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HMCS *Montréal* in the Gulf of Oman, January 2003.

OCEAN INTELLIGENCE IN THE MARITIME BATTLESPACE: THE ROLE OF SPACEBORNE SENSORS AND HF RADAR

by Brian G. Whitehouse and Daniel Hutt

For as long as war has been waged at sea, oceanographic conditions have influenced the performance of naval sensors, weapons, vessels, and personnel. In today's Navy, this is relevant to submarine operations, anti-submarine warfare, mine countermeasures, amphibious operations, surface and sub-sea navigation, and ship detection. While meteorological sensors and mathematical models have made accurate weather forecasting commonplace, only a few navies are able to forecast the behaviour of the ocean itself, in addition to the atmosphere above it. This oceanographic capability, which has emerged within the last 10 years, represents a substantive military advantage and is the subject of ocean intelligence.

Among NATO countries, the United States and France are the most advanced in this field as a result of developments in the 1990s: the launching of a broad range of oceanographic satellites, advancements in high-performance computing and environmental modelling, and the internet. The United States has also extended its lead in ocean intelligence through the installation of an extensive network of civilian coastal HF radar stations.[1]

This article addresses two of these developments – spaceborne sensors and coastal HF radar installations. It includes an overview of operational ocean intelligence platforms and identifies optimal spaceborne and coastal HF radar sensors for shallow waters.

OPERATIONAL PLATFORMS

Our understanding of oceanographic influences upon naval operations is often limited by the techniques available to observe them. There are five primary platforms for naval environmental sensors – satellites, aircraft, *in situ* platforms, vessels, and shore-based installations. As all environmental platforms have limitations, the five types usually complement each other rather than compete. The Canadian Forces, for example, make extensive use of airborne, *in situ*, and vessel-mounted sensors when engaged in anti-submarine warfare activities.

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Of significance are the scales in time and space at which these technologies operate, relative to the ocean feature of interest (such as temperature, salinity, currents, etc.).

In situ sensors are the most widely used type of marine environmental sensor. They provide accurate point-source data pertaining to water temperature, salinity, optical properties, sea state, currents, and other features. And, as the atmosphere and oceans are linked like Siamese twins, it is also common to find meteorological sensors on surficial *in situ* platforms, especially wind speed and direction sensors.

All of the environmental features mentioned above can also be measured with sensors mounted on aircraft and satellites. In practice, the question of which platform to employ for a given military operation often comes down to a matter of available resources. The definition of available resources, however, has changed in recent years, to the point that a modern operational meteorological and oceanographic observation and forecasting centre bears little resemblance to its Cold War counterpart.

Within the last decade, a range of oceanographic satellites and coastal HF radar sites have become operational, and practical ocean intelligence applications have been developed for these sensors.[2,3] As a result, the utilization of satellite sensors and coastal HF radar installations is becoming less an option and more an essential element of a comprehensive coastal ocean intelligence programme. The key attribute of these platforms is their synoptic view of the maritime battle space. Satellites and coastal platforms allow us to view shallow waters on spatial scales not sampled by *in situ* or vessel-mounted sensors. Airborne sensors are also capable of providing a synoptic view of coastal waters.[4] They are, however, beyond the scope of this discussion.

OCEAN FEATURES OF MILITARY SIGNIFICANCE

Earth-observation satellites and coastal HF radar installations are used for two general purposes – detecting naturally occurring environmental features and detecting anthropogenic features. The latter includes activities such as ship detection and oil spill monitoring. The first group of applications, involving naturally occurring features, are the ones which collectively define the subject of ocean intelligence and have been the most successful from an operational perspective.

