Research Program on Communications Policy

Massachusetts Institute of Technology

Cambridge Massachusetts 02139

Center for Advanced Engineering Study

Center for International Studies

Center for Policy Alternatives

Electronic Systems Laboratory

(NASA-CR-149803) POLICY ISSUES AND DATA COMMUNICATIONS FOR NASA EARTH OBSERVATION MISSIONS UNTIL 1985 (Massachusetts Inst. of Tech.) 97 p HC A05/MF A01 CSCL 05B

N77-19562

Unclas

G3/43 20596

POLICY ISSUES AND DATA COMMUNICATIONS FOR NASA EARTH OBSERVATION MISSIONS UNTIL 1985

A Report to NASA

by

A. B. Corte & C. J. Warren

POLICY ISSUES AND DATA COMMUNICATIONS FOR NASA EARTH OBSERVATION MISSIONS UNTIL 1985

A Report to NASA

by
Arthur B. Corte
and
Colin J. Warren

in a series by
The Research Program on Communications Policy

and

Center for Policy Alternatives
and
Center for International Studies
Massachusetts Institute of Technology
Cambridge, Mass.

November 1975

Table of Contents

NOTE

This report done for NASA is one of a series of reports of the Datanet Project, a study of the implications of low cost international data communication. Other reports in the series have been done for the Department of State, Department of Commerce, and AID.

Ithiel de Sola Pool, Project Director

SUMMARY AND CONCLUSIONS

The number of potential applications of Earth orbital sensors has mushroomed in the past half decade, and with it the projected estimates of the volumes of data these sensors will provide. There has been concern that practical applications of this data, in particular those applications requiring repeated and timely data sets, will be hindered through a lack of adequate communications facilities, both from the sensor to the ground reception point and from the ground reception point to the user. The guiding objective of the study reported here was to determine if inadequate data communications facilities were, in fact, a valid concern and, in those instances where this was so, to consider the economic and policy implications of the various technical solutions.

A general conclusion reached is that the volume of data that will actually be used on an operational quasi-real time basis are likely to be much smaller than may be suggested by glancing at the raw sensor data rates of future NASA missions. A corollary to this statement is that domestic and international telecommunications facilities are not as inadequate for earth observation data delivery as may first appear, if innovative uses of existing facilities are employed. A detailed exploration of the feasibility of utilizing commercial satellite telecommunication facilities for international distribution of data acquired by earth observing satellite would appear in order. Such a study should consider technical feasibility, economic costs, the legal and regulatory infrastructure of international telecommunications and the influence of that infrastructure on the price of service. Consultation with foreign users of data and with American and foreign telecommunication establishments should be part of such a study. However, before further clarification and qualification of this general conclusion the results of our investigations into five series of future NASA earth orbital missions are presented.

The series of Landsat sensors has the highest potential data rates of the missions examined in this report. Landsat follow-on in 1979 will carry the 90 Mbps Thematic Mapper and future Landsats could carry two of these instruments.

An examination of Landsat imagery uses shows that relatively few require transmission of the full resolution data on a repetitive quasi real time basis. Accuracy of global crop size forecasting can possibly be improved through information derived from Landsat imagery. A current forecasting experiment (LACIE) uses the imagery for crop area estimation only, yield being derived from other data sources. While a series of several images over time may be needed for an accurate crop area estimate, these can be made early in the growing season and the images transmitted by conventional means. (1)

---

(1) This may change. The Thematic mapper to be flown on future Landsats will have additional spectral bands and narrower spectral resolution which should improve the ability to detect plant condition for input to yield models.

However, even if one sets aside these considerations and assumes that crop yield estimates can be made from imagery alone and that complete coverage of all land devoted to major crops (1) is required on a global basis every 17 days (one landsat repetitive coverage cycle), the average daily use of the Tracking and Data Relay Satellite System (TDRSS) high data rate channel for crop prediction (up to 300 Mbps in Ku band) would be only 12 minutes. (2)

The monitoring of rangelands could, in theory, give rise to a greater demand for imagery than crop estimation. (3) The problems of rangeland management in developing nations lie in the institutional reform necessary for centralized control of grazing herds, however, and not in a lack of relevant data. Landsat imagery demand for this use will thus be minimal.

Of the other Landsat applications considered, snow mapping and runoff forecasting, and flood area estimation are the only ones that would require quasi-real time international distribtuion of data. The first application could give rise to 20 minutes per day utilization of the TDRSS Ku band channel, while data flows as a result of the second are sporadic and hard to estimate. As an absolute upper limit, then, we estimate Landsat utilization of the

---

(1) See Table 1.1 for the definition of major crops.

(2) Coverage of minor crops and scattered plantings could increase this figure but it still will be only an hour or so a day at most.

(3) 44 minutes per day average use of the TDRSS 300 Mbps channel if global coverage every 17 days is required. See Table 1.1.

TDRSS high data rate channel to be 3 hours per day, while a more realistic figure, which includes continuous surveillance of major crops and of mountainous areas, would be 31 minutes per day.

Competing with Landsat for the use of the TDRSS Ku band channel are future sea state sensing missions, for which Seasat-A (1978 launch) will be the first. Seasat data could be a valuable input to optimum ship routing algorithms, now being developed, which attempt to minimize costs resulting from fuel consumption, time spent at sea, hull damage and cargo damage. A conservative estimate of the benefits to the U.S. attributable to the Seasat data input is $100 million per year; given these large benefits, operational use of Seasat type spacecraft is likely.

As 70% of the Earth's surface is covered by ocean, the Seasat data collection problem is different from that of Landsat. To collect Seasat data on a quasi-global or global basis it is mandatory to use TDRSS. The only alternative, short of developing new high capacity on board data storage systems, (1) is for the U.S. to be dependent on many foreign readout stations, a situation which the TDRSS system was designed to avoid. To collect Landsat data use of TDRSS is only mandatory if there exisits no Landsat station in the region considered, or if the U.S. shall want to collect data over foreign territory without being dependent on the territory's readout facility.

---

(1) The Seasat Synthetic Aperture Radar data rate is 16 Mbps.

Operational tracking of Seasat would occupy 25% of the TDRSS Ku band capacity, (1) though there would be periods of up to 40 minutes duration when the channel would not be used while Seasat passed over land. Operational tracking of Landsat would consist of having to track the spacecraft during a series of short periods, each lasting a few minutes, during each orbit, because the area over which Landsat can sense is smaller. Data transfer requirements from Seasat to the U.S. are likely to be the more stringent. If three Seasats are orbited to accommodate the U.S. Navy's requirement for a 12 hour repetitive coverage cycle, the currently planned TDRSS system will provide adequate communications capacity.

In addition to Landsat and Seasat, there will be requirements for TDRSS high data rate communications support for a variety of manned and unmanned missions. Examples are a downlink video circuit from the orbiting laboratory while experiments are being conducted and the Large Space Telescope which has a maximum data rate of 2 Mbps and is being designed for up to 40 hours continuous viewing of a source, implying equivalent use of a TDRSS SA channel. Determining what contention problems will exist and how often they will occur will require constructing a model of mission orbits and associated

---

(1) There will be three synchronous tracking satellites in the TDRSS system, one each in the Atlantic and Pacific basins and an in-orbit spare over the U.S., each with two Ku band single access channels capable of a combined data rate of 300 Mbps, as well as lower rate multi-access channels. Seasat data rate is 16 Mbps.

earth surface sensing requirements. (1) The model would derive the transmission schedule for each mission, based on orbit and coverage requirements, and these schedules could then be combined to form an overall TDRSS transmission schedule. Such a model could be used to study several interrelated questions that must be faced in the future:

1. How often problems of contention for access to high data rate channels will arise because three or more missions simultaneously require such channels in an area covered only by a single TDRSS satellite. The model could be used to determine which conflicts are the most frequent as an aid in drawing up mission data transmission priorities and the consequent needs for alternative data collection mechanisms.

2. A limited on board recording capability, either disk or solid state on certain missions may considerably ease contention problems. The model could be used to predict the effects of this alternative and justify the costs of developing it.

3. In a similar vein, the model could evaluate the value of using the Space Flight and tracking data network (STDN) tracking stations and foreign Landsat stations for occasional or routine data collection and relay.

As a result of the complex corrections and processing to be applied to Landsat TM (thematic mapper) data, centralized distribution of

---

(1) Inputs to this model would be the following:

1. Number, type and orbital characteristics of Earth observation missions

2. Areas of the globe over which data must be collected, including a specification of which mission is to collect the data and how often it is needed.

3. Data collection capability and area coverage of existing Landsat and STDN earth stations, as well as the coverage characteristics of TDRSS.

4. Real time communication requirements of other manned and unmanned missions such as Spacelab and Shuttle sorties.

this processed data from the U.S. to those nations requesting it will be more attractive to many foreign users than direct reception. The direct broadcast of Multi Spectral Scanor (MSS) imagery to national and regional readout stations should be continued for political reasons and because it provides backup in the event of TDRSS failure.

In contrast, however, the economics of centralized distribution of meteorological satellite imagery, in particular that which will be sensed by the TIROS-N Advanced Very High Resolution Radiometer (AVHRR), are unfavorable. This is a result of the much lower data rate as compared to Landsat (665Kbps for the AVHRR as opposed to 90 Mbps fpr the TM), enabling direct reception through low cost ($150,000) ground stations being developed by NASA. In addition, meteorological data quickly goes "stale", which means that the transmission delay from a central U.S. site could only be about 2 hours instead of the 24 hours or more possible with most Landsat imagery. As a result the leased international link must have an instantaneous data rate out of proportion to the actual volume of data transferred.

CHAPTER 1

EARTH OBSERVATION SYSTEM COMMUNICATIONS REQUIREMENTS IN THE TDRSS ERA

In the 1975-1985 decade NASA's Spaceflight and Tracking Data network (STDN) will undergo a major reorganization with the introduction in 1979 of the Tracking and Data Relay Satellite System (TDRSS), consisting of two synchronous orbit spacecraft to track and relay data from sub-synchronous satellites. (1) Concurrently, Earth observation satellites that now operate on an experimental basis may enter the operational phase. These satellites will require wideband communication links to earth during portions of their orbits. This chapter discusses the ability of the planned STDN to meet this demand for wideband links and examines the modifications that may be necessary to accomodate future operational Earth observation missions.

1.1: NASA Earth Orbital Missions and STDN: 1975-1985

Figure 1.1 summarizes information currently available on future NASA Earth orbital missions, their orbital heights, periods and data rates. This table and information on the sensors carried on individual missions form the basis for the discussion of communication requirements in subsequent paragraphs.

---

(1) A third in-orbit spare will be positioned over the U.S. where it can provide additional service to orbiting satellites over the American continent and parts of the Atlantic and Pacific basins.

Though the topic discussed concentrates on the demands likely to be placed on TDRSS, Figure 1.1 includes missions that will be orbited prior to the advent of TDRSS. Sensors developed on these missions are likely to be flown on missions after TDRSS is operational and thus provide some insight on future data transfer requirements. Naturally, the confidence with which one can say a mission will be flown and, if so, what its timing will be decreases sharply beyond a period about five years from the present.

The downlink TDRSS capability that will be available to NASA missions consists of two types of channels:

1. Multiple Access (MA) channels: these are 5 MHz in bandwidth and can support a maximum data rate of 50 Kbps, depending on the user transmitter power and antenna gains. These MA channels do not involve tracking of the user by a tracking and Data Relay Satellite (TDRS). Each TDRS has 20 MA channels.

2. Single Access (SA) channels: these channels use the two gimballed TDRSS antennas to track the data generating spacecraft. The increased gain provided by these antennas leads to maximum data rates of 6 Mbps in S band and 300 Mbps in Ku band, with bandwidths of 10 MHz and 225 MHz respectively. Thus one TDRS may support two high data rate users simultaneously, with two SA Ku band channels having a capacity of 300 Mbps between them divisible as desired, or one 300 Mbps SA Ku band channel and one 6 Mbps SA S band channel.

The two TDRSS satellites will be placed over the Atlantic and Pacific Oceans and provide 85% coverage of the globe to users at orbital heights similar to the Landsat. This positioning of the satellites, which enables both to be seen from one point in the U.S., leaves uncovered a zone 4830 miles long and 700 miles wide over west India, as illustrated in Figure 1.2.

Figure 1.1: Nasa Earth Orbital Missions: 1975-1985

	MISSION	DATA RATE	YEAR 75 76 77 78 79 80 81 82 83 84 85	ORBIT	PERIOD (min.)
EARTH MEASUREMENTS & METEOROLOGY	LANDSAT-1	15.06 Mb/s	(July 1972 launch)	900 km	103*
	LANDSAT-2	15.06 Mb/s		900 km	103*
	LANDSAT-C	40 Mb/s		900 km	103*
	LANDSAT-D	105 Mb/s		775 km	101*
	LANDSAT-D'	105 Mb/s	timing under discussion	775 km	101*
	LANDSAT-E	undetermined			
	LANDSAT-E'	undetermined			
	LANDSAT-F	undetermined			
	LANDSAT-F'	undetermined			
	SEASAT-A	16.08 Mb/s		800 km	101
	SEASAT-?	60+ Mb/s			
	NIMBUS-6	12.4 Kb/s		1100 km	107
	NIMBUS-G	810 Kb/s			
	GEOS-C	Kb/s		843 km	101*
	TIROS-N	674 Kb/s			
	HCMM	1.76 Mb/s		600 km	97*
PHYSICS & ASTRONOMY	OSO-8			550 km	92
	HEAO-A	10-100 Kb/s		420 km	94
	HEAO-B	10-100 Kb/s		420 km	94
	HEAO-C	10-100 Kb/s			
	SMM			460 km	95
	SHUTTLE	174 Kb/s			
	SPACELAB	Video & Data			
	LST	2 Mb/s		610 km	98
			← pre-TDRSS → ← TDRSS →		

*sun-synchronous

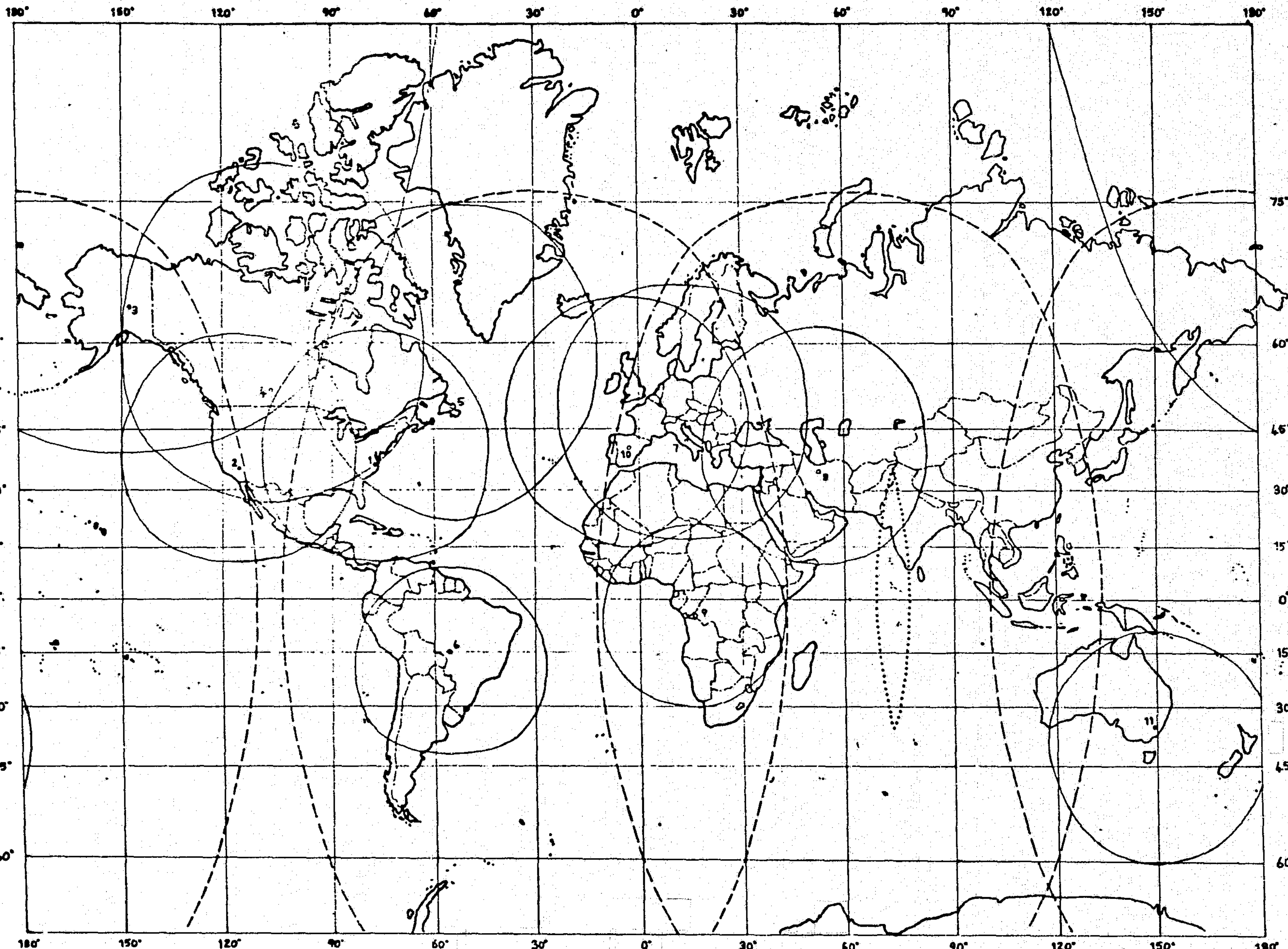

Figure 1.2: Landsat stations, STDN stations and Intelsat coverage zones.

