Assessment of Skill for Coastal Ocean Transients
ASCOT-01

Massachusetts Bay / Gulf of Maine
June 2001

An Experiment for Ocean Coastal Prediction and NATO Rapid Environmental Assessment Skills Evaluation

A.R. Robinson, J. Sellschopp, W. G. Leslie

Harvard University
NATO SACLANT Undersea Research Centre

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1. Introduction

Coastal Predictive Skill Experimentation (CPSE) measures the ability of a forecast system to combine model results and observations in coastal domains or regimes and to accurately define the present state and predict the future state. Rapid Environmental Assessment (REA) is defined in the military environment as "the acquisition, compilation and release of tactically relevant environmental information in a tactically relevant time frame". Ocean forecasting is essential for effective and efficient REA operations. A REA CPSE must be designed to determine forecast skill on the basis of minimal and covertly attainable observations and thus may be most efficiently carried out in the context of the definitive over-sampling provided by a CPSE.

Environmental observations are a necessity for initialization and updating of ocean forecasts. Numerical ocean forecast capabilities in general consist of observational networks, data assimilation schemes and dynamic forecast models. Since observations are the most expensive part of the forecast and are often difficult to achieve, methods that would reduce the requirements are highly desirable. Knowledge of features, structures and the dynamics which evolves them is necessary for successful forecasting. Adaptive sampling of the observations of greatest impact increases efficiency and can drastically reduce the observational requirements, i.e. by one or two orders of magnitude. This project will develop methodology for ocean forecasting using minimum input.

The Assessment of Skill for Coastal Ocean Transients (ASCOT) project is a series of real-time CPSE/REA experiments and simulations focussed on quantitative skill evaluation and cost-effective forecast system development. ASCOT-01, to be carried out in Massachusetts Bay/Gulf of Maine in June 2001, is the first such experiment. ASCOT-02 is planned for somewhere in the Mediterranean Sea in 2002.

2. Goals and Objectives

ASCOT Overall Goal: to enhance the efficiency, improve the accuracy and extend the scope of nowcasting and forecasting of oceanic fields for Coastal Predictive Skill Experimentation and for Rapid Environmental Assessment in the coastal ocean and to quantify such CPSE and REA capabilities.

ASCOT General Objectives:

- obtain data sets adequate for: 1) definitive real-time verification of regional coastal ocean predictive skills, with and without REA constraints; 2) CPSE and REA Observational System Simulation Experiments (OSSEs), both for ASCOT design and more generally; and, 3) definitive knowledge of dynamics
- define useful skill metrics and real-time forecast validation and verification procedures for REA
- assemble, calibrate, exercise in real-time, evaluate and improve a generic, portable, scalable advanced ocean forecast system (dynamical models and data analysis, management and

assimilation schemes) applicable for CPSE in general and NATO REA in particular.

ASCOT-01 Objectives:

- carry out and quantitatively evaluate in Massachusetts Bay (MB) and the Gulf of Maine (GOM) a coupled multiscale interdisciplinary real-time forecast experiment
- obtain a data set adequate to define coupled dynamical processes (submeso-, meso-, bay-, gulf- scales) that govern the formation and evolution of structures and events, including generic processes and the coupling of wind-forced events and buoyancy currents
- obtain an intensive data set adequate for definitive quantitative skill assessment and suitable for the design of minimal data requirements for both REA and for an efficient regional monitoring and prediction system.

REA requires multiscale capabilities for different kinds of warfare (e.g. anti-submarine (ASW), mine warfare (MW), etc.). An experiment which is to assess the predictive skill of a forecast system must therefore measure and evaluate on multiple scales. Knowledge of the multiscale dynamics is essential. For ASCOT-01, the coupling extends from Massachusetts Bay, through the Gulf of Maine, out to the northwest Atlantic. Skill metrics will be designed to take the coupling of scales into account. All coastal regions require both generic and regional-specific metrics for the dominant variabilities. For example, upwelling is a generic process, however, the location and time of occurrence of upwelling is specific to the region.

As a predictive skill experiment, ASCOT-01 will include oversampling, in order that sources of error can be tracked. During the verification survey a significant fraction of the initialization survey will be repeated. Adaptive sampling survey patterns will be designed to address: 1) the interactions of Massachusetts Bay and the Gulf of Maine (inflow updates, exchanges, etc.); 2) response to storms or air-sea exchanges (upwelling, structures of currents and gyres, bifurcation structures in the Gulf of Maine, etc.); coupling of wind-response and buoyancy currents; reduction of multi-variate forecast errors; and, update of information for feature model parameters. Such scenarios will be designed in advance through OSSEs.