Operational Naval Environmental Assessment Requirement	Detectable with Satellites(●) or HF Radar(■)	Relevant Naval Operation
3-D Sound Velocity		ASW, SubOps
Bottom Acoustic Properties		ASW, SubOps
Ambient Noise		ASW, SubOps
Location of Marine Mammals		ASW, SubOps
Bathymetry		ASW, SubOps Navigation
3-D Water Density		ASW, SubOps
Surface Temperature	●	ASW, SubOps Search & Rescue
Subsurface Temperature		ASW, SubOps
Surface Currents	■	Search & Rescue Navigation, SubOps Ship Detection, MCM AmphibOps, ASW
Subsurface Currents		ASW, SubOps, MCM
Surface Winds (speed & direction)	●	Search & Rescue ASW, Navigation Ship Detection
Sea State	● & ■	Search & Rescue ASW, Ship Detection AmphibOps
Sea Ice	●	Search & Rescue Navigation
Internal Waves	●	ASW Ship Detection
Turbidity (concentration & quality)	●	SubOps, ASW MCM, AmphibOps
Beach Conditions	●	AmphibOps

Table 1. Naval requirements for operational oceanographic information (i.e. ocean intelligence) in shallow waters. In this context, shallow = shore to continental shelf. ASW = anti-submarine warfare; SubOps = submarine operations; MCM = mine countermeasures; AmphibOps = amphibious operations. Navigation refers to the navigation of surface vessels.

Table 1 identifies naval ocean intelligence requirements in shallow waters that may be addressed with spaceborne sensors or coastal HF radar technologies. We focus on shallow waters as they are a NATO priority.[5] In this context, we define such waters as those extending from the shore to the continental shelf.

Requirements identified in Table 1, for which there is no applicable satellite or HF radar technology, generally involve subsurface features, which cannot be monitored with sensors mounted on these types of platforms. As Table 1 refers to shallow waters, satellite sensors that have application in oceanic waters but not in shallow waters are not shown. Thus, for example, although spaceborne altimeters provide bathymetric information in oceanic environments, existing systems are not able to do so with sufficient resolution in shallow waters since spatial scales less than 20 km cannot be interpreted with confidence close to shore.[6]

HF RADAR IN COASTAL WATERS

HF radar sensors operate within the frequency band of 3 to 30 MHz, and coastal installations are capable of providing coverage over most of the continental shelf. Their operating range, however, varies with frequency, system design and local environmental influences, with commercially available systems having ranges between a few tens of kilometres to 400 km offshore. These systems monitor the targeted environment continuously, with resulting data delivered directly to the operator within minutes of sampling. In combination, these capabilities result in coastal HF radar being well suited to support certain shallow water military operations.

HF radar systems reported in the civilian literature have been optimized to detect different marine features. Optimal applications, advantages and disadvantages of each system are as much a matter of engineering design and proprietary signal processing techniques as they are of operating frequency. The Canadian Forces, for example, are installing an HF radar system manufactured by Raytheon which has been optimized for ship detection. However, ship detection *per se* is beyond the scope of this discussion of ocean intelligence.

In the context of ocean intelligence, and as indicated in Table 1, coastal HF radar technologies are relevant to naval operations requiring synoptic surface current vectors or surface wave information in shallow waters. Various European HF radar systems, for example, are being optimized to provide synoptic close-in surface wave information.[1]

Without doubt, the most prolific HF radar system is the commercially available CODAR SeaSonde system (See Figure 1), which has been optimized to provide synoptic surface current information. CODAR SeaSonde systems account for more than 80 percent of the coastal HF radars used world-wide for ocean intelligence operations and civilian maritime environmental assessment. To date, CODAR systems have been installed in 11 countries, with the USA having blanketed large areas of its coastline with this technology (See Figure 2).

The Canadian Forces are experimenting with extraction of surface current information from its Raytheon ship detection HF radar system. Although the long-range versions of the Raytheon and CODAR systems operate at similar frequencies, they have fundamental differences in design and signal processing software, which in turn have operational implications. The Raytheon system, for example, may at times operate at a range which is double that of the standard CODAR SeaSonde system.

