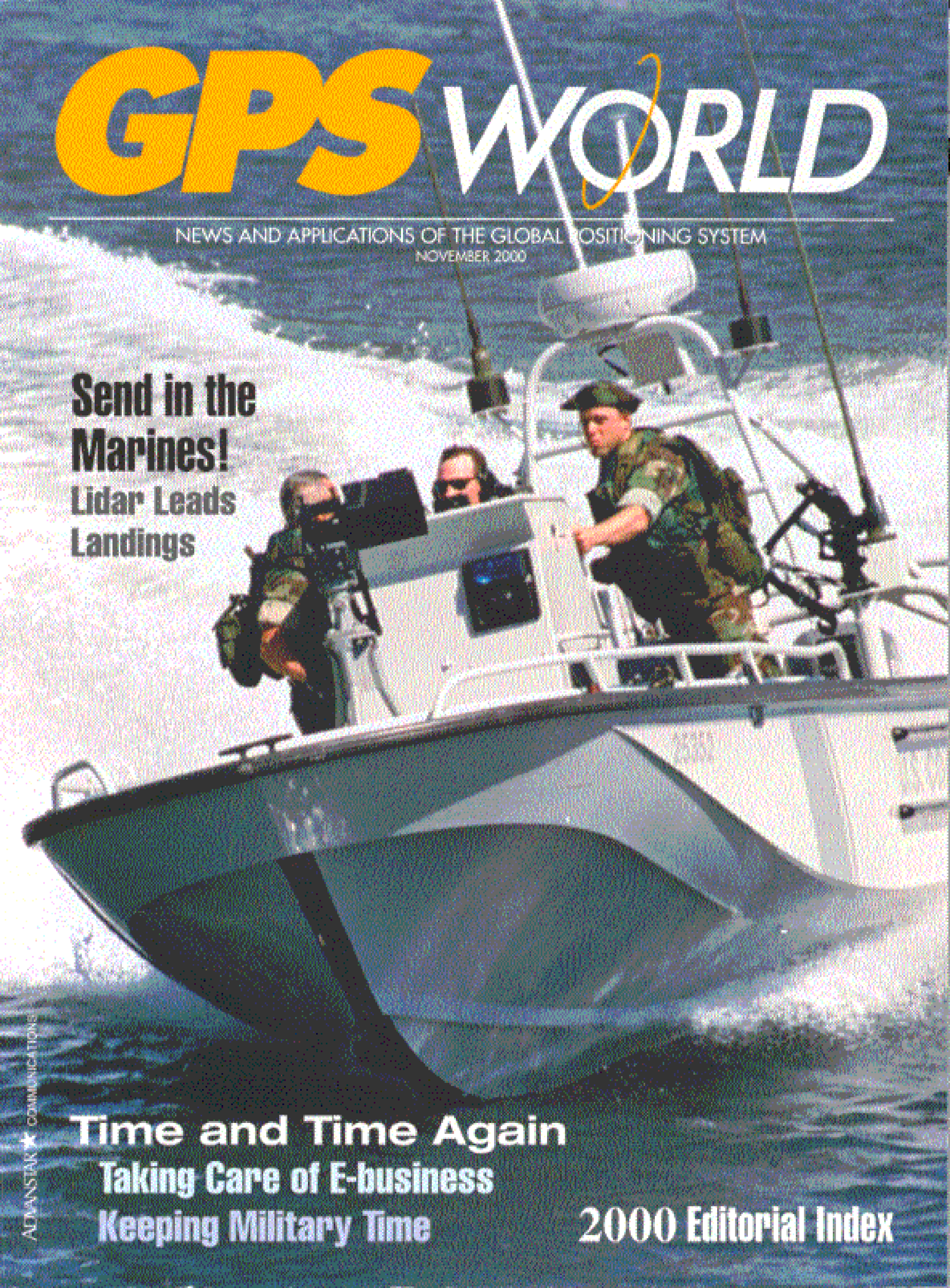
GPS WORLD

NEWS AND APPLICATIONS OF THE GLOBAL POSITIONING SYSTEM

NOVEMBER 2000



Send in the Marines!

