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Quantifying, Predicting, Exploiting Uncertainties in Marine Environments

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Abstracts

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Abstracts are sorted by first author's surname

Application of an adjoint SWAN wave model

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The wave model SWAN is used for daily nowcasts/forecast for various coastal applications. The accuracy of any coastal wave model is often limited by the quality of wave input at boundaries. An adjoint wave model based on SWAN was developed by Walker (2006) to assimilate wave data to derive or improve the input wave condition. The adjoint model has been shown to provide more accurate results than using the forecasting input alone. The NCEX (Nearshore Canyon EXperiement) held in 2003 provides an excellent data set for testing the adjoint model in a complicated bathymetry area where topography effects including shoaling, refraction, diffraction and reflection are active. The work discusses the assimilated results using NCEX data and the limitation of the model.

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Optimum mission planning for a network of gliders

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Present-day naval operations are increasingly focused on coastal-littoral waters. In times of conflict, domination of coastal areas largely depends on the ability to assess the environmental conditions of the battlefield. Gliders are envisioned as key technologies to assure access to denied/unsafe areas of operations. Survey methodologies for these platforms are required to rapidly collect data in denied areas, maximizing its information content and minimizing redundancies. These sampling strategies must adapt to the evolution of the environment, considering glider motion capabilities.

This work introduces a methodology to design optimum surveys for a network of gliders. Specifically, a data fusion engine produces a physically sounded analysis of the battlespace based on the information received from the glider fleet and remote sensors. The estimated uncertainties of the analysis establish the hierarchy of near future sampling strategies of the network. Feasible and optimum glider trajectories are obtained from minimizing a cost function which encodes the uncertainty reduction due to glider measurements. Minimization involves a physical simulation of each glider in the fleet, including heading correction when surfacing, and it is constrained to a given mission time. Simulated annealing, genetic algorithms and pattern search has been considered as optimization engines, showing the latter the best performance. Final optimum trajectories are provided in terms of feasible waypoints for each glider in the network.

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Recent technological advances at NURC: Optical instrument packages, Optical data acquisition accuracy and Optical sensor calibration

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Due to the increased use of optics measurements in different oceanographic disciplines, from ocean colour to bio-optical modelling, NURC's engineering department has acquired instruments and knowledge on optical data collection, validation and calibration.
In situ observations still play an essential role in "initializing/ground truthing" of various models and remote sensing imagery. However, due to the yet-to-mature technologies applied on optical instruments and the related lack of calibration standards, a lot of effort must be spent on data quality control in order to improve and standardize pre/post deployment calibration procedures. Currently, NURC possesses a variety of different sensors, platforms and procedures (some of which are still under development) that enable high quality characterization of the optical properties of water masses.
In keeping with the Centre's historic reputation for data quality, and to resolve the problems associated with collecting high quality optical data, NURC scientists and engineers worked to define calibration and measurement uncertainties. This is especially important for the Centre's latest generation of oceanographic platforms, such as the Slocum Glider fleet, prototype AUVs and towed undersea vehicles capable of a wider spatial coverage though restricted to sensors of a small size and lower resolution. The results are internal procedures for the calibration and characterization of sensors, resulting in reliable and comparable data sets. This is achieved with in house calibration facilities based on an optical laboratory with NIST lamps and alignment systems, high resolution analysis and fully calibrated and characterized Hyperspectral *in situ* profiles for Inherent and Apparent Optical Properties.

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Rao Bounds on Estimates of Principal Components

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Cramer - Rao Bounds (CRB) are fundamental expressions for bounding the mean square error of estimates of parameters. They establish i) a lower bound for the performance of any estimator and ii) if they are satisfied with equality, the maximum likelihood estimator is optimal. Generally, they are tight bounds at high SNRs. They are extensively used in radar, sonar and array processing, in particular for bounding estimates on the range and doppler of a target. The bounds are very general for any problem involving estimating parameters of a stochastic process observed in noise. In this presentation we generalize our previous results to establish bounds on estimates of the principal components of a random process observed in noise when both the signal and noise are Gaussian random processes. We express the signal in terms of a product of stationary random process and its Greens function in which the process is embedded plus a noise process. From this we derive four compact quantities for the Fisher Information Matrix which determines the CRB. These quantities establish the signal to noise, the convexity of the ambiguity peak the biases of the estimate. A tutorial example relevant to oceanographic processes is given.

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Inversion for water column and sediment sound speed profiles in range-dependent environments with application to data from the SW06 Experiment

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In the summer of 2006, the US Office on Naval Research sponsored the "Shallow Water '06" (SW06) experiment which was conducted on the New Jersey shelf area of the North Atlantic. This was a multi-discipline, multi-institutional experiment combining studies on coastal oceanography, geology, and ocean acoustics of continental shelf and slope environments. The New Jersey shelf is a dynamically complex environment where cool, fresh continental shelf water interacts with warmer, more saline water of the continental slope. Intrusions of slope water onto the continental shelf are an important source of water column variability. This environment is also characterized by high spatial variability of the seabed. A dominant feature of the sub-bottom is the "R" reflector, a prominent shallow sub-surface seismic reflector that varies in depth on the middle and outer shelf. The spatial and temporal variability of this shallow-water environment is a source of uncertainty for predictions of acoustic propagation. In this work, it is shown how measurements of horizontal wave numbers can be used to estimate sound speed profiles in both the water column and seabed. The method uses a perturbative scheme which can be applied to rapidly assess environmental variability. During SW06, data were collected by towing a low-frequency sound source out and back along radials, spanning a 90 degree angular sector, from a common receiver location. Range-dependent estimates of horizontal wave numbers were obtained along each of the radials using high-resolution signal processing techniques. The wave number data were used to invert for sound speed in the water column and seabed as a function of depth and range. For the case of the water column, the inversion results revealed the presence of a mass of cooler water responsible for lowering the sound speed over a portion of the ship track. Inversion results for the seabed showed a low-speed sediment layer that became narrower and then disappeared with increasing range from the receiver location.
For both the water column and seabed, the results of the inversion scheme showed agreement with *in situ* measurements. The water column inversion results were compared to measurements made by a CTD chain which was towed from the same ship as the acoustic source. The range-dependent structure of the seabed inversion results were consistent with seismic data which was collected before the experiment.
[Work supported by ONR].

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Accounting for Spatiotemporal Variability in Shallow-Water Waveguides for Prediction and Inversion

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In an operational context, acoustic propagation models are often used for generating predictions to aid in decision making. Accurate predictions require that input model parameters be known and adapted for conditions at the time of the exercise. Likewise, when estimating environmental parameters from field data, it is essential to understand which parameters are sensitive to time and spatial evolution of the propagation environment. Changes in environmental conditions over the course of a measurement must be monitored and then accounted for in analysis. In this talk, we describe an experimental configuration in which spatiotemporal variability in both environmental and acoustic data were measured over a prescribed track throughout the course of a day. The data were collected for the purpose of characterizing the range-dependent sound speed profile in the sediment. The sound field measured on a fixed array of receivers for a source towed along the same track changed significantly over the course of the day. However, by properly accounting for spatiotemporal changes in the propagation medium, a consistent characterization of the seabed was obtained.

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Environmental Observations using Marine Radar Data from a Moving Vessel

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Marine radars mounted on ships can provide remarkable insights into ocean behaviour from distances of several kilometres, placing other *in situ* observations and ship operations into a wider oceanographic context. It has been known for some time that it is possible to map shallow water bathymetry and currents using radar image sequences recorded from shore based stations (Bell 2006, 2009). Those radars were mounted on static platforms allowing long term monitoring of coastal seas and providing valuable insights into the variability and dynamics of such hydrodynamically and morphodynamically active areas. A long standing question from military and hydrographic communities has been whether such techniques can be applied to radar data collected by moving vessels. If so, this presents the possibility of mapping large areas of shallow or coastal seas (albeit with a somewhat course horizontal resolution of 50-100m) prior to the surveying vessel actually having to travel into potentially uncharted shallow water areas. Radar data were recorded by the Canadian Forces Auxiliary Vessel Quest using a Wamos radar digitiser connected to the Decca navigation radar during a number of trials around Nova Scotia in 2008 and 2009. Basic georeferencing corrections derived from the existing ship navigation systems were sufficient to allow the application of the existing data analysis designed for static radar installations. This work presents the results of bathymetry analyses of several datasets recorded from CFAV Quest while the vessel was travelling at speeds up to 12 knots. The bathymetry derived from the radar data compare favourably with independent surveys and with the on-board echo sounder to depths of approximately 30m. The technique is fundamentally limited to waters no deeper than approximately 30m, beyond which the ocean waves used by the analysis do not "feel" the seabed sufficiently for the shoaling effect to be detected. In addition, one of the datasets provides an example of the sea surface signatures of internal waves propagating towards the shore.

Bell, P. S., Williams, J. J., Clark, S., Morris, B. D. & Vila Concejo, A., 2006, "Nested radar systems for remote coastal observations". Journal of Coastal Research, SI 39, 483-487.

Bell, P.S., 2009, Remote bathymetry and current mapping around shore-parallel breakwaters. In Proc. of of 33rd Int. Ass. of Hydraulic Engineering & Research (IAHR) Biennial Congress, Vancouver, Canada, August 9-14, 2009.

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Past and present predictability of severe storms

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We explore the predictability of extreme storms in the Adriatic Sea, as representative of similar situations in small enclosed basins. Two major storms are considered. The first storm occurred on 4 November 1966, when Venice suffered its most dramatic flood event. The damages and loss of lives caused by the storm and the associated flood were extremely high also because the event was poorly forecast. We re-analyse the 1966 event using state-of-the-art meteorological and oceanographic numerical systems. The purpose is to assess whether the poor forecast quality was due to a lack of data or of suitable numerical modelling. The second severe storm we consider happened on 22 December 1979, when Venice experienced the second-worst 'acqua-alta' conditions in its history. The results show that, had the present forecasting methods been available, still using only the data available at the time both the events could have been forecast several, up to five, days in advance. We discuss the extension of this result to the present situation when extensive sets of real time data are available. We also analyse the critical aspects of the forecast when a minor change in the anticipated meteorological situation can dramatically change the oceanographic conditions in the area of interest.

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The Predictability of Near-Coastal Environments using Unstructured Grid Models

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The necessity for skilled forecasts of environmental variables in coastal waters is increasingly recognized. The challenges to forecasting in these environments are formidable and include the lack of detailed bathymetric and topographic information, complexities of the coastal geometry from estuaries to intertidal reaches to rivers, and the appropriate specification of oceanographic and atmospheric forcing. Solutions to these issues are derived by exploiting information from remote-sensed observations and coupling regional scale models to limited domain models based on unstructured grid technology.
Examples illustrating the predictive skill of unstructured grid models in capturing the dynamics of rivers, and coastal waterways are presented. An approach for initializing an unstructured computational mesh from imagery is demonstrated for the Snohomish River, WA and the resulting river model is evaluated for its predictions of currents. A second case study examines two-weeks of 48-hr forecasts for waterways near the mouth of Chesapeake Bay produced by the baroclinic version of the finite element model, ADCIRC. The implications of operational decisions such as the spatial and temporal resolution of the meteorological forcing are evaluated through comparisons of predicted and observed currents.

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Observational and modeling case study of an extreme atmospheric forced event in the Turkish Straits on 22 November 2008

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The U.S. Naval Research Laboratory in collaboration with NATO Undersea Research Centre and the Turkish Navy Office of Navigation, Hydrography and Oceanography, undertook a scientific research program, Exchange Processes in Ocean Straits (EPOS) that included an observational effort from September 2008 through February 2009 of maintaining pairs of bottom-mounted, upward-looking Acoustic Doppler Current Profilers near all entrances (exits) of the Turkish Strait System. These simultaneous current measurements facilitate a study of the level of connectivity of large basins by narrow straits and a study of the importance of modeling the connections of such systems. Here we highlight one event that provides a process study of atmospheric and basin interactions.
On Nov. 22, 2008 a low atmospheric pressure event reaching a -30 mbar anomaly level occurred over the Turkish Straits System. This atmospheric signal was caused by a large-scale low pressure system dipping southward over the region for a period of less than two days and was accompanied by associated northeastward winds in the along-strait direction. In conjunction with the winds and atmospheric pressure, bottom pressure in the northern Bosphorus strongly dropped, while bottom pressure at the other strait entrances/exits weakly rose. The initial response of the currents was a strong reversal of the upper flow in the Dardanelles and southern Bosphorus back towards the Black Sea and a strong increase in the subsurface flow towards the Black Sea in the northern Bosphorus. One day later, the Dardanelles reversed again with flow now towards the Aegean Sea occupying most depths. Meanwhile, the Bosphorus continued through most of a second day of stronger than average flow away from the Marmara towards the Black Sea.
This process study illustrates the complex baroclinic coupling of such narrow straits systems and is a good test case to examine model performance. We will evaluate predictions of system response to this event from an ADCIRC finite element model that includes representations of the complete Dardanelles-Marmara-Bosphorus System. We will also contrast this with the response predicted from a ROMS finite difference model that simulates the Marmara Sea only.

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Backtracking drifting objects using a forward algorithm on a stochastic trajectory model

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The task of determining the origin of drifting objects following an observation is highly complex due to the uncertainties in drift properties and environmental forcing (wind, waves and surface currents). Usually the origin is guessed at by running a trajectory model (stochastic or deterministic) in reverse. However, this carries several problems, most notably the fact that many drifting objects change character nonlinearly (sinking ships, evaporating oil, capsizing lifeboats) underway. This makes it very difficult to naively construct an inverse or "adjoint" to the trajectory model. We propose instead a different approach where the original trajectory model is kept unaltered but a complex seeding and selection process allows us to retain only those particles that end up within a certain time-space radius of the observation. An iterative process is employed where those trajectories that do not make it to the goal are rejected and new trajectories are spawned from an earlier starting time. This allows us to run the model in the forward direction and use full nonlinear physics and chemistry (in the case of oil drift) to determine the probability of a certain point of origin. The method is demonstrated using the Leeway stochastic model for drifting objects (Breivik and Allen, 2008).

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Hydrodynamic Design and Optimization of an innovative SWATH-USV by CFD methods

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Scope of this work is to present the main characteristics of an innovative platform which has been conceived to extend the operational abilities of present Unmanned Surface Vehicles (USV). The main idea which rules the project is the realization of an autonomous system capable of undertake several tasks in the marine environment even with moderate rough sea conditions. The platform designed has mainly the ability to locate and recover other members of the fleet (like AUVs or other underwater devices) and at the same time could carry out a surveillance service of the surrounding areas. To manage with these tasks the vehicle is build to provide a fairly good autonomy which is needed to face with intermediate range missions (200 miles). The choice of a SWATH (Small Waterplane Area Twin Hull) platform has been motivated by its excellent properties of seakeeping qualities, that is combined with a special low resistance underwater hull form which is able to reduce to a minimum the resistance of the vessel especially at higher speeds. These excellent seakeeping performance is guaranteed by a small warterplane area geometry due to its lower reactivity to wave's exciting forces and moments, with the result of a much more stable platform if compared to a more conventional one. Moreover an innovative geometry of the immersed part of the hull lowers the advance resistance thanks to a positive interference effect between the generated wave trains. To obtain the most efficient profile of the underwater bodies a systematic optimization with an automatic procedure have been arranged for the purpose. This is based on a parametric definition of the geometry, a CFD solver and a differential evolution global minimization algorithm. Many experimental data have been verified to test the ability of the computation hydrodynamic solver to predict resistance. Simulations have been made both in the air and in the water to compare software's result with original one and to verify its performance. As expected all the CFD computations have demonstrated the well superior efficiency of the developed unconventional SWATH technology with respect current alternatives of hull typologies.

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Seaglider observations of Iberian upwelling

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The Atlantic coast of the Iberian peninsula is one of Europe's most biologically productive oceanic regions fuelled by coastal upwelling. Upwelling events are investigated using a Seaglider AUV. Data collected from the Seaglider platform are compared with longer term datasets from various collection methods (cruises, mooring and satellite imagery), with the platform demonstrating significant advantages over these traditional' methods, such as allowing a finer spatial resolution than available with satellite imagery, and better temporal resolution than traditional cruises. A 50 km west-east transect across the Iberian shelf and slope at 42°N is being repeated for three months during spring/summer 2010, with oxygen, chlorophyll fluorescence, coloured dissolved organic matter (CDOM), salinity and temperature recorded. Results indicate two broad regimes in the region, the prevalent summer state is a stably stratified water column with minimal upwelling, and a strongly defined deep chlorophyll maxima at 30-50 m depth. The second, more infrequently occurring regime sees an intensified southward flowing surface current, strong upwelling and photic zone mixing, and a fertilization effect that lasts a number of days after the upwelling finishes.

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Cooperative distributed localization and environmental sampling by AUV teams

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One of the most interesting recent technological developments in oceanography is the availability of Autonomous Underwater Vehicles (AUVs). This class of vehicles, which include oceanographic gliders, allows to gather samples of environmental quantities by letting the vehicle carrying the appropriate sensor and executing a preprogrammed mission exploiting its own navigation autonomy. In this way it is not only possible to execute standard field measurements in a cost-effective way, but also to exploit sampling strategies previously considered unpractical or unfeasible if implemented from surface vessels. AUVs can exploit on-board intelligence to increase spatial sampling frequency when fast variations of the sampled field are detected, or the mission can be programmed in order to map specific oceanographic features, as isothermal contours or thermocline depth. The step ahead currently investigated involves the use of multiple AUVs conducting environmental measurements as a team. This line of research involves the autonomous cooperation, coordination and adaptation of the team within a specific large scale mission. While the benefits for environmental assessment of such approach are evident, there are still unsolved challenges to AUV team operations, due to the peculiarities of the underwater environment. In particular, the two main problems are those of underwater localization and communication; however, also mission execution, particularly in case adaptation to the measured quantities is required, has to comply with the constraints due to localization and communication limitations. This contribution analyzes local behavioural strategies that explicitly take into account the range-limited and capacity-limited nature of the acoustic communication channel, in order to accomplish in parallel two tasks: cooperative localization of each member of the team, and adaptive environmental sampling. Cooperative localization assumes that some member in the team plays the role of a georeferenced agent (for instance, by staying at the sea surface with GPS connection), and the others are referenced one with respect to the others exploiting acoustic ranging interleaved with estimated position communication. In this way a distributed time-delayed Kalman-like localization algorithm can be implemented, requiring that each vehicle keeps communication contact with at least one other vehicle in the team. Adaptive environmental sampling is proposed in terms of local increase/decrease of spatial sampling rate on the basis of the local measurements of each vehicle; however, the knowledge of a neighborough vehicle position, together with the maximum allowable communication range (expressed in terms of $(bit/s)/km$) is locally exploited to constraint adaptation in order to maintain communication. Emerging collective behaviours and estimation error analysis will be discussed.

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Particle Tracking in the German Bight, Comparing Drift Climatologies from Different Numerical Models

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We study the degree to which simulated Lagrangian particle transports depend on the choice of a specific hydrodynamic model. Our region of interest is the vicinity of the island of Helgoland (German Bight, North Sea). For different models a total of 3377 Lagrangian transport simulations (particle clouds, 50 days integration time) were initialized once every seven hours within a period of about three years (Jan 2002 Oct 2004). Both forward and backward simulations were performed.
We used hydrodynamic simulations from four hydrodynamics models that differ with regard to spatial resolution, 2D or 3D, atmospheric forcing, or the numerical scheme. The offline particle tracking algorithm we used is 2D so that fields from 3D models had to be vertically averaged. Results were evaluated in terms of the fraction of released particles that crossed each cell of a network of receptor regions centred at the island of Helgoland. Empirical orthogonal function analysis was used for a description of transport variability.
Major differences between the models were found, physical reasons for which are not always clear. Differences refer to both mean conditions and weather driven variability. Although the passive tracer assumption will not be applicable to most practical studies, our analysis reveals constraints that would affect any more complex simulations as well. Uncertainties or systematic biases due to the choice of a specific model may affect the reconstruction of marine conditions or have implications for future scenarios of advection dominated processes.

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Chronic Oil Pollution in the North Sea: a Drift Climatology Represented by a Bayesian Network

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To which extent illegal oil spills along major shipping routes, for instance, affect coastal areas depends on prevailing winds and currents. Model based multi-decadal reconstructions of meteo-marine conditions for the North Sea region (see `www.coastdat.de`) were used for analysing drift paths of hypothetical oil slicks. A large number of such simulations covers the whole spectrum of realistic environmental conditions in agreement with the frequency of their occurrence. This allows for a general assessment of the exposure of the German coast to chronic oil pollution and how this exposure varies in time and between different coastal areas.
High resolution long-term simulations of meteo-marine systems generally require much resources and specialized evaluation tools. We propose the use of Bayesian Network (BN) technology for a summarizing representation of the detailed simulations in terms of conditional probabilities. The probabilistic representation allows for conditioning numerical simulations on external forcing (weather conditions), for instance. Alternatively one might wish to condition on events when pollution was observed in a specific region. In the latter case the Bayesian inversion formula becomes involved to transfer information in a direction opposite to causal dependencies encoded in the hydrodynamic model. Conditioning on travel times allows for taking into account substances with different half-lives. A customized BN provides an interface that facilitates the communication of the essentials of comprehensive ensemble simulations to interested users or their further use in the context of inter-disciplinary projects, for instance.

