 300 platforms each requesting 17 millierlangs (total of 5.1 erlangs), the two expressions yield respectively:

For the zero immunity (worst) case: $P_i = 0.99$

For the full immunity (ideal) case: $P_b = 0.4$

The differences are significant. However, neither the ideal (optimistic) nor the worst (pessimistic) case are correct in practice. We next investigate the realistic case of partial immunity.

6.4 The Partial Immunity (Realistic) Assumption

Discussions with service ARGOS personnel, and diligent search of the literature, failed to reveal tests on other experimental findings relative to the ARGOS system's degree of immunity.

We thus analyzed a data set, supplied by Mr. Charles Cote of GSFC, pertaining to a series of tests performed by Texas Instruments, in 1976, on the TWIRLE/RAMS System. TWIRLE/RAMS is a random-access data relay system, installed on the NUMBUS F satellite, and functionally akin to ARGOS.

The test's objectives were to determine "quality of service" of RAMS, i.e., the probability of throughput of messages issued by in-situ platforms and relayed through RAMS, under a variety of conditions. The test was performed by simulating messages typical of those transmitted by drifters (balloons) lying within the satellite's footprint, and by measuring the ratio of messages successfully received to messages transmitted.

For reasons of cost and expediency, the test did not exactly simulate truly random platform emissions. Nevertheless, the results allow a good assessment of the "immunity" factor.

The TWERLE/RAMS system's specifications pertinent to our purpose are shown in Table 6-2.

Three tests were performed:

- Dynamic range test #1. All platforms transmitted at equal power (600 mw). Frequency separation between platform emissions was reduced down to 500 Hz over a total r.f. bandwidth of 29,500 Hz. The measured probability of success was approximately 95%, indicating that no significant mutual interference was

TABLE 6-2

TWERLE/RAMS SYSTEM SPECIFICATIONS

Nominal Carrier Frequency	401.2 MHZ
Allowable Carrier Frequency Excusion	$\pm$ 5 kHz
Doppler Bandwidth	$\pm$ 9.5 kHZ
Total RF Bandwidth	$\pm$ 14.5 kHz
Platform Transmitted Power, Nominal	600 mW
Platform Message Duration	1 Second
Platform Transmit Rate	One Per Minute
Millerlangs Per Platform	16.7
Message Data Rate, Input	100 bps
Bit Duration	10 msec
Modulation/Encoding	$\pm$ 60^{0}PSK, Manchester
Acquisition Bandwidth	150 HZ
Tracking Bankwidth	18.5 HZ
Number of Channels	8

experienced. It would have been interesting if the test had reduced the frequency separation further, at least down to values commensurate with TWERLE's reported acquisition bandwidth of 150 Hz. Unfortunately, the structure of the test did not allow this.

We conclude that the system operated effectively at least down to 500 Hz frequency separation between signals. This is equivalent to stating that the effective number of **channels** equaled **at least**: 29,500 Hz (total r.f. bandwidth) ÷ 1,000 Hz (separation) ~ **30.**

- Dynamic range test #2. One group of platforms transmitted at 600 mw, the other at 4.8 watts (9 db higher). Frequency separation was varied. The probability of success dropped to about 56% for separations of 500 Hz, but returned to normal at separations of 700 Hz.

We conclude that, in the presence of 9 db interference-to-signal ratios, the effective number of channels equaled at least 29,500 ÷1,400 ~ 21.

Within the limitation of the data, we can infer an additional conclusion. If we can consider the higher-power signal as the interferer, and if the system is linear, the frequency separation at equal power ought to be reduced by the signal voltage ratio corresponding to 9 db, namely 2.8 times, yielding an equivalent separation of 700 Hz ÷ 2.8 ~ 250 Hz. At this separation, presumably, no significant interference would occur if all the signals were emitted with the same power level.

- The random access test simulated 8 platforms, each emitting 600 mw, quasi-randomly spaced in time, and with varying frequency separations. The probability of success did not reduce significantly down to mutual separations of 500 Hz.

Similarly to Dynamic Test #1, we conclude that the number of effective equivalent channels was at least 30.

Despite the fact that the tests did not "push" the frequency separation below 500 Hz -- thus we are constrained to deduce performances "at least as good as" -- these tests support conclusions that can be derived theoretically from information theory:

- In a well designed random access system, the number of effective equivalent acquisition channels ought to equal at least the ratio of total bandwidth to acquisition bandwidth. For TWIRLE/RAMS this ought to approach 29,500 ÷ 150 ~ 200. We note in passing that the full advantage of the "equivalent number of channels" is realized only if the receiving system contains a sufficiently high number of Data Recovery Units (DRU's). Contrarywise, some of the advantage is "wasted".

- If the acquisition bandwidth operates over a fraction of the signal's duration, and is subsequently replaced by a narrower tracking bandwidth, the number of effective equivalent system channels lies in between the ratio of total bandwidth-to-acquisition bandwidth and total bandwidth-to-tracking bandwidth.

Let us apply these results to a "well designed" ARGOS -- not necessarily as ARGOS is now, but as an improved version could be.

Repeating expression 6-5:

$$P_i = 1 - \left(1 - \frac{2t}{T} \frac{2\Delta f}{F}\right)^{N-1} \quad (6\text{-}7)$$

we see that the critical element is Δf.

For an "improved" ARGOS, we can re-write 6-7 by introducing a (fractional) multiplier of $\frac{2\Delta f}{F}$, h, that expresses the number of effective channels. We can re-write 6-7 as follows:

$$P_i = 1-(1-2hE)^{N-1} \quad (6\text{-}8)$$

For ARGOS, the bit rate is 400 bps, thus the tracking bandwidth is of the order of 2 * 800 Hz = 1,600 Hz. The corresponding maximum number of equivalent channels could then equal the available sytem bandwidth (doppler excursion puls inherent bandwidth), ie.e, 24 kHz, divided by the acquisition bandwidth (1,600 Hz) or 24,000 ÷ 1,600 ≈ 15. Thus h in expression 6-8 would become $\frac{2 \times 1{,}600}{F} = \frac{3{,}200}{24{,}000} \approx 0.13$, yielding:

$$P_i = 1-(1-0.26\ E)^{N-1} \quad (6\text{-}9)$$

We note that under conditions of equal received powers at the satellite, and improved schemes of modulation, h could be lower. However, since signal strengths vary across the footprint by about 10 db, see Figure 6-1, and for the moment we are limited to PSK modulation, the chosen value h = 0.13 constitutes a reasonable compromise--at least until such time as better experimental data become available.

The allowable one-shot probabilities of interference as a function of the data loss tolerable by the user are shown in Table 6-1. They are recapitulated in Table 6-3 for the "degraded" case of 8 attempts per footprint for drifters, 3 attempts for fixed platforms.

TABLE 6-3

ALLOWABLE MAXIMUM ONE-SHOT PROBABILITY OF INTERFERENCE
PARTIAL IMMUNITY, REALISTIC ASSUMPTION

Allowable data loss per pass- - Type of Platform	Maximum Allowable One-Shot Probability of Interference (P_i)
1% - Drifter	0.56
1% - Fixed	0.21
5% - Drifter	0.68
5% - Fixed	0.37
10% - Drifter	0.74
10% - Fixed	0.46

Let us now apply 6-9 to the year 2000 platform populations shown in Figure 5-9.

As an example, the densest footprint, over Europe, has 3,240 platforms active at any one time, generating a total traffic of 18.78 erlangs, equivalent to 5.7 mE per average platform.

Application of 6-9 yields:

$$P_i = 1-(1-0.26 \times 0.0057)^{3239} = 0.99$$

By comparing with the maximum allowable values, Table 6-3, this footprint will clearly saturate because the data loss will exceed the maximum desired by the users. The probability of data loss in 8 attempts will be $(0.99)^8 = 0.92$. Thus on the average, most of the data will be lost.

The threshold of saturation will depend on the allowable data loss. It is computed as follows.

Average erlangs per platform (from above), E = 0.0057

Allowable data loss per pass: 5%

This corresponds to values of $P_i = 0.68$ for drifters, $P_i = 0.37$ for fixed platforms (from Table 6-3).

One-shot probability of interference (from 6-9):

$$P_i = 1-(1-0.26 \times 0.0057)^{N-1} = 1-(0.9985)^{N-1}$$

Solving for N, the maximum allowable number of data only platforms per footprint per pass is: for drifter platforms, ~ 770 and for fixed platforms ~ 310. For a 50-50 mix of these two types of platforms, the saturating number of platforms is ~ 540.

6.5 The Case of Two ARGOS Satellites

The above conclusions have been derived for the case of one ARGOS satellite. What happens if there are two? All indications are that most users will tolerate the additional time needed for double coverage (as long as the loss of data is contained to within 5%.

Thus the net effect of the second ARGOS satellite is to double the number of attempted collections: from 8 to 16 (degraded hypothesis) for drifters, from 3 to 6 for fixed platforms -- at the cost of somewhat longer time delays. The corresponding maximum allowable one-shot probabilities of interference become as shown in Table 6-4.

TABLE 6-4
MAXIMUM ALLOWABLE ONE-SHOT PROBABILITY OF INTERFERENCE AS A FUNCTION OF THE ALLOWABLE DATA LOSS--TWO SATELLITES

Allowable Data Loss Per Double Pass	Maximum Allowable One-Shot Probability of Interference
1% - Drifter	0.74
1% - Fixed Platform	0.46
5% - Drifter	0.83
5% - Fixed Platform	0.61
10% - Drifter	0.87
10% - Fixed Platform	0.68

The number of platforms that will saturate ARGOS, assuming an allowable data loss of 10% per two passes, becomes 276. We see from Figure 5-9 that even with two satellites, most footprints will saturate.

