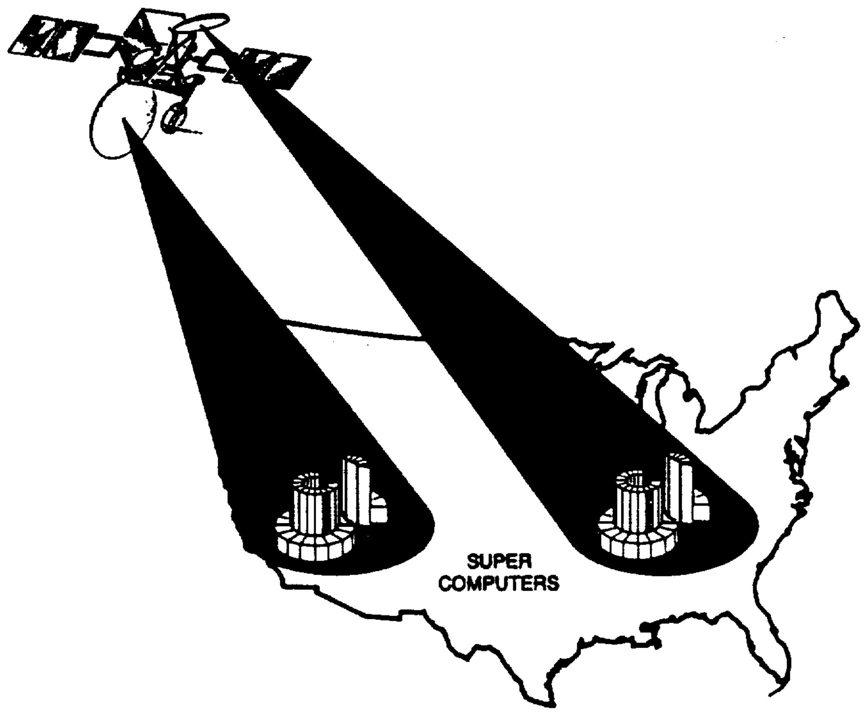
The Advanced Communications Technology Satellite (ACTS) Capabilities for Serving Science



The University of Colorado
Center for Space and Geosciences Policy
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prepared for
The National Aeronautics and Space Administration
Office of Space Science and Applications
Communications and Information Systems Division
Headquarters
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Preface

This report documents the results of research on potential science applications of the NASA Advanced Communications Technology Satellite (ACTS). The work was performed by the University of Colorado Center for Space and Geosciences Policy (CSGP) under a grant (NAGW-1105) from NASA's Communications and Information Systems Division (Code EC).

This work builds upon the results of previous research completed in 1988 by CSGP that was presented in a report entitled, *Report of the ACTS/Science Workshop: Potential Uses of the Advanced Communications Technology Satellite to Serve Certain Communication, Information, and Data Needs of the Science Community.*

The research plan for this report was presented at a meeting at NASA Lewis Research Center on March 17, 1989 during which ACTS program personnel provided a briefing on the technology and current status of the ACTS program.

The overall program of work for this report consists of: 1) general research on communications-related issues, 2) survey of science-related activities and programs in the local area, 3) interviews of selected scientists and associated telecommunications support personnel whose projects have communications requirements, 4) analysis of linkages between ACTS functionality and science user communications activities and modes of operation, and 5) analysis of survey results and projection of conclusions to national scale.

Acknowledgements

This report was made possible by the contributions of the many individuals who participated in the interviews for this research. The Center for Space and Geosciences Policy would like to thank each of them for their individual contributions. A list of the individuals interviewed is given in the appendix. The report was prepared by Thomas R. Meyer with oversight by Radford Byerly, Jr. and review by Joseph N. Pelton.

Contents

Executive Summary

The Advanced Communications Technology Satellite, ACTS, offers the promise of improved telecommunications services for the scientific community at a time when that community is demanding more of such services. Scientific activities in Colorado exemplify the situation. Listed below are several of the major factors that are driving future scientific telecommunications requirements:

- The nature of modern science and the types of scientific problems being addressed today demand unparalleled dynamic connectivity and major increases in bandwidth. A prime example is the need to understand global change. This will involve generation and utilization of the large data bases needed for a synoptic view of the Earth, and also the use of large general computer models of Earth systems. In order for the necessary broad range of scientists to have access to the data and the models, increased telecommunications capacity will be necessary.

- In principle faster computers that process larger volumes of data, powerful workstations that display multiple images, and applications software that can simultaneously access multiple remote databases can meet science needs but they depend for example on the ability of telecommunications services to connect with the remote data bases. There is also a need for improved connectivity and increased bandwidth to provide remote users with access to central supercomputer capabilities.

- As a consequence of this there is a growing mismatch between the capacity of telecommunications services actually available to users and the users' needs and technical capabilities. The problem in part is that services may be available in principle, or may be available to the sophisticated and well-capitalized large user, but may not be available in practice for example to a university researcher.

ACTS technology can help the communications industry address each of these situations.

There are also institutional factors which combine with the factors listed above to create an opportunity for ACTS technology.

- Although fiber optics technology is overtaking satellite capabilities in many areas, satellites still have unique areas of opportunity to supplement terrestrial fiber. Also, satellite technology is improving (*e.g.* by advances in semiconductors) and should enable satellites to stay competitive in some areas. ACTS technology will help satellites remain competitive.

- Since the deregulation of telecommunications a serious connectivity problem has developed due to lagging standards and the difficulty of orchestrating cooperation between the regional telephone companies and the hundreds of small independent companies. ACTS can allow users to leap over this problem and make direct connections through what becomes in effect an ACTS network.

The large industry investment in voice communications technology, the corresponding market and pricing structure, and the supporting, local regulatory environment cause a significant degree of industry reluctance to pursue future needs aggressively. Thus there is an opportunity for ACTS technology to bypass these problems, demonstrate advanced capabilities, and capture a significant market share.

A previous report* described a workshop which convened a sample of scientists from across the nation to discuss how ACTS could serve science. The work reported here focusses on science activities in Colorado, and on in-depth interviews of a broad sample of scientists and telecommunications managers at research organizations. The two efforts reached congruent conclusions, but the interviews produced much richer results. In addition, this work developed an analytic method for correlating science telecommunications needs with specific ACTS capabilities in order to demonstrate directly how ACTS can serve science. This is shown in Figure 6.4 on page 80.

The unique capabilities of ACTS that can best serve science are

- mesh interconnectivity, *i.e.* single-hop interconnectivity;
- dynamic reconfiguration of networks;
- dynamic assignment of bandwidth; and
- high capacity.

These capabilities enable ACTS to serve specific science telecommunications needs, including

- Telescience; the ability to conduct scientific activities remotely, for example the ability of individual astronomers to operate a spaceborne telescope from their home laboratory.

- Telecollaboration; the ability of individual scientists to work effectively together over an extended project while remaining at their home laboratories.

- Remote access to proliferating, distributed data-bases.

In order to realize the potential of these capabilities several concerns are addressed in this report. These include:

- The cost of ACTS terminals, which are high for individual scientists and which could be made more affordable by sharing arrangements.

- The limited lifetime of the ACTS satellite and what will necessarily be an experimental mode of operation, *i.e.* a lower than normal expectation of service availability.

- The need to assure that ACTS is transparent to the user, for whom telecommunications is a means, not an end.

- The need to develop additional materials explaining ACTS capabilities more fully in user's language.

In sum, there are great potentials for serving science in the ACTS program, and efforts should be made to realize these potentials. In order to attract scientific users, most of the effort will have to be made by the ACTS program.

* *Report of the ACTS/Science Workshop* (1988), Boulder: University of Colorado Center for Space and Geosciences Policy.

1 Introduction

The Advanced Communications Technology Satellite (ACTS) was conceived in 1979 to help maintain the United States leadership in the world communications satellite market.

ACTS is a flight verification program for advanced communications technology to support future communications systems and is a key element in NASA's efforts to develop new, currently high–risk, advanced communications technology usable in the higher frequency bands. The program is federally funded due to the high risk, high cost and long range nature of the development.

ACTS is scheduled for launch from the Shuttle in May 1992 for a planned 2-year experiments mission although steps have been taken to extend its life to four years. The ACTS system will be made available to the public and private sectors (corporations, universities and government agencies) for experimentation. Experimenters will test, evaluate and determine the feasibility of key ACTS system technologies.

The ACTS program is the primary space communications flight activity within the Communications and Information Systems division of the NASA Office of Space Science and Applications (OSSA). This division, one of seven within OSSA, is the only activity with a technology focus, the other six being directly concerned with various aspects of space science and applications.

Until recently, the program goal of the Communications and Information Systems Division has been to develop satellite technology primarily for the benefit of the satellite communications industry and the public sector. However recently this program goal was broadened to place specific emphasis on applying information systems technologies to meet the unique needs of the Space Science and Applications program including innovative scientific experiments and applications .

In support of this new OSSA program goal, the objective of this research report is to determine how ACTS technology can best serve science.

The ACTS program has enjoyed congressional support and has received substantial funding since 1985. Appropriations totalled $386.3M through FY1989 and an additional $72M has been authorized by the Senate Commerce, Science and Transportation committee for FY1990.

Pursuant to Congressional action the ACTS program was restructured in 1988, setting a $499M cap, terminating TRW and transfering work to GE Astro (RCA), establishing a tripartite agreement between GE, COMSAT and Lewis Research Center, and setting a new launch readiness date of May 1992.

To meet the $499M cap, funds for government-furnished experimenter terminals were eliminated, except for the development of a prototype (LBR–2) terminal, which is the smaller of the planned configurations. Other options concerning earth station facilities are still under study.

In July 1989, NASA Lewis Research Center announced the selection of the Harris Corp. to develop a prototype Earth station for ACTS. The proposed Earth station will have the capability for multichannel voice and data services at data rates up to 1.544 megabits per second. The prototype unit will be designed so that additional units can be built at reduced cost for the ACTS experiment program. The anticipated contract will include options for the procurement of additional units, depending upon the future needs of the ACTS experiment program.

Traditionally communications satellites have served two major markets in the United States, the larger being broadcast video distribution and the smaller being point–to–point trunking of voice channels. In the last half-decade business networks provided among very small aperture terminals (VSATs) have replace voice applications as the secondary market.

Consistent with the market opportunities perceived at its conception, the ACTS program has focused on developing advanced satellite capabilities for efficiently providing multiple voice and data channels to very small aperture terminals in a single hop.

In the same time frame that ACTS development has been ongoing, several major changes have occured. The U.S. space communications industry as a whole has been forced to adapt to a new environment, including growing international competition in launch services and loss of space markets to terrestrial technologies, especially fiber optics. The long–haul and point–to–point voice market, important for science because the same facilities are also used to carry data, is also the one most rapidly being replaced by terrestrial optical fiber.

Paralleling this, a changing regulatory environment, principally resulting from AT&T divestiture and the elimination of cross–subsidization of local service, has resulted in increased local access costs and decreased standardization of services thus making by–pass options using satellite earth stations more attractive.

Although the target market may no longer be what was originally anticipated, the new satellite technologies being pioneered by ACTS can adapt to the new environment and make possible new types of services for which satellites have strong advantages.

The major new satellite technologies to be demonstrated by ACTS include:

- Ka band technology,
- Electronically hopping multiple narrow–beam high gain antennas, and
- Onboard signal regeneration, switching and routing.

These capabilities together with sophisticated techniques for fade compensation and dynamic management of transponder capacity, make possible flexible satellite networks whose channel capacities and links can be reconfigured virtually instantly, thus making them competitive for serving point–to–multipoint and multipoint–to–multipoint networks including those with mobile elements. These and other aspects of the ACTS technology are discussed in this report in the context of the new and evolving data communications environment we face today.

Although the primary objective of this research is to determine how ACTS technology can best serve science, we also consider the specific requirements for ACTS to be exercised as an advanced satellite technology testbed for science activities.

The results of this research can not only help NASA understand how ACTS can best serve science, but they provide input to OSSA on design requirements for future operational satellite designs, and future earth stations. They also provide guidance on how to best meet future science communications requirements, and help define what should be the space science data system for the 90s.

2 Background

In this section we outline the results of the previous research performed by CSGP on potential science applications of ACTS, critique the results, and discuss the lessons learned that have been incorporated into the objectives of the current study.

2.1 Previous research

Previous research on how ACTS might serve science was completed by CSGP in 1988, and was presented in a report entitled, *Report of the ACTS/Science Workshop: Potential Uses of the Advanced Communications Technology Satellite to Serve Certain Communication, Information, and Data Needs of the Science Community.*

At this workshop, held May 26–27, 1989 in Boulder, Colorado, a select group of science investigators were briefed by NASA–Lewis personnel on the ACTS program and capabilities. Following the briefings, participants were asked to identify possible experiments using ACTS, and to discuss the suitability of ACTS to serve needs within their disciplines. The participants' suggestions on possible ACTS experiments and applications are documented in the report.

The workshop participants identified several theme areas or modes of operation, see Table 1, which they felt represented typical and useful applications of the special capabilities of ACTS to support science. Shown under each mode are examples of science activities or areas that the workshop participants felt were would benefit from ACTS capabilities.

Table 2.1. ACTS operational modes beneficial for science activities.

- Browse-and-Burst Mode
  - Earth Science Applications
  - Clinical Applications
- Interactive Conference Mode
  - Clinical Applications
  - Space Plasma Physics
  - Life Science Applications
- Telescience Activites
  - Astronomy
  - Space Physics
  - Planetary Sciences
  - Weather and Environmental Applications
- Remote Connectivity
  - Earth Sciences
- Field Campaigns
  - Earth Sciences
- Space Station Test Bed
  - Communications Experiments
  - Video Experiments
- Sporadic Events
  - Life and Earth Science Applications

The workshop participants offered a number of observations and recommendations regarding the future directions of the ACTS program and how it might be better presented to potential users. These are summarized in Table 2, Workshop Recommendations for ACTS Program.

Table 2.2. Workshop Recommendations for ACTS Program.

- NASA needs to demonstrate a commitment to the ACTS program and to its use for science.
- There should be both a strong commitment to science as well as involvement of other user groups outside of NASA.
- The possibility of shared ground terminals should be explored.
- The term "experiment" participant is inappropriate for the role a science user would play, and "applications demonstration" was offered as an alternative.
- OSSA's new program goal of supporting science communications must be evident when presenting the ACTS program to potential users.
- The potential for ACTS to encourage the development of new services should be emphasized.
- The costs of participation in the ACTS Experiments Program must be clarified for the potential user, and if possible, terminals should be free or available on a shared use basis at a greatly reduced cost.
- When presenting ACTS to potential users, the emphasis should be on what it does for the user not on how it works or how great the technology is.
- The user needs true transparency and a guarantee of support for the ACTS facilities from NASA.

In summary the ACTS/Science Workshop resulted in three major findings:

1. ACTS has unique capabilities that could be used to meet certain communication, information and data needs of the scientific community.
2. There is an existing interest and need on the part of the science community for the application of ACTS technology.
3. The future direction of ACTS and NASA's presentation of the program should reflect the potential "fit" between advanced communications technology and the evolving communication, information and data needs of the scientific community.

During a followup mailing, the workshop participants and others were asked if they felt there was substantial interest in their user community for ACTS-type capabilities. The response was not strong with regard to incorporating ACTS experiments into their research. The reasons cited were largely programatic rather than specific technical faults of the ACTS system. Respondents reiterated comments cited above, and emphasized drawbacks such as the cost of terminals, the investment of time required to implement an experiment, the short operational lifetime of ACTS, and lack of a clear NASA commitment to use ACTS for science.

2.2 Critique and lessons

A review of the ACTS/Science Workshop results and the participants' responses to the followup mailing, yielded a number of observations and lessons that suggested a shift in our approach for this phase of the research.

Our main concerns in the review were: how well do we understand the capability of ACTS to serve science, and how can this be improved? Secondly, what requirements do science investigators have that must be met in order to facilitate their participation in the ACTS Experiments Program, and their eventual use of an operational satellite capability? A summary of our observations are discussed below.

1. ACTS capabilites are not sufficiently translated into science user terms.

   Participants at the ACTS/Science Workshop were not always able to recognize when there was a good "fit" between ACTS capabilities and their specific communications requirements. As one workshop participant commented, "How it works is difficult to translate into what to do with it."

   We concluded that interviews with science investigators were only partially effective for identifying possible science applications for ACTS. In future research, it would be helpful to utilize analysts who are knowledgable about ACTS capabilities to assist in making the determinations.

2. The end-user (scientist) is not always the best judge of ACTS applicability, but knowledgable telecommunications support staff can make such a determination.

   Although interviews with principal investigators is an effective means of identifying data communications needs, in many cases it is not the principal investigator, but rather his telecommunications system manager, who has better insight into how ACTS can benefit a particular science program. In fact, in many institutions the telecommunications manager oversees local area networks and is responsible for maintaining telecommunications services for multiple science projects within the institution, and therefore is better able to judge the applicability of an ACTS system.

   Thus, future research should include interviews of telecommunications managers and other communications personnel along with the science investigators. Secondly, future research should include more consideration shared ACTS terminals, for example in network nodes and institutional settings.

3. A generalized analytical method is needed to match ACTS capabilities to science communications needs for both experimental purposes and applications.

   One of the main conclusions of the workshop was that the future direction of ACTS and NASA's presentation of the program should reflect the potential "fit" between advanced communications technology and the evolving communication, information and data needs of the scientific community.

   It was evident from the workshop results that certain science communications needs were better served by ACTS capabilities than others. We concluded that a generalized approach or methodology should be developed that would facilitate this determination. Linkages should be defined between the generic modes of communication required by science activities, and the elements of ACTS functionality that facilitate those modes. An example of a generic user mode might be "browse-and-burst", and the corresponding ACTS functionality might be "bandwidth on demand".

These linkages could be determined by examining science communications requirements in a microcosm such as the Washington, D.C. area, Southern California, the Boulder-Denver area or other locations with a high concentration of scientific activity. The results could be used as a tool for understanding ACTS applicability to other science programs, and for projecting ACTS applicability to the science community as a whole. This methodology would also be useful for gaging and comparing the applicability of other communications technologies, such as terrestrial fiber optic networks.

4. ACTS has capabilities for new types of services to meet science needs that have not been adequately explored.

   Although the ACTS/Science workshop participants were able to identify ways in which they could utilize ACTS for traditional modes of communication, it proved more difficult for them to visualize new types of serves that would become possible using the new ACTS technologies.

   We concluded that further work should be done to explore the potential for ACTS to provide new types of services for science utilizing capabilities such as bandwidth on demand, and point-to-multipoint and multipoint-to-multipoint connectivity. This objective will be enhanced by the methodology discussed above and by developing a better understanding of science user requirements.

5. Programatic limitations of ACTS discourage science users from becoming ACTS experimenters and may color their estimates of ACTS applicability.

   We noted that the participants in the ACTS/Science Workshop felt that in general ACTS had valuable capabilities for science and that there was both need and interest on the part of the science community, but on the other hand, they were reluctant to participate in ACTS experiments. We noted that the reasons given were primarily due to ACTS' programatic limitations rather than technical faults of the ACTS system.

   We concluded that a comprehensive understanding of the conditions and requirements necessary to attract science participation in the ACTS Experiments Program was needed in order to better understand the scope of potential science applications of an operational ACTS. A detailed user guide to scientific applications for ACTS would be highly useful for investigators.

6. The attempt to involve practicing scientists in the ACTS Experiments Program is at cross purposes with the scientists' limited time and financial resources.

   We noted that most potential science users of ACTS are largely disinterested in developing advanced communications technologies except in so far as they enable the investigator to meet specific communications needs that can not otherwise be fulfilled. This points up the fact that science users have fundamentally different requirements for participation in the ACTS Experiments Program than do communications engineering experimenters whose primary interest is with the ACTS technology and its potential applications.

   Thus, in the next phase of research, a comprehensive profile of science user requirements for participation should be identified, as well as requirements that will enable the experimental ACTS to simulate an operational system to meet science users' needs.

7. The benefits of shared ground terminals should be further explored.

   The cost of using ACTS and of participating in the experimental program was of particular concern to the ACTS/Science workshop participants. Since Congress has recently capped the ACTS development budget which effectively limited the funds for experimenter terminals, this has created an obstacle for potential experimenters who might otherwise wish to participate.

   Innovative ways must be found to finance the terminals. It is clear that communications nodes can aggregate users and provide traffic volume, funds and interest to justify ACTS use. Since the workshop focused primarily on individual science investigators and programs, we concluded that our future research should examine options to share ACTS terminals between investigators at the same institution or site.

3 Context - Science Data Communications Infrastructure

This chapter describes the context in which ACTS will operate. It gives an overview of the nature of science communications activities, identifies the major entities involved in science communications – particularly those in the Boulder, Colorado area, and summarizes NASA and NOAA missions that may have science communications requirements. The chapter concludes with an overview of key trends in the science uses of communications relevant to ACTS and discusses the emerging competitive challenges for ACTS.

3.1 Overview of science data communications traffic

Science activities often require communications for a variety of purposes before, during and subsequent to the research or experiment program. Most of these communications needs can be supported by ACTS.

At the present time most science communications requirements are served by three basic types of services available on most computer networks: electronic mail, file transfer, and interactive (remote) logon.

Taken from the perspective of the researcher, the items listed in Table 3.1 below illustrate the typical kinds of science activities that require communications support:

Table 3.1 Science activities that require communications support.

- Program Planning
  - Experiment planning
  - Experiment design
  - Simulation
  - Scheduling
- Acquisition
  - On-orbit/flight/experiment operations
  - Monitoring and control
  - Importing flight/field data
  - Data Handling: Processing levels 0,1*
  - Initial analysis
  - Initial objectives satisfaction
- General research/Data management
  - Data set production
  - Data Handling: Processing levels 2,3*
  - Discipline investigations
  - Interdisciplinary applications
  - Model development and testing
- Data storage and maintenance
  - Archiving
  - Retrospective analysis
  - Quality maintenance

* Defined below

Importing flight and field data is perhaps the most obvious use for communications although in many situations ACTS can not service the space-to-surface segment. However it is feasible for ACTS to track other spacecraft in low earth orbit which could burst data up to ACTS when they are in a favorable position.

Typically data goes through several levels of processing which may occur at different sites before it is finally archived. NASA data generally proceeds through four distinct levels of processing.

Level 0 processing occurs during the initial importation throught various communications links and involves removal of all communications artifacts such as packet headers and modulation, so that the data stream is restored to its original form as it left the spacecraft or field instruments.

Level 1 involves error correction, time ordering, and decommutation into separate data streams, but remains true to the detector(s) in that none of the physics content is removed through averageing, compression or similar processing. This processing may occur at an intermediate site or at the investigator's facility.

In Level 2 processing the data remains true to the detector but is reduced to physical parameters. For example, raw digital numbers may be converted to physical parameters such as temperature, pressure, radiance, flux, and the like.

In Level 3 processing the data is mapped into other forms. This may involve computing to grid points, extrapolation, production of maps with contour lines from the data, and mapping into application models possibly in combination with other data.

These processing steps may involve transferring the data to one or more supercomputer sites for processing and may require numerous transmissions of intermediate results back to the investigator in order to guide the processing.

Once data has been archived by the principal investigator it is then usually made available to the general science community so that other investigators may use it, possibly in combination with data from other experiments, in their own research.

There are a number of other uses for communications which are ancillary to handling the experiment data itself. These may include experiment simulation, scheduling and control, and support for experiment operations.

There is a strong trend these days to undertake large scientific programs involving research teams with multiple investigators in several locations. Thus another important use for communications is to support scientific collaboration activities. This accounts for a significant volume of communications traffic often involving the use of electronic mail. Telecommunications may be used for communication between investigators for experiment planning, discussion of research problems, preparation of technical papers, research reports, and journal articles, for sending out meeting notices, news and newsletters, and for a host of other science related needs.

3.2 Entities involved in science communications

There are numerous entities involved in science communications many of which are potential users of ACTS services. These include government agencies, universities, private industries, private science contractors, publishers, professional societies and others. In general these agencies and organizations have facilities and staff in multiple locations who need to exchange messages and data within the organization as well as with other agencies and organizations.

Some organizations also maintain data repositories or archives associated with their activity or area of research. Table 3.2 shows many of the principal government agencies and national laboratories involved in science communications. Those of particular interest for this research are the NASA centers and those organizations that work closely with NASA including NOAA and the university science community. Both NOAA and NASA have important data repositories, listed in Table 3.3, that are important to science activities in Colorado.

Table 3.2 Agencies and Centers Involved in Science Communications

Government Agencies and Facilities

- National Aeronautics and Space Administration (NASA)
- National Oceanic and Atmospheric Administration (NOAA)
- National Science Foundation (NSF)
- United States Geological Survey (USGS)
- Department of Health and Human Services (DHHS)
- Department of Energy (DOE)
- Department of Defense (DoD)
- Defense Advanced Research Projects Agency (DARPA)
- Los Alamos National Laboratory (LANL)
- Lawrence Livermore National Laboratory (LLNL)
- Idaho National Engineering Laboratory (INEL)
- Jet Propulsion Laboratory (JPL)
- National Center for Atmospheric Research (NCAR)

Table 3.3 Examples of Science Data Repositories

NASA Data Systems

- Astrophysics Data System (ADS)
- National Climate Data System (NCDS)
- Pilot Land Data System (PLDS)
- National Space Science Data Center (NSSDC)
- Navigation Ancillary Information Facility (NAIF)
- Ocean Data System (NODS)
- Planetary Data System (PDS)

NOAA Data Systems

- National Climatic Data Center (NCDC)
- National Geophysical Data Center (NGDC)
- National Oceanographic Data Center (NODC)
- World Data Center-A (WDC-A)

3.3 Missions and programs operational in the 1990s

In this section we summarize the space science missions and programs that will be operational during the 1990 decade and identify those that coincide with or overlap the operational period of the ACTS program. ACTS is planned for a two-year operational life, tentatively beginning May 1992, but measures are being taken that may enable it to operate for an additional two or three years.

The logistics of data traffic for science programs is of interest in that it defines the physical sites that may require ACTS terminals. On many missions ACTS can not service the first leg of the data path from the spacecraft to the ground due to incompatible spacecraft locations and communications equipment. However once the data has been received on the ground, ACTS earth stations can be used for all subsequent data communications requirements such as for distribution to processing and archiving centers and to provide remote access for investigators.

The following Table 3.4, shows a tabulation of the primary flight programs of the NASA Office of Space Science and Applications (OSSA) by division and those of the National Oceanic and Atmospheric Administration (NOAA) as a function of the year in which the mission is scheduled to commence. Of the seven major divisions within OSSA, six involve science activities applicable to ACTS. The seventh, the Communications and Information Systems division administers the ACTS program itself. The data in this table is based on missions identified in the 1989 NASA Manifest, NASA 1989 Long Range Plan, and the NOAA NESDIS Satellite Programs Briefing of 1985. These have been compiled in Appendix C.

Table 3.4. Number of NASA and NOAA missions by commencement year.

Division	Mission Commencement Year										
	89	90	91	92	93	94	95	96	97	98	TBD
				ACTS Operational							
Astrophysics	1	5	2	3	1	1	3	-	-	1	3
Solar System Exploration	2	-	-	1	-	1	1	3	1	-	-
Space Physics	-	2	-	3	2	1	2	5	-	1	-
Earth Science and Applications	-	1	3	3	4	2	2	2	1	-	1
Life Sciences	-	1	1	4	2	3	3	1	-	1	-
Microgravity Science and Applns	-	1	-	1	3	2	2	1	2	1	6
Communications and Info Systems	-	-	-	1	1	-	-	-	-	-	1
NOAA	-	2	2	2	1	-	2	-	-	-	1
Total Missions	3	12	8	18	14	10	15	12	4	4	12

3.4 Trends in the use of communications

There are a number of trends that are working to increase the overall volume of scientific communications traffic transmitted over satellite links and terrestrial networks. These include increasing computer literacy, continuing improvements and innovation in information system technologies, the increased availability of new local digital wiring plant in many institutions with easy access to digital services and network connections, proliferation of the number of users and services, user migration to increasingly sophisticated applications, and the trend toward big science programs involving many experiments and investigators.

There are also several significant factors working to offset these increases. Distributed archives are reducing the need for long distance communications to access scientific data. Continuing improvements in the price/performance of computers is making them more affordable and is reduceing the need to access remote supercomputers. CD-ROM replication of data sets which can be shipped by U.S. Mail provides an effective alternative to distribution by computer networks.

3.4.1 Trends tending to increase volume of communications traffic

Trends Tending to Increase Volume of Communications Traffic

- Increased computer literacy
- Improved facilities (workstations, networks, software)
- New digital wiring plant (to every office)
- Proliferation of users and services
- Sophisticated applications, activities
- Big science

Increasing computer literacy

Scientists and professionals are becoming increasingly computer literate and this is having a direct impact on communications use. The younger generation, the first to have grown up with computers and to have used them in school, is moving into professional positions. Furthermore, computer facilities are becoming more available and easier to use and are attracting more and more of the established scientific community.

Improved Information System Technologies

Improved facilities such as workstations, networks, computers, storage systems and applications programs, are important factors driving increased communications use. The installed base of local area networks is continually growing and being upgraded in research groups, departments and entire institutions, and user workstations and personal computers are routinely outfitted with network connections. Institutions are adding more powerful computers and more online data storage facilities that can be accessed from anywhere by local and remote users. Communications software is also becoming easier to use. It is often integrated with other applications so that communications is a natural extension of other computing activities. In some applications and advanced workstations, communications use is entirely transparent. For scientists working at home, in the field or otherwise outside of institutional settings, the cost of modems is decreasing while the supported data rates are increasing and more and more institutions are providing dial-in capabilities for their users.

New local digital wiring plant and network connections

The on-going installation of new wiring in institutions for linking computers to one another and to networks is simplifying access for increasing numbers of users. Many institutions are installing digital lines at every phone jack in every laboratory, office and workspace to accomodate terminals, personal computers and workstations. Institutions are installing local area networks, upgrading their capacity, and establishing links to national and international networks. In addition, many local telephone companies are beginning to offer various types of digital services to complement or replace existing analog service. The net effect of these installations is directly affecting the volume of communications traffic.

Proliferation of users and services

The continual proliferation of users and services is another factor driving up the volume of communications traffic. Within the scientific world the number of users who are able to communicate with one another is growing both as a result of improvements in local connectivity, and because of efforts to link the major networks around the world. We are rapidly approaching the point where nearly all scientific computer networks in the developed countries of the free world and many third world countries will be interconnected. Systems such as the TCP/IP Internet and SPAN now link roughly 100,000 host computers at science related instititutions world-wide. This process will accelerate as individual scientists, users and their institutions realize the value of this capability. Paired with this phenomenon is the rapid growth of the amount of scientific data and information services available online. Most scientific institutions are progressing toward the goal of providing catalogs and access to data stored in standard scientific units and formats. Standardization of formats for the storage and exchange of scientific data is being given an increasingly high priority and has been identified as a possible goal for the international Space Year 1992. This is complemented by services provided by libraries and commercial companies who offer access to databases of citations, scientific journal articles and other services that can be accessed from any personal computer or workstation.

User migration to sophisticated applications

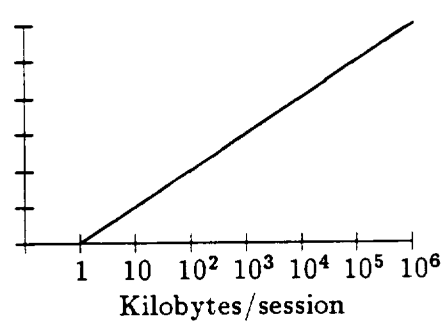
User migration to more sophisticated applications is a trend that is having a strong impact on the volume of communications traffic. Two important components in this trend are the growing competence of the user and the increasingly powerful workstations and software being provided by vendors.

Within the university environment we find more and more scientists are beginning to utilize computers and electronic communications. Word processing and electronic mail are often the entry point for applications involving more sophisticated uses.

A typical progression to increasingly communications intensive applications that might be used by a university scientist is depicted in the following table. The data volume corresponding to each application is, of course, highly subject to the individual situation, but the table is meant to illustrate that order of magnitude impacts are occuring as users become increasingly sophisticated.

Table 3.7. Evolution of Science User Sophistication: Impact on Communications

Scientific visualization
X-window applications
Remote processing
File transfer
Electronic newsletters
E-mail, daily necessity
E-mail, occasional user



Big science

Perhaps the most important factor driving communications volume is big intensive science. The global climate change program will drive bandwidth requirements. Data from Mission to Planet Earth programs will be coming from satellites, land stations, radar, drifting buoys, and other instruments. The data will be shared among many scientists in many locations. There will be huge computing requirements and wide data dissemination needs. As funding for global climate change funding increases, there will be more data produced and stored in archives.

The question of hazards, particularly weather hazards, and the goal of real-time monitoring and forecasting has similar huge data collecting, computing and dissemination requirements. Large amounts of primary data needs to be moved beyond the local or regional station and integrated into global models. New instruments will have large data outputs. For example, NexRad Radar (next generation radar) will have doppler capabilities and will scan circularly in spirals to cover an entire hemispherical region. Weather data processing centers will need to receive, process and disseminate gigabytes of data daily.

The Earth Observing System (EOS) program will be among the largest contributors to future bandwidth requirements in the 1990's. Instruments such as the high-resolution imaging spectrometer (HIRIS), and the synthetic aperture radar (SAR) will produce data rates in the range of 300 mbps. A synthetic aperture radar is also the principal instrument on Magellan, the first in the series of new planetary probes. In fact, Magellan will return more raw data than all previous NASA missions combined.

A projection of the total amount of data to be generated by OSSA programs for all missions (approved, likely and proposed) for FY 1988-2000 is shown is shown in the following table. Note, an alternate number for the Materials Science catagory is shown. This is three orders of magnitude larger than the first estimate and represents data that would result from the proposed Space Station Freedom materials science experiments involving high definition television and other high data rate telescience instruments.

Table 3.8. NASA Mission Generated Data

OSSA Division	Total Generated, Terabits (10^{12})	
Astrophysics	419	
Communications	N/A	
Earth Science	4787	
Life Sciences	180	
Materials Science	15.8	12,929
Solar System	206	
Space Physics	1334	
Total	6942	

Cumulative data generated for all NASA Missions (Approved Likely, and Proposed), FY 1988-2000. NASA Estimate of 12/30/87.

Of perhaps more direct interest are projections of NASA data communications bandwidth requirements between major NASA centers for the early to mid 1990s. These estimates are for dedicated links to support space missions, with much of the data initially coming via TDRS and EOS. The estimates were prepared by Booz-Allen and Hamilton for the General Services Administration in May 1989.

Table 3.9. Science Communications Requirements to 1995

Inter–center Link			MegaBits/sec
LeRC	-	GSFC	45
LaRC	-	GSFC	45
MSFC	-	GSFC	90
White Sands	-	GSFC	300
KSC	-	LaRC	45
KSC	-	MSFC	45
MSFC	-	JSC	90
MSFC	-	White Sands	90
JSC	-	White Sands	135
White Sands	-	JPL (1)	90
White Sands	-	JPL (2)	300
White Sands	-	ARC	90
JPL	-	ARC	90
Total			1.455 gigabits/sec

Interpretation of these estimates by Telecommunications Associates suggests that these requirements will reach 70% utilization by 1993, 90% by 1994 and approach full utilization by 1995. These projected requirements are equivalent to a fully loaded communications satellite.

At the present time most NASA inter-center links are running at T1 rates or 1.5 MBits/sec. All of the data rates shown above are multiples of standard DS-3 rates (45MBits/sec) and represent a minimum of a 30 fold increase in capacity. These increases are consistent with the proposed objectives of the National Research Network to increase the Internet backbone capacity to DS-3 rates or higher by 1992.

Beginning in 1995, NASA is anticipating requirements for further increases in channel capacity for each of the above links. At the present time cost estimates from the common carriers are being requested for data rates of 565 MBits/sec, 1.13 GBits/sec and 1.76 GBits/sec. The capacity purchased will depend on price quotes. In the view of some at NASA, the present network is very expensive and provides very little throughput for the money. Although there is a clear need for more capacity, there may not be sufficient funding to meet it, particularly if present rate structures continue. There are indications however that common carrier rates will drop. For example, AT&T is revising its ACUNET T45 tariff with a drastic price reduction. Other carriers such as Sprint are already 70% below the current AT&T tariff. Meanwhile recent studies of ACTS technologies and projected operational capabilities suggest that a gigabit/second capability might be provided for as little as $400,000 per year.

3.4.2 Factors tending to decrease communications traffic

There are a number of factors at work that are countering the growth of data communications traffic over terrestrial networks and satellites. Some of these are listed in the following table.

Factors Tending to Decrease Communications Traffic

- Distributed archives
- Improvements in price/performance of super computers
- CD-ROM replication of data sets
- Shipment of data media via U.S. Mail/couriers (especially CD-ROMS)

Distributed archives

The use of distributed archives where data sets are replicated at multiple sites is a trend that tends to reduce the impact on long distance communications services while increasing the volume of local and regional traffic because of their improved accessibility. Distributed archives are motivated by multiple factors including: the need for redundant storage to protect valuable data, the decreasing cost and improved reliability of new archiving media such as optical disks, the need for ready access to data for local users, the cost of communications services – especially for transferring large data sets, the lack of reliability of network links, and the inefficiency due to the limited bandwidth of communications channels.

Improvements in price/performance of supercomputers

The continuing improvements in price/performance of supercomputers is a factor that is reducing long distance communications requirements. The computer industry is continuously developing mainframes and supercomputers that are more powerful and less expensive for the same performance than older machines. As more institutions purchase and upgrade machines, this tends to decrease scientists' requirements to go outside of their institutions to use supercomputers at remote locations. However, the purchase of a supercomputer still represents a significant capital investment which is motivated primarily by factors other than the communications cost of accessing a remote supercomputer.

