Dissolved radionuclide measurements used for qualitative and quantitative calibration of hydrodynamic models in the English Channel and the North Sea; validation of "TRANSMER" model.

Bailly du Bois P.[1], Dumas F.[2]

1 IPSN/DPRE - Laboratoire d'Etudes Radioécologiques de la Façade Atlantique - France
2 IFREMER/DEL – Service des Applications Opérationnelles - France

Dissolved radionuclides released by nuclear fuel reprocessing plants are very powerful tools to study the movements of water masses on a scale of European continental shelf and calibration of hydrodynamic models. Some radionuclides as antimony 125 have only one significant source terms with well known characteristics, a conservative behaviour during several years, and it is possible to measure it from the English Channel to the Norwegian Sea. Use of this tracers for qualitative and quantitative determination of water masses circulation, fluxes and dilution factors in the English Channel and North Sea have been already presented [*Bailly du Bois et al*, 1993 – 1999, *Guéguéniat et al*, 1994]. It has also contributed to the validation of long-term hydrodynamic models based on the "lagrangian barycentric method" [*Salomon et al*, 1988 – 1995, *Breton and Salomon*, 1995].

A two-dimensional hydrodynamic model called "TRANSMER" has been developed to simulate the dispersion of the seawater and transfers to the living species and sediments. This model is used for research purposes as studies of transfer functions between seawater and living species, and for evaluation of consequences of releases of radionuclides in marine ecosystem in normal or accidental conditions. It extends from the Loire estuary (Gascogne Gulf) to Denmark, including the English Channel, South of the North Sea and the Irish Sea with a mesh size of one kilometre.

TRANSMER benefits of a very large dataset for its validation, including 1400 measurements performed in this area between 1987 and 1994. These data allow qualitative and quantitative exploitation in order to compare the measured and calculated fluxes and quantities of tracers in the English Channel and the North Sea. The main radionuclide usable for this calibration is antimony 125. Tritium, technetium 99 and caesium 137 data have also been used.

The only adjustment parameter of this model is the calculation of the wind stress at sea surface. The best fitting between measurements and calculations has been obtained by multiplying wind speed by a factor 1.7. Such correction reveals that some important phenomena, associated with meteorological events, are not reproduced by this kind of model. Works are in progress in order to solve this question.

At this state of calibration, the fluxes of radionuclides and water masses in the English Channel and the North Sea are balanced for the whole period of field measurements (1987 – 1994); the correlation factor between the 1400 individual measurements in seawater and calculation results is 0.85 with an average error of 60%. The error attributable to the measurement process only is 20% in average.

Using tracers in a coupled climate model to investigate anthropogenic changes in SubAntarctic Mode Water

H. T. BANKS, R. A. WOOD, J. M. GREGORY

Hadley Centre for Climate Prediction and Research, Met Office, United Kingdom

In the coupled climate model HadCM3 SubAntarctic Mode Water (SAMW) changes its temperature, salinity and potential vorticity under anthropogenic forcing. The changes in potential vorticity may indicate either a change in ventilation rates or a change in the formation properties. The changes in temperature and salinity may be due to either changes in the surface fluxes in the formation region or changes in the circulation. We have introduced two types of idealised tracer into the coupled model to distinguish between possible scenarios; we call them ventilation tracers and passive anomaly tracers.

In the control experiment of HadCM3, SAMW forms at a rate of approximately 18 Sv. The ventilation tracer has a constant flux boundary condition and tells us that ventilation of SAMW is continuing at a similar rate under anthropogenic forcing but has moved to form at a lower density. Heat uptake by SAMW is therefore not expected to change as climate changes.

Passive anomaly tracers are used to determine where changes in surface heat and freshwater fluxes are transported to in the subsurface ocean. The surface boundary conditions are of the anomalous heat and anomalous freshwater flux for passive anomaly temperature and passive anomaly salinity respectively. Distributions of these tracers tell us that changes in surface fluxes are more important than changes in circulation for driving changes of temperature and salinity properties of SAMW. Together with other diagnostics we find that surface heating is the dominant process responsible for changes in SAMW.

Hadley Centre for Climate Prediction and Research, Met Office, London Rd, Bracknell. United Kingdom.

BLACK SEA MARINE METEOROLOGY DATABASE

V. Belokopytov

Marine Hydrophysical Institute, Sebastopol, Ukraine

Ship-based marine meteorology observations are important for operational forecasters, for creating global reanalysis fields such as NCEP or ECWMF gridded arrays and for climate change investigations. In oceanographic application these data used for deriving surface fluxes of heat, salt and wind stress for hydrodynamic modeling or for oceanographic survey analysis.

For the needs of Ukrainian Hydrometeorological Service database of ship meteorological observations in the Black Sea and Sea of Azov was created. It contains only data of research and hydrographic vessels with observers on the staff, which is more reliable than crew's observations. Total amount of data is about 15 thousands observations for the period 1930-1990. List of 20 routine variables includes air temperature and humidity, wind speed, cloudiness, wave height, etc. For the quality control computer software were produced to visualize data spatially and temporarily by user-defined criteria. Linking with other databases by particular time lag enables to use additional sources of meteorological information such as land-based stations and synoptic maps.

As a component part the marine meteorology database belongs to more general geoinformation system on hydrometeorology of the Black Sea and Sea of Azov including geographical, meteorological, hydrological and oceanographic information of the basin.

The path of QC and methods used to determine vertical climatology of conservative and non-conservative tracers in coastal zone/open sea areas in the Central Mediterranean Sea.

M. BURCA[2], S.FONTANI[3], A. GIORGETTI[1], G. M.R. MANZELLA[3]
[1]*Istituto Nazionale di Oceanografia e di Geofisica Sperimentale – OGS, Borgo Grotta Gigante 42c, 34010 Sgonico (Trieste), Italy*
[2]*National Institute for Marine Research & Development «Grigore Antipa», Constanta, Romania*
[3]*Marine Environmental Research Centre - ENEA, PO Box 224, 19100 La Spezia, Italy*

At a particular time of the year and location in the sea, we can expect the physical and biochemical parameters in the water column to have a mean and variability estimated by an average profile, summarising all the historical data available in the area. It could allow the development of a dynamic climatology. Certified and robust statistical values represent the main component approaching physical and biochemical data validation. The concept of geographical regions has been promoted, using of province-specific physical and biochemical parameterisation (climatological values of the key variables), combined with the repeatedly used vertical partitioning of the water column (the thermocline acts as a barrier to the sources of macronutrients). In general, regions could be defined by a functional of a chosen parameter, where the general parameter are single variable or a complex combination of variables. Taking into account the complicated morphology of the Mediterranean Sea, which induces high spatial variability on the nutrient concentration, coastal/shallow water could be identified and isolated from open sea water characteristics. The identification criteria would influence the definition of the geographical regions, which should be large enough to include a consistent amount of measured data and, in the same time, able to isolate the characteristics of the main different water masses.

Optimisation criteria based on estimated standard deviations have been introduced to reduce the effect of measurement errors and uncertainties in the unknown historical data.

Systematic errors in the data (especially errors in the historical data) can be of similar magnitude as characteristic property distributions involved in data averaging, and may bias the mean property values. The implementation of different analysis methods (averaged values on isobaric and isopycnal surfaces) provided the possibility to identify artefacts deriving from analytical errors or sparse sampling.

The vertical behaviour of nitrate and phosphate appear nearly as a mirror image of oxygen, even if important difference in their pattern can be detected, particularly in the upper 1000m. In this extent, combinations of water properties are used as nearly conservative tracers (given by Redfield ratio). The implementation of additional criteria based on nutrient ratio in the Quality Control procedure would increase the validation process of biochemical parameters.

Validation of off-line versus on-line simulations: water age tracer as a tool to assess internal variability effects in OGCM

J.-M. Campin [1] *AND A. Mouchet* [2]

1 *EAPS, MIT, USA*

2 *LPAP, University of Li` ege, Belgium*

Ocean Carbon Cycle Model (OCCM) contains many tracers that evolve according to oceanic dynamics through transport and mixing, and biological and geochemical processes. Since those tracers have no direct impact on the ocean dynamics, uncoupled integration (also referred to as off-line integration) with prescribed hydrodynamical fields is often used to spin-up the carbon model, to conduct sensitivity experiments, or to allow for several millenia long simulations. The hydrodynamical fields are then provided by an Ocean General Circulation Model (OGCM). In this work we investigate how well is the distribution of an idealized passive tracer reproduced in the off-line model with respect to that predicted with the on-line model. The water age tracer has been retained since it combines the advantage of a simple implementation (zero at the surface; interior source term equal to unity) with a distribution that is relevant for ventilation time scale and biogeochemical processes. The two models considered here, the ULg-OCCM and the UCL-OGCM, use the same grid and resolution ($\ldots^{o} \vee 3^{\ o}$). Under steady climatological forcing, the OGCM was integrated until equilibrium. The time averaged hydrodynamical fields (3 D flow fields, temperature, salinity, diffusion coefficient and convection frequency) were then subsequentely used in the OCCM, for the off-line integration. In order to address the sole effect of the off-line technique, the advection scheme applied to the water age is identical in both models. For the same reason, the convective adjustment scheme that consists in increasing the vertical diffusivity in unstable region is selected since diffusion is easily diagnosed and applied in the same way in both models. Therefore, any water age difference can be attributed to the OGCM short timescales internal variability which is not to be found in the off-line integration. Although the two models produce similar water age distributions, differences of both signs appear even in zonal mean diagnostic. Further analysis indicates that, when comparing the on-line results to those obtained off-line, older water age is associated to convection variability, whereas vertical advection variability is responsible for younger water age signal. Corrective terms that intend to represent those two variability-related effects are proposed and expressed in terms of vertical diffusivity. Applying those corrections in the off-line model results in an almost perfect agreement in term of water age between the two models. The magnitude of those corrections and relevance for other tracers or other model formu-lations are discussed. To illustrate this later point, additional water age and ^{14}C comparisons are presented to address the effect of different advection schemes or convective adjustment formulations. Those results strengthen the crucial role of vertical processes in global ocean models.

Hindcasting the Uptake of Anthropogenic Trace Gases with an Eddy-Permitting Model of the Atlantic Ocean

L. Czeschel, J.-O. Beismann and C.W. B\"oning

Institut fuer Meereskunde, Kiel, Germany

The ocean takes up a large fraction of the perturbation CO_2 that enters the atmosphere by human activity. A realistic representation of this uptake in numerical models is essential for future climate studies. The processes that are mainly responsible for the uptake, deep water formation in polar regions and ventilation of water masses between the wind-mixed layer and the pycnocline, are influenced by strong oceanic physical variability at spatial scales between 20 and 100 km.

In the present study, we will focus on the effect of the mesoscale variability on the cumulative uptake of CO_2 and chlorofluorcarbons using an eddy-permitting model of the Atlantic Ocean that was developed as part of the FLAME (Family of Linked Atlantic Model Experiments) hierarchy. The model resolves a significant part of that variability explicitly because of its grid spacing of about 20 km. To our knowledge, this is the first time that an eddy-permitting model was integrated over a timescale of a century to study transient tracer uptake. Results are compared with simulated trace gas distribution obtained from a model with coarser resolution. Both models are forced with heat flux and wind stress taken from the NCEP-NCAR reanalysis.

In comparison with observations, the coarse-resolution model underestimates the ventilation of intermediate and mode waters. Here, we investigate whether the higher ventilation rates simulated with the eddy-permitting model cause significant changes in the CO_2-inventory of the Atlantic Ocean, and we discuss possible implications for the interpretaion of the results of global carbon cycle models. First results indicate that the tracer signal associated with newly formed NADW is more concentrated in the deep western boundary current in the high-resolution model, whereas in the coarse-resolution run the NADW has a much more diffusive signal.

Artificial radioactive tracers as indicators of mixing processes in the Kara and White Seas.

Danilov A. I.[1], Ivanov L. M.[2] and Margolina T. M.[2]

1 Arctic and Antarctic Research Institute, Russia
2 Marine Hydrophysical Institute, Ukraine

Quantitative estimations for the vertical and horizontal mixing processes in the Kara and White Seas were obtained through analysis of concentrations of dissolved and suspended Cs-137 and Cs-134 and dissolved Sr-90 used as radioactive markers of water masses. In our study we have utilized the data collected in the Kara Sea during Russian-Norwegian cruises in 1992-1995 [*Danilov et al.,* 1996] and Russian observations provided in the White Sea from 1980 to 1990 [*Danilov et al.,* 2002].

From mathematical point of view, our analysis is reduced to solving an ill-posed inverse problem. For its solution, the following two-step procedure was applied. At first stage, the reconstruction of concentration fields in knots of a chosen regular grid have been conducted. Herein, we applied the technique that was early developed in [*Eremeev et al.,* 1995; *Ivanov et al.,* 2001]. Then, box models were applied to find the main characteristics of vertical and horizontal mixing processes in the Kara and White Seas.

The annual hydrological cycle for the White Sea was reproduced through a two-layer model including the shallow-water short strait. We estimated some quantitative characteristics of themocline ventilation, such as the replacement velocity and others, mixing in the Gorlo of the White Sea strait and outflow and inflow through this strait. Our calculations reveal the existence of complex hydrological regimes in exchange of water masses and, therefore, radionuclides between the White and Barentz Seas.

The coefficients of vertical exchange, fluxes of river run off and the Kara Gate debit were estimated for the Kara Sea. The mixing processes between shelf and abyssal of the sea were also analyzed. In order to do that isotope ration Cs-137/Cs-134 and Cs-137/Sr-90 were involved. We have found out that there are hydrological conditions, for which the plumes from the rivers of Ob and Enisey can be clearly detected in the central part of the Kara Sea. This circumstance indicates weak mixing in the upper layer of the sea for the studied time period.

Use of tracer method for calibrating and validating of numerical fluid dynamic models as an example of man-caused pollution along mouth region of North Dvina River study

Debolskaya E.I.

Water Problems Institute of Russian Academy of Sciences, Russia

Lignin (xylogen), incoming in solution of manufacturing water from Arkhangelsk pulp and paper milk, was selected as a tracer when studying the water circulation at mouth tidal region of North Dvina River by the numerical modeling method.

Lignin concentrations were measured during different tidal phases and seasons at different downstream ranges from pulp and paper milk. This data was used for verifications of the numerical model of pollution propagation at tidal mouth. The model was based on momentum equations and passive admixture transfer equation.

The particularities of river flow in north regions make suppose that such models must take into account not only really morphology of river bed but two-dimensional character of pollutant propagation and existence of tidal wave and ice cover during long time of the year. Two plan directions of pollutant propagation are taken into account along and across of the flow with assumption of full mixing of the pollutant over the depth. The empirical relations for longitudinal and cross-sectional momentum transfer coefficients are used. For hydrodynamic block of the model the momentum equation for vertical axis must be attracted.