This document details the central stand-alone physics aspects of ASCOT-01. In addition to the acoustics experiment to take place during the experiment, it is hoped that additional collaborators will add other interdisciplinary aspects to the overall program.

3. Geographic and Oceanographic Context

ASCOT-01 will take place in Massachusetts Bay and the Gulf of Maine. Massachusetts Bay (including Cape Cod Bay) forms a semi-enclosed embayment adjacent to the Gulf of Maine. The dimensions of the system are approximately 100km by 50km; bounded by Cape Ann to the north, Cape Cod to the south, the coastline of Massachusetts to the west and Stellwagen Bank to the east. Stellwagen Bank rises to within 30m of the sea surface. There are channels to the north and south of Stellwagen Bank which connect with the Gulf of Maine. The North Passage has a sill depth of 60m and the South Passage has a sill depth of 50m. The deepest part of

Massachusetts Bay is Stellwagen Basin, just to the west of Stellwagen Bank, with depths of 80m-100m. The average depth of Massachusetts Bay is approximately 35m.

Historically, the mean circulation in Massachusetts Bay has been characterized as a cyclonic, southward flow. Water enters the bay flowing southwest as it passes Cape Ann. It then flows southward along the Massachusetts coastline, circulates through Cape Cod Bay and exits to the northeast by Race Point on Cape Cod. This flow is driven by both remote forcing from the Gulf of Maine and by wind stress. In addition to the mean circulation, tidal fluctuations, and upwelling and downwelling events play important roles in the circulation of Massachusetts Bay.

Figure 1, from model results with data assimilation, exemplifies the variability of the general multiscale circulation. Dynamically, much more variability than previously described has recently been found in the circulation structures. Strong wind events can control the qualitative structures of the buoyancy flow. The Gulf of Maine current can have three branches: the Massachusetts Bay coastal current, one which enters the Bay (but not Cape Cod Bay) and then exits at Race Point, and one which flows along Stellwagen Bank without entering Massachusetts Bay. A Cape Cod Bay gyre can be cyclonic, anti-cyclonic or absent. For several days following a wind event, the structure of the buoyancy current is maintained by a combination of inertia, topography, coastal geometry and internal dynamics. Sub-mesoscale vortices form between branches and filaments of the buoyancy Gulf of Maine current and/or mesoscale gyres.

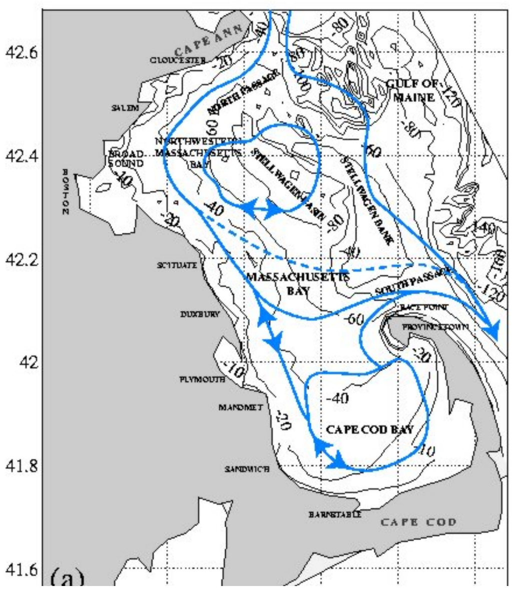

Figure 1 - Schematic of the buoyancy-driven circulation in Massachusetts Bay.

The Gulf of Maine is a semi-enclosed basin which has its natural large-scale circulation influenced by buoyancy driven inflow and outflow conditions, atmospheric forcing, topography, tides, river inflow and basin-wide pressure gradients. The Gulf of Maine is bounded on the north and west by the continental United States and on the east by Nova Scotia and the Bay of Fundy. To the south the Gulf of Maine is partially isolated from the Atlantic Ocean by Georges Bank, which in some areas rises to within a few meters of the sea surface. Exchanges between waters of the Gulf and the coastal Atlantic Ocean are confined mostly to the Scotian Shelf, the Northeast Channel and the Great South Channel. Inside the Gulf are three principal basins, separated at the 200m depth, but connected by sills. Jordan and Wilkinson Basins have maximum depths of about 270m, but Georges Basin, which forms the inner terminus of the Northeast Channel, contains the greatest depth, approximately 380m. A major part of the Gulf of Maine region is affected by the Gulf Stream System and the warm core rings generated by its large-amplitude meandering and growth events. These rings also influence the slope circulation to the south of the Gulf of Maine and Georges Bank ecosystem. The position and transport of the Gulf also plays a role in affecting the variability of the water-mass dynamics in the shelf/slope system.

