Developments in defence and security at sea

"The South African Navy, as the major component of the joint Maritime Defence capability, is required to remain robust and relevant within the evolving nature of warfare and spectrum of conflict so as to protect and defend South Africa's maritime interests through concentric layers of maritime defence involving surface, sub-surface and air dimensions. The concentric layers are focussed on South Africa's ports, territorial waters, trade routes and marine resources."
(RSA Draft Defence Review 2012, p283)

With over 95% of South Africa's trade reliant on sea-borne trade, the freedom of the seas, the right of innocent passage and the protection of the trade routes for merchant shipping have made the maritime domain a fundamental matter of national security.

South Africa has one of the longest coastlines in Africa stretching for about 3,924 km at the high water line, with an exclusive economic zone of 1,553,000 km^2 of which the areas around Marion and Prince Edward Islands comprise 474,400 km^2. This implies that South Africa carries the obligation to control and enforce state authority over 4,340,000 km^2 of maritime territory. In this, it also requires strong inter-related linkages with neighbouring land-locked countries – especially in the Southern African Development Corridor (SADC) – also dependent on maritime trade for economic prosperity.

South Africa's dependence on maritime transport is a factor of its being an Island Economy: The bulk of the country's Gross Domestic Product (GDP) is generated through trade which is conducted via seaborne transport or merchant shipping. For example, 75% of oil importation – a critical economic resource – reach South Africa from the Middle East via the sea. Not only a trade route, our oceans also underpin an important fishing industry and a wealth of natural resources (minerals, energy and marine life) requiring protection against irresponsible harvesting and poaching.

A considerable rise in piracy activity along Africa's coastline, has caused concern for the peace, security and stability of the continent and is seen as a direct threat against the international sea-lines of communication from the Americas and Europe to the Middle East and Asia.

The South African Defence Force has the responsibility to ensure the security of South Africa, its people, sovereignty, territory and national interests. This means having the ability to anticipate, deter, prevent, intervene and stabilise any potential threatening occurrences. Within our joint maritime defence capability involving surface, sub-surface and air dimensions, a major component of responsibility rests with the South African Navy.

This implies that the South African Navy should be technologically advanced and equipped to be responsive, effective and have the robustness to sustain a powerful marine security capability.

Current threats necessitate immediate action, but for the longer term the SA Navy is putting effort into a maritime security strategy.

There can be no doubt that a means of providing an integrated maritime domain awareness capability is critical. A combination of static and mobile platforms and sensors, off-shore and seaborne command and control mechanisms need to form part of this.

Once anticipated or detected, a surface combat capability is required to prevent, deter and counter conflict and surface and sub-surface threats. Typically, this capability is vested in Frigate-type vehicles. However, a challenge lies in that perpetrators use both conventional threats (missiles, guns, torpedos, mines, etc) as well as asymmetric threats, not only at sea, but also in the littorals and the confines of anchorages and harbours.

Detection technologies include radar for both long and close-in detection from both ships and ashore. Often the targets are mainly small contacts – i.e. fishing boats used by abalone poachers. In addition, electro optics and Infrared sensors provide the means to detect – and also classify and evaluate the hostility or not of a threat in our waters. This depends, however, on access to data of vessel signatures for comparison.

Underwater, sonar technologies provide a means of detection. The electronic warfare domain has gone to sea as vessel acoustics, communications and electromagnetic signals fall prey to interception and analysis.

The question is not whether the required technologies exist and whether South Africa has the capability to engineer these into robust defence and security systems. The critical issue is the integration of various detection systems, interoperability in the extreme with the means to rapidly respond, deploy counter measures, launch operations to effectively deal with threats and sustain the combat. The commander needs a situational picture that is transferred between different command centres and deployed forces. This includes compatible data links and associated equipment that is able to transfer the situational picture to other users in real time. At present, the CSIR houses an active interoperability centre on behalf of the SANDF, which is continuously further developed as command and control needs evolve.

Even where technology solutions exist, time is the enemy and obsolescence and reliability become problematic. Research into upgrading technology to newer generations, enhanced sustainment and support to smart acquisition are some means of addressing this. Increasingly also non-real tools are playing a large role in preparing for real threats; Simulation and modelling are affordable means of testing scenarios – for doctrine development, training and enhancing standard operating procedures, and are developed at ever increasing levels of complexity.

