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A. SATELLITE LASER RANGING OPERATIONS

107873

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Satellite Laser Ranging (SLR) is currently providing precision orbit determination for measurements of:

- Ocean surface topography from satellite borne radar altimetry,
- Spatial and temporal variations of the gravity field,
- Earth and ocean tides,
- Plate tectonic and regional deformation,
- Post-glacial uplift and subsidence,
- Variations in the Earth's center-of-mass, and
- Variations in Earth rotation.

SLR also supports specialized programs in time transfer and classical geodetic positioning, and will soon provide precision ranging to support experiments in relativity.

The current trend in SLR is away from localized network measurements that characterized WEGENER/MEDLAS and the California Baja programs, and more toward fixed fiducial sites as part of a fundamental network for programs in global geodynamics and for orbital coverage for specialized projects. The localized mobile networks should be transitioning to GPS in a systematic manner, with SLR then providing some portion of the global geodetic control. The fixed fiducial stations have been viewed as evolving into the geophysical observatories in line with the concepts discussed at Erice and Coolfont.

The NASA stations are introducing automation and new technologies to enhance productivity and data quality, while at the same time reducing station operating personnel. The global network continues to grow, both in terms of stations and geographic coverage, attributable almost entirely to increased foreign participation.

SLR data and data processing are also in a state of change. Field Generated Normal Points (FGNP), available within 24-36 hours of acquisition, are rapidly becoming the standard data product, superseding full-rate data that was taking up to six months or more for full availability. Data processing and assessment are rapidly being automated to speed up feedback to the field stations, both NASA and foreign.

GLOBAL SLR NETWORK AND OCCUPATION PLAN

The global SLR network includes about 40 laser stations (see Figure 1) with capability varying from centimeter to decimeter precision. The centimeter systems are those operated by NASA and a few agencies and observatories in Europe and Australia.

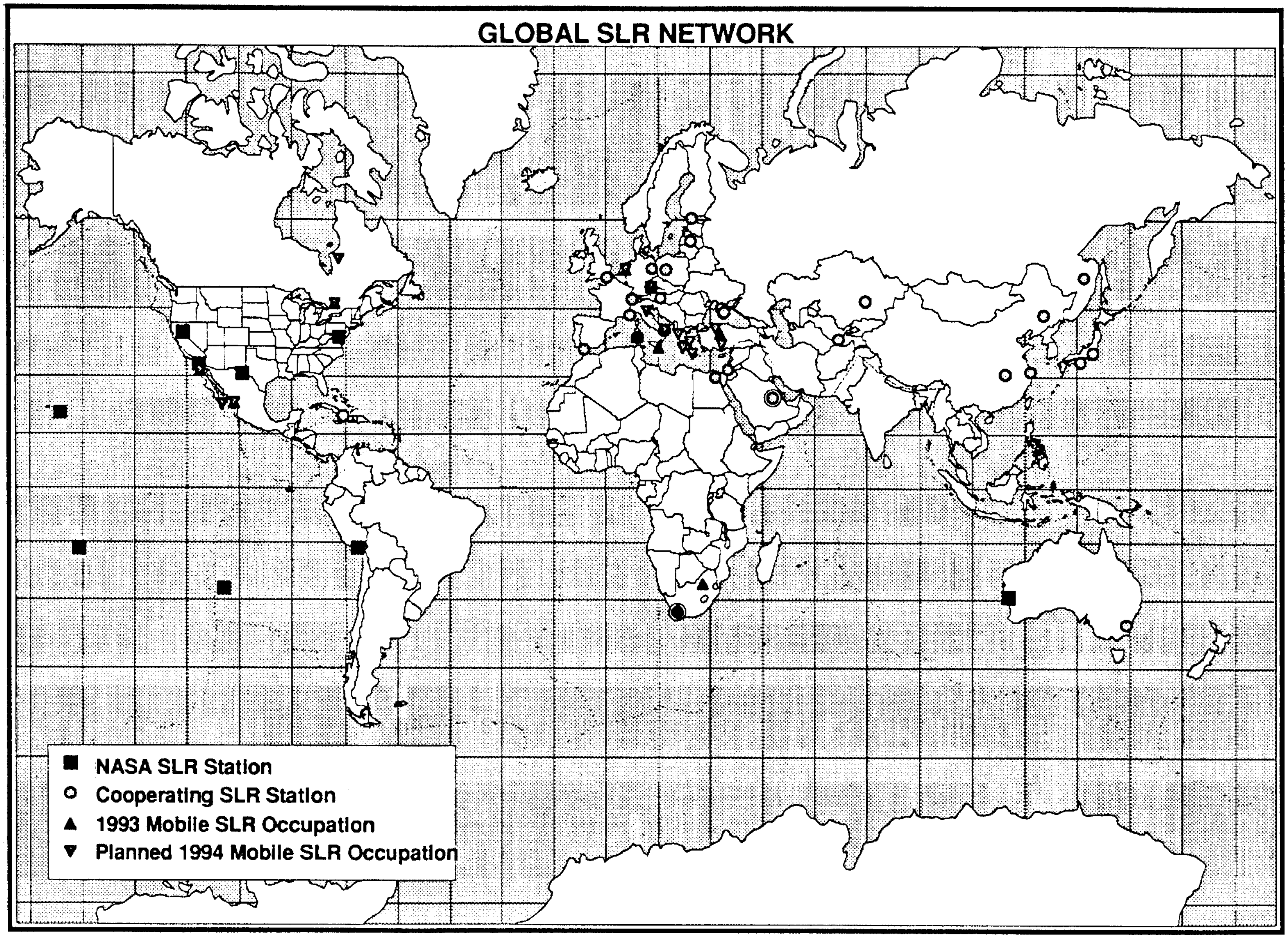
GLOBAL SLR NETWORK
NASA SLR Station
Cooperating SLR Station
1993 Mobile SLR Occupation
Planned 1994 Mobile SLR Occupation

