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144475

TECHNICAL MEMORANDUM

SATELLITES FOR LIFE SCIENCES

Job Order 92-105

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Prepared By

Life Sciences Applications Department
Lockheed Electronics Company, Inc.
Aerospace Systems Division
Houston, Texas

Contract NAS 9-12200

For

HEALTH APPLICATIONS OFFICE
LIFE SCIENCES DIRECTORATE

National Aeronautics and Space Administration

LYNDON B. JOHNSON SPACE CENTER

Houston, Texas

January 1976

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(See instructions on reverse side.)

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13. ABSTRACT

This document summarizes the potential of all available satellites for adaptation of earth resources technology to life science problems.

14. SUBJECT TERMS

Manned & Unmanned Sat.	ATS Satellites	NIMBUS Satellites
Military Satellites	Meteorological Sat.	Geosynchronous Sat.
Earth Resources Sat.	Sensors	NOAA's Satellites

Contract NAS 9-12200
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TECHNICAL MEMORANDUM

SATELLITES FOR LIFE SCIENCES

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PREFACE

The Health Applications Office of NASA is the pioneering organization charged with applying space technology to problems in the life sciences. This office adapts NASA-developed earth resources technology to life science problems, developing new techniques as necessary.

The Health Applications Office uses earth resources survey techniques in many of its projects. It differs from other users in the types of projects that it undertakes; it applies these techniques to projects on the life sciences. However, these projects do not include certain life science fields that have been preempted by other users, such as agriculture and forestry.

In the early days of the Health Applications Office, its new personnel, including the author of this document, needed orientation on satellites that were available for their use. In particular, there appeared to be no document which summarized, in a meaningful way, the potential of all available satellites.

This document was prepared to satisfy this need. It has been revised several times, but this is its first major rewriting. In addition to many new references, it also includes references to manned satellites. It is about twice as large as the first edition (ref. 1), which was issued in 1973.

INTRODUCTION

The launching of Sputnik I by Russia in 1957 ushered in the space age. Since then about 1,600 satellites have been launched to scan the earth and its atmosphere, the moon and its sister planets, and the sun (ref. 2). As of December 31, 1974, 718 satellites in several thousand fragments remain in space, a few in active missions, most waiting to decay and fall out of orbit (ref. 3).

The United States and Russia have launched the largest number of satellites, but other countries have also participated. Table I shows the countries and consortia that have participated in this newest adventure of mankind (ref. 2).

NASA's Health Applications Office in its missions uses data from satellites. For the benefit of this office, this report will give perspective to NASA's range of satellite programs. It will be concerned primarily with the technical details of the satellite sensors which show potential for applications to the public health or to the biological sciences; by and large, these are the same sensors that are useful for studies of earth resources.

TABLE I. – SPACECRAFT TOTALS (AS OF DECEMBER 31, 1974)

SPACECRAFT ORBITED

Sponsor	Earth Orbit	Lunar Missions	Planetary Impact/Orbit	Solar Orbit	Totals
Australia[1]	2	–	–	–	2
Canada[1]	6	–	–	–	6
ESRO[1]	7	–	–	–	7
France[1]	12	–	–	–	12
Germany[1]	4	–	–	1	5
Intelsat[1]	18	–	–	–	18
Japan	5	–	–	–	5
NATO[1]	2	–	–	–	2
Proc	2	–	–	–	2
UK[1]	11	–	–	–	11
US[2]	697	29	1	16	743
USSR[3]	834	23	9	8	874
Netherlands[1]	1	–	–	–	1
Spain[1]	1	–	–	–	1
Italy[1]	4	–	–	–	4
TOTALS	1606	52	10	25	1693

[1]Includes launches from the U.S. or by U.S. boosters, of satellites built by sponsors or built jointly under cooperation agreements with the U.S. [2]U.S. totals consist of exclusively U.S.-sponsored satellites, including unidentified satellites, but not including Atlas-Centaur, Saturn, or Titan III non-functional payloads. [3]USSR totals include unidentified Russian spacecraft; do not include Earth-parking platforms used for injecting payload spacecraft into other orbits.

SPACECRAFT STILL IN ORBIT

Sponsor	Earth Orbit*	Lunar Orbit	Solar/Planet Orbit	Totals
Australia	1	–	–	1
Canada	6	–	–	6
ESRO	2	–	–	2
France	11	–	–	11
Germany	4	–	1	5
Intelsat	18	–	–	18
Japan	5	–	–	5
NATO	2	–	–	2
Proc	2	–	–	2
UK	9	–	–	9
US	330	5	16	351
USSR	281	6	16	303
Netherlands	1	–	–	1
Spain	1	–	–	1
Italy	1	–	–	1
TOTALS	674	11	33	718

**Does not include non-functional payloads, nor parking-orbit platforms.*

MANNED SPACE FLIGHT RECORDS

	Total Flights	Earth Missions	Lunar Missions	Total Man-Hours
United States	30	21	9	21,851 5
USSR	23	23	–	5,965.5
TOTALS	53	44	9	27,817.0

First Manned Flight: Vostok 1
First EVA: Voskhod 2
Longest Flight: Skylab 4 (84 days 1 hr. 16 min.)
First Rendezvous Mission: Gemini 7 and 6
First Docking Flight: Gemini 8

First Lunar Orbit: Apollo 8
First Crew Exchange: Soyuz 4 and 5
First Manned Lunar Landing: Apollo 11
First Triple Spacecraft Launch: Soyuz 6, 7 and 8
Heaviest Spacecraft: Skylab 1 (164,597 lbs.)

2. SOURCES OF INFORMATION

References on NASA space programs are not always well indexed. The profusion and confusion of names and acronyms for satellites hamper persons learning about NASA programs for the first time. Access to even the available references is sometimes difficult, but with persistence, most documents can be examined.

The National Space Science Data Center (NSSDC) is charged with supplying the professional community with general information on satellites and space experiments. This organization furnishes a wide variety of publications and gives some information by phone. Their most valuable source of information, "Reports on Active and Planned Spacecraft and Experiments," is an extensive publication issued or supplemented on a quarterly basis (ref. 4). Correspondence or subscription requests should be addressed to:

The National Space Science Data Center
Goddard Space Flight Center Code 601
National Aeronautics and Space Administration
Greenbelt, Maryland 29771
Telephone: (301) 982-6695

NSSDC also distributes single copies of such important documents as the Nimbus user guides (ref. 5) and others (refs. 6 and 7).

A companion organization at the same address and telephone, World Data Center A, Rockets and Satellites, conducts international exchanges of geophysical observations under the auspices of the U.S. National Academy of Sciences. This organization furnishes information on earth satellites, space probes, and some sounding rocket launches. The information on satellites is limited to very general data concerning launches by all countries. Requests for special information are handled on an individual basis.

The Satellite Situation Report (ref. 3), issued monthly, lists those satellites still in orbit, those still functioning, and those which have decayed. It is probably based on automatic scanning of the skies and includes a few orbiting objects of unknown origin. Figure 1 shows a summary page from a recent issue, and figure 2 shows a page of data from the same issue.

The TRW Space Log (ref. 2), now issued annually, publishes very readable descriptions of the programs and satellites of all countries. It also maintains a log of all space flights and publishes a "Box Score of U.S. Space Launches." It is a fine reference for a person fairly new to the field who needs an overall perspective.

Locating reports on specific satellites requires use of an aerospace literature indexing system. The most important of these is the RECON computerized reference retrieval system (ref. 8). In theory, all NASA and NASA-contractor reports are indexed in this system by key words, titles, authors, and sponsoring institutions. In practice, RECON includes all materials indexed in Scientific and Technical Aerospace Reports (STAR) (ref. 9) and International Aerospace Abstracts (IAA) (ref. 10). RECON also includes some older materials not included in these indexes, as well as other non-indexed materials, such as certain quarterly reports. Figure 3 shows the nature of citations in these systems.

RECON contains references from 1962 to date. It is certainly much more convenient to use than the separate indexes in book form, but also it shares the defects of these indexes. For example, STAR depends on the timely submission of reports by NASA monitors (the directors of contracted work) and NASA documentation experts of technical reports of work. As a practical matter, most technical reports generated at JSC are not submitted to STAR at all.

RECON and other systems locate references and describe them. The JSC library has an excellent collection of documents on

SPACE OBJECTS BOX SCORE

	OBJECTS IN ORBIT	DECAYED OBJECTS
AUSTRALIA	1	1
CANADA	7	0
ESA	1	0
ESRO	2	8
FRANCE	61	18
FRANCE/FRG	2	0
FRG	7	3
INDIA	1	0
ITALY	1	3
JAPAN	14	0
NATO	2	0
NETHERLANDS	1	3
PRC	5	2
SPAIN	1	0
UK	12	3
US	2439	1301
USSR	1094	3424
TOTAL	3651	4766

Figure 1. — Satellite Situation Report (ref. 3) box score.

microfiche. Other documents are on file and references are available in journals or books in the library's collection. The staff will borrow other references from cooperating libraries, although interlibrary loans can take months.

Other aspects of information retrieval are discussed in an introductory lecture for newcomers to the Life Sciences Applications Department of the Lockheed Electronics Company (ref. 13). This and other limited distribution documents are available in the Research Data Facility, REDAF, of the Project Support Office of the Earth Observations Division at JSC. When possible, REDAF numbers are specified in this document.

A very fine general reference, published by the International Astronautical Federation (ref. 11) shows the present state of earth resources survey satellite systems throughout the world. In addition to present systems, this reference shows the planned facilities of many nations, but this situation is changing very rapidly. It also describes facilities that nations new to the field might acquire and it lists probable costs for them.

Information on launchings planned for the near future are conveniently found in public relations material of NASA (ref. 12).

