REPORT OF THE DEMONSTRATION AND EVALUATION OF THE 406 MHz GEOSTATIONARY SYSTEM

C/S R.008
October 1998

COSPAS SARSAT

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EXECUTIVE SUMMARY

Background

The Cospas-Sarsat Council (CSC) requested a Demonstration and Evaluation (D&E) to confirm the expected benefits of a geostationary search and rescue (GEOSAR) satellite system. The CSC further directed that the D&E establish GEOSAR technical and operational performance characteristics.

The GEOSAR system is composed of geostationary Earth-orbiting satellites and their associated ground processing facilities, that have the capability to detect transmissions from Cospas-Sarsat type approved 406 MHz distress beacons. These satellites orbit at altitudes of 36,000 km at approximately 0° latitude and fixed longitudes, appropriate to the requirements of the space segment provider. Because of the high altitude and fixed orbit position of the geostationary satellites, the geostationary system has the potential to offer several complementary advantages to the LEOSAR System. These advantages include near-instantaneous beacon detection and alerting, near-instantaneous beacon locating for beacons capable of calculating and transmitting their location, and continuous monitoring of the 406 MHz frequency band within the satellite footprint.

Goals

The goals of the D&E were to:

- characterise the technical performance of the GEOSAR components;
- characterise the operational performance of the GEOSAR system;
- evaluate the operational effectiveness of the GEOSAR system and determine the benefits to search and rescue of combined LEOSAR/GEOSAR operations; and
- provide the basis for recommendations to the Cospas-Sarsat Council.

Methodology

A D&E Plan "Cospas-Sarsat Demonstration and Evaluation Plan for 406 MHz GEOSAR Systems" (C/S R.006, October 1996) was developed to provide the framework for the D&E.

The Plan outlined ten technical and eight operational objectives for which tests were to be undertaken, with guidelines for data collection, reporting and analysis. The technical objectives were developed to address the technical compatibility of the various GEOSAR components and to establish the baseline characteristics of the GEOSAR system. The operational objectives were developed to evaluate the contribution to SAR operations of alert data provided by 406 MHz GEOSAR systems and to provide operational experience in the use of GEOSAR alerts. Data collection and evaluation for the technical and operational objectives generally took place between July 1996 and February 1998.

Participation in the D&E was open to all Cospas-Sarsat Participants. Australia, Canada, Chile, France, Spain, the United Kingdom and the United States contributed data in support of technical and/or operational objectives and contributed to the drafting of this report. Other Cospas-Sarsat Participants (Algeria and Japan) also provided input to the drafting to this report.

Results and Discussion

The successful completion of the ten technical objectives was hindered by radio frequency interference from a strong signal emanating from Peru. Because of the interfering signal, several of the technical objectives could not be accomplished or completed and are recommended as actions to be completed at the earliest opportunity. Despite this, the technical objectives confirmed that:

- the GEOSAR system could detect transmitting beacons that met Cospas-Sarsat technical specifications and which were visible;

- the GEOSAR system provided near-instantaneous detection and alerting of 406 MHz beacon transmissions;

- calibrated frequency measurements performed by the GEOLUTs were reliable and accurate enough to permit use of GEOSAR derived frequency data in improving LEOSAR positioning estimates;

- 4° is a conservative value to use as the published minimum elevation angle required to assure reliable GEOSAR reception of 406 MHz beacon transmissions; and

- sufficient technical data had been collected to recommend the incorporation of the GEOSAR system as a complement to the Cospas-Sarsat System.

Results from the eight operational objectives documented the performance and confirmed the effectiveness and benefits of the GEOSAR system. In particular, the D&E indicated, in the area of performance, that:

- the GEOSAR system provided a useful time advantage over the LEOSAR System. On average, the GEOSAR alert was received 46 minutes before the first corresponding LEOSAR alert; the median time advantage was 21 minutes;

- the coverage area of the GEOSAR system was a good complement to LEOSAR System coverage. More than 85% of 406 MHz alerts within the 0° elevation angle

GEOSAR satellite footprints were detected by the GEOSAR system and valid explanations existed for cases which were not detected;

- there were many GEOSAR alerts, not detected by the LEOSAR System, that were single burst messages or of very short transmission duration which could be indicative of inadvertent activation or testing. However, a short duration transmission could also be the only indication of a catastrophic event; and

- the mean time of beacon transmission durations could be useful in computing 406 MHz system traffic estimates and in determination of system capacity.

The time advantage gained by the GEOSAR system's near-instantaneous alerting was clearly shown to benefit the outcome of SAR events. In particular:

- additional lives and property were determined to have been saved in specific distress cases where a GEOSAR alert was received and used by SAR forces; and

- benefits of the earlier GEOSAR alert and the use of encoded position data were shown in an intercontinental road race, where personal locator beacons, some encoded with one of the new Location Protocols, were used as emergency equipment.

The completeness, accuracy, availability and 24-hour access capability of beacon registration databases were shown to be essential for the above benefits of GEOSAR system to be fully realised. The database information was used to:

- distinguish between real and false alerts and could be useful in preventing the launch of resources on false alerts; and

- obtain rough location information, enabling SAR personnel to take advantage of the earlier notification provided by GEOSAR, even when encoded position information was not available in the beacon message.

Analysis of the impact of the GEOSAR system on the Ground Segment of the Cospas-Sarsat System, notably the system-generated false alert rate, workload, and resolution of LEOSAR location ambiguity, indicated that:

- the number of undetected system-generated false alerts was low. All, but three, system-generated false alerts were eliminated through the use of effective screening measures at the MCCs, before transmission to SAR services. However, some concern exists that the system-generated false alert rate could be higher than that found by the D&E and this element needs monitoring. There is also the possibility of a higher frequency of system-generated false alerts as beacons using Location Protocols become more widespread;

- the volume of GEOSAR alert processing varied among the MCCs but was considered to have minimal impact on workload and was justified by the benefits; and

- GEOSAR alert data were effective in resolving LEOSAR location ambiguity, even though manual processes had been used.

Conclusion

The D&E confirmed the complementary nature of the GEOSAR system to the Cospas-Sarsat LEOSAR System. It indicated that incorporation of the GEOSAR system as a complement to the Cospas-Sarsat System would generate significant benefits and would save additional lives and property. It was also concluded that the benefits would increase when beacons with encoded Location Protocols come into widespread use.

The D&E highlighted the requirement that the 406 MHz beacon user community needs to be informed of GEOSAR system performance in respect of the Cospas-Sarsat System. Greater care in the use of 406 MHz beacons will be required as inadvertent activations (even of short-term duration) would probably be detected by the GEOSAR system and could set off an unnecessary chain of events with a corresponding use of SAR resources.

Recommendations

As the D&E confirmed the expected benefits of the GEOSAR satellite system as a complement to the Cospas-Sarsat LEOSAR System, it is recommended that:

1. the Cospas-Sarsat Council consider adopting the GEOSAR satellite system as an enhancement and complement to the Cospas-Sarsat System; and

2. the Cospas-Sarsat Council should initiate all actions necessary for this enhancement including the commissioning, as soon as possible, of the existing experimental GEOLUTs.

In order to ensure the optimal technical and operational performance of the enhanced Cospas-Sarsat System, it is recommended that:

3. the Cospas-Sarsat Secretariat should publish and widely distribute the results of the D&E;

4. all manufacturers, administrations and others who develop educational programs and materials should stress the importance of proper handling, shipping, storage and testing of 406 MHz beacons in view of avoiding false alerts;

5. all administrations should establish and maintain complete, accurate, and up-to-date beacon registration databases that are available for SAR agency access on a 24-hour a day basis;

6. Ground Segment Operators should consider the use of GEOSAR detections to resolve LEOSAR location ambiguity, agree on a standardised procedure for inclusion in document C/S A.001 (DDP), and implement software in the MCCs to automate the agreed procedure; and

7. all administrations should review beacon test policies and procedures and revise them as necessary to reflect the incorporation of GEOSAR alerts in the Cospas-Sarsat System.

Benefits of the Geostationary System in Actual Cases

The saving of additional lives is a critical factor used to assess the benefit of including a geostationary satellite component within the Cospas-Sarsat System. Below are two case reports which clearly highlight this benefit.

Hunters at Hall Beach, Northwest Territories, Canada

On 15 January 1996, two native hunters from Igloolik, set out overland by snowmobile for Repulse Bay with a 406 MHz personal locator beacon (PLB) on loan from the Northwest Territories government. The weather deteriorated the next day, 16 January to a point where their snowmobile froze and they were stranded in a “whiteout”. At approximately 15:00 they activated their beacon. At 15:05, the GOES-8 geostationary satellite relayed the signal and at 15:25, it was processed at the Canadian Mission Control Centre (CMCC). The PLB registry was accessed to identify the owner of the beacon as the Northwest Territories government. Within 10 minutes this information was faxed to the RCMP Operational Communication Centre in Yellowknife, which advised the Igloolik RCMP officer (at 15:55) of the PLB alert in the area. The encoded serial number of the PLB identified it as the one requisitioned by the hunters en route to Repulse Bay. At 16:07 the CMCC provided location co-ordinates, which indicated that the hunters were in the Hall Beach area. The Igloolik SAR Committee transferred SAR responsibility to Hall Beach, and by 21:00, the hunters had been found and rescued.

Fishing Vessel Incident At Sea off the California/Oregon Border, United States

On 1 December 1996, the 40 foot fishing vessel Beach King capsized when hit by a large wave. The vessel was fishing in 20 - 25 foot seas near the California/Oregon border. The crew of three was not able to transmit a mayday call or signal a distress in any way; however, the vessel’s 406 MHz EPIRB activated automatically when the vessel capsized. The transmission from the 406 MHz EPIRB was relayed via the GOES-9 satellite to the USMCC and then on to RCC Seattle. RCC Seattle forwarded the information to the Coast Guard Operations Centres in North Bend, Oregon and Humboldt Bay, California. The Operations Centres issued an Urgent Marine

Information Broadcast while the RCC called the emergency point of contact listed in the beacon registration database. Upon learning that the Beach King was fishing off the Klamath River, the RCC dispatched a rescue helicopter to search the area. The helicopter located the capsized vessel and hoisted two crew members from the cold (11^{o} Celsius) water. The third crew member was never found. The helicopter transported the crew members to a local hospital where one of the crew required intensive care treatment for hypothermia. Post analysis of the case confirmed that the crew members were not wearing survival suits or flotation devices and would have perished had they remained in the water much longer.

The first notification of distress was an unlocated alert from a geostationary satellite, which arrived at the USMCC 47 minutes before a located alert from a low Earth-orbiting satellite. The Coast Guard was able to investigate the alert (i.e., call the point of contact, check the harbour, make radio call-outs, and launch a helicopter) so that rescue forces could proceed to the vicinity of the distress immediately, even without the located alert data. This resulted in saving the lives of two people.

REPORT ON THE DEMONSTRATION AND EVALUATION OF 406 MHz GEOSTATIONARY SEARCH AND RESCUE SYSTEMS

1.0 BACKGROUND

The Cospas-Sarsat Council directed that a Demonstration and Evaluation (D&E) of the 406 MHz geostationary search and rescue (GEOSAR) satellite systems be performed to confirm the benefits of including geostationary satellite and ground segment elements as a complement to the Cospas-Sarsat System, and to establish GEOSAR technical and operational performance characteristics. The overall goals of the D&E were to:

- characterise the technical performance of the GEOSAR components;
- characterise the operational performance of the GEOSAR system;
- evaluate the operational effectiveness of the GEOSAR system and determine the benefits to SAR of a combined Cospas-Sarsat low Earth-orbiting search and rescue (LEOSAR) and GEOSAR system; and
- provide the basis for recommendations to the Cospas-Sarsat Council.

The GEOSAR system is composed of geostationary Earth-orbiting satellites and their associated ground processing facilities, known as GEOSAR local user terminals (GEOLUTs). The system has the capability to detect transmissions from Cospas-Sarsat type approved 406 MHz distress beacons within its field of view or footprint but without location information. Geostationary satellites orbit at altitudes of 36,000 km at approximately 0° latitude relative to the earth and at fixed longitudes appropriate to the requirements of the space provider. Of the several geostationary satellites equipped with 406 MHz repeaters, three (GOES-8 and GOES-9 satellites, provided by the United States and INSAT-2A satellite, provided by India) comprised the GEOSAR system for the D&E. The GEOSAR satellites footprints are centred over the equator and do not reach the geographic poles.

The Cospas-Sarsat LEOSAR System is an international satellite and ground network system designed to assist SAR operations by providing locations of distress beacons operating on 121.5 or 406 MHz. The System is composed of satellites in polar low altitude Earth-orbit (LEO) and local user terminals (LEOLUTs). The current LEOSAR System detects transmissions from 406 MHz beacons and, using the Doppler effect resulting from the movement of the satellite relative to a transmitting distress beacon, calculates the position of the distress beacon.

Because of the geostationary satellites high altitude and relatively fixed position over the Earth, the GEOSAR system offers several advantages to the LEOSAR System. These advantages include near-instantaneous beacon detection and alerting, near-instantaneous beacon locating for beacons capable of calculating and transmitting their location, and continuous monitoring of the 406 MHz frequency band within the satellite footprint.

With the existing constellation of polar orbiting satellites, the time from activation of a beacon to overflight of the beacon's location and detection by a LEOSAR satellite can be in excess of one hour. This "waiting time" is a function of the available satellite constellation, the location of the beacon, and the available LEOLUTs. The "waiting time" for the LEOSAR System is greatest for a beacon at the equator and shortest for a beacon at the poles.

The LEOSAR and GEOSAR systems are, therefore, complementary in respect of their most effective coverage areas and detection capabilities. With the large number of 406 MHz beacons in use which do not have encoded position information as part of the transmitted message, the GEOSAR system provides for near-instantaneous alerting without location data, whereas the LEOSAR system provides location data but with some inherent system delays.

In conjunction with float, or flight plans, and beacon registration information, a GEOSAR distress alert provided shortly after beacon activation (probably earlier than the first LEOSAR alert), may allow search and rescue (SAR) forces to begin mission planning or initiate a search at an earlier time corresponding to the time advantage provided by the GEOSAR system. If there is no encoded navigation position data available in the beacon, LEOSAR location information, when it becomes available, can be provided to SAR forces to focus their search.

In light of the near-instantaneous alerting capability and the distress alerting time advantage provided by a GEOSAR system, there is a potential for considerable benefit to search and rescue operations if the GEOSAR system were to be included as a complement to the Cospas-Sarsat System.

2.0 SCOPE

2.1 D&E Plan

A detailed plan, "Cospas-Sarsat Demonstration and Evaluation Plan for 406 MHz GEOSAR Systems" (C/S R.006") was developed to:

- ensure that the D&E was conducted in a standard manner;
- ensure that results would be collected on an agreed basis; and
- establish the process for translating the results into a set of recommendations to be presented to the Cospas-Sarsat Council for their decision on adding GEOSAR systems as a complement to the Cospas-Sarsat System.

The D&E Plan limited the scope of work to be performed to determining the performance of the 406 MHz GEOSAR equipment and the effectiveness of GEOSAR alert data in SAR operations. The D&E Plan (C/S R.006) should be consulted for additional information on the rationale for the development of the technical and operational objectives, and on the methodology of data collection, analysis, and reporting for those objectives.

The D&E Plan was divided into technical and operational areas of study, with ten technical and eight operational objectives specifically identified. The technical objectives addressed the compatibility of the various GEOSAR components and the determination of the baseline performance characteristics of those components. The operational objectives were structured to:

- assess the performance of individual GEOSAR systems in supporting actual SAR operations;
- assess the effectiveness of GEOSAR system data and of GEOSAR alerts, as used by the SAR services in each participating country;
- evaluate the procedures used by the Ground Segment Operators for the distribution and use of GEOSAR alerts; and
- evaluate the potential impact of the implementation of the GEOSAR system on the Ground Segment of the Cospas-Sarsat System.

Table 2.1 provides the complete timeline and milestone dates for the various activities of the D&E, including the development of the technical and operational documents which would be required to support the inclusion of the GEOSAR system as a component of the Cospas-Sarsat System. The time period covered for the data collection and evaluation of technical and operational objectives is detailed in Table 2.1, and in the results of the individual objectives contained in this Report, as required. In general, data collection for the D&E took place from July 1996 to February 1998.

