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ABSTRACT

Given the focus on global change and the attendant scope of such research, we anticipate significant growth of requirements for investigator interaction, processing system capabilities, and availability of data sets. The increased complexity of global processes requires interdisciplinary teams to address them; the investigators will need to interact on a regular basis; however, it is unlikely that a single institution will house sufficient investigators with the required breadth of skills. The complexity of the computations may also require resources beyond those located within a single institution; this lack of sufficient computational resources leads to a distributed system located at geographically dispersed institutions. Finally the combination of long term data sets like the Pathfinder datasets and the data to be gathered by new generations of satellites such as SeaWIFS and MODIS-N yield extra-ordinarily large amounts of data. All of these factors combine to increase demands on the communications facilities available; the demands are generating requirements for highly flexible, high capacity networks. We have been examining the applicability of the Advanced Communications Technology Satellite [ACTS] to address the scientific, computational, and, primarily, communications questions resulting from global change research. As part of this effort, three scenarios for oceanographic use of ACTS have been developed; a full discussion of this is contained in Appendix B.

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Discussion

Many people, both scientists and laymen, are realizing the complex nature of our ecosystems and their interactions with the changes being wrought by man. As the need for comprehensive information concerning the nature of Earth's environment grows, the more important the overall, end-to-end system of remote sensing and analysis becomes. This system encompasses many facets: collection, processing, analysis, and distribution. To be useful each facet of the system must be capable of handling its share of the load.

The next few years will see an explosion in the amount of data required for addressing problems in the Earth sciences. Driven in part by serious concerns about future climate change, and in part by the development of satellite and ground/sea based sensors capable of a high degree of spatial and temporal resolution, it will result in an unprecedented volume of data available to the global scientific and operational community. With the current generation of sensors, large data sets, well over 100 gigabytes a day per satellite, are generated on a regular basis. As the Earth Observing System [EOS] experiments are activated, the data collection will grow to the order of terabits per day.

As mentioned, the data streams being acquired are large and will grow substantially larger during this decade. Data must be processed to a known, usable state prior to analysis. This data will have to be examined against the framework of existing satellite and terrestrial datasets. The archived data sets, such as AVHRR, are being reprocessed to create a baseline to track whatever processes are being measured. Efforts, such as the NOAA/NASA AVHRR Pathfinder Project, are under way to establish multiple years of background data to create archived, long term data sets. Further, additional data is available from terrestrial platforms, such as buoys, which must be acquired and merged into the data sets to produce integrated products.

The processing requirements to support these efforts strain the computational resources of most institutions today and the additional demands of the newer satellites may well swamp them. Processing the data has gotten to the point that distributed systems involving multiple institutions may offer the solutions to what may become intractable resource requirements.

Once the initial processing of the data has been completed, it must be distributed to a geographically dispersed scientific/user community. The investigators will be collaborating in additional processing and the analysis of the data. These individuals will need access to each other through existing methods such as e-mail and telephone; in addition, there is likely to emerge requirements for teleconferencing to supplement standard contacts. The growth of these contacts will continue the pressure to provide higher bandwidth paths between the researchers.

After the analysis of the data has been completed, it must be made available to the general user community. It is at this juncture that the data can be integrated into large scale multi-disciplinary studies of the earth's ecosystems, global research. The timely analysis and distribution of these data poses a problem. To be useful for operational purposes, say for weather or sea-state forecasting, data from satellite platforms and from remote data collection platforms must be transmitted to processing and analysis centers, and the processed and/or blended products must be broadcast to a client community that is geographically dispersed. Current communications networks will be insufficient to meet the need.

In particular, one of the key problems in Earth science research using data from ground, sea and space-based sensors is in the distribution of that data to qualified researchers. The ability to establish an Earth sciences distributed data network, including distributed collection, analysis and archive, has been a chief goal of NASA's Earth Observation Program. The EOS Data and Information System (EOSDIS) plans to acquire terabits of data per day over the proposed 15 year lifetime of the mission. The current policy leans toward a distributed data system; different data sets will be processed and archived at a number of sites throughout the U.S. Archived data sets will include data from the EOS sensors, as well as data from other sensors such as the Earthprobes line, and *in situ* data. Much of the data will be assimilated into numerical models of the Earth processes; this model output, which could dwarf the sensor measurements, will also require archive and distribution. Current EOS policy specifies that data is to be available to all researchers globally for research applications. Clearly, the communications network must be a high priority.

The result of these efforts is to produce extremely large, if not unprecedented, volumes of data to collect, process, and analyze within a geographically dispersed environment. Although terrestrial networks can provide the necessary bandwidth to support these functions, they must be available and have been installed to perform the functions. There are areas where high bandwidth support is difficult or extremely expensive to obtain. The fixed nature of terrestrial facilities can further inhibit either mobile labs or quick addition of a facility to such an integrated environment.

The Advanced Communications Technology Satellite (ACTS) has several unique features that make it ideal for addressing these communications problems in the Earth sciences. The multibeam communications package, with both fixed and hopping beams, will permit high rates of data exchange between clients in major research centers in the continental United States and would easily allow the development of a distributed data analysis, processing and archival system. For remote data collection platforms, such as untended buoys adrift at sea, or remote untended atmospheric chemistry monitoring stations, the mechanically steerable antenna can provide coverage to any location in the viewed hemisphere. Finally, the possibility exists to use the ACTS as an inter-orbit link between low-earth orbiting satellites and central data facilities.

In this study we have evaluated the commercial and research use of ACTS for: a1) transmission of data from remote data collection platforms, such as untended buoys, to data processing and analysis facilities, a2) transmission of data from remote Earth stations receiving direct broadcast data from Earth observing satellites to central processing and analysis centers, b) direct transmittal of data from Earth observing polar-orbiting satellites via inter-orbit link to processing and analysis centers, and c) the use of multi-point broadcast of reduced data from central data processing and analysis environments to distributed client networks. These uses are discussed at length in Appendix B.

Achievement of Objectives

We have utilized the strengths of ongoing programs and existing resources to accomplish the following objectives. First, a test program was established which consisted of repeated transmission of 100 Mbyte files via Internet between Miami and Dalhousie to simulate the size of a typical AVHRR pass. The limiting factor was found to be the link within Canada that had a nominal bandwidth of 56 Kbps. In practice, the link was much worse and varied from less than 9600 bps to occasionally as much as 32 Kbps. Second, an HRPT/AVHRR receiving station was implemented in Halifax. Raw data from the AVHRR was received in Halifax, Nova Scotia, and transmitted to University of Miami over land-lines (Internet) where it was blended with data collected by a receiving station at the University of Miami. Processed products based on the AVHRR data was then transmitted from Miami to potential users at Goddard Space Flight Center, the University of Rhode Island and Halifax, again via land lines. The capability of the T1 links within the U.S. accommodated this well; the lesser bandwidth to Dalhousie was limiting. Finally, we have evaluated the opportunities and implementation steps necessary for operational use of ACTS for remote data collection and distribution.

At present, full-resolution data collection from remote sensing satellites such as the AVHRR is carried out by tracking Earth stations that access these satellites for the comparatively brief period that they are in the field of view of the Earth station. Tape recording capabilities onboard the spacecraft are limited; typically, only a reduced subset of the data collected is able to be stored onboard that effectively limits the spatial resolution available over large geographical regions. This practice of direct transmission during time of satellite overpass is expected to continue with the Earth Observing System (EOS).

For coastal regions of the world's oceans and perhaps in the open sea, significant variability exists in the ocean sea-surface temperature field at scales smaller than those resolved by the data taped and stored onboard the spacecraft. Examples include frontal instabilities, small scale coastal currents associated with wind events, and topographically controlled features. For a rigorous analysis of the role of the ocean in global heat and carbon cycles, it is imperative that these small scales are resolved, at least for the global coastal regions.

At the present time, there are approximately 25 stations world-wide capable of receiving the real-time L-band transmission from the TIROS-N series of NOAA meteorological satellites and which are in use for oceanographic research. NASA at present makes use of data collected at the Scripps Satellite Facility in San Diego, the Gilmore Creek station in Alaska, and the Wallops station on the east coast, and small stations at the Universities of Louisiana and British Columbia. Data processing, analysis and archival are unique to each station, although the University of Miami currently logs both the Wallops and Gilmore Creek stations as they are retransmitted on DOMSAT. Future stations are planned for the Monterey Bay area associated with the Naval Postgraduate School, the University of Hawaii, and Halifax, Nova Scotia. Typical volumes of raw telemetry data collected are of the order 400 MBytes per day per station.