Figure 1.

The least precise systems are primarily those operated by small observatories or groups that have recently entered the field and are working their way up the experience curve. With the recent growth in participation from China and the former Soviet Union, occupations by mobile systems, and new stations planned for deployment over the next year, global coverage is expanding. The TLRS-3 is now permanently located in Arequipa. The TLRS-2 is being moved back and forth between Easter Island and Tahiti to take advantage of the seasonal weather patterns. TLRS-1 is in the process of being transferred to ASI on long term loan for mobile occupation. Plans are also underway to provide an upgraded Moblas-6 to the South Africans for deployment at Sutherland, and for the Saudi Arabian Laser to be setup at Riyadh during the next year.

In addition to those stations shown on the map, the Russian Time and Frequency Institute is presently deploying a network of SLR stations across Russia and Asia that will be participating in global tracking activities. Groups in Europe are also planning to relocate existing systems to sites in Tunisia and South America. Gaps in global coverage that continue to exist at least for the lower satellites are over the Indian Ocean and the South Atlantic, and we continue to work options for relocation with groups presently working in the more heavily covered regions.

In 1993, mobile lasers (TLRS-1, TLRS-2, TLRS-4, MTLRS-1, and MTLRS-2) occupied sites in:

1. The Mediterranean region for WEGENER/MEDLAS;

2. South Africa to support Topex/Poseidon and general global coverage;

3. Mexico to support the California Baja Project;

4. Canada to begin measurements of post-glacial uplift (DOSE experiment); and

5. Easter Island and Tahiti to provide coverage across the South Pacific.

The plans for 1994 and 1995 are included in Table 1. In 1994, TLRS-1, MTLRS-1, and MTLRS-2 will complete the WEGENER/MEDLAS localized network measurements in Greece and Turkey, with the program then transitioning to GPS. The first GPS measurements were made at these sites in 1993; the second occupation will take place in 1994 with the SLR occupations. Measurements are planned to continue with TLRS-4 in Canada.

After the 1994 WEGENER/MEDLAS Campaign, IfAG is planning occupations at Firusa and Zelenchukskaya in Russia (to support crustal motion and subsidence measurements) prior to moving on to Asia and the South Pacific to participate in the ASEAN Program. Kootwijk is considering keeping MTLRS-2 in Greece, mainly at

Dionysos, under partial support from the National Technical University. The Italian Space Agency (ASI) is considering 1995 occupations of TLRS-1 in Africa, one of the sites being at Malindi.

The French continue to work on the FTLRS. As a result of problems with their prime contractor, the control system software will have to be rewritten, keeping it out of action probably until 1995. At that time it will be available to support the altimeter missions from sites in the Mediterranean and Africa.