It may be shown that consideration of the different of the resistance on bottom and ice surfaces (i.e. non equality of flow parts sizes divided by the surface of zero shear stresses) for concrete task, when time of vertical turbulent mixing is considerably lesser than time of longitudinal mixing, not strongly defines more precisely but strongly makes difficulty the calculations. The equations were solved numerically by splitting method on x and y. The boundary conditions of the second kind at left and right boundaries and at banks were assigned exempt point of output of pollutant where boundary condition of the first kind was assigned.

At first the cross-sectional averaged longitudinal velocity was calculated for conditions of the natural situation (river flow and tidal wave). Then we obtained the values of velocity depending on suite of calculated point in each cross-section and the time taking into consideration the depth changes over flow width.

The comparison of the calculation result with data of observations show that the model is in satisfactory accordance with natural process. The results of the calculations show that the model sufficiently sensitive to the changes of parameter of the discharge of sewage, the duration and original pollutant concentration in output point. The numerical modeling data confirmed the important observation conclusion about significant change of water circulation character during establishment of ice regime.

Evaluation of an Ocean General Circulation Model using the global ocean bomb tritium and water mass age distributions

Dutay J.C[1] *and Jean-Baptiste P*[1]

[1]*Laboratoire des Sciences du Climat et de l'Environnement, Saclay, France*

Realistic three-dimensional Ocean General Circulation Models (OGCM) are essential to study the role of the oceans in the climate system and the carbon cycle, and to predict future climate change.

The accuracy of the various OGCMs at simulating oceanic velocity field and mixing processes need to be tested.

Among chemical substances, purely passive tracers are most challenging for the verification of models circulation and mixing. Tritium is such a tracer. It was released by the nuclear bomb tests of the late 50's and early 60's in amount greatly exceeding its natural background. The time scale of its delivery to the ocean surface as tritiated water (HTO) is best adapted for studying oceanic processes that occur on the time scale of a few decades, such as deep water formation and thermocline ventilation. In addition, its radioactive daughter, ^{3}He, allows us to derive the age of any water parcel, i.e., the time elapsed since the water parcel has left the ocean surface.

In the present study, we modeled the fate of bomb tritium in the ocean, starting in 1950, using the OGCM developed at IPSL (Paris) for climate studies. The simulated tritium and $^{3}H/^{3}He$ age tracer fields are compared with the available oceanic measurements over the period 1972-1996, including the recent oceanic sections of the WOCE program (World Ocean Circulation Experiment).

As a general rule, the model reproduces realistic patterns of the global tritium distribution. However, our study also reveals some weaknesses of the model, which are discussed in detail in relation with specific processes.

Spreading of riverine waters in the Arctic Basin

A.Yu.Dvornikov[1], V.A.Ryabchenko[1], G.V.Alexeev[2] and I.A.Neelov[2]

[1] *St.Petersburg Branch, P.P.Shirsov Institute of Oceanology, Russia*
[2] *Arctic and Antarctic Research Institute, Russia*

A coupled 3D, coupled ocean – sea ice model is used to delineate the pathways and domains of riverine water in the Arctic Basin. The ocean component of the coupled model is based on the primitive equations in rectangular coordinates using the hydrostatic and Boussinesq approximations. The Mellor-Yamada turbulent scheme is applied to describe oceanic vertical mixing. The sea ice submodel includes the two-dimensional equations of ice motion with the viscous-plastic ice rheology as well as the equations for thickness and area concentration of ice cover. The latter is treated as two-layer system (ice and snow). Thermodynamic rates of ice/snow growth and melt are computed from the balance of surface heat fluxes, conduction through ice and snow, and oceanic heat flux. New ice growth in the open-water fraction of a grid cell (lead) is determined from the net heat fluxes from the atmosphere and the ocean. Net absorption of heat is used to melt ice laterally and vertically, or, if all ice is melted, is used to raise the temperature of the top ocean layer above freezing. Unlike other models of the Arctic Ocean, this model instead of the restoring surface salinity to observed value uses the full boundary condition for surface salinity accounting for evaporation, precipitation, melting and freezing of ice. This allows zones of riverine and seawater mixing to be correctly described, especially in the case of anthropogenic changes in river run-off.

The model is forced by 10-days mean atmospheric pressure, temperature, cloudiness, and precipitation obtained by averaging data from the ECMWF simulation for 1979-1993. Climatological monthly mean river run-offs for 7 major rivers are applied as hydrological forcing. At the open ocean boundary with the North Atlantic, mean annual volume transport is prescribed whereas mean monthly temperature and salinity are prescribed at water inflow points and computed from a radiation condition at outflow points. In the Bering Strait, mean monthly varying volume transport, temperature and salinity are prescribed. The model uses a grid with the size of 100 km and has 20 levels in the vertical direction. It was spun up with time step of 3 h so long as the cyclic quasi-stationary state of the ocean after about 300 years of integration was achieved.

The model simulates principal features of the seasonal changes in the current velocity, area and thickness of sea ice, water temperature and salinity in much of the Arctic Basin excepting the Barents Sea. Simulations of the spreading of a conservative tracer from the permanent source in the mouth of each of the major rivers (Ob, Pechora, Yenisei, Lena, Indigirka, Kolyma and Mackenzie) have been carried out. A smallest amount of riverine waters was found in the Norwegian and Greenland Seas. In the Canadian Basin, riverine waters are mainly from the Mackenzie, whereas in the rest of the Arctic Basin, from the Eurasian rivers (principally Ob, Yenisei and Lena). The water from these three rivers contributes mainly to the freshwater outflow through the Fram Strait, the riverine water pathway from the mouths of Ob, Yenisei and Lena up to the Fram Strait taking about 10 years.

An Introduction of Lagrangian Residual Currents and Transports in a highly nonlinear Coastal/Estuarine System

Shizuo Feng, Wensheng Jiang

Institute of Physical Oceanography, Ocean University of Qingdao, P.R. China

It is well known that the tide-induced residual current is one of the important components of the circulation in the shelf sea, such as in the Bohai Sea, China or the North Sea OR IN THE TIDAL ESTURARY, such as the Chasapeak Bay, Unite States. About 20 years have passed since the researchers realized that the Lagrangian residual current represents the tide-induced residual current. Because of the rapid development of the computer capacity and the numerical modelling it seems there is no need to study the residual currents. But the long term results are needed and important in understanding the different processes in the coastal sea. Even if the detailed time series of the results is obtained some kinds of averaging procedure are still required to get long term means, such as daily or monthly mean value. So how to obtain the meaningful long term mean value in the tide dominant coastal sea needs to be considered.

In the present paper the above problem is studied in a nonlinear tide dominant shallow sea by theoretical and numerical tracer method. It is proven that the displacement of the free particle after travelling several cycles of the tidal period depends on the initial release time. In the highly nonlinear case the difference of the displacement due to the initial release time will be of the same order as the displacement itself. So the distribution of any property can not be assumed as the average of the property at one point. The numerical simulation is also carried out and the same results are obtained.

Numerical modelling of the plume of the Rhône. Interpretation using the age of the fresh water tracer

P . Garreau

IFREMER centre de BREST
29280 Plouzane
pierre.garreau@ifremer.fr

A chain of nested three dimensional models has been built for the Western Mediterranean Sea. One is dedicated to the dynamics of the Gulf of Lion. The spatial resolution is about 1 km and a realistic simulation of the last six years has been performed.

According to micro-tidal environment the dynamics of this area is highly variable and can't be defined by residual or mean velocity fields. Computed instantaneous currents reflect more the wind forcing and the inertial motion than a long term circulation. A time integration of the motion by a tracer is needed. The behaviour of the plume of the Rhône river is strongly dependant of the atmospheric forcing. Therefore in a first step this fresh water input is used as natural tracer to investigate the dynamic of the gulf of Lion. Seasonal circulation and response to particular meteorological events are described by salinity signal and compared to available data. The salinity field can be explained in term instantaneous response to wind forcing, frontal dynamics, trapping by regional circulation or in a local upwelling, sinking of dense water…

Biologists, ecologists decision makers need information about time of transit, area of retention, mixing capacity. The concept of age of water masses described by Delhez et al. (1999) has been widely explored to describe more precisely the behaviour of the plume. Adding time scales in the description of water masses allows to reconstitute a part of the history of the water motion and modify our perception of the residence time of the fresh water from the Rhône on the shelf.

Delhez E.J.M., Campin J.M., A.C. Hirst and E. Deleersnijder, 1999 Toward a general theory of the age in ocean modelling. Ocean Modelling, 1 1-27

An anthropogenic radioisotope, Iodine 129, as a tracer for studying the northern limb of the Meridional Overturning Circulation (MOC)

Jean-Claude Gascard, Grant Raisbeck and Francoise Yiou.

A number of observations taken during the 1990s, seem to corroborate the fcat that the northern limb of the Meridional Overturning Circulation (the so-called MOC), is undergoing large scale variability. Arctic Sea-Ice thinning, Overflows slackening, Labrador and Greenland Seas Deep Convection weakening, have recently been reported. Can this large scale variability be intrepreted as a natural variability of the MOC or is it more related to global changes due to anthropogenic effects like greenhouse gases enhancing Global Warming at High Latitudes ?

Iodine 129 resulting from reprocessing nuclear wastes at La Hague (France) and Sellafield (UK), has penetrated through all the variouis parts of the MOC from the Source region : the Norwegian Coastal Current (NCC) coolecting Iodine 129 from the North Sea, to the Sink : the Greenland-Iceland-Scotland Overflows and ultimately to the North Atlantic deep Waters via the Deep Western Boundary Current. During recent years, discharges of Iodine 129 have increased drastically and peaks in Iodine 129 concentrations have already been observed all along the coast of Norway. In this talk, we will first present the most recent results showing the transfer of Iodine 129 through the various parts of the MOC from the NCC down to the North Atlantic Overflows (Denmark Strait), and second, explain how this results allow us to improve our understanding of the MOC system and in particular its variability. This is an important issue for improving reliability of actual numerical simulations of past, present and future behavior of the MOC, which has strong implications for climate related problems.

Modelling CFC distributions with a global ocean model employing non-uniform mixing parameterizations

A. Griesel, M.A.M. Morales Maqueda and M. Montoya

PIK Potsdam

We use Chluorofluorocarbons to asses the representation of horizontal and vertical mixing, bottom water formation and ventilation rates in two versions of the GFDL modular ocean model MOM3 ($...X1$ and 5 $X5$ degree resolution). In the past few years, the introduction of the [?] (GM) adiabatic isopycnal mixing scheme has been shown to improve water mass properties and tracer distributions notably in the Southern Ocean. Yet, the use of this scheme requires an eddy transfer coefficient $\frown$. Several studies have indicated that a spatially non-uniform flow dependent mixing coefficient $\frown$ would improve the GMparameterization. Most of these studies propose a coefficient proportional to $\frown \lhd T2$, where T is the Eady timescale for the growth of unstable baroclinic waves and $\frown$ is a length scale. Different studies favour the appli-cation of different length scales, notably the width of the baroclinic zone ([?]) or the first baroclinic Rossby radius of deformation ([?], BS). We have carried out simulations employing both uniform and non-uniform GM mixing coefficients and contrasted the results against observations. CFC ventilation rates in the North Atlantic appear to be the highest and therefore most realistic when the non-uniform BS scheme is used. The fact that observations indicate that vertical exchanges in the deep ocean are much enhanced over rough topography, prompted [?] to devise a vertical mixing parameterization that takes this effect into account. We compare CFC distributions obtained with both this scheme and the more traditional ones. Our results show that the abyssal CFC distributions are locally enhanced although downward mixing of CFCs is overall reduced. Finally we test the impact of the bottom boundary layer parameterization of [?] on CFC spreading along the ocean floor. The parameterization does not succeed in appropriately simulating the CFC content of lower NADW. Only the NADW upper CFC core can be well represented.

Red Sea deep water circulation inverse modeling using the ^{3}He tracer field

Jean-Baptiste P[1], Fourré E[1], Metzl N[2] AND Ternon J.F[3]

[1]*Laboratoire des Sciences du Climat et de l'Environnement, Saclay, France*
[2]*Laboratoire de Physique et Chimie Marines, Université Paris 6, France.*
[3]*IRD, Cayenne, Guyane Française*

^{3}He is injected in the deep ocean at plate boundaries, in relation with tectonic-magmatic activity and hydrothermal processes. This inert tracer is dispersed by the deep ocean circulation and, eventually, is released to the atmosphere by the various ocean ventilation processes. Its oceanic distribution, which is at a steady-state, shows appreciable vertical and horizontal gradients. Hence, ^{3}He conservation equations may be inverted to determine the flow field and mixing coefficients within the ocean.

Here, we use this technique to investigate the deep circulation of the Red Sea, whose deep thermohaline circulation is comparable to that of a miniature world ocean. Temperature, salinity and ^{3}He data are inverted using a linear inverse box model. The data are a combination of the GEOSECS, MESEDA and MEROU cruises.

The pattern of the Red Sea deep circulation is still open to question, with several yet unsettled hypothesis regarding the deep waters circulation scheme. The present study allows us to discuss the modes of renewal of the deep waters and the details of the internal circulation in the light of the results of the inversion.

In the literature, the rate of renewal of the Red Sea Deep Waters is also poorly constrained, with bulk residence time estimates ranging from a few decades to a few centuries. In our model, the deep water renewal rate is directly dependent on the magnitude of the ^{3}He source. This ^{3}He flux is estimated using two independent approaches. The first method is based on the calculation of the mean ^{3}He transfer flux at the air/sea interface. The second approach relies on recent estimates of the global terrestrial ^{3}He flux. Both methods agree within their respective uncertainties.

The Red Sea Deep Waters renewal rate and circulation scheme are further constrained by simulating the bomb ^{14}C distribution with the same box model in the forward mode and by comparing the simulation to the GEOSECS data. Both isotopes, one steady-state tracer (^{3}He) and one transient tracer (^{14}C), lead to a reasonably good agreement and point to a short renewal rate of the order of a few decades only.

Space and Time Distribution of Phosphate in the Mediterranean Sea

A.Karafistan[1], J.-M. Beckers[2]

[1] Onsekiz Mart Universitesi, SÜF Department of Fisheries, P.K. 56 Çanakkale, Turkey
[2] GHER Université de Liège (B5), B-4000 Liège, Belgium

Nitrate and phosphate are the most common nutrients encountered in the Mediterranean waters and it has long been recognized that the Mediterranean has undergone a general depletion of these nutrient resources. Nitrogen is introduced into the Meditteranean Sea equally by atmospheric and by river discharges (*Karafistan et al. 1998*). In contrast to nitrogen, the phosphorus is primarily discharged from land based sources and local increases of sewage and fertilizers lead to an increasing concentration of phosphorus in some coastal areas. According to the *UNEP* report (1988) the terrestrial phosphate input into the Mediterranean Sea has been increasing considerably since 1960.