The Gulf of Maine regional circulation is characterized by five important sets of circulation features: i) a buoyance driven coastal current; ii) tidal fronts fronts around Georges Bank, giving rise to the anti-cyclonic circulation pattern around the Bank; iii) cyclonic gyres centered around the basins in the deeper waters of the Gulf of Maine; iv) inflow and outflow regions of the basin; and, v) the cold pool. The major features of the region are listed in Table 1. The Gulf of Maine has a distinct inflow region through the Northeast Channel (NEC) and an outflow region through the Great South Channel (GSC). A major feature is the narrow Maine Coastal Current with its bifurcating and trifurcating regions. The deep basin regions are dominated by a topographically controlled cyclonic gyre system, named after the basins, i.e., the Georges Basin gyre, the Jordan Basin gyre and the Wilkinson Basin gyre. The circulation in the Gulf of Maine during the summer season is schematized in Figure 2.

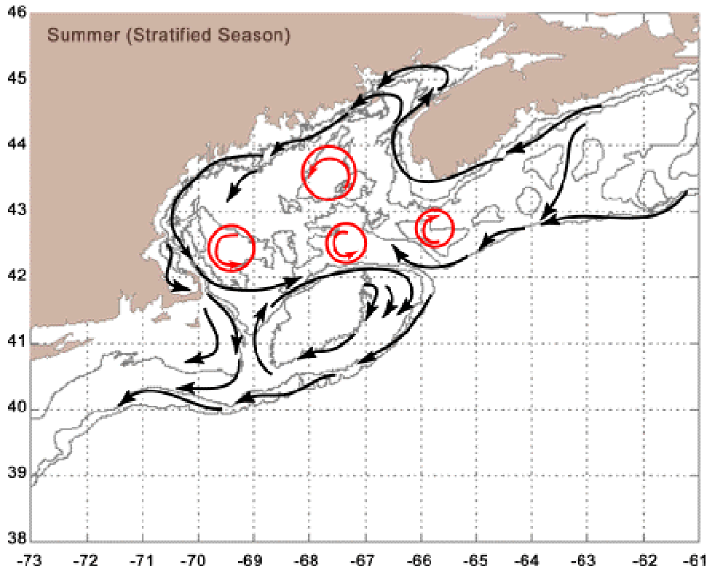

Figure 2 - Schematic of the summer circulation in the Gulf of Maine.

Table 1. List of GOMGB features and selected studies

Features	Selected Studies
Maine Coastal Current	Smith, 1989; Smith et al., 1989; Mountain and Manning, 1994; Beardsley et al, 1985; Brooks, 1987; Chapman and Beardsley, 1989; Bisagni et al., 1996; Brooks and Townsend, 1989; Mavor and Huq, 1996. Lynch et al, Lynch and Naimi, Naimi
NEC Inflow	Ramp et al., 1985
Gyre Circulation	Brooks, 1985; Brown and Irish, 1992; Mountain and Jessen, 1987; Brooks, 1990. Wright et al., 1986; Beardsley et al, 1997

GSC Outflow	Beardsley et al., 1985
Gorges Bank Anticyclonic circulation	Flagg, 1987; Butman and Beardsley, 1987; Butman et al., 1987
Jordan Basin Gyre	Pettiggrew et al, 1996
Wilkinson Basin Gyre	Brown et al, 1998 more….
Geroges basin Gyre	Pettigrew et al, 1996
Cold Pool	Bisagni et al, 1996
NEC Eddy	Bisagni and Smith
NEC Washover	Bisagni and Smith, 1998

4. Nested Modeling Domains

The ASCOT-01 simulation and operational system will consist of a set of three two-way nested domains: the Northwest Atlantic (NWA), the Gulf of Maine (GOM) and Massachusetts Bay (MB). The specifics of the individual domains are given in Table 2 and the domains are shown in the figure below. In the operational context, there will be two-way nesting between the NWA and GOM (NWA/GOM) domains and the GOM and MB (GOM/MB) domains. The NWA/GOM nested run will provide boundary conditions for the GOM during the GOM/MB nested run.