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Sea surface roughness by photogrammetry

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Today the sea surface wave field at small scales is one of the major unknowns in radar remote sensing and underwater acoustics. Such knowledge is critical for radar clutter and surface wind speed prediction by modelling of electromagnetic scattering at the air-sea interface. Reverberation from sea surface roughness is also a source of interference for active sonar and communications in shallow water. Sea surface reverberation models needs a spatial domain measurement (in one or two dimensions) of the water/air interface roughness with a sampling interval comparable with the sound source wavelength (a few millimetres for a high frequency sonar source). SSUP (Sea SUrface Photogrammetry), a stereo photographic system developed to measure the three dimensional wave field of the ocean surface at varying scales and different environmental conditions (e.g. wind, atmospheric stability and rain), is presented in this work. The system includes a supporting frame with two high-performance low noise cameras and lenses and the snapshot synchronizer. The system is calibrated with a printed board and the output of the calibration procedure is used to correct spherical and chromatic aberration of the lenses and to measure the camera relative orientation and position in the space. The stereo reconstruction software has been developed in house and uses the three colours of the raw stereo-images to reduce correlation errors. From the reconstructed three dimensional wave fields (some examples obtained by the system are given), it is possible to retrieve various wave parameters: in particular the smaller scale ($< 1\ m$) spatial wave spectra that are otherwise difficult to measure.

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A novel EOF-based methodology to study the internal wave effects on acoustic propagation

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This work presents a novel approach to synthesize realistic environment for ocean acoustic parametric studies. In its current form, this methodology applies to internal waves and tides. An Empirical Orthogonal Function (EOF) decomposition is applied to a temporal series of temperature profiles. It can be observed that the first two time-dependent expansion coefficients are dynamically linked. When they are plotted one versus another in a scatter diagram, the cloud of points consists of a crescent shape that can easily be represented by a polynomial fit. If the first two expansion coefficients capture enough variability in the temperature profiles, the EOF modes plus the polynomial can be used to reconstruct temperature profiles independently from the set of data. This realistic synthesized environment can then be input to acoustic propagation models. This approach is applied to the case of the Messina Strait in which internal waves are known to be intensive. From a short term series of temperature profiles collected on a thermistor string, range-dependent profiles along and across the strait are reconstructed. The acoustical impact study is conducted with the RAM parabolic equation model. The methodology presented in this work is simple to run and requires a very affordable set of data. It could be used as an efficient alternative to ocean and acoustic model coupling for process studies or for regional studies especially in poorly known areas of highly variable areas, where it is difficult to obtain good sound speed profile prediction from ocean models.

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Assessment of uncertainty and predictability of wave forecast systems

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We analyse the problem of predictability of sea storms and of the related uncertainty of the forecasts. We have used state-of-the-art and high-resolution results from the ECMWF archive and also those from some devoted experiments. We have focused our attention on the Adriatic Sea as representative of minor basins where the predictability is usually lower than in the open oceans and conditions can be made more difficult by the bordering orography. Specifically we have analysed five severe and extreme storms happened both in the 60s and 70s and in present times. This has allowed a determination of the relevance of the amount of data on the definition of the initial conditions, hence on the quality of the forecasts. We have used both deterministic and ensemble approaches. This has allowed to determine not only the average reliability of the classical deterministic approach, but also the range of uncertainty that goes with any forecast. Our results show that in the considered conditions of inner enclosed seas single forecasts provide reliable results till four or five days in advance. This is true not only for severe events that are expected to have large impact on the atmospheric conditions, but also for minor storms. Besides, our results indicate that the use of ensemble extends the time range of useful information of one or two further days, hence till almost one week before the events.

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Glider Command and Control Centre

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Autonomous underwater gliders technology is mature enough to allow extensive oceanographic data collection and application for naval operations. Gliders Command and Control Centre facilities play a significant role in achieving successful surveys. These are technological infrastructures where a fleet of gliders is supervised and commanded, and the information received is centralized, pre-processed and distributed. The NURC proposal for Gliders Command and Control Centre (or Glider Operations Room) is a place where decision makers and pilots find all relevant information to properly plan and execute gliders missions. Environmental models (meteorological, winds and wave's forecasts), *in situ* data measurements (drifters, deployed moorings, HF radar), AIS data and historical maps, and geographic information can be simultaneously displayed in the Glider Operations Room creating the environmental and operational picture before and during the missions. Near real time data processing is provided to evaluate mission progress and allow for rapid decision on possible mission changes.

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A Regional Ocean Modeling, Data Assimilation and Forecasting System: Anywhere and Anytime

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Experience and lessons learned from developing a regional ocean modeling, data assimilation and forecasting system for real-time operations will be presented. The model is based on the Regional Ocean Modeling System (ROMS), and the data assimilation is based on the multi-scale 3-dimensional variational (MS-3DVAR) method. The ocean forecasting system assimilates a number of *in situ* and remotely sensed data including both satellite and land-based high-frequency (HF) radar observations. The impact of the various observational data on the forecasting skill will be described. The developed real-time forecasting system has been implemented for Monterey Bay, Southern California Bight, and Prince William Sound, Alaska. Issues and challenge to apply this ROMS-based forecasting system anywhere and anytime over the world ocean will be discussed.

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Thermal RECharging (TREC) Profiling Float Powered by Ocean Thermal Energy

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This poster will describe the development, implementation and field testing of the first profiling float that is completely powered by ocean temperature differences. The innovation is to use a phase change material (PCM) power generator that uses ocean temperature differences to produce electricity. The PCM power unit was integrated to a Scripps Argo Float, known as Sounding Oceanographic Lagrangrian Observer (SOLO). SOLO-TREC was successfully deployed on 30 November 2009. It makes 3 dives per day from the surface to 500-m depth and generates approximately 6100 Joules or 1.6 Watt-hours per dive, which equals or exceeds all the power needs of a profiling float. The original goal of the float was to survive 3 months, which was accomplished on 1 March 2020, and the float continues to operate flawlessly to this date. The most recent surfacing location can be found at the project web site: `http://solo-trec.jpl.nasa.gov`showing both the science and engineering data. As of August 2010, it has made close to 1000 dives, approaching the largest number of dives for a profiling float.

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Numerical modeling of the surface circulation in the Sea of Marmara during the TSS experiment

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Between September 2008 and February 2009, the international scientific program "Turkish Straits System (TSS) 08-09" was carried out under the coordination of the NATO Undersea Research Centre (NURC, La Spezia, Italy), jointly with the NRL project "Exchange Processes in Ocean Straits" (EPOS). The NR/V Alliance sampled extensively the Marmara Sea waters with the deployment of several different instruments (e.g., CTDs, moorings, bottom-mounted ADCPs and profilers, surface lagrangian drifters, Wave Raider, meteorological buoy etc.), some of them providing 1 to 6 months time-series of currents, tracers or meteorological conditions.
Several realistic numerical experiments of the Marmara Sea circulation have been carried out in order to understand the ongoing dynamics, providing simulations of the autumn-winter general circulation and the windstorm-induced circulation. Model results show a general circulation in agreement with previous literature and the data collected as well as a remarkable impact of windstorms with complete reversal of the surface flow and frequent upwelling events.

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A summary of the COASTALT project and its contribution to the monitoring of coastal sea level

Paolo Cipollini and the COASTALT team

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In the last few years the European Space Agency has actively supported research and development of altimetry in the coastal zone - a key region for the impact of changing oceans on society - via the COASTALT Project. The Project has delivered a number of key contributions to the advancement of the topic and has gained visibility within the lively international community of researchers involved in the development of coastal altimetry.
In this poster we will give an overview of what the Project has achieved so far in terms of: (i) issuing recommendations on the corrections for coastal altimetry; (ii) implementing novel wet tropospheric and tidal corrections; (iii) defining product specifications and producing the relevant documentation; (iv) testing and implementing retracking techniques in the coastal region, both more established ones and experimental/innovative ones, and (v) designing and implementing a standalone coastal altimetry processor.
COASTALT is now in its Phase 2 (2010-2011) and is about to release version 2.0 of the products whose ensuing validation against *in situ* data over the pilot sites by the COASTALT partners will allow the start of the scientific exploitation that make coastal altimetry an effort well worth the investments currently being made by ESA and by the research community. This includes investigating the rate of coastal sea level rise.

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State-of-the-art of DSSs at NURC and future trends

Marco Cococcioni, Raffele Grasso, Peter Ranelli and Michel Rixen

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Decision Support Systems (DSSs) are those systems aimed at helping a human decision maker in making decisions. The analysis of the Recognized Environmental Picture (REP) for maritime operation support is one of the most challenging DSS fields of application for several reasons. Maritime operation planning requires the extraction of information and knowledge from a variety of multi-source METOC data distributed over space and time in order to assess operation risk and decide course of action. This task is even more difficult in high dynamic and uncertain areas, such as littoral ones, resulting in a dramatic increase of the workload for the decision maker. Effects of data uncertainty and its exploitation, multi-source data fusion, data dissemination and presentation, and human factors are the aspects in which researchers and system designers in this field are particularly focused including performance assessment. This work, after an introduction of basic concepts, provides an overview of past and recent results of the research on DSSs for maritime operations at NURC with a focus on fuzzy logic based systems, use of probabilistic METOC forecasts and impact of data uncertainty on the decision process. In the second part of the work we revise new research directions aimed at improving both uncertainty handling and human performance under stress fatigue and time pressure. Under investigation the possibility to exploit the Computing With Words (CWW) framework to reduce cognitive workload. Performance assessment, which requires specific metrics and evaluation methodologies, is also under study.

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Self Organizing Network of Gliders for Adaptive Sampling of the Ocean

Marco Cococcioni, Alberto Alvarez, Raffaele Grasso, Daniele Cecchi and Charles Trees

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Underwater Gliders are a cost-effective technological solution to sample the ocean. In highly dynamic areas, adaptive sampling is preferable to static sampling, in order to increase performance by optimally making use of a limited number of gliders. The relatively low cost of these sampling platforms, is opening the door for many research institutions to purchase a fleet of gliders. When a fleet of gliders has to sample for a long period of time *in situ* measurement like conductivity, temperature and depth, there is the need to continuously update the glider missions to take into account sampling needs. How to plan the paths of a fleet of gliders is the topic of this work. Using a global cost function, we are able to mesh the area of interest in such a way that finer resolution is used on regions needing a more accurate sampling, while coarser resolution is used on the rest. Once the mesh has been obtained using a meshing algorithm, the associated knots, considered as points in a two-dimensional space, give us an idea on how to adaptively sample the area. This set of points can be fed to a clustering algorithm (like the fuzzy c-means algorithm) in order to get the position of the centroids, where the number of clusters is equal to the number of available gliders. The positions of the centroids can be used at the next surfacing points for each of the associated gliders (a glider is associated to its closest centroid). Since gliders can be programmed to surface approximately at the same instant in time, this control rule allows to self organize the fleet of gliders. At the next surfacing (often programmed to happen in three/four hours), the area of interest is re-meshed, the clustering algorithm is re-executed and the new surfacing positions are re-sent to each glider in order to update their missions. Meteorological and oceanographic (METOC) forecasts of environmental conditions can be used to compute the expected cost function for the next three/four hours. This further improves the performance of the self organizing algorithm. Simulation experiments support the application of this approach. Future work will try to exploit in depth the parallelism between self organizing artificial neural networks (SOANNs) and self organizing glider networks (SOGNs), where gliders play the role of artificial neurons, trying to adapt state-of-the-art learning algorithms developed for SOANN to SOGNs.

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High resolution data assimilation into ocean models through a 4-dimension re-analysis

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Inputs to decision making and planning of operations in coastal regions seldom use water temperature and salinity and water velocities, usually estimated by observations combined into analysis and by numerical models providing their space-time extrapolations. Since observations are rarely enough to represent the full regions and the dominant dynamics, special care needs to be taken when extrapolating them towards the local areas and scales of interest. The resultant model innovations used to correct numerical simulations in both space and time need also to be carried on with special care such that scales detected by the data but not seen by the model or not resolved by the data but reproduced in the model will not interfere with the analysis process. These limitations will be augmented in coastal regions where unconstrained high frequency dynamics are expected to dominate. Besides this initialization/analysis error source, models can also have large uncertainties due to errors in their boundaries, forcing fields and unrepresented physics requiring corrections that cannot be consistently performed only through these re-initialization steps. The combination of models and local observations has been widely used in operational ocean models through the assimilation of local state observations and has shown to improve the consistency of forecasts. In the recent past work has also been done using synthetic ocean states derived from observed anomalies of non-state parameters (e.g. optical data or sound speed) into the assimilation process. This work will combine both and discuss an operational methodology to use *in situ* temperature, salinity and velocity observations and other high resolution observed variables by cycling a standard smoother assimilation step (3DVAR and/or MVOI) with a higher resolution local 4 dimension re-analysis (using the Ensemble Transform Kalman Filter). While the regular assimilation step will provide overall grid maximum likelihood model corrections, the re-analysis step will improve higher resolution local parameter estimation over shorter range forecasts, hence addressing the multi-scale nature of the analysis and assimilation process. This presentation will discuss examples showing significant improvements in sound speed and velocity estimates over 12 to 24 hour forecasts, when compared with the model estimate prior to re-analysis and to corrections persistency.

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Reporting on Three Years of Activity on Oil Spill Classification from Optical Satellite Images

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The presence of oil spills at sea represents a relevant issue for government institutions since these are causing serious damages to the marine and coastal ecosystem. The exploitation of satellite sensors for oil spill detection allows for large areas monitoring and remote zone control, thus offering many advantages in economical and time saving terms. In particular, the use of multi-spectral satellite data for the development of techniques for oil spill detection and classification could provide a valuable support to SAR-based solutions, in order to meet the need of environmental protection authorities for efficient and cost effective monitoring tools.
This work describes the potential of oil spill detection from optical satellite images, as investigated during three years of activity. The work is focused on the classification of possible region of interests (ROIs), which have been extracted from multi-spectral satellite images, in two classes, namely oil spills and look-alikes. A dataset of more than 300 ROIs has been built by analyzing a number of MODIS-TERRA and MODIS-AQUA images, acquired during the years 2008 and 2009, over the entire area of the Mediterranean Sea. In particular, bands B1 and B2 [visible (VIS) at 0.65 micrometers, and near-infrared (NIR) at 0.85 micrometers], which are the only available bands from MODIS at the highest spatial resolution (250 m), have been used.
In order to characterize the ROIs, a set of geometrical and grey level features from SAR literature have been exploited. These features have been used to feed different classical machine learning classifiers (multi-layer perceptron, radial basis function, neuro-fuzzy classifiers), achieving promising results. Moreover, recent results from an on-line cost oriented classification approach, based on an ensemble of support vector machines, are reported.

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Bathymetry Estimation from Multi-Spectral Satellite Images Using a Neuro-Fuzzy Technique

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The aim of this work is the study and the development of a technique for bathymetry estimation, which is based on the exploitation of information contained in optical images, collected by satellite sensors. The use of satellite images allows to inspect a wide geographical area, and to produce the corresponding bathymetric map, in an economical way. Since remote areas can easily be observed by satellite sensors, remote sensing techniques could represent a useful support to Rapid Environmental Access (REA) activities, that consist in getting information on hardly accessible zones. Moreover, the exploitation of high resolution satellite sensors data, such as Quickbird data, allows to describe the coastal zone with high accuracy, although this implies a reduction of the spectral information. In this work we propose an accurate supervised method based on the use of a neuro-fuzzy system, whose input is made of only three spectral bands. The method consists in the application of an Adaptive-Network-based Fuzzy Inference System (ANFIS) to the optical satellite image of the area of interest. We applied the technique to two Quickbird images of the same area, acquired in different years and in different meteorological conditions. In particular, the first one has been acquired in calm sea conditions, and is supplied with a large dataset of *in situ* measured depths for the training and the validation of the method. The second image has been acquired in slight sea conditions and is supplied with a limited dataset of *in situ* measured depths, collected along two transepts in the scene. These two cases allow to study and compare the performance of the presented technique, taking into account the effect of both meteorological conditions and training set size reduction on the overall performance. On the first image we achieved a mean STD of 36.7 cm for estimated water depths in the range $[-18, -1]$ m. We then studied the performance of the method in realistic situations of limited *in situ* data availability, that is using as a training set only data collected along closed paths in the same image. In this case we obtained a mean STD of 45 cm. In addition, we studied the effect of limited data availability together with unfavorable sea conditions by applying the method to the second image. In this latter case we achieved a mean STD of about 64 cm, which is still a good result.

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TOPAZ system: an Arctic forecasting system

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Monitoring the dynamics in the Arctic is complex because the scale of the ocean processes is small and the ice behaves non-linearly and quickly. This justifies the use of advanced ensemble-based data assimilation methods like the Ensemble Kalman Filter. In 2010, a new version of the TOPAZ system has been developed with improvements of the HYCOM model parameterization, dynamics, and resolution as well as in the data assimilation setup. A pilot reanalysis of 5 years is proceeding. The system assimilates observations of SST, along-track SLA, ice concentrations, icedrift and Argo T/S profiles with the EnKF. The along track SLA and ice drift data are assimilated in asynchronous mode. The system shows satisfactory skill, but presents some limitations when assimilating ice concentration because of insufficient ensemble spread. The problem is solved by using an improved the perturbation system, and a better way to handle representation error. The TOPAZ system constitutes the Arctic forecasting system of the MyOcean project.

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Assimilation with the Ensemble Kalman Filter for decadal climate model prediction

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The 5th assessment of the IPCC, scheduled for 2014, will partly be dedicated to evaluating the feasibility of decadal-scale climate predictions. Skillful prediction on inter-annual to decadal timescales will fill the present scientific and mitigation gaps between the established fields of seasonal forecasting and future climate change projection. We intend to study the capability of the Ensemble Kalman Filter to assimilate satellite data (at first sea surface temperature) within the NorESM. The Ensemble Kalman Filter is a state of the art multivariate data assimilation method able to handle non-linear forecasting application and provide the uncertainty of the prediction. First, a reduced and uncoupled version of the climate system is used to identify the most responsive parameters of the ocean model, and analyze for how long the benefit of the assimilation persists once observations are no longer assimilated.

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Turning MREA operatives into modellers

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The Relocatable Ocean-Atmosphere Model (ROAM), and the Littoral Ocean Modelling System (LOMS) are software packages that have been developed to enable the Royal Australian Navy (RAN) to predict ocean temperature structure and nearshore wave and current conditions, respectively, out to several days.
The reduction of uncertainty in Naval operations necessitates the use of the best approaches to environmental prediction. However, the most sophisticated modelling packages are not usually available to non-specialists. Eight years ago, a partnership was established between CSIRO (an Australian government research agency), the Bureau of Meteorology (BoM, the national weather agency), and the RAN. Part of the mandate was to establish a global ocean-prediction service at the BoM. The second task was to build, for the Navy, forecasting tools they could use themselves in operational circumstances.
The ROAM package runs atmospheric, surface-wave, and ocean-circulation models, automatically nesting inside global models. Typically, the nesting takes the resolution from 10 km, for the global grid, down to 2 km. The operator has only to set up the model grid, using a graphic editor, and specify the forecast period. For the ocean model, in particular, ROAM establishes the bathymetry, reads forcing, initial and boundary data from the BoM global models, runs the model on a remote cluster, and delivers output to Navy headquarters. The primary use of the output is in prediction of sonar performance. Automated data-assimilation is presently being tested in ROAM.
LOMS is an extension of the ROAM software (invoked by a different login) intended to support amphibious and other nearshore operations. It is configured for use on a field laptop, and presently runs the Delft University of Technology modelling package XBeach. XBeach incorporates a coupled spectral wave model and depth-integrated circulation model. The user specifies the model grid, graphically, and the forecast winds and offshore waves. LOMS sets up and runs XBeach, and provides graphical output of the nearshore wind and wave conditions on the laptop. LOMS is designed to run at resolutions of only tens of metres. At this resloution, in the southern Asia-Pacific region, there is usually huge uncertainty in nearshore bathymetry. At present, the very low resolution ($> 250\, m$) default bathymetry must be supplemented, usually in the field, by (clandestine) on-site surveys.