In this paper, the distributions phosphate is assessed in space and time, both by statistical and theoretical modelling methods. For this purpose, we have processed all available concentrations measured during various campaigns over the last 30 years in the western basin, as well as the historical nutrient data of the *World Ocean Atlas Data*, collected from 1945 to 1987. We statistically analyzed and systematically processed all the phosphate data which we were able to gather from several sources. These included all nutrient data which were selected from the *World Ocean Atlas Data* (*WOA*, 1994) together with phosphate concentrations measured during the Mediprod campaigns in the western basin. A preliminary quality check on each datum was made in order to minimize the risk of extracting erroneous measurements from the initial data sets.

The first question we have attempted to answer was to verify if there is there any evidence of a time trend in phosphate concentrations measured in the deep Mediterranean waters. The role of anthropogenic discharge through rivers was also searched for phosphorus. In the statistical analysis we have assumed that the bottom layer is represented by a single water mass situated below 650 meters depth. This is justified by the homogeneity of this layer for most tracers. From the application of the conventional statistical tests no statisctically significant trend in time for the deep nitrates or phosphates was found. Interpretation of this result was improved by reconstructing continuous data fields from the scattered measurements by mathematical modelling tools. For the reconstruction of data in space we have used the Variational Inverse Model (VIM). All historical phosphate data were gathered into specific data sets and mean horizontal distributions of phosphate were reconstructed for the whole Mediterranean Sea. For this purpose the 're-gridded' data sets were calculated by means of a finite element method. The results for phosphate were then employed as initial conditions for the more elaborate time-dependent GHER 3D dynamical model coupled with biology (GHER). Space and time variability of the phosphate concentrations obtained by this model give interesting results especially in turbulence zones such as in the Gulf of Lions. Temporal phosphate distributions in a deep water layer are presented graphically, and the results of the modelling analysis are compared with other models for a time trend spanning several decades.

According to some authors, the increasing nutrient inputs to the Mediterranean Sea have already had an impact on the primary productivity of the coastal zone. It is not an easy task, however, to evaluate the anthropogenic input of nutrients in the Mediterranean Sea and forecast their fate when data are still lacking in some areas. Results of inverse modelling were useful for a complete global view of phosphate distributions. They also provided the initial and boundary conditions for a more elaborate 3-D model coupled with biology. Despite the importance of the river inputs, preliminary results obtained by the 3-D modelling indicate that the contribution of the Rhone River

alone in phosphate only is about 0.5 % of the phosphate upwelled in the whole Mediterranean Sea. The total terrestrial input of phosphorus represent about 10 % of this same amount. Thus, the permanent upwelling of nutrients in the highly productive areas would suggest a strict removal of phosphorus.

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Age Tracers and Transit-Time PDFs in an Ocean GCM

Samar Khatiwala 1, Martin Visbeck and Peter Schlosser

1 Department of Earth, Atmospheric and Planetary Sciences Massachusetts Institute of Technology, Cambridge, MA

2 Lamont–Doherty Earth Observatory, Department of Earth and Environmental Sciences, Columbia University, NY

Observations of transient-tracers such as tritium and helium-3 are frequently combined to construct "age-like" quantities generally interpreted to represent time elapsed since a fluid parcel was last at the surface. In a turbulent ("diffusive") environment such as the ocean, we must regard the fluid parcel as being composed of material fluid elements which have spent different lengths of time since their last contact with the surface. Hence, they are characterized by an age spectrum or distribution of transit-times. In this study we ex-plore the concepts of tracer-derived "ages" and the transit-time probability density function (PDF) with the aim of improving our understanding of their interpretation. Using an ocean general circulation model, we illustrate the effect of mixing on tracer-derived "ages" within the Atlantic Ocean. The mixing biases such ages towards younger values with respect to the ideal or mean age of a water parcel. In the North Atlantic, this bias is particularly pronounced in the thermocline due to large vertical gradients in tracer concentration, and in the deep ocean where the penetration of recently ventilated water creates large gradients along isopycnal surfaces. In contrast, the effect of mixing appears to be relatively small in the subtropical subduction region. Calculations of the transit-time PDF in the ocean model show, however, that the mean age can potentially be very large due to contributions from long transit-time pathways, inspite of the fact that such pathways make up a small fraction of the fluid parcel. These results illustrate the key idea that tracer-derived ages are weighted towards the leading part of the transit-time distribution, while the ideal age is more sensitive to its "tail". These tracers are thus sensitive to and help constrain different time scales. We also find that the ideal age converges much more rapidly to the mean age compared with the first moment of the age spectrum, an important consideration in numerical studies.

Analysis of multi-tracer ages in the Mediterranean Sea

B. Klein and W. Roether

Transient tracer data have been very useful in the past to describe the thermohaline circulation of the Eastern Mediterranean. Repeated measurements of CFCs, helium and tritium, dating back to 1987, have not only revealed principal circulation pathways in the deep water but also provided information on the ventilation in different layers of the Mediterranean. The dramatic increase in the thermohaline circulation in the Eastern Mediterranean after 1987 and the assosciated increase in ventilation of the deep water could be decribed very well on the basis of tracer data.

To obtain age information from in-situ measurements is a non-trivial problem, due to mixingin the ocean and a complicated age structure of most water masses. Helium/tritium ages are compared to CFC concentrations in order to determine some information on the age structure in the water mass. Helium/tritium ages represent basically the 'young' freshly ventilated component of the water sample and the corresponding CFC concentration is then used to determine a dilution factor. The experimentally derived ages are compared to numerical simulations of 'ideal age tracers' obtained with a general circulation model.

Because the thermohaline circulation of the Eastern Mediterranean is in a transient phase since 1987, ages also show a non-stationary behaviour. The evolution of ages are represented on selected isopycnal surfaces and the changes in the water mass composition are discussed. Two effects are noted: a) during the earlier stages of the transient a significant amount of 'old' water was uplifted in shallower levels increasing the dilution factor b) during the lateststages of the transient lack of ventilation is noted in increasing ages and also non-linear mixing effects have to be considered.

SUBMARINE MONITORS AND TRACER METHODS FOR INVESTIGATIONS OF GROUNDWATER DISCHARGE INTO THE COASTAL ZONE

Evgeny A. Kontar

P.P. Shirshov Institute of Oceanology Russian Academy of Sciences, Moscow, Russia

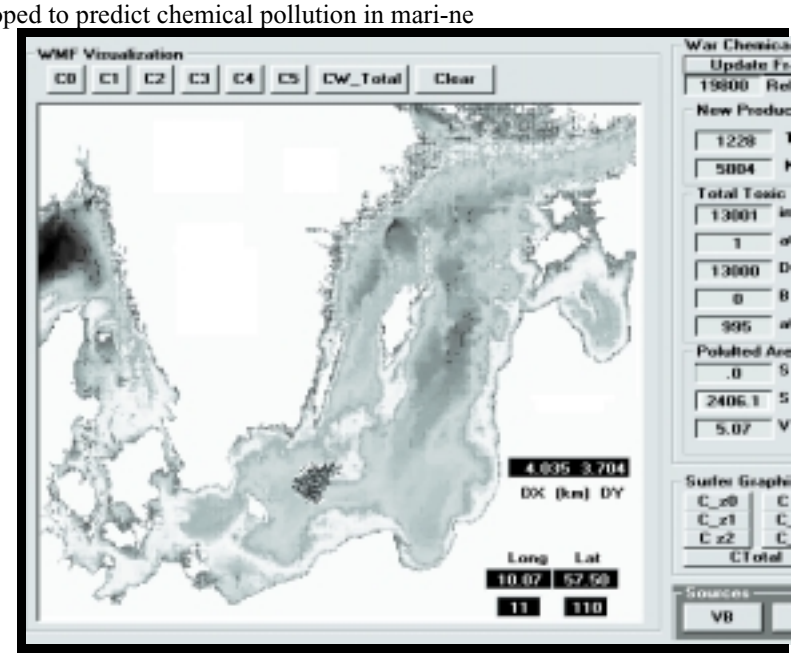
While the major rivers of the world are reasonably well gauged and analyzed, thus allowing comparatively precise estimates of riverine inputs to the ocean, it remains very difficult to evaluate the influence of direct groundwater discharge into the ocean. In spite of the recognition that many land-sea interfaces of the world are characterized by "leaky" continental margins, it is unclear how important groundwater-derived springs and seeps are in terms of overall marine geochemical budgets. Submarine springs and seeps are not only an overlooked source of fresh water but also contamination and dissolved species to the coastal zone. Volumetric estimates of their global extent range over several orders of magnitude. This is unfortunate as groundwater discharge into the ocean should occur anywhere that an aquifer with a positive head is hydraulically connected to the sea, i.e., most coastal areas. Submarine groundwater discharge has been documented to be significant for nutrient input in some regions, and could be of importance for issues relating to pathways of pollutants to the coastal zone. The problem is how to find and measure direct groundwater flow into the coastal zone. Methods of quantitative assessment of groundwater discharge into the coastal zone can be subdivided into two groups: (1) methods based on quantitative analysis of groundwater discharge formation within a coastal part of the land by hydrological and hydrogeological observations, and (2) methods based on studying different anomalies in the lake water areas caused by submarine groundwater discharge. The first group includes: (a) a hydrodynamic method of calculating groundwater discharge formed in the land and directed into the sea, by-passing the river system; (b) method of calculating groundwater discharge by equations of mean perennial water balance in the areas of groundwater recharge, and (c) complex hydrologic-hydrogeologic method. These methods are mostly applied for regional assessments of groundwater discharge into the coastal zone. The second group includes: (a) measurements of subaqueous flow (discharging into the sea bottom) rate by different flow meters; (b) methods of prospecting and detecting different anomalies in the sea water or bottom subaqueous discharge (anomalies in lacustrine water temperature and composition, in composition and properties of the bottom sediments, in chemical, isotope and gas composition of near the bottom water layer, etc.), remote sensing and isotope group can be used under detailed studies of subaqueous groundwater discharge in separate typical areas of the coastal zone.. The prior studies indicate that groundwater seepage is usually patchy, diffuse, and temporally variable. It has been shown that radon (^{222}Rn) can be a valuable tracer of direct groundwater discharge. Finding points of discharge is an important first step, especially when contaminated groundwater may be involved. A modeling approach may also be used to estimate quantitatively the volumes of contaminated groundwater being discharged. Although ^{222}Rn in water may be measured reliably by classical methods such as radon emanation techniques, this approach can only provide information about water bodies over limited time periods. Ideally, studies of groundwater discharge would include measurements of dissolved radon concentrations integrated over various periods including time scales of days to weeks. Unfortunately, fine-scale temporal analysis is invariably limited by sampling logistics and time constraints. Therefore, it is desirable to develop a detection system which could be deployed and provide monitoring either in real time, for a rapid site assessment, or moored for a more extended period to provide a continuous record.

Particle tracking technique in an operational system for the prediction warfare chemical pollution dumped in Baltic Sea

K.A. Korotenko

P.P. Shirshov Institute of Oceanology, Moscow 117851, Russia

An operational system was developed to predict chemical pollution in mari-ne environment with a special reference to warfare chemicals dumped in the Baltic Sea. The system is built to use the real-time collection of environmental data, its assimilation, and utilization in the couple transport/hydrodynamic model for monitoring and forecasting potential toxic levels and distribution of the concentration of warfare chemical agents in different regions of the Baltic Sea.



The transport module of the model takes the predetermined velocity field and uses the random walk technique to predict the motion of individual particles, the sum of which constitute a considered chemical agent.

Several different approaches for modeling are used for different kind of chemical agents. Basic processes affecting the chemicals to be modelled are hydrolysis, solubility, polycondensation, and microbiological destruction.

The chemical algorithms are assumed to describe reactions producing toxic and nontoxic products: the are the following two type of reaction:

$$\text{(A) } CWA \underset{k}{\Rightarrow} SNTP \text{ ; (B) } CWA \underset{k}{\Rightarrow} (1-\varepsilon)SNTP + \varepsilon STP ,$$

where CWA is Chemical Warfare Agent, SNTP is Stable Non-Toxic Products, STP is Stable Toxic Products, k is hydrolysis rate, and ε -is the mass fraction determined by stoichiometry of reaction.

Source of chemical pollution in the Sea are considered as steady state (chronic) *point* and/or *distributed* releases because principally different two methods were used in dumping CW: 1) concentrated dumping of containers, shells, and bombs together with ships; 2) dispersed dumping of individual containers, shells and aircraft bombs from moving vessels.

Figure shows the system interface, which allows controlling the current state and level of pollution as well as to output main parameters and fraction of a given agent.

The system was developed for the Baltic Sea but could be also used for other regions of the World Ocean where chemical munitions were dumped.

Numerical Drifter Experiments in the Black Sea

K.A. Korotenko

P.P. Shirshov Institute of Oceanology, Moscow, Russia

A 3-D interactive coupled flow/ particle tracking model has been developed to predict the dynamics of the Black Sea and hypothetic drifters trajectories. The transport module of the model takes predetermined current and uses Lagrangian tracking to predict the motion of individual particles-drifters. Currents used in the model have been generated by high resolution, low-dissipative numerical circulation model, Die-CAST (Dietrich,1997), implemented for the Black Sea. The circulation model was spin-up over 20 years to get realistic quasi-stationary climatic fields.

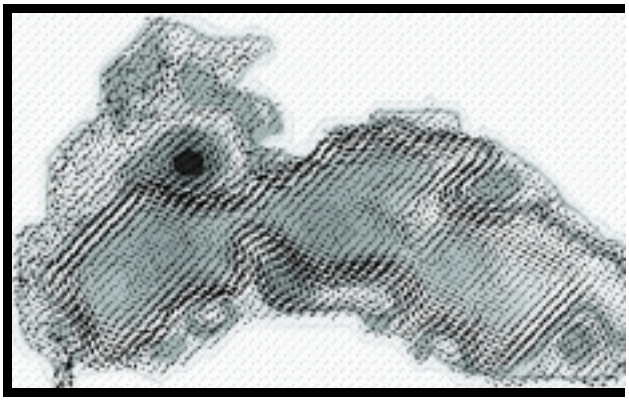


Fig.1. Predicted surface height and current velocity on day 135.

Fig.1 depicts surface height and current velocity and shows general features of circulation in the Black Sea (Rim Current, cyclonic and anticyclonic eddies, jets and filaments). DieCAST reproduces relatively small elongated antyciclonic eddies lodged between the shelf-break gyre and the coast that have diameters of order of 30-40 km or sometimes they reach 60-80 km, meanwhile their are of critical importance for the ventilation of the coastal seas is very well discussed (Ovchinnikov and Popov, 1996, Ovchinnikov, 1998). Understanding the mechanism of the ventilation and coastal water-open sea exchange is partly possible with a use of surface drifters only even if they are provided with modern satellite tracking systems and satellite imagery. Thus drifter experiments should be planned with drifters deployed throughout the Black Sea basin and at different depths since major coastal water-open sea exchange processes occur in deep layers.