Lidar Leads Landings

Time and Time Again

Taking Care of E-business

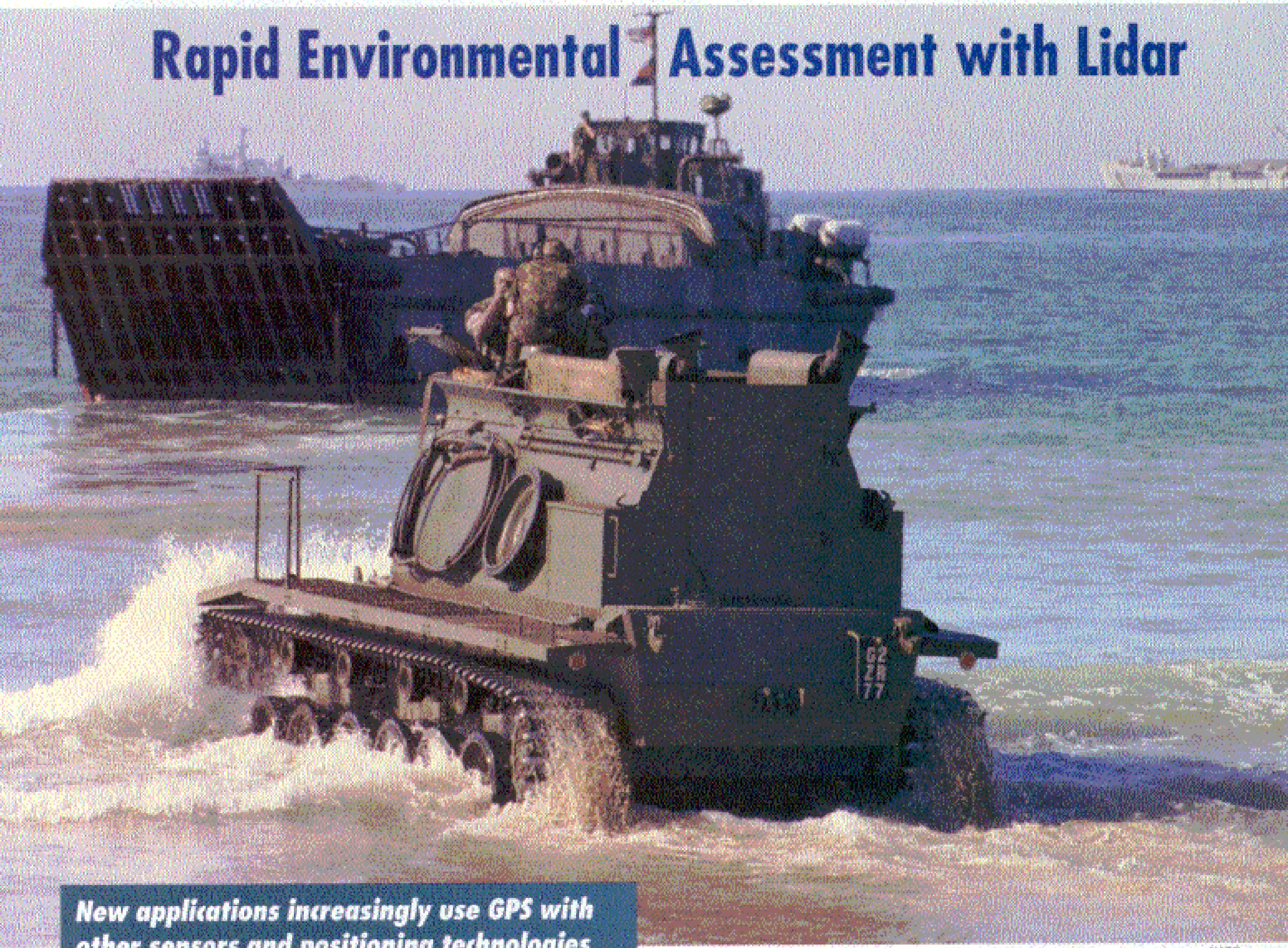
Keeping Military Time

2000 Editorial Index

ADVANSTAR ★ COMMUNICATIONS

GPS Sends In the Marines

Rapid Environmental Assessment with Lidar



NATO

New applications increasingly use GPS with other sensors and positioning technologies for synergistic results. SHOALS (Scanning Hydrographic Operational Airborne Lidar Survey) combines kinematic and differential GPS with laser technology to survey coastal water depths. SHOALS gets the job done more rapidly than conventional bathymetric surveys, and can operate in more adverse weather conditions. The authors provided clear, precise information to multinational Marine units landing on unknown beaches — an operation often fraught with uncertainty and critical vulnerability.

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The two-mile ride from the Landing Platform Dock (LPD) ship anchored offshore seems like an eternity to the Marines in the Landing Craft Vehicle and Personnel (LCVP). Confined in a flat-bottomed shoebox-shaped craft, with sea-keeping qualities to match, they check their equipment, brace themselves through a heavy roll, or reach for a bucket as breakfast escapes. Devoid of outside references except for the sky above, they wait for the ramp to go down and the first few minutes ashore that will determine the outcome of their landing.

The craft slows, the ramp lowers, and the Marines enter an environment requiring quick appraisals and split-second decisions. Eyes immediately leap to the skyline backing the beach, where exit routes and objectives must be quickly identified. The approaching beach presents exposed terrain where they will be at their most vulnerable. Down the ramp, they see blue-gray water through which they must struggle while attempting to keep themselves and their equipment as dry as possible. Ashore, an unknown host may lie in wait, intent on throwing them back into the sea. The Marines are landing, in an environment beset by uncertainties.

