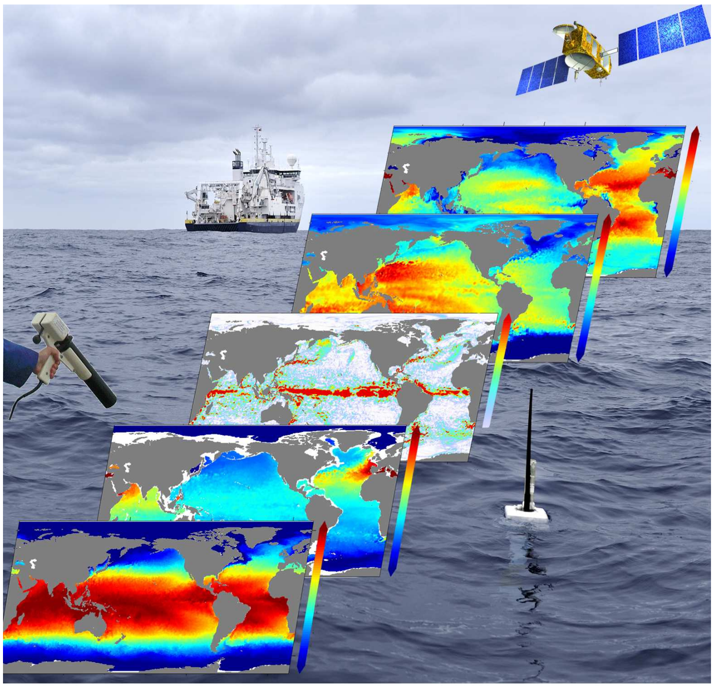
Quarterly Newsletter – Special Issue with Coriolis

This special issue introduces a new editorial line with a common newsletter between the Mercator Ocean Forecasting Center in Toulouse and the Coriolis Infrastructure in Brest. Some papers are dedicated to observations only, when others display collaborations between the 2 aspects: Observations and Modelling/Data assimilation. The idea is to wider and complete the subjects treated in our newsletter, as well as to trigger interactions between observations and modelling communities

Laurence Crosnier, Editor

Sylvie Pouliquen, Editor



Editorial – April 2010

Greetings all,

Over the past 10 years, *Mercator Ocean* and *Coriolis* have been working together both at French, European and international level for the development of global ocean monitoring and forecasting capabilities. For the first time, this Newsletter is jointly coordinated by *Mercator Ocean* and *Coriolis* teams. The first goal is to foster interactions between the french *Mercator Ocean* Modelling/Data Asssimilation and *Coriolis* Observations communities, and to a larger extent, enhance communication at european and international levels. The second objective is to broaden the themes of the scientific papers to Operational Oceanography in general, hence reaching a wider audience within both Modelling/Data Asssimilation and Observations groups.

Once a year in April, *Mercator Ocean* and *Coriolis* will publish a common newsletter merging the *Mercator Ocean* Newsletter on the one side and the *Coriolis* one on the other side. *Mercator Ocean* will still publish 3 other issues per year of its Newsletter in July, October and January each year, more focused on Ocean Modeling and Data Assimilation aspects. The present issue will be posted simultaneously on *Mercator Ocean* and *Coriolis* websites.

We will meet again next year in April 2011 for a new jointly coordinated Newsletter between *Mercator Ocean* and *Coriolis*. Regarding next July 2010 Newsletter coordinated by *Mercator Ocean* only, it will display studies about coastal ocean systems.

We wish you a pleasant reading,

The Editorial Board

Contents

This issue includes a new section called "**Working together**" displaying ongoing initiatives aiming at enhancing interactions between the Modelling/Data Asssimilation and Observations communities. The following paper by Bahurel and Pouliquen is telling us about new services provided by MyOcean, Mercator and Coriolis within the **GMES framework**. Then, Le Traon et al. provide an update on the **Euro-Argo** European Research infrastructure. Next article by Petit de La Villéon et al. provides an overview on how the Coriolis data center is interfaced with **JCOMM networks**.

Scientific articles coming next are organized according to three main topics: **new products** elaborated from in situ and modeling products, improvements in **instrumentation** for operational oceanography, scientific **projects** using Coriolis data:

1. Cabanes et al. provide comprehensive information on the CORA product, designed for ocean reanalysis objectives and its use for the GLORYS reanalysis. Von Schuckmann et al. present the climatic indices derived from CORA and Mercator reanalyses. Finally Ollitrault and Rannou present ANDRO the new deep velocity atlas developed from Argo data.

2. As far as instrumentation is concerned, Le Reste et al. provide an update on PROVOR and ARVOR float technology. Then, Leblond et al. present RECOPESCA a new instrumentation for regional observation that equips fishermen vessels and fit both the needs of operational oceanography and fishery monitoring.

3. Finally, Roquet et al. present how Argo is used to study Fawn Trough, a major pathway for the Antarctic Circumpolar Current.

WORKING TOGETHER

This is a new section which displays ongoing initiatives in the Operational Oceanography community aiming at enhancing interactions between the Modelling/Data Asssimilation and Observations communities.

The Mercator quarterly quality report

By Marie Drévillon
Mercator-Ocean,Toulouse, France

In order to foster larger interactions between the Mercator Modelling/Data Asssimilation and Coriolis Observations communities, Mercator will soon publish on July 2010 the first issue of the ***Mercator quarterly quality report***. Most Numerical Weather Prediction (NWP) centers already publish quality reports on a regular basis which record the strengths and weaknesses of the forecasting systems, as well as the technical changes in the systems, or the spatial and temporal coverage of the input data. Following the spirit of those NWP quality reports and based on the existing ocean metrics and on various data comparisons, the ***Mercator quarterly quality report*** has two main goals:

- First, foster regular interactions between the Mercator Modelling/Data Asssimilation and Coriolis Observations communities. Indeed, the ***Mercator quarterly quality report*** will measure and keep track of the performances of the Mercator systems in order to identify possible improvements. This includes measuring the impact in the Mercator systems of the changes in the real time observation network and giving useful feedback information to the Coriolis center for the improvement of this network.
- Second, foster regular interactions between the Mercator Modelling/Data Asssimilation group and the users of Mercator products as the scientific communities for example, so that they can derive the level of confidence (or the correction they have to make) for the use of the Mercator products for their own application.

The first issue of the ***Mercator quarterly quality report*** will be published in July 2010 and will be first available by a restricted amount of users. It should become available to a larger public later on, when it will have reached its final format. The first issue will include maps of the spatial coverage of the input data. The main technical informations from the data centers shall also be included. In addition, data rejected by the data assimilation system will be listed, which will point out undetected biases in the observations. Consequently this report will provide useful material to interact with the data centers.

Coriolis initiative

By Sylvie Pouliquen

Coriolis, Ifremer, Centre de Brest, France

Since its creation in 2001, Coriolis has worked in close partnership with Mercator to be able to evolve in coherence with new needs in term of in-situ data while Mercator was moving from North Atlantic to Global Ocean, and then from global to regional scales and now developing ecosystem models.

As in-situ data are sparse and managed without enough coordination both at international and European level, it is important to define new needs early enough for Coriolis to set up the appropriate partnerships in order to collect and qualify the relevant observations. Together we are developing the capacities for reanalysis and the collaboration between Mercator and Coriolis on CORA product was useful to enhance the quality of in situ data for the past 30 years. Coriolis has set up partnership in Europe within EuroGOOS and now MyOcean to provide similar services in regional seas and in particular on seas surrounding France. Similar developments started for biogeochemical data both at global scale within EuroArgo and EGO but also at European scales within MyOcean.

In 2010, Coriolis started a partnership with the EEA to define the in situ observing system necessary for GMES Marine Core Service in collaboration with Mercator on the Global Ocean and the IBI-ROOS area and EuroGOOS partners. Feedback from Mercator and forecasting systems in general is important to define priorities both for assimilation and validation activies and seek for additional funding mechanism at national and European levels.

WHAT NEW SERVICES WILL BE PROVIDED BY MYOCEAN?

By Sylvie Pouliquen[1], Pierre Bahurel[2]

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MyOcean is the implementation project of the GMES Marine Core Service, aiming at deploying the first concerted and integrated pan-European capacity for Ocean Monitoring and Forecasting. This 3-year FP7 project has started in April 2009.

MyOcean has started one year ago, and as expected has kicked off the European Marine Core Service. Myocean has allowed us, providers of marine services in Europe, to re-consider our organization, our service portfolio and our user data base. On the first day of the project (April 1st 2009), we have opened the version 0 of the MyOcean service hence giving access to a first range of ocean monitoring and forecasting products issued from our own systems.

The five “thematic assembly centres” (ie observation-based products) and the seven “monitoring and forecasting centres” (ie model-based products) contributed to the products catalogue (see figure 1): around 20 different entities throughout Europe are sharing products and disseminating them under one brand only: MyOcean, the European Marine Core Service. Six months later (October 2009), an updated catalogue was available on an “open & free” basis which is the foundation of the MyOcean data policy.

This **MyOcean Catalogue v0** (figure 1) can be seen by all on www.myocean.eu. It is an open door to remote-sensed data on sea level, ocean color, sea surface temperature, ice & wind, in situ data (see figure below), and assimilative model outputs on the global ocean, the arctic, the baltic sea, atlantic north-west-shelves area, the atlantic irish-biscay-iberic (IBI) area, the mediterranean sea and the black sea.

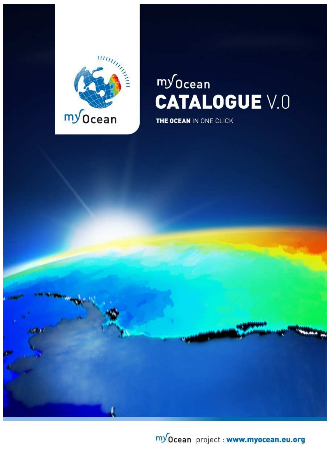

Figure1

Front page of the MyOcean V0 catalogue available at www.myocean.eu.

This version 0 provides a direct link to the production centres (e.g. Coriolis for in situ or Mercator Ocean for global ocean model outputs). The version 1 (end of 2010) and version 2 (end of project) will enrich the core service provided on this basis, with a seamless access to the products directly to Brest, Toulouse, Nice, Bologna, Copenhagen, Exeter, Bergen, Madrid, Sebastopol, … without any technical boundary for the user.

The French producers involved into this new European Core Service are Mercator Ocean, Ifremer, CNRS, Météo-France, CLS and Acri. They have accepted for this 3-year period to deliver on an open & free basis to anyone in the world a part of their production through this European catalogue. CLS contributes to this core service with sea level altimeter data, Acri with ocean color data, Météo-France with sea surface temperature data, Ifremer with in situ data, and remote-sensed ocean color and sea surface data, CNRS with model reanalyses, and Mercator Ocean with model reanalyses and real-time analyses and forecasts on the global ocean and on the IBI area. This is an important move for operational oceanography and its business model: it means that there is today a clear distinction between the “core service” – “public-good” information on the ocean available to anyone – and the downstream services – where adding-value services are built for a specific market area and its user category.

The existence of the MyOcean Marine Core Service is expected to foster the development of services in **four market areas (figure 2)**. They are: (1) marine safety (2) marine resources (3) marine and coastal environment, and (4) climate and weather forecasting. Each one needs a reliable and accurate Marine Core Service on the ocean as inputs to their activities.

The **marine safety** area gathers service providers involved in marine operations, pollution and oil spill combat, ship routing, defence, search & rescue… and all marine activities requesting offshore operations. The **marine resources** area gathers service providers involved in evaluation, monitoring and advice for the sustainability of living marine resources such as fish stock management and aquaculture. The **marine and coastal environment** area gathers service providers involved in coastal zone monitoring and environment assessment activities. The **climate, seasonal and weather forecasting** area gathers mainly services involved in weather medium-range forecasting or further, but also services monitoring polar ice extent evolution and other global environment issues impacted by climate change.

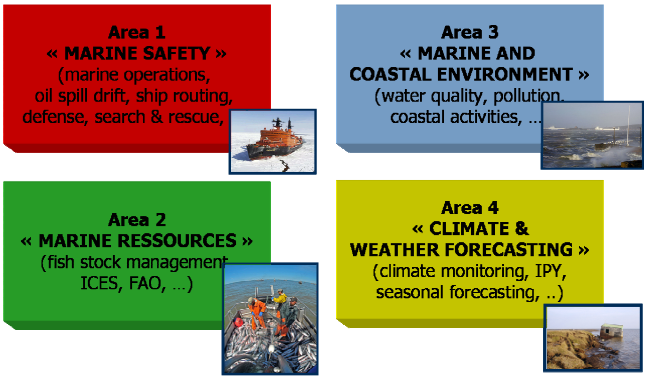

Figure 2

The four MyOcean market areas: Marine Safety, Marine Resources, Marine and Coastal Environment, Climate Seasonal and Weather forecasting.

From MyOcean, we expect developments of new service offers to the corresponding users in the above areas. There are two good reasons to believe that it will happen:

- first, the Marine Core Service gathers the best "core" information available in Europe under one single access point: service providers (e.g. teams running oil spill drift models) will have access to the best currents elaborated in ocean centres in Europe; they will receive a new and better information to initiate or force their systems.
- secondly, with a core (upstream) information elaborated and secured on the European side, service providers will have a better chance to allocate their resources on the downstream area where the real added-value for users is built (e.g. improve oil spill models); they will develop further their skill area for the benefit of their users.

This is what the Marine Core Service is about: implementing the best conditions to service providers to help them developing new services for their users. Our current priority is clear: gathering the best data set and facilitate access to it.

Within this project, the in situ Thematic Assembly Centre (INS TAC) of MyOcean is a distributed service integrating data from different sources for operational oceanography needs. The MyOcean in-situ TAC is collecting and carrying out quality control in a homogeneous manner on data from outside MyOcean data providers (national an international networks), to fit the needs of internal and external users. It provides access to integrated datasets of core parameters for initialization, forcing, assimilation and validation of ocean numerical models which are used for forecasting, analyses (nowcast) and re-analysis (hindcast) of ocean conditions. Since the primary objective of MyOcean is to forecast ocean state, the initial focus is on observations from automatic observatories at sea (e.g. floats, buoys, gliders, ferrybox, drifters, SOOP) which are transmitted in real-time to the shore at *global* (V0 now) and *regional* (V1 end 2010) scales both for *physical (temperature, salinity, current and sea-level) and biogeochemical (chlorophyl, oxygen and nutrients) parameters*. The second objective is to set up a system for re-analysis purposes that requires *products integrated over the past 25 years for temperature and salinity parameters*.

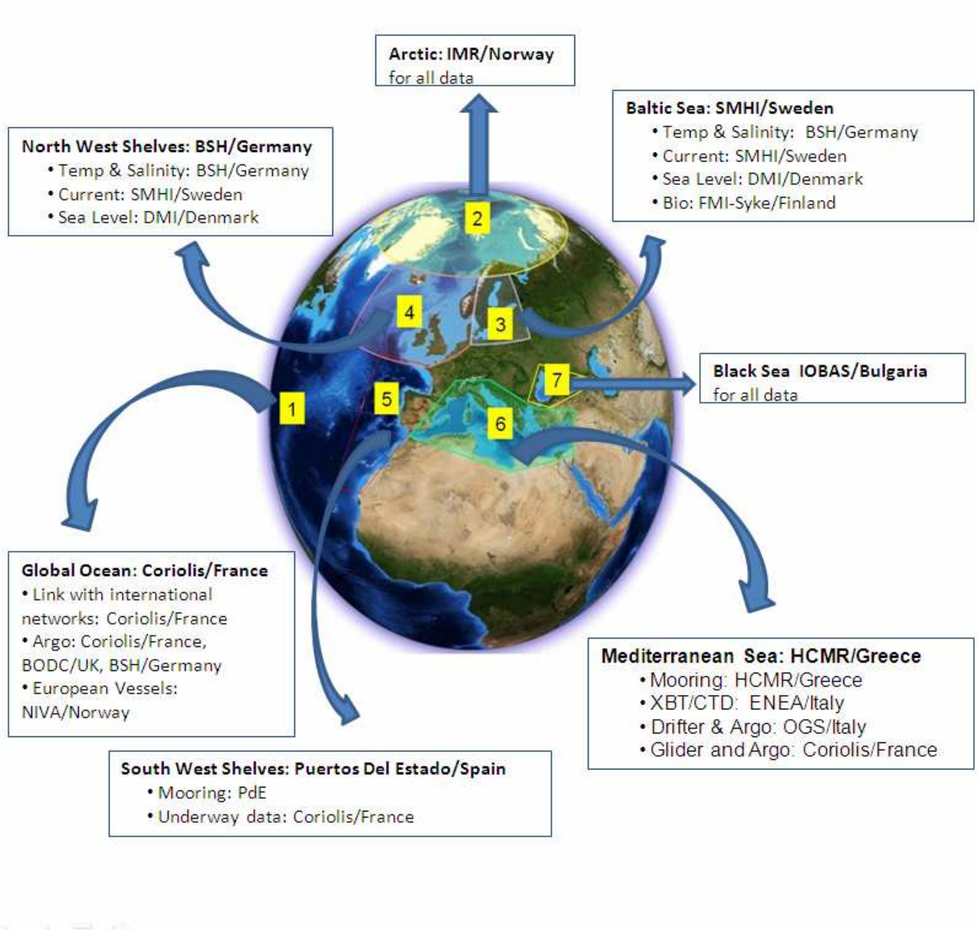

Figure 3

Coriolis coordinates the MyOcean In situ Thematic Assembly Centre and integrates the data collected at regional level in the global products to serve both European and global scale applications.

Coriolis coordinates the In situ TAC, integrates the data collected at regional level (figure 3) in the global products to serve both European and global scale applications. At regional level Coriolis coordinates with Puertos Del Estado (Spain) the South West Shelves region (figure 4) and contributes to the Mediterranean Sea region.

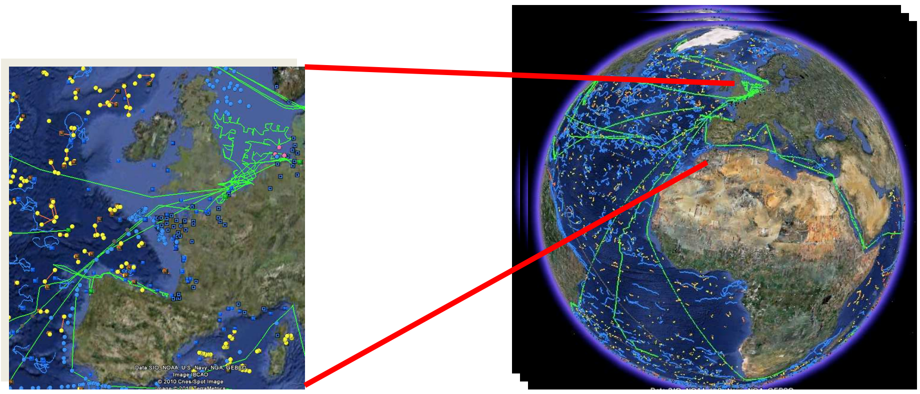

Figure 4

Regional products from the South West Shelves areas are integrated within a global dataset for European and Global scales needs

It is important for Coriolis to contribute to such an infrastructure as it increases the quantity of QUALIFIED data integrated at European level to fulfil the national and European needs, it shares the qualification and assessment of the in situ products among European parners in a homogeneous and standardized manner. For Coriolis it reduces the interfaces in Europe while extending the number of parameter managed to be able to serve both physical ecosystem modeling communities.

Finally, the In Situ Tac is developed in a distibuted manner that allows the EuroGOOS regional alliances (Arctic Roos, BOOS, NOOS, IBI-ROOS, MOON and Black Sea GOOS) to extend these regional portals to other parameters and serve also the national system and the downstream services that are developped at regional scales.

EURO-ARGO: TOWARDS A SUSTAINED EUROPEAN CONTRIBUTION TO ARGO

By Pierre Yves Le Traon[1], Yves Desaubies[1], Emina Mamaca[1], Sylvie Pouliquen[1], Hartmut Heinrich[2], Birgit Klein[2], Olaf Boebel[3], Jurgen Fischer[3], Detlef Quadfasel[3], John Gould[4], Brian King[4], Fiona Grant[5], Isabel Ambar[6], Maria Chatzinaki[7], Gerasimos Korres[7], Kjell Arne Mork[8], Laurent Kerleguer[9], Pierre Marie Poulain[10], Andreas Sterl[11], Jon Turton[12], Pedro Velez[13], Waldemar Walczowski[14], Elisaveta Peneva[15], Emil Stanev[15]

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The Euro-Argo research infrastructure

In November 2007, the international Argo programme reached its initial target of 3,000 profiling floats. This is the first-ever global, in situ ocean-observing network in the history of oceanography, providing an essential complement to satellite systems. Maintaining the array's size and global coverage in the coming decades is the next challenge for Argo. Around 800 new floats will be required each year to maintain the 3,000 float array.

Euro-Argo will develop and consolidate the European component of the global network. Specific European interests also require increased sampling in European regional seas (Nordic seas, Mediterranean Sea, Black Sea). Overall, the Euro-Argo infrastructure should comprise 800 floats in operation at any given time. The maintenance of such an array will require Europe to deploy about 250 floats per year. Euro-Argo must be considered in its entirety: not only the instruments, but also the logistics necessary for their preparation and deployment, field operations, the associated data streams and data centres and links with the research and operational oceanography communities.

The Euro-Argo preparatory phase (January 2008-December 2010)

As a new European research infrastructure (figure 1), Euro-Argo (www.euro-argo.eu) started a preparatory phase funded through the EU 7th Framework Research Programme. Euro-Argo preparatory phase (PP) includes all European Member States involved in Argo (France, United Kingdom, Germany, Ireland, Italy, Spain, Netherlands and Norway) and several potential new actors (Greece, Portugal, Poland and Bulgaria). The PP started in January 2008 and will end in December 2010. Its main objective is to undertake the work needed to ensure that Europe will be able to deploy and operate an array of 800 floats on the long-term and to provide a world-class service to the research (climate) and operational oceanography (GMES Marine Core Service) communities.

Figure 1

Euro-Argo is one of the 35 new European research infrastructures selected by the European Strategy Forum on Research Infrastructures (ESFRI) in its first roadmap in 2006.

The main activities and achievements of the Euro-Argo PP for its first two years are summarized below:

- Development and consolidation of long term national plans for Euro-Argo.
- Links with the GMES Marine Core Service and MyOcean project.
- Work on the development of a long term European Commission funding through GMES, DG Research and DG Mare.
- Preparation of several reports on infrastructure description, costs, float technology, deployment issues, data processing issues and improvements, impact of Argo data for ocean and climate research and operational oceanography.
- Technical developments and improvements of the Argo data system (quality control, array monitoring, extension to biogeochemical variables).
- Float technology tests: communication (Arvor, Iridium, Argos3), Sea Ice and Oxygen sensors.
- Strengthening the user community in Europe through the organization of annual user meetings.
- Education and capacity building (educational WWW site, training workshops).
- Definition and agreement on the future governance and legal structure.

More information on Euro-Argo preparatory phase can be found on the Euro Argo WWW site (www.euro-argo.eu).

The EURO-ARGO long term research infrastructure

One of the main objectives of the preparatory phase is to define and agree on a long term organization and structure for Euro-Argo. This will allow us:

- To supervise operation of the infrastructure and ensure that it evolves in accordance with the requirements set forth by the research and operational communities.
- To coordinate and supervise float deployment to ensure that Argo and Euro-Argo objectives are fulfilled (e.g. contribution to Argo global array, filling gaps, improve regional coverage, open data access, etc).
- To decide on the evolution of the Euro-Argo infrastructure (e.g. data system, products, technology and new sensors, number or floats deployed per year).
- To share expertise on all scientific/technological developments and use of Argo.
- To monitor the operation of the infrastructure (e.g. array performance monitoring) and to maintain the links with research and operational (GMES) user communities.
- To organize float procurement at European level (e.g. in case of direct EC funding and for small participating countries).
- To conduct R&D activities at European level.
- To fund and link with the international Argo structure.