——————— Landsat station coverage based on minimum 3° elevation angle (2900 km, 1800 mile radius) and 900 km orbit

··········· TDRSS zone of exclusion for 900 km orbit

– – – – – Intelsat coverage zones, 5° minimum elevation

Landsat & STDN stations are numbered:

1 Rosman	5 Newfoundland	9 Zaire
2 Goldstone	6 Brazil	10 Madrid (STDN)
3 Fairbanks	7 Italy	11 Canberra (STDN)
4 Saskatchewan	8 Iran	

Another component of the post-1979 STDN is the network of six NASA ground stations in the U.S., Spain and Australia which will remain open primarily to support planetary and deep space missions. Coverage zones for these stations have been shown for the current Landsat orbit (900 km), though only the U.S. stations now receive Landsat data. Another two, stations in Bermuda and Malagasy will retain equipment for launch tracking only.

1.2: Landsat Missions and TDRSS: Imagery Demand

The first Landsat mission to use TDRSS will be Landsat follow-on, planned for early 1979, which will carry two high data rate imaging sensors. These sensors are the multispectral scanner (MSS), being an operational unit based on the current MSS in orbit, and the thematic mapper (TM), which senses in six spectral bands and has a higher resolution than the MSS. Data rates are 15 Mbps for the MSS and 90 Mbps for the TM, and the resultant images will cover the same area as current Landsat sensors - trapezoids of 185 km/side.

The potential uses for data acquired by Landsat satellites have been enumerated in a study done for the Department of the Interior (1) as follows:

- crop acreage forecasting
- crop yield forecasting
- agricultural land stratification
- design and operation of irrigation projects
- pest suseptibility mapping

---

(1) "Earth Resources Survey Benefit-Cost Study" prepared for U.S. Department of the Interior, Geological Survey by the Earth Satellite Corporation and the Booz-Allen Applied Research Corporation, November 22, 1974.

flood damage assessment in agriculture
water resources management
snow mapping and runoff forecasting
surface water extent
location and extent of ground water
hydrolic response of water shed
flood area assessment
range land management
range inventory
range monitoring
range feed conditions
forest inventory
forest vegetation mapping
forest fire management
timber management
forest pest detection and control
state land use planning
site and route selection
federal land planning
cartorgraphic mapping
environmental monitoring of wetlands
strip lands, water quality, air quality
geological exploration,
petroleum exploration,
mineral,
marine resources management
living marine resources management
water borne transportation
ocean and coastal engineering
disaster warning and relief

Examination of this study indicates that the number of such uses requiring Landsat satellite data in real time is limited. These uses are:

1. Crop yield and acreage forecasting
2. Range land management and monitoring
3. Forest fire and pest detection
4. Snow mapping and runoff forecasting
5. Flood area assessment
6. Water borne transportation (mapping of ice fields to facilitate arctic navigation)

To arrive at a reasonable estimate for an upper bound to future Landsat utilization of TDRSS, global land use patterns are used here as the basic data. Each of the above six "real time" applications will be examined in turn as to the volume of data generated and the urgency of the real time need.

As an absolute upper bound consider how much transmission time Landsat would require to cover all of the Earth's land areas in one 17 day cycle. (1) Allowing for image overlap this would amount to 13,000 images, or an average daily transmission time of 360 minutes for 17 days.

A more realistic estimate of the demand for Landsat coverage is presented in Table 1.1. High and medium estimates of the demand for repetitive land coverage by Landsat have been formulated for three categories of land - arable, meadow and forested land. The remaining 37% of the world's surface is comprised of what is classified as "other" land, which consists of unused land, mineral lands, built-up areas, parks, roads, barren land and water bodies. (2) By not including "other" land in these demand estimates, coverage of cities for urban planning and of land for mineral resource prospecting is not included. However, this use of landsat data requires only limited repetitive coverage. The aim of the estimates in Table 1.1 is to arrive at figures which provide some idea of the maximum demands that could arise for repetitive imagery.

---

(1) The Landsat-D orbit will be slightly lower than current Landsats, leading to a reduction in repeat coverage time from 18 to approximately 17 days.

(2) Production Yearbook 1970, Vol. 24, FAO, Rome 1971.

Land Area Classification	Images required to cover area[1]		Daily minutes of transmission via TDRSS[1]	
	HIGH	MEDIUM	HIGH	MEDIUM
1 Total arable land[2]	750		21	
2 Land devoted to major crops[2]		430		12
3 Permanent meadows & pastures[2]	1575		44	
4 Permanent meadows & pastures, certain countries excluded[3]		1170		33
5 Total forest area[4]	2160		60	
6 Forest in productive use, certain countries excluded[3]		740		21
7 TOTALS	6727	2350	189	66
8 World land area	13000		360	

Notes:

1. Each image is 185km by 185km, and 20% of the image area consists of overlap. One third of each image is assumed to consist of areas of no interest to the application under consideration. Transmission time is 28 seconds per image and complete coverage of the globe takes 17 days.

2. Data from Production Yearbook 1970, Vol. 24, FAO, Rome, 1971. Major crops that enter the world market are wheat, rye, barley, oats, maize, millet, sorghum, rice, buckwheat, soy beans, groundnuts, cotton, flax, hemp, jute, abaca, agaves, sugar cane, tea and coffee.

3. Brazil, Canada, Iran, Italy and Zaire have been excluded as they either have or will have Landsat reception stations and this data is not of global interest; data can thus be collected locally. The USSR and China (PRC) are excluded on the basis that they would not find it politically acceptable to be operationally dependent on the US for resource survey data.

4. Data from World Forest Inventory 1963, FAO, Rome.

Table 1.1: Landsat imagery repetitive demand estimates

A high estimate, based simply on providing images of all arable, meadow and forested land is 6727 images, or a daily transmission time of 125 minutes over the 17 day Landsat repeat coverage cycle. Not all land area included in the imagery will consist only of the three types specified here but will include "other" land and water bodies. It is assumed that such unwanted coverage accounts for one third of the imagery obtained, so the above figures must be increased by 50% to 4485 images and 125 minutes per day transmission time (line 8 of Table 1.1). What is termed a medium estimate is also presented in Table 1.1. This estimate, though termed medium, can still be considered an upper bound to what may be expected in the future.

Crop Yield Forecasting

Monitoring of growth and assessment of the areal extent of crops that enter major world markets appears to be one of the potential applications of Landsat data that would require repeated coverage of arable land, though not on the 17 day cycle assumed here. Though this application has received considerable publicity, present use of Landsat data for forecasting crop sizes consists only of estimating crop area from the imagery. Yield is based on ground truth and meteorological data. Such a scheme requires imagery only a few times per year. Until crop discrimination methods improve and until methods of assessing crop yield and stage of growth from Landsat imagery are developed, only a limited number of images per year will be sufficient, reducing data flows below the estimates of Table 1.1. The capability to predict crop yield from remote sensing data alone is currently of very limited accuracy and major improvement may possibly prove unfeasible. (1)

The yield is currently best forecast by a model whose most important input is crop moisture data as gained through meteorological information derived from both terrestrial and remote sensing sources. As crop acreage can be determined relatively early on in the growing season and entered into the crop yield model, subsequent satellite data would appear unnecessary as crop acreage undergoes limited change during the season. Since the growing seasons are measured as a matter of several months, delivery of Landsat data for crop acreage estimation could be effected by relatively slow means. Such data will have been acquired early on in the growing season when yield forecasts contain a great deal of uncertainty as they can be greatly influenced by subsequent weather conditions.

---

(1) The following quotation, taking from a study of the potential of sythetic apature radar, is believed equally applicable to Landsat data. "Crop growth can be detrimentally effected by either too little water or too much. In the case of too little water very small deficits in the plants are sufficient to decrease growth and production: effects on crop growth occur long before even temporary wilting takes place. Thus, significant losses can occur in situations where the morphology of the crops is not altered and the small changes in water content involved would hardly effect the dielectric properties of the crop. SLR would only seem to be a promising tool for monitoring water deficits or small changes in the dielectric properties capable of being detected. It would, of course, be potentially capable of detecting the effects of extreme drought which led to visible changes in the crop such as shrivelling and loss of leaves." Roberts, E. H. "Agricultural Applications of Side Looking Radar in Side Looking Radar Systems and their Potential Application to Earth Resource Surveys", Vol. 3, ESRO Report CR (p) - 138, August 1972.

Notwithstanding the above conclusion, data flows resulting from the use of Landsat imagery for crop size forecasting are given in line 2 of Table 1.1. Crops included are all cereals, soybeans, groundnuts, sugar cane, tea, coffee and fibre crops. No countries are excluded from this estimate as it is presumed that global information will be necessary to improve world market mechanisms.

Range Land Management and Monitoring

Landsat data may be used to determine range feed condition which is, in effect, the height of the grass and the degree of moisture of a particular piece of range. This information may be used to rotate herds of animals so they feed on those ranges in best condition, avoiding a situation in which the grass in any given part of the range is eaten down to such a level that its rate of recovery is decreased. There is a worldwide need for improved range land management as overgrazing is a major problem in developing areas. The desertification of the Sahel area is in large measure due to the excessive pressure of animals upon the land. This has been clearly shown in Landsat imagery in which a ranch in a Sahel country showed up on Landsat imagery. Subsequent ground inspection showed that the grass grew higher on the ranch land than on the surrounding unmanaged land.

Range land management can be effective, as on that ranch, without the use of Landsat data. The importance of this application notwithstanding, it is unlikely to give rise to significant demand for quasi-real time Landsat data.

The difficulties in implementing range land management techniques stem not from lack of knowledge of range land management or lack of information about range conditions, but from the lack of institutional arrangements by which range lands in many countries can be managed. As clearly evidenced by the above mentioned picture of a ranch in the the Sahel, range land management techniques can produce great improvements in yields from existing ranges in developing countries using information available to date. Where the range land is under centralized management these techniques may be implemented easily. Where the range is open and public, as it has traditionally been in most African countries suffering from overgrazing, the political, social and cultural problems of converting from a society of nomadic herdsmen where each man grazes his animals in accordance with his own desires, bounded only by long sanctified tribal delineations, to the type of centralized control necessary for the implementation of range land management system, are staggering. The fundamental ethos of these societies would have to be changed.

Something of this nature has happened in Somalia where the nomadic herdsmen of the northern part of the country have been resettled in the South as farmers. However, it required an exceedingly severe drought which killed all of their animals leaving them absolutely no choice as well as government pressure and offers of free land to move them.

Unlike the case of crops, information on the state of pasture land is not of interest on a global scale. Though the animal products grown on pasture land may be traded internationally, there is little information that can be gained about the state of the animals from Landsat imagery (100 metre resolution) or from that of the future thematic mapper (30 metre resolution). The only possible inferences on animal product yield of the pastures are those based on the state of the pasture itself. Methods of arriving at such inferences, using Landsat imagery, that approach the quality of current ground truth data have yet to be developed.

For the above reasons the anticipated real time demand for Landsat imagery from foreign users will be relatively small. The estimates presented in lines 3 and 4 of Table 1.1 are thus upper bounds. The medium estimate in line 4 excludes those countires that possess Landsat tracking stations and the USSR and the Peoples's Republic of China, on the basis that the latter two would not find it acceptable to be dependent on the U.S. for such a service. The same exclusions were made in the case of forest lands, where repeated coverage is of use in timber management, pest and fire detection - all of which are "local" uses.

Forest Fire and Pest Detection

With regard to forestry applications of Landsat imagery it should be noted that much of the world's forest resources lie in areas with considerable cloud cover - northern latitudes and humid tropical areas. The northern coniferous forests of Canada and the

USSR (constituting about 20% of the world forest land area) lie in a zone having only 2 or 10 days of good weather per month. (1) As most forestry applications, apart from inventory, such as pest and fire detection and control, require short systems response times, a satellite sensing on a repeat cycle measured in days may be a poor tool. Infrared sensing of forest fires from geostationary satellites, aircraft whose flight can be coordinated with the weather, or radar sensing from aircraft or satellites that is not affected by cloud cover may ultimately prove to be better tools than Landsat. (2) For these reasons demand estimates here should be regarded as upper bounds.

Snow Mapping and Runoff Forecasting

The measurement of the areal extent of snow in mountain water sheds for the timely prediction of runoff and the assessment of the flood hazards due to the rapid melting of snow would appear to require quasi-real time Landsat data. The information contained in these Landsat data will make it possible to manage reservoirs in such a way as to improve their use for purposes such as hydroelectric power generation, flood control, irrigation and recreation.

The areas of the earth's crust from which such data is required consists roughly of mountains exceeding 4,000 feet elevation in

---

(1) Side-Looking Radar Systems and Their Potential Application to Earth Resource Surveys, Vol. 3: "Potential Applications of SLR to the Remote Sensing of Earth Resources", ESTEC, July 1972, p. 28.

(2) Project TADAM in Brazil has used side-looking radar to survey the Amazon basin forests.

temperate climate zones. A conservatively calculated upper bound for the average number of Landsat scenes which will have to be transmitted each day to fulfill the requirements for snow pack monitoring is 42 per day or 20 minutes per day of TDRSS transmission time, although peak loads will exceed this figure. (1)

Flood Area Assessment

The utilization of Landsat data to assess the impact of flooding on agriculture is a realistic use. No quantitative estimate of the data flows arising from this use have been made as its very nature makes it intermittent, and subject to severe peak loads.

Water Borne Transportation

The use of Landsat data to assist ships in navigating through ice fields in the northern lattitudes has been noted. Benefits arise both from improved utilization of ship time due to decreased voyage time and in decreased damage to the ship resulting from collisions with ice. Benefits from this service has been estimated at approximately $100 Million. However, as regards the demand for real time transfer of this data via TDRSS, two points should be noted: firstly, the Canadian government already has a Landsat station with the capability to monitor the Canadian Arctic; Secondly, in the future the Seasat system with its synthetic aperture radar will likely be capable of providing similar information.

---

(1) Estimated from Times Atlas of the World Maps.