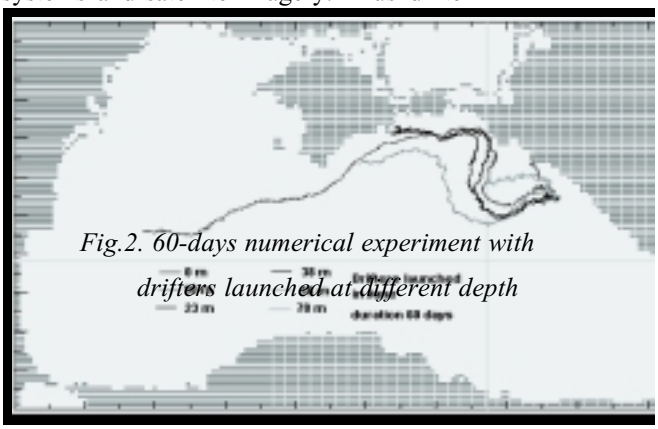


Fig.2. 60-days numerical experiment with drifters launched at different depth

Numerical simulations were performed with a special reference to study the mesoscale variability and associated cross-shelf transport in the Black Sea. Fig.2 depicts trajectory of six drifters launched in the northeastern part of the Sea at different depth in June. The trajectories of the drifters indicate strong on/off-shore transport associated with the presence of a near-shore anticyclonic eddy.

Results of the numerical experiments are compared with field drifter experiments performed in the Black Sea in 1999.

New approach for modeling evaporation in particle tracking models for simulation of oil spill transport and dispersal in the sea

K.A. Korotenko, L.A. Korotenko

P.P. Shirshov Institute of Oceanology, Moscow, Russia

A 3-D hybrid flow/transport model has been developed to predict the dispersal of oil pollution in coastal waters. The transport module of the model takes predetermined current and turbulent diffusivities and uses Lagrangian tracking to predict the motion of individual particles (droplets), the sum of which constitute a hypothetical oil spill. Currents used in the model are generated with ocean circulation models (POM and DieCAST) implemented for the Caspian and Black Seas. The basic processes affecting the fate of the oil spill are taken into account and parameterised in the transport module.

The distribution of the number of particles in fractions (hydrocarbon groups) is initially assigned and distributed randomly depending on the type of oil. An example of fraction content of crude oil is shown in Fig.1.

The total number of the particles launched in the model usually does not exceed 10^6; nevertheless, the behavior of the tracked particles proved to be representative of the entire spill, even though each droplet represents only a small part of the total volume of the oil. Within each fraction, each droplet is also randomly distributed to have its own half-life according to the empirical exponential laws (Yang and Wang, 1977).

In practice, those distributions are assigned randomly by means of a random number generator giving uniform numbers chosen uniformly between 0 and 1, and then they are transformed into an exponential distribution with a weight dependent on wind speed and oil temperature (Mackay and Matsugu, 1973). The 'long-living' oil fractions are randomly exponentially distributed within a range corresponding to the rather slow effect of total degradation. Their half-life for total degradation is chosen to be 250 hours (Proctor *et al*., 1994).

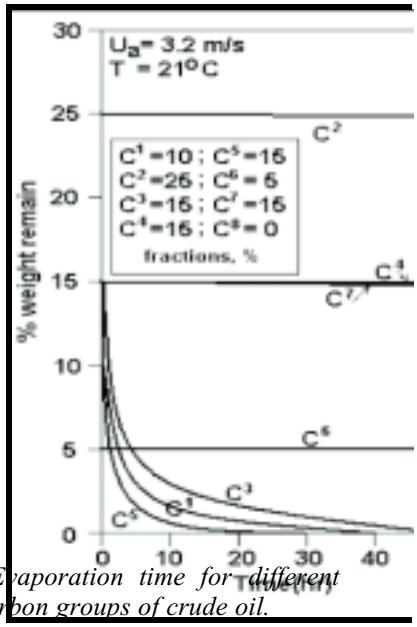


Fig.1. Evaporation time for different hydrocarbon groups of crude oil.

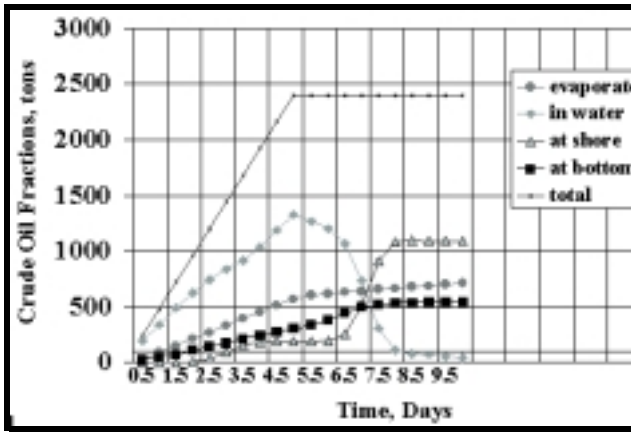


Fig.2. Time balance of crude oil fractions for and 5-days blowout

Numerical simulations were performed with a special reference to study oil spill transport in southwestern part of the Caspian Sea resulting from 5-days blowouts. Fig.2 depicts the mass balance for different fractions of oil: evaporated, left in water, beached and dumped on the bottom.

A special version of the model is developed to be used for deep water blowouts.

The spatial-temporal focusing of the trapped Kelvin waves in the ocean

Kozelkov A.S., Kurkin A.A.

Nizhny Novgorod State Technical University, Department of Applied Mathematics, Nizhny Novgorod, Russia

Recent years an interest in examination of wave motions in a border zone of an ocean (in a shelf zone, in equator zone etc.) increased sharply. The main property of border zones is their capability for wave energy concentration at the expense of formation boundary trapped waves (for example, Kelvin waves). It is known that phenomena like topographical vortexes, flow meandering, upwelling, coastal circulation and transportation of sedimentary stuff is related closely with boundary waves. Among all variety of cited above waves examination of long waves, linear scale of which is from decades to decades of thousands kilometers and periods from several minutes to several months, is of the most interest. That fact related with that namely long waves define properties of majority of hydro- and geophysical processes appearing in an ocean. These motions play significant role in large-scale circulation forming in an ocean and exert influence on climate forming. Such way, studying of trapped waves dynamics may be useful for prediction of ecological situation changing. Dispersion properties trapped Kelvin waves are investigated rather well [1]. Linear (swinging by storm waves at them diffraction on vertical barriers or dispersion on irregularities of a coastal line, excitation by dot pulse sources, generation by atmospheric disturbance) and nonlinear (excitation of Kelvin waves at the expense of nonlinear interaction with Puankare waves [2]) mechanisms of their generation are investigated also. In the given work the mechanism of Kelvin waves of anomalous large amplitude formation related to the spatial-temporal focusing is studied. It is found that Kelvin waves of anomalous large amplitude formation is possible also from the random field of waves of open ocean and the numerical simulation describes the details of this phenomenon. It is show that this waves can be generated not only for specific conditions, but also for relative wide classes of the wave trains. This mechanism explains the rare and short-lived character of the Kelvin waves of anomalous large amplitude.

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Development of an 'activable' stable element tracer technique in an estuarine environment using Neutron Activation Analysis in support of Estuarine pollution modelling

Abigail Lloyd and SJ Parry

Department of Environmental Science and Technology, Imperial College, School of Science Technology & Medicine
Neil Lynn, Department of Nuclear Science and Technology, Ministry of Defence

'Activable' tracers are stable elements that can be measured using neutron activation analysis (NAA) following field sampling. The use of stable tracers overcomes some of the limitations associated with conventional tracer techniques and increases the range and flexibility of tracing estuarine dynamics.

NAA is a multi-elemental analytical technique typically used for the determination of trace elements down to detection limits of μg/g and in some cases ng/g. The technique works on the principal that certain stable elements can be transformed through neutron capture into a radioactive isotope following irradiation for a specific time period. The radionuclude then undergoes decay emitting β particles and a characteristic *y*-ray spectrum. The lanthanides are particularly sensitive to NAA and as such ideally suited to this form of analysis.

Characterisation of the natural variation of element concentrations in suspended, deposited and dissolved phase has identified that the lanthanide concentrations are sufficiently constant along the estuary to allow increases in concentration due to artificial tracer to be quantitatively determined (using ratios). Background concentrations were found to be low for Eu (1.33μg/g), Tb (0.90μg/g) and Yb (2.91μg/g) with a relative standard deviation of 10-15%, which makes these elements particularly suitable for a tracer study. Iridium detection limits were also found to be low (<5ng/g).

The evaluation of the solid-liquid distribution coefficient is a key parameter in predicting the fate of trace metals in the estuarine environment. Tracing sediment dispersion can also provide valuable data for improved estuarine management. The poster describes the development and field application of a method to study the partitioning of trace elements between dissolved and solid phases in saline water and the development and application of tagged sediment in the estuary. In addition the uncertainties associated with sampling are identified and discussed.

Tracing the point sources of the oil pollution in the Black Sea north-western shelf area

Lyubartseva S.P.

Marine Hydrophysical Institute, Ukraine

The tracing of pollution sources in the Black Sea coastal zone based on experimental data is an essential prerequisite of any investigation to improve the ecological situation in the basin.

This report deals with a further development of the variational method for reconstructing the discharge of the pollutant sources. The pollutant is considered as a conservative admixture. Its concentration is described by means of the two-dimensional unsteady advection-diffusion equation. We assume that location of the point sources of pollution is known. The circulation is also assumed to be known due to experimental data or model simulation. To reconstruct source locations and discharges we have to solve the inverse problem. The inverse problem is considered in terms of variation values. The conditions of optimization are determinated and the approximate solution is found with the help of the gradient iterative algorithm.

This method is tested in the framework of quasi-real computing experiment. The direct problem with known sources is solved. Then the simulated concentrations of pollutant are used to reconstruct the power of sources. The efficiency of the proposed method depends on the choice of initial approximation. The influence of errors in initial conditions is studied.

The method is tested on real data. We study concentration of oil and polyaromatic hydrocarbons measured in the sea water near Odessa port in the Black Sea north-eastern shelf. Reconstructed source discharges and locations are in a good agrement with annual load of these pollutants.

Physical and Biochemical averaged vertical profiles, an important tool to trace water masses climatology in the Mediterranean regions and to validate incoming data.

B. Manca[1], M. Burca[2], A. Giorgetti[1], C. Coatanoan[3]*

[1]Istituto Nazionale di Oceanografia e di Geofisica Sperimentale – OGS, Borgo Grotta Gigante 42c, 34010 Sgonico (Trieste), Italy
[2]National Institute for Marine Research & Development "Grigore Antipa", Constanta, Romania
Ifremer/Sismer, BP 70, 29280 Plouzane, France

Seasonal averaged vertical profiles of temperature, salinity, dissolved oxygen, nutrients and some biological parameters have been computed from in-*situ* observations in different regions of the Mediterranean Sea using the recently created MEDAR/MEDATLAS II data base. The regions have been defined according to known dynamics of the physical forcing, potentially important in the formation, transformation and spreading of water masses. Some regions were not well covered as the biological data are concerned, but they serve as suggestion for future improvements in data rescue within incoming initiatives on assembling comprehensive oceanographic data bases.

The vertical distributions of hydrological properties reflect the layered structure of water column and thermohaline circulation patterns. Several important aspects of dynamics, as advection and convective mixing, are easily identified and related to the spreading of water masses and their transformation among adjacent basins. Moreover, temporal trends evaluation has been revealed essential, especially in the deep layer, where a climatic shift of transient nature of deep circulation in the Eastern Mediterranean has been documented during last decade, as well as human impact might have altered the steady state of the entire Mediterranean Sea.

Spatial and temporal variability of nutrients and principal biological parameters at climatological and seasonal scales are derived along with some guideline on trophic conditions of the different regions. The strongest signal of such a variability is along the vertical, however horizontal inhomogeneities are associated to the physical forcing that may act on temperature distribution as well as on modification of the concentrations due to transport processes. Further variation may occur as consequence of internal hydrodynamics in the investigated regions. Characterization of water masses (Atlantic Water, Levantine intermediate Water and Bottom Water in the Eastern and Western Mediterranean) in terms of T-S water properties and biochemical contents has been assessed. The chosen biochemical parameters, in conjunction with classical hydrographic measurements, may serve as appropriate tracers and can provide information on the formation, spreading and mixing processes of water masses. However, the whole ecosystem impact on pool changes and degradability along the path can not be excluded.

In a first approach, the results presented in this study may serve as a comparative analysis of climatological fields and the estimation of interannual, and possibly seasonal, variability of physical and biochemical properties throughout the Mediterranean Sea. Secondly, a step over has been done in obtaining climatologies for the quality control of the incoming

data, by setting up documented procedures to improve data assembling protocols oriented to gain the total confidence of scientific community. Finally, the climatological analyses addressed in this paper is conceived as a prerequisite to understand the whole ecosystem functioning, as well as in perspective of data assimilation into ocean modelling studies, with the aim to provide the best possible "background" picture of the vertical properties distribution, on top of which mesoscale or interannual anomalies may be detected.

Keywords: Mediterranean Sea; physical forcing; dynamics; climatological vertical profiles; physical and biochemical parameters.

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'Tracer methods in geophysical fluid dynamics'
**Corresponding Author: Beniamino B. Manca*
E-mail address: bmanca@ogs.trieste.it

North Atlantic Potential Vorticity From an Isopycnal Climatology

Paul G. Myers

Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta

Grey and Haines (1999) recently produced an isopyncal climatology of the North Atlantic where all processing was performed on local potential density surfaces, avoiding unrealistic mixing of water masses. Although the final climatology is given on a regular level grid it is possible to transform properties back onto isopycnal surfaces. Maps of the large-scale North Atlantic potential vorticity q are presented, where q is given by f dρ/dz, with f the coriolis frequency, ρ the potential density and z the vertical coordinate. The maps are used to examine formation regions and the dispersal patterns for mode waters, concentrating on the sub-polar gyre. The results suggest that sub-polar mode water formation is generally found in narrow frontal regions, often associated with topographic features. Comparisons are made with the output from a regional ocean general circulation model of the sub-polar gyre. Using subsets of the climatology compiled for different time periods, from the 1950's to the 1990's, changes in the formation regions and the dispersal of different water masses are considered.

On the relationship between tracer microstructure and coarse-grained "effective diffusivity"

N. Nakamura[1]

[1]*Department of Geophysical Sciences, University of Chicago, U.S.A.*

With all the recent progress in the statistical theories of tracer microstructure, it is not immediately clear how this knowledge can be harnessed for diagnosing/modeling large-scale tracer transport. In this paper I will discuss the relationship between the locally defined second-order structure function and coarse-grained "effective diffusivity" of a tracer. The theory is based on an arbitrary Eulerian average of advection-diffusion equation and applicable to both ocean and atmosphere. I will demonstrate the utility of the effective diffusivity diagnostic for identifying mixing barriers in the upper troposphere and stratosphere.