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Bio-Optical Ensemble Prediction

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The Naval Research Laboratory has implemented state-of-the-art bio-optical formulations which have been incorporated into the Navy's primary ocean general circulation physical models: the Navy Coastal Ocean Model (NCOM) and the HYbrid Coordinate Ocean Model (HYCOM). Both are coupled to the 9-component COSINE model [Chai et al., 2002, 2003], and to several optical schemes (Lee et al., 2005; Fujii et al., 2007; Penta et al., 2008). The models receive (initial) boundary forcing from either Global NCOM or Global HYCOM, and atmospheric forcing from either the Naval Operational Global Atmospheric Prediction System (NOGAPS) or the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS). The models are capable of assimilating data via the Modular Ocean Data Assimilation System (MODAS) and/or the Navy Coupled Ocean Data Assimilation (NCODA) system. Multiple configurations can be instantiated to provide multi-model ensemble results. These bio-optical-physical coupled models have been setup in various configurations and are being evaluated in the Gulf of Mexico and the Monterey Bay regions as part of ongoing NRL projects ("Littoral Battlespace Sensing Fusion & Integration –LBSF&I" and "Bio-Optical Studies of Predictability and Assimilation for the Coastal Environment–BIOSPACE"). An outline of the multi-model ensemble development will be presented along with the results from the various simulations in these two regions. The results are compared and evaluated against *in situ* and remotely sensed observations, emphasizing the relative skill of multi-model ensemble vs. single-model results. The bio-optical-physical models can significantly benefit from exposure to the upcoming Recognized Environmental Picture (REP) sea trials to be conducted by the NATO Undersea Research Centre. The data collected during these experiments can be used to assess the ensemble predictive skill and evaluate its suitability for operational and tactical use. In mutual benefit, the assimilation of environmental variables can be used to constrain the models and provide forecasts that can be used for decision making, like resource placement and asset allocation. The REP experiments will potentially provide a suitable test bed for investigating the benefits of bio-optical ensemble prediction as a tool to improve skill and reduced uncertainty over single-model results.

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Analysis of Active Sonar Waveform Design by Echolocating Mammals

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Echolocating mammals adapt their active sonar emissions based on environmental uncertainty. Given the adaptability of biological sonar to a variety of tasks, understanding the waveform design by mammals may improve the efficacy of man-made sonar systems. Big brown bats (Eptesicus fuscus), for example, transmit wideband multi-component FM pulses. The inter-pulse intervals (IPI) are short enough to induce pulse-echo ambiguity, yet the animals appear immune to this effect. Close inspection of the spectrograms from pulse-to-pulse reveal slight modifications to the time-frequency structure that likely depend upon the echolocation task, proximity to nearby objects, and density of acoustic clutter. To characterize the significance of these changes, we analyzed an extensive database of echolocation pulses emitted by E. fuscus as it flew through varying densities of clutter in a controlled laboratory environment (Brown University, Rhode Island, USA). The time-frequency and time-scale analysis of multi-component signals is traditionally limited by a tradeoff between resolution and cross-term interference of the various components. Common interpretations of mono-component, narrowband signals, such as instantaneous frequency (IF) and amplitude (IA) lose physical meaning in the analysis of wideband, multi-component signals. We addressed this problem in our research through several successive processing stages. The first stage incorporates recently developed phase-warping techniques that isolate the mono-component signals comprising each harmonic of the waveform. This is followed by a decomposition of the resulting mono-component FM waveforms into intrinsic mode functions (IMF). We then generate the Hilbert spectrum to extract detailed time-frequency information, using spline functions that estimate IF and IA. The results were compared to traditional time-frequency representations, including well-known decomposition techniques such as empirical mode decomposition (EMD). This analysis was performed on echolocation calls by multiple bats over the course of a year. Statistically significant variations in the time-frequency structure between individual pulses, flights, and other bats are presented along with our signal processing methods. Applications to detection, classification, and communications associated with the reduction in time-frequency and time-scale ambiguity are also presented.
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GIS Tools for Ocean and Weather Analysis and Model Performance

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Knowledge of the ocean structure is important in supporting naval operations particularly in anti-submarine warfare (ASW). The oceanographers and forecasters at the ASW Reach-back Cell (RBC) at the Naval Oceanographic Office (NAVOCEANO) analyze oceanographic and atmospheric data to generate oceanographic assessments for regions of interest to the Fleet. The ASW Reach-back Cell Ocean Analysis System (ARCOAS) provides a user interface that utilizes geographic information system (GIS) technology. ARCOAS is designed and built with an object-oriented approach that incorporates dialog boxes and interactive displays to offer the user tailored tools for analyzing model predictions against *in situ* data. Algorithms have been developed to read multiple data formats and compute derived oceanographic parameters such as sound speed and sonic layer depth. To assess the physical environment, data confidence and model trends, model output and measurement data from numerous sources can be displayed and compared interactively, including profile plots, time series, cross sections and animations. On systems where the models are run, an automated system in real-time matches measurements with model predictions spatially and temporally. The resulting matched data is used in ARCOAS to compute and plot statistics for any user-selected region, range of time and depths, pinpointing data uncertainty and model performance metrics to a specific area and time of interest.

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A Concept for Automated Oceanographic Sampling with Autonomous Marine Vehicles

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We are motivated by the following scenario: An oceanographer using an ocean prediction model, having identified a region of uncertainty, remotely deploys one or more autonomous sensors (AUVs or gliders) to gather *in situ* measurements. The path taken by the sensor platform can either be predetermined or adaptive, determined only by the real-time sensor measurements. Adaptive missions can be used to sample phenomena such as fronts or thermoclines, as well as to optimize the sampling path with regards to minimum sampling time while still meeting minimum spatial and temporal sampling requirements based on their respective length scales. Multiple sensors can collaboratively segment the sampling area or collaborate in sensing an area of interest by sharing sensory data via acoustic communications. Once sampling is complete, the sensor platforms will transmit data back to a centralized modeling location where it is used to update the current ocean model. This cycle can then be repeated as additional areas of uncertainty evolve. The current state of the art is unable to meet this scenario either operationally or technically. Current oceanographic sampling by mobile sensors is limited to single vehicles following pre-determined sampling paths. The capability of the vehicle to detect and adapt its sampling path to newly detected oceanographic phenomena such as fronts, eddies, thermoclines, etc. is non-existent as is the ability to determine the appropriate spatial or temporal length scales in real-time for optimizing the sampling path. Operationally, this lack of onboard autonomy, collaboration ability, and mission automation results in the need for unnecessarily large numbers of vehicles to do sampling as well as large numbers of mission support personnel.

This work will describe a concept for automated oceanographic sampling with autonomous marine vehicles with five major components currently being developed at NUWC. These components are: real-time onboard determination of spatial and temporal length scales in the ocean, an optimal survey strategy for volume sampling, a general approach to oceanographic feature tracking, a strategy for sampling with multiple vehicles, and automated mission planning and data collection by shore-based modeling cells. The results of previous efforts will be reviewed as well as research plans for next several years.

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Methodology and Architecture for Using Oceanographic and Meteorological Ensembles to Improve Forecast Skill and Guidance in Support of Tactical Planning and Operations

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Ensembles of oceanographic and meteorological numerical forecast models are an excellent tool for quantifying the uncertainties in the marine environment that impact tactical operations. One challenge in exposing the information rich ensemble data to military operators and to existing Tactical Decision Aids (TDAs) is to distill the information into a look and feel that the operator quickly understands and to format it so that it can be put into TDAs. Our approach is to use the ensemble to improve forecast skill and guidance as it applies to the specific operation being supported without exposing the consumer to the probabilistic information about the ensemble. In a post processing engine, known as the Ensemble Forecast Application System (EFAS), the ensemble is distilled into a forecast that has a familiar deterministic look and feel for the operator, and it fits into their existing TDAs. EFAS first applies a bias correction to some of the ensemble parameters to improve their forecast skill. For example; we see that forecast of temperature, pressure, wave height, and wind speed are improved by applying bias corrections, while wave and wind direction forecasts are not. Then by using a consensus finding algorithm based on the RMSE history of the forecasted parameter, it is possible to select the most skillful forecast value or forecast field from the ensemble. From the parameter's ensemble members, one can also extract a spread around that forecasted value by forming the probability density function from the ensemble members. The parameter's probability density function, based on the operator's requirement for accuracy or the operator's tolerance in the forecast error, can also be used to state the confidence (high or low) that the forecast will meet the operator's needs as it pertains to the operation. The architecture for such a forecast system can be implemented in three virtual locations. The ensemble generation is accomplished at the large central computing sites. The on-scene operator interfaces with the post processing engine to derive the specific information needed to support their operation. And the post processing engine which aggregates and distills the ensembles for use, can be at any location deemed appropriate by the area commander, provided the engine has access to the raw ensemble data sets.

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SAR Uncertainty Estimates and its Application to Tropical Cyclone Wind Retrieval

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A sensitivity study has been performed estimating the effect of uncertainties in incidence angle, wind direction and normalized radar cross section (NRCS) using different geophysical model functions (GMF) on C-band SAR wind vector retrieval. It is shown that the sensitivity of SAR wind speed retrieval on typical incidence angle uncertainties is negligible. For uncertainties in wind direction the error increases with wind speed and decreases with increasing incidence angles. For radar pointing direction around 60 and 120 degrees relative to the upwind directions the error is largest. In general the error due to wind direction uncertainties will have to be considered in particular at low incidence angles and wind speeds above 10 m/s. The main error source in SAR wind speed retrieval is due to the uncertainty of the NRCS. The typical radiometric accuracy of today's SAR systems is $\sim$0.5 dB, which leads to significant errors in SAR wind speed retrieval. The error is largest at cross winds and decreases with increasing incidence angle. The error is significant for wind speeds above 10 m/s and low incidence angles ($<$ 30 deg). For the important case of high wind speeds using the recognized standard C-band GMF CMOD5, the error cannot be calculated for incidence angles below 30 deg and wind speeds above 25 m/s. Investigation of a large number of SAR imagery of tropical cyclones (peak U10N exceeds 33 m/s) showed that the NRCS frequently exceeded the definition range of CMOD5. In particular at incidence angle $<$ 25 deg and at high wind speeds the error in wind speed is significant ($>$20%). This fact leads to significant implications for the wind speed retrieval under tropical cyclone conditions.
Preliminary results indicate that considering such uncertainties map for estimating the pressure field by means of a hybrid boundary layer model that incorporates approximations to the nonlinear dynamics inherent in tropical cyclone cores and that seeks a best fit solution for the image as a whole leads to significant improvements of the wind speed retrieval under hurricane conditions. More details on this ongoing research will be illustrated at the conference.

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Rapid deployment of HF radars with open-mode analysis for near-shore oil spill and search and rescue

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An HF radar system designed for rapid deployment (1-2 days) is presented. The system is currently being planned for deployment on the northern coast of Norway where its usefulness in monitoring near-shore currents and tracking oil and drifting objects will be evaluated by deploying drifters. The system employs open mode analysis and a detailed coastline to improve the quality of the total vectors derived from the individual radars. Taken together with surface current fields from an operational ocean model, a blended field of surface current vectors will be produced where the HF measurements give way to pure ocean model fields outside radar coverage and for prognostic times (beyond real time). Preliminary results from field trials with rapid deployment of HF radars will be presented. Estimates of the time required to set up OMA fields for better exploitation of nearshore current fields are also presented.

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Quantification of environmental uncertainty and its effect on acoustic propagation

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The problem of accurately predicting both the ocean environment and the propagation of an acoustic field through such an environment are issues that have received considerable attention in recent years. From a modeling perspective, a major goal of this research effort is to achieve robust quantitative estimates of uncertainty associated with the quantities of interest so that decisions based on the results of numerical simulation accurately reflect the current state of knowledge. Accurate modeling of acoustic propagation in ocean waveguides assumes the parameters, fields and boundary conditions necessary to solve the appropriate differential equations are known. In most instances, exact knowledge of these quantities is not available and one can represent this incomplete state of knowledge (uncertainty) by probability distributions on environmental parameters and fields. Such uncertainty can be interpreted as propagating along with the acoustic field - now considered as a stochastic process since it is dependent on the probabilistic characterization of the environment. We are investigating the application of stochastic basis expansions as representations of uncertainty for both the ocean environment and acoustic field, allowing computation of moments of the field and its probability density function within the waveguide. Some examples of their application in simulation-based prediction are presented for computing both the space-time evolution of the sound speed distribution and the acoustic field in the presence of multiple sources of environmental uncertainty. Implementation issues and outstanding problems are also discussed in the context of modeling and exploiting uncertainty in littoral environments.
[Work supported by ONR].

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NURC's Unique CTD and Oceanographic Calibration Facility

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Situated at NURC within the Oceanographic Branch, the Internationally recognized CTD Calibration facility, provides services to NURC's scientists, NATO navies and Customers in support of oceanographic data standardization and quality. The facility is thermally and humidity controlled and is equipped with the highest standards for measuring of sea water temperature, conductivity-salinity and pressure parameters in CTD systems. The laboratory includes three NURC designed salt water calibration baths, two of 385 liters for CTD calibrations and a newly constructed 700 liters bath to permit Glider CTDs to be calibrated whilst connected to the glider. All baths have high thermal stability, regulated by modular computer controlled heat exchanging units. The laboratory is WOCE Standard and issues a calibration certificate in accordance with NURC internal standard protocol for ISO approval. In this work we discuss the technological solution adopted for building the three calibration baths.

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Interactive artificial intelligence based spatial predictive modeling of rare plant species occurences

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Modeling the geographical distribution of a rare plant species is a key issue regarding its conservation. To gain an understanding of the distribution of such plants, particularly those that can be used to serve medicinal purposes, certain obvious facts regarding the species must be carefully and accurately assessed−for example, locations where the species thrive and what their requirements are for survival. Often for a threatened economic plant species, this type of conceptual knowledge is embedded in the culture of indigenous people of a particular region. Exploring relationships between folk knowledge, ecosystems, geospatial particulars, machine learning and artificial intelligence based modeling techniques, and empirical observations for predicting species distribution is far from simple. Inferential procedures that provide robust and reliable predictions for species distributions thus become critical to biodiversity analyses of medicinal plants as well as for the appropriate stratification in applying conservation strategies which can protect them. In this work, a habitat suitability model for rare plant species is developed by combining spatial predictive modeling techniques and an artificial intelligence based optimization technique known as Interactive Evolutionary Optimization (IEO). The interactive spatial evolutionary computation based predictive modeling enables an analyst to combine advanced mathematical geospatial and pattern recognition modeling techniques, conceptual knowledge, available empirical data and expert-interactive dynamic data visualization techniques to predict species distributions. This methodology represents a step toward identifying regions where species are likely located to base argument for appropriate stratification in applying culturally relative conservation strategies to protect them and promote overall enhanced ecological integrity to the region. We demonstrate the potential of combining ethnobotany and botanical spatial information with indigenous ecosystems concepts and experts knowledge (e.g. indigenous Q' eqchi' Maya healing knowledge) via spatial evolutionary computation-based predictive modeling. The model accuracy was assessed statistically by testing for independence between predicted occurrence and actual occurrence using k-folded cross-validation tests. The model accuracy was assessed statistically using filed ethnobotanical data for medicinal plants collected within the remote and rugged, heavily forested region of the Maya Mountains in Belize 16°S,17°N, -88°E, -89.25°W by testing for independence between predicted occurrence and actual occurrence using cross-validation. The probabilistic map of the species occurrence accurately predicted 71% of the field observations and was able to avoid major classification distortions caused by the north-eastern region and coastal areas. These are areas of mangrove and littoral forest as well as low land savannah, which are not suitable habitat for the species of medicinal plants considered.

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Experimental Results Using Forward-Looking Multistatic Transmitter Sonar to Achieve Super Resolution

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Observational uncertainties have a high potential to negatively affect the ability of an unmanned underwater vehicle (UUV) or a torpedo sonar system to successfully detect, classify, and localize targets of interest. Imaging ambiguities can be greatly reduced by increasing resolution, typically by using larger arrays or operating at higher frequencies. This work presents experimental results demonstrating the effectiveness of a novel active sonar technique that improves the spatial resolution of a sonar array by a factor of two (or four if considering two dimensional processing) without increasing the array size or operating frequency. This processing technique allows for the use of smaller, lighter sonar systems, or operation at lower frequencies with commensurate reduction in acoustic attenuation. To further improve image quality, a highly effective and computationally-inexpensive sidelobe cancellation technique was adapted for sonar and applied to sonar imagery. Expanded Real Aperture Sonar (ERAS) is a technique similar to Synthetic Aperture Sonar (SAS) in that there are two or more transmissions are processed coherently. However, rather than utilizing sequential pings from multiple locations, orthogonal (non-interfering) signals are simultaneously transmitted from disparate locations within an array. This effectively creates a two-ping (or more) synthetic array, resulting in two-way responses that are half as wide as the real aperture receive beams. A series of ERAS proof-of-concept in-water tests were successfully carried out during 2008 through 2010 in a number of test facilities. In each test sequence a forward-looking sonar array assembly configured for ERAS operation was fixed on a rotating shaft and actively operated against stationary and non-stationary targets. Transmitted signals used were spectrally separated CW and oppositely-sloped linear FM waveforms. Signal parameters such as center frequency, signal duration and bandwidth were varied. Test range parameters (depth, target geometry, target velocity, etc.) were also varied to gain a solid understanding of how each affects ERAS performance. ERAS array performance was assessed relative to that of a real aperture array. Analysis of moving-target tests was carried out to characterize the decorrelation of peaks of the orthogonal linear FM signals (induced by Doppler shifts as a function of target velocities).

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Surface drifter measurements during TSS project (Aegean, Marmara and Black Seas)

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Within the framework of the Turkish Strait System (TSS) project, the surface circulation dynamics of the Marmara Sea and of the neighbouring Aegean and Black Seas were studied using low-cost satellite-tracked CODE drifters. In addition to the standard positioning and data telemetry provided by the Argos Data Collection and Location System (DCLS), the drifters were equipped with GPS receivers to have a more frequent and a better determination of their positions. Particular focus was given to the Marmara Sea that was seeded with about 30 drifters in two seasonal episodes (September 2008 and February 2009). Deployments occurred at key locations south of the Bosphorus Strait and in the middle of the Sea to maximize the geographical coverage and mainly in small (1 nm) clusters of three drifters. In total, 25 and 10 drifters were released close to the Bosphorus (in the Black Sea) and the Dardanelles Straits (in the Aegean Sea), respectively. The drifters sampled adequately the Marmara Sea, but the southern part was covered by drifters mainly during the first experiment (September deployments) and the northern part mainly during the second one (February deployments). The Black Sea was well-monitored only in its southern part, while the drifter coverage in the Aegean is quite limited. The lifetime of the drifters in the Marmara and the Aegean Seas are very low due to the recovery by seafarers and stranding. Drifters survived longer in the Black Sea. The overall surface flow of the Marmara Sea is westward oriented from the Bosphorus to the Dardanelles. A jet-like flow entering the Marmara Sea from the Bosphorus Strait prevails during the entire study period. A complex eddy activity (mainly anticyclonic) is also clear. In the Black Sea, the well-known Rim Current is evidenced on the southern continental slope. In the Aegean the drifter trajectories are very complex due to the presence of numerous Islands. In particular, they show the Dardanelles outflow branching around Lemnos Island. Additionally, the drifter trajectories were also superimposed over a selection of satellite images of sea surface temperature displaying an overall agreement between the drifter trajectories and the thermal fronts.

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Uncertainty, Information, Decision

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All environmental predictions involve uncertainty. Decisions informed by such predictions must address this uncertainty in order to assess risk. A quantitative assessment of risk therefore requires quantification of predicted uncertainty.
Shannon in 1948 introduced a technical meaning for information, and uncertainty, which has had a profound impact on technology and on fundamental science. Information and uncertainty are tightly-coupled, technical concepts that are properties of probability distributions as descriptors of knowledge.
As the operational command in the U.S. Navy responsible for delivering geophysical knowledge products to the fleet, we believe that future products must assess information content, or certainty, associated with our forecasts.
This work discusses information as an organizing principle for future science and technology investment and progress from the point of view of fleet needs and opportunities. A theoretical basis for quantification of predicted uncertainty will be reviewed. A number of examples will be presented demonstrating approaches for application of uncertainty estimation to practical problems in decision-making. Science and technology investment implications related to adoption of a quantitative approach to decision superiority will be discussed.

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Maritime Decision Support Systems Validation Involving METOC Officers During REP10 Cruise

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During NURC REP10 cruise a number of experiments will be conducted using underwater gliders. Planning missions related to gliders is not an easy task, since glider missions (such as way-point planning, gliders deployment, surfacing and recovery) are heavily affected by meteorological and atmospheric (METOC) conditions. From this comes the need for decision support tools. NURC is developing decision support systems for generic maritime operations since 2002 and today a decision support architecture is operational. Provided that it is appropriately configured, it is able to mimic human expertise in judging whether environmental conditions are favourable or not for glider deployment, recovery and surfacing etc. How good and useful such decision support architecture is has to be carefully evaluated. During REP10 two METOC officers will be available. They will be asked to fill a questionnaire each morning and afternoon, concerning forecasts of gliders' positions and how good would be their recovery in the future in specific positions. They have to answer first with the use of METOC forecasts only, and then together with the help of a decision support system. The goal is to demonstrate whether or not the decision support system biases them towards better predictions or not. A similar scheme will be adopted for testing the usefulness of another decision support tool developed at NURC (called model-based), which predicts future trajectories of gliders (and the associated uncertainties). In case the validation succeeds, it can be used to raise alarms when a glider is expected to exit the assigned working area.

