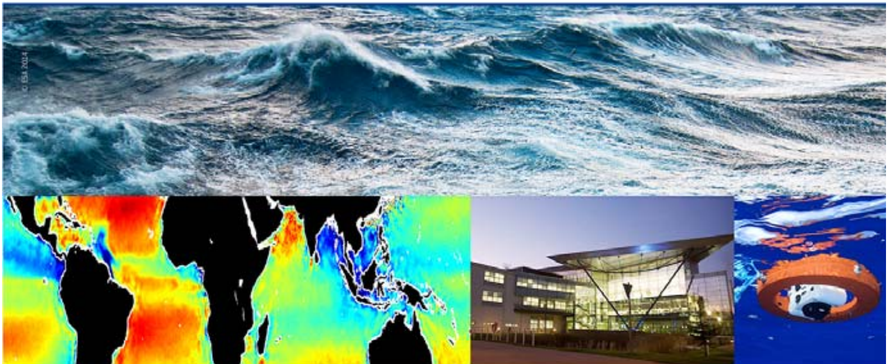
→ OCEAN SALINITY SCIENCE AND SALINITY REMOTE SENSING WORKSHOP



ABSTRACT BOOK

26–28 November 2014 | Met Office | Exeter, UK

smos+ sos
support to science element

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Abstract

Overall Purpose of the SMOS+SOS Final Workshop

Ash, E.[1]; Gommenginger, C.2; Banks, C.[2]; Tzortzi, E.[2]; Reul, N[3]; Boutin, J.[4]; Martin, M.[5]; 5[5]; Donlon, C.[6]
[1]Satellite Oceanographic Consultants; [2]National Oceanography Centre (NOC), Southampton; [3]IFREMER; [4]LOCEAN; [5]Met Office; [6]ESA

We present the workshop objectives, which are: • Review the progress in our understanding of ocean salinity and associated processes • Present the status of satellite remote sensing of sea surface salinity and its contribution to ocean science • Explore techniques and challenges associated with the use of salinity data in ocean models • Identify the most promising future applications for satellite-derived estimates of sea surface salinity • Review user requirements for future satellite-derived estimates of sea surface salinity • Prioritise future activities for ocean salinity science We also present a summary of the ESA-funded SMOS+ Surface Ocean Salinity (SOS) project. SMOS+ SOS began in December 2012 and the team has been working since to demonstrate the performance and scientific value of SMOS Sea Surface Salinity (SSS) products through a number of well-defined case studies. We highlight principal results from these five oceanic case studies, which are: 1) Amazon and Orinoco Plumes; 2) Agulhas and Gulf Stream; 3) Tropical Pacific and Atlantic; 4) Sub-tropical North Atlantic (SPURS); 5) Equatorial Pacific. Additional presentations of project results are contained within the remainder of the programme and will be clearly pointed out.

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In-situ Observations of Surface Salinity (SSS): Reference Datasets, Cross Validation and Complementarity with Satellite Measurements

Gaillard, F.[1]; Boutin, J.2; Reverdin, G.[2]; Reul, N.[3]
[1]Ifremer; [2]LOCEAN; [3]LOS/Ifremer

While the first satellites measuring Sea surface salinity started operating, the in-situ networks already in place have increased the quantity, quality and timeliness of salinity measurements and international collaborations are underway for their validation. Following the efforts done from both the space and in-situ communities a data portal, with particular focus on SSS, is being designed to put in relation the various in-situ datasets and the satellite products. Datasets considered are: the near surface measurements from the standard and High vertical resolution Argo profilers, Thermo-salinometers and similar devices (Ferrybox, low cost autonomous T-S sensors), Drifting buoys, near surface measurements from moorings and Coastal profilers. Particular attention will be paid to document the data acquisition method and validation processing. Datasets of different levels will be considered: real-time or near real time data, on which automatic quality controls are applied, delayed mode data, that are prepared by scientists in expert centres or research laboratories and gridded products that synthetized a wide range of in-situ measurements. Beyond facilitating access to the datasets, we aim at identifying the degree of reliability of each dataset and the range of their possible use to produce a satellite-in situ matchup database. In particular, one needs first to identify the scales resolved in the data and the accuracy in the bias corrections. Finally, merged satellite and in-situ observations products will be proposed through a close collaboration with the Pre-TEP. The SSS portal will include tools for the data discovery, selection and extraction. Various possibilities of use will be considered from validation of satellite or in-situ data that require to extract collocated observation along satellite or ship track, to grid to grid comparisons of products. International collaboration and coordination is presently sought to carry this effort.

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Changes in the Seasonal Cycle of Sea Surface Salinity During the Argo-era (2004-2013)

Reagan, J.[1]; Boyer, T.2; Antonov, J.[3]; Zweng, M.[2]
[1]University of Maryland; [2]NOAA/NODC; [3]UCAR

The Argo program has provided the scientific community with near-global, seasonally uniform coverage of hydrographic profiles over the past decade. Recent launches of the SAC-D/Aquarius and SMOS satellites have provided near real-time snapshots of global ocean sea surface salinity (SSS). The importance of understanding changes in SSS in both time and space cannot be overstated as it is a direct reflection of changes in our global hydrological cycle and is a major component of ocean circulation. This study attempts to advance our understanding of interannual changes in SSS by looking at year to year changes in the seasonal cycle over the past decade. We utilize near-surface salinity data from the World

Ocean Database (WOD) to compute gridded monthly SSS fields from January 2004 through December 2013. The WOD includes Argo salinities along with other salinity profile data which augment Argo data. In addition to in situ derived monthly analyses, level-3 monthly data from SMOS and Aquarius are also utilized for the 2010-2013 and 2012-2013 calendar years, respectively. For each calendar year (2004-2013), a Fourier decomposition is applied and the first and second harmonics are examined for year to year changes in salinity. Furthermore, monthly precipitation data from the Global Precipitation Climatology Project (GPCP) and monthly evaporation data from the Objectively Analyzed air-sea Fluxes Project (OAFlux) are decomposed through a Fourier analysis. The changes in the precipitation and evaporation seasonal cycles are compared to changes in the salinity seasonal cycle. In addition to analyzing and understanding the changes in the seasonal cycle of SSS over the past decade, a brief analysis of the vertical propagation of the seasonal cycle of SSS is conducted.

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Meridional variability of SSS in the North Atlantic Ocean From Satellite and In-Situ Data

Ballabrera, J.[1]; Hoareau, N.1; Garcia, E.[1]; Turiel, A.[1]; Portabella, M.[1]

[1]Institut de Ciencies del Mar, CSIC

Satellite imagery has revealed a series of ocean structures as meandering fronts, eddies and filaments. A high percentage of ocean energy has been found to accumulate at a range of scales (ranging from tens to a few hundred kilometers) known as the ocean mesoscale. Thanks to the SMOS and Aquarius missions, more than four years of satellite-derived sea surface salinity (SSS) data are available. For the first time, satellite data have been providing quasi global, synoptic information of the spatial variability of the ocean surface salinity. However, validation of the satellite data relies on sparse in-situ observations mostly provided by a single observing system, i.e. the Argo autonomous profilers. The aim of this work is to compare the point-to-point validation of satellite-derived SSS products by respect Argo data and the spectral validation through the help of the wavenumber power density spectra (PDS). Several remote sensing SSS products are analyzed: SMOS Level 3 (L3) binned, SMOS L3 optimally interpolated, SMOS L4 data fusion, and Aquarius L3. The study focuses in the North Atlantic Ocean, a challenging region because of the presence of radio frequency interferences (RFI). Analysis of the slope of the various PDS distributions indicates that, despite their different error characteristics, all products share similar spectral properties (k-3 slope) at large scales. Spectral differences arise at shorter scales. The comparison with Argo SSS data indicates that agreement with in-situ point-wise data does not imply a realistic spectrum at short scales. Indeed, although Aquarius L3 and the climatology provide the closest values to the in-situ SSS, their slope display a flattening below 300 km scales and strong variance decay below 1500 km scales, respectively, far from the expected theoretical slopes. Theoretical arguments exist to expect similarities between the salinity and temperature PDS. The debate about if, at short scales, salinity fields should display a k-3 or a k-4 slope is highlighted by the results reported here. The SMOS L4 SSS PDS displays a k-3 slope at all scales. On the contrary, OSTIA SST, and the SMOS L3 OI display PDS slope switch from k-3 to k-4 at short scales.

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ESA's Soil Moisture and Ocean Salinity Mission - Mission Status and Performance

Mecklenburg, S.[1]; Kerr, Y.2; Font, J.[3]; Martin-Neira, M.[4]; Delwart, S.[4]; Drusch, M.[4]; Daganzo, E.[4]

[1]European Space Agency; [2]CESBIO; [3]ICM; [4]ESA

The scientific objectives of the European Space Agency's (ESA) Soil Moisture and Ocean Salinity (SMOS) mission directly respond to the need for global observations of soil moisture and ocean salinity, two key variables used in predictive hydrological, oceanographic and atmospheric models. SMOS observations also provide information on the characterisation of ice and snow covered surfaces and the sea ice effect on ocean-atmosphere heat fluxes and dynamics, which affects large-scale processes of the Earth's climate system. This paper will 1. Provide an overview and update on the performance of the mission after 5 years in orbit, summarising the technical and scientific status of the mission and the plan for mission extension. SMOS was the first satellite mission operating in the ITU resolution 750 (WRC-12) protected L-Band. Nevertheless strong interference sources have been detected worldwide. The paper will provide an update on the improvements made with regards to the RFI situation and its effect on the data. The paper will also provide an overview on the MIRAS instrument performance, including the instrument calibration and level 1 brightness temperature data processing. 2. Provide information on the recent evolution of the SMOS data products, in particular focussing on the recent improvements in the drifts and spatial biases in the level 1 brightness temperatures and its impact on the level 2 data products. Further to the already available level 1 near-real time (NRT) data products distributed by ESA, WMO's GTS and EUMETSAT's EUMETCast systems, new operational data products are under development, based on the requirements from the continuously growing user community. The paper will provide information about present and future data product development, with a focus for applications over ocean. 3. Provide information on how to address the detailed recommendations that were made by ESA's Earth Science Advisory Committee as part of the recent mid-term mission extension review, outlining the objectives for the extended mission operations. 4. Summarise the collaboration with other space-borne L-band sensors, such as NASA's Aquarius and SMAP missions.

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Status of Aquarius Salinity Retrievals and Applications

Le Vine, D.[1]; Dinnat, E.2; Lagerloef, G.[3]; De Matthaeis, P.[4]; Kao, H. Y.[3]; Meissner, T.[5]; Wentz, F.[5]
[1]Goddard Space Flight Center; [2]Chapman Univeristy; [3]Earth and Space Research; [4]GESTAR/USRA; Space Research; [5]Remote Sensing Systems

This paper will give the status of the Aquarius instrument and salinity retrieval, mention some new applications of the data and summarize the current research issues being addressed to improve the retrieved salinity. Aquarius was launched on June 10, 2011 to monitor the global salinity field in the open ocean. This radiometer/scatterometer (i.e. passive/active) instrument is part of the Aquarius/SAC-D observatory. The instrument has been operating continuously since being turned on in August and the initial map of sea surface salinity was released one month later (September, 2011). The quality of the salinity retrieval has improved continuously since then and is approaching the goal of 0.2 psu accuracy (RMS globally each month). The maps produced by Aquarius show dynamic features of the salinity field such as the freshening in the Bay of Bengal due to increased run off during the Indian monsoon; and now after three years of operations, data is available to give a first look at the inter-annual changes in the global salinity field. An improved salinity product, Version 3.0, has just been released to the public (June, 2014) and includes significant refinements in the retrieval algorithm such as reduced ascending/descending differences and improved calibration (see: http://podaac-ftp.jpl.nasa.gov). Mapping the salinity field in the open ocean is a challenging remote sensing task, and to accomplish this Aquarius has a number of unique features. These include an active instrument (scatterometer) to help correct for surface roughness, a polarimetric channel in the radiometer to help correct for Faraday rotation and rapid sampling to help mitigate radio frequency interference (RFI). These features have been carefully tailored to work together to improve the salinity product. They are also the source of novel applications such as the potential for retrieving sea ice thickness and identifying the effects of topography on the radiometric signal over land. Monthly maps of the salinity field and other products from Aquarius (e.g. RFI maps and soil moisture and salinity at high latitudes) are available at the Aquarius website:
http://aquarius.umaine.edu/cgi/gal_data.htm.
Work continues to improve the salinity product including research to refine the geophysical corrections and to extend the calibration to the warm (land) and cold (sky) temperature ranges and to become less dependent on a reference ocean scene.