The future long-term structure for Euro-Argo has been agreed by all partners. It will include a central facility (Central RI) and distributed national facilities. The central RI will be a light structure (2 people for the time period 2011-2013 and up to 4 to 5 from 2013 when the structure starts float procurement at European level). It will provide the overall coordination for the programme and will organize and distribute the work in the national facilities. It will also organize float procurement at European level (includes logistics and test facilities). Its legal form will follow the new EU legal framework for European Research Infrastructure Consortium (ERIC). This new legal form is designed to facilitate the joint establishment and operation of research facilities of European interest. The governance and organization of the structure will be made through a council, a management board, a programme manager and a scientific and technical advisory group. All these bodies will be set up by the end of 2010. France will host the central infrastructure for an initial period of 5 years.

All PP partners will participate to the Euro-Argo ERIC. Germany, UK, France, Italy, Netherlands, Bulgaria will be full members while Norway, Spain, Greece, Ireland, Poland, Portugal will more likely be observers. Several observers are likely to become full members pending on national commitments. New European and non European countries are also expected to join the Euro-Argo ERIC as the infrastructure develops.

The validation at national (ministerial) and European Commission levels of the Euro-Argo ERIC application is expected to be completed by the end of 2010 so that the Euro-Argo ERIC can be set up in early 2011.

The Euro-Argo ERIC will be initially set up based on member state contributions. An additional long term European Commission funding must be ensured, however, so that Euro Argo fulfills its objectives. Euro-Argo will thus continue to work in 2010 with GMES and important European stakeholders (European Environment Agency, EuroGoos) to develop a long term European Commission funding for Argo.

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CORIOLIS: A ONE–STOP SHOPPING TO OCEAN DATA COLLECTED FROM THE JCOMM NETWORKS

By Loic Petit de la Villeon, Thierry Carval, Sylvie Pouliquen

Coriolis IFREMER, Brest, France

Introduction

Data useful to operational oceanography are obtained by diverse means including in-situ platforms (ships, drifters, floats, moorings, etc) and satellites. They come in very different forms, from a single variable measured at a single point to multivariate four dimensional collections of data that represent data volumes from a few bytes to gigabytes. In past 10 years, we have seen the emergence of assembly centres that:

- integrate data coming from a wide variety of platforms and providers (scientists, national data centres, satellite data centres and operational agencies),
- get enough information from the originators to be able to know exactly how the data have been acquired and processed (documented and commonly agreed QC procedures, history of the processing),
- Distribute data and meta-data in agreed standardized formats ("speaking the same language").

Coriolis, one of these Data Assembly Centers, has originally been designed to provide the French ocean forecasting centers, MERCATOR-Océan and French Hydrographic Service (SHOM), with real-time qualified and integrated products, for assimilation and validation purposes. With the advent of re-analysed products, such as CORA (Cabanes et al. 2010, this issue), Coriolis is also able to serve the research community.

This article aims at explaining how Coriolis is organised to produce global integrated products. It will describe the partnerships that has been developed between Coriolis and the JCOMM (Joint Commission WMO-IOC) Observations Panel Area (OPA) components in particular with Argo, GOSUD and OceanSites.

Coriolis data center contribution to JCOMM Networks data processing and distribution

Overview

The operational observing system specified for JCOMM activities is build on complementary elements as shown in the figure below. A lot of these data, available on the GTS (Global Telecommunication System), are not easily accessible to institutes others than Met Offices and may be poorly documented with meta-data. Coriolis users require an integrated access to Temperature, Salinity and current measurements at global scales from profiling floats, research and opportunity vessels, moorings and drifters as they use all these data together in their applications.

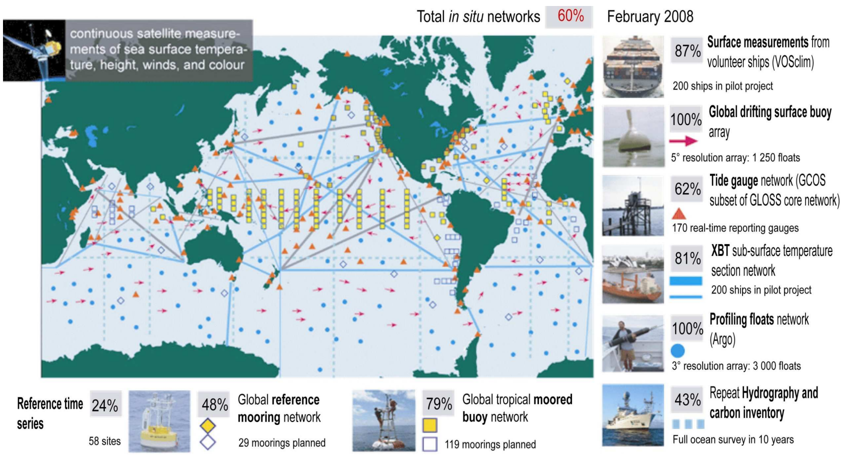


Figure 1

JCOOM Observing System

Instead of developing bilateral partnerships to fulfil its needs, Coriolis decided to work with the JCOMM programs. They provide the inputs to set up the viewing and downloading integrated services that will be helpful not only for the Coriolis data center but also to the users who access to data via Internet network. The concept of Global Data Center (GDAC) for JCOMM programs was borne to provide a unique portal to the best copy of data processed by all the national contributors. The added value of the GDACs is that they can serve through internet, the research and operational oceanography communities that are not connected to GTS and can provide a dataset with a standardized level of quality control.

Argo

The distribution of Argo data is supported by two GDACs fed by 10 national data assembling centres (DAC). Coriolis acts in two fields within the Argo project. Firstly, Coriolis is one of the 2 GDACs, the second one being hosted by the US-GODAE server in Monterey/USA, and secondly Coriolis plays the role of a national DACs, processing in real-time and delayed mode the French floats and in real time most of the European floats, except UK and Irish ones that are processed by BODC. As a DAC it is responsible of the quality of the data it processes, as a GDAC he has to provide a reliable distribution channel to data whose quality has been controlled by the other DACS. The master copy of the Argo dataset is available on ftp at ftp://ftp.ifremer.fr/ifremer/argo and WWW (http://www.argodatamgt.org). It represents a dataset of about 6700 floats. Among them about 3000 floats are active.

Surface data within GOSUD

The main objective of the GOSUD (Global Ocean Surface Underway Data) Pilot Project is to collect, process, archive and disseminate in real time and delayed mode oceanic variables collected underway by research and opportunity ships. At present, the data collected are sea surface salinity and sea surface temperature. Like for Argo, a distributed architecture based on DACs and GDACS has been set up. Coriolis data center acts as a GDAC for the project and as a DAC for French research vessels and vessels of opportunity managed by IRD (Institut de Recherche pour le Développement). In 2009, 80 vessels provided their data via ftp ftp://ftp.ifremer.fr/ifremer/gosud and on the www http://www.gosud.org. There are plans to extend the scope to other variables such as current from ADCP or pCO2, etc.

OceanSITES

For a long time, eulerian observing networks have provided long reference time series, mainly in delayed mode, but generally distributed directly by the providers. Only data from the TAO/TRITON/PIRATA networks are distributed in real time and delayed mode through a unique portal. Based on the success of the data system set up for ARGO and TAO programs, managers of eulerian observing systems have decided to coordinate an OceanSItes program that will address both the technological and scientific common goals but also will facilitate the access to their data. It was decided to set up two GDACS, one at Coriolis and one at NDBC (National Data Buoys Center)/USA. Both data centres will provide an integrated access to all OceanSites data in a common format and portal set up. The goal is also to converge on real-time QC procedure whenever possible.

The FTP address is: ftp://ftp.ifremer.fr/ifremer/oceansites. A Web site is under development.

Drifters

The DBCP (Data Buoy Coordination Panel) coordinates a drifter program. The data are transmitted in real-time on the GTS. The delayed mode data are available at the AOML data center. The issue is to provide a Near Real Time access (within a week) to get current data deduced from the drifters, as they are essential for ocean model validation purposes. In collaboration with Météo-France, Coriolis has set up a FTP portal that provides access to the current derived from drifter data that have not lost their anchor. These data are available on ftp ftp://ftp.ifremer.fr/ifremer/coriolis/lagrangian_buoy.

European Gliders

In Europe, the teams who deploy gliders had previously been involved in Argo and recognized the value of the data services provided by Argo. As gliders are complementary to profiling floats, they want to ensure that the data are widely-available to the oceanographic community and in particular to the forecasting centres. Coriolis was contacted to set up a portal for the EGO initiative (European Gliding Observatories) to distribute glider data in a common format, once the same real time automatic procedures have been applied. Data from 20 gliders are currently processed and distributed by Coriolis. Discussions are in progress at international level to extend this service to other countries. The European glider data are available at ftp.ifremer.fr/ifremer/co/ego.

Data collected from sea mammals

Sea mammals such as seals or sea elephants, when equipped with CTD sensors are remarkable platforms which allow to sample polar areas that are not easy to monitor with autonomous platforms, because of the sea ice coverage, or from research vessels, because they are far away and dangerous to access, especially in winter. In collaboration with the Muséum d'Histoire Naturelle, Coriolis started to integrate sea lion CTD data in the Coriolis data base and provide these data to operational forecasting center. There are discussions at international level to set up integrated access to these data and Coriolis may be solicited to play a role in this network.

From GDACS to products

Integrating data from different networks into a coherent dataset

Setting up GDACs at Coriolis has eased the global dataset collection from various networks, but Coriolis has to integrate them into a single data base and complement them with data only available on GTS (Global Telecommunication System). This is done in collaboration with Météo-France and ISDN-Canada through the GTSPP (Global Temperature and Salinity Profile Project). The dataset is also complemented at European scale by the real-time data acquired by the EuroGOOS ROOSes (Regional Operational Oceanographic systems). European integration is under consolidation within MyOcean In Situ TAC. Over 10 years, the amount of data processed by Coriolis has been multiplied by a factor of 6 for temperature and salinity parameters, in real time and delayed mode.

Figure 2

From observational networks to integrated products at Coriolis Data Center

Coriolis has also developed and implemented additional quality control procedures that scrutinize the global data set useful to detect suspicious measurements that are not detected by automatic tests, or profiles/time series that are not consistent with their neighbors. A visual inspection is done on each profile or time series suggested as suspicious by the consistency check methods and a feedback to the data providers is done. This method is easy and can only be done at data assembly centers such as Coriolis. In the past such activities were only carried out in delayed mode (WOCE Data centers, World Ocean Data Base at NODC-USA…).

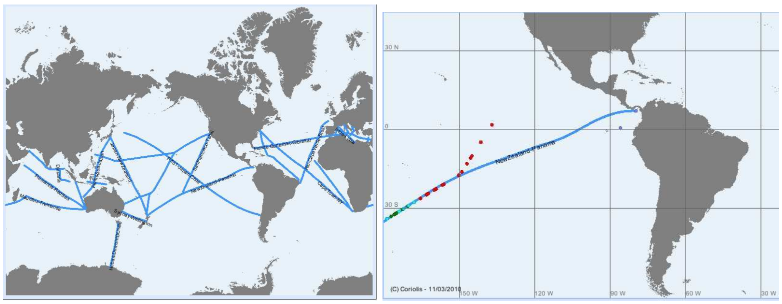
Providing efficient distribution means

Elaborate well documented and reliable products of high quality needs a lot of efforts which are made by the Data Assembling centres. These products must be advertised in catalogues such as Camioon (**http://projets.ifremer.fr/coriolis/Data-Services-Products/Catalog/CORIOLIS-products**) so they can be used by a wide community instead of being left on individual hard disks. With the explosion of Internet capabilities we are now used to find in a few mouse clicks a lot of information, so why not data from ocean observing systems? This is the reason why Coriolis is developing various means to distribute its products in order to serve a wider community:

- On FTP servers for operational users that need to integrate the latest data available or researchers that want to gather global datasets
- On WWW for users who need to subset the data according to specific criteria (period, geographical area, platform, parameter...)
- On GoogleEarth to allow an easy and friendly overview of the available datasets
- Via OPenDap and OGC protocol to allow interoperability with other applications

Detailed description of Coriolis distribution services are published at http/::www.coriolis.eu.org under Data Access session

To fulfil the user new requirements, Coriolis is continuously adapting its tools. For example Coriolis recently developed the capability to download data along the SOOPIP lines.



Selection

Woce line #569 : NewZealand-Panama, 01/01/2007 to 11/03/2010

	Platform	Stations	Start Date	End Date
■ (red)	HANSA FLENSBURG	14	26/09/2007	02/10/2007
■ (cyan)	HANSA FLENSBURG	8	25/08/2008	26/08/2008
■ (green)	HANSA FLENSBURG	6	20/10/2008	22/10/2008

Figure 3

SOOP-IP data selection: The available lines on the left.
On the rigtht the "New Zealand Panama line" was sampled 3 times between September 2007(red dots: 14 stations) and October 2008 (green dots: 6 stations)

Informing the users

During the past years Coriolis team has worked to improve information delivery to users and to be reactive to questions through a centralized service desk at codac@ifremer.fr operated on working days all year round. It has set up a mailing list ***coriolis_users*** that is used by the data center to inform users on major changes in the Coriolis database (new formats, new functions), unavailability of Coriolis system when scheduled and other important information that Coriolis data center partners would like to share with the users. To subscribe, send a message to sympa@ifremer.fr with the following subject *SUB coriolis_users First_Name Family_Name.* (Ex: SUB coriolis_users Loic Dupont)

The team is also working on a new version of the web site that in particular will improve the viewing and subsetting tools, will better inform on the service provided and will highlight the scientific results achieved by the scientific community using the Coriolis database.

For more information please connect to http://wwww.coriolis.eu.org or contact codac@ifremer.fr

CORA (CORIOLIS OCEAN DATABASE FOR RE-ANALYSES), A NEW COMPREHENSIVE AND QUALIFIED OCEAN IN-SITU DATASET FROM 1990 TO 2008 AND ITS USE IN GLORYS

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Introduction

An ideal set of oceanographic in-situ data comprehends global coverage, continuity in time, is subject to regular quality controls and calibration processes (i.e. durable in time), and encompasses several space/time scales. This goal is actually not easy to reach and reality is often different especially with in-situ oceanographic data, such as temperature and salinity profiles in our case. Those data have basically as many origins as there are scientific campaigns to collect them. Some efforts to produce such an ideal dataset have been done for many years, especially since the initiative of Levitus (1982).

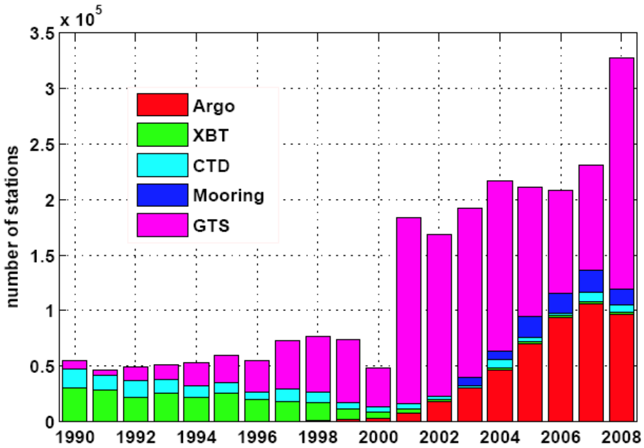
A program named Coriolis has been setup at Ifremer at the beginning of the 2000's in the wake of the development of operational oceanography in France. The project was launched in order to provide ocean in situ measurements to the French operational ocean analysis and forecasting system (Mercator-Océan) and to contribute to a continuous, automatic, and permanent observation networks. The Coriolis data centre has been set up to gather, qualify (Coatanoan and Petit de la Villéon, 2005) and distribute data from the global ocean both in real and delayed time. The Coriolis database (http://www.coriolis.eu.org/cdc/data_selection.htm) is a real time dataset as it is updated every day as new data arrive. On the contrary, the CORA database corresponds to an extraction of all in situ temperature and salinity profiles from the Coriolis database at a given time. CORA is re-qualified to fit the needs of both re-analysis and research projects. The Coriolis data center and the R&D team are now working together to produce a new release of CORA for the period 1990 to 2008 and to be able to update it on a yearly basis. We first present a description of the CORA dataset and the quality controls applied, and then we give examples of the main uses for which those data are meant for such as ocean reanalyses.

Description of the Dataset

This new release of CORA dataset (CORA2.2) basically contains temperature and salinity data at observed levels, data interpolated at standardized levels as well as gridded fields of T/S. The observed dataset is global, and corresponds to sub-surface ocean profiles of in-situ temperature and salinity for the period 1990-2008. Those data were extracted from the real-time Coriolis database at the beginning of 2008 (and early 2009 for 2008 data). From those data at observed levels, T/S profiles data are interpolated at standardized levels and then mapped through an objective analysis on a horizontal ½° Mercator isotropic global grid and 59 levels ranging from 5 to 1950m.

The Coriolis centre receives data from Argo program, French research ships, GTS data, GTSPP, GOSUD, MEDS, voluntary observing and merchants ships, moorings, and the World Ocean Database (not in real time for the last one). CORA thus contains data from different types of instruments: mainly Argo floats, XBT, CTD and XCTD, and Mooring. The data are stored in 7 files types: PF, XB, CT, OC, MO, BA, and TE. The data from Argo floats directly received from DACS (PF files) have a nominal accuracy of 0.01℃ and 0.01 PSU and are transmitted with full resolution. XBT or XCTD data received from research and opportunity vessels (XB files) have accuracy within 0.03℃ to 0.1℃ for temperature and 0.03 to 0.1 PS U for salinity. The CT files contains CTD data from research vessels (accuracy on the order of 0.002℃ for temperature and 0.003 ps u for salinity after calibration) but also data from sea mammals equipped with CTD (accuracy is on the order of 0.01℃ for temperature and 0.02 psu for salinity but can be lower depending of the availability of reference data for post-processing, see Boehme et al, 2009) and some sea Gliders. Others CTD data are found in the OC files and come from the *high resolution CTD* dataset of the World ocean database 2009. Mooring data (MO files) are mostly from TAO TRITON RAMA and PIRATA mooring and have accuracy generally comparable to Argo floats (except for S near surface). The two last categories (TE and BA files) are for all the data transmitted trough the GTS (data from Argo floats not yet received at the DACS, mooring...). This transmission system imposes limitation on the accuracy: data is truncated two and one places beyond decimal point for TE and BA type respectively. Figure 1 shows the number of temperature and salinity profiles in the CORA2.2 database for the whole period 1990-2008 and their repartition among the different file types. From 2001, a large number of data has come from the GTS as a consequence of the real time needs of the Coriolis data centre. It is however possible to distinguish the different instrument types of the GTS data using their WMO instrument type number.

1990-2008	Stations	Temp profiles	Salinity profiles
ARGO	474056	473983	464013
XBT,XCTD	234777	234777	493
CTD	155324	155322	153222
MOORING	86725	86703	58913
GTS	1427644	1427606	532019
TOTAL	2378526	2378391	1208660



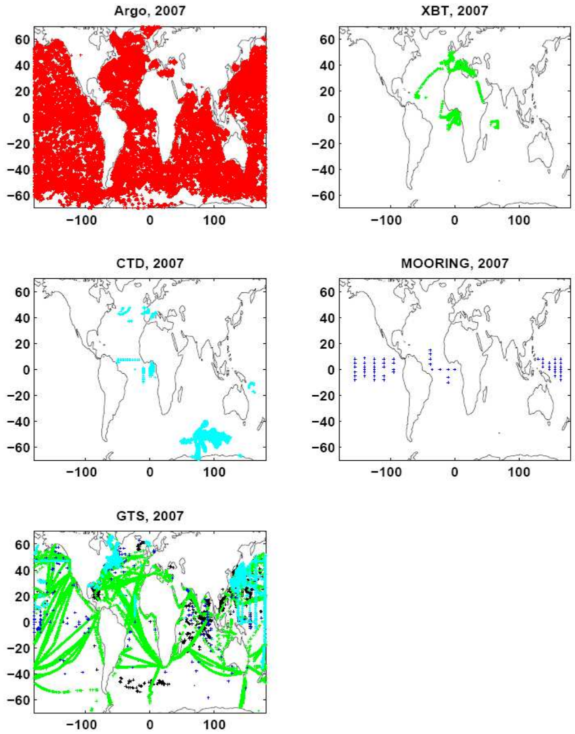


Figure 1

Temporal (left) and spatial distribution for 2007 (right) for the different type of data used in CORA.

Data received by the Coriolis data centre from different sources are put through a set of quality control procedures (Coatanoan and Petit de la Villéon, 2005) to ensure a consistent dataset. Each measurement for each profile is associated with a control quality flag ranging from 0 to 9. Basically, a flag 1 stand for good data, a flag 4 stand for bad data. A complete description of control quality flags and their definition is provided in Coatanoan and Petit de la Villéon (2005). Beside those tests, several other quality checks have been developed or applied to produce CORA2.2 in order to reach the quality level required by the physical ocean re-analysis activities. These checks include some simple systematic tests; a test against climatology and a more elaborate statistical test involving an objective analysis method (see Gaillard et al., 2009 for further details). Visual quality control (QC) is performed on all the suspicious temperature and salinity profiles. For the Argo platforms, the float was controlled over all its life period if suspicious values were found recurrently. After these visual checks it is decided to change or not the control quality flag. A profile fails a systematic test when pressure is negative, T and S values are outside an acceptable range depending on depth and region, T or S are equal to zero at bottom or surface, values are constant along depth, values are outside the 10σ climatological range, if there is large salinity gradient at the surface (more than 5 PSU within 2dB) or a systematic bias. Each time a profile failed a systematic test it was visually checked. A test against climatology that we call *Anomaly Method* was also applied. In this case, a profile failed the test if at least 50% of its data points lie outside the 5σ climatological range. This allows detecting smaller deviations compare to the 10σ check. The statistical test is based on an objective analysis run (Bretherton et al., 1976) with a three weeks window. Residuals between the raw data and the gridded field are computed by the analysis. Residuals larger than a defined value produce alerts that are then checked visually. This method combines the advantage of a collocation method since it takes into account all neighbouring sensors, and the comparison with climatology. Finally, Argo floats pointed out by the altimetric test (Guinehut et al., 2009 and ftp://ftp.ifremer.fr/ifremer/argo/etc/argo-ast9-item13-AltimeterComparison/) were systematically verified over all their life period and quality control flags were modified when necessary.

CORA2.2 database not only contains the raw parameters (temperature, salinity, pressure or depth as received from the instrument) but also the adjusted parameters if it exists (temperature, salinity, pressure or depth corrected from a drift or an offset etc…). For Argo data, the adjusted parameter is mainly the salinity. This parameter is corrected in delayed mode by the PI of the float by comparing the observed value to neighbouring historical CTD trough the Owens and Wong method (Wong et al., 2003; Böhme and Send, 2005; Owens and Wong, 2009). For the CORA2.2 database, the adjusted parameters for Argo data are those received at the GDACs at the date of the extraction (i.e. at the beginning of 2008, and early 2009 for 2008 data). Then, the errors recently identified in pressure (see http://www.argodatamgt.org/Data-Mgt-Team/News/Pressure-Biases) are not yet corrected for in CORA2.2. Recently, adjusted depth and/or temperature values for the XBT data were also computed and included in the CORA2.2 database. That correction follows the one applied on the World Ocean Database 2009 (Johnson et al., 2009). We first perform a correction on depth for the XBT types that requires it. It is based on the updated depth-time equation of Hanawa et al. (1994). Then we make a temperature correction depending on the year and depth of the data. Those temperature corrections have been computed statistically from collocated XBT and OSD/CTD data (Levitus et al. 2009). The quality control flags of the adjusted parameters are copied from the existing real time flags as the quality of the corrected data regarding our quality control tests does not basically change.