Although theoretically feasible, from a cost perspective it is unlikely that any navy would use the Raytheon system operationally to obtain synoptic surface current vectors. The reason for this is that only one HF radar site is required for ship detection, whereas two sites are required to generate synoptic surface current vectors, and the distance between the two sites must be no more than 40 to 60 percent of the system's range. This equates to a distance between sites for surface current monitoring which is substantially less than that required for two adjacent sites optimized for ship detection. With the CODAR surface current system costing approximately one-twentieth the price of the Raytheon ship detection system, the international user community has gravitated toward the substantially less expensive CODAR system to satisfy needed ocean intelligence requirements.

Another factor in favour of the CODAR system is that the Raytheon system cannot see littoral waters. In fact, it does not operate within the first few tens of nautical miles from shore, whereas the CODAR system can be operated within this zone. The littoral zone is a key area for several relevant military operations, such as amphibious operations and mine countermeasures.
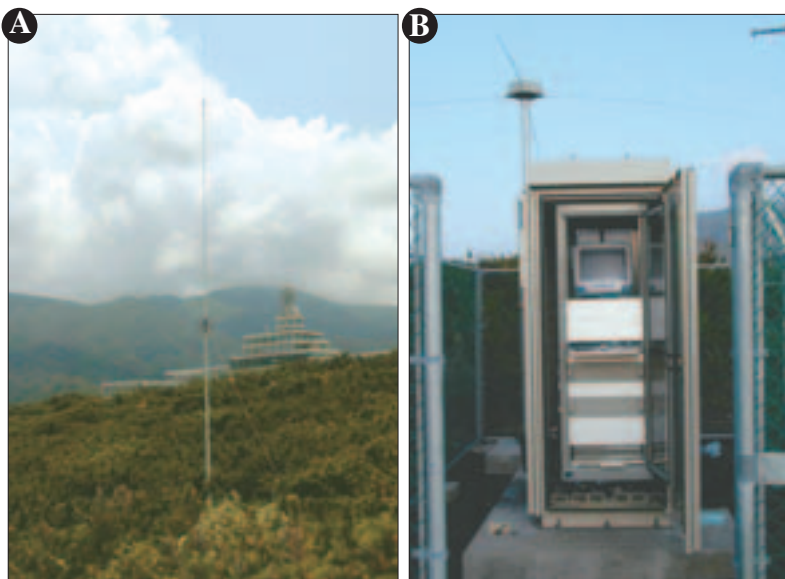

Figure 1. A typical CODAR HF radar site installation, with this particular installation being located in Japan. The Japanese Coast Guard operates CODAR SeaSonde HF radar systems at the entrances to Tokyo and Sagami Bays. 1(a) the system's transmit antenna. 1(b) The system's receive antenna and accompanying on-site electronics. Photos courtesy of the Japanese Coast Guard and CODAR Ocean Sensors Ltd.
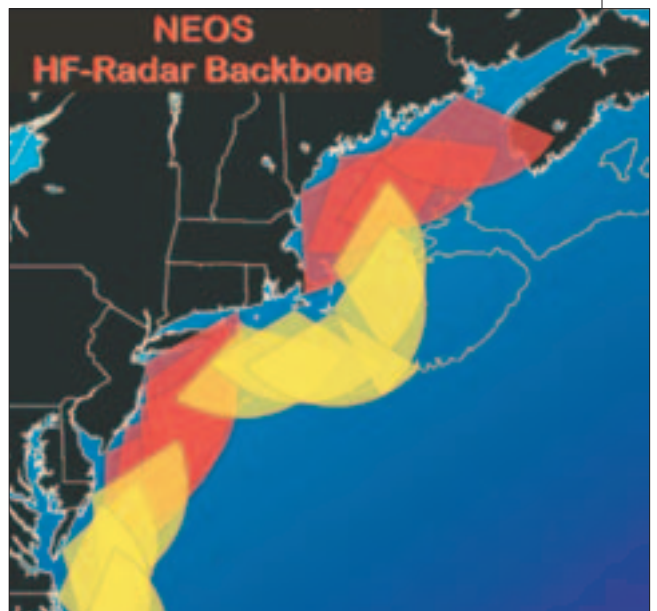

Figure 2. Existing (red) and planned (yellow) CODAR HF radar installations along the north-eastern coastline of the USA. Image courtesy of the North East Observing System Web site (http://marine.rutgers.edu/neos/) and Rutgers University.