The CSIR has been involved in maritime security since South Africa required capabilities to project maritime force. The optimisation of the RSA's maritime strategic defence acquisitions (Meko Class Frigates and S109 Class Submarines) relied heavily on technologies developed within the CSIR in order to ensure that operational missions along the African coastlines are successful.

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The ship motion simulator is a modified version of the 3 DOF (Degrees of Freedom) Stewart platform. It operates on a roll and pitch axis at different frequencies and amplitudes using a combination of pneumatic actuators and position feedback into a custom control system. The ship motion simulator will be made available to a local university for postgraduate research on mathematical modelling and control systems studies.

Creating stability in rough seas

Surveillance is integral to the ability of a country's defence force to keep its citizens safe. In the maritime defence environment, our ships at sea need stable images – ideally, even in a 'sea state 7' where ships encounter very rough conditions with 8 m swells every 100 m, cameras on board should provide the crew with stabilised images.

Funded by the Department of Defence through Armscor, CSIR senior control systems engineer, Frenando Camisani-Calzonari, and team member Jason de Villiers tackled the challenge of mechanically stabilising on-board cameras by simulating rough-sea frigate motion in a laboratory.

They used a pan-and-tilt unit to simulate rough sea conditions and only the data from a lighthouse image that had to be kept upright and centered vertically in the camera's field of view in the simulated rough sea conditions. De Villiers undertook the photogrammetric measurements, while Camisani-Calzolari developed the control system.

The deviation or absolute error data was fed back to the pan-and-tilt unit to keep the image stable amidst the sea surges and without the need for costly inertial measurement equipment.

Ongoing work deals with challenges such as the glare of changing light, and processing extensive volumes of incoming data from the hi-resolution cameras. But over time, the outcome was a system that could pick up a specific object, follow it, zoom in on it, fully identify it – in real-time, to allow for immediate action. The team will be working on other platforms for the surveillance systems – such as land-based patrol or response vehicles.

Underwater 3D sonar for South African shipping corridors

CSIR-developed sonar technology is used to produce images showing detailed feature information taken under water, at a level not previously achieved with so few sensor elements. The system is lightweight and easy to handle, less expensive than many other imaging systems and, due to its acoustic properties, of a much higher resolution.

This is the world's first low element-count three-dimensional (3D) underwater imaging system and a comprehensive threat detection system that can locate underwater objects in planar imaging (two dimensional), 3D imaging as well as moving targets. Conventional imaging systems make use of a two-dimensional planar array of sensors to produce an image of a scene. In the underwater domain the discrete nature of these sensors leads to an extremely high level of complexity and cost.

The team developed a set of transducer arrays that exhibit high levels of acoustic performance, a transmission frequency bandwidth of circa 200 kHz as well as specialised signal processing techniques for both the transmit and receive arrays. A range resolution of 4 mm has been measured in laboratory conditions which will enhance the classification and recognition of objects. With range resolution depending on pulse bandwidth rather than pulse duration, an improvement in range resolution of up to 100 times can be achieved. These broad band transducers were made, not just as single element devices but also as multi-element arrays, making use of the composite sensor material properties to be able to pattern electrodes directly to a monolithic structure. This achieves a reduction in device assembly complexity and greatly improves reliability.

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CSIR-developed removable davit system enables integrated anti-piracy operations

The Cape sea route has become a preferred option for shipping companies in response to increasing incidence of piracy along the East African coast line. In response, South Africa has had to consider effective means to combat such activities and safeguarding the integrity of our maritime territory. The South African National Defence Force (SANDF) identified the need to have a larger, more agile, high-speed maritime capability ready for rapid deployment on the ocean. The CSIR developed a novel hosting system that allows for the loading of more – and different types of – vessels onto larger navy ships. During the development phase and undertaking of sea trials, the SANDF needed to respond to an actual piracy threat on the East coast of Africa. With the pilot model of the hosting system installed, the SA Navy had their first success with the CSIR's new system – despite still being in demonstrator version. With such technology as building block to a highly mobile, integrated maritime capability, the SA Navy is in a stronger position to counter maritime threats, protect maritime assets (including natural resources) as well as the economic sea-lines of communication against multi-national crime syndicates and safeguarding the integrity of waters along the South African – and broader African – coasts.