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Decision Support during REP10

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An automatic decision support system has been tested during the Recognised Environmental Picture 2010 experiment to support glider operations. METOC data (winds, currents and waves) and vessel traffic information were fused by using a hybrid Fuzzy/Bayesian approach in order to assess the impact of the environment on operations and decide a course of action to safely operate. The impact of the input data uncertainty was assessed by using METOC probabilistic forecasts (ensemble and super-ensemble models) and a methodology based on the Unscented Transform (UT) to propagate the data uncertainty through the decision making system. The Fuzzy/Bayesian system was integrated with a model based decision support system making use of a glider kinematic model and the Unscented Kalman filter to predict the glider path considering the sea current field in which it operates. Three dimensional probabilistic forecasts of the sea current speed were used to predict glider position mean and covariance matrix and calculate risk indexes helping the responsible of the mission in minimising operation risks. Results of the investigation will be reported and discussed.

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Dynamically coupling INTEL and METOC to predict the risk of pirate attack

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The dynamic coupling of METOC and INTEL guidance enables the estimation and communication of the likely distribution of pirates operating off the Horn of Africa (HOA) and in the Gulf of Aden (GOA), and the associated risk of pirate attack as a function of location and forecast lead.

The heart of the effort is the construction of a model of pirate behavior that takes into account INTEL (e.g. pirate CONOPS, equipment performance, base locations, numbers) and METOC (e.g. winds, waves, and currents). The pirate behavior model predicts the track of a single pirate skiff as a function of time. The uncertainty associated with the INTEL and the METOC information is accounted for by running the pirate behavior model not once, but tens of thousands of times sampling from all available distributions, whether they be a subjective distribution of pirate base location or an objective distribution like a wave ensemble. This will generate millions of possible pirate locations, and these millions of points can be interpreted as draws from a distribution function.

Because we don't know exactly when or where real pirates are leaving their bases, where they are going, or how they are behaving at any given time there will be simulated pirates in many different phases of their mission. They will have obtained their simulated locations in a manner consistent with the recent history of INTEL and METOC as well as the predictions of INTEL and METOC. As INTEL or METOC information changes (e.g. a new METOC forecast becomes available) the predicted distribution of pirates will be updated. The manner in which the update occurs is dependent upon the type of information obtained.

Perhaps the most innovative aspect of the pirate distribution approach is that because the integrated quantity is pirate location, observations of pirate activity can be directly assimilated to produce updated distributions.

The approach represents the first example of dynamically coupling INTEL and METOC information so that their joint impact is distributed in space and time. It is not possible to replicate this product by treating INTEL and METOC separately and overlaying two independent products.

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A Study Of The Warm Core Cyprus Eddy With Ocean Gliders And Data Assimilation

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In March 2009, two gliders began occupying a hydrographic endurance line for measurements of temperature, salinity, dissolved oxygen, optical backscatter, and fluorescence in the Levantine Sea south of Cyprus in a butterfly pattern over the Eratosthenes Seamount. The line extends in space and time an historical one. Comparison with past hydrographic cruise data show similarities. In particular, a large anticyclonic eddy, the Cyprus Eddy, near the Eratosthenes Seamount dominates, with traces of Atlantic Water around the periphery. In November 2009, a joint project, "EYE of the Levantine", was carried out in which 6 gliders were deployed to investigate in more detail the Cyprus warm core eddy observed earlier in the year by both glider and shipboard CTD in the frame of CYBO cruise 22. In December 2009, the TARA Oceans was involved as well with CTD and water samples and the deployment of 4 surface drifters and 2 profiling floats in and around the eddy. Near the end of the experiment, the eddy was sampled again with shipboard ADCP sampling and a CTD grid carried out by the RV Maria S. Merian from mid December 2009 to mid January 2010. About 2000 profiles down to 1000 m and 1000 profiles down to 200 m have been collected by the fleet of gliders including measurements of temperature, salinity, fluorescences (Chl a, CDOM) and backscatters (at 470, 532, 660, 700, and 880 nm).
During the experiment the eddy had a radius of about 40 km and consisted of a core of LIW extending down to 500 m. Currents averaged over the 1000 m dives peaked at the edge with magnitudes of 0.3 ms^{-1}. During the experiment, the eddy shifted about 10 km to the east. The slightly fresher AW is found just below the thermocline, most often around the periphery of the Cyprus Eddy. Dissolved oxygen, optical scattering, and chlorophyll fluorescence typically show maximum values also in the layer just below the thermocline.
Remote sensing products showed little evidence of the eddy. Operational forecasts were only somewhat successful in predicting eddy presence: MOON/CYCOFOS forecasted a similar eddy, but in a slightly different location and time. The first result of applying the 3DVAR "OceanVar" data assimilation scheme with glider profiles to the operational forecasts at OC-UCY will be presented.

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Optimal Glider Sample Strategies for Uncertainty Reduction

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Ocean models are capable of forecasting conditions out to reasonable periods of time (days) provided initial and ongoing conditions can be measured. With limited assets, the intelligent placement of these measurements is critical. In many ocean environments, sonar performance is critically sensitive to the ocean features and accurate ocean forecasting for ASW planning and prediction is required. In this work, ocean model forecast uncertainty and ocean acoustic propagation uncertainty are combined to generate cost functions to define an optimal search for glider path planning. The glider sampling optimization problem is posed as a constrained (glider speeds, operational depths, waterspace management issues) non-linear optimization problem and is solved by a Genetic Algorithm approach. Constituent cost functions including ensemble forecast uncertainty, spatial and temporal dynamic oceanography and ASW sensitivity are combined to form a weighted cost function. The technical approach will be described as well as its application to various experiments off the coasts of Taiwan, the United States and Italy.

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Ocean model validation methods

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Ocean models are useful tools for understanding and predicting oceanographic conditions in an area. Ocean models may be used as a planning aid for rapid environmental assessment missions, for instance by determining the presence of unstable oceanographic areas. In such areas higher concentrations of oceanographic measurements are required. The validity of ocean models is frequently assessed by comparing its output to either measurements or outputs of a reference oceanographic model. Methods of comparison used range from statistical methods to visual comparisons of snapshots. In this work different methods of comparison are presented. The pros and cons of each method are identified and discussed. Methods of comparison are also tested on an oceanographic data set from the Norwegian Trench. The data set consists of both modelled and measured data. The modelled data is taken from the MI-POM model. The data measurements were made using a moving vessel profiler.

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Finding acoustically stable areas through EOF classification

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Validity of sonar performance models is generally limited by environmental uncertainty, and particularly uncertainty in the sound speed profile (SSP). Rapid environmental assessment (REA) missions, e.g. using gliders, and advanced ocean models may be used to reduce this uncertainty prior to sonar operation in hostile waters. The presented work shows how data from ocean models may be used for planning of REA missions. The area of operation is divided into oceanographically stable subareas using empirical orthogonal function and different methods of clustering analyses on SSPs from the ocean model. The acoustic stability of each subarea is assessed using sonar performance modelling. Acoustically unstable areas are divided into smaller subareas. Acoustically stable groups are represented by a single SSP. A map of acoustically stable areas in the area of operation is the main output. Large, geographically contiguous groups indicate acoustically stable areas where frequent SSP measurements are unnecessary, e.g. low concentration of gliders. Small and non-contiguous groups indicate the opposite. Other applications include determination of suitable locations for sonar tests that require stable sonar conditions, and efficient optimization of sonar operation in acoustically stable areas.

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Buoy Tracking Using Monte-Carlo Techniques

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The presented work combines direct observations from local buoys or any other source with multiple ocean numerical model runs, starting from perturbed initial fields and using forcing from an atmospheric ensemble. It post-processes the model fields in near real-time; to produce consensus forecast buoys trajectories. The model solution being used is based on the Navy Coastal Ocean Model (NCOM) nested within a global run, assimilating all available local and remote sensing observations through the Navy Coastal Ocean Data Assimilation (NCODA) system and including tidal forcing (e.g. Coelho et al. 2009 for an example). The Monte-Carlo ensemble is created using the Ensemble Transform technique (Mclay at al., 2009) based on the analysis errors being estimated through NCODA and that are sensitive to the recent past observations. For this particular application there were 32 independent runs but the ensemble population was augmented by introducing a one step space-time shift on all the runs, to a final population of 862. The post-processing technique being applied follows the same approach used for multi-model consensus analysis as described in e.g. Coelho et al., 2005, Rixen et al.2007 among others. It essentially attributes a relative weight to each possible outcome based on its local fitness to observations during a recent past training period, run as a hindcast. These weights are then assumed to persist during a certain forecast range and are used to compute a consensus weighted average for that same period. Results shown that the true trajectories predicted for a 24 hours forecast range were always contained within the ensemble population. Furthermore, the observed error in the forecasts followed very close the predicted error distributions, guaranteeing the ensemble scheme to be an accurate model predicting the buoys separation errors and uncertainties. Benchmarking metrics show that the method was also able to provide forecast trajectories with separation error on average below 7 km after 24 hours and 80% of the time below 6 km after a 12 hour forecast.

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Surf Zone Characterization from UAV Imagery

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Very shallow water littoral domains are one of the most challenging operational areas yet the most difficult to predict. Because the environment changes rapidly both in space and time, REA predictions require up-to-date observations of bathymetry and hydrodynamic conditions. This has traditionally been a dangerous special operations mission, and safer remote sensing methods have long been sought. The purpose of this work is to consider potential solutions based on unmanned airborne systems (UASs).

The research will focus mainly on data from UASs or surrogates.. Studies will start with fixed platform surrogate data, degraded to mimic limitations in UAS records. Geo-referencing issues will then be examined using actual UAS data. The results will be cast in terms of the performance of cBathy, a robust algorithm to estimate the frequency, direction and wavenumber of observed ocean waves in a clutter environment, and celerity-derived equivalent bathymetry.

Compared to its fix-platform counterpart, UAS-derived time series are typically short and will always be gappy for at least part of the image field, obvious limitations for traditional analyses. We will present modifications of spectral methods to deal with gappy records and we will examine the impact of fewer degrees of freedom. A key issue is the quality of geolocation of image pixels. Actual image viewing angles are not well represented by the highly-filtered yaw, pitch and roll data from the airframe. Removal of the resulting image jitter usually requires geo-registering to fixed (land-based) features, a tedious process that places severe limitations on the required mix of land and ocean in each scene.

In fact, the imaged ocean contains an abundance of wave contrast that could be used to stabilize viewing geometries. But these features are not fixed like their ground-based counterparts and instead move steadily, usually with the celerity of the observed waves. Since that celerity depends on the unknown depth, the convolved geometry error and wave motion signals appear un-separable. However, errors in estimates of each of the three viewing angles will introduce a unique, predictable distortion to the observed wave patterns. For instance, errors in the camera pitch will yield distortion that increases roughly linearly with distance from the plane. Similarly roll error will yield cross-look distortions. We will discuss the potential for a low-dimensional solution to this problem.

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Coupled Ocean-Atmosphere Ensemble Prediction

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A coupled ensemble prediction system has been developed by the Naval Research Laboratory. It is designed to take into account major sources of uncertainty in: (1) non-deterministic dynamics, (2) system forcing, and (3) initial states. The purpose of the system is to provide ensemble forecasts for use in probabilistic products, such as reliability and frequency of occurrence, and in risk management applications. The system components include COAMPS (Coupled Ocean Atmosphere Mesoscale Prediction System) and NCOM (Navy Coastal Ocean Model) for atmosphere and ocean forecasting, and NAVDAS (Navy Atmospheric Variational Data Assimilation System) and NCODA (Navy Coupled Ocean Data Assimilation) for atmosphere and ocean data assimilation. NAVDAS and NCODA are 3D-variational analysis schemes. The ensembles are generated using separate applications of the Ensemble Transform (ET) technique in the atmosphere and ocean. The atmospheric ET is computed using wind, temperature, and moisture variables, while the oceanographic ET is derived from ocean current, temperature and salinity variables. Estimates of analysis error covariance, which is used as a constraint in the ET, are provided by both the ocean and atmosphere 3DVAR assimilation systems. A variety of coupled ensemble forecast experiments have been performed including: (1) moving nest tropical cyclone cases in the Atlantic (Hanna and Ike, Sep 2008) and western Pacific (Rick, Choi-Wan, and Lupit, Sep-Oct 2009) with a focus on cyclone track and intensity forecasts; (2) piracy case studies in the western Indian Ocean with a focus on risk management applications; and (3) the ABCANZ (American, Britain, Canada, Australia, New Zealand) field program in the Bay of Plenty, New Zealand, with a focus on EM/radar propagation.

In this talk we give an overview description of the system and present results from some of the coupled model forecast experiments. In addition, we provide future plans for the system, which include development of ensemble ocean-atmosphere coupled covariances using innovative localization techniques. This approach will enable ensemble 4D-variational coupled data assimilation. The ensemble 4DVAR system will provide improved state estimates of the coupled system and increase the effectiveness of ensemble based targeted observation approaches that are currently limited by spurious ensemble correlations and by neglected error correlations between atmosphere and ocean variables.

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REP10A: Lightweight Autonomous Underwater Vehicles (AUV) Performing Coastal Survey Operations to Meet Military Oceanography Requirements

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The Recognized Environmental Picture 10A (REP10A) exercise offers an opportunity to evaluate the operational effects of low-powered, man-portable AUVs in coastal survey operations addressing military oceanography requirements. These lightweight AUVs are employed for multi-vehicle coordinated operations in shore- and ship-launched scenarios that trim timelines, minimize time-smearing errors, and reduce mission risk. On-scene mission planning and rapid deployment/recovery times are paired with operability in developing data products for quick-look tactical assessments, while data is utilized in reach back cells to provide integrated model products and forecasts. AUV data provide initialization for the models, guidance for model calibration, and ground truth for validating both models and products generated from remotely sensed data. Survey optimization behaviors integrated in the AUVs through the Mission Oriented Operating Suite (MOOS) demonstrate further streamlining of data survey timelines with a priori or on-scene, through-the-sensor data inputs, and both operational and statistical effects on product fidelity are evaluated. The Naval Undersea Warfare Center, Faculdade de Engenharia - Universidade do Porto, Marinha Portuguesa, and OceanServer Technology, Inc. are the primary participants bringing in-water AUV resources to REP10A. Technical support and products are provided by the Naval Research Laboratory Stennis Space Center, Naval Oceanographic Office, NATO Undersea Research Centre, University of Massachusetts Dartmouth, and YSI, Inc.

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Uncertainty quantification in a HYCOM-based Gulf of Mexico simulation using polynomial chaos expansions

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Polynomial Chaos expansions have been developed in the engineering community to propagate uncertainties in model inputs to uncertainties in model outputs. The approach relies on expressing the dependence of the solution on the uncertain input in terms of an orthonormal series of polynomials of the input random variables. The coefficients of that expansion are then computed by a non-intrusive spectral projection that avoids modification to the original code, and that requires only an ensemble calculation at a carefully selected realizations of the stochastic variables. The method's main advantages include an efficient representation using a small number of coefficients for smooth dependencies, no a priori limits on the linearity of the model or constraints on the input/output statistics. Here we present a first application of this methodology to a HYCOM simulation of the circulation in the Gulf of Mexico. The uncertainty in nesting boundary conditions is propagated through the HYCOM model, and its impact on the evolution of the Loop Current is analyzed. The potential advantages and limits of this methodology within the context of realistic ocean forecasts will be discussed.

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The impact of variable shallow water environment on source localization uncertainty

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Ocean environment is known to have a significant effect on sound propagation in the water. In shallow water regions, the properties of ocean bottom and water column are the most crucial parameters for sonar performance prediction. This work describes a Bayesian inference approach to investigate the impact of seabed geoacoustic parameters and variable water column sound speed profile on matched field processing based sound localization. The acoustic data were collected during the Office of Naval Research funded shallow water experiment carried out from mid July to mid September in 2006 on the New Jersey Continental Shelf. A vertical line array was deployed in a 70 m of water. Multi-tonal continuous waves were transmitted at a distance of 1 km from the vertical array. The water column sound speed profiles measured at the array and the source position showed significant variation in the thermocline depth during the experiment. The uncertainties of the seabed and water column properties were estimated first by Bayesian matched field geoacoustic inversion. The impact of the ocean environment on matched field source localization uncertainty was then examined by mapping the estimated ocean environmental marginal probability distributions. It is shown in the analysis that the uncertainty of the water column sound speed has greater effect on source localization than the ones of sea bottom properties.

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Slocum Glider: Expanding the Capabilities

Clayton Jones, Ben Allsup and Thomas Altshuler

Teledyne Webb Research

"We have found, over the years, that the payoff in increase of knowledge often is greatest the more unconventional the idea, especially when it conflicts with collective wisdom." Henry Stommel, The SLOCUM Mission, 1989.
Two decades have passed since Henry Stommel popularized Doug Webb's dream of bringing underwater gliders to life.
In this period of time, Slocum gliders have become an integral part of the oceanographer's toolbox with surprising rapidity over the last decade. Teledyne Webb Research (TWR) has been involved with autonomous underwater glider design since its inception and continues to push the technology to further the distance travelled, energy balance, sensors integrated, and mission endurance.
We will review highlights of the latest sensor integrations, available battery solutions, and in collaboration with the Rutgers University Coastal Ocean Observation Lab (RU-COOL) the recent Trans-Atlantic crossing.
Presented also, is the next generation Slocum glider (G2) architecture, launch and recovery features, and an advanced visualization command and control (C2) toolset.
The daring objective of deploying fleets of capable, sensor-laden gliders for multi-year transoceanic operation is a goal that we collectively are in the process of achieving.

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Results of University of Washington's research on web tools for conveying and comprehending environmental uncertainty

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Recent research at the University of Washington has explored the usefulness of web-based applications to enhance awareness of uncertainties in the marine environment. The website `www.Probcast.com` was developed as a mechanism to both convey probabilistic forecast information and study how people understand that information. (Mass et al., 2009). The probabilistic information in Probcast is derived from the University of Washington's Mesoscale Ensemble (UWME). The UWME uses the 5th generation mesoscale community model (MM5) to generate multiple forecast members, each using different starting conditions. These forecast members are combined with observational data and relayed to a post-processing system that uses a Bayesian Model Averaging technique, which outputs calibrated and bias corrected probabilistic forecast parameters. The interface in Probcast was based on controlled, cognitive experiments that tested different ways to describe and visualize probabilistic information (Joslyn et al., 2009). The Boater Information System (BIS) is a web application that helps people visualize the impact of weather and water conditions on their boating activities (Jones and Maclean, 2007). The system was developed after a comprehensive investigation of user needs via an outreach campaign that included a web survey, visits to boat shows and marinas, interviews with boaters, and the formation of an 18 member advisory board. BIS uses Adobe Flash technology to enhance the responsiveness and interactivity of the browser client. The user has the ability to display wind and temperature forecasts from the University of Washington's WRF (a mesoscale atmospheric model) and tidal information from an implementation of XTide. Within the BIS interface, users can examine the environmental information in ways that help them determine its potential impact on their own particular decision problem. For example, the user can set forecast thresholds, loop the forecasts in time, and develop boat routes on the map and view the forecasted weather or tides along that track, in time and space. More research is required to determine if the enhanced interactivity in a tool such as BIS helps users develop a better understanding of model forecast strengths and weaknesses, and thereby increases their trust and reduces their uncertainty. The poster for this presentation will provide views of the different user interface displays, information on the usability testing, and analysis user statistics.

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Adaptive estimation of iceberg parameters using the Ensemble Kalman Filter

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Navigation is expected to increase with the reduction of sea ice in the Arctic Ocean and particularly in the Barents Sea. Hence, there is an increasing demand for accurate monitoring of icebergs, considered as a potential treat. An iceberg drift model has been implemented for the Barents Sea using a nested configuration of HYCOM and ERA-interim as forcing fields. It is a non-linear Lagrangian type of model. Previous modeling studies in that region showed large sensitivity of the results to the shape of the iceberg and to the forcing fields. Here, we used the Ensemble Kalman Filter data assimilation method in order to correct the position of the iceberg and estimate form drag parameters. From observed trajectories, we derived the evolution in time of the form drags and identified the error in the icebergs' mass as well as in the forcing fields.