A two-way nested domain pair consists of a dynamical model defined in two domains, one with coarser resolution containing the other with finer resolution. Information from the finer resolution domain is used to replace information in the coarser resolution domain areas which intersects with the finer resolution domain (up-scale). Information from the coarser resolution domain around the boundaries of the finer resolution domain is interpolated to improve boundary information in the finer resolution domain (down-scale).

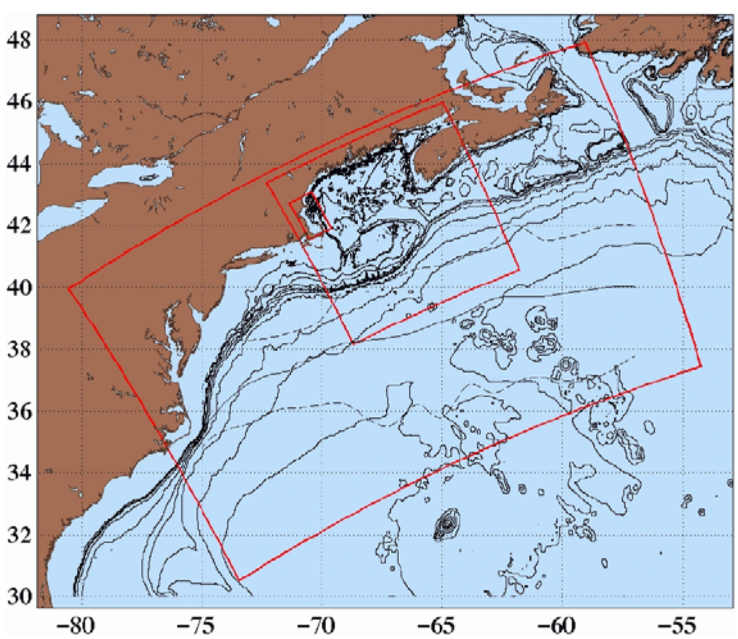

Figure 3 - Nested modeling domains

Table 2. Modeling Domains

DOMAIN	DESCRIPTION/ SPECIFICATION
Western North Atlantic	Resolution: 0.135 degrees (~15km) Size: 130x83x16 (nx x ny x nz) Transform center: 39.439352N, 67.1515W Domain offset: delx = 0 deg.; dely = 0 deg. Domain rotation: 25.5 degrees
Gulf of Maine	Resolution: 0.045 degrees (~5km) Size: 131x144 x16 (nx x ny x nz) Transform center: 39.439352N, 67.1515W Domain offset: delx = 1.2825 deg.; dely = 2.0475 deg. Domain rotation: 25.5 degrees
Massachusetts Bay	Resolution: 0.015 degrees (~5/3km) Size: 53x90x16 (nx x ny x nz) Transform center: 39.439250N, 67.1515W Domain offset: delx = -0.9675 deg. dely = 3.6975 deg. Domain rotation: 25.5 degrees

5. Ship requirements and instrumentation

The ASCOT-01 operational center will be aboard the NRV Alliance. The scientist in charge of ocean observations and the principle investigator for ocean modeling will embark with their groups. At least one additional ship is required for the experiment relating ocean variability to acoustic variability and coherence. In order to assure the presence and faithful operation of all systems for four days of the acoustic trial, the second ship is required for a period of seven days, optionally divided into 48-hour periods. Additional assets such as (coastal) ships and autonomous underwater vehicles are desired for fine-scale resolution of bay features, extended measurements in the Gulf of Maine, coupled and interdisciplinary experimentation (biogeochemical/ecosystem dynamics, acoustical dynamics, etc.).

Main instrumentation on Alliance consists of:

- Navigation
  - Integrated navigation system
  - Differential GPS

- Moorings
  - 600 kHz ADCP (Barny)
  - Two 300 kHz ADCPs (Sentinel)
  - Two real-time ADCP and profiling systems (SEPTR)
  - Wave rider buoy
  - Vertical hydrophone line array
  - Bottom mounted sound source (tower)

- Vertical profiles
  - Seabird CTD
  - Niskin Bottles

- Towed instruments
  - CTD chain

- Remote sensing
  - Sea Surface Temperature (AVHRR) satellite receiving and processing system
  - Ocean Color Scanner (SeaWiFS) receiving and processing system

- Data communications
  - Spread spectrum radio connection to tow ship
  - High bandwidth link with SACLANTCEN
  - Inmarsat B

- Computing
  - Processing systems for all acquired data
  - Powerful workstations for ocean modeling

See the appendix for additional information on the NRV Alliance or visit the Alliance web site at: www.saclantc.nato.int/ships/alliance.html.