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Satellite Sea-Surface Salinity Data and Product Biases and Differences

Bayler, E.[11]NOAA/NESDIS

Satellite sea-surface salinity (SSS) observations provide broad coverage that contributes to addressing spatial and temporal gaps due to irregular observations in the in situ record. While satellite SSS retrievals continue to mature, significant differences continue between the SSS observations from the European Space Agency's (ESA) Soil Moisture – Ocean

Salinity (SMOS) mission and the joint United States and Argentine Aquarius/SAC-D mission. In part, these differences result from differing impacts from radio frequency interference (RFI) and land contamination due to the different satellite instrument designs. It is important that users understand these biases and differences when employing these satellite data sets in their applications. The recently completed reprocessing of the Aquarius data record (version 3.0) incorporates significant retrieval updates, significantly improving the mission's Aquarius Data Processing System (ADPS) products from version 2.0. When comparing the latest versions of the Aquarius data (ADPS version 3.0 and the Aquarius Combined Active-Passive (CAP) version 3.0) and SMOS version 2.0 data, differences in bias magnitudes and seasonalities with respect to Argo float data are evident in a global context. Regional strengths and weaknesses are also noted. The issues evident in the Level-2 swath data carry into the Level-3 products employed for user applications.

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Assessment of Rain Freshening Effects and Salinity Stratification in the Tropics Based on the Aquarius Version 3 Salinity Product

Meissner, T.[1]; Wentz, F.1; Scott, J.[1]; Hilburn, K.[1]
[1]Remote Sensing Systems

The Aquarius Version 3.0 salinity product has been released to the public in June 2014. The retrieval algorithm and the quality of the data constitute a major improvement from earlier versions. Our presentation starts with a brief overview of the major components of the Aquarius V3.0 salinity retrievals and upgrades that were implemented since prior releases. A validation study of the Aquarius V3.0 salinity product comparing it with measurements form ARGO drifters, moored buoys and the HYCOM model shows a global RMS error of about 0.24 psu for Aquarius monthly 150 km salinity maps, which is close to the requirement of 0.2 psu. However, local biases up to 0.4 psu are observed when comparing Aquarius salinities with those other products. Aquarius is salty at high latitudes and fresh at low latitudes. These biases show strong correlation with sea surface temperature. In Aquarius V3.0 a mitigation has been implemented for the biases that are allocated to the imperfection of the geophysical model function used in the salinity retrievals. In order to do this it is essential to separate those biases from real rain induced freshening effects which occur in the upper ocean layer. The Aquarius radiometer measures the salinity within a few centimeters of the ocean surface, whereas the ARGO and moored buoys measurements are taken at 5 meter and 1 meter depth, respectively. Other rain induced effects that obscure the freshening are surface splashing and atmospheric liquid water absorption. The CONAE K/Ka-band microwave radiometer MWR on board the SAC-D spacecraft provides observation of surface rain rate and atmospheric absorption collocated to Aquarius in space and time. Rain rate observations from other microwave satellites (SSMIS, WindSat, TMI) can be used to quantify rain effects that occur within a certain time before the Aquarius measurements. The surface splashing effect can be removed by analyzing combinations of the vertical and horizontal polarizations, which are measured by the Aquarius radiometer and which have little or no dependence on salinity. It is thus possible to quantitatively assess the size of the rain freshening at the ocean surface and the stratification within the upper 5 m of the surface layer. On average the rain freshening is about 0.2 psu between surface and 5 m depth and about 0.1 psu between surface and 1m depth. We discuss the dependence on rain accumulation before the Aquarius observation.

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ynergy Between Remote Sensing Variables: Level 4 Research Products of Sea Surface Salinity

Umbert, M.[1]; Portabella, M.2; Guimbard, S.[2]; Ballabrera, J.[2]; Turiel, A.[2]
[1]Institut de Ciencies del Mar; [2]ICM-CSIC

Remote sensing imagery of the ocean surface provides a synoptic view of mesoscale signatures from different ocean scalars advected by the oceanic flow. The most probable origin of the observed structures is the turbulent character of the oceanic flow as they slowly evolve and are very persistent over time scales compatible with ocean mesoscale dynamics. At spatial scales of kilometers, turbulence is mainly 2D, and a complex geometry, full of filaments and eddies of different sizes, emerges in remote sensing images of surface chlorophyll-a concentration (Chl-a) and sea surface salinity (SSS), as well as in the better resolved sea surface temperature (SST) and sea surface height (SSH). A fusion technique has been recently proposed to exploit these common turbulent signatures between variables. This technique is theoretically based on the geometrical properties of advected tracers [Turiel et al., 2005b]. Coherent vortices in a turbulent flow strongly interact, leading to permanently stretch and fold small-scale filaments ejected from vortex cores, and generate small-scale tracer gradients between eddies. Therefore the spatial structure of a tracer inherits some properties of the underlying flow. This geometrical arrangement of the flow is intimately linked to the energy cascade. A key point in this approach is the assumption of a multifractal structure in ocean images [Lovejoy et al., 2001]. It is assumed that singularity lines of ocean variables coincide [Umbert et al., 2014]. In turn, the gradient of both variables can be related by a smooth function. As a first and simple approach, the relating function is expressed as the identity, leading to a local regression scheme. This simple approach allows reducing the error and improving the coverage of the resulting Level 4 product of one variable using another variable as a template. Moreover, information about the statistical relationship between the two fields can also be obtained. This methodology is been applied to Aquarius SSS using SSH from AVISO as template in the Gulf Stream. Resulting SSS Level 4 product contain the mesoscale structures seen by SSH and a significant reduction of the uncertainty.

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Revealing Geophysically-Consistent Spatial Structures in SMOS Surface Salinity Derived Maps

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Present remote sensing estimates of sea surface salinity are based on L-band measurements from the Soil Moisture and Ocean Salinity (SMOS) and the Aquarius missions. Ocean remote sensing at L-band is challenging as the signal is affected by many external noise sources and processing issues, notably for SMOS (e.g., radio-frequency-interference sources, Land-sea contamination, latitudinal biases, etc.), that undermine the quality of the final products. Direct comparisons with in situ measurements provide information on point-wise deviations in remote sensing sea surface salinity (SSS) maps, but not on their geophysical consistence. A method to characterize geophysical structures in SSS maps in a systematic way by means of the singularity analysis technique is proposed. Singularity analysis is very sensitive to artifacts and to correlated noise, while filtering uncorrelated noise and revealing coherent structures in ocean maps of different variables. The method allows not only to obtain a qualitative assessment of the quality of SSS maps but also to quantify their closeness to an appropriate template of geophysical structures (e.g., derived from accurate high-level SST maps). The method is used both to improve the L-band processing algorithms and to perform oceanographic process studies. For example, the method is able to assess the quality associated with different ways of processing SMOS data. In particular, the distribution of SMOS measurement errors is shown to be strongly non-Gaussian and hence non-linear filtering must be applied to optimize the quality of SSS maps. Singularity-based quality assessment shows that the new SSS maps contain geophysical coherent structures (mainly eddies and filaments), which are not present in the corresponding climatological maps and less evident in the standard SSS products. Moreover, the latter contain artifacts not seen in the new product. The new SSS maps can then be used to assess the presence of haline fronts, the position of temperature fronts, and the propagation of tropical instability waves, as well as to track strong river discharges in the ocean. These maps will also be used to discuss the evolution of the currently expected 2014 El Niño event.

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A Multi-Dimensional Covariance Model to Combine and Interpolate Sea Surface Salinity with Sea Surface Temperature

Buongiorno Nardelli, B.[1]; Droghei, R.2; Santoleri, R.[21]Consiglio Nazionale delle Ricerche; [2]CNR

Remote sensing provides accurate estimates of the Sea Surface Salinity only when averaging over sufficiently long space and time intervals. In order to provide mesoscale-resolving gap-free maps of SSS, new techniques thus need to be explored. Here, we combine SMOS data with Sea Surface Temperature and in situ salinity measurements through a multi-dimensional optimal interpolation algorithm. As shown in Buongiorno Nardelli (2012), this can be done by representing SSS as a function of space, time, and high-pass filtered SST (fSST) or, in other words, to define SSS in the four-dimensional space (x, y, t, fSST). In practice, a new covariance model is defined by including a thermal decorrelation term. This particular covariance model allows to give a higher weight to the SSS observations that lie on the isothermal of the interpolation point with respect to observations taken at the same temporal and spatial separation but characterized by different SST values. This technique has been already applied to interpolate SSS ARGO measurements at 1/10°x1/10°, daily resolution, using GHRSST L4 SST data to compute the covariances. In the framework of ESA-OSMOSIS STSE project, this technique will be adapted to ingest SMOS (end eventually AQUARIUS) L2 and/or L3 data. Preliminary results of will be presented here.

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A Modeling Study of the Processes of Surface Salinity Seasonal Cycle in the Bay of Bengal

Durand, F.[1]; Akhil, V. P.2; Lengaigne, M.[1]; Vialard, J.[1]; Keerthi, M.G.[3]; Gopalakrishna, V.V.[3]; Deltel, C.[4]; 1[1]; De Boyer Montégut, C.[5]

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In response to the Indian Monsoon freshwater forcing, the Bay of Bengal exhibits a very strong seasonal cycle in sea surface salinity (SSS), especially near the mouths of the Ganges-Brahmaputra and along the east coast of India. In this paper, we use an eddy-permitting (~25 km resolution) regional ocean general circulation model simulation to quantify the processes responsible for this SSS seasonal cycle. Despite the absence of relaxation towards observations, the model reproduces the main features of the observed SSS seasonal cycle, with freshest water in the northeastern Bay, particularly during and after the monsoon. The model also displays an intense and shallow freshening signal in a narrow (~100 km wide) strip that hugs the east coast of India, from September to January, in good agreement with high-resolution measurements along two ships of opportunity lines. The mixed layer salt budget confirms that the strong freshening in the northern Bay during the monsoon results from the Ganges-Brahmaputra river discharge and from precipitation over the ocean. From September onward, the East India Coastal Current transports this freshwater southward along the east coast of India, reaching the southern tip of India in November. The surface freshening results in an enhanced vertical salinity gradient. Our results reveal that the erosion of the freshwater tongue along the east coast of India is not driven by northward horizontal advection, but by vertical processes that eventually overcome the freshening by southward advection and restore SSS to its pre-monsoon values. The salinity-stratified barrier layer hence only acts as a “barrier” for vertical heat fluxes, but is associated with intense vertical salt fluxes in the Bay of Bengal.

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Data Assimilative Simulation of Multi-Scale Upper Ocean Salinity Processes

Li, Z.[11]Jet Propulsion Laboratory

The Salinity Processes in the Upper Ocean Regional Study (SPURS) field campaign took place during 2012-2013, focusing on the salinity maximum of the North Atlantic. Intensive measurements sampled a primary region of about 150 km X 150 km, centered at (38°W, 24.5°N). The observations showed that the SPURS region is very complex synoptically and dynamically, and energetic salinity filaments, fronts and eddies span through almost all the spectrum of meso-scales down to a few km within dimension of the SPURS region. To model those meso-scale processes, we carried out a set of multi-scale data assimilative simulations. A Regional Ocean Modeling System (ROMS) is used with a spatial resolution of 1 km. Satellite, Argo and other observations are assimilated into the ROMS model using a multi-scale data assimilation (MS-DA) scheme. With its unique capability, the MS-DA constrains only the component with the spatial scales larger than 200 km. In these simulations, the large-scale component is well constrained, and the dynamic consistency is ensured in the meso-scale component. The results will be shown to characterize the meso-scale processes and quantify their contribution to the upper ocean salinity variability in the region.