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Operational satellite monitoring of oil pollution in the Baltic Sea

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Shipping activities in the Baltic Sea, including oil transport and oil handled in harbors, have a number of negative impacts on the marine environment and coastal zone. Oil discharges from ships represent a significant threat to marine ecosystems. Oil spills cause the contamination of seawater, shores, and beaches, which may persist for several months and represent a threat to marine resources. One of the main tasks in the ecological monitoring of the Baltic Sea is an operational satellite and aerial detection of oil spillages, determination of their characteristics, establishment of the pollution sources and forecast of probable trajectories of the oil spill transport. Oil pollution monitoring in the Mediterranean, North and Baltic Sea is normally carried out by aircrafts or ships. Satellite SAR imagery can help greatly identifying probable spills over very large areas and then guiding aerial surveys for precise observation of specific locations.
Since 1993 there is no regular aerial surveillance of the oil spills in the Russian sector of the southeastern Baltic Sea and in the Gulf of Finland. In June 2003 LUKOIL-Kaliningradmorneft initiated a pilot project, aimed to the complex monitoring of the southeastern Baltic Sea, in connection with a beginning of oil production at continental shelf of Russia in March 2004. Operational monitoring was performed in June 2004 November 2005 on the base of daily satellite remote sensing (AVHRR NOAA, MODIS, TOPEX/Poseidon, Jason-1, ENVISAT ASAR and RADARSAT SAR imagery) of SST, sea level, chlorophyll concentration, mesoscale dynamics, wind and waves, and oil spills. As a result a complex information on oil pollution of the sea, sea surface temperature, distribution of suspended matter, chlorophyll concentration, sea currents and meteorological parameters has been received. In total 274 oil spills have been detected in 230 ASAR ENVISAT images and 17 SAR RADARSAT images received during 18 months. Several examples from the oil spill gallery will be presented. The interactive numerical model Seatrack Web SMHI (The Swedish Meteorological and Hydrological Institute) is used for a forecast of the oil spill drift.

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Variability of the sea ice cover in the Barents and Kara Seas

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The Barents and Kara seas are among the most sensitive regions in the Arctic Ocean to climate change. One of the key parameters to follow consequences of the regional climate change is sea ice cover. In 2007, from June to September the record (minimum) sea ice extent was observed in the Arctic. According to the US National Snow and Ice Data Center (NSIDC), on September 16, 2007 it was 24% below the previous record, set in September 2005, and 38% below the average sea ice extent calculated for 1979-2000 (or lower by 2.61 million km2, an area approximately equal to the size of 10 United Kingdoms). Thus, sea ice extent in the Arctic Ocean dropped to 4.13 million km2. The summer of 2007 brought an ice-free opening through the Northwest Passage that lasted several weeks, however, the Northeast Passage was not yet open because of a little tongue of ice remained along the Russian coast (Taimyr Peninsula). It is clear that long-term opening of both passages would have global impacts on trade and natural resource use. The sea ice coverage charts are produced at the National Ice Center (NIC, NOAA) basing on remotely sensed data and observations. RADARSAT, DMSP/OLS, NOAA/TIROS, and DMSP/SSM-I sensors comprised the majority of the sensors used in the analysis and for the production of the charts. We used this data set to investigate seasonal and interannual variability of the sea ice cover in the Barents and Kara seas in 1981-2008. The analysis includes sea ice extent (ice surface), ice margin retreat in the periods of maximum and minimum ice extent, shift of these periods, trends in the sea ice extent, forecast for the sea ice extent, pecularities in different geographic regions, and correlation analysis with some of the meteo parameters aquired at meteo stations located at Bear Island, Svalbard, Franz Josef Land, and Novaya Zemlya. The Advanced Microwave Scanning Radiometer (AMSR-E) instrument onboard the NASA's Aqua satellite is also a perfect tool for regular monitoring of the sea ice extent in the Arctic. The ice cover variability in the Arctic Ocean in 2003-2010 will be shown also.

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A Comparative Analysis of Various Data Sources for Use in Anti-Submarine Warfare Operations

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An integral part of anti-submarine warfare is the use of acoustic propagation models to calculate sonar detection ranges. While there are many factors that influence detection ranges, both sonar-dependent properties and external environmental conditions, the most important oceanographic input is arguably the sound speed profile. A major challenge, particularly in littoral areas where oceanographic variability occurs on multiple time and length scales, is therefore to provide sonar operators with accurate sound speed data.

The western coast of Norway is characterised by two main water masses, each associated with northward flowing currents: Cold, fresh coastal water in the inshore regions, and warm, saline Atlantic water further offshore. Between the two water masses is a frontal region with frequent meandering and eddy formation. As such, the area represents significant challenges for numerical prediction models, and combined with the sparsity of observations naval forces often rely on climatological data when estimating detection ranges.

We evaluate the detection ranges from three different sources of ocean temperature and salinity off the western coast of Norway; Climatology, a numerical prediction model from the Norwegian Meteorological Institute, and observations. The relative merits of each source is considered both in terms of naval utility, the practical implications for the warfare officer, and constraints regarding data availability for REA purposes.

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Terrain Navigation for Underwater Autonomous Gliders

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The navigation of a totally autonomous AUV is a major problem. Most AUV are based on low drift inertial navigation system designed to sustain submerged operation for long period of time. To improve this dead reckoning navigation estimation, we can rely either on long or on ultra short baseline acoustic positioning. But those processes require for one, the set up of a series of transponders, and for the other the assistance of a mother ship. Due to operational costs, it is desirable to reduce the amount of external equipment required for an AUV to operate independently.
Moreover, for a glider mission, many others aspects such as energy savings, complete autonomy, payload constraints, have to be taken into account for the navigation estimation process.
In this context, the use of underwater terrain navigation provides an enabling capability for low-cost navigation on underwater vehicles. The idea towards using terrain information for the purpose of navigation is to incorporate information provided by a priori maps into the estimation process. Thus, the ability to use natural features will allow a submersible body to be deployed in a large range of environments without the need to introduce artificial beacons or rely on acoustic tracking technology.
The aim of this simulation is to implement on a glider an underwater terrain navigation algorithm using particle filtering.
The main objective of particle filtering is to track a variable of interest as it evolves over time, typically with a non-Gaussian and potentially multi modal probability density function (pdf). The basis of the method is to construct a sample-based representation of the entire pdf, distributing weights to particles according to the likelihood between the depth measured at their position and the own glider's depth measurement.
The final objective of this simulation is to study the feasibility of a glider's deployment under the Arctic using this method for its navigation estimation.

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The NL research programme (2009-2012) for military oceanography

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For most operations naval activity has shifted to littoral waters. Due to this shift, as well as due to progress in technology and modeling capabilities, environmental knowledge will make a difference in effective operations. In support of the Royal Netherlands Navy, TNO is performing a research programme in military oceanography (as part of rapid environmental assessment, REA). Goal and elements of this programme will be presented. Three elements will be highlighted: operational benefits for several areas (like ASW, amphibious operations, sea-basing), special oceanographic features that need attention (eddies, fronts, internal tides and waves) and contributions to international research activities. For the latter, examples will be presented of consequences of acoustic propagation in an area potentially dominated by internal solitary waves. This research is part of a collaboration with WHOI and MIT.

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Integrated monitoring of coastal waters in the Ligurian and North Tyrrhenian seas: comparison of empirical and semi-analytical chlorophyll regional algorithms in MOMAR

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Global ocean color algorithms, which compute chlorophyll concentration in the ocean surface, normally overestimate values in the Mediterranean sea. The objective of the present investigation is to compare the performance of both empirical (SAM-LT) and semi-analytical (OC3, MedOC3, OC5) algorithms in the Ligurian and North Tyrrhenian sea. A prototypal tool for marine monitoring in the North Tyrrhenian area is being implemented in the framework of the EU-funded project MOMAR, leaded by Tuscan Regional Government.
The satellite remote sensing component of the project mainly focuses on chlorophyll (from MODIS and MERIS) and SST (from different platforms) measurements, via algorithms calibrated for the area of interest, in order to use chlorophyll and SST as tracers for hydrodynamics. The current poster presents the first results of a study conducted to evaluate these algorithms versus *in situ* measurements of chlorophyll concentration collected during recent oceanographic campaigns.

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Uncertainties in operational drift modelling

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Nowadays, many authorities in charge of rescue-at-sea operations lean on operational oceanography products to outline research perimeters. Moreover, current fields estimated with sophisticated ocean forecasting systems can be used as input data for oil spill/ adrift object fate models. This emphasises the necessity of an accurate sea state forecast, with a mastered level of reliability.
This work focuses on the uncertainties inherent to drift modelling, dealing in the first place with several aspects of errors in the estimation of current fields. For that purpose, benchmarked drift scenarios were set up from real surface drifters data, collected in the Mediterranean sea and off the coasts of Angola. The idea is to generate series of current fields of different qualities (each one with different modelling options and physical processes) and then qualify them in term of drift prediction efficiency. For the ocean prediction, we used some regional oceanic configurations based on the NEMO 2.3 code, nested into Mercator 1/12° operational system. Drift forecasts were computed offline with Mothy (Mto France oil spill modelling system) and Ariane (B. Blanke, 1997), a Lagrangian diagnostic tool. We were particularly interested in the importance of the horizontal resolution, vertical mixing schemes, and any processes that may impact the surface layer. The aim of the study is to ultimately point at the most suitable set of parameters for drift forecast use inside operational oceanic systems.
We are also motivated in assessing the relevancy of ensemble forecasts regarding deterministic predictions. Several tests showed that mis-described observed trajectories can finally be modelized statistically by using uncertainties over the initial position of the drifting material.

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Interannual variability in the North Atlantic: intercomparison between observations, hindcasts and reanalyses

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This study aims at characterising and quantifying the differences between large-scale oceanic climatic indices simulated by a 9-member set of realistic numerical ocean simulations (5 hindcasts and 4 reanalyses). We focus on North Atlantic meridional overturning circulations (AMOC), focusing on their variability at interannual time scales. We evaluate the sensitivity of this simulated climatic index to numerical parameters, such as grid resolution, and to various sequential data assimilation schemes.
Model solutions exhibit a substantial diversity concerning the averaged values and the temporal variations of the AMOC. The uncertainty concerning the mean values of AMOC reaches 25% between a 2° and a 1/4° hindcast. We separate the AMOC into different dynamical components. The processes controlling the interannual variability of the AMOC are shown to depend on the model resolution.
The ocean reanalyses considered in this study, although constrained (locally) towards the observed ocean, do not converge towards a consistent large-scale climatic behavior. Mean values and interannual variability of the AMOC are quite diverse among the various reanalyses considered in this study. The uncertainties on the AMOC in these reanalyses illustrate the difficulty to simulate consistent large-scale climatic indices with local data assimilation.

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Sea State Measurement Using Synthetic Aperture Radar Data

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This presentation will introduce global and coastal sea state measurement using Synthetic Aperture Radar (SAR) data. With respect to global sea state measurement, the so called SAR wave mode data, i.e. small SAR images covering 6 km x 5 km to 10 km x 5 km are acquired along the orbit every 100 km or 200 km, are used for deriving integral wave parameters, e.g., significant wave height and mean wave period.
We developed the CWAVE_ENV algorithm for retrieving sea state parameters from ENVISAT/ASAR wave mode data. Comparison and validation of the empirical algorithm are presented. Having the particular characteristic of globally continuous acquisition, SAR wave mode data are also available for statistical analysis of sea state. The global mean and maximum significant wave height derived from one year ASAR wave mode data are demonstrated for the application. In coastal area, the sea state is highly variably as it experiences shoaling, refraction/diffraction, and dissipation caused by rapidly changing bathymetry.
The numerical wave models, generally limited by the spatial resolution or the boundary conditions, cannot often resolve the fine structure of coastal wave field.
We use the high resolution TerraSAR-X (TS-X) data to investigate spatial variations of sea state parameters including two-dimensional wave spectrum and integral wave parameters, particularly over offshore platforms.

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The NURC OpenSea Development platform

Michel Leonard

NURC

Within the realm of the net centric warfare, maritime systems have evolved in terms of sophistication, complexity and capabilities. Designing, testing and validating maritime systems of systems can be a real challenge especially when distributed amongst various nations, forces or authorities.
OpenSea is a real-time open development platform used to facilitate and provide a coherent and common perception to maritime situations by means of realistic or augmented scenarios using synthetic environments and advanced artificial Intelligence. It covers several areas of applications such as synthetic movies, serious games, simulation and visualization, training and augmented training, design and validation of concept of operations and concept of use, augmented virtual reality and augmented reality.
OpenSea offers a set of valuable tools to stakeholders involved in the development of such complex systems by allowing rapid virtual prototyping, assessment of intelligent behaviors, incremental testing in mixed world and reducing the risk associated to developments. Current projects focus on Harbor Protection and Anti-Submarine Warfare.
Future enhancements will allow very complex behaviors and tactics for swarms of unmanned vehicles. It will incorporate simulation of human civil activities. It will also allow simulating specific human behaviors induced by different cultures, stress, misunderstanding and misperception. Long-term developments will propagate communication and intelligence down to the equipment at sea.
The architecture and the functionalities of the next release of the OpenSea are presented.

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Transferring oceanographic to acoustic uncertainty using polynomial chaos expansions

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The transfer of oceanographic induced sound speed uncertainty to acoustic uncertainty is described using the method of polynomial chaos (PC) expansions. In a coupled normal mode framework a second-order PC expansion of the log of the modal amplitudes is obtained which allows the explicit evaluation of the non-adiabaticity of the acoustic response to the sound speed fluctuations. Results from this intrusive formulation as well as non-intrusive and Monte-Carlo results are compared to the adiabatic approximation as a function of sound speed variability and frequency. Conclusions regarding the usefulness of the adiabatic approximation as well as the log modal amplitude polynomial chaos expansion method are drawn and ways forward for modelling the transfer of higher dimensional and/or stronger uncertainty are discussed.

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Uncertainty Prediction for Ocean Fields

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A grand challenge in ocean sciences and applications is the ability to quantitatively predict the accuracy of predictions. Optimal prognostic approximations of the Fokker-Plank equations must capture the essence of the complex system while being computationally tractable. We derived new Dynamically Orthogonal (DO) equations that decompose the solution into mean and stochastic dynamical components. This leads to a coupled system of field equations consisting of a PDE for the mean field, a family of PDEs for the orthonormal basis that evolves the error subspace where the stochasticity 'lives' as well as a system of SDEs that define how the stochasticity evolves in the time varying error subspace. For this derivation, we impose nothing more than a rate-of-change of the subspace dynamically orthogonal to the subspace itself. Our work extends and generalizes the classic Proper-Orthogonal-Decomposition and the generalized Polynomial-Chaos equations. Using these DO equations and the ideas of Error Subspace Statistical Estimation (ESSE), we provide adaptive schemes for learning the size of the error subspace. We discuss new DO numerical schemes and apply them to viscous Navier-Stokes flows as well as to idealized ocean and climate simulations, and we compare our results with Monte Carlo simulations.

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Intelligent Sampling for Ocean Fields

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A grand challenge in ocean sciences and applications is to develop algorithms for optimal sensing of the Ocean and Earth System using large numbers of smart vehicles. The more intelligent they become, i.e. the more knowledgeable about the predicted future dynamics and about the predicted effects of their sampling on field estimates, the greater their impact. We review our experience and future directions focusing on ocean uncertainty reduction. The schemes we have developed include: adaptive sampling via ESSE with non-linear predictions of error reductions; Mixed Integer Linear Programming for path planning; nonlinear path planning using Genetic algorithms; Dynamic programming and onboard routing for path planning; Level-Set methods for ocean sampling swarms; adaptive sampling with DO-assimilation and POMDPs; and, Command and control of autonomous surface craft over the Web, directly from ocean model instructions.

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Statistical Distribution Modelling with the Kernel DM+V Algorithm Application to Oceanographic Data

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This work discusses the application of a statistical approach to model the spatial distribution of environmental parameters such as salinity, for example. A statistical approach to distribution modelling treats sensor measurements as random variables and attempts to estimate the underlying random process from the observations.
The statistical modelling method used is the 2D Kernel DM+V algorithm. It treats distribution modelling as a density estimation problem and learns a statistical model from a sequence of spatially distributed observations. The learned model is represented as a set of grid maps, corresponding to the information density of the samples, the distribution mean and the predictive variance per grid cell. As a model-free algorithm, Kernel DM+V makes no assumptions about a particular functional form of the model. The algorithm also does not require equidistant sampling.
Kernel DM+V was first applied to model the distribution of airborne pollutants. This work presents salinity distribution models from data obtained in the Mediterranean Sea. Apart from providing decision makers with a comprehensive overview over a large set of measurements, the learned distribution model is also useful to select future sampling locations (adaptive sampling), e.g. in areas of high concentration or large uncertainty. High concentrations correspond to high values in the predicted mean. However, there are two types of uncertainty represented in the Kernel DM+V distribution model. First, the uncertainty about the mean and variance estimate (which is related to the observation density) and, second, the expected variability of the observations, represented by the predictive variance.
A remarkable observation in the domain of airborne pollutants was that the spatial structure of the predictive variance was found to indicate the location of gas sources more reliably and more precisely than the predictive mean. The predictive variance estimated with Kernel DM+V for the salinity data also reveals a pronounced spatial structure though it remains to be investigated what the "variance hotspots" indicate in case of oceanographic data. The basic Kernel DM+V algorithm has been extended to include flow information and to create 3-d models. It can also handle uncertain information about the measurement locations and it can model higher statistical moments. All these possibilities will be discussed in the final work and exemplified with real-world salinity distribution models.

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Interaction between currents, meteorological and topographic forcings; the case study of Portofino Promontory (northern Ligurian shelf) in summer 2004

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Hydrological, current-meter and meteorological data were acquired in the northern Ligurian sea in summer 2004. Data have been collected using different kind of instruments and resolutions. This work merges different sources of data to describe the coastal dynamic around the Cape of Portofino and to define its relation with the general cyclonic circulation in the area (represented by Arenzano current), the orography and the meteorological forcing. The unusual squared-shape of the cape seems to play an important role in setting up the typical dynamical aspects of the coastal currents. The circulation was studied by means of a two months continuous time series (July 1st to August 30th) provided by a bottom mounted profiler (Shallow water Environmental Profiler in Trawl-safe Real-time configuration, SEPTR) in the west part of the promontory. This local circulation was compared with ADCP data acquired in front of Arenzano. The Portofino current shows a local South-westward circulation indicating an anti-cyclonic eddy in the lee side of the cape and the other one detects the general current flowing South-westward along the Arenzano coast, and it is assumed as representative of Ligurian Provenal Current. The spatial analysis of temperature and salinity, acquired around the headland on August 8th, suggests the presence of two different water masses around the cape: the first one, located westward, behind the cape, probably associated to the local eddy, while the second one, offshore the cape, could be associated to the general cyclonic circulation. The analysis, applied on ADCP data, highlights the significant role of the baroclinic component in the current flowing westward of the cape, while the barotropic component prevails on the general coastal current (Arenzano flow). Spectral analysis evidences that the currents are prevalently induced by shorter time scale phenomena, such as meteorological disturbances passing over the area. The integrated study of the wind stress (acquired in four coastal stations along the Ligurian coastline during 2004) and current-meter data demonstrate that both currents are intrinsic part of general circulation of the Ligurian Sea, but the Arenzano current is mostly affected by the meteorological forcing while the currents nearby Cape of Portofino are affected by the orography of the promontory, that contributes to generate an anti-cyclonic eddy in the western side of the cape.

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Oceanic model error reduction at the Naval Oceanographic Office

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The Naval Oceanographic Office uses the Navy Coupled Ocean Data Assimilation (NCODA) system to perform data assimilation for ocean modeling (Cummings, 2005). This system runs on the Navy DoD Supercomputing Resource Center (DSRC).
Currently the system uses a 3D multivariate optimum interpolation (3DMVOI) algorithm to produce outputs of temperature, salinity, geopotential, and u/v velocity. NCODA is run in a stand-alone mode to support automated ocean data quality control (OcnQC) and to test software updates. NCODA is also coupled with the tide-resolving high-resolution Regional Navy Coastal Ocean Model (RNCOM) (Rowley, 2009).
Reduction of modeling error in the RNCOM/NCODA system is being carried out via three complementary approaches: (a) Improving the data assimilation algorithm by transitioning from the 3DMVOI method to a 3D variational (3DVar) method; (b) Running ensembles of RNCOM to quantify the modeling error and get a better representation of the best model state; (c) Performing adaptive sampling and prediction (ASAP) to reduce errors in the analysis and forecasts by placing observations in the best possible locations to reduce the future forecast bias and RMS.
Additions to the data assimilation algorithms that help reduce the analysis errors include choices of different horizontal and vertical correlation models, introduction of flow-dependence by means of a flow-dependent contribution to the background error covariance matrix, and introduction of a "land-tensor" (in 3DVar) to improve results near the coast.
The RNCOM ensembles are produced by perturbing the forcing (winds) and the initial conditions. The winds are perturbed by a space-time deformation (Hong, 2007) and the initial conditions by use of Ensemble Transform (ET) technique (Bishop, 1999).
The ASAP methodology (Coelho, 2008) is based on the Ensemble Transform Kalman Filter (ETKF) method (Bishop, 2002), and makes use of the RNCOM ensembles. This method allows prediction of the future impact within a target area, of observations taken within an operational area at previous times. Thus, limited assets can be used more effectively for applications such as ocean acoustics. The impact of the observations and ASAP predictions are assessed by means of spread-skill diagrams and tracking the RMS during targeted glider deployments. Results will be shown of (a) how the 3DMVOI compares to the 3DVar, (b) how the ensembling technique is performing, and (c) how effective the ASAP process has been at reducing the forecast error during glider exercises.