OBJECTS IN ORBIT

INTER-NATIONAL DESIGNATION	CODE NAME	CATALOGUE NUMBER	SOURCE	LAUNCH	PERIOD MINUTES	INCLI-NATION	APOGEE KM.	PERIGEE KM.	TRANSMITTING FREQ.(MC/S)	NOTES
1975 LAUNCHES (CONT'D)										
1975 077D		8135	US	27 AUG	98.3	26.9	1071	281		
1975 079A	31ST MOLNIYA 1	8187	USSR	2 SEP	717.8	62.9	39743	613		
1975 U79B		8188	USSR	2 SEP	90.2	62.7	372	202		
1975 079C		8189	USSR	2 SEP	89.2	62.8	300	180		
1975 079E		8274	USSR	2 SEP	735.9	62.8	40534	715		
1975 081A	14TH MOLNIYA 2	8195	USSR	9 SEP	717.6	62.8	39900	450		
1975 081D		8418	USSR	9 SEP	733.9	62.6	40846	299		
1975 082A	KIKU	8197	JAPAN	9 SEP	105.9	46.9	1103	975		
1975 082B		8352	JAPAN	9 SEP	105.9	46.9	1103	975		
1975 083A	VIKING 2	8199	US	9 SEP	TRANS-MARS TRAJECTORY					
1975 083B		8272	US	9 SEP	HELIOCENTRIC ORBIT					
1975 086A	COSMOS 761	8285	USSR	17 SEP	114.6	74.0	1484	1401		
1975 086B	COSMOS 762	8286	USSR	17 SEP	115.1	74.0	1487	1439		
1975 086C	COSMOS 763	8287	USSR	17 SEP	115.8	74.0	1511	1475		
1975 086D	COSMOS 764	8288	USSR	17 SEP	116.0	74.0	1527	1480		
1975 086E	COSMOS 765	8289	USSR	17 SEP	116.3	74.0	1552	1480		
1975 086F	COSMOS 766	8290	USSR	17 SEP	114.9	73.9	1486	1419		
1975 086G	COSMOS 767	8291	USSR	17 SEP	115.3	73.9	1488	1457		
1975 086H	COSMOS 768	8292	USSR	17 SEP	115.5	73.9	1492	1473		
1975 086J		8295	USSR	17 SEP	117.8	74.0	1686	1482		
1975 087A	METEOR 22	8293	USSR	18 SEP	102.3	81.2	903	834		
1975 087B		8294	USSR	18 SEP	102.4	81.2	924	827		
1975 089A	COSMOS 770	8325	USSR	24 SEP	109.1	82.9	1211	1167		
1975 089B		8326	USSR	24 SEP	109.0	82.9	1201	1163		
1975 091A	INTELSAT 4A F-1	8330	US	26 SEP	1426.1	0.5	35823	35358		
1975 091B		8331	US	26 SEP	657.3	21.8	36749	578		
1975 092A	D2-B	8332	FRANCE	27 SEP	96.8	37.1	710	499	136.740	5*
1975 092B		8333	FRANCE	27 SEP	96.9	37.1	719	500		
1975 092C		8336	FRANCE	27 SEP	96.7	37.1	700	500		
1975 092D		8337	FRANCE	27 SEP	97.2	37.0	726	524		
1975 092E		8340	FRANCE	27 SEP	96.6	37.1	696	496		
1975 092F		8341	FRANCE	27 SEP	96.8	37.1	708	502		
1975 092G		8342	FRANCE	27 SEP	96.7	37.1	704	495		
1975 094A	COSMOS 773	8343	USSR	30 SEP	100.8	74.0	807	791		
1975 094B		8344	USSR	30 SEP	100.7	74.0	809	778		
1975 094C		8346	USSR	30 SEP	100.6	74.0	808	773		
1975 096A	EXPLORER 54	8353	US	6 OCT	124.8	90.0	3652	144	137.230,2289.500	5*
1975 096B		8354	US	6 OCT	122.5	90.0	3445	150		
1975 097A	COSMOS 775	8357	USSR	8 OCT	1445.9	0.0	36220	35737		
1975 U97D		8414	USSR	8 OCT	631.9	47.2	35748	281		
1975 097E		8415	USSR	8 OCT	633.0	47.1	35697	387		
1975 098A		8360	US	9 OCT	89.2	96.4	351	123		
1975 099A	TIP 2	8361	US	12 OCT	95.2	90.7	706	358		
1975 099B		8364	US	12 OCT	95.2	90.7	704	357		
1975 099C		8409	US	12 OCT	96.2	90.8	760	404		
1975 099D		8410	US	12 OCT	94.2	90.6	655	307		
1975 100A	GOES 1	8366	US	16 OCT	1435.9	1.0	35796	35769	136.380,468.825, 1682.500	5* 5*
1975 100B		8367	US	16 OCT	95.6	28.2	907	188		
1975 100C		8368	US	16 OCT	651.0	23.8	36795	200		
1975 100D		8371	US	16 OCT	92.4	28.2	599	185		
1975 100E		8372	US	16 OCT	92.4	28.3	599	184		
1975 101C		8373	USSR	17 OCT	88.9	62.7	255	191		
1975 101D		8412	USSR	17 OCT	88.5	62.8	214	187		
1975 102A	COSMOS 777	8416	USSR	29 OCT	93.3	65.0	442	428		

Figure 2. — Satellite Situation Report (ref. 3) page of data.

TYPICAL CITATION FROM IAA

NASA SPONSORSHIP — AVAILABLE ON MICROFICHE
AIAA ACCESSION NUMBER — TITLE
AUTHOR — AUTHOR'S AFFILIATION
TITLE OF PERIODICAL — PREVIOUSLY ISSUED AS
CONTRACT, GRANT, OR SPONSORSHIP — PUBLICATION DATE

A71-16573 * # Acceleration patterns in quasi-steady MPD arcs. Robert G. Jahn, Kenn E. Clark (Princeton University, Princeton, N.J.), Ronald C Oberth, and Peter J. Turchi. *(American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 8th, New York, N Y., Jan. 19 21, 1970, Paper 70 165.)* AIAA Journal, vol. 9, Jan 1971, p. 167-172. 29 refs. Grant No NGL-31-001-005.
(For abstract see issue 06, page 1132, Accession no. A70-18208)

TYPICAL CITATION AND ABSTRACT FROM STAR

NASA SPONSORED DOCUMENT — AVAILABLE ON MICROFICHE
NASA ACCESSION NUMBER — CORPORATE SOURCE
TITLE — PUBLICATION DATE
AUTHORS — AVAILABILITY SOURCE
CONTRACT OR GRANT — COSATI CODE
REPORT NUMBER

N71-10429*# Lockheed Missiles and Space Co., Sunnyvale, Calif
LIMITATIONS IN THERMAL MODELING Technical Summary Report, 6 Jun 1967 - 8 Dec 1969
R E Rolling, D O Murray, and K N Marshall Dec 1969 245 p refs
(Contract NAS8-21153)
(NASA-CR-102566; LMSC-6-78-69-41) Avail NTIS CSCL 20M
An analytical and experimental study was made of the possible limitations existent in utilizing small-scale models for determination of spacecraft thermal behavior A potential limitation in scale factor experimental accuracy and accuracy in model design is associated with each spacecraft design Individual problem areas of thermal modeling are treated separately. Author

TYPICAL CITATION AND ABSTRACT OTHER THAN IAA AND STAR

ACCESSION NUMBER → W71-020

NOISE CHARACTERISTICS OF AN SSB-FDMA/PhM MULTIPLE ACCESS SYSTEM ← TITLE

AUTHOR(S) → E. E. Crampton, Jr., and S. J. Andrzejewski

Westinghouse Electric Corporation ← AFFILIATION

REPORT NUMBER → May 1971
DATE OF PUBLICATION

Contract NAS 5-21595 ← GRANT OR CONTRACT

This report describes the results of a 3.5-year communication experiment to determine the magnitude and spectral characteristics of three basic types of noise in an SSB-FDMA/PhM multiple access system. The types of noise are identified as thermal, intermodulation, and threshold noise. The experiment, part of the NASA Applications Technology Satellite program, employed two spin-stabilized satellites (ATS-1 and ATS-3) and ground stations at Mojave, California; Rosman, North Carolina; and Cooby Creek, Australia. Noise measurements were made in six test loops to investigate the noise characteristics in the three basic subsystems: the single-sideband transmitter, the single-sideband phase modulation spacecraft unit, and the ground receiver. Equipment configurations are illustrated, noise levels and components are shown, and the results of the study are summarized.
(52 pages, 16 illustrations)

c07 ← IAA STAR CATEGORY CODE

070100 15 ← TDR SECTION/CATEGORY NUMBER; COSATI NUMBER

Figure 3. — Sample Citations.

3. MANNED NASA SATELLITES

In general, manned satellites can only be expected to furnish retroactive data for most projects. Only in coincidental circumstances will astronauts be able to furnish observations that would have current value. However, such circumstances can occur. For example, a Saharan drought situation occurred during the Skylab flights; as a result, the Skylab astronauts could have operated the multispectral scanner over the drought area and brought back the magnetic tapes.

For retrospective studies of the earth, both the Gemini and the Apollo programs furnished many color photographs of the earth. Many of these photographs were taken when the astronauts had free time, or when they saw something interesting, but many others were taken as a result of deliberate experiments (ref. 14). The astronauts in these missions used Hasselblad 70-mm cameras. Some multispectral photographic experiments were also included in Apollo IX.

All Gemini and Apollo 6, 7, and 9 photographs are listed in a computer printout called GEMSORT (ref. 15). This reference is fairly difficult to find, but copies are available for use in the REDAF facility, and it has been indexed in STAR. No instructions for its use are included in the text, which makes it difficult to learn to use. It needs to be revised and a useful text prepared, but there are no plans for this in the near future.

Perhaps more useful are two references which contain index maps to these photographs, one for Gemini missions (ref. 16) and the other for Apollo 6, 7, and 9 (ref. 17). Both are available in REDAF, and both have been indexed in STAR. No such reference exists yet for the Apollo-Soyuz Test Project.

Photographs identified from these references can be scanned on microfilm viewers. Films and viewers are located in building 17, room 1070 of JSC, part of the Applications Support Section of the Project Support Facility.

Gemini and Apollo photographs identified as useful can be ordered directly from the Photographic Technology Division at JSC. A few may still be available through the Project Support Facility. They can also be purchased from:

EROS Data Center
Sioux Falls, South Dakota 57198
Telephone (605) 594-5611 (FTS 784-6511)

The three Skylab flights furnished a tremendous quantity of data that may be useful. These include handheld 35-mm color photography, handheld 70-mm color photography, 70-mm multispectral photography (S 190A), 5-inch single band earth terrain photography (S 190B), infrared spectrometry (S 191), multispectral scanner data (S 192), microwave radiometry data (S-193), and L-band radiometry (S 194).

The EREP Data Catalog (ref. 18) contains a geographical listing of all S 190A and S 190B photographs, the vertical multispectral and vertical high resolution photographs. Other references can be used to find handheld photography (ref. 19-21). No index maps exist to expedite searches for handheld photography, but some alphabetical listings (ref. 22-24) allow a person to locate many photographs of interest.

Useful public health and life sciences data will primarily have been taken by coincidence since HAO projects were not included in Skylab. On request, useful data will be identified by personnel of the Project Support Facility. Photographs can be ordered from the Photographic Technology Laboratory or bought from EROS. The latter maintains complete files of these data including geographic coordinate listings of all of them.

A major challenge for the future concerns the Shuttle program. Manned flights will probably be available on a regular basis, and great flexibility should allow optimum sensors to be flown for public health or life science applications. At this stage, little preparation has been made for these potentially very useful flights.

4. UNMANNED NASA SATELLITES

The publicity surrounding manned space flight obscures the tremendous variety of unmanned satellites at work for NASA. Unfortunately, the manner of naming and numbering them also discourages the non-professional. Acronyms for satellites often do not agree with satellite program acronyms. Acronyms change radically after launch or after testing; and numbers and letters also change in a way that appears haphazard to the outsider.

Table II (ref. 25) lists many of NASA's unmanned programs. For general information, table III (ref. 26) lists the current series of Russian satellites, and table IV (ref. 12) shows current launchings.

Data from very few of NASA's satellites can be applied to projects of the Health Applications Office. The satellites marked with an asterisk in table II are the most promising, and are discussed individually in this report.