6. Schedule and sample tracks

The ASCOT-01 cruise of NRV Alliance is flanked in time by two cruises to the American East Coast. Passage of the NRV Alliance across the Atlantic Ocean will be in April and July. Port calls between cruises will be in Boston, each of two days duration.

Local time = Eastern Daylight Time (EDT)

Jun 04	0900	Alliance enters port of Boston
		Embark oceanographic groups, install equipment
Jun 06	0600	Alliance leave port
		Deploy ADCPs near Plymouth, near Race Point and near Cape Ann
	1800	Begin multiscale towed initialization survey of Massachusetts Bay (Fig. 4)
		Deploy CTD chain for towing on 70m water depth
Jun 07	0600	Shorten chain to 30 m
	1600	Shorten chain to 15 m
Jun 08	0600	Recover CTD chain north of Boston harbor.
		Begin Gulf of Maine CTD initialization survey (Fig. 4)
Jun 12	0600	Deployment of wave rider buoy, hydrophone vertical line array, source tower and CTD chain, the latter to be picked up by another survey ship
	1500	1st fixed range acoustic experiment on temporal and spatial variability

Jun 13	0800	Rearrangement of the acoustic track
	1400	2nd fixed range acoustic experiment on temporal and spatial variability
Jun 14	0600	Recover wave rider, acoustic source and receiver
		Adaptive Sampling CTD stations
Jun 15	0800	Deploy wave rider, acoustic source and receiver
	1500	3rd fixed range acoustic experiment on temporal and spatial variability
Jun 16	0800	Rearrangement of the acoustic track
	1400	4th fixed range acoustic experiment on temporal and spatial variability
Jun 17	0600	Recover wave rider, acoustic source and receiver, pick up CTD chain from second ship
		Adaptive Sampling CTD stations
Jun 18	0800	Port call Boston, disembark acoustics team
Jun 19	0800	Alliance leaves port of Boston
		Adaptive Sampling CTD stations
Jun 20	0900	Begin multiscale towed verification survey of Massachusetts Bay
		Deploy CTD chain for towing on 70 m water depth
	2200	Shorten chain to 30 m
Jun 21	0800	Shorten chain to 15 m
	2000	Recover CTD chain north of Boston harbor.
	2200	Begin Gulf of Maine CTD verification survey (see map and table)
Jun 25	1200	Interrupt CTD survey for ADCP recovery
Jun 26	0800	Alliance enter port Boston
		Disembark oceanographic groups

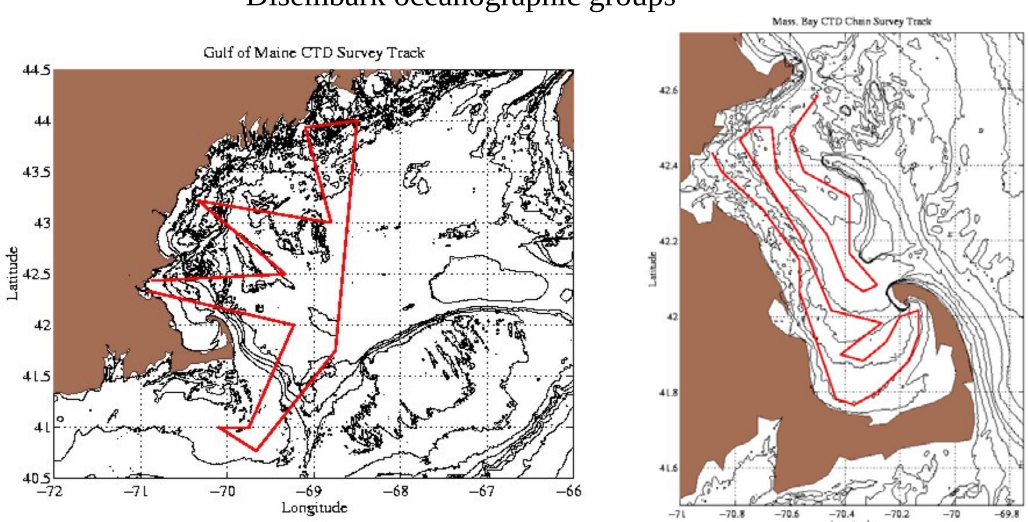

Figure 4 - Potential cruise tracks. Left - Gulf of Maine CTD survey. Right - Massachusetts Bay Towed CTD Chain survey.