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Surface current map reconstruction from a single coastal radar-site

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Surface current measurements from coastal radar need two distant stations to reconstruct the current field from radial velocity data. However,it can happen that only one radar is available, e.g. because the failure of the other one. Here, we propose a new surface current field reconstruction method deduced from the current stream function, the CMVR (Characteristics Method for Vector Reconstruction). The vector velocity is computed by solving a partial differential equation assuming a non divergent surface current field and using radial data measured by a single-site coastal radar. Tests on idealized circulations and on numerical results in the Gulf of Lions are very promising for realistic applications.

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Decision Making under Conditions of Uncertainty: The Impact of Uncertainty on Operator Performance

Yvonne Masakowski

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The distributed theater environment requires operators to make decisions under conditions of uncertainty in a limited time, and often with competing sources of information. There is a need to de-conflict information and enhance situational awareness and facilitate decision making in the distributed team environment. The plethora of data received from a wide array of sources, while necessary for effective decision-making, can nonetheless quickly overwhelm the ability of an operator to synthesize the data and process it into a form that best supports decision-makers facing a rapidly changing situation. This is especially true in large-scale and/or dynamic and rapidly changing maritime environments. Most of the environmental information contains considerable amount of uncertainty which must be resolved by maritime domain experts. Thus, achieving an understanding of areas of uncertainty is critical for operators working within the maritime environment. We must consider how best to present complex information to the operator as a means of supporting their decisions. This presentation will focus on the development of enhanced visualization tools for representing areas of uncertainty that will assist operators in complex problem solving and decision making. Much of the information used by environmental/maritime domain experts contains considerable uncertainty in the measurement and/or analysis process. Understanding areas of uncertainty is essential for operators working within the maritime environment as it informs their decision making. Thus, understanding the implications of uncertainty representation on decisions is critical to human information, as well as to Navy and NATO missions. To effectively address these challenges, decision-makers require tools for enhancing situation awareness and reasoning tools to facilitate making rapid, robust and accurate decisions. This presentation will focus on the proposed methods and analyses to address these issues which will include cognitive task analyses, maritime sensemaking analyses. This analysis will inform the designer of future requirements to support the decision aid tool.

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Overview of ESA Earth Observation missions and programme: from Science to Applications

Pierre-Philippe Mathieu

ESA

This talk will provide an overview of ESA "Earth Observation" (EO) missions, including Research satellites (e.g. ENVISAT, ERS, SMOS, GOCE, CRYOSAT) and User-driven satellites (e.g. SENTINELS), and programmes, such as the "Climate Change Initiative" (CCI) and the "Global Monitoring for the Environment & Security"(GMES). A particular focus of the talk will be on the ESA CCI, discussing the challenges and oppportunities related to the generation of long-term, consistent Climate Data Records of Essential Climate Variables (ECV), the characterisation of their errors and their assessment within model context.

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Dispersion prediction uncertainty

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Data from 13 surface drifters deployed in the Adriatic Sea during the DART06 international program are compared with results from NCOM high-resolution forecast model, in terms of single trajectory and dispersion patches prediction. The uncertainty is evaluated by traditional error metrics as well as spreading maps, by introducing a Lagrangian subgrid scale model which parametrize the unresolved part of the eddy field. Final goal is to estimate the model error and to eventually correct in quasi-real time the dispersal patterns for real applications (SAR, oil-spills..), according to bias and local dynamics.

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Uncertainty forecast by 3-D super-ensemble multi-model fusion in the ocean

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The super-ensemble (SE) technique, which combines outputs from several operational models, was shown to provide improved forecasts of environmental conditions when applied to atmospheric (e.g. [Krishnamurti et al., Science, 1999]) or oceanic (e.g. [Rixen et al., JMS, 2009]) variables. The technique consists in the optimization, in terms of the distance to observations, of the weighted linear combination of several models during a specified learning period. The weights are then used to combine model predictions and generate the new forecast. In the oceanographic context characterized by sparsely distributed observations, an evolution of the technique, called 3-D super-ensemble (3DSE), has been developed, based on the introduction of three-dimensional variable model weights. The new method is evaluated using a set of CTD and glider profiles, mooring data and satellite SST collected during LSCV08 and REP10 oceanographic campaigns in the Ligurian Sea. Forecast skills are improved compared to individual models and their Ensemble Mean (EM). During LSCV08 and over a 4-day forecast period, the surface and vertical temperature RMSD with observations are respectively reduced by 64% and 33% compared to EM. In addition, as a data assimilation procedure, the technique provides an estimate of the a posteriori error associated with the model combination. Issues regarding the calibration and validation of the 3DSE uncertainty estimate will be discussed in this presentation.

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An autonomous underwater vehicle for seabed characterization

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In 2009 NATO Undersea Research Centre (NURC) conducted the CLUTTER'09 experiment on the Malta Plateau, Strait of Sicily in the Mediterranean Sea, in collaboration with the CLUTTER JRP partners from USA and Canada. One of the main objectives of this experiment was to characterize the seabed for geoacoustic properties using a newly NURC-developed sound source and 32-metre horizontal line array towed behind the Ocean EXplorer Autonomous Underwater Vehicle (OEX-AUV). The source transmitted linear-frequency-modulated signals in the frequency band 800-3500 Hz, and these signals were received on the horizontal line array. The array has a 4-level aperture which allows both for utilizing individual hydrophone data and beamformed data for the seabed characterization. The advantage of using the OEX-AUV is that measurements can be performed close to the seabed and efficiently map the geoacoustic properties on spatial scales of 10-100 metres. These spatial scales can be difficult to obtain from conventional cores, cone penetrometers or sonar systems towed from a surface vessel. Results of environmental characterization using the OEX-AUV from a selected region on the Malta Plateau are presented and compared to independent findings from previous experiments. The method applied here for the environmental characterization is based on matched-field geoacoustic inversion where the acoustic data received on the horizontal array are matched to numerical modelling results. An efficient global search algorithm is used to search for the model environment that gives the best match between model and data which is then defined as the "true" environment (Maximum A Posteriori). Further, uncertainties in the derived bottom properties caused by measuring and modeling errors are estimated by the probabilistic Bayesian formulation of the inversion problem. These environmental uncertainties are important for assessing the environmental contents in the acoustic data and to estimate uncertainties in sonar performance predictions. The geoacoustic model of the bottom estimated by the inversion is compared to the experimentally derived reflections coefficient for sanity. The reflection coefficient is calculated by time gating individual multi-path arrivals and normalizing by the direct arrival.
[Work supported by NURC and ONR (OA321)].

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Uncertainty in Internal Wave Fields: Coherent Structures and Nonlinear Waves

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Reducing uncertainty in the oceanic internal wave field implies improving physical knowledge of extreme events such as solitons. It has been recently discovered that tabletop solitons (with both positive and negative polarity) can also occur when the soliton paradigm is extended to higher order. Wave packet solutions called "breathers" have also been found. I investigate these solutions in 1+1 dimensions (x, t) and 2+1 dimensions (x, y, t) and discuss their properties. A natural observation is that internal waves that propagate from deep to shallow water often go from a regime of KdV-type solitons to a regime of positive/negative tabletop solitons and breathers; the complexity of internal wave motions is thereby increased substantially in shallow water regions. I demonstrate that the leading order nonlinear approximation (the KdV and KP equations) is easily extended to higher order (the Gardner equations in 1+1 and 2+1 dimensions). These two steps in nonlinearity belong to an infinite hierarchy of approximations that lead to the Euler equations for internal wave motions. In this scheme the solitons, breathers, shock waves, vortices, etc. are given the name "coherent structures." These latter are nonlinear Fourier components in the theory of nonlinear Fourier analysis, together with other nonlinear wave solutions.*

I discuss further how, to a selected order, nonlinear Fourier analysis provides: (1) physical understanding in terms of the coherent structures and nonlinear wave solutions, (2) space/time series algorithms for the analysis of data (including multiprobe arrays) and (3) hyperfast numerical algorithms for modeling applications. All of these approaches are generally taken to be in 2+1 dimensions. On a modern multicore machine (128,000 cores) my code for the 2+1 Gardner equation runs 10ˆ8 times faster than a conventional FFT spectral code on a single processor. A factor of 1000 was found for a single core plus an additional factor for the parallel use of 100,000 cores. Hyperfast codes for the Boussinsesq, Euler and Navier-Stokes equations are now under development.

*Nonlinear Ocean Waves and the Inverse Scattering Transform, by A. R. Osborne (Academic Press, Boston, 2010, 976 pages).

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An approximate relationship between water depth and geoacoustic properties for application in sonar performance prediction in uncertain environments

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The properties of the seabed typically have a significant impact on sound propagation in continental shelf water depths. In some instances, seabed properties can be the most sensitive parameter governing acoustic transmission loss. Thus, the uncertainty regarding the seabed properties is transferred into uncertainties in sonar performance prediction. The sediments on the Scotian Shelf off eastern Canada have been reasonably well mapped from a marine geology point of view, but not acoustically. Numerous attempts have been made to measure or assign acoustic properties to the sediments, including the development of rapid environmental assessment techniques and tools, and collaborative initiatives with other government departments with mandates to conduct surveys in Canadian waters. Despite these efforts, there remain large areas for which there are no direct measurements of seabed acoustic properties. Where acoustic measurements have been made, they show a reasonable correlation with water depth and sediment type.

The first impression of the surficial geology map of the Scotian Shelf is that the surficial sediment type shows a strong correlation with water depth. This is related to historical sea levels as the shallow bank areas were above sea level during the most recent ice age. The intermediate depths to about 115 m were beaches at various times. The bottoms of the basins, with depths over 200 m, were never exposed sub-aerially and are covered with silt and clay transported from the shallower areas; the coarser sand and gravel having been left behind. These observations lead to a simple mapping between water depth and acoustical properties. When no other seabed acoustic information is available or it is inadequate, we propose to use the water depth as a proxyin lieu of a database of seabed acoustic propertiesto enable acoustic transmission loss predictions for an entire area. It is not meant to be exact, but rather to provide an approximate relation that will limit uncertainty associated with the seabed. Because only the surficial sediments are considered, the application is restricted to acoustic propagation at higher frequencies, say above 1 kHz. Though this specific relationship focuses on the Scotian Shelf, it is supposed that the principles may be applied more widely to other continental shelfs that have experienced glaciation.

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Observation of Strong Current Events in a Time Series of approximately Eleven Years Conducted at the Baltic Coast off the Rerik Sea Resort, and their Impact on the Uncertainties of Surf and Coastal Current Forecasts

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An analysis of circa eleven years of measurements of wind, waves, water level, and coastal currents off the Rerik sea resort at the Baltic coast is presented. The time series of the shallow water coastal current shows in general a very weak current of about 3-5 cm/s, however, there are a lot of events in which the current suddenly increases up to 95 cm/s. The form of the current events is always nearly the same: there is a sharp increase within 1 to 3 hours up to the maximum current, and then a very smooth decay within at least 14 hours to its usual low current value. Seven of the ten strongest current events are in rapid succession or concurrent with the strongest wind events. Their impact on the uncertainties of surf and coastal current forecasts is demonstrated.

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Sensitivity of acoustic propagation to uncertainties in the marine environment as characterized by various Rapid Environmental Assessment methods

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Accurate sonar performance prediction modeling depends on a good knowledge of the local environment, including bathymetry, oceanography, and seabed properties. The function of rapid environmental assessment (REA) is to obtain relevant environmental data in a tactically relevant timeframe, with REA methods categorized by the nature and immediacy of their application, from historical bases through remotely sensed data to *in situ* acquisition. However, each REA approach is subject to its own set of uncertainties, which are in turn transferred to uncertainty in sonar performance prediction. An approach to quantify and manage this uncertainty has been developed through the definition of sensitivity metrics' and Monte Carlo simulations of acoustic propagation using multiple realizations of the marine environment. The statistical properties of the environmental parameters may be obtained from compilations of historical data, forecast conditions, or *in situ* measurements. During a field trial off the coast of Nova Scotia, a set of environmental data, including oceanographic and geo-acoustic parameters, was collected together with acoustic transmission loss data. At the same time, several numerical models to forecast the oceanographic conditions were run for the area, including five-day and one-day forecasts as well as now-casts. Data from the model runs are compared to each other and to *in situ* environmental sampling to gain an understanding of the inherent uncertainties. The forecast and *in situ* data are used with historical geo-acoustic databases and geo-acoustic parameters collected using REA techniques to perform acoustic transmission loss predictions, which are then compared to measured transmission loss. The progression of uncertainty in the marine environment within and between different REA categories, and the consequences on acoustic propagation, are examined.

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Realtime Forecast System and Adaptive Sampling in Support of REP10

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One of the NRL contributions to the REP10 exercise is to provide, in real-time, ocean forecasts in support of the operations at sea, to identify the area of model uncertainties and ocean variability, and finally to guide the gliders at sea with an adaptive sampling procedure. The NRL prediction system, based on the relocatable version of the Navy Coastal Ocean Model (NCOM) (Rowley et al., 2010) , is configured with 3 nesting domains nest0, nest1, and nest2 at resolutions of 4, 2, and 0.6 $km.$, respectively. The data assimilation model is the NRL Coupled Ocean Data Assimilation (NCODA) (J. Cummings, 2006) and the adaptive sampling scheme is from a non-linear Genetic Algorithm (Heaney et al., 2007).
For this application, data are assimilated in real-time on the nest0 and nest1, while nest2 is a free run with a mild nudging to the parent, nest1, domain. Data are from the unclassified operational data server and the measurements collected at sea during REP10. Nest1 is also configured with 32 ensemble members with the ensemble transform technique of Bishop and Toth (1999) and error variance estimates from the NCODA analysis to represent initial condition error. Perturbed surface forcing or an atmospheric ensemble is used to represent errors in surface forcing. The ensemble transform Kalman filter (Bishop, et al., 2001) is applied to assess the impact of adaptive observations on future analysis and forecast uncertainty for ocean properties.
We briefly discuss the main issues associated with real-time operations, the acquisition and deliver of the data, and present preliminary model/data comparison to highlight the skills and limits of the realtime procedure.

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Glider data processing and data comparison in optical parameter estimation for rapid environmental characterization

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Long-range and remotely sensed satellites systems are being utilized in the oceanic and coastal areas to quantify temperature, currents and water properties. Our goal is to integrate Autonomous Underwater Vehicle Gliders (AUVGs) in order to maximize the impact and ground truth capabilities of the more extensive satellite observations. AUVG is a uniquely mobile platform capable of moving to specific location and depths thus providing high resolution water parameters at varying spatial and temporal scales. We will present results from three cruises supported by NURC in the Ligurian Sea: two trials occurred in October 2008 (LSCV 08-Ligurian Sea Cal/Val 2008) and March 2009 (Battlespace Characterization 2009- BP09), while the third was held in August 2010. The common points of those sea trials were the generation of an extensive and accurate optical data set (in coastal and oceanic waters) and the deployment of Slocum gliders. In particular, prior to the BP10 cruise a fleet of six Slocum Gliders will be deployed to survey the Ligurian Sea, providing measurements to assist in the selection of station locations and along track surveys. These gliders have been recently purchased by NURC and outfitted with a variety of bio-optical instrumentation.
The aim of this work is to perform glider data analysis to maximize the optical information content of the collected data and to minimize uncertainties as well as to provide comparisons between *in situ* and remote sensing measurements. The objective is to contribute to the future development of a wide area littoral network, as an approach for integrating *in situ* autonomous platforms and remote sensing for near-real time data fusion. We will present glider sensor reliability in intermediate/shallow waters (from 0 to 100 meters) and retrieval uncertainties of optical properties from glider-sampling transects. A quality assessment of the results will be performed comparing glider products with those available from *in situ* (HyperPRO) measurements and satellite observations (MODIS and MERIS).

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A new method for Ocean Ensemble Forecasting with quantification of wind uncertainties

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A Bayesian Hierarchical Model (BHM) is developed to estimate the surface vector wind (SVW) and its uncertainty, over the Mediterranean Sea and then used to force ocean ensemble forecasts. The BHM-SVW incorporates data stage inputs from analyses and forecasts of the European Center for Medium-Range Weather Forecasts (ECMWF), and from the QuikSCAT data record. The posterior distributions of the winds are then used to force the data assimilation and the 10 days forecast stages of a new Ocean Ensemble Forecasting (OEF) method. During the 14 days data assimilation stage, the wind uncertainty allows the perturbation to grow and evolve in ocean observation free areas. The perturbed initial conditions are then forced by the respective BHM-SVW realizations in the 10 days forecast stage. The BHM-SVW-OEF ocean response spread is amplified at the mesoscales and pycnocline of the eddy field. The new method is compared to an ensemble response forced by ECMWF Ensemble Prediction System (EEPS) surface winds, and to an ensemble forecast started from perturbed initial conditions derived from an ad hoc Thermocline Intensified Random Perturbation (TIRP) method. The EEPS-OEF shows spread at the basin scales while the TIRP-OEF response is mesoscale intensified as in the BHM-SVW-OEF response. TIRP-OEF perturbations fill more of the MFS domain while the BHM-SVW-OEF perturbations are more location-specific, concentrating ensemble spread at the sites where the ocean model response to uncertainty in the surface wind forcing is largest. The BHM-SVW-OEF method offers a practical and objective means for producing short-term forecast spread by modeling surface atmospheric forcing uncertainties that have maximum impact at the ocean mesoscales.

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U.S. Navy's Arctic Forecast Systems

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The Polar Ice Prediction System (PIPS 2.0) is the current U.S. Navy's operational ice forecasting system. PIPS 2.0 forecasts ice conditions in the northern hemisphere with a horizontal grid resolution ranging from 17-33 km depending on the grid location. The system couples the Hibler ice model to the Cox ocean model and exchanges information by interfacing the top level of the ocean model with the ice model. Ice concentration fields derived from the Special Sensor Microwave/Imager (SSM/I) are assimilated into the PIPS 2.0 system along the ice edge. The system produces a 120-hour forecast of ice fields which are sent to the National Ice Center (NIC) to be used in their daily ice forecasts.
More recently, the Naval Research Laboratory (NRL) has performed sea ice hindcasts for the Arctic region derived from the latest coupled ice-ocean prediction system. The 1/12° Arctic Cap Nowcast/Forecast System (ACNFS) is based on the HYbrid Coordinate Ocean Model (HYCOM) coupled to the Los Alamos Community Ice CodE (CICE) and tested using the Navy Coupled Ocean Data Assimilation (NCODA). NCODA uses a three-dimensional variational (3DVAR) data assimilation scheme. The system assimilates surface observations from satellites (altimeter data, sea surface temperature (SST) and sea ice concentration) as well as *in situ* SST's and temperature/salinity profiles. The ACNFS has a horizontal resolution ranging from 3.5 km near to pole to approximately 6.5 km near 40°N.
NRL has validated ice drift, ice thickness, ice edge location and ice concentration against unassimilated observation data sets such as Arctic drifting buoy data, ice mass balance buoys, upward looking sonar moorings and ice edge location maps from the NIC. Results from the validation study will be discussed.

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The Ligurian Dispersion Experiment – LIDEX10

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The Ligurian Dispersion Experiment (LIDEX10) was carried out in the southeastern Ligurian sea in summer 2010. The main goal was to study the horizontal dispersion induced by the near-surface currents in open sea and coastal environments (including across frontal area associated with river plume). CODE drifters with Argos/Iridium telemetry and GPS positioning were released in several deployment episodes in July and August 2010 (in cooperation with REP10 Experiment). The drifters were released in clusters of 9 units separated initially by distance ranging between 50 and 500 m. The deployment locations were selected with the help of satellite images (especially chlorophyll concentration images to identify the frontal area separating rich/turbid coastal waters from the offshore waters) and numerical forecasts of the local circulation. An Argo float (Arvor-I cycling everyday) and a glider (200-m electrically powered Slocum) were operated in the vicinity of the drifters to describe the 3D structure of the water mass properties (temperature, salinity, dissolved oxygen, chlorophyll fluorescence, etc.).
Preliminary results obtained from the drifters, float and glider, complemented by satellite images, will be presented and discussed. These include the convoluted trajectories of the clusters of drifters, initially staying coherent and eventually spreading apart, the effect of the wind forcing on the drifter motion and the effect of the bathymetry/geography (especially the islands near/in the Strait of Corsica). The ability of numerical models to reproduce the drifter advection and dispersion is also discussed.

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Slocum Glider performance with 2Hz optical instruments in Eastsound, WA, USA

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During the month of May 2010, in Eastsound, WA USA, two Slocum Gliders were deployed using the recent Science Data Logging firmware version (SDL 7.0). This firmware upgrade for the Slocum gliders allows for all science data to be recorded to the internal science computer of the glider. After a small investigation, it was found that the upgrade also allowed for the increase of sampling rate of up to 2 Hz for the optical instruments onboard the glider. The increased sampling rate should allow for a more robust, statistical estimate of the optical data values. This work will investigate the performance of the glider and sensors using a 2 Hz sampling rate for the three optical instruments onboard the gliders (backscatter, fluorometer, and beam attenuation). Examples of the bio-optically active thin layers will be shown for Eastsound, WA USA, during the month of May 2010.

