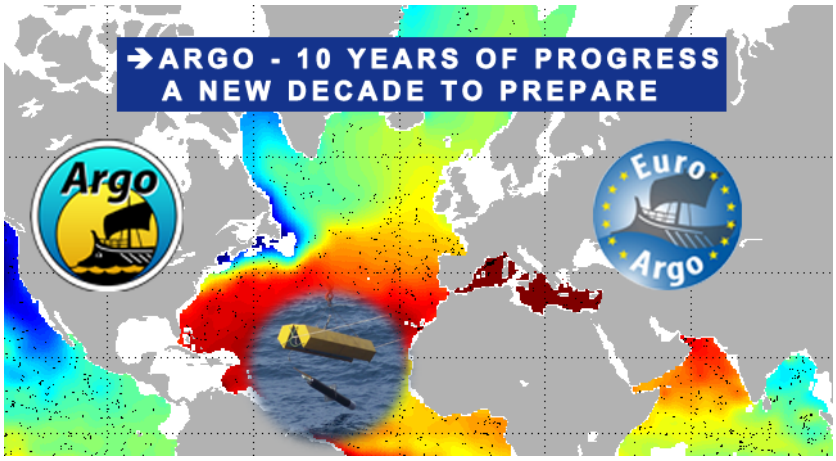
4th Argo Science Workshop

Abstracts Book



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ORAL PRESENTATIONS

OPENING – Thursday 27th Sept

A Decade of Argo: Achievements and Future Challenges

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When first mooted in the late 1990's, the idea of deploying an array of thousands of real-time reporting deep profiling ocean floats spread evenly across the global oceans was considered extremely ambitious by many, and simply preposterous by some. A decade later, the Argo project has largely achieved the goal of sustaining an array of over 3000 active floats delivering high quality temperature and salinity profiles from depths of around 2000m to the surface every 10 days. This data stream has revolutionised our ability to characterise and track subsurface ocean processes across the globe, in particular delivering first order information from poorly sampled regions such as the Southern Hemisphere and winter oceans. In this talk we will describe the status of Argo, its current challenges and possible future missions. These could include extensions to cover existing gaps (deep and ice-covered ocean) and new parameters such as oxygen and optical measurements. We will also touch on some of the new science based on Argo, including what Argo is telling us about fundamental ocean processes, longterm changes in the oceans, and how this relates to the changing global water cycle, sea level and energy budgets.

The long term contribution of Europe to Argo

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The Euro-Argo research infrastructure organizes and federates European contribution to Argo (www.euro-argo.eu); it is part of the European ESFRI roadmap on large research infrastructures. Euro-Argo carried out from January 2008 to June 2011 a preparatory phase project, funded through the EU 7th Framework Research Programme, whose main outcome was to agree on the legal and governance framework (Euro-Argo ERIC) under which to establish the research infrastructure. The formal agreement between all parties to the Euro-Argo ERIC will be signed in 2012 by ministries from 11 European countries which have agreed to form this new legal European entity to organize a long-term European contribution to Argo. The Euro Argo infrastructure is made up of a central infrastructure based in France which is owned and controlled by the Euro-Argo ERIC and distributed national facilities. The distributed national facilities operate with direct national resources. As part of the Euro-Argo research infrastructure, they agree to a multi-annual commitment of resources (in particular in terms of floats to be deployed and for the data system), and to coordinate their activities through the Euro-Argo ERIC.

The Euro-Argo ERIC objectives are:

- to provide, deploy and operate an array of around 800 floats contributing to the global array (a European contribution of ¼ of the global array);
- to provide enhanced coverage in the European regional seas;
- to provide quality controlled data and access to the data sets and data products to the research (climate and oceanography) and operational oceanography (e.g. GMES Marine Service) communities;
- to prepare the next phase of Argo and its extension towards biogeochemistry, deep and polar oceans.

The organisation and governance of the Euro-Argo research infrastructure, its links with GMES and other marine research infrastructures will be presented. The added value of the European organization will be outlined and we will explain how the Euro-Argo ERIC will be a major step forward for the long term sustainability of Argo in Europe. Euro-Argo views on the development and initial implementation of the new phase of Argo will also be discussed.

Understanding the Data Management System for Argo

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The challenges of the Argo data system are to serve both the operational and climate communities with data processed the same way in a distributed organization implementing a free open data policy.

The Argo data management system is composed of eleven data centers that process the float data, two GDACS (Global Data Centers) in USA and France that provide access to the best official version of the Argo data, delayed mode operators who process data in delayed mode and finally the regional centers which check the consistency of the dataset at basin scale level and generate products. In order to serve all the users two data streams have been implemented:

- The first stream in real time aims at detecting and flagging the suspicious or bad data , within 24 hours from acquisition , using automatic procedures. The data is then available on the GTS and at the GDACs.
- The second stream in delayed mode aims at detecting and applying a correction for sensor offset or linear drift using a statistical method that compares Argo data to recent CTD and Argo data that has already been judged good.

The Argo data management system is still improving but the main components have been set up. The first focus has been on the real-time stream and more than 95% of the profiles are distributed on GTS and GDACs within 24h. Bad data are flagged and a grey list is provided to identify suspicious floats. The second step has been the delayed mode processing. The Argo data managers have adapted the method developed by Wong & Owens so that it is effective when applied to data in all oceans. Considerable work has been done to train the delayed mode operators to reduce the effects of subjective analysis. Presently 85% of the floats have been processed. The data team has now started to work on velocity data. We have finished major reprocessing to clean up the trajectory files, and record the missing technical information and metadata necessary to derive accurate velocity fields. Finally tools have been developed to check the consistency of the Argo data in near real time to detect outliers that have passed through the automatic tests or delayed mode QC. This requires comparison with other data such as recent climatology or altimetry… Some of these tools have been implemented both at the Coriolis GDAC and at the Argo Regional Centers.

The Argo data management system has proven its efficiency and reliability over the past 10 years and this architecture has been taken as an example for the GOSUD and OceanSITES observing systems. Its distributed architecture allows sharing the work load among the different institutes without degradation of the quality because the implementation of the agreed procedures is monitored. Also the Argo Information center, managed at JCOMMOPS, ensures oversight of both the implementation of the observing system and its data management activities. The US-NODC is periodically archiving the Argo data to safeguard the Argo dataset for future and also provide hard copy of the Argo data for users with low or no internet connection. The Argo Data System implementation step by step has allowed a constant amelioration of the data.

Changes in format or the way we distribute the data are rarely done within Argo as they need a lot of coordination to be done in all centers at once. Also, this requires effective communication with users to reduce the impact of the changes. Nonetheless changes are sometimes necessary when major steps are taken within Argo (i.e. when Delayed mode processing started, for trajectory work…). When the Argo data management structure and format was designed, no "on the shelf" standards were available. In the past ten years, progress has been made in terms of vocabulary, conventions (CF) and interoperability (OGC standards, OPeNDAP/THREDDS …) that have induced changes in the context where Argo operates. We foresee some further changes in the Argo data management to make it more interoperable with other observing systems within JCOMMOPS and to benefit from enhanced tools developed above these standards.

SESSION B: Sea level and Argo – Thursday 27th Sept

The physical processes underlying interannual variations in global mean sea level as revealed by Argo and their representation in ocean models

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An analysis of the relationship between ocean density variations, as revealed by Argo, and fluctuations in global mean sea level (GMSL) from altimetry for the period 2004 to 2011 is presented. It is shown that although the El Nino Southern Oscillation (ENSO) dominates interannual fluctuations in the upper ocean density field, the ocean's response is such that equatorial Pacific variability alone cannot account for the observed interannual variations in GMSL. However, an analysis of the observed density field below 300m, where the influence of ENSO is weak, reveals correlated variability in the frontal zones of three ocean basins. This makes an additional contribution to the observed changes in GMSL. An examination of atmospheric variability suggests that the correlated frontal zone changes in density arise through ENSO-like atmospheric teleconnections. Thus we posit an additional, extra-tropical link between changes in GMSL and ENSO activity. Finally, comparing the Argo data with results from a range of numerical ocean models suggests the latter misrepresent the ocean's response to ENSO. Consequently, they predict too strong a relationship between ENSO and GMSL variability.

The role of Argo steric sea level within the global sea level budget

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Precise estimations of global ocean indicators (GOIs) such as global ocean heat content (GOHC) and global steric sea level (GSSL) are necessary to observe the ocean's role in the Earth's climate system. To improve accuracy of these estimations, our knowledge of deep ocean and regional contributions to GOIs needs to be quantified. Data from the global Argo array are used here to analyze these contributions during the period 2005 to 2011. GOHC/GMSH rise increases by 25% /35% for the upper 2000m depth compared to the upper ocean 700m depth. A comparison of Argo steric sea level to total sea level from satellite altimetry (AVISO) and ocean mass (GRACE) is performed during this period. We could close the global and regional sea level budgets for 2005 to 2011 in terms of 6-year trends. Results show that largest correlation of global GSSL, ocean mass and global total sea level can be observed in the global tropical basin. Differences of the 6-year trend between global mean total sea level and GSSL in this basin are to a large extend explained by Argo sampling issues. The differences of the 6-year trend in the Southern Ocean can be attributed to mass changes and deep ocean steric changes, whereas in the Northern Ocean mass changes clearly dominate decadal and longer-term variability. The results are only valid under the assumption that no systematic errors remain in either one of the global observing systems, although the comparison of all three observing systems indicates that these errors appear to be small during the years 2005 to 2011.

A global view of steric and sea surface height variability, 2004 – 2011

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The close relationship between sea surface height (SSH) and its steric height (SH) component links satellite altimetric SSH with Argo (0-2000 m) subsurface temperature and salinity profiles, measuring SH. Upper ocean SH is the dominant contributor to SSH variability on a wide range of spatial and temporal scales including those of mesoscale eddies and on large spatial scales from seasonal to decadal timescales. The differences between SSH and upper ocean SH may represent deep ocean steric variability (below 2000 m) and the mass-related component of SSH. Because of the different sampling characteristics of satellite measurements of SSH and of Argo SH, it is challenging to unambiguously estimate the small SSH – SH residuals. The interpolated versions of these data carry biases related to their respective spatial coverage. Therefore we analyze the relationship of SSH and SH by using datasets whose sampling characteristics are as close to equivalent as possible. Over 570,000 high quality Argo profiles were identified during January 2004 - August 2011, and for each of these the nearest altimetric height measurement was selected from along-track data. The co-located SH and SSH data pairs, with a common time mean removed, 2004-2010, were jointly analyzed. Global maps and zonal means of the separate fields, the correlations and residuals of SSH and SH were calculated. The statistics of the co-located datasets, bin-averaged into monthly large-scale fields, were also compared with those of gridded products based on the complete datasets.

SH and SSH anomaly fields are very similar in pattern and magnitude. We considered the variance of the monthly large-scale fields, the seasonal cycles, the ENSO-related interannual variability, the extreme monthly values, and the 8-year trends. Some significant differences between SH and SSH were identified. SSH variance of monthly anomaly fields is greater at middle and high latitudes due to the presence of deep steric variability. The 8-year trends in SSH are greater than SH on a nearly latitude-independent basis due to the global scale of the mass-related residual signal in SSH. Maxima in both fields occur where spatial gradients in mean SH are large, highlighting the strong role of horizontal displacements of the mean field. Prior to the deployment of Deep Argo floats, capable of sampling from the sea surface to the bottom, it is important to anticipate the spatial pattern and depth distribution of deep steric variability and the requirements for sampling the deep ocean.

The relationships between Argo Steric Height and AVISO Sea Surface Height.

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Argo provides global measurements of the steric height of the ocean surface relative to 2000m (SH0-2000), while satellite altimeters provide global measurements of the sea surface height anomaly (SSH). The two properties are related, with SSH being the total of SH through the full water column together with any contributions of extra added mass. While the upper 2000m of the ocean dominates the SH changes, it is known that there are significant changes at depth, and also that there are significant changes in the mass term, especially on inter-annual and longer time scales. In addition the SSH and SH measurements are quite different in nature, with Argo profiles being pseudo-randomly distributed point measurements, while the altimeter measurements have a finite footprint, with high resolution along repeat tracks and are interpolated between the tracks. The main aims of this work are to try to understand the relationship between the SSH and SH0-2000 measurements and make some estimate of the unmeasured deep steric and mass contributions. An associated outcome is that lessons learnt from these analyses are directly applicable to the need for and design of a full-depth Argo array.

The relationships between the Argo SH0-2000 and AVISO SSH are investigated through several analyses. Decadal signals are studied by relating changes in mapped SSH with 0-2000m ocean changes calculated from the differences between Argo profiles and WOCE-era hydrography. Intra-decadal changes are addressed by extracting near-co-located (in time and space) Argo profiles and along-track SSH measurements – the idea being to remove any impacts of objective analyses of either field. This approach is further developed by looking at changes between multiple samplings at nearby locations thereby removing any impacts of local errors in the assumed mean fields. The varying ocean depth is exploited to examine the contribution of deep SH – where the ocean is 2000m deep, Argo already effectively samples the entire water column. The impact of the unknown deep steric component is directly studied by analyzing full-depth hydrographic data that lie below TOPEX/Poseidon tracks: in particular using a sub-Topex hydrographic section in the southwest Pacific that has been sampled ten times. Having the full-depth data here allows the impacts of the 2000m Argo profile depth to be examined, and also offers a direct comparison of the different measurement types.

Understanding the annual cycle in sea surface height.

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The Argo Program, now into its 9th year of global subsurface ocean coverage, has grown from a sparse global array of about 1000 profiling floats in early 2004 to more than 3500 floats today. The lengthening combined time-series of Argo and altimetry grows in value as it approaches a decade of over-lapping coverage. Here we focus on the annual cycle, demonstrating that subsurface steric variability explains a large fraction of the annual cycle in sea surface height (SSH). This is now shown with unprecedented spatial resolution and accuracy on a global basis. Improvements in steric annual cycle estimation are most significant in the southern hemisphere. Steric variability includes both surface layer changes due to air-sea buoyancy fluxes, and subsurface changes due to ocean dynamics. The latter can result from either vertical or horizontal displacements of isopycnal surfaces. Argo profiles extend to depths as great as 2000 m. The depth-dependence of annual isopycnal displacement provides a basis for estimating the vertical scale of the annual cycle, even at locations where it exceeds 2000 m. This allows an estimate of the magnitude of annual steric height variability below 2000 m. Thermosteric as well as halosteric variability is considered. In the surface layers, this variability reveals heat and freshwater exchanges, as well as the signatures of water mass formation processes. In deeper layers, it helps to resolve ambiguities in subsurface horizontal versus vertical displacements. Finally, on large spatial scales we investigate how much of the difference between SSH and steric height is explained by mass-related annual variability in GRACE data, and hence how well the SSH annual cycle budget closes.

Steric and Barotropic Modes of Sea Level Variability in the North Atlantic

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The variability of the North Atlantic sea level and its steric and mass related components is studied for the period 2002 to 2011. Monthly gridded sea levels from the Jason-1/Jason-2 satellite altimeters as well as gridded steric sea levels from Argo floats (Metoffice) and mass related sea level from th GRACE mission (GFZ) are analyzed. The focus of this study is on spatial scales greater than 1000km.