In addition to the data collected by the satellite receiving stations, remote fixed and drifting buoys currently collect data on a variety of oceanographic processes which influence sea-surface temperature. They are also useful in the ongoing calibration effort for the satellite. These remote data collection platforms, which could in principle generate several megabits per day apiece and for which the World Ocean Circulation Experiment plans several thousand, are currently severely limited by dependence on the data rates supported by the ARGOS telemetry system.

There is a need to collect these data in a central facility, from both satellite and remote data collection platforms, and to process, analyze and archive them within a consistent framework. Although this discussion has focused primarily on sea-surface temperature, analogous situations exist with respect to other ocean, terrestrial and atmospheric data. Finally, processed data is required to be distributed in near real-time to end-users who are geographically dispersed, and often in areas not serviced by other terrestrial communications channels. For example, it is often essential to transmit images of the sea-surface temperature field to ships at sea in near real-time in support of operations.

The technology embodied in ACTS provides an ideal solution to these communications problems. Data collected by remote direct downlinks from Earth observing satellites can be uplinked to ACTS and transmitted to a central processing and analysis center where it could be blended and calibrated against buoy data also transmitted over ACTS. Processed data, in the form of, for example, images of the ocean temperature field, could be broadcast to a range of users using the point to multi-point capability. We anticipate that this study will form the basis for a distributed array of direct reception stations that could funnel their data through ACTS to a central analysis facility where data could be processed and distributed, again through ACTS, to a network of end users.

Third, use of ACTS for the provision of high speed data communications to mobile platforms (including remote data buoys and ships) will require antenna systems on the platforms that will track the satellite while the platform is in motion and which will function in the often harsh marine environment. Antenna systems that will accomplish this task may be divided into two categories: 1) fixed geometry-mechanically steered, and 2) fixed geometry-electronically steered. The first category will contain such systems as gimbaled prime and offset reflectors under servo control. The advantages of the electronically steered phased array are: 2) there is a well-developed science concerning the design of phased arrays that will provide superior performance; this science has been exploited extensively in the radar industry, and 2) there are no moving parts. Here we have evaluated to first order the requirements for an electronically steered phased array antenna for ACTS based on an L-band analog. The disadvantage associated with the implementation of electronically steerable phased arrays at Ka-band is the slow development of the various microwave components required to implement such systems and insufficient information concerning the propagation through the marine atmosphere. Conceptual design work has been carried out for electronically steered phased array antenna systems, however lack of funding by Canadian sources inhibited the propagation work.

Summary

In this collaborative study, we have developed and evaluated the necessary conceptual design and implementation strategy for the use of the Advanced Communications Technology Satellite (ACTS) for serving a distributed data collection and client base in the Earth sciences. The focus is on the oceanographic sciences; however, we recognize that our conclusions will encompass the entire range of Earth sciences.

We have established a test-bed system using the NOAA-AVHRR satellite and currently existing land-lines. Raw data from the AVHRR was received in Halifax, Nova Scotia, and transmitted to University of Miami over Internet where it was blended with data collected by a receiving station at University of Miami. The processed product, an image of sea-surface temperature extending from the coats of Brazil to the Labrador Sea, was subsequently produced. Imagery produced and processed by the University of Miami was broadcast in a multicast mode to users at the University of Rhode Island, the Goddard Space Flight Center, and Dalhousie University.

We have evaluated the operational use of ACTS for a) transmission of data from remote data collection platforms, such as untended buoys, to data processing and analysis facilities, b) transmission of data from remote Earth stations receiving direct broadcast data from Earth observing satellites to central processing polar-orbiting satellites to central processing and analysis centers, c) direct transmittal of data via inter-orbit links from Earth observing polar-orbiting satellites to processing and analysis centers, and d) the use of multi-point broadcast of reduced data from central data processing and analysis environments to distributed client networks.

Finally, we have evaluated the opportunities and implementation steps necessary for operational use of ACTS for remote data collection and distribution.

Appendix A: Sample File Transfer Times

The transfer times presented in A.2 and A.3 have been excerpted from longer lists; sample means and standard deviations calculated from these tables may differ slightly from those calculated using the full data set collected. The complete data set is available upon request.

A.1.1 DECnet Transfer Times: Mean and Standard Deviation

$$\bar{x}_{DECnet} = 2516.971 \text{ sec/transfer}$$

$$s_{DECnet} = 850.661 \text{ sec/transfer}$$

A.1.2 FTP Transfer Times: Mean and Standard Deviation

$$\bar{x}_{FTP} = 1570.345 \text{ sec/transfer}$$

$$s_{FTP} = 267.440 \text{ sec/transfer}$$

A.2 DECnet File Transfer Times

Start time = 7-NOV-1992 16:13:08.09	Elapsed time = 0 00:42:38.70
Start time = 7-NOV-1992 15:04:03.42	Elapsed time = 0 00:34:02.36
Start time = 7-NOV-1992 14:03:52.68	Elapsed time = 0 00:34:00.94
Start time = 7-NOV-1992 13:07:11.27	Elapsed time = 0 00:33:18.86
Start time = 7-NOV-1992 12:10:49.43	Elapsed time = 0 00:30:21.46
Start time = 7-NOV-1992 11:13:43.06	Elapsed time = 0 00:32:27.32
Start time = 7-NOV-1992 10:11:45.53	Elapsed time = 0 00:36:02.83
Start time = 7-NOV-1992 09:14:00.95	Elapsed time = 0 00:32:28.47
Start time = 7-NOV-1992 08:10:17.59	Elapsed time = 0 00:37:21.42
Start time = 7-NOV-1992 06:57:49.55	Elapsed time = 0 00:45:39.55
Start time = 7-NOV-1992 05:55:25.98	Elapsed time = 0 00:36:29.03
Start time = 7-NOV-1992 04:51:36.27	Elapsed time = 0 00:37:58.21
Start time = 7-NOV-1992 03:43:34.13	Elapsed time = 0 00:40:06.50
Start time = 7-NOV-1992 02:40:44.47	Elapsed time = 0 00:35:53.53
Start time = 7-NOV-1992 01:37:21.55	Elapsed time = 0 00:35:22.72
Start time = 7-NOV-1992 00:23:14.18	Elapsed time = 0 00:44:47.30
Start time = 6-NOV-1992 23:18:07.53	Elapsed time = 0 00:37:30.05
Start time = 6-NOV-1992 21:56:09.53	Elapsed time = 0 00:51:53.93
Start time = 6-NOV-1992 20:24:41.04	Elapsed time = 0 00:55:38.25

Start time = 6-NOV-1992 17:07:45.83 Elapsed time = 0 02:42:10.51
Start time = 6-NOV-1992 15:55:17.89 Elapsed time = 0 00:41:39.70
Start time = 6-NOV-1992 14:35:53.47 Elapsed time = 0 00:49:58.60
Start time = 6-NOV-1992 13:26:20.97 Elapsed time = 0 00:38:17.50
Start time = 6-NOV-1992 12:24:07.12 Elapsed time = 0 00:33:06.31
Start time = 6-NOV-1992 11:21:55.65 Elapsed time = 0 00:36:12.59
Start time = 6-NOV-1992 10:20:35.96 Elapsed time = 0 00:34:45.60
Start time = 6-NOV-1992 09:26:15.99 Elapsed time = 0 00:29:27.55
Start time = 6-NOV-1992 08:30:21.45 Elapsed time = 0 00:30:15.26
Start time = 6-NOV-1992 07:31:27.67 Elapsed time = 0 00:34:33.29
Start time = 6-NOV-1992 06:34:45.76 Elapsed time = 0 00:32:44.92
Start time = 6-NOV-1992 05:38:38.00 Elapsed time = 0 00:32:39.10
Start time = 6-NOV-1992 04:36:37.11 Elapsed time = 0 00:38:18.45
Start time = 6-NOV-1992 03:30:58.02 Elapsed time = 0 00:39:29.44
Start time = 6-NOV-1992 01:55:38.13 Elapsed time = 0 01:07:46.23
Start time = 6-NOV-1992 00:21:26.20 Elapsed time = 0 01:05:49.51
Start time = 5-NOV-1992 22:55:22.55 Elapsed time = 0 00:45:06.67
Start time = 5-NOV-1992 21:37:06.56 Elapsed time = 0 00:47:55.97
Start time = 5-NOV-1992 20:19:37.79 Elapsed time = 0 00:45:06.86
Start time = 5-NOV-1992 18:53:24.95 Elapsed time = 0 00:57:05.78
Start time = 5-NOV-1992 16:49:42.01 Elapsed time = 0 00:53:28.41
Start time = 5-NOV-1992 15:28:15.83 Elapsed time = 0 00:46:08.80
Start time = 5-NOV-1992 13:11:53.16 Elapsed time = 0 00:34:00.00
Start time = 5-NOV-1992 12:13:45.69 Elapsed time = 0 00:30:01.13
Start time = 5-NOV-1992 11:08:43.90 Elapsed time = 0 00:39:24.32
Start time = 5-NOV-1992 10:05:24.76 Elapsed time = 0 00:35:52.46
Start time = 5-NOV-1992 09:07:26.78 Elapsed time = 0 00:32:22.55
Start time = 5-NOV-1992 08:08:06.75 Elapsed time = 0 00:33:52.87
Start time = 5-NOV-1992 07:09:05.93 Elapsed time = 0 00:34:26.20
Start time = 5-NOV-1992 06:08:16.18 Elapsed time = 0 00:36:20.55
Start time = 5-NOV-1992 04:59:36.16 Elapsed time = 0 00:41:16.99
Start time = 5-NOV-1992 03:48:22.00 Elapsed time = 0 00:43:08.23
Start time = 5-NOV-1992 02:42:31.22 Elapsed time = 0 00:38:23.07
Start time = 5-NOV-1992 01:33:46.02 Elapsed time = 0 00:41:16.68
Start time = 5-NOV-1992 00:23:11.36 Elapsed time = 0 00:43:21.99
Start time = 4-NOV-1992 22:43:57.42 Elapsed time = 0 01:11:01.09
Start time = 4-NOV-1992 21:28:23.72 Elapsed time = 0 00:39:46.19
Start time = 4-NOV-1992 20:11:46.16 Elapsed time = 0 00:39:53.08
Start time = 4-NOV-1992 18:52:40.13 Elapsed time = 0 00:49:00.49
Start time = 4-NOV-1992 17:30:41.94 Elapsed time = 0 00:48:20.34
Start time = 4-NOV-1992 16:10:02.04 Elapsed time = 0 00:48:01.68