[1] Complete adress for the first institution using the « Adresses » style.

Towards Quantitative Evaluation of Ocean Tracer Model Sinulations

James C. Orr [1]1, Kenneth G. Caldeira [22], Karl E. Taylor [3]3, and the OCMIP Group

[1]Laboratoire des Sciences du Climat et de l'Environnment, CEA-CNRS and IPSL, France
[2]Lawrence Livermore National Laboratory, USA
[3]PCMDI, Lawrence Livermore National Labortory, USA

During the Ocean Carbon-Cycle Model Intercomparison Project (OCMIP), thirteen groups used climatologically forced, global ocean models to simulate ocean circulation tracers (CFCs, C-14, and He-3) as well as air-sea C. fluxes. OCMIP has relied on qualitative tests of model per-formance, e.g., comparison of observed and simulated sections for each of the different tracers. Although necessary, such qualitative analysis is tedious and difficult to digest in its entirety. In this presentation, we move towards quantitative model-data evaluation by exploiting a new type of diagram, recently developed for atmospheric model intercomparisons. This "Taylor" diagram summarizes contributions of the different spatial and temporal components to the overall error. It is based on the geometric relationship between four summary statistics: the correlation coefficient, simulated and observed variances, and the centered pattern RMS difference. Here we use this method to evaluate overall model skill, tracer by tracer. Where sufficient data is available, we also diagnose model skill in reproducing the observed meridional and zonal structure. Furthermore, one can also eval-uate the simulated seasonal variability. For example, we found that for the OCMIP sea-air C. fluxes, the simulated zonal annual mean distribution correlates well with that which is observed (R of about 0.9). However, simulated meridional and seasonal variability of the sea-air CO . flux is poorly correlated with the observations. Our focus here will be on presenting similar skill analyses for the OCMIP simulations of C-14 and CFC-11 that have been carried out to quantitatively evaluate modeled circulation on a regional scale.

Transport of pollutants from potential sources in the Arctic Ocean via sea ice – an observational approach

Vladimir K. Pavlov[1], Olga Pavlova[2], Reinert Korsnes[3]

[1]Norwegian Polar Institute, Tromso, Norway
[2]Norwegian Polar Institute, Tromso, Norway
[3]FFI, dep. E, Kjeller Norway

Transport in sea ice is a major mechanism for long range transport and redistribution of pollution in the Arctic. The Kara Sea and other Siberian shelves seas are most likely to receive inputs of pollutants, including radionuclides from atmospheric, riverine and marine sources.

We provided estimations of the ice drift in the Arctic Ocean include utilization of satellite imagery data (SSM/I) and sea level atmospheric pressure data.

These estimates are based on NOAA atmospheric pressure data in addition to monthly mean ice drift and concentration data from the EOS Distributed Active Archive Center (DAAC) at the National Snow and Ice Data Center, University of Colorado, Boulder, CO.

We give estimates of annual and inter-annual variations and long term mean of sea ice and volume flux across borders of the marginal Arctic seas and Arctic basin. The present estimates of ice volume fluxes include utilization of seasonal long-term climatology of sea ice thickness in the Arctic digitised by Benjamin Felzer using Bourke and Garrett maps from submarine under-ice sonar profiles 1960-1982. The National Center for Atmospheric Researc (NCAR) distributes these data.

We also give estimates for the probability that sea ice contaminated at different locations in Siberian seas will drift into bio-productive areas of the Nordic Seas within a given time. These estimates are based on simulation of ice drift trajectories according to a reconstruction of ice drift in the Arctic 1899-2000.

Can drifters be considered as passive tracers?

P.-M. Poulain

Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Trieste, Italy, EU
Also at:
Naval Postgraduate School, Monterey, California, USA

Drifters are routinely used to measure surface currents in many world oceans and marginal seas. Maps of mean circulation and velocity variability, referred to as Eulerian statistics, provide crucial and unique information on the surface water flows. In addition, when released in clusters, drifters provide estimates of absolute and relative dispersion by surface marine currents, also known as Lagrangian statistics. In this last context they are similar to tracers which have been used to track water masses and to study dispersion processes. However, drifters differ from tracers in several ways. First, they are only used in limited numbers in contrast to the large (and continuous) numbers of tracer particles. Second, they have a limited lifetime: after some time, they end up on the beach, are picked-up by sea-farers or the satellite transmissions stop. Third, they do not exactly follow the surface water particles as waves and winds can affect their motion.

Examples of drifter-inferred Eulerian and Lagrangian statistics are presented for selected Mediterranean areas, e.g., the Adriatic Sea and the Sicily Channel. The results are discussed in view of their application to estimate the transport and dispersion of surface tracers. The errors due the fact that drifters are used in limited quantities and have finite lifetimes are discussed. Recent direct measurements of the effects of winds and waves on the drifter motions in the northeastern Pacific Ocean and northern Adriatic Sea, under a variety of sea and wind conditions, are presented. The surface drifters commonly used were demonstrated to follow the surface water with an accuracy of about 1 cm/s in 10 m/s winds.

A new approach for the use of CFCs and CCl_4 as transient tracers in water masses formed by deep convection – Determination of the Labrador Sea Water age in the Northeast Atlantic.

Jacques Pruvost[1], Pascal Morin[1], Bernard Le Cann[2] and Pierre Le Corre[1]

[1]Institut Universitaire Européen de la Mer (UBO) et Observatoire Océanologique de Roscoff (CNRS), France
[2]CNRS / Laboratoire de Physique des Océans, France

CFCs and CCl_4 are used as transient tracers of ocean circulation since the eighties. The usual method of use considers the equilibrium of their seawater concentrations with their atmospheric mixing ratios during water masses formation. It enables to compare CFCs and CCl_4 concentrations, or their ratios, in the water masses with the history of the atmospheric mixing ratios, and, thus, to determine the year of the last contact with the atmosphere, *i.e.* the year of formation. However, in the case of deep convection formation, it has been shown that just after the water masses isolation from the atmosphere, the concentrations are strongly undersaturated. Therefore, this method might provide erroneous age values, even in using CFCs and CCl_4 concentration ratios since the undersaturations may be different from a compound to another. Here, we propose to employ a new approach, which consists in comparing the ratios of concentrations observed in the sampled water mass, with those directly observed in the water mass in its formation area during a time series. This approach is going to be achievable with the consistent WOCE and the future CLIVAR datasets, nevertheless it can already be used for newly formed water masses.

The Labrador Sea Water (LSW) is especially interesting to test the availability of this approach, since it spreads rapidly in the North Atlantic and that CFCs and CCl_4 deep profiles in the Labrador Sea are available yearly from 1992. Hence, we studied the LSW in the Northeast Atlantic. Data collection was carried out in June and July 1998 during the ARCANE 3 cruise, from 39.4°N to 46.4°N and from 21.5°W to the European continental shelf. LSW temperature and depth presented anomalies corresponding to vintages formed after 1988 in the Labrador Sea. The "classical" method using combined CFCs and CCl_4 ratios gives a formation year previous to 1988, whereas, with the new approach, we obtain a formation in 1994-1995. These results will be discussed and compared to those recently obtained with physical oceanography methods.

Fate of biological and chemical tracers in lake Baikal under-ice convective layer — “large-eddy” simulation for

P.Yu.Pushistov[1], *K.V.Ievlev*[1], *T.E.Ovchinnikova*[1], S.V.*Semovski*[2]

1 Institute for Water and Environmental Problems SB RAS, Novosibirsk, Russia
2 Limnological Institute SB RAS, Irkutsk, Russia

The processes of initiation and development of turbulent penetrative convection in the under-ice water layer at sufficient intensity of solar radiation penetrating through the ice layer are usually observed in deep lakes and reservoirs in spring. In depth it propagates to several tens of meters. It has been established experimentally that the essentially nonstationary and nonlinear processes of penetrative convection are hydrophysically dominant in the formation of the detailed thermal and dynamic structure of the under-ice mixing layer. They also provide the biophysical optimum which is necessary for total phytoplankton spring bloom. Lake Baikal provides a good example of these events. The winter-spring under-ice phytoplankton bloom (mostly diatom) is typical for Baikal. The following two factors are of critical importance for spring bloom of diatoms in the water adjacent to ice. These are: the cell fission rate which depends on photosynthetic active irradiance transmission, and the intensity of turbulent convection, which maintains the diatom cells in the photic zone. The Large Eddy Simulation methodology was used to describe the under-ice convective boundary layer of the freshwater deep lake. It is shown that the space-time evolution of this layer directly depends on the thermodynamic and optical properties of the atmosphere and the snow and ice layers that cover the lake. A coupled plankton – convection model was developed. We argue that turbulent convection is a process which maintains the diatom cells in the the photic zone by some results of numerical experiments. The simulated eddy structure of convective layer also produce nutrients pumping into photic layer.

The model gives a possibility to study differences in convection intensity arising by variability in optical properties of ice. Another important process under study is a physical consequences of additional volume heating due to solar energy attenuation in phytoplankton cells.

A HYDROGRAPHIC AND BIO-CHEMICAL CLIMATOLOGY OF THE MEDITERRANEAN AND THE BLACK SEAS: A USEFUL TOOL TO TRACE WATER MASSES

Michel Rixen[1*], Jean-Marie Beckers[2] and Catherine Maillard[3]

[1]Southampton Oceanography Center, European Way, SO14 3ZH, Southampton, UK
[2]GHER B5, Institut de Physique, University of Liege, 4000 Liege, Belgium
[3]SISMER, Ifremer, Centre de Brest, BP70, 29280 Plouzane, France

Corresponding author e-mail: myr@soc.soton.ac.uk.

The aim of the MEDAR/MEDATLAS II project is to archive and rescue multi-disciplinary in-situ hydrographic and bio-chemical data of the Mediterranean and the Black Seas through a wide cooperation of countries and to produce a climatological atlas of 12 core parameters, which include temperature and salinity, dissolved oxygen, hydrogen sulfure, alkalinity, phosphate, ammonium, nitrite, nitrate, silicate, chlorophyll and pH, which represent a useful information to trace water masses. The project was divided into several tasks. First, a global inventory was compiled Duplicates were eliminated by careful cross-checking. Secondly, the data sets were assembled regionally for the Western, Central and Eastern Region and the Black Sea sub-areas., trans-coded in the common ASCII human readable MODB/MEDATLAS format and quality checked by regional experts. Finally, a global integration ensured the assembling and consistency of the regional data sets. The vertical profiles were interpolated on 25 standard vertical levels, chosen according to the vertical distribution of the data. Gridded fields have been computed using the Variational Inverse Model (Rixen et al. 2001) and calibrated by Generalised Cross Validation. They have been produced for both entire Mediterranean and Black Seas and several additional sub-basins including the Alboran Sea, the Balearic Sea, the Gulf of Lions and the Ligurian Sea, the Sicily Strait, the Adriatic Sea, the Aegean Sea, the Marmara Sea and the Danube shelf area at climatic, seasonal and monthly scale when relevant. Inter-annual and decadal variability of T/S for both basins has been computed as well. It should be noted that for a given temporal scale, *all* data have been used, but the temporal correlation length has been adapted accordingly: 3 months for a seasonal analysis, 1 month for a monthly analysis, 10 years for a decadal analysis and 1 year for an annual analysis. The resulting atlas is made available free of charge at *http://modb.oce.ulg.ac.be/Medar* and on CD-Rom. The climatology is then used to trace the different water masses in the Mediterranean Sea, to identify hypothetic climatic changes of the parameters, ...

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Estimates of Oceanic Anthropogenic Carbon based on Chloroflourocarbon Inventories

Paul E. Robbins

Scripps Institution of Oceanography

A new approach is introduced to estimate anthropogenic carbon inventories in the ocean based on CFC (chloroflourocarbon) observations. Previous approaches to this problem have interpreted CFC concentrations as finite measures of ventilation age, and thus, neglected the effects of mixing on the tracer distributions in the ocean. Furthermore, these methods fail for older waters which may contain anthropogenic carbon but no CFCs due to the more recent advent of the latter in the atmosphere. An alternative approach, adopted here, is to incorporate mixing effects by treating each sample observation as a continuous distribution of ages. Likewise, water masses in the ocean can be characterized by their integral age distribution. Employing simple constraints on the functional form of water mass age distributions for steady flow, a generalized transfer function is developed to estimate anthropogenic carbon inventories from observed chloroflourocarbon inventories. Since the method depends on integral age distributions and not assumptions about the age distribution of individual parcels, it is not dependent on specific knowledge of mixing along flow paths. Additionally, the method places implicit constraints on the volume of water containing anthropogenic carbon but non CFCs.

The method is applied to recent WOCE data in the Indian Ocean. Anthropogenic carbon burdens in the upper waters agree with previous methods due to the relatively quick ventilation rate and strong correlation between CFC and anthropgenic carbon over recent decades. Deeper water characterized by ages of a few decades to centuries, show greater discrepancies in estimates of anthropogenic carbon. Systematic errors in the method are estimated by exploring alternative, extreme forms of the integral age distributions (e.g. pipe flow and reservoir mixing). Poor knowledge of the true age distribution of the upper ocean can lead to biases in estimates of oceanic anthropgenic carbon of order 10%.

Numerical Simulation of the Mechanisms affecting the Setting Up of Estuarine Turbidity Maxima

Manuel Ruiz Villarreal and Hans Burchard

Institute for Oceanography, University of Hamburg, Germany

Transport of suspended particulate matter (SPM) in estuaries is a complex process where the interplay between hydrodynamics (mainly tidal movements and stratification effects) and the intrinsic dynamics of the particles determine the relevant spatial and time scales of variability. In some tidal estuaries, as a result of this interaction, Estuarine Turbidity Maxima (ETM) appear. ETM are characterised by high SPM concentrations, usually near the tip of the salt wedge. There are evidences of the biological effects of ETM, that also have a significant influence on the distribution of contaminants in estuaries.

In this contribution, a series of numerical process studies of SPM transport will be presented. They have been designed to clarify the mechanisms that influence the setting up of ETM, particularly in the Elbe estuary. Other numerical studies (\cite{BB}) have put forward that ETM are hydrodynamically controlled(mainly by internal tidal asymmetry and gravitational circulation). The model we have applied (GETM, General Estuarine Transport Model) is a 3D baroclinic mode-splitting model with generic vertical coordinates and a stable drying flooding algorithm. Various high-resolution, monotonicity-preserving advection schemes are implemented for momentum and tracers. Moreover, several turbulence closures are introduced in the model from the extensively tested turbulence module in GOTM (General Ocean Turbulence Model \cite{GOTM}). With this kind of model, it is possible to adequate describe the physics of the system, so that the different mechanisms intervening in ETM formation can be balanced. Another objective of the work is to assess the effect of different model assumptions (vertical coordinates, advection schemes, turbulence parameterisations...) in the simulation of ETM in tidal estuaries. This will allow us to decide on the best assumptions for realistic 3D simulations of SPM transport in the Elbe estuary.