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Upper Ocean Salinity Stratification in the Tropics as Derived from N2 (the Buoyancy Frequency)

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Rather than focusing on the strong halocline above the thermocline, commonly referred to as the salinity barrier layer, the present study takes into account the respective thermal and saline dependencies in the Brunt-Väisälä frequency (N2) in order to isolate the specific role of the salinity stratification in the layers above the main pycnocline. We examine daily vertical profiles of temperature and salinity from an ocean reanalysis over the period 2001-2007. We find significant seasonal variations in the Brunt-Väisälä frequency profiles are limited to the upper 300 m depth. Based on this we determine the ocean salinity stratification (OSS) to be defined as the stabilizing effect due to the haline part of N2 averaged over the upper 300m. In many regions of the tropics the OSS contributes 40 to 50% to N2 as compared to the thermal stratification and, in some specific regions, exceeds it for a few months of the seasonal cycle. Away from the tropics, for example near the centers of action of the subtropical gyres, there are regions characterized by the permanent absence of OSS. In other regions previously characterized with salinity barrier layers the OSS obviously shares some common variations: however, we show that where temperature and salinity are mixed over the same depth, the salinity stratification can be significant. In addition, relationships between the OSS and the sea surface salinity are shown to be well defined and quasi-linear in the tropics, providing some indication that in the future, analyses that consider both satellite surface salinity measurements at the surface and vertical profiles at depth will result in a better determination of the role of the salinity stratification in climate prediction systems

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Differences Between the Subtropical Surface Salinity Patterns

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The subtropical oceans all display relatively salty surface water, forming a regional sea surface salinity maximum (SSS-max), a response to the global hydrological cycle. Regional differences in basin SSS-max intensity and patterns complicate a direct comparison. We apply a methodology to compare the SSS-max regimes between oceans using a reference salinity based on the MIMOC climatology, eliminating the uncertainty due to an arbitrarily chosen isohaline for each ocean. Using the anomaly from the reference salinity reveals marked differences in patterns and location within each ocean subtropical regime, a response to ocean geometry and associated ocean processes. The Aquarius/SMOS satellite missions provide seas surface salinity monitoring with a far better, near synoptic, coverage compared to other observational methods. Thus enabling the community to use the SSS-max as an indicator of change in the hydrological cycle in combination with ocean processes. The average location and shape of the SSS-max in each basin vary significantly. Aquarius captures the SSS-max characteristics, permitting quantification of interannual variability in the subtropical regions. The seasonal cycle (timing and amplitude) of all basins except the South Pacific is captured, introducing an interesting question whether this behavior is due to the Aquarius retrieval error or caused by different dynamics in the South Pacific. For further details see: Gordon, Giulivi, Busecke, Bingham, submitted to the SPURS Oceanography special issue.

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Continuous Estimate of Atlantic Oceanic Freshwater Flux at 26°N

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We combine data from the RAPID-MOCHA array and data from Argo floats to calculate an estimate every ten days of freshwater flux across 26°N between April 2004 and October 2012. The time series of freshwater flux has a mean value of 1.17Sv southward and a standard deviation of 0.20Sv. This implies a freshwater input or divergence of 0.37Sv between Bering Strait and 26°N. The strength and the variability of the freshwater divergence is dominated by the overturning component. The horizontal component is relatively small and northward. A strong linear relationship exists between the strength of the meridional overturning circulation and the freshwater flux. The sensitivity implies an increase in southward freshwater flux of 0.047Sv for each one Sv increase in the overturning circulation. Examination of historical data at 26°N is consistent with an increase in the southward freshwater flux from 0.03Sv to 0.37 Sv resulting from an increase in the Florida Straits salinity (and therefore the northward salinity flux) over 30-40 years since 1974.

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Linking satellite SSS and SST to water mass formation

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A water mass describes a water body with similar temperature and salinity (T-S) characteristics and with a common formation history. A water mass is formed at the ocean surface under specific conditions which determine the temperature and salinity. The sea surface temperature (SST) and sea surface salinity (SSS) and thus also density at the ocean surface are largely determined by fluxes of heat and freshwater. The surface density flux is a function of the latter two and describes the change of the density of seawater at the surface. To obtain observations of water mass formation is of great interest, since they serve as indirect observations of the thermo-haline circulation. Tracing the water masses at the surface may provide an idea of how deeper ocean layers may evolve in the future. In addition, observations are needed in order to compare with and validate model results. Former studies were constricted to climatology fields of SSS. Therefore the SSS data which has become available through the SMOS mission will provide the possibility of studying also the effect of temporally varying SSS fields on water mass formation. In the present study we analyze the formation of water masses as a function of SST and SSS. The formation as a function of SST and SSS can be derived from the surface density flux by integrating the latter over a specific area and time period in bins of SST and SSS and then taking the derivative of the total density flux with respect to density. This study presents a test case using SMOS SSS, OSTIA SST, as well as Argo ISAS SST and SSS for comparison, heat fluxes from the NOCS Surface Flux Data Set v2.0, OAFlux evaporation and CMORPH precipitation. The study area is the North Atlantic and the study period is the year 2011. We present yearly as well as seasonal and monthly water mass formation rates for different SST and SSS ranges. The formation peaks are remapped geographically, which makes it possible to analyze the area of formation as well. Water mass formation derived from SMOS and OSTIA compares well with the results obtained from Argo ISAS, although slight differences in magnitude and peak location occur. Known water masses such as the Eighteen-Degree Water can be identified. Future work aims at extending this study to other ocean basins and to the entire time period of available SSS observations from SMOS. Longer time series will contribute significantly to the understanding of the temporal variability of water mass formation.

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SMOS Salinity in the Subtropical North Atlantic Salinity Maximum : Horizontal Thermohaline Variability

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The seasonal variability of the surface horizontal thermohaline variability is investigated from large to meso-scale in the subtropical and tropical north Atlantic Surface Salinity Maximum (SSM) region. Near surface observations of temperature (SST) and salinity (SSS) across the Atlantic derived from in situ (In Situ Analysis System product interpolated from Argo profiles and shipborn Thermosalinograph) and satellite (Tropical Microwave Imager (TMI) and Soil Moisture and Ocean Salinity (SMOS) missions are used as complementary tools to study the horizontal fields of temperature, salinity, density, and thermohaline variability. During late winter, in north-eastern SSM region, the thermohaline compensation of the contributions due to temperature and salinity to the density gradients is observed, so that there are no density gradients at large scales. At mesoscale, in the region of the Azores current/front, in spite of large and sharp surface thermohaline fronts, the satellite measurements reveal that the density surface horizontal gradient is rather weak. During summer, the Azores current/front is no more defined by temperature front, but only by the haline front. In the south of the SSM, at large scales the density ratio is controlled by the salinity gradient and the horizontal density gradient is enhanced by a constructive contribution of opposite salinity and temperature gradient.

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The Relative Influence of Surface Sea Salinity and Temperature on Surface Density Gradient in the Tropical Pacific Ocean

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Horizontal gradients of surface density in the ocean are important to frontal genesis and instability associated with ocean currents. They also have significant implications to air-sea interaction and biogeochemistry. Sea Surface Temperature (SST) and Salinity (SSS) both contribute to the horizontal density gradient. For the first time surface density can be globally inferred from remote sensing with unprecedented spatial and temporal scales. Since August 2011, NASA's Aquarius/SAC-D satellite mission and since January 2010, ESA's SMOS mission have provided global high resolution SSS datasets. In this study, we use various satellite measurements of SSS and SST to characterize the mean spatial structure and temporal variability of surface density gradients in the tropical Pacific Ocean from 2011 to present. In particular, we identified the regions where salinity or temperature is dominant over the other one in adjusting surface density gradients. We also focus on the relative contributions of SSS and SST on density and contrast them with the estimate from in-situ data based on Argo float measurements. The analysis of multiple datasets of SSS and SST from satellite and in-situ observations allow us to estimate the uncertainties in computing surface density gradients. This comparison furthermore highlights the regions where satellite measurements provide estimated surface gradients at finer scales than sparser in situ observations. The results have strong implications to the interpretation of the characteristics of tropical instability waves as seen from satellite measurements of SSS and SST.

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Studying Dilution Processes in the Amazon Plume Using SMOS and MODIS Data

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A robust relationship between spectral normalized water leaving reflectance measured by MODIS and sea surface salinity (SSS) measured by SMOS in the Amazon river plume is established using neural network approach. The relationship is valid for the range of SSS from 29 to 35 psu, for period of the highest rates of Amazon discharge with RMSE=0.79 psu and r2=0.84. The neural network and linear correction was applied to MODIS L2 data from late summers of 2002 – 2012 and fields of SSS were reconstructed at 10 km resolution. Comparison of MODIS SSS field and daily averaged fields of surface currents simulated by the TOPAZ model revealed striking pattern agreement suggesting that the plume is strongly influenced by the North Brazilian Current meandering structure and and eddy formations: the plume is advected into the tropical Atlantic during in the presence of eddies, whereas without eddies it continues towards the Caribbean Sea.

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The Application of SMOS Salinity and SST to Quantify Carbon Fluxes from the Eastern Tropical Pacific

Brown, C.
LOCEAN

The Eastern tropical Pacific Ocean (ETPO) is a highly variable source of CO2 to the atmosphere. Although the scientific community have amassed over 100,000 surface pCO2 datapoints within the region over the past 25 years, the spatial and temporal resolution of this dataset is insufficient to fully quantify the interannual variability of the region. In order to find an alternative method of calculating regional CO2 flux, it is useful to note that physical processes (in particular, wind-jet driven Ekman upwelling), provide a first order control on sea surface pCO2 concentrations within the ETPO. Thus, the acquisition of sea surface salinity through the SMOS mission, in addition to satellite SST data, provide new tools for observing the signature of physical processes at the ocean surface. Utilising in-situ T,S and CO2 measurements sourced from the SOCAT database, a look up table (LUT) was constructed to describe pCO2 using temperature and salinity. This LUT was applied to gridded SMOS and SST data in order to calculate pCO2 at sufficient resolution to gauge the inter-annual variability of regional CO2 fluxes. Since the availability of the first SMOS data in 2010, a strong La Niña period has occurred. This has been observed to increase the spatial extent of the freshpool region, and reduce the strength of jet-winds compared to neutral ENSO periods. These physical changes have resulted in the near halving of the total CO2 flux in the ETPO compared to neutral ENSO conditions. The combination of SMOS SSS and SST has provided a dataset describing the physical characteristics of the water's surface at sufficiently high temporal and spatial resolution to observe the high variability of pCO2 in the Tropical Pacific under differing ENSO conditions. Thus, this new toolbox is providing useful new insight into a biogeochemically important region.