We note that the saturation numbers of platforms computed above are close to the number that Service ARGOS has announced for the improved ARGOS, namely 200.

6.6 The Limiting Performance

It is of interest to compare our results thus far with the performance of an ideal system obeying the Erlang B formulation. This represents the "ultimate" performance achievable, i.e. the "limit" imposed by laws of nature.

We have seen that, in a system designed to fully exploit the acquisition bandwidth (24 kHz), the possible number of equivalent channels can theoretically go up to 30. We will however assume, in line with the announced Service Argos policy for an improved ARGOS II, 8 channels, and a double satellite pass. Thus the one-shot interference probabilities of Table 6-4 apply. Table 6-5 summarizes the computations.

TABLE 6-5

MAXIMUM ERLANG TRAFFIC DEMAND PER FOOTPRINT THAT CAN BE HANDLED BY 2 ARGOS II SATELLITES HAVING 8 CHANNELS EACH

IDEAL CASE - ERLANG B POLICY

Allowable Data Loss Per Double Pass	Maximum Allowable Traffic Demand, Erlangs
1% - Drifter	30
1% - Fixed Platform	18
5% - Drifter	35
5% - Fixed Platform	18
10% - Drifter	40
10% - Fixed Platform	23

Comparison with Figure 5-9 shows that an "ultimate" system configured in this fashion could handle all the year-2000 data traffic without saturating.

The preceding treatment applies to **data.** We proceed next to investigate the situation as regards the successful achievement of **positional fixes.**

6.7 The Case of the Position Fix for Drifters

In theory, the ARGOS doppler system could provide a position fix for drifters (buoys or balloons) with a minimum of three transmissions. In practice, five transmissions, occurring during one pass, have been shown to be needed with the present system. The need to achieve 5 successes per pass poses a more stringent requirement on the system than is the case for message relays only, that require only one successful attempt per pass.

If the transmission parameters are statistically independent, the probability of loss of fix in s transmission occurring during the same pass is:

$$P_e = 1 - \sum_{i=s}^{R} \binom{R}{i} (1-P_i)^i (P_i)^{R-i} \tag{6-10}$$

where:

P_e = probability of "line blockage" (non-acquisition) in s attempts out of R possible attempts

P_i = one-shot probability of line blockage

Since R=8 (degraded case, see Table 6-1), s = 5, and $\binom{R}{i} = \frac{R!}{i!\,(R-i)!}$, we can re-write 6-10 as:

$$P_e = 1 - \sum_{i=5}^{8} \frac{8!}{i!\,(8-i)!} (1-P_i)^i P_i^{R-i} \tag{6-11}$$

Figure 6-3 shows the relationship between P_e and P_i.

Figure 6-4 compares the probabilities of loss of data with the chance of loss of fixes. We note that the latter is considerably higher than the former: for example a 1% loss of data corresponds to a 76% loss of fixes.

Our queries of the users did not show as great an urgency to obtain successful fixes as is the case for successfully obtaining data. A reasonable estimate for the user's tolerance is offered by the WMO statistics quoted in Section 6.2: the "fix" data loss is currently of the order of 80% per pass (of course, this is remedied in successive passes). The user's attitude appears reasonable when looking at the physics of the phenomena. Currently, see Table 5-1, practically all drifters are buoys. Since ocean currents are relatively slow (order of 0.25 to 1 knot), even as long as a 24-hour interval in position fixing entails only a 6 to 24 nautical mile distance, not very large compared to the geometric scale of ocean phenomena. We anticipate that the case may be quite different if a significant number of balloon users were to become ARGOS subscribers in the future: this is because the drift velocities in the atmosphere range from 10 to 100 times those of oceanic phenomena. A prospective estimate of the number of balloons is given in Table 5-15.

We note that the "improved system" promised by Service ARGOS for 1987 ought to reduce a portion of the losses in position fixes.

Nevertheless, even assuming "perfect" ARGOS performance, the computations--see Figures 6-3 and 6-4--show that ARGOS will saturate much sooner in terms of position fixes than in terms of data throughput.

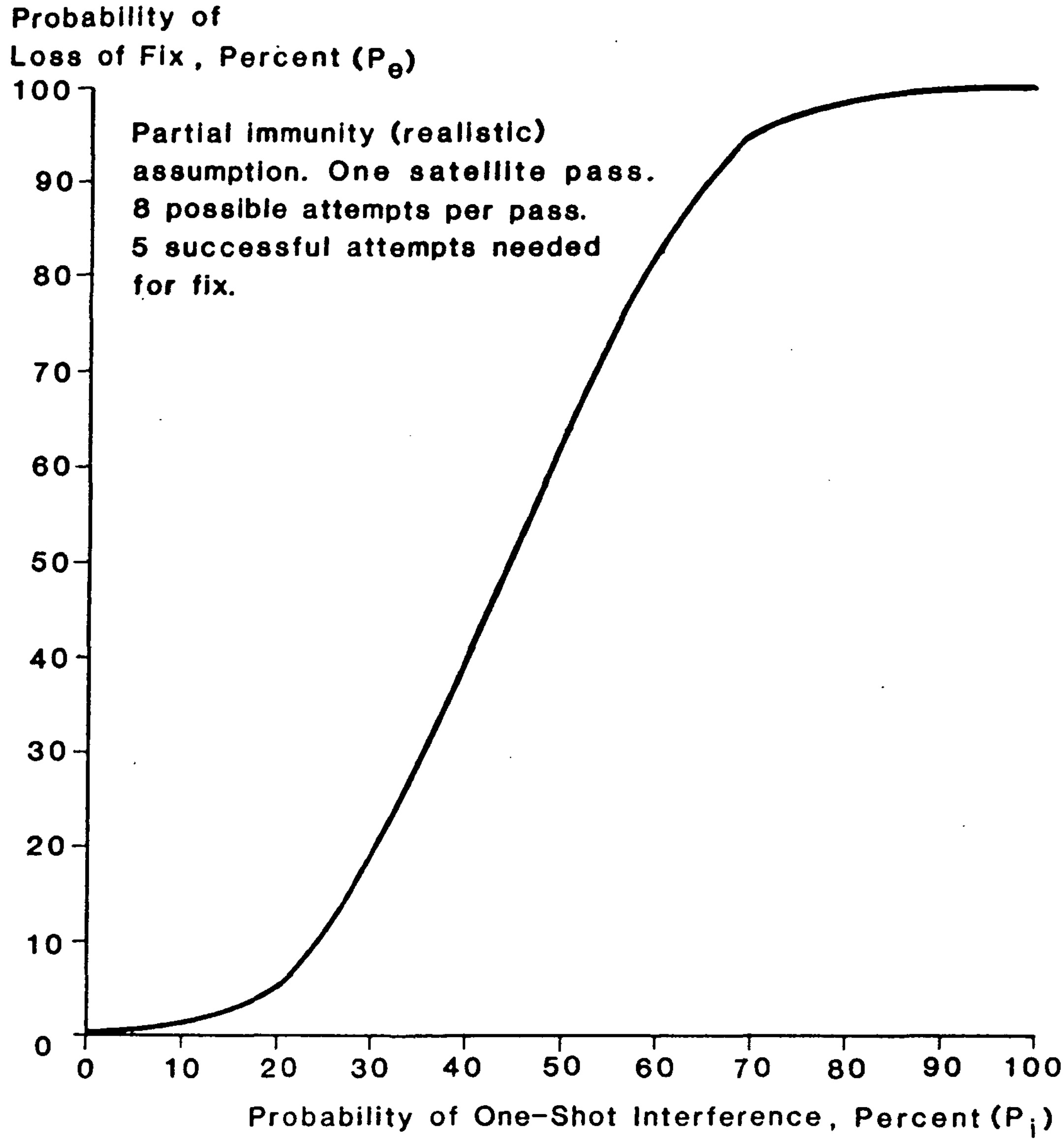

Figure 6-3. Probability of Loss of Fix Versus Probability of One-Shot Interference During One Satellite Pass