Total Landsat Data Flow

The medium estimate of total demand results in a daily transmission of 180 images per day, or 66 minutes transmission time. A two satellite surveying system could double the volume or imagery if it is presumed that all users would want repeated coverage every 8 1/2 days. These figures are based on an over-estimate of most nations' ability firstly to process the flow of imagery such demand projections postulate and secondly to act on the resultant information. Though a new technology may act as a stimulant for change, in itself it will not cause change. The social and economic conditions necessary to effectively utilize the technology must be created by a combination of other forces. Hence it may be that global crop data, which can be processed centrally and for which mechanisms already exist for using the information generated, will be the major source of Landsat utilization of TDRSS in the next decade. If this is so, then Landsat would use TDRSS on average 12 minutes per day. (1)

1.2.2: Orbit and Tracking Considerations

A major difference between the Landsat and the Seasat missions is that Landsat senses in the visible bands only during the daylight portions of its orbit, whereas synthetic aperture radar, being an active sensor, can operate also on the dark side of the earth.

---

(1) This is from line 2 of Table 1.1, increased by 50% to account for unwanted coverage. 430 images would cover the world's major crops.

This makes tracking of Landsat using TDRSS somewhat easier than tracking Seasat. Landsat does have an IR band sensor which operates on the dark side of the earth although the utility of the data for crop prediction is unclear.

Successive Landsat orbit equator crossings are displaced by 26 degrees of longitude. Each TDRSS satellite is within sight of Landsat for a total of 215 degrees of latitude at the equator, with an overlap of 85 degrees in which coverage is provided from both the east the west spacecraft. Figure 1.3 depicts the situation. For continuous coverage the east TDRS could handle Landsat for 8 or 9 successive orbits, while the west TDRS would track the other 6 or 5 orbits; some orbits would occur in the uncovered area over India. On average, then, the daily occupancy rate of the 300 Mbps channels on TDRSS would be approximately 14 hours on one satellite, 9 hours on the other and 1 hour in which neither satellite is used. If only half of each 101 minute orbit is tracked, which would obviate collection of IR data on the dark side. The period in which a TDRSS SA channel is occupied would actually consist of alternate 50 minute periods in which it is used and then not used. As the gimballed tracking antenna may be directed toward another mission in the 50 minute vacant periods it is possible to say that continuous tracking of Landsat would use only 12 hours of TDRSS SA channel time in every 24. However, this statement is predicated on there being missions which can use short periods of TDRSS SA channel time on a schedule determined by the Landsat orbit.

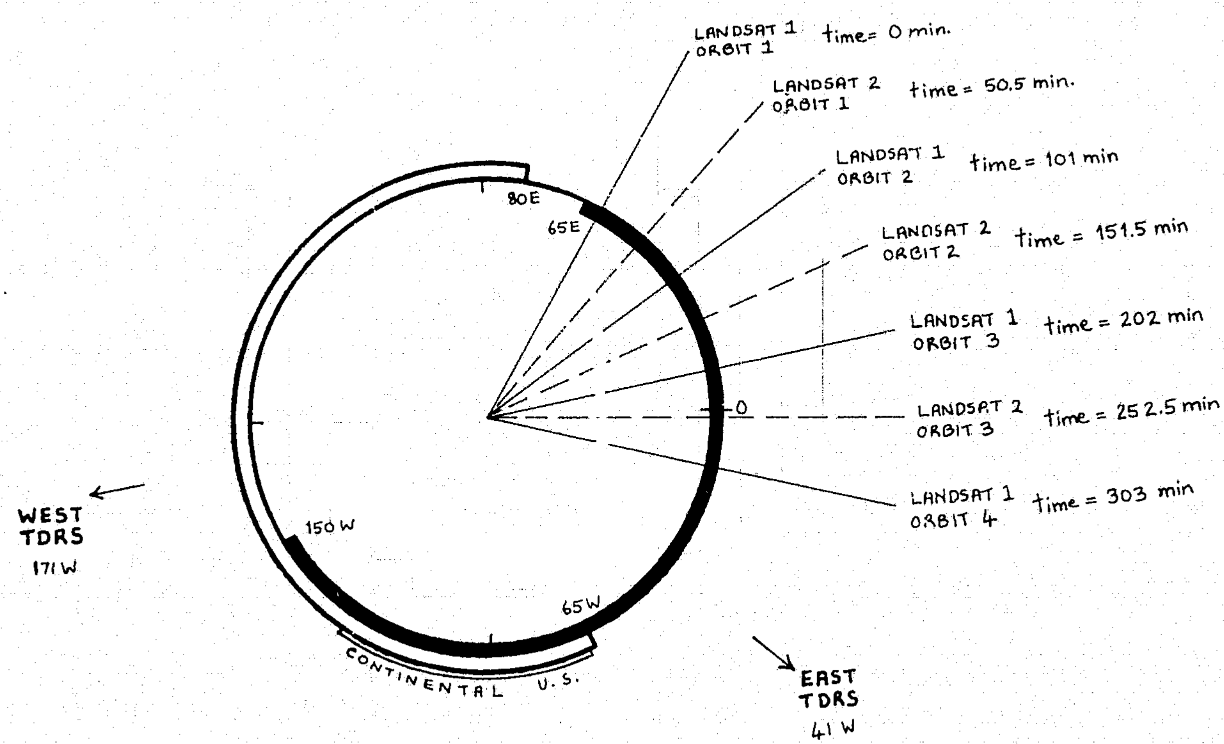

Figure 1.3: Landsat Orbits and the Tracking and Data Relay Satellite System

As with Seasat, simultaneous introduction of a second spacecraft would fill in the "empty" 50 minute periods. A second Landsat would be introduced in an orbit which halved the repeat coverage time, as has been done with the current Landsat-2. As shown in Figure 1.3, Landsat-2 orbits fall mid-way between successive Landsat-1 orbits. The Landsat orbit is sun-synchronous (it passes over the equator at about 9:30 a.m.); as Landsat-1 disappears out of sight of the east TDRS over the Antarctic, Landsat-2 appears over the Arctic horizon. At any one time only one TDRS SA channel need be be used to track two Landsats.

It was estimated above that imagery of the world's major crops would require the relatively low figure of 12 minutes per day of TDRSS transmission time. Even imaging of the world's total arable land would result in only 21 minutes. This implies that continuous tracking of Landsat for such a purpose would be wasteful of TDRSS channel time. Figure 1.4, based on the same statistical source used to arrive at the imagery demand estimates of Table 1.1, verifies this conclusion. Most of the world's arable land is concentrated in the northern hemisphere, with the rest scattered in relatively small parcels. A Landsat passing over Europe, central USSR or North America would transmit data almost continuously. In more southerly latitudes, however, there are large expanses of land void of agricultural production. The communications cost of surveying the remaining scattered areas via TDRSS would be quite high.

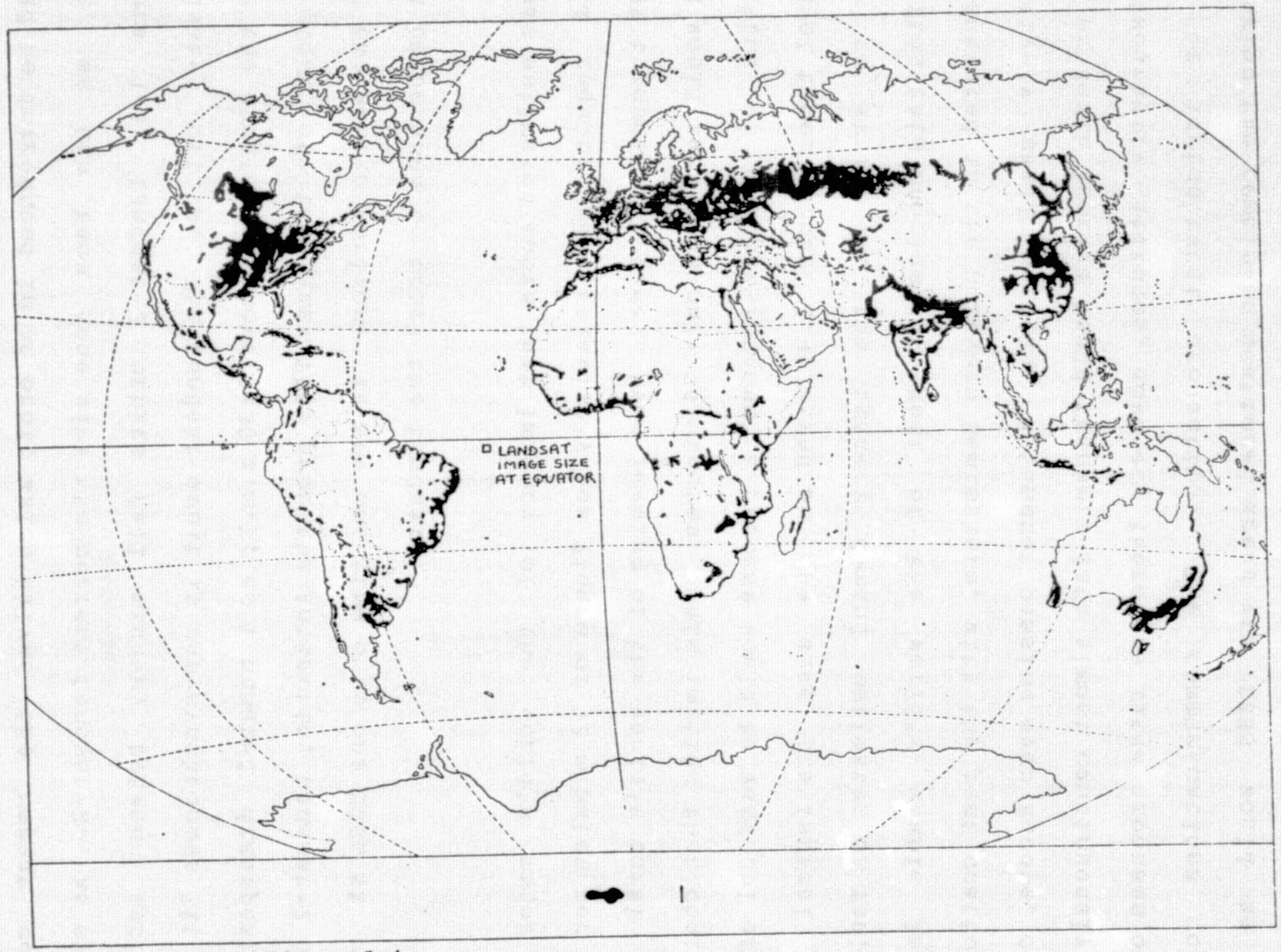

Figure 1.4:
CULTIVATED LAND. This map, compiled from a large number of sources, shows (1) the distribution of cultivated land which is equivalent to what FAO defines as 'arable land and land under tree crops.' The area shown equals the area given by FAO statistics.

Source: "A Geography of World Economy", Hans Boesch, John Wiley and Sons. 2nd Ed., 1974, p. 14.

To deal with this situation two topics warrant further careful consideration. One concerns the utility of having the on board capability to store limited numbers of images (5 or less) which can be dumped to foreign or U.S. Landsat stations as necessary. The second topic is that of developing the data sharing mechanisms outlined in current agreements signed by NASA and foreign nations concerning the reception of data from Landsats 1 and 2. These state that the foreign participant will provide NASA with all data the latter requests that has been obtained through the Landsat station in question. By pursuing this facet of the agreements to the point where foreign Landsat stations provide much of the scattered imagery needed for global crop forecasts the load on TDRSS would be eased and wasteful channel use curtailed. The resulting forecasts would have to be made public if the participating nations are to derive benefits from their cooperation.

When considering future pricing policies for direct reception of Landsat data NASA should not discard the opportunities presented through cooperation on a non-pecuniary basis. If high charges are introduced the user nation may lose the incentive to cooperate in areas such as easy access to their data by NASA, foreclosing the opportunity of implementing the kind of scenario outlined above.

Collection of data relevant to global crop forecasts by foreign Landsat stations leaves open the question of how this data should be transmitted to the U.S. processing centre. The most obvious method is to transmit the images at a rate lower than the imaging rate over the Intelsat system. This may have to be done at night if international circuits to the country are congested during daytime.

An alternative that would be less expensive for NASA would be to use TDRSS and foreign Landsat stations. There will, at certain times, be spare capacity on the TDRSS SA channels. By equipping foreign Landsat stations with an S band (for MSS data) or Ku band (for TM data) transmit capability they could transmit received Landsat data to the U.S. via TDRSS during a period in which the relevant SA channel is vacant. This alternative would be less costly to NASA than use of Intelsat facilities because TDRSS will have spare capabity and foreign Landsat stations will have periods during which they are not used. The transmissions could be timed to fit the TDRSS channel occupancy schedule which will be determined by other missions, thus increasing channel utilization.

This second alternative raises an important policy issue, that of the conflict between NASA's role and that of the international carriers. Once the Landsat data has been received by a ground based terminal, its retransmission to the U.S. via TDRSS would be an intrusion on Intelsat's territory, even if TDRSS were operated by a third party. This also brings one to the boundary between experimental and operational users of NASA missions. If a global crop surveying satellite is providing a significant input to crop forecasting and estimation, information which is used in the commercial world, a determination must be made of the point at which the experimental satellite becomes operational. Also, if the system becomes operational a policy regarding reimbursable use of TDRSS has to be developed.

1.3: Coastal Zone Sensing

The Nimbus-G mission, scheduled for a later 1978 launch, will carry the first sensor designed specifically to monitor coastal waters - the Coastal Zone Colour Scanner (CZCS). The mission is devoted to the field of pollution monitoring and the CZCS itself is to be used to detect chlorophyll, sediment, gelbstoffe, temperature of coastal waters and of ocean currents. Similar to the Landsat Multispectral Scanner, the CZCS will operate in a wider band of the spectrum (.433-12.5*10**-6m) and have greater colour and light sensitivities. The CZCS data is collected at 3.2 Mbps rate but processed for transmission at a rate of 800 Kbps, if maintained or increased for future missions, the CZCS could use a TDRSS SA channel if there were not enough capacity to store an orbit of data on board, and if ground stations did not cover the coastal areas of interest. At present no decision has been made on how future sensors of this type should be orbited, whether as separate missions or combined with other sensor payloads. One possibility is to add it to the Landsat series of spacecraft starting with the next Landsat follow-on mission if sufficient lift capability should exist. The orbiting of more than one high data rate sensor on one bus simplifies the tracking and channel scheduling problem with

TDRSS, particularly in this case where the sensors have similar orbital parameter requirements and have overlapping coverage requirements (the land/sea boundary). A joint Landsat/CZCS mission would permit multiplexing of the data streams onto one SA channel.

One method of estimating the potential demand for CZCS data is to consider the aggregate global continental shelf area on the assumption that this would include most ocean areas that are coastal zones. This global figure is 21.6 million square kilometers. (1) The CZCS has a swath width of 1500 km, so a swath 18,000 km long would result in 21.6 million square kilometers of data. Allowing for a 20% swath overlap, and increasing the area coverage required by a factor of 4 to account for land and sea areas covered by the swaths that are not part of the continental shelf, global coverage of the shelf would require 223 minutes of CZCS data. Averaged over the Landsat repeat coverage cycle of 18 days this is 12.4 minutes per day.

A figure based on more realistic assumptions about the real demands placed on TDRSS for transmission of CZCS data would exclude the continental shelf lying off countries that have Landsat and NASA tracking stations, the U.S.S.R. and the People's Republic of China. Of this group the U.S. and Canada alone "possess" almost 50% of the

---

(1) Gamble, Jr., John K. Global Marine Attributes, Law of the Sea Institute, University of Rhode Island, Ballinger Publ. Co., Cambridge, Mass., 1974. This source gives a country by country breakdown of marine data. The continental shelf is measured to the 200 meter isobath, and thus defined, represents 7.6% of the world's ocean, extending to less than 2 km offshore to over 900 km off Siberia.

continental shelf. These exclusions reduce the data that may be served by TDRSS to 53% of the above world total, or 6.6 minutes per day average over 18 days. As this figure is well within the capacity of current off the shelf space qualified recorders, (1) it is possible to eliminate the use of TDRSS for CZCS data collection.