It is strongly recommended to use the adjusted parameters when they are available instead of the raw parameters. It is also advised to use only data with control quality flags equal to 1 or 2 if the user does not intend to perform its own quality checks.

Goals and uses of the Dataset

Research: CORA database is meant to investigate specific scientific questions. Achieving this goal will lead to the improvement of the quality of the dataset, by detecting abnormal data. That will benefit subsequently to Coriolis data centre and the operational results. It is also a way to monitor ocean variability and to define ocean climate indices which is work in progress (see von Schuckmann et al., this issue) in the context of the MyOcean European project (http://www.myocean.eu.org/).

Using the CORA database to estimate global ocean temperature, heat and freshwater content is a way to asses the quality of the dataset as these global quantities are very sensitive to any sensor drift or systematic instrumental bias. Although our quality controls are meant to detect such instrument problems, they can still miss small unknown drifts or bias. Comparison and sensitivity studies are thus of primary importance in the domain of climatic changes. The paper of von Schuckmann et al, 2009 is a good example of the work needed to assess global and regional changes of ocean properties. Using a re-qualified in situ data set of global temperature and salinity they show that the global ocean continues to warm during the period 2003-2008. The average warming rate in the upper 2000m depth of the global ocean accounts for 0.77 ± 0.11W/m2. The warming signal can be observed at large depths and amplitudes are strongest in the Atlantic Ocean as it was observed for a longer period (1955-1998) by Levitus et al., 2005. Similar studies using the CORA2.2 database are now in progress.

Ocean model validations: CORA can be used to construct elaborated products such as climatologies of heat content, depth of the thermocline or 20℃ isotherms, or climate indic es (niño3.4, MOC, PDO…). Such products are especially useful for validating ocean model outputs and improve their quality or assess their results. For example, de Boyer Montégut et al. (2007) validate their OGCM mixed layer depth outputs against in-situ observations in the northern Indian Ocean. After assessing the realism of their experience, they use the model to investigate surface heat budget variability.

Data assimilation in ocean models: An important application of such a database is also its use in ocean reanalyses. Throughout the world, several reanalyses projects are underway which aim at providing a continuous space-time description of the ocean, synthesizing the information provided by various observation types (remotely sensed and in situ) and the constraints provided by the physics of numerical ocean models. The reader is referred to Lee et al. (2009) or Mercator Quarterly Newsletter #36 (special issue on ocean reanalyses) for further information. In France, global ocean reanalysis activity is a joint collaboration between Mercator-Océan, Coriolis data centre and several oceanographic and atmospheric research laboratories in the framework of GLORYS (GLobal Ocean ReanalYsis and Simulations) project. This project contributes also to the production of coordinated reanalyses at the European level in the context of MyOcean EU funded FP7 project, in collaboration with Italian, English, French and Canadian partners. The goal of GLORYS is to produce a series of realistic eddy permitting global ocean reanalyses. Several reanalyses are planned, with different streams. Each stream can be produced several times with different technical and scientific choices. Version 1 of Stream 1 (GLORYS1V1) covering the Argo era (2002-2008) has been produced using the previous version of the CORA (version 2.1) data set and is available on request from products@mercator-ocean.fr. Further information and results can be found in Ferry et al. (2010).

Quality controlled observation data sets are essential ingredients to produce realistic and accurate ocean reanalysis. However, by means of appropriate data assimilation diagnostics (e.g. Järvinen, 1998), ocean reanalyses can also contribute to identify suspect observations and help to improve observational data sets like CORA2.2. These diagnostics rely on innovation (i.e. difference between the observation and model equivalent) statistical properties that must be verified. Thus, when an observation does not satisfy these statistical tests, it indicates that it should be discarded. It is then possible to blacklist these observations in order to improve the next version of the observational data set. This kind of data quality control is currently being tested and implemented in the upcoming GLORYS1V2 reanalysis as well as in Mercator-Ocean next operational systems. An illustration of this quality check performed offline in GLORYS1V1 is given in Figure 2. For the temperature profile located in the North Atlantic (Figure 2a and 2b), we clearly see that the innovation is not realistic as it exceeds 4℃ between 100 and 300 m d epth, a value much larger than the expected observation plus background error. For the salinity profile displayed in Figure 2c and 2d, the observation presents a suspect spike near 50~100m depth which is not present in the model forecast. Moreover, the quality control exhibits an unrealistic bias below 500m depth which is in disagreement with both the model forecast and Levitus et al. (2005) climatology.

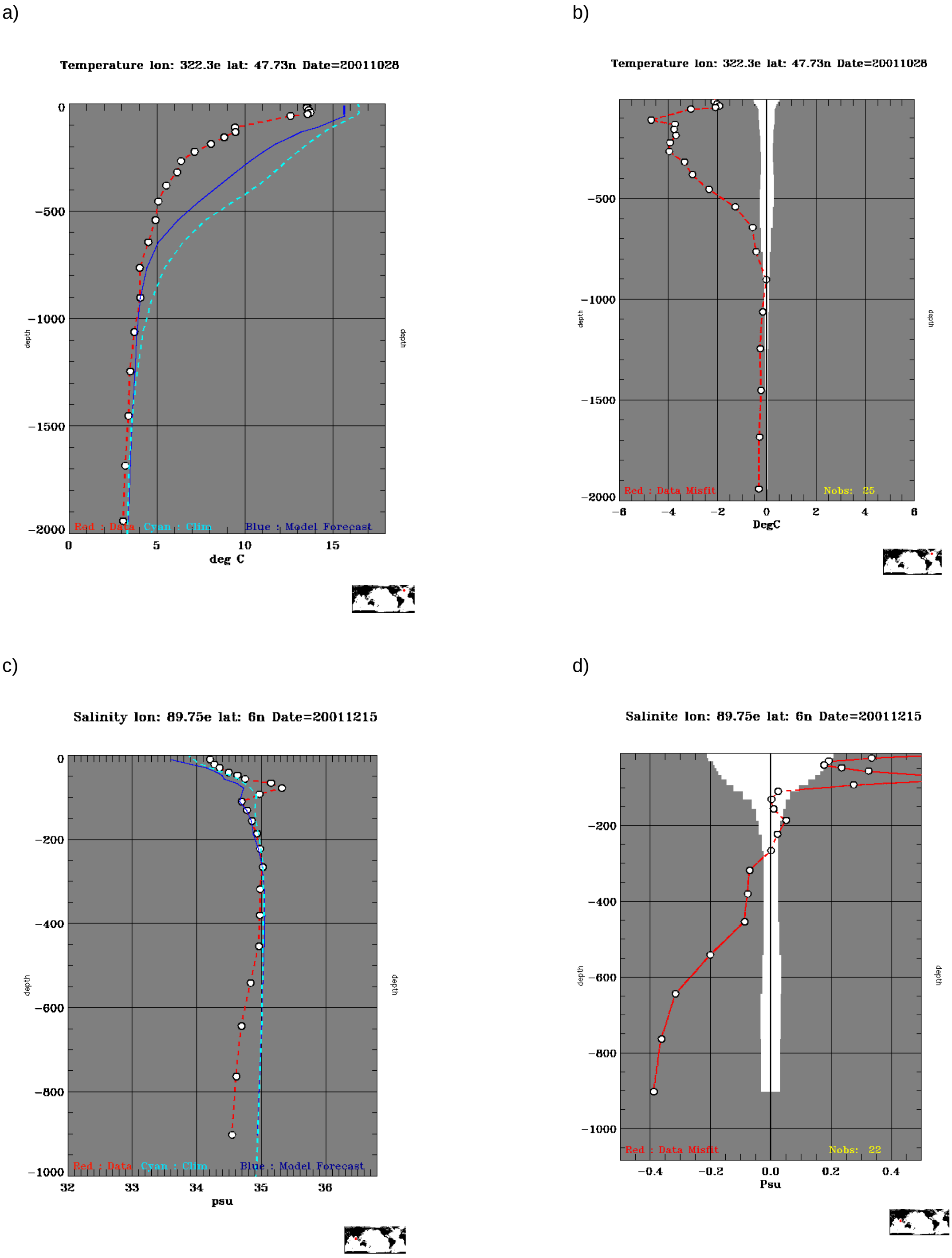


Figure 2

Example of data quality control based on innovation statistics in GLORYS1V1 reanalysis. (a) Observed temperature profile (℃) at (322.3°E, 47.7°N) on the 29/10/2001 (red curve), Climatological value (Levitus 2005, in cyan) and model forecast in blue. (b) Temperature innovation (℃) at the same location. (c) And (d) is similar to (a) and (b) except for an observed salinity (psu) profile at (89.7°E, 6°N) on the 15/12/2001. The white shade d area in (b) and (d) corresponds roughly to the envelope of twice the observation plus background error.

This clearly shows that strong collaborations between ocean observation data delivery centres and operational oceanography centres producing reanalyses will enhance the quality of the observation data sets used for operational applications, reanalyses, research and climate monitoring.

Finally, the CORA dataset is a product of the MyOcean catalogue and aims to be a reference as a dataset produced by the in situ TAC of this European project.

Références

Boehme L., P. Lovell, M. Biuw, F. Roquet, J. Nicholson, S. E. Thorpe, M. P. Meredith, and M. Fedak, 2009: Animal-borne CTD-Satellite Relay Data Loggers for real-time oceanographic data collection Ocean Sci., 5, 685-695

Böhme, L., and U. Send, 2005: Objective analyses of hydrographic data for referencing profiling float salinities in highly variable environments, Deep Sea Research II, 52, 651–664, doi:10.1016/j.dsr2.2004.12.014.

Bretherton, F., R. Davis and C. Fandry, 1976, A technique for objective analysis and design of oceanic experiments applied to mode-73, Deep Sea Res. Oceanogr. Abstr. 23, 559-582

Coatanoan C., and L. Petit de la Villéon, 2005: Coriolis Data Centre, In-situ data quality control procedures, Ifremer report, 17 pp. (http://www.coriolis.eu.org/cdc/documents/cordo-rap-04-047-quality-control.pdf)

de Boyer Montégut, C., J. Vialard, S. S. C. Shenoi, D. Shankar, F. Durand, C. Ethé, and G. Madec, 2007: Simulated seasonal and interannual variability of mixed layer heat budget in the northern Indian Ocean, J. Climate, 20, 3249-3268

Ferry N., L. Parent, G. Garric, B. Barnier, N. C. Jourdain and the Mercator Ocean team, 2010: Mercator global eddy permitting ocean reanalysis GLORYS1V1: Description and results. Mercator Quarterly Newsletter 36, January 2010, 15-27. http://www.mercator-ocean.fr/documents/lettre/lettre_36_en.pdf

Gaillard F., E. Autret, V. Thierry, P. Galaup, C. Coatanoan, and T. Loubrieu, 2009: Quality controls of large Argo datasets, J. Atmos. Ocean. Tech., 26, 337-351.

Guinehut S., C. Coatanoan, A.-L. Dhomps, P.-Y. Le Traon and G. Larnicol, 2009: On the Use of Satellite Altimeter Data in Argo Quality Control, Journal of Atmospheric and Oceanic Technology, 26, 395-402

Hanawa, K.P., P. Rual, R. Bailey, A. Sy, and M. Szabados, 1994: Calculation of New Depth Equations for Expendable Bathythermographs Using a Temperature-Error-Free Methods (Application to Sippican/TSK T-7, T-6 and T-4 XBTs), Intergovernmental Oceanographic Commission Technical Series, 42: 1-46.

Järvinen H., 1998: Observations and diagnostic tools for data assimilation. Meteorological Training Course Lecture Series, ECMWF, 19 pp.

Johnson, D.R., T.P. Boyer, H.E. Garcia, R.A. Locarnini, O.K. Baranova, and M.M. Zweng, 2009: World Ocean Database 2009 Documentation. Edited by Sydney Levitus. NODC Internal Report 20, NOAA Printing Office, Silver Spring, MD, 175 pp.

Lee T, Awaji T, Balmaseda MA, Greiner E, and Stammer D., 2009: Ocean State Estimation for Climate Research. Oceanography 22: 160-167

Levitus, S., 1982: Climatological Atlas of the World Ocean, NOAA Professional Paper 13, U.S. Government Printing Office, Rockville, M.D., 190 pp.

Levitus, S., J. Antonov, and T. Boyer, 2005: Warming of the world ocean, 1955-2003, Geophys. Res. Lett., 32.

Levitus, S, J. I. Antonov, T. P. Boyer, R. A. Locarnini, H. E. Garcia, and A. V Mishonov, 2009: Global ocean heat content 1955-2008 in light of recently revealed instrumentation problems. Geophys. Res. Lett., 36, L07608, DOI:10.1029/2008GL037155.

von Schuckmann, K., F. Gaillard and P.Y. Le Traon, 2009: Global hydrographic variability patterns during 2003-2008, J. Geophys. Res. 114, C09007, doi:10.1029/2008JC005237.

Owens, W.B. and A.P.S. Wong, 2009: An improved calibration method for the drift of the conductivity sensor on autonomous CTD profiling floats by θ–S climatology, Deep Sea Research I, 56, 450-457, doi:10.1016/j.dsr.2008.09.008.

Wong, A. P. S., G. C. Johnson, and W. B. Owens, 2003: Delayed-Mode Calibration of Autonomous CTD Profiling Float Salinity Data by θ−S Climatology, Journal of Atmospheric and Oceanic Technology, 20, 308–318

GLOBAL OCEAN INDICATORS

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Abstract

Work is in progress in the context of MyOcean in order to define ocean climate indices computed both from observations and from monitoring and forecasting system outputs. Global Ocean indicators are evaluated from a field of hydrographic in situ observations provided by the Argo array (ARIVO), from global ocean reanalyses of the French Global Ocean Reanalysis and Simulations (GLORYS) project and a current field derived from multi-parametric observed products (SURCOUF3D). The in-situ measurements are used to define ocean indicators describing the state of the global ocean and its changes over the period 2004-2008. We find global rates of 0.65±0.13 Wm^{-2} for heat storage, 2700±1400 km^3 for freshwater content and 0.95±0.2 mm/yr for steric sea level. Changes of the deep ocean hydrographic field are assessed while determining regional linear trends of steric height and deep temperature anomalies. Areas of a positive trend of steric sea level - which contribute to the global steric rise – occur in all basins and dominate the Pacific Ocean. The global steric seal level rise is larger when evaluated from the GLORYS reanalysis temperature and salinity 3D monthly fields. Due to data assimilation of sea level anomalies, GLORYS total (barotopic and steric) mean sea level rise is very close to the satellite derived observations. Finally the intensity of the Meridional Overturning Circulation (MOC) is evaluated from SURCOUF3D and from GLORYS. Both reproduce the order of magnitude of ship cruise measurements of the MOC.

Introduction

Indicators are used to describe the state of the ocean and its changes. As commonly understood, an indicator is something that provides a clue to a matter of larger significance or makes perceptible a trend or phenomenon that is not immediately detectable (Hammond at al., 1995). In other words, an indicator's significance extends beyond what is actually measured to a larger phenomenon of interest. Indicators are used to communicate as they always simplify a complex reality. They focus on aspects which are regarded relevant and on which data are available.

Assessing global ocean indicators largely depends on the availability of data. Indeed, long time series of e.g. sea level changes exist, but are regionally restricted and thus are less indicative to provide information of the state of the ocean on global scales and its changes with time. Sea level as measured by satellite altimetry delivers global state estimates based on a homogeneous and continuous dataset during the last two decades. To promote information regarding the hydrographic state of the global ocean, all available in-situ measurements of temperature and salinity have been collected to construct a global climatology, thus indicating the state of the global ocean hydrographic field from the surface down to 3000m depth (Locarnini et al., 2006; Antonov et al., 2006, WOA05 hereinafter). This historical data set has been also used to describe global ocean changes from mid-1950s to present day (Levitus et al., 2009).

Global hydrographic estimations are limited before the beginning of this century due to sparseness and inhomogenity in spatial and temporal data distribution, especially in the southern hemisphere oceans. This situation changes drastically with the implementation of the Argo Program as it obtains more continuous, consistent, and accurate sampling of the present-day and future state of the oceans (Roemmich et al., 1999). At the beginning of 2002, Argo sampling covers about 40% of the global ocean, reaches around 70% in 2003, 80% in 2004 and more than 90% after mid-2006 (Cazenave et al., 2009). As a consequence, these data have been used to describe the state of the global ocean hydrographic field and its changes in the last decade (Antonov et al., 2005; Forget and Wunsch, 2007; Willis et al., 2008; Levitus et al., 2009; Cazenave et al., 2009; Leuliette and Miller, 2009; von Schuckmann et al., 2009).

Model reanalyses are precious tools to better understand the processes underlying climate change impacts in the ocean as they give access to a homogeneous time series of 3D ocean temperature, salinity and currents. As described in newsletter #33, the possibility of deducing ocean indicators from Mercator Ocean products (reanalyses and real time) has been evaluated: heat content, upwelling, sea surface temperature (SST) indices, sea ice extent, but also Sahel precipitations, tropical cyclones heat potential, coral bleaching. In the framework of real time monitoring and forecasting of the ocean, the BOSS4GMES project (http://www.boss4gmes.eu/) has tested the implementation of a small and robust ensemble of real time ocean indicators (for instance heat content, SST indices, Crosnier et al., 2008). Mercator Ocean maintains a web page displaying these indicators time series computed with the global analyses and forecast (http://indic.mercator-ocean.fr/html/produits/indic/index_en.html).

Comparing indicators deduced from observations (ARIVO, SURCOUF3D) and the same indicators but deduced from reanalyses like GLORYS is indeed a very promising cross validation process. This should improve reanalyses and data reprocessing validation on past time series but also confirm the interest of monitoring some of these integrated quantities and indicators computed with real time analysis and forecasting systems and with near real time observed products. In section 2, the data used for this study are introduced. In section 3, several global ocean indicators as derived from ARIVO, which is mainly based on Argo profiles, are presented and discussed. A comparison of the ARIVO and GLORYS steric sea level rise is performed in section 4, together with a comparison of the Atlantic MOC as derived from GLORYS and SURCOUF3D.

Data analysis method

Description of ARIVO

Monthly gridded fields of temperature and salinity from the surface down to 2000m depth are obtained by optimal analysis of a global field of in-situ measurements (Coriolis data center) during the years 2004-2008 under the French project ARIVO (http://www.ifremer.fr/lpo/arivo). This data field is based on the Argo array of profiling floats (95% of the data, see http://www.argo.net), drifting buoys, shipboard measurements and moorings. A small fraction of observations has been excluded from the analysis due to existing instrument biases as discussed above, i.e. gray-listed Argo floats of type SOLO FSI and XBTs. The gridding method is derived from estimation theory (Liebelt, 1967; Bretherton et al., 1976) and the method itself is described in detail by Gaillard et al., 2008 and will be not discussed in this context. The analyzed field is defined on a horizontal ½° Mercator isotropic grid and is limited from 77°S to 77°N. The vertical resolution between the surface and 2000m depth is gridded onto 152 vertical levels. The reference field is the monthly World Ocean Atlas 2005 (WOA05, Locarnini et al., 2006; Antonov et al., 2006). A discussion on the statistical description can be found in von Schuckmann et al. (2009).

Description of GLORYS

GLORYS is a project whose objective is to produce a series of realistic (i.e. close to the existing observations and consistent with the physical ocean) eddy permitting global ocean reanalyses. The version 1 of stream 1 (called GLORYS1V1) covering the Argo years (2002-2008) is used in this study (see article in newsletter # 36). The OGCM used in GLORYS1V1 is based on the ocean/sea-ice NEMO numerical framework (Madec, 2008). The configuration is global (-77°S to the North Pole) on a 1/4° ORCA grid. The data assimilation scheme is based on the Singular Evolutive Extended Kalman (SEEK) filter formulation proposed by Pham et al. (1998). A key aspect of the method is the use of a large number of model anomalies (a few hundreds) to model explicitly the background model error covariance. The control vector consists in the barotropic height, the temperature and salinity fields, as well as the zonal and meridional velocity fields. Because there is no simple relationship between the mass field and the circulation near the Equator (e.g. Benkiran and Greiner, 2008), the analyzed velocity near the equator is only partially applied. The velocity increments are set to zero at the equator and increase smoothly with latitude to become maximal at 7°. The length of the assimilation cycle is 7 days and the increment is applied directly to the model state at the analysis time. The assimilated data is sea level anomaly (SLA) corrected from the post-glacial rebound (W.R. Peltier, 2004), in conjunction with the RIO05 Mean Dynamic Topography (MDT, Rio and Hernandez, 2004, Rio and Schaeffer, 2005), SST and in situ profiles. An incremental analysis update is used for the initialization procedure (Bloom et al., 1996) which produces a time continuous ocean analysis. More details about GLORYS1V1 reanalysis can be found in Ferry et al. (2010).

Description of SURCOUF3D

Using the thermal wind equation 3D geostrophic velocity field can be deduced from surface geostrophic current and from a 3D temperature and salinity field. In the case of SURCOUF3D we use the products SURCOUF and ARMOR3D. The SURCOUF field provides geostrophic surface velocities deduced from altimetry. The altimetric data used in the computation of the multimission maps of Sea Level Anomaly (SLA) are from the ERS-1,2, ENVISAT,T/P,GFO, GEOSAT, Jason-1,2 satellites. The CMDT RIO05 (Rio and Schaeffer, 2005) MDT is added to the SLA maps to obtain maps of absolute dynamic topography, that are then used to infer through geostrophy the ocean surface currents. The SURCOUF geostrophic products are computed daily, on a global 1/3° MERCATOR grid. ARMOR3D field is a 3D thermohaline field computed at CLS. It consists first in deriving synthetic thermohaline fields through a multiple linear regression method using altimeter data (described above) and SST from (Reynolds et al., 1994). For the vertical projection, the baroclinic component of the altimeter data is extracted (Guinehut et al., 2006). Then, these synthetic profiles are merged with in-situ T/S profiles (Argo profiling floats, XBT and CTD) using an optimal interpolation method (Guinehut et al., 2004). The ARMOR-3D products are computed weekly, on a global 1/3° MERCATOR grid and on 24 vertical levels from 0 to 1500m depth.

Ocean indicators deduced from in situ observations

Global Ocean heat content

The world ocean is the dominant component of the earth's heat balance as the oceans cover roughly 72% of the planets surface and have the largest heat capacity of any single component of the climate system. The world ocean is responsible for more than 80% of the estimated possible total increase of heat content of the earth system during 1955-1998 (Levitus et al., 2005). Causes for the positive long-term trend in ocean heat content are due to the increase of greenhouse gases in the earth's atmosphere (Levitus et al., 2001). The estimation of ocean heat content implies a measure of the net climate forcing on interannual and long-term period scales (Levitus et al., 2005; Hansen et al., 2005). Therefore changes in globally integrated heat content variability (Figure 1) have very important implications for understanding the earth's energy balance and the evolution of anthropogenic climate change.

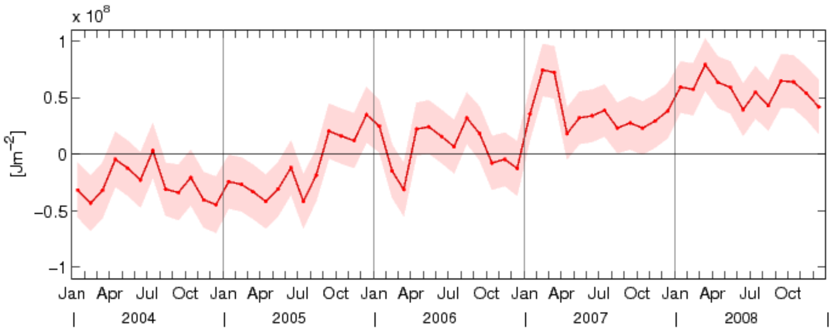

Figure 1

Time series of global mean heat content variability (J.m-2) calculated from the temperature measurements in the upper 2000m depth. The average global warming rate accounts for 0.65±0.13 Wm^{-2} during the years 2004-2008. The shaded area shows the error bar of the global mean heat content estimation.