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Preparatory Activities to Estimate Surface Ocean pH Exploiting Sea Surface Salinity Satellite Observations

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The surface ocean currently absorbs approximately one third of the excess carbon dioxide (CO2) injected into the atmosphere from human fossil fuel burning and deforestation, mitigating the impact of global warming and climate change. However, this anthropogenic CO2 absorption by seawater determines a reduction of both ocean pH and the concentration of carbonate ion. The overall process is commonly referred to as Ocean Acidification (OA), and is nowadays gathering increasing attention as one of the major foci of climate-related research, having profound impact not only at scientific level, but also in its socio-economic dimension. Growing international efforts are being devoted to develop a coordinated strategy for monitoring OA, with an eager need for global and frequent observations of OA-relevant parameters; yet, the datasets acquired are currently mostly relevant to in-situ measurements, laboratory-controlled experiments and models simulations. Remote sensing technology can be integrated by providing synoptic and frequent OA-related observations, upscaling and extending in-situ carbonate chemistry measurements on different spatial/temporal scales, despite the preliminary products developed so far are only regional, empirical or derived with a limited variety of satellite datasets. Within this context, the purpose of this study is to quantitatively and routinely estimate surface ocean pH by means of satellite observations, capitalizing on the recent advent of remotely-sensed salinity measurements. The thematic objectives are 1) to develop new algorithms and data processing strategies to overcome the relative immaturity of OA satellite products currently available, and 2) to produce a global, temporally evolving, quasi-operational suite of relevant satellite-derived data. This will be performed by exploiting the information content of Ocean Colour (OC) data, Sea Surface Temperature (SST), Wind Speed (WS) and Sea Surface Salinity (SSS) parameters (with an emphasis on the latter). A proper merging of these different satellites datasets will allow to compute at least two independent proxies among the seawater carbon dioxide system parameters: namely, the partial pressure of CO2 in surface seawater (pCO2); the total Dissolved Inorganic Carbon (DIC) and the total alkalinity (AT). Through the knowledge of these parameters, the final objective is to come up with the currently best educated guess of the surface ocean pH. A preliminary effort in this sense was the estimation of monthly surface ocean pH maps for 2010 in the North Atlantic, using pCO2 data and computed total alkalinity derived from SMOS salinity measurements. The innovation of this study lies mainly in the effort of unifying fragmented remote sensing studies and generating a novel value-added satellite product: a global and frequent surface ocean pH "cartography", bridging the gap between the satellite and the process studies communities, and benefiting from their cross-fertilization and feedback.

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Suitability of Satellite Sea Surface Salinity Data for Use in Assessing and Correcting Ocean Forecasts

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Ocean forecasting systems such as the Forecasting Ocean Assimilation Model (FOAM) system run at the Met Office aim to produce accurate forecasts of the three-dimensional ocean temperature, salinity and currents, as well as sea-ice variables, for various users including the Navy, search and rescue, oil spill, ship routing, oil and gas, and research users. This system is also now being used in conjunction with the existing Met Office NWP system to develop coupled ocean/atmosphere/sea-ice forecasts on weather forecasting time-scales. For both forced-ocean and coupled ocean/atmosphere forecasting, understanding the errors at the sea surface provides an important method for identifying sources of model forecast error. In this presentation we show comparisons of surface salinity from a reanalysis of the FOAM system at 1/4° horizontal resolution with in situ and satellite salinity data. The model-satellite comparisons are carried out using a range of temporal and spatial averaging characteristics to provide recommendations on how the data might be assimilated in the future. These comparisons also provide an idea of the relative accuracy of the different sources of surface salinity information.

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Investigating the Potential of Satellite Based Measurements of Salinity in Forecasting Tropical Cyclones

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It is known that Tropical Cyclones (TC) in the North Atlantic induce upwelling of cold water from below the thermocline (depths ~300 m) to the surface. This TC induced upwelling has an important role regulating the intensification of TC. Hence, it is crucial to understand the upwelling mechanism in order to improve TC forecasting models. This work compares satellite based observations of both salinity and temperature against output from the Met Office Forecasting Ocean Assimilation Model (FOAM). The FOAM system assimilates sea surface temperature, sea-level anomaly, temperature and salinity profiles and sea ice concentration. The results showed that FOAM was able to show the TC induced changes in temperature throughout the water column. Although FOAM showed TC induced salinity changes, satellite observations were able to capture more precisely pre-TC oceanic conditions at the surface. Therefore, we conclude that satellite based observations of salinity could improve the forecasting model assimilation in the top five meters.

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Sea Surface Salinity from Space: a Future for Operational Oceanography?

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[1]CLS; [2]Mercator Ocean

Improving the SSS (Sea Surface Salinity) constrain at various scales is an important issue for ocean forecasting. It concerns the short term meso-scale and the seasonal anomalies. Both strongly depend on the surface freshwater budget (evaporation, precipitation and runoff). Presently, it is not yet possible to fully remove SSS biases with the poorly sampled Argo network data near the surface (depth < 5m). It encourages us to find the best way to deal with SSS data observed from space (SMOS and Aquarius). Taking into account different errors associated with different scales could fill the gap. In this context, Mercator Ocean and CLS give an overview of dealing with the SSS issues within their operational and reanalysis frameworks. Comparisons with SMOS/Aquarius and systematic biases found in reanalysis and operational results are first presented with the global 1/4° ocean forecasting system. They give us indications on how to take into account errors and/or to sort out corrections. We also show results of first SSS data assimilation experiments performed with this system. Finally, in the context of the operational INDESO project, comparisons of monthly SSS fields with SMOS and Aquarius in the Indonesian seas seem to corroborate a freshwater forcing bias in the representation of South China Sea upper waters.

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Correlative Analysis of Aquarius, Grace and River Discharge Data Indicating the Change of Water Cycle In the India Subcontinent

Yueh, S.; Tang, W.1; Fore, A.[1]; Hayashi, A.[1]; Lee, T.[1]; Bindlish, R.[1]; Jackson, T.[1]
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Aquarius is a combined passive/active L-band microwave instrument developed to map the sea surface salinity (SSS) field from space. The accuracy of Aquarius monthly averaged SSS product derived from the Combined Active and Passive (CAP) algorithm has been estimated to be about 0.1 to 0.2 psu Root-Mean-Square (RMS) between 40 degrees N and 40 degrees S through comparison with the Argo gridded dataset produced by the Asia-Pacific Data-Research Center (APDRC) and tropical moorings. We find that the regions with larger discrepancy include the ITCZ and near the outflow of major rivers, such as the Ganges, where the surface stratification due to precipitation or river discharge appears to be playing a significant role. In addition to the salinity product, Aquarius' radiometer data have been used to produce the surface soil moisture globally. We find that the change of soil moisture over the India subcontinent clearly correlates with the timing of India Monsoon, which produces significant precipitation between June and September. We compared the Aquarius surface soil moisture with the total land mass change derived from the GRACE mission data and find good correlation between them at a few hundred km scale. We analyzed the time series of Aquarius soil moisture over the India subcontinent, river discharge (Ganges River) and Aquarius surface salinity in the Bay of Bengal (BOB). We find excellent correlation between the river discharge and soil moisture throughout all seasons. However we find that the change of surface salinity in the BOB seems to fall behind the change of soil moisture and river discharge by about 2 months before the monsoon season starts in June. This suggests that lighter precipitation starting as early as March does not have much impact on the surface salinity in the BOB. Once the heavier precipitation starts in June, the surface salinity in the BOB shows a rapid drop and the river discharge continues to rise until September when the monsoon season ends. We also compared the time series of Aquarius surface salinity with the Argo APDRC gridded product in the BOB. The comparison suggests that the Aquarius surface salinity in general agrees with the APDRC to within about 0.5 psu off the monsoon season, while during the monsoon season the Aquarius surface salinity tends to be below the APDRC by 1 to 3 psu. The larger discrepancy in August and September is likely due to the surface stratification resulting from rain or river discharge. Our correlative analysis indicates the change of surface salinity in the BOB clearly reflect the precipitation during the monsoon. However, the evaporation appears to dominate the change of surface salinity from March to May.

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Changes in the Global Water Cycle Inferred Using the Water Mass Transformation Framework

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Introduction With the ocean receiving over 80% of the total global rainfall oceanic observations of salinity offer a unique opportunity in terms of measuring the integrated effect of changes in the hydrological cycle. Only recently, however, has the observational network expanded to the point where the mean state, seasonal cycle and trends in upper ocean salinity can be robustly estimated. Method Global water cycle change is inferred from 3-D salinity observations using the water mass transformation framework. In this framework, the distribution of sea water amongst salinity classes is considered. In the long term mean the water cycle transfers approximately 2.6 Sv of fresh water from saline to fresh regions and this is balanced by a diffusive flux from fresh to saline regions. A net input of fresh water will shift the distribution toward lower salinity. Likewise an increase in the transfer of fresh water from high salinity to low salinity regions will broaden the distribution. Changes in the distribution are thus used to quantify and distinguish between these two effects. The net saline-to-fresh transport is the sum of the net change in the water cycle and changes in the diffusive flux. Results An amplification of the net fresh-to-saline transport of 0.036-0.042 Sv is found over 1950-2010 using two observationally based salinity datasets, namely the UK Met Office EN3v2a dataset (http://www.metoffice.gov.uk/hadobs/en3), and the CSIRO dataset. Likewise a global ocean net freshening of 0.024-0.044 Sv is found over the same period. Discussion & Conclusion The net freshening inferred by the observed salinity change could be a real physical change i.e. due to the observed increase in ice melt and/or a general bias in the observations. Importantly, the two datasets disagree by 0.020 Sv with respect to the net fresh water input but only by 0.006 Sv with respect to the net saline-to-fresh transport. This study suggests that some of the observed salinity change previously linked to the water cycle change could be due to a net fresh water input.

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Ocean Salinity and Freshwater Budgets from the Ocean ReAnalysis Intercomparison Project (ORA-IP)

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The ORA-IP project developed by CLIVAR-GSOP and GODAE-Oceanview has brought together 17 different ocean reanalysis products to study the consistency between them as well as the value of the ensemble mean and spread of the products. Most products span the years 1993-2010, including both high and lower resolution products, as well as products based on coupled models. All the products assimilate Argo and other profile salinity data, but otherwise may or may not apply constraints on surface salinity variability. In this presentation we will look at the variability in the ocean surface salinity between the products, both in the mean and any seasonal cycle. We also look at the freshwater transports and budgets from some of the models in comparison with independent datasets, including the transports at the Atlantic AMOC section. Finally we consider the value that new constraints from satellite surface salinity observations would have on consistency.

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Patterns and Changes in Iceberg Melting and Surface Salinity at Southern High Latitudes

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Introduction Surface ocean salinity plays a critical pre-conditioning role in the formation of dense waters that sink to the abyss around Antarctica. Patterns and changes of high-latitude surface salinity are intimately related to the cryosphere. One important, but poorly quantified, term in the surface freshwater budget is iceberg melting. As iceberg calving rates are changing, so is the surface salinity field in this sensitive region. Method Interactive icebergs are included in the NEMO ocean model, globally configured at coarse (2°) and eddy-permitting (0.25°) resolutions, to evaluate the influence of icebergs on the ocean, through comparison with control simulations in which the equivalent iceberg mass flux is applied as coastal runoff, a default forcing in NEMO. Comparing a short (15-year) spin-up of the 0.25° model with a computationally cheaper 105-year spin-up of the 2° configuration, calving, drift and melting of icebergs is evidently near equilibrium in the shorter simulation, justifying closer examination of iceberg influences on salinity in the eddy-permitting configuration. Results Freshwater forcing due to iceberg melting is locally dominant over precipitation, reducing surface salinity by ~0.2 psu around much of Antarctica, with compensating increases immediately adjacent to Antarctica, where coastal runoff is suppressed. Discernible effects on salinity (and temperature) extend to 1000 m. At many locations and levels, freshening and cooling indicate a degree of density compensation. However, freshening is a dominant influence on upper ocean density gradients across much of the high-latitude Southern Ocean, leading to weaker meridional density gradients, a reduced eastward transport tendency, and hence an increase of ~20% in westward transport of the Antarctic Coastal Current. The long-term consequences for bottom water formation are not yet clear. Discussion Iceberg melting is the locally dominant influence on surface salinity in key regions of southern high latitudes, with consequences for density and circulation. With episodic major calving events (such as the collapse of the Larsen-B ice shelf in February 2002) superimposed on a steady ~7% increase in Antarctic iceberg calving over 1992-2010, we further predict that melting icebergs are becoming an increasingly important control on surface salinity around Antarctica, with potential long-term consequences for abyssal waters of the World Ocean.