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Ocean-atmosphere wave coupling: extreme event analysis, forecast and effects in the Mediterranean Sea in May 2010

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The coastal areas of the north-western Mediterranean Sea are well known as one of the most challenging places for ocean forecasting. This region is frequently exposed to intense and episodic storm events where strong air-sea interactions are observed; significant ocean heat loss has been observed as well as large amplitude surface gravity waves that can have severe consequences on the coastal areas. Understanding the oceanic/atmospheric processes and increasing our capability to predict these events and their impacts will enhance our ability to effectively manage the response to individual storm events, as well as to the cumulative effect of multiple storms and long-term coastal change. To investigate the significant air-sea interactions, we used the Coupled Ocean-Atmosphere-Wave-Sediment Transport (COAWST) Modelling System, which is comprised of the Model Coupling Toolkit to exchange data fields between the ocean model ROMS, the atmosphere model WRF, the wave model SWAN, and the sediment capabilities of the Community Sediment Transport Model. This formulation builds upon previous developments by coupling the atmospheric model to the ocean and wave models. High-resolution grids of each of these models were prepared to simulate storm events and their associated oceanic response.
A severe storm occurred in May 2010 over the western Mediterranean Sea. This storm has been chosen as a suitable study case for a first implementation of the coupled system. During this event, a mesoscale/submesoscale cyclone evolved northward and generated surface gravity waves with 8 meters significant height which caused damages, in particular on the French Riviera. Available *in situ* data shows that intense ocean/atmosphere interactions were responsible for the trigger of the atmospheric cyclone. A detailed heat budget analysis shows that the intense cooling associated with the passage of the disturbance was mainly driven by air-sea heat fluxes and oceanic horizontal advection. Results point out the high sensitivity of the coupled system: the atmospheric main features of the storm strongly depend of the sea surface temperature and the surface gravity waves are sensitive to both ocean and atmospheric coupling.

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A review of recent super-ensemble multi-model challenges, developments, results, and perspectives for the coastal ocean

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An increasing number of models are now able to provide forecasts for the coastal ocean. Nevertheless, due to the nature of coastal ocean dynamics (multi-processes, multi-scales, multi-interactions, multi-forcings), the predictive skill of these numerical models is inevitably limited, affected by (i) an incomplete representation of ocean processes, (ii) a scale-limited formulation of ocean physics, (iii) a number of simplifying hypothesis which tend to de-couple processes, and (iv) uncertainties in the atmospheric and boundary forcings. To improve forecast skills, data assimilation is generally used to integrate information from satellite and *in situ* measurements into the forecasting system. Observations of the ocean surface are routinely provided by Sea Surface Temperature (SST) and Sea Surface Height (SSH) operational satellites. High-frequency coastal radars also measure coastal surface currents in an increasing number of littoral regions. Moreover, when deployed in the area of interest, mooring measurements, ship-based XBT/CTD profiles and autonomous underwater vehicles (gliders) provide additional information about the vertical structure of oceanic variables.
Based on the idea that (i) different models may have different skills in reproducing the ocean state, and (ii) these skills probably evolve in time due to the temporal variability of coastal ocean dynamics, multi-model fusion methods have been developed with the aim to improve our ocean forecast skill. One of such method, known as Super Ensemble (SE), produces an optimal weighted model combination which minimizes the mismatch with observations over a specified learning period. This optimal combination is then used to produce an optimal ocean forecast. The SE approach was demonstrated to improve the forecast skills with respect to single models and to the model Ensemble Mean when applied for surface drift and acoustic profile prediction. It was also shown to improve the temperature predictions in a coastal ocean environment.
After a review of recent achievements in the field, we will present further evolutions of the SE technique using a 3D Kalman Filter in the weights space, which eventually exploits the multivariate covariance of underlying numerical models. This new three-dimensional Super Ensemble method (3DSE) allows for the dynamic and multivariate evolution of model weights. Results and ideas for improvements will be discussed.

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Features of Monthly and Seasonal Temperature Ensemble Forecasts for the Baltic Sea

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In this work we explore the statistical features of ensemble forecasts for the Baltic Sea, with a special emphasis on forecasting temperature and other physical variables. We concentrate on monthly and seasonal forecasts, with time spans from one to six months, which have numerous potential applications ranging from optimization of ice management activities to ecological risk management.
The natural conditions of the Baltic Sea are unique. Water is brackish and salinity is horizontally relatively homogeneous. Temperatures vary heavily during the year and sea ice forms annually affecting maritime activities and ecology significantly. During severe ice seasons the whole basin can be covered with ice.
For this study we analysed monthly and seasonal ensemble forecasts produced weekly and monthly, respectively. BalEco, operational biogeochemical modelling system of the Finnish Meteorological Institute, was ran with perturbed weather scenarios from European Centre for Medium-Range Weather Forecasts. There were 50 ensemble members for monthly forecasts and 30 members for seasonal forecasts. From this system we obtained physical variables such as temperature, velocity and salinity, three chemical components and four biological components.
The ensembles were diagnosed with different methods adapted from e.g. meteorological forecasting analyses . These methods include simple statistical parameters, but also more sophisticated analysis tools. With different diagnostics measuring among others bias, spread and uncertainty, it is possible to obtain an overall picture of the quality of the forecasts and, in the end, to convey uncertainties to the end-user in an easily comprehensible manner. Bearing this in mind, we also discuss the communicational aspects of ensemble forecasting.

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A multispectral electromagnetic footprint method for determining sediment conductivity profiles

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The most common technique for (sub-) bottom mapping is based on acoustic time travel analysis. In areas where the acoustic properties are such that the sound propagation is impeded, e.g. bottom-trapped gas or in shallow areas, electromagnetic sounding techniques have show to be an alternative technique. This technique is based on retrieving data by transmitting a known signal through the seawater and the underlying bottom and detecting the response at specified locations and is known as Controlled Source EM (CSEM). In this investigation both the transmit and receiver instrumentation are towed as an alternative to more standard techniques that uses a mobile transmitter and stationary receivers. Each illuminated footprint represents the underlying bottom structure along the tow-track. The data is matched to a physical parameterization of the environment via an iterative solution method where the parameters are adjusted until the model fits the data. This is known as model-based inversion and has been used extensively within geophysics and oceanography. The tuning of the model parameters is dependent on the quality of the data, but also on the number of independent observations, which is a key issue for footprint methods since the integration time over each bottom segment becomes limited. In the present investigation a technique for maximising the number of independent data points while keeping the transmit amplitude finite. The technique also avoids beats or DC-frequencies which occurs when mixing harmonic signals. Analysis of data from a sea trial from the southern Swedish Archipelago based on the aforementioned technique shows promising results for quantifying the underlying sub-bottom structures.

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Adaptive selection of the background estimation procedure for target detection IR systems in naval surveillance applications

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The detection of long-range targets in a sequence of InfraRed (IR) images characterized by a highly structured background is a problem of great relevance in many civilian and military applications. A special application, which is investigated in this work, is dim point target detection in naval surveillance IR systems where the background clutter is that encountered in a typical maritime scenario. In this framework, a well-established detection scheme is composed of two cascaded stages. First, background clutter is estimated and removed in order to simplify the detection strategy, then some a priori knowledge of the target is used to operate detection over the residual clutter. The environmental conditions determine the characteristics of the background clutter which can be considered as the undesired signal that undermines the target detection performance. Since background clutter evolves dynamically, it is necessary to analyze methods that can adaptively follow such temporal changes. In this point of view, it is important to devise automatic procedures to select the background removal (BR) technique that better fits the specific environmental conditions at the time of data acquisition. This motivation led us to introduce a novel procedure to automatically select the best background estimation algorithm (BEA) on a given operating scenario. In the BEA selection criterion a target-free image representing the scenario of interest is assumed to be available. Simulated targets are implanted in different positions of the target-free image to investigate the detection performance of the IR system for several BEAs and different values of the parameters setting. The BEA selection procedure can be periodically updated in order to take into account changes of the background signal. The proposed procedure was tested by means of an IR experimental data set representing a typical maritime scenario. The validation of the results was carried out by comparing the performance of the detection schemes based on different BEAs for different values of the design parameters. The performance was evaluated in terms of EXperimental Receiver Operating Characteristics (EX-ROC). The effectiveness of the BEA selection criterion is illustrated on a set of experimental IR data. The results show that the performance can be improved in terms of false alarm rates (FAR): fixed a fraction of detected targets, the FAR can be decreased up to two orders of magnitude.

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Boundary condition uncertainty in the NRL relocatable ocean ensemble forecast system

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A globally relocatable regional ocean nowcast/forecast system has been developed to support rapid implementation of new regional forecast domains. The system is in operational use at the Naval Oceanographic Office for a growing number of regional and coastal implementations. The new system is the basis for an ocean ensemble forecast and adaptive sampling capability.
The forecast system consists of core ocean data analysis and forecast modules, software for domain configuration, surface and boundary condition forcing processing, and job control, and global databases for ocean climatology, bathymetry, tides, and river locations and transports. The analysis component is the Navy Coupled Ocean Data Assimilation (NCODA) system, a 3D multivariate optimum interpolation system that produces simultaneous analyses of temperature, salinity, geopotential, and vector velocity using remotely-sensed SST, SSH, and sea ice concentration, plus *in situ* observations of temperature, salinity, and currents from ships, buoys, XBTs, CTDs, profiling floats, and autonomous gliders. The forecast component is the Navy Coastal Ocean Model (NCOM). The system supports one-way nesting and multiple assimilation methods.
The ensemble system uses the ensemble transform technique with error variance estimates from the NCODA analysis to represent initial condition error. Perturbed surface forcing (or an atmospheric ensemble) may be used to represent errors in surface forcing. Two methods for generating perturbed boundary conditions have been developed to assess the contribution of boundary condition error to the overall ensemble spread. The first uses a simple space-time deformation approach as is used to perturb the atmospheric forcing. The second follows the information theory technique of Richman and Miller (JAOT, submitted), which uses a training dataset from the large-scale host model to identify a reduced state space for the model and an orthogonal error space. Then, random samples from the error space are added to the reduced state space projection to generate perturbations of boundary condition data for the regional ensemble.
We present an overview of the ensemble forecast system and an initial assessment of the impact of boundary condition perturbations on the ensemble spread in limited-area models.

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Glider observations of an abrupt mixing event in the upper ocean

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In the framework of the sustained glider observational program conducted by IMEDEA since 2007 in the Balearic Sea, a new glider mission was carried out from 9 to 20 December 2009. The strategy for the glider mission consisted of a section almost perpendicular to the Balearic Current situated to the North of Mallorca Island. This trajectory was coincident with track 70 of the Jason-1 satellite. 700 CTDs profiles were collected between surface and 180 m, covering a total length track of about 135 nm. Glider mission took place during the evolution of an intense atmospheric front developed in the Northwestern Mediterranean. We will show preliminary results on the upper-ocean response to the intense atmospheric forcing. High resolution glider data allow to describe the spatial structure of an abrupt deepening of the mixed layer (more than 40 m) along the glider track. Additionally using *in situ* buoy and atmospheric modelled data we will evaluate the impact of this atmosphere-ocean interaction on the heat budget components. First results demonstrate that latent and sensible heat loss dominate the net surface heat flux. The final objective of this study is to better understand and quantify the role of strong winds forcing in driving subduction processes in the upper ocean.

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Improved heat fluxes in ocean circulation models by optics

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The present work proposes the use of optical data and models for a better characterization in ocean circulation models of the incoming heat flux from solar radiation. An accurate definition of this parameter is crucial since as it not only affects heat content and hence model dynamics, but also biogeochemical processes occurring within the water column.
In oceanic circulation models, incoming heat flux from solar radiation is provided as a forcing parameter from meteorological models and is parameterized as radiant flux incident on the sea surface. Then, the propagation in the water column of this incident radiant flux is calculated following Paulson and Simpson (1977) formulation for a predefined Jerlov optical water type and vertical attenuation for the entire basin. Heat fluxes from solar radiation are calculated as the decrement of shortwave irradiance in between ocean layers in the model.
Optical oceanography has significantly evolved in the past 30 years with advanced optical instrumentation and computational models. The use of such radiance formulations in the physical model can now be considered obsolete. This work presents new forcing schemes for incoming solar radiation based on *in situ* observations, a review of propagation patterns within the water column and heat estimates from solar irradiance based on optical modeling.

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Relative dispersion in the Liguro-Provencal basin: from submesoscale to mesoscale

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Relative dispersion in the Liguro-Provencal basin (a subregion of the Mediterranean Sea) is investigated using clusters of surface drifters deployed during two Marine Rapid Environment Assessment (MREA) experiments covering different months in 2007 and 2008 respectively. The clusters have initial radii of less than 1 km, or an order of magnitude below the typical deformation radius (of the order of 10-20 km). The data set consists of 45 original pairs and more than 50 chance pairs in the spatial range between 1 km and 200 km. Relative dispersion is estimated using the mean square separation of particle pairs and the Finite Scale Lyapunov Exponents (FSLEs). The two metrics show broadly consistent results, in particular indicating a clear exponential behavior with an e-folding time scale between 0.5-1 days, or Lyapunov exponent λ in the range or 0.7-1 days–1. The exponential phase extends for 4-7 days in time and between 1 km and 10-20 km in separation spale. To our knowledge, this is only the third time that an exponential regime is observed from drifter data, and it suggests that relative dispersion is predominantly nonlocal, namely controlled mainly by mesoscale dynamics and only weakly by the sub-mesoscale motions. NCOM model results are used to complement the data and to quantify errors arising from the sparse sampling in the observations.

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An Inversion Method for Extraction of Low Wind Speed From HF Radar Backscatter

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Land-based High Frequency (HF) surface wave radar provides the unique capability to continuously monitor coastal ocean surface parameters beyond the horizon at ranges up to 200 km. The power spectrum of the backscattered radar signals is characterized by two strong peaks which are caused by Bragg-resonant scattering from the ocean surface. These peaks are surrounded by a continuum due to second-order scattering. Since decades, the Doppler shift of the first-order peaks has been utilized to measure ocean surface currents, while the second-order continuum provides information on the ocean wave directional spectrum. Wind direction can be derived from the ratio of the first-order peaks, but the measurement of wind speed is still a problem. Up to now, published work in this area presents solutions to estimate wind speed from ocean wave power density spectra, derived from the second-order continuum.

In this work, a new approach to derive low wind speed at the ocean surface from first-order scattering is presented. Based on the growth function of the Bragg resonant ocean waves versus increasing wind speed, and knowing the wind direction as well as the wind-wave directional spreading pattern, the wind speed can be calculated from the synthesized Bragg peak power in wind direction. Up to a wind speed of 1012 m/s, when the height of the Bragg resonant ocean waves becomes saturated, the Bragg waves energy is nearly proportional to the wind speed. With the proposed method, the wind speed measurement can cover much longer range than the second-order methods; it especially does not fail when the second-order continuum is not available due to weak wind conditions or an insufficient Signal-to-Noise Ratio.

The new algorithm has been developed and tested using data from the German Bight provided by the HIPOCAS (HIndcast of dynamic Processes of the Ocean and Coastal AreaS of europe) model operated at the GKSS research center and from an experiment in Tyrrhenian Sea conducted by the University of Hamburg and NURC in 2009. Comparisons of radar and *in situ* meteorological buoy measurements have proved the proposed new method to be effective.

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Coastal Rapid Environmental Assessment in The Northern Adriatic Sea

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A new Coastal Rapid Environmental Assessment (CREA) methodology, based on an operational regional forecasting system and coastal monitoring networks of opportunity, has been developed and successfully applied to the Northern Adriatic Sea.The methodology aims at improving the initial condition estimates from the operational model using available data and a nested model in order to augment the 3-5 days forecast skill of currents and temperature. The CREA modeling system consists of a high resolution, O(800m), Adriatic SHELF model (ASHELF) implemented into the Northern Adriatic basin and nested within the Adriatic Forecasting System (AFS). The observational system is composed by three coastal networks of opportunity sampling the water masses in the near coastal areas, i.e., from the coasts to 20 km offshore. The assimilation technique used to initialize the ASHELF model is blending AFS model data with the available observations by a multi-scale optimal interpolation scheme.
Two CREA study cases have been exhamined in different periods of the year (spring and summer), chosen on the basis of the initialization and verification data availability. Two different atmospheric forcing were considered: ECMWF (0.5°) coarse resolution data set, and LAMI(7 km) high resolution data set. Two initialization methods were applied: first a downscaling approach which interpolates/extrapolates AFS large scale initial fields on ASHELF grid, second the blending approach. In addition to the blending approach, a spin-up time was investigated via a dedicated experiment and it was found that a spin-up period of 7 days is required to generate new circulation features and improve the forecast.
CREA results have been evaluated by mean of standard statistics, exploiting an extensive *in situ* and remotely sensed observational data set. The downscaling only approach improves AFS results of a 12%, while the blending approach shows an average gain of 25%. When a preliminary weekly spin up period is applied to CREA, an additional benefit determines an overall 30% improvement of the skill.

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Transitioning the Multistatic Tactical Planning Aid (MSTPA) towards decision support software

Christopher Strode

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The Multistatic Tactical Planning Aid (MSTPA) is a tool currently in development at NURC which may be used to model the performance of a given multistatic sensor network in terms of the probability of detection, the ability to hold a track, and whether such a track could be correctly classified as a threat. The tool therefore considers the entire chain of events from an initial calculation of signal excess, the generation of a contact considering localization errors, followed by the subsequent tracking and classification processes. In its current form the tool may be used to plan a particular multistatic scenario through operational analysis of Monte Carlo simulations. The future development of MSTPA will transition towards a real time decision support tool to assist operators and planners at sea. This study investigates a number of generic decision support techniques which may be wrapped around the MSTPA tool. In essence, MSTPA becomes a central metric calculator within a greater scheme of decision support processes. These processes include data mining, game theory, and optimisation techniques. The study considers each in turn and provides examples as to how they may be applied to tactical multistatic sonar scenarios.

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Sonar performance prediction from glider measurements using the Multistatic Tactical Planning Aid (MSTPA)

Christopher Strode and Manlio Oddone

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The Multistatic Tactical Planning Aid (MSTPA) is a tool currently in development at NURC which may be used to model the performance of a given multistatic sensor network in terms of the probability of detection, the ability to hold a track, and whether such a track could be correctly classified as a threat. The tool therefore considers the entire chain of events from an initial calculation of signal excess, the generation of a contact considering localization errors, followed by the subsequent tracking and classification processes. Critical to the success of such a tool is a fast and reliable acoustic model which may be called upon within large Monte Carlo simulations and Genetic Algorithm optimisation routines. The acoustic model has been recently updated to include range dependent bathymetry and sound speed profiles while still employing the fast mode theoretic approach. This study presents the results of analysis using the MSTPA acoustic engine with input sound speed measurements taken from recent glider deployments. The aim is to demonstrate the first step in a real-time decision support system, this being the ingestion of full 3D sound velocity measurements and subsequent timely prediction of sonar coverage.

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Littoral Zone Forecasting: Predicting temporal and spatial variability in nearshore waves and currents on a barred beach with diurnal forcing

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The Bluelink Project (`http://www.bom.gov.au/bluelink/index.html`s a collaborative effort involving CSIRO, the Bureau of Meteorology and Royal Australian Navy (RAN) and is aimed at providing ocean forecasts across a range of space and time scales from ocean basin scale to the littoral zone. A component of this project is to develop a relocatable model to provide 3 day predictions of waves, currents and morphological response on an arbitrary beach. The package is built around the model XBeach (Roelvink et al, 2009) with user defined forcing and initial bathymetry. The model is capable of simulating both mean and infragravity motion and has been tested against *in situ* observations of waves and currents on a barred beach from a three week field experiment in February, 2009. In addition to the presence of a shore parallel bar sea breezes cause significant diurnal wind and wave forced mean and infragravity motions. Local wave growth and decay seawards of the surf zone in 8m water depth is observed through four consecutive sea breeze cycles and numerical simulations using SWAN reveal significant departures between observed and modelled wave growth and decay. Mean flows in the surf zone due to both wind and wave forcing also show a strong response to the sea breeze and are predicted reasonably well with XBeach through both the increasing and decreasing phases of the sea breeze forcing. Temporal variability at infragravity and far infragravity frequencies are also observed in the data. Energy in the infragravity band (30-300s) is well correlated with wave height and wind through the seabreeze cycle with the maximum infragravity response occurring with the maximum in the alongshore current at the peak of the sea breeze. Significant far infragravity energy is observed during the first two sea breeze cycles but is much reduced during the last two cycles. XBeach simulations of the infragravity response to the sea breeze cycle are presented, and comparisons are made with the observed infragravity motions. Differences between the modelled response and the observations arise primarily through poorly defined bathymetry. Uncertainties in the model predictions are also due to temporal variability in the nearshore response to diurnal forcing in the mean, infragravity and far infragravity frequency bands

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Predicted and Observed Variability in Sound Speed in the Oceanic Littoral

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From the shelf break to the shoreline, the range of scales of oceanic and hence acoustic variability is wide. This work illustrates and quantifies the temporal and spatial scales of ocean acoustic variability that may be encountered in the littoral, using examples drawn from a predictive shelf model and field measurements. The highlighting and quantification of such variability is critical in order to attempt to reduce sonar detection uncertainties. Within the littoral, microscale variability can be observed at the mouths of estuaries in the form of, for example, tidal intrusion and estuarine plume fronts. Such features have a profound influence on sound propagation over very short spatial (less than one metre) and temporal scales (less than one hour), and hence have the potential to result in significant inaccuracies in, for example, the use of bathymetric survey, mine warfare and diver detection sonars. We present data drawn from field data collections campaigns to assist in the characterisation and quantification of such fine scale variability. On the shelf, internal waves, stratification/tidal fronts and mesoscale eddies can modify the acoustic field over longer scales (weeks, tens of kilometres metres). Here we employ the Proudman Oceanographic Laboratory Coastal Ocean Modelling System (POLCOMS) in the Black Sea to examine temporal and spatial variability in the sound velocity field. POLCOMS was developed and used mostly for the shelf sea areas such as the North West European shelf or the Irish Sea, and has a range of features which allows it to represent accurately sharp fronts and other discontinuities. Comparison of the model output with satellite imagery and *in situ* measurements have shown that the model adequately reproduces the many mesoscale features - including cyclonic and anticyclonic eddies, jets and filaments - in different parts of the Black Sea. Specifically in this study we use the model to examine the modifications to the sound velocity field that may result from the development and decay of mesoscale eddies in the marginal areas of the north western Black Sea.