The 2012 Draft Defence Review states: "The substantial increase in acts of piracy along Africa's coastline is of great concern as it threatens the peace, security and stability of the continent. Somali pirates have operated as far south as the Mozambique Channel and as far east as 72° East towards the Maldives. As a direct consequence of the piracy along the east coast of Africa, a growing number of shipping companies have had to route their ships via the Cape Sea Route instead of using the Suez Canal. Such dynamics, together with requests from foreign governments and multilateral organisations, have compelled South Africa to provide a response to such security threats. As such, Defence will play a key role to help combat piracy, especially since recent incidents have occurred along the SADC coastline."

In stepping up to this challenge, the SA Navy very soon realised that their existing anti-piracy deployment capabilities needed to be extended to be larger, faster and more integrated. This came down to the fact that ships needed to carry more than just their own workboats. Not only adding capabilities to the ship load, the solution also needed the required agility to be rapidly deployed and returned to a mother ship – while at speed.

The CSIR's maritime security group already had experience in the field of controlled surface deployment of boats from moving ships. A removable davit system was one solution that was put to stringent sea trials along the Cape Peninsula with various different boats from the Maritime Reaction Squadron, SA Special Forces as well as the SA Navy.

The system comprises of a wave compensating hydraulic davit system mounted on a load vector compensating base. The base also houses the drive system with controls, stored energy for a full operation as well as the logistic support equipment needed for the boat. The complete system fits onto an ISO container footprint mounted and adapted on the ship's deck. The davit system can accommodate boats of various hull shapes weighing up to 5 tons. The boats as well as crew can be lowered and retrieved safely by the davit system with the hosting ship underway. Two of these davit systems are normally fitted to a ship, with another two boats housed in the ships boat bay on CSIR developed cradle systems.

While sea trials were underway, South Africa – through the SA Navy – was called upon to prepare for anti-piracy operations. The Navy requested use of the newly-developed model of the removable davit system for operational application in their combat exercise.

Apart from successfully supporting integrated naval operations on the East coast of Africa, the CSIR-developed capability has also been used in operations up the West coast of Africa. Uses include visit, board, search and seizure, interdiction, insertion and recovery over beaches, as well as augmenting search and rescue capabilities.

The development of the removable davit system has resulted in technology packages that have attracted international attention. The system also potentially offers good business opportunities for SME organisations to support the manufacturing processes involved, stimulating the engineering environment supporting ship building and support within South Africa.

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The CSIR's published research and expertise on the design and performance of wide-band digital radio frequency memory (DRFM) technology attracted the attention of the Square Kilometre Array (SKA) project team. The CSIR assisted with the characterisation of a wideband analogue-to-digital converter (ADC or A-to-D) for integration into the Karoo Array Telescope (or 'MeerKAT') antennae, as a component of the L-band frequency (0.9 – 1.67GHz) upgrade currently underway. The ADC considered for the MeerKAT development was similar to what the CSIR currently uses in radar and electronic warfare research and technology development. DRFM technology is utilised for the test and evaluation of radars and since the CSIR is involved in the development of radars, the DRFM technology complements this competence. The DRFM technology developed at the CSIR is regarded as world-class.

The MecORT fieldable radar laboratory deployed on Signal Hill in Cape Town during the 2007 measurement campaign.

Radar technology for the detection and tracking of small boats at sea

Radar is the only technology capable of providing wide area persistent surveillance over ranges in excess of 100 km, day and night and in poor visibility. Detection and tracking of maritime surface vessels has been an important research topic at the CSIR for the past number of years. This is a demanding problem as the radar returns from small boats are often comparable to radar returns from the sea surface itself. In addition, the characteristics of the environment in which the surveillance radar must operate are continually changing, and the radar is required to adapt to this changing environment to maximize its automatic detection and tracking performance.

During the development and evaluation of effective automatic radar target detectors, signal models are required for both the small maritime vessels and the environment in which they operate. These models should span the expected range of environment conditions, geometries, radar system parameters as well as target manoeuvres and Radar Cross Section (RCS) characteristics. It is important that the modelling and simulation results be verified through real-world measurements, at least at a number of critical points in the multi-dimensional parameter space. Once results have been verified, trade-offs between various radar system design parameters, such as the radar operating frequency, polarization, dwell time, revisit time, integration time, etc., can be performed.