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Autoregressive analysis of the North Atlantic Oscillation

Dr. Oleg Rybak, Dr. Elena Rybak

Scientific Research Centre of the Russian Academy of Sciences, Sochi, Russia

Decadal climate variations over Europe and over eastern part of North America are governed and orchestrated mainly by the North Atlantic Oscillation (NAO). The NAO regulates wide range of climatic phenomena beginning with storm tracks and their intensities, and to distribution of wet and draught regions.

Time scale of the NAO suggests that the physical mechanism driving air pressure decadal variations includes ocean circulation. To study probabilistic features of the NAO and of its influence on climatic parameters autoregressive (AR) analysis is used. AR analysis establishes links between probabilistic and deterministic approaches to processes in natural systems. Since an AR model represents a random process as a time-dependent residual equation, one can try to find corresponding differential equation, thus giving a physical interpretation to a process. Besides, AR analysis has several essential advantages in implementation. First of all, it is very effective for analysing rather short time series.

Due to influence of many factors on the Climate System behaviour, first of all, due to inherent non-linearity of energy exchange processes within the climatic system, each of which is limited by some spatial and temporal frames, forecasting of Climate apparently seems to be an insoluble problem. Since the NAO has two different modes of behaviour one could try, at least, to determine the probability of switching off of a current mode or switching on of another. This task can be solved within the frame of optimum linear forecasting.

It was found out that the spectral density of the annual NAO index has pronounced bi-modal form. The auto-correlation function of the NAO index depends on time, thus making the process non-stationary. The best representation of the NAO is the alternation of periods of several decades duration when the NAO is best fitted by the white-noise model, with the periods when it acquires something like internal structure. At that period of time, the sign of the NAO index is predictable, in principle, at least one year ahead.

Physical mechanism of the NAO variability is not clear yet. Nevertheless, it can be concluded that the NAO influences not only on the regime of climatic parameters in Europe and the North America. Its impact can be traced also in air temperature variations over the whole Northern Hemisphere and even the world over. A trace of the NAO variations signal was identified in the ice cover variations in the Nordic Seas. It is clear that the phenomenon of the NAO cannot be explained comprehensively without consideration of oceanic circulation. Schematically, transport of the large-scale SST anomalies may be thought of as transmittance of a low-frequency signal in an inertial media from one swiftly varying component (air circulation pattern) to another (air temperature).

It must be emphasized that comprehensive study of the NAO dynamics and its influence on air surface temperature field can clarify the role of artificial impact on climate, which grows from year to year.

From the methodological point of view, the parametric approach is useful for marine climatic data analysis, especially when the large-scale sea surface temperature anomalies are considered in the context of their long term impact on the atmospheric circulation and on the air temperature fields.

Fish larvae as an indicator of transport pattern, dispersion processes, and residence times in coastal waters: Observations and numerical simulations in the eastern English Channel.

A. Senchev[1], K. Korotenkv[2], M. Karpytchev[3]

[1]UPRES-A 8013- ELICO, Université du Littoral - Côte d'Opale, Maison de la Recherche, France
[2]P.P. Shirshov Institute of Oceanology, Moscow, Russia
[3]Centre Littoral de Géophysique, Université de La Rochelle, France

Concentrations of fish larvae observed in spring 1995 are reviewed. The results show that the circulation pattern in the eastern English Channel reveals a number dynamically and biologically different zones: offshore and near-shore zones, and a zone matching the narrowest part of the English Channel - Dover Strait. A hydrological front and a residual circulation pattern showing an anticyclonic gyre in the Dover Strait are assumed to be responsible for fish larvae and phytoplankton retention within these zones.

We seek to apply a fully non-linear primitive equation model coupled with a transport model to determine a transport pattern and residence times in the coastal transition zone.

Results are confronted with real concentrations of fish larvae.

A 3-D hydrodynamic model provides velocity fields, which drive a transport model applied to tracer dispersal in the basin. The transport module of the model takes predetermined currents and turbulent diffusivities from the flow module and uses Lagrangian tracking based on the random walk technique to predict the motion of individual particles**.** The motion of the ensemble of particles stands for larva dynamics. A use of special algorithms in the transport model allows simulating active particle movements, i.e. light dependent vertical migrations.

Much attention is paid to the treatment of the open boundary conditions. First, a 2-D tidal spectral model is used to estimate the tidal effect, and calculations are performed to determine an accurate distribution of about 10 tidal constituents in the English Channel. Then, these tidal constituents are introduced into the limited area model in the form of radiation conditions at the model open boundaries. The limited area model is 3-D primitive equation numerical ocean model, POM, adapted to simulate the tide propagation and the wind induced currents in the eastern English Channel.

Intense tidal currents and strong and variable winds are of primary importance for water dynamics in the English Channel. In the region with a small depth and a fairly irregular bathymetry, tidal currents produce a long-term residual circulation pattern. Wind induced current is generally smaller in comparison with instantaneous tidal movements but the residual current of wind origin might have the same order of magnitude.

The coupled flow/transport model was used in diagnostic and prognostic mode to study the migration of fish eggs and larvae under the variable meteorological conditions. As an application, simulations of drift routes of migration of Sole larvae were performed. The simultaneous release of particles in different zones of the eastern English Channel allowed to determine physical factors that

influence their fate, the rate of transport and dispersal, and the dependence of the residence time in different zones on different forcing conditions.

Vertical structure of nutrients in deep lake — tracers of biological processes and hydrodynamics.

M.N.Shimaraev, V.N.Domysheva, S.V.Semovski

Limnological Institute SB RAS, Irkutsk, Russia

Lake Baikal with is the deepest (1642 m) freshwater lake in the World. Peculiar biological processes (under-ice diatoms bloom et al.) and hydrodynamics (including deep mixing) form specific vertical structure of nutrients (nitrates, phosphorus, silicon) and determine annual and interannual variability. Observed vertical profiles of nutrients can be used for estimation of intensity of some biological and physical processes.

Vertical profiles of nitrates, phosporus and silicon being observed during 1991-1999 have been analyzed using inverse ("filling") box model. Values of some physical parameters were estimated such as vertical mixing, intensity of deep penetration of surface water. Estimations of annual biological activity, relative assimilation of nutrients by diatoms and other groups of phytoplankton and rate of sedimentation were derived using the model.

It is well known that Baikal deep waters are good ventilated due to processes of direct penetration of surface water to bottom layer. Several mechanisms of such penetration are known including convection along thermal bar, slope convection and deep cascading of dense river waters. However, only analysis of differences in concentration of nutrients near bottom can give an information, which process of deep ventilation of Baikal waters is prevailing during specific year.

Numerical Modeling of Bioluminescence Intensity.

Igor Shulman[1] , Steven Haddock[2] , Dennis MCgillicudd[y3] , Jeff Paduan[4]

[1]*USM, USA*
[2]*MBARI, USA*
[3]*WHOI, USA*
[4]*NPS, USA*

The objective of this study is to determine if a short-term forecast (2-3 days) of the bioluminescence potential is possible with the modeling of bioluminescence intensity by tracers. Bioluminescence potential (BL) predictability experiments (predictions of intensity, depth and distance offshore of the BL maximum) were conducted by using tracers dynamics with velocities and diffusivities from the fine-resolution model of the Monterey Bay Area (ICON model, developed in "An Innovative Coastal-Ocean Observing Network (ICON)" project sponsored by the National Oceanographic Partnership Program) and from a finer-resolution submodel of the ICON model (fr-sICON, around the upwelling front at the north of the Monterey Bay). For tracer initialization, observations are assimilated into the tracer model while velocities and diffusivities are taken from the hydrodynamic model and kept unchanged during initialization. This dynamic initialization procedure provides the initial tracer distribution that is balanced with the velocity and diffusivities fields from the hydrodynamic model. After that, three days of prognostic calculations were conducted. Two cross-shore surveys of bioluminescence data conducted at two locations (north of the Bay and inside the Bay) were used in four numerical experiments designed to estimate the limits of bioluminescence predictions by tracers. These cross-shore sections extend around 25km offshore, they are around 30m deep, and on average they are approximately 35km apart from each other. Bioluminescence potential predictability experiments show that assimilation of limited available BL observations into the tracer equations allow, with good accuracy, to reconstruct and predict (over a 72- hour period, and over 25-35km distances) the depth, distance offshore and in-tensity of the BL maximum. The results of these numerical experiments will be discussed and presented.

The time evolution of the tritium distribution in the North Pacific

Stark, S[1], Doney, S.C.[2] and Jenkins, W.J.[1]

[2]*Southampton Oceanography Centre, Southampton UK*
[3]*National Center for Atmospheric Research, Boulder, USA*

Observations of transient tracers such as bomb-produced radionuclides (e.g., ^{3}H, ^{14}C, and ^{137}Cs) and CFCs may provide powerful constraints on ocean circulation and climate models.

Tritium (^{3}H) data, primarily from the GEOSECS and WOCE cruises of the 1970s and 1990s are used to calculate the time evolving ^{3}H inventory of the North Pacific basin. By the time of the WOCE cruises the majority of bomb-produced ^{3}H resides in the surface waters of the subtropical gyre with little ^{3}H having penetrated below 1000m. Over the years there have been changes both laterally and vertically in the distribution of ^{3}H in the North Pacific which reflect the mean circulation of the basin.

A simple multi-box model of the shallow circulation of the North Pacific is developed to explore the long-term redistribution and changes in ^{3}H inventories within the basin. To do this we developed a new estimate of the delivery of bomb ^{3}H to the North Pacific by precipitation for the period 1960-1997. Building on the work of [*Doney et al.,* 1992], we derived a global model function of the ^{3}H distribution in precipitation using World Meteorological Association / International Atomic Energy Agency data. This model function allows the atmospheric delivery of ^{3}H to the North Pacific to be calculated using the standard [*Weiss and Roether* (1980)] hydrological model.

The model tritium budgets compare well with the inventories calculated from the WOCE and GEOSECS data. Vapor deposition dominates over direct precipitation to tritium deposition to the basin, while inputs from continental runoff and the inflow from the south contribute over an order of magnitude less. The relative importance of the circulation increases after 1975 as atmospheric deposition decreases. Within the results there is evidence of a net movement of ^{3}H from the subtropics to the tropics, consistent with work done on bomb radiocarbon and of ^{3}H reaching intermediate depths in the subpolar North Pacific.

Sensitivity of the budget calculations to model circulation and assumptions, as well as uncertainties in observations were explored in detail. It was found that the ratio of tritium in vapor to that in precipitation is the most sensitive variable in the model budget. Despite the lack of ^{3}H in vapor data available an exploration of earlier work in the field allows the ratio to be constrained enough to allow the sensitivity of the budget to other terms to be explored.

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[2] Southampton Oceanography Centre, European Way, Southampton, SO14 3ZH, UK.

[3] National Center for Atmospheric Research, PO. Box 3000, Boulder, CO 80307, USA.

Oceanographic Data and Knowledge Bases Management System

A.M. SUVOROV, A.V.INGEROV, A. Kh. KHALIULIN[1]
Marine Hydrophysical Institute, Ukraine.

For the last years data and knowledge bases development was started equally with working out traditional directions devoted to creation of both universal multidisciplinary and specialized oceanographic data bases with appropriate management systems. In addition to well known methods and schemes of calculating various marine environment parameters diagnostic and forecasting models of its condition are included into the knowledge base. They allow to reconstruct environmental parameters in regions where there are no observations or to forecast their changes.

Simulated data are operated with in the same manner as observed ones. They are used in various researches including estimating the marine environment climatic variability. This field of work is actively elaborated in the Marine Hydrophysical Institute. A database management system being created as a result of this activity realizes the following possibilities:

- To add new metadata and data after a preliminary quality check;
- To change the bank structure (to add new parameters, data obtained with new devices and means of observation, etc.) with subsequent correction of system operation in accordance with changes have been done);
- To select and visualize data, to calculate additional oceanographic parameters (density, sound speed, Brunt-Väisälä frequency, dynamic heights, etc.)
- To calculate requested climatic characteristics with various methods (using diagnostic and forecasting models of the marine environment condition) with possibility of introduction of new methods and their subsequent application;
- To issue calculation results in textual and graphic forms, to provide a user with reference information.

During merging the data, probable errors in spatial and temporal data parameters are determined automatically, quality flags are put for each parameter. Adding of tables into general structure is provided and connection fields with the existing tables are determined if necessary.

Data are selected using visual query builder by forming dynamic SQL-operators or using SQL-editor. To provide for unified call of calculation methods and opportunity of their supplement Dynamic Link Libraries are applied. When new library modules are loaded a user in a dialog mode determines input and output parameters of the method. Additional auxiliary tables were developed in order to keep information on tables structure and links within the bank, library list, functions and procedures called, input and output parameters. The tables are renewed with changing the bank structure and supplementing dynamic libraries.

[1]Marine Hydrophysical Institute, , 2, Kapitanskaya St., Sevastopol, 99011, Ukraine

Atlases of Climatic Characteristics of Low Boundary of Oxic Waters and Upper Boundary of Anoxic Waters of the Black Sea

A.M. Suvorov, E.A. Godin, A. Kh. Khaliulin

Marine Hydrophysical Institute, Ukraine.

The main peculiarity of the Black Sea is a presence of a relatively thin upper oxygen layer (living layer) about 100-150 meters in thickness, and a powerful hydrogen sulphide one locating below it and reaching the sea bottom. The latter forms about 20% of the Black Sea volume, and there are practically no living organisms in it except for certain species of bacteria.

Over the last 15 to 20 years, multiple negative changes have taken place in the structure and functioning of the Black Sea unique ecosystem. This basin attracted oceanographers because of a unique hydrographic structure originating from a combination of restricted exchange with the Mediterranean and a large fresh water input. The resulting sharply-stratified, two-layer structure prevents deep convective mixing of the basin interior and results in the formation of a permanent anoxic pool beneath the pycnocline. Specialists in oceanology and ecology are concentrating on the problem of Black Sea hydrogen sulphide contamination, in view of the existing suppositions and some data indicative of the rise of the oxic/anoxic interface and of the possible disastrous effect of hydrogen sulphide on the human activity in the coastal zone.

To study dynamics of the anoxic zone in the Black Sea it is necessary to take into account not only hydrogen sulphide concentration changes at certain levels but a spatial and temporal variability of the oxic/anoxic interface location as well. The previous estimates of the dynamics of the upper boundary of the H_2S zone (UB of the H_2S zone) obtained to date are based on the limited data set. During the work on MEDAR/MEDATLAS II Project a set of hydrogen sulphide and oxygen observed data has considerably increased that allows to make more reliable estimates of this variability.