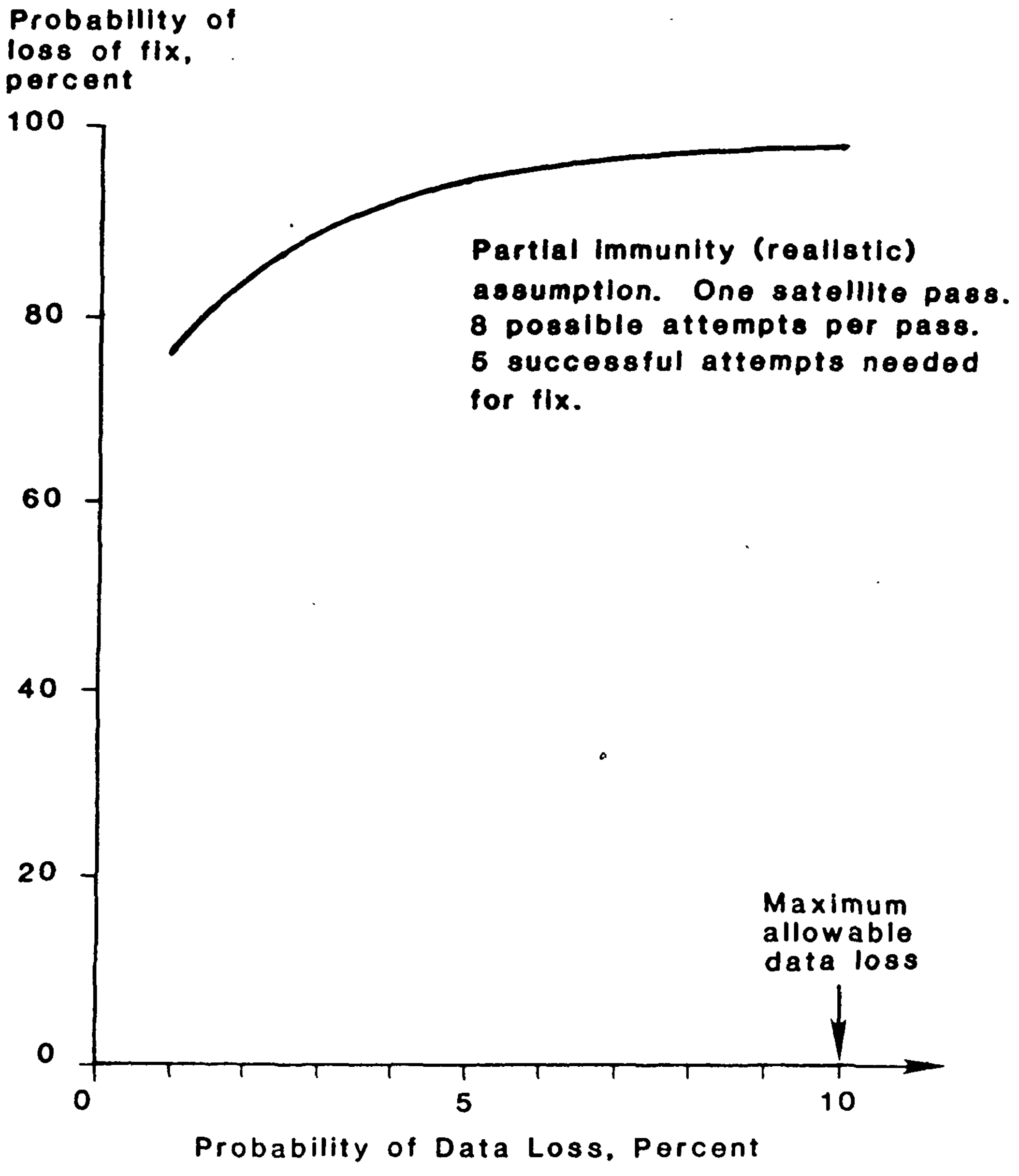

Figure 6-4. Probability of Loss of Fix Versus Probability of Loss of Data for Drifters

The question is: what would happen if the position fix were to require 1 message instead of 5? In this case, the computation of the saturation levels would be the same as that already developed for data, see Table 6-3, from which we see that a 10% loss of data (90% success) is achievable even if the one-shot probability of interference is 74%, or quite highwith respect to the 0.23 approximate probability needed with five messages per fix, see Figure 6-3.

The maximum (saturating) number of drifters (requiring position fix primarily, plus a minimum of data) per footprint can be computed as follows:

Average millierlangs per platform, from Table 5-2 = 6.5

Required one-shot probability of interference, P_i, for 10% (0.1) loss in fixes, from Figure 6-3 = 23% (0.23).

The relationship between P_i and the number of transmitters within a footprint, N, from 6-9 is:

$$P_i = 1-(1-0.26 \times 6.5 \times 10^{-3})^{N-1} =$$

$$= 1- (0.9983)^{N-1}$$

But, from Figure 6-3, P_i equals 0.23.

Solving for N, we obtain N = 153.

Compare this with the "saturation level" of ~ 540 data platforms per footpring computed at the end of Section 6.4. Compare further with Figure 5-3 showing the number of platforms per footprint in year 2000, and with Table 5-1 that indicates that position locations represent 66% of ARGOS data requirements. Assuming this ratio to remain roughly constant, we see that saturation of fixes will be **far more severe** in the future than that of **data messages.**

It is clearly the **position fixing** function that **dominates** the saturation scenario.

In the next section, we investigate remedial measures to alleviate and obviate ARGOS saturation.

7.0 ADCLS REQUIREMENTS

7.1 Limitations of ARGOS and Options for Improvement

In the preceding section we have seen that: 1) the key problem with the ARGOS system is the fact that it will **saturate** by year 1995-2000; meaning that the loss of data will exceed the level that users find acceptable (between 5 and 10%). Other than this factor, our extensive query of the users indicates that they appear pleased with the ARGOS performance-- except for the desire for faster data turnaround, that presumably will be met when service ARGOS will have transferred its Central Station to Suitland circa 1987; 2) particularly severe is the saturation of the position fixes; 3) an **ideal** system operating in accordance with the Erlang B policy, having eight channels and 24 kHz bandwidth, could meet the requirements of the year 2000 data traffic; 4) the current operational ARGOS system, even if it were to be endowed with a strong degree of immunity commensurate with current radio communication technology, will **saturate** by year 2000. This holds true even for the proposed "improved ARGOS" featuring eight channels (meaning 8 DRU's, Data Recovery Units).

Clearly, the system needs to be improved in order to meet the requirements of the traffic estimated to be present by the end of this century. We will hereinafter designate such an improved system as ADCLS.

In accordance with our methodology, let us now proceed to set forth the requirements of an ADCLS capable of meeting the requirements of year 2000 traffic demand.

We observe firstly that Polar Platform, operating at approximately 800 km orbital altitude, can subtend a footprint diameter approximately the same as is the case for ARGOS. We will assume this to be the case.

Three categories of options are available to upgrade system performance: i) options in the **space domain** ii) options in the **information extraction** domain; iii) options in the **frequency domain.**

7.2 Options in the Space Domain.

The principal are:

1) Restrict the field of view (FOV) by providing higher antenna gains

2) Provide space diversity reception

7.2.1 Restrict the Field of View

The effect of increasing antenna gains would be to reduce the footprint area, thus the number of platforms within a footprint, thus the receiver processing requirements. An additional beneficial effect would be the possibility of lowering the power transmitted by each platform. Countering these advantages is the prolongation of the data collection interval. Figure 7-1 shows the tradeoffs. It can be seen that, in view of the users' desire for relatively rapid data turn around, this option does not appear attractive-unless additional Polar Platforms were to be deployed.

7.2.2 Provide Space Diversity Reception

This can be accomplished via a high-gain, relatively large antenna aperture equipped with multiple feeds to provide several distinct smaller footprints. The aggregate of the multiple footprints would provide the same larger footprint as the current system. If a single receiver system having the current 24 kHz bandwidth were to service this type antenna, nothing much

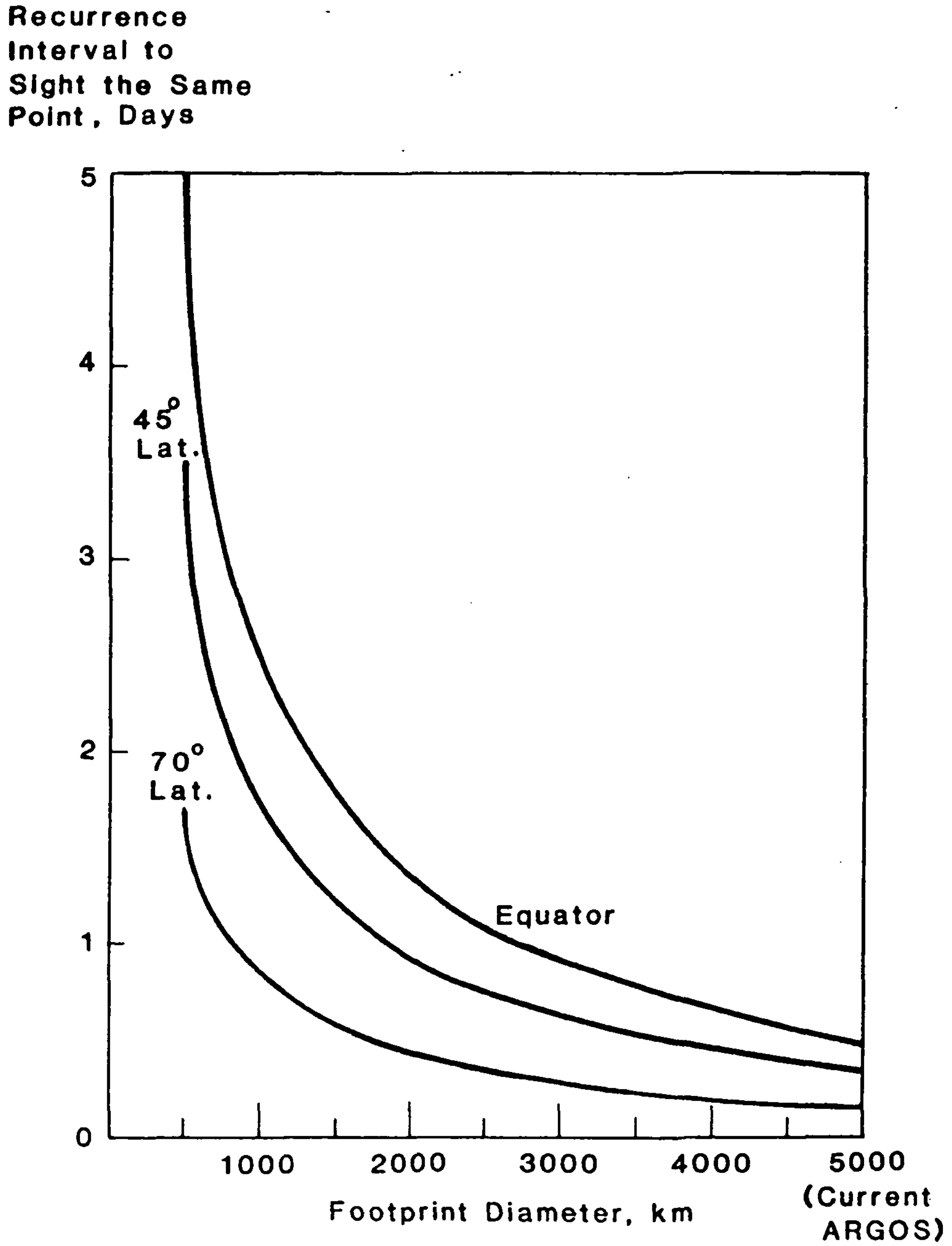

Figure 7-1. Average Recurrence Interval Versus Footprint Diameter for Various Latitudes