The reality of "hitting the beach" has scarcely changed since World War II. D-Day took months to plan, but uncertainties and unknowns meant that some landing craft left their mother ships so far offshore that they were hit by enemy fire before they could make it in; other craft hit the wrong beaches; and most tragically of all, some troops stepped off the ramp into chest-deep surf where they drowned without touching shore.

Despite the advent of helicopters and hovercraft, modern amphibious landings are still based on techniques and principles used in 1944. To complicate this situation, most modern military deployments are initiated at much shorter notice and involve rapid worldwide deployment. The challenges of maneuvering maritime forces in highly variable littoral waters that are not historically well known and where opponents pose a significant threat require commanders to commit considerable resources to assessing and minimizing risks through increased battlefield knowledge.

Requirements to perform missions spanning the continuum of military operations and now including crisis response, peace support, and humanitarian interventions create further challenges.

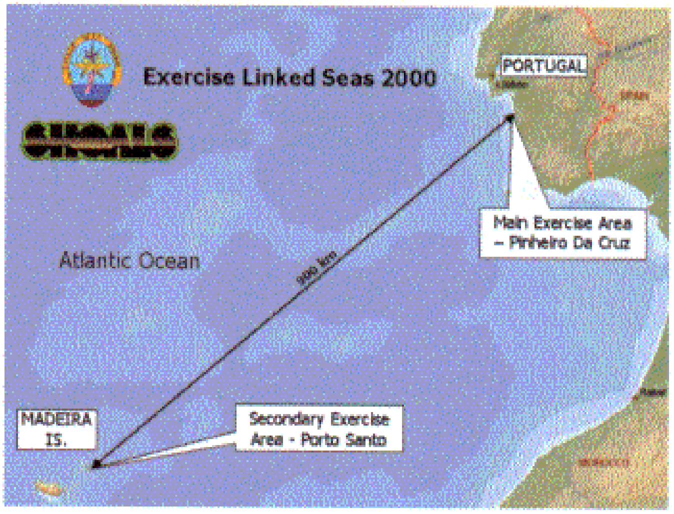
Military planners and the warfighters themselves require faster, more flexible response techniques. And since the battlefield is essentially a geospatial problem, such technologies increasingly incorporate GPS.

LINKED SEAS

In April 2000, the North Atlantic Treaty Organization (NATO) conducted the Linked Seas 2000 (LS00) peace support training exercise. LS00's objective was to resolve a border conflict between two fictional non-NATO countries. The theater of operation covered the eastern Atlantic Ocean including the Bay of Biscay, northwestern Spain, and Portugal's mainland and Madeira Archipelago. LS00 focused on an evolving military vision for crisis response, peace support, and humanitarian interventions, possibly conducted outside NATO's normal area of responsibility.

The focus on crisis response operations has fundamentally changed the nature of ocean and coastal support requirements. To ensure the safe and effective deployment of maritime forces, commanders now require a capability to rapidly characterize regions of interest far from their known environment. Such sensitive areas have recently included Kuwait and East Timor.

Objectives. LS00 goals included a Rapid Environmental Assessment (REA) phase to support 80 warships, two Marine battalions, 11 Special Forces teams, and 125 aircraft. An REA characterizes the physical, meteorological, and hydrodynamic properties of a site. Accurate and detailed terrain and bathymetric (depth measurement) mapping forms REA's core. This information enables the main body of the amphibious task group — the "mother ships" — to approach as close inshore as water depth will allow, minimizing the slow landing craft's transit distance to the beach. Closer inshore, detailed bathymetric information, particularly bottom gradient information, is critical to ensuring that the landing craft drop the troops as close to the beach as possible without becoming stranded. Finally, on the beach, the landing force needs intimate knowledge of the area to make maximum use of the terrain for cover and to clear the exposed beach via the most trafficable routes.