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High Resolution Coastal Ocean Winds Retrieved from TerraSAR-X

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The possibility for retrieving wind fields from C-band synthetic aperture radar (SAR) data is well developed and validated and is currently used to produce operational wind maps. With the X-band SAR aboard the German TerraSAR-X and the L-band SAR aboard the Japanese ALOS, two additional frequencies have become available. It is quite possible that quantitative characterization of differences in SAR imagery of a particular ocean process collected at different radar frequencies can yield significant improvements in the extraction of geophysical parameters. At present several international research groups are addressing multi-frequency and multi-polarization SAR retrieval techniques. One of the major limitations in this research is the lack of a reliable Geophysical Model Function (GMF) that relates the X- and L-band backscatter of the ocean surface to the local surface wind vector. We report here the development of a GMF for X-band, which was utilized to retrieve ocean surface wind speeds from TerraSAR-X data. Therefore, a simple, physics-based X-band GMF was constructed that utilizes wind-dependent models of the ocean surface roughness spectrum. Furthermore, an empirical X-band GMF was developed that is based on the interpolation of the standardized Ku-band and C-band GMFs, which are operationally used for wind retrieval from today's scatterometers (QuikSCAT and ASCAT). Wind directions are retrieved from wind induced streaks visible in the SAR image. The orientations of the streaks are retrieved by the Local Gradient Method used for C-band images, which was adjusted to the needs of TerraSAR-X data. For validation of the X-band SAR wind retrieval algorithm several TerraSAR-X retrieved wind fields were compared to results from a high resolution numerical weather prediction model.

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Meteo-marine measuring system in National park Mljet Croatia

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National park Mljet is one of eight national parks, protected areas in Republic of Croatia. Its unique panoramic landscape of well intended coastline, cliffs, reefs and numerous islands, as well as the rich topography of the nearby hills and especially the salt lakes are a unique geological and oceanographic phenomenon of worldwide importance. The Meteorological and Hydrological service of Republic of Croatia (DHMZ) in coordination with institution of National park Mljet is performing meteorological and water (sea and lakes) temperature measurements since May of 2008 year. Meteo-marine system is consisted of automatic weather station (AWS) which is a part of DHMZ network of climatological stations and measurement of water temperature on three different locations (one on open sea, two in lakes). Communication between buoys and AWS and central PC in building of NP Mljet is done by radio link and GSM, while data and all other communication to DHMZ is done by GPRS. AWS measuring wind speed and direction, air temperature and humidity, air pressure and precipitation, data is averaged and transmitted in 10 minutes intervals. Real time data are sent every 15 seconds to local PC in NP Mljet for national park personnel informational purposes. Buoys are placed on three different locations Veliko and Malo jezero and on open sea. Calibration of processing unit mmSIME3-GSM with temperature sensor is made by separate software which is produced for this purpose via serial port on PC.

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Uncertainty estimates in the joint NSIDC and EUMETSAT sea ice re-analysis

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The joint NSIDC and EUMETSAT sea ice re-processing dataset based on SMMR and SSM/I data from 1978 to 2007 has recently been issued. The project was motivated by a need for assigning uncertainties to the ice concentration estimates and the fact that on a climatological time scale the differences between different ice concentration algorithms amounts to 14% and 22% of the down-going trend in winter Arctic sea ice extent and area, respectively. The climatological changes in atmospheric and water surface emissivity primarily affect the extent trend while the changes in sea ice surface emissivity affect the sea ice area trend. In other words there is a climatic trend in the sea ice time series related to changes in the snow cover and sea ice surface properties and the Arctic atmosphere. The re-processing includes atmospheric correction of brightness temperatures for open ocean surface wind roughness and atmospheric water vapour. A set of three different ice concentration algorithms has been selected due to their low sensitivity to cloud liquid water and ice surface emissivity. A new procedure has been developed where tie points for the ice concentration algorithms are selected dynamically in time and space as a novel method to mitigate inter sensor differences, sensor drift and inter-annual variability. Uncertainty estimates are needed when the ice concentration data are compared to other data sets or when assimilated into numerical models. The uncertainties are computed for each data point using an uncertainty model. The tie-point uncertainty including residual atmospheric noise, sensor noise and tie-point uncertainty is derived from measurements. The SMMR and the SSM/I have large foot-prints on the ground and the algorithms with the lowest sensitivity to both atmospheric and surface emissivity variability use Tb's at different frequencies with different foot-print size. Representing these large foot-prints on a finer predefined grid results in a representativeness error. The representativeness error is simulated. In addition there is the geo-location error, sensor noise, drift, and sea ice variability over the sampling period. The uncertainties are generally independent. A challenging task is the description and handling of the non-Gaussian error statistics at the low (0%) and high (100%) ends of the physical range of sea ice concentration. The ice concentration dataset including the uncertainty estimates is available from:
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Simulation of the sea ice brightness temperature variability at L-band

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The ESA Soil Moisture and Ocean Salinity (SMOS) L-Band radiometer satellite was launched on 2 November 2009. It measures soil moisture over land and ocean surface salinity as the primary mission objectives. However, in this simulation study we investigate its applications for sea ice using a combined sea ice thermodynamic and emission model. The models relates the sea ice physical properties such as density, salinity, ice thickness and temperature to microwave attenuation, reflectivity, emissivity and brightness temperature. The emission model is a sea ice version of Microwave Emission Model for Layered Snow-packs (MEMLS). Because of significant microwave penetration through the ice to the ice water interface for thin saline ice up to about 0.5 m there is an ice thickness signal in L-band brightness temperatures. However, both the ice salinity and ice temperature are affecting the microwave penetration and thin ice transparency and therefore they have a similar effect on the emissivity as thickness does. Never the less, for practical sea ice thickness retrieval applications both the salinity and the temperature can be constrained. The sensitivity to these three ice parameters and snow cover is investigated using the emission model. Further, the seasonal variability of L-band brightness temperatures is assessed using the combined thermodynamic and emission models.

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Simulation of the satellite radar altimeter Arctic sea ice thickness retrieval uncertainty

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Although it is well known that radar waves penetrate into snow and sea ice, the exact mechanisms for radar-altimeter scattering and its link to the depth of the effective scattering surface from sea ice are not well known. Previously proposed mechanisms linked the snow ice interface, i.e. the dominating scattering horizon, directly with the depth of the effective scattering surface. However, simulations using a multilayer radar scattering model show that the effective scattering surface is affected by snow-cover and ice properties. The Arctic sea ice thickness in winter has been derived by measuring its free-board using ERS-1 and 2, ENVISAT and soon CryoSat satellite radar altimeters with high orbital inclination. In this study we evaluate the radar altimeter sea ice thickness retrieval uncertainty in terms of floe buoyancy, radar penetration and ice type distribution using both a scattering model and "Archimedes' principle". The effect of the snow cover on the floe buoyancy and the radar penetration and on the ice cover spatial and temporal variability is assessed from field campaign measurements in the Arctic resulting in ice thickness uncertainties of about 0.3 m for the snow depth variability and 0.3 m for the snow density variability. In addition to these well known uncertainties we use high resolution RADARSAT SAR data to simulate errors due to the variability of the effective scattering surface as a result of the sub-footprint spatial backscatter and elevation distribution sometimes called preferential sampling. In particular in areas where ridges represent a significant part of the ice volume (e.g. the Lincoln Sea) the average simulated altimeter thickness estimate of 2.68 m is lower than the real average footprint thickness of 3.85 m which makes preferential sampling the single most important error source. This means that the errors are large and auxiliary quantities such as snow depth, snow and ice density and ice type distribution are relevant to know a priori. A discussion of the radar altimeter ice thickness retrieval uncertainties will be presented at the conference.

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Multi-Cast Measurement Protocols for Improving Near Surface Radiometric Data

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As part of NASA's Spectral Ocean Radiance Transfer Investigation and Experiment (SORTIE) project and NURC's Scientific Program of Work (2008-2010), three ocean color calibration and validation cruises occurred in the Ligurian Sea in which the proposed multicast' measurement protocol was tested. During these cruises, which sampled both eutrophic and oligotrophic conditions, anywhere up to three hyperspectral radiometers (HyperPRO II) were deployed simultaneously from the stern of the research vessel. Generally, a deep, single cast (100 m) was performed first and then 5 to 8 shallow casts were collected, sampling from the near surface to 10 meters depth. The time to synchronously collect these multicast' profiles varied from 5 to 9 minutes. Near the surface, waves contribute to enhanced localized backscattering due to focusing and defocusing of the waves, thus reducing the accuracy of extrapolating subsurface radiance and irradiance to the surface intercept. These perturbations, collected by profiling radiometers, depend upon the deployment speed and acquisition rate of the instrument. For free-falling profilers like the HyperPRO II, it is important to increase the number of near surface measurements using the multicast' approach, thus improving KLu, KEd, Ed(0-) and Lu(0-) retrievals. Results will be presented to document measurement uncertainties of multicasts' (single HyperPRO II), uncertainties between simultaneous multicasts' (2 to 3 HyperPRO II's in tandem) and methods to merge the multicast' near surface values with the single deep profile.

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New RADARSAT Capabilities Improve Maritime Surveillance

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Launched in 2007, Canada's RADARSAT-2 carries operational C-band synthetic aperture radar (SAR) that offers a variety of modes that trade spatial resolution for swath coverage. The satellite was built, and is owned and operated, by MacDonald Dettwiller and Associates. Much of the satellite funding was secured through a pre-purchase of data by the Government of Canada (GoC). RADARSAT-2 offers multi-polarization products with a low noise floor including selectable single polarization, dual polarization and quad polarization that can improve the accuracy of SAR-derived maritime products. For example, wide swath, low resolution ScanSAR modes acquired with dual polarization have come into vogue for wide area maritime surveillance; cross polarization represents a new capability that permits ship detection at small incidence angles and wind speed retrieval without the use external wind direction information. RADARSAT-2 is currently contributing to operational roles in maritime surveillance including ship detection, sea ice surveillance, oil spill detection, wind field retrieval, and ocean feature detection.

RADARSAT-2 exploitation by Canada's Department of National Defence (DND) is being implemented through the Polar Epsilon (PE) project, which includes new capabilities for the Canadian Forces: Arctic Surveillance (Land) - AS(L); Environmental Sensing - ES; Near-Real Time Ship Detection - NRTSD; and Maritime Satellite Surveillance Radar - MSSR. AS(L) and NRTSD will benefit from new RADARSAT-2 ground stations that are being built on the east and west coasts of Canada. MSSR concerns the development of new RADARSAT-2 ScanSAR modes that are tailored for maritime surveillance and will facilitate image sharing among maritime applications.

RADARSAT-2 will be followed by the RADARSAT Constellation Mission (RCM), a constellation of three small-satellite SARs that will be launched starting in 2014. RCM will be owned and operated by the GoC and will feature a wide swath Compact Polarimetry capability. RCM exploitation by DND will be carried out through the Polar Epsilon 2 (PE2) project, which is currently in definition phase. PE2 scope includes upgrades of the PE capabilities for RCM, implementation of a northern Canada ground station, and hosting of an Automatic Identification System (AIS) payload on the RCM platforms. The latter capability will permit the reliable fusion of SAR-derived ship signatures with AIS self-reporting data.

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Coastal video monitoring system optimization using computational intelligence methods

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On the present contribution, computational intelligence methods are incorporated in an automatic coastal video monitoring system, to improve the accuracy of intertidal topography measurements on a dynamic, reflective beach in South Portugal. Neural network classification models are identified and trained to conduct automatic image quality evaluation, in order to cope with the variability of images resulting from year-long environmental variation and hydrodynamic and morphological conditions. Image thresholding methods on the grounds of pixel intensity histograms and hydrodynamic conditions are used to select the optimal shoreline detection approach. The latter include algorithms processing color or grayscale images, as well as a novel artificial neural network approach that classifies pixels as dry' or wet', given their colour intensities and other statistical image features. The horizontal shoreline positions are linked to elevations estimated using offshore wave data, through models and parameterizations obtained by means of genetic programming algorithms, on the grounds of field measurements from 40 topographic RTK-DGPS surveys. Finally, automatic data quality control and filtering employing on-line adaptation techniques are applied at various processing levels. Shoreline detection produced data return percentages of 85%, while these enhancements, increased system accuracy and robustness during automatic operation. Autonomous 8 months intertidal topography monitoring results showed RMS errors ranging from 10 to 50 cm, with the average error being 25 cm, an improvement of 10% compared to previous results.

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The use of AUVs to map the variability of under-ice topography

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There are important reasons to know the three-dimensional topography of the under-ice surface. The polar ice cover consists of two distinct components: thermodynamic ice, which has reached its current thickness by natural growth; and deformed ice, which can attain a much greater thickness through rafting and ridging. Pressure ridges, formed by the crushing of refrozen leads, can reach a draft of more than 50 m. From the viewpoint of modelling the role of sea ice in climate, this composite nature of the ice cover must be considered in order to deal with dynamics, thermodynamics and mechanics correctly. For the offshore industry, too, ridging is important, as the deepest multiyear pressure ridge represents the design load on offshore structures, while the deepest ridges also control scouring frequencies in the nearshore zone. The topography of sea ice is important for such diverse applications as calculating its containment potential for oil blowouts, its capacity as a substrate for plankton, its impact on icebreaker design, and its scattering potential for under-ice acoustic propagation. True visualisation and measurement of such topography is only possible with multi-beam sonar, and at present the entire body of such data has been collected by the author's research group in Cambridge. The work began with the deployment of a Kongsberg EM2000 sonar on the UK Autosub AUV on a cruise to NE Greenland in 2004, and was followed by its use (Kongsberg EM3002) aboard the submarine HMS "Tireless" on an Arctic Ocean transect in March 2007. In April 2007 the author and his colleagues pioneered small-scale multibeam surveys under ice, using a GeoSwath system from a Gavia AUV deployed through an ice hole on the APLIS-2007 ice station in the Beaufort Sea. This was followed by a self-contained ice camp north of Alert in May 2008 in which the same system was used in a region of multi-year ridging in the coastal deformation zone. The results of the programme point to a fundamental difference in shape between first-year and multi-year ridges. Surprisingly, this is not a difference in average ridge slope (with multi-year ridges being more shallow due to melt and erosion) as previously thought, but rather a difference in crest continuity, with first-year ridges approximating to linear triangular prisms while multi-year ridges are broken up by the intervention of leads into a sequence of individual ice blocks , sometimes losing all evidence of ridge linearity.

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Uncertainties in internal solitary wave modeling due to parameter variability

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EOF analysis indicates that the passage of internal solitary waves trains results in a relationship between the first and second eof coefficients. The relationship takes the form of a scatter hysterisis diagram, to which a parabolic curve can be fitted. From the parabolic curve relationship between the first and second eof coefficients, solitary wave trains can be reconstructed. Such a diagram can be determined used to construct solitary wave trains in regions of interest. In fact, traveling wave ansatzs with a common wave speed, the 1D version of the viscous shallow water equations, also known as the Saint Venant equations, can be solved exactly, albeit implicitly, and yield Taylor shock-like velocity wave profile. Furthermore, for a special case of the wave speed, which is also the bifurcation value of the (common) associated ODE, the model exhibits the hysteresis effect. Initialization of nonhydorstatic models for predicting internal solitary waves (ISW) requires parameters of density, topography, barotropic tidal forcing, and background currents. These parameters exhibit variability and their representation involves uncertainty. We study the uncertainty due to the variation of these parameters in the regions of : Messina Strait, Luzon Strait, Shandong peninsula area of Yellow Sea, New England shelf break, and Setubal canyon off Portugal. We assimilated thermistor chain data from the Random Array Drifting Acoustic Receivers 2007 (RADAR07) experiment, off Portugal, into the KdV and Lamb (1994) models. Scales from internal wave activity and other phenomena were assimilated into the models. The model was guided towards the internal wave solution that it tracks and at the same time is perturbed by other phenomena that it does not track.

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Short Term Forecasting of Sea Surface Temperature Off Canada's East Coast

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The DalCoast coastal prediction system is used operationally at MetOc Halifax to make two day forecasts of sea level, current, temperature and salinity for the shelf waters off the east coast of Canada. Resulting sound speed and temperature profiles are able to be ingested into acoustic range prediction systems for use in ASW planning. The ocean model has recently been one-way coupled to an atmospheric forecast model run operationally by Environment Canada. In addition to forcing by air pressure and wind stress, the coastal ocean model is now forced by heat and freshwater fluxes that are calculated "online" using forecast atmospheric state variables. To ensure the model does not develop significant biases it is spectrally nudged to a high resolution seasonal climatology of water temperature and salinity. A new module has also been added to assimilate observations including snapshots of sea surface temperature observed by satellite-borne sensors (AVHRR and MODIS). The assimilation method is a form of ensemble based multivariate optimal interpolation based on the approach of Oke et al. (2007, Ocean Modelling, doi:10.1016). In this presentation we describe the one-way coupling, the new assimilation scheme and the resulting improvements in forecast skill of the coastal model, focusing on sea surface temperature. The validation data includes surface temperature measured by moored buoys (not assimilated) and future satellite observations. Forecast error statistics calculated from a long run of the system in forecast mode, and results for representative events, show the additions to the system have led to a significant increase in forecast skill in some regions and at certain times of the year.

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A discussion of the use of statistical classification methods to identify SST signatures in SAR imagery

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The Spaceborne Ocean Intelligence Network project began in June 2007 with funding provided by the Canadian Space Agency. Led by MetOc Halifax, SOIN is a multi partner, six-year research and operational development project whose focus is to utilize RADARSAT-2 data to detect oceanographic features, primarily fronts and eddies. Edges on a SAR image are identified using a Canny edge detector in IA Pro, proprietary software developed by DRDC Ottawa. A feature vector consisting of information obtained from backscatter measurements, wind measurements as well as spatial information such as the location of the edge with respect to a specified search region, and the shape of the feature (linear, curve or loop) is constructed from each edge. Components of the feature vector such as the mean and variance of the backscatter and the mean and variance of the divergence and curl of the wind vector field are computed from pixels contained in a small region surrounding the edge. An additional component of each feature vector, used for the purpose of training and validating a statistical model, is a categorical variable that indicates whether or not the edge corresponds to an SST front. A manual comparison of each edge in a given SAR image with its matching SST image (AVHRR or MODIS) determines the value of this variable (0 = not SST, 1 = SST). Various statistical classification methods have been tested and logistic regression was found to be the best, with the probability that an edge is correctly classified being almost 0.80. In an effort to obtain improved efficacy, work is being done to construct a generalized additive model (GAM) to determine class. A GAM is similar to logistic regression, but is nonparametric and so more flexible. In this presentation, statistical methods of classification will be discussed, results-to-date shown and problems to be solved in future research enumerated.

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A hybrid background error covariance model for assimilating glider data

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A hybrid background error covariance (BEC) model for three-dimensional variational assimilation of glider data into the Navy Coastal Ocean Model (NCOM) is introduced. Similar to the existing atmospheric hybrid BEC models, the model combines low-rank ensemble covariances Bm with the heuristic Gaussian-shaped covariances Bg to estimate the forecast error statistics. The distinctive features of the proposed BEC model are a) formulation in terms of inverse error covariances; b) adaptive determination of the rank m of Bm with information criterion based on the innovation error statistics; c) restriction of the heuristic covariance operator Bg to the null space of Bm; and d) definition of the BEC magnitudes through separate analyses of the innovation error statistics in the null space of Bm and in its orthogonal supplement. The BEC model is validated by assimilation experiments with simulated and real data obtained during glider survey of the Monterrey Bay in August 2003. It is shown that the proposed hybrid scheme substantially improves the forecast skill of the heuristic covariance model.

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