All three data sets show similar trend patterns for the observed period. They reflect the North Atlantic tripole with increasing sea levels in the tropics and the subpolar gyre and decreasing sea levels in the subtropical gyre. For the area 0° to 55°N the total trend is ~0mm/year, the steric ~-1mm/year and the mass component ~0.5mm/year (with errors of min. ±0.5mm/year).

The spatio-temporal patterns are studied using Empirical Orthogonal Functions (EOFs). For all three data sets the first EOF mode corresponds to the annual signal. For the anomaly series (annual signal subtracted) of the total and the steric sea level the dominant mode is connected to the North Atlantic tripole and suggest a decreasing height gradient between subtropical and subpolar gyre. The principal component of this mode shows interannual variablity (~4 years) and a trend. Other important modes seem to be related to the position and strength of the Gulf Stream/North Atlantic current system and can be found in all three data sets.

Monitoring Sea Level Variability in the Bay of Bengal: using Argo, Altimeter and other Complementary Techniques

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Sea level may vary in a temporal and spatial scale due to local and global forcing. Measuring sea level change and understanding its causes has considerably improved in the recent years, essentially because of availability of combined in situ (Tide gauge, Argo etc.) and remote sensing observations (Altimeter, GRACE etc.). In the present study, the different sea level components (sea surface height, dynamic height, halosteric height, thermosteric height etc.) have been estimated in the Bay of Bengal, in terms of interannual variability, over different time scales of 1993-2010 (Altimeter) , and 2004–2010 (Grace, Argo and Altimeter) and have been compared with the relative sea level data obtained from tide stations of the northern Bay of Bengal. The thermal expansion of ocean volume, discharge of water mass into the may be responsible for such change. The altimetry-based sea level (sea surface height) data shows a general positive trend of sea level rise during the time window of 1993-2010 in the Bay of Bengal. The rate of sea level rise is estimated to be much higher during 2003-2010 compared to that of 1993-2002 periods. Temporal pattern of sea level variation derived from altimeter observations has been compared with ocean mass and steric signals derived from GRACE and ARGO data. It is observed that the sum of steric sea level and the ocean mass components has a positive trend of 6.26 ± 1.29 mm /yr., in conformity with the total sea level rise of 4.36 ± 1.45 mm /yr. estimated from altimeter data over the period 2004-2010. The discrepancy noticed, may be due to trend errors in altimeter, Argo and GRACE data, as well as to a possible contribution of other atmosphere -oceanic coupled factors.

Tide gauge data of different stations along the northern Bay of Bengal have been studied to verify the stability of the altimetric data in this region. Sea level change has been studied using measured data and records of Permanent Service for Mean Sea Level. This region appears to be one of the most vulnerable areas in the world with respect to sea level rise due to non-gravitational factors as well as for its bathymetry and shape. The severe coastal erosion estimated in this region during the observation period (1990-2010) might have a direct relationship with relative sea level change. The rate of relative sea level rise in Sagar tide station is found to be much higher during the present decade compared to that during past one. However, a finer assessment of vertical land motion, such as subsidence, glacial isostatic adjustment or large-scale tectonic motion, as well as rate of siltation in the estuarine mouth is a pre requisite to correlate relative sea level change accurately with Altimeter or Argo based observations. Though the time frame of observation is a very short period to interpret any long term trend, the general agreement between these complementary in situ and remote sensing based observations, particularly for northern Bay of Bengal is quite encouraging.

SESSION C: Heat and Salt budget – Thursday 27th Sept

Ocean heat and salt calculations using Argo data at NODC

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10+ years of Argo temperature and salinity profiles have afforded an unprecedented opportunity to monitor the global oceans heat and salt budgets. At the US National Oceanographic Data Center, calculations of temperature and salinity anomalies from the surface to 2000 m depth are prepared using quality controlled Argo profiles and other near-real time data sources, providing an ongoing first-look at ocean heat and salt changes on a seasonal basis.

As sufficient historical data, such as research cruise CTDs, are received at NODC, anomalies are recalculated and refined. Our recent findings show that, while ocean heat content has leveled off in the upper 700 m, deeper Argo profiles show that 0-2000m heat content has continued to rise. Salt content changes are being examined regionally and globally to help understand changes to the global hydrological cycle and in the cryosphere.

Estimation of Fresh and Salt Water Transports in the Indian Ocean

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This study describes the fresh and salt water transports in the Indian Ocean using Argo floats data, satellite salinity observations from SMOS (Soil Moisture and Ocean Salinity) and Aquarius, and model simulations using HYbrid Coordinate Ocean Model (HYCOM) and the Simple Ocean Data Assimilation (SODA) Reanalysis. Argo salinity data is used to validate the new satellite-derived salinity measurements from SMOS and Aquarius as well as the model outputs. On seasonal time scales, there is a considerable exchange of salt and freshwater transports from Bay of Bengal (BoB) to the Arabian Sea (AS) and vice versa. The paths of the high/low salinity waters are identified using satellite observations. The Sea Surface salinity (SSS) changes in the Southeastern Arabian Sea are resulted from the advection of low salinity waters from the BoB via coastal Kelvin waves. This study additionally computed the contribution of geostrophic currents to salt transport using geostrophic current velocities derived from Argo data. The long term mean salt transport shows seasonal reversals that are more pronounced in the northern Indian Ocean than in the southern Indian Ocean. Meridional salt transport is northward along the Somali Current (SC) in the Arabian Sea and the East India coastal Current (EICC) in the Bay of Bengal during the southwest monsoon season. The opposite holds during the northeast monsoon season. Mean zonal salt transport is of a higher magnitude than the meridional component and shows significant seasonal reversals in the equatorial region. Empirical Orthogonal Function (EOF) analyses of meridional salt transport show that the variability is primarily seasonally driven and is the result of seasonally reversing monsoonal winds and currents with the first two modes of the 'seasonal' based analysis contributing about 65% of the total variance in salt transport. The amplitudes of the EOFs suggest that the Indian Ocean dipole may also influence the variability. Spatially, the most variable regions are along the northeast African coast, and in the eastern Arabian Sea, the Bay of Bengal and equatorial regions.

Detecting the average footprint of tropical cyclone induced ocean thermal changes based on Argo data

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Global Argo array data is used to estimate tropical cyclone (TC) induced ocean thermal changes on the global scale. We present a technique to quantify ocean thermal changes caused by TCs utilizing track-averaged footprints of ocean thermal changes caused by TCs, by comparing Argo profiles before and after a TC passage. Events are separated into two categories: tropical storm/tropical depression (TS/TD) and hurricane including all events occurring during 2004-2010. The two footprints are functions of three variables: distance away from the track, water depth and time after the TC passed. They are independent of when and where the TC events occurred. We show that Argo system can observe the typical ocean responses to TCs within a time scale of 20 days. In the first 3 days after a storm, TCs pump heat from the ocean to the atmosphere, sustaining the storm. TC-induced air sea heat flux is estimated from the OHC changes during the first 3 days after a storm passage. On average, tropical cyclones are responsible for 9.1 W/m2 heat transfer annually from the ocean to the atmosphere within the first 3 days after storm, within which 3.2 W/m2 is contributed by Tropical storm/Tropical depression (TS/TD) and 5.9 W/m2 by hurricane. Concerning that ocean heat budget can not be balanced in recent re-analyses with a net ocean heat gain of ~10-20 W/m2, we examine the air-sea heat fluxes during the TCs passage in NCEP/NCAR ocean heat flux re-analyses, which shows no TCs signals. Therefore, we suggest that this quick but strong ocean heat lose by TCs can be a substantial missing piece to close the ocean heat budget. After storm passage, the 4-20 days averaged thermal changes show a strong subsurface warming (50-200m depth) and the main thermocline warming (400-800m) for hurricanes, suggesting much deeper ocean effects than previous assumptions. In contrast, TS/TDs influence thermal properties to a much shallower depth (200~300m). On 4-20 days average, ocean experiences a 0.22 PW net heat gain after hurricanes. By contrast, TS/TD cause 0.13 PW net ocean heat loses, suggesting an opposite net ocean thermal effects compared with hurricanes, which implies different contribution of weak and strong storms on ocean energy budget. Further more, a climatology geographical pattern of sea surface temperature (SST) changes is detected, sharing a similar cooling pattern to the previous satellite-based studies. This further confirms the usefulness of the Argo data in terms of detecting TC induced ocean thermal changes. And then a climatologically geographical map of ocean heat content changes caused by TCs is obtained, showing a distinguished pattern compared with SST changes.

Oceanic fluxes and storage of freshwater in the North Atlantic

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An Atlantic temperature and salinity field is generated every 10-days from the early 2000's. These fields are generated using Argo data that have been optimally interpolated on density surfaces. Temperature and salinity anomalies from the Hydrobase climatology are interpolated without making the widely used assumption that the anomalies have a zero mean. In addition to the temperature and salinity fields , uncertainty estimates in each field are quantified and found to be smaller than analysis of the same data on pressure rather than density surfaces.

We use the optimally-interpolated Argo fields in conjunction with full-depth coast-to-coast hydrography and information from the RAPID-MOCHA monitoring array at 26N in the Atlantic to quantify the variability in the oceanic freshwater flux at this latitude. Including the information (from hydrography and Argo) from the interior of the subtropical gyre reduces the southward freshwater flux by 0.1Sv to 0.3Sv southward (1Sv = 106 m3 s-1), compared with using end-point estimates alone. Quantifying the temporal variability of this interior component is only possible using Argo data. The optimally interpolated Argo fields are examined to quantify variability in the oceanic salt content and this is related to the variability in the freshwater flux observed at 26N.

Argo-based estimates of the oceanic heat content variability: impact of the array's geometry

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One of the main objectives of the Argo hydrographic array is to monitor the evolution of the ocean heat content (OHC) over a wide range of timescales. However, the spatial coverage of the array is still inhomogeneous and some regions remain under-sampled (shallow waters, Southern Ocean) and not (yet) sampled (deep ocean, ice-covered areas). We make use of a 50-year ocean/sea-ice global simulation performed by the DRAKKAR consortium to evaluate the impact of the Argo array's geometry on the estimation of the OHC variability.

We first assess how the regions that are poorly or not sampled by the existing Argo array (layer below 2000m, ice-covered and coastal areas) contribute to the seasonal and interannual variabilities of the global OHC. Our results show that among these 3 possible extensions of the existing Argo domain, adding profiles collected in shallow regions would be most beneficial for improving global OHC variability estimates at both timescales.
Focusing on the domain that is presently accessible to Argo, we then evaluate how the estimation of the mixed layer heat content (MLHC) may be distorted by the inhomogeneous Argo geometry. The model simulation is subsampled in time and space at Argo dates and locations between 2004 and 2009; MLHC estimates derived from synthetic Argo profiles are compared to their fully-sampled counterparts in monthly regional bins. Results reveal noticeable sampling biases in certain regions and months, but also significant improvements since the Argo array has reached its objective of 3000 active floats at the end of 2007.

Ours approach and results are presented and discussed. Such model-based investigations may help optimize the design of future Argo missions, e.g. in terms of vertical sampling strategies or horizontal deployment.

Monitoring the Ocean from observations

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Producing comprehensive information about the ocean has become a top priority to monitor and predict the ocean and climate change. Complementary to modeling/assimilation approaches, an observation-based approach is proposed here. It relies on the combination of remote-sensing (altimetry and sea surface temperature) and in-situ (temperature and salinity profiles) observations through statistical methods.
The method uses first a multiple linear regression method to derive synthetic T/S profiles from the satellite measurements. These synthetic profiles are then combined with all available in situ T/S profiles using an optimal interpolation method. The thermal wind equation with a reference level at the surface is finally used to combine current fields from satellite altimetry with the thermohaline fields to generate the global 3D geostrophic current fields. Global temperature, salinity, absolute height and geostrophic current fields are thus available at a weekly period from the surface down to 1500-meter depth and a reanalysis is available for the 1993-2010 periods. The method has been assessed through comparison with independent in situ data sets as OVIDE sections or RAPID current meter array.

An analysis of the ocean variability using the 18-years long time series of the global 3D-fields of temperature, salinity and current has then been performed. The temperature variability of the 1993-2009 periods shows a clear warming that is visible at all depths and for all latitudes. If the variability is baroclinic with strong interannual signals in the tropics, it shows a clear long term trend at high latitude with depth consistent signals. Changes of ocean circulation are also been studied through mass transport at key regions and maximum Atlantic Meridional Overturning Circulation strength. Although high interannual variability is observed in the AMOC time series, it is not possible to extract a clear trend. Our analyses have also been compared to other observation-based approach (Roeammich and Gilson, 2009) and to outputs from numerical models (SODA, GLORYS).

SESSION D: MOC and Large Scale Circulation – Thursday 27th Sept

MOC, Heat Content and Air-sea Interaction during the MOC slow down in 2009

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MONACO aims to study the linkages between the MOC at 26ºN in the N.Atlantic , the heat and freshwater fluxes at 26N, and the seasonal and inter-annual heat and salt content changes in the upper 0-2000m of the water column between 10-70ºN for the period from April 2004 to December 2010. In particular, the MOC event of 2009 when there was a 50% reduction in the overturning circulation, will be related to the changes in heat storage and surface heat flux. This unusual event will be placed in the context of longer records.

Estimating the residual overturning circulation

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The deep meridional overturning circulation (MOC) is dominated by an adiabatic pole-to-pole cell with downwelling in the North Atlantic (NA) and wind-driven upwelling in the Southern Ocean (SO). The transport of heat and freshwater by the MOC strongly depends on the stratification in the Antarctic Circumpolar Current (ACC) region, which in turn depends on the eddy fluxes of heat and freshwater. The total heat transported northward is due to the sum of transports by the large scale flow (including the boundary currents), i.e. the MOC and the flux of heat due to mesoscale eddies. In most of the ocean these two components tend to partially compensate leading to a smaller residual overturning circulation (ROC) than that estimated by including the large-scale flow only. This compensation is illustrated using eddy-resolving computations. The errors arising due to sub-sampling of the eddy-fluxes are estimated and discussed.

Meridional transport in the South Pacific: Assessing ENSO and SAM related variability

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The meridional transport through the Pacific projects strongly onto climate variability. This study investigates the relative roles of the tropics and of Southern Ocean westerly winds in driving transport changes within the mid-latitude south Pacific. Gridded Argo temperature and salinity profiles and atmospheric reanalysis surface winds are used to study the time variability of the meridional transport in the South Pacific Ocean over the 2004-2012 period. North of 32°S, the 0-2000 m geostrophic transport is oriented northward and the Ekman transport is oriented southward. The residual of the basin-wide geostrophic transport and Ekman transport is 10-14 Sv at 32°-5°S, consistent with observations of the volume transport in the main passages of the Indonesians Seas. The ± 2 Sv uncertainty in the Indonesian Throughflow transport results from heterogeneous float sampling density. At interannual time scales, the geostrophic transport north of 11°S shows a strong El Niño Southern Oscillation (ENSO) signature characterized by an increase during La Niña and a decrease during El Niño. The ENSO signature is less evident at 11°-27°S. South of 27°S, geostrophic transport shows a Southern Annular Mode (SAM) signal characterized by an increase during the positive phase of the SAM and a decrease during the negative phase of the SAM. The interannual variability of the geostrophic transport north of 11°S is twice the variability south of 27°S.