Compared to Seasat data, coastal zone data will be collected in much shorter continuous segments, the longest possibly being from the northeastern Siberian coast through the Sea of Japan and the South China Sea to south of Java, a total of 26 minutes. The implication is that, if a decision is made not to carry recorders on future missions, CZCS data collection through appropriately placed ground stations is a feasible alternative, should the synoptic view provided by TDRSS not be needed. Coastal zones in different parts of the globe, it may be argued, are not interconnected through the kind of market system that relates the grain growing regions of the world to one another and makes the centralized processing of Landsat data attractive. The data to be generated by CZCS may be primarily of local interest. Low cost (about $150,000) tracking stations that may track and receive data from lower rate missions such as CZCS, HCMM and TIROS-N are now being developed by NASA and can be expected to serve the majority of transmission needs for coastal zone data. This being so, it is important that the CZCS data stream may be demultiplexed from those

(1) Nimbus-G will be able to record a total of 8 minutes of CZCS data per dump, in up to eight separate segments. The recorders referred to here are not the high capacity units used on Landsats 1 and 2; they have less storage capacity and higher reliability.

of other sensors carried on the same bus (such as the Thematic Mapper) without major additions to earth station electronics.

1.4: Sea State Sensing Programs

Seasat-A will not be TDRSS compatible as its design lifetime expires before TDRSS is operational. However, if methods of using Seasat sensed data to predict sea state and to improve ship routing are successfully developed and yield the benefits now predicted, follow on Seasats, or missions incorporating Seasat developed sensors, can be expected. The U.S. Navy, in addition, is very interested in obtaining Seasat data on a 12 hour repetitive coverage basis, in contrast to the 36 hour cycle of Seasat-A.

1.4.1: Seasat Program Benefits

Of all NASA Earth Observation Satellites programs, the Seasat program has the potential to be one of the most productive continuing benefits. The first of the series, Seasat-A, carrying a variety of active and passive sensors among which will be a synthetic aperture radar (SAR) capable of obtaining data on the height and direction of ocean waves, will be launched in 1977. If it performs as expected, there will be pressures for a follow on operational system because of the sizable benefits available through such a system. (1)

---

(1) Much of the information in this section not specifically referenced was developed in an interview with Professor Ernst

The benefits from an operational Seasat program will be gained by using data acquired on seastate, winds, temperature etc. as input to computerized ship routing programs which will compute recommended courses and speeds at frequent intervals for transmission to the ship by maritime satellite. The benefits of such improved ship routing are:

Decreased fuel consumption

Decreased Weather Damage to Hull and Cargo

Decreased Environmental Damage from Oil Spills

Another possible benefit over a longer term is facilitation of the operation of global maritime traffic control systems which are expected in the future. The economic value of these benefits could be very large as shipping is a major world industry, operating a fleet of some 20,000 ships. Gross revenues are estimated at between 60 and 80 billion dollars (1) with a growth rate of 12% over the past decade. The industry is a major consumer of petroleum, using, by one estimate, 11% of the world's petroleum (2) most of that in carrying other oil to market. (3)

Frankel, Director, MIT Commodity Transportation Laboratory. Professor Frankel served at sea for 16 years, many of them as captain, and does extensive consulting in the maritime industry.

(1) Devanney, John, Lecture Notes, Marine Transportation Economics, Course, 13.66, MIT, Fall 1973

(2) Frankel, Ernst, "The Effects of Changes in Energy Balance and Impact on Maritime Transportation", June, 1974, Israeli Institute of Shipping.

(3) As an example, a 60,000 ton tanker sailing the 8000 miles from the Persian Gulf to the U.S. consumes 110 tons of oil a day to

Consumption of Energy by Shipping (1972) in Billion Barrels/year

Tankers	0.80 BBY
General Cargo	0.50
Liquified Natural Gas carriers	0.05
Bulk carriers	0.20
Total Shipping consumption	1.55 BBY

Ship speeds for a given fuel input with the height and direction of

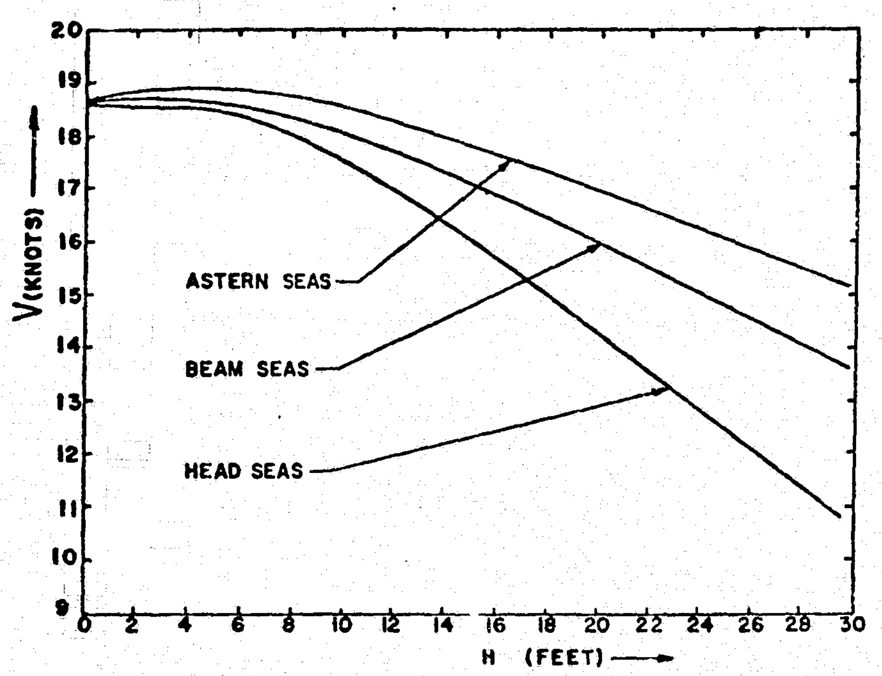

Fig. 12. Variation of average ship speed with significant wave height for head, beam and astern seas as obtained from log analysis data for tanker T5-S-12A of Table 1

the seas in which it is travelling are as shown. Potential savings of 5% in fuel consumed are believed possible through optimized ship routing using dynamic programming together with use of weather and sea state predictive models that process data supplied by existing

---

travel 360 miles, the trip takes 23 days for a consumption of 2500 tons, somewhat less is consumed on the return journey in ballast.

weather sources and the Seasat program.

The Concept of computerized routing is currently in use by the USN and some commercial operators. The USN is using linear programming to predict the fastest route between two points. The MIT Ocean Engineering department is now beginning a study to determine the effect of smaller grid size and shortened time frame of weather information on the effectiveness of the program.

Potential savings from ship routing schemes are likely to be realized. Computerized routing services are now commercially available to ship owners and are in use by line operators. They work with currently available weather data as input. Seasat derived sea state information should increase the value of these services and competitive pressures should spread them throughout the industry.

The full extent of potential fuel savings are not apparent from the graph above because many other factors such as berth availability and port work rules will influence commercial routing algorithms. Ports generally do not work weekends or do so at overtime rates. It will often prove more economic to slow a ship drastically to arrive on a Monday and save fuel than arrive the previous week if unloading cannot be completed for Friday afternoon sailing.

Estimated Economic Benefits through Fuel Savings

The monetary savings from reduced fuel consumption are easily estimated. World shipping consumed 1.55 billion barrels of petroleum in 1972. Current ship fuel costs are: Bunker $62/ton ($9.14/bbl); Diesel $100/ton ($14.70/bbl). A cost of $12/bbl is taken as an average.

Assuming a 5% savings in fuel consumption to be a reasonable potential for ship routing systems, potential monetary savings from optimized ship routing could reach $900 million. This figure would increase with the price of oil.

Some of these savings can already be effected using sea state predictions derived from current weather information from satellites, ships at sea and other sources. Using surface pressure predictions, wind direction and velocity can be predicted from pressure gradients; this wind information is then used to predict sea state by analysis of the duration and fetch of the winds and applying predictive models for the growth, dissipation and propagation of waves.

As a prospective lower bound on the value of Seasat information, assuming a 1% fuel saving as the increment attributed to Seasat data input yields global savings of $180 million/year. It could easily be higher as there is evidence that there may be considerable difference between an optimum and near optimum route and the value of the last increment of information may be high.

Examining the direct return to the US, the US merchant fleet consumes approximately 30 million tons of fuel oil per year valued at $2.4 Billion.

5% saving	$120 million
1% saving	$24 million

Inclusion of US owned vessels operating under flags of convenience would perhaps more than double these totals.

Estimated Economic Benefits through reduced hull and cargo damage.

Insurance is a major ship operating expense, prior to October 1973 it exceeded fuel costs and today approximates 10% of operating costs; a large tanker pays about $1 million/year in premiums. 30-40% of these insurance costs are for hull insurance, caused mainly by weather damage in heavy seas. The balance of insurance costs are for cargo coverage where damage is partly caused by weather and partly by the hazards of loading and unloading.

The 560 ships in the US flag fleet average $400K each in insurance costs, for a total US marine insurance bill of $244 million. Assuming that $100 million is hull insurance deducting the insurers profit and administrative expenses, approximately $70 million is paid yearly in claims for weather damage.

The US flag fleet is 6% of the world fleet; extrapolating the potential savings globally yields a weather damage total of approximately $1 Billion. This could be low, ship repair is a $8 billion business worldwide, about 30% of that hull repair, mainly weather induced. There are in addition savings attributable to decreased cargo damage but an estimate of this would require detailed study.

Unlike fuel savings, where much of the potential benefit can be obtained from existing data sources and only incremental savings can be attributed to Seasat input, significant reductions in weather damage to shipping may result from the last increment of information which makes the difference between a stormy passage and a damaged ship. The savings resulting from Seasat input could therefore be quite high if the measurement accuracy objectives of the program are achieved. (1)

Benefits from Reduced Environmental Damage

Oil Spills arising out of weather damage to tankers are common occurences as shown by the following data. (2)

1st 6 months 1974	60 tankers damaged by weather
1st 6 months 1973	77 tankers damaged by weather

Assigning a value to the benefits of reduced oil spills by storm avoidance using satellite derived data is a very difficult exercise as the effects of pollution are spread over a large number of people. Some benefit does exist however and must be considered as an intangible in deciding on the level of support for Seasat.

Long term potential benefits

---

(1) To be significantly better than present measurements, wave height should be measured to within ± 8 cm and wave period to within one hundredth of a second.

(2) Telephone interview, John Whitmay, Smithsonian Center for the Study of Short Lived Phenomena, Cambridge, Mass.

Ship movements on the high seas are currently uncontrolled. Ship operators anticipate some global control in the future. The US will control a major part of the world's most densely used sea lanes and will have a large stake in the arrangements for such control. Optimal routing systems to save fuel and avoid storms will likely be part of any such control system and should be implemented using the best possible data.

Port facilities are currently inefficiently utilized because ships arrive randomly. Sequencing the arrivals at a port through overall control of routing will improve port operations and reduce costs, both for capital investment in port facilities and demurrage. (1)

Estimated Overall savings of Optimized ship routing Systems Worldwide

Fuel consumption	\$0.5-.9 Billion
Hull Damage	\$0.8-1.5 Billion
Cargo Damage	\$0.2 Billion (2)
Environmental	?
Total	\$1.5-2.6 Billion per year

The US share of these benefits will range between 5%, the proportion of the world's fleet flying the US flag, to 11%, the proportion of that fleet that is more or less US owned. This may

(1) Demurrage - Costs incurred when a vessel must lay idle awaiting a berth to unload.

(2) Assumes 10% of cargo damage weather induced

be reduced by the fact that some of the US flag fleet is engaged in costal trading where the benefits of optimized ship routing may be less than on the high seas.

15 Principal Merchant Fleets of the World

Arranged in Order of Number of Ships Registered Under the Flag as of 31 December 1970

Country of Registry	Number of Ships	Deadweight Tons	Passenger Cargo Ships	Freighters	Bulk Carriers	Tankers
Total—All Countries	19,980	326,999,000	895	11,899	2,954	4,232
Japan	2,109	39,142,000	28	1,284	429	368
U.S.S.R.	1,942	14,302,000	77	1,339	132	394
Liberia	1,840	60,992,000	25	495	590	730
United Kingdom	1,772	37,065,000	75	967	296	434
Greece	1,195	18,214,000	45	757	177	216
Norway	1,173	32,374,000	27	442	341	363
West Germany	993	11,697,000	6	836	92	59
United States	793	14,406,000	19	475	37	262
Panama	629	9,140,000	26	361	69	173
Italy	625	9,803,000	67	237	123	198
The Netherlands	460	7,066,000	15	319	34	92
France	457	9,007,000	19	242	61	135
Spain	403	4,297,000	37	227	30	109
Sweden	366	6,898,000	4	204	78	80
Denmark	285	4,629,000	12	194	26	53

Source: Maritime Administration

Liberia and Panama are flags of convenience and ownership in ships registered there is scattered worldwide with a fair proportion in the U.S.

International Interest in Seasat data as Input to Optimum Routing Systems

Although the benefits derived fom improved weather data will ultimately flow through to all countries who import oil and other goods by water, interest in Seasat programs is likely to be limited to major maritime nations. These are shown as follows.

As noted before, many of the economic savings enumerated above can be attained on the basis of data derived from non-SEASAT sources. However, the absolute value of the potential savings are so large that attributing only 5% of the savings as the marginal increment resulting from the input of SEASAT data, still result in annual benefits on the order of $100 million.

Communication Requirements for SEASAT Programs

SEASAT-A will be launched before the advent of TDRSS and will transmit its data directly to earth stations. These will be located on the east and west coast of the US. Discussions are underway with governments in Europe and Japan concerning foreign participation in the program which may result in additional readout stations.

Should SEASAT-A results meet expectation, the potential economic benefits will generate pressures for an expanded operational system. SEASAT-A will provide global coverage every 36 hours; a three satellite system giving global coverage every 12 hours is more in line with current weather observation practice. While the coverage area of direct readout stations in the US, Europe and Japan will include the heavy travelled north Atlantic and north Pacific sea lanes, most of the worlds's tanker routes (and hence potential benefits) will be excluded. This deficiency may be alleviated either by increasing the number of direct readout stations or using TDRSS.

Providing enough direct readout stations to cover the world's major shipping lanes may require locating them in countries with insuffficent maritime interest of their own to support the costs of running the station. For global coverage such a problem is almost certain. The location of NASA earth stations in developing countries has in the past given rise to problems. Given the economic value of SEASAT data, this is likely to be accentuated should a network of direct readout stations be used for data acquisition. It would appear more desirable to acquire SEASAT data via TDRSS.

1.4.2: SAR and Land Applications

Future applications of synthetic apature radar (SAR) may extend beyond present planned use for sea state sensing to include sensing of land areas. The all weather day and night capability of satellite based SAR may be better suited to operational applications requiring repeated coverage than is Landsat imagery. This would be particularly true in northern latitudes and equatorial regions subject to frequent cloud cover.

The nature of the scattered return from SAR is determined primarily by sensed surface roughness, dielectric properties, geometry and orientation. The complexity of the variables affecting the return makes it difficult to predict the return from purely theoretical considerations and, as a result, SAR image interpretation is still largely an experimental field. There are, however, some land sensing tasks which, with further development of interpretation techniques, could be carried out by SAR.

The first of these is soil moisture measurement. Short wave radar penetrates only the top few centimeters in moist soils, but may go as far as the ground water level in arid areas. Though moisture content of the top layer of soil may be independent of moisture content at deeper (root) levels, repeated coverage of an area may provide a statistical base which would aid in prediction of crop health and yields. Experimentation with different wavelengths and polarizations may be necessary.