TABLE II. – NASA UNMANNED SPACE PROGRAMS

(from ref. 25)

SPACE APPLICATIONS

Communications/Navigation
- Echo Series
- Relay Series
- Alouette Series
- Telstar Series
- ISIS Series
- Intelsat Series
- CAS/CTS
- ATS Series[a]

Meteorology
- Vanguard Series
- Nimbus Series[a]
- TIROS Series
- ESSA Series
- ITOS/NOAA Series[a]
- CAS-A/EOLE
- SMS or GOES Series[a]

EARTH OBSERVATIONS

- ERTS Series[a]
- EOS[a] (under study, no information available)

LUNAR AND PLANETARY EXPLORATION

Lunar Exploration
- Ranger Series
- Surveyor Series
- Lunar ORBITER Series

Planetary Exploration
- Pioneer Series
- Mariner Series
- Viking Series
- Helios Series
- Grand Tour - Outer Planet Studies
- Planetary Explorer

SPACE SCIENCE INVESTIGATIONS

Meteoroids
- Pegasus Series

Biomedical
- Biosatellite Series

Physics and Astronomy
- OGO Series
- OSO Series
- OAO Series
- HEAO Series
- Explorer Series
- ANS
- Ariel/UK Series
- ESRO Series
- FR
- GRS Series
- San Marco Series
- SAS Series
- SSS Series
- LST Series

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[a]These satellites offer data that may be pertinent to the public health or the life sciences.

TABLE III. – RUSSIAN PROGRAMS

(from ref. 26)

Category	Launch Vehicle	Launch Sites	Payload Names	Years 57-66	67	68	69	70	71	72	73	74	Total
Earth orbital science	A	TT	Sputnik	2									2
	A-1	TT	Elektron	4									4
	A-2	TT,PL	Kosmos, Interkosmos			3	1	2	4	8	7	10	35
	A-2-e	TT	Kosmos, Prognoz		1					2	1		4
	B-1	KY,PL	Kosmos, Interkosmos	18	4	7	2	6	1	3	1		42
	C 1	KY,PL	Kosmos, Interkosmos, Oreol					2	3		3	2	10
	D-1	TT	Proton	3		1							4
Earth orbital engineering	A-2-e	PL	MAS							1			1
Communications	A-2-e	TT,PL	Kosmos, Molniya 1,2,3	5	3	3	2	5	3	6	8	6	41
	D-1-e	TT	Kosmos, Molniya 1S									2	2
Weather	A-1	TT,PL	Kosmos, Meteor	5	3	2	2	4	4	3	2	5	30
	B-1	KY	Kosmos	2	1			1					4
Earth orbital man-related	A	TT	Sputnik	1									1
	A-1	TT	Korabl Sputnik	5									5
	A-2	TT,PL	Kosmos, Soyuz	4	3	4				1	3	4	19
	A-2-m	TT	Kosmos					1	2				3
	D-1	TT	Salyut, Kosmos								2		2
Earth orbital manned	A-1	TT	Vostok	6									6
	A-2	TT	Voskhod, Soyuz	2	1	1	5	1	2		2	3	17
	D-1	TT	Salyut						1			2	3
Lunar man related	D-1-e	TT	Kosmos, Zond		2	3	1	1					7
	D-1-m	TT	Kosmos					1					1
Moon	A-1	TT	Luna	3									3
	A-2-e	TT	Kosmos, Luna	13		1							14
	D-1-e	TT	Kosmos, Luna				3	3	3	2	1	3	15
Venus	A 2-e		Venera, Kosmos, Zond	11	2		2	2		2			19
Mars	A 2 e		Mars, Zond, Kosmos	5									5
	D 1 e		Mars, Kosmos						5		6		11
Military observation recoverable	A-1	TT,PL	Kosmos	36	5								41
	A-2	TT,PL	Kosmos	26	17	29	32	29	28	29	35	29	254
Minor military (elint, calibration, environmental?)	B-1	KY,PL	Kosmos	11	8	9	12	11	11	9	9	6	86
	C-1	PL	Kosmos									2	2
Elint (electronic ferret)	A-1	PL	Kosmos					1	1	1	1	1	5
	C-1	TT,PL	Kosmos	5	1	2	2	3	5	4	4	4	30
Navigation, geodesy	C-1	TT,PL	Kosmos	9	2	3	4	3	4	5	4	6	40
Military communications	B-1	KY	Kosmos	2									2
	C-1	TT,PL	Kosmos	11	1	1		9	18	18	25	17	100
Early warning	A-2-e	TT,PL	Kosmos		1	1				1	1	1	5
Ocean surveillance	F-1-m	TT	Kosmos		1	1		1	2	1	1	3	10
Fractional orbit bombardment system	F-1-r	TT	Kosmos	2	9	2	2	2	1				18
Inspector/destructor	F-1-m	TT	Kosmos		1	3	1	2	3				10
Inspection target	C-1	PL	Kosmos						3	1			4
	F-1-m	TT	Kosmos			1		1					2
Vehicle test	A-m	TT	Polet	2									2
	A-1-m	TT	Kosmos	2									2
Orbital launch platform	A-2-e	TT,PL	Tyazheliy Sputnik or	34	7	5	4	7	3	11	10	7	88
	A-2-m	TT	Nositel Sputnik					1	2				3
	D-1-e	TT	Nositel Sputnik		2	3	4	3	5	1	5	4	27
	D-1-m	TT	Nositel Sputnik					1					1
Subtotals													
Kosmos name				137	61	64	55	72	81	72	85	74	701
Earth orbit				209	74	81	75	98	107	106	124	114	988
Lunar distance or beyond				20	1	4	4	5	7	3	7	3	54
Tyuratam				190	42	47	37	38	41	27	33	31	486
Kapustin Yar				33	9	8	4	5	1	2	2	1	65
Plesetsk				6	24	30	38	60	72	80	96	85	491
Primarily civil				123	29	33	26	41	38	40	51	48	429
Primarily military				106	46	52	53	62	76	69	80	69	613
Totals				229	75	85	79	103	114	109	131	117	1042

TABLE IV. – CURRENT LAUNCHINGS

(from ref. 12)

Name	Launch Date	Vehicle	Range	Mission Remarks
RCA-A	Dec. 11	Delta	ETR	First of a series of domestic communications satellites for RCA. Reimbursable.
1976				
CAS-C/CTS	Jan. 13	Delta	ETR	Canadian-US cooperative experimental communications satellite to develop and test the technology of high power satellite communications systems.
Helios-B	Jan. 15	Titan III Centaur	ETR	Second West German/NASA cooperative satellite to investigate the properties of and processes in interplanetary space close to the Sun.
Intelsat IVA-B	January	Atlas Centaur	ETR	Second of a series of improved Intelsat consortium satellites. Reimbursable
ITOS-E2	January	Delta	ETR	Operational meteorological satellite of the National Weather Service to provide daytime and nighttime cloud cover imagery. Reimbursable
NATO-C	February	Delta	WTR	Communications satellite in synchronous orbit to perform communications relay for NATO. Reimbursable
Marisat-A	February	Delta	ETR	Comsat Corp. satellite to provide maritime communications services. Reimbursable.
LAGEOS	1st Qtr.	Delta	WTR	Demonstrate relevant space techniques that will contribute to the development and validation of predictive models for earthquake hazard alleviation, ocean surface conditions and ocean circulation.
RCA-B	1st Qtr.	Delta	ETR	Second domestic communications satellite for RCA. Reimbursable.
Relativity (Gravity Probe)	(Under Study)	Scout	WTR	Scientific satellite to make a test of Einstein's Theory of Relativity.
Comstar-A	1st Qtr.	Atlas Centaur	ETR	Domestic communications satellite for Comsat Corp. Reimbursable
Intelsat IVA-C	May	Atlas Centaur	ETR	Third of a series of improved Intelsat Consortium satellites. Reimbursable.
Marisat-B	2nd Qtr.	Delta	ETR	Second Comsat Corp. satellite to provide maritime satellite communications services. Reimbursable.
Comstar-B	2nd Qtr.	Atlas Centaur	ETR	Second domestic communications satellite for Comsat. Reimbursable.
Indonesia-A (Palapa)	3rd Qtr.	Delta	ETR	Indonesian communications satellite. Reimbursable
RCA-C	2nd Half	Delta	ETR	Third domestic communications satellite for RCA. Reimbursable.
GOES-B	4th Qtr.	Delta	ETR	Second operational satellite to provide continuous daytime and nighttime global cloud cover observations for NOAA. Reimbursable.
ITOS-H	4th Qtr.	Delta	ETR	Operational meteorological satellite to provide daytime and nighttime cloud cover imagery for NOAA. Reimbursable.
Comstar-C	4th Qtr.	Atlas Centaur	ETR	Domestic communications satellite for Comsat. Reimbursable.
Navy Transit	1976	Scout	WTR	Navy navigation satellite. Reimbursable.

5. APPLICATIONS TECHNOLOGY SATELLITES (ATS)

The ATS satellites are designed to develop technology commonly required for a variety of applications, and to provide an orbital testing platform for advanced concepts in space technology (ref. 27). In practice, of the six satellites flown to date, ATS-1, -3, and -6 were largely successful, ATS-5 was marginally successful, and the other two failed.

The sensors of major interest to the HAO were the spin scan cloud camera (SSCC) of ATS, the image dissector camera (IDC) of ATS-3, and the very high-resolution radiometer (VHRR) of ATS-6. The SSCC produced color images of the whole western hemisphere, and the IDC produces black-and-white images of the same area, taken in visible light. The high resolution radiometers produced both visible and thermal infrared images of a whole hemisphere.

The green channel of the SSCC of ATS-3 will still function, with a ground resolution of 8 kilometers, even though the satellite was put into orbit in late 1967. Pictures can be taken at 30-minute intervals and are especially useful for tracking tropical storms. It is no longer used for this purpose since SMS-1/GOES-1 and SMS-2/GOES-2 provide superior images.

ATS-6 was launched on May 30, 1974. This impressive satellite is apparently functioning well in many of its roles, and is presented in table V. However, VHRR data are not available for use, since the sensor has failed. Data on all sensors are available in a user's manual (ref. 28).

A broad view of the capabilities of ATS-6 can also be obtained from the publications release reproduced in appendix A.

TABLE V. — ATS-6 EXPERIMENTS (ref. 27)

Meteorology

- Geosynchronous Very High-Resolution Radiometer (GVHRR) (now defunct)
  .55 to .75 μm and 10.5 to 12.5 μm every 30 minutes
  10-km ground resolution directly below
  "Cloud coverage for cloud studies, tropical storm life cycles, mesoscale phenomena, cloud climatology...earth albedo, earth resources, ocean temperatures."