Use of ARGO floats to study the ocean dynamics south of Africa: what we have learned from the GoodHope project and what we plan within the SAMOC international programme

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South of Africa, the Southern Ocean provides the export channel for North Atlantic Deep Water (NADW) to the global ocean and the passage for heat and salt from the Indian and Pacific oceans to the North Atlantic. This region is influenced by the largest turbulence observed in the ocean. The eastward flowing Antarctic Circumpolar Current, the South Atlantic Current and NADW meet with the westward flow of Indian waters carried by the Agulhas Current, leading to water masses exchanges through jets, meanders, vortices, and filaments interactions. These local mesoscale and submesoscale interactions and the derived meridional fluxes constitute a major link between the Southern Ocean and the global meridional overturning circulation (MOC). At the same time, mixing and air-sea interactions are responsible for significant water masses properties modifications. Owing to the relative isolation of the region, few modern observations time series existed in this sector of the global ocean before 2004. This was the main reason to foster an international cooperation to monitor regularly this oceanic sector. The project has been named GoodHope (GH hereafter) by the Cape of Good Hope. The international partnership is gathering together means (in terms of human, observing platforms, ship time and general financial support) from 11 different institutions and six countries (France, South Africa, United States, Germany, Russia and Spain).

With the relatively important number of GH full-depth hydrographic cruises, of high resolution XBT sampling, of deployed profiling floats and satellite altimetry in complement with numerical simulation analyses we have been able to improve quantitatively the knowledge on regional dynamics and water properties exchanged south of Africa. In particular the increased number of vertical profiles obtained by the repeat deployment of Argo floats along the GH line allowed us to make important progresses on the understanding and quantifying particular aspects of the regional dynamics.

We will describe some of the results we obtained that are based, at least partially, on analyses of Argo data within the GH project. We will also introduce to the design and implementation of the new international partnership on an observational system to monitor the South Atlantic's branch of the Meridional Overturning Circulation (SAMOC).

SESSION D: MOC and Large Scale Circulation – Friday 28th Sept

Examining the Subtropical Mode Water formation rates in the South Atlantic from Argo data

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Changes in the rates of subtropical mode water formation in the South Atlantic ocean are investigated using temperature (T) and salinity (S) profiles obtained by Argo floats. Mode waters are characterized as a large volume of water with a very narrow TS variation. Marked by low stratification within its extent, these water masses can be identified by highly homogeneous TS values, both horizontally and vertically. A potential vorticity minimum is generally used to track the mode water because it is a conservative property. Variations in the rate of formation of mode waters are connected to fluctuations in the air-sea interaction processes, including heat and moisture fluxes but also changes in the subtropical gyre circulation.

Net heat flux, evaporation and precipitation rates are estimated from a combination of microwave satellite data (AMSR, SSMI, TRMM) to correlate them with the changes in the mode water formation. Satellite altimeter data are used to examine low frequency changes in the oceanic heat storage associated with the subtropical mode water. The analysis of Argo data profiles, World Ocean Database, and reanalysis models (GODAS and SODA) allows us to investigate the variability of the parameters in the ocean interior. The moisture flux (E-P) estimated from satellite data shows increasing (decreasing) trends right over the regions where the salinity increases (decreases) in the western South Atlantic between 2003 and 2010. Reanalysis models show more frequent and intense southward excursions of the Brazil Current towards the Brazil--Malvinas Confluence region from 1985 to 2010, contributing to increase the rate of Subtropical Mode Water formation.

South Pacific Tropical Water as seen from Argo data and global GCMs

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The South Pacific Tropical Water (SPTW) identified by a shallow salinity maximum forms in the eastern South Pacific and is transported in the subtropical gyre and along the equator. Since the SPTW has a relatively short residence time and a relatively high subduction rate, its impact on the equatorial Pacific is expected to be faster and stronger than its North Pacific counterpart. The present study investigates the SPTW formation, pathway, and downstream impact using Argo data. Taking advantage of the recent advance in ocean modeling, results from high-resolution GCMs are also examined to identify the SPTW variability and its response to the atmospheric forcing on interannual and longer term time scales.

Effect of Decadal Kuroshio Extension Jet and Eddy Variability on the Modification of North Pacific Intermediate Water

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Salinity modifications in the North Pacific Intermediate Water (NPIW) core layer of 26.7-26.8 sigma_theta in the western North Pacific Oceanare investigated using temperature-salinity data from available profiling float and hydrographic measurements in 2002-09. During 2002-05 when the Kuroshio Extension (KE) jet was intense and zonally elongated, coherent positive salinity anomalies appeared along the inflow KE jet southeast of Japan and in the downstream Mixed Water region east of 152E.

Broad-scale negative salinity anomalies were detected south of the KE jet and in the upstream Mixed Water region west of 152E. The signs of these observed salinity anomalies were reversed in 2006-09 when the KE jet transitioned to a weakened and zonally-contracted dynamic state. By adopting an isopycnal advection-diffusion model and conducting model runs with the time-dependent advective field inferred from the eddy-resolving, satellite altimeter sea surface height data, it is found that the observed salinity anomalies are oscillatory in nature and are determined not only by the decadally-varying KE jet itself, but also by mesoscale eddy signals that modulate temporally and longitudinally along the path of the KE jet.

Argo profiles nonlinear feedback processes associated with the Indian Ocean Dipole

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A well-known nonlinear feature of the Indian Ocean Dipole (IOD) is its positive skewness, with cold sea surface temperature (SST) anomalies over the east pole (IODE) able to grow to a larger amplitude, and a commensurately greater impact, than warm IOE SST anomalies. Several possible mechanisms have been proposed to explain the skewness, but due to a lack of observations, the relative importance of various processes remains contentious. Using Argo profiles and other newly available data, we provide an observation-based depiction of the contribution by various feedback processes. Firstly, our observational analysis reaffirms the role of nonlinear dynamical heating, which reinforces negative IODE SST but damps positive IODE SST. In addition, it shows that the reinforcing effect is far greater than the samping. Secondly, a thermocline-temperature feedback asymmetry, in which cooling anomalies induced by a shoaling thermocline are greater than warming anomalies by a deepening thermocline, is the primary forcing of the IOD skewness. This thermocline-temperature feedback asymmetry is a part of the nonlinear Bjerknes-like positive feedback loop involving winds, SST, and the thermocline. The asymmetry is enhanced by a nonlinear response of the barrier layer, showing a greater thinning associated with an anomalous IODE cooling than a thickening associated with an anomalous IODE warming. Finally, in response to an IODE cooling, a reduction in rainfall, in evaporative heat loss and in ocean-to-air sensible heat transfer and an increase in shortwave radiation, are greater contributing to a greater damping, than those in response to IODE warming. Thus, the IOD skewness occurs in spite of the damping effect, rather than caused, by an asymmetry in the SST-cloud-radiation feedback.

Ocean general circulation near 1000m depth

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A careful reprocessing of the Argo float data collected before January 1 2010 has been done to produce a deep displacement data base (named ANDRO) covering the World Ocean (except the Arctic ocean and south of 65°S around Antarctica, because of ice cover). Most Argo floats (63%) drifted within the layer [900 1100] dbar and cover rather uniformly all the oceans. Maps of the mean currents (with a 1° by 1° resolution) reveal the strongest mean currents near 1000 m depth are the ACC, the western boundary currents (Gulf Stream, Labrador, Kuroshio, Falkland, Agulhas, East Australian and Somali currents), the northern boundary currents (Aleutian, Irminger and Greenland currents) and the equatorial zonal and alternate jets (mostly between 5°S and 5°N). EKE is strongest at the tip of south Africa (the Cape cauldron) and in the Argentine basin (the Confluence zone) reaching 400 cm2 s-2, generally strong in the ACC, the Gulf Stream or the Somali current (reaching 200 cm2 s-2) but not very strong in the Kuroshio and the equatorial band (reaching 100 cm2 s-2 only). This turbulent picture must be compared to the temperature variance, which shows only two main regions of high thermal activity: in the northern hemisphere the Gulf Stream, its recirculation and the North-East Atlantic, in the southern hemisphere the retro flexion region south of Cape town, straddling eastward to the north of Kerguelen. Elsewhere (except near 70°N 5°E and south of Australia) the temperature variance is very small (less than 0.1 C2). The tendency toward zonality of the mean currents is visible in the interior within the tropical zone (even though outside the equatorial band currents are weak). Meanwhile eddy motions are generally isotropic (except near solid boundaries).

SESSION E: Mesoscale Circulation – Thursday 27th Sept

Mozambique Channel eddies as a transport mechanism: The case of Red Sea Water

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Red Sea Water (RSW) is an intermediate water mass formed in the Red Sea which enters the Gulf of Aden between 500 and 800 m then the Mozambique Channel between 900 and 1200 m. RSW is defined by high salinities (34.8 – 34.9 PSU), low temperatures (5.5 – 7.0˚ C), low oxygen levels (1.0 – 2.1 ml/l) and densities between 27.2 and 27.6 sigma-ɵ. RSW is thought to be a dominant component of the salt budget for the intermediate waters of the Western Indian Ocean (as opposed Indonesian Throughflow Water and diapycnal mixing) as well as a significant salt contribution to the South Atlantic through the shedding of Agulhas Rings at the Agulhas Retroflection. Historically, it was thought that the most efficient mechanism of transporting RSW through the Mozambique Channel was by means of mesoscale eddies with the back-ground flow a lesser contribution. This paper analyzes eight years of Argo float data in the Mozambique Channel and compares the positive RSW profiles to an automatic eddy detection scheme using ¼˚ delayed time SLA product (updated AVISO product with RIO9 processed mean dynamic topography) to analyze the transport potential of mesoscale eddies. Contrarily, results show that both cyclonic and anti-cyclonic mesoscale eddies combined only account for 44 % of the transport potential through the Mozambique Channel with the remaining positive RSW Argo float profiles occurring outside of these mesoscale perturbations. Ten events are noted whereby a RSW positive Argo float becomes entrapped within either a mesoscale anti-cyclonic or cyclonic eddy (i.e. > four weeks). These are analyzed further to determine whether eddy kinetic energy (EKE) plays a role in the transport of RSW. Results confirm neither a seasonal signature for the distribution of RSW within the Mozambique Channel, nor mesoscale eddies being the preferred mechanism for transport as suggested in previous studies of the Mozambique Channel. This paper forms a base for future projects planned for the region using Argo floats deployed strategically within mesoscale eddies to monitor the dynamics of the thermocline (i.e. aging and decay of mesoscale eddies).

The southward transport of sub-mesoscale lenses of Bass Strait Water in the centre of anti-cyclonic mesoscale eddies

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The outflow of water from Bass Strait, a shallow ocean region between Tasmania and the Australian mainland is explored using a combined Argo, altimetry and ocean glider dataset. A cascade of dense shelf water from eastern Bass Strait, has previously been understood to travel northward along the continental shelf, and then disperse relatively uniformly eastward into the Tasman Sea. Observations from several deployments of deep ocean gliders, provided the unexpected discovery of lenses of shelf water 40 km in diameter and 200–300 m tall at depth in the centre of three 200 km diameter anticyclonic eddies. The eddy structure and propagation were documented by time series of satellite altimetry. The historical ocean station data provide only a very sparse coverage of the region, however, from a reanalysis of 2420 vertical Argo profiles off the continental slope in the western Tasman Sea we were able to identify 3 additional distinct patches of Bass Strait Water (BSW), all with positive dynamic height anomalies indicative of anticyclones. Through a yet to be understood process, BSW separates from the continental slope and forms a mid-depth lens that aligns vertically with the larger anti-cyclonic mesoscale eddy; and remains at the centre of the eddy for more than 6 months as it is advected 700 km southward. This pathway subducts shelf water into the ocean interior, and provides a link between mesoscale circulation and shelf water transport. The BSW that is captured in anti-cyclones advects south past the east coast of Tasmania. Further samples of BSW are identified off southwest Australia from Argo profiles, indicating that at least some of the BSW lenses move into the eastern Indian Ocean and persist for several years.

High resolution mapping of 3D semi-geostrophic dynamics from a combination of ARGO measurements and satellite observations

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In the last years, the Italian National Research Council (CNR) has worked on the development and test of different techniques and diagnostic models for the retrieval of the 3D ageostrophic currents at mesoscale, starting from a combination of ARGO measurements and different satellite data (active and passive sensors). In this framework, CNR also coordinated the MESCLA project (MEsoSCale dynamical Analysis through combined model, satellite and in situ data), funded in the framework of the MyOcean 2009 Open Call for Research and Development. CNR most recent achievements are related to the implementation of a diagnostic model of the ageostrophic components of the flow in the semi-geostrophic approximation, which is expected to provide more accurate estimates with respect to the classical quasi-geostrophic Omega equation. Preliminary results, as well as foreseen future developments and possible applications, will be discussed.

Western North Pacific Integrated Physical-Biogeochemical Ocean Observation Experiment (INBOX)

Toshio Suga *, Hosoda Shigeki, Inoue Ryuichiro, Sato Kanako, Koketsu Shinya, Kobayashi Taiyo, Kobashi Fumiaki, Toyama Katsuya, Kita Toshiyuki, Honda Makio, Matsumoto Kazuhiko, Sasaoka Kosei, Fujiki Tetsuichi, Kawakami Hajime, Wakita Masahid, Sasai Yoshikazu, Murata Akihiko, Hayashi Kazuhiko, Kawai Yoshimi, Faure Vincent, Nagano Akira, Kawano Takeshi, Saino Toshiro

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Combination of autonomous float and biogeochemical sensor technologies has enabled concurrent measurements of physical and biogeochemical parameters for wide spatial and temporal ranges, which could open a new world of synergistic use of those data to advance not only each discipline but also a holistic understanding of the ocean. Study of mesoscale and submesoscale processes is one of those areas greatly benefitted from the synergistic use of physical and biogeochemical data acquired by autonomous platforms, because our understanding of those processes is still limited mainly due to the difficulty in measuring them despite their importance widely recognized. To acquire physical-biogeochemical data which could resolve mesoscale phenomena in the western North Pacific, JAMSTEC launched an interdisciplinary project "Western North Pacific Integrated Physical-Biogeochemical Ocean Observation Experiment (INBOX)" in 2010. INBOX aims to quantify impacts of physical processes on biogeochemical phenomena, so that we could also ultimately utilize biogeochemical information for understanding physical processes. Through a series of field experiments, we also hope that INBOX could contribute to designing effectively sustained biogeochemical observing system.

As the first phase of INBOX, profiling floats with oxygen sensors were intensively deployed around the biogeochemical mooring station S1 maintained since spring 2010 at 30oN, 145oE, further south of the Kuroshio Extension. We have deployed 5 floats in fall 2010 and 25 floats in summer 2011 with profiling cycles of 2-3 days in the 150 km-square area centered at the S1. The S1 mooring has a profiling buoy (POPPS) equipped with conductivity-temperature-depth-oxygen (CTDO) sensors, a scalar irradiance sensor, and a fast repetition rate fluorometer (FRRF) measuring the top 150 m every one or two days. It also has an acoustic Doppler current profiler (ADCP) measuring horizontal velocity every hour above 500 m depth with 8 m resolution, and time-series sediment traps at 200 m, 500 m and 5000 m. After the deployments, a series of multi-disciplinary ship observations around the S1 have been conducted in winter and fall 2010, winter, spring and summer 2011. Satellite altimetry, ocean color and sea surface temperature data and atmospheric reanalysis data are also important sources of information. Initial targets of this first experiment include quantification of vertical transport of nutrients by mesoscale/submesoscale disturbances as well as mixing and entrainment due to air-sea fluxes, and understanding of their temporal and spatial variations.