To verify a number of such models available from the literature, and to evaluate the performance of some proposed detection and tracking algorithms under realistic conditions, the CSIR conducted a number of measurement campaigns at various locations in South Africa. Three large campaigns specifically aimed at the recording of comprehensive datasets of the radar reflectivity from the sea surface and from small maritime vessels under different weather conditions were conducted from Overberg Test Range near Arniston (2007), from Signal Hill in Cape Town (2007) and in False Bay from the mountain side above Simons Town (2010).

These measurements enabled the CSIR to develop a number of validated mathematical models of the amplitude, temporal and spatial statistics of the radar reflectivity of small boats as well as of sea clutter under conditions relevant to those that can be expected in some of the application domains of the AwareNet system in Southern Africa. The datasets also enable the development and evaluation of detection and tracking algorithms on recorded data of a relevant environment. The detection algorithms were designed specifically to discern between the return from sea clutter and the return from other objects. These objects include targets of interest such as small boats, as well as objects not of interest such as birds. Detections that are deemed to be of interest (based on position on a GIS map, Doppler spectrum or amplitude statistics for example) may be extracted from the output of the detection algorithm while spurious and interfering signals are discarded. Tracks are then formed on the detections of multiple targets of interest. This tracking involves the association of detections with existing tracks or creating new tracks with detections that cannot be associated with any existing track, smoothing/filtering of all the tracks, estimating the speed and heading of the targets, predicting their past and future positions and calculating estimates of the errors in these estimates and predictions.

Following the suggestion of radar specialists in the United Kingdom who considered the recorded datasets to be some of the best of their kind in the world, the CSIR decided to make them accessible via an online database at **www.csir.co.za/small_boat_detection**. This provides researchers from all over the world with much needed data to validate their models and algorithms, and creates opportunities for collaborative research.

The CSIR completed their first MATLAB based technology demonstrator capable of the real-time detection and tracking of multiple radar targets in 2012. During the first phase of the development of this technology demonstrator the focus was on developing the framework and algorithms required to detect and track maritime surface vessels only. The final objective is, however, to be able to detect and track surface based (land and sea) as well as airborne targets.

The future will see additional measurement campaigns and the continued exploitation of the recorded datasets to improve on existing models and algorithms. The R&D focus will also be expanded to topics such as the simultaneous detection, tracking and classifying of targets, the feedback of tracking and classification information to detection algorithms and the enhancement of tracking algorithms when target classification information is also measured by the radar. The results of this R&D programme will be incorporated in future AwareNet related technology demonstrators.

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Radar imaging and classification of airborne and maritime targets

Radars are important sensors capable of detecting and tracking targets at long ranges and in all weather conditions, day and night. In addition to these functions, modern radar systems can extract additional information from the reflections off a tracked object that can be used to classify, and in some cases identify it. It does so by means of special radar modes that produce high resolution range or Doppler profiles or even 2-D (range and cross range) imagery of objects. In the case of maritime targets, trained operators (as well as automated computer programs) can look at this information and extract features such as the overall length and width of the object, the positions and heights of masts and the number of outboard engines from the radar imagery of even small vessels.

The CSIR Radar Target Recognition research group is well positioned amongst the international research community in this field and has, since its establishment in 2004, built a significant capability in the extraction of information from objects using radar, both for maritime and airborne targets. The group has studied the state of the art in this field and in some cases developed some innovative techniques resulting in a capability that nowadays routinely produces high quality results.

Inverse Synthetic Aperture Radar (ISAR) is a radar imaging technique that produces two dimensional images of radar targets. The figures to the right show some examples of such images produced of a number of aircraft and boats using data measured with the MecORT radar research facility in South Africa. Imagery like these can be formed at beyond visual ranges and in all weather conditions. They can be used as additional information to help estimate the intent and threat level of objects detected and tracked in a wide area surveillance system designed to enhance the situation awareness of commanders of security and defence operations.