SAR, being able to penetrate cloud cover, is ideally suited to the mapping of areas flooded by river overflow or heavy rainfall. A three satellite sensing system could provide information within 12 hours. Given knowledge of the land surface topography it would also be possible to estimate water depth and hence discharge rate. For this application, resolution would have to be greater than SEASAT's 25 meters. An application in the same class as flood monitoring, but of rarer occurrence, is the survey of damage caused by earthquakes, where heavy dust clouds rule out aerial photography.

A third promising application of SAR imagery, again with the proviso that further development is required, is the estimation of snow storage on the ground. If radar could be used to determine the equivalent and free water content of snow (snow depth by itself is of little use), surveillance once per week as the melt season approaches could provide large benefits in terms of reservoir management and flood control. It may also be possible to detect possible avalanche conditions.

The above indicates some potential uses of SAR that make use of its cloud penetration capability to provide data at frequent and regularly spaced intervals, or within a certain maximum time period in case of natural disaster. On this count SAR may prove a useful operational tool. A satellite carrying SAR both for land and sea sensing could make almost coninuous use of the TDRSS high data rate channel.

SEASAT Data Flow

A prospective flow chart for SEASAT data is shown in Figure 1.5. It appears highly unlikely that there will be any operational demand for the data stream from the satellite. Processed data in the form of wave height, length, direction, wind speed and direction, air and sea temperature by grid coordinates is more appropriate. For 12 hours coverage on a 10 mile square grid basis, a data rate of 20 kbps is estimated.

The customers for this 20 kbps data stream are likely to be limited to the operators of ship routing services, weather bureaus and a few other specialized users. Within the US, such a data stream can be distributed over the facilities of specialized common carriers. It could be broadcast overseas on a single pcm satellite voice channel to weather bureaus and ship routing services of other nations.

1.4.3: Seasat-A Data Collection Experiments

All ocean areas of the world are not of equal interest. At present, for example, there is amongst shippers more interest in northern hemisphere than in southern hemisphere sea states. Operational use of Seasat, if left to the forces of the market place, is likely to be concentrated in a few areas at first - notably, the North Atlantic shipping routes. Referring to Figure 1.2 it is apparent that, if Canada proceeds with its current plans to install a Landsat tracking station in Newfoundland, by 1976, the important U.S. - Europe shipping route would be provided with complete coverage by it in conjunction with the Italian Landsat station at Fucino or the NASA tracking station in Madrid. Relatively inexpensive modifications of Landsat station electronics will enable them to read and record Seasat data.

The 16 Mbps data stream could be relayed from the Landsat stations to points in the North Atlantic basin without further processing through an INTELSAT global beam transponder. If the full Seasat-A data set is needed for effective utilization of the radar imagery the combined 30 kbps output of the low data rate sensors could also be broadcast via Intelsat. Figure 1.5 depicts the data relay network.

This experiment would require the ground stations to track Seasat-A during the approximately 10 passes it will make every 36 hours between longitudes 0 degrees and 80 degrees West. On each pass approximately 8.4 minutes of data will be collected, between longitudes 30 degrees North and 60 degrees North. (1) If the collected data is retransmitted at a constant average rate, a capacity of 622 kbps would be needed out of the total 60 Mbps INTELSAT transponder capability.

The highest data rate channels currently tariffed by the international record carriers are 56 Kbps links; the link needed for the experiment is 12 times this capacity. Based on the U.S. 56 Kbps tariff, an annual charge for the link from the Landsat station to the INTELSAT satellite would be approximately $750,000 per year. (2) The tariff for the other half of the circuit from the INTELSAT

---

(1) Seasat-A will complete 21.4 orbits every 36 hours. The experiment would cover 80 degrees longitude of a possible 360 degrees total, or 0.223 of the 21.4 orbits. As each orbit has ascending and descending nodes, the resultant number of passes over the North Atlantic area every 36 hours will be approximately 10.

Of a possible 360 degrees total latitude, the experiment area covers 30 degrees. Of each orbit within the longitudes of interest, then, only one twelfth, or 8.4 minutes, would be tracked.

(2) The U.S. half of a 56 Kbps duplex half circuit to Europe costs

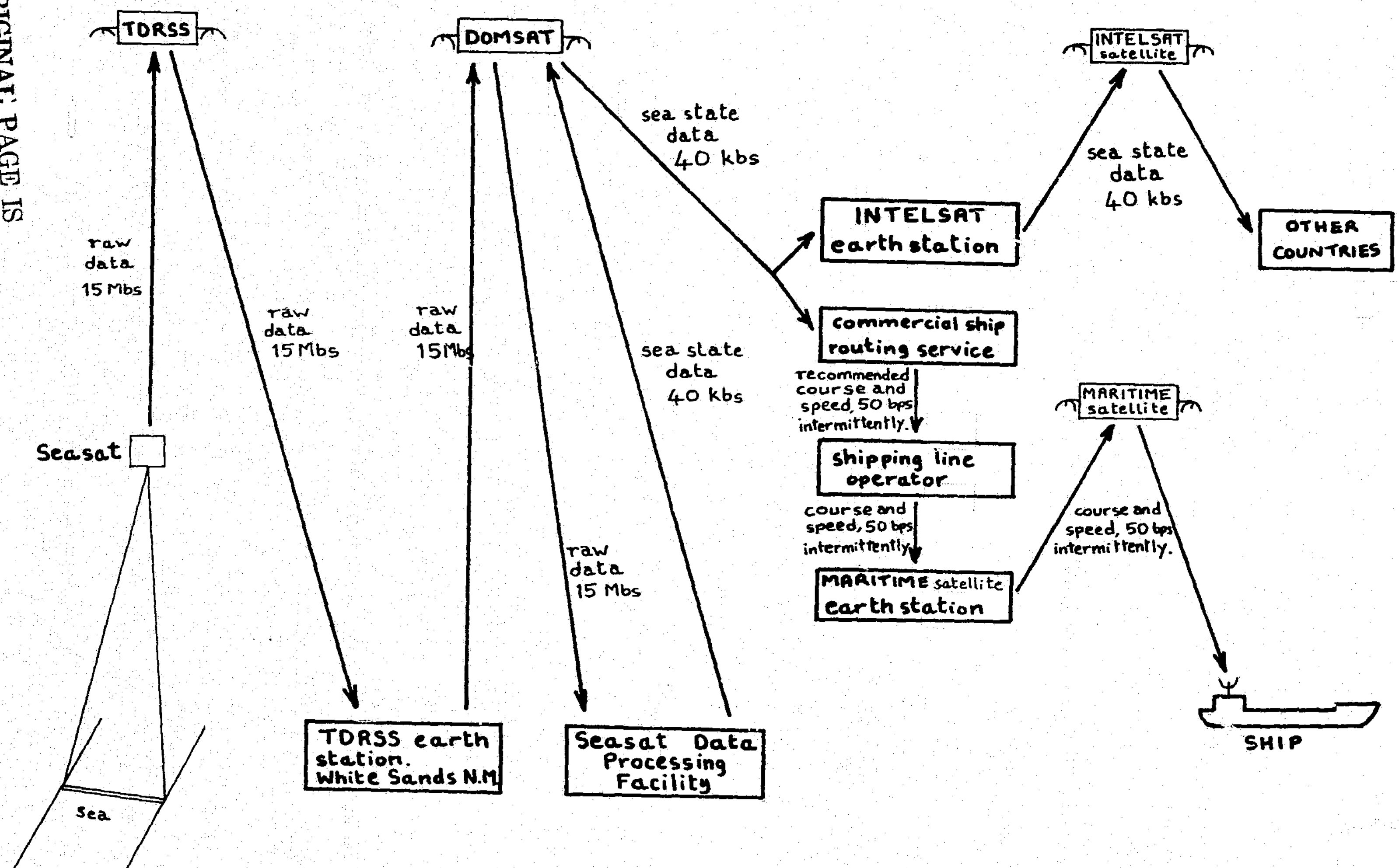

Figure 1.5: Seasat data flow

satellite to countries wanting to receive the data would be set by the telecommuncations administrations of those countries.

Note that this would be a somewhat unusual use of an INTELSAT channels: two ground stations would use an uplink channel on a time-shared basis to transmit data which is then "broadcast" on the downlink to several nations. Whether and how INTELSAT, the international carriers and telecommunications administrations would take the initiative in devising tariffs that bear some logical relationship to costs is an open question. (1) Certainly, some effort in this direction is needed if innovation in international communication services is to occur and if international satellite communications are to move beyond the essentially point-to-point present mode of operation. (2)

As an alternative to a North Atlantic experiment, the Italian Landsat station (or Madrid) could be used to simulate operational

---

$94,000 per year. The method of estimating a tariff for the higher rate link is that described in Chapter 2.2, with the exception that the bandwidth factor here is 12. A more precise calculation would use Canadian and Italian data transmission tariffs.

(1) For example, the current INTELSAT downlink tariff for multiple destination TV transmissions is set at 50% of the uplink tariff for every earth station receiving the "broadcast", though INTELSAT's costs are no different whether one or one hundred stations tune in. Similarly, if two stations share the use of one uplink, INTELSAT's costs are the same as those incurred if only one station accessed the channel. Earth station costs, however, will be different for the two cases.

(2) INTELSAT's demand assigned service (SPADE) is a move in this direction, though it has been used more for load averaging for high volume users than for providing low volume users with a greater variety of international links. One reason for this is the high SPADE equipment cost.

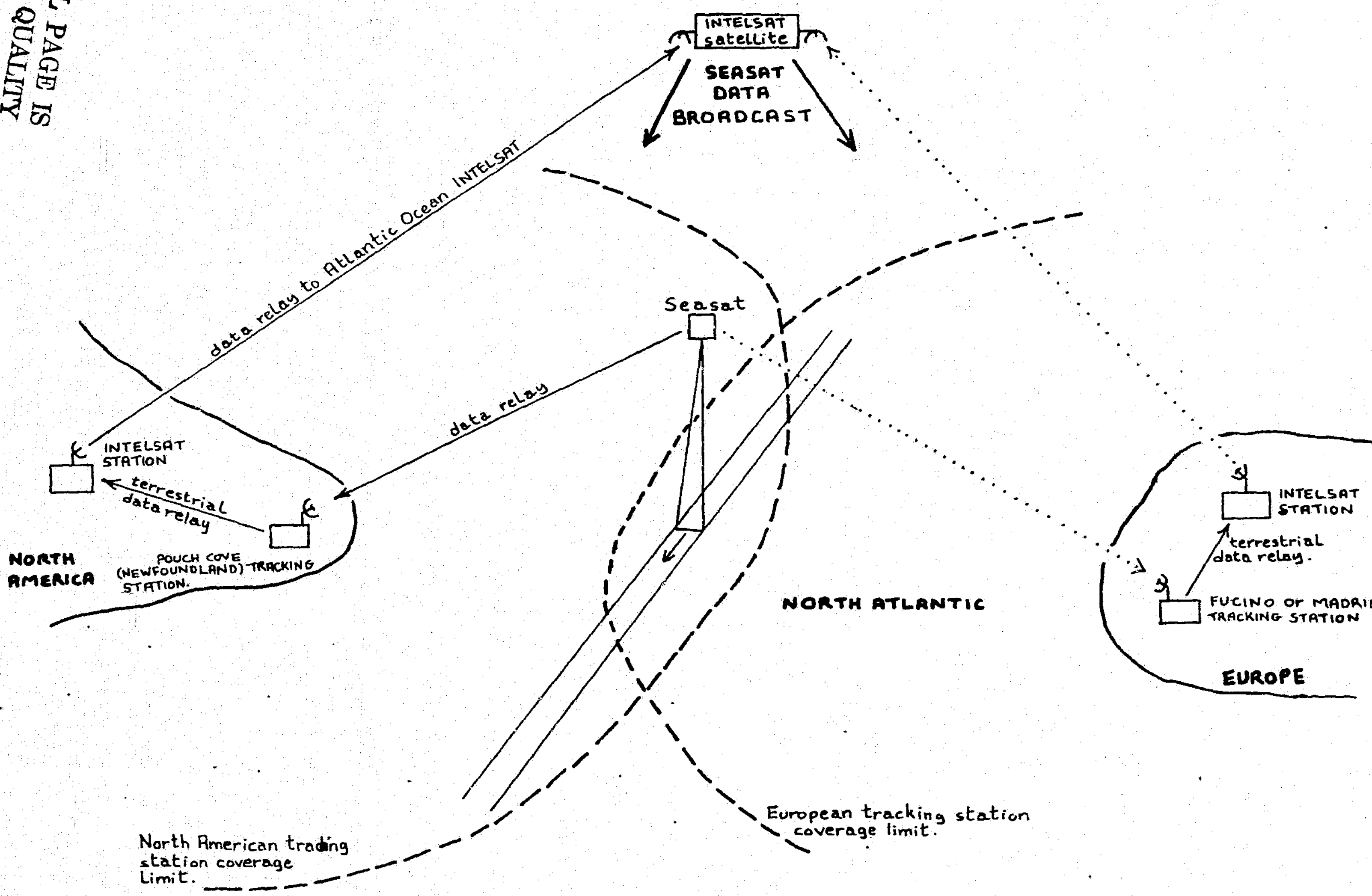

Figure 1.6: Seasat-A North Atlantic data collection experiment

use of Seasat by collecting data over the Mediterranean Sea and providing it to the U.S. Navy, who have developed wave generation and propagation models for this sea. (1) Seasat data would offer greatly improved methods of verifying the models and the experiment would also serve to explore the role data can play in predicting optimum ship routes.

1.4.4: Orbit and Tracking Considerations

The data rate from the Seasat-A imaging radar is 16 Mbps and future spacecraft could have order of magnitude higher rates. Current plans do not provide for on-board storage of this data. On-board data processing and compression for Seasat data is currently being studied, but it is unlikely that the data stream could be compressed to the 50 kbps of a TDRSS MA channel. Seasats beyond the first mission are thus candidate users of the TDRSS Ku band SA link.

Of the earth's surface, 70% is covered by ocean, excluding the icecaps which constitute another 3.5%. On average, then, an operational Seasat system could be sensing the earth's surface during 70% of the time. This figure would be increased slightly if coastal land that can not be excluded from images is included.

---

(1) "A Mediterranean Sea Wave Spectral Model", S. M. Lazanoff N. M. Stevenson, V. J. Cardone, Fleet Numerical Weather Central, Technical Note No. 73-1, March 1973.

Analysis of the Seasat-A orbit shows that the longest continuous stretch of land falling under the orbit swatch would occupy about 40 minutes of the 101 minute orbit period, with another 4 minute stretch on the second leg of the orbit. Other orbits with above average (the average being 30%) amounts of land in their swaths tend to have these divided into smaller parcels of 2 minutes, 5 minutes, and 10 minutes duration. The implication of the lack of on-board storage, limited time periods for delayed transmission and limited compression capability, is that an operational Seasat system covering the world's oceans and supplying data to the U.S. Navy and commercial users will require a dedicated high data rate communications link to the ground.

As this link should be global in coverage, in the absence of significant on-board data reduction, the use of a TDRSS-type link is mandatory. If one compares TDRSS capabilities with operational Seasat requirements it is apparent that TDRSS has the capacity to handle one Seasat, though this would occupy 25% of the systems's Ku band SA link capacity. It does not seem logistically practical for a tracking antenna on a TDRSS satellite to track Seasat only on those portions of its orbit that cover the sea. The only time a Seasat dedicated antenna could give to other satellites would be during the occasional 30 or 40 minutes continuous land segments, and even this presupposes that the communication requirements of other missions to be served fall within these time periods.

The pattern of TDRSS SA channel occupancy can be deduced from the Seasat-A orbit, given that a dedicated link is required at all times from Seasat. Tracking of Seasat would be performed by the east and west TDRS on an alternating basis. Two consecutive half orbits would be within view of one TDRS, while the next half orbit would be within view of the other TDRS. The next two half orbits would again be handled by the first TDRS. (1)

Thus for continuous coverage one of the the Ku band SA channel on one TDRS would be occupied for continuous 101 minute periods (a complete Seasat orbit), while a similar channel on the other satellite would be occupied for continuous 50 minute periods (one half of an orbit).