At present, there are more than 30 civilian satellite sensors monitoring the world's oceans. From an applications perspective, they fall into seven groups, with each having similar applications in maritime waters.[1] The groupings are: land-optimized multispectral sensors, marine-optimized multispectral sensors, thermal IR sensors, altimeters, passive microwave sensors, synthetic aperture radars, and scatterometers.

The complete suite of existing sensors and groupings can be viewed online at www.oeatech.com.[1,2] Here, only the first two groupings are profiled as a means of providing a basic understanding of relevant aspects of these spaceborne sensors, and to provide context for subsequent discussion.

The land and marine-optimized multispectral satellite sensors are listed in Table 2. Table 2(a) lists sensors designed primarily for terrestrial applications, but which are also employed in coastal environments, whereas Table 2(b) lists those whose spectral bands and sensitivities have been optimized for aquatic applications. As defined in the table caption, if an application is reasonably well founded, it is identified with a black bar. In practice, these are the only applications that are likely to be of operational value to military commanders.

A key observation with regard to this aspect of ocean intelligence is that many of the existing civilian sensors were designed for research, development or demonstration purposes. As a result, many of these sensors are not of immediate practical benefit to military operations.

2a

SATELLITE	ORBVIEW 3	QUICKBIRD	IKONOS	SPOT	LANDSAT & EO	SAC-C
SENSOR	multispectral	multispectral	multispectral	HRG	ETM & ALI	MMRS
revisit time (days)[1]	~3	~3	~3	~3	16	9
near-real time[2]	no	no	no	no	no	no
spatial resolution (m)	4	2.5	4	10	30 & 30	175/350
country or agency	USA	USA	USA	France	USA	Argentina
Floods/Storm Surge	■	■	■	■	■	
Fronts/Eddies (biological)						
Fronts/Eddies (thermal)					▨	
Ice	▨	▨	▨	▨	▨	
Surface Temperature	▨	▨	▨	▨	▨	
Turbidity	▨	▨	▨	▨		
Vegetation (beach/nearshore)	■	■	■	■	■	■
Water Coloring Constituents	▨	▨	▨	▨		

2b

SATELLITE	KOMPSAT	OCEANSAT	ORBVIEW 2	ENVISAT	TERRA & AQUA
SENSOR	OSMI	OCM	SEAWIFS	MERIS	MODIS
revisit time (days)[1]	~2	~2-3	~1	~2-3	~1
near-real time[2]	no	no	yes	no	yes
spatial resolution (m)	1000	360	1100/4000	300/1200	1000
country or agency	Korea	India	USA	ESA	USA
Floods/Storm Surge					
Fronts/Eddies (biological)	■	■	■	■	■
Fronts/Eddies (thermal)	■	■	■		■
Ice	▨	▨	▨	▨	■
Surface Temperature	■	■	■		■
Turbidity	■	■	■	■	■
Vegetation (beach/nearshore)					
Water Coloring Constituents	■	■	■	■	■

(Legend: ■ = black bar, ▨ = grey bar)

Table 2. (a) land-optimized and (b) marine-optimized multispectral polar-orbiting satellite sensors used to observe coastal features, as of October 2003. A black bar indicates the application is reasonably well founded. A grey bar indicates the sensor is not optimal for this application but merits consideration. See Notes[7] for further explanation of Tables and a listing of acronyms. Reprinted with permission.[1] [not included in Table 2b: three Chinese research sensors (CMODIS, COCTS, CZI), the data from which are only available within China, and one Taiwanese research sensor (OCI). Table 2 also does not include India's latest satellite, Resourcesat-1, which was in its commissioning phase at time of writing. Visit www.ioccg.org for technical details on these and other ocean color sensors.]