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A.3 FTP File Transfer Times

Start time = 7-NOV-1992 15:38:25.36	Elapsed time = 0 00:34:23.33
Start time = 7-NOV-1992 14:38:10.22	Elapsed time = 0 00:25:41.94
Start time = 7-NOV-1992 13:40:47.16	Elapsed time = 0 00:22:54.18
Start time = 7-NOV-1992 12:41:28.59	Elapsed time = 0 00:25:31.73
Start time = 7-NOV-1992 11:46:29.09	Elapsed time = 0 00:24:09.68
Start time = 7-NOV-1992 10:48:05.49	Elapsed time = 0 00:25:26.42
Start time = 7-NOV-1992 09:46:46.63	Elapsed time = 0 00:24:34.11
Start time = 7-NOV-1992 08:47:56.52	Elapsed time = 0 00:25:53.63
Start time = 7-NOV-1992 07:43:46.53	Elapsed time = 0 00:26:19.78
Start time = 7-NOV-1992 06:32:13.51	Elapsed time = 0 00:25:24.97
Start time = 7-NOV-1992 05:29:58.99	Elapsed time = 0 00:25:15.78
Start time = 7-NOV-1992 04:24:06.03	Elapsed time = 0 00:27:16.02
Start time = 7-NOV-1992 03:17:01.92	Elapsed time = 0 00:26:16.72
Start time = 7-NOV-1992 02:13:22.45	Elapsed time = 0 00:27:10.50
Start time = 7-NOV-1992 01:08:29.98	Elapsed time = 0 00:28:34.80
Start time = 6-NOV-1992 23:56:01.97	Elapsed time = 0 00:26:57.22
Start time = 6-NOV-1992 22:48:23.68	Elapsed time = 0 00:29:30.62
Start time = 6-NOV-1992 21:20:37.52	Elapsed time = 0 00:35:05.66
Start time = 6-NOV-1992 19:52:52.28	Elapsed time = 0 00:31:25.04
Start time = 6-NOV-1992 16:37:21.70	Elapsed time = 0 00:29:56.63
Start time = 6-NOV-1992 15:26:10.75	Elapsed time = 0 00:28:53.58
Start time = 6-NOV-1992 14:04:56.93	Elapsed time = 0 00:30:35.50
Start time = 6-NOV-1992 12:57:30.54	Elapsed time = 0 00:28:39.56
Start time = 6-NOV-1992 11:58:25.53	Elapsed time = 0 00:25:31.22
Start time = 6-NOV-1992 10:55:38.68	Elapsed time = 0 00:26:06.03
Start time = 6-NOV-1992 09:55:54.41	Elapsed time = 0 00:24:30.37
Start time = 6-NOV-1992 09:00:54.92	Elapsed time = 0 00:25:10.44
Start time = 6-NOV-1992 08:06:18.29	Elapsed time = 0 00:23:52.73
Start time = 6-NOV-1992 07:07:47.84	Elapsed time = 0 00:23:29.21
Start time = 6-NOV-1992 06:11:34.10	Elapsed time = 0 00:23:00.91
Start time = 6-NOV-1992 05:15:18.42	Elapsed time = 0 00:23:08.88
Start time = 6-NOV-1992 04:10:56.45	Elapsed time = 0 00:25:23.51
Start time = 6-NOV-1992 03:03:43.80	Elapsed time = 0 00:27:00.46
Start time = 6-NOV-1992 01:27:40.95	Elapsed time = 0 00:27:41.04
Start time = 5-NOV-1992 23:40:48.18	Elapsed time = 0 00:40:12.54
Start time = 5-NOV-1992 22:25:21.57	Elapsed time = 0 00:29:46.85
Start time = 5-NOV-1992 21:07:28.22	Elapsed time = 0 00:29:16.41
Start time = 5-NOV-1992 19:50:49.81	Elapsed time = 0 00:28:35.05
Start time = 5-NOV-1992 18:17:24.00	Elapsed time = 0 00:35:41.77
Start time = 5-NOV-1992 17:43:30.53	Elapsed time = 0 00:28:56.33
Start time = 5-NOV-1992 16:14:45.71	Elapsed time = 0 00:33:21.34

Start time = 5-NOV-1992 14:55:25.19 Elapsed time = 0 00:32:31.39
Start time = 5-NOV-1992 13:46:10.22 Elapsed time = 0 00:31:46.05
Start time = 5-NOV-1992 12:44:04.60 Elapsed time = 0 00:27:37.39
Start time = 5-NOV-1992 11:48:25.21 Elapsed time = 0 00:25:09.81
Start time = 5-NOV-1992 10:41:33.82 Elapsed time = 0 00:26:58.26
Start time = 5-NOV-1992 09:40:06.31 Elapsed time = 0 00:24:56.99
Start time = 5-NOV-1992 08:42:16.86 Elapsed time = 0 00:24:58.14
Start time = 5-NOV-1992 07:43:49.60 Elapsed time = 0 00:24:03.61
Start time = 5-NOV-1992 06:44:53.86 Elapsed time = 0 00:24:00.91
Start time = 5-NOV-1992 05:41:10.41 Elapsed time = 0 00:26:54.78
Start time = 5-NOV-1992 04:31:47.34 Elapsed time = 0 00:27:38.11
Start time = 5-NOV-1992 03:21:13.00 Elapsed time = 0 00:26:55.92
Start time = 5-NOV-1992 02:15:22.48 Elapsed time = 0 00:26:55.45
Start time = 5-NOV-1992 01:06:52.34 Elapsed time = 0 00:26:41.24
Start time = 4-NOV-1992 23:55:15.91 Elapsed time = 0 00:27:44.60
Start time = 4-NOV-1992 22:08:46.03 Elapsed time = 0 00:34:45.72
Start time = 4-NOV-1992 20:51:56.29 Elapsed time = 0 00:36:04.85
Start time = 4-NOV-1992 19:41:57.60 Elapsed time = 0 00:29:34.40
Start time = 4-NOV-1992 18:19:20.17 Elapsed time = 0 00:30:54.93
Start time = 4-NOV-1992 16:58:22.29 Elapsed time = 0 00:31:57.71
Start time = 4-NOV-1992 15:36:02.19 Elapsed time = 0 00:33:33.82
Start time = 4-NOV-1992 14:18:37.77 Elapsed time = 0 00:31:48.52
Start time = 4-NOV-1992 13:07:01.21 Elapsed time = 0 00:28:20.85
Start time = 4-NOV-1992 12:07:42.88 Elapsed time = 0 00:24:19.46
Start time = 4-NOV-1992 11:03:07.44 Elapsed time = 0 00:25:54.87
Start time = 4-NOV-1992 09:54:32.51 Elapsed time = 0 00:29:20.16
Start time = 4-NOV-1992 08:47:26.62 Elapsed time = 0 00:28:08.22
Start time = 4-NOV-1992 07:40:51.48 Elapsed time = 0 00:27:57.10
Start time = 4-NOV-1992 06:38:58.56 Elapsed time = 0 00:26:53.76
Start time = 4-NOV-1992 05:43:10.86 Elapsed time = 0 00:24:46.69
Start time = 4-NOV-1992 04:45:02.09 Elapsed time = 0 00:24:19.11
Start time = 4-NOV-1992 03:46:47.68 Elapsed time = 0 00:23:32.80
Start time = 4-NOV-1992 02:42:02.05 Elapsed time = 0 00:28:17.74
Start time = 4-NOV-1992 01:41:04.62 Elapsed time = 0 00:26:34.27
Start time = 4-NOV-1992 00:28:49.66 Elapsed time = 0 00:28:14.22
Start time = 3-NOV-1992 23:21:57.33 Elapsed time = 0 00:26:10.34
Start time = 3-NOV-1992 21:49:23.72 Elapsed time = 0 00:29:36.75
Start time = 3-NOV-1992 20:31:22.58 Elapsed time = 0 00:32:24.60
Start time = 3-NOV-1992 18:39:58.75 Elapsed time = 0 00:38:07.84
Start time = 3-NOV-1992 17:01:16.05 Elapsed time = 0 00:36:45.99
Start time = 3-NOV-1992 15:10:11.44 Elapsed time = 0 00:29:54.55