would be gained. What is needed to exploit the space diversity feature of a multi-beam system is a multiplicity of receivers. The net result of such an arrangement would be, in practice, to increase the "effective" bandwidth of the system by the number of footprints divided by a "frequency reuse" factor -- at the cost of a more complex antenna system and of multiple receivers. Two "limit" cases are possible: i) frequency reuse factor approaching 1; ii) "normal" frequency reuse factor.

The first case would require the generation of an antenna pattern with very steep skirts, i.e., an oversized antenna aperture. Calculations for a frequency reuse factor of 1, with four beams, equivalent to a ~ 100 kHz bandwidth, yield an approximate antenna aperture diameter of the order of 2.5 meters.

The second case would entail an antenna diameter of order 1 meter, and a frequency reuse factor comprised between 5 and 7. As an example, if the antenna footprint were to subtend a diameter of 1,000 kilometers at the earth's surface, instead of the normal ARGOS footprint diameter of 5,000 kilometers, ~25 effective beams could be generated. With a frequency reuse factor of ~ 6, this would be equivalent to approximately quadrupling the effective receiver bandwidth (reducing the bandwidth per footprint by a factor of 6, and maintaining the overall bandwidth at ~ 24 kHz). Of course, the ADCLS downlink bandwidth would have to be approximately quadrupled in this case.

The advantages of this solution would be: less platforms in a single FOV; lower platform transmitter power possible; maintenance of the current 24 kHz bandwidth; maintenance of the same platform transmitter configuration, hence the system would be "transparent" to the users. The disadvantages are that the design of the onboard receivers and data handling equipment would become considerably more complex than is the case with the current ARGOS. Moreover, the antenna system would become quite complex and costly.

7.3 Options in the Information Extraction Domain

Maintaining the current wide-coverage antenna pattern, the principal options are:

1) enhance the system's immunity by narrowing the acquisition and tracking bandwidth

2) modify the transmission rate

3) exploit the phase information contained in the messages

7.3.1 Narrow the Acquisition and Tracking Bandwidth

The net effect would be to increase the system's immunity to interference. In the ARGOS receiver, the signal is acquired during the 160 msec duration of unmodulated carrier. In theory, the bandwidth could thus be of the order of $\frac{2}{0.16} = 12.5$ Hz. Tracking is effected on the sequence of 2.5 msec. message bits. Use of Minimum Shift Keying (MSK) could in theory reduce the required tracking bandwidth to about 800 HZ ($\pm$ 400 Hz), from the 1,600 Hz bandwidth, corresponding to PSK, assumed in expression 6-9.

The use of MSK and the actual acquisition bandwidth on the unmodulated carrier need to be supported and verified by actual test data.

A further potential improvement could be effected by shortening the message length, in two ways:

1) reducing the length of the CW portion of the message. Utilizing Chirp-Z techniques for rapid detection of transmissions, this could be reduced to about 20 milliseconds [(a)].

(a) C.P. Ashcraft and J. Marini, "A Combined Data Collection and Search and Rescue Satellite Package", Report X-945-81-17, GSFC, June 1981.

2) eliminating the "sensor data" portion of the message for those platforms that require only position fix--the "dumb drifters".

Sub-Option 1), applicable to all platforms, would reduce the total message length by about 140 msec, resulting in total message lengths of 220 to 780 msec (instead of the current 360 to 920 msec)--amounting to an average reduction of the order of 20%.

Sub-Option 2), applicable only to "dumb" drifters, when combined with Sub-Option 1, would further reduce drifter messages from the current 360 msec to 140 msec, for a total reduction by a factor of 0.6.

The net effect of Sub-Options 1) and 2) combined would be a reduction in the traffic demand by about 30% (assuming that drifters will continue to represent ~50% of the total platforms, and "dumb" drifters about half of that).

While interesting, this improvement would not suffice to meet the requirements of the year 2000 traffic demand. A disadvantage would be that the platform transmitters would have to be modified, entailing increased costs to users during the transition phase between the two systems. This disadvantage would dwindle in time, as current transmitters would phase out, and would be gradually replaced by the new design. The spaceborne receiver design would become somewhat more complex--the additional cost would however not be too significant.

7.3.2 Modify the Transmission Rate

By this we mean either to increase or decrease the repetition interval at which the messages are transmitted. Longer intervals (at constant message length) have the net effect of reducing the number of erlangs being transmitted. Thus the one-shot probability of access would increase: however, the number of repeated attempts possible during one satellite pass would also decrease. Shorter intervals would have the opposite effect. The question is which of these factors is dominant to the end of conveying messages to users with the least loss of data.

Combining equations 6-8 and 6-3, repeated here for convenience:

$$P_i = 1-(1-2hE)^{N-1} \tag{7-1}$$

$$P_{ik} = P_i^k \tag{7-2}$$

where:

P_i	=	one-shot probability of interference
P_{ik}	=	probability of interference with k repeated attempts
E	=	erlang traffic per platform
h	=	ratio of acquisition bandwidth to system bandwidth
N	=	number of active platforms

We obtain:

$$P_{ik} = [1 - (1-2hE)^{N-1}]^k \tag{7-3}$$

Although this expression could be expanded in a double binomial series, the result is not very tractable. An analytic tradeoff turns out to be highly non-linear with E and k. However, since we are interested only in conditions of high traffic demand, we can use the practical approach of inserting actual values typical of high density footprints: E = 5.7 millierlangs, h ~0.13 (from expression 6-9), N ~3000.

This yields:

$$P_{ik} = [1-0.012]^k$$

If k=8 (repetition rate of 55 sec), P_{ik} = 0.91. If now we were to double the repetition interval, E would reduce to 2.85 millierlangs, k to 4.

The new value of P_{ik} would be:

$$P_{ik} = [1-0.11]^4 = 0.63$$

Thus, halving the repetition interval would yield a 30% benefit. If we reduced the transmission rate further, say 4 times:

$$P_{ik} = [1-0.33]^2 = 0.45$$

The benefit would only be 28%. Figure 7-2 shows the computed values. Thus, for very dense footprints, reducing the data rate up to an optimum, i.e., increasing the transmission interval, would yield a benefit. As can be seen from Figure 7-2, this benefit is however not overly significant. The probability of interference flattens out if the transmission interval is increased beyond 220 secs. This is true, because the increase in transmission interval reduces the number of attempts as well as the total Erlangs. These two factors work against each other in a highly nonlinear fashion.