Hence the 25% TDRSS occupancy figure alluded to above consists of two-thirds channel time on one satellite and one-third time on the other satellite. If the intervening unused 50 and 100 minute periods on the respective TDRSS communications channels may not be used for other purposes (due to scheduling and TDRSS command and control limitations), then occupancy of these channels by Seasat could be said to be 100%.

If two Seasats were orbited 180 degrees out of phase, one of the Ku band SA channels on each TDRSS satellite would be fully occupied,

---

(1) Some half orbits can be seen by both east and west TDRSs; such orbits occur every three half orbits. Thus, if E denotes a half orbit that can be seen by the east TDRS, W denotes one that can be seen by the west TDRS and EW a half orbit that is within the field of view of both TDRSs, the sequence of half orbits is:

E, W, EW, E, W, EW, E, W, EW, ...

with data lost during the time it takes for the gimballed antenna to stop tracking one Seasat and acquiring the other. This should not exceed a couple of minutes of polar data.

To obtain synoptic global coverage every 12 hours, as requested by the U.S. Navy, three orbiting Seasats would be required. Provision of adequate communications links from these spacecraft would require constant use of one of the two SA Ku band channels on each TDRS, including the in-orbit spare located over the U.S. In the event of a TDRS satellite failure, continuous Seasat coverage would require continuous use of one SA Ku band channel on each TDRS and intermittent use of a second.

An alternative method of ensuring adequate TDRSS coverage of three Seasats is to position a third tracking satellite over the "zone of exclusion" that covers the western part of India under the current two satellite configuration. (See Figure 2) One channel on each TDRS would be sized to the Seasat data rate, and occupancy on all three channels would be 100%. In addition, this alternative eliminates the "zone of exclusion" of a two satellite system. Data transfer from the TDRS over India to the TDRSS ground stations in New Mexico would take place through two intersatellite relays, between the third TDRS and the east and west tracking satellites. Such a double link would provide increased reliability, routing flexibility and satellite interchangability over a single link option.

ORIGINAL PAGE IS
OF POOR QUALITY

1.5: Meteorological Satellite Data Collection

In the field of meteorology sub-syrchronous and synchronous satellites are used on an operational basis to monitor global and local weather patterns. In the US, the National Oceanographic and Atmospheric Administration (NOAA) operates a series of such satellites that are designed and launched by NASA.

Currently NOAA is operating its second generation of polar orbiting satellites, the ITOS (Improved TIROS Operational Satellite) series. launch in 1977. There are three meteorological sensors on these spacecraft:

1. The Scanning Radiometer (SR) provides horizon to horizon images of cloud cover in the visible and infrared bands. Visible band images of sunlit portions of the earth have a resolution of 4km, while resolution of infrared images, which give the system day and night capability, is 8 km.

2. The Very High Resolution Radiometer (VHRR) observations are similar to those taken by the SR, but have a resolution of 0.9 km at the satellite subpoint. In addition to providing images of cloud cover, the SR and the VHRR obtain a measure of sea surface temperature in cloud-free areas. Both data streams are transmitted direct to ground stations and there is an on board capability to store "blind orbit" data.

3. The Vertical Temperature Profile Radiometer (VTPR) measures infrared energy radiated at 6 levels of the atmosphere and at the earth's surface or cloud tops. These measurements are used to calculate the vertical temperature distribution and the total moisture content of the atmospheric column beneath the satellite.

Use of a third generation of polar spacecraft will begin in 1978 when NASA launchs TIROS-N. Seven satellites of this series will carry NOAA through to 1985, when, it is currently planned, the fourth generation will be ready for use. The major benefit to be derived from TIROS-N is improved accuracy of measurement over the current ITOS series. An Advanced Very High Resolution Radiometer (AVHRR) will be orbited on TIROS-N, sensing in a maximum of 5 spectral bands (including visible and infrared) with data rates of 665 kbps during the day and 300 kbps at night. The AVHRR will sense in five spectral bands as compared to the VHRR's two, which will increase the accuracy of sea surface temperature measurements and the ability to differentiate between clouds, water, solid snow and ice, and melting snow and ice.

The questions which arise with regard to meteorological satellite use of TDRSS are whether cloud cover imagery collected over regions not adjacent to the US is of interest to the US, and whether other nations would find it advantageous to receive meteorological data that concerns them from a centralized acquisition site (the TDRSS ground facility) in the US.

1.5.1: US Use of Global Meteorological Imagery

It is possible that the National Weather Service will desire AVHRR data originated on the other side of the globe as cloud cover data from distant areas can be useful in prediction models. Some cloud cover information is available from synchronous meteorological satellites and the need for more detailed AVHRR data is unclear. VTPR data may also be of use in predicting the movements of air masses. For both data, rapid delivery is critical for incorporation in prediction models. Relay of the raw data via TDRS is an alternative. This would greatly increase the SA channel capacity required unless the sensors were flown on a satellite already using TDRSS such as Seasat. For prediction purposes, relay of summarized data from a foreign readout station via commercial satellite links may prove more cost effective. This question bears further study.

Storm and hurricane disaster warning would be a high priority use of AVHRR data, though, again, the detailed information is more likely to be of local interest. In addition, the future global system of five geostationary orbit meteorological satellites (of which NASA's Synchronous Meteorological Satellite -1 and -2 are the first two) is better suited to the task of monitoring storms. This system will be able to provide continuous observation of any part of the globe (except polar regions), whereas coverage through polar orbiting satellites is intermittent. Information on severe weather conditions at locations remote from the US would be available to US users through the existing Global Telecommunications System of the World Weather Watch. (1)

Another potential use of AVHRR data would be to aid in world wide crop size forecasts by providing more information on weather patterns over foreign agricultural areas. Crop yield is heavily

---

(1) The World Weather Watch (WWW) has three components:
a) Global Observation System - observations are made with a variety of sensors, including satellites.
b) Global Telecommunication System - this links all countries participating in WWW through a hierarchical scheme of data transmission links with capacities ranging from 50 bps to 4800 bps.
c) Global Data Processing System - this is a hierarchical scheme for processing the data entering the network.

dependent on meteorological conditions; improvements in the timeliness and quality of the meteorological inputs to a crop forecasting model would no doubt be translated into more up to date and accurate predictions. Of the two prime inputs to the crop production "industry", water and sunshine, AVHRR data is likely to provide more information on the latter. Given a time sequence of images depicting cloud cover over a given region, it may be possible to derive the rate of solar energy input to the crop. This possibility is conditional on the AVHRR resolution of 0.9 km being high enough to make meaningful statements about cloud cover over croplands that may be only a few kilometers in their maximum dimension, and on the imagery providing sufficient data on cloud cover thickness, from which sunlight penetration may be deduced. AVHRR data will not provide as much information on water input to the crop. It cannot indicate the presence or absence of rain below cloud cover. This information may be provided by radar measurements, as discussed in Section 1.4.2.

1.5.2: International Distribution of Meteorological Imagery

Low cost ($150,000) stations to track and receive data from the lower rate NASA earth observation missions are being developed. Most nations already have one or more Automatic Picture Transmission (APT) stations to receive low resolution cloud cover data from ITOS satellites. The options facing nations wishing to receive the improved meteorological imagery are to update their reception facilities by purchasing a low cost tracking station, or to receive data through the international telecommunications network, provided NASA facilitates the latter option by installing necessary data handling equipment at the TDRSS ground terminal. (1)

The first option has the advantage, from the user's point of view, of making him independent of the TDRSS system, of US routing facilities and of international telecommunications link. In the event of severe storms, when reception of imagery is vital, the 95 foot diameter Intelsat standard earth station will be put out of commission before the smaller tracking station as a result of the greater wind stresses it is subject to. (2) A local tracking station may also have appeal as an intermediate step between the simple, manually tracked, APT stations and a high data rate Landsat reception facility. For developing nations with the objective of entering the field of space applications and of training personnel in this field, a tracking station rather than the terminal end of an international data transmission circuit may have more appeal as a nucleus of activity.

A final advantage of direct reception of meteorological data has to do with the financial aspects of the two alternatives. For the meteorological office of a user nation, purchase of a tracking station represents a capital investment, while lease or periodic

---

(1) Received data would have to be formatted and routed to the appropriate communications facilities.

(2) Of course, if submarine cables were used for international data transmission, data reception would depend solely on weather conditions at the US TDRSS ground terminal.

use of an international circuit is a current cost. Though current costs will be incurred in operating the station, they will not approach the outlays required for international communications at current rates. Fiscal approval would be easier to obtain for an annual expenditure of $60,000, of which most is spent on local wages, than for $60,000 of which 30% is paid to a US international record carrier.

International distribution of data from a central US site through the Global Telecommunications System (GTS) of the World Weather Watch is not possible at present. The main trunk of the network operates at 2400 bps, though some links have been upgraded to 4800 bps and there are plans to upgrade the others. The AVHRR daytime data rate is 665 Kbps; the instrument continuously scans across its path of motion from horizon to horizon. The data output is thus a continuous image of which the width covers roughly 14,000 km of the earth. A data user would have to specify the lengths and locations of the segments of imagery he required, which would then be transmitted over the international network within a certain specified time period. (1) Assuming that a typical user nation would want a strip of data 7,000 km long delivered within 2 hours of acquisition, an international link from the US of 90 Kbps

---

(1) Meteorological data becomes "stale" quickly. The US Weather Bureau analyses satellite and other data into maps 2 hours after the acquisition time. It is this time limit that strains the capacity of NOAA's present satellite data acquisition network as the 2 to 3 blind orbits entail a delay of 200 to 300 minutes before data can be dumped.

capacity would be required. (1) These high data rate links would be specially arranged additions to the GTS, in which each user negotiated the setting up of a link with the US international record carriers. Based on current Comsat tariffs for a 56 Kbps channel, the cost to the IRCs of a leased one way 90 Kbps channel could be from $89,000 per year in the Atlantic basin to $152,000 per year in the Pacific basin, these costs being based on low estimates of what the foreign telecommunications administration would charge for its half of the circuit. (2) Thus at current tariff levels it would appear that such a link is not competitive with a $150,000 tracking station.

It may be thought that the above alternative is costly as it involves the point-to-point relay of data which is of interest to a large number of users. The continuous broadcast of AVHRR imagery through a geostationary satellite would be a more economical approach if a sufficient number of users exists. The broadcast could be effected by using Intelsat facilities, (3) the data being

---

(1) The TIROS-N orbit period will be 101 minutes, during which the craft will cover 40,000 km of the Earth. 7,000 km of data thus represent 18 minutes of imaging time, to be transmitted in a 2 hour period. The international link rate must therefore be at least 0.15 of the 600 Kbps imaging rate.

(2) A leased two way 56 Kbps half circuit currently leases for $4625/month in the Atlantic and $7900 in the Pacific. To arrive at the above estimates the cost was increased in proportion to the data rate and the other half of the circuit was assumed to cost the same as the US half. The resultant figure was then halved to arrive at the one way channel cost.

(3) Alternative vehicles for broadcast service could be the Synchronous Meteorological Satellites -1 and -2, and the three similar craft to be launched by Japan, the USSR and Europe. This

routed from the TDRSS ground station to both east and west coast US Intelsat stations. International record carrier rates for such a service, 600 Kbps data transmission, are not listed with the standard offerings; however, based on rates for similar services a figure of $55,000 per month for a one way link from the US ground station to the Intelsat satellite is estimated. (1) As of March 1974 there were 85 Intelsat member nations, of which 52 had earth stations. Distribution of AVHRR data to all members would thus require three uplinks to the Atlantic, Indian and Pacific Ocean Intelsat satellites, and 51 downlinks (excluding the US). For this broadcast service Intelsat charges 50% of the uplink charge for each downlink. The total cost of the leased international circuits, averaged over the 85 member nations, would be $18,800 per member per month, or $225,000 per member per year.

---

would require modifications of these satellites so that future models had the capability to track the sub-synchronous TIROS spacecraft and then broadcast the collected data. Compared to use of Intelsat this scenario is less attractive as only those nations with SMS readout stations would have access to AVHRR data, whereas there are already 85 Intelsat member nations.

(1) The leased service rates on which this estimate is based are the 1.544 Mbps PCM/PSK data channel offered by Intelsat to its members at $22,320 per month, and the current rate for TV transmissions. A 600 Kbps channel has less than half the capacity of the above PCM/PSK service, leading to $11,000 per month as an estimate of Intelsat's charge. Comsat's charges to the IRCs for use of TV transmission service, charges which must cover the costs of the ground station as well as Intelsat's tariffs, are 2 to 3.5 times Intelsat's tariffs. The IRC tariff, which is that at which service is available to the public, is approximately 5 times the Intelsat tariff. By this rationale, then, one arrives at an estimated lease cost of $55,000 per month for a one-way 600 Kbps half circuit data channel from a US gateway city. Data source: "US International Telecommunication Rate History", US Department of Commerce, Office of Telecommunications, OT Report 73-25, December 1973.

It should be noted that cost estimates for both individualized and "broadcast" distribution of AVHRR data do not include charges for use of TDRSS, nor costs of terrestrial links to gateway cities; these two components could double or triple the total cost. (1)

In summary, one may say that the economics of international data communication are unfavorable to the centralized distribution of high resolution cloud imagery. Those able to benefit from the increased resolution of AVHRR data as compared to current imagery received through APT stations have both economic and political incentives to purchase their own tracking stations, particularly when one considers that this then gives them access to data from certain other earth observation missions. (2) The most likely future scenario is one is which a certain number of nations choose to receive and process the higher resolution imagery, while the majority rely on derived products flowing through the low data rate GTS network. There would be incentives to alter this situation only if international data communication tariffs fell

---

(1) TV transmission from San Francisco to the Pacific basin costs $25/minute for the link to the satellite. The same service to the Pacific from New York costs $64/minute; transcontinental relay thus adds $40/minute to the cost of international relay.

(2) an example is an experiment recently (September 1974) conducted as part of the CARP Atlantic Tropical Experiment (GATE) with the Direct Readout Ground Station (DRGS) developed by NASA. A prototype DRGS was installed in Senegal to receive cloud imagery from the ITOS system. The DRGS has also been designed to receive SMS synchronous orbit imagery. Though the results of SMS data reception experiment indicated a need for further development of the technology, this one station has the potential of providing nations with meteorological data fom both synchronous and sub-synchrohous satellites.

substantially, or if the Intelsat broadcast service tariff structure were revised to reflect the fact that space segment costs are independent of the number of receivers.

1.6: Scientific Missions and TDRSS

Within the next decade there will be earth orbital missions, dedicated to purposes other than observation of Earth, that will make occasional use of TDRSS high data rate channels. Such missions currently being developed are the Large Space Telescope (LST), Spacelab, (1) and the associated Shuttle launches. The Solar Maximum Mission (SMM), to be launched in 1978-79 into a 460 km circular orbit, will carry recorders to store data for later dump to ground stations. The High Energy Astronony Observatory (HEAO) series of missions will also carry a record capability; in addition, this series has medium data rates (10 - 100 Kbps) and is more likely to make use of the multiple access channels on TDRSS if real time data transfer is needed.

LST is a potential user of a 6 Mbps SA TDRSS channel, having a maximum data rate of 2 Mbps. Not being related to potential practical uses as are the earth observation missions, demand schedules for data transfer from scientific missions are harder to arrive at. However, an important requirement imposed on the LST to ground communication link is for long periods of data transfer, up to 40 hours, during which LST continuously views a source of

---

(1) This is a manned multi-experiment mission scheduled for 1980.

radiation. As the on board storage of 1 Gb capacity can not handle such long viewing periods it will be necessary either to perform a sequence of store and dump operations or, more simply, to use a TDRSS link.