Ocean heat content variability HS is defined here as the deviation from a reference period (2004-2008) and is closely proportional to the average temperature change from the surface to z = 2000 m depth of the global ocean:

$$HS = \int_{z_1}^{z_2} \rho_0 c_p (T_{mth} - T_{clim}) dz,$$

Where the reference density ρ_0 = 1030 kgm^{-3}, the specific heat capacity cp = 3980 J/kg℃, T_{mth} is the monthly gridded in situ temperature field. T_{clim} is the reference climatology derived from the gridded in-situ temperature measurements during 2004 to 2008. The units of HS correspond to Jm^{-2}. Note that ocean heat content is calculated from 60°S-60°N. It is of utmost importance to associate precise error bars to these estimations which is a non trivial exercise. The error bar which is composed of the measurement error and the mapping procedure (von Schuckmann et al., 2009) is marked in Figure 1. More work will be done on the error estimation. These efforts include comparisons to other data sets to improve the error estimation. The key message of Figure 1 includes a clear heat increase with an average warming rate of 0.65±0.13 Wm^{-2} for the 0-2000 m depth layer during 2004-2008. This number lies in the range of estimations during the last decade (e.g. Levitus et al., 2009, Willis et al., 2004), but discrepancies are quite large because of different estimation periods as decadal changes play an important role (e.g. von Schuckmann et al., 2009, Roemmich et al., 2007).

Global Freshwater content

Owing to a lack of direct salinity observations, previous discussions on signatures of ocean hydrographic changes have been concentrated on the temperature field. The salinity effect cannot be neglected. In the upper part of the global ocean, large salinity changes are mostly controlled by coupled ocean-atmosphere modes (e.g. Kessler, 1998; Delcroix et al., 2007; Reverdin et al., 2007). Large-scale coherent salinity trends are also detected in the deeper layers of the global ocean during the past 50 years (e.g. Antonov et al., 2002; Curry et al., 2003; Boyer et al., 2005; Böning et al., 2008). The monthly gridded salinity measurements in the upper 2000m depth are used to evaluate freshwater content FW:

$$FW = -a \int_z \frac{\rho(T,S,p)}{\rho(T,0,p)} \frac{S'}{(S_r + S')} dz,$$

Where *a* is the area of the near global ocean (60°S-60°N), ρ is the density of seawater, S_r the mean salinity derived from the ARIVO product (S_r = 34.63) and p is the pressure. Details of this method can be found in the paper by Boyer et al., 2007. This method is valid under the assumption that the salt content is relatively constant over the analysis time and that any changes in salinity are due to the addition or subtraction of freshwater to the water column – including vertical movements of the isopycnal surfaces and convection processes. Many mechanisms can lead to the addition or subtraction of freshwater, e.g. air-sea freshwater flux, river runoff, sea-ice formation as well as freshwater exchange of continental glaciers. However, the global average of FW is dominated by interannual changes (Figure 2). The average global freshwater rate is positive but small and accounts for 2700±1400 km^3 during the years 2004-2008.

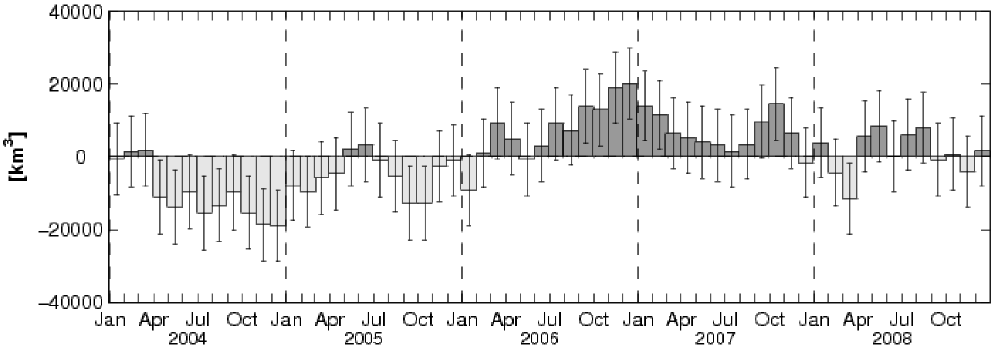

Figure 2

Time series of global mean freshwater content (km3) calculated from the salinity measurements in the upper 2000m depth. The average global freshwater rate accounts for 2700±1400 km^3 during the years 2004-2008. Error bars of the global mean freshwater content estimation are marked.

Global steric sea level

Steric expansion of the oceans is one of the major causes of global mean sea level rise, which is an alarming consequence of anthropogenic climate change (Bindoff et al., 2007). Estimations of sea level rise is of considerable interest because of its potential impact on human populations living in coastal regions and on islands (> 50% of the world population). The monthly temperature and salinity gridded in-situ measurements allow a direct calculation of global mean steric sea level (Figure 3). Rise in steric sea level is driven by volume increase through the decrease of ocean salinity (halosteric increase) and the increase of ocean temperature (thermosteric increase), from which the latter is known to play a dominant role in the global average. Combined with sea level rise derived from satellite, steric sea level rise allows a determination of the mass change of the ocean (e.g. due to the melting of continental ice).

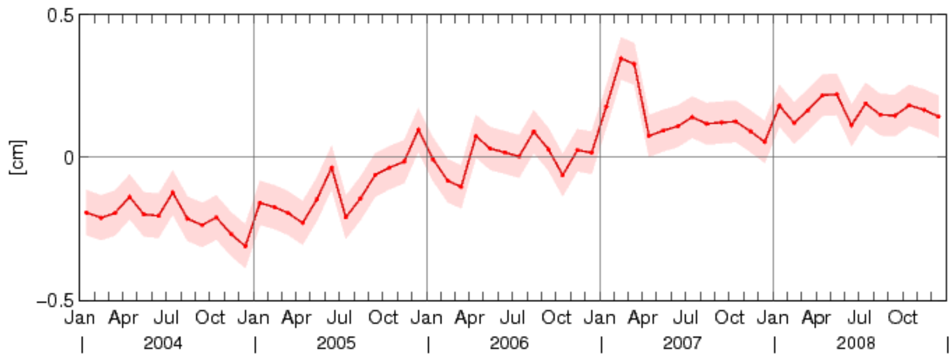

Figure 3

Time series of global mean steric sea level (cm) calculated from temperature and salinity measurements between 10-1500 m depths. The average steric rise accounts for 0.95±0.2 mm/yr during the years 2004-2008. The shaded area shows the error bar of the global mean steric sea level estimation.

The calculation of steric height between two depth layers $h(z_1,z_2)$ involves a vertical integration of ocean density ρ, which in turn can be estimated from temperature T and salinity S measurements, and the ocean pressure p (ρ(T,S,p)):

$$h(z_1,z_2) = \int_{z_1}^{z_2} \left(\frac{1}{\rho(T,S,p)} - \frac{1}{\rho(0,35,p)} \right) * \rho_0 dz \, ,$$

Where ρ_0 is a reference density (Tomzcak and Godfrey, 1994). Steric height $h(z_1,z_2)$ has the dimension of height and is expressed in meters. Due to current data capacities, the density changes between the surface (z_1 = 10m) and z_2 = 1500m depth have been addressed in this calculation and the error bar which is composed of the measurement error and the mapping procedure (von Schuckmann et al., 2009) is indicated in Figure 3. Also for this parameter, more work will be done on the error estimation. The key message of Figure 3 includes a clear steric sea level rise of 0.95±0.2 mm/a for the 10-1500m depth layer during 2004-2008. Interannual fluctuations of global steric sea level exist but are small compared to the long-term variability. The 5-year changes based on steric contribution alone constitute about 40% to the total sea level rise during that time (von Schuckmann et al., 2009).

Regional linear trend of steric sea level

The major causes of global mean sea level rise are steric expansion of the ocean and eustatic rise due to increased melting of land-based ice as well as mass exchange between the oceans and other reservoirs (Bindoff et al., 2007). Together with fluctuations in ocean circulation, these processes cause geographically non-uniform sea level changes. In some regions, rates are up to several times the global mean rise, while in other regions sea level is falling. Ultimately the effect of climate change (e.g. sea level rise) is felt at regional level. Steric sea level will rise where the ocean warms and fall where it cools, since the density of the water column will change. More observations and understanding of regional changes of sea level rise must be developed which is of considerable interest because of its potential impact on human populations living in coastal regions and islands.

Regional changes of steric sea level from the year 2004 to 2008 are shown in Figure 4. The steric height estimations contain a considerable amount of interannual and decadal variability which are coherent throughout large parts of the ocean. For example, an approximately 15mm/year fall of steric sea level emerges in the tropical Pacific Ocean accompanying the El Niño Southern Oscillation event which accounts for the largest fraction of thermosteric ocean variability (Lombard et al., 2005). Areas of a positive trend of steric sea level - which contribute to the global steric rise - occur in all basins and dominate the Pacific Ocean.

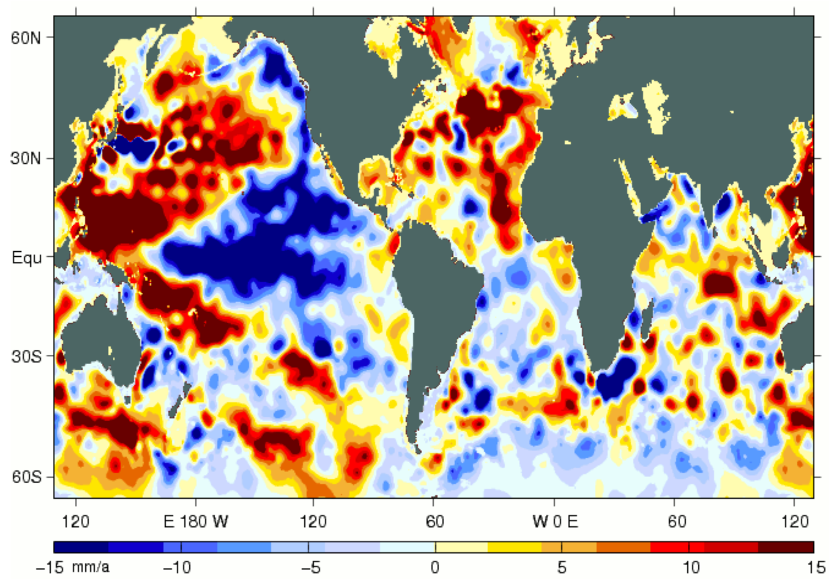

Figure 4: Linear trend (mm/year) during the years 2004-2008 of steric sea level calculated from gridded temperature and salinity in-situ measurements between 10-1500m depths**.**

Comparisons with a model reanalysis: GLORYS1V1

Atlantic MOC

As mentioned in Bryden et al. (2005) the Atlantic MOC carries warm upper waters into far-northern latitudes and returns cold deep waters southward across the equator. Its heat transport makes a substantial contribution to the moderate climate of maritime and continental Europe, and any slowdown in the overturning circulation would have profound implications for climate change. Volume transport along a section can be monitored from different complementary methods based on in-situ and satellite observations or a numerical model (Hirschi et al., 2003). In situ measurements are useful to validate models but they are spatially and temporally limited despite the current international effort to operate repetitive sections in all oceans over several years like what has been done in the framework of the WOCE, Rapid-MOC, or OVIDE projects. On the contrary the SURCOUF3D and GLORYS 3D velocity products are global. The former gives a picture of the observed ocean over the 15-year-altimetric time period, while the latter has been computed over a shorter period (the 'Argo' period, 2002-2008). The monthly average of SURCOUF3D MOC shows a very high variability with a standard deviation of 6.4 Sv (Figure 5). Over the common period 2002-2008 the four methods (Surcouf3D, Glorys, Rapid and Bryden et al., 2005) show reasonably good agreement. Note that the RAPID-MOC averages for 2004 and 2007 have been computed for incomplete years (April to December in 2004 and January to September in 2007). The corresponding mean values are given for the SURCOUF3D and the GLORYS products as red and black triangles, respectively, which improves the comparison with the RAPID data. Larger disagreements are observed in 2005 between SURCOUF3D and RAPID and in 2003 between SURCOUF3D and GLORYS. In 2005 this difference mostly comes from a strong discrepancy (higher than 8 Sv) in May and October that has to be further investigated. In 2003, the disagreement is due to the sampling of eddies in the western boundary current off the Bahamas. Between 73.5°W and 72°W SURCOUF3D resolves southward cur rent that count for -8Sv (integrated up to 1000m) while GLORYS field does not see southward current at this location.. Because of the high variability of the MOC, this kind of intercomparison is quite useful for the cross validation of the various datasets as well as for assessing the error on the MOC computation.

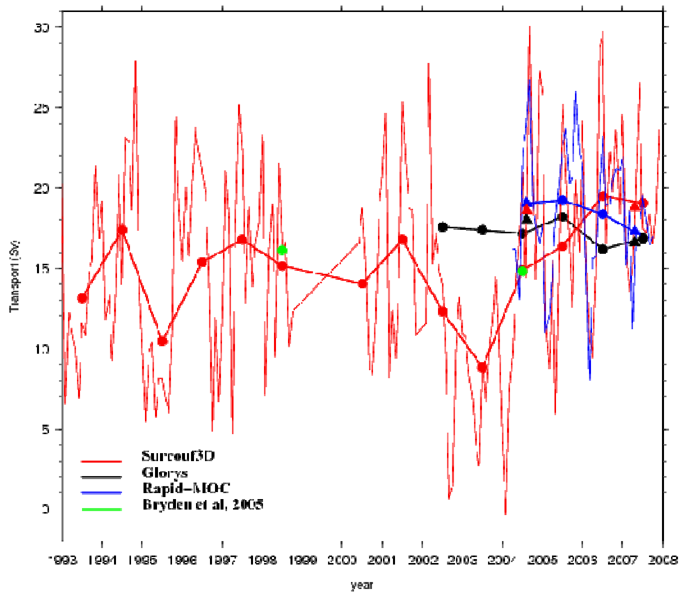

Figure 5

Atlantic Meridional Overturning Circulation at 26.5°N. In red: Sum of geostrophic transport (Sv) from Bahamas to Africa from the surface to 1000m computed from SURCOUF3D and the Ekman transport (Sv) from Bahamas to Africa computed using ERA-Interim reanalysis and Florida current transport monitoring using cable measurements. In black: volume transport from Florida to Africa and from the surface to 1000m computed with GLORYS. In blue: AMOC computed from RAPID-MOC data (Hirschi et al., 2003, Cunningham et al., 2007). In green: AMOC computed by Bryden et al, 2005. Thin lines are monthly average. Dots are yearly average (January to December). Triangles are incomplete yearly average (April to December in 2004 and January to September in 2007) to be coherent with RAPID-MOC data.

Conclusion

Here we present global ocean indicators reflecting the state of the ocean and its changes during the years 2004-2008. A global uniform field of gridded temperature and salinity measurements is used to derive those indicators. We find global rates of 0.65±0.13 Wm^{-2} for heat storage, 2700±1400 km^3 for freshwater content and 0.95±0.2 mm/yr for steric sea level. Freshwater content is dominated by interannual fluctuations. Areas of a positive trend of steric sea level - which contribute to the global steric rise – occur in all basins and dominate the Pacific Ocean.

Recently, the Argo array is fully developed and produces a uniform monitoring of the global ocean, thus reducing errors caused by undersampling and revealing consistent and accurate estimates of the ocean state. The global ocean indicators presented here will be updated every year from reprocessed and delayed mode data. With the growing data set of Argo a long-term and robust description of the state of the ocean and its changes will thus be available. The basic material to assess global indicators includes reprocessed data which have been mapped on a regular grid using statistical assumptions. Therefore, the sensitivity of ocean indices with respect to data processing and different types of measurements need to be tested which is the objective of present and future research of Mercator Ocean and Coriolis.

A second GLORYS1 experiment is in progress using reprocessed data (CORA02V2) as well as improvements such as bias correction, the use of a new MDT, a more recent version of NEMO and a new atmospheric surface forcing (INTERIM Reanalysis). ARIVO and GLORYS (which also include model experiments without data assimilation), together with ARMOR3D, SURCOUF3D all with different approaches make an optimal use of this unprecedented well observed period starting with the ARGO network. Observed products help to validate and improve the models and reanalyses, and reanalyses influence the reprocessing of observations or the design of new observation networks. Moreover, comparing observed products - for instance indicators - with reanalysis products yields a better understanding of the limitations of each approach.

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References

Antonov J., S. Levitus and T. Boyer, 2002: Steric sea level variations during 1957-1994: Importance of salinity, Journal of Geophysical Research, 107, doi:10.1029/2001JC000964.

Antonov J., S. Levitus and T. Boyer, 2005: Thermosteric sea level rise, 1955-2003, Geophysical Research Letters, 32, L12602, doi:10.1029/2003GL018851.

Antonov J., R. Locarnini, T. Boyer, A. Mishonov and H. Garcia, 2006: World Ocean Atlas 2005, vol. 2, Salinity, NOAA Atlas NESDIS, 62, edited by S. Levitus, 182 pp., NOAA, Sivler Spring, Md.

Benkiran M. and E. Greiner, 2008: Impact of the Incremental Analysis Updates on a Real-Time System of the North Atlantic Ocean. Journal of Atmospheric and Oceanic Technology 25(11): 2055.

Bindoff N.L., J. Willebrandt, V. Artale, A. Cazenave, J. Gregory, S. Gulev, K. Hanawa, C. Le Quéré, S. Levitus, Y. Nojiri, C.K. Shum, L.D. Talley and A. Unnikrishnan, 2007: Oceanic Climate Change and Sea Level. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solmon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Böning C., A. Dispert, M. Visbeck, S. Rintoul and F. Schwarzkopf, 2008: The response of the Antarctic Circumpolar Current to recent climate change, Nature Geoscience, 1, 864-869, doi:10.1038/ngeo362.

Boyer T., S. Levitus, J. Antonov, R. Locarnini and H. Garcia, 2005: Linear trends in salinity for the world ocean, 1955-1998, Geophysical Research Letters, 32, L01604, doi :10.1029/2004GL021791.

Boyer T., S. Levitus, J. Antonov, R. Locarnini, A. Mishow, H. Garcia and S. Josey, 2007: Changes in freshwater content in the North Atlantic Ocean 1955-2006, Geophysical Research Letters, 34, L16603, doi :10.1029/2007GL030126.

Bloom S. C., L. L. Takacs, A. M. DaSilva, and D. Levina, 1996: Data assimilation using incremental analysis updates, Monthly Weather Review, 124, 1256–1271.

Bretherton F., R. Davis and C. Fandry, 1976: A technique for objective analysis and design of oceanic experiments applied to Mode-73, Deep-Sea Research, 23, 559-582.

Bryden H. L., H. R. Longworth, and S. A. Cunningham, 2005: Slowing of the Atlantic meridional overturning circulation at 25°N, Nature, 438, 655-657.

Cazenave A., K. Dominh, S. Guinehut, E. Berthier, W. Llovel, G. Ramilien, M. Ablain and G. Larnicol, 2009: Sea level budget over 2003-2008: A reevaluation from GRACE space gravimetry, satellite altimetry and Argo, Global Planet Change, 65, 83-88.

Crosnier L., M. Drévillon, S. Buarque and F. Soulat, 2008: Three ocean state indices implemented in the Mercator-Ocean operational suite, ICES Journal of Marine Science, 65: 1504–1507.

Cunningham S. A., T. Kanzow, D. Rayner, M. O. Baringer, W. E. Johns, J. Marotzke, H. R. Longworth, E. M. Grant, J. J.-M. Hirschi, L. M. Beal, C. S. Meinen, H. L. Bryden., 2007: Temporal variability of the Atlantic Meridional Overturning Circulation at 26.5°N, Science, 317, 935-938.

Curry R., B. Dickson and I. Yashayaev, 2003: A change in the freshwater balance of the Atlantic Ocean over the past four decades, Nature, 426, 826-829.

Delcroix T., S. Cravatte and J. McPhaden, 2007: Decadal variations and trends in tropical Pacific sea surface salinity since 1970, Journal of Geophysical Research, 112, C03012, doi:10.1029/2006JC003801.

Gaillard F., E. Autret, V. Thierry, P. Galaup, C. Coatanoan and T. Loubrieu, 2008: Quality control of large Argo data sets, Journal of Atmospheric and Ocean Technology, 26, 337-351, doi: 10.1175/2008JTECHO552.1.

Guinehut S., P.Y. Le Traon, G. Larnicol and S. Philipps, 2004: Combining Argo and remote-sensing data to estimate the ocean three-dimensional temperature fields – a first approach based on simulated observations, J. Mar. Sys., 46, 85-98.

Guinehut S., P.Y. Le Traon, and G. Larnicol, 2006: What can we learn from Global Altimetry/Hydrography comparisons, Geophysical Research Letters, 33, L10604, doi:10.1029/2005GL025551.

Ferry N., Parent L., Garric G., Barnier B., Jourdain N. C. and the Mercator Ocean team, 2010: Mercator Global Eddy Permitting Ocean Reanalysis GLORYS1V1: Description and Results. Mercator Ocean Quarterly Newsletter #36, January 2010, 15-27. http://www.mercator-ocean.fr/documents/lettre/lettre_36_en.pdf

Forget G. and C. Wunsch, 2007: Estimated global hydrographic variability, Journal of Physical Oceanography, 37, 1999-2008.

Hammond A., A. Adriaanse, E. Rodenburg, D. Bryant and R. Woodward, 1995: Environmental indicators: a systematic approach to measuring and reporting on environmental policy performance in the context of sustainable development. Worl Resource Institute, Washington, DC.

Hansen J., L. Nazarenko, and R. Ruedy, and M. Sato, and J. Willis, and A. Del Genio, and D. Koch, and A. Lacis, and K. Lo, and S. Menon, and T. Novakov, and J. Perlwitz, and G. Russell, and G.A. Schmidt, and N. Tausnev, 2005: Earth's Energy Imbalance: Confirmation and Implications, Science, 308, 1431-1435, doi:10.1126/science.1110252.

Hirschi J., J. Baehr, J. Marotzke, J. Stark, S. A. Cunningham and J. O. Beismann, 2003: A monitoring design for the Atlantic meridional overturning circulation, Geophysical Research Letters, 30, No 7, doi:10.1029/2002GL016776.

Kessler W., 1998: Interannual variability of the subsurface high salinity tongue south of the equator at 165°E, Journal of Physical Oceanography, 29, 2038-2049.

Le Sommer J., T. Penduff, S. Theetten, G. Madec, B. Barnier, 2009: How momentum advection schemes influence current-topography interactions at eddy permitting resolution, Ocean Modelling, 29, 1-14. doi:10.1016/j.ocemod.2008.11.

Leuliette E.W. and L. Miller, 2009: Closing the sea level rise budget with altimetry, Argo, and GRACE, Geophysical Research Letters, 36, L04608, doi:10.1029/2008GL036010.

Levitus S., J.I. Antonov and J. Wang and T.L. Delworth and K.W. Dixon and A.J. Broccoli, 2001: Anthropogenic Warming of the Earth's Climate System, Science, 292, 267-270, doi:10.1126/science.1058154

Levitus S., J. Antonov, and T. Boyer, 2005: Warming of the World Ocean, 1955-2003, Geophysical Research Letters, 32, doi:10.1029/2004GL021892

Levitus, S., J. Antonov, T. Boyer, R. Locarnini, H. Garcia and A. Mishonov, 2009 : Global ocean heat content 1955-2007 in light of recently revealed instrumentation problems, Geophysical Research Letters, 36, L07608, doi:10.1029/2008GL037155.

Liebelt P., 1967: An introduction to optimal estimation, Addison-Welsey, 267-269.

Locarnini R., A. Mishonov, J. Antonov, T. Boyer, and H. Garcia, 2006: World Ocean Atlas 2005, vol. 1, Temperature, NOAA Atlas NESDIS, vol. 61, edited by S. Levitus, 182 pp., NOAA, Silver Spring, Md.