CD-ROM replication of data sets

The increasing use of the optical compact disk read-only memories (CD-ROM) for data storage and distribution is a trend that is reducing many scientists' requirements for data communications. The CD-ROM can store very significant quantity of data, on the order of 550 megabytes (4 gigabits). This capacity is sufficient to hold the entire data set from one or more mission experiments. The cost of producing optical disks has dropped drastically, and for a relatively small investment ($1000), a CD-ROM player can be purchased as a peripheral for a personal computer or attached to a local area network. The low cost of CD-ROMs, their convenience and non-reliance on communications, makes them very attractive to scientists whose work does not require real-time access to data as it is being generated.

Another technology now being introduced from Japan is digital audio tape. It has many of the same characteristics as audio tape; it is easy and inexpensive to record, but access rates are inherently slow. The capacity of digital audio tapes will be about twice that of CD-ROMs, making them very attractive for economical delivery of data on demand.

3.5 New technical and competitive challenges for ACTS

3.5.1 Fiber optics

Since the ACTS program began in 1979 a major revolution in communications technology has been initiated by fiber optics. Fiber has multiplied the potential practical bandwidths of terrestrial networks by several orders of magnitude, it is driving down communications costs, and making possible whole new classes of communications applications and services.

As of 1989, Bell Laboratories achieved fiber transmission out to 6000km (3700 miles) without regeneration (repeaters) using soliton pulses, and the current anticipated achievable throughput of fiber is expected to be at least 100 Gbits/s.

Interexchange carriers are developing fiber transmission services and installing fiber backbone circuits. Fiber is being used in new high speed data networks for point-to-point and multi-point applications. It is being used to network mainframe computers and to link them to controllers and peripherals. Conventional LANs are being tied together with fiber and it is being used to extend their nodal distances. Fiber is being installed in campus backbones, it will be employed in metropolitan area networks (MANs), and phone companies will soon be installing fiber on customer premises. In addition, a host of new products are being developed that will link directly to fiber and take advantage of its wider bandwidth and digital capabilities.

The on-going replacement of microwave links and copper cables with fiber has been an important factor that has caused satellites to loose their competitive advantage. But problems with satellite system quality such as delay, inadequate echo suppression, and intensive over use of circuit multiplication and speech interpolation equipment have also contributed to satellite unpopularity. Furthermore, in the equal access era since divestiture, the other common carriers no longer enjoy the 55% discount in access charges relative to AT&T. This has greatly reduced the price competitiveness of satellite carriers as well as all other carriers.

As a result all major domestic long-distance two-way carriers have abandoned satellites for almost all two-way voice circuits. Nevertheless, there remain several thousand equivalent voice and data circuits on VSAT networks operated on the satellite systems such as Hughes Communications, GE Satcom, Contel ASC, GTE Spacenet, and STL Corporation. AT&T is also replacing many of its overseas satellite links with fiber under a long-term agreement made between Comsat and AT&T and approved by the FCC.

The trends toward increased transmission bandwidth, ubiquitous digital connectivity, and data communications intensive products and applications made possible by fiber optics pose a major challenge for ACTS technology.

Future operational satellites using ACTS-type technology will need to achieve increasingly high performance, particularly in digital environments, in order to remain competitive, and they will need to focus on applications where they have unique advantages. This suggests that satellites may migrate more toward mobile and radio determination services, personal communications services in remote areas, DBS, domestic overseas satellite services, international satellite services and niche markets such as specialized VSAT private networks, and rural satellite services. In addition, satellites using refined ACTS-type technology may be able to compete with terrestrial services for providing broadband ISDN services particularly for multi-session, multi-media applications. In all these areas, direct link with the public switched telephone network and ISDN compatibility will be important for interconnectivity and restoration.

3.5.2 National research and education network

One of the most important developments that will impact ACTS opportunities to serve science is the proposal to build a National Research and Education Network (NREN). The goal of the NREN is to put in place a high speed fiber backbone for a research network that will provide a distributed computing capability linking the U.S. government, industry, and the higher education community.

The NREN planning began initially with five government agencies, the National Science Foundation (NSF), the Defense Advance Research Projects Agency (DARPA), the Department of Energy (DOE), the National Aeronautics and Space Administration (NASA), and the Department of Health and Human Services (DHHS) who formed the Federal Research Internet Coordinating Committee (FRICC).

The NREN development plan developed by FRICC designates NSF as the proposed lead agency and calls for building on the existing network infrastructure by:

- upgrading and interconnecting the existing facilities through a cooperative effort among the major government agencies who will maintain their own communications facilities over the near term;
- expanding data communications rates through the use of existing technology to the major U.S. research institutions over a shared communications facility;
- developing a networking architecture in the gigabit-per-second range and also supporting the technology required to implement it.

Over the period from 1989 through 1996 the NREN goal is to increase data rates in steps from current rates of 56Kbits/s or less, to 1.5 Mbits/s, to 10 Mbits/s, to 45 Mbits/s and finally to the range of 1-3 Gbits/s.

Not all institutions would be linked by the fiber backbone operating at 3 Gbit/s rates; many facilities such as supercomputers, national database resources, university and industry nodes and the like would be connected to the primary backbone by tail circuits and subnetworks operating at lower data rates. Nevertheless, the prospect is for thousands of institutions, much of the U.S. science community, to be connected to the NREN.

The ACTS Experiments Program will become operational during the same time period as the proposed NREN development program. The NREN will provide services into the same localities as planned for ACTS and the NREN will have an equal or higher capacity. Both programs have program goals to serve science. A critical question is what role can ACTS play in the NREN development and what long-term role could an operational ACTS have in such a network.

In view of the NREN plan, in the long run one of the most important roles for satellites may be to provide complementary services for the terrestrial network. ACTS may have unique capabilities to extend the resources of the terrestrial fiber network to off-network locations, for example to facilities that are mobile and to sites that are remote, temporary or have terrain or environmental conditions that are incompatible with terrestrial services.

ACTS could play a major role in scientific field campaigns operating on land or on ships to collect data, transfer it central processing sites, and return results to guide field activities. ACTS also has the capability to track and communicate with air planes and satellites in low earth orbit anywhere on the disk of the earth visible from its orbital position, and to integrate these with other terrestrial field operations. The steerable antenna on ACTS makes possible demonstrations of this nature within the ACTS Experiments Program.

Another important role for ACTS in relation to the NREN and other sophisticated terrestrial networks could be to extend broadband ISDN services to off network locations. ACTS could also play a role as a backup capability for terrestrial links, and for handling unusual high burst requirements for which terrestrial circuits are inadequate. ACTS could be used as a pilot test facility and to provide transition services prior to completion of fiber terrestrial links.

3.5.3 OSI/ISDN

Over the past decade there has been a steady increase in the use of communications for the transmission of digital data, primarily for computers. This decade has also seen the development of sophisticated digital packet communications technologies that are expected to reach maturity in the 1990s. These packet technologies will not only support computer communications but will foster another revolution, the transition of existing analog services, particularly voice communications, to digital. Thus the performance of satellites in digital environments will be an increasingly important issue. If satellites can adapt to provide high quality ISDN services then this technology will do well in the 1990s; if not satellites will be consigned to niche markets.

At the heart of modern packet technologies are protocol definitions and agreements used to manage the communications processes and make possible the interoperability of heterogeneous multi-vendor systems. Two important architectures for these technologies are called Open Systems Interconnection (OSI) and Integrated Services Digital Network (ISDN). Both are the subject of on-going international development and standardization efforts.

OSI is primarily concerned with communications between computer systems, while ISDN is largely concerned with digital service for telephone networks, central office technology, and digital service to customer premises. OSI and ISDN are complememtary with respect to many future computer and communications services.

OSI is particularly important to the science community which has a large investment in networks and systems using current generation technology that is planned for migration to OSI. As ISDN becomes available, it will target business applications as its first market but will be valuable for science as well.

OSI and ISDN represent a challenge for satellites because they define what is becoming an increasingly pervasive environment in which satellites must operate. Further, because the packet technologies depend on the exchange of protocol messages to manage the communications processes, the propagation delay inherent in satellite links tends to degrade communications performance by slowing the exchanges of protocol messages needed to manage the communications processes. The effect may be negligible or severe depending on the type of protocol being employed and the type of application being served. High Level Data Link (HDLC) protocols have in fact been developed to compensate for satellite delay however, and these have generally performed well.

Most communications protocols however have been developed through the cooperative efforts of computer manufacturers, communications carriers, and telephone companies with relatively little input from the satellite communications industry. As a consequence most communications protocols have not been optimized for use over satellites. A review of the technical challenges for satellites under ISDN and current efforts to include satellites in the standardization process are discussed in our earlier work entitled *NASA and the Challenge of ISDN: The Role of Satellites in an ISDN World,"* by The University of Colorado, Center for Space and Geosciences Policy.

The principal tasks for the satellite industry are to work with standards bodies to optimize communications protocols for use with satellites, and to perfect satellite technology to better adapt it to the digital environment. This has for instance lead to the creation of the Satellite Coalition for ISDN under the leadership of Hughes Communications and INTELSAT in 1986 with some 30 organizations actively participating.

Neither OSI or ISDN standards are complete, and opportunities to introduce modifications exist. Critical parts of OSI, particularly the Network Management protocols are incomplete but are now receiving considerable attention. Important work on OSI upper layers also remains to be done. OSI is expected to be viable by the early 1990s but continuing refinements will be required for many years before it is mature.

ISDN standards agreements are still not complete but various vendor-specific islands of services for basic-rate interface (two bearer channels plus a signaling or data channel (2B+D)) services or 144 kbits/sec have begun to be available. Hundreds of companies are expected to be using ISDN by 1991 with the technology viable by 1992. Broadband ISDN standards are also progressing but will be longer in development and deserve priority attention by the satellite community as well.

Tests of selected protocols modified to provide improved performance over satellites have already demonstrated that modifications are feasible without significantly impacting other applications. It is however a formidable task to review all existing protocols, track on-going protocol development, develop appropriate solutions where required, participate in the necessary standards committees, and win industry consensus on the appropriate modifications. Alternatively, focusing on critical issues such as File Transfer Access and Manipulation (FTAM) protocol modifications may be all that is feasible.

3.5.4 Commercial carriers

The telephone companies and interexchange carriers are the primary commercial entities that dominate and define the communications market infrastructure. The nature of their terrestrial services including the technology, standards, and rate structures both proscribe and create many of the opportunities for services that can be provided by satellites. It also defines the opportunities and conditions under which ACTS might compete with and complement terrestrial services.

At the present time switched analog voice service continues to be the dominant communications application, however applications for digital services continue to grow. Within the science community, digital communications applications already dominate. With the coming of primary rate ISDN in the early 1990s voice applications will begin to migrate from analog to digital technology. Later, as the transition to broadband ISDN occurs, circuit oriented digital communications services will give way to a connectionless mode services that utilize the packet oriented architecture of broadband ISDN. This, in broad outlines, represents the probable evolution of communications technology that satellites as well as most terrestrial carriers will need to accomodate. ACTS will fly approximately in the 1992-1995 time frame when primary rate ISDN services will be proliferating but the adaptability of ACTS technology to broadband ISDN will be the most important challenge.

As the telephone companies and common carriers continue to convert their terrestrial networks to optical fiber, the terrestrial networks represent increasingly formidable competition for communciations satellites. The fiber networks have advantages in longevity, bandwidth, bit error rate, and the potential for lower cost.

The life of a fiber link is not well understood but many believe it to be 20 to 30 years. This compares with a life expectancy of about 10 to 15 years for communications satellites. Key factors determining the life of a communications satellite are its supply of station-keeping propellant and longevity of its batteries and power supply. Fiber optic installations have no equivalent terminal process but power failure and physical damage is a continuing problem.

COMSAT has been trying to promote a method for obtaining longer life from its communications satellites using a method known as the COMSAT Maneuver. Two satellites are placed in approximately the same orbital position and allowed to follow a North-South drift to minimize the amount of station keeping propellant required thus extending their life and improving their competitiveness.

The introduction of optical fiber offers the potential for significant rate reductions. For roughly the same installation cost, fiber cable offers at least a factor of 100 increase in capacity over copper. However, this savings is offset by the cost of the new termination and switching equipment needed to accomodate the increased bandwidth.

Although the tariffs charged by carriers have been dropping, they still largely reflect the traditional voice service pricing structure. There is considerable reluctance on the part of the carriers to lower prices for fear of devaluing their voice market, their primary source of income. Secondly, regulatory constraints and inertia further inhibit change.

Thus the terrestrial common carriers have little incentive to develop new services that take unique advantage of low cost wide bandwidth facilities. Although even modest price reductions in terrestrial services present a challenge for communications satellites, the opportunity exists for satellites to meet user needs for new types of wideband services such as video, multi-media, and business and scientific data applications.

If common carrier tariffs remain high, this will create incentives for the development of private, dedicated fiber networks and high capacity satellite services. According to an analysis by Telecommunications Associates of Laguna Niguel, California, under current common carrier tariffs and at a requirement level of 4 to 6 DS–3 (45 MBit/sec) channels, large government communications clients such as NASA or the Air Force, can afford to build their own fiber optic links between any two points. If low cost right of ways were available, for example if the Federal Highway Administration were to cooperate, then the break even point could drop to as little as 2–3 DS–3 links.

Thus the improved cost/performance ratio for fiber optics tends to reduce the natural monopoly enjoyed by the common carriers and there is likely to be both a migration of users away from common carriers, as well as considerable pressure to reduce the rates that the common carriers charge or are allowed to charge by the regulatory agencies. This analysis suggests the type of challenging economic regime in which future satellites would compete.

A variation on the above scenario is to use the common carriers from POP (point of presence) to POP and then to install dedicated fiber to the user sites. The motivation for this arises from the fact that many of the problems associated with a link are with the local telephone companies who service the "last mile." Concerns over lack of uniform standards, bit error rates, reliability, systems availability, and access charges make by-pass alternatives attractive to users.

The lack of uniform communications standards and interface protocol arrangements between the various entities that comprise the national network is a problem that has become increasingly significant in the post-divestature environment.

The difficulty in developing common standards agreements between the regional Bell operating companies, the more than 1000 small independent telephone companies, and the long distance carriers, together with the uneven process of upgrading facilities has made it difficult for the growth of advanced communications services such as ISDN. In many instances new central office equipment has been installed that is incompatible with equipment in other regions. In addition, users must deal with complex company jurisdictions and pricing policies, and inflexible rate structures.

This situation is creating a window of opportunity for satellites to bypass these problems and provide advanced uniform services from end-to-end. This is a problem that ACTS can solve. Even when the seven regional Bell operating companies come to agreement on common standards and implement solutions, it may take much longer before the many independent telephone companies are able to conform. This problem is exasperated in point-to-multipoint applications where advanced communications processes must access distributed resources. Here the mesh connectivity capability of ACTS together with its ability to provide a uniform solution is particularly advantageous.

At the institutional or regional level, if one considers that the locations where ISDN services are available will be like islands for some years to come, ACTS can also link these islands together.

3.5.5 Optical disks

The growing use of optical disks represents a challenge to satellite communications and other carriers for certain applications, particularly where interactive communications or timely delivery of data is not required.

The costs of production and duplication have dropped dramatically to the point where mailed or hand-carried optical disks can compete very effectively with VSAT terminals which might otherwise be the only available communications options for remote locations not served by terrestrial networks.

The U.S. Mail and other physical message carrier services compete very effectively with satellite and terrestrial data communications services when "transmitting" optical disks. An often heard communications homily goes: "Question: What is the widest bandwidth, coast-to-coast communications channel available? Federal Express carrying CD-ROMs counter-to-counter."

This points up a fact of life for many institutions who need to deliver data to distant locations. Large volumes of data are routinely shipped on magnetic tape, floppy disks, or CD-ROMS by institutions that generate or process scientific data. Both the economics and practicality favor this approach for shipping large volumes of data where real-time or interactive access is not required.

4 Research Approach

In this section we discuss the objectives and program of work for this research report.

The basic approach in this research was to identify science user communications requirements and modes of activity by conducting a survey of science programs in the Boulder Colorado area. We took the Boulder area science community as a sample recognizing that while there are many diverse activities in this area, it may not be a fully representative sample. Nevertheless it is an inexpensive way to get a start on the problem.

In our approach, the potential science applications of ACTS were characterized by defining linkages between ACTS subsystem technologies and the contributions they could make to the various types of science communications activities. This provided an analytical method for evaluating communications needs in the wider scientific community, and for identifying those activities which can be best served by ACTS capabilities. This methodology was also useful for guiding further inquiry during the survey, and for analyzing the results.

The factors considered in this research include the lessons learned from the previous research performed by CSGP, the elements of the local communications infrastructure in the Colorado area including competitive technologies such as terrestrial networks, and projections of future growth in telecommunications services and user needs.

4.1 Objectives

The first objective of this research is to identify potential science applications of the NASA Advanced Communications Technology Satellite (ACTS).

A second objective is to identify fruitful ways to enable science users to participate in the ACTS experimental program.

4.2 Program of work

The overall program of work for this report consists of:

- general research on communications related issues in order to develop a context,
- survey of science-related activities and programs in the local area,
- interviews of selected scientists and associated telecommunications support personnel whose projects have significant communications requirements,
- development of a methodology for identifying linkages between ACTS functionality and user communications activities and modes of operation, and
- analysis of survey results and projection of conclusions to a broader scale.

4.3 User survey

The primary focus of the user survey was to study the communications needs of science programs being conducted by investigators in the Boulder, Colorado area, and to determine the applicability of ACTS to meet these needs. Principal investigators and telecommunications managers were interviewed to determine the types of communications modes needed for their activity.

In the survey, individuals at the following institutions were contacted: the University of Colorado, the National Center for Atmospheric Research (NCAR), the National Oceanographic and Atmospheric Administration (NOAA), the National Institute for Science and Technology (NIST), and the National Telecommunications and Information Administration (NTIA).

4.4 Methodology

A methodology was developed for conceptually analyzing ACTS applicability to various science communications requirements. It can serve as an analytical tool for comparing various communications modes in terms of their compatibility with ACTS functionality.

The methodology was developed in conjunction with interviews of science investigators and telecommunications personnel to identify the various modes and types of communications activities used for science, and their compatibility with ACTS capabilities. From this data, we defined linkages between the specific communications modes needed for science activities and the elements of ACTS subsystem technology that support them. The results can be presented using a matrix with ACTS functionality on one axis and generic user modes of communications on the other axis. Values of the matrix elements could represent the degree of linkage or applicability.

This technique can provide a way of generalizing from specifice instances of ACTS applicability, to whole classes of science applications. It can be used to compare the merits of other communications technologies and it aids in the overall definition of the fit between ACTS capabilities and the evolving information, communications and data needs of the science community.

5 Colorado User Survey

In this section we report our survey findings beginning with a description of the survey approach and a listing of some of the Colorado area organizations and institutions involved in science. The survey findings are grouped into five general catagories although many topics tend to overlap.

First we review telecommunications facilities in use by the Colorado science community that are relevant to ACTS and to telecommunications in general. Next we discuss technical and science related activities that may impact present and future telecommunications requirements. Thirdly we discuss some of the science programs that may have significant telecommunications requirements and may benefit from ACTS capabilities. A section on technical issues focuses on topics that are specifically relevant to ACTS. Finally we report on science user interest, concerns and requirements for participation in the ACTS program.

5.1 Survey approach

One of the primary methods used in this study to identify potential ACTS users and their requirements was to conduct a survey of science investigators and their communications support staff.

The survey was limited to the Colorado area because of the logistic simplicity, and the availability of a large number and variety of science programs being pursued in the area. The microcosm is believed to be sufficiently rich that most of the conclusions drawn from this group could be extended to the science community as a whole. At least, they will form useful working hypotheses for future investigation

Consistent with the lessons learned from our earlier research, this survey placed more emphasis on interviewing telecommunications support staff so that approximately equal numbers of these personnel and science investigators were interviewed. It should be noted that in some groups, particularly in the smaller research groups, there is no telecommunications manager. For them the necessary support services are provided by equipment vendors with some support duties being absorbed by the research scientists.

One of the early observations made in this research was that potential science users have different requirements for participation in the ACTS program than do the ACTS experimenters who are studying the technical aspects of ACTS performance. This study attempts to differentiate between ACTS experimenters and science users.

The survey method relied on indepth interviews rather than on written questionnaires. The topics were guided by the interviewer who began each interview with a brief introduction to the ACTS program and its communications capabilities. The duration of the interviews averaged over two hours and included identification and discussion of the information listed in the Table 5.1.

Table 5.1. Topics for Communications Survey Interviews

- Organization and contact persons
- Description of science program
- Activities involving communications (e-mail, remote processing, etc.)
- Modes of communications required (voice, data, video, etc.)

- Location of remote sites (computers, users)
- Terrestrial networks, carriers and satellite services used/planned
- Service parameters required/used (data rates, protocols, etc.)
- Future communications needs
- Earth station and work station requirements
- ACTS programatic and technical issues
- Opportunities to utilize ACTS

5.2 Organizations and institutions

There are a significant number of major organizations in the Colorado area involved in scientific research most of which contain numerous divisions, research centers and affiliated institutes.

The interviews for this research were conducted at NCAR, NOAA, NTIA, NIST and selected departments at the University of Colorado at Boulder.

The University of Colorado is the largest science employer in the area and has over 450 researchers, engineers, and full-time support staff involved in space research. These are distributed across some 22 discipline-specific laboratories and institutes as well as academic departments at all four campuses. At present, over 250 separate contracts and grants are in force.

Due to the limited resources for this research project, it was not possible to conduct interviews in all possible centers and departments involved in science and applications, however it is believed that an expanded survey could yield additional valuable information concerning ways in which ACTS could serve science requirements.

The following tables illustrate the breadth of science and engineering activities in Colorado. Table 5.2 lists major Colorado organizations involved in scientific research.

Table 5.3 lists the departments, research centers and institutes at the four University of Colorado campuses whose research is related to space. The third column of the table indicates whether the department is engaged in science, engineering or policy research and is marked SCI, ENG, or POL accordingly.

Table 5.4 lists the departments within the NOAA Environmental Research Laboratory organization plus the NOAA/Joint Institutes located in Boulder and other on university campuses throughout the country.

Table 5.4 lists the eleven research divisions within the NOAA Environmental Research Laboratory (ERL) organization. Also listed are the six NOAA/Joint Institutes that also perform research in the environmental sciences. Five of the ERL divisions and one Joint Institute are located in Boulder, Colorado. Most of the ERL divisions and Joint Institutes have various requirements for data communications with one another and this list illustrates that a great deal of NOAA communications involves laboratories in Boulder.

Table 5.2. **Colorado Organizations Engaged in Science Programs**

	UNIVERSITY
UCB	University of Colorado at Boulder
UCCS	University of Colorado at Colorado Springs
UCD	University of Colorado at Denver
UCHSC	University of Colorado Health Sciences Center, Denver
CSU	Colorado State University
CSM	Colorado School of Mines
UCAR	University Corporation for Atmospheric Research
NCAR	National Center for Atmospheric Research
	GOVERNMENT
NOAA	National Oceanographic and Atmospheric Administration
NIST	National Institute for Science and Technology (formerly NBS)
NTIA	National Telecommunications and Information Administration
USGS	United States Geological Survey
SERI	Solar Energy Research Institute
	MILITARY
DoD	National SDI Testbed, Colorado Springs
	U.S. Air Force Academy
	Peterson Air Force Base
	USAF Space Command
NORAD	North American Air Defense Command
	INDUSTRY
	Ball Aerospace, Boulder
	Martin Marietta Aerospace, Denver
	IBM Corporation, Boulder
	Ford Aerospace, Colorado Springs
	External Tanks Corporation, Boulder
	EG&G Inc. (DOE, Rocky Flats Plant), Denver

Table 5.3. Space Related Programs at University of Colorado

CU-BOULDER

CASA	Center for Astrophysics and Space Astronomy	SCI
CATA	Center for Atmospheric Theory and Analysis	SCI
LASP	Laboratory for Atmospheric and Space Physics	SCI
JILA	Joint Institute for Laboratory Astrophysics	SCI
ICS	Institute for Cognitive Science	SCI
SBO	Sommers-Bausch Observatory	SCI
FP	Fiske Planetarium	SCI
UNAVCO	University Navstar Consortium	SCI
CLgFT	Center for Low Gravity Fluid Dynamics and Transport Phenomena	SCI
CIRES	Cooperative Institute for Research in the Environmental Sciences	SCI
INSTAAR	Institute of Arctic and Alpine Research	SCI
NSIDC	National Snow and Ice Data Center	SCI
WDC-A	World Data Center-A For Glaciology	SCI
CSES	Center for Study of Earth From Space	SCI
CCAR	Colorado Center for Astrodynamics Research	SCI
APAS	Department of Astrophysical, Planetary and Atmospheric Sciences	SCI
	Nuclear Physics Laboratory	SCI
	Department of Anthropology	SCI
	Department of Geography	SCI
	Department of Geology	SCI
	Department of Physics	SCI
AES	Department of Aerospace Engineering Sciences	ENG
ECE	Department of Electrical and Computer Engineering	ENG
ITP	Interdisciplinary Telecommunications Program	ENG
BSTC	Bioserve Space Technology Center	ENG
CAAI	Center for Applied Artificial Intelligence	ENG
OCSC	Optoelectronic Computing Systems Center	ENG
CSSC	Center for Space Structures and Controls	ENG
CSC	Center for Space Construction	ENG
ITP	Center for Advanced Research in Telecommunications	ENG
GAS	Get-Away Special Student Project	ENG
	Data Libraries and Information Systems	ENG
	Onizuka Space Operations Laboratory	ENG
CSGP	Center for Space and Geosciences Policy	POL

Table 5.3 cont'd. Space Related Programs at University of Colorado

CU-COLORADO SPRINGS

	Department of Physics	SCI
EE	Department of Electrical Engineering	ENG
IMGEL	Image, Map & Geographic Education Laboratory	SCI
MERL	Microelectronics Research Laboratory	ENG
SPCL	Signal Processing/Communication Laboratories	ENG
SFSL	Space and Flight System Laboratory	ENG
EML	Electromagnetics Laboratory	ENG

CU-DENVER

	Departments of Physics	SCI
CES	Center for Environmental Sciences (Anal Chem Lab)	SCI
CMG	Computational Math Group	SCI

CU-HEALTH SCIENCES CENTER

	Space Medicine Research Program	SCI
	Space Physiology	SCI

Table 5.4. NOAA Environmental Research Laboratories and Joint Institutes

NOAA – ERL

STORM	Storm Program Office	Boulder, CO
AL	Aeronomy Laboratory	Boulder, CO
ESG	Environmental Sciences Group	Boulder, CO
SEL	Space Environment Laboratory	Boulder, CO
WPL	Wave Propagation Laboratory	Boulder, CO
NSSL	National Severe Storms Laboratory	Norman, OK
GLERL	Great Lakes Environmental Research Group	Ann Arbor, MI
AOML	Atlantic Oceanographic and Meteorology Lab	Miami, FL
PMEL	Pacific Marine Environmental Laboratory	Seattle, WA
GFDL	Geophysical Fluid Dynamics Laboratory	Princeton, NJ
ARL	Air Resources Laboratory	Silver Spring, MD

NOAA/JOINT INSTITUTES

CIRES	Coop Inst for Research in Environmental Sciences	CU, Boulder, CO
WDC	World Data Center-A	CU, Boulder, CO
NSIDC	National Snow and Ice Data Center	CU, Boulder, CO
CSES	Center for Study of Earth From Space	CU, Boulder, CO
CIRA	Coop Inst for Research in the Atmosphere	CSU, Ft Collins, CO
CIMMS	Coop Inst for Mesoscale Meteorological Studies	OU, Norman, OK
CIMAS	Coop Inst for Marine and Atmospheric Studies	UM, Miami, FL
JISAO	Joint Inst for Study of the Atmospheric & Ocean	UW, Seattle, WA
JIMAR	Joint Inst for Marine and Atmospheric Research	UH, Honolulu, HI

5.3 Inventory of science related telecommunications facilities in Colorado

5.3.1 Networks used for science

Terrestrial communications networks are utilized by nearly all scientific institutions in Colorado. The network infrastructure is complex, involving numerous independent, overlapping and cooperative physical and administrative entities. Some of the networks that are important for science in Colorado are described below.

The primary gateway through which most science institutions access other national and worldwide facilities, is at the National Center for Atmospheric Research (NCAR) in Boulder. NCAR is a main artery for the Internet (NSFNET) and the NASA Science Internet (NSI). The capacity of the main communications arteries serving institutions in Colorado varies from T1 rates (1.5 Mbits/s) downward, but there are plans to upgrade these and to upgrade the Internet link at NCAR to DS-3 (45 Mbits/s) by 1991.

Internet/NSFNET

The Internet encompasses all U.S. government networks that utilize the DoD standard Transmission Control Protocol/Internet Protocol (TCP/IP). The Internet evolved from DoD's ARPAnet, then other nets developed and linked to it. Internet interconnects various government agencies including DARPA, DOE, HHS, NASA, and NSF, forming a collection of approximately 60,000 hosts. Recently it has come to be called NSFNET as the main science network in the U.S. with NSF as the lead agency. The primary backbone of NSFNET uses T1 links and its topology is shown in Figure 5.1.

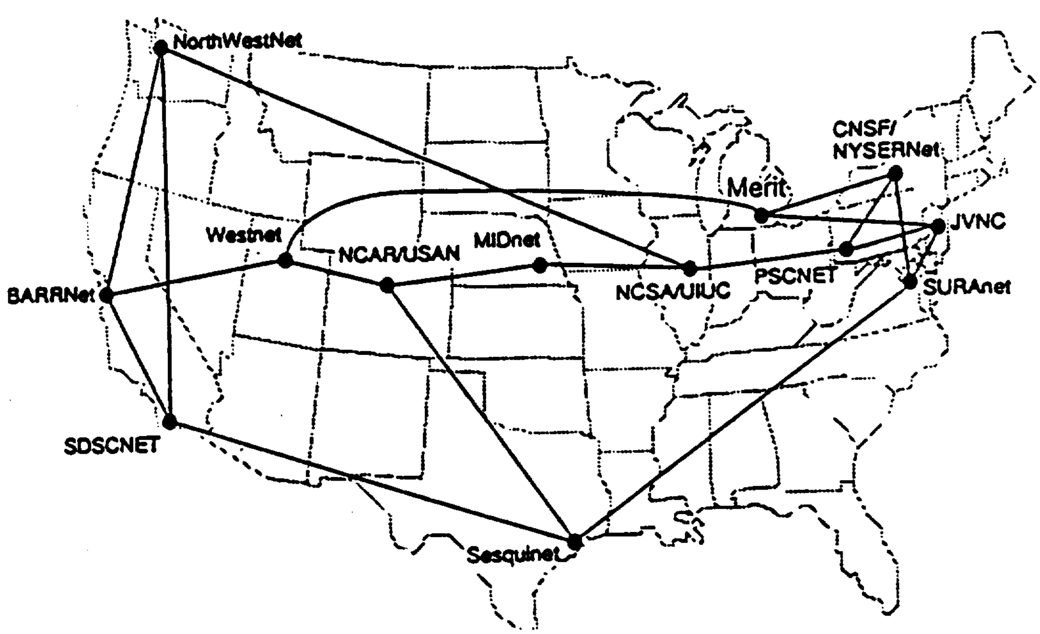


Figure 5.1. NSFNET T1 Data Network Backbone Topology

NSF also sponsors several major regional networks and supercomputer networks. The supercomputer networks include the Jon von Neumann National Supercomputer Center Network (JVNC-NET), the National Center for Supercomputing Applications Network (NCSANET), the Pittsburg Supercomputer Center Academic Affiliates Group Network (PSCNET) and the San Diego Supercomputer Center Network (SDSCNET). Other networks sponsored by NSF include ARPANET, the Bay Area Regional Research Network (BARRNET), CSNET X25 Sites, MERIT, MIDNET, NORTHWESTNET, the New York State Education and Research Network (NYSERNET), the Texas Sesquicentennial Network (SESQUINET), the Southeastern Universities Research Association Network (SURANET), the University Satellite Network (USAN), and WESTNET comprising sites in Colorado, New Mexico, Arizona and Utah, These NSF networks and supercomputer networks are shown in Figure 5.2.

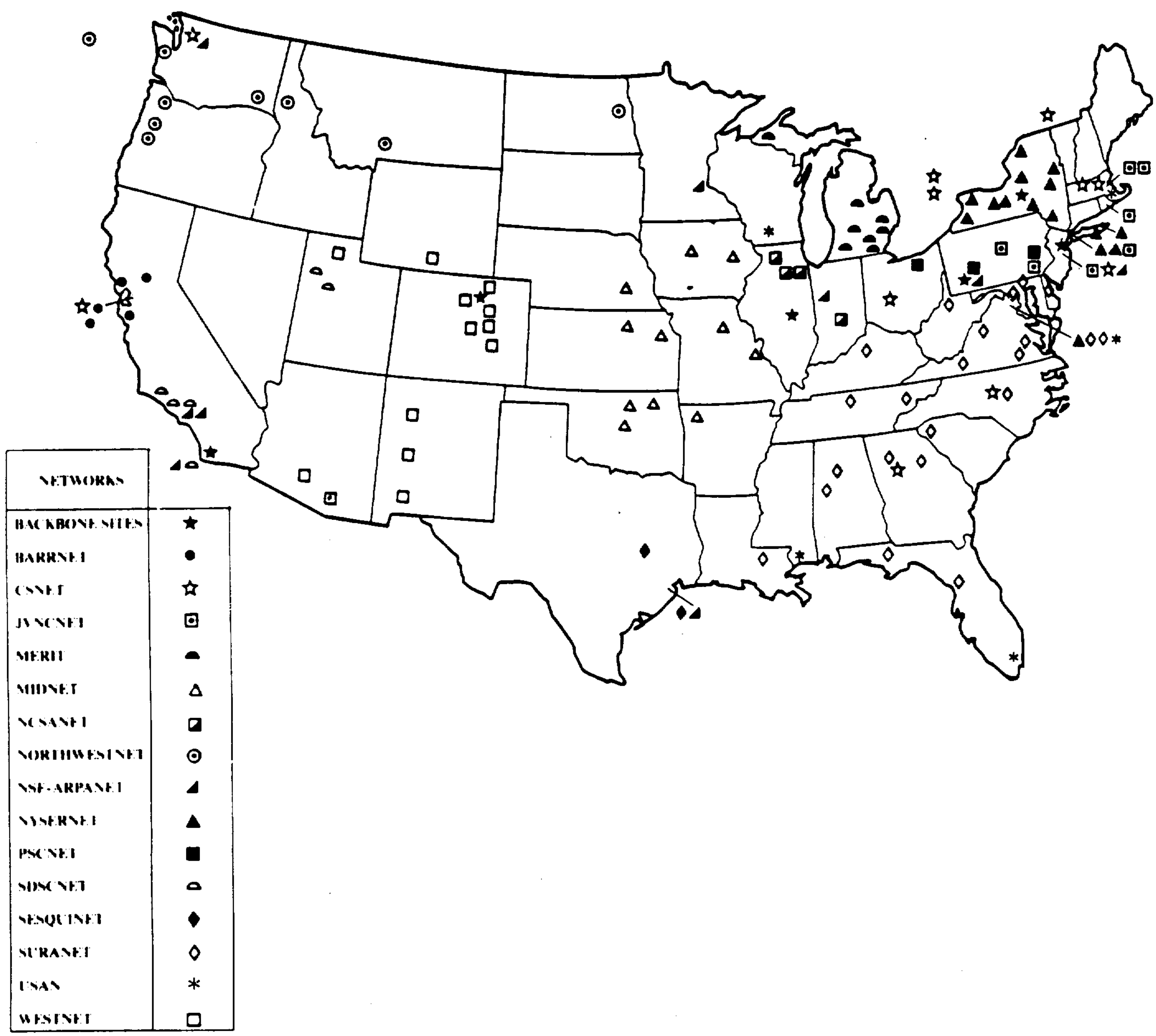


Figure 5.2. NSF Sponsored IP Networks

NSFNET is managed by Merit Corporation under the Michigan Education Research Triad consisting of Merit, IBM, and MCI. IBM donated all the hardware and software and MCI provided free installation and provides the transmission services at quite reduced rates.

NSFNET is part of the Internet and is linked to other TCP/IP networks around the world which comprise over 750 active physical networks and approximately 1/2 million users. Internet is growing exponentially and is moving toward a worldwide network. It already extends to Europe. Recently Norway and Canada joined, and links to Mexico, Japan and the Pacific Rim countries are being established.

There are no official links to eastern block countries, and U.S. policy requires that humans must be in the loop at all interfaces, for example, to hand carry tapes from one machine to the other. However, plans for links to China and the USSR are being worked on.

The NCAR site in Boulder, Colorado is both a supercomputer center and a regional network gateway for NSFNET serving institutions in Colorado and elsewhere in the region. The wide area network connections at NCAR are illustrated in Figure 5.3.