In this presentation, following the overall description of INBOX, we will introduce highlights of early results. In order to fully utilize data from the float array with a nominal resolution of "30 km x 2 days" for describing mesoscale physical-biogeochemical fields, oxygen sensors should be calibrated appropriately. The calibration procedure will be presented briefly. Details of those results will be given in the poster presentations.

SESSION F: Impact Models – Friday 28th Sept

Development of Observation Impact Statements under GODAE OceanView

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GODAE OceanView seeks to accelerate and improve the development of operational ocean forecasting capabilities around the world. All ocean forecast and analysis systems are underpinned by observations – using some form of data assimilation. A new initiative under GODAE OceanView is the development and dissemination of Observation Impact Statements (OISs). The objective of an OIS is to quantify the impact of all assimilated, or analysed, observations on each forecast or analysis at all operational centers. The information in each OIS includes basic metrics, like what data are used; data assimilation-based metrics that quantify the impact of each observation on each system's analysis; and forecast-based metrics that quantify the improvement in forecast skill due to each and every assimilated observation. Results from a preliminary series of OISs will be presented, along with examples of other metrics that may be included in OISs. It is the goal of GODAE OceanView that all operational centers routinely produce OISs – and that these OISs be disseminated to the broader oceanographic community on a regular basis.

Impact of Assimilation of Argo Data in Global HYCOM

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An adjoint-based procedure has been developed to determine the impact of the assimilation of Argo profiling floats on reducing forecast error in the Navy's global HYCOM system. Adjoint-based observation sensitivity provides a feasible all at once approach to estimating observation impact for any set or subset of observations. The method is computationally inexpensive and can be executed routinely as an integral part of an analysis/forecast system allowing the impact of observations to be regularly assessed. HYCOM is executed daily in real-time on a global 1/12° resolution grid. Assimilation is done using 3DVar and a 24 hour update cycle. Forecast error is calculated as the difference between 72 and 48 hour forecasts of the ocean state valid at the same time relative to a verifying analysis. The adjoint of the 3DVar data assimilation system extends the model forecast error estimate into observation space and provides the information to assess observation impact using actual model-data differences (innovations). Data impact results are available for individual observations which can then be grouped into contributions made by observing systems and analysis variables. In this talk we describe the data impact methodology and present some preliminary results. In terms of total data impact the most numerous data types tend to have the biggest overall impact (SST and altimeter SSH). However, on a per observation basis Argo consistently ranks number one. In particular, Argo salinity is found to have the largest impact of all data types assessed so far.

Impact of Argo data and quality control in Mercator Ocean global and regional Reanalysis systems

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Mercator Océan has developed a regional forecasting system at 1/12° resolution over the North East Atlantic (IBI: Iberia, Biscay and Irish), taking advantage of the recent developments in NEMO source code for shelf applications, by example with the use of an astronomical tidal forcing or variable volume. Based on this new operational system, it was considered to produce a first regional reanalysis, with GLORYS (GLobal Ocean ReanalYses and Simulations, a Mercator Océan product) as the provider of lateral boundary conditions. It covers the period from January 2002 to December 2009 and the forcing fields (including the atmospheric pressure) are based on ERA-interim products (frequency: every 3 hours).

The assimilation system is based on a reduced-order Kalman filter (SEEK: Singular Extended Evolutive Kalman filter), in which the error statistics are represented in a subspace spanned by a small number of 3D error directions. To apply the increments, an Incremental Analysis Update (IAU) approach is employed to limit initial shocks, thus allowing a smooth trajectory of the simulation. This data assimilation system allows to constrain the model in a multivariate way with Sea Surface Temperature data (AVHRR + Multi-satellite High resolution), together with all available satellite Sea Level Anomalies data, and with *in situ* observations from the CORA-03 data base (produced by the CORIOLIS data centre), including ARGO floats temperature and salinity measurements.

During the 2000s, the deployment of ARGO floats allowed to increase the number of in situ observations in a powerful way and therefore a better constrain of operational ocean forecasting systems. Similar to atmospheric forecasting systems (for example, the Integrated Forecasting System developed at ECMWF), quality control of observations plays a key role in the performances of the system. A part of this quality control is done at the CORIOLIS data centre and another one is performed during the integration of the reanalysis simulation, based on the innovation vector.

In this presentation, we describe the results obtained with the regional reanalysis system and a comparison with the global reanalysis. A special focus will be made on the automated quality control methods developed in GLORYS and IBI12. It reveals that close to 50% of the observations pointed out by GLORYS's automated QC were in turn flagged as bad by the CORIOLIS data centre.

Using observing system evaluation experiments to test the value of Argo data in FOAM

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FOAM is the Met Office operational ocean forecasting system. As part of GODAE-Oceanview we have run a series of operational observing system experiments. Between February and July 2011 we ran a system parallel to the operational suite which is identical except that certain observation types are excluded. At the start of each month the parallel system was reset to the operational restart and a run started with a different observation type excluded. The data withheld for each month were: February - XBT; March - TAO; April - Jason-2; May - all altimeter; June - AVHRR/METOP; and July - Argo data.

We present selected results of the impact on FOAM of excluding the observation types. Withholding Argo data for one month results in a 5% increase in the RMS observation-minus-background differences. We also see impacts on other model variables. For instance, there are large scale changes of ±5cm in SSH. This implies that Argo data is a key-stone for FOAM and if Argo data were excluded for the long term that the performance of altimeter assimilation would be degraded.

Evaluation of the Argo float impacts on the ocean data assimilation systems in JMA/MRI.

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Temperature and salinity profiles observed by Argo floats are essential data for ocean data assimilation systems. In Japan Meteorological Agency (JMA)/ Meteorological Research Institute, we, therefore, evaluate the impact of Argo float data on the ocean data assimilation system, MOVE/MRI.COM, continually in order to appeal the importance of those data to the managing institutes and general public. MOVE/MRI.COM has been used in JMA for the operation since March 2008 for monitoring and forecasting of the seasonal climate, ENSO, and the ocean state around Japan. This system is constituted of the ocean general circulation model, MRI.COM, and the data assimilation system, MOVE. In this presentation, we introduce recent two approaches to the evaluation of Argo float impact.

The first approach is an Observing System Experiment (OSE) using the 0.5-degree resolution North Pacific system, MOVE/MRI.COM-NP. In this OSE, we performed 5 assimilation runs using 80%, 60%, 40%, 20%, 0% of available Argo float profiles, and the accuracies of these assimilation runs are evaluated using the 20% of Argo float profiles which are not used in all assimilation runs, that is, we evaluate the accuracies using independent observation data. The accuracy is monotonically improved with icreasing the number of assimilated Argo floats from 0% to 80%, which means that Argo float data effectively improve the data assimilation result. It is also noted that the impact of Argo float data on the salinity field is always larger than that on the temperature field. Although the relatively low resolution of the system used in this study limits the reliability of the result, we plan to perform a similar experiment to the higher-resolution system in order to issue more general result.

The second approach is an OSE for evaluating the impact of Argo floats on the ENSO forecast. The ocean initial condition for the coupled model, JMA/MRI-CGCM, is prepared by the global version of MOVE/MRI.COM-G in the JMA ENSO forecasting system. In the OSE, we prepare two data assimilation runs with and without Argo float data. We, then, perform 13-month 11-member ensemble forecast from these two assimilation runs using the JMA's operational coupled model, JMA/MRI-CGCM. The forecast scores for 6-month lead time are better in the forecasts started from the data assimilation runs with Argo float data for NINO3, NINO3.4 and NINO4 SST, and this impact is enhanced for 12-month lead time. This improvement also influences several atmospheric fields, including the sea level pressure, precipitation, and the divergence in the upper troposphere. In the presentation, we additionally show the result of an OSE experiment for evaluating the impact of TAO/TRITON data on the ENSO forecast.

Impact of ARGO Data on the East Sea Circulation Modeling

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The impact of ARGO float-observed temperature data on the East Sea circulation modeling study is carried out using the 3-dimensional variation data assimilation method with the Modular Ocean Model (MOM ver. 3.1). The surface current estimated from the surface drifter track was used to compare the results between the model and observation, and the model simulation experiments were separated into two cases: all data assimilation case and no-ARGO data assimilation case. The linear correlation between drifter-driven surface current and all data assimilation case showed mostly 0.5 (maximum value 0.9), however it rapidly decreased less than 0.2 for the no-ARGO data assimilation case. According to the effects of individual ARGO float's temperature profile, the profile data strongly affected the middle layer temperature structure, for example 100 - 300 meters in depth of the Warm Eddy area. During the summer and fall season in 2009, it was shown that the ARGO data contributed to changing the fluctuation pattern of the surface currents especially around 39 - 40degN 129 - 131degE and 36 - 38degN 133 - 135degE areas. When the ARGO data were assimilated, the East Korea Warm Current (EKWC) could reached over 40degN and the width of fluctuation to the east direction was increased, and surface warm current along west coast of Japan was also intensified. More specific results of temperature and current structure change by ARGO data in the subsurface and middle layer will be introduced in the presentation

SESSION G: Extension of Argo to Marginal Seas and Sea Ice Saturday 28th Sept

Extending Argo into marginal Seas: the Mediterranean and Black Seas

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More than 120 Argo floats have been deployed in the Mediterranean and Black Seas between 2001 and 2011, providing about 12,000 CTD profiles throughout these marginal seas. Sampling strategy recommendations made a few years ago (as part of the EuroArgo PP project) include: alternated cycles to 2000 and 700 m every 5 days, a parking depth near 300-400 db where the Levantine Intermediate Water prevails, deployments in and out of the major circulation features, and a minimum fleet of 35 floats for the Mediterranean and Black Seas. Iridium data telemetry was highly recommended to reduce the probability of thefts and stranding while the floats are at the surface, and hence to increase the float operating lifetimes (significantly less than in the open ocean). Regarding EEZ issues, the float deployers have all been working with the ATC to notify countries of float deployments. There have been no formal complaints from countries in the Mediterranean and Black Seas yet about floats being deployed in their EEZs. Additional sensors (dissolved oxygen, chlorophyll concerntration, turbidity, optical irradiances, etc.) have been fitted on some floats deployed in the Mediterranean and Black Seas. The MedArgo ARC has done delayed mode quality control on most floats in the Mediterranean and Black Seas. The standard OW method can be used with adjustments to some of the thresholds and parameters. Plans for the continuation and further development of Argo in the Mediterranean and Black Seas are discussed.

Mediterranean intermediate circulation estimated from Argo data

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The trajectories of Argo profiling floats, deployed in the Mediterranean Sea since October 2003, are used to describe the intermediate circulation in regions with good data coverage (Western Mediterranean, Ionian and Levantine sub-basins, Cretan Passage). These floats were programmed to execute 5-day cycles, to drift at a neutral parking depth of 350 m and measure temperature and salinity profiles from either 700 or 2000 m up to the surface. At the end of each cycle the floats remained at the sea surface for about 6 hours, enough time to be localised and transmit the data to the Argos satellite system. The Argos positions were used to determine the float surface and intermediate displacements. At the surface, the float motion was approximated by a linear displacement and inertial motion. Intermediate velocities estimates were used to investigate the Mediterranean circulation at 350 m, to compute the pseudo-Eulerian statistics and to study the influence of bathy metry on the intermediate currents. Maximum speeds, as large as 33 cm/s, were found northeast of the Balearic Islands (western basin) and in the Ierapetra eddy (eastern basin). Typical speeds in the main along-slope currents (Liguro-Provençal-Catalan, Algerian and Libyo-Egyptian Currents) were ~ 20 cm/s. In the central and western part of Mediterranean basin, the pseudo-Eulerian statistics show typical intermediate circulation pathways which can be related to the motion of Levantine Intermediate Water. In general our results agree with the qualitative intermediate circulation schemes proposed in the literature, except in the southern Ionian where we found westward-flowing intermediate currents. Fluctuating currents appeared to be usually larger than the mean flow except in some coastal regions characterised by permanent currents. Intermediate currents were found to be essentially parallel to the isobaths over most of the areas characterized by strong bathymetry gradients, in particular, in the vicinity of the continental slopes.

Oxygen dynamics in the Black Sea: Two years of Argo profiling floats data.

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Observations collected from May 2010 until February 2012 from two Argo floats with oxygen sensors revealed serious under-sampling problems in the past observations. New data resolved well biogeochemical evolution in the upper photic zone (e. g. the seasonal variability of subsurface oxygen maximum), as well as the cold water mass formation. Continuously measured oxygen profiles shed a new light into the coastal-open ocean exchange and dyapycnal mixing. It was demonstrated that earlier theories claiming that major vertical structure of water masses could be well described as controlled by isopycnal alignment of properties were coarsely applicable to both coastal and interior part of the Black Sea. The dynamics of the oxic-anoxic interface was dominated by rigorous mesoscale processes bringing locally anoxic waters up to about 70 m from the sea surface. Alternatively, oxygenation (ventilation) of the pycnocline in the coastal zone penetrated down to about 150-200 m.

Observing the ice-covered oceans around Antarctica by profiling floats

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Since 2007, University of Washington has deployed more than 80 autonomous profiling floats in the sea ice zone around Antarctica. These floats are equipped with an ice-avoidance algorithm that instructs the floats to store profiles and remain submerged below the ice during the winter months. Many of these floats have lasted four complete annual cycles in the sea ice zone, with several of them now entering their fifth austral winter under the ice-covered oceans. The mean lifetime of these instruments operating in such extreme conditions is therefore comparable to the mean lifetime of similar instruments operating at mid-latitudes, thus demonstrating that Argo floats can be used successfully to make observations at polar regions. Data collected by these floats reveal the vertical processes at play in the upper ocean around Antarctica as sea ice forms and decays. The dominant vertical processes include brine rejection associated with sea ice formation, accumulation of fresh melt water during spring thaw, and active entrainment of water from the permanent pycnocline into the seasonal mixed layer during the winter months. We demonstrate the application of a one-dimensional mixed layer model in quantifying some of the winter flux terms. In addition, we show some of the regional differences between the Weddell Sea and the East Antarctic region, including episodes of winter outflow of newly formed dense water from the broad continental shelves.

Bio-Argo and the emergence of profiling float as key platforms to measure ocean

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In this talk I will summaries the technical and scientific advances that have made biogeochemical measurements on profiling floats possible and reliable. Reliability is key to insure quality measurements through 3-5yr lifetime of a standard Argo float. These measurements are key to increase our understanding of the role of the oceans in elemental cycling and climate feedbacks necessary to anticipate future Earth climate.

Through efforts by individual scientists in collaboration with sensor and float manufacturers, feasibility experiments have been conducted with a variety of bio-optical and chemical sensors. Workshops and working groups insured communication and dissemination of knowledge across the community, which has contributed to expanded use of the technology by non-experts.

We are now at a point where some existing biogeochemical sensors are mature enough to be deployed on Argo floats and provide quality data throughout the deployment lifetime. Work on data quality procedures, similar to those currently applied to T and S Argo data, are being developed, and will be presented and reviewed in the upcoming ADMT in Nov. 2012.

Recently, several large experiments using 10-100's of floats equipped with biogeochemical sensors have been funded or are under review. In anticipation of their potential contributions to the Argo data set, it is important that the Argo community be informed and involved.

POSTERS

Viewing **on Friday 28th Sept,**
from 16h30 to 17h30

Sala Adriatico.