Lombard A., A. Cazenave, K. DoMinh, C. Cabanes and R.S. Nerem, 2005: Thermosteric sea level rise for the past 50 years; comparison with tide gauges and inference on water mass contribution. Global and Planetary Change, 48, 303-312.

Lombard A., D. Garcia, G. Ramillien, A. Cazenave, R. Biancale, J.M. Lemoine, F. Flechtner, R. Schmidt and M. Ishii, 2007: Estimation of steric sea level variations from combined GRACE and Jason-1 data. Earth and Planetary Science Letters, 254, 194-202.

Madec G., 2008: NEMO ocean engine. Note du Pole de modélisation, Institut Pierre-Simon Laplace (IPSL), France, No 27, pp205. ISSN No 1288-1619.

Peltier W.R., 2004: Global Glacial Isostasy and the Surface of the Ice-Age Earth: The ICE-5G (VM2) Model and GRACE, Ann. Rev. Earth and Planet. Sci., 32, 111-149.

Pham D. T., J. Verron and M. C. Roubaud, 1998: A singular evolutive extended Kalman filter for data assimilation in oceanography. J. Mar. Sys., 16, 323-340.

Reverdin G., E. Kestenare, C. Frankignoul and T. Delcroix, 2007: Surface salinity in the Atlantic Ocean (30°S-50°N), Progress of Oceanography, 73, 311-340.

Reynolds R. W. and T. M. Smith, 1994: Improved global sea surface temperature analyses using optimum interpolation, Journal of Climate, 7, 929-948.

Rio M.-H., and F. Hernandez, 2004: A mean dynamic topography computed over the world ocean from altimetry, in situ measurements, and a geoid model, Journal of Geophysical Research, 109, C12032, doi:10.1029/2003JC002226.

Rio M. H., P. Schaeffer, 2005: The estimation of the ocean mean dynamic topography through the combination of altimetric data, in-situ measurement and GRACE geoid, Proceedings of the GOCINA international workshop, Luxembourg.

Roemmich D. and the Argo Science Team, 1999: On the design and implementation of Argo: An initial plan for a global array of profiling floats. International CLIVAR Project Office Report 21, GODAE Report 5. GODAE International Project Office, Melbourne, Australia, 32 pp.

Roemmich D., J. Gilson, R. Davis, P. Sutton, S. Wijffels, and S. Riser, 2007: Decadal spin-up of the South Pacific subtropical gyre, Journal of Physical Oceanography, 37, 162-173.

Von Schuckmann K., F. Gaillard and P.-Y. Le Traon, 2009, Global hydrographic variability patterns during 2003-2008, Journal of Geophysical Research, 114, C09007, doi:10.1029/2008JC005237.

Tomczak M. and J.S. Godfrey, 1994: Regional Oceanography: An Introduction, Pergamon, New York, 21-24.

Willis J., D. Chambers and R. Nerem, 2008: Assessing the globally averaged sea level budget on seasonal to interannual timescales, Journal of Geophysical Research, 113, C06015, doi:10.1029/2007JC004517.

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ANDRO: AN ARGO-BASED DEEP DISPLACEMENT ATLAS

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Abstract

During the first decade of the 21st century, approximately 6000 Argo floats have been launched over the World Ocean, gathering temperature and salinity data of the top 2000 m, at a 10-day or so sampling period. Meanwhile their deep displacements over 8 or 9 days can be used to map the ocean circulation at their drifting depth (mostly around 1000 m). A comprehensive processing of the Argo data collected has been done to produce a world atlas (named ANDRO) of deep displacements fully checked and corrected for possible errors found in the public Argo data files (due to wrong decoding or instrumental failure). So far, 75% (to be updated soon) of the world data has been processed to generate the present ANDRO displacements (which are based only on Argos surface locations). In a future version, improved deep displacement estimates will be based on float surfacing and diving estimated positions.

Introduction

Building on the knowledge accumulated from subsurface acoustic floats, particularly during the last decade of the 20th century, profiling floats measuring Pressure, Temperature and Conductivity (or Salinity) while rising to the surface, were developed to be used within the framework of the Argo program. Argo aims at measuring the physical state of the global ocean (actually T and S in the upper 2000 m) with a synoptic array of roughly 3000 floats (thus approximately with a 300 km resolution with floats launched uniformly) cycling every 10 days (generally), and over a period of several years (possibly one or two decades). Float launchings began in 1999, but the number of 3000 floats working at sea at the same time was reached only in 2007 (by and large the uniform distribution of floats over the ocean was also attained). Since floats live only a few years, new ones have to be launched regularly to maintain the array of 3000 floats. Most floats have no acoustic tracking but new models can now measure O_2 and soon other climate related parameters such as pCO_2 (partial pressure of CO2 in the ocean) for example.

A primary objective of Argo was to provide a quantitative description of the changing state of the upper ocean and the patterns of ocean climate variability from months to decades, including heat and freshwater storage and transport.

It appeared soon however that the float displacements at depth (roughly 8 days and a half over a 10 days total cycle time) could provide estimates of absolute velocity (averaged over the displacement times) all over the world with an approximate 10-day sampling period. Although such a velocity field is mainly restricted to one depth (1000 m), if the estimates are accurate enough, it may solve the long-standing problem of the reference level (Wunsch, 2008 e.g.) for the first time. As far as the mean circulation is concerned the accuracy of the velocity estimates is quite sufficient (Ollitrault et al., 2006, e.g.) but may be questionable for studies focusing on monthly variations and in specific areas (as the equatorial band). Errors on deep velocities come mainly from Argos location uncertainties and to a lesser extent from unknown advection during diving and surfacing (Davis and Zenk, 2001).

Yoshinari, Maximenko and Hacker (2006) first produced an atlas of velocity estimates (so called YoMaHa'05) by using the then available Argo data. YoMaHa'07 (Lebedev et al., 2007) is a regularly updated version (available at http://apdrc.soest.hawaii.edu/projects/Argo/data/trjctry/). This atlas uses Argo data from the public NetCDF files found on the Global Data Assembly Center (GDAC) websites (http://www.coriolis.eu.org/ or http://www.usgodae.org/argo/). Generally float displacements from YoMaHa'07 looks quite realistic. But a few percent show high speed or have drifting depth obviously wrong (if they are found drifting over the continental shelf while their drifting depth is given as 1000 m, for example).

This convinced us to look more closely into the Argo data (and if possible to start anew from the very first ARGOS raw data received at the different Data Assembly Centers (DAC)) for checking and (if necessary) correcting the various parameters measured by the floats and used to estimate the float displacements.

We present here what we have done so far with the three largest data sets from Atlantic Oceanographic and Meteorological Laboratory (AOML, USA), Coriolis (France) and Japan Meteorological Agency (JMA, Japan) DACs (80% of the world data). First the various floats used are presented: functioning, parking data measurement and transmission. Then the processing done on DAC NetCDF files and (available) Argos raw ASCII files is explained. In the third part, we present our deep displacement (velocity) atlas named ANDRO (for Argo New Displacements Rannou and Ollitrault, or because it is the name of a traditional dance of Brittany meaning a round or a swirl), resulting from our processing of Argo data. A last section explains what could be done to improve the deep displacement estimates.

The various Argo Floats

There are three main types of Argo floats: APEX, SOLO and PROVOR contributing 61%, 26% and 11% respectively to the total number of Argo floats used since 1999. A few other float designs have been developed (for example NEMO in Germany, PALACE in USA or NINJA in Japan) but contribute only 2%.

APEX float

The APEX float is designed and manufactured by Webb Research Corporation (USA). It uses an aluminum pressure case (16.5 cm diameter and 130 cm long) and a hydraulic mechanism to stabilize it at a prescribed depth. Each instrument is tailored and its mission programmed by the manufacturer, depending on the final user desires but without any intervention of him.

Four parameters are essential for the APEX mission: DOWN TIME which comprises the descent from the surface, the float drift at its park pressure and the (possible) descent to its deepest profile pressure, UP TIME which comprises the ascent from the deepest profile pressure and the surface drift with the ARGOS (or Iridium) transmission, PARK PRESSURE and DEEPEST (profile) PRESSURE. Thus APEX cycles are DOWN TIME + UP TIME long. Prior to the first dive, APEX stays for 6 hours at surface and transmits continually a test message, which contains the mission parameters. Then the float begins its mission proper, cycling until battery exhaustion. At the end of each cycle, a number of data messages (approximately proportional to the profile size) are sent repeatedly for several hours (usually 12h).

During the drifting phase, APEX regularly measures P,T and S (Pressure, Temperature and Salinity) triplets but only the last one (sampled at parking phase end) is transmitted. Newer APEX versions, however, also transmit statistics for P, T and S regularly sampled during the parking phase. Because APEX floats have evolved since the beginning of Argo, there are many firmware versions. Presently we have developed 43 APEX decoders (all with Argos transmission).

SOLO floats

The SOLO floats come in two models: the WHOI SOLO developed at the Woods Hole Oceanographic Institution on the East coast of USA and the SIO SOLO developed at the Scripps Institution of Oceanography in California (both models contributing equally to the Argo fleet). These floats share the same pressure case with APEX. However each float mission must be programmed by the user.

For WHOI SOLO, each cycle is exactly N days long (10 days generally) and the time reference is at the beginning of the parking phase which is always at 0h (or midnight), when the float is supposed to have reached its park pressure. The drift phase is Dr hours long (generally Dr=8 days and 5 h). Then the float descents to its DEEPEST (profile) PRESSURE, which should be reached within Dm hours (generally Dm=4 h). Thus, with the example given, the float ASCENT START is 8 days and 9 h after DESCEND END, whether or not the deepest profile pressure was reached. The time necessary for profiling is quite similar to that for APEX since the vertical float velocity is also of the order of 10 cm s^{-1}, but is not known precisely (same for APEX). Argos transmission lasts exactly Su hours (generally Su=12 h). During the drift phase, the float acquires 6 P, T and C (Conductivity) (or S) triplets, if equipped with FSI (Falmouth Scientific, Inc) or SBE (Sea-Bird Electronics) sensors. The first and last triplets are taken at the beginning and end of the parking phase (thus 8 days and 5 h apart in our example). The four other triplets are measured 1day 1h, 3days 1h, 5days 1h and 7days 1h after the reference time. These are averages over the previous intervals.

There are three types of Argos messages: one for profile data, one for drift data and one for engineering data. The engineering message contains P, T and C (or S) at beginning and end of the drift phase, given in full range. In the drift message instead, the four other P, T and C (or S) triplets are given as remainders modulo 409.6 dbar, 4.096° C and 1.024 PSU (or mS cm^{-1}) respectively.With each of these four triplets, a very useful parameter is also given modulo 4096: the variation of volume of the float DV counted as number of turns of the piston driver. Actually, ΔPark Pres = 0.75 *DV to a high accuracy, and this enables to solve the modulo uncertainties on the pressures measured during the drift phase.

The SIO SOLO functioning is rather different of the WHOI SOLO. All times except the rise time (for profiling) are fixed. For example with a mission at 1000 dbar (parking depth), the fall time is generally 500 min, followed always by two repositioning phases 5 h each (to get closer to the prescribed depth). The park time proper lasts 20 times a sampling interval (generally 20 times 557 min). Descend to deepest profile pressure is always 5h long, after which the float ascends as fast as it can by moving out its piston completely (a 1000 m rise takes roughly 2 h but this is slightly variable). Then the float emits to Argos for a fixed duration (e.g. 18 h). While drifting at its parking depth, 20 measurements of P, T and S are acquired but only the averages for the first and second halves are transmitted.

There are two different message types: Data message for P, T and S measurements taken either during the parking or the profiling phases, and Engineering message for various parameters of the float functioning. Presently we have developed 2 WHOI SOLO and 3 SIO SOLO decoders (all with Argos transmission).

PROVOR float

This float is designed and manufactured by NKE (previously TEKELEC then MARTEC) in partnership with IFREMER. It is slightly taller (1.60 m) than its American counterparts. Each instrument mission must be programmed by the user.

Each cycle is N days long and the reference time is at the beginning of the ascending profile (the day and hour of the reference time is programmable). PROVOR is controlled hydraulically to follow its park pressure within 30 dbar and does P, T and S measurements every H hours (generally every 12 h) while drifting. All these measures are transmitted and many are dated by the float clock. PROVOR ascent velocity is of the order of 10 cm s^{-1}.

PROVOR messages are of two types: technical and data messages. Technical messages contain information about the float functioning. Data messages come in three types: one for descending profile (if required), an other one for the parking phase and a last one for ascending profile data. In each data message, there are between 5 and 7 P, T and S triplets with the first triplet dated. Presently there are 18 different PROVOR versions using Argos transmission and 5 versions using Iridium.

Data processing

From the NetCDF public Argo files, we first generate a data set (called DEP in the following) comprising all the useful information given by the various floats. Then the data are checked, corrected and improved with extra information kindly provided by the DACs (float documentations, mission programming, etc…) or through a decoding of the original Argos raw ASCII files. Some complementary estimated data are also added. The final data set is then used to generate our ANDRO deep displacements atlas.

DEP data set creation

ASCII DEP files (there is one file for each float) are created from the public NetCDF (meta.nc, traj.nc, prof.nc and tech.nc) files. Argos positions, dates and location classes come from the traj.nc files together with the (real time) P, T and S measurements during the parking phase. Real time P, T and S values sampled during profile come from prof.nc files. A few other measurements or data are recovered from the meta.nc and tech.nc files, to be used in the future (for an improved version of ANDRO, discussed at the end of the paper).

Argos raw data pre-processing

In order to check and improve the DEP data set, we asked the DACs for providing the original Argos raw data. All Argos data from each DAC are first concatenated to be sorted afterwards by Argos PTT number. Then WMO float numbers are attributed to the data (sometimes one Argos PTT may have been consecutively shared by two or more different WMO numbers). Finally, the data are split into different cycles (there is one Argos raw data file for one received float cycle).

Additional Argos locations

Examination of the Argos raw data files revealed that some Argos locations are not found in the traj.nc files. Missing positions were added in the DEP files (sometimes improving the accuracy of existing ones because of a better location class).

Argos Data decoding

At the beginning of our work (in 2007) we discovered several errors on physical parameters given in the NetCDF files possibly due to unreliable decoding (for example roll-over errors for P, T and S parking values). Thus, we decided to decode anew the Argos raw data (the DACs provided roughly 95% of the whole Argo data). Newly decoded park and profile P, T and S values are then added to the DEP files (they replace existing ones).

All floats (except SIO SOLO) have an error detection code imbedded in the Argos messages (called CRC for Cyclic Redundancy Check) that we have used to reject possibly corrupted messages. Furthermore among all the received copies of a one transmitted message, the most redundant one is preserved.

Meta data check

At this stage, we are able to check the following parameters given in the meta.nc files:

- REPETITION_RATE which gives the number of times the float does the same cycle mission (defined by fixed CYCLE_TIME, PARKING_PRESSURE and DEEPEST_ PRESSURE parameters),
- CYCLE_TIME (theoretical cycle duration),
- PARKING_PRESSURE (theoretical subsurface drifting pressure),

- DEEPEST_PRESSURE (theoretical starting pressure of ascending profile).

These parameters (corrected if necessary) are stored in a separate file to be used in the following steps.

Representative park pressure

For each cycle, we determine a realistic estimate of the float parking depth, which is very important if we want to use Argo float deep displacements to track water motions. This Representative Park Pressure (RPP) is computed as follows:

- If the float provides regularly sampled park pressure values, RPP is the average value,
- If the float only provides the mean of the (regularly sampled) park pressures, it is RPP,
- If the float provides only one park pressure (generally sampled at the end of the drifting phase), it is RPP,
- If the float provides the minimum and maximum pressures sampled during the drifting phase, RPP is the middle value,
- If no pressure measurement is available during the drifting phase, RPP is given by the theoretical PARKING_PRESSURE value (in this case we need to check if the local bathymetry is not shallower and if the induced deep velocity seems realistic).

Then a systematic visual check on the RPP time-series is done to detect possible errors due to float pressure transducer ill function (mostly on APEX) or transmission error. Existing RPP values are then replaced by: a default value if the RPP is not correctable, 0 dbar if the float is obviously at the surface, the theoretical PARKING_PRESSURE if the float seems to be working nominally.

Cycle number

In order to be reliable for scientific use, a deep displacement must be defined between two **consecutive** cycles. Thus it is very important to be confident in the cycle number. The check is easy with the APEX floats because they transmit the cycle number in one Argos message. For all the other floats, we need to cross check the Argos location dates with the CYCLE_TIME parameter.

Unusable cycles

If a float hits the bottom while drifting, it is considered grounded, and this cycle will be excluded from our ANDRO atlas. Grounded cycles are detected by comparing RPP with a precise local bathymetry (SRTM30+ worldwide bathymetric atlas available at http://topex.ucsd.edu/WWW_html/srtm30_plus.html). Some floats are recovered at sea or after beaching, while still functioning. The corresponding cycles are deleted from the DEP files.

ANDRO generation

From the final DEP files, one then generate the ANDRO atlas, which basically contains the deep displacement estimates defined as the distance between the last Argos fix and the first Argos fix of two consecutive cycles. Only Argos location classes of 1, 2 or 3 (i.e. with 1km, 350m or 150m accuracy) are used. Furthermore only those Argos positions that pass the Nakamura et al. (2008) test are preserved. Grounded cycles are also excluded by the generating process.

ANDRO actual contents

ANDRO atlas is available as an ASCII file (containing 28 columns) whose format is identical to YoMaHa'07 (except we use WMO number instead of their float ID). Thus, in ANDRO, one finds float depths, deep and surface displacements, times, deep and surface associated velocities with their estimated errors.

Presently, ANDRO contains data from AOML, Coriolis and JMA from the beginning of the Argo program (July 1999) until December 31st 2008 (later versions of ANDRO will cover following years). There are a total of 3624 floats contributing 315820 displacements (over 326185 cycles done). Table 1 gives the numbers of displacements within five pressure intervals and figure 1 shows the actual depth repartition.

Parking pressure (dbar)	Number of displacements (3624 floats)	
0 ≤ P ≤ 250	11 570	3.7%
250 < P ≤ 750	11 472	3.6%
750 < P ≤ 1250	248 697	78.7%
1250 < P ≤ 1750	31 725	10.0%
1750 < P ≤ 2250	9 294	2.9%
Undefined	3 062	1.0%
Total	315 820	

Table 1

ANDRO atlas displacement depth repartition

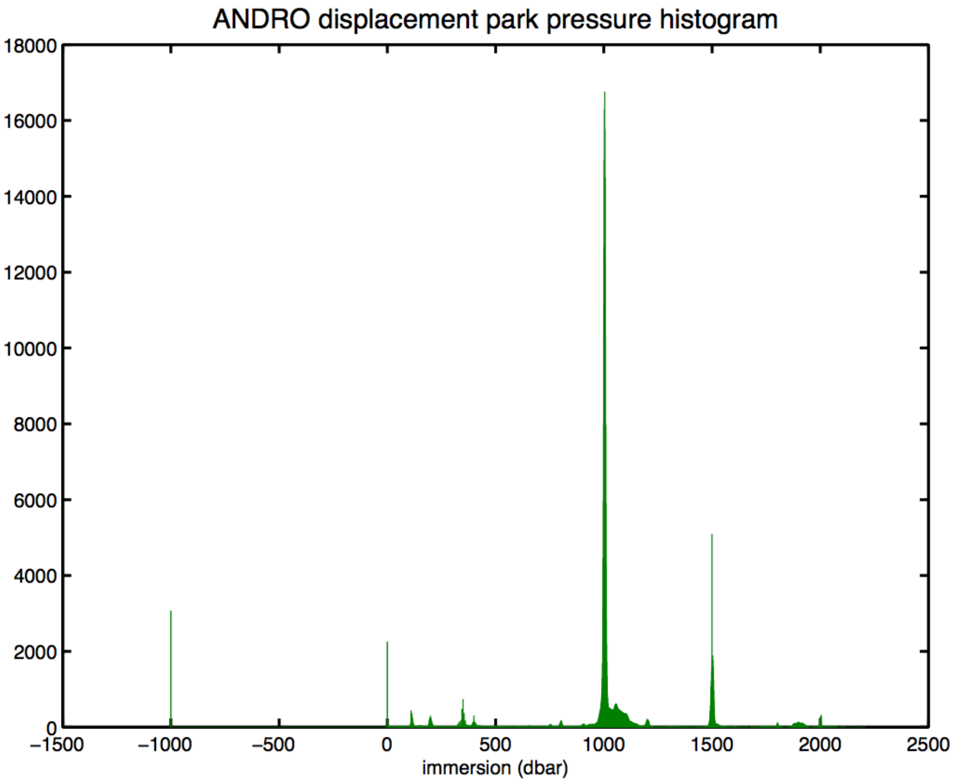

Figure 1

ANDRO displacement depth repartition. Ordinate gives the number of displacements within 1dbar layers. Unknown depths are defaulted to –999.9.

Figures 2 and 3 below show the 750-1250 dbar displacements in the Northeast Atlantic and over the world Ocean respectively. The first displacement for a given float is plotted as a red arrow.

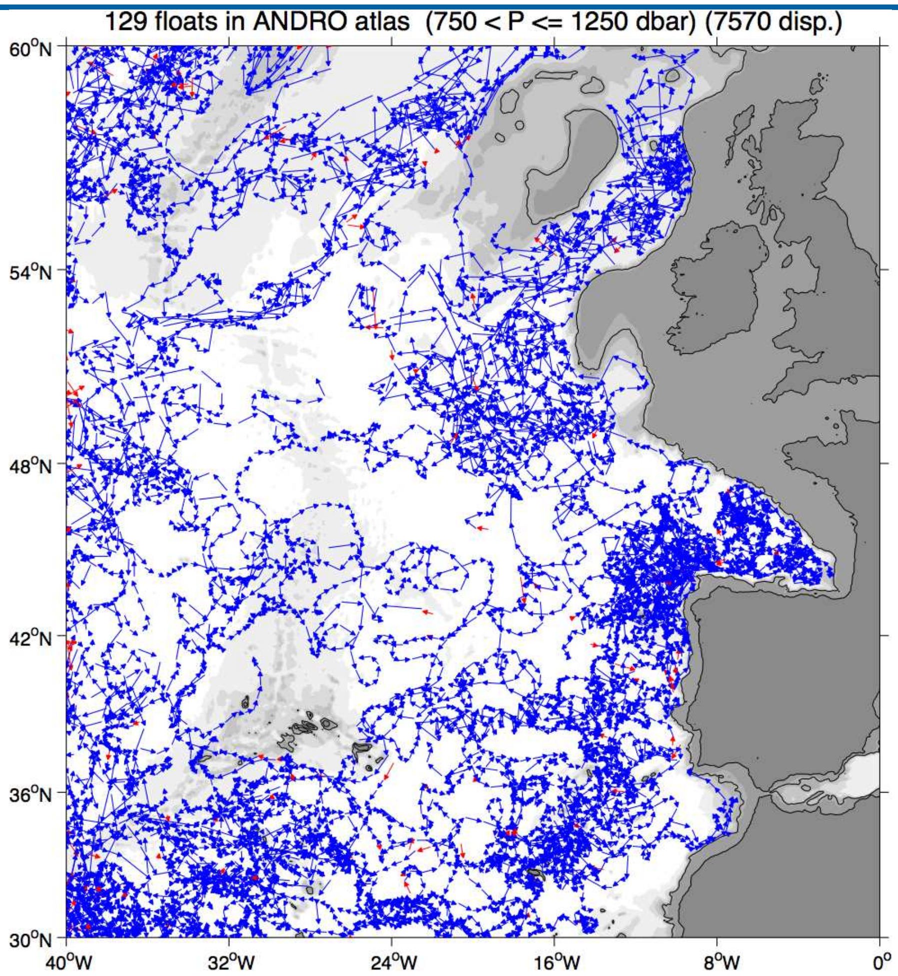

Figure 2

ANDRO float displacements around 1000 m depth (750-1250 dbar layer). Red arrow corresponds to the first displacement of a given float.