Communications

- Instructional Television (ITV) Relay
  Educational television relayed to Indian villages
- Millimeter Wave
  Propagation studies at 20- and 30-GHz wideband
- 10.6 μm Laser Experiment
  Satellite-ground communication at 28,000 GHz
  Feasibility of satellite to satellite communications for deepspace probes
- Radio-frequency Interference (RFI) Experiment
  Measure interference power at 6 GHz for planning spectrum utilization
- Radio Beacon Experiment
  Continuous emission in many frequencies to study the effect of particles beyond the earth's atmosphere

Spacecraft Applications

- Data Relay Satellite System (DRSS)
  Communications with NIMBUS E and other satellites
- Cesium Bombardment Ion Engine Experiment
  Obtain operational data on ion microthruster electric propulsion system
- Spacecraft Attitude Maneuvering Optimal Control (SAMOC)
- Self-adaptive Precision Pointing Spacecraft Attitude Control (SAPPSAC)

Navigation

- PLACE
  Improve methods of aircraft position location
  Demonstrate two-way communications between ground terminals and many aircraft

Scientific Experiments

- Low-energy Proton-Electron
- Low-energy Protons
- Solar Cosmic Ray
- Auroral Particles
- Particle Acceleration
- Magnetometer
- Solar Cell Radiation Damage

Access to ATS data is arranged through the following office:

ATS Office
Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland 20771
(301-982-6865)

Basically, all data taken for existing projects is available to the rest of the scientific community, but arrangments must be made with this office.

6. NIMBUS SERIES OF EXPERIMENTAL SATELLITES

Nimbus spacecraft serve as testbeds for the research, development, and configuration of sensors and systems for primarily meteorological applications. The improved weather forecasting techniques resulting from Nimbus experiments serve in operational satellites such as ITOS, which provide daily worldwide cloud-cover pictures and weather forecasting.

Nimbus sensors are described in a series of user guides, (ref. 29-34) and nonmeteorological uses are compiled in other publications (ref. 35). Attractive publications present illustrations of fine images from Nimbus I through IV (ref. 35-36).

Tables VI and VII list the sensors on board the Nimbus 5 (ref. 33) and 6 (ref. 34) satellites. Some data, such as that collected by the scanning radiometer, can be applied directly to HAO projects. Other data will require testing and ingenuity before being useful, and some, such as that gathered by the solar radiation and ozone monitors, will probably never be used by this office. Some of the experiments on Nimbus 6 are discussed below in extracts from reference 34.

6.1 TEMPERATURE HUMIDITY INFRARED RADIOMETER (THIR)

The two-channel scanning radiometer is designed to measure earth radiation from two spectral bands. A 10.3 μm to 12 μm (11.5 μm) window channel provides an image of the cloud cover, and temperatures of the cloud tops, land, and ocean surfaces. A 6.5 μm to 7.1 μm (6.7 μm) channel provides information on the moisture content of the upper troposphere and stratosphere, and the location of jet streams and frontal systems. The ground resolution at the subpoint is 8.2 km for the 11.5 μm channel and 22.5 km for the 6.7 μm channel. Both will operate continuously to provide day and night global coverage.

TABLE VI. – NIMBUS 5 EXPERIMENTS

(from ref. 33)

Experiment	Spectral Bands	Main Purpose	Experimenter
Temperature Humidity Infrared Radiometer (THIR)	10.5-12.5μm 6.5-7.0μm	Daytime and nighttime surface and cloud top temperatures Cloud mapping Atmospheric water vapor mapping	A. McCulloch, NASA/GSFC Greenbelt, Maryland 20771
Surface Composition Mapping Radiometer (SCMR)	8.3-9.3μm 10.2-11.2μm 0.8-1.1μm	Distinguish acidic from basic rocks Map surface temperatures Map surface features (600-m resolution)	Warren Hovis, NASA/GSFC Greenbelt, Maryland 20771
Electrically Scanning Microwave Radiometer (ESMR)	16-19.255- 19-475 GHz	Map surface features even in the presence of clouds Map distribution of polar ice Map precipitating clouds over ocean areas (25-km resolution)	T. Wilheit, NASA/GSFC Greenbelt, Maryland 20771
Infrared Temperature Profile Radiometer (ITPR)	3.8μm 11μm 15μm (4 bands) 20μm	Vertical temperature profile of the atmosphere	W. L. Smith, NESS/NOAA Suite 300, 3737 Branch Ave. Hillcrest Heights, Maryland 20031
Selective Chopper Radiometer (SCR)	2.08μm 2.59μm 2.65μm 3.5μm 11.1μm 13.8-14.8μm (4 bands) 15μm (4 bands) 18.6μm 46.5μm 100μm	Vertical temperature profile of the atmosphere Water vapor distribution in the atmosphere Density of ice particles in cirrus clouds	J. T. Houghton Oxford University Oxford, England S. D. Smith, Heriot-Watt University, Edinburg, Scotland
Nimbus E Microwave Spectrometer (NEMS)	27.23 GHz 31.4 GHz 53.65 GHz 54.90 GHz 58.80 GHz	Vertical temperature profile of the atmosphere even in presence of clouds Atmospheric water vapor	D. H. Staelin, MIT Cambridge, Massachusetts 02139

TABLE VII. – NIMBUS 6 EXPERIMENTS

(from ref. 34)

Experiment	Spectral Bands	Main Purpose	Experiment
Temperature Humidity Infrared Radiometer (THIR)	10.5-12.5 μm 6.5-7.0 μm	Daytime and nighttime surface and cloud top temperatures Cloud mapping Atmospheric water vapor mapping	A. McCulloch, NASA/GSFC Greenbelt, Maryland 20771
High Resolution Infrared Radiation Sounder Experiment (HIRS)	17 near IR and IR bands	Temperature and water vapor sounding	A. McCulloch, and A. B. Johnson, NASA/GSFC Greenbelt, Maryland 20771
Scanning Microwave Spectrometer Experiment (SCAMS)	22.235 GHz 31.650 GHz 52.850 GHz 53.850 GHz 55.850 GHz	Tropospheric temperature profiles over ocean surfaces Abundances of liquid water and water vapor in the atmosphere	W. B. Lenoir Johnson Space Flight Center Houston, Texas 77058
Electrically Scanning Microwave Radiometer (ESMR)	250 MHz band centered at 37 GHz (0.81 cm)	Map surface features even in the presence of clouds Map distribution of polar ice Map precipitating clouds over ocean areas (25-km resolution)	T. Wilheit, NASA/GSFC Greenbelt, Maryland 20771
Earth Radiation Budget Experiment (ERB)	22 visible and infrared channels	Highly accurate measurements for terrestrial radiation budget	W. L. Smith et. al., NESS/NOAA Washington, D. C.
Limb Radiance Inversion Radiometer Experiment (LRIR)	14.9-15.5 μm 14.4-16.9 μm 8.6-10.2 μm 23.0-27.0 μm	Determine vertical distribution of temperature, ozone, and water vapor from 15 to 60 km above the earth	J. C. Gille NCAR Boulder, Colorado 80303
Pressure Modulator Radiometer Experiment (PMR)		Measure temperature distribution from 40 to 85 km above the earth	J. T. Houghton Oxford University Oxford, England
Tropical Wind Energy Conversion and Reference Level Experiment (TWERLE)		Use balloons to record weather data	C. Cote GSFC Greenbelt, Maryland 20771
Tracking and Data Relay Experiment (T&DRE)		Cooperative satellite experiment with ATS-6	P. E. Schmid GSFC - Greenbelt, Md.

6.2 THE ELECTRICALLY SCANNING MICROWAVE RADIOMETER (ESMR)

The Nimbus 6 ESMR receives the thermal microwave radiation upwelling from the earth's surface and atmosphere in a 250-MHz band centered at 37 GHz (0.81 cm). The antenna beam is scanned electrically through 71 discrete positions on each sweep. Each sweep takes 5-1/3 seconds. Brightness temperatures are measured at each scan position. At GSFC these temperatures are used to produce images and digital tapes of microwave brightness temperatures. The data can be used to map the liquid water content of the clouds, the distribution and variation of sea ice cover and snow cover on the ice, and characteristics of land surfaces (ref. 37).

The operating wavelength is 0.81 cm (37.0 GHz) for the Nimbus 6 ESMR and 1.55 cm (19.35 GHz) for the Nimbus 5 ESMR. The most significant effect of this wavelength difference is roughly to triple the instrument's sensitivity to water droplets, while keeping its sensitivity to water vapor essentially the same. This change will make it easier to distinguish light rain areas from areas of high water vapor. A secondary effect will be roughly to double the contrast between first year ice and multiyear ice. However, there will be a slight increase in ambiguity in the determination of the percent of open water in the ice within the instantaneous field of view, but this problem is not expected to be significant. The decrease in operating wavelength will also decrease the brightness temperature over snow, making it possible to identify and map snowfields. Reference 38 also presents information on an application of this sensor.

6.3 THE HIGH RESOLUTION INFRARED RADIATION SOUNDER (HIRS) (ref. 39)

The Nimbus 6 HIRS is a third generation infrared radiation sounding experiment possessing many new features for greatly improving the capability of sounding the earth's atmosphere from an orbiting spacecraft. HIRS measurements in the 4.3 μm and 15 mμ CO_2 bands permit better vertical temperature profile resolution to be achieved in the lower troposphere and extend vertical coverage up to the stratopause. It has a channel to measure reflected sunlight to improve the capability of recognizing cloud contamination during the day, especially that caused by low altitude or small element clouds which are difficult to sense with infrared window measurements. Similar to its Nimbus 5 predecessor (ITPR), the HIRS obtains simultaneous measurements in the 3.7 μm and 11 μm window channels to enable the detection of cloudiness, both day and night, and to permit accurate specification of the temperature of the earth's surface, even under partly cloudy sky conditions. Water vapor channels in the weak and strong portions of the 6.3 μm H_2O band permit the specification of the abundance of water vapor of the lower and upper troposphere and aid in the detection of thin cirrus cloudiness. Quantitative estimates of the heights and amounts of clouds within the HIRS field of view are obtained from radiance observations in the three most transparent 15 μm CO_2 band channels in a manner previously demonstrated with the Nimbus 5 ITPR radiance observations. High spatial resolution of 25 km (13 n.mi.) and contiguous geographical sampling enable profiles to be obtained down to the earth's surface under all but extensive overcast cloud conditions. In overcast situations, the profile derivations are limited to altitudes above the clouds.

Since the thermal emission of the earth results in a smooth spectrum and there is little reflected infrared light, the irregularities in the spectrum seen by IRIS are caused by absorption and emission of the gases in the atmosphere. Since the spacecraft orbits in the vacuum above the atmosphere, these irregularities measure the total composition of these gases, i.e., the integrated concentration at high as well as low altitudes. The spectrum is more complex than one can observe in the laboratory because absorption spectra of gases vary with temperature and pressure. The pressure varies from an atmosphere to a vacuum, and the temperature varies from ground temperature to the very low temperatures of space.

Because of the difference in absorption spectra at different pressures, and since altitude and atmospheric pressures are related, the composition of gases may be calculated as a function of altitude. Profiles have been constructed for both ozone and water vapor in the atmosphere, as shown in figure 4 (ref. 36). Theoretically, profiles could also be constructed for CO and other constituents.

In addition, since spectra vary with temperature, the temperature profile of the entire atmosphere can be calculated. A temperature profile calculated from the same data is also shown in figure 4. See reference 39 for more details on this application.