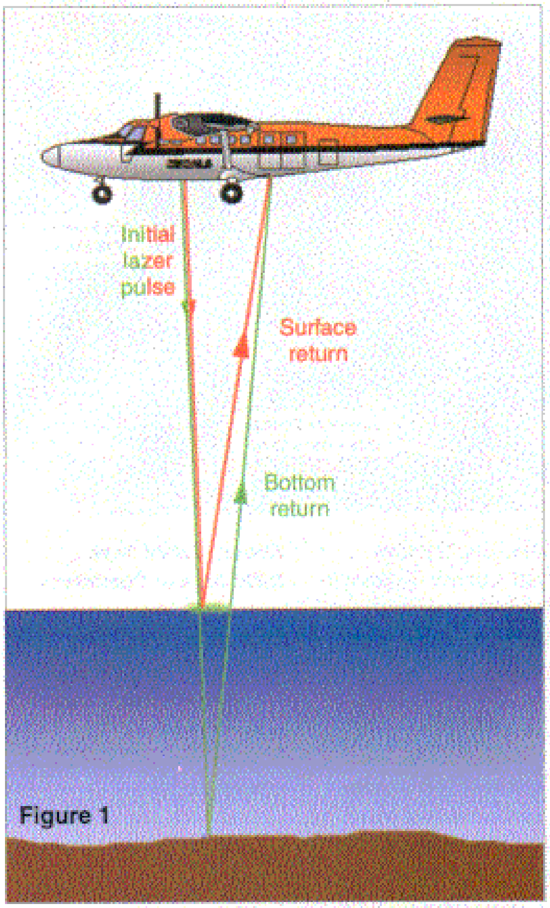


Above, Linked Seas 2000 Area of Operations

Facing page, amphibious landing of Spanish Marine Battalion armored vehicle at Pinheiro da Cruz (NATO photo)

FUSING SENSOR DATA

The LS00 REA tested operational assets for rapidly carrying out a coordinated environmental reconnaissance of unfamiliar littoral operating areas, employing air, sea, and space sensors and fusing this data with data from archive searches and computer modeling. SHOALS (Scanning Hydrographic Operational Airborne Lidar Survey) system for mapping and charting came to the head of this testing list. The Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX), a partnership between the U.S. Army Corps of Engineers (USACE) and the US Naval Meteorology and Oceanography Command (COMNAVMETOCOM), operates the SHOALS program. JALBTCX set out to demonstrate the value of airborne lidar (light detection and



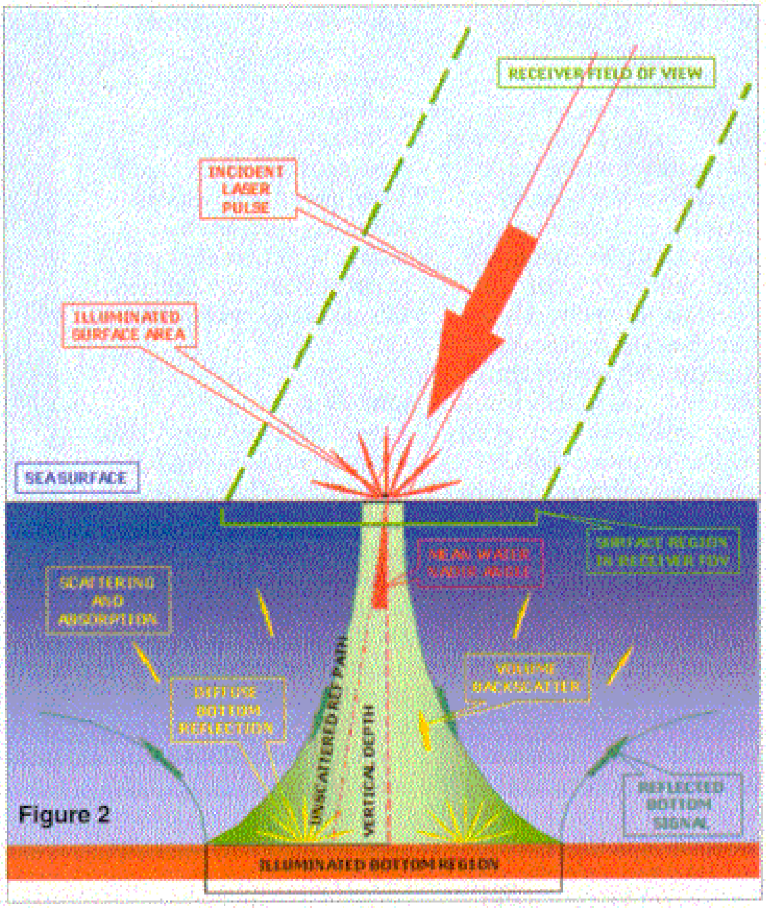


Figure 1 Infrared light is reflected from the sea surface, while blue-green light is reflected off the seabed. The time difference between the two indicates the water depth.

Figure 2 Laser energy is lost due to refraction, scattering, and absorption effects. In practical terms this means that depth detection is limited to three times the visible depth.

ranging) mapping and charting, incorporating GPS technology, to support the warfighter.

LIDAR HYDROGRAPHY

An airborne lidar hydrography (ALH) system uses laser technology to directly measure water depths. An aircraft–mounted laser transmitter/receiver (transceiver) transmits a laser pulse that travels to the air-water interface where a portion of its energy reflects back to the transceiver. The remaining energy propagates through the water and reflects off the sea bottom. The system derives water depth from the time lapse between the surface return and the bottom return, and appropriately corrects each sounding for surface waves and water level fluctuations (see Figure 1).