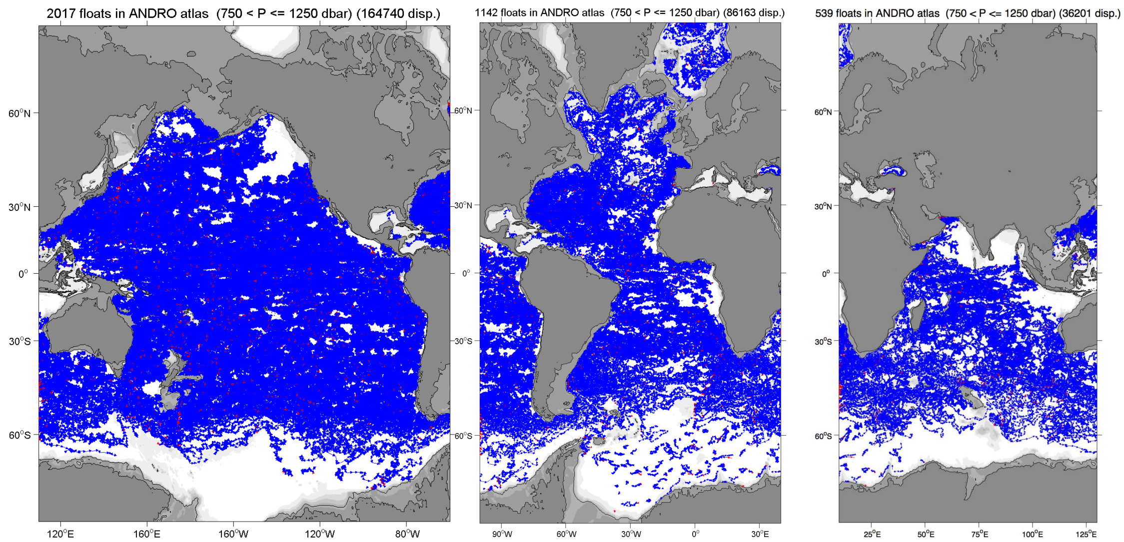

Figure 3

Actual ANDRO world displacement atlas for the 750-1250 dbar layer.

Towards better deep displacement estimates

The actual deep displacement estimation relies only on Argos locations. However, Argo floats are not (generally) located when they do surface (or dive), but slightly later (or sooner) implying possibly a few km error on the deep displacement estimated, if the delay is of one hour or two.

In order to estimate the true surfacing or diving positions, one needs to determine first the corresponding times, to then extrapolate the surface float trajectory (sampled by the Argos locations) at these times. For most of the floats, the surfacing time can be precisely estimated (within a few minutes), contrary to the diving time, for which one can use the envelope method proposed by Park et al. (2005). We have presently estimated these times for all floats except the SOLOs.

The extrapolation can be done, for example, by fitting a uniform velocity and a circular inertial motion to the Argos fixes (Park et al., 2004). We have tested this method on 750 floats, but with partial success (consequently, those estimates have not been saved in the DEP files yet). Figure 4 gives an example of such an extrapolation (with a good fit), showing a large distance (13 km) between surfacing and the first Argo fix. Fortunately this is not representative of the general case: our study with 750 floats gives an average delay (after surfacing or before diving) of 80 ± 60 min corresponding to an average 1.5 ± 1.5 km error. This would imply an average 3 mm s^{-1} on deep velocity. If one considers also Argos position uncertainties and position change during ascent/descent, the final error may be of the order of 1 cm s^{-1}.

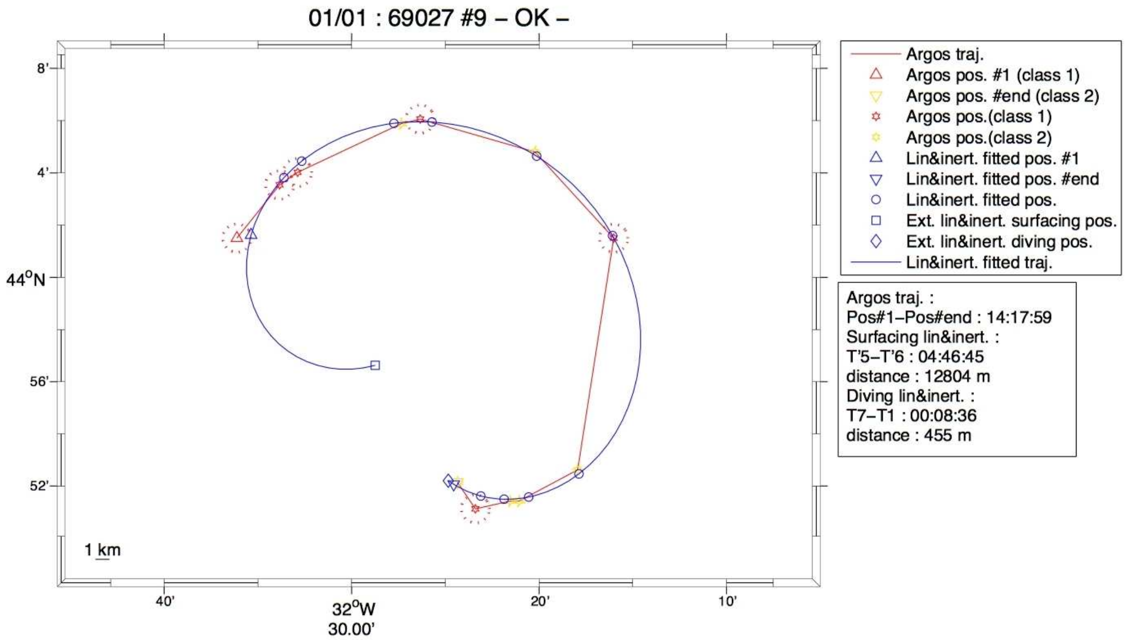

Figure 4

Least square fit of a uniform velocity plus a circular inertial motion on Argos fixes, with extrapolated surfacing and diving positions. Dotted circles are Argos location 1 σ uncertainty.

A second planned improvement will consist in estimating the current shear between the surface and the parking depth, in order to be able, using a modeled vertical float velocity, to integrate the horizontal motion of the float during descent and ascent. An upper bound of the correction (Davis and Zenk, 2001) would be 2 mm s^{-1} (estimated with a 50 cm s^{-1} shear over the upper 400 m).

Conclusion

All ANDRO atlas displacement depths are in-situ measured values. YoMaHa'07 displacement depths are the programmed ones (copied from the meta.nc files), implying erroneous drifting depths for almost 10% of the displacements (even with perfectly filled meta files, 3% would remain, due to instrument ill function).

Thanks to the Argos raw data provided by the DACs, we have been able to get rid of decoding errors and to concentrate on the float functioning proper. Furthermore we have slightly enlarged the Argo data set with cycles not publicly available (for unknown reason to us).

Meanwhile, the DACs progressively update their NetCDF data files, as a result of our work. Since YoMaHa'07 atlas is regenerated periodically, the differences between ANDRO and YoMaHa'07 will tend progressively towards 3%. During this year, the same treatment we did on AOML, Coriolis and JMA data will be done on the Argo data of all the other willing DACs. After completion, the ANDRO atlas (covering the period July 1999 to December 2008) will be freely available on Coriolis website by the end of 2010.

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References

Davis, R.E. and Zenk W. 2001: Subsurface Lagrangian observations during the 1990s. International Geophysics Series vol. 77, 123-139.

Lebedev, K.V., Yoshinari, H., Maximenko, N.A. and Hacker, P.W. 2007: YoMaHa'07-Velocity data assessed from trajectories of Argo floats at parking level and at the sea surface. IPDC Tech. Note n°4(2).

Nakamura, T., Ogita, N. and Kobayashi, T. 2008: Quality control method of Argo float position data. JAMSTEC Report of Research and Development. 7, 11-18.

Ollitrault, M., Lankhorst, M., Fratantoni, D., Richardson P. and Zenk, W. 2006: Zonal intermediate currents in the equatorial Atlantic Ocean. Geophys. Res. Letters. 33, L13307, doi:10.1029/2005GL025368.

Park, J.J., Kim, K. and Crawford, W.R. 2004: Inertial currents estimated from surface trajectories of ARGO floats. Geophys. Res. Letters. 31, L13307, doi:10.1029/2004GL020191.

Park, J.J., Kim, K., King, B.A. and Riser, S.C. 2005: An advanced method to estimate deep currents from profiling floats. J. Atmos. and Ocean. Tech. 22, 1294-1304.

Wunsch, C. 2008: The past and future Ocean circulation from a contemporary perspective. AGU Geophysical Monograph 173, 53-74.

Yoshinari, H., Maximenko, N.A. and Hacker, P.W. 2006: YoMaHa'05-Velocity data assessed from trajectories of Argo floats at parking level and at the sea surface. IPDC Tech. Note n°4.

BI-DIRECTIONNAL SATELLITE COMMUNICATIONS ON NEW PROFILING FLOATS.

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Introduction

Argos is the well known satellite communication system which has been used for several years for profiling float applications. It fits the need for ocean global coverage, combined with open seas, as spending a few hours at surface to transmit data is acceptable for such applications. Several new requirements appeared these last years for profiling float applications:

- First, the performances of these instruments, for Argo deployments, could be affected in marginal seas where specific requirements are needed. In particular, it is critical to reduce the transmission time at surface to lower the risk of thefts, trawling or impacts in these highly trafficked seas, to delay the time for beaching on the shores, and to have better estimates of subsurface currents with a given reduced cycling period (e.g. 5 days).
- For coastal applications, one main objective is to realize successive profiles at the same location in order to delay beaching. The float is on standby between each profile, standing on the sea floor. It behaves as a "virtual mooring". Moreover, in shallow waters, operation at low depth and proximity of the coast increases the development of bio-fouling. These constraints require minimizing the drift of the float at, i.e. reduce the time spent to transmit data.
- The remote control of the float is a major improvement that gives new possibilities to the users, for example to adapt mission parameters to specific events that are monitored. It is now possible on floats by using the downlink capabilities of the satellite transmission systems.

In order to answer to these requirements, we have adapted two recent satellite transmission systems on our floats: Iridium and Argos 3. The first system, Iridium, is a 66 satellites Low Earth Orbit system, which gives a global and permanent earth coverage, with 2 ways communication. Messages transmitted from the float are delivered to the user by email. The Arvor float has been fitted with an Iridium modem coupled with a GPS receiver and a high pressure antenna, for Argo marginal seas requirements. The Arvor-C is dedicated to coastal applications; it has also been equipped with the same communication system.

But the first generation of the Iridium constellation, in operation since 1998, is coming to its end in the next few years, and some satellites will stop their operation before 2014. This will have impacts on the Iridium system coverage, which will not be permanent anymore. Information on this degradation of the system and its impacts are difficult to find. A new program is underway, called Iridium Next. Satellites are planned to be launched between 2013 and 2016, but funds are still to be found! This is why it is important to maintain Argos transmission system and particularly its new generation, Argos 3, on our floats.

The second system, Argos, now offers new improvements. Among the 6 non-stationnary polar orbit satellites, one (Metop-A) is fitted with the operational third generation transmitting system (Argos 3), which gives low and high rate data transfer with acknowledgement, and a two ways communication. This communication mode is being designed in order to be embedded on Arvor, for marginal seasrequirements. In 2011, two other Argos 3 satellites will be launched: Saral and Metop B, and in 2012, Metop C. To sum up, there will be five Argos 3 satellites in operation by the end of 2012. The coverage will not be permanent, but the time interval between two satellites will be highly reduced, which offers interesting perspectives in terms of data transmission performances. This will allow our floats to respond to the new demands as explained before, and will save energy as transmission duration will be reduced.

Moreover, the integration of Argos 3 on Arvor floats only concerns the low data rate transmission of this system. But Argos 3 satellites also embed a high data rate transmission, which is not fully in operation today, but gives perspectives of performance improvements in the near future. Hereafter, we introduce the work done in 2009.

ARVOR: Iridium satellite transmission

All of the standard Arvor specifications have been maintained, and some specific features have been added as following.

The transmitting algorithm has been modified and data has been gathered in 200 bytes SBD (short burst data) messages. The software drivers of the iridium modem and the GPS receiver has been improved (compared to previous one used on ProvBio). The technical message contains more information about the behavior of the float and includes the last CTD raw data before stopping the CTD pump at the end of the rising profile. This is useful for the knowledge of the surface properties. The parameters of the mission (period cycle, parking depth, profile depth…) can be remotely modified during operation by the downlink capability of the satellite transmission.

The first Arvor-i was given to OGS in order to be deployed in the south of Cyprus. It was launched from the Tara ship in early December. The float was programmed to cycle every day from 700 m depth. Up to early march, this float has done 90 cycles. The 2nd float was launched in Adriatic Sea on February 2010 (figures 1 and 2).

Figure 1: Arvor-I

Only 3 minutes are needed to transmit the data when the float is at surface. The total time at surface is around 30 minutes, including the time to increase the buoyancy for good satellite transmission, the duration of the transmission, and then the time spent to reduce buoyancy to start a new cycle (to be compared to more than 8 hours today with Argos). The objective to reduce the time at surface has been reached.

Figure 2

Arvor-I deployement

Arvor-C: A Coastal Autonomous Profiling Float with Seabed Stationing Capability for Real-Time Monitoring of Coastal Seas

A growing number of users, from private individuals to professionals, need forecasts or real time information about the coastal seas. Operational Coastal Oceanography programs require good quality time series of real time *in situ* data, in order to develop numerical models to make predictions, or to provide real time information.

A major breakthrough in coastal observation has been made by Ifremer, the French Research Institute for Exploitation of the Sea. The autonomous profiling float Arvor-C (figure 3) was designed to make repetitive *in situ* measurements along profiles from the seafloor to the surface, providing complete three-dimensional high rate data. The Arvor-C is a vertical untethered profiling float, easy to set up and ready to be deployed. It behaves like a virtual mooring, for short to long term observations. It can take measurements at the same location for each profile thanks to the optimized time of ascent and descent through the water column, the short time of transmission at the surface, and its seabed stationing capability.

In standard mode, the Arvor-C operates autonomously. One of the major features is its Iridium™ satellite bi-directional link: firstly, it offers a fast uplink to transfer data when surfacing after each profile, and secondly, it provides a downlink remote control to reconfigure the mission parameters during operation. For example, users can increase the number of profiles per day and the sensor sampling frequencies when a bloom is detected. The Arvor-C provides a standard set of measurements (pressure, temperature and conductivity), as well as a set of technical information. Multidisciplinary sensors can be integrated on this vertical vehicle, which is designed as an open platform. Additional sensors are being currently fitted to measure dissolved oxygen, turbidity and fluorescence.

The Arvor-C was successfully deployed during the ASPEX cruise in the Bay of Biscay, and it has provided CTD profiles since July 2009. Every cycle, a few minutes at surface are needed to transmit the data.

Figure 3: Arvor-C

ARVOR with Argos3 satellite transmission

In order to have an alternative way to improve communication performances on floats, assessment of the new PMT (Plateform messaging transmitter, supplied by CLS-Argos) has been done. Tools have been designed to understand and evaluate Argos3 performances (figure 4). The aim was to find an appropriate methodology for using Argos3 on floats. The capability of transmitting one profile during one satellite pass has been assessed (less than 15mn).

- An electronic waterproof case has been fitted with one PMT (Argos3 modem) with an aerial antenna and placed on a flat roof at Ifremer to have a clear view of the horizon. It is driven by a computer.
- Evaluation software has been designed to do the trials. The aim was to test random protocol (Argos2 mode), interactive mode (Argos3 low data rate mode) or "pseudo-ack" mode (based on satellite pass predictions). Assessment has been done on transmission performance (error rates, influence of satellite elevation and orientation, power balance, scheduling strategy for the float to surface, using pass prediction tables), and downlink communication.

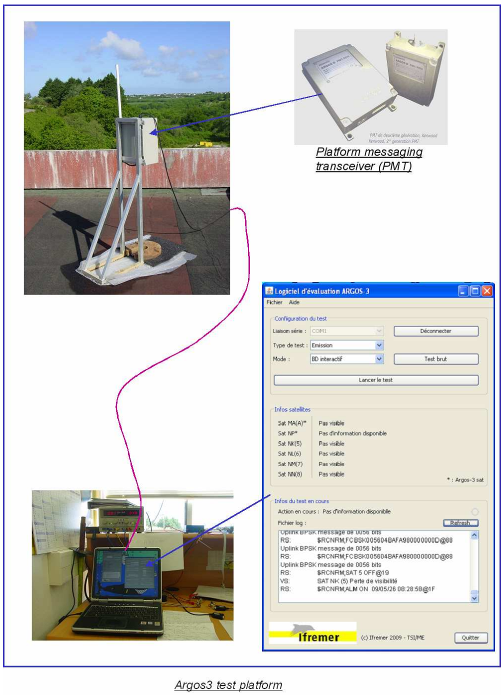

Figure 4: Argos3 test platform

Thanks to these tests, we determined the most suitable algorithm for the implementation in a profiling float. The specifications of the software have been written, using UML description. Finally, the software has been written on the embedded processor target, and partially tested. In other respects, the design of a new double band and pressure resistant antenna has started. The whole test of the embedded software is ongoing using a wide set of transmission configurations. A first lab demonstration was performed at the end of January by transmitting more than 1 kbyte of data, from a float electronics platform, using a unique Argos3 satellite pass. Two Arvor floats should be ready in spring 2010. These floats will be tested in pressure tank and in the pool at Ifremer. Then, they will be deployed in the Mediterranean Sea.

RECOPESCA: A NEW EXAMPLE OF PARTICIPATIVE APPROACH TO COLLECT IN-SITU ENVIRONMENTAL AND FISHERIES DATA

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Abstract

Faced to the lack of data to assess precisely the spatial distribution of catches and fishing effort and for the environmental characterization of the fishing area, Ifremer has implemented since 2005 a new project, Recopesca. It consists in fitting out a sample of voluntary fishing vessels with sensors recording data on fishing effort (and at mid-terms catches) and physical parameters such as temperature or salinity. Recopesca aims at setting up a network of sensors, for scientific purposes, to collect data and improve resources assessment and diagnostics on fisheries, and environmental data required for ecosystem-based management initiatives.

The challenge was to develop sensors with no trouble for the fishermen, tough enough to be fixed up on fishing gears, self powered and autonomous. Insofar as the sample of targeted vessels intends to be representative of all the metiers and fleets, the sensors are modular and scalable to collect new data.

Different sensors have been implemented: (i) a temperature-salinity sensor, able to record physical parameters, depth and duration of immersion, for passive and active gears, and (ii) a specific sensor to record number or length of passive gears. A GPS monitors the position of the vessels and the temperature or salinity profiles and series. Each sensor is equipped with a radio device transferring the data to a receiver on-board, called “concentrator” that sends the data to Ifremer central databases by GPRS. An anti-rolling weigh-scale has been developed and is currently on test to record catches per species and fishing operation. The presentation will show the first data and results of this participative approach.

Introduction

Even if different countries have implemented Fisheries Information System for a few years, especially in relation with the EU Data Collection Regulation (Council regulation (EC) No 1543/2000; Commission regulation (EC) No 1639/2001 modified by Commission regulation (EC) N° 1581/2004), the lack of reliable data to assess precisely the catches and fishing effort is undeniable. The evaluation of fishing effort and catches and their spatial distribution are fundamental to assess the states of exploited resources and to make a diagnosis on fisheries. Data currently available for French fisheries comes mainly from the fishermen’s declaration (log-books), at the scale of ICES statistical rectangles (30 minutes latitude, 1 degree longitude). This scale is inadequate for most research projects and a fine analysis of the fishing sector. Moreover, the coverage of these data is often partial and their reliability sometimes hard to appreciate.

Moreover, the local environmental conditions and their variability, especially on the continental shelf, are often little-sampled, especially because of the specific conditions: low depth, significant current (especially tidal current), various human activities (professional and recreational) making vulnerable the measure devices. Thus, even for basic parameters such as temperature or salinity, most of the available measures are limited to the oceanographic campaigns.

Face to this lack of data, especially on areas which are precisely fishing sectors, Ifremer has been implemented since 2005 a new project, Recopesca, consisting in fitting out a sample of voluntary fishing vessels with sensors recording data on fishing effort (and at mid-terms catches) and physical parameters such as temperature or salinity. Recopesca aims at setting up a network of sensors, for scientific purposes, to collect data allowing improving resources assessment and diagnostics on fisheries, and environmental data required for an ecosystem approach to fisheries (EAF) or to feed oceanographic models e.g. for circulation of water masses. Specific sensors are implemented on the fishing gears and aboard a sample of vessels representative of the whole fishing fleets.

Recopesca is a project of national scale, including overseas island and is a concrete achievement of participative approach: scientists and fishermen team up to give to the voluntary fishermen a role of scientific observer. Recopesca provides an innovative tool to collect data, especially through the integrated multidisciplinarity. The collected data can be used by both fisheries scientists and physicists, who will have information for areas non- or little-accessible till now.

Sensors fitted to conditions and constraints aboard fishing vessels

The existence of the project involved the development of sensors and measure devices. The challenge was to develop devices tough enough to be fixed up on fishing gears, self powered, autonomous, affordable and able to run without any intervention of the fisherman neither trouble for the fishing activity. Because the sample of targeted vessels intends to be representative of all the metiers and fleets, the sensors are modular and scalable to collect new data. Different sensors have been developed and implemented onboard.

A specific sensor allows to record physical parameters at the bottom and along the water column, pressure (and thus depth) and duration of immersion. A first version included only temperature sensor (Figure 1a), a second one has been developed to measure salinity (Figure 1b). Autonomous and small-size, he is tough enough to be fixed up on all types of fishing gears, active (trawls, dredges) or passive (nets, long-lines, pots). The sensor records the parameters along each stage of the fishing operation (descent, fishing action and raise of the gear) with a frequency configurable according to the gears and their carrying out. The device allows building temperature or salinity series and profiles. The maximum immersion depth varies from 300 to 1200 meters, depending on the version. In addition to the environmental parameters, the measure of duration of immersion is a good indicator for the fishing time of the gear, active or passive.

Figure 1a
Temperature-depth sensor fixed on a net

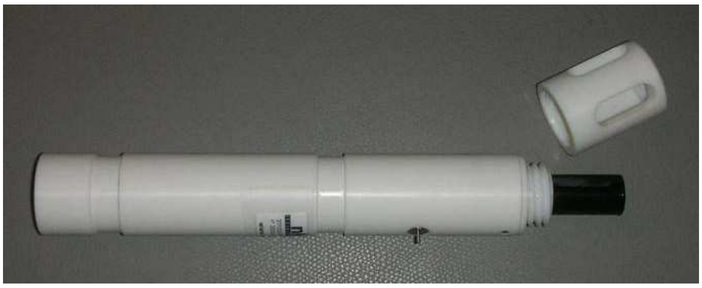


Figure 1b
Temperature-conductivity-depth sensor

Another specific sensor, called the “turns-counter”, has been specified to equip the hauler of passive gear (gill-nets, pots or lines). Fixed on the rotation axis, the sensor records the number of turns, from which is deduced the number or length of passive gears hauled at each fishing operation. As well as the other sensors, this device is autonomous and small-size (Figure 2). This sensor is currently on test on a netter vessel.

Figure 2

The “turns-counter” fixed in a gill-net hauler

In order to know the position of the physical measures and follow the course and areas of fishing activity of the vessels, a GPS is implemented on-board and tracks the location of a given vessel at configurable and regular frequency (most of the time, a quarter of an hour). The knowledge of its speed allows moreover characterizing approximately the different actions of a fishing trip (on fishing, on route…).