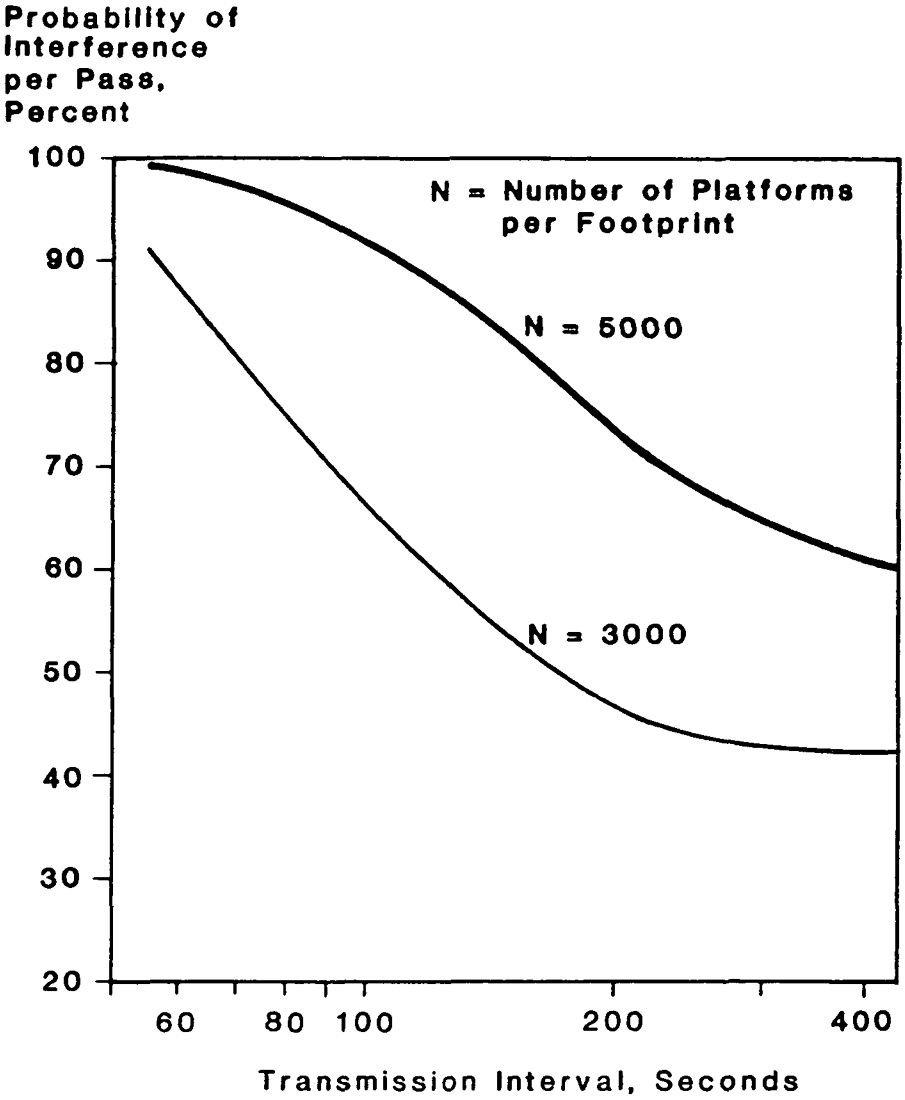

Figure 7-2. Effect of Varying Platform Transmission Interval - Partial Immunity (Realistic) Assumption

7.3.3 Exploit Phase Information

This options entails use of multiple antennas (at least 2 to provide a fix in one dimension, at least 3 to provide two-dimensional fixes).

In practice, 4 antennas are generally used, because this simplifies the system's operation.

The resulting instrument is known as an interferometer. Its major advantage is that a position fix can be effected upon receipt of a **single** message instead of five. Thus under conditions approaching saturation, the quality of service (probability of interference) is greatly reduced with respect to the probability of receiving five successful messages per satellite pass. Specifically, the probability of interference for position fixes is reduced to the level corresponding to the probability of interference for data messages. In other words, a "fix message" becomes equivalent to a "data message"; the preceding treatment becomes applicable to both fix and data transmissions.

The other major advantage is the fact that the system can operate with the current ARGOS transmitter at no additional burden to the users.

Other advantages are: i) capability to provide accurate fixes for fast-moving platforms, e.g., balloons; ii) capability to resolve ambiguities induced by the doppler fixes; iii) possibility of adapting the system to also serve the Search and Rescue (S&R) function.

7.4 Options in the Frequency Domain

Maintaining the current wide-coverage antenna pattern, the principal options in the frequency domain are:

1) Increase the system's transmission-reception bandwidth.

2) Employ a platform polling policy.

7.4.1 Increase the System's Bandwidth

The net consequence of this improvement -- if effected without changing any other system parameter -- would be equivalent to increasing the number of "pseudochannels". A sufficient number of DRU's must of course be made available. With reference to expression 6-8, repeated here for convenience:

$$P_i = 1-(1-2hE)^{N-1} \quad (7-4)$$

where

P_i = probability of one-shot interference
E = traffic demand per platform, erlangs
N = number of active platforms
h = ratio of acquisition bandwidth to system bandwidth

we see that the effect of increasing the system bandwidth would be to reduce the factor h. For example, if the system bandwidth were quadrupled to 96 kHz (nominally 100 kHz), expression 7-4 would read:

$$P_i = 1-(1-0.065\ E)^{N-1} \quad (7-5)$$

Applying 7-5, by way of example, to the densest cell in year 2000 (3240 platforms, 5.7 mE per platform), we obtain:

$$P_i = 1-(1-0.065 \times 0.0057)^{3239} = 0.7$$

We note by comparing with Table 6-3 that this level of one-shot interference would essentially meet the user requirements for data from drifters (8 contacts per pass), and would increase the data loss above 10% for fixed platforms (3 contacts per pass), even for the densest cell predicted for year 2000.

In fact, the maximum number of data-transmission platforms (exclusive of the position fix function) per footprint per pass computes out for drifters to be N $\cong$ 2,850 at 5% data loss, 3370 at 10% data loss. For fixed platform at 10% data loss, N $\cong$ 1,540.

In summary, increasing the bandwidth to ~ 100 kHz would not preclude the ARGOS system from saturating in year 2000.

We note that use of the nominal 100 kHz bandwidth would impose the requirement on the transmitter manufacturers of having their center frequencies randomly "dispersed" over a band of 76 kHz (total band of 96 kHz less doppler excursion of 20 kHz). This should not affect the cost to the users: it would probably call for some management of the crystal oscillator frequencies on the part of the community of manufacturers -- with some guidance on the part of the user community and the operator of the system -- so as not to result in biases caused by "bunched" frequencies.

7.4.2 **Use of Platform Polling Policy**

Platform Polling implies that the platforms would transmit only upon being queried by the spacecraft. This would in effect reduce the Erlang demand at the cost of increased complexity in the platform's communications package, that now would require a receiver in addition to a transmitter.

If the polling were random, the effect of this policy would be tantamount to reducing the repetition rate--or, equivalently, to increasing the transmission interval. In the limit, the repetition rate can be reduced to once per satellite pass. Perusal of Figure 7-2 shows that only a moderate improvement can be gained from this method to the effect of reducing saturation. A truly random polling policy would require polling all the platforms during the nominal spacecraft overpass time of approximately 10 minutes. Assuming a query-response time of the order of 1 second, only 600 platforms could be polled during an overpass. To poll say 3,000 platforms would require at least 5 times the bandwidth (considering necessary overlaps). The additional costs, especially the added costs to the users, do not appear to warrant further consideration of this policy.

If the polling were systematic, and highly organized, then in the limit the number of platforms that the satellite could query in one pass would equal:

$$N = \frac{T_p \times n}{t} \qquad (7\text{-}6)$$

where:

T_p = time duration of overpass, ~ 600 sec.
t = time duration of one message, say 1 sec.
n = number of equivalent channels, say 4
N = number of platforms

With the above assumptions, N is approximately 2,400 for a "perfect" systematic polling.

In practice, "perfect" systematic polling would not occur unless the polling signals were separated in frequency sufficiently to avoid doppler interference among signals. This would require that the multiple channels be spaced beyond the potential doppler interference from adjacent channels, thus needing a substantial bandwidth (for 3,000 platforms, within a footprint, approximately 125 kHz).

The implementation of such a scheme would require a sophisticated form of on-board processing in the satellite. More importantly, it would require that each platform be equipped with a receiver capable of i) accepting the polling call; ii) evaluating whether the call addresses the specific platform; and iii) triggering the transmitter.

While such a receiver could be developed, its cost would add a burden to the user. At an estimated sales price of $200 (projected to the 1995-2000 era), the forecasted 18,000 users in year 2000 would collectively have to disburse $3.6 Million.

7.5 Synthesis of the ADCLS Requirements

7.5.1 Screening of Options

The preceding examines major options to overcome the ARGOS system saturation that is expected to occur in the 1995-2000 era.

We will now summarize the advantages and disadvantages of these options, discard those that are obviously of low value, and compare those that promise the greatest cost/effectiveness.

Space Domain Options

1) **Restrict** the **FOV** by providing higher antenna gains.

Advantages: i) reduces footprint area, hence the number of platforms per footprint, hence the saturation level, ii) allows lowering the transmitter power level, hence increases platform battery life.

Drawbacks: increases the data collection interval, see Figure 7-1.

Tradeoff: **Shelve**--most users wish rapid data collection.

2) Provide **space diversity** reception via a high-gain antenna equipped with multiple squint feeds.

Advantages: i) provides effective large footprint (5,000 km diameter), hence rapid acquisition of data; ii) allows less platforms in a single FOV, hence increases the saturation threshold, iii) maintains the current ~24kHz bandwidth, hence imposes no additional burden on users.

Drawbacks: i) greatly increases complexity and cost of satellite antenna configuration, ii) requires multiple satellite receivers and corresponding data processing circuitry; iii) might still require a wider-band system, because of constraints on frequency reuse.

Tradeoff: **Retain** for further analysis

Information Extraction Options

1) **Narrow** the **acquisition** and **tracking bandwidth**

Advantages: improves traffic handling capability (possibly up to a factor of 2).

Drawbacks: i) increases complexity of satellite receiver, ii) adds burden to users by requiring modification of current transmitter design.

Tradeoff: **Shelve** as major tradeoff option. **Retain** as a potential engineering improvement to finally selected option.

2) **Modify the transmission rate (repetition interval)**

Advantages: in situations approaching saturation (numerous platforms per footprint), optimized transmission rates alleviate erlang demand somewhat, hence reduce traffic congestion by a factor of up to 100%.

Drawbacks: the optimum transmission rate is a function of the platform density within each footprint, Figure 7-2. Optimization of this parameter would require that the transmission rate be made variable as a function of the platform's geographic location, and with aforeknowledge of the density of platforms sited in the same geographic area (footprint). The relatively small advantage that can be derived from this policy is not sufficient to compensate the increased onus on the users of having to "tailor" their transmission rates, and on the system managers of having to keep track of regional platform densitites on a continual basis.