In practical applications, laser energy is lost due to refraction, scattering, and absorption at the water surface, sea bottom, and as the pulse travels through the water column (Figure 2). The combination of these effects limits the strength of the bottom return and therefore limits the maximum detectable depth. Optical water clarity is the most limiting factor for ALH depth detection. Typically, an ALH collects through depths equal to three times the Secchi (visible) depth.

THE SHOALS SYSTEM

In 1994, the USACE completed development of the SHOALS system, and it became the first fully operational ALH system available for use by the Department of Defense. Mounted on either a fixed-wing Twin Otter, a Bell 212 helicopter, or other aircraft of opportunity, SHOALS operates at an altitude of 300 meters and a speed of 30 meters/second, giving a survey swath width of 110 meters and a horizontal data point spacing (spot density) of 4 meters. SHOALS' survey rate is nominally 16 square kilometers per hour.

The SHOALS system uses a scanning, pulsed, infrared (1064 nanometers) and blue-green (532 nanometers) laser transmitter with four receiver channels that each record energy versus time (waveforms). The longer wavelength infrared light reflects from the sea-surface and provides air-water interface detection, while the blue-green light penetrates the water and reflects off the seabed, yielding depth data. Two receiver channels track the blue-green light, one optimized for shallow water (less than 13 meters) and the other for deep water (more than 6 meters). The other two channels track the sea surface. One receives reflected infrared energy, but in flat calm sea conditions much of this is reflected away, requiring another solution. The fourth channel detects Raman (645 nanometers) energy resulting from excitation of the surface

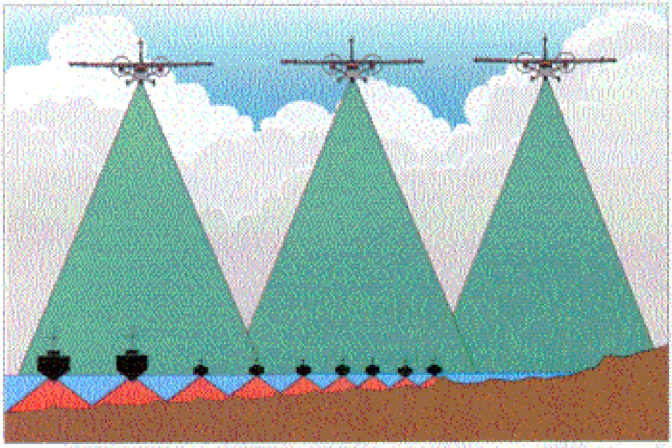


Figure 3 Multibeam (MBES) surveys become progressively more inefficient (and hazardous) as water depth decreases. ALH in contrast provides quick, high resolution results seamlessly across the land/water interface.

water molecules by the blue-green light. This also helps distinguish between land and sea returns since land returns little or no Raman energy.

GPS IN SHOALS

In response to the USACE's need to map the upland beach, dunes, and above-water portion of coastal structures, SHOALS incorporated kinematic GPS (KGPS) technology in 1996 to include topographic capabilities. Unlike most topographic lidar systems, which use an infrared frequency, SHOALS uses its blue-green frequency to measure topographic elevations.

SHOALS positioning comes either from differential GPS (DGPS) provided by US Coast Guard beacons and the OmniSTAR satellite system or from KGPS provided by local stations. DGPS is used for projects with minimal or no requirement for land topographic elevation data since it is used for horizontal positioning only and all vertical measurements are referenced to the local water surface. In practical terms this means that land elevations can only be determined if they constitute less than half of the 110-meter swath. Consequently, vertical accuracy is heavily controlled by conventionally measured or modeled tide elevations. When KGPS is used, this limitation is overcome since vertical measurements are then directly related to the GPS-observed ellipsoidal height and are therefore independent of the water surface.

An inertial reference system mounted with the laser optics orients individual laser shots within the angular reference frame and is not integrated directly with the GPS output. Collection of 400 measurements per second makes timing critical, and GPS is thus pivotal in the whole system.

Table 1 summarizes SHOALS current performance characteristics.

In addition to the lidar depth and elevation measurements, a georeferenced down-look video camera provides a visual record of the survey area. These video recordings frequently assist with positioning coastal structures, navigation aids, piers, and other objects of interest. The video also serves as an auxiliary check for anomalous data.

Table 1: SHOALS performance specifications.