Spacelab is another example of a mission that will use the TDRSS SA channel to derive maximum benefit from the mission. Recent airborne simulations of the Spacelab mission, using two-way audio circuits and downlink video from the aircraft, indicated that the television link was useful for troubleshooting and for viewing hard copy. (1) It seems fairly certain that this link will be included in the final mission plan.

Future manned missions of the Spacelab series, and launches and retrivals using the Shuttle, will give rise to a continuing, if sporadic, demand for tracking by TDRSS over a period of days. The current TDRSS User's Handbook states that the high data rate channels are intended for dedicated use only to manned missions. (2) The implication is that other missions such as Landsat and Seasat, if they use TDRSS at all, will have to formulate data collection priorities for those periods in which the necessary channels on TDRSS are unavailable.

---

(1) Aviation Week and Space Technology, July 14, 1975, p. 44.

(2) Tracking and Data Relay Satellite System (TDRSS) User's Guide, Revision 1, September 1974, Goddard Space Flight Center.

CHAPTER 2: ALTERNATIVE LANDSAT DATA DELIVERY ARRANGEMENTS

This chapter concentrates on methods for transmitting data received from multispectral scanners and thematic mappers to users around the world. As previously noted, the data streams from data collection platforms are very small in relation to other potential sources and can be easily handled.

The same is true of Seasat. While the data stream from the satellite is in the megabit range, the information desired by end users around the world will be much less, comprising wind speed and direction, wave height and direction, wave length, air and water temperature, etc. for some grid system of points in the ocean. Assuming satellite coverage every 6 hours, a 10 mile square grid system and 200 bit reports on conditions in each grid, data on the state of all the world oceans would make up a data stream of less than 15 Kbps.

In the following discussion of data relay arrangements, only costs for transmission of the data to the INTELSAT satellite will be considered. The costs for the services of the foreign earth stations are ignored as these costs are to a great extent matters of internal accounting rather than the incremental costs of providing the services. The earth station is a sunk cost. The incremental costs of adding the necessary equipment to receive high speed data streams are relatively small by comparison.

The rationale for excluding foreign costs is that the organizations operating foreign earth stations are in many cases either part of the government directly such as PTTs, or owned by the government, either wholly or in part. As the marginal cost of providing the service is small, any substantial charges for receiving signals relayed through the satellite can be considered an internal transfer of funds within the government rather than a real expenditure.

It must be noted that international telecommunication rates are far higher than domestic ones. If overseas satellite links were available at rates comparable to those available from the highly competitive U.S. domestic satellite communications industry, most countries could receive computer compatible tapes of MSS images of their country at a yearly communications cost of less than $20,000. (1)

The costs shown in the following discussions of alternatives are derived from published tariffs of INTELSAT, COMSAT and U.S. international record carriers. For services where no tariffs exist, costs have been estimated from the closest equivalent tariff.

The costs shown are likely to be much higher than those which NASA or other organizations seeking data relay services would obtain if

---

(1) American Satellite Corporation offers transcontinental voice circuits for $12,000 per year. The bandwidth can support a 56 Kbps pcm voice or data signal. An additional $8,000 a year is allowed for the extra cost of the special modulation equipment involved.

the services were put out to bid. The high data rates involved for several of the alternatives and the dollar volume of the contracts involved ensure that most alternatives would be provided under special construction tariffs where competition among the carriers can reduce prices.

2.1: Broadcast of Landsat Output to All Nations in the Atlantic and Pacific Ocean Basins via INTELSAT 60 MBPS Channels.

The transmission of 400 scenes of multi-spectral scanner data in computer compatible tape form, (each scene comprising 234 Mbits) over a 60 Mbps satellite link requires 26 minutes a day of satellite time. At the current rate charged by U.S. carriers for TV transmission (1) of $850 for the first 10 minutes and $25 per each additional minute, 26 minutes would cost $1250, approximately $3.13 a frame. This is doubled for distribution in two ocean basins.

The annual cost of these transmissions, $912,500, divided over the membership of the United Nations is about $7,000 a year. (2)

---

(1) "U.S. International Telecommunication Rate History," OT Report 73-25, U.S. Department of Commerce, December 1973.

(2) Intelsat tariffs for multidestination service impose an additional 50% charge for each receiving station. We have assumed that any extensive use of Intelsat for this purpose would result in a special tariff more favorable than the current TV tarriffs used in the estimates, it being in the interest of member nations to arrange such tarrifs. There are 13 nations in the Indian Ocean Basin not covered by this scheme. Including them would require retransmission from an earth station accessing both Atlantic and Indian Ocean satellites. This should increase the costs by 50%.

Using an entire transponder to distribute Landsat data has one major drawback however. Tape recorders capable of operating at 60 Mbps are currently at the limits of the state of the art. Widespread distribution and maintenance of such recorders to all the earth stations of the world would be both expensive and technically difficult. Distribution alternatives involving less sophisticated technology are preferable.

The figures above apply only to the distribution of data from existing multipsectral scanners. The higher resolution thematic mapper to be flown on future missions would increase all costs fivefold.

2.2: Broadcast of Landsat Output to All Nations in the Atlantic and Pacific Ocean Basins via INTELSAT 1.5 Mbps Channels

400 235 Mbit MSS scenes can be transmitted over a 1.544 Mbs satellite channel in 17 hours. (1) There is sufficient extra capacity to allow the multiplexing of lower rate data streams such as those from data collection platforms or Seasat into the same channel.

There are no tariffs for international 1.544 Mbs service by the international record carriers or COMSAT. The only tariff for such a service is for INTELSAT and that tariff is 24 times the rate for a voice channel. This factor of 24 is used to compute a hypothetical IRC tarriff for the service, as a 1.544 Mbs bit stream

---

(1) 1.544 Mbs channels are capable of bit error rates of 1**-8 to 10**-10 with off the shelf forward error correction equipment.

requires 24 times the bandwidth of a 56 Kbps pcm voice channel.

56 Kbps data channels to Europe are available from the IRCs at a tariff of $94,000/year for a duplex half circuit. Multiplying this by 24 to get the bandwidth and reducing by a factor of .65 to adjust for the savings arising from economies of scale and not having to provide two way capability yields a yearly cost per ocean basin of $1,466,000 or approximately $3 million for both ocean basins. This cost, spread over the UN membership would be about $23,000 per country.

Most of the costs above are attributable to terrestial relay in the U.S. and the IRC markup for profit, and administration, as the costs of 56 Kbps channels to Europe from COMSAT are $39,000/year. The use of domestic satellite circuits for relay from GSFC or Sioux Falls to the INTELSAT earth stations should reduce terrestial relay costs; these savings should flow through to the overall rate.

While the transmission costs per scene of this option are several times higher than the preceeding option, the total system costs are likely to be lower. Tape recorders capable of recording 1.544 Mbps are off the shelf items, relatively inexpensive and widely distributed and serviced. Savings here should offset the higher transmission cost.

2.3: Distribution to Individual Countries of Landsat Data Obtained Over the Respective Countries.

Successive passes of Landsats in sun-synchronous orbits are separated by approximately 1780 miles at the equator. In consequence, except for a limited number of large countries whose breadth exceeds that figure (U.S., USSR, Canada, Australia, China, Brazil, etc.), most countries will have only one Landsat pass per day and the maximum number of images will be roughly equal to the milage between its extreme northern and southern boundaries divided by 115 miles/image. For most countries this maximum number of images will be less than 20 per day.

Distribution of 20 MSS scenes per day in computer compatible tape form can be effected over a leased 56 Kbps satellite circuit from GSFC to the country's LANDSAT data analysis facility in 23.4 hours. The current IRC tarriff for the U.S. half of such a circuit is $94,000/year. Error rates are in the order of 10**-6 with rates of 10**-10 available with forward error corection and reduced bit rates of 48 Kbps.

As most countries will not need the full capacity of such a circuit for the relay of LANDSAT data, its lease offers the opportunity of multiplexing in a 2400 bps digitized voice circuit to link that country's government with its UN Delegation and Embassy to the United States, as well as teletype circuits to the Embassy and a higher speed data circuit for the relay of other data from earth observation satellites such as data collection systems.

2.4: Occasional or limited distribution of selected scenes to individual countries.

As indicated elsewhere in the report, the demand for quasi real time distribution of large amounts of Landsat imagery is likely to be limited. This leaves the problem of arranging for rapid delivery of such data on a limited or occasional basis such as meeting requirements for snow coverage data for a few months a year or requirements arising out of a natural disaster such as floods, etc.

For such purposes, the 56 Kbps demand access satellite circuits available via the INTELSAT SPADE system offer a solution. Currently some 14 nations have the necessary earth station facilities to offer this service, with 14 more scheduled for future installation. Hopefully, as usage of international telephone service increases, all INTELSAT earth stations will find the roughly three quarter million dollar investment in SPADE equipment worthwhile and install the capability.

SPADE channels are not tariffed for public use since their function is to take up peak loads in the international telephone system as these peak loads move across time zones, eliminating the need for telephone companies to size their international circuit capacity to the busy hour and freeing preassigned satellite circuits for more efficient use.

The COMSAT tariff for SPADE circuits is currently $0.46/minute. Allowing a 100% markup by the IRCs, a price of roughly $1.00/minute is a reasonable estimate of the price at which such service might be publically available. At this rate, transmission of a single MSS scene in CCT form comprising 234 M bits and taking 70 minutes would cost $70/scene. (1)

While the cost per scene via this option is much higher than previous alternatives, the total annual cost is less than option 3 for average throughputs of less than 3.6 scenes/day. However, the value of a dedicated circuit offering voice and real time data relay capability for a data collection system will influence choices between the two.

---

(1) $70/scene is not a prohibitive rate for important uses. For a 200 mile square watershed, the total cost of 30 weeks coverage (the snow melt runoff period), is less than $10,000, small in relation to prospective benefits.

CHAPTER 3: PUBLIC COMMUNICATION SERVICES AND NASA NEEDS

3.1 Domestic Communications

Data communication facilities available domestically from Domsat carriers and internationally from INTELSAT appear sufficient to meet any conceivable NASA need for data transmission.

The application of domestic satellites in meeting NASA's needs for relaying data from the TDRSS ground station in White Sands, N.M., to Goddard Space Flight Center and the United States Geological Survey center in Sioux Falls, S.D., has already been the subject of a NASA supported study. (1) We concur in the conclusions of that study.

There are currently 2 vendors of domestic satellite transponder capacity with the potential for others in the future. One potential future vendor could be the supplier of TDRSS service to NASA.

As currently conceived, the TDRSS system will be procured from a vendor as a service, rather than NASA owning the facilities as has generally been the case in the past. The rationale for this arrangement is that the vendor may be able to supply other satellite communication services from the TDRSS spacecraft, spreading the launch and space bus costs over more services and

---

(1) ERS Data Transmission Study, Final Report, National Scientific Laboratories, November 15, 1974.

thus reducing the costs to NASA.

The current TDRSS system configuration calls for an in orbit spare located roughly over the center of the U.S. This location is excellent for a domestic satellite. The supplier of domestic services should be interested in supplying TDRSS in order to take advantage of the opportunity to lower their launch costs. This is in fact what has happened, with the first TDRSS system study contract having been won by a consortium of Western Union Telegraph and RCA, both of which are domestic satellite service vendors.

The location of the TDRSS satellites in the Atlantic and Pacific basins is such that they could be used for intercontinental communication and thus would be of interest to INTELSAT. While INTELSAT could be a potential supplier of TDRS service, we understand that they have no intention of seeking to supply that service.

Transponders in those satellites could be made available for international use by the satellite owner. This could be done through INTELSAT by leasing them the transponder capacity for subsequent resale to users. They could also be leased directly to foreign administrations for domestic or international use. In the latter case, such a transaction would be subject to the U.S. policy of not encouraging international satellite systems that could cause significant economic harm to INTELSAT.

3.2: International Communications

For purposes of determining the adequacy of international public data facilities to meet NASA needs for data transmission, a transmission delay of less than 24 hours was considered acceptable for the delivery of high data rate flows such as Landsat data. Potential data flows requiring immediate delivery, such as those originating from data collection platforms, are of such low volume as to be easily handled by a limited number of voice channels.

E.g. - The worldwide potential for data collection platforms has been estimated at 250,000. Assuming a 100 bit per platform transmission every five minutes, the total bit rate is 83.3 Kbps, less than the capacity of 2 pcm satellite voice channels.

Within the delay constraints mentioned above, the relay of high data rate transmission via the INTELSAT system can be accomplished by using facilities not fully utilized by their primary service function on an off peak basis. Foremost among these are the transponders on INTELSAT satellites used for TV transmission.

INTELSAT has currently available for television relay service, 3 transponders in the Atlantic basin, 2 transponders in the Pacific basin and 1 transponder in the Indian Ocean basin. Each transponder is capable of transmitting 60 Mbps at error rates of 10**-6. (1) Reliability is high, the 1974 figure for the

---

(1) The average bit error rate is misleading; in practice there is perhaps 100 hours of error free transmissions, then a burst of garble. In any event, forward error correction (FEC) schemes are

satellites is 99.993%, for the earth station 99.950% and for the average path 99.888%. (1)

The utilization of these transponders is very low, in March 1975 the INTELSAT system carried a total of 256 hours of television, or 6% of capacity. This low utilization rate is expected to continue as TV transmission on the INTELSAT system has been growing only 1% to 2% a year. The factor responsible for this slow growth is the lack of programming of sufficient international interest to justify real time broadcasting. That is unlikely to change with time. For planning purposes one can assume that these transponders would be available to NASA 18 hours per day. This is optimistic as some of this capacity is on occasion needed to restore service during breakdown of submarine cables. However, as will be seen, the margin of space capacity so exceeds potential needs that we can ignore the constraint.

INTELSAT TV service transponders could be made available almost immediately for NASA data relay from the U.S. Sale of INTELSAT transponders capacity is a tariffed service. Modification to the tariff for data relay could be quickly done, as could the necessary modifications to earth stations to handle such transmissions.

Should the capacity of the transponders available for TV be insufficient for NASA needs, there is additional spare capacity in

---

being developed by COMSAT which promise to reduce this to 10**-9 or 10**-10.

(1) INTELSAT System Status Report, March 1975.

the INTELSAT system that could be utilized. Most of the capacity of INTELSAT satellites is used to provide dedicated circuits for intercontinental telephone service. Because of the peak load nature of telephone traffic, especially between the U.S. and Europe, those circuits are idle for most of the day. The transponder capacity used to provide most of these circuits could be reassigned for data relay during off peak hours. However, such utilization would require fundamental changes in the way INTELSAT operates.

There is little likelihood of this capacity being needed however, as the TV transponder should have sufficient capacity for any forseeable needs. As an upper bound on the data relay requirements, assume a system of two Landsat satellites, each carrying 2 thematic mappers and having a total data output of 360 Mbps. As only 30% of the earth's crust is land, and half of each satellite orbit is on the dark side of the earth, the average data rate over a 24 hour period would be 54 Mbps, well within the 60 Mbps capacity of one INTELSAT transponder.

3.3: Economic Effects of NASA Use of Public Systems

The effects of using public systems to relay NASA data should be wholly beneficial to the public interest. Domestically the use of transponders leased from common carriers should reduce the costs of the space segment to NASA and give the carrier a larger traffic base over which to distribute his satellite, launch and operating expenses with a potential reduction in overall charges.

Internationally, the beneficial effects of using INTELSAT are even more pronounced as NASA can meet its needs by utilizing off peak capacity at no marginal cost to INTELSAT. The contribution to INTELSAT revenues resulting from service to NASA should be translated into lower INTELSAT rates for satellite services.

3.4: Reliability of Public Systems

The reliability of the INTELSAT system is extremely high as shown by the figures for the INTELSAT system status report for March 1975. Most outages result from problems in earth stations. Satellite transponders themselves give very little trouble.

Domestic systems show similar results.