Table 2.1: GEOSAR Milestones

as of: 18 June 97

MILESTONES	1996							1997												1998									
	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O
01 - GEOSAR Experts Meeting	▲																												
02 - JC-10 Review Work Plan	▲																												
03 - JC-10 Finalise Changes to C/S R.006	▲																												
04 - Perform Initial D&E (O)					━	━	━																						
05 - Submit Report of D&E (OT)									▲																				
06 - Task Group on D&E Matters										▲																			
07 - Perform Final D&E (O)											━	━	━	━	━	━													
08 - JC-11 Review D&E Matters													▲																
09 - Perform D&E (T)		━	━	━	━	━	━	━	━	━	━	━	━	━	━	━													
10 - Modify System Description (C/S G.003)		━	━	━	━	━	━	━	━	━	━	━	━	━	━	━	━	━	━										
11 - Develop Technical Documents								━	━	━	━	━	━	━	━	━	━	━	━	━	━								
Space Segment (C/S T.011)																													
GEOLUT Specification (C/S T.009)																													
GEOLUT Commissioning (C/S T.010)																													
12 - Modify Operational Documents		━	━	━	━	━	━	━	━	━	━	━																	
C/S A.001 (DDP)																													
C/S A.002 (SID)																													
13 - Participants Submit Data for Final Report (OT)														▲				▲											
14 - Consolidate National D&E Reports																			━										
15 - Task Group Prepare Final D&E Report																						▲							
16 - JC-12 Review and Agree Final D&E Report																									▲				
17 - Submit Final D&E Report to Council																													▲
18 - GEOSAR Systems Operational																													▲

Notes: O - Operational Objectives
T - Technical Objectives
OT- Both

2.2 D&E Participants

During the 406 MHz GEOSAR D&E, GEOSAR alert data from the experimental GEOLUTs was distributed within the existing Cospas-Sarsat Ground Segment as if it were operational data. Therefore, the D&E was open to participation and input from all Cospas-Sarsat Participants. Technical objectives were designed to be completed by the operators of the experimental GEOLUTs in operation during the D&E, with the operational objectives to be completed by any MCC Operator receiving GEOSAR alert data. Australia, Canada, France, India, Spain, the United Kingdom and the United States provided data covering the results of the D&E efforts in their respective countries. Canada, France, India, the United Kingdom and the United States, submitted data supporting specific technical objectives, and all the participants, noted above, submitted data in support of the operational objectives. Several other Participants, including Algeria, Chile, Japan and Russia supplied data for analysis and contributed to the development and drafting of this Report.

2.3 Report Organization

This 406 MHz GEOSAR D&E Report is provided in two volumes. Volume I documents the results of the D&E, draws conclusions and makes recommendations. The data in Volume I is presented in summary format, except where national differences were significant and required further explanation or discussion. Volume II provides the individual technical test results, tables containing the detailed operational objective results, the national reports from D&E participants noted above, and other reports assessed during the D&E. Because of the physical amount of information contained in Volume II, this volume is published separately from Volume I, and is archived by the Cospas-Sarsat Secretariat for use and access as required.

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3.0 LEOSAR AND GEOSAR DEMONSTRATION AND EVALUATION CONFIGURATION

3.1 Status/Description of Ground Segment

The ground segment equipment in place for at least some portion of the D&E consisted of:

- experimental GEOLUTs located in Canada, Chile, India, Spain, and the United Kingdom; and
- the existing operational Cospas-Sarsat Ground Segment equipment, which at the end of the D&E data collection period included 39 LEOLUTs and 22 MCCs.

It should be noted that not all LEOLUTs had the capability to process 406 MHz SARR (search and rescue repeater) data from the Sarsat spacecraft (see Table 3.1). In some cases this may have impacted on data collection as beacon transmissions may have been detected by overflying LEOSAR satellites with only SARR capability, but not processed because there were no LEOLUTs with mutual visibility with the capability to process the SARR channel (see section 3.2.1 below).

3.2 Status/Description of Space Segment

3.2.1 Cospas-Sarsat 406 MHz (LEOSAR) Space Segment

The Cospas-Sarsat LEOSAR satellite constellation during the D&E period is summarised in Table 3.1. The 406 MHz instrumentation onboard the LEOSAR satellites consists of a search and rescue processor (SARP) and a search and rescue repeater (SARR). The SARP provides "processed" data consisting of beacon identification, received power level and frequency and time measurements for use in location calculation by the LEOLUTs. The SARP operates in both local and global modes so that complete world coverage is attained. The SARR, as a repeater, is effective only in local mode when mutual visibility exists between a satellite, beacon, and LEOLUT. With the SARR, beacon identification and frequency and time measurements are accomplished in the LEOLUT using a process commonly referred to as ground-SARP (G-SARP). Not all LEOLUTs had the capability to perform G-SARP processing.

Table 3.1: LEOSAR Satellite Configuration and Operational 406 MHz SAR Equipment

Satellite	**406 Local Mode**	**406 Global Mode**
COSPAS-4*	SAR Processor (SARP)	SAR Processor
COSPAS-6	SAR Processor	SAR Processor
SARSAT-2	SAR Repeater (SARR)	Not Operational
SARSAT-3	SAR Repeater	Not Operational
SARSAT-4	SAR Processor	SAR Processor
SARSAT-6	SAR Repeater	Not Operational

* limited operation in southern hemisphere

It should be noted that six LEOSAR satellites with 406 MHz capability were in orbit during the D&E, two more than the nominal complement of four that the Cospas-Sarsat Space Segment Providers have agreed to operate. The additional satellites had the effect of decreasing the time it would take for the LEOSAR System satellites to come within sight of randomly positioned beacons, and thus may have lowered the potential time advantage that a GEOSAR system would have compared to the nominal Cospas-Sarsat System. A separate document which calculates a theoretical potential time advantage that GEOSAR alerts have in respect to a nominal four satellite LEOSAR constellation is provided in Volume II.

3.2.2 406 MHz GEOSAR Space Segment

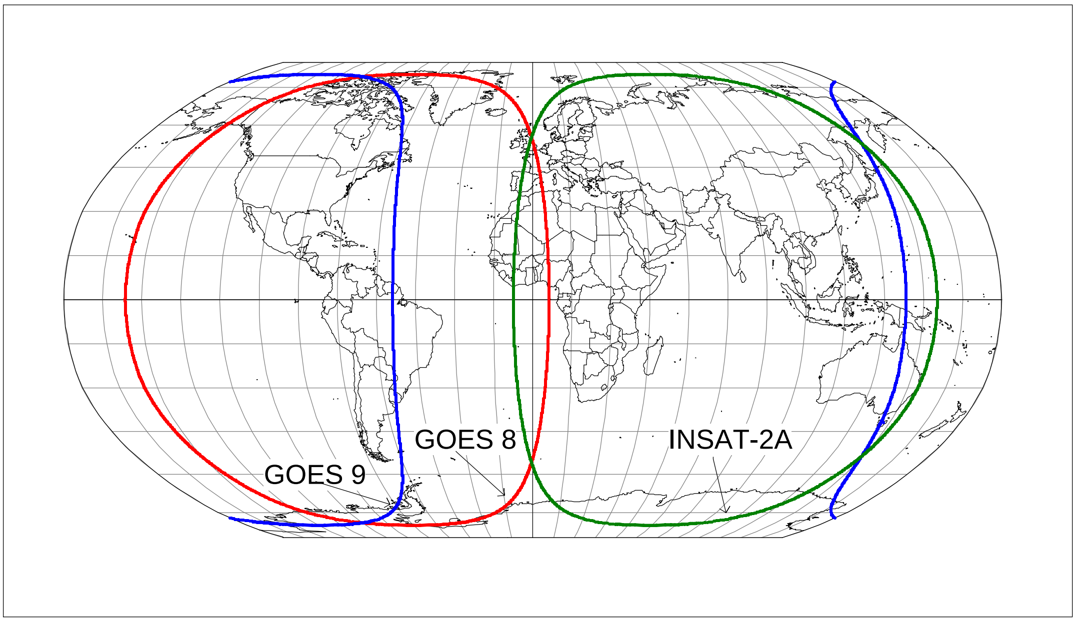
The GEOSAR satellite constellation and GEOLUTs available during the D&E are reflected in Table 3.2.

Table 3.2: GEOSAR Satellites and Associated GEOLUTs

Satellite	**GEOLUT**				
	Canada	**Chile**	**India**	**Spain**	**United Kingdom**
GOES-8	Yes	Yes	No	Yes	Yes
GOES-9	Yes	No	No	No	No
INSAT-2A	No	No	Yes	No	No

The theoretical footprint (coverage area) of the geostationary satellites is shown in Figure 3.1.

Figure 3.1: GEOSAR Satellite System Coverage during the D&E



The coverage diagram shown in Figure 3.1 indicates that the zero degree footprint of a GEOSAR satellite covers about 140 degrees, 70 North to 70 South and an equivalent distance East and West of the satellite sub-point (the position on earth directly under the satellite). Although the positions of the satellites were not optimised for international SAR support and therefore the satellites were not spaced equidistant around the equator, the combined coverage of GOES-8, GOES-9 and INSAT-2A provided global GEOSAR coverage to the mid-latitudes during the D&E.

3.3 Use of Beacon Simulators

A number of the technical measurements for the D&E required the use of beacons with adjustable transmission power levels and coding. These stringent requirements were best met by the use of beacon simulators rather than by using many different real beacons. To support the testing, the National Aeronautics and Space Administration (NASA), located at Goddard Space Flight Centre in Maryland, United States, and Centre National des Etudes Spatiale (CNES), located in Toulouse, France provided computer controlled beacon simulators. The simulators were capable of generating signals simulating multiple beacons transmitting simultaneously. Using these simulators, beacon identification coding, frequency and power level could all be precisely varied and controlled, burst to burst.

Canada and the United States combined to produce detailed joint technical measurements, with the United States beacon simulator providing the uplink signals, and Canada providing reception, processing and documentation of the down-link results. France provided the uplink signals for some of the technical measurements undertaken by India. Detailed information on the use of the NASA beacon simulator is contained in the joint document “Canada-United States Mission Support Plan for Technical Objectives” which is provided in Volume II.

Data was collected for the completion of the operational objectives by using existing operational beacon transmissions or by using special “test” coded type approved beacons in known conditions.

3.4 Data Distribution Procedures Used during Demonstration and Evaluation

406 MHz GEOSAR alert messages were distributed in accordance with the “Cospas-Sarsat Data Distribution Plan” (C/S A.001) following the procedures provided for the distribution of 406 MHz unlocated alerts. That is, GEOSAR alerts during the D&E were distributed based on the country code contained in the beacon identification of the beacon message since the actual position of the beacon was not known from the use of GEOSAR data alone. It should be noted that there were no operational type-approved beacons with encoded position data in use during the D&E period, and that in the future, GEOSAR alerts (and LEOSAR “unlocated” alerts) containing encoded position information will be distributed to the relevant RCC based on the encoded position.

Data distribution procedures were slightly modified during the D&E so that GEOSAR alerts were transmitted without the normal redundancy checking by MCCs to ensure that GEOSAR alerts coming from different GEOLUTs could be collected for analysis. Additionally, the GEOSAR D&E participants agreed to exchange narrative messages on any change in the status of GEOSAR system components that might affect the results of the D&E objective measurements so that this could be taken into account during the analysis.

No other special data distribution procedures were in use during the D&E period.

4.0 TECHNICAL OBJECTIVES RESULTS AND DISCUSSION

The technical objectives were developed to assess the technical compatibility of the various GEOSAR components and to establish the baseline performance characteristics of the GEOSAR system. Most of the technical tests required a beacon simulator or at least one special test beacon whose power output and message content could be controlled and varied. These tests were conducted over several weeks to collect statistically valid data. Some tests, however, were performed for shorter durations using regular commercial beacons (coded with a test protocol) operated under controlled conditions, in order to assess GEOSAR system performance with typical operational beacons.

The results of some tests could be used as the basis of future GEOSAR technical specifications and commissioning standards, as they determined a minimum level of acceptable performance for future GEOLUTs and GEOSAR repeaters.

There were ten technical objectives to be achieved during the D&E. Summary results and discussion are provided here for each. The detailed technical reports are contained in Volume II of this report. Five of the technical tests could not be completed due to radio frequency interference emanating from Peru[1] which impacted the GOES-8 and GOES-9 satellites; these tests, T-4 Beacon Processing Capacity, T-5 Impact of Interference, T-7 Impact of Updating Encoded Position Data, T-8 System-generated False Alerts, and T-9 Impact of System Beacons, are identified in Section 6.3 for completion after the conclusion of the D&E. It was noted that despite the fact that the interferer rendered test data unreliable for completing these technical objectives, the GEOSAR system was still able to detect beacons and provide useful operational SAR data during the interference. India's INSAT-2A was not affected, however, India was not involved in two of the five tests, T-7 and T-9.

4.1 Processing Threshold and System Margin (T-1)

The processing threshold is the minimum value of the ratio of beacon carrier power to noise density (C/No) received at the GEOLUT that results in a 99% probability of detection of an error free message (PDEFM) at the GEOLUT. The system margin is the difference between the effective isotropic radiated power (EIRP) of the beacon at threshold C/No and the EIRP of a nominal beacon, which is 37 dBm. The reason for this test is to confirm the expectation that nominal Cospas-Sarsat beacons have sufficient power, and that GEOSAR system has sufficient sensitivity, that beacon messages can be detected and processed with a high degree of probability, despite the fact that GEOSAR satellites orbit at a much higher altitude than LEOSAR satellites.

The test was carried out using the beacon simulator from NASA Goddard or CNES Toulouse, both of which could simulate multiple beacons at controlled frequencies, codes, and power

[1] A strong interferer, emanating from the telephone company in Juliaca, Peru, consisting of five constant components spaced approximately 1600 Hz apart within the band of 406.022 to 406.025 MHz was present during a test run in April 1997.

levels. The beacon signals were based on a scenario of 20 unique beacon codes grouped into 5 time blocks of 4 beacon codes each. Each beacon code was sent 20 times. In order to ensure that beacon code messages were not confused in the GEOLUTs, transmissions of the 4 beacon codes within each time block were off-set in frequency from one another by 1000 Hz; they were further distinguished by being off-set an additional 100 Hz from the messages in the previous time block. This construction of the signal scenario provided 3 means of identifying each message block: time of transmission, identification code, and frequency. In order to generate enough message bursts to provide a measure of statistical precision, the scenarios were run 3 times at each power level.

Values of C/No were provided directly by the GEOLUTs, which also logged the times and number of error free messages received. This provided a clear means to compute the value of C/No which corresponded to the reception, without errors, of 99% of the messages sent. This value was the processing threshold at 99% PDEFM. The system margin was the difference between the nominal Cospas-Sarsat beacon power of 5 Watts, and the recorded or calculated value of the transmitter power of the beacon simulator which produced the C/No at the processing threshold.

The only full technical submission received for this objective was provided in the joint Canada-United States technical submission, however, France and India provided summary data. The results, shown in Table 4.1, came from three different GEOLUT designs (Canada, France and India), working with two different GEOSAR satellites (GOES-8 and INSAT-2A). The table also includes the data from the Message Transfer Time (MTT) test, T-2, which is explained in Section 4.2.

Table 4.1: Processing Threshold, System Margin and Message Transfer Times at 99% PDEFM

GEOLUT	Satellite	Processing Threshold dBHz	System Margin dB	MTT 50 Sec	MTT 90 Sec
Canada	GOES-8	26	12	50	350
France	GOES-8	28	6	240	780
India *	INSAT-2A	27.7	7	nil report	618

*Results were obtained using a modified but equivalent test procedure than that detailed in C/S R.006. Specific details are available in Volume II.

Table 4.2 provides the processing threshold, system margin, and message transfer times for a 95% PDEFM which correspond to the GEOLUT specifications.

Table 4.2: Processing Threshold, System Margin, and Message Transfer Times at 95% PDEFM

GEOLUT	Satellite	Processing Threshold dBHz	System Margin Db	MTT 50 Sec	MTT 90 Sec
Canada	GOES-8	25	13	50	350

4.2 Message Transfer Time (T-2)

The message transfer time is the time between the activation of a beacon with a power output at the GEOLUT's processing threshold and the time the GEOLUT produces the first error free message.

The reason for this test is to confirm the expectation that beacon message transmissions could be quickly processed by the GEOSAR system. While it is clear that the GEOSAR satellite would relay data on the beacon transmission immediately, relatively weak signals may need to be integrated a number of times in the GEOLUTs before an error free message is produced.

The test set-up for this objective is identical for that of Section 4.1, and the data was collected at the same time. MTT-50 is the time taken to produce error free messages from 50% of the beacon transmissions, and MTT-90 is the time taken for 90%.

The transfer times were found to be between 0.833 and 4.0 minutes (50th percentile) MTT-50 and 5.83 to 13.0 minutes (90th percentile) MTT-90 (Table 4.1). Variations were probably due to processing differences between GEOLUTs, but might have been influenced by the downlink margins. Table 4.2 provides the message transfer times for the 95% PDEFM.

These values confirmed the GEOSAR system capability for a very short alerting time from beacon activation to receipt of the alert message from the GEOLUT.

4.3 Carrier Frequency Measurement Accuracy (T-3)

The objective of this test is to measure the accuracy with which the GEOSAR system measures the frequency of a beacon transmission carrier frequency. The purpose of the test is to evaluate the accuracy of the GEOLUT's measurement of the RF carrier frequency transmitted by 406 MHz emergency distress beacons. This measurement is of interest as it may be used to improve the accuracy of the Doppler position estimates produced by the LEOSAR System for beacon signals which are detected simultaneously by both systems. The accuracy is expressed as the difference between the measured frequency and the actual frequency of the beacon transmission. See Section 4.10.

The test set-up for this objective was identical for that used in Section 4.1 except that the transmitted power of the simulated beacon was held constant at the nominal value of 5 Watts (37 dBm). During the test scenario the beacon frequency was adjusted in 100 and 1000 Hz steps over a total of 240 message blocks each containing 20 message bursts. The GEOLUT recorded the beacon identification code and frequency measured for each error free message received.