Maximum depth	to 60 m
Vertical accuracy	±15 cm
Horizontal accuracy	
DGPS	±3 m
KGPS	±1 m
Sounding density	4-m grid (variable)
Operating altitude	300 m (variable)
Scan swath width	110 m (variable)
Operating speed	50 to 70 m/s

LIDAR ADVANTAGES

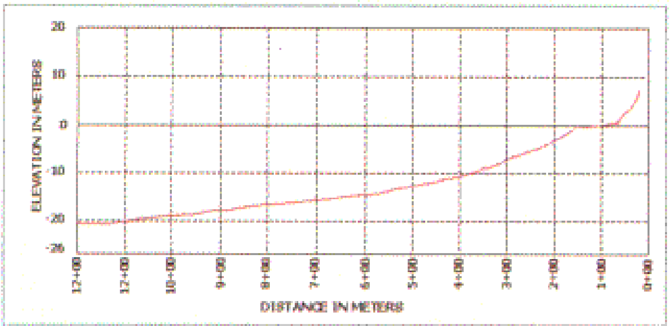
As it exists today, ALH (specifically the SHOALS system) has several significant advantages over conventional acoustic fathometer surveys which typically involve using single-beam or multibeam echosounders (SBES and MBES) from launches and combining their data with terrestrial land-leveling techniques to measure a series of gradients (profiles) across the beach. Such methodologies suffer primarily from their slow speed of progress and exposure of the survey launch to the same sub-surface hazards that threaten the landing craft. The uncertainty in the areas between discreet surveyed gradients creates a further problem. Although KGPS techniques would appear to offer some opportunities, their impact has been severely restricted by the tendency of many landing beaches to be affected by multipath and masking associated with adjacent cliffs.

ALH overcomes almost all of the limitations experienced by surface assets, providing quick, high-resolution results seamlessly across the land/water interface with much reduced exposure to hazards.

Comparison. In a typical conventional beach survey incorporating a survey launch and a beach team, up to seven personnel might survey 10 beach gradients spaced 25 meters apart from the back of the beach to the 10-meter depth contour during a 3-hour period (250 meters of beach). In an equivalent period, SHOALS with a crew of three could provide complete coverage at 4-meter data point spacing for up to 10 kilometers of similar beach out to the 20-meter depth contour. The ALH solution allows the military planner far more flexibility to choose alternatives within the larger area, while the high density of the data provides seamless terrain models from the nearshore through the adjacent upland area for LOTS (Logistics Over The Shore) and other tactical operations.

DATA COLLECTION

The SHOALS REA mission required bathymetric surveys of Pinheiro da Cruz and Porto Santo, Madeira. Pinheiro da Cruz is located about 30 km south of Lisbon and is an unpopulated stretch of coast consisting of high sand dunes and wide beaches. Porto Santo, Madeira, is located 1,000 km offshore of Portugal and included three small survey sites. Two of these sites perch between rock headlands and the third sits



Top, Pinheiro da Cruz, 30 kilometers south of Lisbon. The picture was taken during a low-level pass by SHOALS.

Middle, the beach adjacent to the main harbor at Porto Santo in the Madeira Islands.

Bottom, beach gradients cut across the SHOALS data are critical for evaluating landing craft beaching areas.

along open coast next to the main harbor.

Our involvement began on April 11, 2000, when we redeployed five team members from a UK project to Sintra in Portugal, near NATO's South Atlantic Headquarters (SOUTHLANT). The next day our Twin Otter aircraft with two pilots and one flight engineer arrived at Sintra Portuguese Air Force base and flight planning for the first scheduled SHOALS flight began.

The LS00 REA team produced meteorology and oceanography forecasts and U.S. Naval Oceanographic Office (NAVOCEANO) provided navigation charts for survey flight-line planning. Each planned survey flight was to collect land elevations, water depths, video imagery, and digital pictures of the area.

After a delay due to an unrelated live-fire exercise in the operational area, April 16th dawned revealing very poor weather conditions: steady onshore winds around 25 to 30 knots, sea/swell heights between three and five meters and a similar forecast for the next few days. These conditions ruled out operations by the ship-based beach survey teams, hove-to off Pinheiro da Cruz waiting for an opportunity to get onto the beaches. But the SHOALS team went ahead.

FLIGHT NARRATIVE

The airborne operator picks up the story from here.

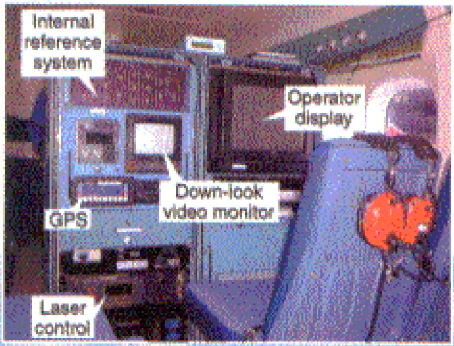
"After pre-flight calibration of the inertial system and system checks, including the OmniSTAR link, we took off for the survey area. Just prior to arriving at Pinheiro we descended to 300 meter survey altitude and test fired the laser in preview mode. I gave the pilots the 'OK' to reference their altimeter to the altitude output from the system. Sitting behind the operator panel five meters aft of the pilots, I have no visual contact with them, so precise communications are very important.