Furthermore, in the European Community regulation framework, vessels over 15 meters overall length are concerned by the Vessel Monitoring System (VMS): electronic devices, or “blue boxes”, are installed on board vessels and automatically send data to a land base station and the appropriate monitoring centre (CROSS ETEL in France). Recopesca solicits the fishermen’s agreement to have an access to their VMS data in order to validate the Recopesca GPS data by cross-checking.

Finally, a proposal of both scientists and fishermen was to develop and install an “anti-rolling” weigh-scale onboard (Figure 3). Recording the catches per species and fishing operation, and in association with the other Recopesca sensors, this device allows linking fishing effort and catches at the finest scale of the fishing operation. The first weigh-scales have been implemented aboard voluntary vessels at the end of 2009. First results will be available later in the year 2010.

Figure 3

Recopesca weigh-scale (pan and command module)

Between the last years, the developments and tests carried out with around thirty voluntary vessels allowed analyzing mechanic tolerance of the sensors, improving their resistance, validating their autonomy and their maintenance needs and optimizing their placement onboard and on the gears. During the period, the sensors have considerably evolved, especially to improve the quality and reliability of data, take into account the autonomy constraints and give more security and durability in their use. Furthermore, each sensor has been equipped with a radio device transferring the data to a receiver on-board, called “concentrator” (containing the GPS device) that sends the data to Ifremer central databases (Figure 4). The automatic transmission of the data at land is done by GPRS, once the vessel is within range of GPRS network, without any human intervention. This approach (quasi real time) has been chosen in order to track quickly dysfunction, interruption or loss of sensors.

Figure 4: “Concentrator” of data onboard

Regarding the computing infrastructure, Recopesca relies on existing operational data centers:

- Coriolis, for operational oceanography
- The Fisheries Information System, FIS (Leblond et al., 2008) of Ifremer and its database Harmonie

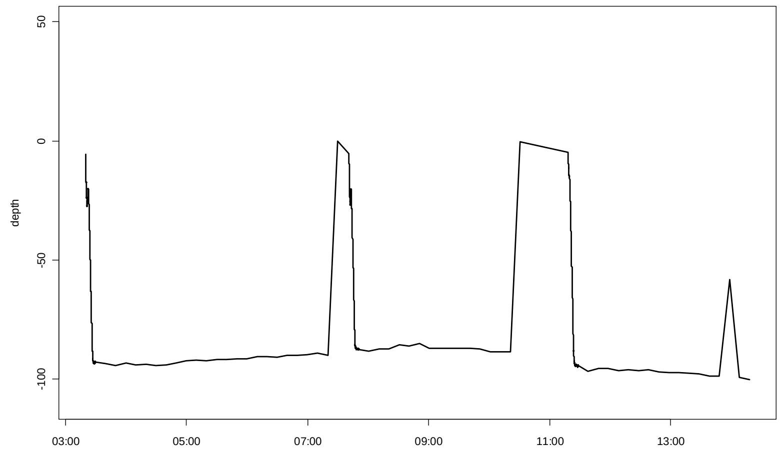
Once the data emitted by the “concentrator” is received by Ifremer, the physical data (temperature and salinity series and profiles) are stored in the *Coriolis* database. As for the fisheries data (per fishing operation), they are stored in the *Harmonie* database.

This management of data by the thematic data centers ensures quality control and dissemination of data to the users. Confidentiality of individual datasets (especially fishing data) is also guaranteed.

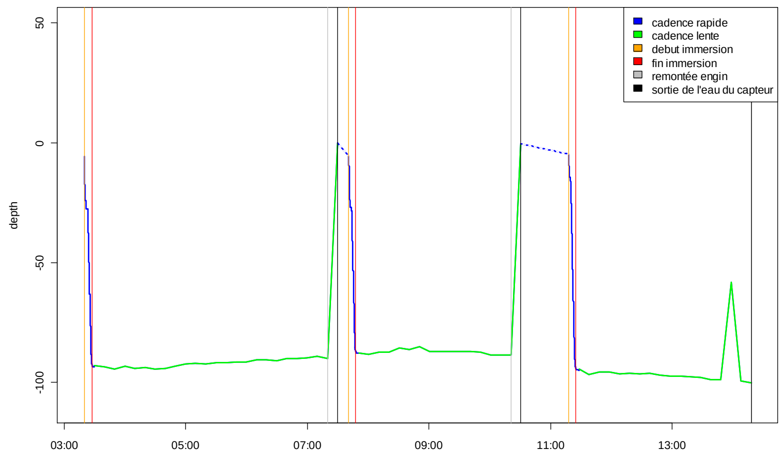
A new source of objective fisheries data

The fisheries data (activity, fishing effort and catches), resulting from direct measures, and not from fishermen's declarations or estimation by survey, supply the Fisheries Information System of Ifremer. However, information from sensors and GPS can not be used directly and has to be processed to become usable. Two generic algorithms have been developed:

- The first one aims to define/rebuild the fishing trip of a given vessel, on the basis of GPS positions (generally with a frequency of 15 minutes) or VMS positions (1 hour). Especially, the date and port of the beginning and the end of the fishing trip are identified, on the basis of the distance from the nearest port and the speed of the vessel. Moreover, the algorithm allows identifying the fishing and steaming period of the vessel, on the basis of the speed between two positions and the following assumption: if the average speed between 2 positions is less than 4.5 knots, the vessel is fishing. Otherwise, it is steaming (Laurans and Leblond, 2009).
- The second algorithm processes the data of the physical sensors implemented on fishing gears, and especially the depth and duration of immersion, and allows rebuilding the different fishing operation of a trip. It analyzes the depth profile of the sensor and reconstructs the key stages of each fishing operation: launching of the gear, arrival at the bottom, beginning of the rise and end of the operation (figure 5).



(a)



(b)

Figure 5: From depth profiles (a) to fishing operations (b): identification of fishing operations (Example of a trawler). An algorithm processes the depth data, collected by a sensor fixed on the trawl, to identify the key stages of the fishing operation: launching of the gear (orange line), arrival at the bottom (red line), beginning of the rise (grey line), and end of the operation (black line).

An application has been developed to visualize and validate the processing of the data from both algorithms. It produces a graph, for each Recopesca fishing trip, showing the result of the processing (limits of the fishing trip and operations) and the speed recorded by the GPS and VMS (figure 6).

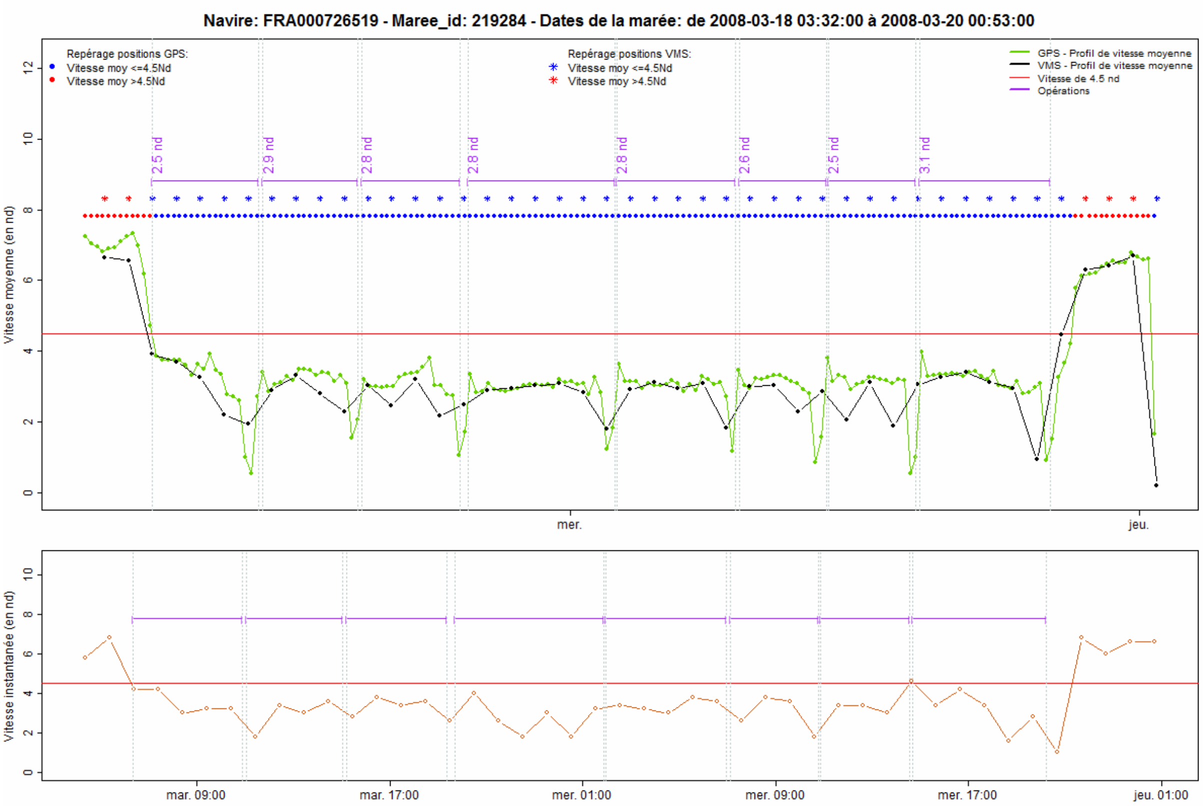


Figure 6

Example of graphs produced by the Recopesca application for a trawler fishing trip between March 18 and 20. The top graph shows the average speed profile calculated on the basis of GPS positions (*green curve*) and average speed profile from VMS positions (available only for vessels over 15m, *black curve*). The *red line* indicates the threshold of 4.5 knots used to distinguish fishing and steaming periods. The dates of GPS and VMS recordings are represented respectively by dots and asterisks: *blue* when the average speed between two points is less than 4.5 knots, and *red* when the average speed is more than 4.5 knots. The purple segments indicate fishing operations, based on the deep profile of sensors positioned on the gear. Above each purple segment is shown the average speed of the vessel when the gear is at the bottom. The bottom graph shows the profile of instantaneous speed (provided by the VMS only) and includes the purple segments of fishing operations.

First conclusions of the analysis show that fishing operations identified on the basis of the sensors are consistent with the observations of average speeds calculated on GPS or VMS positions. The 15 minutes positions (GPS) allow a finest representation of fishing operation than VMS data (1 hour), the tendency of the curve being very close to the course of operations deduced form depth sensors. Furthermore, the average speeds are more representative of the fishing activity than instantaneous speed (provided only by the VMS system). Finally, the assumption of 4.5 knots, historically based on the bottom trawlers behaviour, seems to be a good compromise for all the gears that have been equipped (nets, pots, dredges and trawls).

Recopesca can provide an objective measure of activity and fishing effort, especially for vessels less 15 meters overall length or coastal vessels, part of the fleet generally poorly known (in particular because of a lighter legal framework). Especially, it provides:

- A comprehensive and detailed view of all the fishing trips realized by the vessels.
- A map of the path traveled by the ship during the trip (figure 7) and the precise location of the fishing sector exploited by the vessel.
- For each trip, the identification and description of all the fishing operations: duration, location, depth, environmental conditions such as temperature and salinity (table 1).

- A fine estimation of the fishing effort by fishing sector (figure 8).

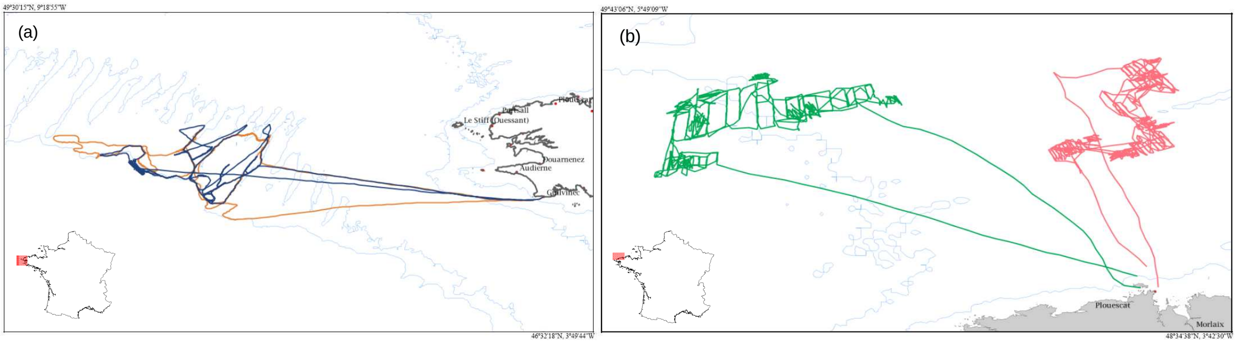


Figure 7

Examples of path recorded by Recopesca GPS. (a) Trawler fishing trips from South Brittany.
(b) Potter fishing trips from North Brittany. (Coastlines: SHOM©, NOAA / NGDC©; Bathymetry: GEBCO ©).

#	General characteristics of the fishing trips						Average parameters at the bottom				
	Beginning of the fishing operation		End (Hauling of the trawl)		Duration (hh:mm)	Distance (naut. miles)	Duration (hh:mm)	Speed (knots)	Depth (m)	Temp. (°C)	Salinity (PSU)
	Date	Position	Date	Position							
1	26/04 9:28	48.18°N, 6.92°W	26/04 15:28	48.34°N, 6.97°W	06:00	13.45	05:33	2.2	152	11	35.7
2	26/04 15:32	48.34°N, 6.97°W	26/04 21:22	48.32°N, 7.28°W	05:50	14.03	05:21	2.4	154	10.9	35.6
3	27/04 03:27	48.16°N, 7.43°W	27/04 9:28	48.07°N, 7.54°W	06:01	13.63	05:30	2.3	162	11	35.7

Table 1

Examples of parameters of fishing operations obtained from Recopesca sensors implemented on a trawler.

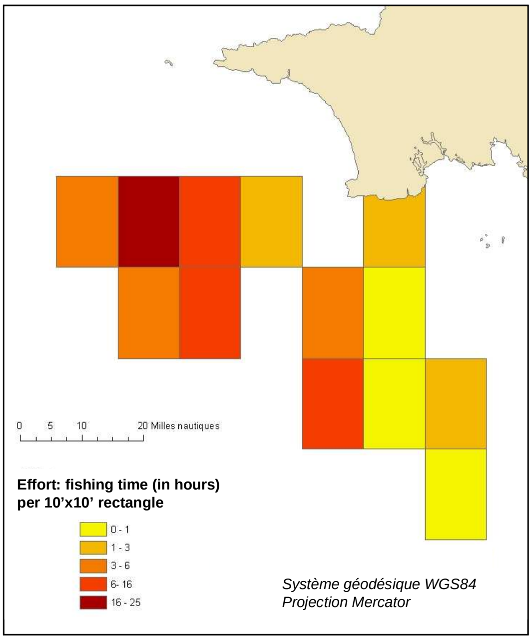


Figure 8

Spatial distribution (10' latitude x10' longitude rectangle) of fishing time
of a Bay of Biscay nephrops trawler during May 2008.

A description of the whole water column, from the surface to the bottom

The physical environmental data of Recopesca are available in *Coriolis* which supplies oceanographic research, operational oceanography tools or hydrodynamics models. The current activity of *Coriolis* represents around 350.000 stations (profiles) per year. The perspective of Recopesca, with a 400 vessels sample, could be more than 200.000 further stations. Since 2008, more than 8000 profiles of temperature and/or salinity recorded in the Atlantic Ocean by around 15 vessels have been loaded into *Coriolis*.

Figure 9 presents the location of CTD casts obtained during 2009 specifically in the Bay of Biscay. Over the whole year, 1706 casts have been collected, they are distributed as follows: respectively 257, 378, 559 and 512 in winter, spring, summer and autumn (namely January-March, April-June, July-September, and October-December). This total has been obtained with 7 fishing vessels equipped. We benefit of a good spatial cover over limited areas, ie; the offshore coastal water located South West and South of Brittany, the slope area near 48°N and South of the Gironde estuary. In these areas, a nearly diurnal CTD cast is available. This high frequency at the seasonal scale allows a good description off the annual variability over the shelf.

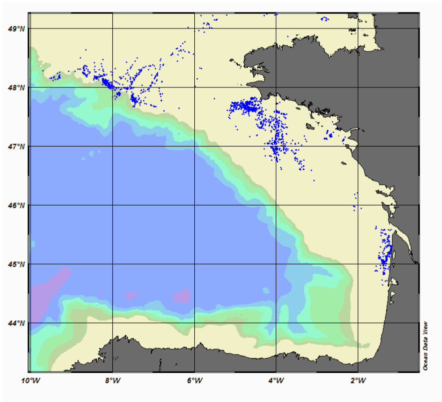


Figure 9

Location of CTD casts obtained during 2009 in the Bay of Biscay

As an example, figures 10 and 11 show time evolution of temperature from surface to bottom. Each vertical line is a cast. Localisation of the casts is shown on the map. Temperature variability at seasonal scale (figure 10) and interannual scale (figure 11) are illustrated:

Temperature at seasonal scale (Figure 10)

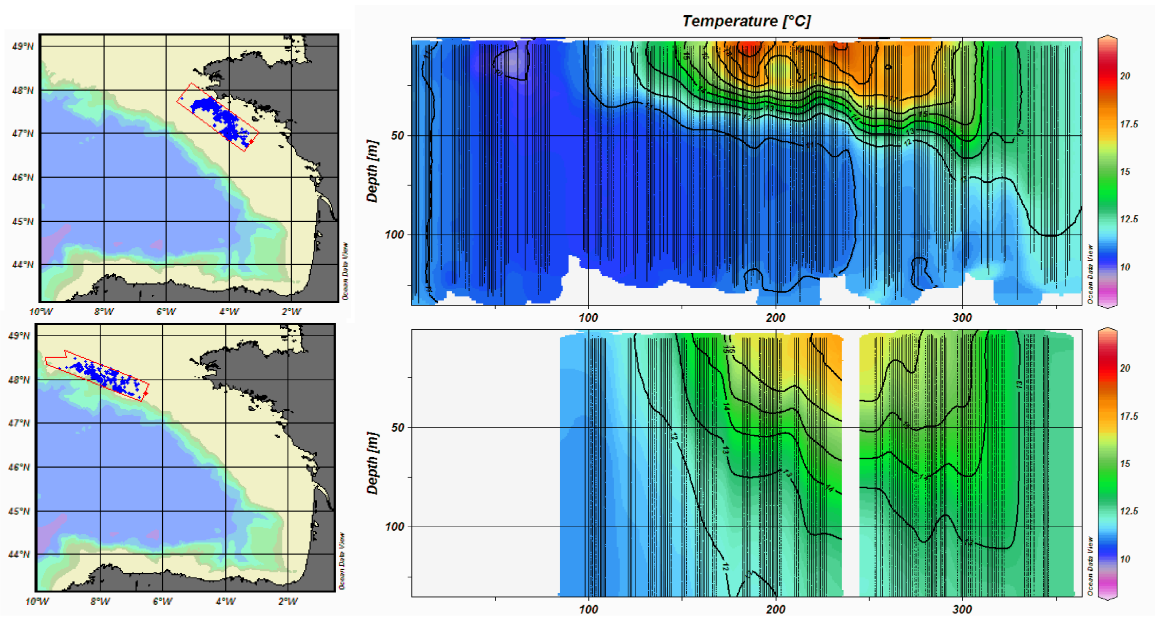


Figure 10

Evolution of temperature in 2 areas over the Bay of Biscay shelf during 2009.
Location of CTD casts is shown on the maps located on the left.

Over the shelf, the stratification begins at the end of March. Maximum temperature occurs in summer (from end of June to end of August) and reaches 19℃ at 1m below the surface. A t the end of August, surface temperature decreases slowly to 12℃ at the end of the year. This cooling reduces the density differences between surface and bottom layers. Meanwhile, autumnal episodic strong winds induce an enhancement of the vertical mixing. As a result, the thermocline deepens: the 12℃ isotherm located 25m below the surface in May reaches 100m at mid December. Whereas bottom temperature is nearly constant at 10.4-10.8℃ from January to September, it slowly increases to a maximum at 11.9℃ by mid December. Near the shelf break , temperature distribution exhibits a different pattern. The heating of surface layer begins in March but is distributed of a thicker layer. As a result, the maximum temperature barely reaches 17.6 ℃ in August. The thermocline is much less pronoun ced than over the shelf, denoting a greater mixing in this area. This mixing is induced by internal tides which are known to be of great amplitude in this area (Pingree *et al*, 1986).

Inter-annual variability of bottom temperature (Figure 11)

Another advantage of that network is that daily to weekly observations in a limited area allows a continuous monitoring of water properties which are not accessible by satellite observations, namely non surface temperature or salinity. Figure11 illustrates the differences between the summer 2008 and 2009 over the shelf in south Brittany. 400 CTD casts have been collected over the shelf in summer 2008 and 230 during summer 2009. Some interesting features are visible: whereas the depth of the thermocline is nearly the same, the bottom temperatures differ. They vary in the range 10.65℃-10.8℃ in 2009, whe reas it was between 11.3℃ to 11.7℃ in 2008. This inter-annual variabi lity of bottom temperature has been previously suspected and described with few campaigns (Puillat *et al*, 2004). The Recopesca data allow a more robust description because the evolution of bottom temperature is described throughout the year and not only during specific (but rare) field trip.

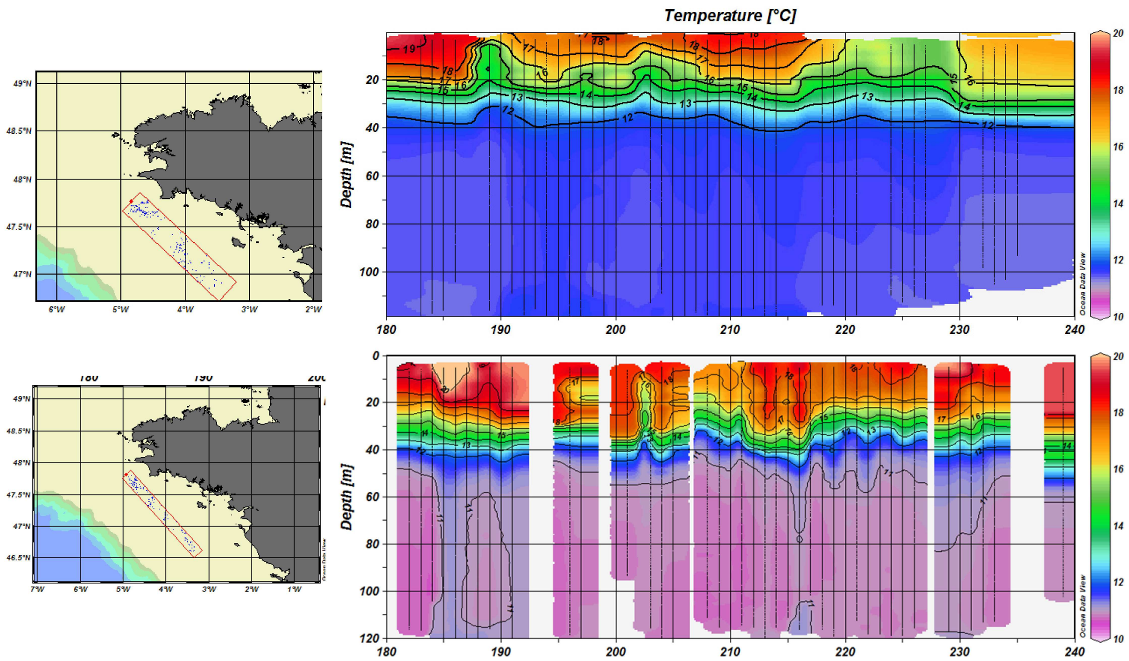


Figure 11

Evolution of temperature during summer 2008 (top panel) and summer 2009 (bottom panel)

Conclusion

Recopesca constitutes an innovative tool to collect data and contributes to supply the existing information systems. It must be considered as a means and not as a goal in itself.