P01

Development of a Deep Ocean Profiling Float

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Over the last decade the Argo program has transformed our understanding of the ocean. This highly successful international effort has provided unprecedented spatial sampling of the top 2000 meters of the water column. But, given the evidence of temperature increases in the deep ocean, Fukasawa, et al., 2004, an affordable, profiling float that can provide spatial sampling on par with the Argo program to depths of up to 6000 meters is essential for improved ocean modeling. Teledyne Webb Research (TWR) has undertaken a development effort to produce a deep float to address this need.

This paper will provide an overview of the new TWR Deep Float, the Autonomous Profiling Explorer – Deep (APEX-Deep). A high level description of the float design and anticipated capabilities will be presented. The float exploits the highly successful APEX float pedigree as a starting point. It is designed to achieve in excess of 150 profiles to 6000 meters. At the heart of the APEX-Deep are the new TWR APF-11 controller and a novel large displacement buoyancy engine to permit highly efficient water column profiling. These subsystems will enable the float to operate effectively in a significant fraction of the world's oceans and undertake complex missions that can be easily reconfigured by the user to profile.

The system will have a variety of optional configurations and sensor suites. It can actively change profiling depth based on downloaded local bathymetry or an optional, on-board altimeter. One necessity for this type of system is a robust design that is priced to permit scaling to a large enough population to augment the current Argo Network.

This paper will conclude with the current status of the APEX-Deep development program, preliminary test results from the prototype floats, and a roadmap that will provide the community a clear picture of the system availability.

Argos technology evolution for ARGO floats

P02

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Argos is a unique worldwide location and data collection satellite system dedicated to studying and protecting the environment. The ARGO project selected this satellite communication system for two main technical reasons: reliability and robustness as well as for his semi-public structure dedicated to environment and supported by main Space agencies in a cost recovery protocol. In order to prepare the next decade and new challenges for ARGO, design of the next generation of profiling float is required.

Improvement on data transmission is one of the main objectives for the next decade of ARGO. Next challenges for the ARGO program in term of satellite communications are: 1) maintain the reliability 2) stay less time on surface 3) transmit higher resolution profiles 4) get lower cost per profile and 5) use two-way controls for tuning mission parameters.

Thanks to a downlink signal, an interactive data collection mode as well as an uplink high data rate (4800 bps) the Argos-3 technology integrated in profiling floats offers the possibility to reach these 5 goals. Furthermore with three Argos-3 operational satellites (METOP-A & B from EUMETSAT and SARAL from ISRO) at the end of 2012, the third generation of Argos instrument can now benefit to ARGO.

The Argos-3 technology was integrated for the first time in 2010 in an ARVOR float thanks to collaboration between CLS, Ifremer and NKE. Two prototypes using the downlink signal and the interactive transmission mode have been deployed in the Mediterranean Sea in 2011. Under the NAOS project (Novel Argo Ocean observing System) next developments as the use of the high data rate channel, will be achieved in 2012 in order to fully use the Argos-3 capabilities. Results, benefits and development plans will be illustrated in the presentation.

The sustainability of the Argo floats network using the Argos system is already ensured with the development of the fourth generation of Argos instrument by the French space agency. First Argos-4 satellites are scheduled to be launched in 2016 with a backward compatibility, increased system capacity and a wider frequency spectrum.

P03

Oxygen sensor characterization and calibration - Providing the Argo-O2 essentials

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Of all biooptical or chemical extensions of the Argo core mission, autonomous oxygen measurements received the highest attention due to the maturity of the sensors available. Here we present laboratory and field results to make their use fully operational. A dedicated laboratory calibration setup based on an electrochemical O2 generation has been developed, providing individual multipoint laboratory calibrations with an accuracy of 1 µmol/L. While these have been validated successfully in the field, oxygen optodes have been observed to drift between calibration and deployment. In-air oxygen measurements can provide an in-situ calibration reference. A field accuracy of 2 µmol/kg can thus be obtained as demonstrated by a prototype CO2/O2-float off Cape Verde. Detailed investigations of the sensor's dynamic response behaviour as well as the hydrostatic pressure effect complement the prerequisites for routine high quality oxygen measurements. Seasonal cycles, air-sea oxygen fluxes, ventilation events, net community production rates, or oxygen-derived particulate organic carbon fluxes can be obtained from such float timeseries.

P04

Microstructure velocity measurements from an ARGO float

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The traditional method for deploying microstructure sensors for oceanic turbulence measurements is from ship-borne vertical profilers.However these measurements are scarce since ship operations are costly and provide only limited spatial coverage and more measurements are required in order to better characterize turbulence and its relationship with larger scale motions. This requires joint fine-scale and microstructure measurements over long time periods. To this aim we have developed a turbulence measurement system based on a PROVOR profiling float that will enable us to conduct autonomous, continuous profiling measurements for several weeks.Our prototype system consists of a /PROVOR/ profiling float and a /MicroRider/ self-recording turbulence instrument, which carries two velocity shear probes and two fast-response thermistors. We tested the prototype system in a 10-m deep tank and conducted a series of dives to assess the performance of the turbulence sensors. Of particular interest was the amount of signal contamination of the shear probe data caused by vibrations of the profiling float and by the SBE pump. We show that the signal to noise ratio is always beyond 10 and that the pump has a weak impact on dissipation estimate. These preliminary results also suggest that the resolution of the system is of the order of 3.10^-10W/kg. These preliminary results need to be confirmed at sea where the behaviour of the system under a realistic sheared current will be tested. Results from a test cruise scheduled in June will allow us to draw conclusions about the usefulness of this measurement system for global turbulence observation.

Nke profiling floats update

P05

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Nke company manufactures and develops profiling float based on Provor and Arvor technology in industrial partnership with Ifremer (Institut Français de Recherche pour l'Exploitation de la Mer) for many years. NKE offers standard Argo floats in the configuration of TS, but also profiling floats equipped with various sensors. The "Provor" line's main characteristic is an hydraulic system which avoid the constraints of preballasting prior to deployment and to easily accept the addition of sensors. Provor already embeds sensors such as the biogeochemical and dissolved oxygen. The capacity of the vector control electronics is increased by the addition of electronic board measures for sensors management. These cards allow the increase of sensors number (a CTD and 6 sensors with serial connection) and enable pretreatments on measures such as average, standard deviation, median. The automatic modification of parameters of a profile and of the Profiler's mission is in development: for example, the variations of a measure will automatically increased sampling. The increase in the capacity of battery improves the number of cycles, enables power supply of sensors with energy requirement and reduces the unit cost of each cycle is available. The transmission mode of Iridium Rudics allows at optimum cost the transfer of an important volume of data. This generation enables the deployment in-situ of sensors with similar parameters for their validation, it opens perspective of new measures deployment on autonomous floats.

P06

SST profiles from pumped and un-pumped near-surface Argo measurements

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The Argo array of profiling floats provides profiles of temperature and salinity from 2,000 m depth to around 4 or 5 m below the surface. In highly turbulent well-mixed conditions the temperature profile in the upper 10 m or so is fairly homogeneous, but this is not so in light wind conditions where significant gradients can develop. There is a need from the GHRSST (Group for High Resolution Sea Surface Temperature) community for additional measurements closer to the surface to better describe the vertical structure (and its diurnal variation) in near-surface temperature.

In recent years a significant number of Argo floats have been deployed that permit sampling of temperature much closer to the surface. In most of these floats, that have Argos communications, the CTD pump is switched off between 5 and 10 m before the float reaches the surface, but the floats continue to sample until the float reaches the surface. These floats also provide non-pumped and pumped temperature measurements at 20, 15, 10 and 5 dbar depth for cross-calibration. Also over 70 Iridium floats have been deployed that permit pumped samples to be taken at 1 dbar resolution to 1 dbar depth.

Work in the summer of 2011 demonstrated the ability of such floats to observe temperature gradients in the upper 10 m of the ocean. However, we now have another 12 months of near-surface data from more floats and these data will now be evaluated and, where possible, compared against representative (co-located) measurements from drifting buoys and/or satellites. Techniques used to adjust (QC) the near surface data will also be presented.

P07

GREEN MERCATOR: Impacts of Physical Data Assimilation on the Integration of Biogeochemistry into Mercator Ocean operational systems

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The integration of marine biogeochemistry to operational systems is a timely development within the context of international initiatives focused on carbon monitoring and accounting, as well as science-based management of marine ecosystems and resources.

The objective of Green Mercator (Mercator-Vert project) is to implement a marine biogeochemical and ecosystem component at the global scale into MERCATOR operational systems. The global configuration of the state-of-the-art multi-nutrient and multi-plankton biogeochemical model PISCES has been successfully integrated to operational Mercator Ocean systems.

In order to evaluate the impacts of physical data assimilation on modeled biogeochemical tracer distributions, two simulations were carried out: (i) a biogeochemical simulation forced by a physical free run (without physical data assimilation) and (ii) a biogeochemical simulation forced by a physical reanalysis (with physical data assimilation). We present a first evaluation of the capability of GREEN MERCATOR models to reproduce large scale distributions of biogeochemical tracers. To this end model output is compared to climatologies and data from one time series stations. The comparison of simulated biogeochemical fields provides a first assessment of impacts of physical data assimilation on modeled biogeochemical tracer distributions.

P08

Ocean mixed layer heat budget near the North Pacifc Ocean subarctic front east of Japan.

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We investigate the Ocean Mixed Layer (OML) heat budget close to the North Pacific Subarctic Front in an area where the front is quasi-stationary (155 E). This area is of particular interest because strong air-sea heat exchanges there may affect the North Pacific storm track. Also, it is thought to be a formation area of central mode water. The heat budget is computed using satellite sea surface temperature (AMSRE), altimetry (AVISO), surface wind stress data (QuikSCAT) and air-sea heat fluxes from the J-Ofuro data set. Argo profiling float temperature and salinity data are used to estimate the depth of the mixed layer.
The heat budget seasonal cycle is investigated in two boxes representative of two different regimes of the budget: a deep mixed layer box south of the front where the winter mixed layer depth reaches up to 300 m, and a shallow mixed layer box where winter mixed layer reaches 125 m. In the deep OML box, strong winter cooling mostly due to heat loss to the atmosphere is amplified by both lateral advection due to Ekman transport and vertical entrainment from below the mixed layer (the two latter terms contribute 25 percent of the cooling). In the shallow OML box, strong winter cooling by lateral Ekman advection is largely balanced by lateral geostrophic advection due to the front.
The effects of this balance on the winter OML water properties linked to Transition Region Mode Water formation are subsequently investigated.

P09

Going beyond Argo-O2 - In situ CO2 and O2 measurements on Argo floats

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In recent years profiling floats are also being considered as platforms for marine biogeochemical research. This study showcases the utility of floats as a novel tool for combined gas measurements of CO2 partial pressure (pCO2) and O2. A typical Argo float was equipped with a small-sized and submersible pCO2 sensor and an optode O2 sensor for high resolution measurements in the surface ocean layer. Four consecutive deployments were carried out during Nov. 2010 and June 2011 near the Cape Verde Ocean Observatory (CVOO) in the eastern tropical North Atlantic. The prototype profiling float performed upcasts every 31 h while measuring pCO2, O2, salinity, temperature and hydrostatic pressure in the upper 200 m of the water column. In order to maintain accuracy, regular pCO2 sensor zeroings at depth and surface, as well as optode measurements in air, were performed for each profile. Through the application of data processing procedures (e.g., time-lag correction) accuracies for float-borne measurements of pCO2 were greatly improved (10 – 15 µatm for water column and 5 µatm for surface measurements). O2 measurements yielded an accuracy of 2 µmol kg-1. With the data obtained, highly resolved air sea gas exchange for O2, CO2 and APO (Atmospheric Potential Oxygen) could be determined accurately. However, this was only made possible through the thorough pre-calibration and in situ drift control of both sensors named above.
Our results show the possibility of using profiling floats as platforms for detailed and unattended observations of the marine carbon and oxygen cycle dynamics – a valuable extension for future Argo.

Argo based statistics for climate monitoring

P10

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Since the setting up of the Argo array, monitoring the inter-annual and decadal variability of the ocean interior has become possible. Many climatological studies, but also dynamical modeling and reconstruction methods rely on elementary statistics, among which the definition of a mean appears as a fundamental. Most of the time, the mean state is obtained by merging all data over the largest available period, which, for the ocean barely starts in the 1950s. This imposes to combine data that are inhomogeneous both in quality and vertical resolution. Moreover, the strongly irregular time sampling leads to uneven weighting of the different periods. Taking advantage of the global coverage and the high vertical resolution of the Argo array, we have initiated the computation of time-referenced statistics that should fit the standards for modern data analysis and comparison of datasets and time series from different observing arrays of the Earth system.

Gridded monthly fields of temperature and salinity were produced over the decade 2002-2011 using the optimal analysis tool ISAS (In Situ Analysis System). The horizontal grid step is 0.5° (Mercator scale), and 151 levels are represented between 0 and 2000m. The Argo data set were carefully screened based on post analysis diagnostics. The cleaned data set are complemented by delayed mode CTDs, marine mamals and mooring data. The 10 years period is averaged to produce a monthly mean atlas of temperature and salinity. Variances and extreme values are also provided. Quantities such as density and Rossby radius are later derived from the primary variables. These products can be considered as a coherent statistical representation of the first decade of the third millennium.

P11

Properties and pathways of the Atlantic Water in the Greenland Sea observed with Argo floats

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Two Argo floats deployed by IO PAS from aboard R/V Oceania in summers 2009 and 2010 in the Greenland Sea succeed to circulate along the West Spitsbergen slope and then re-circulate south of the Fram Strait. Both floats were NEMO type and were equipped with ARGOS or Iridium modems and RAFOS technology. The first of them (with ARGOS system) collected 46 profiles from July 2009 to February 2010. The second one (with Iridium modem) collected 111 profiles from July 2010 to May 2011. Both floats survived until they finally finished transmission in the sea ice region east of Greenland. The gathered data sets allow to analyze water masses properties as well as pathways of the Atlantic Water advection. The data have been also compared to results obtained during repeated in situ observations performed recently by IO PAS in the Nordic Seas. Further analysis will allow to develop better algorithm for sea ice sensing in the Arctic and sub-Arctic seas and also test various data transmission technologies.

P12

Observing System Evaluation for the Black Sea: Focus on ARGO floats and altimetry during 2005-2012

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Availability of ARGO float observations for the Black Sea varied strongly over the last years. Ongoing efforts increased and will further increase the number of deployed floats therefore an objective estimate of the enhancement of the quality of observing network may give useful information for further development strategies. An observation system evaluation (OSE) exploiting the combined observations from ARGO floats and altimetry during the period from 2005 up to now has been performed.

The analyses are focused on the temperature, salinity and steric sea level elevation. Based on statistical background information derived from numerical simulations the OSE gives a quantitative estimate of the feasibility to reconstruct data of larger areas based on the availability, the accuracy and the spatial configuration of the measurements. Additional state reconstruction experiments were carried out in order to optimise the usage of the data, to check the plausibility of estimates derived from the OSE and for a detailed investigation of the utilised correlation patterns. During the investigated period measurements from altimetry and at least one float were available at all time. The highest density of observations including measurements from four and six floats were found during the time intervals from July-2006 to October-2010 and from March-2011 to January-2012, respectively. Preliminary observation system simulation experiments (OSSE) assuming idealised ARGO measurements with a regular distribution of floats gave support to the optimistic hypothesis that a state reconstruction of the deeper part of the Black Sea would be feasible within a reasonable error range based on observations from five floats. By investigating the mentioned two periods with relatively high density of measurements this hypothesis is reviewed under realistic conditions.