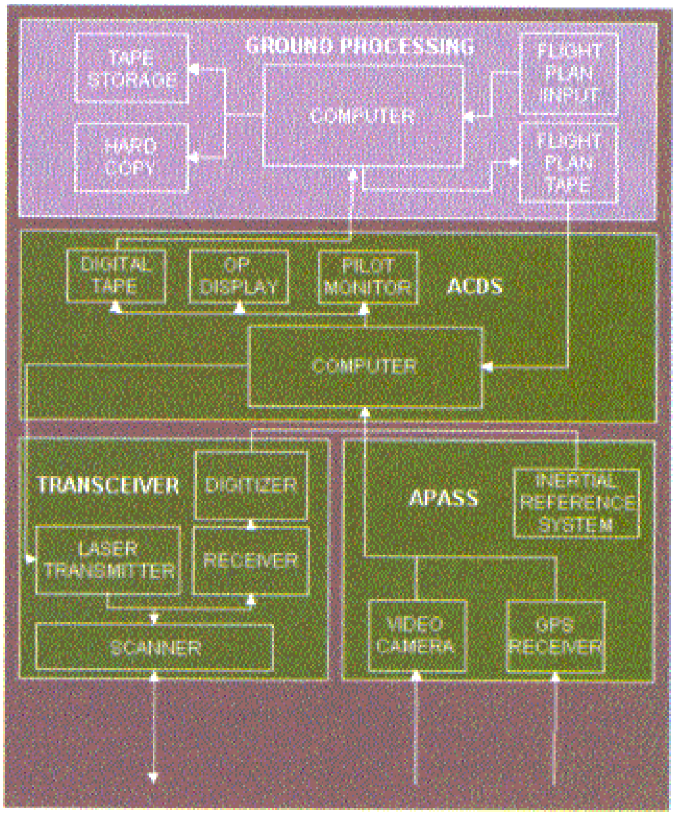
"We selected the first waypoint for the work area and continued down the coast to begin the survey in earnest. I instructed the pilots to perform a shoreline pass, placing the plane directly over the land /water interface to check the accuracy of the digital shoreline used in flight planning, and to collect data along the beach relative to the water surface.

"While the relatively straight shoreline orientated North/South would in theory aid survey economy, the strong west wind caused a crab angle of about 20 degrees, which reduced the effective swath width. In extreme conditions this can require flying extra lines. The beach topography, with a broad slope leading up to a pronounced dune line with sand cliffs, also created bumpy flying conditions. Off to the west we saw both amphibious shipping and survey ships waiting for the weather to subside.

"The surf zone along the beach was very active, with breakers extending out 100 meters from shore, while gray, overcast conditions gave a gloomy cast to the whole day. However, this was not all bad since the lack of bright sunlight meant that sun glare and glint which can cause processing difficulties, would not be a concern. Completion of the first line along the coast set the pattern for the rest of the flight, and we began 'mowing the grass,' flying a pattern of consecutive lines in alternating directions."

Despite the weather, the four-hour flight covered the required 16-kilometer section of coastline, with land elevations up to 14 meters above the low water line and depths down to 22 meters. As we had feared, severe surf, a strong light reflector,





Top right, schematic of the SHOALS system. The lower three boxes comprise the airborne system.

Top left, the SHOALS airborne system is a compact and rugged installation which can be operated by one person.

SHOALS is currently flown in a DHC6-300 Twin Otter, a versatile STOL aircraft with a survey endurance of more than five hours.

Bottom, the transceiver, co-located with the inertial reference system, is positioned over a standard photogrammetric window in the fuselage.

prevented data collection across the surf zone. The Twin Otter returned early next morning to take advantage of slightly calmer weather conditions. We completed data collection in the critical shallow portion of the area (depths between 0 and 2 meters).

On to the Madeiras. Three beaches 1,000 kilometers southwest of Portugal in the Madeira Islands presented our next challenge. On April 18th SHOALS flew to Porto Santo. The following day, we flew three sites and the aircraft returned to Sintra that evening. This concluded SHOALS aircraft operations for LS00 and on 21 April the SHOALS system departed for the United States.

DATA PROCESSING

Following each survey flight, we processed data at our Sintra hotel to produce elevations and positions: approximately 100,000 measurements per square kilometer. Each survey (Portugal and three on Porto Santo) required 24 to 36 hours to complete, with two people processing data and one person generating maps and charts.

SHOALS processing incorporates five stages: tape stripping, auto-processing, manual processing, data cleaning/anomaly classification, and product generation.

Tape stripping and auto-processing run at a 1:1 time ratio with data collection and comprises the most complex part of the process. The stripper reads the tapes, interpolates data from low-rate sensors including GPS to the 400-Hz laser pulse repetition rate, and performs time deskewing and quality checks.

The auto-processor then calculates positions and depths, correcting the latter for tides (in this case predicted tide levels provided by the REA team). This data is then available for geographic display in the manual processor where the surveyor can access individual waveforms and quality indicators, and reprocess or edit as necessary. Once the surveyor is satisfied that the data has been optimally processed it is viewed in a separate 3-D editing package that allows investigation of anomalies.