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Towards a Better Description of the Atlantic SSS Variability from SMOS and the Role of Freshwater Fluxes

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A novel synthesis of SMOS surface salinity (SSS) data with evaporation (E), precipitation (P) and river discharge (R) observations provides new insights into Tropical Atlantic SSS variability. SMOS reveals the seasonal variability in 2010 is dominated by eastern and western basin SSS regions ('poles') dominated by riverine input, with seasonal ranges up to 6.5 pss, that vary out-of-phase by 6 months and largely compensate each other when considering SSS for the region as a whole (Tzortzi et al., 2013). The growing satellite SSS record also offers new insights into the interannual variability of SSS seasonal cycle in the Tropical Atlantic. The two poles of strong SSS variation continue to be apparent the following two years, 2011 and 2012. Their seasonal compensation holds on interannual time-scales, resulting in a small, relatively constant variability of SSS over the whole Tropical Atlantic. The dominant controlling processes are investigated using GPCP P, OAFlux E, Dai and Trenberth climatological and ORE-HYBAM R datasets. Their interannual phase-relationships show P and R as the primary drivers in both poles, competing with each other for their dominant effect on SSS variability. In contrast, E varies little both seasonally and interannually. Regional SSS variations in the two river-influenced poles seem to play a key role in the Tropical Atlantic salinity budget, with potential consequences for the higher latitude, larger-scale Atlantic circulation and variability. In addition, SMOS observations are used to describe the spatial and temporal scales of SSS in the Tropical/Subtropical Atlantic, which encompasses the dynamically different E-dominated Subtropics and P-dominated Tropics. This study explores how quickly consistent SSS changes evolve over the different regimes of the basin, identifying regions with persistent in time SSS variations. Likewise, regions with spatially homogeneous SSS changes on sub-annual to interannual time scales are identified. Determination of the time and space scales of SSS offers insight into the different controlling mechanisms of SSS leading to a better understanding of its variability. This work contributes to the potential future use of satellite SSS observations for assimilation into ocean and operational models.

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Surface Freshwater Plumes Contributing to the Formation of the Barrier Layer and Salinity Fronts

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[1]Nova Southeastern University Oceanographic Center; [2]Department of Physical Oceanogralyuphy Woods Hole Oceanographic Institution

Surface freshwater plumes contributing to the formation of the barrier layer and salinity fronts Some areas of the World Ocean are characterized by substantial influx of freshwater. Localized rain and river runoff may produce relatively shallow, near-surface freshwater plumes. Due to buoyancy forces, these plumes have a tendency to spread in the horizontal direction. These buoyancy-driven flows are a type of the organized structure resembling a classical gravity current. Buoyancy-driven surface currents are an important component of the oceanic environment, leading to water mass exchange by horizontal advection and enhanced vertical mixing. The freshwater plumes can be linked to larger scale features such as the barrier layer and fronts, contributing to the salinity field in the Aquarius and SMOS footprints. The dynamics of freshwater plumes are inherently three-dimensional. We have applied a computational fluid dynamics (CFD) model to study the structure and dynamics of low-density near-surface plumes. Our fully three-dimensional, non-hydrostatic CFD model is able to reproduce in detail the near-surface propagation as well as the interaction between surface gravity current, ambient stratification, and wind stress. The modeling results are being compared with available observational data from the tropical oceans and from coastal areas with large river runoff.

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Observations of a Rainfall Event with an Upwardly-Rising Microstructure Profiler

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Observations and Modeling of Rain-Induced Near Surface Salinity Anomalies

Asher, W.[1]

[1]University of Washington

Vertical salinity gradients in the top few meters of the ocean surface can exist due to the freshwater input from rain. If present, they will complicate comparing salinity measured by ARGO drifters at typical depths of a few meters to salinities retrieved using L-band microwave radiometers such as SMOS and Aquarius, whose measurement depths are on order of 0.01 m. Therefore, understanding the spatial scales and the frequency of occurrence of these vertical gradients and the conditions under which they form will be important in understanding sea surface salinity maps provided by SMOS and Aquarius. Salinity gradients in the near-surface ocean caused by rain were measured using a towed profiler that measured vertical gradients in the top two meters of the ocean with a minimum measurement depth of 0.1 m. These measurements were made in December, 2011 aboard the R/V Kilo Moana. In addition, an underway salinity profiling system was installed on the R/V Thomas G. Thompson. This measured near-surface salinity at depths of 1 m and 2 m. Both the towed profiler and the underway system found the occurrence of negative salinity anomalies (i.e., salinity decreasing towards the surface) was correlated with the presence of rain. The results show that precipitation produces vertical gradients in near-surface salinity with horizontal spatial scales comparable to the footprint of Aquarius and that the magnitude of these gradients can be significant in terms of the overall accuracy of the satellite. Numerical studies of the ocean surface mixed layer show that the formation and evolution of the observed salinity anomalies are consistent with a one-dimensional turbulence diffusion model.

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Posters

Reconstruction of SMOS Data Over the North Atlantic Ocean Using DINEOF

Alvera-Azcarate, A.[1]; Barth, A.1; Beckers, J. M.[1]
[1]University of Liege

Sea surface salinity (SSS) data obtained from SMOS over the North Atlantic ocean will be analysed using DINEOF (Data Interpolating Empirical Orthogonal Functions) in order to reconstruct missing data. DINEOF analyses are obtained by iteratively computing an EOF basis, and only a truncated basis is retained. Therefore, the noise level in the reconstruction is decreased as noise is typically found in high-order EOFs. Outliers will be also detected by examining the departure of SSS data from the truncated EOF basis, and they will be removed from the data. The distribution of these outliers in space and time will be examined to determine the main reasons for the presence of outliers in the SSS data. The truncated EOF basis used to reconstruct the missing data will be studied in order to assess the main SSS processes present in the dataset and the typical spatial scales of SSS variability over the North Atlantic ocean. Attention will be given to the differences of these scales over summer and winter seasons.

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Reconstruction of Sea Salinity Profiles from Surface Parameters in the Tropical Atlantic Using Neural Networks.

Arnault, S.[1]; Gueye, M. B.2; Thiria, S.[3]; Niang, A.[2]
[1]IRD; [2]LTI/ESP; [3]LOCEAN

Geophysical systems (ocean, atmosphere,...) have many properties of complex systems. To study these systems, different approaches are used, the most common one being the numerical modelling. However it does not always take into account the complexities that characterize these systems through their parameters. Methods based on the knowledge related to the observations offer new opportunities to this problem. The work presented here aims to reconstruct salinity profiles from surface parameters using neural networks. This approach will allow to get information on the salinity sub-surface variability even if only surface -for instance satellite-parameters are available. First, a study of the inter-relationship between the salinity at different depths has shown the binding aspect of this parameter at different levels. Extraction of relevant features is then applied to the surface data to keep the best parameters for the inversion model. The model consists of two parts in which the parameters are considered in terms of their ability to describe the salinity variability. In a first step, the salinity profiles associated with the relevant physical surface parameters are classified to depict the various oceanic situations sampled. This learning procedure is mainly based on in situ data such as Argo floats. The second step concerns the inversion. The model has been applied on surface parameters over the tropical Atlantic ocean where and during which in situ salinity profiles can be further used for validation. A comparison between real in situ salinity profiles and estimated profiles shows good agreement and strong correlation. However, regions highly variable such as the Maximum Salinity Waters areas are more difficult to reproduce.

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HadIOD: an integrated database of ocean temperature and salinity observations

Atkinson, C.[1]; Rayner, N.1
[1]Met Office

Observations made by surface-based instruments and sub-surface profiling instruments have largely been treated separately, motivated by a focus on different ocean domains. However, activities such as coupled climate reanalyses, long-term forecasting, satellite validation and climate monitoring increasingly want consistent information from across these domains. To address this we have created an 'Integrated' Ocean Database of global temperature and salinity observations, presently covering 1900-2013, which we name HadIOD. The database merges data from release 2.5.1 of the International Comprehensive Ocean-Atmosphere Data Set (surface observations) and version 4 of the Met Office Hadley Centre EN dataset (sub-surface observations). Quality flags are assigned to each observation. Wherever possible, we also assign to each observation bias corrections and uncertainty estimates. We present here the current status of HadIOD and plans for further development from a salinity perspective. All salinity observations in HadIOD are taken from EN4 as ICOADS does not presently include salinity. Salinity observations are under-represented relative to temperature observations in HadIOD, constituting about 24% of the total observations (where an observation is a measurement of a single geophysical variable at a given time, position and depth). Whilst this is largely a feature of the historical observing system, in future we plan to boost the number of salinity observations by merging other datasets into HadIOD, e.g. the Global Ocean Surface Underway Data (GOSUD) project and ICOADS release 3.0 (planned for release in 2015 and to include salinity). Some refinement of the uncertainty estimates allocated to salinity observations in HadIOD would also be desirable, in particular to better account for instrumental drifts and biases which are a known issue with conductivity sensors.

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Building Climatological Sea Surface Salinity Products from SMOS

Banks, C.[1]

[1]*National Oceanography Centre*

As we approach the fifth anniversary of routine sea surface salinity (SSS) measurements from space, we report on work concerned with building a climatological SSS product based on data from SMOS. A number of approaches have been used to minimise the differences observed in SSS from ascending passes (SSSA; SMOS moving south to north at approximately 6 am local time) and SSS from descending passes (SSSD; SMOS moving southwards at ~ 6 pm). Focussing on a study region in the North Atlantic sub-tropical salinity maxima (SPURS), there is an obvious seasonal cycle in the values of SSSA minus SSSD (other study regions demonstrate this variability is a function of location as well as time). In this study we used SMOS data from 2010 through 2013 to provide daily, one-degree by one-degree climatologies (separate for ascending and descending passes) using a moving window approach (in time and space). These daily, one-degree products can then be used to provide values of climatological SSS at lower spatial or temporal resolution. Direct comparisons have been made with monthly products from the World Ocean Atlas 2013 at the same spatial resolution. The climatological products have also been used to produce SSS monthly anomalies for both ascending and descending passes calculated by subtracting the climatology from the monthly data (ANOMA and ANOMD). For the SPURS region the maximum peak-to-peak value of ANOMA minus ANOMD are significantly less than that for SSSA minus SSSD. In addition, the correlations between SSSA and SSSD are ~0.2-0.3 whereas the correlations are higher between ANOMA and ANOMD (~0.6-0.8). This suggests that the anomaly values are capturing true geophysical variability and are therefore more likely to give insights into the geophysical processes underlying the measurements.

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Seasonal Mixed-layer Salinity Balance in the Tropical Atlantic Ocean: Focus in the Equatorial Region and the Northern Salinity Maximum Region

Camara, I.[1]*; Mignot, J.2; Kolodziejczyk, N.*[3]*; Lazar, A.*[3]*; Gaye, A. T.*[4]

[1]*LPAO-SF;* [2]*LOCEAN/UPMC/IRD/CNRS/MNHN,Paris, France / Climate and Environmental Physics, and Oeschger Centre of Climate Change Research, University of Bern, Switzerland;* [3]*LOCEAN/UPMC/Paris, France;* [4]*LPAO-SF/ESP/UCAD/Dakar-Sénégal*

A regional numerical simulation is used to investigate the different processes that control the seasonal cycle of the mixed-layer salinity in the tropical Atlantic ocean. The simulated variations are validated against recent observations. In this study, we focus on the equatorial area and the region of the northern salinity maximum. Results show a very weak seasonal cycle in both regions. In the region of maximum salinity, the strong increase of salinity due to evaporation is compensated by the strong advection due to poleward ekman transport of fresh anomalies. In the equatorial cold tongue, atmospheric and oceanic contribution are both weak. The latter is due to the compensation of vertical diffusion and horizontal advection. These oceanic components are coupled by the surface currents. In the western equator, oceanic and atmospheric contribution are strong and opposed leading to weak seasonal cycle. This opposition is due to a coupling effect by precipitation. This study shows that although salinity variations are relatively weak, they often mask strong seasonal variations of physical processes. This may induce substantial variations of density below the thermocline.