P13

Impacts of meso-scale eddy on air-sea fluxes of CO2: Utilizing Argo profiling float

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The subtropical gyre in the western North Pacific is one of the strongest areas acting for sink of anthropogenic CO2 in the world oceans. However, we do not understand well the mechanism of maintaining the strong sink. The area also experiences active meso-scale disturbances and turbulent mixing, which impact CO2 cycling in the upper layers. Unfortunately this scale of phenomena cannot be usually detected by shipboard observation. Thus we attempted to reconstruct surface seawater CO2 using data obtained by the Argo profiling floats.

24 Argo floats were deployed around 30N, 145E during late July to early August, 2011. 22 of the floats were active as of Mach 2012. All the floats drifted within a grid box of longitude 139E-147E and latitude 27N-32N for about 2 months, data of which have enough resolution for meso-scale analyses. Individual Argo profiling floats are equipped with a dissolved oxygen (DO) sensor (Oxygen Optode 3830, Aanderaa). The DO was calibrated based on Uchida et al.'s [2008] method [Sato et al., 2012], and resulted in having a standard deviation of 3.3 µmol kg-1 at a depth of around 2000 dbar. The DO data from the Argo floats, along with data for water temperature (T) and salinity (S), were converted into a grid data of 0.2 degree x 0.2 degree spacing and tow-day time resolution for 60 days.

To estimate surface seawater pCO2, we attempted to construct an equation relating surface seawater pCO2 to T, S, and DO, which were observed in the area ranging from 28N to 32N and from 143E to 147E by the Japan Meteorological Agency in the years from 2005 to 2011. As a result, we obtained a multiple linear regression equation as follows:

$$pCO2\ (\mu atm) = 13.6 * (T0 - 22.93) - 6.49 * (T50 - 21.41) + 0.59 * (AOU50m + 8.3) + 351.4,$$

where T0 and T50 are water temperatures in C measured at a depth of 0m and 50m respectively, and AOU50 indicates apparent oxygen utilization in µmol kg-1, which is defined as the difference between the observed concentration of DO in µmol kg-1 and the saturated DO concentration at the water temperature and salinity. The statistics of the equation are n = 118, R2 = 0.917, RMSE = 9.6 µatm.

With the equation and the grid data for T and DO, we reconstructed surface seawater pCO2. Monthly averaged surface seawater pCO2 in the entire area (28.5N–30.7N; 143E–145.2E) was estimated to be 416 µatm and 393 µatm for August and September, 2011, respectively. These averaged values are comparable to previously reported values in the area. Meso-scale temporal and spatial variations of surface seawater pCO2 will be introduced in the workshop.

P14

Heat penetration of downward net heat flux below shallow seasonal thermocline during spring- summer season in the North Pacific Ocean

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Seasonal changes in the surface layer temperature and the relationship between ocean heat content (OHC) and downward net heat flux (Qnet) are investigated using gridded monthly averaged Argo float and satellite observational data sets, to clarify a role of the subsurface ocean for the downward Qnet during spring-summer. Thin surface mixed layer (ML) above shallow seasonal thermocline develops during spring-summer season in the mid- and high-latitudinal oceans because of heating by the downward Qnet. Since subsurface layer clearly separates from the ML with the shallow seasonal thermocline, it is generally considered that ocean takes a passive role for atmospheric variability associated with climate change or summer monsoon. As a result, only sea surface temperature (SST) variation tends to be considered as a boundary condition in almost climate change studies. However, mechanisms of seasonal change in OHC in the subsurface layer, which strongly affects SST changes, is still unclear because of a lack of enough accurate oceanic data.

Seasonal changes in the surface and subsurface temperature indicate an importance of the subsurface ocean below the seasonal thermocline. That is, phase of maximum subsurface temperature lags behind maximum SST with increase of depth, suggesting a gradual heat penetration from the sea surface to the subsurface layer. Therefore, we analyze the heat penetration depth (HPD), which is defined as a depth of influence of the downward Qnet after the coldest winter, focusing on a relationship between Qnet and OHC from sea surface to HPD in one vertical dimension. In the subtropical ocean, the HPD deepens even below seasonal thermocline until winter, showing that the downward Qnet accumulates in the subsurface layer. Further, a hypothetical estimate of SST increasing rate, which assumes balancing between Qnet and dOHC/dt in the shallow ML, represents unrealistically large SST increasing rate, about 6 times as large as the observed, suggesting that the observed SST is the result on being moderate to effectively accumulate heat in the subsurface ocean below the seasonal thermocline. These situations can be widely observed in the North Pacific Ocean; especially it clearly appears in the subtropical region.

Regards of the mechanism on the heat penetration below the seasonal thermocline, Qiu and Chen (2006) indicated that internal wave plays an important role of the vertical mixing above the subtropical mode water, resulting from dissipation process of low potential vorticity after formation of the seasonal thermocline. Although such mode water does not always exist in the whole North Pacific Ocean, the vertical mixing may be one of effective processes for the downward heat penetration into the subsurface layer.

P15

Advancing Glider Technology to Complement and Enhance the Future Argo System

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Advancements in commercial autonomous ocean gliders in the past few years presents the potential for a crossover in which gliders can economically perform the tasks of ARGO floats, while providing better science data. The current Argo network requires the replacement of between 750 and 800 floats per year, due to loss or depletion of stored energy. The question now arises if it would begin to be more economic and scientifically beneficial to start to replace some of the Argo network with gliders as floats leave the system, especially in regions where groundings are common, or whenever more variety of chemical or physical sensor data would be scientifically significant. As commercial gliders soon will be able to operate to at least 3000 meters carrying multiple sensor payloads, the case for this approach becomes technically feasible and justified both economically and for the potential benefit of qualitative improvement in the ARGO science data collected.

This presentation will show a novel method whereby buoyancy powered gliders can match the endurance of the ARGO system while providing more replete sensing and better data repeatability . This approach would effective allow a single glider to cover four times the area intended for a float deployment, with the added benefit of less spatial randomness in the sampled areas . Examples of how AUV gliders have already proven that they can repeatably cover such a specified region by automatically compensating for observed predominant currents. Finally, the economics of commercial gliders as compared with that of the ARGO float technology, and a means to achieve cost parity between drifting floats and buoyancy propelled gliders will be proposed.

P16

Water characteristics and temporal variations of the warm core rings in the Kuroshio-Oyashio Extension region observed by Argo floats

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The present study investigated water characteristics and temporal evolutions of two warm core rings (WCRs) in the Kuroshio-Oyashio Extension region by using Argo profiling floats and ship and satellite observations. We mainly analyzed two Argo data with a high temporal resolution with 2-day cycle, which were deployed off the east coast of Japan in January 2009 and continued the observations near and/or within WCRs until July 2009. The two WCRs that we focused on were detached from the Kuroshio Extension almost at the same time around February 2007, and then were moved to the north by different excursions. During 2009 they stayed almost at the same positions. One is near the Kuroshio Extension and sometimes go through the interaction with the Kuroshio Extension (hereinafter WCR1). The other is far north from the Kuroshio Extension (hereinafter WCR2). The WCR1 and WCR2 have both vertical structures of anticyclonic eddy, containing warmer and saltier water of the Kuroshio within the eddy than ambient water in the surrounding area, on isopycnal surfaces. Calculation of the mixing ratio of Kuroshio and Oyashio waters shows that the mixing ratios are about 20~50% for WCR1 and more than 80% for WCR2, respectively, indicating that WCR2 was subject to vigorous mixing with the ambient Oyashio water. It was found that WCR1 has a marked temporal change in water characteristics. Cold and fresh Oyashio water around the eddy intrudes into the eddy intermittently with short time intervals in very narrow density ranges. The water characteristics of the eddy gradually change to the Oyashio water, suggesting that the small-scale intrusion of the Oyashio water is responsible for the change in water characteristics of the WCRs.

P17

Decadal variations of the North Pacific subtropical mode water and their dynamical influence on the subtropical gyre

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One of the remarkable features within the North Pacific subtropical gyre is the subtropical countercurrent (STCC), which is a narrow eastward jet on the southern side of the subtropical gyre, where the barotropic flow is westward as predicted by the Sverdrup theory. Together with theories, recent enhanced observations and model simulations have revealed the importance of mode waters in its formation. In particular, the subtropical mode water (STMW) plays a crucial role in forming the STCC around 23N in the western subtropical gyre. The STMW is a thick layer of vertically uniform properties and is dynamically characterized by low potential vorticity (PV). It is originated in the wintertime deep mixed layer within and south of the Kuroshio Extension, subducted into the main thermocline and advected by the wind-driven gyre circulation to a wide region of the subtropical gyre. The thick STMW raises the upper thermocline above the STMW, causing subsurface temperature front along the southern flank of the mode water and generating surface-intensified STCC by the thermal wind relation.

The present study examined how decadal changes in the STMW affect the STCC, by using Argo float data and satellite altimeter observation during 2001 to 2011. Consistent with previous studies, the STMW exhibits distinct decadal variations likely associated with the stability of the Kuroshio Extension. When the Kuroshio Extension takes a stable path, a thicker mixed layer forms in winter and is followed by the formation of the lower PV STMW during 2003 to 2006. In contrast, the STMW is considerably less intense during 2007 to 2010 when the Kuroshio Extension is relatively unstable. The change in the STMW is spread quickly to the south possibly by the Kuroshio recirculation, reaching to the north of the STCC within one year from the formation region. It is found that the Kuroshio recirculation tends to be intensified when the STMW is thicker, which perhaps helps carry the thicker STMW to the south.

The STCC also exhibit decadal variations in a manner consistent with those of the STMW. The thicker and lower PV STMW forces the upper thermocline to shoal, by which the upper thermocline is inclined to the north, intensifying the STCC on the decadal timescale. This result indicates that mode waters are not merely passive water masses but have dynamical effects on the upper ocean circulation.

P18

Deep NINJA: A new profiling float for deep ocean observation

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The importance of deep ocean observations in accurately understanding oceanic effects on anthropogenic climate changes, especially the oceanic heat content and the sea level rise, has been gradually recognized. One suitable device for deep ocean observation is a deep float. Thus, OceanObs'09 held in 2009 determined that a monitoring network for deep ocean consisting of many deep floats should be built by 2020 as one of international guidelines of observational ocean sciences. The monitoring network is deep-ward extension of the Argo and the Argo community considers thoroughly the "deep Argo" as an important objective in the near future. However, the development of the deep Argo has not yet begun, because there are no floats that can be available in the deeper ocean below 2,000 m.

Japan Agency for Marine-Earth Science and Technology and Tsurumi Seiki Co. Ltd. started to develop a deep float, Deep NINJA, in 2010 after a feasibility study to develop a buoyancy engine available in deep ocean. Deep NINJA is designed to be available at a depth of up to 4,000 m, which means it can observe from the sea surface to (the upper part of) bottom waters. It has a height of 210 cm (including antenna) and a mass of approximately 50 kg. Thus, Deep NINJA can be easily handled by two persons because of its multi-stage-shaped aluminum-alloy pressure hull. A conductivity-temperature-depth sensor is attached on the top, but the deep float is designed to have sufficient capacity to load additional sensors, for example, dissolved oxygen. The short burst data service of Iridium is used to transmit observed data to stations on land and it also enables two-way communication between float and operator. The float locations at the sea surface are accurately fixed by the global positioning system. The deep float can operate most patterns for observation requested by users. The patterns are changeable by changing parameters before deployment and by sending commands from operators after deployment. Finally, the deep float, which will be used in the polar region, has a function to avoid problems due to sea ice.

Deep NINJA is driven by lithium batteries, which provide a longer lifetime for operation in the sea. A trial estimation of its energy budget yields that a theoretical lifetime of Deep NINJA is more than 3 years with an observation interval of 10 days under the assumption that it observes 2,000 m profiles normally and 4,000 m profiles every 5 cycles until all the energy of batteries is consumed.

The first prototype of Deep NINJA was built in March 2011 and, recently, the second prototype, which is similar to a future mass-production model, was assembled in March 2012. Field tests have been carried out in coastal waters since 2011 spring. The first dive to a depth of 4,000 m is planned for summer 2012, and the mass-production models will be made available around 2013.

P19

Evolutions of Arvor & Provor floats.

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The continued improvement and evolution of float technology is crucial for the success of the international Argo project and the Euro-Argo infrastructure. Technological innovation is needed to answer new science requirements to further explore the oceans (e.g. new biogeochemical sensors, deeper measurements) and to provide more reliable and cheaper instruments.

This work is being done in the NAOS WP2 (Novel Argo Ocean observing System, work package n°2) framework that started in 2011. The actions that will be described cover many aspects including extended life time, improved reliability, better satellite communication capabilities, deeper measurements, new and flexible electronics (the float will be easily equipped with new sensors e.g. oxygen, bio-optics, density) and will have under sea ice capabilities. The presentation will mainly focus on 2 developments.

1st, we will talk about the capability for the float to reach greater depth (new Arvor 3500). Some design issues will be presented like hydraulic motor for buoyancy management, high pressure casing, sampling performances, lifetime assessment. The tests of 2 prototypes and their preliminary results will be showed.

2nd, we will present the implementation of the Argos 3rd generation satellite communication on the Arvor float. We will describe the way we are using the Argos3 modem, the results of prototypes at sea in low data rate mode, and the performance we expect to reach by using the high data rate mode.

NAOS – Preparing the new decade for Argo

P20

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NAOS (Novel Argo Ocean observing System) is one of the projects selected as part of the Equipex call for proposals from the French programme d'investissements d'avenir. The overall objective of the project is to consolidate and improve the French and European contribution to the international Argo observing system and to prepare the next decade of Argo. The challenge is to set up an effective monitoring of the world ocean and to strengthen French leadership in ocean and climate research and prediction. NAOS is a partnership between Ifremer (coordinator), UPMC (co-coordinator), CNRS, UBO/IUEM (PRES UEB), SHOM, CLS and the SME NKE. The project started in June 1st, 2011 and will end in December 2019.

The project has two main objectives:

1. To strengthen the French contribution to the Argo core mission (temperature and salinity from the surface down to 2000 m depth) by deploying between 10 to 15 additional floats per year over the 2012-2019 time period (110 floats in total). With the NAOS Argo floats, the French contribution to Argo will reach the target of 70 to 80 floats deployed each year.
2. To develop, validate and deploy the next generation of French Argo profiling floats. About 70 new generation floats will be deployed in three pilot areas: Mediterranean Sea, Arctic and North Atlantic. New float capabilities will include: more efficient design of the vehicle, improved transmission rates, integration of biogeochemical sensors, deeper measurements and under ice operations in the polar seas.

P21

Distribution and seasonal variation of the water mass near the Luzon Strait revealed by Argo data

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Based on temperature and salinity data collected by Argo profiling floats from January 2003 to September 2011 near the Luzon Strait (LS), the distribution and seasonal variation of the water mass are studied. The results show that the water mass features in the area of 121º–123ºE, 19º– 23ºN are in between the South China Sea (SCS) water and the North Pacific water and water exchange across 19ºN in the SCS is not evident . The intrusion of the North Pacific Tropical Water (NPTW) into the SCS through the LS is fairly weak in summer, strengthens in autumn and becomes the strongest in winter during the northeast monsoon, consistent with previous studies. There is, however, no evidence to indicate the intrusion of the North Pacific Intermediate Water (NPIW) into the SCS. In fact, the data suggests that high salinity intermediate water of the SCS can go into the Pacific through the LS with the strongest trend in summer and the weakest trend in winter.