Mapping. Finally we mapped the data using a standard CAD package and digital pictures of the area incorporated into comprehensive planning charts for the REA and amphibious teams. All data, including a digital version of the down-look video was also provided on CD-ROM for use by the amphibious landing planners.

Although SHOALS-collected data meets USACE Class 1 and International Hydrographic Organization (IHO) Order 1 accuracy standards, we set out to demonstrate here a "quick and dirty" capability. KGPS would have been ideal for provision of topographic information further inland, but the establishment of ground reference stations was contrary to the exercise scenario. Consequently, the use of predicted tide-levels somewhat compromised vertical accuracy, and this error was especially significant when the Pinheiro beaches were affected by extreme meteorological conditions. OmniSTAR horizontal positioning was reliable throughout and SHOALS achieved stated Table 1 accuracies.

NATO

Amphibious landing at Pinheiro da Cruz.

This application . . .

On the Fly

demonstrated

- the advantages of airborne lidar surveying over seaborne singlebeam or multibeam echosounders
- the practicality of airborne lidar in adverse weather and surf conditions
- the rapid data acquisition and digital output formats afforded by lidar
- the importance of rapid, accurate shoreline information characterizing unknown areas in crisis response and humanitarian intervention worldwide

STOIC CHARTS

The final product for the Pinheiro da Cruz site was an unclassified NAVOCEANO Special Tactical Oceanographic Information Chart (STOIC) consisting of color-contoured elevations and a variety of ancillary information, including the SHOALS survey, landing site pictures, beach survey and cross sections, and sea bottom type. The STOIC was produced at NAVOCEANO and digitally transmitted to the theater where it was plotted and disseminated to those planning the landing operations.

The final deliverables for the three Porto Santo sites were similar to the NAVOCEANO STOIC, but were produced onsite by the SHOALS team. We generated these charts in the field specifically to test the ability to create and disseminate final products in-theater.

SUPPORTING THE TROOPS

We designed our final SHOALS products and schedules for the LS00 REA mission with the objective of using operational assets to rapidly carry out a coordinated environmental reconnaissance, fusing data and information to characterize unfamiliar littoral operating areas. Our final paper plots conveyed detailed information about each site, yet in a simple format. Each SHOALS plot included color-contoured depths, beach elevations and beach survey cross-sections plotted on several transect lines along with the overall map. Digital pictures collected during each flight and included on the final plots augmented this data. One plot, the size of an average nautical chart, presented complete environmental information to the warfighter.

In addition to the paper plots, all SHOALS data was provided to the REA Commander for other purposes. Digital elevations and depths helped create grids for numerical forecast models, and the video provided a qualitative understanding and knowledge of the area.

And so they landed. All LS00 landings by Spanish, Portuguese, French and Romanian marines, supported by multinational naval forces including the US Coast Guard, ran smoothly in almost perfect weather conditions (which SHOALS had nothing to do with). They were assisted by comprehensive bathymetric and topographic information, including both perspective and overhead digital photography (which SHOALS had everything to do with). During the survey period the weather remained adverse off the Pinheiro beaches and the ship-based teams never made it ashore, leading one LS00 participant to comment "SHOALS put the Rapid in REA." ■

ACKNOWLEDGMENTS

The authors would like to thank the field team, pilots, and all SHOALS and JALBTCX personnel for their hard work, long hours, and dedication. Special recognition goes to Cdr. Elizabeth A. Spencer for her leadership of the REA Team and her contributions to the SHOALS mission. The US Naval Oceanographic Office, US Army Engineer District, Mobile, and US Army Engineer Research and Development Center provided funding and work for the projects, analysis, and resulting data described here.

For further information about SHOALS and lidar surveys, see http://shoals.sam.usace.army.mil.

MANUFACTURERS

Optech Inc. (Toronto, Canada) designed and developed the SHOALS system under a development effort begun in 1988, and cost-shared between the USACE and the Canadian government under the U.S./Canadian Defense Development Sharing Program. The main components of the system are a diode-pumped laser built by **Cutting Edge Optronics, Inc.** (St. Charles, Missouri) and a **Litton Aero Products** (Woodland Hills, California) *LTN 90* inertial navigation system. The system incorporates **Ashtech** (Santa Clara, California) *Z12* dual frequency receivers in the aircraft. WADGPS services are primarily provided by **OmniSTAR** (Houston, Texas). The system has been operated since its delivery under contract by **John E. Chance & Assoc. Inc.** (Lafayette, Louisiana), one of the **Fugro** group of companies, and is currently flown in a DHC6-300 Twin Otter aircraft from **Kenn Borek Air Ltd.** (Calgary, Canada).

The use of trade names does not constitute an endorsement in the use of these products by the U.S. Government.

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