Using the GOES-8 satellite and the CMCC GEOLUT, the frequency measurement of the test beacon operating at 406.025 MHz with an output power of 37 dBm was found to be an average of 407.6 Hz higher than the actual frequency being transmitted. The short-term standard deviation of this measurement over a six-hour period was 4.4 Hz. This offset from the actual frequency was found to remain constant when the transmitted frequency was varied over a range of +/- 3400 Hz centred on 406.025 MHz. Temperature sensitive components within the satellite repeater caused a 24 hour period cyclic variation of approximately 50 Hz. The balance of the measurement offset was due to frequency shifts caused by the GEOSAR satellite and the GEOLUT frequency down conversion process.

It was noted that the French experimental GEOLUT was able to measure frequencies to an accuracy better than +/- 0.5 Hz.

The Canadian GEOLUT is capable of measuring the beacon frequency with a resolution of 4 Hz; this is sufficient to improve LEOSAR Doppler beacon position estimates, provided a reference beacon of known frequency is also transmitting within the LEOSAR satellite visibility area to calibrate the GEOSAR frequency offset and drift.

Due to constraints in time and personnel resources, this test was only conducted for a nominal beacon transmitting at 5 Watts. Since it is possible that the GEOLUT’s frequency measurement may deteriorate for lower beacon power signals, it is recommended that further testing be carried out at lower beacon power levels.

4.4 Beacon Processing Capacity (T-4)

The objective of this test is to determine the number of simultaneous beacons a GEOSAR system can process before its PDEFM and MTT performance degrade. The purpose of the test is to gain assurance that the GEOSAR system performance will not significantly deteriorate when a large number of beacons are transmitting simultaneously within its admittedly large footprint. It is assumed that the limiting effects will be noticeable in the GEOLUTs before the GEOSAR satellites, because of the requirement for the GEOLUTs to process received data whereas the GEOSAR satellites only have to relay the data.

The methodology for the test was to use the NASA beacon simulator to add increasing numbers of beacons to the scenario whilst maintaining sufficient numbers of beacon bursts to be able to determine values of PDEFM and MTT for GOES-8 and GOES-9. The CNES beacon simulator would provide similar support to India’s INSAT-2A. Conclusions were to be drawn by the number of beacons at nominal power required to reduce the PDEFM from

100% to 99%, and to note the effect on MTT. The exact criteria to determine Beacon Processing Capacity" was not specified for degradation in MTT.

The appearance of an interfering signal from Peru (see T-5) made it impractical to attempt this test for the GOES satellites. This test should be rescheduled as soon as possible and the results reported to the Joint Committee.

In November 1997, India, with support from CNES France, performed a modified beacon processing capacity test using the CNES beacon simulator, INSAT-2A and the Indian GEOLUT. The nature of the test was different from that described above and in document C/S R.006. It consisted primarily of determining how many of 15 simulated beacons could be detected within a 10 minute period. This was carried out using 6000 Hz and 7000 Hz GEOLUT bandwidths and beacon frequency separation of 200 to 500 Hz. Beacon bursts were programmed for a 50 second repetition period. No simultaneous bursts were programmed. The results of the test are summarised in Table 4.3.

Table 4.3: Beacon Processing Capacity Test Results INSAT-2A

	Beacon Separation Hz	GEOLUT Band Width Hz	Simulated Beacons Radiated	Simulated Beacons Detected	Other Beacons Detected	Total Beacons Detected	Detected Within 10 Minutes
1	500	6,000	10	9	5	14	13
2	500	6,000	10	9	3	12	12
3	500	6,000	10	10	4	14	12
4	500	7,000	15	12	0	12	12
4	500	7,000	15	12	1	13	5
5	200	7,000	15	14	2	16	14
6	200	7,000	15	14	2	16	15
7	200	7,000	15	10	0	10	10
8	200	7,000	15	14	3	17	13
9	200	7,000	15	15	3	18	12

During the testing period, a number of actual test beacons with country codes from China and Russia were detected, together with four operational beacons, one, detected twice, with country code of the Bahamas, two with country code Panama, and one with country code Malaysia.

The tests indicated that the INSAT-2A GEOSAR system could detect 88% of the simulated beacons when 10 and 15 beacons were transmitting simultaneously.

Since the INSAT-2A test results could not be used to determine the degree of degradation of PDEFM and message transfer times which is expected to occur as the number of simultaneous beacons increased beyond the system design capacity, it is recommended that the T-4 capacity test detailed in C/S R.006 should be carried out as soon as practical. If the capacity is not considered adequate for the expected levels of beacon activity, decisions on a more efficient use of the frequency band may be required.

4.5 Impact of Interference (T-5)

The purpose of this test is to evaluate the ability of the GEOLUT to provide valid alert messages and to suppress invalid messages in the presence of various types and strengths of interference and noise in the 406 MHz frequency band. The results of the evaluation could be used to make recommendations concerning modifications to the GEOLUT systems in order to increase their ability to tolerate interference without unnecessarily degrading their ability to recover valid 406 MHz beacon messages.

This objective considers anomalies that could be caused by radio frequency (RF) interference generated external to the system and indicates the GEOSAR system's ability to provide timely and accurate messages in the presence of noise and interference in the 406 MHz band.

The test procedure is to uplink a known standard 406 MHz beacon signal plus various types of controlled interference to the GEOSAR satellites and to then monitor the effects of the interference on the GEOLUT's ability to correctly recover and process the standard beacon signal.

As part of the requirements for this test, Canada installed baseband monitoring equipment at the two Canadian GEOLUTs. This equipment was to be used to monitor the baseband while the beacon and controlled interference signals were uplinked from the NASA beacon simulator. During the test, the GEOLUT's output was to be monitored for lost, corrupted, and false beacon messages during the specific periods of controlled interference. This analysis was to be carried out with various types of interfering signals, and the resulting data would provide an indication of the GEOLUT's susceptibility to these forms of interference under operational conditions.

However, due to the presence of strong uncontrolled interference, it was not possible to perform the controlled interference portion of the test. A strong interferer, emanating from the telephone company in Juliaca, Peru, consisting of five constant components spaced approximately 1600 Hz apart within the band of 406.022 to 406.025 MHz was present in both the GOES-8 and GOES-9 basebands during a test run in April 1997. After some time, the location of the source of this interference was determined by the LEOSAR System and confirmed in subsequent investigation by Peruvian national authorities. It is recommended that objective T-5 be completed according to the procedures described in C/S R.006 as soon as practical.

Since it was not possible to find a period which was free of interference, a modified test was performed on 28 April 1997 in the presence of the interfering signal. The test was a modification of the Processing Threshold test using a similar test procedure to that described in Section 4.1. The data obtained were compared to the similar data set obtained during the autumn of 1996, before the interferer was radiating. Only about 20% of the beacon bursts above threshold were recovered in the presence of the interfering signal as compared to about 90% without the interfering signal. This significantly reduced the message throughput which could have resulted in a loss of alert data, an increase in the message transfer time, and 406 MHz beacon bit errors.

4.6 GEOSAR Satellite Coverage (T-6)

The objective of this test is to confirm the GEOSAR satellite footprints, within which detection of nominal Cospas-Sarsat beacons is expected. The purpose of the test is to confirm that operational beacons are visible and detectable everywhere within the footprint subject to clearance from obstructions.

Although the footprints can be calculated theoretically from technical considerations, tests of operational beacons were used to confirm coverage. Beacons were carried by a number of expeditions by sea, air and land to locations suitable for testing coverage. Tests for beacon detections near the sub-orbital point of the geostationary satellites were to determine if high beacon-to-satellite elevation angles adversely affected detection, and tests near the edge of the coverage tested detections where the elevation angle tended toward zero degrees. Australia, Canada, India, the United Kingdom and the United States supported France.

There were eleven expeditions: three led by Australia, two lead by the United Kingdom, three by the United States, and three by France. Table 4.4 summarises the expeditions, the lead country, the satellites, GEOLUTs, test locations, dates, and maximum or minimum elevation achieved. Figure 4.1 shows the GEOSAR zero degree elevation angle footprints of the satellites and the expedition areas. The angles measured were based on geometric line-of-sight and did not take atmospheric refraction into account.

Table 4.4 Summary of T6 Coverage Tests

	Expedition Name	Lead Country	Satellites	GEOLUTs	Test Locations	Test Date	Elevation/Satellite	
							Min	Max
1	North Sea	United Kingdom	GOES-8	United Kingdom	North Sea	26/03/96 29/03/97	- 0.9*	0.7
2	Malcolm Baldridge	United States	GOES-8. GOES-9	Canadian Canadian	Panama	04/05/96 06/05/96	69.0 No data	80.0
3	Miller Freeman	United States	GOES-8 GOES-9	Canadian	Alaska Gulf	15/07/96 19/07/96	-0.1 * 21.4	2.8 30.7
4	North Sea Return	United Kingdom	GOES-8	United Kingdom	North Sea	15/11/96 17/11/96	- 0.4*	1.7
5	Ile de France	France	GOES-8	Canadian	France	20/01/97 23/01/97	-0.7 0.4 *	3.0 3.0
6	North Canada	United States	GOES-8 GOES-9	Canadian	Canada Polar circle	06/06/97 18/09/97	1.1* 3.0	5.7 13.2
7	Msc Lauren	Australia	GOES-9 INSAT-2A	Canadian Indian	Australia	02/10/97 12/10/97	-0.9 * 1.88	4.8 32.4
8	Turakina	Australia	INSAT-2A	Indian	Australia New Zealand	23/10/97 27/10/97	- 0.6*	1.9
9	Turakina return	Australia	INSAT-2A GOES-9	Indian Canadian	New Zealand Australia	03/11/97 05/11/97	- 0.9 * No data	33.0
10	Brittany	France	INSAT-2A GOES-8	Canadian	France	28/11/97 03/12/97	-0.3* 1.4	4.9 3.5
11	Guyana	France	GOES-8	French	Guyana	May 96		63

(*) Last received burst elevation angle

Figure 4.1: Map of Expedition Routes

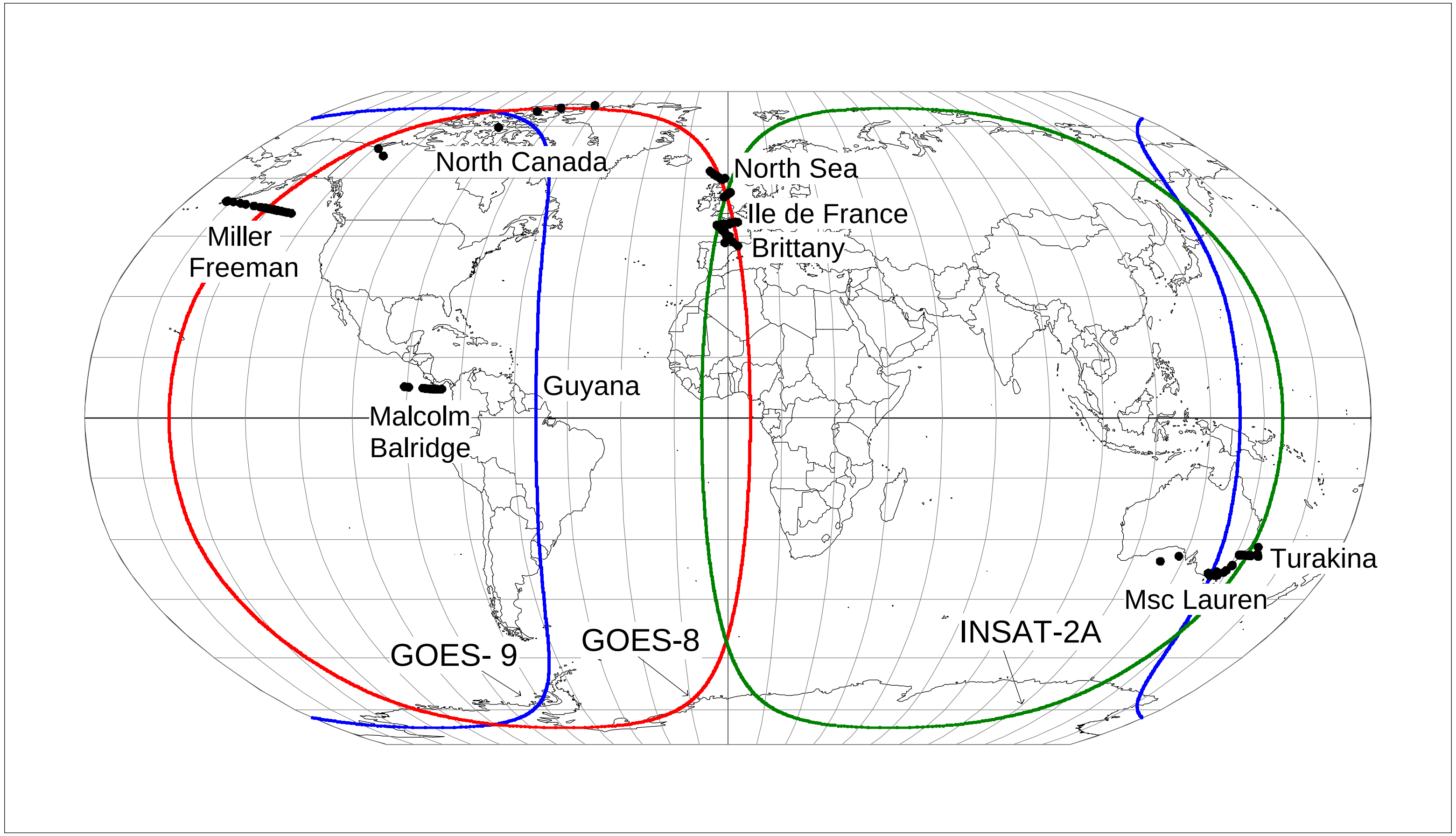
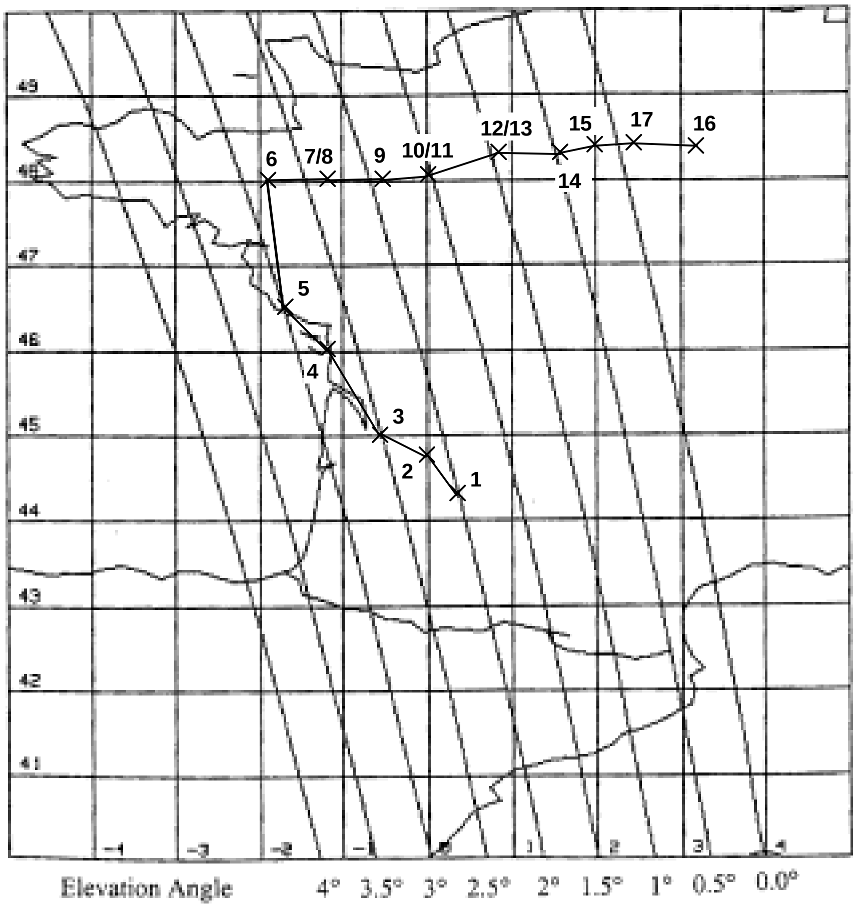


Figure 4.2 displays the elevation angles and transmission locations for the Ile de France expedition.

Figure 4.2: Ile de France Expedition Routes, Coverage and Elevation Angles to Satellite GOES-8



The probability of detection of beacons near the sub-orbital points, measured by the Malcolm Baldridge expedition, appeared to be unaffected by the low beacon antenna gain in the vertical direction even at elevation angles approaching 80 degrees. This probably occurred because of reflections from the metallic surfaces of super structure of the ship which were directed towards the satellite, and possibly because of the limited rolling and pitching motion of the ship which would move the antenna null away from the vertical. This finding is significant for ships at sea near the sub-orbital points of GEOSAR satellites.