Since weather is clearly of interest to public health, the ability to measure these three-dimensional parameters is a landmark achievement. Relating these data to specific projects of the HAO provides a great challenge.

The spectrograms produced by HIRS may contain information directly pertinent to the public health. Most gases in the air, except N_2, O_2, and other homopolar diatomic molecules, absorb infrared light in this region. It should be possible to measure whole-atmosphere concentrations of oxides of nitrogen, methane, and other gaseous pollutants if their concentrations are high enough. However, because of temperature and pressure complications, these measurements may be complex. Only research can define the potential application of HIRS data to public health problems.

6.4 THE SCANNING MICROWAVE SPECTROMETER (SCAMS)

The Scanning Microwave Spectrometer (SCAMS) is a five-channel radiometer. Observations by the instrument will be used to produce global maps of tropospheric temperature profiles, and over ocean surfaces, the abundances of liquid water and water vapor in the atmosphere. Knowledge of these parameters is important for meteorological purposes, such as providing initial boundary conditions for numerical weather forecasting. Information about snow cover, ice type, soil moisture, and ocean roughness will also be contained in these miltifrequency maps of the earth.

SCAMS is an advancement of the successful microwave spectrometer experiment (NEMS) on Numbus 5. Whereas NEMS observed atmospheric parameters only at nadir along the subpoint track, SCAMS will scan to either side of this track and produce maps of these parameters with nearly full earth coverage every 12 hours, and with spatial resolution of about 145 km (80 n.mi) near nadir and 330 km (180 n.mi) at the scan limit.

6.5 AVAILABILITY OF NIMBUS DATA

In the normal case, Nimbus data cannot be taken directly from the satellites. NASA distributes data from the office established for that purpose:

The LANDSAT/Nimbus Project
Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland 20771
(301) 982-6142

However, under certain circumstances, arrangements have been made for direct reception of certain data, primarily ESMR, that are needed operationally.

The office mentioned above distributes data catalogs on a routine basis. A typical issue will show one ESMR pass per day, a

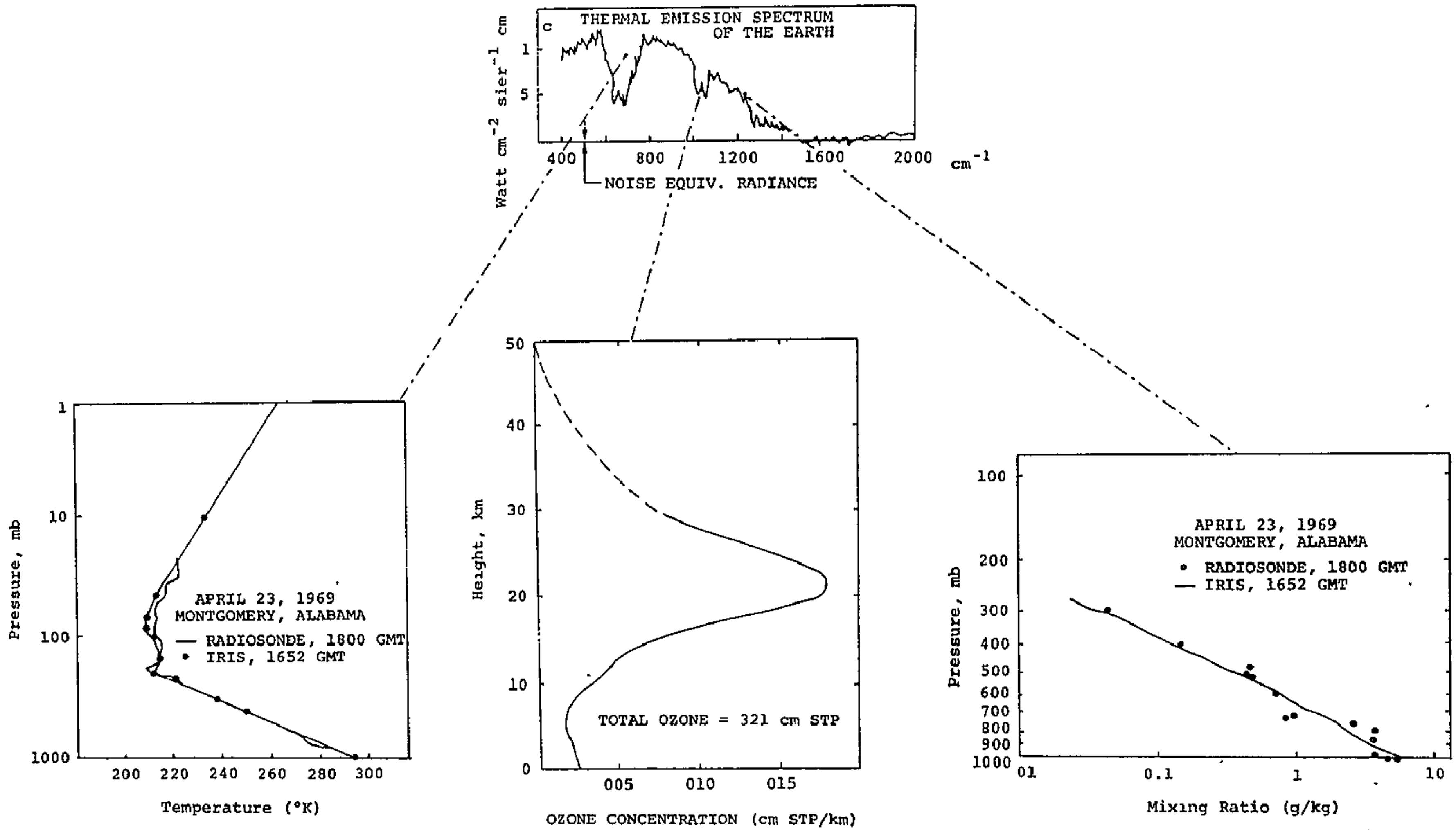

Figure 4. — Results of the infrared interferometer experiment on Nimbus 3 (ref. 36).

whole-world THIR mosaic for every day and night; it will also list the periods of operation of each sensor, together with comments on the quality of data (ref. 40).

The office also provides many other products as needed. Photographic reproductions of imagery are available at cost of reproduction, and virtually all data is available on digital tapes. It is best to discuss possible needs for data with persons from that office.

7. NOAA's POLAR ORBITING SATELLITES

The National Oceanic and Atmospheric Administration (NOAA) maintains at least one polar satellite in operation. The present series consists of NOAA-2 through NOAA-5 or so, respectively named by NASA ITOS-D through ITOS-G (Improved TIROS Operational Satellites). At this writing, NOAA-4 (ITOS-F) is in full operation, broadcasting data from an altitude of 1500 kilometers for the benefit of all who have receiving stations anywhere in the world.

7.1 HISTORY

These satellites are the result of a sustained development program which began with the TIROS (Television and Infrared Observation Satellite) program. The ten TIROS satellites, launched from 1960 to 1965, proved the concepts and instrumentation that became the mainstay of later satellites.

The TIROS program was followed by the TIROS Operational Satellites (TOS), named ESSA 2 through 9 after the previous Environmental Science Services Administration (ESSA-1 being a TIROS satellite). This program has been completed, but ESSA-8 could still be used for cloud pictures in 1975, as can be seen from table VIII (ref. 41).

The first ITOS satellite, TIROS-M (later called ITOS-1) was launched in January 1970. The second, NOAA-1 (apparently called ITOS-A), was launched in December 1970. The third, ITOS-B, failed to orbit and ITOS-C also failed. The fifth, ITOS-D, was launched in October 1972, and is designated NOAA-2. ITOS-E failed on launch but ITOS-F was successfully launched in November of 1973 and is now named NOAA-3. NOAA-4/ITOS-G was launched in late 1974 and is now the operational polar orbiting satellite of NOAA. More NOAA satellites will be launched, but their numbers and functions have not yet been decided.

TABLE VIII. – CURRENTLY ACTIVE DIRECT READOUT SATELLITES
(as of 1 Sept. 1975)

Satellite	Launch Date	Orbit	Service*	Sensor*	Frequency (MHz)	Incl. (Deg.)	Period	Height Apogee/Perogee
NOAA-3	6 Nov. 1973	Polar	APT HRPT DSB	SR VHRR VTPR**	137.50/.62 1697.5 136.77/137.14	102.0	116.2 min.	1509/1500 km 937/931 nm
NOAA-4	15 Nov. 1974	Polar	APT HRPT DSB	SR VHRR VTPR	137.50/.62 1697.5 137.14/136.77	101.7	115.00 min.	1457/1443 km 786/779 nm
ESSA-8	15 Dec. 1968	Polar	APT	TV	137.62	101.5	114.7 min.	1463/1412 km 790/762 nm
ATS-1	7 Dec. 1966	Geostationary	WEFAX	--	135.60	6.98	24 hrs.	35847/35763 km 19356/19310 nm
ATS-3	5 Nov. 1967	Geostationary	WEFAX	--	135.60	5.36	24 hrs.	35885/35678 km 19376/19265 nm
SMS-1	17 May 1974	Geostationary	WEFAX --	-- VISSR	1691.0 1687.1	1.79	24 hrs.	35831/35825 km 19347/19345 nm
SMS-2	6 Feb. 1975	Geostationary	WEFAX --	-- VISSR	1691.0 1687.1	0.60	24 hrs.	35804/35768 km 19330/19311 nm

*Service/Sensor Acronyms

- APT -- Automatic Picture Transmission
- HRPT -- High Resolution Picture Trans.
- DSB -- Direct Sounding Broadcasts
- WEFAX -- Weather Facsimile
- SR -- Scanning Radiometer
- VHRR -- Very High Resolution Radiometer
- VTPR -- Vertical Temperature Profile Radiometer
- TV -- Television (vidicon camera)
- VISSR -- Visible/Infrared Spin-Scan Radiometer

** On stand-by

7.2 SENSORS ON NOAA-2 THROUGH NOAA-5

Two of the primary sensors shown in table IX (ref. 41) have been used in life sciences applications. The high-resolution scanning radiometer (SR) and the very high-resolution infrared radiometer (VHRR) are suitable for monitoring changes in the equivalent blackbody radiation temperature of the surface of the earth and cloud tops. The two radiometers are used much like the thermal channel of the Nimbus THIR. However, the SR data are directly available by automatic picture transmission (APT) (ref. 43) or from the National Environmental Satellite Services (NESS) after some processing, including the addition of geographical grids. For details consult:

> Environmental Data Service
> National Climatic Center of NOAA
> Satellite Data Services Branch
> Washington, D. C. 20233

The only other sensor on these satellites, the vertical temperature profile radiometer, VTPR, is mostly used for deriving temperature profiles which are used in preparing operational forecasts. Some of the VTPR data can also be used for correcting VHRR data. See reference 39 for more details on this type of sensor.

Table X compares the resolution of radiometers on this series of satellites with several others.