"Ocean intelligence in shallow waters is a perishable commodity in that it is often only of value to the operational commander for a period of hours."

Table 2 includes information intended to help the operational commander determine whether the sensor has significant operational utility. For example, in addition to listing the sensor's spatial resolution, which refers to the smallest physical unit discernible by the sensor,[8] the table lists the sensor's revisit time, which refers to how often the sensor revisits a given geographic area. In general, relevant naval operations require ocean intelligence sensors that revisit shallow waters at least daily. This requirement is less stringent for most operations involving the open ocean, or beach areas, where sensors that revisit every few days can be of significant operational benefit.

Another key operational parameter is whether the satellite programme operates in near-real time. Ocean intelligence in shallow waters is a perishable commodity in that it is often only of value to the operational commander for a period of hours. Thereafter, these waters may have changed to such an extent that they need to be re-sampled to determine existing conditions. A near-real time satellite programme routinely delivers Earth-observation data to the user within two hours of satellite overpass.[2] Most of the satellite programs designed for research and development purposes, or for terrestrial purposes, are not able to do this.

Multispectral satellite sensors listed in Table 2(a) are well known for their terrestrial mapping applications. These sensors have also proven to be useful in aquatic coastal projects involving tropical and subtropical waters, where the water is relatively clear. And with spatial resolutions ranging from a couple of metres to tens of metres, they meet the spatial resolution requirements of near-shore mapping operations.

On the other hand, sensors listed in Table 2a are not optimal for observing in-water constituents, as indicated by their optimal applications. And, as they were designed for terrestrial mapping purposes, they have revisit times that are too infrequent to monitor most littoral processes. In addition, they are not near-real-time data sources, which means that commanders operating in littoral waters are unlikely to obtain the ocean intelligence derived from these sensors within required time constraints. Another relevant consideration is that most of these sensors are flown on commercial

satellites and therefore their data must be purchased. For operational programmes, such data costs can amount to millions of dollars per annum.

NASA's spaceborne Coastal Zone Color Scanner sensor, which was launched in 1978 and produced data for the period 1979 to 1986, forever changed the way we view the world's oceans, and subsequently encouraged the development, and eventual launch, of the marine-oriented multispectral sensors listed in Table 2(b). The more recent sensors listed in this table, such as Modis and Meris, have spectral bands that improve their ability to distinguish colouring constituents that may be present in shallow waters, such as those of terrestrial, benthic and pelagic origin.

An example of a Modis image, taken off the coast of Argentina, is provided in Figure 3. Note the abrupt changes in water clarity, which are caused by the presence of in-water constituents – in this case marine phytoplankton. Substantive changes in water clarity in shallow waters are of relevance to anti-submarine warfare, mine countermeasures, submarine, and amphibious operations. Although water-clarity (e.g. turbidity) maps can be generated from data collected by sensors mounted on aircraft, satellites represent the only practical platform from which to generate synoptic maps of the quantity and quality of in-water constituents on a routine basis in hostile territories.

Even among these marine-oriented multispectral sensors, certain programmes have been designed for research, development, and demonstration purposes, whereas others have clear operational advantages. Meris, for example, has a higher spatial resolution than Modis (300 m versus 1 km), and early research results indicate that the quality of Meris data is very good. However, Meris' effective revisit time is not optimal for operational military applications, and the quality of multispectral data required for research purposes may be much greater than what is required for operations utilizing relatively simple turbidity maps. In addition, Modis allows for direct reception using inexpensive X-band receiver dishes, and, therefore, the user can obtain resulting information within minutes of satellite overpass. Modis also senses both optical and thermal properties concurrently, thereby greatly increasing its utility for applications such as anti-submarine warfare, search and rescue, and submarine operations.