On the land side, the French expedition to Guyana[2] achieved successful detections, with vertical beacon antennas, to elevation angles of 63 degrees. The signal power received at the satellite was improved by 9 dB if the beacon antenna was tilted from the vertical and was

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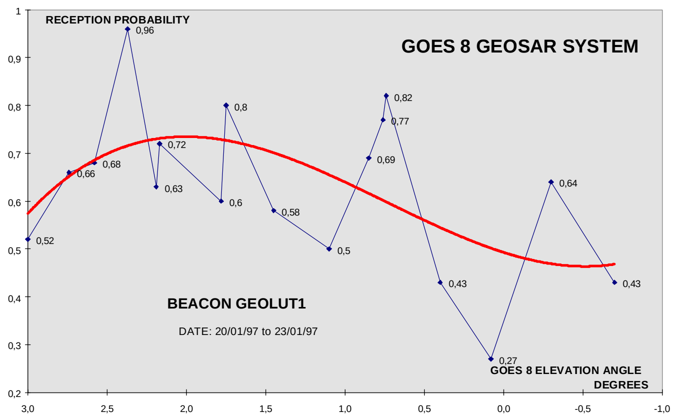
2 Some Experimentation with the New Location Protocols by P. Pressecq/B. Roger-CEIS TM France and H. Castetbert/L. Fourcade – CNES, France. Proceedings of the 1996 Cospas-Sarsat Seminar, Workshop No. 3- Presentation No. 6

further enhanced by 6 to 7 dB if the antenna was laid flat on the ground (parallel to the earth's surface).

Coverage close to the edge of the footprint degraded slowly as the zero degree elevation angle contour was approached. A significant drop in received signal strength was observed between two and one degrees of elevation, primarily caused by multi-path effects. Multi-path is the term used to describe effects of the same signal arriving at a receiver via two (or more) paths of different lengths. Depending on the difference of the path lengths of the signals, they will be increased or decreased in strength. If the signal components arrive in-phase they will build, if they arrive out-of-phase they will tend to cancel one another, and thereby reduce the power of the received signal. The Ile de France expedition showed that over land, generally the probability of detection (PD) remained at or above 0.5 above 1 degree elevation, with some beacons detected at elevation angles as low as - 0.5° to - 0.7° (Figure 4.3).

Figure 4.3: Reception Probability and GOES-8 Elevation Angle (Ile de France expedition)



At sea, the Turakina voyages between Sydney and Auckland, showed that a 406 MHz EPIRB could be detected at the edge of the Insat-2A coverage down to -0.6° elevation during the out-going voyage and -0.9° on the return voyage. Similar results were obtained with GOES-8 in the North sea and in the gulf of Alaska (see Table 4.4).

It was found that detection at low elevation angles was complicated by a number of factors, the most important of which were sensitivity to obstructions and multi-path effects. For these reasons, and the slight movement of the GEOSAR satellites, it was difficult to predict with assurance a minimum elevation angle, and hence footprint, within which beacon detection would be reasonably assured.

Not withstanding the foregoing, the test results from a beacon in northern Canada in representative terrain (hilly to 2000 feet MSL) produced a minimum reception elevation angle of 3.0 degrees. This result coupled with the uncertainty of position of the satellite (+/- 0.5 degree), suggested that 4° was a conservative number to adopt as the minimum elevation angle required to assure reliable GEOSAR reception of 406 MHz beacons. This value was agreed at TG-2/98.

4.7 Impact of Updating Encoded Position Data (T-7)

This objective determines the effects on GEOLUT processing of changing encoded position data, in both the protected data fields PDF-1 and PDF-2 of the 406 MHz beacon messages.

Since future beacons will be able to periodically change their message content, this test assesses the impact that changing position data encoded in a beacon has on the PDEFM and MTT of the GEOLUT. The reason for the test is to quantify adverse affects the changing coding might have with regard to false alerts generated, lost messages, PDEFM and MTT changes. The results could have an impact on minimum time interval between position updates specified in the Cospas-Sarsat beacon specifications, which currently is not less than every 20 minutes.

The test was to be a modified Processing Threshold and Message Transfer Time measurement activity in which the position data in the code is changed in each successive simulated beacon message. The scenario was to be repeated ten times for each power level and the resulting changes to PDEFM and MTTs noted.

France carried out a modified test in Guyana[2] using a GPS encoded beacon which changed its encoded position in real time. Messages were stored in the GEOLUT, and were retrieved for analysis. It was found that the positions transmitted to the GEOLUT were generally accurate down to transmitted power levels of 33 dBm, but below that power level, uncorrectable bit errors occurred. It was also determined that the second protected field (PDF-2) was more prone to bit errors than the first protected field (PDF-1).

Except for France, this test was not completed because of the interferer located in Peru (Section 4.5). The test will be scheduled for completion as soon as possible and the results reported following the D&E.

4.8 System-generated False Alerts (T-8)

This test assesses the number and causes of system-generated false alerts, including any possibly produced by the beacon self-test signal, which has the inverted frame synchronisation bit pattern. The reason for the test is to determine the generation rate of false alerts caused by system processing overall. Particular emphasis is to be placed on the potentially large number of beacon self-tests which would be detected by the GEOSAR system, and which would be reported as 406 MHz alerts if the inverted frame synchronisation pattern became shifted or distorted. A high system-generated false alert rate would seriously degrade confidence in the system.

This test was not completed due to the Peruvian interferer, but system-generated false alerts were observed as part of operational test (Section 5.5).

New beacon processing requirements have been included in the GEOLUT specification that should further reduce the number of system-generated false alerts, and should provide the capacity to deal with bit errors. It is recommended that this test be completed as soon as possible and the results reported to the Joint Committee.

4.9 Impact of System Beacons (T-9)

This objective assesses the impact of 406 MHz orbitography and reference beacons on the available GEOSAR capacity and the message transfer time of the GEOLUT. The purpose of the test is to determine the operational cost to the GEOSAR system of this essential component of the LEOSAR System. If the test indicates that the presence of these beacons significantly reduces the operational capacity of the GEOSAR system, these beacons might be geographically relocated outside the GEOSAR coverage, reduced in number, or assigned a different frequency in the 406 MHz band.

This test was not completed due to the Peruvian interference problem (Section 4.5). The test will be scheduled for completion as soon as possible and the results reported to the Joint Committee.

4.10 Combined Operations (T-10)

The test objective is to characterise the capability of the GEOSAR system and the LEOSAR System working together, to process and distribute 406 MHz alerts. The goal of combined processing is to seek improvements in the Doppler derived LEOSAR position estimates by incorporating the actual beacon frequency measured by the GEOSAR system into the position calculation. The test also dealt with the use of the GEOSAR measured frequency bias in increasing the accuracy of discriminating between the correct Doppler derived position and its image. The test report was compiled by Canada with support from France and the United States.

The test was accomplished through a series of theoretical analyses and by implementation and field testing, in the Canadian CTEC LUT. The two algorithms developed and tested were the centre frequency extraction and frequency difference of arrival (FDOA) algorithms. In the former a single frequency was measured; in the latter, the frequency of each beacon burst was measured and used in the calculations.

In centre frequency extraction testing which covered 61 LEOSAR satellite passes and a reference beacon signal, the location accuracy was improved by 1.8 km for cases of 5 Doppler points or fewer. The improvement decreased as the number of points increased. The algorithm was also used in a 12 case sample to convert two Doppler point detect only solutions to three point locations. The average location accuracy was a 4.3 km with a standard deviation of 3.0 km. The worst case accuracy was 11 km. These results are notable because they imply that acceptable accuracy can be achieved from two point detections when GEOLUT frequency measurement data is used to provide the third point. However, these results should also be interpreted with a measure of caution because of the small sample size used in the test.

The FDOA algorithm aims at obtaining the transmit frequency of each burst from the beacon. The same passes used in the centre frequency extraction testing were used to test the FDOA algorithm. The results showed an average increase in the accuracy of 2.5 km for cases with 5 or fewer Doppler points. There was minimal improvement for cases with greater than 5 points, and a marginal degradation (0.1 to 1.3 km) for cases with more than 12 Doppler points. The result of applying the FDOA algorithm to the two point Doppler detections were three point locations with an average location accuracy of only 20.6 km, much worse than the centre frequency extraction method (mean accuracy of 4.3 km for the same 12 case data set). Two cases had location differences greater than 90 km.

Field testing of the centre frequency extraction algorithm in the Canadian CTEC LEOLUT collected approximately 700 three point Doppler location solutions from the Thule orbitography beacon and 21 solutions for operational beacons with known locations which were "found" from two Doppler points plus the GEOLUT frequency measurement. From the Thule beacon measurements it was found that combined LEOSAR/GEOSAR solutions were almost always more accurate than LEOSAR three point solutions, and in the few cases where a degradation occurred, the increased error was always less that 5 km. Three point LEOSAR only solutions were within 10 km of the true location only 36% of the time, whereas the combined LEOSAR/GEOSAR solutions were within 10 km 85% of the time. It was also found that of about 245 errors greater than 50 km from LEOSAR only three point solutions, that application of LEOSAR/GEOSAR processing reduced the number of greater than 50 km errors to less than 5. Testing using the 21 operational beacons which had two point Doppler detections converted to three point LEOSAR/GEOSAR positions resulted in 3 errors of over 50 km, offset by 9 with errors less than 5 km. The cumulative probability of the error being 10 km or less was 54% and of being 20 km or less was 75%. The results of the above tests confirm the effectiveness of using combined LEOSAR/GEOSAR solutions whenever there are five or fewer Doppler data points.

The potential use of the GEOLUT's frequency measurement to help resolve the LEOSAR's Doppler ambiguity was also studied. The study was complicated by the fact that the GEOSAR frequently measurement accuracy is not currently adequate for this task; as a consequence, orbitography and reference beacons of known frequency had to be used. Another factor was the very high success rate demonstrated by LEOLUT processing, using only Doppler data to distinguish the real position from the image. This success rate was 98.5% without any GEOSAR frequency input. The results indicated that when actual frequency data was combined with LEOLUT solutions having an Doppler ambiguity in the range of 50-60%, the success rate of correctly identifying the correct side was found to be 99.3%, which is approximately 1% higher than the basic success rate of the LEOLUTs alone. However, when applied to LEOSAR three point solutions, the use of actual frequencies was particularly helpful, increasing the success rate of correctly identifying the correct side from 66.3% (LEOSAR only) to 84.3% (combined LEOSAR/GEOSAR).

In summary, analysis showed potentially that combining an actual GEOLUT derived frequency of a 406 MHz beacon signal with the LEOLUT's Doppler processing for that beacon, the resulting location accuracy would be generally improved over that obtained by the LEOLUT's Doppler processing alone. The improvement was most pronounced in cases where there were five or fewer Doppler measurements. The possibility of producing accurate locations for cases of two Doppler measurements plus a GEOLUT frequency measurement was also demonstrated. However, a calibrated beacon source, such as an orbitography or reference beacon was required in both satellites' uplink fields of view, in order to remove time and frequency offsets in GEOLUT data.*

In order to achieve these benefits, the GEOSAR frequency measurement of a 406 MHz beacon frequency must be accurate to +/- 1 Hz.

In general, for LEOSAR/GEOSAR combined processing, the results of the analysis are promising in terms of better location accuracy but the sample size was statistically small. It is therefore recommended that further detailed evaluation be carried out before the procedures for combining LEOSAR and GEOSAR data are formalised by Cospas-Sarsat.

* A subsequent Canadian research paper (see document JC-12/4/25) suggests that a single reference beacon within the footprint of the geostationary satellite is sufficient for the processing of combined LEOSAR/GEOSAR data.

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5.0 OPERATIONAL OBJECTIVES RESULTS AND DISCUSSION

The GEOSAR D&E evaluated the contribution to SAR operations of alert data provided by 406 MHz GEOSAR systems and provided operational experience in the use of GEOSAR alerts. The operational objectives were developed to:

- assess the performance of individual GEOSAR systems in supporting actual SAR operations;
- provide SAR services in each participating country with experience using GEOSAR alert data and assess the effectiveness of GEOSAR alerts;
- provide Cospas-Sarsat Ground Segment Operators experience in the distribution and use of GEOSAR alerts; and
- evaluate the impact of GEOSAR systems on the Cospas-Sarsat 406 MHz System.

Eight specific operational parameters were measured to provide the basis for this evaluation. The detailed definition of the parameters are presented in "Cospas-Sarsat Demonstration and Evaluation Plan for 406 MHz GEOSAR Systems" (C/S R.006).

A 3-month trial was undertaken in 1996 following the procedures in C/S R.006 to evaluate and test the proposed methods of data collection and analysis for the operational objectives. The results were reviewed and modifications made to C/S R.006 for the final data collection period.

The operational data reported here, cover the six month period April to September 1997, with the exception of Objective 8 data, which cover the entire D&E period and the data from the United Kingdom, which cover only the 3 month period, April to June, 1997.

Results and discussion follow for each objective.

5.1 Potential Time Advantage (O-1)

The Potential Time Advantage (PTA) measures the time advantage of GEOSAR alert notification over the first available LEOSAR alert notification. The PTA is determined by measuring the elapsed time between the receipt at a MCC of the first GEOSAR alert notification and the first LEOSAR alert notification for the same beacon. The data collected was limited to beacons activated within a MCC's service area and beacons coded with a country code of a country within the MCC's service area. MCCs received GEOSAR alerts based on the country code of the beacon and LEOSAR alerts based on the Doppler position or the country code.

A total of 1,926 cases were reported by Australia, Canada, France, India, Spain, the United Kingdom and the United States. In 286, or 15% of the cases, the LEOSAR alert arrived before the GEOSAR alert. These cases were not analysed further and were not considered in the results. Additional analysis could be performed to determine why LEOSAR alerts are received at a MCC prior to GEOSAR alerts for the same beacon.

The remaining 1,640 cases were evaluated to determine the mean and median time advantage of the GEOSAR alert. Table 5.1 summarises the time advantage by GEOSAR satellite and by Country of MCC.

Table 5.1: Time Advantage by GEOSAR Satellite and Country

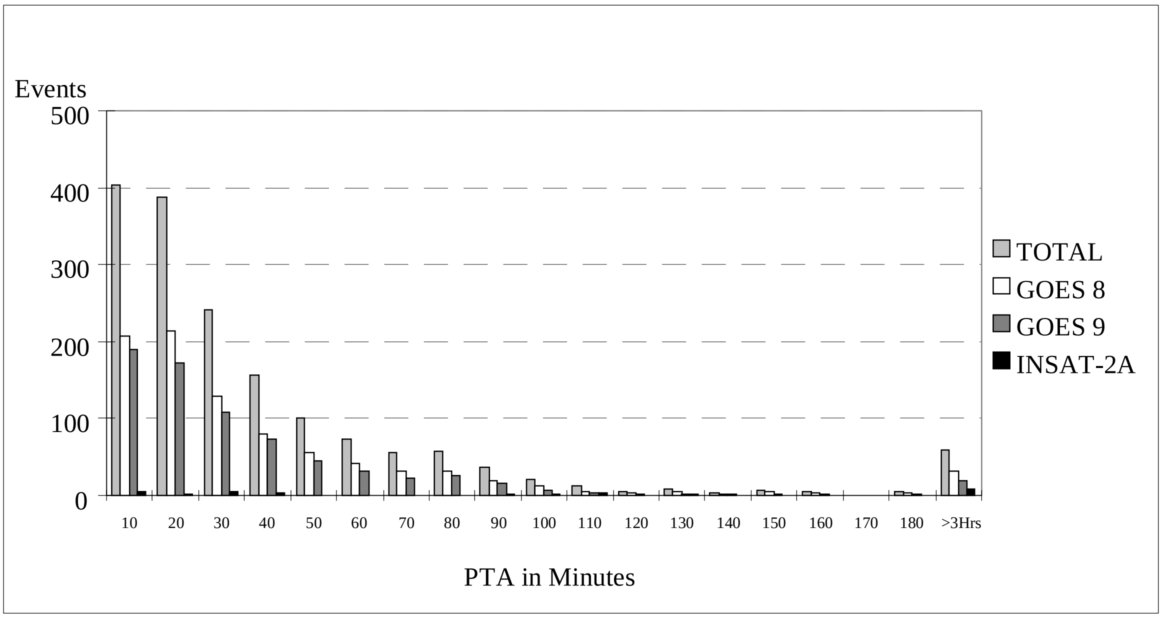
	Number of Cases	Mean (Minutes)	Median (Minutes)	Standard Deviation (Minutes)
GEOSAR Satellite				
INSAT-2A	32	98.8	40.0	110.7
GOES-8	884	47.5	21.7	111.6
GOES-9	724	42.0	20.0	91.8
Country				
Australia	12	94.5	26.8	153.0
Canada	81	44.6	19.4	138.0
France	161	92.0	32.3	206.3
India	5	45.0	60.0	55.8
Spain	32	22.4	17.0	62.0
United Kingdom*	11	35.5	35.5	13.4
United States	1,338	40.8	20.5	79.2
All	1,640	46.0	21.2	103.6

* Represents 3 months data only

The mean time advantage was 46 minutes, the median time advantage was 21 minutes and the standard deviation was approximately 104 minutes. There appears to be no significant difference when analysing the results between the two GOES satellites, most likely due to the fact that time advantages were reported for many of the same beacon activations. However, there is a difference in the mean time advantage when comparing the GOES series of satellites and the INSAT-2A satellite. This can be a result of the geographic location of the beacon activations analysed, the sample size of the analysis, the location of operational LEOLUTs, or long space segment delays via global-mode satellite coverage. However, further analysis is required to determine conclusively the reason for the difference in the reported time advantage between the different series of GEOSAR satellites.