3.5: Transmission Security

There is no transmission security for information relayed through public satellite systems. All stations within the area of coverage of the antenna beam used may receive the transmitted data. Encryption of the data stream is necessary to prevent interception.

As NASA policy is to operate in an atmosphere of full public disclosure of its activities, with no attempt to limit distribution of data, the absence of transmission security in satellite relay via public systems should have no effect on its acceptability to meet NASA requirements.

CHAPTER 4: DISTRIBUTION OF EARTH RESOURCE DATA: FUTURE TECHNOLOGY AND POLICY ISSUES

Between now and 1980 when the TDRSS becomes operational, there will be a need for Landsat data delivery to foreign countries that cannot be filled from the US because of limitations on spacecraft tape recorder capacity and reliability. This need could be met by foreign earth stations and associated data processing and image generation facilities. NASA's Office of International Affairs has encouraged foreign countries to purchase earth stations to read out Landsat data directly from the satellite, and also the facilities to produce imagery. Several nations already have installed this capability and other are planning to do so.

These foreign Landsat stations represent an investment of approximately $600K for the antenna and $2-6M for the data processing and image production facilities. (1) Some perform geometric corrections by analog means and are incapable of producing computer compatible tapes (CCT) suitable for automatic change detection. These stations have the capacity to process between 25 and 50 multispectral scanner (MSS) scenes per day. (2) They can supply countries within approximately 1800 miles with

---

(1) Lowe D., Summers R., Greenblat E., An Economic Evaluation of the Utility of ERTS Data for Developing Countries, Vol. II, Environmental Research Institute of Michigan.

(2) At costs of about 100 dollars per scene, assuming 10 year amortization of the facilities at a 10% cost of capital (see Appendix 1)

Landsat data products.

Facilities to analyze Landsat data products are relatively inexpensive. Light tables and other aids to photo interpretation needed to work with images cost only a few thousand dollars. The computer capability necessary to analyse data in the form of CCTs is estimated to cost about $300,000.

Under the terms of the memoranda of understanding with foreign goverment agencies establishing Landsat direct readout stations, the foreign agency agrees to unrestricted public availability of its Landsat data products on the same basis that NASA itself does, at a fair and reasonable charge based on actual cost. (1)

4.1: Future Problems of Foreign Direct Readout Landsat Stations

With the onset of TDRSS service in 1979-1980 and the launching of Landsat follow-on, the operators of the then existing foreign direct readout stations will be faced with several decisions concerning the future of their operations. Four future problems for foreign owners of readout stations are noted here.

---

(1) Foreign earth stations can in theory be held to their commitments by the US as NASA has the capability of turning off the transmitter in their area. The utility of this approach is questionable since an outright failure to comply is unlikely. Combating slow delivery or high charges may be more difficult.

1. Change to Ku band direct readout downlink: Landsat follow-on will generate data at an order of magnitude higher rates than its predecessors, requiring a switch to Ku band (12-15MHz) for the direct readout downlink in order to support the very high data rates involved. Accomodation of existing S band (4MHz) antennas to operate in Ku band will require some modification of the antenna dish and complete replacement of the RF circuitry. The cost of conversion has been estimated to be in the order of $1.5M (1)

This change in Landsat downlink frequency to Ku band is forced by the inability of the existing S band downlink to support the more than 100 Mbps data rates of future Landsats. While this could be accomodated in X band (8-10MHz) where there is an existing allocation, the probability of still higher rates in the future makes a move to Ku band at this time a wise one.

There is currently a global allocation for the earth observation satellite service at 22 GHz which was obtained at the 1971 space WARC. While this frequency was sought by the US at that conference, new developments in sensor technology have rendered that allocaion less attractive. The 22 GHz water absorbtion band is very near to this allocation and recent studies indicate that water vapor sensors operating at that frequency will be interfered with by the 22 GHz downlink.

---

(1) Interview with Lorne Roberts

As a shift to the existing K band allocation is undesirable because of this sensor interference problem, the use of Ku band appears to be a desirable alternative. This use currently has only footnote status; a worldwide primary allocation is desirable. Moving the Landsat downlink frequency to Ku band should facilitate obtaining an allocation this band at the 1979 WARC.

As that WARC will fix frequency allocations for some time, perhaps decades, ensuring the availability of a downlink frequency ultimately capable of much higher data rates is of extreme importance to the future of space applications. On the other hand, rain attenuation problems at Ku band in some foreign areas may require diversity reception to ensure adequate reliability. The additional costs involved may engender opposition to a Ku band allocation in favor of X band. The possibility of X band direct readout must be left open.

2. LANDSAT STATION EQUIPMENT FOR THEMATIC MAPPER DATA RECEPTION: the bit stream from Landsat-D will be of the order of 115 to 190 Mbps and tape recorders capable of these speeds are currently well beyond the state of the art. (1) While it is anticipated that the necessary recorders will be developed by 1979 when Landsat-D becomes operational, such recorders are likely to be very expensive and difficult to maintain outside the US.

---

(1) State of the art recorders operate at speeds in the area of 50 Megabits/second.

As Landsat-D is currently planned to have an MSS with a 15 Mbps output in addition to the experimental thematic mapper (TM) with its 90 Mbps stream, (1) a foreign station could break down the bit stream to the MSS's 15 Mbps and record that on its current tape recorder. However, this approach would deny it the improved resolution of the TM, reducing its operation to second rate status and decreasing the appeal of its data products to end users when compared with the TM product likely to be available from the US.

3. DIGITAL IMAGE PROCESSING AND THE OBSOLESENCE OF PRESENT ANALOGUE FACILITIES: Concurrent with the obsolesence of the earth station and the high speed tape recorder requirement, the data processing facility will require replacement or extensive additions if the full benefits of Landsat-D are to be obtained. Most existing Landsat data processing facilities (including that at Goddard Space Flight Center(Goddard Space Flight Center)) correct the data for geometric distortion by analog means, a manual process which is insufficiently accurate to produce computer compatible tapes with good enough geometric registration to permit automatic change detection by computer. Such detection requires that temporally different images be in registration to within less than one pixel. Such registration can only be produced by wholly digital data processing.

---

(1) The thematic mapper is similar to the MSS, but scanning in 6 bands with a resolution of 30 meters.

Full digital processing of Landsat data also leads to higher quality imagery produced directly in 1:1,000,000 form by use of a laser beam recorder driven by digitally processed computer compatible tapes. (1) The elimination of the various duplicative processes between the separate 70mm masters for each spectral band and the final 1:,000,000 product produces a higher quality picture with accurate registration between temporally different scenes. This cannot be done with existing analog systems.

4. INCREASED VOLUME OF DATA FROM THE THEMATIC MAPPER: the thematic mapper, with its higher resolution, will increase the amount of data processing necessary to produce one scene by a factor of four or five. This will reduce the capacity of existing foreign facilities to between 5 and 10 scenes per day, a number probably insufficient to meet regional and perhaps the host country's own needs.

With present computer technology, there are economies of scale in processing facilities and the cost of a wholly digital processing facility to produce the 25 or so scenes required by a regional facility is not proportionally less than that required for a

---

(1) In the current process, the output of each spectral scanner is used to produce an image on 70mm film with an electron beam recorder. This original is used to make master copies which are then used to produce the 1:1,000,000 imagery (9.5 in. square) which is requested by most end users. Some degradation of image quality ocurrs with each reproduction process. Geometric correction for better registration adds another reproduction to the process.

capacity of 200 scenes a day. (1) In fact, Goddard Space Flight Center plans to install a digital processing capability by 1977 capable of handling 400 scenes a day, the maximum daily output of a Landsat with a single MSS. In brief, Goddard will have a digital processing capability able to fulfill the whole world's needs for computer tapes with 48 hour turnaround. The EROS data center, the organization distributing Landsat data to the public is upgrading its facilities accordingly.

The Goddard Space Flight Center data processing facility will have other demands upon it that will impact its ability to process foreign data. However, the special purpose hardware which will locate ground control points and do geometrical corrections is unlikely to be impacted by the other demands. As these corrections constitute most of the computational load, the Goddard facility to process all Landsat data will require mainly additional peripherals at a small incremental cost.

The capabilities of the Goddard Space Flight Center facility discusssed above have dealt only with MSS data. Thematic mapper output requires a fivefold increase in processing capability (not necessarily in price). The provision of a processing capability for a significant proportion of TM output will require some study by NASA. Its provision is likely, however, since to do otherwise

---

(1) Earth Resources Survey (ERS), Operational System Study, Final Report, Goddard Space Flight Center, Nov. 1973. Paragraphs 5.6 &5.6.4.1.

would deprive the US of one of the principal benefits of the Landsat program, specifically global crop forecasting.

The ability to forecast crop sizes is a benefit of the Landsat program that has received considerable attention. This capability does not produce benefits in the tangible form of more crops but in the form of information about the supply of crops, either national or worldwide. This information can then be used by farmers in making planting decisions and by governments in making their food import decisions in a manner that will, theoretically , increase the benefits to both producers and consumers.

The U.S. as the world's major food exporter has the most to gain from a complete knowledge of world food markets. It is hard to imagine the U.S. denying itself the improved market knowledge arising out of a capability to process to process TM data (1) of all the world's cropland in order to save the marginal cost of extra processing facilities. Indeed, after the Russian grain deal, the provision of sufficient data processing capability to process global TM data seems a foregone conclusion.

The capacity needed to process enough scenes to make global crop forecasts is not large. The global acreage devoted to grain

---

(1) The need for an improvement of Landsat spatial resolution to 40 meters (about that of the TM) has been noted by Nordbery, W, "Needs for Earth Observations from Space in the Past ERTS Era", paper presented to the AIAA meeting, Washington D.C. 25 February, 1975.

production is 700 million hectares, (1) or the coverage area of 264 scenes. Assuming that twice this number of scenes is required to compensate for non crop land included in the frames, 528 scenes every 18 days results in 30 scenes per day to be processed. (2)

The need for Landsat imagery for crop prediction may prove even more limited, with the estimates above being a peak load. The present Large Area Crop Inventory Estimation Experiment (LACIE) utilizes Landsat data to estimate crop acreage, which needs to be done only once per growing season, although several images over a period of time may be needed for this estimation. Crop yield estimation is obtained by applying the acreage data thus obtained into a yield model together with meteorological data obtained from other satellites and ground based sensors.

The technology and algorithms of crop area estimation are still in the experimental stages. The LACIE experiment is being conducted this summer (1975) and it is too early to predict the degree to which Landsat coverage over the growing season is necessary for crop inventory purposes. It is conceivable that establishing a global crop estimation capability will depend more on the use of TDRSS to relay the output of NOAA weather satellites back to the US than on the relay of Landsat data. The SAR data from SEASAT has

---

(1) The World Food Situation and Prospects to 1985, USDA Foreign Agricultural Economic Report No. 98, December 1974. This is equivalent to 2,640,000 square miles.

(2) These figures could be low, however, even an order of magnitude increase is within GSFC planned processing capability.

the potential of being very valuable for this purpose.

Another factor reducing somewhat the peak demand for Landsat data relay is the difference in growing seasons between the northern and southern hemispheres and, to a lesser extent, between different growing areas in each hemisphere.

4.2: The Case for Centralized Landsat Data Processing

The capabilities of TDRSS will permit the U.S.to gather data over the rest of the world while foreign earth stations will be restricted to an 1800 mile arc around their location. Given the discussion of the benefits of world wide crop forcasting mentioned above, this would give the US an undisputed advantage in marketing its crops were the US to manage its internal information flows to take advantage of it. This is in fact unlikely as a variety of domestic forces will probably result in worldwide crop predictions arising from the analysis of Landsat data being made publically available by the Department of Agriculture (with great prepublication secrecy) as at present. (1)

---

(1) An indication of the economic value of crop forecasts is given by the extraordinary security measures surrounding the release of USDA crop data. Employees preparing the final report are sequestered in a locked area under armed guard and permitted no contact whatever with anyone outside. Dissemination is accomplished by placing a copy of the forecast face down in phone booths in the press room; at an official's signal, reporters step across a line into the booths and gain access to the information.

Such a policy will help, but it is not likely to be enough to satisfy the rest of the world when the centralizing implications of TDRSS sink in on them. In a rational, apolitical world a strong case could be made for omitting a direct readout capability from Landsat D and relying on relay from the U.S. The reasons are:

(1) TDRSS has sufficient redundancy to guarantee relay of all Landsat data to the U.S. The U.S. need for worldwide crop predictions will ensure that TDRSS capability is maintained.

(2) The US will have the capability of processing the global output of Landsat-D into computer compatible tape form in quasi-real time (less than 24 hours) and the incremental cost of doing so will be very small. It could thus furnish other nations with CCT data, eliminating the need for expensive data processing facilities and earth stations overseas.

Data processing facilities are best and most economically bought, maintained and operated in the U.S. This, combined with some economies of scale for digital scene processing will make the cost of producing computer tapes at Goddard Space Flight Center much lower than at foreign centers, perhaps by as much as 5 to 1. (1)

---

(1) capacity (scenes/day)	25	250
System cost	$2.57M	$6.19M
Operation and Maintenance	$580K/yr	$880K/yr
Cost per scene	$108	$26

"Earth Resources Survey (ERS) Operational System Study", Final Report, Goddard Space Flight Center, September 1973, Table 5.80

U.S. studies of the economies of scale indicate savings of 80% for large processing installations. Higher processing costs abroad could magnify these savings.

(4) INTELSAT now has and will continue to have sufficient spare capacity on its TV transponders to relay all Landsat data overseas within 24 hours. As this capability is in place and is a sunk cost, the opportunity cost to the world community of using this capacity for Landsat relay approaches zero. The price at which this capability is made available is another question dealt with elsewhere in this study.

(5) The neccessity of improving their international communications facilities and the desire for live television coverage of certain events of international importance will push almost all of the world's countries to install standard INTELSAT earth stations by 1980. Many will have domestic satellite systems with a terminal colocated with the INTELSAT earth station providing the capability to deliver Landsat data to regional centers in quasi real time.

(6) Unless each nation installs its own Landsat station, quasi real time delivery of Landsat data will require satellite relay from the processing facility. As it is unlikely that regional facilities can be cost competitive with those in the U.S. and as satellite communications are distance insensitive, centralized distribution of data from the U.S. makes economic sense.

(7) Such a system will give all nations global Landsat coverage in quasi real time, something that cannot be achieved by regional stations without a data relay system which will probably cost as least as much as that required for centralized distribution.

(8) In addition, the data stream carrying Landsat data will be capable of having low data rate streams from other NASA satellites multiplexed into it at marginal cost, eliminating the need for separate delevery systems.

However, national concerns of other countries make such a rational, centralized system unattractive. Pride is not the only consideration. Insecurity about the U.S. guarantee of making sensitive crop information universally available to all at the same time is another. Also there might be concern at the price a U.S. monopoly might charge for the data.

The savings in earth station and data processing costs that accrue to foreign users as a result of centralized distribution should be sufficiently large to allow NASA to institute user charges for the data that are high enough to make a significant contribution to the US balance of payments. To this should be added the US satellite carriers charges, borne by overseas users, for transmission to the INTELSAT satellites.

For all these reasons foreign nations are likely to be concerned about TDRSS implications unless a readout capability to regional ground stations is provided. The alternative that may be proposed is to turn the whole operation over to an international organization. Given the complications and time delays introduced by such an arrangement, it seems eminently worthwile to provide direct readout instead. Cost considerations make it unlikely that many countries would take advantage of that readout, but even if only a couple did, the political suspicions a monopoly would create would be set at rest.

The discussion above has ignored that part of the earth's crust within the shadow zone where TDRSS relay capability does not exist. For this area, absent a direct readout capability, Landsat coverage would be impossible to obtain without spacecraft tape recorders. As a gap in coverage seems undesirable for both political and crop forecast reasons, a third TDRS would appear to be the answer. This possibility is currently being considered by ESRO which would undertake to sponsor such a satellite, relaying the data onwards via INTELSAT.

C.2