The VHRR is an extremely valuable tool which has proven its worth in the screwworm eradication project of the Health Applications Office. Its resolution and precision permit quite accurate measurements of effective radiation temperature for areas as small as 0.9 kilometer. Subsequent passes can conveniently be registered to better than about 5 km in ordinary operations over large areas, and they may well be registered to 1 or 2 kilometers with greater care over smaller areas. Many products can be prepared from them, such as estimated mean air temperatures and degree day sums, as in the screwworm program. In addition, useful composite images can be prepared by combining imagery from different days.

VHRR data are broadcast continuously for the orbiting NOAA satellites, and any person can collect and use the data as he pleases without permission from NOAA. However, ground stations are much more costly than APT stations. Under certain circumstances, NOAA can furnish VHRR data on tapes, as it has done for the screwworm project.

7.3 TIROS-N AND ITOS-H THROUGH -J (ref. 48 & 49)

Prototypes of the next generation of polar-orbiting meteorological satellites are said to be under construction at this time. The first of these should be launched in 1978.

As can be seen from table XI, these satellites will have about the same resolution, but they will have more spectral channels of data. They will probably have only one scanning radiometer which can broadcast at high or low resolution instead of two separate instruments.

Unofficial documents suggest that the spectral channels have been changed from those listed in table XI. There are also indications that the new generation of Air Force satellites will be build on the same chassis, a logical step since the satellites are quite similar.

TABLE IX. — SENSORS OF ITOS-D THROUGH ITOS-G OPERATIONAL METEOROLOGICAL SATELLITES (ref. 42).

I. PRIMARY SENSORS

- Two Scanning Radiometers (SR), Redundant; Analog Data. Direct automatic picture transmission (APT):

Two channels;	
Visible	.5 to .7μm
IR	10.5 to 12.5μm
Ground resolution;	
Visible	4 km (directly below)
IR	7.5 km
Noise equivalent to temperature (NEΔT);	
IR	3°C (after processing)

- Two Vertical Temperature Profile Radiometers (VTPR), Redundant:

Ground cell	60 km by 60 km
CO^2 channels	668, 677, 695, 708, 725, 747 cm^{-1} (around 14μm)
Water channel	535 cm^{-1} (about 19μm)
IR window	835 cm^{-1} (about 12μm)

- Two Very High-resolution Radiometers (VHRR), Redundant. Direct picture transmission during playback to ground; analog data stations (HTRP):

Two channels;	
Visible	.6 to .7μm
IR	10.5 to 12.5μm
Ground resolution;	
Visible	.9 km
IR	.9 km
NEΔT	3°C (after processing)

II. SECONDARY SENSOR

- Solar Proton Monitor. . . . .

TABLE X.— RESOLUTION OF SELECTED SATELLITES (ref. 42 and 44-47)

(Resolution is based on the instantaneous field of view directly below the satellite)

	High resolution channel		Low resolution channel	
	Visible	Thermal Infrared	Visible	Thermal Infrared
ITOS-D (NOAA-2) series (ref. 42)	0.9	.9	4	7.5
SMS (GOES) (ref. 44)	0.93	-	-	7.4
Defense Meteorological Satellite Program (DMSP)				
Block 5BC series (ref. 45)	0.63	0.56*	3.7	4.4
Block 5D (ref. 46)	0.6	0.6*	-	-
LANDSAT-C (ref. 47)	0.1**	-	-	0.3

*broadband thermal infrared

**two visible and two near-infrared channels

TABLE XI – TIROS-N AND ITOS-H THROUGH ITOS-J SENSORS (OPERATIONAL METEOROLOGICAL SATELLITES) (from ref. 48)

SENSOR	DIGITAL DATA	DESCRIPTION
1. Advanced Very-high Resolution Radiometer (AVHRR):		
Four channels;		
Channel 1.	0.4 to 1.0 μm (visible)	
Channel 2.	0.75 to 1.0 μm (near infrared)	
Channel 3.	10.5 to 12.5 μm (thermal infrared window)	
Channel 4.	6.5 to 7.0 μm (water vapor)	
Ground Resolution;		
Channels 1-3	1 km	
Channel 4.	4 km	
2. TIROS Operational Vertical Sounder (TOVS)		Seventeen channel spectrometer will; • be operable in visible and infrared bands • probably include a microwave sensor • allow calculation of the vertical distribution of temperature, water vapor, and ozone.
3. Data Collection System (DCS), and Platform Localities		Designed for; • utilization in the US and to support GARP • reception of signals from free-floating balloons, ocean buoys, fixed ground sensor platforms, and other satellites • organization and retransmission of received signals to Command and Data Acquisition (CDA) stations • observation of doppler frequency shift
4. Space Environmental Monitor (SEM)		Designed to monitor; • proton directional fluxes • alpha particles • electrons

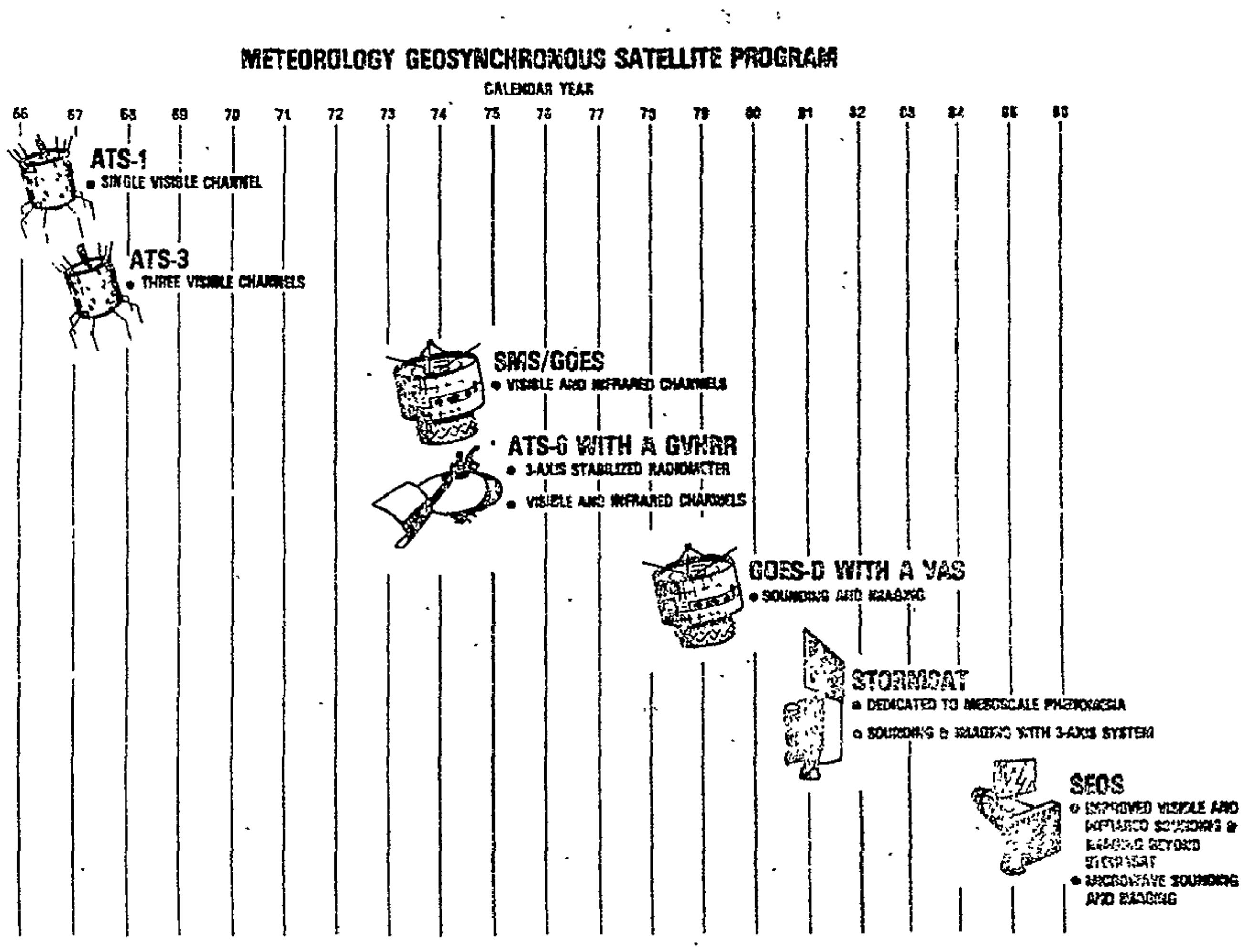

Figure 5. – Evolution of geosynchronous satellites (ref. 50).

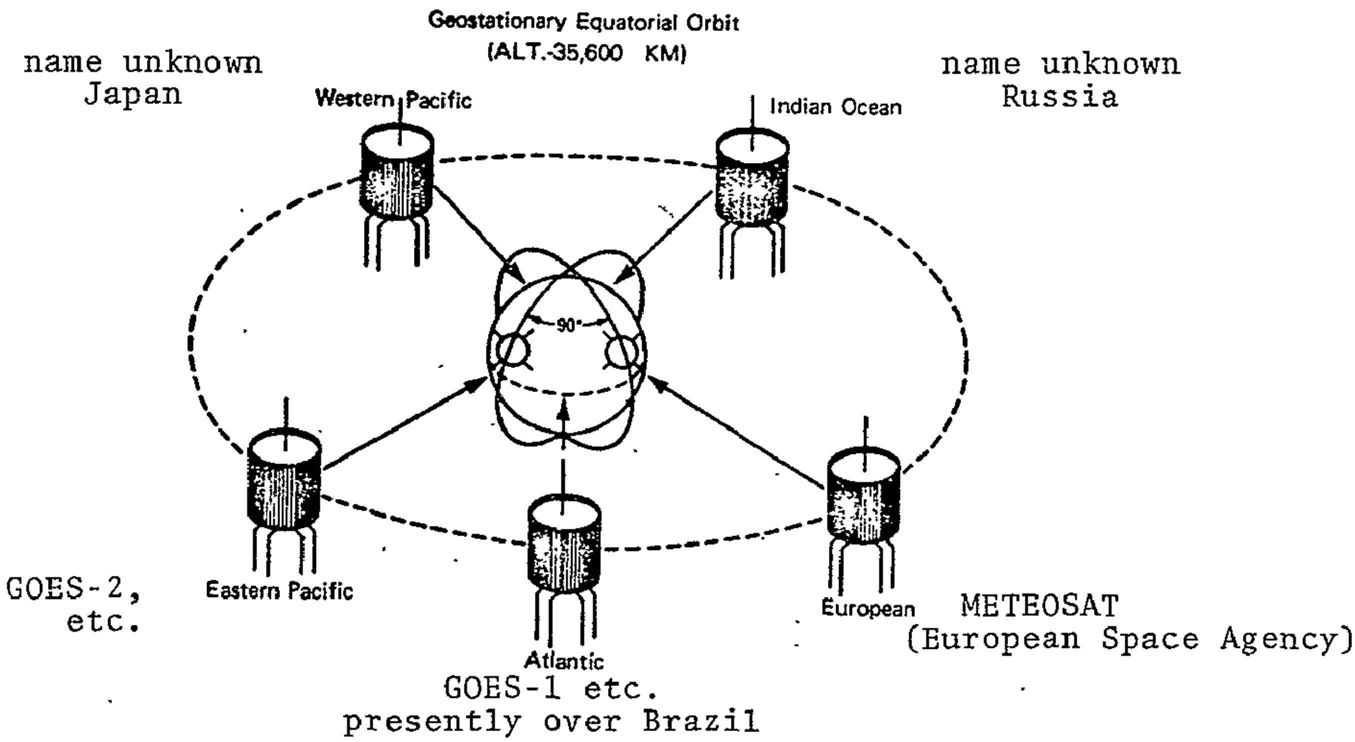

Figure 6. — Geostationary Satellite Network (ref. 50).