Tradeoff: **Shelve**, because the advantages are relatively small, further they do not appear to compensate the disadvantages.

3) **Exploit phase information** (by using an interferometer)

Advantages: i) in situations approaching saturation, interferometry, that utilizes one message instead of five for position fixing, alleviates the congestion caused by traffic demand for position fixing; ii) does not require modifications to the platform transmitter, thus places no additional burden accrues on the users; iii) can handle platforms that move more rapidly than sea-going platforms, e.g., balloons; iv) can assist in resolving ambiguities originating with the doppler fixes.

Drawbacks: i) requires more complex and costly satellite on-board systems.

Tradeoff: **Retain** for further consideration.

Frequency Domain Options

1) **Increase** the **System's Bandwidth**

Advantages: i) alleviates the saturation problem--a bandwidth of ~ 100 kHz, plus additional options, for example, interferometer, reduced transmission rate (increased interval between transmissions) would meet the requirements of the year

2000 traffic; ii) does not require significant changes to the platform transmitter, except for selection of center frequencies.

Disadvantages: requires that manufacturers of transmitters and possibly system's operators coordinate the placement of the transmitter's center frequencies to insure their uniform spread across the frequency band.

Tradeoff: **Retain.**

2) **Use of Platform Polling Policy**

Advantages: i) Random polling would have little or no advantage towards reducing saturation; ii) systematic polling could circumvent saturation at least up to year 2000.

Disadvantages: i) Polling in general would require the addition of a receiver and data analyzer to each platform, with added expense to the user; ii) systematic polling would require a prior knowledge of each platform's location--possible with fixed platforms, costly for drifters; iii) a sophisticated form of on-board processing would be needed on the satellite.

Tradeoff: **Retain** for further comparative analysis.

7.5.2 Comparison of "Best" Options

From the preceding, the surviving options are:

a) Provision of space diversity via a high-gain, multiple feed antenna

b) Reduction of erlang traffic demand for data by systematic polling

c) Reduction of traffic demand for position fixing by use of interferometer

d) Provision of more equivalent channels by increasing the system's bandwidth (and providing the necessary number of DRU's).

Let us now proceed to trade these remaining four options among themselves.

The tradeoff criteria that we used, in descending order of importance, are:

1) Principal criterion: minimum impact on platform-related costs to the users.

2) Second-echelon criterion: minimum impact on the ground segment, specifically as regards: a) cost of processing (because it indirectly reflects on user tariffs); b) timeliness of delivery (because it affects the "quality of service" expected by the users).

3) Third-echelon criterion: minimum impact on the cost of the space segment (because it may affect the decision to proceed on the part of NASA/NOAA management).

The major elements entering the tradeoff are recapitulated following.

Option a. Space Diversity

We have seen in Section 7.2.2 that there are two possible suboptions: 1) with frequency reuse factor approaching 1; 2) with a "normal" or "conventional" frequency reuse factor.

Suboption 1 would require antenna patterns with very steep skirts, e.g., 4 oversized antenna apertures of order 2.5 meters diameter (to achieve say an equivalent 100 kHz bandwidth). If we used suboption 2, in order to achieve a factor of 4 in equivalent bandwidth, with a frequency re-use factor of ~6, the 5000 km diameter footprint ought to be subdivided into ~25 beams, each beam subtending a footprint diameter of ~1,000 km. Thus the antenna diameter, at 400 MHz, from an orbital altitude of ~800 Km, would be approximately 1 meter when looking towards nadir, approximately 3.2 meters when looking towards the outermost edges of the 5000 km footprint. The key drawback would be that, since most of the frequency excursion is induced by the doppler frequency shift, the system would require a wider radiofrequency bandwidth, because of beam-shape constraints on frequency reuse. Practical frequency-reuse schemes, such as are used in the planning of land-mobile relay satellites, allow a maximum frequency reuse factor of 4. Thus they work well when the doppler excursion is small, e.g., from geosynchronous orbit: from LEO, the doppler excursions occuring in adjacent FOV's will overlap, thus needing a distinct separation of carrier frequencies.

This option thus merges with Option d), wider bandwidth.

Option b. Systematic Polling

The key requirement would be the addition of a receiver and data handling circuitry to each platform. Assuming an added cost per platform of $200 for each of the forecasted 18,000 platforms in year 2000, this would amount in the aggregate to a $3.6 Million burden to the users.

Moreover, choice of Option b would necessitate a sophisticated on-board processing system on the spacecraft: and/or a sophisticated ground-based system with an up-link to the spacecraft. This is needed to maintain track of the stationary platforms (from knowledge of their position and of the satellite's ephemerides, to compute the corresponding doppler shift). For drifting platforms, such a system would have to essentially dead-reckon the platform's motion since the latest fix--conceptually not a difficult chore, yet quite demanding of computational resources in view of the large number of platforms to be tracked. Furthermore, the uncertainty of any drifter's position would induce uncertainties in the doppler frequency to be addressed, thus broadening the system's bandwidth and negating a portion of its advantages.

In view of these negative factors, the option of systematic polling does not appear advantageous because: i) it is costly to the users; ii) it is expensive for the ground segment; iii) it is cumbersome and costly for the space segment.

Option c. Exploit phase information

The principal advantage of this option is to reduce the number of messages needed to achieve fixes from 5 per satellite pass to 1, thus alleviating the saturation for position-fixing platforms (oceanic buoy and atmospheric balloon drifters). Theoretically, the number of fix messages would be reduced to those applicable to data messages.

The disadvantage is the requirement for a phase-sensitive device (interferometer). If, however, the interferometer's design is kept simple, i.e. broad-coverage, avoiding complex antenna structures, the cost will be moderate.

No impact would result to the users if the interferometer is made to operate in conjunction with existing platform tranmitters.

Option d. Increase the system's bandwidth

This option, coupled with Option c, appears to be the "cleanest" and least expensive. The impact on the user's costs would be minimal, because existing transmitters would work just as well with a ~ 100 KHz bandwidth (0.025% of carrier frequency) as with the current ~ 25 KHz bandwidth. The only impact would be the requirement for manufacturers (on their own and/or guided by the system's managers) to spread the crystal frequencies over an ~ 75 kHz band rather than over the current ~ 5 kHz band. The impact on the ground processing system would only be proportional to the increased number of users--this would have to be upgraded anyway, no matter which option were chosen. The impact on the satellite receiving, processing and re-transmitting system would be confined to added circuitry, that is light-weight; and to an increase in the satellite downlink bandwidth. Sophisticated on-board antennas would not be required.

Table 7-1 recapitulates these tradeoffs. In the Table, "baseline" connotes the simplest and least costly system (increased bandwidth), upgraded only to the extent of being able to handle the increased traffic demand. The legend "not intrinsically affected" pertaining to the column headed "timeliness of data delivery" connotes the fact that there are no basic reasons impeding the rate of data turnaround--except cost, that is reflected in the second column.

We see that, based on the tradeoff criteria stated in Section 7.5.2, Option b, Systematic Polling, infringes the primary criterion of low cost to the users. Option a, Space Diversity, infringes the criterion of low cost of the space segment. We are thus led to favor Options c, Interferometer, and d, increase the system's bandwidth. We note that an advantage of selecting these two options is that they are complementary.

TABLE 7-1

TRADEOFFS FACTORS OF ADCLS OPTIONS

OPTION	ADDITIONAL COST TO USERS *	ADDITIONAL COST OF GROUND PROCESSING **	TIMELINESS OF DATA DELIVERY	COST OF SPACE SEGMENT
A. SPACE DIVERSITY (MULTIBEAM)				
I) WITH NO FREQUENCY REUSE	NONE	SLIGHT	NOT INTRINSICALLY AFFECTED	VERY HIGH
II) WITH FREQUENCY REUSE	NONE	SLIGHT	NOT INTRINSICALLY AFFECTED	HIGH
B. ONE-MESSAGE POSITION FIX (INTERFEROMETER)	NONE	SLIGHT	NOT INTRINSICALLY AFFECTED	MODERATE
C. INCREASE SYSTEM BANDWIDTH	NONE	BASELINE	NOT INTRINSICALLY AFFECTED	BASELINE
D. SYSTEMATIC POLLING	HIGH ($3.6M)	HIGH	NOT INTRINSICALLY AFFECTED	HIGH

* ABOVE AND BEYOND CURRENT ARGOS

** ABOVE AND BEYOND BASELINE COSTS

8.0 ADCLS Specifications and General Configuration

8.1 ADCLS Specifications

From the foregoing, we see that a data collection and position location system capable of meeting the anticipated year 2000 traffic demand ought to incorporate the following functions:

Primary Functions -- required to obviate saturation

1) Capability of performing position fix based on a single platform message (instead of the currently required five messages).

2) Capability of relaying random access data messages in a manner similar to ARGOS--but over a bandwidth of up to 150 kHz (instead of the current ~ 25 kHz).

3) Should 150 kHz not be possible incorporation of one or more additional improvements, e.g. narrower acquisition and tracking bandwidth, optimized transmission rate

Secondary Functions -- desirable to enhance "quality of service" characteristics

4) Capability to exploit the doppler frequency shift to obtain platform velocity (instead of the current differencing of two position fixes).

5) Enhance capability to perform position fixing based on doppler messages--as a complementary feature to Primary Function 1) above -- primarily aimed at resolving positional discrepancies of interferometer fixes.