TABLE 1

MOBILE STATION OCCUPATIONS
(Planned for 1994 and Beyond)

	TLRS-1	TLRS-4
1994	Matera Medicina Basovizza Xrisokellaria Matera (Upgrade)	Enceneda Cabo San Lucas La Grande Algonquin Mazatlan
1995*	Upgrade Mediterranean/ Africa	Canada
	MTLRS-1	**MTLRS-2**
1994	Kootwijk (Upgrade) Wettzell Yigilca Melengiclik	Kootwijk (Upgrade) Roumelli Karitsa Dionysis
1995*	Russia, Asia	Greece
	FTLRS	**HTLRS**
	Mediterranean/ Africa	Japan/Islands

* Final Full-Site Occupations for WEGENER/MEDLAS (Second GPS Occupation)

SATELLITES

In the late-1980s, the SLR network was tracking Lageos-1 for Crustal Dynamics plus Starlette and Ajisai for gravity field modelling. Since that time, the role of the network has expanded dramatically (see Figure 2). Ten additional satellites have been added to the list including the altimeter satellites ERS-1 and TOPEX/Poseidon, the gravity mission Stella, and the large complex of high altitude satellites associated with the GPS and Glonass programs. The slate of new retroreflector satellites scheduled over the next three years is equally as impressive, including many specialized satellites requiring SLR for both routine tracking and as part of the on-board experiment/measurement system.

DATA YIELD

Data yield from the global network has grown by a factor of 3-4 over the last five years with both the NASA and foreign stations contributing to this increase (see Figure 3). The reasons for the increase in the NASA network data yield are:

- A change in operational philosophy to prioritize satellites by altitude, lowest first, and to give the station operators more flexibility in operational trade-offs;
- Additional operating shifts scheduled for Topex, but having a major impact on all satellites;
- Additional satellites; and
- System upgrades including:
  - Real-time data processing to allow increased satellite tracking coverage;
  - Satellite pass interleaving to avoid loss of passes due to conflict;
  - Improved signal link for higher satellites; and
  - Refurbishment of mounts and telescopes to improve reliability.

The increase in the data yield from the foreign network occurred for similar reasons, plus some stations are now much further up experience curve and are becoming more productive, and some new stations have become operational.

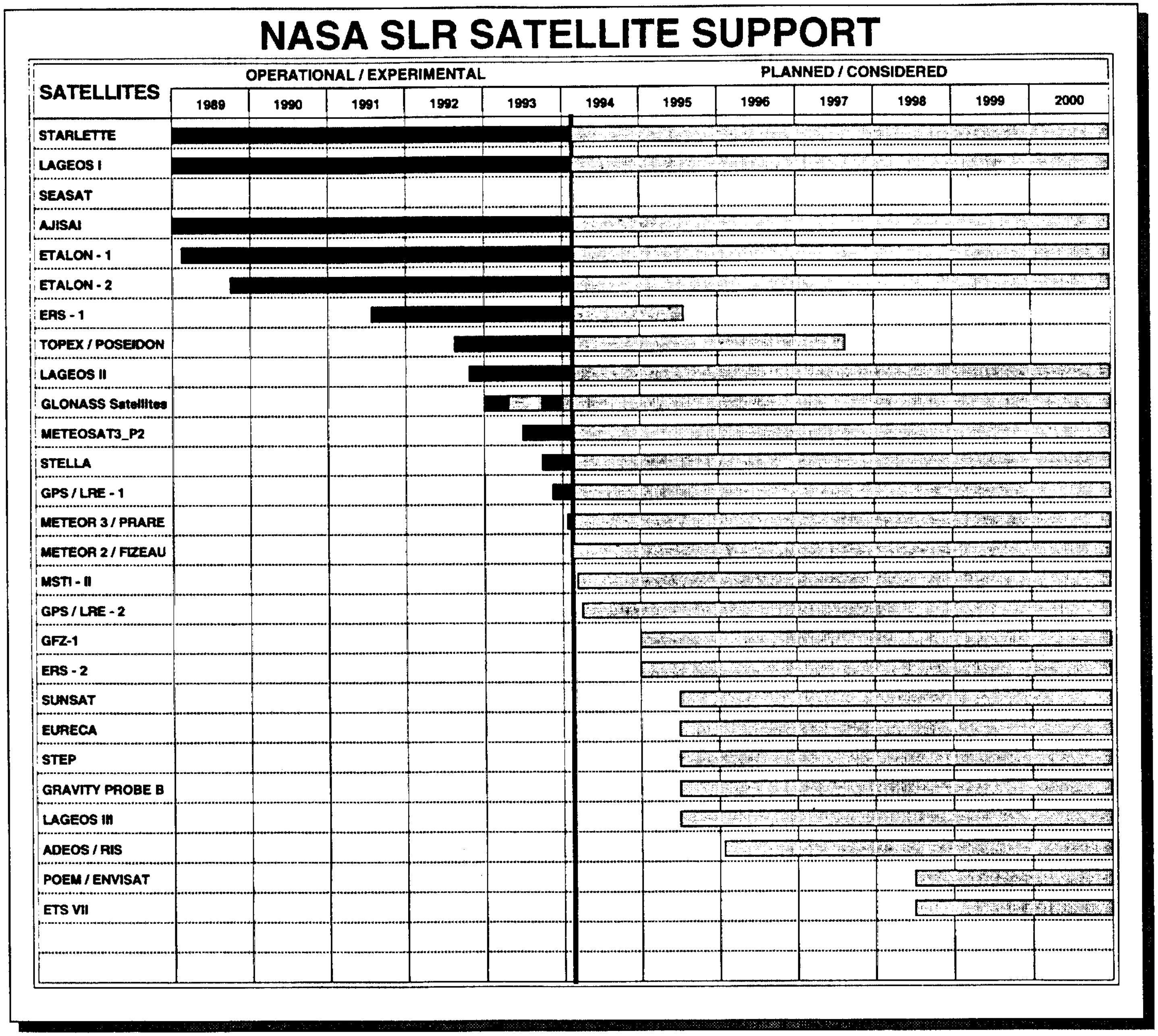
NASA SLR SATELLITE SUPPORT
OPERATIONAL / EXPERIMENTAL
PLANNED / CONSIDERED
SATELLITES
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
STARLETTE
LAGEOS I
SEASAT
AJISAI
ETALON - 1
ETALON - 2
ERS - 1
TOPEX / POSEIDON
LAGEOS II
GLONASS Satellites
METEOSAT3_P2
STELLA
GPS / LRE - 1
METEOR 3 / PRARE
METEOR 2 / FIZEAU
MSTI - II
GPS / LRE - 2
GFZ-1
ERS - 2
SUNSAT
EURECA
STEP
GRAVITY PROBE B
LAGEOS III
ADEOS / RIS
POEM / ENVISAT
ETS VII