A.4 Transfer Routines

A.4.1 DECnet Routine

```
$ set noon
$ set noverify
$
$ file = f$search ("dua0:[jim]*.n11")
$ if file.eqs."" thenE xit
$ name = f$parse(file,,,"name")
$ type = f$parse(file,,,"type")
$ alq = f$file(file,"alq")
$E of = f$file(file,"eof")
$ write sys$output "Working on ''file' (''name'''type') ''eof'/''alq'" $
$ do_decnet:
$ if f$search("savaii::dra2:[avhrr]"+name+type+"-decnet;0").nes."" then -
      delete/log savaii::dra2:[avhrr]'name''type'-decnet;*
$ start = f$time()
$ write sys$output "Start(Decnet): ''start' size ''eof'/''alq'"
$ copy 'file' savaii::dra2:[avhrr]'name''type'-decnet/log
$ seve = $severity
$ stop  = f$time()
$ write sys$output "Stop(Decnet):  ''stop'"
$ delete/log savaii::dra2:[avhrr]'name''type'-decnet;*
$
$ if seve.ne.1 then goto copy_failed
$ open/write/err=e1 lun savaii::dra2:[avhrr]'name'.log-
decnet $ write lun "Start: ''start' size ''eof'/''alq'"
$ write lun "Stop:  ''stop'"
$ close lun
$ goto copy_ok
$ copy_failed:
$ open/write/err=e1 lun savaii::dra2:[avhrr]'name'.log-decnet-failed
$ write lun "Start: ''start' size ''eof'/''alq'"
$ close lun
$ copy_ok:
$E 1:
$
$ proc = f$envir("procedure")
$ proc = proc -
f$parse(proc,,,"version") $ name =
f$parse(proc,,,"name")
```

```
$ purge/keep=5 sys$login:'name'.log
$!submit /que=slow$batch_miami
'proc'
$ pdir = f$parse(proc,,,"device")+f$parse(proc,,,"directory") $
submit /que=slow$batch_miami 'pdir'send-gene-ftp.vms
$E xit
```

A.4.2 FTP Routine

```
$ set noon
$ set noverify
$
$ file = f$search ("dua0:[jim]*.n11")
$ if file.eqs."" thenE xit
$ name = f$parse(file,,,"name")
$ type = f$parse(file,,,"type")
$ alq = f$file(file,"alq")
$E of = f$file(file,"eof")
$ write sys$output "Working on "file' ("name"'type') "eof'/'alq'" $
$ do_ftp:
$ if f$search("savaii::dra2:[avhrr]"+name+type+"-ftp;0").nes."" then -
      delete/log savaii::dra2:[avhrr]'name''type'-ftp;*
$ kTemp = "ktemp.tmp"
$ FTP_Host = "savaii.gsfc.nasa.gov"
$ FTP_UserName = "jim"
$ FTP_Password = "xxxxxxxx"
$ localname = name + type + "-ftp"
$    open/write kFd 'kTemp'
$    write kFd "$ ftp /struct=file /type=image /user=", -
            FTP_UserName, " /pass=", FTP_Password, " ",
FTP_Host $!!write kFd "hash"
$    write kFd "cd dra2:[avhrr]"
$    write kFd "put ", file, " ", localName
$    close kFd
$    set prot=(gr,wo) ktemp.*;*
$! sndmsg -s"'kTemp'" jim <'kTemp'
$ start = f$time()
$ write sys$output "Start(Ftp): "start' size "eof'/'alq'" $
      @'kTemp'
$ stop  = f$time()
$ write sys$output "Stop(Ftp):  "stop'"
$       delete 'kTemp'.*
$ delete/log savaii::dra2:[avhrr]'name''type'-ftp;*
```

```
$
$ open/write/err=e2 lun savaii::dra2:[avhrr]'name'.log-ftp $
write lun "Start: "start'  size "eof'/"alq'"
$ write lun "Stop:  "stop'"
$ close lun
$E 2:
$
$ proc = f$envir("procedure")
$ proc = proc - f$parse(proc,,,"version")
$ name = f$parse(proc,,,"name")
$ purge/keep=5 sys$login:'name'.log
$!submit /que=slow$batch_miami 'proc'
$ pdir = f$parse(proc,,,"device")+f$parse(proc,,,"directory") $
submit /que=slow$batch_miami 'pdir'send-gene-
decnet.vms
$E xit
```

Appendix B: Discussion of NASA ACTS Satellite Earth Observation Experiments

NASA ACTS
SATELLITE EARTH OBSERVATIONS EXPERIMENT CONCEPTS

TABLE OF CONTENTS

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NASA ACTS
SATELLITE REMOTE SENSING EXPERIMENT CONCEPTS

1.0 OVERVIEW

The purpose of this study is to outline three remote sensing based experiment concepts designed to utilize NASA's Advance Communications Technology Satellite (ACTS) to the benefit of the earth observations community. In particular, emphasis will be placed, where possible, on experiments which could show the utility of an operational ACTS-type spacecraft during the EOS era.

There are three primary remote sensing data communications "problems" which can be potentially solved using the ACTS satellite. These include multi-point to point remote data collection from autonomous data collection platforms (drifting sea buoys or land-based data collection platforms) and remote sensing satellite ground data reception stations; inter-orbit satellite data communications links from future remote sensing satellites to centralized ground facilities--in particular the collection of global data sets using ACTS or and ACTS-type satellite as a commercial data relay satellite in place of, or complementing, on-board storage devices; and point to multi-point data distribution networks for derived information products from commercial and government remote sensing systems.

This study, and the subsequent experiment concepts, are focused on the oceans aspects of earth observations missions. This focus stems from our long-term participation in these programs and the relatively well defined requirements of the oceans community. Two data sets in particular, the Pathfinder data set from the Advanced Very High Resolution Radiometer (AVHRR) sensor and the Ocean Color data set from the Sea-WiFS sensor, will serve as testbeds for ACTS experiments. These two data sets will be available during the ACTS time frame and could serve as prototypes for an Earth Observing System network which would operate with an operational ACTS type satellite.

Generally the focal points of the experiment concepts are the University of Miami, Dalhousie University and Oregon State University, all of whom were participants in the first NASA NRA.

2.0 REMOTE DATA COLLECTION

An important component of any earth observation program is the collection of "ground or ocean truth" measurements which are used in conjunction with space-based measurements to model earth and ocean processes. These ground or ocean truth measurements are collected by individuals using monitoring equipment or through automated remote data collection platforms. These measurements are then correlated and/or combined with space-based observations in order to better interpret those observations and to use them not only for retrospective analysis but also for predictive modelling. Because the focus of this study is on the ocean environment, the remainder of this section focuses on the requirements of the ocean science community.