When analysing the results by country, the mean time advantage varied from a low of 22.4 minutes reported by Spain to a high of 94.5 minutes reported by Australia. The possible reasons described above could also explain the time advantage differences by country, however, no conclusions can be reached with the analysis performed to date. It should be noted that the results from India only contain data for cases where the time advantage was three hours or less. Figure 5.1 presents the distribution of the time advantages, in 10-minute increments, for each satellite system.

Figure 5.1: Potential Time Advantage of GEOSAR Alert



The data in Figure 5.1 confirms that the median time advantage is 21 minutes. The data also shows that there were a total of 59 cases where the reported time advantage was over three hours. A preliminary investigation showed that delays just over three hours were usually due to lack of LEOSAR coverage in the area after beacon activation. However, for some of the very large time advantages, LEOSAR coverage was available, but no LEOSAR alert was received at the MCC. In the future, Participants may wish to study long delays in the reporting of alerts from the LEOSAR System.

The mean and median time advantages calculated were a result of six LEOSAR satellites in operation during the D&E data collection period. It can be reasonably concluded that the PTA for a nominal four-satellite constellation may be higher because of reduced satellite coverage. Also affecting the time advantage results is the location where operational beacons were activated. Due to their near-polar orbits, the LEOSAR satellites view the polar regions more frequently. Therefore, the time advantage is affected by the latitude at which a beacon is activated, as it will be greatest for beacons activated at the equator and decrease for beacon beacons activated at higher latitudes.

The mean time advantage of 46 minutes is significant in that this time advantage will permit SAR forces to begin their response sooner. Even if no position information is provided, the beacon registration information can be used to obtain general location information from contact persons, enabling SAR personnel to respond earlier and save additional lives. This time saving is particularly significant in cases where severe trauma or insertion into cold water is a factor. A further benefit of the near-instantaneous detection of the beacons by the

GEOSAR system is for short duration transmissions which would not be detected by the LEOSAR System (e.g. a beacon quickly destroyed by fire). In these cases, the GEOSAR alert may be the only alert provided.

The benefits of the GEOSAR time advantage are reflected in the cases described in section 5.8. These benefits will become even greater as beacons with encoded position information become operational and SAR personnel receive both alert and location information significantly earlier.

5.2 Complementarity and Effectiveness of the GEOSAR/LEOSAR Systems (O-2)

The complementarity and effectiveness of GEOSAR/LEOSAR systems measures the percentage of 406 MHz beacon transmissions, within the coverage area of a particular geostationary satellite, that are detected by only the GEOSAR system, only the LEOSAR System, or by both systems. This analysis measures the ability of the GEOSAR system to detect beacons within the satellite coverage area using confirmed detections by the LEOSAR System as a reference. The INSAT-2A and GOES satellites were used in the analysis. Data for this objective were collected by Australia, Canada, France, India, Spain, the United Kingdom and the United States. These countries reported on all beacon activations within a GEOSAR footprint that had country codes of countries within their MCC's service area. The effectiveness and unique contribution of the LEOSAR and GEOSAR systems are summarised in Table 5.2 and Figure 5.2.

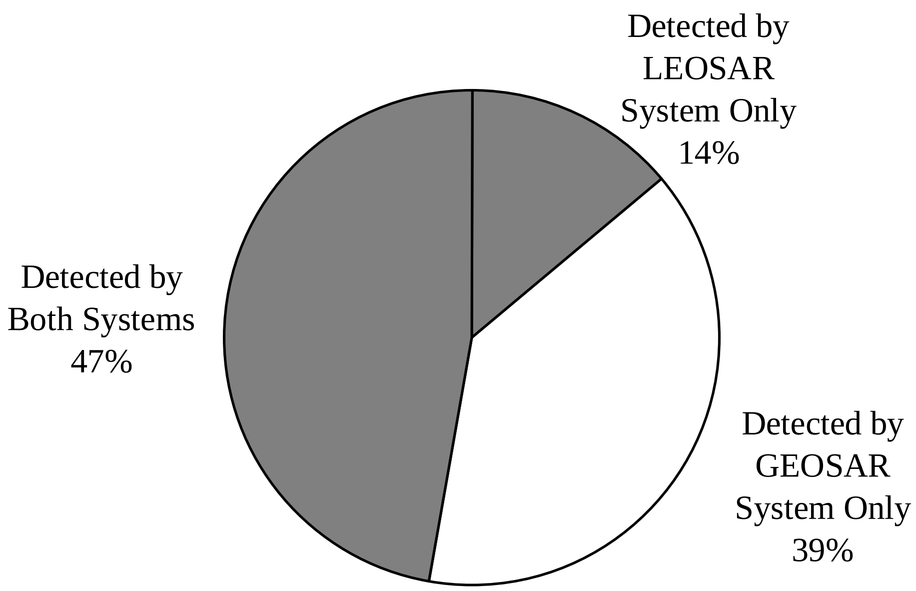
In Table 5.2 the GEOSAR effectiveness is defined as the percentage of alerts detected by the GEOSAR system within a GEOSAR satellite footprint. The GEOSAR and LEOSAR effectiveness is the percentage of alerts detected by both the LEOSAR and GEOSAR systems within a GEOSAR satellite footprint. The GEOSAR and LEOSAR unique contribution measures the percentage of alerts detected only by the GEOSAR and LEOSAR Systems respectively.

Table 5.2: Complementarity and Effectiveness of GEOSAR/LEOSAR Systems

	INSAT-2A	GOES-8	GOES-9	ALL
Total alerts in GEOSAR footprint	243	1,931	1,648	3,822
Alerts Detected Only by GEOSAR	22	819	639	1,480
Alerts Detected by Both Systems	56	925	829	1,810
Alerts Detected Only by LEOSAR	165	187	180	532
GEOSAR Effectiveness	32.1%	90.3%	89.1%	86.1%
GEOSAR and LEOSAR Effectiveness	23.0%	47.9%	50.3%	47.4%
GEOSAR Unique Contribution	9.1%	42.4%	38.8%	38.7%
LEOSAR Unique Contribution	67.9%	9.7%	10.9%	13.9%

A total of 3,822 alerts within the theoretical zero degree elevation angle GEOSAR footprints were reported. The GEOSAR system detected 86.1% (3,290) of these alerts and was the only system to detect 38.7% (1,480) of the alerts. Only 13.9% (532) of the alerts were detected by the LEOSAR System and not by the GEOSAR system. It was noted that the effectiveness of the GEOSAR system was consistent between the two GOES satellites, however, the effectiveness for the INSAT-2A satellite was much lower. Further analysis demonstrated that the INSAT-2A effectiveness, as reported by India was high (93.8% for a sample size of 16 cases), however the INSAT-2A effectiveness reported by other Participants was much lower (0.0% to 32.8% for a total of 227 cases). This suggests that the INSAT-2A may have detected a greater number of beacons than were transmitted by the Indian MCC to other countries.

Figure 5.2: Complementarity/Effectiveness of GEOSAR and LEOSAR Systems



Additional analysis was performed by some of the D&E Participants to verify the GEOSAR effectiveness and to ensure that logical explanations existed for those cases where only the LEOSAR System provided notification. All alerts detected by the LEOSAR System but not detected by the GEOSAR system during a two-week period were analysed in more detail. The investigation included:

- contacting SAR personnel and beacon owners/operators to determine the presence of local obstructions;
- determining the level of interference present within the GEOSAR footprint; and

- determining the received power level of the beacon at the LEOSAR satellite (if the received power level of the beacon can be shown to be below a certain threshold then it is possible to conclude that the GEOSAR system could not have detected the beacon).

The analysis concluded that factors such as local obstructions, low beacon power, MCC processing anomalies, the inability of a GEOLUT to produce an error free message, or bit errors in the frame synchronisation caused the GEOSAR system not to report a beacon activation. Even though the analysis was limited, it was concluded that logical explanations existed for the 532 (14%) alerts not detected by the GEOSAR system.

Figures 5.3, 5.4 and 5.5 display the actual locations of 406 MHz alerts which were detected by the LEOSAR System but not the GEOSAR system. The presentations are provided separately for each geostationary satellite (GOES-8, GOES-9 and INSAT-2A). Alerts in the overlap areas of the geostationary satellite footprint are reported for each satellite. All footprints shown in this report are based on zero degree elevation angles.

Figure 5.3: Confirmed Alerts Detected by LEOSAR Not Detected by GOES-8 in GOES-8 Footprint

N=187

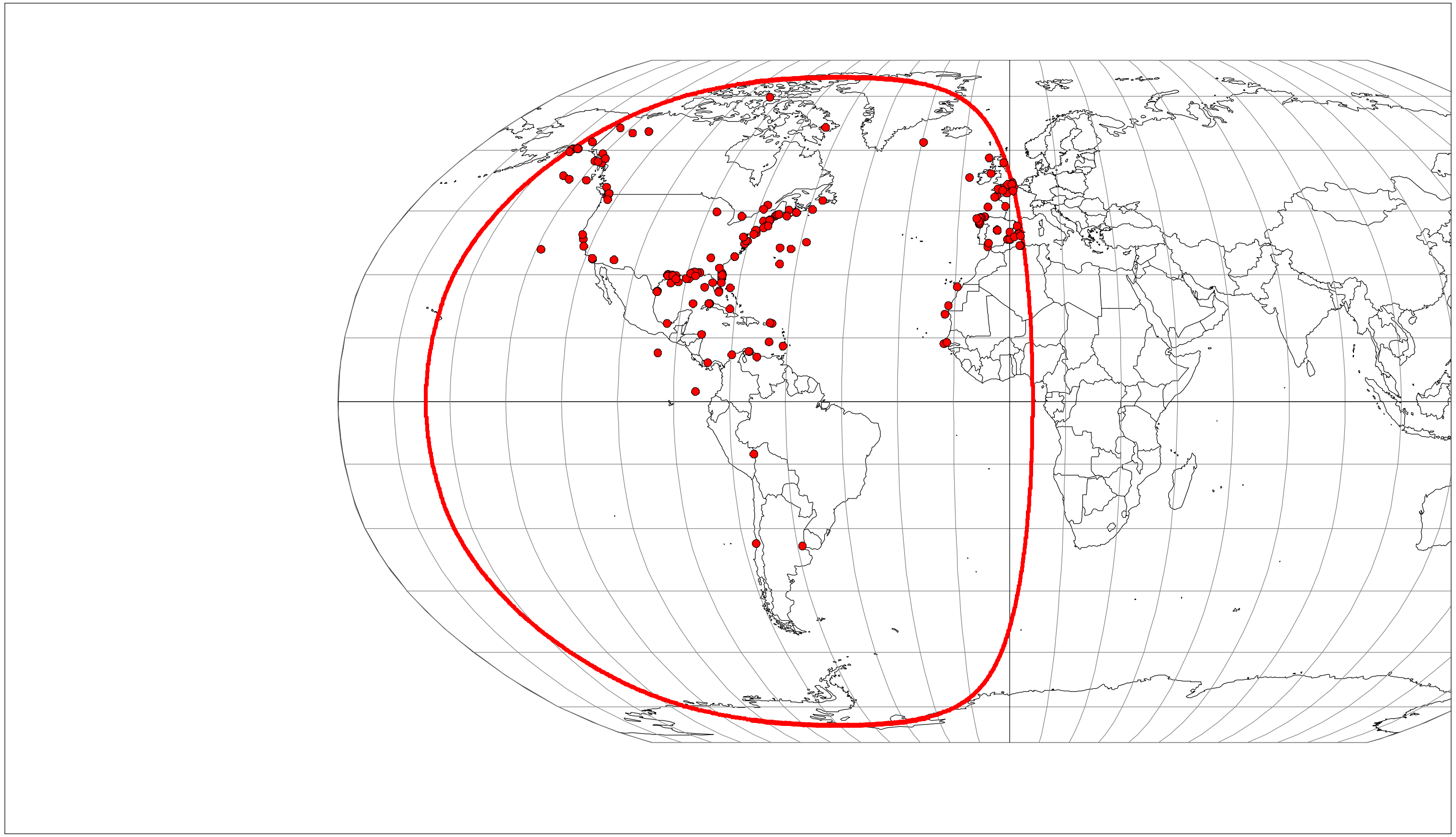
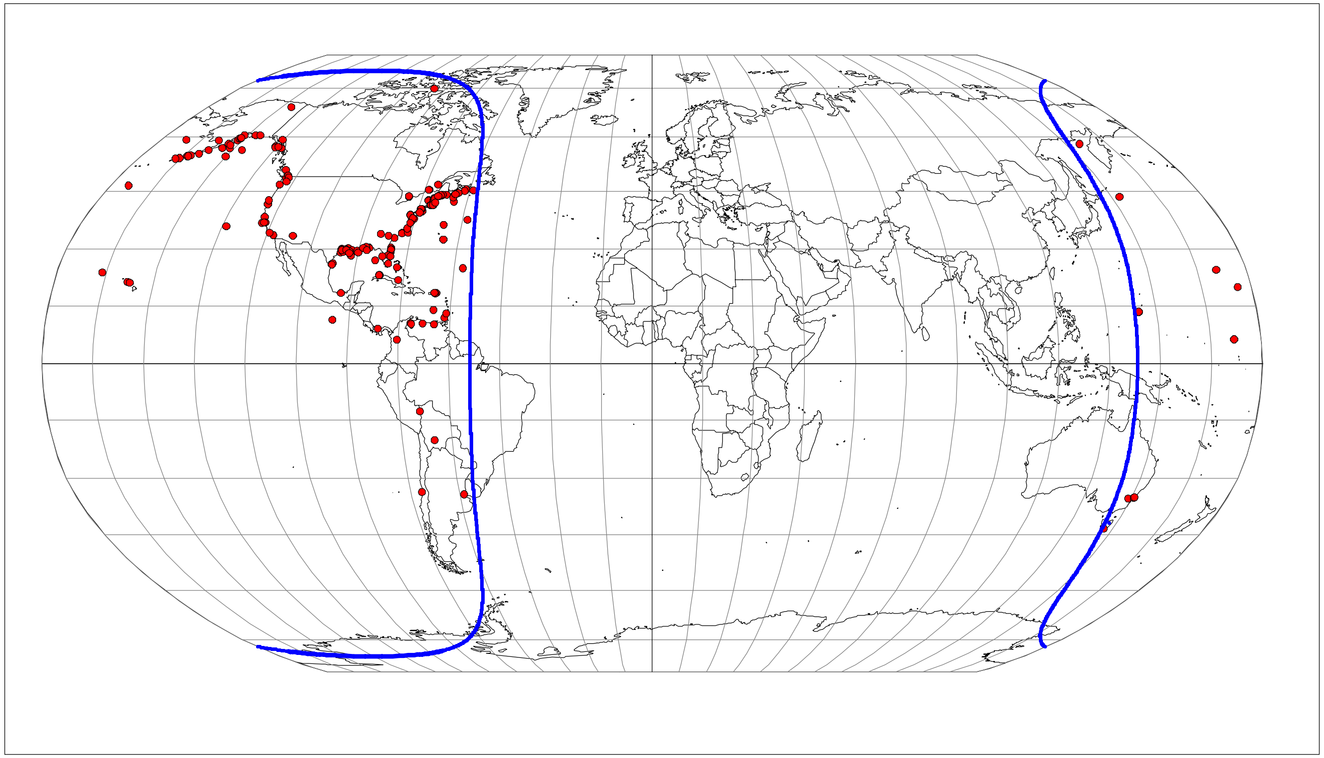


Figure 5.4: Confirmed Alerts Detected by LEOSAR Not Detected by GOES-9 in GOES-9 Footprint

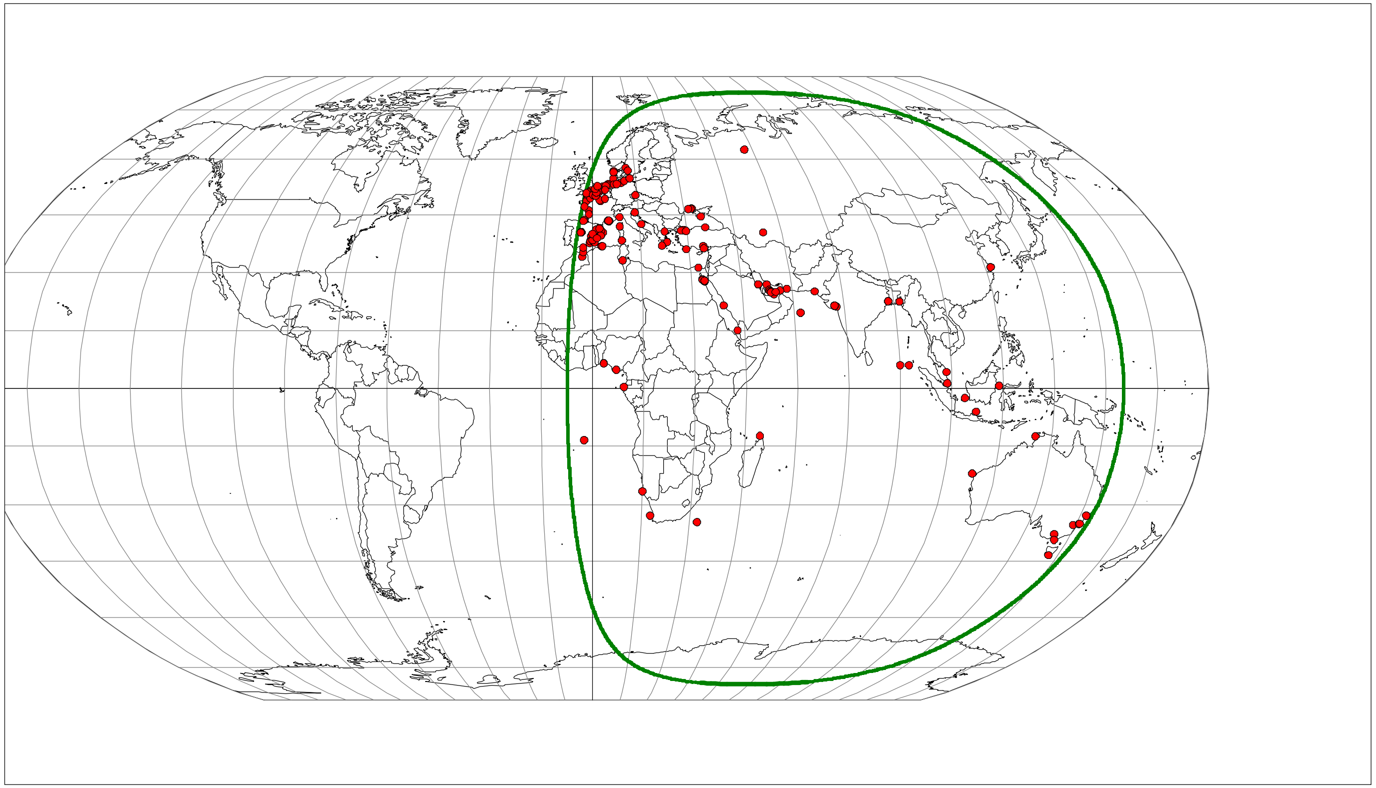
N=192[3]



[3] The number of cases plotted is based upon data files provided by D&E Participants and differs slightly from the total reported in Table 5.2 which is based upon summary data provided by Participants.