Apart from the benefits of object classification as part of providing a recognised situation picture, the fact that radar detections can be classified can also help to improve track quality and tenacity (for example, to ensure that tracks on the commander display do not get confused with one another when the target trajectories cross, or renumbered when a target track is lost behind an obstacle and another track is formed when it re-appears).

This research is planned to continue, next focussing on improving the automatic extraction of information from the radar imagery, and on finding ways to form 3-D images of objects using a single radar antenna.

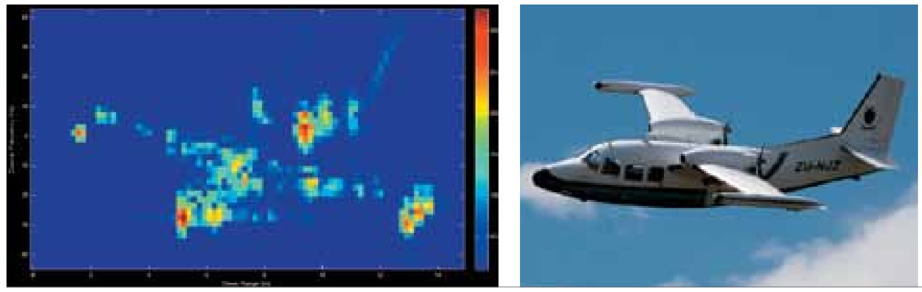

Figure 1: Inverse Synthetic Aperture Radar (ISAR) image compared to an optical image of a P166 Aircraft – notice the strong reflections off the wingtips, nose and tail of the aircraft in the radar image.

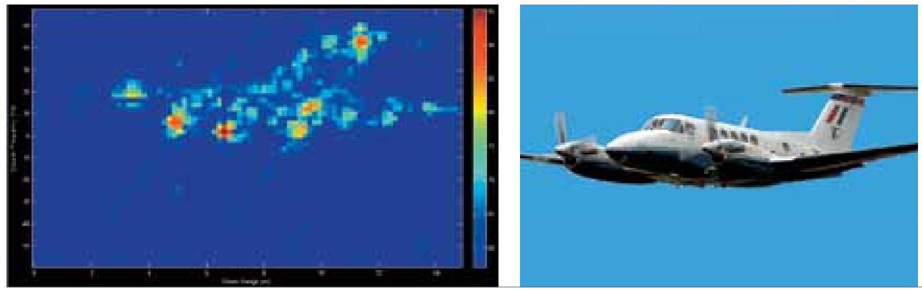

Figure 2: ISAR and optical images of a King Air 200 aircraft – notice the engines, nose, tail and wingtip of the aircraft that reflect strongly in the radar image.

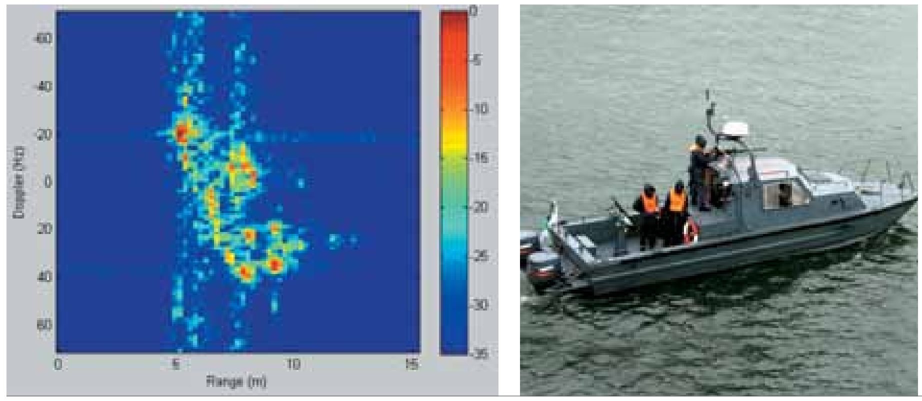

Figure 3: ISAR image (top view) of a Naval Harbour Patrol Boat (left) and optical image (right) for comparison. Note the strong reflections from two outboard engines, the cabin and the bow in the radar image.