2.1 User Requirements

The oceans play a large role in moderating both short-term weather and global climate. At present, the oceans are severely undersampled compared to the network of atmospheric measurements that currently are assimilated into both short and medium term weather forecasts and global climate models. This significantly reduces the confidence levels in the predictions; to alleviate this, the global ocean community has ambitious plans to populate the world's oceans with remote oceanographic and meteorological buoys which would make required observations and transmit them in near to real time to the users. Increasingly, new sensors are being developed which can be deployed on autonomous buoys which can also provide ground truth for satellite missions over inhospitable regions of the world's oceans. Additionally, the oceans community will continue to take advantage of satellite remote sensing ground stations which collect oceans data from satellite. These two sources of data will be essential to ocean science and our understanding of the Earth in the coming decades.

2.2 Data Requirements

This section looks at the data requirements of the two remote data collection activities--remote data collection platforms/buoys and remote satellite ground data reception stations.

2.2.1 Remote Data Collection Platforms/Autonomous Buoys

The technology to develop new remote buoys and their associated sensors, and to deploy them for operational lifetimes in excess of one year, has outstripped the currently available data transmission bandwidth. This represents the single largest constraint to increased use of these low-cost ocean observing systems. The CLS/ARGOS system, which has transponders aboard the NOAA polar-orbiting meteorological satellites, is the most commonly used transmission path. The data rate is extremely small (256 bit transmissions), temporal coverage of the globe is restricted to the small number of satellite transceivers (the number of opportunities to transmit data per day nominally ranges from 7 at the equator to 16 at 55 degrees latitude), the communications channel is one-way only (which results in the necessity for continuous transmission in the hope that a satellite is within field of view, a situation which degrades the operational lifetime of the buoys because of battery drawdown), and data must be relayed through France for data collection and position location.

The current "market" for ARGOS services involves approximately 1500 active data collection platforms with an average of some 130,000 messages per day, or approximately 85 messages per platform per day (platforms may send more than one 256 kbit message during each view of the satellite). Given that the maximum length of any ARGOS message is 256 bits, an average total of approximately 22 kbits per day is sent from a remote buoy through the ARGOS system, or a total of 32.6 megabits of data for all 1500 users. The cost of ARGOS ground systems hardware, as well as transmission costs and system constraints, discourage more widespread use of the system.

As an example of the type of application for which ACTS could be used, the World Ocean Circulation Experiment plans deployment of some 500 buoys at any given time; this is in addition to current meteorological buoys (say 50) and buoys developed for other special purposes by civilian and defense interests (say 100). For the purpose of sizing the system, one could assume that each buoy logged hourly averages and three associated statistics for each of 15 channels of data at 12 bits; the total data volume would then be approximately 20 kbits per platform per day. Some buoys would require much higher data volumes, others significantly less. Based on past experience, it is likely that the data rate would grow if more bandwidth were available since this is the current limiting factor. For WOCE buoys then, under the above assumptions, the total data volume would be 13 Mbits per day.

The implementation of a remote data collection platform network using ACTS will require the establishment of a low speed data communications network utilizing the ACTS USAT terminal interfaced to a central data collection and processing facility.

2.2.2 Remote Sensing Ground Stations

For many of the current and planned Earth Observation missions, data is continuously broadcast to receiving stations in the field of view of the satellite. This is advantegous, even if storage capability is available onboard the spacecraft: it is available in real-time for the local area of interest, it permits a higher spatial resolution to be achieved because of the necessity to reduce spatial resolution for onboard storage, and in many cases, the data are inexpensively acquired. For example, the current NOAA polar-orbiting meteorological satellites operate in a Global Area Coverage (GAC) mode for onboard recording.

This GAC coverage is at a spatial resolution of only 4 km. The instrument however, is capable of 1 km resolution; to record the high resolution data (Local Area Coverage or LAC) would outstrip the memory on the spacecraft. The LAC data is however, continuously broadcast, (High Resolution Picture Transmission, HRPT) and can be retrieved by stations in the view of the satellite as it passes overhead.

For many science missions, there is a requirement for the high resolution data permitted by the HRPT transmission. For coastal regions in particular, significant variability exists at scales smaller than those resolved by the GAC resolution. For these regions of the world, there is a great deal of interest in receiving the LAC data locally, and then retransmitting it to central archive and distribution sites. The U.S. has the beginnings of such a plan for the coastal U.S. waters. The data rate however, is relatively high (approximately 60 Mbytes per pass, 3-4 passes per day per station). Assuming 5 such stations could cover U.S. coastal waters, the total data volume would be approximately 1.0 Gigabytes per day (200 Mbytes per station).

In order to establish a "wideband" data communications network the remote satellite ground data reception stations would have to be connected through a Harris T-1 VSAT terminal to the central ACTS ground facility at NASA Lewis (or other sites) for relay to the central ground data processing facility (for ocean sciences, this will be at the Goddard Space Flight Center in Greenbelt Maryland).

Should there be future interest in similar coverage internationally, the data rate would be correspondingly higher. Ideally, as the ground stations become more autonomous, it would be of interest to automatically route the incoming satellite data stream back through a communications channel to a central site for common data processing and product generation.

2.3 Interface Requirements

In order to implement an ACTS-based remote data collection platform/autonomous buoy network, each remote data collection site will have to install an ACTS USAT terminal which will have to be interfaced to the remote platforms measuring capability. The data can be transmitted from the remote platform to the central ACTS processing center at Lewis and relayed from there to the end user or the data can be transmitted through the MSM on-board the ACTS satellite to any of the three downlink beams. Stations in those beams would have to be configured to collect data from, and to transmit data to USAT's.

The interfacing of the satellite ground data reception stations to each other or a central facility will require that each facility obtain, or have access to, the ACTS T-1 VSAT terminal currently being built by the Harris Corporation. This network could utilize either the MSM or the BBP, although at the present time it would be on constrained to operate with the BBP because the Harris T-1 terminal is not compatible with the MSM.

2.4 ACTS Technology and Applications

If a communications channel such as those provided by ACTS were routinely available, data rates from the buoys could be significantly increased. This would utilize many of the new technologies to be implemented on ACTS, including the baseband processor, the microwave switched matrix, high-powered spot beams and the Ka-Band frequency spectrum. Of greatest importance would be the work currently being done in relation to the ACTS Ultra Small Aperture Terminal (USAT) and the implementation of a remote data collection network using the Microwave Switched Matrix on-board the satellite.

2.4.1 The ACTS USAT Terminal

Of particular interest to the implementation of a remote date collection platform network using ACTS is the planned USAT terminal development. This terminal, originally sized for (SCADA (Supervisory Control and Data Acquisition) systems, will provide the capability for remote stations to be polled anywhere from 4 to 60 times an hour with a data rate of 1000 bits per poll. Additionally, and very importantly, the return link (from the central facility to the remote platform) will be 50-100 bits per poll. This allows a single data collection platform to transmit a minimum of approximately 4 kbits per hour (assuming 4 polls per hour) or 96 kbits per day. This is approximately 4 times that available from ARGOS--and it is the minimum polling frequency for which the USAT is sized.

2.4.2 The Microwave Switch Matrix

In the context of a remote data collection platform, the ACTS satellite would most likely be configured in the MicroWave Switched Matrix (MSM) as there is no real requirement for a "mesh" type network and/or signal regeneration which are the real strength of the on-board baseband processor. The MSM will allow the establishment of a multi-point to multi-point (or point) data collection network as well as a multi-point (or point) -to-multipoint broadcast mode for control messages sent from the hub to the remote platforms. The MSM will also enable the transmission of data directly from a remote data collection platform to the user or users of interest thereby circumventing the need for the data to be collected at a single point and then re-transmitted to end users.

In conjunction with ACTS high powered SPOT beams, the size of the USAT terminal can be kept smaller than with currently operating geosynchronous communications satellites as well as making that terminal potentially less expensive if it were to be built in volume.

2.5 Competitors to ACTS Technology

Currently, as discussed briefly above, the ARGOS system is used as the primary means of collecting environmental information or ground/ocean truth from remote data collection platforms. An ACTS type system would overcome many of the limitations of the ARGOS system including the fact that the ARGOS system is: constrained to environmental applications (there can be no commercial use of the system); severely constrained in bandwidth availability; designed such that the lifetime of remote data collection platforms is severely limited due to the inefficient use of battery power; constrained to between 7 and 16 contacts per day for any one platform; is constrained to one-way communications, hence the remote platform cannot be controlled; and the ARGOS system must transfer data through a facility in France--the data cannot be transmitted directly to the user.

Of more interest in a competitive sense are the new low earth orbit communication satellite systems. These systems (ORBCOMM, STARSYS, LEOSAT and VITA have all filed applications with the Federal Communications Commission) will provide low data rate data communications services on a continual basis--one of the constellation of low earth orbit satellites will be in view of any place on earth at any given time. The data rate for these systems will be 2400 kbps up to a maximum of 9600 kbps. The ground terminal cost is projected to be approximately $75 to $150 per unit. At this price, if the cost of transmission time is not too expensive, these systems would provide a strong competitor to the use of ACTS technology for remote data collection platforms/autonomous buoys.