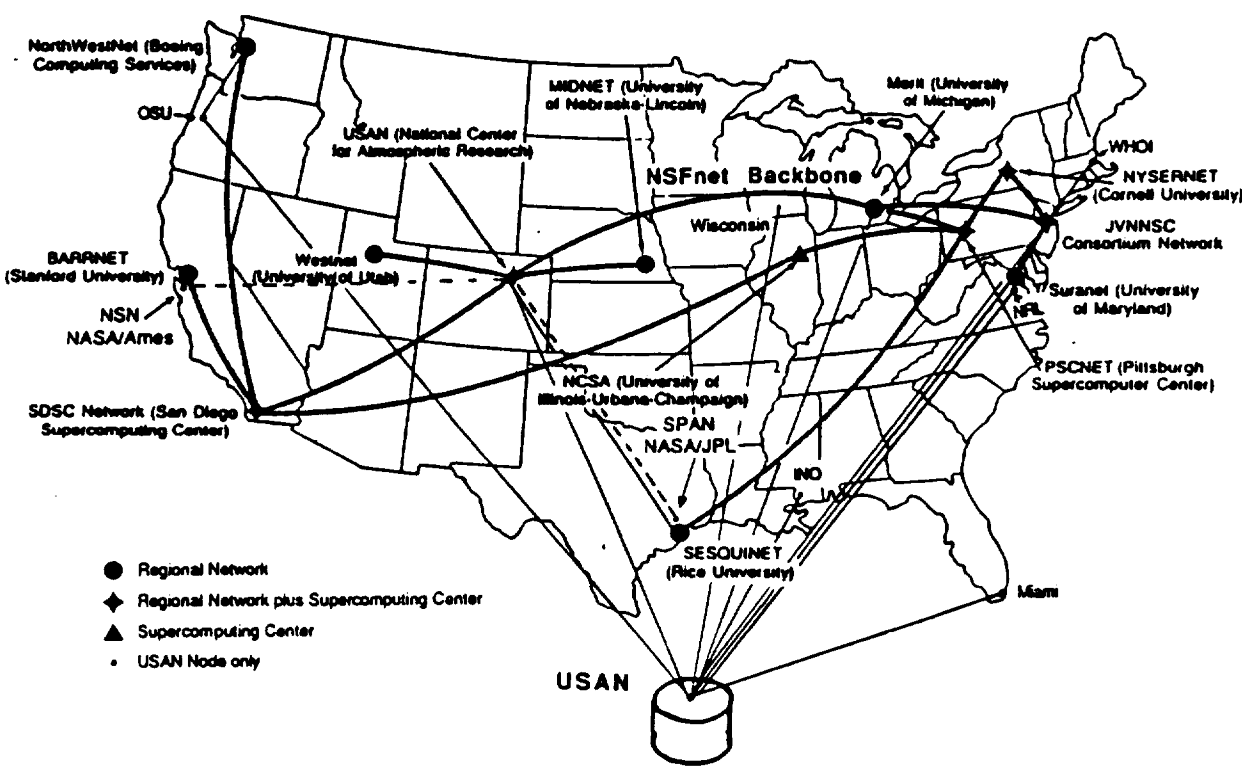


Figure 5.3. Wide area network connections at NCAR

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NASA Science Internet (SPAN, NSN)

The NASA Science Internet is a program of OSSA for the space science community that combines a subset of the Internet called the NASA Science Network (NSN) running TCP/IP protocols, with the Space Physics Analysis Network (SPAN) running DECNET protocols. The NASA Science Internet is illustrated in Figure 5.4. Both the NSN and SPAN support network functions including remote login, file transfer, and electronic mail, and NSI provides important gateways between NSN and SPAN for these functions. The NASA Science Internet is currently expanding via the Pacific Communication Network (PACCOM) from Hawaii to Japan, Australia, and New Zealand. A link to Mexico is also being established. NSI formally cooperates with NSFNET and shares some physical lines. The NASA Science Internet budget pays for the NSI backbone, tail circuits are paid for by individual science programs that utilize the network. The NASA Science Network is a subset of the Internet that consists of several hundred host computers at NASA centers, universities, and contractor sites around the U.S. that use the TCP/IP protocol. The Space Physics Analysis Network consists of approximately 2300 hosts located at NASA and ESA field centers, universities and research institutions located throughout the U.S., Canada, Europe and Japan. SPAN currently uses the DECNET Phase IV communications protocol. The primary SPAN link from NCAR in Colorado to JPL runs at 56 kbits/s.

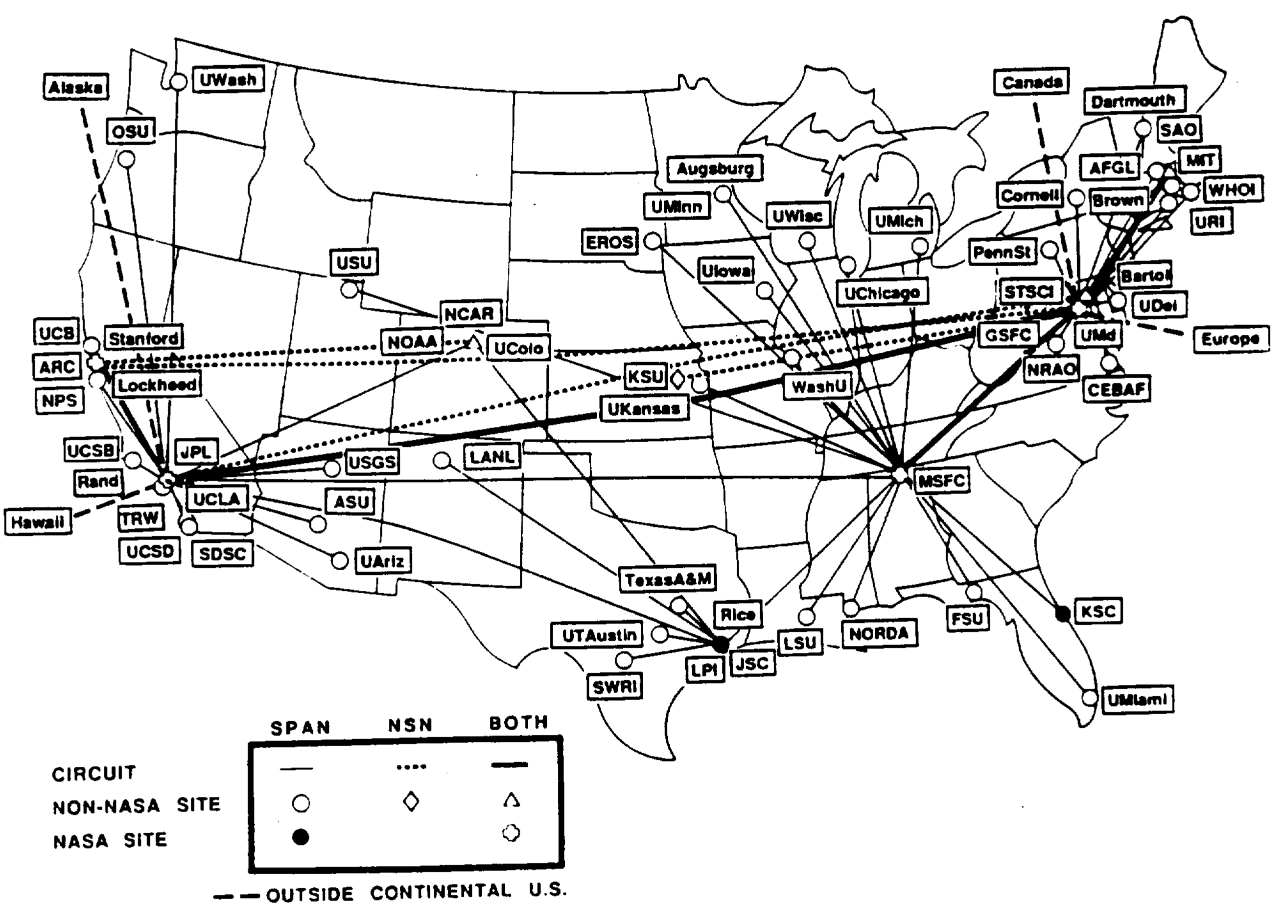

Figure 5.4. NASA Science Internet

DECNET Internet

SPAN is part of a larger network known as the DECNET Internet which consists of networks owned by institutions and agencies such as the DOE, The University of Texas System, and the CERN-European Laboratory for Particle Physics. These form a larger group of about 12,000 hosts that are able to communicate with each other using the DECNET Phase IV protocol.

Through the use of gateways between different networks, such as those between NSN and SPAN provided by NSI for the space science community, the Colorado science community is able to access hosts and other users on nearly any of the Internet and DECNET Internet networks throughout the U.S. and the world. With appropriate authorization users can perform remote logins on hosts anywhere in the network, execute file transfers, and send electronic mail. These functions can generally be performed using local terminals at the participating institutions or using remote terminals or personal computers from home or field sites.

WESTNET

WESTNET is another important network in Colorado. It is sponsored by NSF and operated by Colorado State University. It links universities, government labs, and commercial companies in Colorado, New Mexico, Arizona, and Utah. All links run at 56 kbits/s except there is a new T1 (1.5 Mbit/s) link from CU to NCAR and some Ethernet links (10 Mbits/s) mainly in New Mexico. WESTNET is heavily used for science communications between institutions in these states. WESTNET uses TCP/IP protocol and is part of the Internet.

Colorado Supernet

Colorado Supernet is a project of the Colorado Advanced Technology Institute (CATI) which originally funded the network. Although the Supernet was established first, it has now become a subset of the Colorado portion of WESTNET which funds many of the connections. The WESTNET gateway is at CU.

MFENET

The University of Colorado maintains a link to the magnetic fusion energy network (MFENET) for fusion research. The energy services network is run by the DOE, and the research program is centered at Lawrence Livermore National Laboratory, in California. Access to the network is provided by NCAR in Boulder on a 9.6 kbit/s link. The network provides exceptional graphics and file transfer capabilities. Planning is underway to upgrade it to EasyNet.

BITNET

A link that is used for BITNET traffic operates between the University of Colorado and Utah State. The link operates at 9.6 kb and uses DECNET protocol. There is some interest in collapsing it into WESTNET at some point but this will require a protocol change. The BITNET backup is via SPAN.

Consolidated Scientific Computing System (CS^2) Network

The Consolidated Scientific Computing System network serves NOAA and NIST. It links all of the NOAA Environmental Research Laboratory (ERL) sites to one another via links to the primary ERL computing facility at Gaithersburg. The other ERL sites include Ann Harbor, Boulder, Miami, Norman Oklahoma and Seattle. Boulder has two 56 kb circuits bundled in a T1 line to Gaithersburg and Miami has one. The links to all of the other sites run at 9.6 kb.

CU Four-Campus Fiber Network

The University of Colorado has in place a fiber optic network interconnecting its four campuses located at Boulder, Colorado Springs, Denver and at the Denver Health Sciences Center. This facility replaces the microwave system that formerly linked the campuses.

The fiber network is currently used for video conferencing and instructional video distribution. The network accommodates both two-way video conferences between the campuses and video classrooms.

Although it is not presently used for data transmission, it is capable of high-speed data transfer between all four campuses of the CU system. Utilization of this capability is being considered for the future. The present hardware has the capacity for one T1 channel and could be easily upgraded to four T1 channels.

CU-Net/CU Ethernet

The University of Colorado has links between all four campuses and each has individual port-on access to NSFNET, ARPAnet, SPAN, Bitnet, Supernet and Westnet. In addition, on the Boulder campus high-speed direct NASCOM lines are used for the Solar Mesospheric Explorer (SME) satellite and payload flight control.

The University of Colorado at Boulder uses a local area network with fiber optic links to interconnect its campus facilities. In close proximity to the Boulder campus are NOAA, NCAR, NTIA, NIST and other agencies that are linked to the CU network. All of these groups are linked to NCAR in order to access the NCAR supercomputers, the Internet, the NASA Science Internet, and other gateways.

CU has a good fiber plant that was recently installed along with the new phone system, but projections suggest it may turn out not to be inadequate. CU also needs higher capacity on its campus LAN. The campus network currently uses Ethernet technology (10 Mbits/s) but the University is considering upgrading to Fiber Distributed Data Interface (FDDI) technology that runs at 100 Mbits/s.

The link from the CU-Boulder campus network to the NCAR supercomputer site and Internet node, has recently been upgraded from 56 kbits/s to T1 running TCP/IP protocol. The purpose of the upgrade was primarily to handle wideband burst requirements rather than average daily volume.

Departmental local area networks

Throughout the University of Colorado, NOAA and other area science organizations, more and more groups and departments are installing LANs and linking to other LANs within their discipline, as well as to the campus area network and to wide area national networks. Most departmental LANs are operating at 4 to 9.6 kb.

Boulder Campus telephone system and computer network wiring plant

Approximately six years years ago the CU-Boulder telephone system was upgraded with the purchase of an AT&T System 85. In addition a digital jack providing access to the Campus local area network was installed at every phone jack. These connections operate at 9.6 kbits/s, but can be programmed for lower speeds, terminal adaptors are used and modems are not required. Large modem pools for off-campus access are also supported. Thus computer and communications use is no longer confined to University laboratories, but has been extended to offices, class rooms and even dormitories.

Whether CU has future compatibility for ISDN with the present phone system depends on the upgrade options for the System 85. Some originally wanted CU to purchase an AT&T No. 5ESS or similar switch supporting ISDN, but the System 85 was cheaper. The System 85 is a digital version of the old Dimension product. It has the same organization and logic as Dimension but totally digital internal communications and PCM coding. A possible upgrade route to ISDN is to add (numerous) integration modules and enhancements. This would make the System 85 compatible with the System 75, a system designed for forward compatibility with ISDN and T1 interfacing but otherwise too small for CU needs. This adaption of the System 85 is called the Definity model. It should be noted that ISDN is currently available elsewhere in Boulder since the main US West telephone exchange in central Boulder has recently been upgraded to a No. 5ESS. ISDN services are also available in Denver.

U.S. West communications services

US West, the regional Bell operating company for Colorado, is based in Denver and serves a 14 state region. It offers a variety of digital services including ISDN (2B+D) in many exchanges. It supplies the fiber lines for the CU Four-Campus Fiber network, and it has installed fiber from Fort Collins to Pueblo covering all of the major cities along the Colorado Rocky Mountain front range.

US West is considering trials of Metropolitan Area Networking (MAN) technology following IEEE 802.6 standards. It could provide high-speed multi-point services over optical fiber operating at 155 Mbps or higher on loops up to 30 miles. A companion technology for interconnecting MANs that is being examined would use the Bellcore Synchronous Optical Network (SONET) standards for broadband ISDN. SONET can be deployed both in the interoffice and loop environments. Bellcore has proposed user-network interfaces of 155 Mbit/s for SONET and an additional standard at about 620 Mbit/s which is under study. This capability could serve large commercial and institutional users.

5.3.2 Communications satellites in use in Colorado

The University of Colorado and National Center for Atmospheric Research are the primary Colorado users of satellites for scientific communications. The satellites and associated facilities are summarized below.

USAN satellite

The National Center for Atmospheric Research (NCAR) makes the most extensive use of satellites for scientific purposes in Colorado. NCAR has its own network called the University Satellite Network (USAN) illustrated in Figure 5.3. USAN operates in the Ku band and broadcasts from NCAR to 8 remote sites including Woods Hole Oceanographic (WHOI), Miami, and Oregon State (OSU) at Corvalis, Wisconsin, Merit/University of Michigan, Maryland, the Institute for Naval Oceanography (INO) in Bay St. Louis, and the Naval Research Laboratory (NRL) in Washington, DC. Each remote site filters for its own traffic. The USAN satellite does not use TDMA, but rather FDMA. NCAR transmits at 244 kbits/s and the remote sites reply at 56 kbits/s. The network uses TCP/IP protocol. Time on the satellite is purchased from Vitacomm, a company that has pioneered Ethernet-to-Ethernet satellite connections. The system is very economical, NCAR pays for the uplink and the remote sites pay for the return plus their own local maintenance which comes to about $18k/year. Figure 5.3 illustrates the USAN satellite network with the participating universities.

NCAR plans to establish a similar service to Mexico using a different satellite.

NCAR TVRO satellite

NCAR receives weather data, TVRO from the National Weather Service. This data is not received directly from the NWS but comes via Zepher, a private company.

CU satellite link to Princeton

The University of Colorado utilizes a satellite connection to the John von Neumann Research Center in Princeton, NJ. The service operates at 56 kbits/s outgoing and 112 kbits/s incoming to CU. The University plans to abandon this satellite link because the NSFNET connection offers less delay and higher throughput.

5.3.3 Teleconference facilities

Television studio

CU produces about 16 hours of educational programming per day. The recently completed construction of two new television production studios on the Boulder Engineering campus will increase the output of video programming from the University.

Satellite uplink at CU-HSC

There is a Ku band uplink at the University of Colorado Health Sciences Center in Denver. It is capable of full/half duplex transponder operation with 400 watts of power. The dish is fully steerable and can see any satellite above a 5 degree elevation angle. The uplink subcarrier is available and could be used for data communications.

Satellite uplink at CU-Boulder

A Ku band satellite uplink at the University of Colorado Events Center is used for a variety of purposes including video conferencing. It is often used in support of meetings, conferences and public events held at the CU Events Center auditorium. It can support voice, data and broadcast video.

5.3.4 Supercomputers in Colorado

NCAR supercomputer facility

The National Center for Atmospheric Research (NCAR) in Boulder is a supercomputer site serving approximately 1200 users, 500 of whom are in the local area, while the others are distributed throughout the U.S., Europe and other parts of the world. There is however heavy use from the east coast corridor between Washington, DC and New York.

The NCAR Scientific Computing Divison (SCD) provides supercomputing resources and services that support research in the atmospheric, oceanographic, and related sciences. Facilities are emphasized for developing and executing large numerical models and simulations and for archiving and manipulating large datasets. The network and data communications capabilities required for a national research user community to access NCAR computational and data resources are also emphasized.

NCAR has assembled a computer network that offers a variety of hardware, software, and communications facilities. Functionally, the NCAR network has the following four components: distributed computing, mainframe computing systems, network servers, and a mainframe and server network (MASnet) and a Local Data Network (LDN).

Distributed Computing The NCAR Scientific Computing Division supports a state-of-the-art distributed computing environment. Through advanced telecommunications technology including local area networks (LANs), wide area networks (WANs), network gateways, user workstations, and window interfaces, SCD assimilates local and remote computers and computing systems into an integrated environment with the mainframes and network servers of the NCAR computing facility.

Local Access: Using a combination of ethernet technology, the Transmission Control Protocol/Internet Protocol (TCP/IP), other protocols and network gateways, most NCAR divisions enjoy full interconnectivity including access to the NCAR supercomputer facilities. Dedicated and dialup circuits can also be used to access the NCAR mainframe systems from dumb terminals or via a 1024 x 1024 port switch. SDC supports communications at NCAR and among the other NCAR organizational units throughout Boulder County with voice, data, and slow scan video services.

Remote Access: Until 1988, the public packet network service from Telenet was the principal avenue of access for remote users. Today NCAR is a node on selected national and international networks. These networks are the National Science Foundation Network (NSFNET), the NASA Science Network (NSN), NASA's Space Physics Analysis Network (SPAN), and Because It's Time Network (BITNET).

NCAR SCD has also managed a project called the University Satellite Network (USAN) to test satellite technology for high-speed remote interactive access. USAN connects NCAR with eight remote satellite sites in atmospheric, oceanic, and related sciences. This network also connects the remote sites to NSFNET, NSN, and SPAN resources. In addition, USAN provides connectivity to NSFNET for several regional networks (see Figure 5.3).

Mainframe Systems Mainframes in the NCAR computing network include a Front-end system, a CRAY-1A, and a CRAY X-MP/48. The Front-end is an IBM 4381 configured to support inter-activity. It has dual processors, 16 megabytes of memory, 20 gigabytes of disks, and 126 ports. It uses the IBM Virtual Machine/System Product (VM/SP) operating system.

The CRAY-1A is a Serial #3, the first CRAY-1 delivered with an operating system and error-correcting memory. It has a million, 64-bit (1 megaword [Mw]) words of memory and 600 Mw of disk storage.

The CRAY X-MP/48 has four processors sharing 8 Mw of memory. It also has a 256-Mw Solid-state Storage Device (SSD) and 2400 Mw of disk storage. Both the CRAY-1A and the CRAY X-MP/48 run the batch-oriented CRAY Operating System (COS).

Network Servers The NCAR supercomputers are not equipped for long-term storage of information. Instead, archival storage is concentrated in the Mass Storage System (MSS) and output is processed on the Text and Graphics Servers (TGS). MSS and TGS provide the storage and output services to both the mainframes and the distributed processors.

The MSS allows users to store and access massive amounts of data. On a daily basis, in 1988, the system handled about 3,000 requests involving about 800 gigabits. 1988 data listed the MSS as storing about 380,000 files totaling 60 terabits of information. The system consists of a control processor, as well as a tape farm and a disk farm.

The TGS consists of two XEROX laser printers and two DICOMED film recorders. Both text and graphics can be output from the laser printer.

Mainframe and Server Network (MASnet) MASnet provides a hardware/software mechanism for interconnecting the mainframes and the servers, as well as providing access to them from UCARnet and national networks. MASnet has been constructed from Network Systems Corporation HYPER-channel hardware components and from software written by NCAR SCD.

Local Data Network (LDN) The LDN provides direct transmission at close to 3 MBps (megabytes per second) between the MSS storage devices and the supercomputers. The LDN is an evolutionary development that reflects the use of large files and datasets at NCAR. It is also prototypical of the high-speed "backend" networks that many supercomputer centers are planning for the 1990s.

Table 5.5. 1988 Supercomputing Usage at NCAR

Discipline Area	Percent of Use
Climate	23%
Climate	
General Circulation	
Radiative Processes	
Satellite Meteorology	
Statistical Meteorology	
Oceanography	16%
Oceanography	
Basic Fluid Dynamics and Miscellaneous	6%
Basic Geophysical Fluid Dynamics	
Numerical Methods	
Turbulence	
Wave Processes	
Economic and Societal Impact Studies	
Computer Science	
Other	
Regional Meteorology	25%
Planetary Boundary Layer	
Dynamic Meteorology	
Mesoscale and Regional Scale Models	
Surface Conditions, Hydrology	
Tropical Meteorology	
Numerical Weather Prediction	
Objective Analysis and Diagnostic Studies	
Chemistry and Upper Atmosphere	8%
Aerosol Physics	
Atmospheric Chemistry	
Upper Atmosphere Dynamics and Aeronomy	
Cloud Physics	18%
Radar Meteorology	
Severe Storm and Cloud Physics	
Data Processing (Aircraft, Balloon)	
Astrophysics	4%
Astrophysics	
Solar Interplanetary Medium	
Solar Physics	
Physics of Planetary Atmosphere	
Solar-territorial Relations	
Magnetohydrodynamics and Plasma Physics	
	100%

The NCAR Data Support Section has approximately 300 distinct data sets available, with over 80 terabits ($80x10^{12}$ bits or 10,000 Gbytes) accessible within 2 minutes. The NCAR multilevel store has 150 Gbytes of online disk storage accessible in seconds and the balance available via tape mounts in 2 minutes.

NCAR has five scientific divisions: the Atmospheric Technology Division, the Climate and Global Dynamics Division, the Atmospheric Chemistry Division, the High Altitude Observatory, and the Mesoscale and Microscal Meteorology Division. These are described in Appendix B.4.

A summary of the types of use made of the NCAR supercomputing facility by both local and remote users is shown in Table 5.5. The table shows the percent of use as a function of scientific discipline.

NOAA supercomputer plans

NOAA is planning the development of an advanced supercomputer facility at the Environmental Research Laboratory (ERL) in Boulder to support mesoscale research through the 1990s. The objective is to improve 1 to 36 hour weather forecasts by provision of comprehensive raw data, analysis and predictive model access to the research community. The domain would be somewhat larger than the 48 states, with input from all major data sources, and processing at hourly resolution with nearly continuous operation. The system would provide raw data and analysis outputs at meso beta resolution to the entire STORM community, and would provide a community modeling system for all ERL labs.

The overall data input for this program would be on the order of a gigabyte per day. The central processor being considered is a Connection Machine, a parallel processor that is about four times faster than a Cray X-MP/4. Due to its parallel architecture, the Connection Machine would be able to produce a 1-hour forecast in about 6 minutes as compared to 40 minutes for the Cray.

CU computing facilites

A wide variety of computing facilities exists for both space data analysis and flight hardware design/development. Over two-dozen VAX mainframes and microvaxes reside in space-dedicated research facilities. Researchers at CU have acquired Pyramid 90 and Intel iPSC/2 hypercube parallel processing machines, and have access to CYBER 205, CRAY 2, and Cray XMP supercomputers. A variety of data processing and AI workstations are also available, including HP64000 microprocessor development workstations, HP9000 series 350 Bobcat AI workstations, and Sun image processing workstations. CAD/CAM design and manufacturing workstations are used for both flight hardware development and student training. Access to local-area and national data networks, as well as the fiber optic CU-Net, is available to essentially all of these computing facilities.

5.3.5 Data repositories in Colorado

CU data repositories

CU data analysis systems dedicated to the CU space research effort include the NASA Planetary Data System Atmospheres Node, the Defense Meteorological Satellite Program archive, the NASA IUE/HEAO/IRAS Regional Data Analysis Facility, the NASA Voyager, Pioneer-Venus, and SME mission data bases, the TOPEX/LAGEOS/Seasat topographic/orbit determination data archive, a

LANDSAT data-tape library, and the World Data Center–A/National Snow and Ice Data Center. Major data collections are also available from the NOAA National Geophysical Data Center, as described below.

Additionally, plans for integrated earth systems/global change data bases are now being implemented.

World Data Center-A (WDC-A)/National Snow and Ice Data Center (NSIDC)

The World Data Center-A for Glaciology (WDC-A) and the co-located National Snow and Ice Data Center (NSIDC) are operated under contract to NOAA/NESDIS (National Environmental Space Data Information Service) by the Cooperative Institute for Research in the Environmental Sciences (CIRES) at CU-Boulder. Their main purpose is to facilitate the national and international exchange of data on all forms of snow and ice: glacier fluctuations and mass balance, polar ice sheets, sea ice, fresh water ice, seasonal snow cover, avalanches, permafrost, and paleoglaciology.

The Center for Glaciology in Boulder is one of eight branches of WDC–A in the United States. Each World Data Center-A facility is co-located with a national data center; for example, the World Data Center-A for Glaciology (WDC-A) and the co-located National Snow and Ice Data Center (NSIDC). This provides a basis for partitioning the data into that which is available world-wide and that which is proprietary to the United States, for example, data which may be restricted for national security reasons. Table 5.5 shows the eight branches of WDC–A, the national centers with which they are affiliated, and the scientific disciplines of each center.

In addition, there are two other World Data Centers, WDC-B in the Soviet Union and WDC-C comprising a number of discipline centers in Western Europe and Japan.

Table 5.6. WDC-A Data Centers

Glaciology - CU/CIRES, Boulder, CO
- Glacial Geomorphology
- Ice Sheets
- Mountain Glaciers
- Paleoglaciology
- Permafrost
- Sea Ice and Freshwater Ice
- Seasonal Snow and Avalanches

Solar-Terrestrial Physics - NESDIS NOAA, Boulder, CO
- Aeronomy
- Airglow
- Aurora
- Cosmic Rays
- Geomagnetic Variations
- Interplanetary Phenomena
- Ionospheric Phenomena
- Solar Activity

Marine Geology and Geophysics – NESDIS NOAA, Boulder, CO
- Bottom Composition
- Bottom Topography
- Geological Data
- Geophysical Data

Solid-Earth Geophysics – NESDIS NOAA, Boulder, CO
- Accelerograms
- Archeomagnetism
- Earthquakes
- Earth Tides
- Gravimetry
- Heat Flow
- Paleomagnetism
- Recent Crustal Movements
- Terrestrial Magnetism
- Tsunamis
- Volcanology

Oceanography – NESDIS NOAA, Washington, DC
- Biological Data
- Currents
- Physical and Chemical Data
- Sea-Surface State, including measured Wave Data

Meteorology – NESDIS NOAA, Asheville, NC
- Atmospheric Chemistry
- Atmospheric Electricity
- Marine Meteorology
- Ozone
- Radioactivity
- Rocketsonde
- Solar Radiation (Penetrating the Atmosphere)
- Surface & Upper Air Observations

Rockets and Satellites – NASA, Greenbelt, MD
- Orbit Data for Artificial Satellites
- Rocket Launches
- Satellite Launches & Situation
- Space and Earth Scientific Data From Satellites

Rotation of the Earth – US Naval Observatory, Washington, DC
- Polar Motion
- Rotation Rate of Earth
- Time

WDC-A has approximately 50 data collections of all kinds including digital data, image data including 1.3 million transparencies, plus charts, maps and field notebooks. Three of the data sets are considered major collections. The nature of data sets is further described below under the National Geophysical Data Center.

Most data is archived on optical disk and distributed on magnetic tape and floppy disk. Data is also now starting to be distributed on CD-ROMS. Although the center is a SPAN node, there is little demand for network access to the data, and the cost of developing an on-line repository has been a deterrent.

The World Data Center-A/National Snow and Ice Data Center is further described in Appendix B.1.

National Environmental Satellite, Data, and Information Service (NESDIS)

NESDIS is an agency of the Department of Commerce's National Oceanographic and Atmospheric Administration (NOAA). NESDIS manages U.S. civil operational Earth-observing satellite systems, as well as global databases for meteorology, oceanography, solid-earth geophysics, and solar-terrestrial sciences. NESDIS operates data and information centers in three locations, Boulder, Colorado; Asheville, North Carolina; and Washington, DC.

THE NATIONAL CLIMATIC DATA CENTER (NCDC), Asheville, NC, acquires, processes, archives, analyzes, and dissiminates global climatological data; develops analytical and descriptive products to meet user requirements; and provides facilities for the World Data Center-A (Meteorology). It is the collection center and custodian of all United States weather records and the largest climatic center in the world.

THE NATIONAL OCEANOGRAPHIC DATA CENTER (NODC), Washington, D.C., acquires, processes, archives, analyzes, and dissiminates global oceanographic data; develops analytical and descriptive products to meet user requirements; and provides facilities for the World Data Center-A (Oceanography). It was the first NODC established and houses the world's largest usable collection of marine data.

THE NATIONAL GEOPHYSICAL DATA CENTER (NGDC), Boulder, CO, acquires, processes, archives, analyzes, and dissiminates global solid Earth and marine geophysical data, as well as ionospheric, solar, and other space environment data; develops analytical, climatological, and descriptive products to meet user requirements; and provides facilities for World Data Center-A (Glaciology, Solar Terrestrial Physics, Solid Earth Geophysics, and Marine Geology and Geophysics).

It should be noted that the NESDIS data centers are the national data centers for these disciplines and correspond with the respective World Data Centers-A for these same disciplines, see Table 5.5 above.

National Geophysical Data Center

The National Geophysical Data Center (NGDC) is a branch of the NOAA National Environmental Satellite, Data, and Information Service (NESDIS) described above.

The NGDC is located in Boulder, Colorado and is the national facility corresponding to the World Data Centers-A for Solar Terrestrial Physics, Solid Earth Geophysics, and Marine Geology and Geophysics. NGDC also provides facilities for World Data Center-A, Glaciology, at CRIES at the University of Colorado. In addition, NGDC has an Information Services Division for dissemination of data from these centers.

NGDC acquires, processes, archives, analyzes, and dissiminates global solid Earth and marine geophysical data, as well as ionospheric, solar, and other space environment data; develops analytical, climatological, and descriptive products to meet user requirements;

University Navstar Consortium (UNAVCO)

UNAVCO is a multiuniversity consortium developed to assemble, test, and administer the deployment of instrument packages that use radio signals from the Department of Defense NAVSTAR Global Positioning System (GPS) satellites to perform geodetic measurements. UNAVCO is supported by the National Science Foundation and the University of Colorado is its lead institution. Other participants include Columbia, CalTech, Harvard, MIT, Princeton, and the University of Texas.

CU is now utilizing this powerful new tool for worldwide crustal deformation and earthquake studies in tectonically active areas.

Approximately 20 sets of GPS tracking equipment plus water vapor radiometer equipment are now operated and managed by UNAVCO. They have been used in observation campaigns in California, Yellowstone National Park, New England, Colorado, the Dominican Republic, Iceland, Greenland, Hawaii, and South America. Typical campaigns involve up to eight hours of satellite observations every day for several weeks and include additional GPS tracking equipment operated by collaborating agencies and research groups.

Over the past two years UNAVCO surveys have begun to acquire a significant amount of geodetic data. Each UNAVCO GPS receiver acquires about 1-4 megabytes of data per day. Approximately 3 gigabytes of data were acquired during the summer 1989 field campaigns and the repository currently contains about 6 gigabytes of data. As data is accumulated year by year, it will become increasingly valuable as a historical record of earth plate tectonic movements and other phenomena.

Of particular concern is the need to safely transport the raw data back to the processing center, particularly when data is acquired in foreign countries. Currently field data is recorded on floppy disks and cassettes which are carried back to the processing center in Boulder and transfered to 9-track tape. UNAVCO is considering transferring field data via VSATs as one possible solution.

Additional information on UNAVCO is given in Appendix B.1.

5.3.6 CU Space operations facilities

CU is the only University both to operate a NASA spacecraft and to have the capability to remotely conduct IUE satellite observations. Facilities on the CU-Boulder campus for such operations include the Onizuka Space Operations Laboratory and the Remote IUE Users Facility. Other space operations facilities include the OASIS spacecraft remote operations control workstations, developed at CU. University researchers at CU also routinely operate GPS dual-frequency receivers and GPS water-vapor radiometers. Also in use are UV, visible, IR, and microwave spectrometers, various beam machines, lasers and other ground based equipment used for solar and atmospheric research.

5.4 Network traffic in Colorado

There are three types of network applications that account for most of the communications traffic on science networks in Colorado. These are: E-mail, file transfer, and interactive (remote) logins, the primary applications supported by the Internet and SPAN. The latter is the most powerful since it allows the authorized user to access all of the capabilities of the remote computer as if it were at his local site. Most other communications applications are derived from these capabilities. There are however some multi-media projects on the Internet, but the University of Colorado does not participate although it does have the capabilities.

Network system managers estimate that E-mail accounts for the largest number of network transactions followed by remote logins. In terms of numbers of transactions, file transfer is much less often used, but the volume of individual transactions is often high. File transfers are usually done with the Kermit protocol which is widely supported by scientific institutions around the country.

E-mail at the University of Colorado accounts for the largest volume of routine traffic and is estimated to be 20-30 Mbytes/day.

Network news group traffic, which uses E-mail facilities for delivery, represents a volume of 2-3 Mbytes/day. Much of it comes from USENET. Most CU and NOAA users do not have direct access to USENET News groups since most of the computer environments use DEC (Digital Equipment Corporation) equipment, but there a few UNIX systems that can access USENET including SPOT and TRAMP at CU, and also machines at NCAR.

The capacity of the main communications arteries serving institutions in Colorado varies from T1 (1.5MBit/s) downward. The Internet link at NCAR is a T1 line and there are plans to upgrade it to DS-3 (45MBit/s) by 1991. A T1 line is also installed between NCAR and CU. The SPAN link from Colorado to JPL runs at 56KBit/s. The links between the NOAA Environmental Research Laboratory and its supercomputer facility at Gaithersburg is supported by two 56KBit/s lines plus one 56KBit/s line to the Internet connection at NCAR. The Bitnet link between the University of Colorado and Utah State runs at 9.6KBit/s, as does the link from NCAR to MFEnet.

5.4.1 Networking needs in Colorado

Future needs for digital and video services include links to the other state schools including Colorado State University in Fort Collins, the School of Mines in Golden, Fort Lewis College in Durango, schools in Greeley, Grand Junction and others along the back range, plus links to schools in Wyoming. Cooperative science activities will be among the primary beneficiaries of this expansion, however there is also interest in providing instructional services for all k-12 schools in Colorado.

5.5 Trends in the use of telecommunications for science

Telecommunications managers and key scientists in Colorado predict that large data volume increases are coming. These increases are due to numerous factors including increasing numbers and sophistication of users, the use of more powerful computers, workstations and software, and increasingly demanding science applications.

Increasing computer literacy and telecommunications use

There is an overall trend toward increasing use of communications and computer networks by the research community in Colorado. The numbers of users are steadily growing and research scientists, professors, students and administrators are becoming increasingly computer literate and are using ever more sophisticated software. A typical user might progress from using E-mail to performing file transfers, to utilizing advanced workstations with windowing applications and on to performing analysis on supercomputers. The majority of these activities will be local but a significant number will involve remote resources around the nation or beyond.

Network managers predict this trend will have an on-going impact on local facilities and network resources including requirements for increased bandwidth, numbers of circuits, and transaction capacity of nodal processors and switches.

Larger document files

The recent trend to incorporate graphics, images and even speech segments into documents is greatly multiplying the size of the document files that users routinely send over telecommunications links. Where users were once content with simple ASCII text files, they are now increasingly using workstation software that allows graphics and pictures to be created or scanned into a document. These in turn are supported by capabilities such as high resolution laser printers now available on most local area networks. These files may contain font and formatting data as well as graphics and images that greatly increase the file sizes as compared to simple ASCII text files. As users begin to routinely exchange these types of files, the transmission times become increasing long, host processors slow down, and electronic mailbox capacities become inadequate. Thus system administrators face requests for more bandwidth on communications links, more powerful host processors, and increased storage capacities and account sizes for users.

Increasing use of advanced workstations

Advanced workstations are increasingly being introduced for the analysis of scientific data. They are often used to perform computations and to access databases and other resources on remote computers. Advanced applications frequently employ windowing software (see below) to access multiple heterogeneous resources over networks to bring data into workstation applications.

The use of windowing software can give users the power and convenience of transparent access to remote resources. This can have a significant impact on communications requirements because it often involves the use of multiple simultaneous network sessions or circuits. Furthermore, the trend in applications is toward more use of bit-mapped displays for graphical and image data, and the use of color further impacts the workstation communications bandwidth requirements.

In the Colorado area notable applications for advanced workstations are found in the planetary and earth sciences. These are moving from the experimental stage to routine use. There is also considerable activity among vendors to supply advanced workstation software. The long-term trend is for bandwidth requirements to continue to grow as applications evolve toward the further integration of text, data, graphics, voice and video.

Accessing remote data and remote computing

One of the capabilities needed most by scientists is the ability to access remote databases and computing resources. An increasing number of repositories for scientific data sets can be accessed over computer networks using dumb terminals, PCs or advanced workstations. Examples of NASA and NOAA data repositories of interest to investigators in Colorado are shown in Table 3.3.

On-line directories and catalogs enable researchers to locate and browse directory listings and data, to order data, and to initiate file transfers. Additionally, researchers may perform processing of the data on machines at the repository, at remote supercomputer sites, or at their local facility.