P22

Use of Argo data for inter-comparison of GHRSST gap-free analysis fields

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Many sea surface temperature (SST) gap-free gridded analysis (Level 4, or L4) fields are produced by various groups in different countries. The Group for High Resolution SST (GHRSST) is an international collaborative body which has formed the inter-comparison technical advisory group (IC-TAG), to advise SST producers and users on the relative performance of these SST fields. This paper describes the GHRSST Multi-Product Ensemble (GMPE) system, which is run on a daily basis at the UK Met Office, taking various L4 analyses as inputs, transferring them onto a common grid, and producing an ensemble median and standard deviation. The various analysis fields ingested in the GMPE are discussed, highlighting areas of commonality between the contributing L4-systems as well as those aspects where there is less agreement on the appropriate algorithmic or parametric choices. The characteristics of the contributing L4 analyses are demonstrated by comparing them to near-surface Argo profile temperature data, which provide an independent measurement of SST and have been shown to provide a good estimate of foundation SST (the SST free of diurnal warming). The feature resolution characteristics of the L4 analyses are demonstrated by calculating horizontal gradients of the SST fields (on their original grid). The accuracy and resolution of the GMPE median are compared with those of the input analyses using the same metrics, showing that the GMPE median is more accurate than any of the contributing analyses with a standard deviation error of 0.40K globally with respect to near-surface Argo data. For use in climate applications such as trend analysis or assimilation into climate models, it is important to have a good measure of uncertainty, so the suitability of the GMPE standard deviation as a measure of uncertainty is explored. This assessment shows that, over large spatial and temporal scales, the spread in the ensemble does have a strong relationship with the error in the median, although it underestimates the error by about one third.

P23

The Southern Ocean Observing System: towards implementation

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The Southern Ocean provides the principal connection between the Earth's ocean basins and between the upper and lower layers of the global overturning circulation, with impacts on global climate patterns and the cycling of carbon and nutrients. It is also home to unique and potentially vulnerable ecosystems, and has impacts on global issues such as sea level rise. Changes in the Southern Ocean therefore have global ramifications.

The region is warming more rapidly than the global ocean average; salinity changes driven by changes in precipitation and ice melt have been observed in both the upper and abyssal ocean; the uptake of carbon by the Southern Ocean has slowed the rate of atmospheric climate change but caused basin-wide ocean acidification; and Southern Ocean ecosystems are reacting to changes in the physical and chemical environment. These results, and their implications, all demonstrate the need for sustained, multidisciplinary observations of the Southern Ocean.

The Southern Ocean Observing System (SOOS) has been developed to address this need. It will address the following key challenges of scientific and societal relevance: 1) Global heat and freshwater balance, 2) Overturning circulation stability, 3) Future of the Antarctic ice sheet and its contribution to sea-level rise, 4) Ocean uptake of CO2, 5) Future of Antarctic sea ice, 6) Impacts of global change on Southern Ocean ecosystems. This presentation will outline the development, status and future plans of SOOS.

P24

The North Atlantic Ocean main pycnocline from Argo data

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At mid-latitudes, the oceanic vertical structure of density is caracterised by a permanent highly stratified layer: the pycnocline. The pycnocline is the transition layer between surface water masses ventilated every winter when penetrated locally by the mixed layer and deeper water masses which have been ventilated at high latitudes and circulate equatorward. The pycnocline thus reflects a large scale balance between the penetration of local air-sea interactions and the re-emergence of remote ones.

The overall question we want to address is whether and to which extent the variability of the pycnocline properties (depth, thickness and thermohaline caracteristics) are influenced by those of air-sea interactions.

To this end, we first developped a new method to caracterise the permanent pycnocline properties from Argo data. We then applied this method to study the pycnocline in the subtropical North Atlantic Ocean. We will present the first results of this analysis: the climatological (over the Argo observational period) and seasonal variability of the pycnocline properties.

P25

How well can we track global steric sea level and heat content of the upper ocean from the Argo observing system?

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Ocean global mean steric sea-level and heat content are critical in balancing the Earth's sea-level and energy budget and important in attributing relative changes to natural or anthropogenic sources. Therefore, it is important to quantify mapping uncertainties in these estimates. With 3500 (as by 18-March-2012) autonomous Argo floats currently deployed, simultaneous salinity-temperature-pressure profiles from the ocean surface to 2000 dbars are now available in near real-time providing an unprecedented spatio-temporal distribution of observations when compared to conventional ship/mooring/buoy platforms. Based solely on Argo measurements over the 2004 to 2011 period, we reconstruct regional and global steric and heat content estimates of the upper ocean using Reduced Space Optimal Interpolation (RSOI) techniques applied to Argo anomalies (differences from climatologies spanning the periods 2004-2011 based on Argo observations only, and based on a wider set of observations). We investigate the sensitivity of RSOI reconstructions to the choice of the underlying climatology, and apriori covariance fields derived from altimetry, ocean reanalysis products and ocean models and compare our results with other analyses. Furthermore, RSOI global mean steric and heat content time series vary as function of land/ocean/ice mask extent. RSOI solutions can be extrapolated into marginal seas, ice zones and shallow water, but are poorly constrained there because of lack of regional Argo data. A conservative choice of land/ocean mask, relying on Argo observational footprint and discarding shallow water, probably underestimates the global mean metrics. We will attempt to separate out the differences in the reconstructions due to choice of basis data set versus the masking issue. The size of error in global budgets due to the poorly sampled regions will inform any cost/benefit of expanding the Argo global climate mission into the seasonal ice zone
s and the marginal seas for the purposes to tracking global budgets.

P26

Experiments of ocean state estimation and forecast in 2010-2011 using K7 global 4D-VAR coupled data assimilation system and effects of Argo data

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A global 4D-VAR data assimilation system based on a fully coupled GCM (K7 system) is developed to reproduce and predict basic climate states in 2010-2011. In this system, ocean initial condition and bulk parameters are optimized by assimilating 10-day mean observations into the model. Here, we adopt 3-month for the assimilation window, and use several atmospheric observational data, an observational SST data and Argo profiling float data (temperature and salinity) for the assimilation elements. To examine impact of Argo data, we performed two reanalysis experiments: one with Argo data (Argo case) and the other without Argo data (non-Argo case). The results show that the ocean state is better reproduced in Argo case, in particular shallow layers. Using optimized oceanic initial conditions and bulk parameters from the assimilation experiments, 11-member ensemble forecast experiments are conducted for 3 years in each case. There are some differences between non-Argo and Argo cases in the forecast experiments, although the results well predict major tropical climate variations in both cases. We will clarify the impacts of Argo data through these experiments.

P27

Impact of simultaneous assimilation of intermediate velocities derived from Argo float trajectories together with temperature and salinity profiles in a high-resolution 4-dimensional variational data assimilation system

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We developed a data assimilation system for the northwestern North Pacific focusing on meso-scale variabilities in the energetic Kuroshio Extension region which play an important role in the heat transport, the watermass formation, the atmosphere-ocean interaction, and the oceanic ecosystem. Our system assimilates in-situ temperature and salinity (T-S) profiles including Argo data and remote sensing data (sea surface temperature and sea surface height) into a high resolution ocean general circulation model using a 4-dimensional variational assimilation method (adjoint method). Although Argo data have the critical impact on the realism of assimilated results, their spatial distribution is not sufficient with the aim of monitoring meso-scale variabilities. In the previous studies, Taillandier et al. (2008) and Nilsson et al. (2011) successfully extended their forecasting system for Mediterranean Sea to include Argo float trajectories drifting at 350 m depth for a 4.5-day period (referred to as MedArgo floats). Following their encouraging results, we try to utilize the intermediate velocity information derived from Argo float trajectories in our data assimilation system in order to make better estimation of meso-scale variabilities and more efficient use of T-S profiles. Since most of Argo floats in our model region drift at deeper depth for a longer period (1000m, 10 day) than MedArgo, our attempt will become more challenging than the previous studies. The sophisticated adjoint method used in our system is expected to resolve this difficulty.

As the first step in assimilating information derived from Argo float trajectories, we use the quality-controlled data of YoMaHa'07 (Lebedev et al., 2007) dataset of velocities derived from Argo float trajectories and provided by APDRC/IPRC. We confirm that the YoMaHa'07 dataset capture the meso-scale structures in the Kuroshio Extension region to some extent and have misfits to the output of our system on the magnitude of the monthly-variation of our model. This preliminary analysis suggests that the YoMaHa'07 data have the potential for improving the reproducibility of our system. To clarify the impact of a simultaneous assimilation of T-S profiles and velocities derived from Argo float, experimental results with T-S profiles from Argo float (Exp. Ref) and with T-S profiles and velocity data from Argo float (Exp. YMH) are compared for the period during Jun-Dec 2009 (6 cases of monthly assimilation experiment) when YoMaHa'07 data frequently captured meso-scale structures such as the frontal jet and meso-scale eddies. Satellite and in-situ data available in this period are used for the validation of assimilated results as independent data.

At the writing of this abstract, 10 forward-adjoint minimization steps had been completed for the period June 2009 and the intermediate velocity field of Exp. YMH become more consistent with YoMaHa'07 dataset than that of Exp. Ref (Root-Mean-Square Difference has been reduced by approximately 10%) without the decrease in the performance for T-S profiles. Moreover, in terms of the consistency with independent data, the tentative result of Exp. YMH is comparable, partly superior, to that of Exp. Ref. At the workshop, we will present the subsequent results and detailed analyses.

P28

Is the Ionian Sea getting warmer and saltier? A case study using 26 years of data obtained from profiling floats and CTD casts

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The use of in-situ data as provided by profiling floats and CTD surveys allows to investigate the 3D spatial structure and temporal evolution of the thermohaline properties of seawater in a marginal sea at sub-basin scale, such as the Ionian Sea. The float data are also fundamental for assimilation in nowcasting and forecasting models (e.g., the Mediterranean Forecasting System - MFS) whose target is to improve the knowledge of the Mediterranean dynamics and climate. When regularly sampled, the profiling float and CTD data permit to analyze the temperature and salinity trends at various depths. Trends in water temperature and salinity are important indicators to monitor the climate and environmental evolutions that have a large impact on the marine circulation and global change. Several studies have shown that the temperature and salinity of the Mediterranean Sea have increased during the last 50 years. In this study we use about 20 years of CTD data (1985-2008) and 11 years of float data (2000-2011) to describe the thermohaline variability in the Ionian Sea at selected depths: the sub-surface level at 50 m below the most variable water column portion, the level close to 300 m characterized by the Levantine Intermediate Water (LIW), the intermediate level near 600 m and the deep level close to 2000 m. The results show positive temperature trends with an annual increment of a few thousandths of a degree in the intermediate and deep levels and a few hundredths in the LIW level, while the sub-surface level has a slightly negative trend; a positive trend of a few thousandths PSU per year is also found for the salinity at all the selected levels.

P29

Global Eddy-Permitting Ocean Reanalyses and Simulations of the Period 1992 to Present

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The GLORYS (Global Ocean reanalysis and Simulation) Project is motivated by the need of a realistic description of the ocean state and variability over the recent decades, at the global scale, and at the scale of the ocean basins and regional seas. The French research community (CNRS), the operational ocean forecasting center MERCATOR-Ocean and the CORIOLIS data center, have gathered their skills and expertise in physical oceanography, ocean modeling and data assimilation, to carry out global ocean reanalyses at eddy scale resolution for the period 1993 to present. This reanalysis effort is part of the project MyOcean granted by the European Commission within the GMES Program (7th Framework Program).

This paper will present the GLORYS reanalysis system relies on the ORCA025 global model configuration developed by the DRAKKAR consortium, on the basis of the NEMO3 ocean/sea-ice general circulation model. ORCA025 uses a horizontal grid resolution of 1/4° and 75 vertical levels, which permits the growth of mesoscale eddies. It is used for both operational and climate applications.
The data assimilation scheme is an adaptation of the data assimilation scheme used for operational forecasting by MERCATOR-Ocean. The data assimilation method is based on a reduced order Kalman filter (SEEK formulation) and an incremental analysis update, in conjunction with a bias correction scheme for temperature and salinity. Assimilated data are from the delayed time CORA data base specifically prepared for ocean reanalysis by the CORIOLIS data center, and from AVISO for altimetric data. Sea Surface Temperature, along track Sea Level Anomalies and in situ Temperature and Salinity profile data are assimilated. GLORYS reanalyses are forced with atmospheric surface variables from ERA-INTERIM atmospheric reanalysis, and control simulations with no observation assimilated are systematically produced.

Two reanalyses and one reference simulation with no data assimilation have been produced, validated and are distributed. The first one, GLORYS1, covers the “Argo era” (2002-2008). The second one, GLORYS2, covers the “altimetric era” (1992-2009) and will be updated until 2011. The reference simulation also covers the "altimetric era, and uses the exact same atmospheric forcing as GLORYS2. The paper will present assessments and measures of the quality of GLORYS products obtained from a validation protocol based on recommended GODAE and CLIVAR-GSOP reanalysis diagnostics, and from a comparison with the reference experiment. The scientific value of the GLORYS reanalysis products will be illustrated with results from independent scientific studies obtained in a wide range of areas such as climate, mesoscale processes, mixed layer processes, sea ice, etc.

P30

Western North Pacific Integrated Physical-Biogeochemical Ocean Observation Experiment (INBOX): Adjustment of dissolved oxygen data and calibration of dissolved oxygen sensors on JAMSTEC profiling floats deployed in the western North Pacific

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JAMSTEC launched a cross-disciplinary project "Western North Pacific Integrated Physical-Biogeochemical Ocean Observation Experiment (INBOX)" in 2010, which aims not only to understand physical processes governing biogeochemical phenomena but also to utilize biogeochemical information for understanding and quantification of physical processes. We have deployed 5 floats in fall 2010 and 25 floats in summer 2011 around the biogeochemical time-series station S1 (30N, 145E). All floats are equipped with oxygen sensors (Optode 3830) and their profiling cycles are 2-3 days. In order to fully utilize data from the float array for describing mesoscale physical-biogeochemical fields, oxygen sensors should be calibrated appropriately and oxygen data should be adjusted. The adjustment of oxygen data obtained by floats and calibration of oxygen sensors equipped with floats are reported in this presentation.

We compared oxygen data of each float with that of temporally and spatially nearest shipboard RINKO observation adjusted to Winkler oxygen data, and found that the former is lower than the latter by up to 30 umol/kg. This difference is consistent with the bias of Optode sensors equipped on profiling floats reported previously (e.g., Kobayashi et al., 2006) and is larger than the accuracy provided by AANDERAA. We adjusted the oxygen data obtained by the floats according to the calibration equations proposed by Uchida et al. (2008) as follows.