2.6 Experiment Concept

The goal of a remote data collection platform experiment for earth observations is to prove the viability of using ACTS to collect ground-based data (ground or ocean truth data) in conjunction with satellite collected data as part of a precursor to the EOS mission. The remote data collection experiment on ACTS would entail the placement of ocean buoys along the east coast of the United States and Canada which would be operated in conjunction with current ocean observation missions including the NOAA polar orbiting AVHRR mission and Orbital Sciences Corporations SeaStar mission.

As part of an overall remote sensing data communications experiment (see Section 4.0) it is planned to have ground stations capable of receiving AVHRR and SeaStar data at Oregon State University, the University of Miami and Dalhousie University connected using ACTS. It is planned, then, to have ocean going buoys/data collection platforms located within the coverage circles of these stations with that data transmitted to the NASA Lewis station and then re-transmitted to the three sites which form the basis of the testbed network. In this way, all of these stations will have access to coastal satellite coverage of the United States and a limited amount of ocean truth data from the same areas.

3.0 DATA COMMUNICATIONS FOR FUTURE EARTH OBSERVATIONS SATELLITES

One of the key problems facing future earth observing system missions is the collection of global data sets from polar orbiting satellites. At present these global data sets are collected through the use of on-board tape recorders and/or digital storage devices which store data from an orbit and then downlink that data to a "host" ground station. Most civilian earth observation satellites utilize these on-board storage devices, however at least one program--the Landsat program--experimented with the use of an inter-orbit satellite link by which data was by the spacecraft and then, rather than being stored on--board, was immediately transmitted via NASA's Tracking, Data and Relay Satellites (TDRS) to a central facility at White Sands, New Mexico. The data was then relayed from there to the data processing facility at the Goddard Space Flight Center.

This method for collection of global data sets reduces the need for onboard storage devices (except as back-up) and has the additional advantage of enabling "real-time" collection and dissemination of data (i.e., one does not have to wait until the earth observing satellite is in view of the "host" ground station). Additionally, at present the data is sensed at 1.13 Km spatial resolution but the global data set is sub-sampled to 4.5 Km spatial resolution before it is stored and dumped to the "host" ground station. This is done, in large part, to minimize the data rates of the store and dump downlink. The ability to collect real-time full resolution data has particular advantage for commercial and some government operational applications.

3.1 User Requirements

There are a wide range of users interested in the AVHRR and Sea-WiFS data sets--they can generally be divided into three types of users: Government research users, Government Operational Users and Commercial Users (primarily commercial fisheries, off-shore engineering and ship routing).

Government research users require access to the Global data set but do not need the data in real-time except for a limited amount to support real-time research cruise planning activities. Government operational users generally do not require a Global Data Set, instead they require data of a specific area which can be collected via direct downlinks from the earth observing satellite. In other words, US Government operational users are interested, generally, in data of US coastal waters. As such there is not a major requirement for a global data set. However, agencies with a broader mandate, particularly the US Navy, are interested in global data sets and they require the data in real-time. As such, they are interested in any technology which enables them to capture the data in as close to real-time as possible.

Finally the requirements of the commercial industry are mixed. The commercial fishing industry requires data in real or near-real-time. The current system of storing the data on-board the satellite is adequate for the purposes of the commercial fishing industry--however the sooner the data can be delivered to the end user the more valuable it is. As such, commercial fisheries have a keen interest in technology which enables the more rapid collection of satellite data. Off-shore engineering applications generally require local coverage which can be collected directly from the satellite without use of on-board storage or inter-orbit satellite links. Finally ship routing applications require global coverage in real-time to be effective. This suggests high interest in inter-orbit links for collection of the global data set. Table 1 summarizes the needs and interests of various users in the use of inter-orbit satellite links for collection of global ocean data sets.

3.2 Data Requirements

The data rates and formats of the AVHRR and Sea-WiFS sensors are identical--the sensors generate full resolution data (data with 1.13 km spatial resolution), when fully formatted, at a rate of 665 kbps. When the data is sub-sampled to 4.5 km spatial resolution the data rate is approximately 41 kbps. The duty cycles for the instruments are also about the same. Users would like the AVHRR sensor to be "on" nearly all of the time--that is for each orbit users would like to see the sensor operated nearly the entire 100 minutes of the orbit because the sensor collects useful data in both daylight and at night. The Sea-WiFS sensor, however, does not collect useful information in darkness--as such its duty cycle is approximately half of the AVHRR . At the present time however, the AVHRR sensor operates continuously, and the SeaWiFS sensor is scheduled to operate, approximately 40 minutes per orbit.

This raises an important issue; that is how much of a polar orbiting satellite orbit would be visible to an operational ACTS satellite. Obviously the ACTS spacecraft will only view portions of any current polar orbit over the United States and selected areas which might be accessible using the scanning spot beam. The steerable antenna on ACTS can be pointed nearly anywhere on the disk of the Earth visible from its geosynchronous orbit, and is therefore capable of tracking any spacecraft as it transits this region. Both the AVHRR and Sea-WiFS missions, as well as most future Polar Orbiting Earth Observing Missions will be trackable by ACTS or an operational ACTS satellite.

Table 1
User Requirements and the Need For Inter-Orbit Satellite Links

Need For USERS	Require Global Data Sets	Require Real-Time Data Access	On-board Store and Dump System Adequate	Inter-orbit Links
Govt. Research	Yes	No	Yes	Low
Govt. Operational--Domestic	No	Yes	Yes	Low
Govt.	Yes	Yes	OK	High

Operational--International				
Commercial--Fisheries	Yes	Yes	OK	High
Commercial--Off-Shore Engineering	No	Yes	Yes	Low
Commercial--Ship Routing	Yes	Yes	OK	High

3.3 Interface Requirements

If an operational ACTS satellite were to be used to collect a global data set from Earth Observing Systems such as the AVHRR and SeaWiFS missions, those earth observing systems would have to carry Ka-Band transmitters (these would be 30 GHz transmitters) which would send data from the earth observing spacecraft to the operational--ACTS spacecraft (for the purposes of this discussion an operational ACTS spacecraft is assumed to have the same general characteristics of the ACTS spacecraft--this would obviously not be the case for a truly operational ACTS satellite).

Another interface might be required. If the operational ACTS TDRS downlinked data to a central facility then the ground processing facility for AVHRR and Sea-WiFS data, currently located at the Goddard Space Flight Center (GSFC) would have to be linked via electronic communications to the central operational ACTS ground station (the station to which the operational ACTS satellite downlinks it signal). This would be equivalent to the NASA facility at White Sands which receives signals from NASA's TDRS satellite. As an alternative, an operational ACTS satellite could downlink relayed data in real-time directly to user sites--thereby bypassing the central data collection facility. This would involve use of the on-board baseband processor to route earth observations data to appropriate user locations.

In discussing an experiment using ACTS, this presents an insurmountable problem in that both the AVHRR and SeaWiFS missions are already under construction and there is no possibility that they would add a Ka-Band transmitter to link the earth observing satellites to the ACTS satellite. As such an experiment can only be designed to demonstrate how such a system could work. If a user demand could be demonstrated, and it could be shown that an operational ACTS type system would be of greater utility than the TDRS system, then a commercial venture might be possible by which an operational data and relay satellite (or piggyback payload) might be implemented.

3.4 ACTS Technology and Applications

There are various components of ACTS which are of particular interest for remote sensing data communications applications of the type being discussed here. Of particular interest are the key technologies to be tested on ACTS; the Microwave Switch Matrix (MSM), the On-board Baseband Processor (BBP), high powered spot beams and the Ka-Band itself.

3.4.1 The Ka-Band

The use of Ka-Band is of interest in the context of inter-orbit links for remote sensing data communications for four primary reasons. First, the problems associated with rain fade on the uplink are largely eliminated because the uplink is well above the area where rain fade would cause a problem. However, rain fade on the downlink would still have to be overcome.

Second, there is currently no frequency allocation for a commercial TDRS system. If Ka-Band is allocated as a General Satellite Service (GSS) then this type of service would likely be an acceptable use of the band. It is not clear that the current TDRS allocation would be available for use by commercial satellites (if the Government were to decide to incorporate some ACTS technology on future TDRS missions and offer these services as a Government service, then the advantages of Ka-Band become less real).