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Observed Year-to-Year Sea Surface Salinity Variability in the Bay of Bengal during the Period 2009 – 2014

Durand, F.[1]; Chaitanya, A.V.S.2; Mathew, S.[3]; Gopalakrishna, V.V.[2]; Papa, F.[1]; Krantikumar, C.[2]; Lengaigne, M.[1]; 1[1]; Venkatesan, R.[3]
[1]IRD; [2]NIO; [3]NIOT

The upper Bay of Bengal presents a marked stratification in salinity on the vertical. This peculiar stratification results from massive freshwater supply to the basin. It is believed to play a key role in the dynamics of Asian monsoon. The present study investigates the interannual variability of sea surface salinity (SSS) observed in the Bay during the 2009-2014 period. It is based on an original compilation of all available in situ SSS observations, assembled in a 2°-resolution tri-monthly gridded field. We find that the year-to-year variability of SSS is particularly strong in the North-Eastern part of the Bay. Over the recent years, this variability takes the form of two successive and opposite phases: a saltening phase from mid-2009 to late 2010, immediately followed by a freshening phase from late 2010 to late 2011. The typical magnitude of each of the anomalous spells is about one unit (in the practical salinity scale), making this area one of the most variable of the tropical oceans, at interannual timescales. Based on a simple diagnostic mixed-layer model forced by observed fluxes, we found that this year-to-year variability is prominently driven by the variability of the freshwater fluxes to the ocean (precipitation and river runoff, with the two factors acting independently). However, the variability of oceanic surface circulation associated to the Indian Ocean Dipole mode also exerts an active role (in particular for the freshening period observed during the 2011 positive dipole event).

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Validation of SMOS and Aquarius Remotely-Sensed Surface Salinity in the Bay of Bengal

Durand, F.[1]; Akhil, V. P.2; Lengaigne, M.[1]; Vialard, J.[1]; Gopalakrishna, V.V.[3]; Boutin, J.[4]; Keerthi, M.G.[3]; 5[5]; Reul, N.[5]
[1]IRD; [2]LEGOS - Toulouse; [3]NIO; [4]CNRS; [5]IFREMER

The Bay of Bengal (BoB) provides an excellent test bed for assessing the accuracy of SMOS and Aquarius sea surface salinity (SSS) retrievals. First, this region displays a contrasted SSS distribution, with very fresh water to the North, induced by heavy monsoonal precipitation and river runoffs, and saltier water to the south. Second, this semi-enclosed basin surrounded by land is also a difficult region for satellite retrievals, due to the risk of radio-frequency interferences and land-induced contamination. The present study thus validates level-3 gridded (1˚×1˚) monthly salinity products from SMOS and Aquarius against an exhaustive in-situ SSS product in this climatic important region. While both satellite products display a good spatial coverage south of 15°N, Aquarius outperforms SMOS north of 15°N. Both products exhibit a basin-scale fresh systematic bias (0.35 for Aquarius against ~0.1 only for SMOS). SMOS-derived SSS salinity does not perform better than existing seasonal climatologies when compared with available in situ observations. This is in stark contrast with Aquarius that outperforms both SMOS and existing SSS climatologies everywhere in the Bay. Aquarius captures large-scale interannual anomalies, with a ~0.9 correlation with in situ data over large boxes, and is for instance able to represent the spatial and temporal patterns of an anomalous freshening event depicted by in situ data in early 2012. The serious issues encountered by SMOS in this region advocate for drastic improvements of its SSS retrieval algorithm in this key-region.

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Fishermen-collected Salinity Measurements Reveal a "River in the Sea" Flowing along the East Coast of India

Durand, F.[1]; Chaitanya, A.V.S.2; Lengaigne, M.[1]; Vialard, J.[1]; Gopalakrishna, V.V.[2]; Kranthikumar, C.[2]; Papa, F.[1]; 3[3]
[1]IRD; [2]NIO; [3]INCOIS

Being the only tropical ocean bounded by a continent to the north, the Indian Ocean is home to the most powerful monsoon system on Earth. Monsoonal rains and winds induce huge river discharges and strong coastal currents in the Northern Bay of Bengal. To date, the paucity of salinity data has prevented a thorough description of the spreading of this freshwater into the Bay. The potential impact of the salinity on cyclones and regional climate in the Bay of Bengal is however a strong incentive for a better description of the water cycle in this region. Since May 2005, the National Institute of Oceanography conducts a program in which fishermen collect seawater samples in knee-deep water at eight stations along the Indian coastline every five days. Comparison with open ocean samples shows that this cost-effective sampling strategy is representative of offshore salinity evolution. This new dataset reveals a salinity drop exceeding 10 g/kg in the northern part of the Bay at the end of the summer monsoon. This freshening signal propagates southward in a narrow (~100 km wide) strip along the eastern coast of India, and reaches its southern tip after two and a half months. Satellite-derived alongshore-current data shows that the southward propagation of this "river in the sea" is consistent with transport by seasonal coastal currents, while other processes are at stake in the ensuing erosion of this coastal freshening. This simple procedure of coastal seawater samples collection could further be used to monitor phytoplankton concentration, bacterial content and isotopic composition of seawater along the Indian coastline.

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Observed Year-to-Year Sea Surface Salinity Variability in the Bay of Bengal During the period 2009 – 2014

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[1]National Institute of Oceanography;
[2]IRD/Laboratoire d'études en Géophysique et Océanographie Spatiales (LEGOS)

The upper Bay of Bengal presents a marked stratification in salinity on the vertical. This peculiar stratification results from massive freshwater supply to the basin. It is believed to play a key role in the dynamics of Asian monsoon. The present study investigates the interannual variability of sea surface salinity (SSS) observed in the Bay during the 2009-2014 period. It is based on an original compilation of all available in situ SSS observations, assembled in a 2°-resolution tri-monthly gridded field. We find that the year-to-year variability of SSS is particularly strong in the North-Eastern part of the Bay. Over the recent years, this variability takes the form of two successive and opposite phases: a saltening phase from mid-2009 to late 2010, immediately followed by a freshening phase from late 2010 to late 2011. The typical magnitude of each of the anomalous spells is about one unit (in the practical salinity scale), making this area one of the most variable of the tropical oceans, at interannual timescales. Based on a simple diagnostic mixed-layer model forced by observed fluxes, we found that this year-to-year variability is prominently driven by the variability of the freshwater fluxes to the ocean (precipitation and river runoff, with the two factors acting independently). However, the variability of oceanic surface circulation associated to the Indian Ocean Dipole mode also exerts an active role (in particular for the freshening period observed during the 2011 positive dipole event).

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Role of Fronts in the Formation of Arabian Sea Barrier Layers During Summer Monsoon

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[1]IRD; [2]IFREMER; [3]MERCATOR-OCEAN; [4]CNRS

The barrier layer (a salinity stratification embedded in the upper warm layer) is a common feature of the tropical oceans. In the northern Indian Ocean, it has the potential to significantly alter the air-sea interactions. In the present paper, we investigate the spatio-temporal structure of barrier layer in the Arabian Sea during summer monsoon. This season is indeed a key-component of the Asian climate. Based on a comprehensive CTD and ARGO-based dataset of in situ hydrographic profiles, we find that a Barrier Layer (BL) exists in the central Arabian Sea during summer. However, it is highly heterogeneous in space, and intermittent, with scales of about ~100 km or less and a couple of weeks. The BL patterns appear to be closely associated to the salinity front separating two water masses (Arabian Sea High Salinity Water in the Northern and Eastern part of the basin, fresher Bay of Bengal Water to the south and to the west). An ocean general circulation model is used to infer the formation mechanism of the BL. It appears that thick (more than 40 m) BL patterns are formed at the salinity front by subduction of the saltier water mass under the fresher one in an area of relatively uniform temperature. Those thick BL events, with variable position and timing, result in a broader envelope of thinner BL in climatological conditions. However, the individual patterns of BL are probably too much short-lived to significantly affect the monsoonal air-sea interactions.

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The Influence of Salinity and Freshwater Fluxes on the Stability of the AMOC

Jackson, L.[1]
[1]*Met Office*

The Atlantic Meridional Overturning Circulation (AMOC) plays a crucial role in the climate of Europe through the meridional transport of heat in the ocean. There have been suggestions that this circulation is bistable and has both stable 'on' and 'off' states. Here we show how biases in a climate model's salinity field and freshwater fluxes can influence the behaviour of the AMOC through changing the sign of important feedbacks. We also explore some of the processes behind the biases.

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Upper-ocean heat and salt budgets during the SPURS field campaign

Ash, E.[1]*; Farrar et al., Tom2*
[1]*Satellite Oceanographic Consultants;* [2]*WHOI*

The Salinity Processes Upper-ocean Regional Study (SPURS) was a field campaign focused on understanding the physical processes acting to maintain the climatological sea surface salinity (SSS) maximum in the subtropical North Atlantic. An upper-ocean salinity budget provides a useful framework for guiding progress toward that goal. The SPURS measurement program included a heavily instrumented air-sea interaction mooring, which allows accurate estimates of the surface fluxes, and a dense array of measurements from moorings, Argo floats, and gliders. These data will be used to estimate terms in the upper-ocean salinity and heat budgets during the year-long SPURS campaign, with the goal of gaining insight into the physical processes contributing to the mean and variability of SSS in the North Atlantic SSS maximum region.

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IQuOD (International Quality Controlled Ocean Database) - an International Initiative to Design, Deliver and Maintain a Climate Standard Subsurface Global Ocean Dataset

Good, S.[1]
[1]*Met Office Hadley Centre*

Research into the role of the oceans in the Earth's climate system, whether through data assimilation or direct analysis, has been hampered by the lack of availability and mixed quality of ocean subsurface data and metadata. To greatly improve this situation, the IQuOD initiative aims to develop a global subsurface ocean dataset of temperature and (eventually) salinity that is of the highest possible standard. This will be achieved by pooling international resources and expertise into a single, best practice community effort. The dataset will be quality controlled by a combination of automated and manual procedures, will include all available metadata, will contain uncertainty estimates on individual profile observations and be freely distributed.

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EN4 - Quality Controlled Temperature and Salinity Profiles and Monthly Objective Analyses with Uncertainty Estimates

Good, S.[1]*; Martin, M.2; Rayner, N.*[2]
[1]*Met Office Hadley Centre;* [2]*Met Office*

Good quality observations of the temperature and salinity of the subsurface of the ocean are required for a variety of applications such as estimation of ocean heat content change, ocean reanalysis and decadal forecasting. We present the EN4 dataset, which aims to meet this requirement. It covers 1900 to present (the dataset is updated monthly). Profile observations from anywhere in the oceans are included and are sourced from a number of data collections in order to achieve the best possible coverage. A series of quality control checks are run on the data. All observations and quality control decisions for a month are collated in a single file. The EN4 dataset also includes monthly objective analyses of potential temperature and salinity formed from the quality controlled observations. Uncertainty estimates are provided with the analyses. We describe briefly the novel method used to generate these. Both the observations and analyses are made available in NetCDF files and are freely available for research and private study from www.metoffice.gov.uk/hadobs.