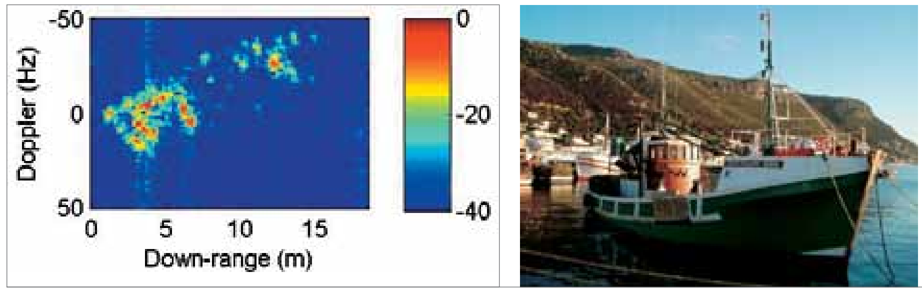

Figure 4: ISAR image of a Fishing Trawler (left) and optical image (right) imaged during a measurement trial in False Bay. Note the scattering from the cabin, from the outline of the hull as well as from the mast. Note that the image produced by the radar shows a top-view even though the measurement was made from a near horizontal viewpoint. This is a useful characteristic of radar imaging that a top view is produced from a stand-off, oblique viewpoint.

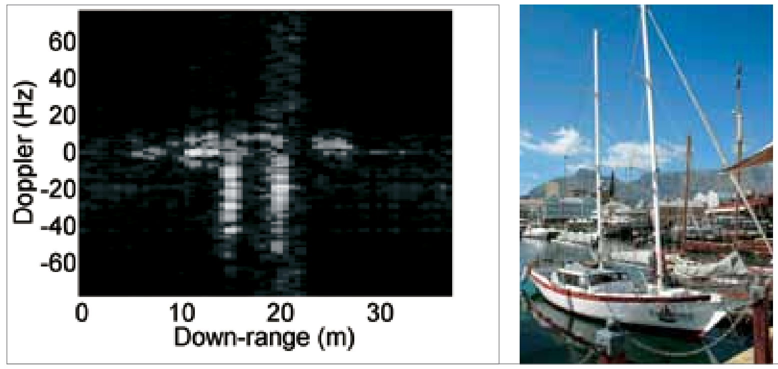

Figure 5: Radar image – mixed top and side view (left) and optical image (right) of a sailing yacht – note the shape of the hull, the fact that there are two masts and their positions along the length of the boat in the radar image. These characteristics are often quite specific and can be used to identify the type of boat being observed.

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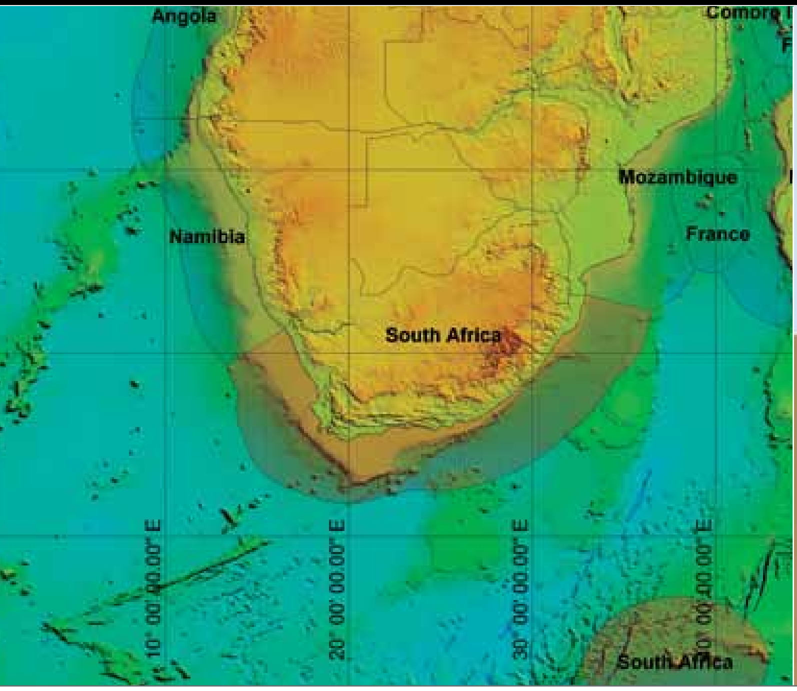
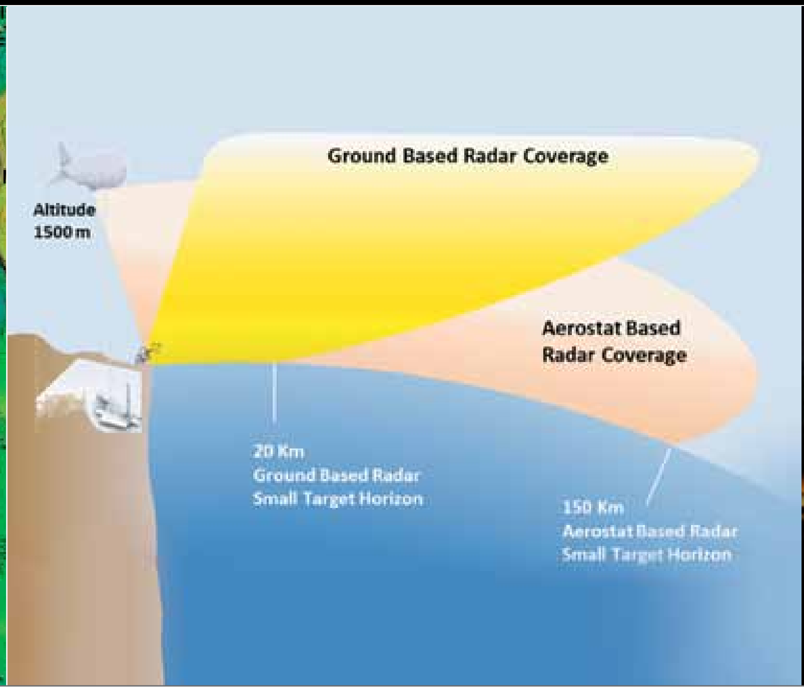