The availability of broadband communications links often determines which types of tasks are considered feasible over networks. For example, if such links are available they make it practical to routinely transfer large data files between sites for processing and to monitor remote processes using scientific visualization techniques (see below). Coupled with these activities will be activities which typically are not broadband applications such as accessing remote data catalogs, browsing data, and commanding processes on remote systems. This suggests the need to dynamically allocate the bandwidth of the communications links to match real-time needs. This is a capability offered by ACTS that would optimize the use of the communications resources.

Many investigators in Colorado make do with communications links limited to 56 kbits/sec or less and this limits the types of research activities and computer applications that they are able perform over networks. Those with direct access to the NSFNET backbone can share its T-1 (1.54 Mbits/sec) capacity, but even DS-3 (45 Mbits/sec) rates, which are planned as the next upgrade of NSFNET, are considered inadequate for certain applications, particularly remote operation of scientific visualization processes performed on supercomputers.

At this point in time, ACTS could provide the added bandwidth not currently available on many networks and also dynamically allocate that bandwidth to achieve the most efficient use of the communications resources.

Investigators who need to access remote databases and computers must sometimes communicate through heterogeneous networks with dissimilar communications characteristics and service capabilities. Here robust capabilities for file transfer and remote job control can be critical. This is also an area where ACTS may offer solutions by by-passing incompatible networks to provide uniform service to users.

In the long run, the trend is to develop robust network protocols and applications that enable users in remote locations to access data and computing resources across heterogeneous networks including satellites. The trend in applications is to incorporate natural language queries and hierarchical menus and to provide transparent access to multiple remote heterogeneous databases for the user.

Windowing technology

Window environments represent an important software technology being incorporated into work-stations that places powerful capabilities in the hands of the researcher. For example, the popular X-Window environment together with its Graphical User Interface (GUI) enables the user to run multiple local and remote tasks operating simultaneously under control of the workstation.

X-Windows, originally developed at MIT in 1984, is a windowing environment that is supported under the UNIX operating system commonly found on workstations used for scientific research. There are similar products for other types of workstation platforms: Window Manager on the Macintosh, Presentation Manager on IBM's OS/2, and several products that run under IBM's DOS, notably Microsoft Windows.

The primary advantage of X-Windows over DOS- and OS/2-based graphical user interfaces is its network transparency. X-Windows, currently in Version 11, is particularly powerful because an X11 application does not need to run entirely in the workstation, but rather it can run on a client, a more powerful machine elsewhere on the network. The program displays graphical output on the workstation, called the server, and also receives user input from it. The server can display several different programs running on several different clients in various remote locations.

Thus big resources, such as large remote databases and remote computing facilities, can be put at the disposal of the workstation and appear as if they were local. Because the X-Windows easily handles processes on multiple machines across communications links it can have a major impact on computing resources and communications requirements.

X-Windows will play a big role in visualization applications because it has the network environment built into it and makes calls to remote hosts transparent. It is expected to have a significant future and is likely to experience an evolution similar to UNIX. Both MIT and Digital Equipment Corporation have strong development programs. There is good agreement in the vendor community on binary-compatibility but there are two major contenders attempting to control the evolution of the user interface, AT&T and Sun in one camp and the Open Software Foundation, a consortium including IBM, DEC, the Santa Cruz Operation (SCO) and Hewlett-Packard in the other.

What increasing use of windowing environments and GUIs imply for the future is that there will be increasing requirements for multiple simultaneous network connections to remote resources, and wideband multi-media operation. These are requirements ACTS is well suited to meet.

Scientific visualization

Scientific visualization is an important new technology for science that enables researchers to obtain images resulting from processes running on supercomputers in order to monitor and control these processes. This technology will enhance productivity, economize machine use, and minimize bad runs.

The advancement of this technology involves the software development of visualization tools that can look at data to guide processing on a supercomputer and even guide the course of a scientific experiment itself. Not only is visualization a tool for deciding if a supercomputer process is going well, but it can be a technique intimate to the research itself.

Scientific visualization represents one of the most demanding applications for data communications. While currently many visualization processes must be performed at workstations at the supercomputer site, as increased communications bandwidth becomes available, interactive video and full-motion image displays will become commonplace on remote network workstations.

Visualization software supplied by vendors is starting to become available for workstations and is expected to see major growth beginning in 1990. Initial products allow complex renderings to be transferred over an X-Window system network to user workstations.

At NCAR in Boulder, there is a Scientific Visualization Group that is currently doing 2D and 3D work. Members of this group point out that a T1 data rate (1.5 MBit/s) is not enough for many visualization applications. DS-3 rates (45 MBit/s) may be acceptable for some applications, while others are likely to require even more bandwidth such as SONET at 155 Mbits/sec or even higher.

For example, there is a Connection machine at NCAR that produces 32 Mbit/sec graphic images. Output from the Connection 32000 processor frame buffer is coupled to a workstation on the CU campus a few miles away located in the computer science department. Current bandwidth limitations prevent the viewing of this output in realtime at the CU workstation, although this would be possible if DS-3 service were available between NCAR and the Boulder campus.

By contrast, the CRAY XMP at NCAR will also be used for visualization. It has a frame buffer that yields 800 MBits/sec that can only be used in local mode because the data rate is so high. While researchers currently must do their work on-site at NCAR, were there high capacity links to remote locations, they would most certainly be utilized.

If ACTS were available now it could support NCAR visualization requirements for remote users by supplying DS-3 (45MBit/s) service, but by 1992 NCAR expects to have upgraded its primary Internet backbone links to DS-3 to meet the objectives of the National Research Network. Therefore opportunities for ACTS may diminish but will continue to be valuable for users who are off of the main backbone.

A powerful new technique for scientific visualization makes use of cyberspace technology being developed by companies such as AutoDesk and VPL, and by NASA-Ames. Using hardware like the cyberspace helmet with "eyephones" (small video displays imaged on the eyes) and a sensor filled "DataGlove," the user is able to visually enter a three-dimensional "virtual reality" entirely created and controlled by graphics software on a supercomputer. Position sensors on the helmet enable him to turn his head to look about in the artifical environment and to have the feeling of being there. The software also simulates an image of the glove so that the user sees it as his own hand in the virtual reality and is able to hold and manipulate simulated objects or edit the virtual reality.

By pointing his or her finger the user is able to move about in the virtual world. This enables the user to experience being inside three-dimensional data spaces, for example, inside architectural drawings, inside a stream of visible wind turbulence, in the interior of body organs, and so on. Coupled with computer aided design (CAD) software, the user can, for example, edit architectural drawings from within. The user can visually experience being inside of any environment, real or abstract, for which for a data set can be acquired or generated thus providing opportunities for intimate investigation and direct insight into the nature of designs, processes and phenomena. This powerful technique will increase demands for very high bandwidth communications links between network users and supercomputer sites. Downstream data at DS-3 (45 Mbits/sec) rates or greater will be required to support full motion graphics or image data for the user, but only modest up stream data rates will be needed to receive the control signals from the helmet position sensors and glove.

Archiving trends

Trends toward distributed archives will have an impact on communications demand. NCAR is promoting distributed archives which are becoming easier to establish because of the availability of optical disk technology. Distributed archives will reduce telecommunications requirements at NCAR and allow the load to be shared by other centers. However, overall data usage may increase due to better regional or local accessibility elsewhere. The implications for ACTS as well as terrestrial communications is that there will be an increase in emphasis on remote computing and interactive applications that make use of distributed data archives and repositories, and along with this corresponding increases in the demand for telecommunications services.

Advanced networking between mainframes

One of the coming advances in network technology discussed by network managers is the development of protocols that implement peer-to-peer relationships between operating systems. The "networking" of operating systems will have a big impact on data traffic volume as processors begin to be able to share loads and tasks and optimize network activities.

The overall implication of the technology trends described above suggests that powerful computing tools and resources will become increasingly available to the scientist. The time constraint for performing complex computer processing tasks will be reduced, and so scientists will do more projects that they would not have previously considered because they can be achieved in days rather than years. Thus the technology and the science will regeneratively multiply communications requirements.

5.6 Science telecommunications needs

Telecommunications has a role in most space and earth science activities discussed by survey participants. Research activities can be divided into four general phases: program planning, data acquisition, general research and data storage. Many of the specific activities performed during these phases benefit from or require telecommunications support. In addition, telecommunications support for collaboration between investigators during all phases is essential. In sum, scientific activities are increasingly characterized as "telescience" when telecommunications is used to link investigators, flight and field instruments, data sources, computing facilities and other resources that are widely distributed.

Program planning

There are numerous activities associated with the planning of scientific research programs that may involve telecommunications. Most present-day research activities are collaborative efforts between several scientists that may be located in different institutions. Requirements for communications by telephone and by electronic mail are common throughout all phases of the research program from the earliest stages of conception, proposal writing, planning and scheduling through data acquisition and general research, to the final preparation of reports and papers.

Some research programs utilize computer simulations to develop and refine the experiment and to develop the instruments and techniques to be used. Mathematical models may also be developed that will accept experiment data and process it in real-time during the course of the experiment. The development and testing of these may utilize supercomputers and other remote computer resources that must be accessed over networks by different members of the research team from their respective locations.

In the case of flight experiments where there may be only one opportunity to perform the experiment and obtain data, there may be numerous rehearsals and runs with simulated data. The scheduling of experiment events may be critical to their success and may involve automated sequencing of the events occuring in one or more locations linked by telecommunications, such as for example, earth science experiments that coordinate satellite remote sensing with field operations on land or at sea.

Data acquisition

The data acquisition phase of scientific research programs is often heavily dependent on telecommunications. During this phase data is collected on-orbit, in flight or from field operations and is transmitted to processing and storage centers. Some parameters may also be sent to mission control to guide the mission activity.

Data processing during the data acquisition phase is usually limited to what is called level 0 and level 1 processing in NASA parlance. The former occurs during the initial importation through various communications links and involves removal of all communications artifacts such as packet headers and modulation, so that the data stream is restored to its original form as it left the spacecraft or field instruments. Level 1 processing involves error correction, time ordering, and decommutation into separate data streams. At this level it remains true to the detector(s) in that none of the physics content is removed through averaging, compression or similar processing.

This processing may occur at intermediate sites or at the investigator's facility. Sometimes additional processing (level 2, see below) is done in real-time to get a direct readout of important parameters to be used by mission controllers to guide the subsequent course of the mission. Often the resulting data output is sufficient to perform the initial analysis and to satisfy the initial program objectives.

Many space related experiments and missions allow some degree of teleoperation that require telecommunications links between the spacecraft and mission controllers. This may involve maneuvering the spacecraft, controlling scientific instruments, or reprogramming the spacecraft computer to alter data collection sequences and flight trajectories.

Telepresence is a variant of teleoperation where images from a remote vehicle or experiment site are transmitted back to a researcher who in turn is able to control the remote vehicle or its instruments. For example, cameras may be placed onboard a spacecraft, rover or space station and the investigator may be able to operate instruments, manipulators, or experiment apparatus while watching the results.

An important technique for implementing teleoperation and telepresence on remote experiments makes use of the technology from AutoDesk and others (see discussion of scientific visualization above) where the investigator wears a helmet with "eyephones" and head position sensors and a sensor filled data glove that allows manipulation of real and virtual remote devices. This technique greatly multiplies the effectiveness with which the investigator is able to monitor events and interact with manipulators and instruments onboard the remote spacecraft or vehicle.

Large bandwidths may be required for downlink transmission of slow scan or full motion images required for telepresence operations while comparatively modest uplink bandwidths may be needed for controlling the craft or instruments. NASA Ames is studying applications of telepresence for doing field geology on Mars using a rover. A wide range of telescience applications are being studied at the University of Colorado in the Laboratory for Atmospheric and Space Physics for use on Space Station and other space missions.

General research/Data analysis and management

General research and data management activities commence once a sufficient amount of mission data has been received. On longer missions, this activity may overlap the data acquisition phase.

At this stage specific discipline investigations are performed to satisfy the original research objectives. In addition, interdisciplinary applications may also begin as the results become available to the wider scientific community.

Data processing in this phase often involves level 2 and level 3 processing to produce data sets and to develop and test models. In Level 2 processing the data is reduced from raw digital numbers to physical parameters such as temperature and pressure. In Level 3 processing the data is mapped into other forms. This may involve computing to grid points, extrapolation, production of maps with contour lines from the data, and mapping into application models possibly in combination with other data.

Most space research involves multiple investigators who collaborate on various aspects of the mission. Often they are located in different institutions throughout the United States or in other countries. Thus there can be a significant need for telecommunications network support to enable them to access the primary mission data, to share results, and to exchange messages and information. Advanced telecommunications applications including multi-media communications is particularly desirable to support collaborative activity.

The data analysis tasks may involve transferring the data to one or more supercomputer sites for processing and may require numerous transmissions of intermediate results back to the investigators in order to guide the processing. Advanced workstations are often used to access multiple remote data sets and control one or more remote processors simultaneously.

Scientific visualization techniques may also be employed for the analysis. Because scientific visualization can be very demanding of telecommunications bandwidth and can not be supported by most current computer networks, this activity is often limited to being performed on local workstations at supercomputer sites.

Data storage and maintenance

When a science program reaches completion the data is usually archived in a facility that follows procedures to maintain the data quality and integrity. This facility may also serve as a data repository that makes the data accessible to the general research community.

The data may be stored on various media as may be convenient or appropriate including, printed reports, film, microfiche, photographs, magnetic tape and disks, floppy disks, and optical disks.

Data repositories often publish printed catalogs and provide on-line catalogs accessible over computer networks. Some data is stored on-line and can be directly accessed through computer networks, but the majority of data at most repositories is stored on magnetic tapes that must be mounted on network tape drives. Often this can be done within a few minutes of receiving a request. It is also common for data to be copied onto magentic tapes and floppy disks at the user's request and distributed by mail. In addition, optical disks are becoming a preferred way to store and distribute data.

Once data has been archived in a repository it becomes available to the general research community. Investigators may perform retrospective analysis and to use it in combination with other data sets for new areas of research. Thus requirements for telecommunications network access to scientific data repositories will continue to grow as more and more data is acquired and stored in standard formats.

Collaboration activity

The current trend in science is toward collaborative or team oriented research in fields such as biotechnology, space science, atomic and nuclear research, and atmospheric and ocean research. Members of the research group may be located at many different agencies and institutions throughout the country or abroad. These include for example, the NASA centers, national laboratories such as Lawrence Livermore and Los Alamos, universities and industries, and also equivalent agencies over seas, plus regional agencies and laboratories such as E.S.A. and CERN.

Many collaboration activities make use of, or could benefit from advanced telecommunications services to support meetings, experiment operations, data analysis, preparation of technical reports, distribution of news and mail, and so on. Collaborative research is an activity that is able to realize major benefits from the increased communications transparency that can be provided by advanced telecommunications applications.

The science community makes extensive use of the standard network capabilities for electronic mail, file transfer and interactive logon to remote computers provided by SPAN and the Internet. Scientists also make extensive use of voice communications, conference calling and FAX service.

Advanced telecommunications capabilities that survey participants felt would be particularly valuable to support collaborative research activities include: simultaneous viewing of workstation displays and electronic blackboards during conference calls; teleconferencing facilities that support voice, video and computer graphics; facilities for distributed group editing of multi-media documents (text, graphics); and support for telescience operations including multi-circuit, multi-media links for investigator communications, mission operations and general research activities.

Terrestrial science network support

Terrestrial science networks are built almost entirely around SPAN and the Internet (NSFNET). There is a need to provide backup capabilities for terrestrial links in case the lines are cut or fail.

Science activities tend to be of short duration with dynamic requirements for different telecommunications links and capacities. At times there are needs to link islands of isolated capabilities such as ISDN and FDDI networks where the intermediate carriers do not support the necessary capacity, services or protocols.

There is also a need for systems to provide additional capacity to carry transient high volume loads that would overburden existing networks or delay time-critical mission objectives. Science activities also have varying requirements to link to off-network sites and facilities, particularly temporary and mobile facilities.

Survey participants felt that satellites such as ACTS could complement terrestrial services and provide the additional capacity and felxibility needed by science.

5.7 Telecommunications managers views of ACTS

Telecommunications managers provided considerable insight into the applications, current problems with existing computer network services, and plans for the future enhancements. They also offered perspectives on the various advantages and disadvantages of ACTS and pointed out potential opportunities for ACTS.

Cost issues

The cost of purchasing ACTS earth stations, interfacing them to existing networks and the cost of operation were issues of major concern to telecommunications managers.

Managers felt that if ACTS earth stations were to cost $10k to $20k they would be very attractive, but there were very few projects that could justify a terminal costing $200,000.

For comparison, the price for receive-only earth stations for a proposed NOAA Port satellite broadcasting weather data at 7-8 Mbits/sec was expected to be $20,000.

Some managers felt that the justification for implementation of satellite services should be based on costs. An example of a program that provides a basis for cost comparisons is the National Center for Atmospheric Research (NCAR) University Satellite Network (USAN) which transmits to 8 remote sites at 244 kbits/s and the remote sites reply at 56 kbits/s. The NCAR site installation cost was $150k and the remote university site costs were $50k to $90k each depending on the data rate. Operating costs for the sites is about $10K per year. NCAR has considered expanding to 100 sites but the costs are considered prohibitive. Furthermore this plan may not proceed because of plans for NSFNET expansion.

According to NCAR telecommunications managers, with an annual budget of $50 million per year at NCAR they still have difficulty obtaining $15k for an earth station when in reality they need about twice that amount. This situation defines the limitations under which they operate.

In a related situation which gives some indication of agency limitations, NCAR managers commented that recently the National Weather service would not pay $43k per month for a cross country T1 link to distribute weather data.

Some managers tended to make direct comparisons between the costs of ACTS and commercially available facilities. The fact that ACTS might be more costly due to its experimental nature was no consolation when considering the prospect of participation in an ACTS experiment.

They commented that while ACTS boasts that costs are reduced because it offers bandwidth on demand, the fact is that the high cost of the terminals swamps out this benefit. The user is in effect, buying a dedicated circuit, especially in the the experimental phase where there are very few sites with which to communicate.

The only cost to the user for using SPAN or the Internet is for the tail circuit because the backbone is paid for by NASA or NSF. Usually those science programs that are the primary users of these networks pay for the tail circuits. Individual users and many smaller groups and laboratories connected to the local area network see no direct charges but benefit from their mutual connectivity to these wide area networks.

Some managers felt that ACTS costs should compete with the cost of shipping tapes, although the added value of immediate access and computer processing options made possible by ACTS should be taken into account. NCAR charges approximately $90 for a high density tape copied from its archives and mails out about 1800 high and low density tapes per year.

At the World Data Center-A/National Snow and Ice Data Center all data distribution is done by mailing media. Data is archived on CD-ROM and distributed on magnetic tape, floppy disks and CD-ROMs. While they are a SPAN node, the cost of implementing an on-line repository or satellite network is considered prohibitive.

Telecommunications managers suggested that an important strategy for reducing the costs of purchasing ACTS terminals is to share them with as many users as possible by integrating them with local area networks. This also reduces the high front-end cost of installing and integrating the terminals for each participating user or experimenter.

Another suggestion was to purchase only the communications portion of the ACTS earth station and to build the telecommunications components at the university as an educational project. Two or more terminals would need to be produced for most applications.

It was emphasized by several telecommunications managers that if a mechanism could be found to underwrite the cost of purchasing and installing ACTS terminals so that the cost to the user was in the range of $10k-$20k each, then it might be easy to obtain hundreds of participants for ACTS experiments.

Performance issues

Telecommunications managers' concerns for performance focused on several issues: the ease of establishing links, satellite delay, bit error rate and its impact on data integrity, and the reliability of the connections particularly for transferring large files.

The ease of establishing links over ACTS was a common concern. Managers felt that the use of ACTS should be transparent to the user and that connection establishment and teardown should not cause a significant delay in the workstation operation.

The delay was named as the most undesirable aspect of satellites but was only considered a problem for interactive sessions and protocol intensive transactions. On being questioned, most users' experience was with double hop delay rather than the single hop delay that would be characteristic of ACTS.

ACTS applications for file transfer were seen as attractive, particularly the availability of wide bandwidth for sending large files. Many users of terrestrial networks have experienced difficulty sending large files over low data rate lines due to host and link interruptions since long transfer times afford a greater opportunity for an interruption.

In general the bit error rate was not perceived to be a problem since it was expected to be comparable to terrestrial standards.

Similarly, most felt that adequate fade protection was provided by ACTS, however some scientists expressed concern that the Ka band was as yet untested and may be more susceptable to fade and total interruption than the older Ku band technology. For mission critical communications where reliable transmission was essential, this could be a serious drawback.

A brochure that addressed ACTS capabilities and performance limitations and that provided a comparison with other carrier services would be an effort well worth the investment.

Standards issues

Survey participants offered a number of comments and insights on communications standards issues and how they may impact opportunities to use ACTS in science communications networks.

<u>Harmonize Standards for Terrestrial Networks and Satellites</u> The central issue is that if satellites are to be effectively integrated into terrestrial networks, communications protocol standards will need to be harmonized with communications satellites.

<u>Migration to New Protocols</u> The predominant communications protocols in use today on science networks are TCP/IP and DECnet, however vendors are committed to migration to OSI (Open Systems Interconnection) standards. The user community is also anticipating this evolution. NASA is planning for the further integration of NSN (TCP/IP) and SPAN (DECnet), and their eventual migration to OSI. Telecommunications system managers that utilize these networks in Colorado have similar interests.

Thus if ACTS satellites are to become viable components in future science networks, they will need to interface with terrestrial networks running OSI protocols, and their performance in this environment will be a critical issue.

<u>Modify Protocols to Accomodate Satellites</u> The key problem for satellites is that their performance under OSI is unnecessarily poor because the OSI protocols have not been designed to accomodate satellite characteristics. The principle satellite performance parameters of concern are the propagation delay, bandwidth and bit error rate. These interact with protocol operation in complex-ways, but it is easy to see, for example, the effect of propagation delay on the efficiency

or throughput of communications processes that are protocol intensive or that are paced by request/confirm sequences that must be exchanged between peer protocol entities over a satellite link.

Because historically satellite interests have not been well represented in the standards making process for OSI, the protocols have not been optimized for use with satellites. Studies by COMSAT Laboratories and others have shown that modifications to OSI protocols can significantly improve performance over satellite links and that such modifications often have negligible impact or even improve performance of terrestrial links.

Participation in Standards Activities is Necessary Because the protocol procedure for most enhancements requires mutual agreement between peer protocol entities and can not be undertaken unilaterally by only one communicant, changes to the standards have to be proposed. The proposed changes will in general need to be introduced as new work items in the OSI and ISDN architecture committees and be taken through multiple stages to reach world-wide concensus before they can be accepted as Addendums to the standard. Because OSI and ISDN are not yet mature and the standards bodies are currently active, it is still relatively feasible to undertake these efforts. However, given the large number of committees, and the terrestrial-oriented industry composition of the membership, the level of effort required should not be underestimated.

Several areas where standards accomodation with satellite technology might be pursued were discussed by survey respondents. These include broadband standards, routing and other lower layer protocols, and network management.

Some observers felt that future science programs will require significantly wider communications bandwidth than is available today, and that OSI standards will need to be enhanced or that new protocols will be needed for use in science networks that operate at gigabit speeds, such as the proposed National Education and Research Network (NERN). Protocols could be optimized for use with both satellite and terrestrial network elements. The standards groups most likely to undertake this work are the OSI architecture committees.

Survey participants commented that there are weaknesses in OSI routing capabilities and that OSI is inadequate to handle the network architecture we have today. OSI has not taken the lessons learned from IP (Internet Protocol) which has been refined during years of operational service and is still being improved today. However, as OSI matures, routing issues are likely to receive further attention. Relevant committees include those for the Network layer, and Network Management.

One of ACTS most important capabilities is the ability to route messages or packets using its dynamic onboard baseband switching technology. Harmonizing this technology with evolving routing standards may benefit ACTS performance and aid future efforts to optimize this technology for use in the next generation operational satellites using ACTS technology.

OSI Management is an area that has lagged in the OSI development process but is now receiving considerable attention because of the real market need. Network Management was not part of the original OSI model but was added later. It is highly complex because it interacts with almost all protocols and layers associated with the seven layer OSI architecture, see Figure 5.7, and across all OSI entities in the OSI environment (network). Its scope is to manage all OSI resources and there is some debate over whether it should also manage non-OSI resources (e.g. hardware). In any case, network management standards will have implications for the management of satellites in OSI networks. There are at least ten standards organizations directly concerned with aspects of

OSI Network Management in the U.S., plus related groups dealing with ISDN Access Management and other standards.

Table 5.7. OSI Seven Layer Reference Model with Intermediate Node

Application			Application
Presentation			Presentation
Session			Session
Transport			Transport
Network	Network	Network	Network
Data Link	Data Link	Data Link	Data Link
Physical	Physical	Physical	Physical
Transport Interconnection Medium			

Migration Scenarios Another problem for ACTS satellites is when and how to phase them into science networks. The transition to OSI protocols will not come suddenly overnight due to the large infrastructure already committed to the older protocols. What is anticipated is a transitional period where various hybrids of old and new protocols will be used. This is a complex issue but a few possible approaches have been discussed.

Some have proposed running OSI upper layers (e.g. the rich suites of applications services) on top of TCP/IP. Another approach would be to run complete dual protocol stacks side-by-side over the same links to accomodate systems that have not yet migrated to OSI. There are already precidents for dual protocol networks, for example, running TCP/IP and DECnet on the same lines. DECnet itself faces similar issues, but being a proprietary protocol, the vendor may provide a more optimal transition, although a transition coordinated with TCP/IP is desirable. Another approach, perhaps more attractive for satellites, would be to upgrade selected links or whole networks and provide gateways or bridges to other networks running different protocols. Each approach has significant implementation impacts.

The transition period to OSI is likely to occur in the time frame that ACTS will be operational. Measures to optimize protocols for use with satellites during this period may not be practical. The question to be further investigated is how well will ACTS perform in different transition environments and which applications will best demonstrate its capabilities?

Connectivity issues

Survey respondents felt that the lack of integration of satellite networks with terrestrial networks was a factor that decreased the attractiveness of satellites. Satellites would have an uphill battle competing with the large installed base of terrestrial networks with their many nodes and connections. This reflects the fact that most users' experience with satellites has been limited to single link point-to-point types of applications.

Only a few of those interview had had direct experience with the effect of propagation delay on computer communications, an effect that is inherent in current generation satellite networks that require multiple hops routed through a common base station. But nearly all shared the opinion that delay was a problem. Some persons' opinions derived from experiences with telephone calls over satellites. It was apparent that few could appreciate the potential improvement from the use of single hop mesh connectivity that is possible using ACTS technology. However it was commented that in order to reverse the misconceptions about satellite delay it will be important to demonstrate advanced applications using ACTS that involve a large number of persons from the science community.

Telecommunications managers pointed out that science activities have sophisticated connectivity requirements that could make good use of all types of connection topologies that can be supported by ACTS. These include single channel point-to-point (private), multichannel point-to-point (multimedia), point-to-multipoint (broadcast and multi-session), and multipoint-to-multipoint (network) topologies.

The most common requirement is for single channel point-to-point links for voice or data communications. The use of ACTS for this type of service becomes increasingly attractive when coupled with ACTS capability for demand assigned bandwidth, a capability beneficial for many science applications that require occasional transfers of large amounts of data, but for which dedicated high capacity links can not be justified.

Multimedia applications are those that require two or more channels between sites, possibly of differing bandwidths. They may be used, for example, to support simultaneous voice and viewing of workstation displays, or multi-task computer applications. It was pointed out that basic rate ISDN service will support two channels that could be used in this way, and that an ISDN interface to allow ACTS to be integrated with terrestrial ISDN services would be a valuable feature to develop.

Broadcast mode or point-to-multipoint communications is needed for applications such as news distribution or the real-time distribution of science mission data to investigators. From the user's point of view these appear to be one-way transmissions, although in reality the file transfer protocols generally involve two-way communications to manage the file transfer.

Multi-session mode also uses point-to-multipoint topology, but the emphasis is on two-way interactive communications. Application examples include advanced workstation or computer applications that access multiple remote databases or other remote computing resources that may be geographically dispersed.

Network mode or mesh connectivity has a multipoint-to-multipoint topology and is required for computer networks and applications where both the users and the resources are geographically dispersed. This mode is particularly applicable for teleconferencing and for telescience activities where the investigators, databases and computer resources must be linked to support real-time monitoring, analysis and mission control.

Existing terrestrial networks often have significant limitations in capacity, ease of connection establishment, dynamic reconfigurability, number of circuits available to the user, and reliability. Telecommunications managers questioned how ACTS would be implemented. Although it has the potential to overcome these limitations and to compete with or complement terrestrial services, the prospect of having a very limited number of (very costly) earth stations would not allow some of ACTS best capabilities to be realized or demonstrated.

Geographic coverage issues

The logistic requirements for science communications are driven by factors such as the increasing emphasis on interdisciplinary and team research and the trend toward increasingly large science endeavors. There is a continual need for communications between government centers, private institutions, universities, companies and individuals within the U.S. and other countries. Certain disciplines, particularly the earth sciences, also have requirements to communicate with remote field sites, research vehicles, ships and spacecraft that may be operating anywhere throughout the world. There is an accelerating trend toward networking the entire international science community. Thus the geographic communications coverage requirements for science are becoming global.

From the standpoint of their relevance to ACTS, science communications logistic requirements may be evaluated first according to whether the locations in question fall within ACTS' various antenna coverage patterns, and secondly whether they are or can be served by other communications carriers, most importantly, the terrestrial computer networks.

The subsystem on ACTS that provides continuous coverage over the largest geographic area is the baseband processor and multibeam antenna system. It uses hopping beams to provide coverage over two contiguous areas that include most of the northeastern portion of the United States plus 13 additional isolated spots, each approximately 135 miles in diameter, that are fixed on key cities within the 48 States. The other major communications subsystem on ACTS, the intermediate frequency microwave switch matrix, has three additional stationary spot beams over major cities. In addition, ACTS has a single steerable antenna that can be coupled to either communications subsystem and which services a 290 mile diameter spot that can be positioned anywhere on the disk of the earth visible from 100 degrees West longitude. The coverage provided by these ACTS antenna systems is detailed in Figure 5.5.

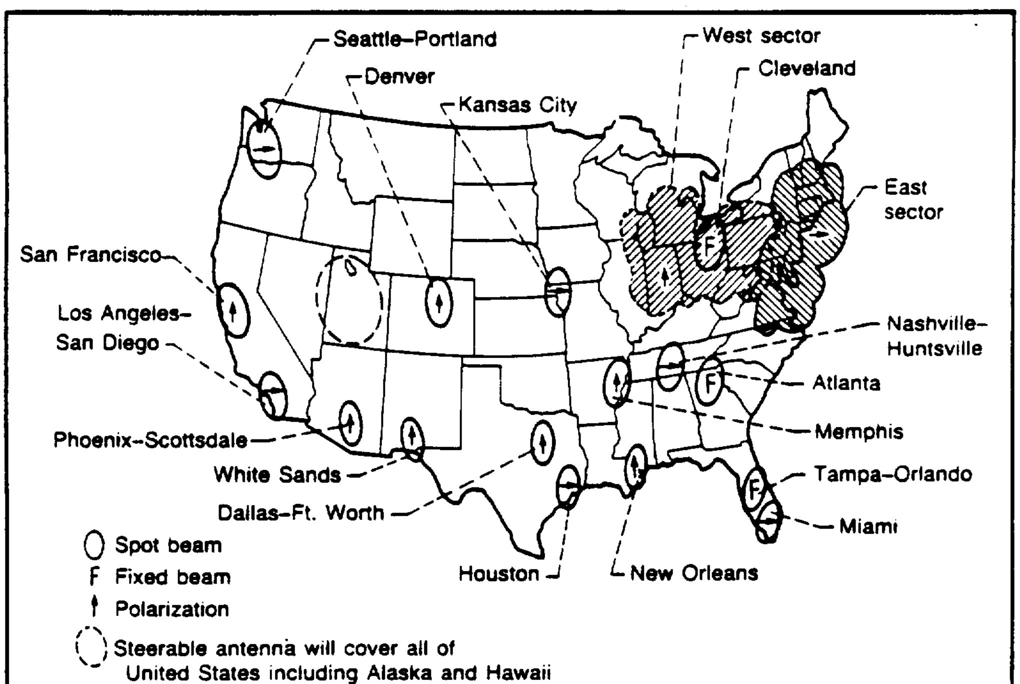

Figure 5.5. ACTS Multibeam Antenna Coverage

In terms of ACTS ability to serve science applications from a geographic perspective, three catagories of clients visible to the various ACTS antenna systems may be distinguished, those at

1. sites already connected to existing terrestrial networks,
2. off-network sites including temporary and mobile facilities that fall within ACTS fixed or hopping spot beams, and
3. remote sites and terrestrial field sites, and those on research vehicles, ships, airplanes, satellites and spacecraft that can be tracked by ACTS' steerable antenna.

It should be apparent from Figure 5.5 that the geographic coverage provided by ACTS' fixed and hopping beams coincides with geographic areas in which there is considerable scientific activity including many NASA centers, government laboratories and universities.

Telecommunications managers familiar with existing terrestrial networks pointed out that nearly all major institutions and centers of scientific activity that fall within ACTS planned areas of continuous coverage are already connected to terrestrial computer networks. Those that are not, are likely to be connected in the next few years, and all links are likely to be upgraded to higher capacity (typically T1 or T3) by the time ACTS flys. Thus it was suggested that the majority of ACTS applications should focus on enhancing the existing terrestrial services an on applications that are unique to ACTS.

The second catagory of ACTS clients, those at off-terrestrial-network sites that fall within ACTS spot beams, constitutes a significantly smaller percentage of the overall U.S. scientific community, but may represent a unique and important clientele for ACTS. These include temporary and mobile facilities, and those that require a temporary enhancement to their terrestrial services or those that for other reasons can not obtain the necessary terrestrial services.

The third catagory of clients for ACTS are those that are not located under ACTS' fixed or hopping spot beams and can only be linked via ACTS steerable antenna. This catagory represents a rather significant component of the science community if one considers the many locations in the U.S., and in other countries throughout North and South America, and the many possible field sites, research vehicles and spacecraft that could make use of ACTS. It should also be noted that science institutions in foreign countries are more likely to lag in the implementation of terrestrial networks and may be good candidates for ACTS.

Although clients using the steerable antenna would enjoy the same ACTS functionality as the other clients, they would need to time-share the steerable antenna with users at other locations. Thus the steerable antenna could become highly oversubscribed and not meet all the operational needs of science activities located outside of the region of coverage of the fixed and hopping beams.

Even though ACTS was not specifically designed to meet the needs of the science community, it is a valuable test bed that can validate these types of science applications. If in the future an operational satellite were built using ACTS technology to meet science needs, then an advanced antenna system might be incorporated to provide continuous service to a wider geographic region.

Type of service issues

Most survey respondents felt that the propagation delay of satellite links was undesirable for interactive sessions and was the reason that they preferred terrestrial links. This is primarily an user-friendliness issue rather than one of system efficiency. This same issue finds its parallel in the voice services market where long distance carriers are progressively shifting much of their overseas voice telephone traffic to undersea fiber optic cable.

Some of the telecommunications managers who we interviewed pointed out that among science users not all communications activity is interactive and that propagation delay is usually not a problem for functions such as file transfer, and e-mail.

A hypothetical solution to this problem is to distinguish the type of service being invoked by the user so that interactive sessions can be routed over terrestrial lines while non-interactive modes can go via satellite.

The difficulty with this approach is that the communications router, using present day technology, can not distinguish the type of service. However in the future, under OSI, at least some types of service could be recognized by the switch if it were to monitor the protocol transactions. This is possible because many of the activities performed under OSI invoke specific application layer services that support particular activities such as e-mail, file transfer, virtual terminal service, transaction processing and various industry-specific applications protocols.

Router/switch issues

The switches used in present day networks are the primary factor placing an upper limit on network speeds. The fastest switches in use on SPAN and Internet operate at T1 (DS1) rates or 1.544 mbits/s. The major router vendors are CISCO, Proteon, and Wellfleet plus some minor players. The University of Colorado, for example, uses IP routers made by CISCO.

There is little or no switching equipment available for T3, (DS3) 45mbits/s, however such equipment is being developed by vendors and is expected to be available to meet the objectives to increase the backbone speeds of the proposed National Research Network (Internet/NSFNET) to T3 rates by 1992.

Herein lies a possible opportunity for ACTS to meet requirements for T3 links using its proposed LBR-1 class Earth Stations. ACTS could be used to upgrade existing links, or to provide backup for T3 terrestrial links that will be established. The ACTS earth stations would need to include an appropriate telecommunications interface subsystem to support T3 service.

The combination of ACTS mesh connectivity made possible by the baseband processor and its 64kb dynamically allocated channels would allow it to efficiently service multiple network nodes. Its routing technology would however be different than from that used by a terrestrial network. The integration of ACTS Earth Stations with terrestrial network nodes is likely to be a substantial development effort in itself. The major deterrent to this proposal is the very high cost of the LBR-1 Earth Stations.

5.8 Science user views and requirements for ACTS

5.8.1 User views of the ACTS program

User reactions to the ACTS program were quite varied, ranging from very positive and enthusiastic about the possibility of obtaining new capabilities, to being decidedly against using ACTS. It is useful to analyze the comments of the latter group as they provide a guide to how to better educate potential users regarding any misconceptions they may have, and can be valuable for identifying future technology and program improvements.

Some users felt that they could use the Internet for all current needs and expected to be able to use it for all future needs. Having free access to ACTS is not good enough because a nominal two-year experiment period is insufficient for them to switch or make the necessary investment.

Data rates available on current services were considered adequate by many users. Rates in the range of 1200-9600 baud were common in many situations. However it was pointed out that these low data rates limited the very types of applications that scientists might even think of using.

As was pointed out by various telecommunications network managers; users seldom ask for new capabilities, but once they are installed, rapidly make good use of them.

Some scientists felt that ACTS has no functions beyond what they can get from the area regional Bell operating company. Since new service can be obtained in 2-3 weeks, ACTS has only a limited fast setup advantage.