Third, while the AVHRR and Sea-WiFS sensors require relatively little bandwidth, other earth observing systems will generate data far in excess of that generated by AVHRR and Sea-WiFS and will therefore require substantially more bandwidth. For instance, the Landsat Thematic Mapper on Landsat 6 will generate data at a rate of 85 mbps. This type of data rate requires substantial bandwidth, bandwidth which may be found only at Ka-Band.

Fourth, it is also of considerable interest that both ESA and NASDA are currently planning to implement TDRS type missions at Ka-Band. A US system operating at this frequency would be complementary to these international programs.

While demonstration of a commercial TDRS using ACTS will focus on technologies which are largely band-independent, demonstration of those technologies for a commercial TDRS application at Ka-Band is important to any operational implementation.

3.4.2 The Microwave Switched Matrix (MSM) and the Baseband Processor (BBP)

A demonstration of ACTS as a test bed for inter orbit satellite links for collection of global data from earth observing satellites would require that the ACTS scanning beam be used as the "uplink" from the earth observing satellite to ACTS. This scanning beam, because it would be a "western family" beam precludes the use of the BBP (when the BBP is in operation, NASA Lewis must be the western family beam). The scanning beam would uplink data to the MSM which would then route the data in real-time to any of three downlink beams in ACTS eastern family. Users within these downlink beams who are equipped with compatible ground stations could receive the data in real time. Unfortunately, the T-1 VSAT terminal which has been developed by Harris is only compatible with the BBP mode of operation. A T-1 terminal which would interface with the MSM is under discussion and would handle the 665 kbps data rate of the two sensors under consideration.

In an operational system the satellite would likely be configured such that the uplink beam would be a conus like beam to cover a wide area and this would be connected through a MSM to users through multiple high powered spot beams. In a sense this becomes a point-to-multi-point data distribution network--with the data source being an earth observing spacecraft rather than a ground based facility. The BBP mode of operation is probably not directly relevant for this application.

3.4.3 High Powered Spot Beams

For the purposes of a demonstration using ACTS a VSAT type terminal compatible with the MSM is required. The use of high powered spot beams to service these terminals is attractive in that they allow smaller ground terminal antennas. If an operational system were implemented at Ku-Band rather than Ka-Band spot beams would still be attractive in lowering the size and cost of end user ground terminals. The use of ACTS will demonstrate the feasibility of the concept independent of frequency band.

3.5 Competition

There are two primary ways to collect global data sets from polar orbiting earth observation satellites, through on-board storage devices which store and then dump data to a host ground station and through NASA's TDRS system which relays data from the earth observing satellite to the NASA ground station facility at White Sands, New Mexico. On-board storage devices have, to date, been dominated by tape recorders. New digital storage medium are now being implemented and are expected to be used on many upcoming missions. The main problem with these systems is that there is a delay in collecting the data and transmitting that data to the host ground station. Additionally on-board recorders have been vulnerable to failure. Where timeliness of data is critical and to the extent that there is concern over the in-orbit failure of on-board storage devices, the use of a relay satellite is attractive.

NASA's TDRS system has the capability to provide for relay of data from earth observing satellites to users. However, the use of TDRS by earth observing systems has relatively low priority in the NASA hierarchy and as such TDRS is less than ideal for support of operational missions due to its use by NASA for support of Shuttle and other NASA missions. The NASA TDRS satellite only downlinks data to the NASA ground station facility in White Sands. The data is downlinked at X-Band for high data rate missions and S-Band for lower data rates.

The use of an ACTS-type satellite for data relay has several advantages. First an operational ACTS satellite would be able to give high priority to operational missions which cannot currently use TDRS with confidence. Second, an ACTS type system is configured to downlink the data, through the MSM, to a variety of users directly from the relay satellite. At present the TDRS system will only downlink data directly to White Sands and the data must be relayed from there to users. Third, a high powered Ka-Band link from the earth observing spacecraft to an ACTS type spacecraft might be less expensive to implement than the current TDRS Ku-Band tracking antenna which is required to relay data to the TDRS spacecraft. Obviously a cost analysis of such a system is required.

3.6 Experiment Concept

The timing of the ACTS mission unfortunately precludes an experiment which includes installation of any instrumentation on an upcoming earth observing mission--any satellite that will fly in the same time window as ACTS is already under construction. As such an experiment which uses the ACTS satellite as a data relay satellite will have to use some other platform for data collection.

One approach to an experiment of this type would be to utilize the space shuttle as the data collection platform, install a 30 GHz transmitter onboard the shuttle and transmit data collected by the shuttle through ACTS to one or more ACTS ground stations.

Another, much less expensive approach, would be to simulate the collection of Sea-WiFS or AVHRR data at a ground facility and then uplink that data through the ACTS scanning spot beam as if the ground facility were an earth observing satellite then relay the data to users through the MSM. Given the difficulties of scheduling a Shuttle mission for such an experiment a ground based simulation is probably the most appropriate way to demonstrate the use of ACTS as a earth observations data relay satellite.

In this context the source of the data simulation could be any location which the ACTS scanning beam covers. This location would be configured to appear to ACTS as an earth observing spacecraft. It would uplink data to the ACTS spacecraft through an ACTS ground station; the satellite would switch the data to the proper downlink beams and users in those beams would receive the data at NASA ground station facilities. The key development cost associated with an experiment of this nature is the development of a ground terminal capable of handling the required data rates and of working with the MSM (this would require, at least, the modification of the Harris T-1 VSAT terminal currently configured to interface with the BBP).

4.0 DATA DISTRIBUTION and RESEARCH NETWORKS FOR FUTURE REMOTE SENSING MISSIONS

Within the context of the earth science community there are a number of critical needs which must be met to ensure the greatest possible use of data collected from upcoming earth observation missions. In particular there is a strong need for a distributed research environment which will facilitate the use of earth science data by a wide range of researchers. In the context of commercial applications of earth observations data there is a strong need for rapid data availability though distribution of data via electronic means.

4.1 User Requirements

There are a wide range of science applications for which ACTS could be a useful testbed. These include, among others[1]:

Telescience

Telescience covers a wide range of activities but generally "occurs in situations where the scientific investigations involve collaborators, instruments, data sources and computing facilities that are widely dispersed, and where the close interactions of the investigators are necessary."[2]

Remote Database and Information Systems Access

One of the key resources required by earth scientists is access to remote data bases. This included the capability to locate, browse, select, order and obtain data by

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[1]These applications were enumerated in a working group which resulted in the following report: "The Advanced Communications Technology Satellite (ACTS) Capabilities for Serving Science", The University of Colorado, Center for Space and Geosciences Policy, Boulder Colorado, May 15, 1990.

[2]Ibid., p. 81.

electronic means in an on-line fashion. This is also, perhaps, the greatest requirement of the commercial community in the area of earth observation data communications.

Remote Computing

Wideband data communications will enable routine transfer of large data files in addition to allowing a researcher at one site to utilize data sets and files at another site without transferring the data.

Scientific Visualization

Scientific visualization is a process by which a remote researcher can monitor the progress of a computer program and/or process taking place on a supercomputer as the process is transmitted graphically to that researcher. He/she can also control the process through relatively low speed data command links. This is becoming increasingly popular as a way of enabling researchers access to computer power which had otherwise been out of reach.

Collaboration Activities

Collaboration activities refers simply to the ability to provide enhanced communications between researchers in support of collaborative research activities. The ACTS satellite will provide the bandwidth required to provide an ISDN interface, for example, between remote researchers and do so in a mesh, rather than a star, network.

Of greatest interest to the ocean science community are the need for a distributed research environment which provides for new methods of data visualization and analysis as well as for new methods of scientific collaboration in the areas of algorithm development and data analysis.

Key requirements identified to date involve use of ACTS high bandwidth capabilities (T1-T3 data rates) for connecting researchers in participating institutions, use of ACTS flexibility to add researchers within the coverage areas of ACTS on an as needed basis, and integration of ACTS capabilities into existing ground based networks.

In keeping with the focus on oceans remote sensing, we have identified four initial nodes for an ocean science research network using the ACTS satellite. These include the GSFC (AVHRR and SeaWiFS data), the University of Miami (which collects data and develops algorithms for its use), Oregon State University (with a supercomputer and the expertise to work in the area of algorithm development) and Dalhousie University in Nova Scotia (with auxiliary data bases and field data as well as data collection capabilities).