8. NOAA's GEOSYNCHRONOUS SATELLITES

NOAA also maintains at least two operational satellites in geosynchronous orbit (see table VIII). The satellites presently in operation are called NASA's Synchronous Meteorological Satellite (SMS) and NOAA's Geostationary Orbiting Earth Satellites (GOES). At this time SMS-1 scans the hemisphere from about 70° W over the equator, and SMS-2 does the same from about 135° W. SMS-3 has been launched and awaits failure of one or the other. Two satellites will always be located for optimal coverage of the entire United States; as a result, one of them will always see all of South America and most of North America.

These satellites follow in the tradition of ATS-1, -3, and -6, as can be seen from figure 5 (reg. 50) but they go far beyond them. Their raidometers function in both thermal and visible channels, while the radiometers of the first two had only visible channels; and the resolution of their sensors is far greater. While the ATS satellites were experimental, the SMS/GOES satellites are distinctly operational.

These satellites are potentially very valuable tools for projects of the Health Applications Office in the Western Hemisphere. The quality of the data provided by the first two satellites was very fine, much better than expected, and the data is easily accessible. Due to their potential usefulness, more details are given here about these satellites and their products.

There will eventually be five SMS-type satellites around the world as can be seen in figure 6 (ref. 50) for participation in the First Global GARP Experiment (FGGE). NOAA is now maintaining two for the Western Hemisphere. METEOSAT will be placed by the European Space Agency over Africa, and satellites in sight of Asia will be furnished by Russia and Japan.

METEOSAT and the Japanese satellite are essentially identical to SMS/GOES, except for some details in transmission of signals; details on the Russian version are not available. METEOSAT will directly broadcast stretched data, so that no intermediate stretching station is necessary. As a result, any country in Europe and Africa can directly receive data from this satellite. Direct reception of METEOSAT data would be useful for projects involving the Sahara desert.

The SMS satellites are able to furnish images every half hour, day and night. Due to the tremendous volume of data, NOAA only maintains photographic images; tapes are erased the same day. These images can be purchased from the

Environmental Data Service
National Climatic Center
National Oceanic and Atmospheric Administration
Washington, D. C. 20233

The great disadvantages of these photographic images is their "enhancement," which is the NOAA term for the grey-scale rendition of infrared images. Most are scaled to show differences in clouds; as a result, they are marginal for showing differences on the surface of the earth.

NASA maintains a fairly complete archive of these images on digital tape. They are kept in a special high-density format (pulse code modulated digital data on wide-band analog tape). These tapes are rewritten onto more ordinary tapes for outside users such as the Health Applications Office. It should be noted that a full days data would require many data tapes, so that one needs to be very selective about ordering tapes for his use. Tapes are normally ordered through the

National Space Science Data Center
Goddard Space Flight Center Code 601
Greenbelt, Maryland 20771
Phone: (301) 982-6695 (FTS 982-6695)

SMS was not yet launched at the beginning of the screwworm project, and the higher resolution VHRR data from NOAA-2 et seq., were chosen for use. Still, given the resolution finally accepted for the applied products of the Screwworm Eradication Data System, SMS-1 could have been used instead of the NOAA satellites. Registration would have been different, more complex in theory, but probably much less cumbersome in practice. Resolution of the infrared image is slightly below what would be preferable, but the quality of the data is said to be higher than NOAA data.

As with NOAA data, there is the potential of automatic calculation of degree-day sums, mean surface air temperature, and many other parameters. However, the precision of these parameters will be much greater, since a daily temperature cycle can be sampled up to 24 hours each day.

Future generations of operational geostationary satellites are shown in figure 5. The next major advance will involve the addition of a vertical sounder to the present form of the SMS satellites. Future satellites, STORMSAT and SEOS, will advance resolution, time of repetitive coverage, sounding capabilities, and multispectral coverage; they will also include microwave sensors.

It is interesting to note that resolution limits are lower in geosynchronous satellites than in polar orbiters. For example, physical limitations force resolution on SEOS to be less than 300 meters in visible channels, a kilometer in thermal infrared, five kilometers in the microwave region, and 13 kilometers in sounders. For higher resolution one must look to polar satellites.

Data from the geostationary satellites will probably be a mainstay of the Health Applications Office in the near future. Strong efforts should be made to transfer technology developed for NOAA satellites to this class of satellite.

9. EARTH RESOURCES TECHNOLOGY SATELLITES

The LANDSAT program is demonstrating that remote sensing from space can help manage earth's resources. LANDSAT-1 and -2 cover all parts of the earth every 18 days from polar orbit, with considerable overlap in polar regions. They record high-quality images of the earth on command, and relay data from automated remote platforms to ground collecting stations. Table XII (ref. 51) provides the technical details on the LANDSAT-1 and LANDSAT-2 sensors and data products.

At this writing, both satellites continue to yield excellent images of the earth from the MSS on a direct broadcast basis. However, due to failures of the tape recorders, only a limited number of images can be recorded.

At present, LANDSAT images can be used much as color infrared photographic images of the same resolution. They contain three bands approximating the three spectral regions of color of such film, but add one more near-infrared channel. Since they are digital, recorded on tapes, they can be processed electrically.

Images from these satellites are being tested in a wide variety of applications. Due to their quality and coverage, they are a useful adjunct to almost any project of the HAO, as background if not as prime working data.

Although LANDSAT satellites pass over all parts of the earth, data is collected only over those countries that have specifically requested data gathering. Disclosure agreements must be signed, and then only for approved projects for principal investigators. For this reason, adequate data will usually not be available for the Health Applications Office in other parts of the world unless arranged in advance.

TABLE XII. – SENSORS OF LANDSAT-1 and LANDSAT-2 (ref. 47).

- Data Collection System (DCS)
    - Receives, translates frequency, and retransmits burst messages from Data Collection Platforms (DCP)
    - Does not record, process, or decode data
    - Does not track platforms
    - Assures high probability of receiving at least one valid message from 1000 DCP's deployed throughout U.S.
- Return Beam Vidicon (RBV)
    - A Television-like scanner that takes images in the following nominal spectral ranges:

green	.475 to .575μm
red	.580 to .680μm
near IR	.690 to .830μm

    - Advantage: Geometric accuracy.
- Multispectral Scanner (MSS)
    - A radiometric scanner that collects images in the following nominal spectral ranges:

green	.5 to .6μm	near infrared	.7 to .8μm
red	.6 to .7μm	near infrared	.8 to 1.1μm
thermal infrared	10.4 to 12.6μm	(only on ERTS-B)[b] as of October 9, the decision was again made to fly ERTS-B without the thermal scanner.	

    - Advantage: radiometric accuracy.
- Common characteristics of RBV and MSS Images
    - Ground coverage - 185km^2
    - Resolution is difficult to define, but probably better than 100m by an definition (300m for thermal infrared on ERTS-B)
- Principal Image Products of RBV and MSS
    - System-corrected Images (SYCI), formerly called Bulk Images

        9 1/2-inch square positive transparencies, suitable for direct overlays on 1/1,000,000 maps such as ONC
        9 1/2-inch square positive paper prints
        70-mm positive transparencies
        70-mm negative transparencies

    - Scene-corrected Images (SCCI), formerly called Precision Images

        9 1/2-inch square positive paper prints
        9 1/2-inch square positive transparencies
        9 1/2-inch square negative transparencies
        Some color composites
        Some computer tapes

    - Image Availability
        - For Principal Investigators

            ERTS User Services/563
            NASA/Goddard Space Flight Center
            Greenbelt, Maryland 20771
            301/982-4018

        - For Others

            EROS Data Center
            Sioux Falls, South Dakota 57198
            605/336-2381

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[a]Both satellites will have polar sun-synchronous orbits at 912 kilometers.

[b]Verbal Communication, R. Feinberg, ERTS Users Services, Goddard Space Flight Center.

Older LANDSAT satellites will probably give images only on direct line-of-sight with available receiving stations. This means that images will be available only for North America, north of central Mexico, including Canada. On completion of the station being built in Brazil, line-of-sight should also include all of Brazil and most of South America. In addition, stations are projected or being built in Iran, Chile, Zaire, and several other countries.

LANDSAT C will probably be launched in 1977, although no firm commitment has been made. If launched, it will probably include the thermal infrared channel of the multispectral scanner that was omitted from the first two satellites.

Uses of these satellites are well illustrated by the five volumes in reference 51 and in the proceedings of the yearly symposia at JSC (ref. 52) and the University of Michigan (ref. 53.).

10. MILITARY SATELLITES (refs. 45 & 46)

Satellites which are sponsored by the U.S. Department of Defense are not listed in many standard compilations, such as those published by the NSSDC. However, some information is now available on at least one such series which could be quite useful to the Health Applications Office.

The U.S. Air Force, through its Space and Missile Systems Organization (SAMSO), conducts an ongoing program of surveillance of weather by satellite. Its Defense Meteorological Satellite Program (DMSP) (formerly called DAPP) keeps two polar-orbiting satellites in operation to permit six-hour coverage of any portion of the earth.

The DMSP satellites are parallel to the NOAA satellites in several ways. The current operational satellites, the Block-5C, are similar in capabilities to NOAA-2 and NOAA-3 satellites. They have low-resolution (2 n.mi.) and high-resolution (1/3 n.mi.) visible and thermal infrared sensors that read out in analog form.

The next generation Block-5D satellites will contain only high-resolution sensors (9.3 n.mi.) that will produce digital data, as do TIROS-N and ITOS-H through ITOS-J. However, they will have on-board processing facilities that will allow degradation of high-resolution images. This will allow storage of complete swaths and will produce low-resolution data at the receiving station. This capability is also rumored for TIROS-N and ITOS-H through ITOS-J.

DMSP normally furnishes its data to civil users. Positive transparencies are available from:

Space and Science and Engineering Center
The University of Wisconsin
1225 West Dayton Street
Madison, Wisconsin 53706

The transparency collection dates as far back as February 1973, but there are gaps. Both low and high-resolution data can be found, but in general, the high-resolution archives are sparse.

Analog tapes of these data are made available by special arrangement with the U.S. Air Force Air Weather Service. Under normal circumstances, tapes are recycled after one month. Permanent records are only maintained as positive transparencies.

Both Block-5C and Block-5D satellites contain other sensors, which are probably classified. Both satellite types are known to have radiometers which allow calculation of atmospheric temperature profiles, much like sensors on the NOAA, TIROS-N and ITOS satellites.