These functional requirements give rise to the following **technical specifications**:

- Carrier frequency: 401.6 mHz (same as ARGOS)
- Doppler Bandwidth: ~ 20 kHz
- Allowable Carrier Frequency Excursion up to ~ $\pm$ 65 kHz
- Total RF Bandwidth: ~ up to 150 kHz
- 4-Antenna Interferometer for position fixing
- Data Format and Modulation: Same as ARGOS
- Message Duration/Repetition rate: Similar to ARGOS
- Number of Equivalent channels: ~ 100 to 150
- Number of Data Recovery Units: ~ 15 to 30

8.2 General Configuration of ADCLS

Based on the specifications set forth in previous Section 8.1, Figure 8-1 depicts the overall ADCLS system configuration. The system consists of the following three major functional elements:

- space segment
- communications relay subsystem (see Figure 8-1)
- ground data processing and dissemination subsystem

The configuration synthesized in this section pertains to the space segment, i.e., that portion of the ADCLS system that is located on the polar platform. The configuration's major elements are depicted in Figure 8-2.

In accordance with the specifications set forth in Section 8.1, the operational concept of ADCLS employs a combination of Doppler frequency measurements and radio frequency interferometer phase difference measurements for position location. The ADCLS instrument includes two RF interferometers with extended lateral antennas, consisting of four, approximately ten meter booms at right angles to each other, each bearing an antenna at its end, and one doppler antenna.

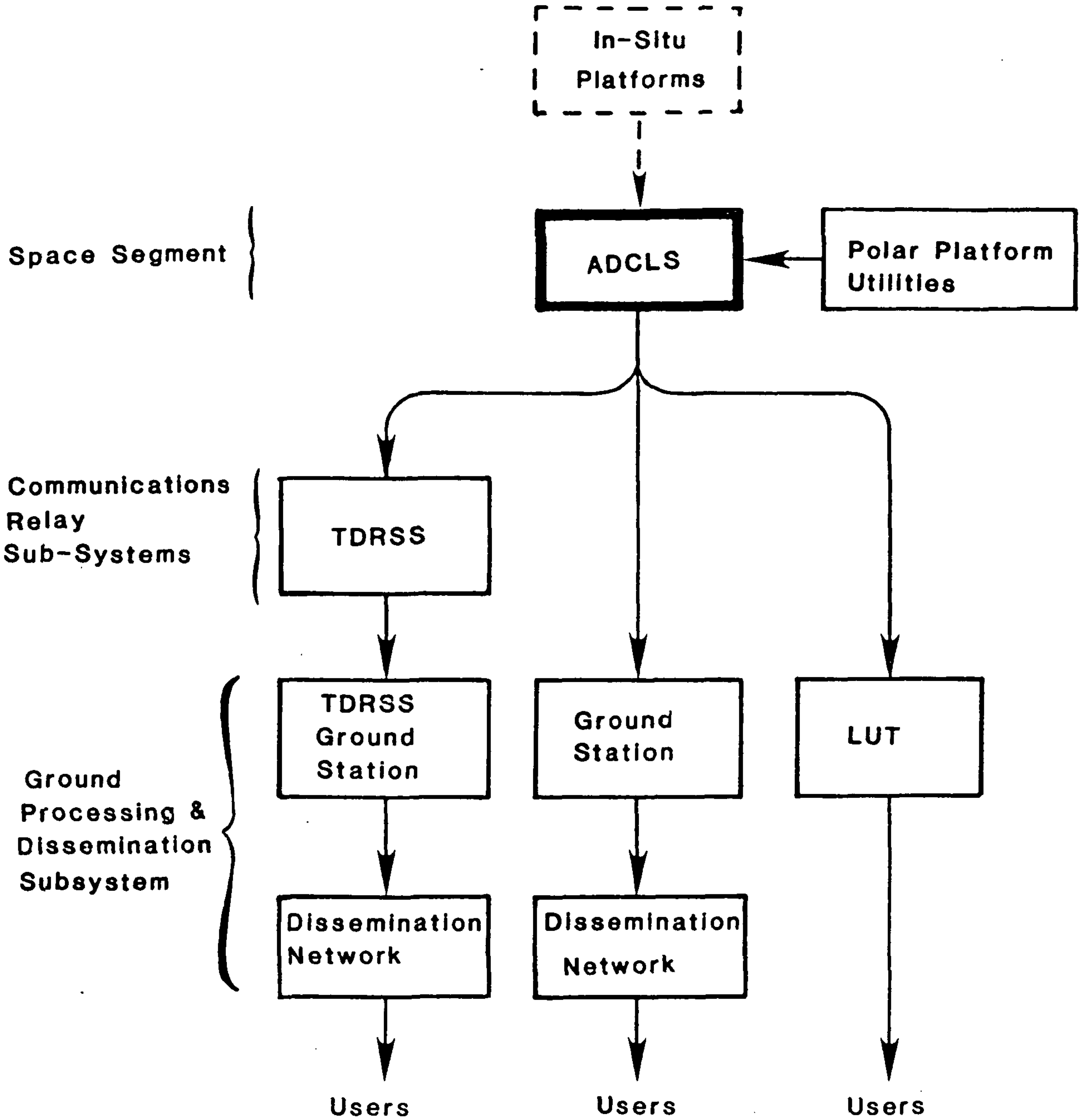

Figure 8-1. The Overall ADCLS System

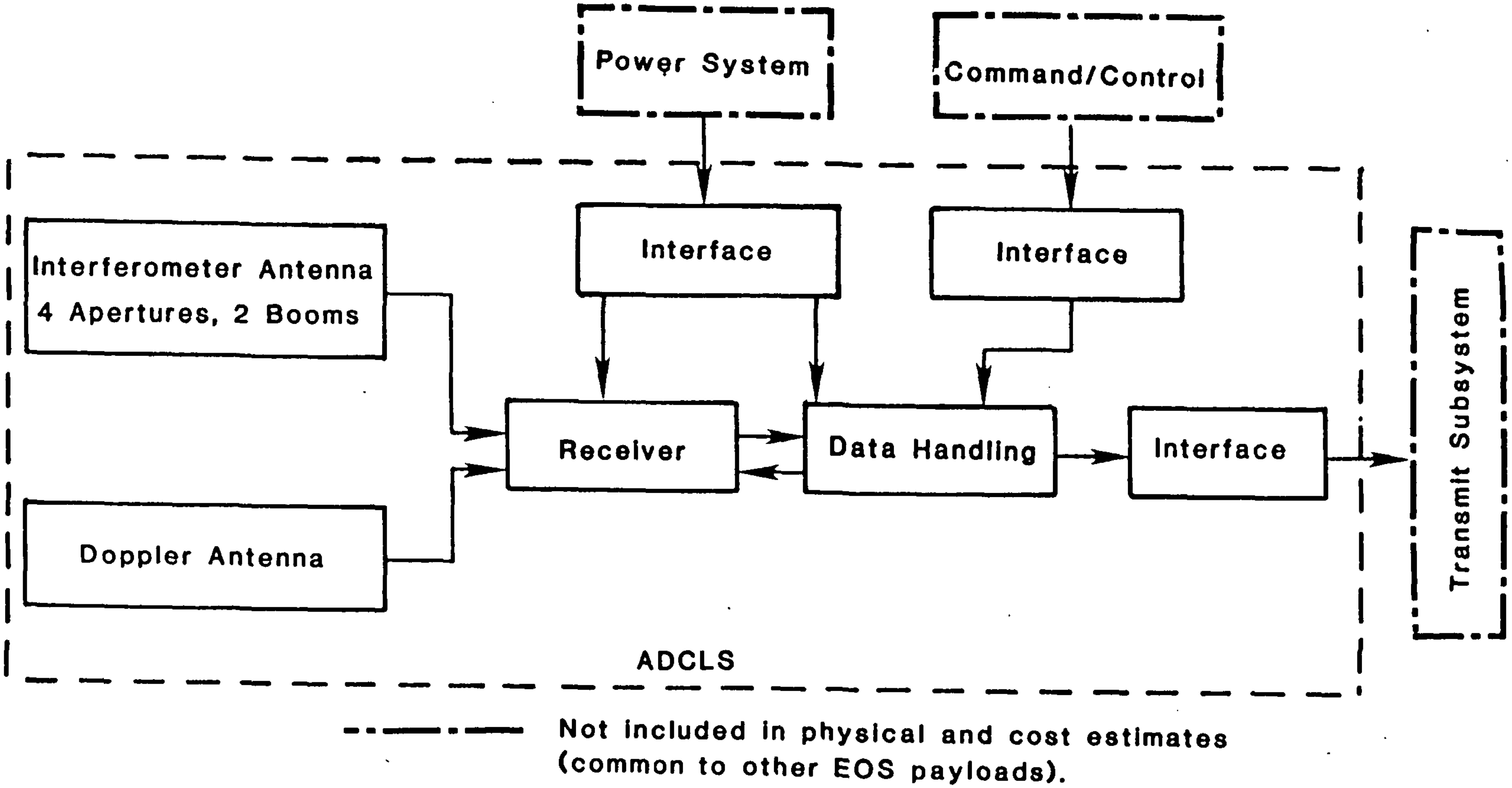

Figure 8-2. Major Elements of ADCLS Configuration

Signals transmitted by the in-situ platforms are simultaneously received by the ADCLS antennas, are demodulated, amplified, and then conveyed to the on-board data handling system. This latter system measures the received signal's frequency, detects phase differences between the two input signal representations, and extracts the data transmitted by the surface platform(s). The collected and processed data is then in turn supplied to the on-board transmission subsystem for downloading to the ground processing facility and/or to local user terminal(s) (LUT's). The downloading can be conceptually effected in three ways: via TDRSS; direct to local user termals (LUT); dumped to ground-based antennas when in view of the polar platforms. The definitive choice among these transmission options--whether all three, or only TDRSS--is under analysis by the EOS system designers. Since however, we assume that EOS will provide either option as a "service" to ADCLS, the ultimate choice will not significantly influence our physical estimates.