Using new database the digital atlas, which describe the characteristics of the oxic/anoxic interaction zone were created. This atlas consists of three sections:

- maps of the location of the UB of the H_2S zone,
- maps of the location of the lower boundary (LB) of oxic waters,
- maps of the depth of isopycnal σ=16.20.

The analysis of the oxic/anoxic interaction zone spatial - temporary variability was accomplished using the most complete data set. Relationship between the oxic/anoxic interface and the Black Sea waters density structure was established. The linear regressive equation connecting the H2S-zone UB depth, LB of oxic waters depth and 16.20 isopycn depth was proposed. It allows to specify the oxic/anoxic interface in the regions lacking measurements. The results obtained are of scientific and practical importance. The large hydrological data set can be used in order to get information on the oxic/anoxic interface. The oxic/anoxic interface location in the regions lacking measurements was specified due to the deduced regressive equations with the help of indirect characteristics. The additional section of the digital atlas containing the H2S-zone UB depth maps was prepared. Hydrophysical factors domination in the totality of the processes determining the H2S-zone UB long-term variability was confirmed.

The high level of connection between the oxic/anoxic interface variability with hydrophysical parameters was confirmed not only for specific periods and regions, but for the entire sea during the whole period of measurements as well.

Estimation of long-term variability of oceanographic parameters of the Black Sea

A.M. Suvorov, A. Kh. Khaliulin, E.A. Godin

Marine Hydrophysical Institute, Ukraine.

In framework of MEDAR/MEDATLAS II Project considered to be European MAST/INCO concerted action and a regional contribution to UNESCO/IOC Global Ocean Data Archaeology and Rescue (GODAR) Project the hydrological and hydrochemical database for the Black Sea was significantly supplemented.

On the material of the database created a long-term variability have been studied for the following parameters:

- upper boundary of the H_2S zone;
- lower boundary of oxic waters;
- depth of isopycnal σ=16.20;
- temperature and salinity for different levels under Cool Intermediate Layer.

An attempt was made to estimate a behavior of the above mentioned parameters for the years when there were no correspondent observation in the Black Sea by setting a connection between those and some environmental parameters reflecting global climatic variations and having longer set of measurements, such as:

- Rossby index of atmospheric circulation;
- A number of days with various form of atmospheric circulation in accordance with A.A. Girs;
- Observations of sea level at certain posts of the Azov-Black Sea Basin.

The accomplished investigation of the long-term variability allowed to come to the following conclusions:

- In the long-term variability of all investigated characteristics of the marine environment and atmosphere there are variations with periods equal to 3-5, 7-8, 11-12, 23-25 and by reckoning 90-100 years.
- A connection between the variability of the all parameters mentioned above and the atmosphere circulation characteristics and sea-level changes is significant.
- Phase shifts were found in the multi-annual course of the above-mentioned parameters in comparison to that of the parameters of atmospheric circulation and sea level observations.

Thus, the results of the long-term variability investigation allow to understand better the processes taking place and to increase accuracy and reliability of estimates of the Black Sea climatic parameters.

Information resources of marine institutes and centres of Ukraine: the contribution into Medar/Medatlas II project

A.M. Suvorov, A.KH. Khaliulin, E.A.Godin

Marine Hydrophysical Institute of Ukrainian National Academy of Sciences, Ukraine

At modern stage of the World Ocean study information support of investigation based on advanced computer technologies becomes of particular importance. In Ukraine a great attention is paid to work on rescuing and archiving of oceanological observation data and creation of oceanological data banks. The Ukrainian institutes and centres of the marine profile accumulated a considerable experience in this field in framework of both national and international programs.

The Marine Hydrophysical Institute of the National Academy of Science of Ukraine as Designated National Agency takes active part in IODE IOC UNESCO program to insure safeguarding of the national data collected by the different institutes and it is a focus point for national and international exchange. Participation of Ukraine in MEDAR/MEDATLAS II Project is considered to be a logical continuation of its activity in this field.

Marine Hydrophysical Institute of the Ukrainian National Academy of Sciences co-ordinates the national contribution for the EC MEDAR/MEDATLAS II concerted action (MAS3-CT98-0174 & ERBIC20-CT98-0103) to develop a quality database of oceanographic data through a wide co-operation with the other participants of the project. MHI worked over the MEDAR/MEDATLAS II Project in accordance to MEDAR/MEDATLAS II Technical Annex and in close cooperation with other Ukrainian Marine Institutions: Institute of Biology of Southern Seas (IBSS) (Sevastopol); Southern Scientific Research Institute of Marine Fisheries and Oceanography (SSRIMFO) (Kerch); Marine Branch of Ukrainian Research Hydrometeorological Institute (MB of UkrRHMI) (Sevastopol); Odessa Branch of the Institute of Biology of Southern Seas (OB of IBSS) (Odessa), Ukrainian Scientific Center of the Ecology of Sea (UkrSCES) (Odessa).

In total, data obtained from more than 34000 oceanographic stations accomplished in the Black and Mediterranean Seas were prepared by the Ukrainian institutes in framework of the Project (see Table). It is a weighty part of the entire volume of data prepared during MEDAR/MEDATLAS II Project fulfillment.

Table. Number of stations prepared by the Ukrainian institutions in framework of MEDAR/MEDATLAS II Project (after data duplicates were deleted)

Institution	*Bottle stations*	*CTD-stations*	*MBT-stations*	*otal*
IBSS	68	2963		**031**
MB OF UKRNIGMI	8218	74		**292**

MHI	450	53 42		**792**
OB OF IBSS	127 6			**276**
UGNIR O	103 02		86	**0388**
UKRNC ES	189 1	34 86		**377**
	222 05	**11 865**	**86**	**4156**

The experience accumulated during the MEDAR/MEDATLAS II Project realization shows fruitfulness of the joint efforts of different countries on rescuing and archiving of observed oceanological data and expedience of their continuation in this direction as well.

Traser observations use in sea-land ecological economic system

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I.E. Timchenko and. E.M. Igumnova

Marine Hydrophysical Institute, Sevastopol, Ukraine. E-mail: timchenko@stel.sebastopol.ua

This paper deals with the problem of rational balance between private economic objectives of natural marine bioresources use and common social goals of biodiversity conservation. The healthy and stable marine environment conditions considered as valuable social capital to be protected from devastation by special trasers using systems. The base for creation of such systems presents the new information technology, which was called Adaptive Balance of Causes (ABC) [1]. As an example of ABC technology a new model of ecological economic system of "sea-land" type[2] was suggested and the processes of marine bioresources consumption by industrial enterprises were investigated. Special attention was initiated into the problem of traser observations use for ecological economic system modeling. This means a correct description of the system, based on a priori expert knowledge about its economic part and information about marine dynamics, based on four-dimensional analysis of field contact and remote measurements. This task should be broke down on such sub-tasks - to investigate how an inner structure of ecological economics system depends on objectives of the system management, - to propose a method for the system state variable vector determination, - to work out a general method for ecological economics systems concept modeling and finally - to suggest an objective procedure of influence functions determination from traser data about marine bioresource dynamics and pollution environment state. This part of the problem is most important one, because there is no effective method for dynamic model construction, starting from qualitative or graphic description of a field traser move. It requires in general to fined out a standard form of dynamic equation for any sub-systems contained inside the system and to work out a method for cause functions evaluation. For this aim ABC modelling and intelligent agents were used [3]. The next task objective was to adjust model-originated scenarios of trasers behaviour to reality by observational data assimilation in model [4]. Procedure of simulation experiments was inferred to validate the adjustment of model predictions to the traser observations. An example of a concept model the "sea-land" natural-economic system for the Sea of Azov (South Ukraine) region was constructed aiming on the support of prescribed values of bioresource and pollution concentrations in marine environment by the trasers monitoring of the industrial impact. Various scenarios of bioresource and pollution behavior were calculated under changed external forcing (weather conditions, industrial production activities) and simulated traser observations. The economic control parameters: resource rent and ecological fine, were applied to the industrial sub-system for the whole system management. Various charts of the system's development scenarios were presented for space-time variable fields of hydrological, ecological and economic parameters. General conclusions about the efficiency of the proposed ABC ecological economic model and four-dimensional trasers data analysis were made. Some ways of its implementation for marine traser control of bioresource and pollution concentration were suggested.

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Submitted to Florida Bay

The New ABC-Technology for Environmental Quality Control in Sea-Land Ecological Economic Systems

I. E.Timchenko and Ekaterina M. Igumnova

Marine Hydrophysical Institute, Sevastopol, Ukraine.

The lasting gap between the natural resources consumption and their protection and restoring could be overcame by the new informational technologies of natural resources management. The innovation approach to System Dynamics method by J. Forrester, which was called Adaptive Balance of Causes (ABC), is one example of such technology[1]. This paper includes the experimental examination of the ABC technology, its validity and reliability. The new model of ecological economics system of "sea-land" type was suggested and the processes of marine bioresources consumption by industrial enterprises were investigated. Special attention was initiated into the problem of ecological economics systems concept modeling. This means a correct description of the system, based on a priori information about it, which contains the expert knowledge about considered management problem. This task should be broke down on such sub-tasks - to investigate how an inner structure of ecological economics system depends on objectives of the system management, - to propose a method for the system state vector determination, - to work out a general method for ecological economics systems concept modeling and finally - to suggest an objective procedure of influence functions determination from verbal description of causes driving the system. This part of the problem was most important one, because there is no effective method for dynamic model construction, starting from verbal or graphic concept model. It requires to fined out a standard form of dynamic equation for any sub-systems contained inside the system and to work out a method for cause functions evaluation. Next task objective was to adjust model-originated scenarios of system development to the reality by observational data assimilation in model. Procedure of simulation experiments was used to validate the adjustment of model predictions to the observations. An example of a concept model of "sea-land" natural-economic system for the Sea of Azov (Sough Ukraine) region was constructed aiming on the support of prescribed values of bioresource and pollution concentrations in marine environment by controlling the industrial impact. Various scenarios of bioresource and pollution behavior were calculated under changed external forcing (weather conditions, industrial production activities). The economic control parameters: resource rent and ecological penalty, were applied to the industrial sub-system for the whole system management. Various charts of the system's development scenarios were presented for space-time variable fields of ecological and economic parameters. General conclusions about the efficiency of the proposed ABC method and associated informational technology was made and some ways of its implementation were pointed out.

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The second part contains the systematic presentation of the ABC method. The essence of it is as follows. Firstly the assumption is made, that a controllable system consists of uniform modules being in the state of dynamic balance. Secondly it is suggested, that these balances are

supported by influence functions, connecting one module with others modules and forming the system's structure. Influence functions reflect the causes and effect interactions inside a system and keep up the state of general balance, which could be changed by external forcing applied to the system.

Numerous feedbacks and delayed influences act inside a system, producing nonlinear processes and complicated development scenarios. Nevertheless due to the ordinary and common type of the suggested ABC-model equations, representing interactions between modules, adapted to the reality development scenarios could be constructed in the relatively simple way.

To raise the reliability of prognostic development scenarios two manners of the observational data utilization are foreseen in the ABC-method. First of them is based on the reanalysis of stochastic linkages between predicted and real scenarios, observed at some time interval. Cross correlation coefficients permit the evaluation of influence functions. Second way makes it possible the predicted scenarios correction by the observational data assimilation in the system dynamic model. Stochastic method of data assimilation is suggested, based on the assumption, that a newcomer observation makes an additional influence on the predicted scenario. The AÂC dynamic models in a combination with the algorithms for influence functions identification and data assimilation form the ABC-technologies of system management.

The use of tracers for remote monitoring of climate variability in water mass formation regions.

MATTHIAS TOMCZAK

School of Chemistry, Physics and Earth Sciences, the Flinders University of South Australia, Adelaide SA 5001, Australia

One of the aims of the Climate Variability and Predictability (CLIVAR) component of the World Climate Research Programme (WCRP) is the development of an observational data set that allows the identification of climate variability and climate change in the oceanic environment.

Although the One-Time Hydrographic Survey of the World Ocean Circulation Experiment (WOCE) created a comprehensive, high quality data base of hydrographic parameters including a range of natural and industrial tracers, detailed studies of the data (Johnson *et al.*, 2001) and comparison with high quality historical data (Gouretski and Jancke, 2001) show that biases between individual cruises may still be large enough to mask possible climate variability.

Time series observations performed by a single institution eliminate the problem of different measurement standards and practices between institutions. They are thus potentially more suitable for the detection of weak climate signals.

Two high quality time series stations have been maintained on a monthly basis for over a decade in the subtropics of the North Atlantic (Bermuda Atlantic Time-series Study - BATS) and North Pacific Oceans (Hawaii Ocean Time-Series - HOTS). Logistical considerations make time series observations in polar and subpolar regions, where most water masses are formed, unrealistic at present.

This paper describes an attempt to identify variations of water mass properties in the formation regions from hydrographic observations at the BATS location south east of Bermuda. It uses observations of temperature, salinity, oxygen and nutrients to perform an Optimum Multiparameter (OMP) analysis (Poole and Tomczak, 1999).

The full inverse problem is nonlinear and ill-posed. As a first step OMP analysis assumes that the water mass properties in the formation regions are invariable in time and analyses time variations in the residual error fields. It is shown that residual errors are small for most of the observation period, indicating stability of water mass properties over a decade. Two periods with elevated residual error levels of several months' duration are observed, indicating the occasional influx of water with slightly modified properties. Possibilities of tracing these back to variability in air-sea interaction processes during water mass formation are discussed.

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Sart Tilman B5
B-4000 Liège
Belgium

or

Dr. POULAIN Pierre-Marie
Department of Oceanography
Naval Postgraduate School, Code OC/Pn
Monterey, CA 93943-5000
USA

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Covert advection pathways in the Gulf of Mexico

M. Toner[1], A.C. Poje[2], A.D. Kirwan, Jr[1], L. Kanth [3], L. Kuznetsov[4], C.K.R.T. Jones[4]

1 College of Marine Studies, University of Delaware, USA
2 College of Staten Island, City University of New York, USA
3 Colorado Center for Astrodynamics Research, University of Colorado, USA
4 Lefschetz Center for Dynamical Systems, Brown University, USA

We study advection pathways in the Gulf of Mexico using Lagrangian methods adapted from dynamical systems theory. The analysis is based on the Colorado University Princeton Ocean Model run in a data assimilative mode. Two types of pathways are identified. One, termed overt advection, is the movement of the core fluid within warm and cold core rings and eddies. In contrast, covert advection is associated with advection pathways between rings and eddies. One surprising result is that covert advection pathways can transport fluid across the Gulf in either direction in about four weeks, whereas time scales for east to west trans-gulf overt advection are of the order of six months. It is the covert advection pathways we focus on here.