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Levantine Intermediate Water properties observed in the eastern Levantine

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Interannual-to-Decadal Salinity Variations in the North Pacific Related to Changes of Precipitation and Subtropical Gyre

Hosoda, S.[1]; Nonaka, M.2
[1]JAMSTEC; [2]JAMSTEC RCGC

The subtropical mode water in the North Pacific (STMW) is known as one of the most dominant water masses in the North Pacific and variability in its temperature and volume has been investigated in detail as it is considered to reserve and represent impacts of atmospheric variability on the ocean (e.g., Hanawa and Kamada 2001). Its salinity variability, however, has not been investigated probably due to limited observations. In the present study, variability in STMW salinity and its relation with sea surface salinity (SSS) and precipitations over the North Pacific is investigated based on observational data. Here we use monthly gridded Argo data (MOAA GPV; Hosoda et al., 2008) and monthly gridded precipitation data (GPCP; Adler et al., 2003). Then we investigate variability in salinity in the STMW region (25-34N, 130-150E) and its relation with SSS/precipitation over the North Pacific based on lagged correlation analyses. Salinity of STMW shows significant interannual-to-decadal variability in the era of Argo observation, and it is clearly different from variability in STMW temperature, indicating that properties of the water mass, STMW, are affected more than one process. Our lagged correlation analysis indicates that the change in SSS in STMW follows SSS anomalies in the Philippine Sea around 20N, the upstream of Kuroshio, with lags of one to two years. This relationship is consistent with the analysis by Nagano et al. (2014) and similar analyses for sea surface temperature and precipitation suggest that the SSS anomaly in the Philippine Sea is associated with precipitation change with El Nino Modoki. In our analysis, the horse-shoe-like pattern of SSS correlation also appears in the tropical Pacific, which corresponds to the quasi-decadal variability found by Hasegawa et al. (2014). Additionally, there is positive correlation of SSS with the STMW-SSS in the central North Pacific, suggesting that the STMW-SSS is likely to be related to not only change in precipitation but also the subtropical gyre structures. Our results show variability in salinity in the western North Pacific and its relationship with SSS/precipitation over the North Pacific based on the long-term accumulated observational data. To understand further mechanism, we will present the results based on a numerical model data.

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Interannual-to-Decadal Salinity Variations in the North Pacific Related to Changes of Precipitation and Subtropical Gyre

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The Influence of Salinity and Freshwater Fluxes on the Stability of the AMOC

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CO2 Fluxes and Ocean Acidification Using SMOS

Land, P.[1]; Shutler, J.1
[1]Plymouth Marine Lab; [1]Plymouth Marine Lab

Since the beginning of the industrial revolution humans have released approximately 500 billion metric tons of carbon into the atmosphere from burning fossil fuels, cement production and land-use changes. About 30% of this carbon dioxide has been taken up (or absorbed) by the oceans, however the flux of CO2 from atmosphere to ocean has strong regional and seasonal variability, and is often reversed. The long-term oceanic uptake of carbon dioxide leads to a change in marine carbonate chemistry resulting in a decrease of seawater pH and carbonate ion concentration, a situation that is commonly called 'Ocean Acidification' (OA). Oceanflux Evolution is a proposed European Space Agency (ESA) project focusing on the use of satellite Earth Observation (EO) in the quantification of ocean-atmosphere fluxes of CO2 and other gases. The project will exploit data from ESA's Soil Moisture and Ocean Salinity (SMOS) to quantify the effect of sea surface salinity (SSS) on Arctic CO2 fluxes. Pathfinders-OA is an ESA feasibility study focusing on the role that EO can play in supporting and expanding OA research. The project will exploit SMOS and other EO data to evaluate algorithms for retrieving carbonate system parameters (total alkalinity, dissolved inorganic carbon, partial pressure of CO2 and pH) from EO retrievable parameters such as SSS, sea surface temperature and chlorophyll. We will present an overview and initial results from both projects and show examples of satellite derived OA relevant data, focusing on the period 2010-2012.

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Aquarius Surface Salinity and the Madden-Julian Oscillation

Lee, T.[1]; Guan, B.1; Waliser, D.[1]; Halkides, D.[1]
[1]Jet Propulsion Laboratory

Sea surface salinity (SSS) data from the Aquarius satellite are analyzed along with auxiliary data to investigate the SSS signature of the Madden-Julian Oscillation (MJO) in the equatorial Indian and Pacific Oceans, the effect of evaporation-minus-precipitation (E-P), the implication for the role of ocean dynamics, and the SSS influence on surface density and potential energy. MJO-related SSS changes are consistent with E-P forcing in the western Indian Ocean throughout the MJO cycle and in the central Indian Ocean during the wet phase of the MJO cycle. However, SSS changes cannot be explained by E-P in the central Indian Ocean during the dry phase and in the eastern Indian and western Pacific Oceans throughout the MJO cycle, implying the importance of ocean dynamics. SSS has an overall larger contribution to MJO-related surface density and potential energy anomalies than SST. It partially offsets the SST effect in the western-to-central Indian Ocean and reinforces the SST effect in the eastern Indian and western Pacific Oceans. Ocean modeling and assimilation need to properly account for salinity effects in order to correctly represent mixed layer variability associated with the MJO. Our results also clarify some discrepancy in previous studies about the E-P effect on MJO-related SSS variations.

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SSS Variability in the Coral Sea, Southwest Pacific Ocean.

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The small-scale features in SSS and SST of the Coral Sea are examined using high horizontal spatial and short-term temporal in situ measurements. These features are extracted from thermosalinograph sensors (TSG) gathered onboard commercial and research vessels and at one long-term fixed station. The analyses are performed along the vessel tracks and the structures of small-scale features are extracted by high-pass spatial filtering the original TSG data. For SSS, it is shown that the features at the scale of mesoscale eddies (around 100 km) vary from about -1.1 to +0.6 psu in the Coral Sea region. Processes sustaining such range include rainfall events, stirring by mesoscale eddies, and the latitudinal displacement of the sharp front associated with the edge of the Western Pacific Warm Pool at the seasonal time scales. The TSG data have revealed the presence of a sharp front (0.4–0.6 psu) between the subtropical and equatorial waters instead of a smooth gradient in the standard SSS climatologies. Within the context of recent remotely sensed observations of salinity, this could represent an important limitation for the validation and calibration of satellite products. Estimates of the satellite products in the region will be also presented and discussed. In addition to these spatial considerations, temporal variations at one long-term station near Vanuatu show that the coupled air-sea responses to intraseasonal tropical variability, such as the Madden-Julian Oscillation, may have a signature in both SST and SSS fields. However, this response is found to be complex and little coherency at the seasonal time scales is observed.

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On the Retrieval of SSS in Coastal Areas

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Ocean salinity is crucial to the understanding of the role of the ocean in climate through the global water cycle. Salinity in combination with temperature determine ocean circulation by defining its density and hence thermohaline circulation. Additionally, ocean salinity is one of the variables that regulate CO2 uptake and release and therefore control the oceanic carbon cycle. A renewal of interest for the radiometric L-band Sea Surface Salinity (SSS) remote sensing appeared in the 1990s and led to the Soil Moisture and Ocean Salinity (SMOS) satellite launched in November 2009 and to the Aquarius mission (launched in June 2011). However, due to low signal to noise ratio, retrieving SSS from L-band radiometry is very challenging. In addition, the spatial resolution of the microwave radiometer, while adequate for many global applications, prevents their applications in coastal areas. These areas are characterized by strong and variable SSS gradients (several practical salinity units (psu)) on relatively small scales: the extent of river plumes is highly variable, typically at kilometric and daily scales. Monitoring this variability from satellite radiometer measurements is particularly challenging because of their resolution (typically 30–100 km) and because of the contamination by the nearby land. In this study, we investigate techniques to enhance the spatial resolution of radiometer data to: a) provide SSS on a finer resolution grid; b) analyze the uncertainties associated to the estimation of SSS from radiometer data at enhanced spatial resolution. Case studies on actual L-band radiometer data will be shown and discussed.

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Multi-temporal Monitoring of Salinity in Eastern Mediterranean Region Using SMOS L2 OS Satellite Data and in Situ Measurements.

Palantza, D.[1]

[1]*Self Employed*

This study has been motivated to assess, for the first time, the performance of Sea Surface Salinity, SSS of the Soil Moisture and Ocean Salinity (SMOS) satellite launched by the European Space Agency (2009), on the Mediterranean Region. The SMOS satellite is a microwave radiometer which records at 1.4 Ghz frequency and at a wavelength l = 21cm, the microwave radiation emitted from the surface of the oceans. The physical properties of the sea water, salinity and temperature are the key factors that need to be constantly monitored. This constant monitoring contributes to a better understanding of the motion of ocean currents. Ocean currents transfer a large amount of heat from the equatorial regions to the poles, sustaining this way the global climate. Until recently the monitoring of salinity and temperature, took place mainly by ship measurements and monitoring stations (Buoys) located in the open ocean, which were sparse, regional and highly costly to maintain. The SMOS mission launched in November 2009, would record for the first time the soil moisture and ocean salinity from space. The mission's objective is the global observation of salinity with a monthly accuracy of 0.1 psu. The data used for the study are L2 OS gridded in bins of 0.5° in latitude and longitude (by Reul, N.) and in-situ data provided by the Hellenic Centre of Marine Research/HCMR and the POSEIDON project. The area of interest is the East part of the Mediterranean (Fig.1) and both the satellite and in-situ data cover a period of three years (2010-2012). Due to the absence of Buoys in the broader area of East Mediterranean, hydro dynamical forecasting models were used provided by the HCMR's Live Access Server/LAS portal for the comparison of the data. The results of the study show very poor quality of SMOS-derived SSS values due to "land contamination" and RFI emissions.

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Salinity in the GloSea5 Ocean and Sea Ice Analysis

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[1]*Met office*

As part of the initialization of the ocean and sea ice component of the Met Office Seasonal Forecast system, GloSea5, we have performed an ocean re-analysis for the period 1989 through 2013. This analysis uses the NEMOVAR ocean assimilation system making use of observations of sub-surface salinity and temperature profiles from EN3, along with satellite observations of SST (also includes in-situ observations), sea level anomalies and sea ice concentration. I will present some results on the performance of the system with regards to integrated quantities such as ocean salinity content during the analysis. Comparisons with EN3 gridded products, along with differences arising from correcting fall rates of XBT in the EN3 profiles will be highlighted. Regional areas with significant interactions with ocean heat content and ultimately important to the air-sea interaction such as the tropical Pacific (ENSO) and North Atlantic with also be explored.

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Examination and Comparison of SMOS and MyOcean Global Salinity Data

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Sea Surface Salinity fronts Variability in the South Atlantic

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The South Atlantic plays an important role in the global meridional overturning circulation. It connects the Atlantic with the other oceans through the Southern Ocean and serves as a conduit of surface waters from the Indian ocean. Dominated by the evaporation over precipitation, the South Atlantic subtropical gyre is marked by high mean salinity values. Dynamics and thermodynamics are connected. The wind-driven circulation advects salinity (S) and temperature (T) anomalies within the subtropical gyre and changes the characteristics of the water masses and vice-versa. These interactions contribute to transport the TS characteristics acquired at the surface, horizontally and vertically. The Tropical Surface Water and the Central Water are the main water masses found in the subtropical gyre, above the main pycnocline. Strong and persistent gradients of surface salinity are found in the form of oceanic fronts along the edges of the subtropical gyre. In the northwestern South Atlantic, the transition region between the tropics and the subtropics is marked by the formation of highly saline water by subduction which spreads equatorward and poleward as a subsurface salinity maximum. Also, the convective mixing that takes place near the Brazil Current Recirculation gyre and the Brazil--Malvinas confluence regions, in the southwestern side of the basin, during the winter months propiciates the formation of mode waters. In this study, we use remote sensing salinity data to identify and quantify the variability of these salinity fronts in space and time. The competing air--sea processes in the determination of such salinity signatures at the surface is examined by analysing the variability of wind stress divergence and curl (a dynamical process), evaporation, and precipitation (thermodynamical processes) measured by microwave satellites in the South Atlantic.