Figure 2.

SLR Data 1988 - 1993

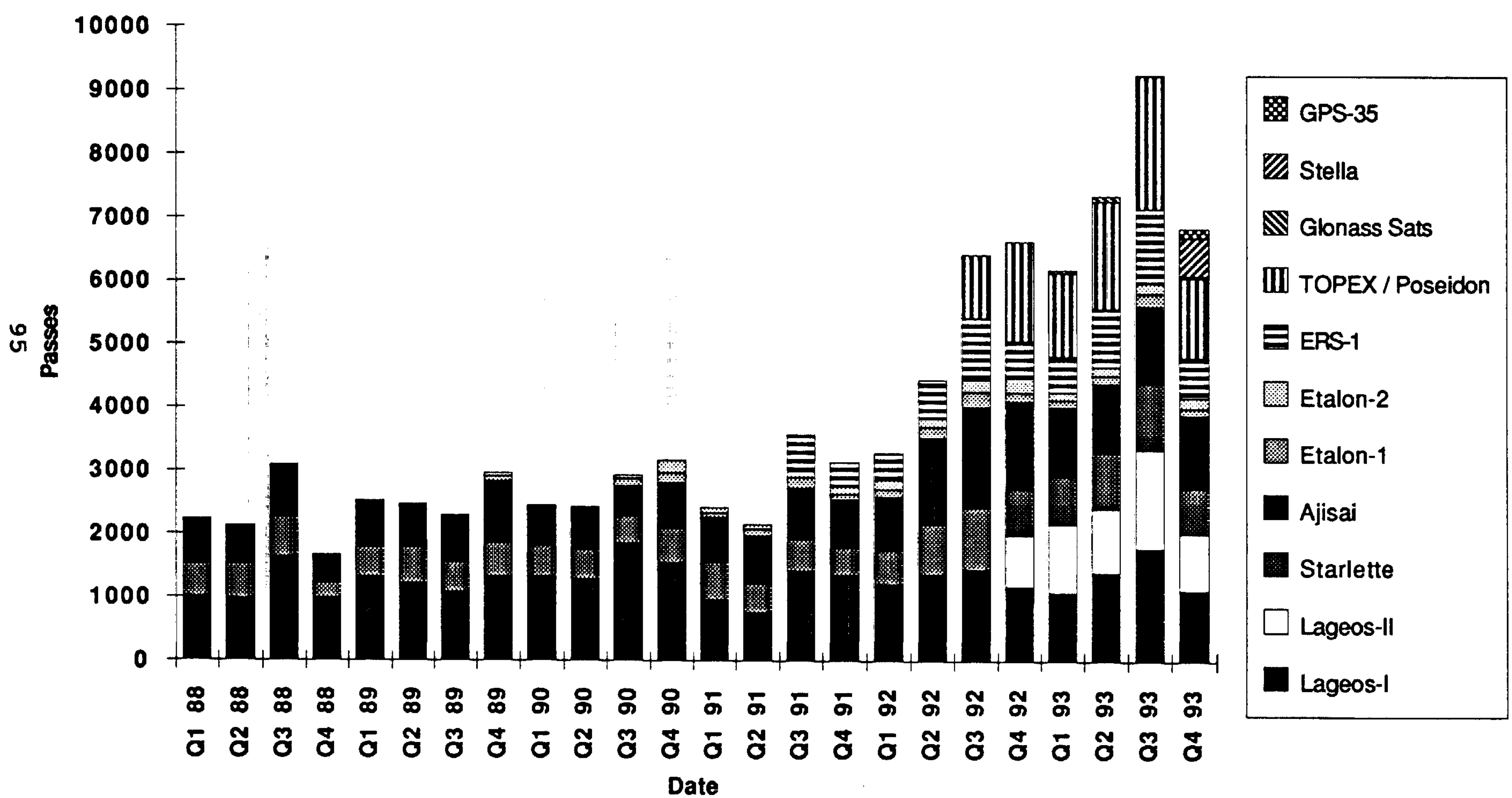

Figure 3.

PROGRAMS UNDERWAY FOR COST REDUCTION

Field Stations

The configuration of the current NASA SLR field stations is the result of their historical evolution since their design 20 years ago. They have been updated, but their upgrades have been constrained by configuration and by requirements to remain operational to support on-going programs. Original designs assumed a full crew for operations, maintenance, and safety, which included aircraft spotting, perimeter security, and the fulfillment of general OSHA requirements. In addition, alternative design and development programs, both in the US and abroad, have introduced non-uniformities in both hardware and software. Through the years, consolidations and upgrades have reduced the required station manpower and the system-to-system differences, and we continue to identify opportunities and implement provisions to reduce station operating costs and to increase standardization.

Aside from the operating cost, the relocation of mobile systems, including shipment, logistics, and personnel dislocation allowance has been very expensive. This cost will be reduced significantly as this type of activity is reduced.

In this regard, the NASA network has been focussing on the following:

- Automation and consolidation at the field stations to reduce personnel;
- Improvement in the utility of the network to improve performance and reliability; and
- Best utility from the foreign network.

In terms of automation and consolidation, the following are underway or have been included in the network plan:

1. The installation of the data processing computers at TLRS-1, TLRS-2, and Moblas-2 to give all sites the capability of producing FGNP and standardizing system I/O; all of the other NASA systems and most of the foreign systems have been given this capability over the last three years.
2. The installation of aircraft radar and motion sensors to automate most of the safety functions. The prototype radar and motion sensor now working on Moblas-7 have already proved to be more effective in spotting aircraft and shutting down the system than visual spotters.
3. The computerization of logistics and administrative functions to eliminate forms and paper handling; much of

the software to handle these functions is in process and will be ready for testing on Moblas-7 later this year.

4. The installation of the new system controller to provide improved and standardized operator interface; this is under development on Moblas-6 and will be ready for full system testing mid-year.

5. The completion of Internet connections to all sites to provide standardized high-quality, reliable, low cost data communications; ARC is in the process of implementing the network requirements.

6. The installation of the GPS Steered Timing Standard at all of the NASA SLR stations to provide fully time corrected FGNP directly from the field to the users; the prototype is ready for installation and testing on Moblas-7 and the design is ready for production.

7. The improvement in the reliability of the lasers by upgrading components to current standards or by replacing subsystems with newer commercial items to eliminate the need for laser monitoring and adjustment during operations.

Moblas stations currently require three people per shift; TLRS systems require two. With the steps above, personnel could, in principle, be reduced to one person per shift, if the OSHA requirements can be met without having two people on-site. Alternatively, the second person could have much lower technical requirements than current operators or could have responsibility for other measurement systems located at the same site (to take advantage of the already existing infrastructure).