These comments must be understood from the perspective that most science users are relatively uninformed about the newer telecommunications technologies (such as ISDN) and their limited availability and longer installation lead times.

Some experimenters felt that rates for T1 lines are cheap enough. Field experimenters have limited budgets for telecommunications and $200k for a ground station is far above what they can afford to pay for auxillary equipment. These kinds of costs are not consistent with most science budgets. In fact some felt their budget is so limited that they could not affort to buy capabilites currently available. Scientists also felt their personal time resources were equally limited. They need to spend it on their own research, NOT data communications experiments. They also had limited interest in joint experiments (with other ACTS experimenters doing communications technology studies).

Under the circumstances, ACTS needs some spectacular new functions in order to be of interest. ACTS needs some major incentive such as significantly more bandwidth than T1, it would need to be guaranteed to be available for a guaranteed number of years or operating schedule, and it would need to be cheaper than current services.

Some potential users were politically biased in that they felt that industry, not NASA, was the proper community to develop new communications technologies such as ACTS, and should bear the cost. For these persons, industry involvement in ACTS demonstration programs might ameliorate this issue to some degree.

On the positive side, some survey participants, including both scientists and telecommunications managers, were eager to get any new communications capacity they could. Most of them were already in need of improved facilities. Their focus was on filling conventional needs rather than on utilizing the advanced capabilities of ACTS to provide new types of services for which there was no precident.

An important exception to this was from those individuals already engaged in developing advanced workstation and database applications to meet the needs of their organization. These people found the ACTS advanced capabilities to be particularly attractive. This is important information.

One of the most common suggestions from survey participants was that ACTS should be easy to use. If possible the invocation of ACTS services should be entirely transparent to the user whether ACTS is servicing voice, workstation or computer communications.

5.8.2 Science user requirements for participation in ACTS experiment program

Based on the survey we concluded that the attempt to involve practicing scientists in the ACTS Experiments Program tends to be at cross purposes with the scientists' main goals given their limited time and financial resources.

Potential science users of ACTS are largely disinterested in developing advanced communications technologies except in so far as they enable the investigator to meet specific scientific needs that can not otherwise be fulfilled.

For the most part, potential science users could not conceive of or appreciate applications that might take advantage of ACTS unique capabilities. If such advanced capabilities were offered then reluctant users might reconsider.

Often it is the telecommunications or network manager of an institution that is the person most willing to consider experimenting with ACTS rather than the individual science investigators. The majority of science activities are small and rely on local facilities. The telecommunications system managers are often in a better position to assess the usefulness of ACTS. Therefore it may be more appropriate to invite the university network service departments to be ACTS experimenters rather than focusing exclusively on the scientists themselves.

In order to make it feasible to involve science users in ACTS experiments it may be necessary to deploy ACTS earth stations at network nodes or on local area networks to enable multiple users to have access to the service, to make it possible to spread the cost of the equipment and implementation among multiple users, and to increase the number of opportunities for different types of science applications.

The difference in requirements for participation for science users verses communications engineering experimenters must be kept in mind when developing a demonstration program for science users.

In sum, science users have neither the interest, competence, time or financial resources to engage in communications experiments which are outside of their field. Their requirements for scientific participation in an ACTS experiment are different and more extensive than those of a communications engineer: Science users require all of the attributes of an operational facility.

In the following table we have listed criteria which represent a profile of science user requirements for participation in ACTS experiments and define ways in which the ACTS system can simulate an operational system to meet science user needs.

Table 5.7. Guidelines for successful application of ACTS to science

1. Only large science projects improve their effectiveness enough to justify the time and expense of ACTS involvement.
2. An earth station placed on a local area network can serve multiple users, allow cost sharing and multiply service opportunities.

3. The investigator has a major need to be a data communications service provider.
4. A science objective is uniquely enabled by ACTS.
5. ACTS provides a unique service not previously available.
6. Use of ACTS does not compete for the researchers' limited time and financial resources.
7. Users can complete their objective within ACTS lifetime, or
8. Users have an acceptable service transition beyond ACTS lifetime.
9. In the experimental phase, experiments do not need to utilize the full capacity of ACTS, but only demonstrate useful and innovative applications.
10. Placing an ACTS terminal at a major center (NASA center, University, etc.,) provides a single multi-faceted implementation of ACTS rather than many small independent applications thus spreading the high implementation costs among many users.
11. Capability should be provided for rapid earth station setup and interfacing to local facilities.
12. ACTS must be easy to use and transparent to the science user.

5.8.3 User requirements for ACTS earth stations

Telecommunications managers felt there were a variety of user acceptability criteria that were important for ACTS earth stations. The overall installation impact of an ACTS earth station should be minimal. The siting of the earth station should be easy with minimal impact to existing structures. The equipment should have multiple flexible mounting options. Because science requirements tend to be dynamic and transient, it should be practical to move the earth station to different locations. The prospect of a small antenna was particularly appealing to many.

The interface between the earth sation and the user telecommunications equipment should be versatile and accomodate a variety of standard telephony, computer and local area network interfaces and use stand connectors. The ACTS earth station should be easy to fully integrate with the local equipment.

When making a decision to install ACTS earth stations, the prospective user needs a concise description of ACTS features, capacities, options and telecommunications interface specifications. This information should not be complicated by technical descriptions of how ACTS works. This suggests that the whole terminology associated with the ACTS program should be renamed to make it more user-friendly. For instance, the LBR-2 (LBR = low bit rate) might be called the "ACTS Dish" and the LBR-1 might be called the "ACTS Super Dish."

5.8.4 User requirements for workstations using ACTS

Based on our interviews with research scientists, the principal user requirement for ACTS earth stations is for transparency. This theme was expressed in a variety of ways. Potential users felt the ACTS earth station should be easy to use, it should be fully integrated with the local equipment (LAN, router, PBX, etc.), and its operational features should be no different than those for terrestrial services.

Telecommunications managers suggested that ACTS Experiments Program might be a good opportunity to develop creative terminal designs. Innovative hardware and software could be developed that would take advantage of ACTS advanced capabilities. Workstation software should provide transparent circuit setup and teardown, capability to invoke multiple circuits, transparent bandwidth requests, and type of service detection and routing. These capabilities would be particularly effective for multi-media applications and windowing applications on advanced workstations. Terminal hardware might include multi-screen displays, integrated voice and visual display terminals, and eye-phone terminals with data glove and remote manipulator interfaces.

5.8.5 Gateway requirements for ACTS

During the interviews telecommunications managers suggested that ACTS earth stations should be modularized for maximum mounting and interfacing flexibility and they should have standardized interfaces between the terrestrial interface equipment and the user telecommunications equipment. In some cases it may be desirable to interface with network routers or local area networks, and in other cases with central office telephony equipment. An ISDN interface was considered particularly desirable to allow ACTS to interwork with terrestrial ISDN network.

In addition it was suggested that software be developed for use with user equipment, particularly computers and advanced workstations, so that end-user applications can make effective use of ACTS' advanced features.

Application layer protocols and software modules, preferably OSI compatible, could be designed to enable applications developers to easily incorporate capabilities such as circuit setup and teardown, bandwidth requests, and invocation of multiple circuits into workstation applications so they are transparent to the end-user. Capabilities might also be incorporated to provide automatic type of service detection and routing so that the user traffic can be carried either by ACTS or other terrestrial carriers as required.

Managers were also concerned that the user telecommunications equipment avoid ACTS specific features, except in software, so that equipment could be reused elsewhere after the ACTS experiments.

5.8.6 Financing and partnership arrangements for ACTS earth stations

Survey participants suggested several approaches to financing ACTS earth stations. The most common suggestion for financing ACTS earth stations was to share the use of the earth stations among many users particularly in situations where one earth station could serve the needs of an institution and might be integrated with its local area network. At least three levels of service should be considered for interfacing ACTS to local networks. These are Ethernet at 10 Mbits/sec, Fiber Distributed Data Interface (FDDI) at 100 Mbits/sec, and Metropolitan Area Network (MAN) at 155 Mbits/sec or higher.

With the possible addition of some local links this approach would allow participation from various labs and small experimenters in the area that might have only occasional communications needs and that could not afford the entire cost. The facility could be operated on a pay as you go basis.

A related suggestion was to form a consortium of experimenters each of whom would pay a share of the cost in exchange for the exclusive use of the earth station for a proportionate amount of time.

A suggestion for how a university might finance an earth station was to develop the station as an educational project within its engineering or telecommunications department. This would limit the necessary outlays to only the unique components that would need to be purchased from the terminal vendor with the balance covered by donated labor, existing resources and departmental funds.

An approach for obtaining funding for multiple earth stations was suggested that would depend on the creation of an ACTS Applications Demonstration Program. Financing for terminals could be part of a larger program to demonstrate ACTS technology in a simulated operational setting that included the terminals, facilities and applications software development to serve one or more science user applications.

There is a distinct advantage to having an application that is common to many users as opposed to several independent applications. A common application can take advantage of economies of scale for procurement of equipment and software, and has an advantage in solicitation of funds.

In the case of independent applications, each user/experimenter must bear the high front-end cost of the terminal equipment, the high cost of independent implementation, plus the operations cost. Thus the overall program cost is higher and there are likely to be fewer program participants.

Industry sponsorship was suggested as a way to finance the ACTS earth stations. This approach would require involving private industry in the development of specific applications from which they would be able to obtain new technology, earn revenue and have free use of ACTS resources.

Many of the larger telecommunications companies are associated with foundations that may be willing to provide grants for ACTS experiments, particularly if the purposes of the experiments are relevant to the interests of the telecommunications industry.

6 How ACTS Serves Science

One major trend in contemporary science is to examine problems of increasing complexity and broader scale involving greater numbers of investigators from multiple disciplines and utilizing diverse instruments, data sets, computers and communications equipment. The study of global change is an example. The corresponding science communications requirements are also becoming increasingly complex.

The typical communications needs range from conventional low data rate point-to-point requirements to relatively sophisticated needs involving very high or variable data rates with point-to-multipoint, multichannel and mesh connectivity that can be dynamically reconfigured. The science communications needs are often transient and vary with the phase of the research activity, including experiment planning, data acquisition and experiment operations, general research, archiving and retrospective analysis, plus general collaborative activity.

ACTS technology has unique capabilities to meet sophisticated science communications needs. In this section we summarize the ACTS functionality that is important for science, review the principle activities associated with scientific research, particularly space science and field research and then summarize the telecommunications requirements associated with scientific activities.

In subsection 6.4 charts are presented to show how the various elements of ACTS functionality serve identified science communications requirements, and how they meet the needs of scientific collaboration and telescience activities.

In order to further show how ACTS can serve science, the final chart in this series (Table 6.4) analyzes several key areas of science communications activity, identified in this study, that represent a good fit or particularly benefit from ACTS functionality.

6.1 ACTS functionality important for science

In order to analyze how ACTS might best serve science activities, we have developed a summary of the ACTS functionality and characteristics based on our communications user survey, that are important for science applications. These are shown in Table 6.1.

For each component of ACTS functionality listed in the table, important technical and user aspects are shown. Because of the interdependence and mutual synergy of the various ACTS features, the technical and user aspects listed in the table are at best only a first approximation and may vary widely with the particular application being considered.

The ACTS features listed in column one of Table 6.1 will be used in additional tables below which present matrices that show the linkage between the elements of ACTS functionality and various science requirements.

Table 6.1. ACTS functionality important for science users.

ACTS Feature	Technical Aspect	User Aspect
OSBS/TDMA		
Baseband switched	Efficient for low volume/distributed	Multiple dynamic connections
Hopping beams	Efficiently match nonuniform demand	More capacity for users/services
FEC encoding	Maintain link budget during fade	Maintain bit error rate
SMSK modulation	Most efficient encoding	No alternative for user
Steerable beam antenna	Accomodate remote, moving nodes	No site constraints
SS/TDMA		
IF switched	Efficient for high volume/trunked	High volume/low cost
Switched stationary beams	Dynamicly switched, freq. reuse	High volume/low cost
Adjustable downlink power	Dynamic rain fade compensation	Predictable BER
No onboard modulation	User selectable modulation	Maximum equipment flexibility
Steerable beam antenna	Accomodate remote, moving nodes	No site constraints
Capacity		
Demand assignment	BW mgmt, Optimize use of resources	User cost saving
Single 64KBS circuit	BW compatible with other services	Meets common service rqmts
Multiple 64KB circuits as one	BW compatible with other services	Meets advanced appl'n rqmts
High data rate (to DS-3)	BW Compatible with other services	Meets adv appl'n rqmts, file transfer
Asymetric links (hi/lo BW)	Optimum use of resources	Control remote processes, visualization
Connectivity		
Mesh interconnectivity	No indirect routes	Maximum connection versatility
Point-to-multipoint simplex	Efficient broadcast distribution	User cost saving
Multi-Channel	Integrated voice, data, video	Increased transparency
Fast circuit setup/teardown	Dynamic reconfiguration	Support advanced workstations
Rapid reconfiguration of links	Dynamic reconfiguration	Support advanced workstations
Quality		
Spot beams/high EIRP	Frequency reuse, Small antennas	Less expensive user terminals
Signal regeneration	Improved S/N	Smaller VSAT antennas
Single hop	Small delay	Better interactive operation
Bit Error Rate $< 5 \cdot 10^{-7}$	Minimal retransmission rqmts	Data integrity
Terminal versatility		
Multiple terminals same spot	System flexibility	Service versatility
Shared terminal	Smaller installation impact	Cost sharing, higher contention
Temporary fixed terminal	Quick installation	Meets transient needs
Mobile terminal	Portable terminal	Meets field operation rqmts
Deficiencies		
Link delay	Single hop delay	Slow interactive/protocol response
Fade	Reduces total thruput	Impact on network systems
Cost of terminal	Costs exceed $200,000	Prohibitive for users/sharing reqd
Satellite life-time	Two to four year life	Inadequate for long missions

TDMA - Time Division Multiple Access
OSBS/TDMA - Onboard Stored Baseband Switched/TDMA (refers to ACTS' baseband processor subsystem)
SS/TDMA - Satellite Switched/TDMA (refers to ACTS' intermediate frequency microwave switched subsystem)
FEC - Forward Error Control

6.2 Summary of science research activities

Research programs, particularly field science such as space missions and environmental research, generally involve four phases of activity: program planning, acquisition, general research, and data storage and retrospective analysis. Some of the specific activities that typically occur in these phases are shown below.

Program Planning
- Experiment planning
- Experiment design
- Simulation
- Scheduling

Acquisition
- On-orbit/flight/experiment operations
- Monitoring and control
- Teleoperation
- Importing flight/field data
- Data Handling: Processing levels 0,1
- Initial analysis
- Initial objectives satisfaction

General research/Data analysis and management
- Data set production
- Data Handling: Processing levels 2,3
- Discipline investigations
- Interdisciplinary applications
- Model development and testing

Data storage and maintenance
- Archiving
- Retrospective analysis
- Quality maintenance

These represent many of the principal activities that occur in the course of performing scientific research. Nearly all of these areas can be aided by or require telecommunications support. The specific telecommunications requirements implied by these science activities are outlined below.

6.3 Summary of science communications requirements

The research activities described in the previous section imply numerous telecommunications requirements. In this section we summarize the telecommunications modes and applications needed for science, plus the associated bandwidth, connectivity, and geographic coverage requirements.

The communications modes needed for research range from conventional voice communications to advanced services such as multi-media communications involving diverse bandwidth, connectivity and logistic requirements. The following list encompasses most of the principal communications modes needed for science. The ability of ACTS to support these modes is further analyzed below and Table 6.2 shows how these modes are served by the various elements of ACTS functionality.

Communications modes needed for science
- Voice
- Digital data
- Video
- Slow scan video
- High Definition Television (HDTV)
- Conference calling
- Interactive digital: remote logon, advanced workstations
- Multi-media: voice, data, video, remote manipulators

There are a variety of telecommunications applications that are particularly useful for science. Those applications already in wide use and implemented on SPAN and the Internet are electronic mail, remote logon and file transfer.

Conventional computer network applications
- E-mail
- Interactive (remote) logon
- File transfer

Many secondary applications can be implemented using these capabilities. There are also additional applications that are particularly useful for science activities that can be implemented in advanced workstations and that have advanced telecommunications requirements such as are available from ACTS.

Communications applications needed for science
- Simultaneous viewing
- Remote/group editing
- Electronic blackboard
- Electronic bulletin board access
- Document delivery
- Information systems access
- Remote data processing

The latter three items listed above can be further broken down into a number of specific applications that are particularly necessary for science. These are used either directly in the performance of research or indirectly for general scientific communications.

Document delivery
- FAX
- E-mail/distribution lists
- Electronic newsletters
- File transfer

Information systems access
- Library services (citations, journals)
- Remote databases (science data)
- Browse and burst capability
- Access to multiple databases
- Archive access/maintenance

Remote data processing
- Remote database access
- Distributed computing
- Supercomputer access
- Scientific visualization
- Interactive graphics
- Image Processing
- Data archival

The bandwidth and circuit requirements needed to support the applications listed above range from modest narrowband circuits to very high data rate circuits and, to be efficient, include requirements for rapid setup, teardown and reconfiguration. Some of the applications also have widely varying data rate requirements and would benefit from a service that could allocate bandwidth on demand.

Bandwidth and circuit requirements for science
- Narrowband (fractional T1)
- Broadband (T1 to DS-3)
- Dynamically allocated bandwidth
- Rapid connection setup/teardown
- Rapid circuit reconfiguration

Advanced applications in science can take good advantage of the full scope of possible connectivity arrangements including multi-channel mesh-connectivity and all diminutive connectivity arrangements.

Connectivity requirements for science
- Private mode (point-to-point)
- Multi-channel (multichannel point-to-point)
- Broadcast mode (point-to-multipoint)
- Network mode (multipoint-to-multipoint)

Science activities require connections to government centers, private institutions, universities and companies as well as to remote field locations where data is being gathered or relayed. Communications coverage requirements are global and may involve fixed, temporary, or mobile communications nodes.

Geographic coverage/logistic requirements for science
- Spot locations
- Full CONUS
- Multi-continent
- Temporary
- Mobile
- LEO Satellite

6.4 How ACTS serves science communications requirements

In order to further analyze how ACTS serves various science requirements, we have used the following matrices, Tables 6.2 – 6.4, to show the linkage between the elements of ACTS functionality shown in column one of Table 6.1 and various identified science telecommunications requirements.

These tables reflect the results of our survey and interviews and attempt to show which specific elements of ACTS' functionality support various communications modes and scientific activities.

Table 6.2 summarizes how ACTS supports the principal communications modes needed by science such as voice, data and video service that were identified and analyzed in the previous section.

By looking at the distribution of ones (indicating that ACTS is advantageous for serving the indicated need) in the table one can see at a glance how the various communications modes are served by the different elements of ACTS functionality.

Tables 6.3 and 6.4 apply this same type of analysis to selected scientific activities that are discussed in the following section. Table 6.3 addresses the specific requirements for scientific collaboration and details a variety of ordinary and advanced communications applications that would facilitate cooperative communications and activities between scientists.

Table 6.4 shows the correspondence between the various elements of ACTS functionality and a select list of science activities that we have identified as able to take particular advantage of ACTS capabilities.

A few points for interpretation of the tables are in order. Note that values shown in the columns for voice communications in Table 6.2 and Table 6.3 differ. This is because the voice requirement in Table 6.2 includes high volume trunked applications, whereas Table 6.3 emphasizes voice communications that is of a low volume dispersed nature characteristic of collaboration activity. Similarly the values for conference calling in these same tables differ in that the steerable beam and potential mobility of ACTS earth stations are important for collaboration activities that may involve field operations, but may be less important in general (Table 6.2) because most activity is between permanent sites.

The SMSK modulation for the baseband processor is shown as a possible disadvantage for telescience and terrestrial network support, see Tables 6.3 and 6.4 because survey participants felt it may be desirable to have the option to use other modulation methods for the most demanding applications.

Table 6.2
ACTS functionality important for science communications modes.

ACTS Functionality	Communications Modes	Voice (inc. trunked)	Digital data	Video	Slow scan video	High Definition TV (HDTV)	Conference calling	Interactive digital: remote logon, adv. workstation	Multi-media: voice, data, video, remote manipulators
OSBS/TDMA									
Baseband switched/routed		1	1	1	1	1	1	1	1
Hopping beams (TDMA)		1	1	1	1	1	1	1	1
FEC encoding		-	1	-	-	-	-	1	1
SMSK modulation		-	-	-	-	-	-	-	-
SS/TDMA									
IF switched/bent pipe		1	1	1	-	1	-	-	-
Switched stationary beams		1	1	1	-	1	-	-	-
Adjustable downlink power		1	1	-	-	-	-	-	1
User modulation option		-	-	-	-	-	-	-	-
Capacity/data rate									
Demand assigned bandwidth		-	1	-	-	-	-	1	1
Single circuit (64K - T1)		-	1	1	1	-	-	1	1
High data rate (T-3)		1	1	1	-	1	-	1	1
Asymetric links (hi/lo BW)		-	1	-	-	-	-	1	1
Connectivity									
Mesh connectivity		1	1	1	-	1	1	1	1
Point-to-multipoint simplex		-	1	1	1	1	-	-	-
Multiple circuits		1	1	-	-	-	1	1	1
Fast circuit setup/teardown		-	1	-	-	-	-	1	1
Rapid reconfiguration		-	1	-	-	-	-	1	1
Steerable beam		-	1	-	-	-	-	1	1
Quality									
Spot beams/high EIRP		-	1	-	-	-	-	1	1
Signal regeneration		-	1	-	-	-	-	1	1
Single hop/small delay		1	1	-	-	-	1	1	1
BER $< 5 \cdot 10^{-7}$		-	1	-	-	-	-	1	1
Terminal versitility									
Shared terminal on node		1	1	1	1	1	1	1	1
Temporary/fixed terminal		1	1	1	1	1	1	1	1
Mobile (field/spacecraft)		1	1	1	-	1	-	1	1
Deficiencies									
Link delay		0	0	-	-	-	0	0	0
Fade reduces total thruput		-	0	-	-	0	-	-	0
Cost of terminal		0	0	0	0	0	0	0	0
Satellite life-time		-	-	-	-	-	-	-	-

Values: 1 Advantage, 0 Disadvantage, - Don't care/not applicable

Table 6.3
ACTS functionality important for science collaboration activities.

ACTS Functionality	Collaboration activities	E-mail, file transfer	FAX	Voice communications	Conference calling	Multi-media teleconferencing	Simultaneous viewing	Electronic blackboard	Remote/group editing	Telescience/experiment operations
OSBS/TDMA										
Baseband switched		-	-	1	1	1	1	1	1	1
Hopping beams (TDMA)		-	-	1	1	1	1	1	1	1
FEC encoding		1	1	-	-	-	1	1	-	1
SMSK modulation		-	-	-	-	-	-	-	-	0
SS/TDMA										
IF switched		-	-	-	-	-	-	-	-	1
Switched stationary beams		-	-	-	-	-	-	-	-	1
Adjustable downlink power		-	-	-	-	-	-	-	-	1
User modulation option		-	-	-	-	-	-	-	-	1
Capacity/data rate										
Demand assigned bandwidth		1	-	-	-	-	1	-	-	1
Lo-Hi BW circuits (64K-T1)		1	1	-	-	1	1	1	1	1
High bandwidth (T-3)		-	-	-	-	1	1	-	-	1
Asymetric links (hi/lo BW)		1	1	-	-	-	-	-	-	1
Connectivity										
Mesh connectivity		-	-	1	1	1	1	1	1	1
Point-to-multipoint simplex		1	-	-	-	-	-	-	-	1
Multi-channel		-	-	1	1	1	1	1	1	1
Fast circuit setup/teardown		-	-	-	-	-	-	-	-	1
Rapid reconfiguration		-	-	-	-	-	-	-	-	1
Steerable beam		1	1	1	1	1	1	1	1	1
Quality										
Spot beams/high EIRP		1	-	-	-	-	1	-	1	1
Signal regeneration		1	-	-	-	-	1	-	1	1
Single hop/small delay		-	-	1	1	1	1	1	1	1
BER $< 5 \cdot 10^{-7}$		1	1	-	-	-	1	-	1	1
Terminal versitility										
Shared terminal		1	1	1	1	1	1	1	1	1
Temporary fixed terminal		1	1	1	1	1	1	1	1	1
Mobile terminal		1	1	1	1	1	1	1	1	1
Deficiencies										
Link delay		-	-	0	0	0	0	0	0	0
Fade reduces total thruput		-	-	-	-	-	-	-	-	0
Cost of terminal		0	0	0	0	0	0	0	0	0
Satellite life-time		-	-	-	-	-	-	-	-	0

Score: 1=Advantage, 0=Disadvantage, -=Don't Care/not applicable

Table 6.4
ACTS functionality important for science activities.

ACTS Functionality	Science Activity	Telescience	Remote database/Info systems access	Remote computing	Advanced workstation applns	Scientific visualization	Collaboration activities	Multi-media communications	Terrestrial network support	Science activities in Earth orbit	Terrestrial field science
OSBS/TDMA											
Baseband switched		1	1	1	1	1	1	1	1	1	1
Hopping beams (TDMA)		1	1	1	1	1	1	1	1	–	1
FEC encoding		1	1	1	1	1	1	1	1	1	1
SMSK modulation		0	–	–	–	–	–	–	0	–	0
SS/TDMA											
IF switched		1	–	–	–	1	–	–	1	–	1
Switched stationary beams		1	–	–	–	1	–	–	1	–	1
Adjustable downlink power		1	–	1	1	–	–	–	1	–	1
User modulation option		1	–	–	–	–	–	–	1	–	1
Capacity/data rate											
Demand assiged bandwidth		1	1	1	1	1	1	1	1	1	1
Lo-Hi BW circuits (64K-T1)		1	1	1	1	1	1	1	1	1	1
High bandwidth (T-3)		1	1	–	–	1	–	1	1	1	–
Asymetric links (hi/lo BW)		1	1	1	1	1	–	–	1	1	1
Connectivity											
Mesh connectivity		1	–	–	1	–	1	–	1	1	1
Point-to-multipoint simplex		1	–	–	1	–	1	–	1	1	1
Multi-channel		1	1	–	1	–	1	1	1	1	1
Fast circuit setup/teardown		1	1	–	1	–	1	–	1	1	1
Rapid reconfiguration		1	1	–	1	–	1	–	1	1	1
Steerable beam		1	–	–	–	–	–	–	1	1	1
Quality											
Spot beams/high EIRP		1	–	–	–	–	–	–	1	1	1
Signal regeneration		1	–	–	–	–	–	–	1	1	1
Single hop/small delay		1	–	–	–	–	1	1	1	1	1
BER $< 5 \cdot 10^{-7}$		1	–	1	1	–	–	–	1	1	1
Terminal versitility		1	–	–	–	–	1	–	1	1	1
Shared terminal same node		1	1	1	1	1	1	1	1	–	–
Temporary fixed terminal		1	–	–	–	–	–	–	1	1	1
Mobile terminal		1	–	–	–	–	–	–	–	1	1
Deficiencies											
Link delay		0	–	–	–	–	0	0	0	0	0
Fade reduces total thruput		0	–	–	–	0	–	–	0	–	0
Cost of terminal		0	0	0	0	0	0	0	–	–	0
Satellite life-time		0	–	–	–	–	–	–	0	0	0

Values: 1 Advantage, 0 Disadvantage, – Don't care/not applicable

6.5 Science applications of ACTS

In order to further analyze how ACTS can serve science, we have selected several areas of science communications activity, identified in this study, that would particularly benefit from ACTS functionality. These are:

Table 6.5. Science areas and applications that can benefit from ACTS

- Telescience
- Remote database and information systems access
- Remote computing
- Advanced workstation applications
- Scientific visualization
- Collaboration activities
- Multimedia communications support
- Terrestrial science network support
- Science activities in Earth-orbit
- Terrestrial field science

Although some of these areas overlap one another, they represent focal points where ACTS technology might be effectively applied to support science. Each of these areas is discussed below and some of the detailed communications requirements relevant to ACTS are identified.

In order to provide a concise analysis of how ACTS serves these science activities, we have developed a summary of the ACTS functionality and characteristics that are important for science applications. Using this, Table 6.4 presents a matrix that shows the linkage between the various elements of ACTS functionality and the requirements for each of the identified science applications. Each column shows a communications mode needed for science and each row shows a feature of ACTS functionality. The values in the table represent our estimates, based on our interviews and analysis, of whether the feature is an advantage (1) or disadvantage (0) for science users. Items marked with a dash are not applicable or are believed to be not important.

6.5.1 Telescience

Some of the most comprehensive requirements for advanced telecommunications facilities occur 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. This is generally referred to as telescience, and often involves teleoperation of experiments, as for example on the space station. Additionally it may involve remote or distributed computing, and collaboration activities.

Telescience

- Teleoperation of remote instruments, experiments
- Monitoring and control
- Distributed computing facilities
- Access to remote databases
- Teleconferencing between investigators

6.5.2 Remote database access

One of the most important capabilities needed by scientists is the ability to access remote databases and computing resources using advanced workstations. ACTS' capability for demand allocated bandwidth is particularly useful in this application. For example, a user might first browse a data catalog at some remote archive and then request the transfer of a large data set to his or her local facility. Similarly, advanced work station programs may be designed to automatically access remote databases and transfer data to the users host computer or to a supercomputer at a third site for processing.

- Remote database access
  - Use of advanced workstations
  - Access directories and catalogs
  - Locating data
  - Accessing data
  - Browsing data
  - Ordering data from various data centers
  - File transfer
  - System requirements
    - Users operate from remote locations
    - Access over heterogeneous networks
    - Simultaneous access to multiple heterogeneous databases
    - Using natural language queries and hierarchical menus

6.5.3 Remote computing

The availability of broadband communications links often determines which types of tasks are considered feasible over networks. For example, they make it practical to routinely transfer large data files between sites for processing and to monitor remote processes using scientific visualization techniques. At this point in time, ACTS could provide added bandwidth not currently available on many networks and also dynamically allocate that bandwidth to achieve the most efficient use of the communications resources.

- Remote computing
  - Transfer programs and data to supercomputer
  - Monitor and control computing process
  - Interim results
  - Scientific visualization

6.5.4 Advanced workstations

Advanced workstations place powerful tools in the hands of the researcher and are becoming increasingly necessary because they enable tasks to be performed which were previously impractical due to the time involved or cumbersome nature. They allow multiple processes to be performed simultaneously on local and remote computing facilities and may involve varying bandwidth requirements. Thus they require support for multiple communications links of varying capacities that are dynamically reconfigurable.

Advanced workstations are characterized by:
- Windowing environments
- Multiple processes on local and remote machines
- Access to multiple heterogeneous databases over networks
- Low and high data rates, text, graphics
- Multiple communications channels
- Transparent communications
- Ability to accelerate research productivity

6.5.5 Scientific visualization

Scientific visualization is a technique that is finding increasing use in research involving large data sets or massive computing requirements. It is generally used as a way of monitoring and controlling processes on supercomputers. It typically involves the production of graphic images derived from the process. These may be transmitted to the investigator located at a remote site who in turn controls the process with relatively low data rate commands.

Scientific visualization
- Control processes on supercomputer
- 2-D and 3-D graphic representations of data
- Graphic images require wideband communications
- Low data rate commands to control supercomputer processes

6.5.6 Collaboration activities

Support for human communications is another highly important component of science communications requirements. There is a strong trend these days toward collaborative, team-oriented and interdisciplinary research where various members of the research group may be located at many different agencies and institutions throughout the country and abroad.

Science User Groups
- NASA
- Government labs
- Universities
- Industry
- Foreign

Collaboration may involve meetings, experiment operations, joint analysis and discussion of research, remote editing, preparation of technical reports and journal articles, sending of meeting notices and newsletters, and so on. Collaboration activities can be supported by a variety of conventional and advanced telecommunications applications, including ISDN.

Below are listed some conventional as well as advanced communications applications that can support collaborative activities. All of these could be effectively implemented using ACTS. Table 6.3 shows an analysis of how these applications are supported by the various elements of ACTS functionality.

Collaboration activities
- E-mail
- FAX (Group 3, analog; Group 4, digital)
- Voice communications
- Conference calling
- Multi-media teleconferencing: Video, Voice, Graphics
- Simultaneous viewing
- Electronic blackboard
- CAD and Modeling
- Group editing multi-media documents, (eg., text, graphics)
- Telescience/experiment operations

6.5.7 Multi-media communications support

In addition to their role in supporting the collaborative activity of the science community, multi-media communications will play an increasingly important role in telescience. Multi-media communications provides enhanced transparency by providing the necessary sensory monitoring information to the investigator and by the transfering necessary control signals to the remote site or spacecraft. This capability is critical for effective teleoperated science experiments.

Multi-media communications
- Supports telescience requirements
- Improved transparency for collaboration activities
- Voice and data compatible with ISDN service capabilities
- Teleconferencing applications: Voice, data, tablet/blackboard, video
- Teleoperation applications: Data, video, remote manipulators
- Telepresence applications: Data, video, remote control rover/spacecraft

Terrestrial science network support

Terrestrial science networks are built almost entirely around SPAN and the Internet (including NSFNET). ACTS could play a role in several key areas: as a backup for terrestrial links, as a complement to terrestrial links for carrying high volume loads, for transient high volume loads, and as a system for linking off-network sites.

Science activities tend to be of short duration with dynamic requirements for different telecommunications links and capacities. ACTS could serve to link islands of isolated capabilities such as ISDN and FDDI networks where the intermediate carriers do not support the necessary capacity, services or protocols.

ACTS could also be used to as a pilot facility for new site pre-fiber trials, as a transition service for new sites planning fiber installations, and as an ISDN extender capability.

There is also a need for systems to provide additional capacity to carry transient high volume loads that would overburden existing networks or delay time-critical mission objectives. Science activities also have varying requirements to link to off-network sites and facilities, particularly temporary and mobile facilities.

Terrestrial network support
- ACTS complements SPAN, Internet
- Bypass: Overcoming terrestrial service non-uniformity
- Backup for terrestrial links
- Complement terrestrial links for high volume and transient high volume loads
- Linking research centers
- Pilot facility for new site pre-fiber trials
- Transition capability for new sites planning fiber
- Linking ISDN "islands"
- ISDN extender capability

6.5.8 Science activities in low Earth orbit

A detailed list of the specific NASA and NOAA missions and programs that will be contemporary to ACTS lifetime are shown in Table 6.6 below. The list is based on the assumption that ACTS might remain operational for four years. The missions are organized in chronological order and are grouped by OSSA division. The NOAA missions are included under the NASA Earth Science and Applications catagory. This table also includes missions that were launched before ACTS but whose operational life overlaps that of ACTS. Table 6.6 is a subset of Appendix C which shows all NASA and NOAA missions as cited in the references for the table The data in this table as well as Table 6.7 and Appendix C is based on missions identified in the 1989 NASA Manifest, NASA 1989 Long Range Plan, and the NOAA NESDIS Satellite Programs Briefing of 1985. The mission beginning and ending dates are shown where known. Those whose ending dates are marked SR, are mission payloads that are operated on a Shuttle flight and end when the Shuttle returns to earth. Both the platform and general destination of the missions is shown in the table. The last column indicates those missions whose spacecraft fly in orbits that would be visable to ACTS and could be tracked by ACTS steerable antenna. These are discussed below.

Table 6.6. Missions Contemporary with ACTS.

ASTROPHYSICS

BEGIN	END	ACRONYM	NAME	PLAT	DEST	VIS
90 03 26	05	HST	HUBBLE SPACE TELESCOPE	FF	LEO	V
90 06 04	92	GRO	GAMMA RAY OBSERVATORY	FF	LEO	V
91 08 -	93	EUVE	EXTREME ULTRAVIOLET EXPLORER	EP	LEO	V
92 08 27	SR	ORFEUS	ORBITING, RETRIEVBL FAR & EXTREME UV SPEC	STS	LEO	V
93 05 03	SR	ASTRO-3	ASTRO	STS	LEO	V
94 07 10	96	XTE	X-RAY TIMING EXPLORER	EP	LEO	V
95 05 03	SR	BBXRT	BROAD BAND X-RAY TELESCOPE	STS	LEO	V
95 12 -	11	AXAF	ADVANCED X-RAY ASTROPHYSICS FACILITY	SSCO	LEO	V
95	97	GRAV-B	GRAVITY PROBE-B	FF	LEO	V

SPACE PHYSICS

BEGIN	END	ACRONYM	NAME	PLAT	DEST	VIS
90 06 -	93	CRRES	COMBINED RELEASE & RADIATION EFFECTS SAT	FF	EO HE	
90 10 05	95	ULYSSES	ULYSSES SOLAR PROBE	FF	SP	
92 06 -	-	SAMPE	SOLAR ANOM. & MAGNETOSPH. PARTICLE EXPL	FF	EO	
92 07 -	98	GEOTAIL	GEOTAIL MISSION (COSTR/ISTP)	FF	EO HE	
92 12 -	98	WIND	WIND MISSION (GGS/ISTP)	FF	EO HE	
93 06 -	98	POLAR	POLAR MISSION (GGS/ISTP)	FF	EO HE	
93 06 -	-	SWAS	SUBMILLIMETRE WAVE ASTRONOMY SAT	FF	EO	
94	00+	PIMS	PLASMA INTERACTION MONITORING SYSTEM	SSAP	LEO	V
95 08 -	-	OSL	ORBITING SOLAR LABORATORY	FF	SO	

SOLAR SYSTEM EXPLORATION

BEGIN	END	ACRONYM	NAME	PLAT	DEST	VIS
89 10 18	97	GALILEO	GALILEO	FF	JP	
92 09 -	95	MO 1	MARS OBSERVER 1	FF	MO	
94	00+	CDCF	COSMIC DUST COLLECTION FACILITY	SSAP	LEO	V
96	00+	ATF	ASTROMETRIC TELESCOPE FACILITY	SSAP	LEO	V

EARTH SCIENCE & APPLICATIONS

BEGIN	END	ACRONYM	NAME	PLAT	DEST	VIS
90 01 -	-	NOAA-D	NATIONAL OCEANIC & ATMOSPHERIC ADMIN	FF	PEO SS	V
91 05 -	-	NOAA-I	NATIONAL OCEANIC & ATMOSPHERIC ADMIN	FF	PEO SS	V
91 11 27	95	UARS	UPPER ATMOSPHERE RESEARCH SATELLITE	FF	LEO	V
91 12 -	94	TOPEX	OCEAN TOPOGRAPHY EXPERIMENT	FF	LEO	V
92 06 15	SR	SRL-1	SPACE RADAR LABORATORY	STS	LEO	V
92 07 09	SR	ATLAS-2	ATMOSPHERIC LABORATORY FOR APPLNS & SCI	STS	LEO	V
92 09 -	-	NOAA-J	NATIONAL OCEANIC & ATMOSPHERIC ADMIN	FF	PEO SS	V
92	95	NSCAT	NASA SCATTEROMETER	PP	LEO	V
93 01 -	-	TOMS	TOTAL OZONE MAPPING SPECTROMETER	FF	LEO	V
93 07 15	SR	ATLAS-3	ATMOSPHERIC LABORATORY FOR APPLNS & SCI	STS	LEO	V
93 08 12	SR	SRL-2	SPACE RADAR LABORATORY	STS	LEO	V
93 11 -	-	NOAA-K	NATIONAL OCEANIC & ATMOSPHERIC ADMIN	FF	PEO SS	V
93 12 -	-	FASE	FAST AURORAL SNAPSHOT EXPLORER	FF	LEO	V
94 04 21	SR	ATLAS-4	ATMOSPHERIC LABORATORY FOR APPLNS & SCI	STS	LEO	V
94 06 -	99	RADARSAT	RADAR SATELLITE	FF	LEO	V
95 04 -	-	NOAA-L	NATIONAL OCEANIC & ATMOSPHERIC ADMIN	FF	PEO SS	V
95 09 30	SR	ATLAS-5	ATMOSPHERIC LABORATORY FOR APPLNS & SCI	STS	LEO	V
95	99	TRMM	TROPICAL RAINFALL MEASUREMENT MISSION	SSAP	LEO	V
96	01	GRM	GEOPOTENTIAL RESEARCH MISSION	FF	LEO	V
96	10	EOS-1	EARTH OBSERVING SYSTEM	PP	LEO	V

Table 6.6 cont'd. Missions Contemporary with ACTS.