Figure 5.5: Confirmed Alerts Detected by LEOSAR Not Detected by INSAT-2A

N=167[4]



[4] The number of cases plotted is based upon data files provided by D&E Participants and differs slightly from the total reported in Table 5.2 which is based upon summary data provided by Participants.

As shown in Table 5.2 and Figure 5.2, the LEOSAR System did not detect 38.7% (1,480) of the alerts detected by the GEOSAR system. The LEOSAR System has few screening or shielding limitations and should detect all nominal Cospas-Sarsat beacons which transmit for a period long enough for a LEOSAR satellite to overfly and detect the beacon. The requirement for a lengthy beacon transmission time was demonstrated by the average waiting time of 44 minutes for a LEOSAR satellite to detect a beacon during the Exercise of 1990. Thus, both the duration of the beacon transmission and the beacon location have an effect on the likelihood that the LEOSAR System will detect a beacon which has been detected by the GEOSAR system.

Therefore, the beacons detected only by the GEOSAR system were probably a result of the geometry of the LEOSAR satellite system and the transmission duration of active beacons. Analysis in section 5.3 demonstrates that over half of the beacon activations had transmission durations of less than 10 minutes. Consequently, it is unlikely that these short duration beacon transmissions would have been detected by a LEOSAR satellite.

The GEOSAR effectiveness of 86.1% (3,290 alerts) indicates that the GEOSAR system was able to detect most of the 406 MHz beacon activations in the GEOSAR footprint and provide the alert data to SAR forces. For the 47.4% (1,810) of alerts detected by both the GEOSAR and LEOSAR systems, the SAR forces could initiate investigation of incidents sooner using GEOSAR alert data, then use the LEOSAR data to focus search activities. In this manner the two system complemented each other.

Figures 5.6, 5.7 and 5.8 display the actual locations of 406 MHz alerts which were detected by both the LEOSAR and GEOSAR satellite systems. As with the presentations of the alerts detected only by the LEOSAR System, the presentations are provided separately for alerts for each geostationary satellite and alerts in the overlap areas of the geostationary satellite footprints are shown in each presentation. The number of alerts shown on Figures 5.5 through 5.7 is less than that shown in Table 5.2. This is because there were 406 MHz alerts detected by both LEOSAR and GEOSAR systems which did not have location data. These alerts do not appear in these Figures but are counted in Table 5.2.

Figure 5.6: Confirmed Positions of 406 MHz GEOSAR Alerts as Confirmed by LEOSAR in GOES-8 Footprint

N=622

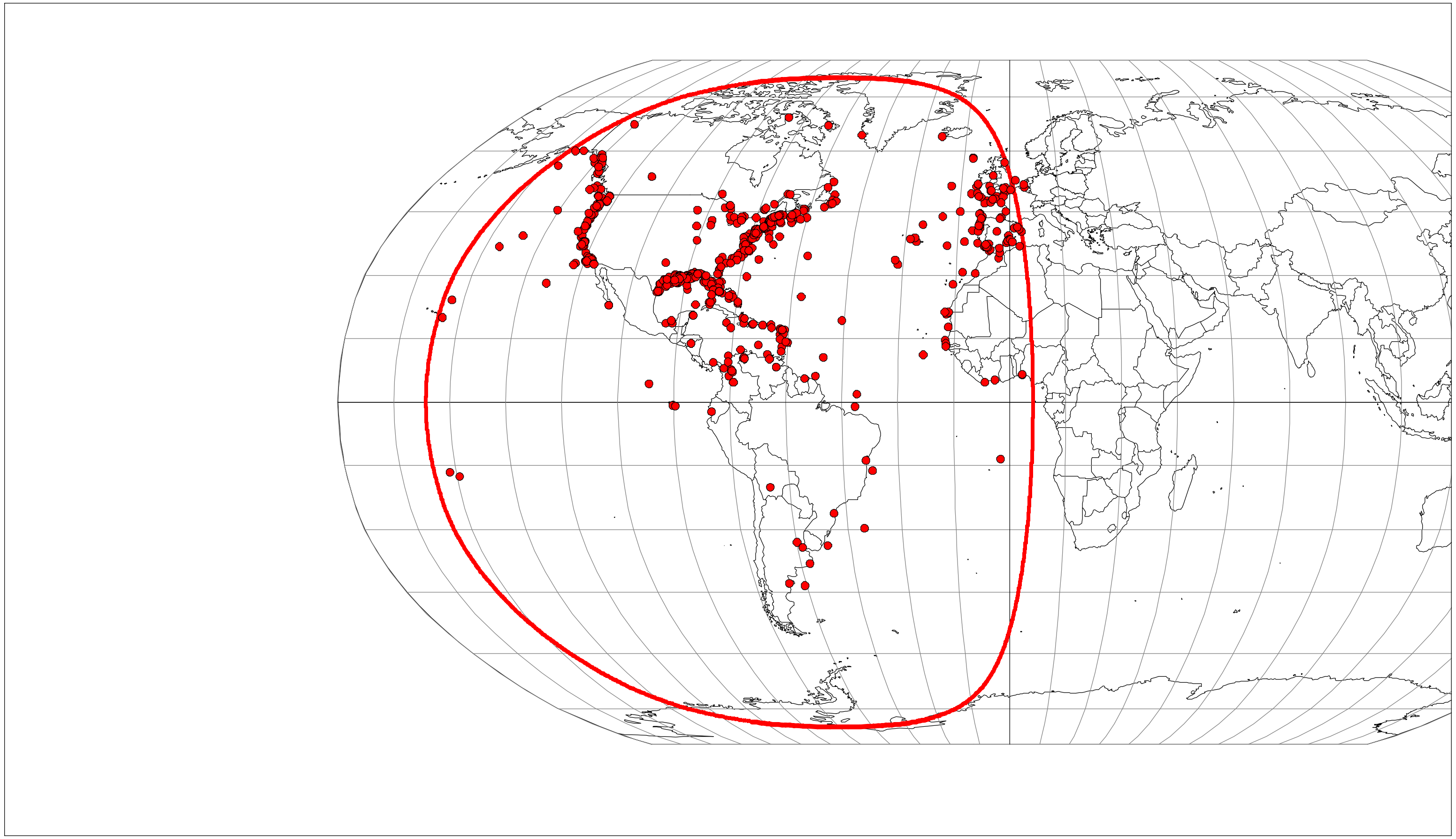


Figure 5.7: Confirmed Positions of 406 MHz GEOSAR Alerts as Confirmed by LEOSAR in GOES-9 Footprint

N=570

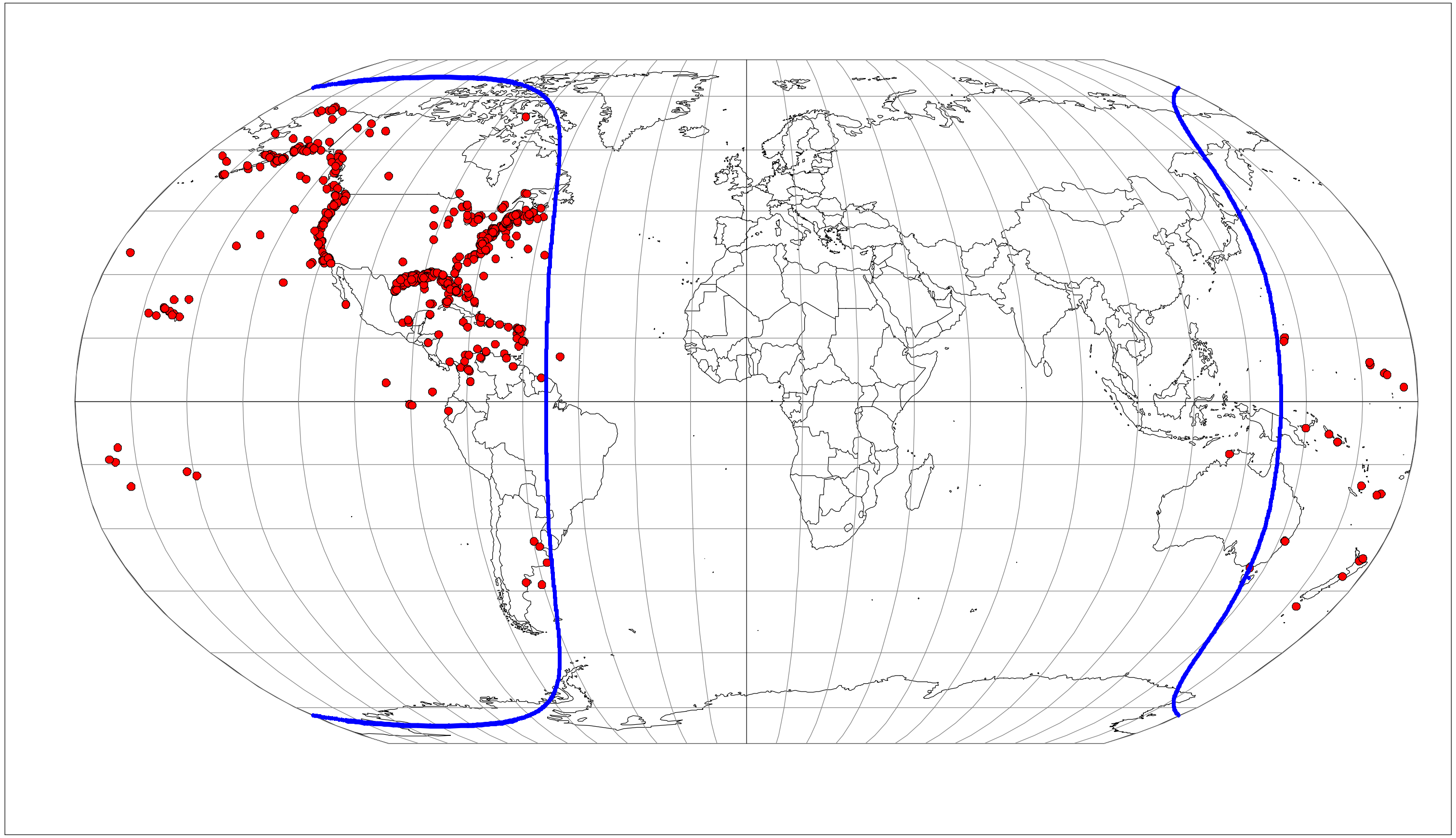
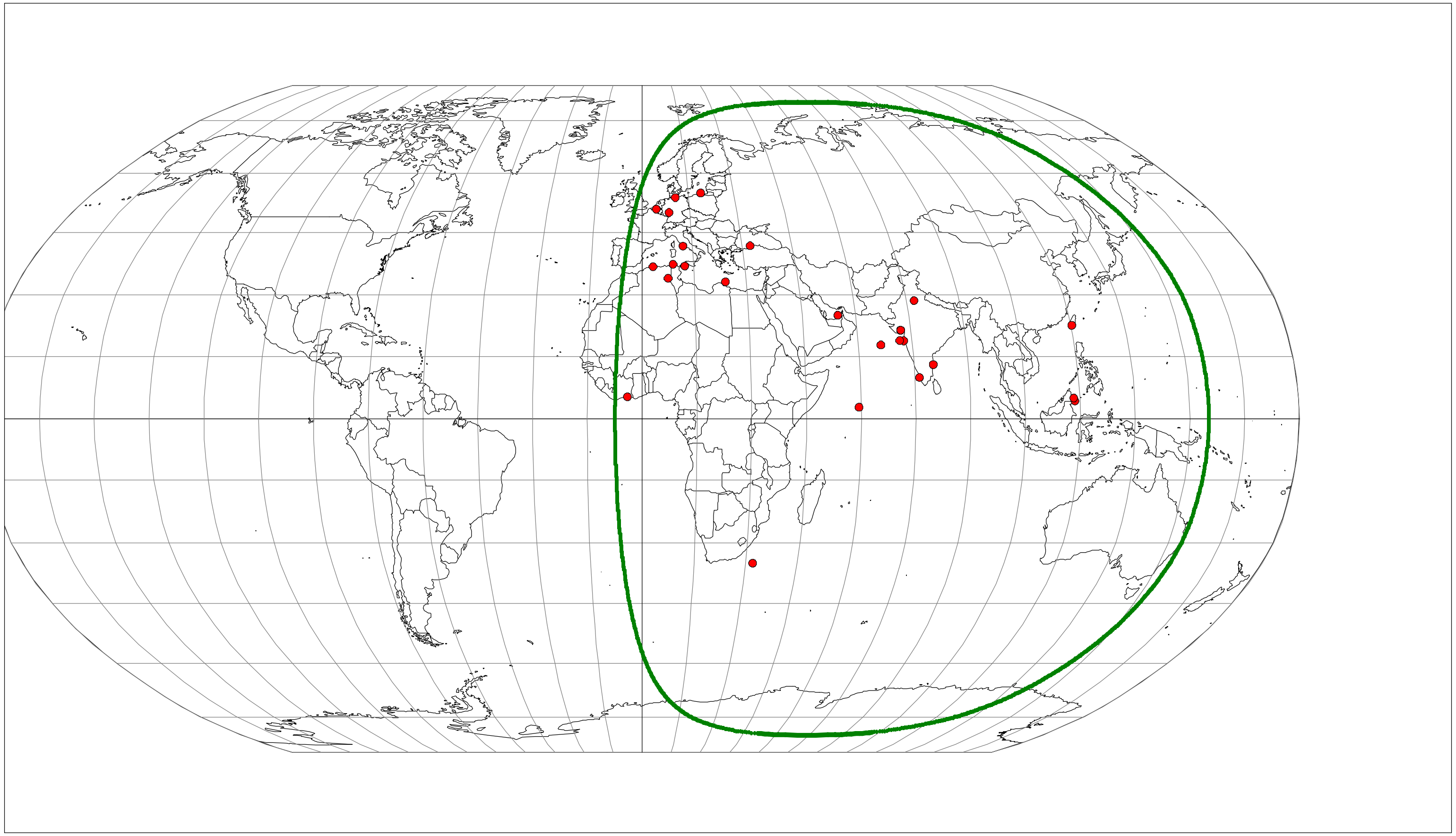


Figure 5.8: Confirmed Positions of 406 MHz GEOSAR Alerts as Confirmed by LEOSAR in INSAT-2A Footprint

N=29



5.3 Durations of 406 MHz Transmissions (O-3)

The analysis of 406 MHz transmission durations provides information on how long operational beacons are active. Short duration transmissions could be the result of a catastrophic event or the result of a false alert (e.g., inadvertent activation due to testing). Transmission durations less than two hours may not be detected by the LEOSAR System, and therefore, provide some assessment of the complementarity of the LEOSAR and GEOSAR systems. Transmission durations in excess of two hours may have a significant impact on system capacity.