In the EOS mission baseline concept the ADCLS instrument will be placed on the Polar Orbiter, as one among several other sensory and housekeeping payloads. We assume here that these other payloads will have common power supplies, and common housekeeping, transmission, telemetry and command and control subsystems. The ADCLS system-peculiar requirement is to provide interfaces to and from these common subsystems.

8.2.1 Physical Characteristics

The estimated volume, mass and power requirements are based on an instrument comprised of two interferometers, one doppler antenna and the electronic package. The estimates are as follows:

Power requirement	≅	61 watts
Mass (including antennas)	≅	37.35 kg (82.17 lbs)
Volume (including antennas)	≅	61.95 liters

The features assumed for these estimates are twenty to thirty channels (DRU's); operational frequency is 402 MHz. The itemized details of the conceptual ADCLS system are shown in Table 8-1. The estimates shown in Table 8-1 were abstracted from the following two sources:

1. NASA Space System Technology Model Volume IIB Space Technology Trends and Forecasts. NASA Headquarters, 1984.

2. NOSS/ALDCS Analysis and System Requirements Definition Final Report. ORI-Feb., 1981.

The weight and volume of each components were further reduced to reflect the development of advanced technologies in circuitry design, fabrication and installation, estimated to be possible in the later portion of the 1980 decade. For example, significant savings in weight and size accrue to use of digital signal processing schemes in place of analog schemes (currently used in ARGOS).

8.2.2 Cost Estimates

The costs of the ADCLS elements were estimated utilizing the Unmanned Spacecraft Cost Model (USCM) developed by the Space Division of the Air Force Systems Command. The model employs an empirical parametric estimating technique: it reconstructs the costs of a number of "functionally equivalent" subsystems and components -- e.g., antennas, telemetry packages -- that have been used in various civil and military missions, regresses them, and derives a "best fit" expression relating costs to key parameters of the subsystems and/or components being evaluated.

The USCM segregates the costs into non-recurring and recurring. Non-recurring costs are those associated with all the

TABLE 8-1

PHYSICAL CHARACTERISTICS ESTIMATES OF VARIOUS ADCLS COMPONENTS

	PHYSICAL CHACTERISTICS		
ADCLS COMPONENT	MASS (KG)	VOLUME (LITERS)	POWER (WATTS)
ONE-5 CHANNEL RF AMPLIFIER DOWN CONVERTER, DISTRIBUTOR	1.25	1.35	3
ONE-SIGNAL DETECTOR	0.3	0.5	3
ONE-CONTROLLER	1.0	1.5	5
FOUR-INTERFEROMETER ANTENNAS AND ONE DOPPLER ANTENNA	20.0	37.5	0
FOUR PHASE COMPARATOR ASSEMBLIES AND ONE LOOP ASSEMBLY	3	5	5
TWENTY PHASE COMPARATOR UNITS	1.5	2.0	2
TWO-POWER DIVIDERS	0.2	0.1	0
TWENTY-LOOPS	2.5	3.0	10
TWENTY-DATA DETECTORS	2.0	3	10
TWENTY-FREQUENCY COUNTERS	2.5	4	10
ONE-FREQUENCY SYNTHESIZER	1.6	2.0	3.0
ONE-POWER CONDITIONER	1.5	2.0	10
TOTAL	37.35	61.95	61

activities of design, development, manufacturing and testing of a single space qualified **prototype.** The recurring costs are those associated with all the activities of fabricating, manufacturing, integrating, assembling and testing of the **flight hardware.** The USCM subdivides the cost items by hardware elements and by subdivision of work for each element as depicted in Figure 8-3. For the purposes of costing the ADCLS falls within the communication area of activity. We have computed the recurring and non-recurring costs for the elements that are ADCLS-peculiar. Costs associated with the power supply, transmission and command and control system components are excluded from the cost estimates. Costs related to housekeeping functions, i.e. thermal control, attitude control, and propulsion are also excluded because they are common to other payloads on the platform.

The USCM is constructed based on the historical cost data of various spacecraft programs. The USCM Cost Estimating Relationships (CER) were developed by using multiple regression analysis, engineering logic and programmatic information. The relationship represents the best fit through the data. The cost estimating relationship for complete communication system analogies to ADCLS are of the following form:

$$y = a\ x^{b}$$

where:

y = cost in thousand of 1979 constant dollars

a,b = CER constants

x = weight of the complete system in lbs

The CER constants applicable to the above relationship for ADCLS cost estimates are:

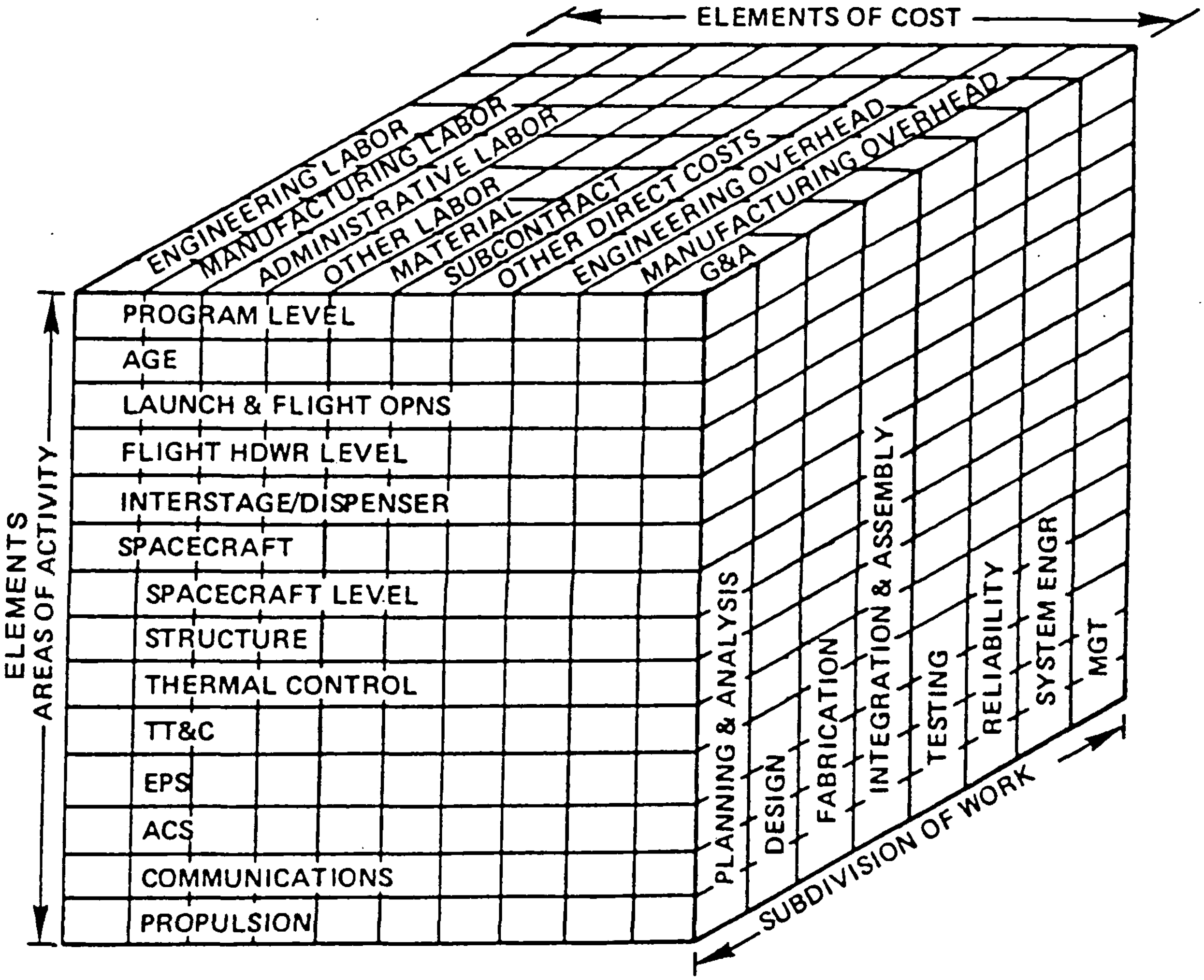

Figure 8-3. Elements of the Cost Model

	CER Constant a	b
For Recurring Cost:	49.96	0.87
For Non-Recurring Cost:	564.68	0.56

The corresponding ADCLS costs derived from the USCM are:

Recurring Cost:	\$2,314,318 (1979 \$) = \$4.65 million (1985 \$)
Non-Recurring Cost:	\$6,668,710 (1979 \$) = \$13.5 million (1985 \$)

The sum of the recurring and non-recurring costs of the ADCLS instrument expressed in 1985 dollars is \$18.15 million.

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