4.2 Data Requirements[3]

The AVHRR and SeaWiFS data sets each generated at least 2 Gigabites of low resolution (4.5 km spatial resolution) data per day which is downlinked directly from the

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[33]This section dovetails with the requirements spelled out in Sectio 2.2.2 earlier in this study.

satellites to the NASA facility at Goddard. In addition, Oregon State University, Dalhousie University and the University of Miami will each collect on the order of 200 Megabytes of high resolution (1.13 km) data per day. A first requirement will be to transmit this data from Dalhousie and Miami to the Goddard facility and to make the data at the Goddard facility availability to the other three nodes of the "network". The beginnings of such a network will be miplemented soon in the form of a terrestrial T-1 link between Miami and Goddard. A T-1 link is also required between Dalhousie and Goddard for transmission of data to the Goddard facility. Additionally, for purposes of data distribution links are required between the remote locations (in this case OSU, Miami and Dalhousie, although anyone with an ACTS terminal and appropriate software should be able to join the network) and Goddard which allow those remote locations to query and access the AVHRR and SeaWiFS data bases.

A second requirement is to establish higher speed data links (T-3) in order to facilitate remote data visualization, modelling and large data base computational analyses. Additionally it may be of interest to develop an ISDN network using ACTS which links the researchers together in a collaborative framework.

4.3 Interface Requirements

The interfaces required by the proposed network are straightforward for establishment of a T-1 VSAT type network to allow for transmission of data from remote sites to Goddard and then access to the Goddard data bases from those remote sites. Each site will require a Harris T-1 VSAT terminal and appropriate software will have to be built to enable remote sites to query and access the Goddard data bases. This can be done using the BBP or the MSM.

The establishment of higher speed data links (T-3) and a mesh network (with ISDN compatibility) will require the more expensive high data rate ground stations being developed currently by ARPA. Additionally software controllers for interface to and control of the ISDN network through ACTS is required.

4.4 ACTS Technology

ACTS utilizes several technologies of interest to the implementation of these science data networks. Again, of particular interest are the key technologies to be tested on ACTS; the Microwave Switch Matrix (MSM), the On-board Baseband Processor (BBP), high powered spot beams and the KaBand itself.

4.4.1 The Ka-Band

The use of Ka-Band is of particular interest in the earth science community due to the large data rates that will be required to implement a high speed data network. In the context of an initial experiment using AVHRR and SeaWiFS data, high data rates are not critical for data distribution (a T-1 link will do). However for future EOS missions and for other functions such as remote data visualization and science collaboration, higher data rate links will be required. Because of the bandwidth constraints at C and KuBand, Ka-Band becomes the only feasible satellite option for implementation of such a data network.

Ka-Band is also of interest in this area due to the fact that the problem of rain fade may be less severe due to the fact that these high data rate communications and collaborative science efforts can probably tolerate lower reliability in the link then voice or video communications.

4.4.2 The Microwave Switched Matrix (MSM) and the Baseband Processor (BBP)

A demonstration of ACTS as a test bed for data networks will require the use of the Harris T-1 VSAT terminals in conjunction with the BBP mode of operation on-board the satellite. High speed data links (T-3) will require use of the MSM mode of operation on-board the satellite. This is due to the fact that the high data rate (T-3) ground stations currently being built are constrained to work with the MSM and not the BBP.

The advantages of the BBP on-board switching mode for the development of a distributed research environment is the ability to implement a "mesh" network whereby any researcher can talk to any other researcher without necessarily going through a hub station. In this way data, algorithms and/or models stored at any one facility can be accessed and utilized by researchers at any other facility. Electronically, as long as one knows who has what data, the storage of the data does not have to be centralized. At this point, the only ground terminal being configured to work with the BBP is the T-1 VSAT being developed by Harris. High speed links would be desirable for use with the BBP in the establishment of mesh research networks, however in the initial experiment the network will be limited to T-1 data rates.

The MSM on-board the satellite will support the development of wideband point-to-point and point-to-multi-point data networks. The MSM does not allow for implementation of mesh networks but will support data distribution from a single centralized facility to multiple locations as well as the use of a central data base by dispersed researchers. At this time there is no T-1 VSAT ground system capable of working in the MSM mode, however such a ground system is under consideration. In the meantime, the MSM mode will be used to initiate the T-3 link necessary for remote science experimentation.

4.4.3 High Powered Spot Beams

The use of high power spot beams enables the use of higher data rates to transmit data to smaller (and hopefully less expensive) ground terminals than would be possible in other frequency bands. This enables wider distribution and hence, wider use, of data by the science community. As discussed above, the use of high powered spot beams at Ku-Band could also serve this community if there was sufficient bandwidth available at KuBand. However, such is not likely to be the case. The use of ACTS will demonstrate the effectiveness of high powered spot beams in developing high speed data networks independent of frequency band.

4.5 Competition

The are a wide range of ways in which data can be shared among researchers including the US Mail, Federal Express, Fiber Optic Networks and the use of high powered satellites at Ku-Band.

Clearly the use of the US Mail and/or Federal Express allow for distribution of data and information from one facility to another. However these data distribution methods do not facilitate real-time use of data or real-time science collaboration. They also do not allow access at one research facility to data and research at another facility without duplication of storage devices. There will be some applications where the US Mail and/or Federal Express will be sufficient, however this will have to be decided on an application by application basis.

Fiber optics present a formidable competitor to the use of satellites for establishing nationwide high speed science data networks. The primary advantage of satellites, at this time, is their ability to develop new networks quickly and to transmit and receive data from nearly everywhere regardless of whether cable has been installed. As such satellites are not biased against smaller towns or rural areas where fiber is yet to be installed. When fiber is installed on a truly nationwide basis the role of satellites in these high speed data networks will be lessened. Until that time, satellites can play an important role in establishing those networks.

Finally there is the potential for using high powered Ku-Band satellites to establish these high speed data networks. The primary drawback to the use of Ku-Band are limitations on bandwidth which preclude the development of truly high speed networks. Additionally limits on satellite power may constrain the development of small user terminals at Ku-Band. If these networks can tolerate the problems associated with rain fade at KaBand, then Ka-Band may well be the frequency of choice for the development of these networks.

4.6 Experiment Concept

The goal of this experiment is to develop a mini-Earth Observing System (EOS) data communications network to demonstrate the utility of such a network to support the utilization of EOS data sets by nationally distributed researchers. Due to the nature of the ACTS satellite and its current capabilities (in terms of ground station development) there are three phases to the experiment.

Phase 1 of the experiment is the pre-launch phase--during this phase ACTS T-1 VSAT links will be simulated with leased lines between Miami and Goddard. Phase 1 will consist of developing and finalizing appropriate protocols for interaction between remote sites over the ACTS satellite and demonstrate that interaction using leased land lines. Appropriate software will be built to enable a remote site to query and access the data base. Additionally development of methods for use of the T-1 link for collaboration on algorithm development and scientific/data visualization will be conducted with the intent of implementing those applications through use of the BBP/T-1 VSAT capability on ACTS. Finally, these applications will be established in the context of an ISDN type interface between remote sites. This will require the development of appropriate software for a Mesh VSAT/ISDN network over ACTS.

Phase 2 of the experiment will follow launch of the ACTS satellite and will consist of implementing this mini-EOS network over ACTS using the BBP and operating at T-1 data rates. Implementation will include access by remote researchers to the NASA central AVHRR and Sea-WiFS data bases and the implementation of the mesh VSAT/ISDN network which will enable scientific collaboration among researchers.

Phase 3 will follow the establishment of this VSAT network and will involve the implementation and use of the high speed ground terminals (T3). This phase will build on the earlier phases and provide for applications which are not possible at the slower data rates. The cost of the high data rate terminals will be a limiting factor in this phase of the experiment, and may well be budgeted separately from Phases 1 and 2.

5.0 SUMMARY

This study has outlined three experiment concepts for the use of ACTS to support the earth sciences community. These three experiments involve the use of ACTS for remote data collection, as a data relay satellite for the collection of global data sets, and for the establishment of a distributed research environment.

The study has focused on the ocean science community and two key data sets--the Pathfinder data set using AVHRR data and the SeaWiFS data set from the SeaStar mission. The key centers to be involved will be Dalhousie University, the University of Miami, Oregon State University and the Goddard Space Flight Center.

The essential ingredients of these experiments are a remote data collection platform/autonomous buoy network using the ACTS USAT terminal; the establishment of a T-1 remote data communications network using the ACTS T-1 VSAT terminal (currently being built by Harris) and eventually establishing a T-3 network using the ACTS high-speed terminal.

The establishment of these networks (particularly the USAT and T-1 networks) will provide a prototype for the types of data and research communications networks required to ensure that data from the EOS missions and the EOSDIS program are used to their greatest effect.