South Africa has a land area of 1,2 million square kilometres, a maritime economic exclusion zone (EEZ) of 1,5 million square kilometres and an air space covering both these areas. The land borders span 4862 km and the coastline 3924 km.



Elevating a radar above the area of interest improves its coverage against surface and low flying targets

The MecORT R&D laboratory deployed outside Simons Town in False Bay during May 2008. Radar data was recorded in support of R&D on small boat detection in sea clutter and radar target recognition using high range resolution and inverse synthetic radar (ISAR) processing.

MecORT deployed above Simons Town during October 2010 for the first AwareNet integrated sensor experiments. Data from the MecORT and Spider radars, electro-optical and signal intelligence sensors, IFF transponders as well as AIS and GPS position reporting systems were collected via a real time sensor network, integrated into a sensor fusion database, geo-referenced and displayed on a GIS-based common operating picture.

The AwareRad radar development in support of the AwareNet concept

South Africa, like other countries, faces the challenge of protecting its territory and its people from activities such as illegal border crossings, weapons trafficking, smuggling, piracy, poaching, organized crime and terrorism on land, at sea and in the air. The country's assets available for monitoring and securing its large air, land and maritime territory against these kinds of threats are relatively small, resulting in unfavourable force-to-space ratios. Since 2004 the Council for Scientific and Industrial Research (CSIR) has been involved in research and development based on international technology trends to address the requirements implied by these types of problems. The initial focus was on the radar detection, tracking and classification of small maritime objects of interest such as rigid hull inflatable boats (RHIBs) in a realistic maritime propagation and clutter backscatter environment.

This program, AwareNet, has the aim to develop indigenous technology on which a series of South African innovations can be based for use by departments and agencies of the State, typically members of the Justice, Crime Prevention and Security (JCPS) cluster, to enhance national security. The operational concept would be to enhance the real time situation awareness of commanders by providing them with recognized sea, air and/or land pictures and thereby achieve a force multiplication effect to overcome challenges caused by the low force-to-space ratios in their areas of responsibility.

The AwareNet concept is for complementary long range remote sensors such as radars, electro-optic sensors and signals intelligence sensors to be flown on elevated, semi-geostationary platforms (such as aerostats) and for their sensed data to be fused with each other and with other information and intelligence sources to produce the required real-time persistent (all the time), ubiquitous (everywhere at once), recognized maritime, air and/or land situation pictures.