OPERATIONAL OCEAN INTELLIGENCE SENSORS

In Table 3, all seven categories of satellite sensors are cross-referenced with Table 1. This results in a presentation of civilian spaceborne sensors and HF radar that can be used for operational ocean intelligence purposes.

Figure 3. Modis (Terra) image off the coast of Argentina taken on 10 February 2003 showing extensive blooms of phytoplankton. Image generated by Jacques Descloitres of NASA's GSFC and provided courtesy of James Acker. For further information access http://visibleearth.nasa.gov/cgi-bin/viewrecord?25060

Operational Requirement	Optimal Sensor Type	Applicable Satellite Sensors or HF Radar•	Country or Agency	Naval Operation
Surface Temperature	thermal IR	AVHRR, Modis	USA	ASW, SubOps Search & Rescue
Surface Currents (littoral)	HF radar	CODAR SeaSondes•	not applicable	Search & Rescue, SubOps, Navigation Ship Detection AmphibOps, ASW
Surface Winds (speed & direction)	scatterometer	Quickscat ERS Scat	USA, ESA	Search & Rescue Ship Detection, Navigation
Turbidity	multispectral (marine-oriented)	Seawifs, Modis, Meris	USA, ESA	ASW, AmphibOps SubOps, MCM
Sea Ice	SAR	Radarsat, Envisat	Canada, ESA	Search & Rescue Navigation
Sea State (surface waves)	HF radar altimeter SAR	all HF radars•, GFO Topex/Poseidon, Jason Radarsat, Envisat	USA, France Canada, ESA	Search & Rescue Ship Detection, AmphibOps
Geostrophic Currents, Ocean Bathymetry, Fronts & Eddies	altimeter	Topex/Poseidon GFO, Jason	USA, France	Search & Rescue Navigation Ship Detection
Beach Mapping	multispectral (land-oriented)	Quickbird, Ikonos Orbview 3, Spot	USA, France	AmphibOps

Table 3. Civilian satellite sensors & coastal HF radars that address operational requirements for ocean intelligence. Sensors and requirements listed with a yellow background refer to shallow waters (shore to continental shelf). Requirements shown with a grey background either pertain to oceanic waters or to aspects of the beach and foreshore (i.e. beach mapping). See Notes for definition of acronyms.

Note that this synthesis, in which we have cross referenced requirements with technologies, results in a table that does not include several identified ocean intelligence requirements (Table 1), and only includes 16 of the more than 30 satellite sensors. As discussed previously, this reflects the facts that several requirements involve subsurface features, which cannot be detected by sensors mounted on satellites and shore-based platforms, and that many of the existing spaceborne programmes were not designed for operational military purposes.

Sensors highlighted in yellow in Table 3 will be of benefit to maritime commanders conducting operations in shallow waters. There are spaceborne sensors that can detect an oceanographic parameter highlighted in yellow but are not included in this table because they do not meet certain practical operational requirements, as discussed previously in association with Table 2. The ATSR sensor flown on the Envisat satellite, for example, does an excellent job of detecting sea-surface temperature, and with greater accuracy than the listed AVHRR sensor, but its data are not obtainable in near-real time in most geographic locations. This essentially precludes its use for operational ocean intelligence purposes in shallow waters. The ATSR sensor was designed primarily for climatological research purposes.

With the exception of coastal HF radar technologies, all of the sensors highlighted in yellow can also be used operationally in oceanic waters. In fact, for oceanic waters, where operational time and space requirements are often less stringent than for shallow waters, certain sensors excluded from Table 3, such as the ATSR sensor flown on Envisat, may be of practical benefit.

Sensors highlighted in grey in Table 3 refer to requirements that involve oceanic waters or the foreshore (i.e. two zones which bound shallow waters). These include determination of geostrophic currents in oceanic waters with spaceborne altimeters, and mapping foreshore terrestrial features with land-optimized multispectral sensors. Neither of these applications requires data to be delivered in near-real time, and the sensors' revisit time does not need to be daily or better.