LIFE SCIENCES

BEGIN	END	ACRONYM	NAME	PLAT	DEST	VIS
92 08 27	SR	SPACEHAB-2	SPACEHAB	STS	LEO	V
92 09 30	SR	SLS-2	SPACELAB LIFE SCIENCES LABORATORY	STS-SL	LEO	V
93 06 24	SR	SPACEHAB-3	SPACEHAB	STS	LEO	V
93 11 18	SR	SL D3	SPACELAB	STS-SL	LEO	V
94 01 13	SR	SPACEHAB-4	SPACEHAB	STS	LEO	V
94 06 09	SR	SLS-3	SPACELAB LIFE SCIENCES LABORATORY	STS-SL	LEO	V
94 07 10	SR	SPACEHAB-5	SPACEHAB	STS	LEO	V
95 02 03	SR	SPACEHAB-6	SPACEHAB	STS	LEO	V
95 08 08	SR	SPACEHAB-7	SPACEHAB	STS	LEO	V
95	00+	1.8-M	1.8-METRE CENTRIFUGE	SSF	LEO	V

MICROGRAVITY SCIENCE & APPLICATIONS

BEGIN	END	ACRONYM	NAME	PLAT	DEST	VIS
92 05 18	SR	USMP-1	UNITED STATES MICROGRAVITY PAYLOAD	STS	LEO	V
93 01 21	SR	IML-2	INTERNATIONAL MICROGRAVITY LABORATORY	STS-SL	LEO	V
93 02 22	SR	USMP-2	UNITED STATES MICROGRAVITY PAYLOAD	STS	LEO	V
93 09 30	SR	USMP-3	UNITED STATES MICROGRAVITY PAYLOAD	STS	LEO	V
94 03 03	SR	USML-2	UNITED STATES MICROGRAVITY LABORATORY	STS-SL	LEO	V
94 09 08	SR	USMP-4	UNITED STATES MICROGRAVITY PAYLOAD	STS	LEO	V
95 04 14	SR	IML-3	INTERNATIONAL MICROGRAVITY LABORATORY	STS-SL	LEO	V
95	00+	MMPF-1	MICROGRAVITY & MATERIALS PROCESSING FACIL	SSF	LEO	V
96 03 -	SR	USML-3	UNITED STATES MICROGRAVITY LABORATORY	STS-SL	LEO	V

BEGIN: Begin date; END: End date, SR=Shuttle Return of Payload on Same Mission
PLATFORM: FF=Free Flyer; STS=Space Shuttle, SL=Space Lab, PP=Polar Platform, SSAP=Space Station Attached Payload, SSCO=Space Station Co-orbiting, SSF=Space Station Freedom, EP=Explorer Platform, STS-P=Shuttle Proximity
DESTINATION: PL=Planetary Probe, SP=Solar Probe, SO=Solar Orbit, EO=Earth Orbit, LEO=Low Earth Orbit, SS=Sun Synchronous, GEO=Geosynchronous Orbit, PEO=Polar Earth Orbit, HE=High Eccentricity, HEO=High Earth Orbit, MO=Mars Orbit, JP=Jupiter Probe
VIS: V=Visible to ACTS.

An important potential application for ACTS is to communicate directly with mission spacecraft and field sites on the earth surface. The steerable antenna on ACTS is particularly relevant here because it can be pointed nearly anywhere on the disk of the Earth visable from geosynchronous orbit at 100 degrees west longitude, and it is capable of tracking any spacecraft as it transits this region.

6.5.9 Spacecraft visible to ACTS

The column labeled "VIS" in Table 6.6 above indicates those missions that will fly in earth orbits that will pass across the disk of the Earth under the field of view of ACTS. These spacecraft could in principle transmit their data up to the steerable antenna on ACTS as well as receive commands. These spacecraft may also need to track ACTS and/or use orbital alignment opportunities to burst their data to ACTS.

Although many of the spacecraft designs for the missions shown in Table 6.6 are frozen and direct communication with ACTS is not a real option, nevertheless this analysis points up the fact that there are many on-going opportunities. In fact, the great majority of all missions planned for the 1990 decade are logistically compatible with direct communication to ACTS from earth orbit (see comprehensive list of NASA and NOAA missions shown in Appendix C).

Table 6.7, shows a further breakdown of the NASA and NOAA missions visible to ACTS. Mission totals are shown as a function of the type of platform on which they fly, and the free flyers are further broken down by destination. Included are the primary missions to fly on the Space Shuttle, Space Station and other platforms, as well as those on individual equatorial and polar orbiting satellites in low earth orbit.

6.5.10 Terrestrial field science

Terrestrial field science campaigns often have similar requirements to those of space related telescience except that humans typically accompany and operate the research instruments. Thus there is the need for communications for logistic support. Field campaigns are also more amenable to dynamic program modifications as data is processed and information is relayed back to field crews.

Terrestrial field science operations

- Gather and upload field data to processing facility
- Receive processed data and images to guide further observations
- Logistic communications for field crews
- Link distributed investigators

Missions involving field campaigns that take place anywhere on that portion of the earth surface visible to the ACTS' steerable antenna are the other major type of missions that could make direct use of ACTS. In this case ACTS terminals could be co-located with field instruments or survey teams operating in almost any location in North and South America and the adjoining oceans visible to ACTS from its geosynchronous position at 100 degrees West longitude. For example, data collected from seismic surveys and weather stations could be transmitted via ACTS to processing centers at other locations, and ACTS might also be used to communicate messages and results back to field crews to subsequent activities. NASA missions within the Earth Science and Applications division as well as NOAA programs, particularly those involving field campaigns such as the TOPEX, TRMM and EOS programs are potential candidates for this application.

Table 6.7. NASA and NOAA spacecraft visible to ACTS.

Platform	Visible	Mission Commencement Year										
		89	90	91	92	93	94	95	96	97	98	TBD
Space Shuttle	*	-	3	2	8	6	4	3	-	-	-	-
Space Lab	*	-	2	1	3	2	2	2	2	1	2	-
Polar Platform	*	-	-	-	1	-	-	-	2	1	-	-
Explorer Platform	*	-	-	1	-	-	1	-	-	-	-	1
Space Station Freedom	*	-	-	-	-	-	-	-	1	-	1	6
SS Attached Payload	*	-	-	-	-	-	-	2	1	4	-	-
SS Co-orbiting	*	-	-	-	-	-	-	1	-	-	1	-
Free Flyer		-	-	-	-	-	-	-	-	-	-	-
LEO	*	1	3	2	1	3	1	2	2	-	-	2
SUN SYNC	*	-	1	1	1	1	-	1	-	-	-	1
EO HE		-	1	-	2	1	-	-	-	-	-	-
GEO		-	1	1	1		-	1	-	-	-	-
SUN-EO		-	-	-	-	-	-	1	-	-	-	-
Planetary		2	1	-	1	-	-	2	2	1	1	-
Airplane	*	-	-	-	-	-	-	-	-	-	-	1
Total Missions		3	12	8	18	13	10	15	12	4	4	11
Total Visible	*	1	9	7	14	12	10	11	10	3	3	11

Many of the research and collaboration activities described above would benefit from the capabilities provided by ACTS including rapid connection establishment and reconfiguration, multi-media operation, demand assigned bandwidth, multiple simultaneous connections, portable earth stations, and mesh connectivity to diverse locations and resources. These capabilities go beyond conventional telecommunications facilities but could be implemented with ACTS technology.

7 Conclusions

The power of the ACTS satellite in terms of raw throughput, on-board intelligence, and highly adaptable network architecture, especially in terms of mesh-like interconnections, represents an important new telecommunications potential. In short, ACTS technology represents a break-through capability. The question is, how does the scientific community see this new capability, especially in light of its own telecommunications requirements which are not only growing rapidly but also changing in nature. The dynamism frequently leads to new approaches to research such as telepresence, telecollaboration, scientific visualization in two and three dimensional formats, remote log-on using X-window capabilities in advanced workstations, and supercomputer to supercomputer links.

Despite off-setting trends such as use of local computing power, digital compression techniques, and transfer of information by means of physical exchange of CD-ROMs, the scientific community's telecommunications needs are clearly on the rise. Even if fiber optic cables are used for many scientific applications there remain many areas where satellites are best. Further, hybrid systems and backup services for fiber optic cable restoration are factors critical for future satellite planning. This suggests that there is a natural and strong affinity between ACTS and the scientific user community that stands ready for cultivation and rapid exploitation. However, many in the scientific community remain unconvinced or only partially convinced of ACTS' utility, partly because the community is not aware of its potential or because of perceived complexities in becoming involved in the program. On the other hand, many members of the scientific community are eager for the increased capabilities offered by ACTS.

Data on the usefulness of ACTS was gathered by means of a workshop involving scientists from across the U.S. and by means of in-depth interviews in the Boulder, Colorado area both with telecommunications managers at research institutions and with a broad range of scientists.

The findings of the interviews and the workshop were congruent, and in particular there was agreement that ACTS could be very useful to science. This leads to a fundamental conclusion that the ACTS experiment program should include activities intended to demonstrate to the scientific community the usefulness of ACTS. Clearly, if these demonstrations are to be most convincing they should involve genuine scientific usage.

Further, it is very likely that users will apply the new capabilities of the satellite creatively and will discover new applications not contemplated in this study. In other words studies such as this one can point the way, but experience will be the real measure.

A second general conclusion has to do with involving the scientific community in the ACTS experiment program. In advance of any successful demonstrations, members of the science community have little incentive to go out of its way to use ACTS (or any other new medium) because, unlike the communications engineers who will be doing many of the experiments on ACTS, the scientists' goal is science and telecommunications is only a means to that end. Accordingly the community may be very conservative in its choice of communications modes. In addition its business will be solicited by commercial telecommunications companies.

The conclusion is that ACTS program management may need to be proactive in attempting to involve the science community in the experiment program. This will involve addressing concerns such as the high cost of ground stations and the relatively short lifetime and experimental nature of the program. It will also involve translating the capabilities of ACTS into science user terms and making sure that the community knows of ACTS. A fruitful approach might be to concentrate initially on telecommunications managers at research institutions who would be more likely to understand the usefulness of ACTS for science.

Finally, the effort to involve science in the ACTS program definitely will be worthwhile. The scientific need and the telecommunications capabilities are there, what is missing is only a mechanism to realize their potential utility.

Appendices

APPENDIX

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B Science and engineering activities that may benefit from ACTS

In this section we review the science and engineering activities that may benefit from ACTS at the University of Colorado, the National Oceanographic and Atmospheric Administration (NOAA) Environmental Research Laboratory (ERL), and the National Center for Atmospheric Research (NCAR) in Boulder. The activities at all four campuses of the University of Colorado (CU-Boulder, CU-Denver, CU-Colorado Springs and the Health Sciences Center in Denver) are included in the review. The NOAA activities reviewed are limited to those being performed in Boulder, Colorado. In all cases the emphasis is on space science and earth science related activities, and particularly those that may have telecommunications requirements.

B.1 Science activities at the University of Colorado

B.1.1 Department of Anthropology, CU-Boulder

There are four space-related research programs under way within the Anthropology Department; three are in archaeology and one is in physical anthropology.

A CU-NASA-NSF program is utilizing satellite and aircraft sensors to explore human settlement and volcanic activity over the past 6000 years in the tropics of northwestern Costa Rica. Sixty-two archaeological sites have been found and investigated. The studies utilize color infrared aerial photography and digital data from the LANDSAT Thermal Infrared Multispectral Scanner (TIMS). These same techniques are being used to study interethnic trade and conflict the in the Galisteo Basin of New Mexico and the the prehistoric relationships among the Anasazi in the Yellowjacket area of Southwest Colorado.

Physical anthropologists are using digitized images of human and primate teeth to explore prehistoric diets. Scanning electron microscopy of microwear on teeth from known diets is being compared with microwear of prehistoric primates and human ancestors, using image processing techniques developed by NASA scientists.

In the past years, CU anthropologists have studied the ruins of Gran Paten, Peru using a unique combination of on-site investigations and orbital radar/LANDSAT remote sensing data.

A conference was held late in 1987, sponsored by the University of Colorado and the National Science Foundation to bring remote sensing technology into human ecological-ethnographic research.

B.1.2 Department of Astrophysical, Planetary and Atmospheric Sciences (APAS), CU-Boulder

Research is conducted in observational and theoretical astrophysics, in theoretical, observational and laboratory atmospheric and planetary science, and in theoretical and experimental plasma physics.

Facilities outside the University are frequently used by students and faculty. Examples include the National Optical Astronomy Observatories, the National Radio Astronomy Observatory, the National Center for Atmospheric Research, and the National Oceanic and Atmospheric Administration.

B.1.3 Joint Institute for Laboratory Astrophysics (JILA), CU-Boulder

The Joint Institute for Laboratory Astrophysics (JILA) is operated by the National Institute for Standards and Technology (NIST) and the University of Colorado.

JILA is involved in studies in theoretical and experimental atomic interactions; spectroscopy and line broadening; chemical physics; optical resonance phenomena; precision measurement; gravitational physics; geophysical measurement techniques; stellar atmospheres and radiative transfer; stellar interiors; solar physics; the interstellar medium; and galactic astronomy. JILA maintains a large vibrationally isolated underground research facility and has a VAX 8600 computer that serves most of its scientific computing needs.

Research is performed under support received from NSF, NASA, DOD, and DOE. Substantial collaboration exists with various neighboring institutions such as LASP, HAO, NCAR, and CIRES, as well as with groups in the Boulder laboratories of the National Institute for Standards and Technology, and the National Oceanic and Atmospheric Administration (NOAA).

B.1.4 Colorado Center for Astrodynamics Research (CCAR), CU-Boulder

Members of Colorado Center for Astrodynamics Research (CCAR) at CU-Boulder conduct basic experimental and theoretical research and carry out a strong academic program in the areas of astrodynamics and remote sensing. Astrodynamics involves the study of the theory and applications of orbit determination, orbital mechanics, navigation, guidance, and control. Remote sensing activities concentrate on the systems aspects of remote sensing and include the study of sensors, media effects, data processing, and geophysical applications. CCAR researchers employ sophisticated numerical techniques and work large and diverse data sets, including those from SEASAT, GPS, and GEOSAT. Future plans include a major role in the NASA/CNES 1990's Topex Mission.

The following descriptions exemplify research being conducted at CCAR. Much of this research is collaborative with co-investigators from NASA, NOAA, NCAR, GSFC, NORDA, JPL and APL.

SATELLITE OCEANOGRAPHY emphasizes microwave, visual, and infrared sensing of the oceans using active and passive sensors and in situ data. Typical projects in this area include the development of techniques for ingesting satellite and in situ data into numerical ocean circulation models, use of satellite altimetry for feature detection in the tropical Pacific, and use of Advanced Visual High Resolution Radiometry (AVHRR) data for measuring ocean circulation and ice motion.

SATELLITE METEOROLOGY involves use of NOAA polar orbiting satellite data to map cloud top temperature, height, and thickness, and to compute atmospheric profiles of temperature and water vapor. CCAR operates a NOAA Polar Orbiter Satellite Receiving Station (POSRS) in Boulder.

SATELLITE GEODESY involves the use of extraterrestrial and Earth-orbiting sources to measure terrestrial baselines and perform precise marine and land-based positioning, essential in predicting natural phenomena as disparate as earthquakes and ocean tides.

ORBITAL MECHANICS involves mathematical modeling of satellite motion, mission planning and design, and precise orbit determination. A number of research programs are concerned with existing satellite missions such as the US Navy's GEOSAT, DOD's Global Positioning System (GPS), and NASA's Topex/Poseidon.

EARTH SYSTEM SCIENCE activities include developing methodology, algorithms, and data systems to facilitate the understanding of Earth's oceans and atmosphere and how they affect our weather and climate. Emphasis is on the application of large-scale satellite missions such as the Earth Observing System (EOS).

B.1.5 Department of Geography, CU-Boulder

The Department of Geography at CU-Boulder offers theoretical and practical work in physical geography, including climatology, geomorphology, and biogeography; conservation of natural resources, including environmental education and conflict analysis; human geography including urban, social, economic, political, historical, cultural and population geography; and regional analysis, including mountains, natural hazards and specific regional courses.

The Department of Geography is involved in teaching and research in environmental remote sensing and encourages interdisciplinary work through faculty affiliated with Boulder campus research institutes, such as the Cooperative Institute for Research in Environmental Sciences (CIRES), the Institute for Behavioral Sciences (IBS), the Center for Study of Earth from Space (CSES), and the Institute for Arctic and Alpine Research (INSTAAR).

Recent research projects utilizing remote sensing include estimates of population density and mapping changes of vegetation associated with land-use practices in Tanzania using LANDSAT data; studies of Arctic sea ice using passive microwave data; and research on polar cloud cover and snow melt processes on the pack ice from visible and infrared imagery.

B.1.6 Department of Geology, CU-Boulder

The Department of Geological Sciences at CU-Boulder is involved in studies in planetary geology, space geodesy and Earth remote sensing.

Research activities in planetary geology are coordinated with the Laboratory for Atmospheric and Space Physics (LASP), the Center for the Study of Earth from Space (CSES), and the Department of Astrophysical, Planetary and Atmospheric Sciences (APAS). Research in space geodesy and Earth remote sensing is performed in cooperation with research institutes in the Cooperative Institute for Research in the Environmental Sciences (CIRES) and others in planetary sciences.

Current areas of ongoing research in planetary geology include remote sensing of Earth, Mars, and surfaces of other terrestrial planets; eolian processes on Mars, climate and climate evolution of Mars (including surface-atmosphere interactions); and surface-evolution processes on comets and on the satellites of Jupiter.

B.1.7 Departments of Physics, CU Boulder, Denver and Colorado Springs

The Physics Departments at CU Boulder, Denver and Colorado Springs represent a major technical and educational element in the CU Space Program. Research programs at CU Boulder include high-energy physics, nuclear physics, low-temperature physics, atomic, molecular, and optical physics, gravitational physics and geophysics. Joint research is carried out with members of CASA, CIRES, LASP, and JILA, as well as the College of Engineering, and several faculty are jointly rostered in APAS and Physics. The presence of the National Institute for Standards and Technology (NIST) in Boulder provides additional opportunities for graduate research.

CU research in geophysics is particularly relevant to space and involves both crustal dynamics research employing laser ranging to orbiting spacecraft such as LAGEOS I and II, and the planned TOPEX/Poseidon oceanographic spacecraft that will be used to determine the sea-surface geoid to unprecedented accuracy.

Gravitational physics at the CU Boulder Physics Department is being done in cooperation with members of JILA and centers on work on gravity wave and general relativity. It involves both laboratory work and planning of space-based experiments in general relativity.

The Department of Physics at CU-Denver participates in space research primarily through the gamma ray and other high energy astrophysics work. Faculty members cooperated with CASA at CU-Boulder in the CASA rocket flight to observe Supernova 1987a in the extreme UV.

The Department of Physics at CU-Colorado Springs has a strong focus in solid-state physics research. It is also involved in variable star research and in research projects carried out in both the Electromagnetics and Space and Flight Systems Laboratories at UCCS.

B.1.8 Center for Astrophysics and Space Astronomy (CASA), CU-Boulder

The Center for Astrophysics and Space Astronomy (CASA) at CU-Boulder provides a focal point for the efforts of its astronomers and is developing special expertise in the areas of space data acquisition and analysis.

The space data acquisition activities at CASA include design and development of state-of-the-art rocket and satellite payloads. For example, a CASA rocket payload was flown from Woomera, Australia in order to collect ultraviolet data on the supernova 1987a–a star that exploded in the large Magellanic cloud. The rocket discovered fluorescence of interstellar molecular hydrogen. This rocket payload is also the prototype for a proposed far ultraviolet spectroscopic explorer (FUSE) satellite. Data from FUSE will allow astronomers to probe halos of galaxies and the hot corona of stars. CASA expects to play a central role in the development of FUSE, particularly for spectrograph and science operations.

CASA has on-going activities in the field of multiwavelength astrophysics data base work. At the center of this effort is CASA's Regional Data Analysis Facility (RDAF). The international ultraviolet explorer (IUE) regional data analysis facility serves as the focal point for researchers combining those data with radio, infrared, optical and x-ray measurements from various telescopes and satellites. CASA's goal is to expand the IUE data center into a wide-ranging multiwavelength analysis facility. CASA is also spearheading the collaboration with the University of North Carolina and the national optical astronomy observatories in development of a new large 4-meter telescope to be placed in the southern hemisphere but operated remotely from Boulder.

B.1.9 Center for Atmospheric Theory and Analysis (CATA), CU-Boulder

The Center for Atmospheric Theory and Analysis (CATA) is housed within the Department of Astrophysical, Planetary, and Atmospheric Sciences (APAS) at CU-Boulder. CATA facilitates interaction and collaboration between the atmospheric program in APAS and researchers at NCAR and several Environmental Research Laboratories at NOAA.

CATA atmospheric science research is aimed at advancing the understanding of the Earth's atmosphere through theoretical studies, numerical modeling, and observational analyses involving atmospheric dynamics, photochemistry, radiation, climate, and remote sensing. Satellite data play an important role in research activities in CATA. Global archives of data on the Earth's cloud field, planetary circulations, and a variety of atmospheric constituents are maintained at CATA. These complement theoretical investigations of global-scale dynamics, and the data are used to study convective motions in the tropical troposphere, the transport and photochemistry of ozone in the stratosphere, and a variety of local and planetary-scale wave phenomena figuring centrally in the general circulation of the atmosphere.

CATA operates an Atmospheric Science Laboratory including an integrated network of computers. In addition to performing computations for satellite data analysis and numerical modeling, this computing facility provides high speed data communication to the NCAR supercomputer mainframes on which large-scale simulations are conducted. Daily meteorological information and satellite imagery are also received and displayed through the facility. As part of this computer network, an interactive image analysis system has been developed to allow space-time analysis of satellite cloud imagery with real-time speed. Another component of the facility is a three-dimensional graphics system, which aids researchers in simulating complex behavior of circulations and atmospheric constituents such as ozone. Together, these computing elements represent capabilities unique to the Boulder atmospheric sciences community.

B.1.10 Laboratory for Atmospheric and Space Physics (LASP), CU-Boulder

The Laboratory for Atmospheric and Space Physics (LASP) at CU-Boulder conducts basic experimental and theoretical research into fundamental questions in the areas of planetary science, atmospheric composition and processes, and solar physics. LASP provides opportunities for participation in national space programs for researchers, particularly those from the Department of Astrophysical, Planetary and Atmospheric Sciences, the Department of Physics, and the College of Engineering and Applied Sciences.

A coordinated, multi-objective research program has evolved at LASP based on ultraviolet spectroscopy techniques and is devoted to understanding terrestrial and planetary atmospheres and investigating processes occurring on the Sun. This core program has diversified in recent years to encompass optical, infrared, and X-ray technologies and data management and mission operations capabilities.

LASP has taken part in several major space exploration missions including the Solar Mesosphere Explorer (SME) satellite operated from the Onizuka Space Operations Laboratory on campus. The SME program has demonstrated LASP's ability to conceive, design, fabricate, test, and operate space vehicles and instruments and to exploit the data from space experiments. This technological and scientific competence is also in evidence in the Pioneer Venus and Voyager 2 missions, an ongoing effort to develop and perfect the CODACON detector and other instruments, and a sounding rocket program for planetary, solar, and astronomical investigations.

Research and development programs at LASP provide new techniques for data manipulation and image processing as well as new instruments and sensors for space applications. This capacity enables the laboratory to establish interactive scientific data bases, such as the Atmospheres Node of the Planetary Data System Project.

When the Galileo spacecraft reaches Jupiter in 1995, its instruments will make the first close-up, long-term observations of the giant planet and its system of moons. Galileo will carry an ultraviolet spectrometer experiment designed and fabricated at the Laboratory for Atmospheric and Space Physics. Data from the CU instrument will be used in studies of the composition and dynamics of the atmosphere of Jupiter, the surfaces of its satellites, and the plasma torus of Io.

Among the 10 instruments aboard the UARS Spacecraft is the Solar Stellar Irradiance Comparison Experiment (SOSTICE) being constructed at the Laboratory for Atmospheric and Space Physics. Launch of the large craft is scheduled for 1992. CU's instrument will measure solar radiation entering Earth's atmosphere and compare solar irradiance with the ultraviolet flux of several bright blue stars. These baseline measurements will allow future investigators to determine the long-term variability of our Sun.

B.1.11 Sommers-Bausch Observatory (SBO), CU-Boulder

The Sommers-Bausch Observatory (SBO) is located on the CU-Boulder campus and is operated by the Department of Astrophysical, Planetary and Atmospheric Sciences (APAS) as a teaching facility and to provide special research opportunities for University of Colorado astronomers. Telescopes include 16- 18- and 24-inch Cassegrain reflectors and a 10-inch aperture heliostat.

The 24-inch telescope has available a Texas Instruments 3-phase, 800 x 800-pixel charge-coupled device (CCD) for both spectroscopic and direct imaging applications. This advanced technology detector gives the 24-inch telescope at SBO a light-detecting capacity comparable to the Palomar 200-inch telescope with conventional photographic plates. A Sun 3/180 workstation is used for data reduction and analysis. Current research includes long-term spectroscopic monitoring of variable stars and of luminous, mass-losing stars. The telescope and ancillaries have been used for optical observations in conjunction with the Very Large Array (VLA) radio telescope and the International Ultraviolet Explorer (IUE) satellite.

B.1.12 Center for Low Gravity Fluid Dynamics and Transport Phenomena (CLgFT), CU-Boulder

The research programs in the Center for Low-Gravity Fluid Dynamics and Transport Phenomena (CLgFT) at CU-Boulder focus on the physical phenomena occurring in fluid systems located in a reduced gravity environment. The primary goal of participants is to develop a fundamental knowledge base encompassing both experimental and theoretical sciences that can be applied to specific problems in material processing and handling of liquids and multiphase fluids in space.

B.1.13 Institute of Arctic and Alpine Research (INSTAAR), CU-Boulder

The Institute of Arctic and Alpine Research (INSTAAR) is an interdisciplinary research institute of the Graduate School at CU-Boulder that emphasizes the environmental and social sciences (anthropology, biology, geography, and geology), especially as they pertain to high altitudes and high latitudes and to former cold environments of the Quaternary period.

INSTAAR collaborates with with other programs for the study of the Earth from space, with particular emphasis in global change as it relates to and can be studied from the polar regions. In addition to field work and theory, INSTAAR researchers are employing LANDSAT, SPOT, and other satellite imagery.

INSTAAR has laboratories in Boulder for research in geomorphology, sedimentology, micropaleontology, paleontology, palynology, plant ecology, animal ecology and geochronology. It also operates The Mountain Research Station (MRS) which lies 40 km west of Boulder, at 2880m altitude in the Front Range of the Rockies. The Station has a long history of biological, geological and climatological research in alpine, subalpine and montane forest areas. Weather stations up to 3750m altitude have been maintained since 1952. Niwot Ridge is a Long-Term Ecological Research (LTER) area of the National Science Foundation.

Arctic and alpine ecological studies both utilize satellite imagery. In the alpine, the LTER program uses LANDSAT and SPOT imagery to study the influence of landscape pattern on ecosystem function or processes in the tundra of the Front Range. The hierarchical nature of ecosystems allows detailed ground-level studies of nutrient cycling and species interaction to be scaled up to regional-level interpretations. In the Arctic, the INSTAAR Plant Ecology Laboratory has collaborated with U.S. Geological Survey and scientists at NASA/Ames to produce land cover maps of northern Alaska utilizing LANDSAT imagery.

The National Science Foundation has funded the University of Colorado's INSTAAR, the Center for the Study of Earth from Space (CSES) at CU-Boulder, and the Natural Resources Ecology Laboratory (NREL) at Colorado State University (CSU) in Fort Collins to establish a Joint Facility for Regional Ecosystem Analysis. This facility includes remote sensing and geographic information system workstations able to capture and archive satellite images for the analysis of large geographical data bases.

B.1.14 Cooperative Institute for Research Environmental Sciences (CIRES), CU-Boulder

The Cooperative Institute for Research in Environmental Sciences (CIRES) is sponsored jointly by CU-Boulder and the Environmental Research Laboratories (ERL) of the National Oceanic and Atmospheric Administration (NOAA).

The major research themes of CIRES are Environmental Chemistry, Atmospheric and Climate Dynamics, and Solid Earth Geophysics. The research programs are aimed at understanding a variety of basic and applied problems associated with the physics and chemistry of the solid earth and its atmosphere, cryosphere, and oceans.

CIRES Fellows have academic affiliations with numerous departments at CU. In addition, CIRES maintains active research programs in collaboration with several of the NOAA Laboratories, including the Aeronomy Laboratory, the Air Resources Laboratory, the Space Environment Laboratory, the Wave Propation Laboratory, and with NOAA scientists in the Environmental Research Laboratory/Environmental Sciences Group, the National Geophysical Data Center of NOAA/National Environmental Data Information Service (NESDIS), and the Institute for Telecommunication Sciences of the National Telecommunications and Information Administration (NTIA) of the Department of Commerce.

Satellite remote sensing is a technique common to many of the topical research programs at CIRES. Remote sensing is of crucial relevance to studies of the Earth because it provides noninvasive measurement techniques for global-scale observations and represents the only feasible method for monitoring the changing global environment. Two institutes at CIRES that utilize satellite remote sensing are the Center for the Study of Earth from Space (CSES) and the University NAVSTAR Consortium (UNAVCO).

The climatic importance of polar snow and ice cover is also a topic of CIRES research. Much of this involves satellite remote sensing in conjunction with data sets archived at the National Snow and Ice Data Center and the World Data Center-A for Glaciology (Snow and Ice) at CIRES.

Additional remote sensing research at CIRES involves the development of improved data analysis techniques to detect and classify clouds from satellite images, the use of temperature and moisture soundings to develop stability indices for the tropical atmosphere, the development of methods to improve the accuracy of satellite observations of the Earth by removing atmospheric interference, and the use of satellite data to monitor and understand the dynamics of stratospheric ozone depletion over Antarctica.

B.1.15 National Snow and Ice Data Center (NSIDC)/World Data Center-A for Glaciology (WDC-A) [Snow and Ice], CU-Boulder

The World Data Center-A for Glaciology (WDC-A) and the co-located National Snow and Ice Data Center (NSIDC) are operated under contract to NOAA/NESDIS (National Environmental Space Data Information Service) by the Cooperative Institute for Research in the Environmental Sciences (CIRES) at CU-Boulder. Their main purpose is to facilitate the national and international exchange of data on all forms of snow and ice: glacier fluctuations and mass balance, polar ice sheets, sea ice, fresh water ice, seasonal snow cover, avalanches, permafrost, and paleoglaciology.

Information on the temporal and spatial variability of snow cover and sea ice extent is needed to detect possible global trends in these variables. Comprehensive global information on snow cover and sea ice extent has become available through the use of satellite remote sensing only since the late 1960s; reliable digital data sets exist in each case only since 1972.

Studies of sea ice conditions and climate interactions in the North American Arctic have been carried out with support from NSF and the NOAA-Offshore Continental Shelf Environmental Assessment Program (OCSEAP). Subsequently, attention has turned to large-scale snow/ice-climate interactions, specifically high-latitude cloudiness. An analysis of satellite data has been a central element of these investigations. Recently, the relationships between ice velocity and ice amounts in the Arctic were established from a combination of satellite remote sensing, drifting buoy and sonar data.

On June 19, 1987, the Defense Meteorological Satellite Program launched the Special Sensor Microwave Imager (SSM/I), a high-resolution microwave imager, which is providing real-time microwave data on sea ice, atmospheric moisture and precipitation, soil moisture, and ocean parameters. The National Snow and Ice Data Center supported by NASA's Ocean Data System (NODS) is developing a long-term, secure archive and distribution center for data products over the polar oceans derived from the SSM/I. The project involved installation of a minicomputer-based data management and data retrieval system developed by the Jet Propulsion Laboratory (JPL), and delivered to NSIDC through a technology transfer agreement.

NSIDC will receive orbital data from NESDIS and will produce global, swath mapped, brightness temperature data and temporally and spatially averaged, polar gridded data on ice concentration, ice edge and multiyear fractions. The Cryospheric Data Management System will provide an interactive data catalog; distribute data to the user community (foreign and domestic); incorporate other non-SSM/I cryospheric data; and implement revised microwave algorithms. Algorithms for the geophysical data have been developed and used for NIMBUS 7 SMMR to prepare sea ice data for 1979-1984. Related research by graduate students in Geography is sponsored by NASA, NSF and ONR (Office of Naval Research).

The World Data Center-A and the National Snow and Ice Data Center collect and distribute snow and ice data under a NASA contract to distribute meteorological data. Although they are a SPAN node, most data is distributed on magnetic tape and floppy disk. Data is now also starting to be distributed on CD-ROMS. There is little demand for network access to the data and the cost of developing an online repository has been a deterrent.

B.1.16 Center for Study of Earth From Space (CSES), CU-Boulder

The Center for the Study of Earth from Space (CSES) is within the Cooperative Institute for Research in Environmental Sciences (CIRES), at CU-Boulder. CSES focuses on the use of remote sensing techniques to understand the Earth and its biosphere. Research areas include studies of quaternary geology and paleoclimate studies, land-atmosphere interaction, vegetation dynamics, and hydrology. Participating departments are Geology, Geography, Anthropology, Aerospace Engineering Sciences, Civil Engineering, and Electrical and Computer Engineering. Participating centers include CCAR and LASP.

CSES is concentrating on the use of image data acquired by airborne and spaceborne sensors throughout the electromagnetic spectrum. Correlative atmospheric, geophysical, geological, and geographic data is incorporated to provide the basis for comprehensive modeling of the Earth. A major goal of CSES is to become a national center of excellence for the analysis of data from NASA's Earth Observing System (EOS), on the polar-orbiting Platform, slated for the mid-1990s. EOS will be a major source of remote sensing data for the Earth well into the 21st century.

CSES has developed three facilities to support remote sensing research. The primary facility is an image-processing laboratory built around individual workstations linked locally and to other campus facilities by a high-speed network. By using individual workstations, the facility can be expanded and upgraded with maximum flexibility and minimum cost. A spectroscopic laboratory exists for the analysis of surface sample properties in the 0.4-200mu region, both in reflection as well as emission. A digital X-ray diffractometer has been installed. Field-portable spectrometers and radiometers are also available.

Initial research problems being addressed at CSES are centered around the newest family of remote sensing instruments, such as the HIRIS imaging spectrometer. Aircraft data, consisting of images acquired in more than 200 spectral bands simultaneously, are being acquired by NASA/Jet Propulsion Laboratory (JPL). Research at CSES uses these data for direct mineral identification in soils surrounding intrusive bodies.

Signal analysis and pattern recognition techniques are being developed for this new type of data. Previous multispectral sensors had a maximum of seven spectral bands. Sensors with 200 or more spectral bands require a radically different approach to data reduction and analysis–the application of deterministic techniques as well as statistical analysis. The specificity of imaging spectrometer data will open whole new lines of research and applications for remote sensing.

CSES will have significant applications for image processing once EOS is operational. Much of the communications traffic will be with JPL and CSES will make extensive use of the CU Ethernet to access local computers. Although the operational window for ACTS does not overlap EOS very well, there are potential applications for ACTS in preliminary simulation studies.

B.1.17 University Navstar Consortium (UNAVCO), CU-Boulder

UNAVCO is a multiuniversity consortium developed to assemble, test, and administer the deployment of instrument packages that use radio signals from the Department of Defense NAVSTAR Global Positioning System (GPS) satellites to perform geodetic measurements. UNAVCO is supported by the National Science Foundation and the University of Colorado is its lead institution. Other participants include Columbia, CalTech, Harvard, MIT, Princeton, and the University of Texas.