Headquarters

Reductions will continue in headquarters data staff as FGNP completes their emergence and full-rate data is discontinued. This process is made possible by the computer capability in the field, the new field software, communications, and the GPS steered timing systems. It will be expedited by providing as much standardization as possible, most notably data processing software to assure standardized algorithms, data screening procedures, and diagnostics. Data handling and review at headquarters for network feedback and quality control is now almost fully automated, with 95-98% of the data requiring no intervention. Most passes requiring personnel scrutiny are either from systems with engineering changes underway or from foreign stations with configuration issues. The processing and data handling algorithms continue to be improved to further automate the process.

The headquarters engineering staff represents a wide spectrum of technical expertise required to handle the complexities of the

SLR systems introduced by history and lack of standardization. In reality, less and less of this resource is being spent on maintenance and sustaining engineering and increasingly more of it is being dedicated to the upgrades discussed above and to the development of future, automated systems.

IMPROVEMENTS IN THE UTILITY OF THE NASA NETWORK

Eventually SLR systems must be fully automated and designed to include the already existing technology that will bring total ranging capability to the mm level. In the meantime, improved ranging performance of the current SLR system depends upon: 1) quality control to ensure that data is not corrupted by equipment or operational shortcomings; 2) improved precision of the ranging machine; and 3) better understanding of the external environment influencing the range measurement.

The most critical issue in performance is the reliability of the data quality and achievement of a more uniform data set. This situation is improving with the additional efforts that have been placed in quality control and station feedback, in great part accelerated by the needs of the TOPEX Project. However, some systematic problems are still taking too much time to diagnose and a better review process and inquiry process needs to be implemented.

The inherent instrument accuracy of the SLR technique is demonstrated by the history of collocation, or side-by-side ranging experiments by two or more systems. The NASA systems typically demonstrate comparisons at the level of a few millimeters.

The largest uncertainties in the NASA laser systems at the moment are believed to be from the external environment: the refraction correction and the spacecraft center-of-mass correction. The current refraction models should be verified over a wide range of meteorological conditions using some of the multiple wavelength technology already available. This would have a fundamental impact on the design of new generation SLR systems and on the understanding of the influence of refraction on all of the space geodetic techniques. The adequacy of the models for the satellite center-of-mass vary greatly depending up the spacecraft geometry and the amount of effort applied to each satellite. Great care should be given to the design of new arrays and to the refinement of models for current satellites.

Hardware upgrades to improve instrument precision by about a factor of four are either commercially available or have been demonstrated. These upgrades include: shorter laser output pulse, improved MCP detectors, improvements to the time interval unit, and the addition of precision optical calibration techniques. All can be retrofit into the current hardware and all would be a basic step in development for the next generation SLR.

BEST UTILITY FROM THE FOREIGN NETWORK

NASA is reducing its support for SLR while the number of retroreflector satellites continue to increase. This places increased priority on improved data quality, quantity, and flow from the foreign network. NASA is intimately involved in the coordination of the foreign network, including: scheduling, priorities, predictions, communications, and quality review. We have strong partners in these activities including the European Data Center in Munich who now shoulder a substantial part of the load. NASA has been the focal point for standardization and baselining of the global network systems including: procedures, data products, reporting, and analysis models, and to a lesser degree hardware and software. With the requirements of the TOPEX project we are now active in configuration monitoring and system modelling for data interpretation. All of these activities should be continued, and in terms of standardization and quality assurance, stress should be increased.

NASA has also been active in providing technical assistance, pieces and parts, and even full systems to other groups to operate as part of the global network. The systems at Matera, Bar Giyyora, and TLRS-1 are all very active systems on long term loan from NASA. Arrangements are now in process for similar arrangements with Moblas-6 to South Africa.

Two items that would have a very major impact on our return from the foreign network are to:

1. Provide a PC with standardized software including predictions, data processing, FGNP, reporting, communications, etc. to those foreign stations that do not yet have these capabilities in place or with whom standardization and compatibility issues have been very difficult to resolve; this would provide more uniformity, reducing the need for special engineering and data handling at headquarters. It would also provide a more uniform means of software and model updates when required.

2. Develop a portable standard that could be shipped to overseas stations to perform engineering tests to check the key subsystems. Collocations are the best means of engineering checkout. On the other hand, they are expensive and require personnel travel. The portable standard has been configured for compact shipment and operation by the local station staff.