The towed CTD chain survey will precede the Gulf of Maine CTD survey. The towed CTD chain survey is designed to follow isobaths within Massachusetts Bay, thereby minimizing the number of manipulations (raising and lowering) of the CTD chain. The ship will survey inflow conditions first. The Gulf of Maine survey will begin subsequent to the completion of the Massachusetts Bay survey.

7. Logistics

When NRV Alliance arrives in Boston, she will have all equipment on board except for the workstations of the Harvard group. Two days in port will be used for rearrangements in the laboratory.

An acquisition system for the CTD chain and spread spectrum radio communications must be installed on the second ship prior to the acoustic experiment. Under favorable weather conditions this might be possible at sea, an installation in port is preferred however. For the transfer of equipment between Alliance and the other ship, a van is required during the first and second port call in Boston. The CTD chain and communications systems on the second ship should be operated with the assistance of two SACLANTCEN technicians.

Ocean modeling carried out on NRV Alliance requires input from the outside such as atmospheric forcing fields. Since another group of modelers will be located elsewhere and the other group's model fields are required for nesting or comparison and vice versa, the data communications requirements exceed those of previous REA experiments. A satellite communication system will be installed on Alliance prior to the cruise by which transmission costs will be drastically reduced as compared with Inmarsat B.

8. Forecasting and Real-Time Products

Data analysis, data assimilation and numerical simulations will be carried out on a daily basis in real-time throughout the duration of the exercise. *In situ* data will be acquired by the NRV Alliance as well as by other chartered vessels or ships of opportunity. Remotely sensed data will be available via SACLANTCEN or other sites. Data will be analyzed, quality controlled and processed as it is received and made available for assimilation into the Harvard Ocean Prediction System (HOPS).

It is desirable to have the forecasts carried out in two modes: in Predictive Skill Assessment mode - i.e. using all data as acquired in order to most accurately predict future states; and in REA mode - i.e. using a reduced data set in order to mimic REA conditions and demonstrate the ability to utilize minimal data. This goal will be met if conditions and assets allow for separate forecast teams.

Forecasts will be available on a daily basis after the initialization survey in order to provide adaptive sampling patterns for the subsequent day's sampling. Products will be available via the experiment web site. Example products might include (for both the Gulf of Maine and Massachusetts Bay modeling domains): synoptic maps and forecasts of temperature or salinity with superimposed velocity vectors for levels of interest, vertical sections of chosen quantities at locations of interest, profiles of temperature or sound speed at locations of interest, etc.

9. Potential for Collaborations

The scientific plan presented here is for a self-consistent ASCOT-01 physical dynamical and forecast experiment. However, the core ASCOT-01 experiment provides an exceptional opportunity for extended physical experimentation and additional coupled interdisciplinary research in acoustics and biogeochemical/ecosystem dynamics and processes. The ASCOT-01 scientists welcome collaborations both of mutual interest and that would extend the impact or utility of the core experiment.

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Appendix - Alliance Characteristics

Length overall	93 m
Length between perpendiculars	82 m
Moulded beam	15.20 m
Depth, moulded	8.70 m
Draught, full load	5.2 m
Displacement, loaded	2,920 t
Gross tonnage	3,180 t
Net tonnage	960 t
Fuel capacity	315 cubic m
Fresh water	100 t
Shaft power (max. continuous)	2970 kw
Sustained sea speed	16.3 knots (Clean Hull)
Effective range at 11.5 knots	7200 n.mi
Endurance port to port	26 days
Main Masthead height	33.3 m (top of radar antenna)
Secondary Mast height	23.9 m (top of radar antenna)
Fore Mast	15.4 m (Railing top)

The vessel is equipped with twin (outward turning) screws, twin rudders, bow thruster and diesel/gas turbine electric propulsion machinery.

The vessel is designed for unmanned machinery and one-man bridge operation (daylight hours) for 24 hours a day when in a steady steaming condition.