The fisheries data (activity, fishing effort and catches), resulting from direct measures, and not from fishermen’s declarations or estimation by survey, supply the Fisheries Information System of Ifremer. Especially, Recopesca provides an objective measure of activity and fishing effort for vessels less 15 meters overall length or coastal vessels, part of the fleet generally poorly known (especially because of a lighter legal framework). Through the FIS (Fisheries Information System), the Recopesca fisheries data can contribute to the whole fisheries research projects, especially in the framework of an ecosystem approach to fisheries, and for fishing stock assessments. They are complementary with log-books and VMS data.

Regarding physical data, from the two years experience of Recopesca data, some first conclusions can be drawn:

- The Recopesca observations are restricted to limited regions with a good temporal frequency. It allows a seasonal to annual monitory depending of fishing activities of the basic hydrological parameter
- It gives a description of the whole water column, from the surface to the bottom. It allows a first monitoring of the bottom temperature which is of great importance for the analysis of the benthic ecosystem and the repartition of demersal and benthic fishes.

The main point to be improved now is the salinity measurement which is not fully satisfactory. So far, the precision which is 0.2 PSU is suspected to be rarely reached (the precision of temperature is less than 0.05℃). However, the validation of salinity is a difficult task because of the great variability of salinity on the shelf in the Bay of Biscay due to large inputs of fresh water and strong inter-annual variability. Some crude qualifications based on the range of reasonable variations of salinity (from 25 to 35.6 PSU) have leaded us to reject a lot of measurements. A more severe maintenance is required to bring more confidence on the observations.

Recopesca has begun the deployment of an operational and autonomous sensors network during the last two years. In early 2009, approximately 30 vessels, divided on the Atlantic coast and the Caribbean Islands, are equipped. This panel may seem low, but the deployment has been moderate while computer and technological development are completed. Now that an operational and autonomous system is available, allowing to provide data to data center and voluntary fishermen, the deployment is about to resume at an expected rate of 40 vessels per year. Recopesca aims to establish a network of 300 to 400 vessels, split along the French coasts. The deployment plan is built in accordance of the need of both fisheries scientist (a sample representative of the diversity of the fleets and the fishing metiers) and physical oceanographers. The mobilization of fishermen is carried out by the observers' network of the Fisheries Information System (FIS) of Ifremer.

Acknowledgements

Recopesca wishes to thank the voluntary fishermen who have accepted to integrate the Recopesca network and put their vessels at the disposal of the project. We thank also the technical team of Recopesca, especially Thomas Loubrieu and Matthieu Bourbigot, and the observers of the FIS.

References

Council regulation (EC) N° 1543/2000 of 29 June 2000 establishing a Community Framework for the collection and management of the data needed to conduct the Common Fisheries Policy – OJ L 176, 15.7.2000, p.1-16.

Commission regulation (EC) N° 1639/2001 of 25 July 2001 establishing the minimum and extended Community programmes for the collection of data in the fisheries sector and laying down detailed rules for the application of the Council Regulation (EC) N° 1543/2000 – OJ L 222, 17.8.2001, p.53-115.

Commission regulation (EC) N° 1581/2004 of 27 August 2004 Amending regulation (EC) N° 1639/2001 establishing the minimum and extended Community programmes for the collection of data in the fisheries sector and laying down detailed rules for the application of the Council Regulation (EC) N° 1543/2000 – OJ L 289, 27.8.2004, p.6-53.

Leblond, E., Daures, F., Berthou, P. and Dintheer, C., 2008: The Fisheries Information System of Ifremer: a multidisciplinary monitoring network and an integrated approach for the assessment of French fisheries, including small-scale fisheries. ICES Annual Science Conference 2008, 22-26 September, Halifax (Canada). ICES CM 2008/K:11.

Laurans, M. and Leblond, E., 2009: Developing standard European protocol for estimating fishing effort from VMS data. *in* Cooperation to Develop Fisheries Information from the North Sea. FISH/2006/15-Lot 7: 85-86.

Pingree R.D., G.T. Mardell, and A.L. New, 1986: Propagation of internal tides from the upper slopes of the bay of biscay. Nature, 321, 154-158.

Puillat I., Lazure P., Jégou A.M., Lampert L., Miller P.I. , 2004: Hydrographical variability on the French continental shelf in the Bay of Biscay, during the 1990's . Cont. Shelf Res., Volume 24, Issue 10, 1143-1163.

THE FAWN TROUGH: A MAJOR PATHWAY FOR THE ANTARCTIC CIRCUMPOLAR CURRENT ACROSS THE KERGUELEN PLATEAU

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Introduction to the circulation around the Kerguelen Plateau

Owing to its large meridional extent (~18° in latit ude) and relatively shallow depths, the Kerguelen Plateau constitutes a major barrier to the eastward flowing Antarctic Circumpolar Current (ACC) in the Indian sector of the Southern Ocean (Figure 1). Previous work showed that most (~100 Sv, 1 Sv = 10^6 m^3 s^{-1}) of the ACC transport is deflected north of the Kerguelen Islands (Park et al., 1993), which implies that a substantial remainder (~50 Sv) has to cross the plateau through two deep passages: the Fawn Trough (56°S, 2650 m) in the middle part, and the Princess Elizabeth Trough (64°S, 3650 m) close to Antarctica. Using two hydrographic WOCE sections (I8 and I9), McCartney and Donohue (2007) suggested a transport of about 40 Sv across the Fawn Trough. Yet, this estimation was only indirect, because the two WOCE sections did not cross optimally the Fawn Trough and Princess Elisabeth Trough areas. These authors also suggested a powerful Australian-Antarctic cyclonic gyre with an unprecedented transport (~100 Sv) in this basin, while the traditional view barely mentions the possibility of such a subpolar gyre. This gyre is associated with a powerful western boundary current strongly concentrated along the eastern flank of the southern Kerguelen Plateau.

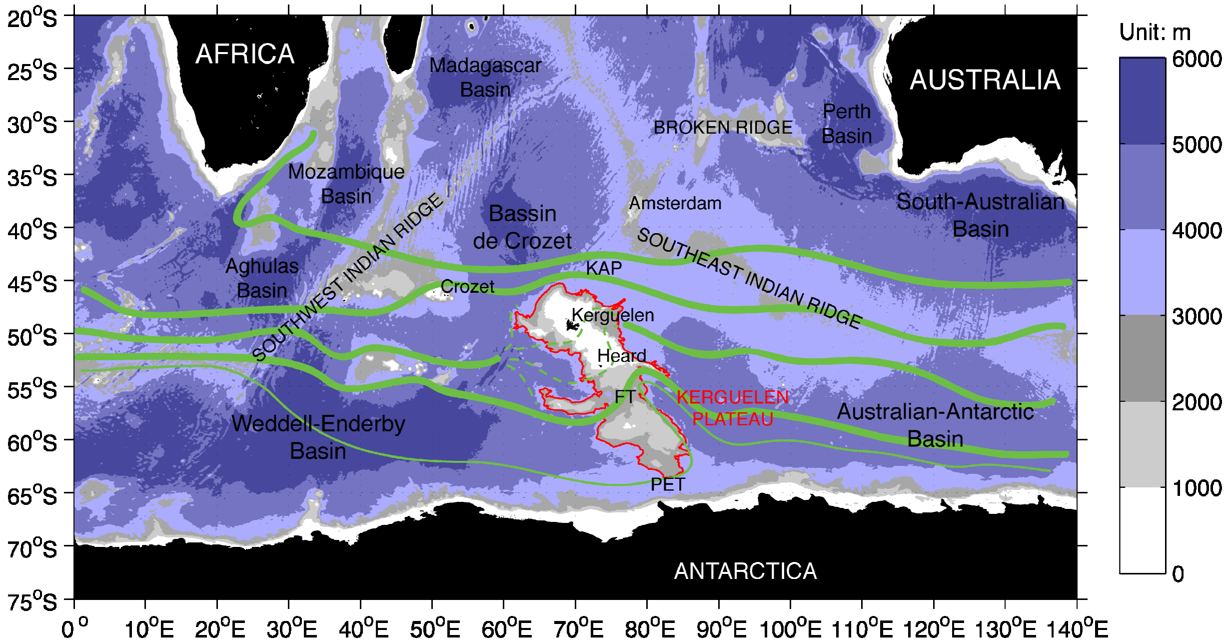

Figure 1

Bathymetry (meter) of the South Indian Ocean. The Kerguelen Plateau is highlighted using the 3000 m contour line. The Fawn Trough (FT) lies in the middle of the Kerguelen Plateau, while the Princess Elizabeth Trough (PET) lies to its south. Also, main ACC pathways are indicated (blue lines): from north to south, the Agulhas return current, the Sub-Antarctic Front, the Polar Front (splitted over the shallow Northern Kerguelen Plateau), the Southern ACC Front, and the Southern Boundary. Adapted from Roquet (2009b).

The analysis of hydrographic data collected by instrumented elephant seals has recently confirmed the existence of a strong northeastward current across the Fawn Trough (Roquet et al., 2009a). The Fawn Trough appeared to act as a veritable bottleneck, channeling the quasi-totality of the cold Antarctic Surface Water found south of the Ice Limit (58°S) and the Circumpolar Deep Water transiting the Enderby Basin toward the Australian-Antarctic Basin. Other more conventional datasets (hydrography, satellite and floats) together with oceanic general circulation models have consistently provided additional clues supporting the existence of the Fawn Trough current (Roquet, 2009b). Yet, a quantitative knowledge of the transport across the plateau was still missing due to the lack of ship-based observations over the plateau.

The TRACK project

This knowledge gap has been largely filled thanks to finely resolved hydrographic data and direct current measurements made in the Fawn Trough area during the two legs of the TRACK project (TRACK1 in January-February 2009 and TRACK2 in January 2010) on board the R/V Marion Dufresne II. TRACK (TRansport ACross the Kerguelen plateau, PI: Y.-H. Park) aimed at quantifying the ACC transport through the Fawn Trough and its variability. The field program of the project also included a 1-year-long deployment of three mooring lines of current meters across the passage, and the deployment of 12 ARGO floats. We will now present some results based on hydrographic and current measurements obtained during the two surveys.

During TRACK1, 60 CTD-O2 casts have been sampled, along 7 sections (Figure 2, black dots). TRACK2 has been designed to complement efficiently the first leg, redoing the sections crossing the Fawn Trough and the Deep Western Boundary Current. A transect between Heard and Kerguelen Islands has also been added. Finally, 57 casts have been sampled during TRACK2 (Figure 2, red dots). For each cast, direct current measurements have been performed simultaneously using two LADCPs and the Marion Dufresne SADCP.

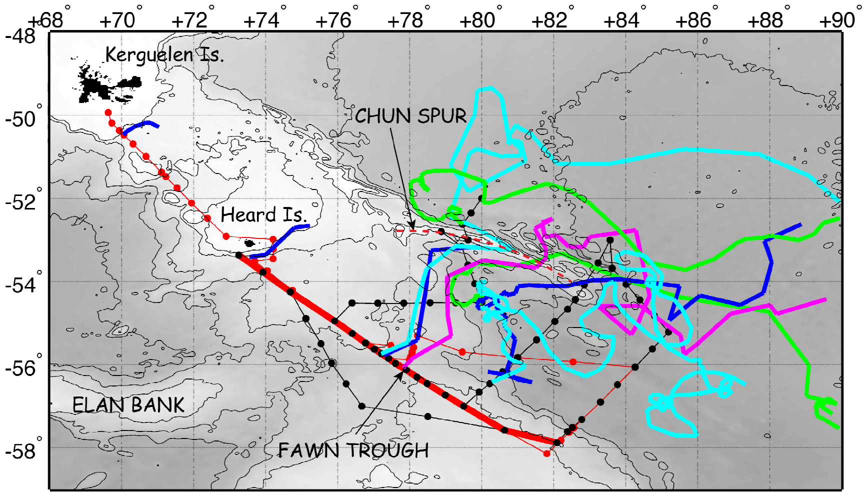

Figure 2

Cruise map of TRACK cruises, showing the leg 1 (Feb-March 2009, black dots) and the leg 2 (Jan 2010, red dots). The trajectories of ARGO floats deployed during TRACK are also shown. The thick red line indicates the stations used to plot the properties across the Fawn Trough in Figure 3.

Hydrography and transport across the Fawn Trough

The Fawn Trough section sampled during TRACK1 is presented in Figure 3. This section shows clearly the powerful and deep-reaching 50-km wide jet (stations 17-22), associated with a 43 Sv transport according to LADCPs. A strong baroclinic structure is observed in the temperature and salinity fields. Consequently, velocities are largest at the surface (up to 70 cm/s), then decreasing gradually to a yet non-negligible 15 cm/s bottom velocity (2600 m). The two hydrographic markers of the Fawn Trough current proposed by Roquet et al. (2009a) are well observed in this section: the crossing of the 0ºC isotherm in the subsurface minimum temperature layer, and of the 2ºC isotherm in the deep maximum temperature layer.

The coldest and freshest bottom water is not observed at the deepest part of the Fawn Trough sill, but further south along the southern flank of the sill (station 23). This bottom water, carried northward by the Deep Western Boundary Current, is meandering westward across the Fawn Trough section, before returning eastward and then southward in the Australian-Antarctic Basin. A 6 Sv branch is also detected just south of Heard Islands, which is thought to be the main pathway of water masses flowing over the shallow Northern Kerguelen Plateau (Park et al., 2008).

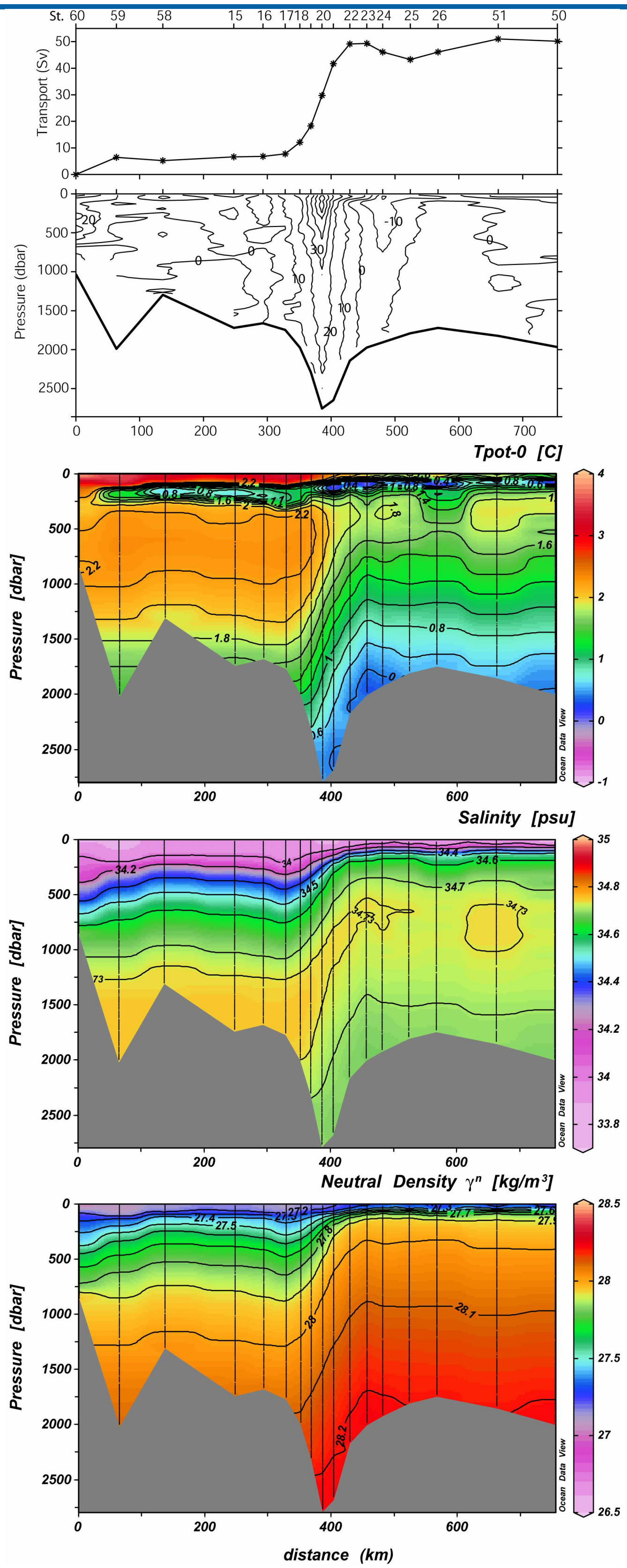

Figure 3 - Properties across the Fawn Trough (see thick red line in Figure 2 for casts position), as measured during the first leg of TRACK. From top to bottom, cumulative transport (Sv), LADCP speeds (cm/s), potential temperature (ºC), salinity (PSU) and neutral density (kg.m-3). The Fawn Trough current is clearly seen between stations 18 and 22 as an intense jet associated with enhanced meridional gradients of hydrographic properties. From Roquet (2009b).

A more thorough analysis of LADCP data obtained during TRACK1 revealed a net eastward transport of 58 Sv south of the Kerguelen Islands, which represents ~40% of the regional ACC transport (~150 Sv) (Park et al., 2009). The 43 Sv of the Fawn Trough current thus represents ~30% of the ACC transport, demonstrating the major importance of this ACC branch. The Princess Elizabeth Trough, south of the Kerguelen Plateau, originally thought to be a major passage for the ACC flow (Orsi et al., 1995), was finally found to be only minor (7 Sv). Although substantially weaker than in the McCartney and Donohue (2007) study, the Australian-Antarctic Gyre is well detected along the eastern flank of the Southern Kerguelen Plateau with a substantial 36 Sv transport.

ARGO deployments

A total of 12 ARGO floats have been deployed in the cruise area to obtain a better coverage of the hydrographic sampling. During TRACK1, we deployed 5 PROVOR and 2 ARVOR around the Fawn Trough. During TRACK2, 5 additional PROVOR have been deployed. A total of 717 profiles were logged on the 15th of February 2010, including more than 200 profiles in the TRACK cruise area. A delayed-mode procedure based on comparison of deep T/S correlations between the different ARGO floats and the TRACK data showed an overall satisfying quality of ARGO data, with salinity accuracy within the standard range ±0.01 psu. The trajectory of these floats revealed two interesting features of the fine-scale circulation between the Fawn Trough and the Chun Spur (Figure 2). Firstly, it could be clearly seen that the Chun Spur blocks efficiently most of the circulation, inducing a southward deflection of the flow along its western edge. Only a rather small surface flow is allowed around 53ºS, 78ºE. Secondly, 3 ARGO floats remain still during several months in a limited area lying at the centre of the circle formed by the cyclonic trajectory of the Fawn Trough current (54ºS, 80ºE), associated with subpolar waters carried by the Deep Western Boundary Current (see also Figure 4).

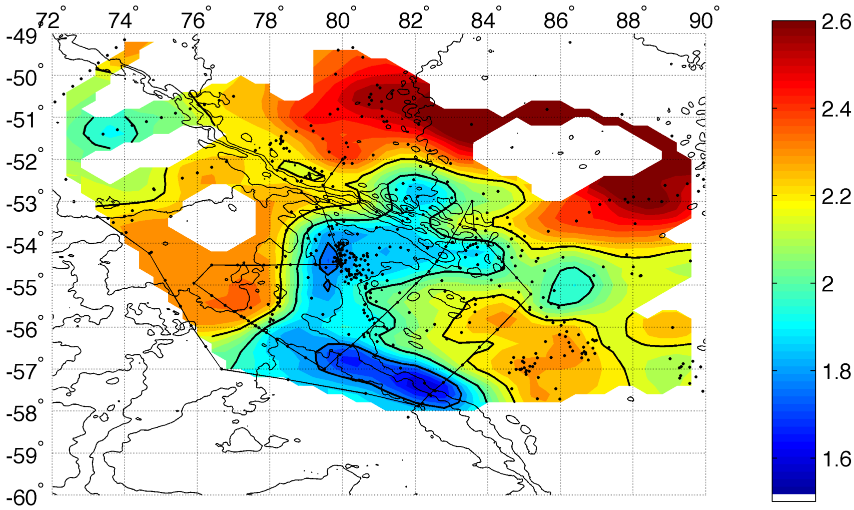

Figure 4

Map of the potential temperature (ºC), within the deep maximum temperature layer characterizing Upper Circumpolar Deep Water.

The combination of these several sources of profiles allowed us to map hydrographic properties at fine-scale for the first time in the Fawn Trough area. In Figure 4, we present a map of temperature taken in the maximum temperature layer characteristic of the Upper Circumpolar Deep Water south of the Polar Front. This map has been obtained by combining data from TRACK1, TRACK2, the 12 ARGO floats, and KEOPS data (see Park et al., 2008) to complete the picture over the Northern Kerguelen Plateau. We remark that the ARGO profiles complemented very efficiently the coverage of the two TRACK surveys, especially in the area along the Chun Spur. The Fawn Trough current can be accurately followed by the 2.2ºC and 2ºC isotherms in the maximum temperature layer. A tongue of cold water (<1.8ºC), characteristic of subpolar regions, is also seen along the eastern flank of the southern Kerguelen Plateau, gradually fading out while forming a U-turn in the area between the Fawn Trough and the Chun Spur, thus indicating the presence of mixing with surrounding warmer waters.

Discussion

So far, TRACK has fulfilled several of its objectives. The transport across the Kerguelen Plateau has been measured directly for the first time, demonstrating the major path across the Fawn Trough, and its jet-like structure. The CTD-O2 profiles obtained during the two surveys complement very efficiently the oceanographic database in a key area that was still so badly sampled. It is now confirmed that the area upstream the Fawn Trough sill is a major convergence area between ACC and subpolar waters, and thus should be regarded as a possible key area for monitoring the southern ocean variability. The on-going analysis of mooring data in combination with satellite altimetry and models should allow us to quantify the transport variability across the Kerguelen Plateau, and hopefully to determine what sets this variability.

Acknowledgments

This project is a French contribution to the IPY (International Polar Year) activities, and the only contribution in the Indian sector of the Southern Ocean. We thank the captain and crew of the R/V Marion Dufresne 2 for their assistance during the two TRACK surveys. TRACK has been financially supported by the CNES, CNRS/INSU and GMMC/IFREMER. IPEV provided us with ship time and logistical support.

References

McCartney, M. S. and K. A. Donohue, 2007: A deep cyclonic gyre in the Australian-Antarctic Basin, Prog. Oceanogr., 75, 675–750, doi:10.1016/j.pocean.2007.02.008.

Orsi, A. H., T. Whitworth III, and W. D. Nowlin, 1995: On the meridional extent and fronts of the Antarctic Circumpolar Current, Deep Sea Res. I, 42, 641– 673, doi:10.1016/0967-0637(95)00021-W.

Park Y.-H., L. Gambéroni and E. Charriaud, 1993: Frontal structure, water masses and circulation in the Crozet Basin, J. Geophys. Res., 98, 12361-12385.

Park Y.-H., F. Roquet, I. Durand and J.-L. Fuda, 2008: Large scale circulation over and around the northern Kerguelen Plateau. Deep-Sea Research II, 55, 566-581.

Park Y.-H., F. Vivier, F. Roquet and E. Kestenare, 2009: Direct observations of the ACC transport across the Kerguelen Plateau. *Geophysical Research Letters*, 36, doi:10.1029/2009GL039617.

Roquet F., Y.-H. Park, C. Guinet, F. Bailleul and J.-B. Charrassin, 2009a: Observations of the Fawn Trough Current over the Kerguelen Plateau from instrumented elephant seals. *J. Mar. Sys.*, doi:10.1016/j.jmarsys.2008.11.017.

Roquet F., 2009b : La circulation autour du plateau de Kerguelen: de l’observation à la modélisation. PhD thesis, UPMC.

NOTEBOOK

Articles:

The Fawn Trough : a major pathway for the antarctic circumpolar current accross the Kerguelen plateau

By Fabien Roquet, Young-Hyang Park, Frédéric Vivier, Hela Sekma

Notebook

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