Satellite surveying surpasses traditional ground-based surveying in both efficiency and accuracy and is a state-of-the-art tool for geodesy. The purposes of UNAVCO are to serve the research community in two different roles. The first is the development and testing of GPS terminals and techniques with the highest possible accuracy and efficiency. The second is offering GPS equipment and assistance to the academic community for research in earth sciences, and also providing training, as well as operational and analytical support.

CU is now utilizing this powerful new tool for worldwide crustal deformation and earthquake studies in tectonically active areas. UNAVCO is currently concentrating its research efforts on the improvement of vertical accuracy, precise surveying in a dynamic rather than a stationary mode, development of reliable and well-documented baseline analysis software, interactive computing and graphics, data archiving, and application of GPS technology to the detection of "global greenhouse" effects.

Several sets of GPS tracking equipment plus water vapor radiometer equipment are now operated and managed by UNAVCO. They have been used in observation campaigns in California, Yellowstone National Park, New England, Colorado, the Dominican Republic, Iceland, Greenland, Hawaii, and South America. Typical campaigns involve up to eight hours of satellite observations every day for several weeks and include additional GPS tracking equipment operated by collaborating agencies and research groups. As additional GPS satellites are launched, they will allow around-the-clock surveying worldwide.

B.1.18 Image, Map & Geographic Education Laboratory (IMGEL), CU-Colorado Springs

The Image, Map, and Geographic Education Laboratory (IMGEL) at CU-Colorado Springs was funded by the National Science Foundation with the express purpose of introducing the technology and theory of remote sensing and computer cartography into the undergraduate curriculum at CU-Colorado Springs including the applied aspects of image analysis.

Students at IMGEL are responsible for obtaining research projects from a number of agencies and private firms; students also solicit remote sensing/computer cartography projects from a variety of sources including but not limited to local and regional governments, the private sector, and other university entities. IMGEL students design each project, act as liaisons between the IMGEL Laboratory and the client, do the image analysis, produce the final product, and present the work to the requesting agency or organization.

The lab uses state-of-the-art satellite data from several sources including the Thematic Mapper instrument on LANDSAT, the new French SPOT satellite, and the Space Shuttle Imaging Radar (SIR) payload. The Laboratory is capable of stand alone analysis of virtually any satellite or airborne scanner image/aerial photograph whether stored on tape, film, or hard copy.

Another important component of CIRES research involving satellite remote sensing is the University NAVSTAR Consortium, The scientific objective is to monitor crustal reformation in tectonically active areas.

B.1.19 Computational Math Group (CMG), CU-Denver

The Computational Math Group (CMG) resides in the Department of Mathematics at CU-Denver. CMG is a broad-based response to the rapid and dramatic changes in various fields of computation and conducts research and provides education in advanced computer architectures and computational mathematics.

It draws upon a group of well-known experts in the field of computational mathematics and advanced computer architectures at the Department of Mathematics at CU-Denver and is also an interdisciplinary organization with associates in other departments at CU-Denver, on other campuses of the Front Range, and within the business and research community of greater Denver.

Funded primarily by DOD, DARPA, NASA, and NSF, the CMG provides a variety of resources to students, associates, and the Denver community. CMG has established a laboratory that contains various advanced computing resources including an eight-processor Sequent Symmetry 581 shared memory multiprocessing system and a 32-processor Intel IPSC/2 distributed memory hypercube. The laboratory is connected to several local and international networks that allow easy access to an unlimited range of remote supercomputers.

CMG researchers work with both the Center for Space Construction and the Center for Space Structures and Controls at CU-Boulder. The Group is also a source of expertise for the Front Range research community which, with its many technological industries, has an ongoing involvement with computation. The Group also organizes workshops and conferences that involve local participants as well as experts from outside of the region.

B.1.20 Space Medicine Research Program, CU-Health Sciences Center, Denver

The Space Medicine Research Program involves space-related research at the three schools at the University of Colorado Health Sciences Center in Denver (Dental, Medical and Nursing).

Medical research is focusing on understanding and preventing osteoporosis. Research at the Dental school concerns the study of salivary glands and their secretions that help maintain the integrity of the soft tissues in health and disease under normal and microgravity conditions. The materials used in dental restorations can have an effect on pain during space flight. Studies at UCHSC are focusing on conventional and newer, more biocompatible materials to alleviate this potential problem.

A Space Nursing program may also be developed at UCHSC. This program will include policies related to human caring and human caring ethics, as well as research programs into human interaction in nursing.

A prototype computer model has been developed for managing cardiorespiratory fitness in a space environment. This system schedules medical testing in the context of mission needs and monitors and interprets the results. Regimens for correcting health defects would be suggested. Another part of this project will lead to the development of a sophisticated model permitting respiratory and cardiovascular responses to be anticipated during work in space. CU researchers are now participating in system testing of this equipment at NASA/JSC.

B.1.21 Space Physiology, CU-Health Sciences Center, Denver

The Space Medicine/Physiology group at the University of Colorado Health Sciences Center in Denver is currently pursuing two projects with NASA.

In the purpose of the first project is to implement a computer-based system for assessing cardiorespiratory fitness in the Space Station environment. The project involves computer control of a cycle ergometer, a treadmill, and a rowing machine. The data acquisition system involves EKG, blood pressure, O_2 consumption, CO_2 production, N_2 exchange, ventilation and breath timing.

Analysis of data from the system is designed to yield indices of cardiorespiratory fitness as deconditioning occurs in response to zero gravity adaptation. These data are important for the design of the exercise countermeasure prescription in which astronauts will attempt to minimize physiological adaption. An expert systems approach is being used to implement the data management and the exercise prescription for each astronaut for the training regime on the cycle ergometer, treadmill, and rowing machine.

The second project involves developing the hardware for the respiratory data acquisition. A miniaturized quadruple mass spectrometer is being developed for use in the Shuttle Orbiter, and Space Station. The quadruple spectrometer is computer based, modularized, and miniaturized to fit this application. It has the capability of measuring respiratory gases and flow as well as low concentrations of nitrogen which occur when astronauts breath 100% oxygen before EVA activities. It also can measure trace gases used to estimate pulmonary blood flow and lung gas exchange parameters.

B.2 Engineering activities at the University of Colorado

B.2.1 Department of Aerospace Engineering Sciences (AES), CU-Boulder

The Department of Aerospace Engineering Sciences (AES) at CU-Boulder provides academic and research programs with emphasis in fluid dynamics, astrodynamics and remote sensing, dynamics and control of aerospace structures, life support/neuro-bioengineering, and systems engineering and aerospace design methodology.

Four interdisciplinary research centers are contained in the Department of Engineering, the Colorado Center for Astrodynamics and Remote Sensing (CCAR); the Center for Space Structures and Controls (CSSC); the Bioserve Space Technologies Center (BSTC), a NASA Center for the Commercial Development of Space; and the Center for Space Construction (CSC). AES is also a participant in the Center for Applied Parallel Processing (CAPP) in the hypersonic flow applications.

A variety of laboratories have been developed in the Department including a Computational Fluid Dynamics laboratory, wind tunnels, a design laboratory, a satellite oceanographic imaging laboratory and a space bioastronautics laboratory.

B.2.2 Department of Electrical and Computer Engineering (ECE), CU-Boulder

The Department of Electrical and Computer Engineering at CU-Boulder is one of the fastest-growing departments in the country. Research activities are divided into 11 major areas: bioengineering, communication engineering, computer engineering, control and robotics, electromagnetics and microwaves, optics and lasers, power and power electronics, propagation and remote sensing, semiconductor devices and solid-state materials, signal processing and systems theory, and VLSI design automation.

The department maintains close ties to related research groups in computer science, mathematics, and physics. Faculty and graduate students work cooperatively with research personnel in nearby government and industrial laboratories.

Major space-related and satellite communications research efforts in the Department include: 1) an NSF project to derive upper atmospheric wind profiles on the Arctic Circle, in Colorado, and in Peru using meteor echo radars and VHSIC data processing technology, 2) a NASA Langley project to apply parallel processing to the mechanics of space structures, and 3) a JPL project to improve tropospheric and lower stratospheric wind profiles through doppler radar antenna design, signal processing, and automated radar operation enhancements.

B.2.3 Department of Electrical Engineering, CU-Colorado Springs

The Electrical Engineering Department at CU-Colorado Springs is involved in space technology through research being conducted in several departmental laboratories. Electromagnetics Laboratory (EML) is the major laboratory facility at CU-Colorado Springs. EML is a large broadband (100 MHz to 40 GHz) semi-automated anechoic chamber in which electromagnetic measurements on electronic components, full-scale spacecraft, and satellite antennas can be performed. Activities of the EML involving space research are in the areas of remote sensing, high-power microwave sources, imaging, hardening, electromagnetic pulse phenomena, electromagnetic interference, electromagnetic compatibility, and radiation effects on electronic materials. EML is involved in research on non-volatile, radiation-hard computer memories which have direct application to space systems. In conjunction with Kaman Sciences, it is involved in research on superconductive materials which have applications to low-loss interconnects, generation of power, and magnetic shielding for space applications.

Microelectronics Research Laboratory (MERL) are a group of facilities dedicated to performing advanced research in microelectronic circuit design, microelectronic device fabrication, and solid-state sciences. The laboratories included within MERL are the following: Advanced Development, Device Characterization and Analysis, VLSI Design, Advanced Materials, and the Device and Process Simulation.

Signal Processing/Communication Laboratories (SPCL) provides research facilities for the performance of research on systems for the generation, processing, and transmission of signals for the conveyance of information. One current project involves characterization of spread spectrum communications systems for space applications in fading and jamming environments. Another project is concerned with the analysis of intercept receivers for extracting information from spread spectrum signals; and the design of such signals to minimize detection.

B.2.4 Interdisciplinary Telecommunications Program (ITP), CU-Boulder

The Interdisciplinary Telecommunications Program (ITP) at the University of Colorado at Boulder is the oldest telecommunications program in the United States. It was established under a National Science Foundation grant. Today its $5 million telecommunications laboratory is equipped for the latest experimentation in areas such as ISDN, B-ISDN, and packet data switching. The laboratory facilities include state-of-the-art equipment from Northern Telecom, Rolm, AT&T, MCI, Mountain Bell, 3M, and Racal-Milgo.

The ITP offers a master of science program to prepare students for leadership positions in telecommuications. The program emphasizes interdisciplinary studies in telecommunications covering engineering technology, policy, law and regulation, computer systems and technology, and finance and management.

Current space related telecommunications research activities carried out by ITP focus on communications satellite technology and ISDN and include the following projects.

A study for NASA to examine "scientific research, ACTS (the Advanced Communications Technology Satellite) and ISDN" is focusing on the potential for ACTS to support advanced telecommunications requirements in the field of scientific research and the role of ISDN over ACTS.

Additionally, ITP provides NASA ACTS tests and demonstration coordination for ISDN related experiments.

ITP is also performing research for NASA under the Satellite Communications Advanced Research (SCAR) Program. This is a three-way partnership among CONTEL, the NTIA/ITS (National Telecommunications and Information Administration/Institute for Telecommunications Sciences), and ITP to study advanced communications satellite concepts.

Other research at ITP includes studies on HDTV (high definition television) and ISDN applications for INTELSAT, and a study on Rural Satellite Service for the U.S. Congress, Office of Technology Assessment.

B.2.5 Space and Flight System Laboratory (SFSL), CU-Colorado Springs

The Space and Flight Systems Laboratory (SFSL) at CU-Colorado Springs performs basic and applied research in support of space and flight systems. Specific areas include space defense technology, flight control systems, software engineering, and artificial intelligence applications. Within these areas specific projects include research in target acquisition and tracking, system error analysis, guidance and control, signal processing, and computer engineering. The Space and Flight Systems Laboratory is responsive to the research and development needs of the local aerospace community.

The Space and Flight Systems Laboratory assists in the development of research projects involving government, industry and the College of Engineering and Applied Science–with special emphasis in the space technology areas. The capabilities of the SFSL are extended by facilities within the College. These are the Electromagnetics Laboratory, the Microelectronics Research Laboratories, and a Communications Group. In addition, the Space and Flight Systems Laboratory has a significant computer resource network available through the Computing Services Office of CU-Colorado Springs. This network provides access to the CU-Boulder and Denver Campuses, Colorado State University (CSU), and Colorado School of Mines (CSM). The network also provides access to ARPANET and various supercomputer facilities, and expansion plans include access to the University of Denver and the United States Air Force Academy.

B.2.6 Bioserve Space Technology Center (BSTC), CU-Boulder

Located at CU-Boulder, Bioserve Space Technology Center (BSTC) is a NASA-supported Center for the Commercial Development of Space (CCDS) and is a consortium, composed of university, business, foundation and government interests. The intent of the CCDS program is to involve the best talents of universities, business, and government in specific research programs that will lead to the best possible commercial exploitation of space research. Bioserve's research mandates are in the general areas of bioproducts technologies and processes, agrigenetics materials and advanced film and membrane technologies. Bioserve's enabling hardware research effort will involve the parallel development of an Autonomous Biomedical Test Pallet (ABTP).

BSTC research is focused on a variety of films, membranes and liquid membranes that should be produced more easily and uniformly in space. It is also studying new types of nitrogen-fixing plants that could significantly reduce the costs and energy required to fertilize plants.

Bioserve's initial orbital experiments will be conducted on board GAS Cans (Get-Away Special Canisters). As Bioserve's space capabilities improve with time, GAS Cans may be "ganged" to form larger experimental platforms. Ultimately, a platform will be developed on which commercially viable orbital production of Bioserve's various products will occur.

B.2.7 Center for Applied Artificial Intelligence (CAAI), CU-Boulder

The Center for Applied Artificial Intelligence (CAAI) is part of the Graduate School of Business Administration at CU-Boulder. The Center's role encompasses the research, instructional, and service missions of the school. CAAI professional staff solicits and conducts sponsored research and maintains its own program of internal research and development. The Center's service mission includes the management of Colorado's industry/university research consortium in the field of AI, the Colorado Institute for Artificial Intelligence.

Specific CAAI areas of research expertise and experience include maintenance of engineered systems (such as a radar, an aircraft, or a fleet of aircraft), complex combinatorial problems (such as resource allocation, scheduling, or portfolio management), intelligent tutoring systems (for maintenance training and for management training), and specific business applications of artificial intelligence (in the fields of accounting, finance, management, marketing, decision sciences, and information systems).

At CAAI, two space related projects are under way: The Communicator Project and The Troubleshooter. The Communicator Project, where computer-supported collaborative work software is being developed is a strategic research program in the Center. The objective is to provide a medium to represent, channel, and organize the communications acts behind project planning and project management. Applications relevant to space sciences include support of a quasi-economic market to allocate resources for Space Station and tracking and rescheduling Space Station crew operations.

A second strategic space-related research program at the Center involves the development of model-based,"second-generation" expert system for device diagnosis. Artificial intelligence applications to device diagnosis emphasize a systems engineering approach encompassing the entire system's life cycle from concept through deployment. The approach is integrated by common reference to a "device model" for reference to reliability, testability, maintainability, training, and logistics support.

B.2.8 Optoelectronic Computing Systems Center (OCSC), CU-Boulder

The Optoelectronic Computing Systems Center (OCSC) at CU-Boulder is operating under an NSF grant of $14.5 million for five years and is the national focal point for assuring continued U.S. progress in optoelectronic computing.

The Optoelectronic Computing Systems Center was formed to conduct research in areas where optoelectronics has a clear advantage over electronics in computing. The cross-disciplinary team, from both the University of Colorado and Colorado State University, consists of computer scientists, digital signal processors, optics researchers, scientists, digital signal processors, physicists, chemists, and semiconductor device engineers. These specialists are working together to perform focused and exploratory research leading to the creation of processing and artificial intelligence.

The Center has three systems programs and a materials and devices program. These programs are structured to explore and exploit the primary advantages of optics: speed, parallelism, and high connectivity. Each program has both exploratory and highly focused research projects.

The Digital Optical Computing (DOC) program emphasizes research on appropriate architectures for optoelectronic computers. It has a focused goal: the design, construction, and operation of a complete, stored program optical digital computer. In the first phase of this program, a proof-of-principle demonstration system will be constructed using existing lithium niobate switches.

The Optical Signal Processing (OSP) program has as its main objective the matching of signal processing algorithms and optical implementations. The focused research has as a goal the construction of optical cellular and broadcast arrays that implement projection operators for very high speed signal processing.

The Optical Connectionist Artificial Intelligence program includes research on optical neural networks, optical symbolic logic, and optical associative memory. Focused goals for the first three years are to implement an optical neural network that can be easily trained and also to expand the capabilities of the current optical associative memory system.

The Materials and Devices (M&D) program coordinates research with the systems groups and provides the optoelectronic devices needed for the systems programs. The focused research is directed toward the development of devices that are already identified as needed for the proof-of-principle machines. The exploratory research identifies and develops new optoelectronic devices. This group is also responsible for interfacing with device research groups outside of the Center.

B.2.9 Electromagnetics Laboratory (EML), CU-Colorado Springs

Electromagnetics Laboratory (EML) on the CU-Colorado Springs campus maintains a quiet, echo-free (anechoic) chamber that simulates the electromagnetic environment of free space. In the chamber, diagnostic equipment and a source to generate microwaves offer a unique testing facility.

Researchers are using the anechoic chamber to seek answers to some of the more challenging problems of electronic "pollution." Electromagnetic (EM) measurements are performed to support and verify theoretical EM predictions made of the intensities of the electric and magnetic fields generated by, scattered from, or coupled into complicated electronic systems.

The chamber is semiautomated and under computer control to produce reliable and repeatable measurements over a broad band frequency range. EML researchers use the chamber for a variety of purposes largely related to how microwaves interact with materials. Scattering from metallic objects and coupling through apertures in partially shielded enclosures are of special interest.

Electromagnetic interference and compatibility are also topics of research interest. A special infrared technique can be used to map electromagnetic fields by their thermal image. EML is also measuring the scattering of energy from cylinders with and without coatings, a study with broad practical applications to radar.

The facility is used to study how microwave energy can be coupled to complicated metallic structures that house electronic equipment that could be damaged by electromagnetic energy. The data obtained in the tests will enable engineers to develop better ways to protect electronic equipment from damage by microwaves. Classical EM probe techniques are also being developed.

B.2.10 Center for Space Structures and Controls (CSSC), CU-Boulder

The Center for Space Structures and Controls (CSSC) at CU-Boulder is addressing the theoretical and computational needs of large space structures and control. Fast algorithms simulating multibody dynamics on both serial and concurrent computers are under development. Work on accurate modeling of long, slender tubular trusses is also being pursued. Other projects include symbolic computations for formulating complex dynamical equations, and mathematical analysis for estimating errors in the computer models of general structures.

Future research will expand into integrated modeling and analysis of structure-control systems, computer implementation procedures for evolving advanced structure-control simulation software systems, and thermal- structural problems. In addition, the researchers plan to introduce cooperative programs with government and industry to facilitate the transfer of the results of their research by complementing governmental and industrial experimental and systems analyses with the analytical, computational and software capabilities of the University.

B.2.11 Center for Space Construction (CSC), CU-Boulder

The Center for Space Construction (CSC) operates under a five-year center of excellence award from NASA and provides research into construction methods for space stations, manned interplanetary spacecraft, orbital antenna arrays and lunar and planetary bases.

Specific problems being addressed at the Center for Space Construction include the orbital logistics and scheduling of delivery of construction materials to space stations and extra-terrestrial bases under construction. Researchers also will be investigating robotics vs. bionic devices for use by astronauts in space construction tasks, as well as the construction of lunar and planetary structures using extraterrestrial materials.

B.2.12 Data Libraries and Information Systems, CU-Boulder

University of Colorado scientists pioneered the concept of distributed data centers for space missions. CU operates many archives of data obtained from space instruments. This brings scientists from all over the world to CU to obtain and analyze data. One such data center is the International Ultraviolet Explorer (IUE) Regional Data Analysis Facility. CU has also been selected to host a regional data center for the Hubble Space Telescope, the biggest telescope yet planned for space. CU astronomers also expect to host a similar regional data center for the German satellite, ROSAT. In addition, CU plans to link all of these data centers together to form a single astrophysics data archive where scientists can simultaneously make use of data from several different instruments operating in different wavelengths. This would allow a user to compare the emissions of a single object in space in wavelengths from radio to infrared to visible to ultraviolet to X-ray.

The University of Colorado also participates in the NASA Planetary Data System (PDS) Project, which is developing the capability to collect, store, and distribute the information returned by the nation's interplanetary spacecraft. The PDS Project is sponsored by NASA's Office of Space Science and Applications and is managed by the Jet Propulsion Laboratory (JPL). Key elements of PDS are the discipline data centers to be located at both NASA Centers and universities. Currently, there are three prototype discipline data centers, one of which is the Planetary Atmospheres Center at CU. CU scientists are developing the techniques required to store and disseminate large volumes of information on planetary atmospheres. Scientists will be able to access the CU atmospheres data base or have a portion of the data base transferred to them along with software that can aid in their analysis.

As the builder and operator of the Solar Mesophere Explorer (SME), CU serves as the curator for the complete set of data from that satellite, making it available for researchers throughout the world.

The University of Colorado is a strong participant in the NASA land remote sensing program. CU is establishing an image processing facility for the analysis of LANDSAT and other remotely sensed data. In addition, CU is the site of the National Snow and Ice Data Center/World Data Center-A, which processes data from Defense Meteorological Satellite Program satellites

Because the volume of space data is so large, CU must apply new technology to the problems of storing, accessing and analyzing it. Technology development efforts are under way in communications, micro-computer workstations, data base management, and optical disc storage. CU has been particularly active in evaluating data base management systems and optical disc storage systems. CU is currently working with JPL and the U.S. Geological Survey to place 6000 images taken by the Voyager spacecraft during its encounter with Uranus onto digital compact discs. CU is also working with NASA in the development of information systems for the planned Space Station.

B.2.13 Mission Operations and Telescience, CU-Boulder

The University of Colorado-designed Solar Mesophere Explorer (SME) was launched by NASA in October 1981 and died in 1989. For several years the University of Colorado was the only university to operate its own satellite. The SME vehicle consisted of an observatory module. designed and built by the University of Colorado, and a spacecraft "bus," constructed by the Ball Aerospace Systems Division of Boulder. The SME was designed to answer global environmental questions with data from five precision instruments, measuring ozone and other components of our atmosphere.

The SME Mission Control Center at CU-Boulder was in direct contact with the SME through NASA's new telecommunications satellite system, the Tracking and Data Relay Satellite System (TDRSS). SME was operated 365 days per year by students. The SME operations system handled realtime satellite communications and control as well as mission support activities such as data formatting, attitude determination and control, orbital data processing, experiment planning, spacecraft performance analysis, tape recorder and battery monitoring, thermal analysis, and command memory management.

In addition to Mission Operations, CU's satellite control group is also developing hardware and software to perform Telescience activities in Earth Orbit.

One outstanding example of CU Telescience projects is the OASIS (Operations and Science Instrument Support) package that CU is developing for use on other NASA and University projects. The OASIS is being applied to several NASA missions, including Space Station testbeds, instruments on the Upper Atmosphere Research Satellite (UARS), Explorers, and several Shuttle Hitchhiker experiments. The OASIS will be used throughout the entire life cycle of an instrument, from early ground testing and integration to flight operations and analysis. With this approach, users will be able to operate space instruments, access scientific data from a range of missions, and communicate with other scientists – all from their own home "OASIS" workstation.

B.3 Science activities at NOAA Environmental Research Laboratories (ERL), Boulder, Colorado

This section is a review of activities with the U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), Environmental Research Laboratories (ERL) that may benefit from ACTS and may have telecommunications requirements. The ERL headquarters is in Boulder, Colorado. The mission of ERL is to conduct an integrated program of fundamental research, related technology development, and services to improve understanding and prediction of the geophysical environment comprising the oceans and inland waters, the lower and upper atmosphere, the space environment, and the Earth. ELR's program includes fundamental research to develop technology and improve NOAA services to the public.

The emphasis of this review is on the activities related to four major ERL units located in Boulder, Colorado. These units are the Environmental Sciences Group (ESG), the Wave Propagation Laboratory ((WPL), the Aeronomy Laboratory (AL), and the Space Environment Laboratory (SEL).

B.3.1 Environmental Sciences Group (ESG), NOAA Boulder, Colorado

The Environmental Sciences Group (ESG) plans, conducts, and coordinates well-defined, high priority programs on environmental research and technology development, which frequently require an intensive, concerted, or interlaboratory approach for success. Research findings and technological advances are actively transferred to other NOAA line organizations and the national user community.

ESG's ongoing research and development activities are directed toward understanding precipitation and convective weather processes; developing and evaluating advanced environmental monitoring, forecasting, and modification technologies; and building environmental data bases for use by the scientific community. ESG also works with the Joint Institutes and other outside organizations.

In FY 1988, ESG included the Program for Regional Observing and Forecasting Services (PROFS), the Profiler Program, the Weather Research Program, the Weather Modification Program, and Special Projects.

At the beginning of FY 1989, NOAA will replace ESG by bringing into existence the Forecast Systems Laboratory. The new Laboratory will include PROFS, the Profiler Program, and the Analysis and Prediction Division. The Weather Modification Program and the Gust Probe Special Project will be moved to WPL. The Special Project on Aerosol and Precipitation Chemistry will be moved to ARL.

The focus of the new Laboratory will be on transferring new technologies and scientific advances to the operational arms of NOAA. Its mission will include exploratory system development, research and research applications, system validation, and technology transfer.

Profiler Program

The Profiler Program Office (PPO) was established in 1985 to direct the procurement and installation of the wind profiler equipment, management of data, and the assessment of the Wind Profiler

Demonstration Network. The network will consist of 30 wind profilers deployed across the central United States. The goal is to demonstrate that such a network can support routine operations of the National Weather Service (NWS) and major scientific and meteorological field experiments, and can foster advances in atmospheric research.

The Colorado network of four profilers has operated continuously, has made data available to PROFS and NWS for use in operations and research, and has supplied data which has been used regularly by the Denver NWS Forecast Office for about 2 years.

Program for Regional Observing and Forecasting Services (PROFS)

Using the results of atmospheric and systems research, PROFS (1) develops technology that incorporates observations, computer processing, and human intervention, and (2) integrates capabilities into observing and forecasting systems. PROFS works closely with other members of the weather research community, soliciting ideas for forecast workstations and test exercises. PROFS interacts with other ERL groups, the National Center for Atmospheric Research (NCAR), the National Ocean Service (NOS), the U.S. Navy and Air Force, the National Environmental Satellite, Data, and Information Service (NESDIS), and various universities.

The EXPLORATORY DEVELOPMENT FACILITY consists of the computers, mass-storage devices and other peripherals, data-ingest interfaces, communication links, and display devices for using, testing, and evaluating advanced weather information systems. Real-time data, including PROFS mesonet, conventional and Doppler radar, upper-air sounding, surface aviation observations, profiler, and/or satellite imagery were provided to researchers at NCAR, NCAR's Terminal Doppler Weather Radar project, Colorado State University (CSU), Metropolitan State College, the Department of Energy's Rocky Flats operations, ERL groups, and the STORM Education and Research System.

The EXPLORATORY DEVELOPMENT GROUP provides expertise for analysis, design, and development of meteorological and supporting systems. This expertise, coupled with experience in applications, is applied to assist many NOAA programs. It supported AWIPS-90 and NOAAPORT (NOAA's Broadcast Communication System) by assisting NESDIS and NWS in defining requirements to generate centrally prepared information streams.

The HETEROGENEOUS DATA INTEGRATION BRANCH is responsible for acquiring data from advanced sensors, such as satellites and radars, and making those data available to forecasters and researchers. This includes the development of acquisition systems as well as processing software to reduce the high-volume data sets into understandable presentations. Information is received and processed from the GOES Data Acquisition System and TIROS. The National Ocean Service and the U.S. Navy jointly funded the Integrated Marine Analysis and Forecast System. Datasets include marine and atmospheric model output products from the National Meteorological Center and the Navy Fleet Numerical Oceanographic Center, satellite imagery, and ship and buoy reports.

The ANALYSIS AND PREDICTION BRANCH develops computer-based techniques to process meteorological data and produce short-term predictions. The results of this effort will benefit aviation and the general public in the form of better weather information. The major activity is the refinement of a Mesoscale Analysis and Prediction System (MAPS), which is now regularly assimilation asynoptic data at 3-h intervals. Related activities include the development of quality control algorithms for specific observing systems and a training program for NWS on the interpretation of wind profiler data.

The FORECAST RESEARCH GROUP activities are aimed at finding ways for automated systems to process the varied sources of data into information operationally usable for local weather diagnosis and forecasting. As many new sources of data are developed to provide data at a high time frequency and spatial density, such as remote-sensing instruments like Doppler radar and passive profilers, local weather offices will be flooded with far more information than can be assimilated by a working forecaster. Data must be combined and processed to represent elements understood by forecasters, such as winds, temperature and moisture. This processing by the Forecast Research Group is critical if weather offices are to provide specific, limited-area forecasts expected after the modernization. A system called the Local Analysis and Prediction System (LAPS) was designed and developed to assimilate various new-sensor data types, including surface analysis, upper air winds, temperatures, moisture, and cloud detection.

The EXPERIMENTAL FORECAST SYSTEMS BRANCH is responsible for specifying the functional and operational requirements for advanced meteorological systems. In addition, the branch manages development, implementation, and operation of these systems in a real-time environment and participates in development of advanced meteorological workstations. Much of this work is in direct support of the NOAA-NWS modernization initiatives, including AWIPS-90, and the Modernization and Restructuring Demonstration. The Norman Program is establishing an advanced forecast workstation with supporting communications, data ingest, and processing systems and the National Weather Service Forecast Office (WSFO) in Norman, Oklahoma. This workstation will interface with the first operational Next Generation Weather Radar (NEXRAD) and with other systems as part of the NWS modernization effort. The Norman system will ingest data from local sources and form the central Washington, D.C., data feed of satellite images, graphics, gridded data, observations, and forecasts.

The SYSTEM DESIGN AND IMPLEMENTATION BRANCH is responsible for assisting PROFS projects with new workstation system specifications, high-level system designs, workstation development, and system integration.

Weather Research Program (WRP)

The Weather Research Program conducts research to understand the genesis, structure, evolution, motion, dissipation, and predictability of synoptic-scale and mesoscale weather systems. and to improve forecasts of their attendant weather phenomena, such as high wind, excessive rains or snowfalls, and flash floods. WRP places great emphasis on transferring research results and new knowledge to the National Weather Service and the national user community. WRP has conducted research in China on hail, with Minneapolis-St. Paul WSFO and the Anchorage River Forecast Center on flash floods, with various WSFOs in Indianapolis, Alaska, Denver, and Albuquerque. Major research activities will include the uses of conventional surface and upper-air data along with quasi-geostrophic diagnostics and data from Doppler radar, wind profilers, and ground-bases radiometer, as well as GOES water vapor imagery.

Weather Modification Program (WMP)

The Weather Modification Program supports, conducts, and coordinates basic and applied research to understand cloud and precipitaion processes and their role in the hydrologic cycle, under natural influences and with inadvertent and purposeful modification.

COOPERATIVE RESEARCH – UTAH/NOAA analysis projects addressed concerns in three areas of research: 1- the spatial and temporal distribution and evolution of supercooled liquid water in winter storm clouds over the Tushar Mountains of Utah; 2- the physical processes responsible for precipitation development and the trajectories of the precipitation particles; 3- the atmospheric circulations that determine the transport of seeding material from ground-based silver iodide generators to the clouds. Doppler radar was used in these analyses.

COOPERATIVE RESEARCH – NORTH DAKOTA/NOAA has focused on the development of an atmospheric tracer technology using sulfur hexafluoride to track seed parcels of air through cumulus clouds, so that the evolution of the precipitation embryos can better be determined.

Special Projects

The ARTIFICIAL INTELLIGENCE (AI) PROJECT informs the broader environmental science community about potential applications of this new technology in areas of interest to NOAA, and applies that technology in selected areas.

The AEROSOL AND PRECIPITATION CHEMISTRY PROJECT conducts laboratory and field experiments to improve understanding of aerosol formation, transport, transformation, and dry and wet deposition. The focus is on the effects of aerosol physico-chemical properties on precipitation quality (acid rain), cloud coverage, and radiation. Both urban polluted air masses and the remote oceanic clean atmosphere are investigated for comparison. The results can assist in prediction of global climate changes.

B.3.2 Wave Propagation Laboratory (WPL), NOAA, Boulder, Colorado

The Wave Propagation Laboratory's mission is to improve the Nation's geophysical research and services through the development, demonstration, and dissemination of cost-effective remote measurement systems. To achieve this goal, WPL successfully performs the following functions:

- Conducts detailed theoretical and experimental studies of the interactions of acoustic and electromagnetic waves with the atmosphere or ocean, with particular reference to the use of such interactions for remote-sensing purposes.
- Develops and experimentally evaluates new geophysical remote-sensing concepts and systems.
- Applies the unique advantages of newly developed remote-sensing techniques to atmospheric and oceanic research.
- Improves the Nation's atmospheric and oceanic research, and forecasting and warning services, through transfer of remote-sensing technology.

Weather Research

WPL's contributions to weather research support NOAA's largest and most important single service, namely, weather forecasts and warnings. This service is required on many space and time scales. WPL's remote-sensing program includes contributions on all scales from the micrometeorological to the global.

Research on micrometeorological processes in the atmospheric boundary layer is important because these processes, which include turbulent fluxes of heat, moisture, and momentum, change the dynamic and thermodynamic properties of air masses. Remote sensors contribute uniquely to the research by providing the resolution and continuity in both space and time that are required to observe, monitor, understand, and predict these important boundary layer processes.

Air Quality

NOAA's weather service mission includes research to understand meteorological processes relevant to air quality. WPL contributes to this program by using its remote sensors to measure three-dimensional fields of wind, turbulence, and aerosols in experiments relating to air pollution.

Climate

Research into climate have included data generation from the First ISCCP (International Satellite Cloud Climatology Project) Regional Experiment (FIRE).

Ocean and Great Lake Research

This research includes remote sensing of the ocean's nondirectional temporal wavelength spectrum by the use of underwater acoustic echoes.

B.3.3 Aeronomy Laboratory (AL), NOAA, Boulder, Colorado

The Aeronomy Laboratory conducts research on chemical and physical processes of the Earth's atmosphere to advance the capability to monitor, predict, and control the quality of the atmosphere. The research concentrates on the stratosphere and troposphere, but also involves the mesosphere and thermosphere.

The research methods involve both in-situ and remote measurement of critical atmospheric parameters, including chemical composition and dynamic properties such as wind velocity, turbulence, and wave motion. Theoretical programs in atmospheric photochemical modeling and in atmospheric dynamics and transport support the observation programs. An experimental laboratory chemical kinetics program supports the theoretical photochemical modeling program and also supplies input for the development of new atmospheric monitoring and measurement technology.

The major focuses of research are Air Quality and Climate. Several environmental issues are currently addresses: stratospheric ozone depletion (global and Antarctic), tropospheric ozone production by pollutants, greenhouse effect, acid rain, El Nino-Southern Oscillation, and climate change.

Atmospheric Waves and Turbulence Theory

This program is devoted to theoretical studies of turbulence, wave, and eddy transport of constituents, energy, and momentum in the atmosphere. These phenomena are basic to many areas of geophysics, including meteorology, climatology, pollution dispersal, oceanography, space physics, and aeronomy.

Atmospheric Chemical Kinetics

The Atmospheric Chemical Kinetics program investigates chemical reactions that are important in the atmosphere. Its aims are to study the effects of anthropogenic chemical species on Earth's atmosphere, and to understand the natural, unperturbed atmosphere.

Atmospheric Dynamics

The Atmospheric Dynamics program combines observational and theoretical studies of atmospheric dynamical processes, focusing on internal gravity waves, vertical motion, and turbulence. The data base for this research is obtained using clear-air Doppler radar, also called the wind-profiler technique or the Mesosphere-stratosphere-Troposphere (MST).

Tropical Dynamics and Climate

The primary contribution of Tropical Dynamics and Climate research lies in the use of remote-sensing wind profilers, developed within the Aeronomy Laboratory, to provide continuous information on atmospheric winds and turbulence in the tropical Pacific. Two profilers, installed on Pohnpei and Christmas Islands, are providing a revolutionary new data base for studies of the tropical atmosphere. Continued use of the extensive rawinsonde data base covers, for some tropical stations, a period of many years. This data is used to study the properties and dynamics of the tropopause and the neighbouring regions of the upper troposphere and lower stratosphere, with the goal of producing the first adequate description of tropopause properties in the tropical regions of the Earth.

Research is carried out with the University of Colorado, the National Meteorological Center, the Atmospherics Dynamics Program Area and Control Data Corporation. Data is used from the Solar Mesosphere Explorer.

Theoretical Aeronomy

The Theoretical Aeronomy Program undertakes theoretical studies or important atmospheric problems, constructs and uses computer models of the chemistry and dynamics of the lower atmosphere, and analyzes atmospheric data collected within the Laboratory or by collaborative experiments. Recently, the principal concern has been with problems related to minor constituents of the troposphere, notably ozone. The ultimate goal of the program is to attain an understanding of the composition and energy budget of the atmosphere sufficiently detailed that trends can be accurately predicted. Research takes place into the Photochemistry of Ozone Production, and Tropospheric Responses to Column Ozone Change. Data is generated from both model calculations and field measurements.

Optical Aeronomy

The Optical Aeronomy Program uses spectral measurements of the atmosphere as a tool for studying fundamental atmospheric processes. The Center for the observational program is the Fritz Peak Observatory situated in the mountains west of Boulder, Colorado. The program emphasizes studies of the lower atmosphere including both the stratosphere and troposphere. Attention to the composition and chemistry of the lower atmosphere has increased as the fragility of the ozone layer and problems with pollution and the greenhouse effect have become apparent.