Regions of covert advection are identified by the particle escape time. For example, escape times for the western Gulf are computed by the first crossing of the 271° meridian. To quantify how these escape times are associated with eddy boundaries, we compute specific material curves (manifolds) that emanate from hyperbolic (saddle) regions of the flow. These material curves coordinate fluid movement between and within the eddies. The similarity of the material curve pattern with the escape time contours indicate the crucial role these special material curves play in the covert advection process.

This Lagrangian analysis technique has effectively delineated eddy boundaries generated by this model in the eastern Gulf \cite{Kuz01}. Additionally, drifter data has corroborated

the model velocity \cite{Ton01}.

Tracer modeling by means of direct and inverse techniques

Tsvetova E.A., Penenko V.V.

Institute of Computational Mathematics and Mathematical Geophysics SD RAS, Russia

Some theoretical aspects and practical implementations of tracer modeling are discussed. Namely, the methodology of the combined use of direct and inverse modeling procedures is considered. It is based on the application of variational principles and splitting methods. The essential elements in it are adjoint problems and sensitivity functions. The feature of the methodology is the feasibility of a joint use of the models and measured data.

The transport models are implied as the basis level of the methodology for tracer studies. There are the two options in the statement of the problem: Lagrangean form or Eulerian one. These approaches complement each other . We use both of them in two modes – direct and inverse. In Lagrangean form, we propose a new algorithm with Monte-Carlo method to involve the turbulent diffusion in the frames of the concept of local approximations. The tracer models are combined with the hydrodynamics models of divers types.

Which kind of problems can be solved with the help of methodology? There are the following main classes: (1)direct problems of tracer transport, i.e. the so-called problems of source-receptor type; (2)inverse problems including a wide range of them connected with reconstruction of the state functions and parameters with respect to measured data.

The variational principle, that is the base of the methodology, allows the sensitivity relations between the various general characteristics of the processes under investigation and the model parameters to be calculated. In particular, the sensitivity functions bind the variations of measured characteristics with the variations of initial state, sources and parameters. Hence, they can serve for organization of the feedback to reconstruct the state function from the data observed. In this sense, the sensitivity theory methods play the most useful role in tracer and hydrodynamics studies. Sometimes, the problem arises to discover the source of tracer from the concentration measured. Itcan also be solved by means of inverse modeling with the use of sensitivity functions.

Some case studies for atmospheric and lake applications will be presented to demonstrate the features of the methodology proposed.

Tracer experiments as a means for determining energy spectra of horizontal water movement in the sea

G.C. van Dam[1] and J.M. Suijlen[2]

[1]Aqua Systems International, Voorstraat 11, 2685 EH Poeldijk, The Netherlands
[2]Rijkswaterstaat, National Institute for Coastal and Marine Management / RIKZ, The Netherlands

An energy spectrum (in wave number space) for the horizontal velocities in the North Sea was derived from a set of tracer experiments of the instantaneous release type. Most of the trials were performed with fluorescent dyes. The tracer methods and data handling are briefly described.

The energy spectrum was derived from the time behaviour of the tracer patches (size or maximum concentration) without an analysis of the internal structure. This approach for determining the energy spectrum is probably rather unique.

The time dependent dispersion rate of the tracer patches is determined by the spectral energy distribution of the horizontal eddies as well as by the vertical shear of currents (mainly tidal), combined with vertical mixing. For an analysis it is therefore necessary to simulate the complete dispersion process with a mathematical model. The model has to be three-dimensional so that it can account for the horizontal eddy structure as well as for the vertical velocity distribution and the vertical mixing. By iterative runs of the simulation model it was finally found that a single spectrum is sufficient to represent the main characteristics of the extensive set of tracer data, such as the scale dependent dispersion rate. The scale dependent width of the band of data points can be fully explained by the variability of the vertical shear dispersion.

The observed tracer clouds cover scales from a few mm up to several hundred km. To cover the same range in the simulations, discrete particle modelling was used. Acceptable computation times were obtained by applying scale dependent time step sizes.

The method can also be applied to basins much larger than the North Sea. The lowering of the detection limit for fluorescent dyes accomplished in recent years (Suijlen et al, this colloquium[1]) permits the surveying of tracer clouds up to horizontal scales of several thousand km.

Evaluation of transport of fine-grained dredged material at the Belgian coast by the combined use of radio-active tracer experiments and numerical modelling

Dries Van den Eynde

Management Unit of the North Sea Mathematical Models, Brussels, Belgium

The silting up of the Belgian sea harbours and of the fair channels towards them is enormous. Between 1980 and 1989 on average around 33 million ton dry material was dredged each year to maintain and to deepen the fair channels and the harbours. Most of this material is dumped back into sea. The selection of dumping sites with a high efficiency, *i.e.* the ratio between the mass of the material which stays at the dumping site and the mass of the material which was dumped there, is therefore essential in the issue of dumping at sea. Further it is important to assure that the dumped mud is not recirculating to the places where it was dredged initially.

To investigate the dispersion of the dredged material at the Belgian coast, an integrated approach is adopted here, where measurements of the sediment transport are combined with results obtained using mathematical models.

A series of tracer experiments with long-life radio-isotopes were executed by HAECON NV between April 1992 and April 1994. These experiments illustrated the complexity of the problem and gave some insight on the behaviour of the mud at the Belgian coast. The experiments suggested that the mud in front of the Belgian coast is trapped in a so-called "turbidity maximum", from which the mud cannot escape.

However, it is clear that, although the tracer experiments provide a very valuable source of information, the interpretation of the results of these experiments is not obvious and the conclusions drawn from the experiments can be subject to discussion.

In parallel with the measuring campaigns, numerical models were developed at MUMM. A vertically integrated sediment transport model is used to simulate the dispersion of dredged material at the Belgian coast. The model is a Lagrangian model, based on the Second Moment Method. Different sediment types can be taken into account. The bottom stress is calculated under the influence of prevailing currents and waves.

Although lots of uncertainties still remain in modelling sediment transport, the sediment transport model gives satisfying results in simulating the tracer experiments. Therefore, the model results are shown to be very useful for the help in the interpretation of the results of tracer experiments.

It is shown that by a careful interpretation of the results of the experimental and model results, a better insight can be gained on the transport of the dredged material at the Belgian coast.

Inferring the Age Spectrum from Transit Tracers

Darryn W. Waug [1], Timothy M. Hall[2], Thomas W.N. Haine[1], Hong Zhang[1]

[1]Department of Earth and Planetary Science, Johns Hopkins University, USA
[2]NASA Goddard Institute for Space Studies, New York, USA.

Measurements of chemical tracers whose spatial gradients are primarily due to the time dependence of sources and/or sinks (``transient tracers'') can be used to estimate transport time scales (``tracer ages'') in geophysical systems. However, because there is in general a distribution of transit times (the ``age spectrum''), tracers with different time dependencies yield different ages. We examine the sensitivity of the different tracer ages to the characteristics of the age spectrum, and whether it may be possible to infer aspects of the age spectrum (and infiltration of pollutants) from measurements of multiple transit tracers. We consider transport in both the stratosphere and oceans.

In the stratospheric context, we consider the combination of a tracer with approximately linear growth rate (e.g., SF$_6$ or CO$_2$) together with the CFC-replacement gas HFC-134a, which has undergone significant nonlinear growth over the last decade. It is shown that measurements of this pair of tracers can constrain the first two moments of the spectra (``mean age'' and ``width'').

In the ocean context, we consider a range of measured transient tracers, including conserved tracers with changing surface concentration (e.g., CFCs and CCl$_4$) and tracers with radioactive decay (e.g., tritium and argon-39). It is shown that there can be significant differences among the tracer and that a given tracer age can evolve in time even for stationary transport. These diffrerences depend on the characteristics of the age spectra. Under certain circumstances, it is possible to constrain the first two moments of the spectra from different combinations of these tracer ages.

Formation of anoxic conditions in the Sea of Azov as a result of hydrophysical structure changes in July 2001 (observations and modeling)

Yakushev E.V.

Southern Branch of the P.P. Shirshov Institute of Oceanology RAS, Russia

The Sea of Azov is a shallow (averaged depth of 6 m) 618 sq. km basin with very high biological productivity. During the July-August 2001 RV "Akvanavt" cruise there was studied the bottom anoxic zone that was formed there. The anoxic zone was found practically in all deep regions of the Sea and had thickness from 0.5 to 4 m above the bottom. The concentrations of hydrochemical parameters were similar to the pronounced anoxic conditions (about 90 uM of hydrogen sulfide, 17 uM of ammonia, 6 uM of phosphates, 7 uM of manganese). These concentrations can be found in the depths of the Black Sea about 100 m deeper the hydrogen sulfide boundary. The observed chemical compounds vertical gradients in the Azov redox zone exceeded . 35.9 uM/m for hydrogen sulfide, 14.5 uM/m for ammonia, 3.8 uM/m for manganese and 2.0 uM/m for phosphates.

The hydrophysical structure of the Sea was characterized by the uniform distribution of temperature in the upper 6-7 m layer. Bellow it the think (0.4-0.8 m) layer of thermocline was observed. The vertical gradient of density (sigma-tau) here was about 0.9 - 2.1 kg m^{-4} and the estimated vertical turbulent diffusion coefficient – 1 10^{-5} m s^{-2}. The vertical distribution of salinity characterized by increasing or decreasing of concentrations with depth in different regions of the Sea. The boundary between the oxic and anoxic waters was characterized by the lower values of transmission as it is known for all the anoxic basins.

The reason of this phenomenon formation was connected with this summer weather conditions peculiarities. In June a very intensive influx of river waters occurred because of the intensive rains. That leaded to large input of allochton organic matter and inorganic nutrients, consumed for the additional autochthon organic matter production. In July the weather was characterized by the absence of winds and the thermocline was formed. As the result the oxic decay of organic matter in the bottom layer became impossible, and the denitrifiction and sulfatereduction processes were leaded to the anoxic conditions formation.

This scenario was studied with a 2D hydrodynamical model based on the momentum equation, turbulent kinetic energy equation in the Prandtle-Kolmogorov assumption [Debolskaya, Zyryanov, 1994] together with the O-N-S-Mn anoxic condition formation hydrochemical sources model [Yakushev, 200]. As the result it was shown that in the Sea of Azov a stable hydrochemical structure with the bottom anoxia can be formed in conditions of absence of wind and decreasing of vertical turbulent diffusion coefficient down to 10^{-5} m s^{-2}.

During the November 2001 RV "Akvanavt" cruise there was found uniform hydrophysical and hydrochemical parameters vertical distribution connected with intensive vertical mixing.

Black Sea Horizontal Mixing Studies Based on Satellite Imagery, Argos-tracked Drifters and CTD Survey

A. Zatsepin[1], V. Zhurbas[1], M. Evdoshenko[1], A. Ginzburg[1], A. Kostiano [1], B. V. Kremenetskiy [1], S. Poyarkov [1], N. Sheremet [1], O. Stroganov [1], V. Krivosheya [2], A. Skirta [2], V. Yakubenko [2], V. Eremeev [3], S. Motyzhov [3], Yu. Ratner [3], D. Soloviev [3], S. Stanichny [3], P.- M. Poulain [4]

[1]*P.P.Shirshov Institute of Oceanology, Moscow, Russia*
[2]*South Dept. of P.P.Shirshov Institute of Oceanology, Gelendzhik, Russia*
[3]*Marine Hydrophysical Institute, Sevastopol, Ukraine*
[4]*Department of Oceanography, Naval Postgraduate School, Monterey, USA*

Among the seas of the Mediterranean basin the Black Sea (after the Azov Sea) has the poorest ecological conditions, which are the result of its limited water exchange with the open basins, weak vertical mixing due to the strong density stratification and enhanced contamination by river discharges, city and tourist resort wastes, oil and other discharges from shipping and oil terminals. Because most of the contamination comes from the shore and near-shore regions of the sea, the processes of horizontal mixing and shelf/open sea water exchange are of the great importance. However, these processes are poorly studied.

One of the basic aims of the report is to provide more observational evidence on the existence of intensive lateral water exchange between the near-shore and central parts of the Black Sea and to investigate the role of mesoscale eddies. Most of observations described below were carried out during the Black Sea multidisciplinary scientific studies conducted by oceanographers from P. P. Shirshov Institute of Oceanology, Russian Academy of Sciences, in collaboration with other Russian Institutes and Universities and with Ukrainian and USA scientists in 1999 - 2001. The main strategy of the abovementioned Black Sea expeditions was based on the joint application of satellite imagery, Argos-tracked drifters and hydrographic, chemical and biological surveys. This strategy has never been used before in the Black Sea studies.

Statistical analysis of Black Sea near-surface currents was carried out using the Argos – tracked drifter data. Power spectra of Lagrangian velocity components show well pronounced peaks near the inertial time scale (about 18 hours) and synoptic time scale (5 – 15 days). Using Taylor's approach, drifter estimates of lateral eddy diffusivity were obtained. Estimates of the Lagrangian length scale L in the Black Sea was shown to fit well a dependence $L=Ro$, which implies a parameterization of the lateral diffusivity of the form $K=\sigma Ro$, where σ is the r.m.s. Lagrangian velocity fluctuations and Ro is the internal Rossby radius.

The research of phenomenon of formation of anomalous high boundary waves in rotating ocean

Kurkin A.A., Zaytsev A.I.

Nizhny Novgorod State Technical University, Department of Applied Mathematics
603600, Nizhny Novgorod, 24 Minin St, Russia
kurkin@kis.ru

The phenomenon of formation of anomalous high waves on a surface of a liquid, when one or two crests unexpectedly arise frequently during a calm and also unexpectedly disappear, is characteristic for many areas of the world ocean. Such waves, named as “freak waves”, have served as the reason of many catastrophic situations (13 cases) with ships near the south-eastern shore of the South Africa [1], for example accident with the ship “Taganrogsky Zaliv” in 1985 year. Mathematically, anomalous waves are waves, which height exceeds twice significant height of wind waves (average meaning of one third of high waves). The probable reason of formation of such waves (see, for example [1]) is the strong current in this region, reducing to amplification of surface waves. However, anomalous waves were observed on shelf’s of the European seas and in the Mexican Gulf, where the currents are not significant [2]. It is our agreed that basic mechanism of formation of freak waves is the known phenomenon of compression (focusing) of wave packages in dispersive mediums. Qualitatively this mechanism is rather clear, and it was shown in laboratory experiment [3]. In the given work the quantitative theory of formation of the boundary trapped waves of anomalous high amplitude in a shelf zone of ocean based on the mechanism of dispersive compression of wave packages connected with dispersion of waves on water is offered. The method of a finding of wave packages, which evolution results in formation of “freak waves” is offered. As boundary trapped waves are considered single-mode as well as multimode Stokes waves. The effect of formation of anomalous high waves is demonstrated for 2D and 3D waves in the presence of random wave field at various structures of shelves.

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