We selected the matching sets of float oxygen data and shipboard RINKO oxygen data in order to adjust float oxygen data. At first, we selected pairs of float profile and shipboard CTD/RINKO profile, satisfying the following requirement: (i) float profile is observed within +-4 days from the day of RINKO observation and (ii) the location of float profile is nearest to from RINKO profile. In each pair, we selected the matching sets of float oxygen data and RINKO oxygen data satisfying the requirement depending on the pressure. We determined calibration coefficients of the equations of Uchida et al. by means of the quasi-Newton method and adjusted oxygen value by using these coefficients. The adjustment was repeated 3 times. After the 1st adjustment, the following condition was added. In the 2nd (3rd) adjustment, we selected float oxygen data and RINKO oxygen data satisfying the requirement that |OXY(RINKO)-OXY(float)| are less than 3 times standard deviation of the difference between 1st (2nd) adjustment oxygen data and RINKO oxygen data. Ultimately, the standard deviation of the difference between 3rd adjustment oxygen data and RINKO oxygen data is 3.3 umol/kg. Although the differences between 3rd adjustment oxygen data and RINKO oxygen data are +-10 umol/kg large in the layers shallower than 200 dbar, the float oxygen data were significantly improved.

In 2012, we are planning to calibrate Optode 4330 sensors equipped on profiling floats before deployment. We will report the result of Optode 4330 calibration in this presentation.

P31

On the structure and variability of zonal and meridional transports in the subtropical South Atlantic

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Understanding and documenting the oceanic circulation in the South Atlantic is crucial to accurately model the region for climate prediction. Of primary interest are the not well documented variability of the subtropical gyre and the variability across the basin of the meridional heat and volume transports related to the meridional overturning circulation (MOC). In this study ocean observations are analyzed to study these topics.

A 1° x 1° three-dimensional field of the absolute velocity is derived from hydrographic and trajectory observations in the South Atlantic between 5°S and 50°S. In areas where the correlation between the merged AVISO product and the in situ dynamic height is good the former will be used to fill in gaps of the velocity fields. The transport along the western boundary that are needed to estimate the transports of the MOC are obtained from and array of inverted echo sounders at 34.5°S. High-resolution model fields from HYCOM and OFES will be compared with observations in the Brazil Current at various latitudes to determine how well they can be used to complement observed transports at latitudes with insufficient observations in the western boundary regime. Quantifying the deviation between models and observations will allow an analysis of the transports of the MOC at various latitudes and a determination of the significance of differences of these estimates.

Results of an analysis of the circulation in the subtropical gyre show that the transports carried by its eastward and westward branches at intermediate depth have a marked longitudinal dependence. Moreover, the corresponding transports at different depths reveal a similar pattern. Results of the analysis of the MOC indicate that a significant portion of its volume and heat transport occur in the interior of the basin. This contribution as well as the contribution from the boundaries, shows a strong dependence.

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Eddy detection by means of a Kalman filter approach applied to multi-mission altimetry

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None of the individual satellite altimeter missions operating in the past 20 years provides a sufficient spatio-temporal sampling to identify and track meso-scale circulation pattern like Eddies. However the sampling capability of a multi-mission scenario (with at least two contemporaneous missions since 1993) fills the diamond-shaped gaps of a single mission and thereby improves the situation significantly. Nevertheless, interpolating heights or anomalies of the sea surface for a particular location and epoch remains a challenging task. We investigate an approach performing the interpolation in space and time by a Kalman filter in order to account for the stochastic properties of the altimeter observations. This is applied to all data, available from carefully cross-calibrated altimeter missions like Envisat, Jason-1, Jason-2, Topex, Cryosat-2, etc.. The interpolated sea level anomalies enable a robust identification of eddies in strong ocean currents. The temporal evolution of these Eddies is compared with the movement of drifter and ARGO floats.

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Interannual variation of North Pacific Subtropical Mode Water: Changes in the formation and distribution regions

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Temperature and salinity data from 2003 through 2011 from Argo profiling floats have been used to investigate a formation and distribution of the North Pacific Subtropical Mode Water (STMW), which is characterized by a vertical homogeneous layer with a core-layer temperature between 16° and 18°C over the western North Pacific. The STMW is formed in a late winter in the zonally-elongated region south of the Kuroshio Extension (KE), which extends north of about 30°N, from 140°E to the International Date Line. In the formation region, the STMW persistence nature is associated with the KE path states; STMW persists under the seasonal thermocline through a year in 2003-2005 when the KE path takes a relatively stable state with the two quasi-stationary meanders. On the other hand, in 2006-2010 when the cold eddies are detached southward from the KE when the KE path tends to be convoluted (unstable state), the STMW is quickly lost until summer. The STMW distribution region in the northwestern corner of the subtropical gyre also shows decadal-scale variations; elongated distribution with thicker thickness in 2003-2005, western boundary of which reaches about 130°E and the southern boundary extends to 20°N, and contracted distribution with thinner thickness in 2006-2010, western boundary of which is located at 140°E and southern boundary is done at 25°N. It can be pointed out that the changes in the STMW distribution over the western part of subtropical gyre reflect the ocean states in the STMW formation region, that is, the KE path states.

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Validation of oxygen data measured by Argo floats equipped with oxygen sensors and preliminary use of those data to estimate mixed layer depth in low stratified regions

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Since 2008, we deployed about 30 Argo profiling floats in the North-Atlantic Ocean. These floats (PROVOR-DO) were equipped with Aanderaa optode sensors to measure oxygen concentration in the upper 2000m of the ocean. To assess the overall quality of the oxygen data, we present results from pre-deployment checks in a 20m deep pool at Ifremer, from comparisons with oxygen concentrations measured on discrete samples by Winkler titrations just before the float deployments, and from comparisons of the float time series with the WOA09 climatology. We then present preliminary results on the use of oxygen concentration to precisely estimate mixed layer depth, especially in low stratified regions such as the subpolar gyre of the North Atlantic Ocean.

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Delayed mode quality control of Argo salinity Data from the North Indian Ocean

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Thadathil et al. (2012) suggested a new method for quality control of Argo salinity data from neighboring match-up profiles within the time-space de-correlation scale using Argo and ship-board CTD data from the Sea of Japan. The new method of Thadathil et al.(2012) has been validated further in the Indian Ocean.

Recently, significant drift in pressure sensors have been reported from Autonomous Profiling Explorer (APEX). In this study, quality of Argo data from the Northern Indian Ocean is examined with special reference to the APEX floats. For this purpose the exiting ship-board CTD archives have been used. Salinity data reported in many initial profiles from different floats show larger bias compared to later profiles. Thadathil et al. (2012) suggested a new method for quality control of Argo salinity data from neighboring match-up profiles within the time-space de-correlation scale using Argo and ship-board CTD data from the Sea of Japan. The new method has been used for examining quality of Argo salinity data from the Northern Indian Ocean.

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Annual subduction rate of the North Pacific and its interannual variation

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Subduction rate of the North Pacific from 2005 to 2011 is estimated by dynamic diagnostic method using ocean temperature and salinity data from Grid Point Value of the Monthly Objective Analysis using the Argo data (MOAA_GPV) and surface forcing data from JRA-25/JCDAS. Data from sustained Argo array enables observational estimation of subduction rate for individual years. Estimated subduction rate shows year-to-year variation along with longer term variation, with the total subduction volume fluctuation from 35Sv to 25Sv. The former is predominantly related with year-to-year variation of winter mixed layer depth and the latter is presumably related with PDO. Geological distribution of the subduction rate also changes largely from year to year, none of which is very much similar to that of the climatology. Temporal variability of subduction rate of the Western and Eastern Subtropical Mode Waters are anti-correlated, which is consistent with recent model result. Subduction of the Central Mode Water also fluctuates largely, with almost complete disappearance in 2006 and 2009. Annual obduction rate is also estimated, but little temporal variability is detected for the analysis period. Volume of the permanent pycnocline water show significant temporal variability, which is largely consistent with that of sum of the subduction and obduction volumes. That is, it is suggested that the volume change of the subtropical pycnocline is largely controlled by the subduction change. Nonetheless, difference between these two exhibits year-to-year change, suggesting substantial year-to-year change in the export of the subtropical pycnocline water to the tropics.
While the annual subduction rate estimated by the dynamic method used in this study depends on the 1-year Lagrangian trajectory of parcel released from the base of winter mixed layer, depth and density of the winter mixed layer, and Ekman pumping estimated from wind stress, it is shown that the year-to-year change of the subduction rate is predominantly controlled by the mixed layer depth changes. Since the mixed layer depth and properties can change significantly over time scales of a month or so, selection of the month from which the 1-year integration starts may cause non-negligible error in the subduction rate. This error will also be evaluated and discussed in the presentation.

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A study for establishment of high-quality dissolved oxygen measurement by using an optical oxygen sensor and a reference material

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A fast-responding optode-based oxygen sensor, Rinko (JFE Advantech Co., Ltd., Japan), has been developed. The Rinko was used in the CLIVAR/Carbon repeat hydrography cruises by R/V Mirai, and gave us more reliable oxygen data than the other available oxygen sensors, although the Rinko must be calibrated in situ by using oxygen data from discrete water samples measured by means of the Winkler titration method. However, oxygen data is not ensured comparability worldwide and shows offset of a few umol/kg among the WOCE cruises in deep waters, since no reference material for dissolved oxygen is available at this time. Moreover, interfering substances for the Winkler method in an open ocean can lead to an overestimation of oxygen (about 0.6 umol/kg). Therefore, a bias-free method and a reference material for dissolved oxygen need to be developed urgently for the oceanic oxygen measurements. To solve these problems, we are developing 1) a calibration method of oxygen sensor based on oxygen standard gases, 2) a small and fast-responding oxygen sensor based on technology of Rinko, and 3) a reference material of dissolved oxygen. In addition, equations to estimate oxygen solubility in seawater are evaluated by the Winkler method. The Rinko was calibrated by the oxygen standard gases in the laboratory and used in the R/V Mirai cruise. For 384 samples obtained at 11 stations, the Rinko agreed well with the Winkler method and the difference between the two measurements was small (-0.8±1.5 umol/kg). The small oxygen sensor is also calibrated by the standard gases. It can measure dissolved oxygen in a water sample bottle and the reference material (500 ml aluminum bottle) directly and is intended to use as a reference in oxygen measurements. Actually, it was used in the laboratory calibration of Argo oxygen sensors as a reference.

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Volume variation of the Western Pacific Warm Pool and warm water getting into and out of the pool revealed by Argo

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Based on the Argo profiling data from January 2004 to December 2010, the three dimensional structure of the Western Pacific Warm Pool (WPWP) and its seasonal and annual volume variations as well as the relations between the variation of zonal flow rate into and out of the pool and its volume variation are studied using P-Vector inverse method. The results show that 1) the maximum depth of climatic WPWP could be up to 120m and its volume could be 1,86× 1015m3; 2) its seasonal volume variation has 1a and 1/2a periodic change and the latter has a typical double-peak structure; 3) the zonal flow rate into the pool is about 39Sv which is mainly in its upper layer with the inward eastern boundary current in the lead, while the outward zonal flow rate is about 18Sv which is mainly in the mid and lower layers with the outward western boundary current in the lead; 4) the seasonal variation of the net zonal flow rate getting into and out of the pool is closely related to the seasonal volume variation of the pool and both are closely related to ENSO events.

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Geostrophic Meridional Transport in the Tropical Northwest Pacific Based on Argo Profiles

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Absolute geostrophic currents in the North Pacific Ocean are calculated from the newly gridded Argo Profiling float data using the P-vector method for the period of 2004 through 2009. The meridional volume transport of the geostrophic currents is found significantly different from the classical Sverdrup balance, with as large as $10\sim20\times10^6$ m^3 s^{-1} difference in the interior northwestern tropical Pacific Ocean. Analyses have shown that errors of wind stress estimation cannot account for all of the differences. The largest differences are found in the area immediately north and south of the bifurcation latitude of the North Equatorial Current west of the dateline and in the recirculation area of the Kuroshio and its extension, where nonlinear eddy activities are rigorous. It is, therefore, suggested that the linear, steady wind-driven dynamics of the Sverdrup theory is deficient in explaining the meridional transport of the tropical northwestern Pacific Ocean interior circulation.

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An Improved Correlation Scales in Objective Analysis of Argo

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In this paper, we developed gradient-dependent correlation scales based on the objective analysis of Argo using optimal interpolation, improved the empirical formula of background error covariance matrix which widely used in data assimilation or objective analysis system. So that it can automatically adapt to the change of the ocean hydrological gradient; And Gaussian pulse and space energy spectrum analysis were used to test the new scheme theoretically and have a experiment using one dimensional simulation data. The result proved that gradient-dependent correlation scales can improve the adaptability of objective analysis system, make it fully absorb shortwave information of observation in the area with larger gradient. This scheme is applied in Optimum Interpolation for Argo data objective analysis experiment in Pacific, and the analysis result was closer to the real ocean.

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Seasonal and interannual variability of interior pathway in North Pacific Ocean and it's dynamics

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Absolute geostrophic currents (AGC) in the North Pacific Ocean are calculated from the newly gridded Argo Profiling floats data using the P-vector method for the period of 2001 through 2010. The seasonal and interannual variability of the Interior pathway (IPW) in North Pacific Ocean are investigated. The 3D structure of the IPW shows that southward velocity core is centered around 164ºW, with two or three velocity cores occurring from 6ºN to 9ºN. The IPW is mainly confined above 200m depth, it shoals from 164ºW to the east. The zonal integrated upper 150m volume transport of the southward flow amounts to the maximum value of 30-42Sv in June near west pacific ocean, with transport increasing at low latitude .The interior exchange pathway is highly seasonal, with pulsed southward occurring during the fall and early winter as the thermocline thickens. This is associated with the strong surface southward flow caused by active tropical instability waves. The interannual variability of the IPW shows a relationship with the ENSO.

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Euro-Argo ERIC: The long term contribution of Europe to Argo

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The Euro-Argo research infrastructure organizes and federates European contribution to Argo (www.euro-argo.eu); it is part of the European ESFRI roadmap on large research infrastructures. Euro-Argo carried out from January 2008 to June 2011 a preparatory phase project, funded through the EU 7th Framework Research Programme, whose main outcome was to agree on the legal and governance framework (Euro-Argo ERIC) under which to establish the research infrastructure. The formal agreement between all parties to the Euro-Argo ERIC will be signed in 2012 by ministries from 11 European countries which have agreed to form this new legal European entity to organize a long-term European contribution to Argo. The Euro Argo infrastructure is made up of a central infrastructure based in France which is owned and controlled by the Euro-Argo ERIC and distributed national facilities. The distributed national facilities operate with direct national resources. As part of the Euro-Argo research infrastructure, they agree to a multi-annual commitment of resources (in particular in terms of floats to be deployed and for the data system), and to coordinate their activities through the Euro-Argo ERIC.

The Euro-Argo ERIC objectives are:

- to provide, deploy and operate an array of around 800 floats contributing to the global array (a European contribution of ¼ of the global array);
- to provide enhanced coverage in the European regional seas;
- to provide quality controlled data and access to the data sets and data products to the research (climate and oceanography) and operational oceanography (e.g. GMES Marine Service) communities;
- to prepare the next phase of Argo and its extension towards biogeochemistry, deep and polar oceans.

The organisation and governance of the Euro-Argo research infrastructure, its links with GMES and other marine research infrastructures will be presented. The added value of the European organization will be outlined and we will explain how the Euro-Argo ERIC will be a major step forward for the long term sustainability of Argo in Europe. Euro-Argo views on the development and initial implementation of the new phase of Argo will also be discussed.