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"The utilization of satellite sensors and coastal HF radar installations is becoming less an option and more an essential element of a comprehensive coastal ocean intelligence programme."

Table 3 does not include altimeters in sun-synchronous orbit, and it is noted that altimeters are only used to determine the time variant component of geostrophic currents, not the absolute current itself. This reflects our limited ability to measure the marine geoid, which is used as a reference surface for such calculations.[10] However, this situation is changing. In March 2002, the German/US Grace satellite was launched with the objective of measuring the geoid with greater accuracy than previously possible. The European Space Agency is planning to launch a similar type of mission in 2007. Thus, the operational utility of spaceborne altimeters is likely to increase substantially over the coming years. There is a caveat, however, that such sensors will continue to be limited to mesoscale and basin-scale processes as long as there is an insufficient number of altimeter sensors in orbit to meet the time and space requirements of finer scale processes. Mesoscale variability is defined as being on the order of 50 to 100 km and 10 to 100 days at mid-latitudes.[10]

The operational requirement for information pertaining to surface waves, listed in Table 3 as "Sea State", represents a unique grouping inasmuch as information pertaining to surface waves can be obtained with both HF radar and spaceborne sensors.

Furthermore, two of the seven categories of spaceborne sensors are relevant to this requirement. Yet, we are unaware of any military that relies primarily on these sensors to obtain operational sea state information in shallow waters. The surface wave field is usually determined operationally with sensors mounted on *in situ* platforms, or it is forecast with models that are constrained by *in situ* data.

Where applicable, Table 3 indicates which country or agency is controlling the satellite since this provides insight into a particular organization's ability to gain access to the satellite's data. For example, Table 3 indicates that the USA and France have exclusive ownership of the civilian land-optimized multispectral spaceborne sensors and of all spaceborne altimeters that are not in sun synchronous orbit. This analysis does not include multispectral sensors flown on Indian Earth-observation satellites and other such civilian satellites having restrictive data distribution policies (e.g. relevant Chinese satellites).

"Ocean models of shallow waters are of great significance to the field of ocean intelligence, and therefore to naval operations in such waters."