Data from the GEOLUTs in Canada, Spain and the United Kingdom were analysed. The Indian GEOLUT was not able to provide a report on duration of beacon transmissions. Table 5.3 summarises the results. Note that differences in signal processing techniques used in the GEOLUTs resulted in a difference in how the duration was calculated, therefore, the data could not be combined.

Table 5.3: GEOSAR Beacon Durations by GEOLUT Provider

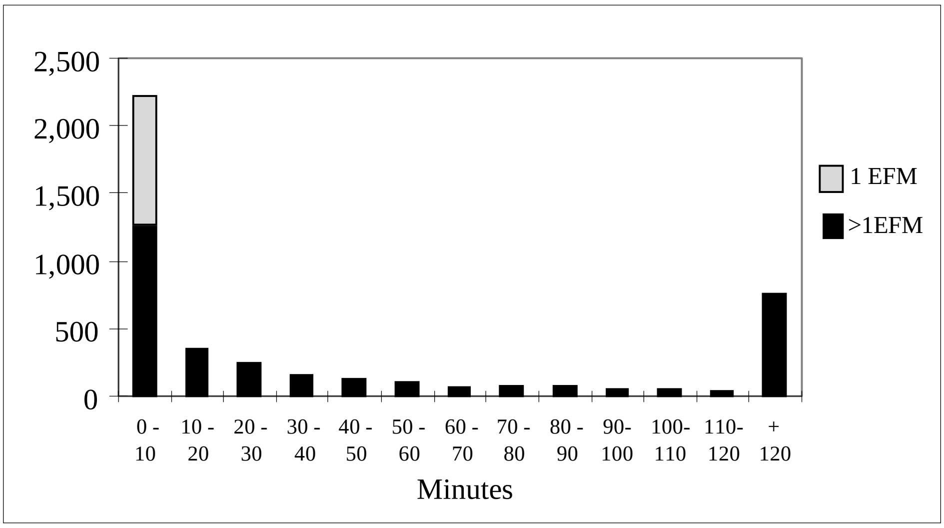
Country	Reports	Mean (Minutes)	Median (Minutes)	Standard Deviation (Minutes)
Canada	2,333	163.2	7.8	667.2
Spain	1,209	152.8	19.1	614.6
United Kingdom*	740	97.8	7.8	n/a

* Represents 3 months data only

A total of 4,282 transmission durations were measured. The mean and median values were not provided by the United Kingdom, however, estimates of them were derived from the distribution of transmission durations. From analysis of the mean and median duration values presented above, it was clear that although the median duration was low, a number of beacons continued to transmit for extended periods causing the mean to be high. There does not appear to be a significant difference in the mean values of 152.8 minutes reported by Spain and 163.2 minutes reported by Canada. However, the value calculated for the United Kingdom GEOLUT was considerably lower.

Figure 5.9 and Table 5.4 present the beacon transmission durations in 10-minute increments. Additionally, an indication of the number of error free messages (EFM) is provided for the transmissions with a duration less than 10 minutes. Single error free messages are those where the GEOLUT detected only one burst from a beacon and was able to generate an alert with no bit errors.

Figure 5.9: Duration of 406 MHz Transmissions



The results in Figure 5.9 indicate a considerable number of alerts with only one error free message and the predominance of short-duration transmissions. Almost all of the error free messages were determined to have originated from an operating beacon.

Table 5.4: Transmission Durations

Duration (Minutes)	**Country**			**Total**
	Canada	**Spain**	**United Kingdom***	
0-10 (1 EFM)	569	111	263	943
0-10 (> 1 EFM)	647	393	211	1,251
10-20	190	113	44	347
20-30	125	92	34	251
30-40	90	52	20	162
40-50	70	36	19	125
50-60	59	41	8	108
60-70	35	26	4	65
70-80	41	26	6	73
80-90	42	28	7	77
90-100	26	17	9	52
100-110	24	20	3	47
110-120	15	15	5	35
> 120	400	239	107	746
Total	2,333	1,209	740	4,282

* Represents 3 months data only

The Canadian GEOLUT produced a single error free message in 24% (569) of the cases whereas the United Kingdom GEOLUT produced a single error free message in 36% (263) of the cases. Overall, just over half of the beacon transmission durations were less than 10 minutes. This percentage varied between GEOLUTs, from 42% for Spain, to 52% for Canada and to 64% for the United Kingdom. These results may explain why the number of alerts detected by only the GEOSAR system is high; most of the transmissions were too short to expect detection by the LEOSAR System. The high percentage of short duration transmissions recorded by the United Kingdom may explain the United Kingdom's lower mean duration transmission value. However, additional analysis is required to determine why a difference in the percentage of transmission durations less than 10 minutes existed between the various GEOLUTs.

The analysis suggests that improper testing or inadvertent activations may cause over half of all beacon alerts detected by the GEOSAR system. Users of the system should be made aware of the fact that the GEOSAR system can detect and process single burst messages, therefore, care should be exercised when handling or testing beacons. However, it is noteworthy that a beacon transmitting for a short duration may be the only indication of catastrophic events where the beacon is quickly destroyed. The mean duration transmissions presented in Table 5.3 could be used as input in determining the GEOSAR and LEOSAR System capacity.

5.4 406 MHz Registration Database Effectiveness (O-4)

The 406 MHz registration database effectiveness is a measure of the usefulness of 406 MHz registration information to the SAR forces. The database effectiveness is evaluated by calculating the percentage of 406 MHz GEOSAR alerts received at a MCC for which a database exists and the registration information could be used by the SAR forces. As most beacons only contain identification information, the full benefits of the GEOSAR system are only realised if useful registration data is available and can be provided to the SAR forces to take advantage of the earlier GEOSAR alert. The results reflect the database effectiveness for Cospas-Sarsat Participants, who have established, maintain and provide access to registration databases, on a 24-hour access basis. It should be noted that due to an inconsistency in guidelines provided in document C/S R.006 for the calculation of the "ratio of false alarms resolved before launch", this value could not be calculated.

Table 5.5 presents the results of the database effectiveness in determining if an alert is a real distress. The Ratio of Alert Discrimination is measured by dividing the number of alerts where the registration information was useful in determining whether an alert was a real distress or a false alarm, by the number of alerts provided to SAR forces with registration information.

Table 5.5: 406 MHz Registration Database Effectiveness

Measurement	**Canada**	**France**	**Spain**	**United States**
Alerts for which database information was acquired and provided to SAR forces	105	198	58	965
Alerts where beacon registration data allowed SAR forces to discriminate between real and false alerts	102	168	n/a	600
Percentage of Alert Discrimination	97.1%	84.8%	≈ 80%	62.2%

There were 1,326 beacon alerts for which database information was available and provided to SAR forces. Of these, the ability to discriminate between real and false alerts varied between 62.2% and 97.1%. Note that Spain estimated that approximately 80% of the registered alerts were useful in resolving the incident. This clearly shows that registration information is valuable to SAR forces in quickly determining if an alert is a real distress incident or a false alarm.

This objective also examined the search initiation/false alarm determination time improvement. Information from a GEOSAR alert and the registration data may permit the RCCs/SPOCs to initiate a search or determine that an alert is false earlier than if only a LEOSAR alert is received. The time improvement, for cases where a GEOSAR and LEOSAR alert exists, is the elapsed time between when the RCC/SPOC could initiate a search or confirm a false alarm and the time of receipt of the first LEOSAR alert. Table 5.6 summarises the search initiation/false alarm determination time improvement.

Table 5.6: Search Initiation/False Alarm Determination Time Improvement

Country	**Number of Cases**	**Mean (Minutes)**	**Median (Minutes)**	**Standard Deviation (Minutes)**
Canada	23	51.8	12.0	120.3
France	97	56.0	26.0	91.0
Spain	2	38.4	38.4	50.7
United States	83	18.8	12.0	22.9

Canada, France, Spain and the United States measured the search initiation/false alarm determination time improvement on 205 incidents. The mean time improvement was 40 minutes and the median was about 16 minutes. Although a determination that an alert is false, 40 minutes earlier, may not be very significant, it may release the SAR forces for other tasks. A determination that an alert is real, 40 minutes earlier, is very significant to SAR forces.

Although new Location Protocol beacons will be able to provide identification and position information, the registration database will still be an important element of data provided to SAR forces. Receipt of simultaneous alert and location information will mean that RCCs and

SPOCs will need to make prompt decisions regarding the launch of resources. Accurate registration database information is therefore essential to prevent the unnecessary tasking of resources.

The registration database information, coupled with the time advantage of an earlier GEOSAR alert, will be of particular life-saving benefit in distress cases. The database information will allow the SAR forces to begin planning the response earlier than they could by waiting for the receipt of a LEOSAR alert. Registration database information is an essential complement to GEOSAR alerts and National Administrations should ensure that they establish and maintain useful, 24-hour registration databases, for the retrieval of information by SAR agencies.

5.5 Operational Impact of GEOSAR System-generated False Alerts (O-5)

The analysis of GEOSAR system-generated false alerts measures the operational impact of system-generated false alerts on the SAR forces. System-generated false alerts, or invalid alerts, are defined as those alerts received at an MCC which are generated from non-beacon sources or are received corrupt. In GEOSAR systems the recovery of the digital signal from 406 MHz beacons is performed by the GEOLUT. As there are factors (e.g., bit synchronisation) that may affect the GEOLUT's ability to properly recover 406 MHz beacon messages, the number of system-generated false alerts was evaluated. Canada, Spain, India, and the United States provided data for this analysis.

Table 5.7 provides a summary of the number of GEOSAR alerts and the number of system-generated false alerts detected by the different countries. The ratio of GEOSAR system-generated false alerts received at an MCC is measured by dividing the number of invalid GEOSAR alerts received at an MCC by the total number of GEOSAR alerts received at the MCC. The ratio of GEOSAR system-generated false alerts transmitted to RCCs/SPOCs is measured by dividing the number of invalid alerts transmitted to a RCCs/SPOCs by the total number of GEOSAR alerts transmitted to RCCs/SPOCs.

Table 5.7: Operational Impact of GEOSAR System-generated False Alerts

	Canada	India	Spain	United States	Total
GEOSAR alerts received at MCC (from associated GEOLUTs or other MCCs)	234	16	199	4,648	5,097
GEOSAR alerts passed to RCCs/SPOCs	108	16	137	1,364	1,625
GEOSAR alerts received confirmed invalid by MCC	6	0	0	42	48
GEOSAR alerts forwarded invalid to an RCC/SPOC	0	0	3	0	3
Percentage of GEOSAR alerts received at MCC confirmed as invalid by the MCC	2.6%	0%	0.0%	0.9%	0.9%
Percentage of GEOSAR system-generated false alerts transmitted to RCCs and SPOCs	0.0%	0%	2.2%	0.0%	0.2%

The number and percentage of system-generated false alerts were found to be low. Of the 5,097 GEOSAR alerts transmitted in the MCC network, 48 (0.9%) were determined to be invalid. However, of the 1,625 GEOSAR alerts passed to RCCs/SPOCs, only three (0.2%) were system-generated false alerts. The three system-generated false alerts transmitted to RCCs/SPOCs were a result of the procedures implemented by Spain, where alerts were validated against registration databases at the RCC level.

It was noted that some countries are pro-active in screening for system-generated false alerts, and have implemented validation measures in their MCCs to suppress these alerts. It was also noted that the validation of GEOSAR alert messages at the MCC was effective during the D&E period because a majority of operational beacons in use were coded with the User Protocol. The User Protocols contain mainly identification information, which MCCs can generally validate against known or reasonable values.

However, a new generation of beacons using Location Protocols is entering into operation and will be in widespread use in the future. The new Location Protocols allocate a significant portion of the message for transmission of encoded position data. This reduces the portion of the message dedicated to identification of the beacon, thereby reducing the effectiveness with which MCCs can validate messages. The validation of Location Protocol beacons should be reviewed by the Participants to determine if additional validation is possible or required.

5.6 Volume of GEOSAR Alert Processing at MCCs (O-6)

The volume of GEOSAR alert messages is collected to evaluate the increase in message traffic and processing requirements resulting from the transmission of GEOSAR alerts between MCCs. The purpose of the analysis is to determine the impact of the increased message traffic on Ground Segment operations. The GEOSAR traffic ratio presented in Table 5.8 is calculated by comparing the number of GEOSAR alert messages received and transmitted by an MCC to the total number of LEOSAR alert messages received and transmitted by that MCC. Australia, Canada, France, India, Spain, the United Kingdom and the United States supplied data for analysis.

Table 5.8: Volume of GEOSAR Message Processing

Country	GEOSAR Satellite from which Alerts were Received	Number of GEOSAR Alert Messages	Number of Non-GEOSAR Alert Messages	GEOSAR Traffic Ratio
Australia	INSAT-2A	114	17,940	0.6%
Canada	GOES-8 GOES-9	4,063	25,413	16.0%
France	INSAT-2A GOES-8 GOES-9	4,905	85,000	5.8%
India	INSAT-2A	16	5,672	0.3%
Spain	INSAT-2A GOES-8 GOES-9	1,418	9,824	14.4%
United Kingdom*	GOES-8 GOES-9	881	1,892	46.6%
United States	GOES-8 GOES-9	6,331	151,225	4.2%

* Represents 3 months data only

The total number of GEOSAR alert messages processed was 17,728 compared with 296,966 for the LEOSAR System. The traffic ratio ranged from less than 1% for Australia and India to 46.6% for the United Kingdom, with, as expected, MCCs with associated GEOLUTs having higher volumes. The high United Kingdom percentage reflects the fact that the United Kingdom does not send 121.5 MHz alert messages unless ambiguity is resolved, thereby reducing the number of LEOSAR alerts transmitted. The low INMCC traffic did not correspond with the results from other MCCs because the Indian data was limited to alerts in India's service area that were coded with a country code of a country in India's service area.

It should be noted that the traffic reported here is higher than MCCs would normally experience because of the special data distribution procedures in place during the D&E period where redundant alerts from different sources were transmitted to allow analysis. Following normal operational procedures, redundant alert messages will be filtered at the MCCs.

For some MCCs the routing of GEOSAR alerts was automatic, but for others, manual intervention was required causing an impact on the workload. However, all Participants agreed that the workload increase did not have a significant adverse impact on any MCC's operation and was considered justified by the potential benefits of the GEOSAR system.

5.7 Resolution of LEOSAR Location Ambiguity Using GEOSAR Alert Data (O-7)

This objective measures the effectiveness of using GEOSAR alerts to resolve 406 MHz LEOSAR Doppler location ambiguity. As is generally known, the LEOSAR Doppler processing produces two solutions for each satellite overflight; a "real" position corresponding to the actual location of the beacon, and an "image" position on the opposite side of the satellite track. It is possible to use the footprint of the GEOSAR satellite to determine the "real" location in cases where the "image" solution falls outside the GEOSAR footprint. This determination is only helpful when the LEOSAR ambiguity has not already been resolved. Therefore, the analysis was limited to cases where the GEOSAR alert was available prior to receiving the second LEOSAR alert which would usually provide location ambiguity resolution.

Australia, Canada, Spain, France, India, and the United States supplied data for this analysis. It should be noted that none of the countries had implemented procedures to automatically resolve LEOSAR location ambiguity with GEOSAR data during the D&E period. Instead, a theoretical analysis was undertaken after the data collection period using all data available at the MCC. Table 5.9 summarises the ambiguity resolution effectiveness ratio which is calculated by dividing the number of LEOSAR first locations where ambiguity was resolved successfully by the total number of LEOSAR first locations processed by an MCC.

Table 5.9: Resolution of LEOSAR Ambiguity using GEOSAR Data

Country	GEOSAR Satellites Used to Resolve Ambiguity	Resolutions using GEOSAR	Total LEOSAR Locations	Ambiguity Resolution Effectiveness Ratio
Australia	INSAT-2A GOES-8 GOES-9	5	82	6.1%
Canada	GOES-8 GOES-9	6	31	19.4%
France	INSAT-2A GOES-8 GOES-9	93	783	11.9%
India	INSAT-2A	22	50	n/a
Spain	GOES-8 GOES-9	53	1,494	3.5%
United States	GOES-8 GOES-9	123	1,674	7.3%

Of the total 4,114 LEOSAR alerts which occurred within the GEOSAR coverage areas, 302 were in positions where one LEOSAR location was inside the GEOSAR system coverage area and the other was not. The data indicated differences in the effectiveness between countries of using GEOSAR alert data to resolve LEOSAR location ambiguity. The effectiveness depended on the location of the GEOSAR footprint boundary, the LEOSAR satellite geometry and the areas where beacon activations are concentrated. The effectiveness varied from a low of 3.5% for Spain to a high of 19.4% for Canada.

The variance may be due to the different interpretation of the guidelines provided in document C/S R.006, resulting in some Participants (Australia and Canada) limiting their analysis to data within their MCC service areas and others (India**,** France, Spain and the United States) reporting on all service areas. India could not compute an Effectiveness Ratio because the data collected by India on resolutions using GEOSAR were all outside INMCC service area whereas the data on total LEOSAR locations was within the INMCC service area.