The lower-atmosphere studies have generally used spectrographic measurements of molecular absorption in the stratosphere and long-path absorption in the troposphere. These techniques exploit the extraordinary sensitivity of optical absorption for the detection and quantitative measurement of minute quantities of chemically important species. Spectrographic measurements have been carried out at a number of world locations using both ground-based and aircraft platforms. A new program was begun to measure small changes in stratospheric trace gas abundance over long periods of time form several global locations.

Meteorological Chemistry

This program investigates the coupling between meteorological and chemical processes in the Earth's atmosphere, particularly how the coupling affects the ozone content. The ozone content of the atmosphere is of central interest from the scientific and policy points of view. It is crucial to climate in both stratosphere and troposphere, and its abundance may be affected by other trace gases that are partly or wholly anthropogenic. The program's principal focuses are: 1) the genesis, maintenance, and dissipation of the "ozone hole" in the lower Antarctic stratosphere and the similar but less intense effects in the Arctic, 2) the flux of air between the stratosphere and troposphere, particularly in the tropics, and 3) the nitrogen oxide and ozone content of the clean Pacific troposphere.

Tropospheric Chemistry

The aim of the Tropospheric Chemistry program is to understand the chemistry that shapes the composition of the troposphere. The research includes the following topics in atmospheric chemistry and surface exchange: 1) the tropospheric photochemical cycles responsible for the production and destruction of regional and global ozone and other oxidants, 2) the transport, transformation, and deposition processes involved in acid deposition, and 3) the natural emissions that contribute to atmospheric acidity, alkalinity, and oxidant formation.

Middle Atmosphere Studies

The Middle Atmosphere Studies Program undertakes theoretical and field studies aimed at a fuller understanding of the chemistry and transport processes taking place in the Earth's middle atmosphere (apporximately 10 to 100 km). The field program is based primarily on acquisition and interpretation of optical data at sites such as McMurdo Station, Antarctica, and Fritz Peak, Colorado. Particular emphasis is places on understanding the effects of chemistry and transport on the distributions and variability of trace species in the stratosphere and mesosphere. The special ozone chemistry of polar regions is a major research focus.

B.3.4 Space Environment Laboratory (SEL), NOAA, Boulder, Colorado

The Space Environment Laboratory is NOAA's organization to gather data, conduct research, and make predictions about the near-Earth environment. SEL is unique in ERL in that it provides an around-the-clock service of real-time monitoring, forecasts, and warnings of solar and space disturbances and, at the same time, conducts research to support and improve the service activities. SEL is composed of three divisions: Space Environment Services, Research, and Systems Support. Space environment Services are provided by the Space Environment Services Center, which provides monitoring and forecasting services to meet a wide variety of civilian, military, commercial, and Federal agency requirements. The Research Division carries out research with the dual objectives of improving our understanding of the effects of solar and magnetospheric disturbances on human activities and improving our capabilities to forecast and analyze these events. The Systems Support Division plans, develops, and provides instrument and data systems. Research in the Services Division includes forecast verification and the development of forecasting algorithms.

Activities of SEL are directed toward understanding, monitoring, and forecasting solar and geomagnetic events that have undesirable, harmful, and costly effects on activities on and near Earth. SEL activities encompass real-time collection of solar-terrestrial data; dissemination of indices and a portion of these data; issuance of forecasts, alerts, and warnings of adverse solar-terrestrial conditions: archiving and processing of global data from satellites and observatories: and development of a better understanding of the behavior of the solar-terrestrial environment to yield significant service improvements.

Space Environment Services

The Space Environment Services Center (SESC), the national space weather service, operates 24 hours a day, 7 days a week, to maintain up-to-the-minute watch on storms and disturbances in the solar-terrestrial environment. It receives observations from other Federal agencies as well as public and foreign institutes. The data are sent in real time to SESC, where they are used to monitor key variations in solar activity and solar radiation and the effects on Earth's environment. Indices are compiled, activity is summarized, and forecasts are made. These products are issued to programs whose activities are affected by such variations in space weather. SESC also functions as the World Warning Agency for the International Ursigram and World Days Service (IUWDS), operated under the aegis of the International Council of Scientific Unions, to provide international exchange of space weather data and daily forecasts. In this role, SESC exchanges data with similar centers in Regional Warning Centers around the world.

SEL acquires data from a multitude of sources:

- The Solar Observing Optical Network (SOON), operated by the Air Weather Service (AWS).

- The Radio Solar Telescope Network (RSTN), also operated by AWS.
- Culgoora Observatory, for solar observations, operated by the Australian government.
- The National Solar Observatory, operated by the National Science Foundation with assistance from the Air Force, NASA, and NOAA, to obtain observations of solar magnetic fields and coronal holes.
- Space Environment Monitors (SEMs) on NOAA's GOES satellites.
- Remote Geophysical Observing Network (RGON), consisting of magnetometers and riometers.
- The High-Latitude Monitoring Station (HLMS) at Anchorage, Alaska, operated by USAF and NOAA.
- Table Mountain Observatory (TMO) in Colorado, operated primarily to receive x-ray data from GOES and magnetometer data from the local USGS instrument.
- Boulder Solar Observatory, at SEL, for hydrogen-alpha and white-light images.

The objectives of ATMOSPHERIC-IONOSPHERIC-MAGNETOSPHERIC INTERACTIONS are to understand the transfer of energy (in the form of both electrical and mechanical energy) from the magnetosphere into the upper atmosphere, and to understand and characterize the various possible consequences in the Earth's ionosphere and upper atmosphere. This research has used observations from the Total Energy Detector (TED) instrument aboard the TIROS/NOAA polar-orbiting satellites.

The objective of the MAGNETOSPHERIC PHYSICS PROJECT is to improve our understanding of dynamical processes that influence the transfer of energy from the solar wind and interplanetary space into the magnetosphere, storage of energy within the magnetosphere, and dissipation of energy from the magnetosphere into the Earth's atmosphere or back into interplanetary space via the Earth's geomagnetic tail. Space Environment Monitors will be placed on the GOES I-M satellite series.

TESTS OF THE 2 1/2 DIMENSIONAL INTERPLANETARY GLOBAL MODEL (IGM): Studies of the interplanetary manifestations during the major solar flares and major geomagnetic storms in earth February 1986 (at solar maximum) were conducted in collaboration with Japan and the U.K., and have received data from the Sakigake and Giotto spacecraft. Other participants were Czechoslovakia, the U.S.S.R., and Spain; other spacecraft were Prognoz 10, VEGA 1 and 2, and ISEE-3.

The SOLAR PHYSICS PROJECT studies the nature of solar activity, its origins, and its evolution, to provide the new fundamental knowledge needed for improving predictions of solar- terrestrial disturbances. These studies include observations of the solar cycle, creation of a model of the solar cycle, solar mapping in collaboration with NASA Marshall Spaceflight Center, and sunspot classification. The SEL SPECTROHELIOGRAPH was used to obtain monochromatic digital images of the Sun. The SOLAR X- RAY PHYSICS PROJECT researches into the structure and evolution of the solar corona to improve forecasts of medium- and long-term solar activity. SOLAR X-RAY STUDIES have utilized data from GOES-6 when the moon passed between it and the Sun while a small flare was in progress. SEL plans to launch its first non- spinning sensor in the near future. Members of SEL are co- investigators on a number of NASA-ESA space science mission experiments, such as the Solar Heliospheric Observatory (SOHO), and have joined two Harvard-Smithsonian teams in the proposal for the Earth Observing System (EOS).

Systems Support

The SEL DATA ACQUISITION AND DISPLAY SYSTEM (SELDADS) is a large, distributed, processing system that supports the operation of SESC. The data processed vary greatly in format, time resolution, and transmission media. Types of data include text, summary codes, raw digital streams, continuous data, irregular data, occasional data, data in order of time observed, and data randomly mixed in time of observation. The SEL SOLAR IMAGING SYSTEM (SELSIS) is a digital image acquisition, transmission, processing, and display system designed to handle the image-processing needs of SESC operations and SEL research. The interim version of SELSIS, which in FY 1988 replaced the analog wirephoto system of image transmission, gathers and processes approximately 300 images a month from the regularly contributing observatories in New Mexico, Colorado, Arizona, and Australia. Plans to place Space Environment Monitor (SEM) systems on the TIROS-K, -L, AND -M spacecraft continue.

Wide-area computer networking is becoming increasingly important to SEL as a means of communication between cooperating scientists and institutions, disseminating SEL data, and acquiring data from other institutions and data centers. SEL now has links to the UUCP (Units-to-Units CoPy) network, the BITNET, and the NASA SPAN (Space Physics Analysis Network).

The Mullard Radio Astronomy Observatory (MRAO) at Cambridge University in England is currently being reactivated to observe interplanetary scintillation. MRAO, ERL, Rutherford Appleton Laboratory (RAL) and the British Antarctic Survey (BAS) cooperated to renovate the MRAO antenna array. The new array is expected to start generating data in FY 1989.

B.4 Science activities at National Center of Atmospheric Research (NCAR), Boulder, Colorado

This section is a review of activities at the National Center for Atmospheric Research (NCAR) that may benefit from ACTS and may have telecommunications requirements. NCAR operates under the principal sponsorship of the National Science Foundation and is managed by the University Consortium for Atmospheric Research (UCAR), a consortium of 57 universities. NCAR programs, in partnership with universities, annually provide a wide range of scientific and technical contributions. These contributions expand knowledge of the atmospheric and related sciences.

There are six major units within NCAR. These are the Scientific Computing Division, the Atmospheric Technology Division, the Climate and Global Dynamics Division, the Atmospheric Chemistry Division, the High Altitude Observatory, and the Mesoscale and Microscale Meteorology Division.

B.4.1 Scientific Computing Division

The NCAR Scientific Computing Division (SDC) provides supercomputing and telecommunications resources and services that support NCAR research in the atmospheric, oceanic, and related sciences. Facilities for the development and execution of large models, for the development and execution of large numerical simulations, and for the archiving and manipulation of large data sets are emphasized.

Along with providing a supercomputing environment, SCD is also responsible for providing network and telecommunications capabilities to the other NCAR divisions. These network and telecommunications capabilities are required to access NCAR computational and data resources. The NCAR computing network contains the four components of distributed computing (with both local and remote access), mainframe computing systems, network servers, and a mainframe along with a server network (MASnet) and a local data network (LDN).

There are six sections in the SDC, each with specific functions that address the broad service requirements of the research community and the other NCAR divisions.

B.4.2 Atmospheric Technology Division

The Atmospheric Technology Division (ATD) has two major goals. One is to provide unique centrally administered observing facilities for use in research programs of the atmospheric sciences community. The other goal is to improve these facilities and to develop next-generation facilities as community requirements dictate, by means of strong internal development programs. ATD's operational capabilities include interactive computing facilities. Included in ATD's plans are improved communications systems and a wide variety of remote-sensing systems for more rapid and complete acquisition of four-dimensional observational data sets. To accomplish its objectives, the division works closely with other NCAR divisions, with universities, with the National Science Foundation (NSF), and with other federal agencies to ensure that the facilities it operates and its longer-range plans provide the instruments and services most needed by the community.

Two of the significant accomplishments by the five management units of the ATD are the large amount of data-processing support and ATD-designed software provided internationally to investigators and also a completed and installed sounding system for the Tropical Ocean and Global Atmosphere program (TOGA) climatological studies. Of interest is the sounding system - it will make daily soundings from Kanton Island in the Pacific that will be communicated through the Geostationary OperationalEnvironmental Satellite (GOES) and placed on the global telecommunications system (GTS).

B.4.3 Climate and Global Dynamics Division

The Climate and Global Dynamics (CGD) Division aims to better understand the physical causes of present and past climates and large-scale atmospheric and oceanic dynamics and to thereby contribute through research to the scientific basis for prediction of weather and climates.

Research activities for CDG are organized into the following eight sections and groups.

- Climate Sensitivity and CO_2 Research Group - A global atmospheric model coupled to a global ocean model with an increase in carbon dioxide.
- Climate Modeling Section (CMS) - Ozone studies are an example of research conducted by this section.

- Climate Analysis Section (CAS) - One main focus is on meteorological phenomena such as the 1988 North American drought.
- Satellite Data Analysis Group (SDAG) - Research has included the radiative properties of marine stratocumulus (clouds).
- Oceanography Section (OS) - Research has focused on an understanding of large-scale ocean circulation through studies of the important processes in the global ocean. An important element of this work is to examine the relationship of these processes to the dynamics of climate, thus involving studies in ocean modeling, theory and observation, and air-sea interaction.
- Global Dynamics Section (GDS)- The goal of the GDS is to improve understanding of the dynamics of global-scale motions on time scales through diagnostic analyses of global atmospheric data and theoretical and numerical studies of global circulations which will lead to establishing the conceptual basis for extended-range prediction. GDS research is relevant to the support of the overall NSF Climate Program, the WCRP (World Climate Research Programme), and to the United States participation in TOGA (Tropical Ocean Global Atmosphere) program.
- Environmental and Societal Impacts Group (ESIG) - The research activities of the ESIG are geared toward providing insights into how societies might better understand and cope with interactions between human activities and atmospheric processes.
- Interdisciplinary Climate Systems (ICS) Section - Considerable attention has been focused in the United States and the international scientific communities on earth systems problems involving interactions of many disciplines. The ICS focuses on problems in which climatic subsystems interact or in which state-of-the-art knowledge from several disciplines needs to be combined to study the earth as a system.

B.4.4 Atmospheric Chemistry Division

The Atmospheric Chemistry Division (ACD) has organized its research activities into the following four sections.

- The Atmospheric Chemistry of Transient Species (ACTS) Section, which emphasizes laboratory and field investigations of reactive gases and aerosols.
- The Global and Remote Observations (GRO) Section, which uses remote sensing to investigate global distribution of trace species in the atmosphere. Data taken during the NASA Airborne Antartic Ozone Experiement provided a fairly complete picture of the ozone hole in that region.
- The Atmospheric Chemical Modeling (ACM) Section, which develops computer-based theoretical models to compare with observational data in order to better understand processes that control the composition of the global atmosphere.
- The Biosphere-Atmosphere Chemistry (BAC) Section, which studies the global distribution of organic and biogenic trace gases, their fluxes from specific plant of animal sources, and the effects of reactive gases on plant processes.

B.4.5 High Altitude Observatory

The research goals of the High Altitude Observatory (HAO) cover a broad spectrum of problems encompassing the causal mechanisms and spectral form of solar variability together with its terrestrial consequences. There is also significant work on problems of stellar physics. The HAO has organized its research in the following four sections: the Coronal/Interplanetary Physics (CIP) Section, the Solar Activity and Magnetic Fields Section, the Solar Interior Section, and the Terrestrial Interactions Section.

B.4.6 Mesoscale and Microscale Meteorology Division

The Mesoscale and Microscale Meteorology (MMM) Division conducts research to better understand how the atmosphere responds to and organizes the flow of energy, momentum, moisture, and chemical species between and among layers of the free atmosphere and the planetary surface. This knowledge can be applied to improvements of short-term weather, including severe weather prediction; to the understanding of past and present climates and the prediction of future climates and their impacts; and to the understanding of the cycling of chemical species between the atmosphere and other components of the earth system. The division is organized into three sections: Mesoscale Prediction Section (MPS), Convective Meteorology Section (CMS), and Microscale Meteorology Section (MMS).

The MMM Division is also the administrative home for NCAR's Office of Field Project Support. This office provides an NCAR/NSF focal point for interagency and international field project planning and implementation. The office supports atmospheric sciences on a broad front, including mesoscale and microscale meteorology, climate, and atmospheric chemistry.

B.4.7 Supercomputer usage at NCAR

The following table shows the amount of supercomputer usage at NCAR during 1988 as a function of scientific discipline.

1988 Supercomputing Usage at NCAR

Discipline Area	Percent of Use
Climate	23%
Climate	
General Circulation	
Radiative Processes	
Satellite Meteorology	
Statistical Meteorology	
Oceanography	16%
Oceanography	
Basic Fluid Dynamics and Miscellaneous	6%
Basic Geophysical Fluid Dynamics	
Numerical Methods	
Turbulence	
Wave Processes	
Economic and Societal Impact Studies	
Computer Science	
Other	
Regional Meteorology	25%
Planetary Boundary Layer	
Dynamic Meteorology	
Mesoscale and Regional Scale Models	
Surface Conditions, Hydrology	
Tropical Meteorology	
Numerical Weather Prediction	
Objective Analysis and Diagnostic Studies	
Chemistry and Upper Atmosphere	8%
Aerosol Physics	
Atmospheric Chemistry	
Upper Atmosphere Dynamics and Aeronomy	
Cloud Physics	18%
Radar Meteorology	
Severe Storm and Cloud Physics	
Data Processing (Aircraft, Balloon)	
Astrophysics	4%
Astrophysics	
Solar Interplanetary Medium	
Solar Physics	
Physics of Planetary Atmosphere	
Solar-territorial Relations	
Magnetohydrodynamics and Plasma Physics	
	100%

C Manifest of NASA and NOAA Missions in the 1990's

Appendix C. Manifest of NASA and NOAA Missions in the 1990's.

ASTROPHYSICS

BEGIN	END	ACRONYM	NAME	AGENCY	STAT	VEHICLE	PLATFORM	DESTINATION	NOTE
(78 - -)	90 - -	IUE	INTERNATIONAL ULTRAVIOLET EXPLORER	NASA	C	—	FF	GEO	-
89 11 -	90 - -	COBE	COSMIC BACKGROUND EXPLORER	NASA	M	DELTA	FF	PEO	-
90 02 -	92 - -	ROSAT	ROENTGEN SATELLITE	NASA/FRG	M	DELTA	FF	LEO	-
90 03 26	05 - -	HST	HUBBLE SPACE TELESCOPE	NASA	M	DIS 31	FF	LEO	CV
90 04 26	SR	ASTRO-1	ASTRO	NASA	M	COL 35	STS	LEO	-
90 04 26	SR	BBXRT-1	BROAD BAND X-RAY TELESCOPE	NASA	M	COL 35	STS	LEO	-
90 06 04	92 - -	GRO	GAMMA RAY OBSERVATORY	NASA	M	ATL 37	FF	LEO	CV
90 11 01	SR	IBSS	INFRARED BACKGROUND SIGNATURE SURVEY	NASA/FRG	M	DIS 39	STS-P	LEO	-
91 05 -	SR	SHEAL II	SHUTTLE HIGH ENERGY ASTROPHYSICS LABORATORY	NASA	R	STS	STS	LEO	-
91 08 -	93 - -	EUVE	EXTREME ULTRAVIOLET EXPLORER	NASA	M	DELTA	EP	LEO	CV
92 04 06	SR	ASTRO-2	ASTRO	NASA	M	ATL 54	STS	LEO	
92 04 06	SR	BBXRT-2	BROAD BAND X-RAY TELESCOPE	NASA	M	ATL 54	STS	LEO	
92 08 27	SR	ORFEUS	ORBITING, RETRIEVBL FAR & EXTREME UV SPCTRMTR	NASA/FRG	M	END 59	STS	LEO	CV
93 05 03	SR	ASTRO-3	ASTRO	NASA	M	COL 67	STS	LEO	CV
94 07 10	96 - -	XTE	X-RAY TIMING EXPLORER	NASA	M	DIS 84	EP	LEO	CV
95 05 03	SR	BBXRT	BROAD BAND X-RAY TELESCOPE	NASA	M	COL 67	-	LEO	CV
95 12 -	11 - -	AXAF	ADVANCED X-RAY ASTROPHYSICS FACILITY	NASA	R	STS	SSCO	LEO	CV
95 - -	97 - -	GRAV-B	GRAVITY PROBE-B	NASA	P	—	FF	LEO	CV
98 06 -	00+	SIRTF	SPACE INFRARED TELESCOPE FACILITY	NASA	R*	T IV	SSCO	LEO	-
- - -	- - -	FUSE	FAR ULTRAVIOLET SPECTROSCOPY EXPLORER	NASA	P	—	-	LEO	-
- - -	- - -	NAE	NUCLEAR ASTROPHYSICS EXPLORER	NASA	P	—	EP	LEO	-
- - -	- - -	SOFIA	STRATOSPHERIC OBSERVATORY FOR IR ASTRONOMY	NASA	P?	Boeing 747	Boeing 747	UPPER ATMOS	-

SPACE PHYSICS

BEGIN	END	ACRONYM	NAME	AGENCY	STAT	VEHICLE	PLATFORM	DESTINATION	NOTE
(72 - -)	00+	IMP	INTERPLANETARY MONITORING PLATFORM	NASA	C	—	FF	VARIOUS	-
(80 - -)	90 - -	SMM	SOLAR MAXIMUM MISSION	NASA	C	—	FF	EO	-
(81 - -)	- - -	DE	DYNAMICS EXPLORER	NASA	C	—	FF	EO HEO/LEO	-
(84 - -)	- - -	CCE	CHARGE COMPOSITION EXPLORER	NASA/FRG/UK	C	—	FF	EO	-
(85 - -)	89 - -	ICE	INTERNATIONAL COMETARY EXPLORER	NASA	C	—	FF	COMET FLY-BY	-
90 06 -	93 - -	CRRES	COMBINED RELEASE & RADIATION EFFECTS SAT	NASA/DOD	M	A/C	FF	EO HE	C
90 10 05	95 - -	ULYSSES	ULYSSES	NASA/ESA	M	ATL 41	FF	SOLAR-PROBE	C
92 06 -	- - -	SAMPE	SOLAR ANOM. & MAGNETOSPHERIC PARTICLE EXPLOR.	NASA	M	SCOUT	FF	EO TBD	C
92 07 -	98 - -	GEOTAIL	GEOTAIL MISSION (COSTR/ISTP)	NASA/ISAS	M	TBD	FF	EO HE	C
92 12 -	98 - -	WIND	WIND MISSION (GGS/ISTP)	NASA	M	TBD	FF	EO HE	C
93 06 -	98 - -	POLAR	POLAR MISSION (GGS/ISTP)	NASA	M	TBD	FF	EO HE	C
93 06 -	- - -	SWAS	SUBMILLIMETRE WAVE ASTRONOMY SAT	NASA	M	SCOUT	FF	EO TBD	C
94 - -	00+	PIMS	PLASMA INTERACTION MONITORING SYSTEM	NASA	P	STS	SSAP	LEO	CV
95 03 -	97 - -	SOHO	SOLAR AND HELIOSPHERIC OBSERVATORY	NASA/ESA	M	TBD	FF	SUN-EO	-
95 08 -	- - -	OSL	ORBITING SOLAR LABORATORY	NASA	R*	TBD	FF	SOLAR-ORBIT	C
96 - -	00+	CLUSTER	CLUSTER MISSION (COSTR/ISTP)	NASA/ESA	?	ARIANE	FF	EO	-
96 - -	02 - -	STO-1	SOLAR TERRESTRIAL OBSERVATORY	NASA	P	STS	PP	LEO	-
96 - -	06 - -	STO-2	SOLAR TERRESTRIAL OBSERVATORY	NASA	P	STS	SSAP	LEO	-
96 - -	00+	ASTROMAG	ASTROMAG	NASA	P	STS	SSAP	LEO	-
96 - -	00+	POF	PINHOLE OCCULTER FACILITY	NASA	P	STS	SSAP	LEO	-
98 05 -	- - -	S-PROBE	SOLAR PROBE	NASA	R*	T IV	FF	SOLAR-PROBE	-

COMMUNICATIONS/INFORMATION SYSTEMS

BEGIN	END	ACRONYM	NAME	AGENCY	STAT	VEHICLE	PLATFORM	DESTINATION	NOTE
(66 - -)	CONT	ATSS	APPLICATION TECHNOLOGY SATELLITES	NASA	C	—	FF	GEO	-
(88 - -)	CONT	SARSAT	SATELLITE AIDED SEARCH AND RESCUE PROGRAM	NASA	C	—	FF	EO	-
92 05 -	96 - -	ACTS	ADV. COMM. TECHNOLOGY SATELLITE PROGRAM	NASA	M?	STS	FF	GEO	-
93 03 -	CONT	MSAT	MOBILE SATELLITE PROGRAM	NASA	M	TBD	FF	GEO	-
- - -	- - -	——	OPTICAL COMMUNICATIONS PROGRAM	NASA	P	—	—	EO	-

SOLAR SYSTEM EXPLORATION

BEGIN	END	ACRONYM	NAME	AGENCY	STAT	VEHICLE	PLATFORM	DESTINATION	NOTE
(77 08 20)	00 - -	VOYAGER 2	VOYAGER 2	NASA	C	—	FF	PLANET-PROBE	-
(78 05 20)	92 08 -	PVO	PIONEER 12 VENUS ORBITER	NASA	C	—	FF	VENUS-ORBIT	-
(89 05 04)	91 - -	MAGELLAN	MAGELLAN	NASA	C	ATL 30	FF	VENUS-ORBIT	-
(89 10 18)	97 - -	GALILEO	GALILEO	NASA	M	ATL 34	FF	JUPITER-PROBE	C
92 09 -	95 - -	MO 1	MARS OBSERVER 1	NASA	M	T III	FF	MARS-ORBIT	C
94 - -	00+	CDCF	COSMIC DUST COLLECTION FACILITY	NASA	P	STS	SSAP	LEO	CV
95 08 -	01 - -	CRAF	COMET RENDEZVOUS ASTEROID FLYBY	NASA	M	T IV	FF	COMET PROBE	-
96 04 -	06 - -	CASSINI	CASSINI	NASA/ESA	R*	T IV	FF	SATURN-ORBIT	-
96 10 -	97?- -	LO	LUNAR OBSERVER	NASA	R*	TBD	FF	LUNAR-ORBIT	-
96 - -	00+	ATF	ASTROMETRIC TELESCOPE FACILITY	NASA	P	STS	SSAP	LEO	CV
97 06 -	- - -	MO 2	MARS OBSERVER 2	NASA	R*	TBD	FF	MARS-ORBIT	-

EARTH SCIENCE & APPLICATIONS

BEGIN	END	ACRONYM	NAME	AGENCY	STAT	VEHICLE	PLATFORM	DESTINATION	NOTE
(75 10 16)	- - -	GOES-1	GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SAT	NOAA	C	—	FF	GEO	-
(77 06 16)	- - -	GOES-2	GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SAT	NOAA	C	—	FF	GEO	-
(78 06 16)	- - -	GOES-3	GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SAT	NOAA	C	—	FF	GEO	-
(78 10 24)	- - -	NIMBUS-7	NIMBUS	NOAA	C	—	FF	LEO SS	-
(79 06 27)	- - -	NOAA-6	NATIONAL OCEANIC & ATMOSPHERIC ADMIN	NOAA	C	—	FF	LEO SS	-
(80 09 09)	- - -	GOES-4	GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SAT	NOAA	C	—	FF	GEO	-
(81 05 22)	- - -	GOES-5	GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SAT	NOAA	C	—	FF	GEO	-
(81 06 23)	- - -	NOAA-7	NATIONAL OCEANIC & ATMOSPHERIC ADMIN	NOAA	C	—	FF	LEO SS	-
(82 07 16)	- - -	LANDSAT-4	LANDSAT	NOAA	C	—	FF	LEO SS	-
(83 04 28)	- - -	GOES-6	GEOSTATIONARY OPERATIONALY ENVIRONMENTAL SAT	NOAA	C	—	FF	GEO	-
(84 10 05)	89?- -	ERBE	EARTH RADIATION BUDGET EXPERIMENT	NASA	C	CHL 13	FF	EO	-
(84 12 12)	- - -	NOAA-9	NATIONAL OCEANIC & ATMOSPHERIC ADMIN	NOAA	C	—	FF	LEO SS	-
90 01 -	- - -	NOAA-D	NATIONAL OCEANIC & ATMOSPHERIC ADMIN	NOAA	M	A-50E	FF	PEO SS	C
90 10 -	- - -	GOES-I	GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SAT	NOAA	M	A-1	FF	GEO	-
91 03 28	SR	ATLAS-1	ATMOSPHERIC LABORATORY FOR APPLNS & SCIENCE	NASA	M	COL 45	STS	LEO	
91 05 -	- - -	NOAA-I	NATIONAL OCEANIC & ATMOSPHERIC ADMIN	NOAA	M	A-34E	FF	PEO SS	CV
91 11 27	95 - -	UARS	UPPER ATMOSPHERE RESEARCH SATELLITE	NASA	M	ATL 50	FF	LEO	CV
91 11 -	- - -	GOES-J	GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SAT	NOAA	M	A-1	FF	GEO	-
91 12 -	94 - -	TOPEX	OCEAN TOPOGRAPHY EXPERIMENT	NASA/CNES	?	ARIANE	FF	LEO	CV
92 05 -	- - -	GOES-K	GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SAT	NOAA	M	A-1	FF	GEO	-
92 06 15	SR	SRL-1	SPACE RADAR LABORATORY	NASA	M	COL 56	STS	LEO	CV
92 07 09	SR	ATLAS-2	ATMOSPHERIC LABORATORY FOR APPLNS & SCIENCE	NASA	M	ATL 57	STS	LEO	CV
92 09 -	- - -	NOAA-J	NATIONAL OCEANIC & ATMOSPHERIC ADMIN	NOAA	M	A-11E	FF	PEO SS	CV
92 - -	95 - -	NSCAT	NASA SCATTEROMETER	NASA	P?	STS	PP	LEO	CV
93 01 -	- - -	TOMS	TOTAL OZONE MAPPING SPECTROMETER	NASA	M	SCOUT	FF	LEO	CV
93 07 15	SR	ATLAS-3	ATMOSPHERIC LABORATORY FOR APPLNS & SCIENCE	NASA	M	END 70	STS	LEO	CV
93 08 12	SR	SRL-2	SPACE RADAR LABORATORY		M	COL 71	STS	LEO	CV
93 11 -	- - -	NOAA-K	NATIONAL OCEANIC & ATMOSPHERIC ADMIN	NOAA	M	T II	FF	PEO SS	CV
93 12 -	- - -	FASE	FAST AURORAL SNAPSHOT EXPLORER	NASA	M	TBD	FF	LEO	CV
94 04 21	SR	ATLAS-4	ATMOSPHERIC LABORATORY FOR APPLNS & SCIENCE	NASA	M	ATL 81	STS	LEO	CV
94 06 -	99 - -	RADARSAT	RADAR SATELLITE	NASA	M	TBD	FF	LEO	CV
95 04 -	- - -	NOAA-L	NATIONAL OCEANIC & ATMOSPHERIC ADMIN	NOAA	M	T II	FF	PEO SS	CV
95 07 -	- - -	GOES-L	GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SAT	NOAA	M	A-1	FF	GEO	-
95 09 30	SR	ATLAS-5	ATMOSPHERIC LABORATORY FOR APPLNS & SCIENCE	NASA	M	END 99	STS	LEO	CV
95 - -	99 - -	TRMM	TROPICAL RAINFALL MEASUREMENT MISSION	NASA	P	STS	SSAP	LEO	CV
96 - -	01 - -	GRM	GEOPOTENTIAL RESEARCH MISSION	NASA	P	—	FF	LEO	CV
96 - -	10 - -	EOS-1	EARTH OBSERVING SYSTEM	NASA	P?	STS	PP	LEO	CV
97 - -	12 - -	EOS-2	EARTH OBSERVING SYSTEM	NASA	P	STS	PP	LEO	-
- - -	- - -	MELTER	MESOSPHERE & LOWER THERMOSPHERE EXPLORER	NASA	P	—	—	LEO	-
- - -	- - -	NOAA-M	NATIONAL OCEANIC & ATMOSPHERIC ADMIN	NOAA	P?	—	FF	PEO SS	-

LIFE SCIENCES

BEGIN	END	ACRONYM	NAME	AGENCY	STAT	VEHICLE	PLATFORM	DESTINATION	NOTE
90 08 16	SR	SLS-1	SPACELAB LIFE SCIENCES LABORATORY	NASA	M	COL 40	STS-SL	LEO	-
91 06 17	SR	SL-J	SPACELAB	NASA	M	DIS 47	STS-SL	LEO	-
92 01 16	SR	SPACEHAB-1	SPACEHAB	NASA/ESA	M	DIS 49	STS	LEO	-
92 02 06	SR	SL D2	SPACELAB	NASA	M	END 52	STS-SL	LEO	-
92 08 27	SR	SPACEHAB-2	SPACEHAB	NASA/ESA	M	END 59	STS	LEO	CV
92 09 30	SR	SLS-2	SPACELAB LIFE SCIENCES LABORATORY	NASA	M	COL 60	STS-SL	LEO	CV
93 06 24	SR	SPACEHAB-3	SPACEHAB	NASA/ESA	M	ATL 68	STS	LEO	CV
93 11 18	SR	SL D3	SPACELAB	NASA	M	COL 75	STS-SL	LEO	CV
94 01 13	SR	SPACEHAB-4	SPACEHAB	NASA/ESA	M	ATL 77	STS	LEO	CV
94 06 09	SR	SLS-3	SPACELAB LIFE SCIENCES LABORATORY	NASA	M	COL 83	STS-SL	LEO	CV
94 07 10	SR	SPACEHAB-5	SPACEHAB	NASA/ESA	M	DIS 84	STS	LEO	CV
95 02 03	SR	SPACEHAB-6	SPACEHAB	NASA/ESA	M	DIS 91	STS	LEO	CV
95 08 08]	SR	SPACEHAB-7	SPACEHAB	NASA/ESA	M	COL 97	STS	LEO	CV
95 - -	00+	1.8-M	1.8-METRE CENTRIFUGE	NASA	P	STS	STS-SL	LEO	CV
96 06 -	SR	SLS-4	SPACELAB LIFE SCIENCES LABORATORY	NASA	R	STS	STS-SL	LEO	-
98 06 -	SR	SLS-5	SPACELAB LIFE SCIENCES LABORATORY	NASA	R*	STS	STS-SL	LEO	-

MICROGRAVITY SCIENCE & APPLICATIONS

BEGIN	END	ACRONYM	NAME	AGENCY	STAT	VEHICLE	PLATFORM	DESTINATION	NOTE
90 12 06	SR	IML-1	INTERNATIONAL MICROGRAVITY LABORATORY	NASA	M	COL 42	STS-SL	LEO	-
92 03 05	SR	USML-1	UNITED STATES MICROGRAVITY LABORATORY	NASA	M	COL 53	STS-SL	LEO	-
92 05 18	SR	USMP-1	UNITED STATES MICROGRAVITY PAYLOAD	NASA	M	END 55	STS	LEO	CV
93 01 21	SR	IML-2	INTERNATIONAL MICROGRAVITY LABORATORY	NASA	M	COL 63	STS-SL	LEO	CV
93 02 22	SR	USMP-2	UNITED STATES MICROGRAVITY PAYLOAD	NASA	M	DIS 64	STS	LEO	CV
93 09 30	SR	USMP-3	UNITED STATES MICROGRAVITY PAYLOAD	NASA	M	ATL 73	STS	LEO	CV
94 03 03	SR	USML-2	UNITED STATES MICROGRAVITY LABORATORY	NASA	M	COL 79	STS-SL	LEO	CV
94 09 08	SR	USMP-4	UNITED STATES MICROGRAVITY PAYLOAD	NASA	M	END 86	STS	LEO	CV
95 04 14	SR	IML-3	INTERNATIONAL MICROGRAVITY LABORATORY	NASA	M	COL 93	STS-SL	LEO	CV
95 - -	00+	MMPF-1	MICROGRAVITY & MATERIALS PROCESSING FACILITY	NASA	P	STS	SSF	LEO	CV
96 03 -	SR	USML-3	UNITED STATES MICROGRAVITY LABORATORY	NASA	R	STS	STS-SL	LEO	CV
97 04 -	SR	IML-4	INTERNATIONAL MICROGRAVITY LABORATORY	NASA	R*	STS	STS-SL	LEO	-
97 - -	00+	MMPF-2	MICROGRAVITY & MATERIALS PROCESSING FACILITY	NASA	P	STS	SSF	LEO	-
98 03 -	SR	USML-4	UNITED STATES MICROGRAVITY LABORATORY	NASA	R	STS	STS-SL	LEO	-
- - -	- - -	——	MODULAR MULTIZONE FURNACE FACILITY	NASA	P	STS	SSF	LEO	-
- - -	- - -	——	MODULAR CONTAINERLESS PROCESSING FACILITY	NASA	P	STS	SSF	LEO	-
- - -	- - -	——	ADVANCED PROTEIN CRYSTAL GROWTH FACILITY	NASA	P	STS	SSF	LEO	-
- - -	- - -	——	BIOTECHNOLOGY FACILITY	NASA	P	STS	SSF	LEO	-
- - -	- - -	——	FLUID PHYSICS/DYNAMICS FACILITY	NASA	P	STS	SSF	LEO	-
- - -	- - -	——	MODULAR COMBUSTION FACILITY	NASA	P	STS	SSF	LEO	-

BEGIN: Beginning date; END: Ending date, SR=Shuttle Return of Payload on Same Mission
AGENCY: ESA=European Space Agency, ISAS=Japanese Institute of Astronautical Sciences, CNES=Centre National d'Etudes Speatiales, FRG=Federal Republic of Germany, UK=United Kingdom, DOD=US Dept. of Defence
STATUS: C=Currently Operational, M=Manifested, R=Requested, P=Proposed, *=For NASA planning purposes
VEHICLE: DIS=Discovery, COL=Columbia, ATL=Atlantis, END=Endeavour, CHL=Challenger, T=Titan ELV, A=Atlas ELV, A/C =Atlas Centaur ELV
PLATFORM: FF=Free Flyer; STS=Space Shuttle, SL=Space Lab, PP=Polar Platform, SSAP=Space Station Attached Payload, SSCO=Space Station Co-orbiting, SSF=Space Station Freedom, EP=Explorer Platform, STS-P=Shuttle Proximity
DESTINATION: PL=Planetary Probe, SP=Solar Probe, EO=Earth Orbit, LEO=Low Earth Orbit, SS=Sun Synchronous, GEO=Geosynchronous Orbit, PEO=Polar Earth Orbit, HE=High Eccentricity, HEO=High Earth Orbit
NOTE: C=Missions contemporary to ACTS lifetime, V=Visible to ACTS.

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