CLOSING COMMENTS

Although Earth-observation satellite and HF radar technologies have matured within the last decade, they continue to evolve and have inherent limitations. Foremost, they only detect surficial features, whereas
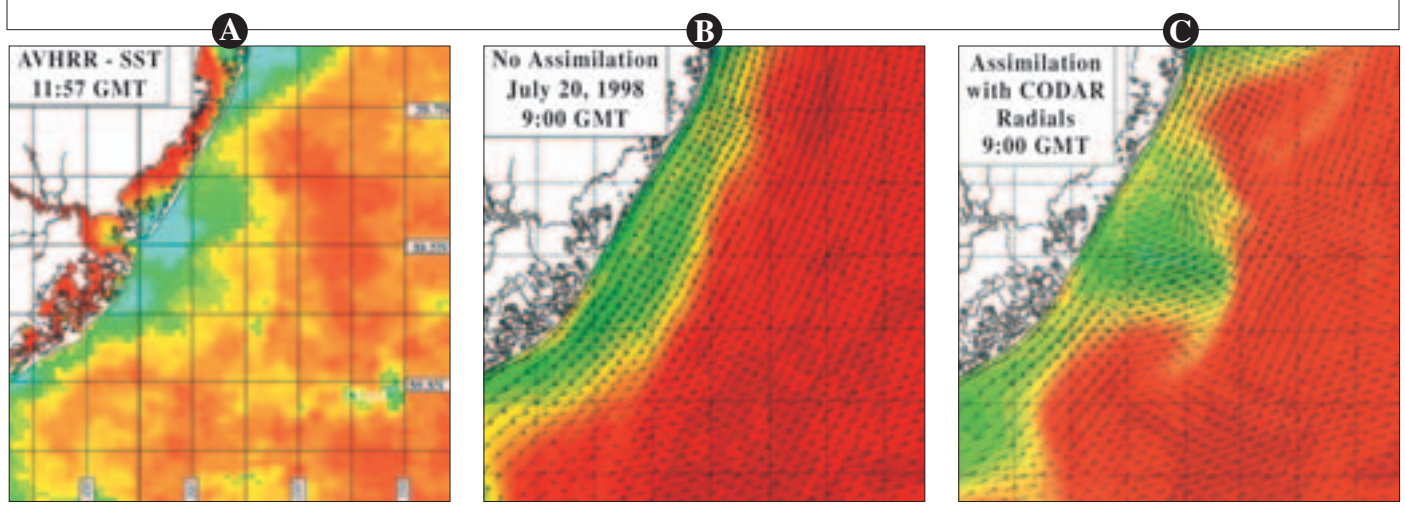
Figure 4. An example of the information content of stand-alone spaceborne and HF radar data for coastal waters versus the benefit of fusing these environmental data into coastal environmental nowcasting and forecasting models. 4(a) Sea-surface temperature map derived from NOAA's AVHRR spaceborne sensor. 4(b) Numerical model output of surface currents and temperature with model constrained by surface wind data only.[11] Model output produced by Rutgers University. 4(c) Numerical model output of surface currents and temperature with model constrained by surface wind data and surface current data derived from CODAR coastal HF radar sensors (five days difference between assimilation and comparison). Images courtesy of Rutgers University.

much of the required naval environmental information pertains to subsurface features. The sensor's depth of penetration into the water column varies from a few microns to a few tens of metres, depending on the particular sensor, platform and body of water.

Second, satellite and shore-based sensors are separated from coastal waters by the atmosphere, and certain types of sensors mounted on these platforms are influenced by or otherwise rendered unusable by atmospheric effects. For example, the atmosphere contributes over 90 percent of the signal recorded by spaceborne marine optical sensors.[9] Cloud cover, which represents but one aspect of this issue, is arguably the greatest practical limitation of optical satellite sensors in maritime waters. Typically, it covers 60 percent of the tropical ocean and 75 percent of the ocean at mid-latitudes.[10]

Although environmental modelling is beyond the scope of this article, it would be misleading to leave the impression that the only ocean intelligence value of sensors identified here is the direct benefit obtained from their real-time data. A substantive indirect benefit of data produced by such sensors is their ability to constrain and improve the results of operational ocean forecasting models.

Ocean models of shallow waters are of great significance to the field of ocean intelligence, and therefore to naval operations in such waters. An example of the utility of coastal models, and the role played by spaceborne and HF radar sensors in such models, is depicted in Figure 4. Note the substantially improved resolution of coastal eddies and fronts when the model is constrained by CODAR SeaSonde HF radar data and surface wind data. Similar improvements are being obtained through the inclusion of various types of spaceborne data, such as altimeter data. This example involves ocean features of relevance to anti-submarine warfare, submarine operations, amphibious operations, mine countermeasures, search and rescue, ship detection, and navigation.

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NOTES

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LIST OF ACRONYMS (EXCLUDING COMPOUND ACRONYMS)

ALI – Advanced Land Imager

ASW – Anti-Submarine Warfare

ATSR – Along Track Scanning Radiometer

AVHRR – Advanced Very High Resolution Radiometer

ERS Scat – European Remote Sensing Scatterometer

ESA – European Space Agency

ETM – Enhanced Thematic Mapper

GFO – Geosat Follow On

HRG – High Resolution Geometric

MCM – Mine Countermeasures

MMRS – Multispectral Medium Resolution Scanner

OCM – Ocean Color Monitor

OSMI – Ocean Scanning Multispectral Imager

SAR – Synthetic Aperture Radar