One of the key sensors of the AwareNet system is foreseen to be a multifunction, medium range radar. This radar, named AwareRad, is the first dedicated sensor being designed and developed as part of the AwareNet program. It is being designed to detect, track and classify multiple targets at sea, in the air and on land. It will employ high range and Doppler resolution as well as radar imaging techniques to enhance the performance of these functions against small targets such as RIHBs, micro light aircraft and small land vehicles.

Its design is being optimized for use on an aerostat flying at an altitude of 1500 m. Operating a radar sensor from such an elevated platform not only increases the line-of-sight range to the radar horizon, but also reduces the multipath null on the surface and at low levels in the air. This overcomes the well-known shortcoming of surface based radars that lead to the expression "flying below the radar". The fact that an aerostat is a pseudo-geostationary platform also allows the radar to be designed as an efficient moving target detector able to discriminate targets with very low radial velocities from stationary sea and land clutter.

The class of aerostat for which AwareRad is intended is able to remain airborne for up to 14 days at a time. This allows on-board sensors to record and analyze the "pattern of life" of objects in its coverage area, identify anomalous behaviour, estimate the intent of a large number moving objects and semi-automatically prioritize those to be displayed to commanders in command centres.

Compared to aircraft or UAVs, the proposed aerostat platform allows for larger sensor apertures and offers a relatively benign operating environment for its sensor payload at a much reduced operating cost. Compared to fixed installations on the ground or on towers, aerostats enable much longer range surface and low level air coverage and options for rapid redeployment of the sensing system.

The AwareRad radar concept is based on analyses of the shortcomings of radar systems currently available on the market and on data and insights gained during several years of R&D and field trials conducted by the CSIR. It will utilize a number of the new radar technologies developed at the CSIR as part of the AwareNet programme over the past decade. This indigenous development is designed to provide national human capital development opportunities, create jobs, help grow the local economy and enable in-country optimisation for local conditions and integration with other elements of the national situation awareness system. Illegal operators usually have the initiative and continuously adapt their operations to keep the initiative relative to a country's security forces. Systems developed indigenously can be upgraded as part of a continuous improvement programme to help the state's security forces to stay ahead of such developments.

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The CSIR recently received a contract from an international research organisation for the development of an upgraded Dynamic Radar Cross-section (RCS) Measurement System. Engineers from the CSIR and the South African industry (MMS and MTEK) worked on integrating subsystems of the new system in Pretoria.

Better identification and characterisation through radar cross-section measurement

The CSIR has developed a novel system that enables radar cross-section (RCS) or radar reflectivity measurements of targets in a dynamic environment. The system can accommodate a wide range of different targets: from the slowest moving helicopters and boats to the fastest supersonic jets. It has an instrumental measurement range of 20 kilometres.

It also provides more data than conventional radar systems, enabling detailed characterisation that aids decision making.

A major benefit of the radar cross-section measurement system is the fact that it is mobile, and can be deployed almost anywhere. The system can be used to independently verify the radar cross-section of ships and aircraft purchased by a country, as well as to develop the required operational doctrine once purchased.

The system can also be used by designers of military platforms to reduce the radar signatures of the platforms they design.

The system is invaluable as a research tool to gain insight into the characteristics of targets in their environments before the development of a new radar system commences. An example of such an application is the CSIR's work on small boat detection in sea clutter, which is relevant in the protection of South Africa's abalone and other natural resources.

The system has attracted international interest and sales. In addition, the specialist shelter required to house electronics and operators, plus the sensor group positioner necessitated custom development which resulted in the enhancement of existing capabilities and technologies of local industry partners.

Young talent blazing the trail

The CSIR places strategic emphasis on human capital development – of its own people as well as to stimulate and grow future talent. This is particularly important in specialist fields such as radar, electronic warfare and systems engineering where the national skills pool is extremely small.

To this end, the CSIR has developed a targeted skills development and pipeline strategy to source, support and foster the growth of new, young technologists.

Involvement starts at school level, offers support throughout tertiary levels and includes vacation work and student- or internships. Specialist study programmes in these fields are custom developed – in partnership with local and international peer organisations and universities. Opportunities are created for under and post graduate engineering students to work on actual radar and EW related projects, giving them access to world-class facilities and mentorship by experts in their fields.