Despite these data collection differences, the analysis demonstrates that using the GEOSAR satellite footprint to resolve LEOSAR Doppler location ambiguity can be of practical use to SAR authorities. Furthermore, enhanced data distribution procedures that use the GEOSAR satellite footprint to resolve LEOSAR location ambiguity may reduce the number of messages transmitted to SAR authorities responsible for the “image” position.

5.8 Evaluation of the Benefits of GEOSAR Systems on SAR Operations (O-8)

This objective measures the direct and indirect benefits of the GEOSAR system to SAR operations. Direct benefits are classified as:

- additional lives saved due to the earlier notification of GEOSAR system;
- reduced search costs resulting from the use of GEOSAR alert data; or
- reduced property losses due to the timeliness of GEOSAR alerting.

Information on indirect benefits, which are harder to quantify, include reports demonstrating the reduced risk to SAR forces and increased public confidence in, and reliance on 406 MHz ELTs, EPIRBs and PLBs.

Most participants experienced difficulty in reporting on this objective and only Canada, France and the United States provided information. Canada reported on a case involving two hunters rescued in the Northwest Territories, which is documented in the Executive Summary. France reported on a rally between Paris and Dakar, which documented the usefulness and reliability of the GEOSAR system including the use of encoded position data. Finally, the United States reported on 19 specific cases where 406 MHz GEOSAR alert data was used in responding to distress events.

France reported that the participants in the Paris-Dakar rally held in January of 1998 used PLBs, many of which were coded with a new Location Protocol and with encoded position information provided by an internal GPS receiver. Of the 348 beacons, 41 were activated during the race. Analysis showed that the encoded position information provided by the beacons agreed well with the calculated Doppler locations, and that GOES-8 was very effective in detecting the 406 MHz alerts. Table 5.10 summarises the results for GOES-8.

Table 5.10: Paris-Dakar Rally GEOSAR Benefits

Measurement	**Result**
Percentage of alerts detected by GOES-8	93%
Percentage of alerts with first detect by GOES-8	88%
Percentage of alerts only detected by GOES-8	25%
Time Advantage of GOES-8 (25 cases)	40 minutes

The rally results, therefore, confirmed in a practical way the value of the GEOSAR system as a complement to the LEOSAR System.

The United States reported on direct benefits by evaluating the property protected, property saved, lives protected and lives saved as a result of 406 MHz GEOSAR alert data combined with beacon registration data. Property protected was defined for situations where a craft required outside assistance, but was not in imminent danger of being destroyed. Property saved applied to craft that required outside assistance or could be destroyed. Lives protected were those lives that required outside assistance, but were not in imminent danger of serious injury or loss of life. Finally, lives saved were those lives that required outside assistance to avoid serious injury of loss of life. Table 5.11 discusses 19 cases where the GEOSAR system provided early distress notification that assisted SAR operations.

Table 5.11: Case Reports Indicating GEOSAR System Benefits

Incident	Location	Time Advantage (Minutes)	Lives Saved or Protected	Notification / Response
F/V GULF HERON Medevac 11/6/96	Port O'Connor, Texas	21	1 Protected	Activated EPIRB because crewman was suffering heart attack. No other communications. CG transported crewman to hospital.
S/V MARY MARIA Taking on water 11/12/96	Naples, Florida	22	1 Protected	Master activated EPIRB and radioed MAYDAY call because vessel was sinking. CG dispatched helicopter which homed in on 121.5 signal.
F/V BEACH KING Capsized 12/01/96	Coast of Oregon	47	2 Saves	Automatic activation of EPIRB after vessel capsized. CG responded to information from emergency point of contact (POC) and hoisted two people to safety.
F/V CAPT JOHN Taking on water 12/22/96	Gulf of Mexico	58	4 Protected	Activated EPIRB when vessel began sinking. No other communications. CG diverted aircraft and ship to assist.
F/V NUMB NUTS Disabled 4/21/97	Cape Romano, Florida	2	3 Protected	Activated EPIRB to alert CG. Vessel had been disabled at anchor for two days. CG aircraft located nearby vessel to assist.
F/V SUNRISE III Disabled 4/21/97	Santa Cruz, California	26	2 Protected	Activated EPIRB and radioed MAYDAY to alert CG. Vessel was disabled and adrift. CG boat located and assisted vessel.

F/V WAINANI Disabled 4/22/97	Kohoolane, Hawaii	9	1 Protected	Activated EPIRB to alert CG. Vessel was disabled and had no other communications. CG helicopter lowered crewman to assist distressed vessel.
F/V FISHERMAN VIII Taking on water 4/26/97	Galveston, Texas	29	4 Protected	Crew radioed MAYDAY to alert CG and then lost communications. Crew activated EPIRB when they abandon ship. CG aircraft located raft and ship recovered crew.
F/V JENNIFER II Disabled 4/27/97	Seabrook, Texas	11	3 Protected	Activated EPIRB to alert CG. No other communications. Vessel disabled with broken rudder. CG boat located and assisted vessel.
F/V LADY JUANITA Taking on Water 4/29/97	Gulf of Mexico	30	2 Saves	Master manually activated EPIRB because he could not reach anyone by radio. Vessel taking on water, CG responded based on information from POC and helped de-water the vessel.
S/V GYPSEA Dismasted and low on fuel 5/18/97	North Atlantic Ocean	50	4 Protected	Master manually activated EPIRB because he could not reach anyone by radio. Vessel taking on water, CG responded based on information from POC. Another vessel responded to CG's request for assistance and provided fuel to S/V GYPSEA.
P/C TRASH FEST Disabled 6/8/97	Charleston, South Carolina	2	2 Protected	Activated EPIRB to alert CG. No other long range communications due to wave-damaged electronics. CG aircraft located and assisted vessel.
All Terrain Vehicle Broken Down 7/7/97	North Slope of Alaska	60	2 Protected	Activated PLB to alert State Police. No other communications. State Police located and rescued two people.

F/V SAINT PETER Medevac 7/22/97	Southwest Pass, Louisiana	50	1 Save 3 Protected	Activated EPIRB to alert CG. No other long range communications. Master injured and crew unable to pilot vessel. CG aircraft evacuated master and ship assisted vessel to port.
F/V VERI AMICI Sank 7/28/97	Martha's Vineyard, Massachusetts	6	2 Protected	Activated EPIRB to alert CG. No other communications. Vessel sank and crew abandon ship. CG aircraft located and recovered crew.
S/V FINAL CALL Sunk 8/18/97	200nm SE of Nantucket, Massachusetts	67	1 Save	Activated EPIRB to alert CG. No other communications. Master abandoned ship when vessel sank. CG aircraft located and recovered crew.
F/V LIBERTY Disabled / Adrift 9/17/97	Texas Gulf Coast	5	5 Protected	Activated EPIRB to alert CG. No other communications. Vessel was disabled and adrift. CG aircraft located vessel and ship assisted.
F/V SEA CRITTER II Vessel Sank 9/10/97	Anclote Key, Florida	34	2 Saves	EPIRB activated automatically when the vessel sank. Crew were scuba diving at the time. CG responded based on information from the POC in the registration database. Helicopter hoisted two people from a life-raft.
F/V FRANKIE Vessel on Fire 9/23/97	Coos Bay, Oregon	No LEO Alert	3 Saves	Master manually activated EPIRB when he lost all communications due to fire. CG responded by posting a lookout in the Coos Bay Tower who eventually sited a flare. CG arrived on scene and extinguished the fire.

The results show that the GEOSAR system provided earlier notification than the LEOSAR System ranging from two minutes to 67 minutes and in some cases provided the only notification. Overall, in the United States service area, 11 lives were saved and 37 lives were protected during the D&E period. Additionally, three vessels were saved and nine vessels were protected which could be attributed to the GEOSAR system.

These cases document the complementary nature of the GEOSAR and LEOSAR Systems. In several cases, the SAR forces were able to launch on the GEOSAR alert and then divert resources to the exact position based upon the LEOSAR alert. The usefulness of the information obtained from the contact person identified in the registration database, available at an earlier time due to the GEOSAR alert, was also shown in many cases.

Using such examples, it may be possible to educate the public on the benefits of the GEOSAR system. This will ultimately lead to increasing the public's reliance on, and use of, 406 MHz beacons. Therefore, the significant benefits of the GEOSAR system should be publicised to all appropriate organisations.

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6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Conclusions based on the analysis of the data collected during the D&E are presented below.

The technical results of the D&E show that:

- beacons meeting the requirements of C/S T.001 (406 MHz Beacon Specification) can be reliably detected by the GEOSAR system;
- the time required for a GEOLUT to produce an alert after beacon activation was only a few minutes, indicating that near-instantaneous detection and alerting of 406 MHz beacons could be expected;
- calibrated frequency measurements performed by the GEOLUTs were reliable and proved accurate enough to permit use of GEOSAR derived frequency data in improving LEOSAR positioning estimates. The testing indicated that the combining of calibrated GEOSAR frequency data with LEOSAR beacon data points could improve the location accuracy of Doppler solutions derived from five or fewer points, and the A/B ambiguity resolution probabilities of LEOSAR solutions;
- even though beacons were often detected out to the edges (and beyond) of the GEOSAR footprints, 4° is a conservative value to use as the published minimum elevation angle required to assure reliable GEOSAR reception of 406 MHz beacons;
- sufficient technical data had been collected and analysed to develop GEOLUT specifications; and
- sufficient technical data had been collected to recommend the incorporation of the GEOSAR system as a complement to the Cospas-Sarsat system, despite technical objectives T-4, T-5, T-7, T-8 and T-9 not having been fully completed.

Operational results from the D&E are summarised in the following paragraphs.

In respect of the potential GEOSAR system alerting time advantage over the LEOSAR System, the D&E results indicate that:

- on average, a GEOSAR alert was received 46 minutes before the first corresponding LEOSAR alert, with a median time of 21 minutes; and
- the time advantage gained by the GEOSAR system's near-instantaneous alerting was clearly shown to benefit the outcome of the SAR activities as additional lives and property could be saved.

Concerning the availability and use of 406 MHz beacon registration data bases, the D&E results show that:

- the usefulness of the earlier GEOSAR alert notification was dependent to a large extent on the availability, completeness and accuracy of 406 MHz registration databases;

- beacon registration information, when available, could be used to obtain rough location information from emergency contact persons, enabling SAR personnel to take advantage of the earlier notification provided by the GEOSAR system even when encoded position information was not available in the beacon message;
- SAR forces could correlate GEOSAR alert data with other types of information (i.e. mayday calls, overdue reports, flare sightings, and high flyer reports), and in those cases with correlating beacon registration information, the GEOSAR alert could be sufficient to initiate search activities without having established any contact with emergency points of contact; and
- for GEOSAR and LEOSAR alerts, database information often allowed the RCCs and SPOCs to gather the information necessary to quickly distinguish between real and false alerts thereby preventing the launch of resources on false alerts.

In respect of the measurements of 406 MHz beacons transmission duration, the D&E results show that:

- because of the near-instantaneous detection capability of 406 MHz distress beacons by the GEOSAR system, beacons which transmit for only a short duration (e.g. catastrophic incidents or beacon failure) would probably be detected by the GEOSAR system;
- in cases in which the beacon transmitted for only a short duration, the LEOSAR System would possibly not detect the transmissions because there was no satellite overflight during the transmission period. This was demonstrated by several documented SAR events where a GEOSAR alert was the only alert received;
- a large proportion of the GEOSAR alerts were derived from single burst messages or from beacons with a very short transmission durations. This would suggest inadvertent activation or testing of beacons. This finding confirmed the need for improved education and training in beacon handling, testing, and maintenance procedures. In addition, the possible implications of these short-term transmissions on the GEOSAR system and SAR forces should be publicised to appropriate international organisations and national administrations; and
- information provided from the D&E on the number of 406 MHz beacons being activated and their average time of operation could be used in computing 406 MHz system traffic estimates and in determination of system capacity.

The D&E results show that the beacon detection capability of GEOSAR satellites within their coverage area was found to provide a good complement to LEOSAR System. The vast majority of alerts within the GEOSAR satellite footprints were detected by the GEOSAR system, and valid explanations existed for those beacons that were not detected.

In respect of impact on the Ground Segment of the Cospas-Sarsat System, the D&E results indicate that:

- the volume of GEOSAR alert traffic processed at MCCs varied among the MCCs, but was generally considered to have minimal impact on the workload of those MCCs;

- the number of system-generated false alerts reaching a RCC or SPOC was extremely low as the D&E participants took effective measures to filter alerts before transmission. However, further analysis would seem to be justified to determine if there is any potential increase in system-generated false alerts as beacons using location protocols become more widespread; and
- GEOSAR alert data was effective in resolving LEOSAR location ambiguity, even though manual processes had to be used during the D&E period.

In summary, the D&E confirmed that the GEOSAR system provided significant benefits which could complement the Cospas-Sarsat LEOSAR System. The D&E indicated that incorporation of the GEOSAR system as a complement to Cospas-Sarsat Programme would provide the potential for saving additional lives and property.

Finally, the D&E highlighted the fact that the 406 MHz beacon user community needs to be informed of GEOSAR system performance in respect of the Cospas-Sarsat System. It should be noted that the implementation of the GEOSAR system as a complement to the Cospas-Sarsat System could have a large impact on users of 406 MHz beacons. The D&E emphasised that greater care in the use of the 406 MHz beacons will be required, as inadvertent activations (even of short-term duration) would probably be detected by the GEOSAR system and set off an unnecessary chain of events with a corresponding use of SAR resources. All Administrations, international organisations, and users of 406 MHz beacons need to be fully educated and warned about the possible consequences of these implications.

6.2 Recommendations

Recommendations arising as a result of the 406 MHz GEOSAR D&E are given below.

As the D&E confirmed the expected benefits of the GEOSAR satellite system as a complement to the Cospas-Sarsat LEOSAR System, it is recommended that:

1. the Cospas-Sarsat Council consider adopting the 406 MHz GEOSAR satellite system as an enhancement and complement to the Cospas-Sarsat System; and

2. the Cospas-Sarsat Council should initiate all actions necessary for this enhancement including the commissioning, as soon as possible, of the existing experimental GEOLUTs.

Additional recommendations were developed related to the actions necessary to ensure the optimal technical and operational performance of the enhanced Cospas-Sarsat System.

The operational results indicate that users of the Cospas-Sarsat System need to be educated about the enhancements provided by the 406 MHz GEOSAR system, and therefore:

3. the Cospas-Sarsat Secretariat should publish and widely distribute the results of the D&E; and

4. all manufacturers, administrations and others, who develop educational programs and materials should stress the importance of proper handling, shipping, storage and testing of 406 MHz beacons.

The technical and operational results indicate that in order to make full use of GEOSAR alert data, that:

5. all administrations should establish and maintain complete, accurate, and up-to-date beacon registration databases that are available for SAR agency access on a 24-hour a day basis; and

6. Ground Segment Operators should consider the use of GEOSAR detections to resolve LEOSAR location ambiguity, agree on a standardised procedure for inclusion in document C/S A.001 (DDP), and implement software in the MCCs to automate the agreed procedure.

Finally, results from the operational tests indicate that, in order to minimise the potential for false alerts to the system:

7. all administrations should review beacon test policies and procedures and revise them as necessary to reflect incorporation of GEOSAR alerts in the Cospas-Sarsat System.

6.3 Actions to be Completed

This section provides a number of recommended actions that should be undertaken by the Cospas-Sarsat Participants. These actions include completion of the technical tests not concluded during the D&E, further investigation of some findings, and the resumption of data distribution procedures according to the DDP. The recommended actions follow.

1. A number of cases were reported during the D&E where the GEOSAR alerting time advantage was over three hours. Further investigation indicated these were usually due to the LEOSAR coverage geometry, although for about one-third of the cases, LEOSAR coverage was available but no LEOSAR alert was received. Additional investigation should be conducted for those cases in which the GEOSAR system provides an alert more than three hours earlier than the LEOSAR System.

2. Participants should review those cases, as appropriate, in which the first LEOSAR alert for a beacon activation is received prior to the first GEOSAR alert. The D&E results show that this condition existed in 15% of the reported cases with no explanation of the apparent anomaly.

3. Ground Segment Operators should continue to study the feasibility, usefulness, and impact on System operations of using GEOSAR derived information in conjunction with LEOSAR beacon messages to produce improved location processing when a minimum number of beacon bursts are available.

4. Technical tests T-4, Beacon Processing Capacity, T-5, Impact of Interference, T-7, Impact of Updating Encoded Position Data, T-8, System-generated False Alerts and T-9, Impact of Systems Beacons could not be completed because of the Peruvian radio frequency interference problem and are, therefore, recommended for completion when the interference problem is resolved.

5. Further testing is recommended for objective T-3, Carrier Frequency Measurement Accuracy at lower beacon power levels and for objective T-10, Combined Operations, because of the small sample size used for the results reported here.

6. With the D&E data collection now complete, the special MCC data distribution procedures no longer apply and MCCs should now conform to the latest issue of the DDP (C/S A.001).

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7.0 INDEX TO VOLUME II

7.1 Technical Objectives Reports

7.2 Operational Objectives Detailed Data Tables

7.3 National Reports

7.4 Other Reports

1. Theoretical Calculation of Potential Time Advantage for a Nominal Cospas-Sarsat System
2. Canada-United States Mission Support Plan for Technical Objectives

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