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Inter-annual Upper Ocean Stratification in Bay of Bengal: Observational and Modeling Aspects

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The coupled ocean- atmosphere interaction over the Bay of Bengal (BoB) is modulated by the upper ocean stratification. Inter comparison of climatological upper ocean stratification shows that Global Ocean Data Assimilation System (GODAS, an assimilation system used for ocean initial conditions in forecast models) underestimates stratification by 30% compared to ARGO observations. The upper ocean salinity budget reveals that this underestimation by GODAS is primarily due to increased mixing. Further analysis reveals that even though model fresh water forcing is higher than the observed one, GODAS underestimates sea surface salinity (SSS) in this region. This cannot be completely explained even by the contribution from advection throughout the year in the model. The low inter- annual variability of SSS tendency in GODAS is attributed to the absence of interannual river runoff in the model. This issue is not completely offset by the assimilation of synthetic salinity profiles in GODAS. It underlines the importance of assimilating salinity profiles from recent observations rather than assimilating synthetic profiles which has been shown to be seriously underestimating the salinity variability and thereby produces severe errors in representing the ocean currents in the model. GODAS is providing initial condition to forecast models such as Climate Forecast System (CFS), and so this error in surface salinity might lead to unrealistic evolution of upper ocean thermal structure. This study underlines the importance of having high quality salinity observations to estimate the salinity budget of regions like BoB.

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An Assessment of Upper Ocean Salinity Content from the Ocean Reanalyses Inter-comparison Project (ORA-IP)

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Salinity variability has a significant impact on the density structure and therefore dynamics of the ocean. Currently, most "second generation" ocean data assimilation systems assimilate both observed temperature and salinity profiles through a variety of assimilation methods. Evaluating salinity reanalyses is very difficult because of the lack of validation data, especially the independent datasets. In this study we looked at the ensemble mean of 14 salinity reanalyses from the Ocean Reanalyses Inter-comparison Project (ORA-IP), and then, compared that with the ensemble mean of three objective analyses that did not use a model. Spread in the 14 salinity reanalyses gives an indication of disagreement between the re-analyses and an estimate of reanalyses error. The signal-to- noise (SNR) ratio provides an estimate of where the signal measured by the ensemble mean dominates over the noise measured by the ensemble spread. Only in limited areas, like the western equatorial Pacific, central Indian Ocean and limited areas in the subtropics and mid-latitudes does the SNR exceed 1. Over most of the oceans the SNR is less than 1, indicating that there is considerable disagreement in the estimates of the variability of the 700m salt content between the different re-analyses. The spread in the inter-annual anomalies of the re-analyses shows values for the 700m salt content exceeding 0.1 (psu*700m) in regions associated with strong variability such as western boundary currents and the Southern Ocean. Argo was shown to have a significant impact on salinity analysis, significantly reducing the spread among the re-analysis during the Argo period, compared to earlier periods.

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SMOS Salinity Retrievals Along Trajectories of Massive Icebergs

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During four years in orbit, SMOS showed its capability to detect icebergs drifting along coasts of Antarctica. Numerous constraints limit SMOS capabilities, in consequence we are able to monitor only massive and not grounded icebergs. In the first step, recognition of icebergs is based on analysis of SMOS L1c browse data of brightness temperature, while from full polarimetry data we derive additional information about iceberg`s properties. Identification of icebergs in the SMOS Level 2 data is not straightforward. When icebergs are in the close vicinity of sea-ice, appropriate flags are raised and retrieval of SSS is not performed. However this is not a case, if a freely drifting iceberg is observed at mid-latitudes (around 50S). The study sums up all recently detected cases of icebergs and provides an analysis of salinity changes along the iceberg`s trajectory. Analysis is supplemented with modelling studies which aim to derive estimates of SST in the close proximity of spotted iceberg.

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Salinity Measurements in the Marginal Ice Zone with an Autonomous Upwardly-Rising Microstructure Profiler

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The Air-Sea Interaction Profiler (ASIP) is an autonomous vertical profiler designed to provide undisturbed measurements of the upper ocean, focusing on processes at the surface. ASIP is equipped with a range of sensors for temperature, conductivity, shear, and PAR measurements. This presentation will focus on a 10-day research cruise in the continental shelf-edge region west of Svalbard and in the eastern part of the Fram Street, up to the marginal ice zone ([77-81°N, 0-13°E]). Warm and saline Atlantic Water (AW) flowing northward with the West Spitsbergen Current through the Fram Street is the main source of heat into the Arctic Ocean. Subsurface heat loss from the AW to surface waters and ice melt is attributed to various mixing processes. The temperature and salinity stratification below the surface mixed layer is favorable for double diffusive convection, which can form a significant heat flux from warmer subsurface layers to the upper layer. The trend of decreasing sea ice cover is hypothesized to increase vertical mixing, thereby speeding up the warming of the Arctic surface waters. For this field experiment, ASIP has been equipped with five different temperature and conductivity sensors, providing resolutions from 5 cm up to 1 millimeter, thereby allowing five independent measurements of salinity. These data provides a valuable dataset to study air-sea interfacial salinity variability.

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Ocean Salinity Effects on Surface Wind

Tomita, H.[1]

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Upper ocean salinity has a significant role on upper ocean structure. For example, salinity changes in the upper ocean causes construction of barrier layer, and it may have significant effects on atmosphere-ocean interaction. The relationship between SST and wind speed have investigated in terms of near ocean surface salinity and upper ocean structures: mixed / barrier layers by analyzing satellite and in-situ observation data. SST and wind speed obtained satellite monthly flux product for 2003-2010 are used. Moreover, to investigate upper ocean structures, we used Argo MOAA GPV data set for a same period. As a result, we found that the barrier layer and mixed layer have an effect on surface wind speed fields and the relationship between SST and wind speed. For temperature range from 24 to 28 degrees Celsius in SST, wind speed tends to be higher over the warm region. Such regions are also corresponding to the regions characterized by barrier layer. For temperature over 28 degrees Celsius, wind is quite low and the relationship between SST and wind shows negative correlation. These results might suggest that the ocean salinity change has significant effects on atmosphere.

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Improvements to a Global Ocean Data Assimilation System Through the Incorporation of Aquarius Surface Salinity Data

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The Aquarius/Satélite de Aplicaciones Científicas (SAC)-D (Lagerloef et al., 2008) satellite, an L-band passive radar system has been providing global maps of sea surface salinity (SSS) since 25 August 2011. In parallel with the ongoing satellite observations, assiduous efforts for reducing measurement errors have been made along with detailed validation campaigns. As a result, there are multiple possibilities for new science. For example, the new SSS field obtained on completion of a few annual cycles of Aquarius measurements will support detailed climate studies and should greatly improve our understanding of the ocean freshwater cycle. In order to enhance the description of oceanic processes by using Aquarius SSS data we make use of a data assimilation approach, which has the advantage of providing four-dimensional analysis fields incorporating the limited observational data within the framework of established dynamical models. Hence, we aim to merge Aquarius data into the global ocean data assimilation system developed in the Meteorological Research Institute (MOVE/MRI.COM) and then assess its impacts on the upper-ocean field. Positive effects by incorporating the Aquarius data can be seen in several regions in the global ocean, although uncertainty in the Aquarius data is expected to be large in some regions. Model biases in the SSS field due to the defects in both the forcing field and the model (resolution and parameterizations) reported in previous studies are reduced by the Aquarius data assimilation. Furthermore, other parameters such as subsurface temperature are affected by the new data through the water-mass formation processes. These results indicate the importance of Aquarius data in deriving improved representations of the global ocean from dynamical models.

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Tools, Services and Support of Aquarius/SAC-D and SPURS Data Archival and Distribution Through PO.DAAC

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[1]*NASA Jet Propulsion Laboratory*

The Physical Oceanography Distributed Active Center (PO.DAAC) serves as the official NASA repository and distribution node for all Aquarius/SAC-D data products in close collaboration with the project. We additionally distribute the JPL Aquarius-CAP dataset and are now also the designated archive for the SPURS field campaign data. Here we report on the status of Aquarius data holdings at PO.DAAC, the range of data services and access tools that we provide in support of this mission, and new efforts to support in-situ salinity datasets from SPURS. Particular emphasis is placed on new tools and services that have come online recently for the Aquarius v3.0 dataset release. These range from OPeNDAP and THREDDS data access services, to web-based visualization via PO.DAAC's State of the Ocean (SOTO) tool and LAS, to PO.DAAC's new, advanced L2 subsetting tool called HITIDE (High-level Tool for Interactive Data Extraction). Dataset discovery via the PO.DAAC web-portal, and user services are also described.

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Sea Surface Salinity Signatures of Tropical Instability Waves: New Evidences from SMOS

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Sea Surface Salinity (SSS) from the Soil Moisture and Ocean Salinity (SMOS) mission from June 2010 to May 2013 provide an unprecedented long-term opportunity to observe the salinity structure of Tropical Instability Waves (TIWs) in the eastern equatorial Pacific Ocean from space. SMOS SSS signals correlate well and have similar amplitude to 1-m salinity from the Tropical Atmosphere Ocean (TAO) array at 5 locations with strong TIW signals. At these locations, the linear relationships between SMOS SSS and OSTIA SST signals are comparable to the ones obtained from TAO. We then focus on SSS and SST signals from June to December 2010, a period when TIWs are strong due to the intense 2010 La Niña. The largest meridional gradients of both SSS and SST appear north of the equator west of 100°W. They shift southward and cross the equator at 90°W. The east-west contrast (with a boundary at 135°W) in peak amplitude of SMOS SSS signals is stronger than in OSTIA SST signals. The amplitudes and longitudinal extents of TIW signals and the dominant westward propagation speed of 17-day TIWs as detected by SMOS at the equator decrease from 2010 to 2013 associated with the transition from a strong La Niña to non La Niña conditions. SMOS and Aquarius observed TIWs from 2011 to 2013 are in relatively good agreement.

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The Role of Sea Surface Salinity in Indian Ocean Warm Pool

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Several studies have drawn attention to the role of Sea Surface Salinity (SSS) in studies of ocean warm pool during recent years. An intriguing aspect of the characteristics of Indian Ocean Warm Pool (IOWP) is that it is defined by SSS. Based on a detailed diagnostic analysis of Aquarius satellite datasets ,GODAS dataset, and reanalysis products , this study examines how the SSS affect the IOWP and combine with SST to reveal this mechanism. The present results reveal that there is significant difference of SSS between Arabian sea and Bay of Bengal, which is that SSS over Arabian basin is higher than that over Bay of Bengal all the year round. Meanwhile, it can be seen that the distribution of SSS is consistent with the IOWP. Besides, the distribution of latent heat flux over Indian ocean also occurs this 'east-west' difference except summer. However it plays negative effect to the consistent warming over Indian ocean. In order to search a reasonable explain for this consistent warming, the SSS is considered. The SSS can control the stratification especially affect the mix layer thickness which means that it can have an influence on heat storage, although it is not directly affect the atmosphere. When there is low salinity, the mix layer thickness is decreasing to some extent which helps to 'trap' heat from shortwave radiation. Thus, the advected low salinity need to be noticed as a very important factor to control the intensity of the IOWP.

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Maintenance and Distortion of the Ocean's Salinity Distribution by the Water Cycle

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Introduction: The water cycle leaves an imprint on ocean salinity through evaporation and precipitation. It has been proposed that observed changes in salinity could be used to infer changes in the water cycle. Method: Here salinity is characterised by the distribution of water masses in salinity coordinates. Mixing acts to collapse the distribution, homogenising salinity, while evaporation and precipitation stretch the distribution, maintaining the contrast between water masses. A simple model is developed to describe the relationship between the breadth of the distribution, the water cycle and mixing, the later being characterised by an e-folding timescale. Results: In a state of the art ocean model we find that ocean salinity responds to a water cycle change with a timescale of order 50 years. This timescale also describes the mean balance in both model and observations. Using observed changes in salinity we estimate that the hydrological cycle has increased by approximately 3.5% over the 50-year record of salinity observations, although the spread among observational products is large. Conclusion: This study suggests that robust and sustained ocean salinity observations can be used to accurately measure changes in the water cycle.

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