11. FOR THE FUTURE

11.1 HEAT CAPACITY MAPPING MISSION

Nimbus-5 flew with a high resolution radiometer, the Surface Composition Mapping Radiometer, roughly similar to VHRR, which failed almost immediately. A backup instrument had been constructed at the same time but was not used. Instead of including it on Nimbus-6, it was assigned to a separate low-cost flight. The resulting mission was called the Heat Capacity Mapping Mission.

This one-time mission is designed to produce thermal maps for thermal inertia measurements, measure plant canopy temperatures, and measure soil moisture effects, etc. However, it is available for any of the variety of uses to which thermal measurements can be put. The many uses of the VHRR of the NOAA satellites suggest that it could be of great use to the Health Applications Office.

The great advantage of this mission is that its thermal data (10.5 to 12.5 μm) have a spatial resolution of about 0.5 km at the subsatellite point, considerably better than the VHRR. Its disadvantage is that it has no on-board recorder, so that data can only be taken within line-of-sight of the receiving station As a practical matter this limits coverage to areas shown in figure 7, which was taken from a briefing aid (ref. 54).

11.2 THE NEXT GENERATION OF SATELLITES

Although some future satellites were discussed in other parts of this report, this section is reserved for some speculations of things to come. After 1979 or 1980, it should be possible to monitor radiometric temperatures within quite high spatial, temporal, and temperature resolutions. Although kilometer resolution is now available from the NOAA series, future LANDSAT satellites will permit about 300-meter resolution in thermal

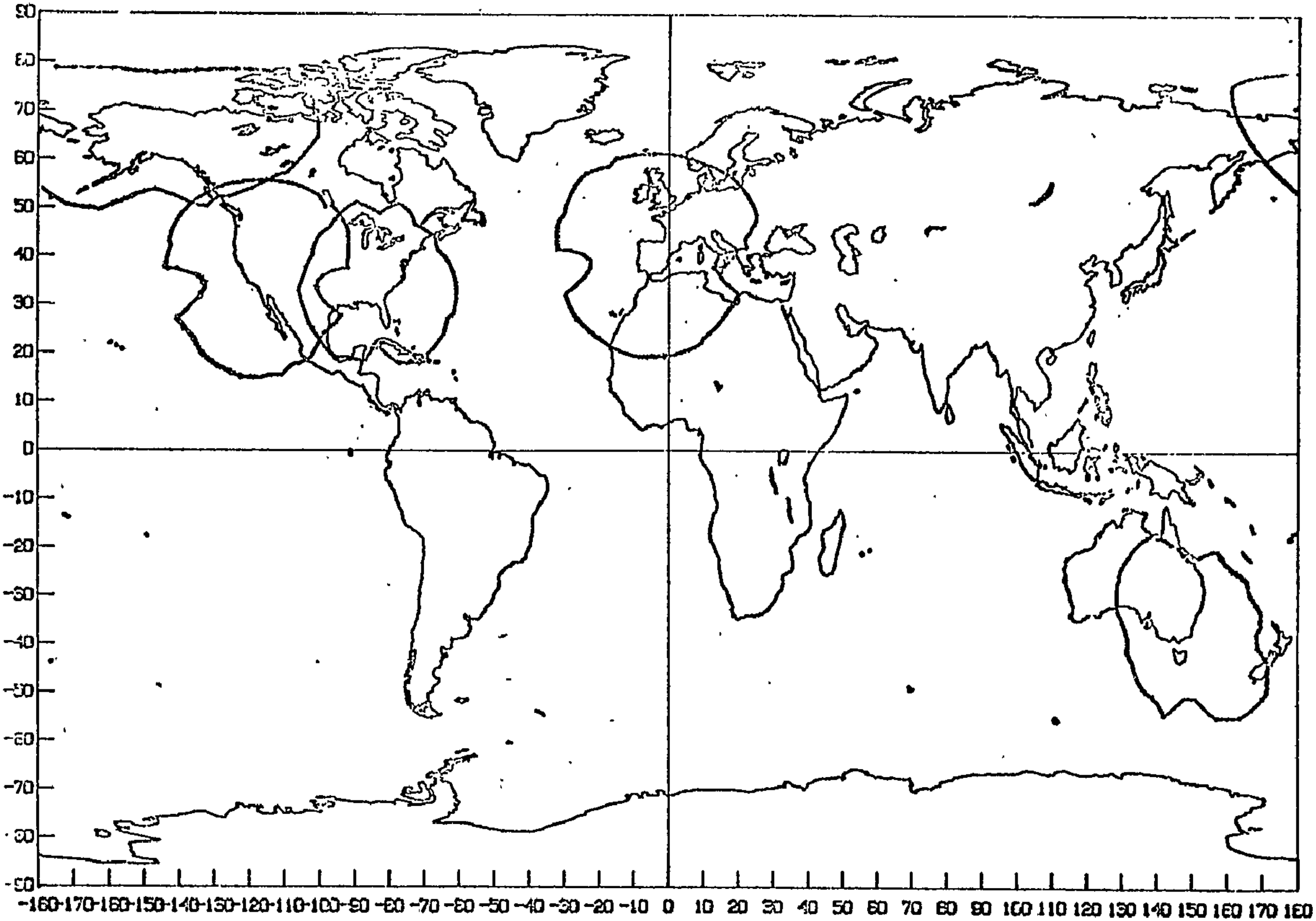

Figure 7. – Planned data acquisition stations for the Heat Capacity Mission.

infrared radiation every 18 days. Eventually, it may be possible to monitor the surface every hour with kilometer resolution from geosynchronous satellites, but this is not yet certain. Temperature resolutions should also improve as most satellite telemetry systems adopt systems to replace the analog systems now in use on NOAA satellites.

For earth observations, future satellites will offer considerable flexibility. We are now limited to multispectral studies of the surface at the 18-day LANDSAT intervals. By about 1979, successors to LANDSAT should offer more channels for our use. For example, EOS will probably have six to eight spectral channels, and SEOS as projected will have six. Several should have steerable sensors, such that high resolution coverage will be available more often than now, and since SEOS will be geostationary, it might provide half-hour high resolution coverage of any portion of its area of view.

Although higher resolution near-infrared channels will probably allow some indication of soil moisture, significant advances in this field await operational microwave scanners. If the microwave scanners of Nimbus 5 and 6 prove their workth, chances are that similar sensors will be flown on future earth resources and meteorological satellites.

At this time, another serious problem is the availability of data from foreign locations. Most receiving stations for U.S. satellites are located in the Western Hemisphere. There is now great activity in constructing stations in other areas, so that by about 1978, advanced reception stations for earth resources satellites will be located on all continents. At this writing, plans call for additional LANDSAT receiving stations in Iran, Zaire, and Chile. Stations to receive data from VHRR sensors of NOAA satellites will be even more widespread, including Japan, France, Germany, England, China, Russia, Australia, and New Zealand in addition to the LANDSAT stations, all of which should be able to receive VHRR signals. Undoubtedly, many others will also be constructed in the near future.

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APPENDIX A

BROAD RANGE MARKS ATS-F EXPERIMENTS

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BROAD RANGE MARKS ATS-F EXPERIMENTS

Washington--Services to be performed by the National Aeronautics and Space Administration Applications Technology Satellite F (ATS-F) range from extensive health and educational television transmissions to air and ship navigation, traffic control, and meteorological and scientific experiments.

Spacecraft lifetime is expected to be at least two and possibly five or six years. Major spacecraft experiments are:

- Educational television
- Satellite instructional television, involving India
- Position location and aircraft communications experiment

The educational television experiment is designed to provide coverage to isolated regions of Alaska, the Rocky Mountains and Appalachia, where terrestrial television transmissions are not feasible.

ATS-F will utilize its two high-power transmitter in the 2,500 MC range to bounce two beams off its 30-foot antenna to form two spot beams on earth covering an area 1,000 x 300 miles. These beams will be targeted toward different geographic regions for predesignated periods of television programming.

About 114 inexpensive glass fiber dish receiver antennas will be located at sites, such as hospital or community facilities or tied into the Public Broadcasting System microwave or cable systems. They will handle an extensive schedule of educational programs and health communications--including medical discussions between specialists in different areas.

The Federation of Rocky Mountain States, under contract to the Department of Health Education and Welfare, has responsibility for directing the operations of the experiment. The federation is constructing a master station in Denver to provide about five hours of programming per day. Four voice channels will accompany the television transmissions so viewers in different locations can select English, Spanish, or one of several American-Indian dialects.

The satellite instructional television experiment involves both the U. S. and the government of India. About one year after launch, the spacecraft will be moved at 45 feet per second (fps) from 94 degrees west to 35 degrees east where it will be able to transmit broadcasts on occupational skills, family planning, food production, and health and hygiene programs to India.

A ground station in Ahmedabad, India, will transmit programs in C band to the spacecraft, which will relay them to low-cost terminals in about 5,000 villages, according to NASA.

Urban areas in India will receive instructional programming via receivers tied in with conventional VHF braodcast systems. The position location and aircraft communications experiment will provide data on navigation and continuous communication between ships at sea and airborne aircraft with their land-based stations. The goal of these studies is to reduce spacing requirements between aircraft and provide more efficient ship navigation.

Atlantic air routes are now assigned a 120-mile wide flight corridor with at least 15 minute spacing. It is hoped an operational system based on the ATS-F data could reduce the corridor to 30 miles with only 5 minute spacing.

Additional experiments that are primary to the ATS mission include:

- The tracking and data relay satellite experiment which will determine and track the orbit of the lower altitude Nimbus-F weather spacecraft and the GEOS-C geodetic satellite, both set for launch later this year. ATS-F will also relay Apollo/ Soyuz communications.
- Radio frequency interference experiments using C band VHF to measure the mutual interference of satellite and terrestrial communications systems.
- The high-resolution radiometer which will image weather patterns for relay to earth in both the visible and infrared spectra.
- Radio propagation characteristics at 13 gigacycles (Gc) and 18 Gc will seek to determine propagation attenuation due to rainfall by sampling at several geographically separated ground stations.
- Millimeter wave experiment which will provide information to be used in future communications spacecraft. Near-earth propagation path characteristics at 30 Gc and 20 Gc over a 1.44 Gc bandwidth will be evaluated.
- A radio beacon experiment which will aid evaluation of the effect of ionospheric particles on radio transmissions beyond the atmosphere.
- Environmental measurements experiment package atop the spacecraft away from interference which contains eight scientific experiments for studies of solar cosmic rays, radiation damage to various types of solar cells, and the earth's magnetic field.
- Altitude control experiment which will demonstrate spacecraft control by ground computer.

- Cesium ion engine experiment to test the capability of an ion engine to maintain a spacecraft in orbital position.
- A laser reflector which will aid precise distance measurements.
- A quartz crystal microbalance experiment to measure spacecraft contamination. Particles registered from the ion engine may help determine if this type of system would create difficult contamination problems on a spacecraft outfitted with substantial ion engine propulsion.