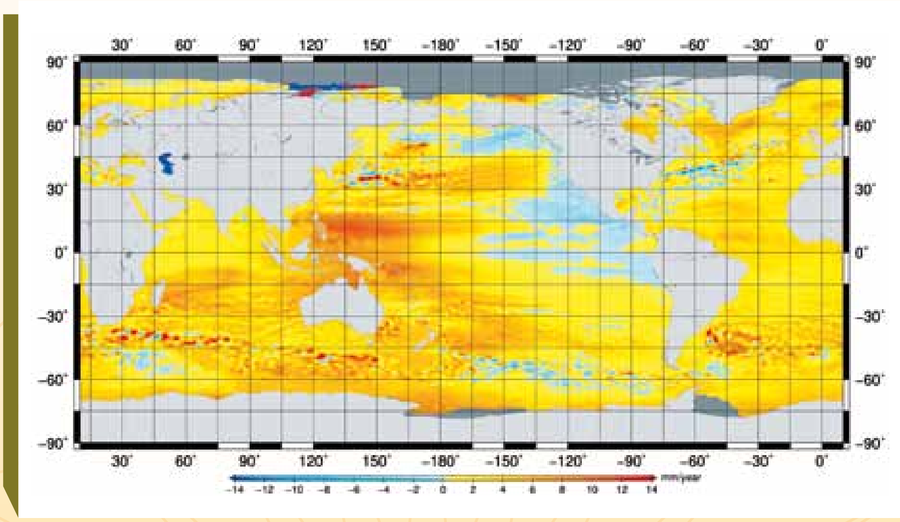
AUTHOR: J. Lambin

Oceanography

[Fig. 1]



Space oceanography at CNES has been progressing along three main paths: a strong involvement in the development of operational oceanography, preparing the future generation of altimetry missions, and exploring new ocean parameters to be monitored from space.

Developments in operational oceanography

On account of its historical major involvement and expertise in space oceanography, CNES has been involved in a wide variety of activities and partnerships in this field, and in all aspects from research to development and operation. Altimetry in particular is a field in which CNES excels, and while the programme lead in ensuring the continuity and robustness of the altimetry constellation has been progressively taken over by other operational agencies, CNES remains deeply involved in the development of satellites, payload, ground segment and applications. This guarantees that altimetry will remain at the highest level, satisfying the wider community of both operational and scientific users.

This is perfectly illustrated by the Jason series of satellites. By December 2012 the CNES/NASA Jason-1 mission had been in orbit for over 10 years. Since the satellite is ageing, but still operational, CNES and NASA have set up an 'end-of-life' strategy: Jason-1 will eventually be moved to a lower orbit in which it will continue to monitor the topography of the sea surface without risk of collision with TOPEX or Jason-2 should it fail. This new orbit might even turn out to be beneficial for specific altimetry applications such as bathymetry and determination of the Earth's geoid.

There is little to be said about the CNES/NASA/EUMETSAT/NOAA Jason-2 mission (note how many operating agencies are involved!): This mission has functioned perfectly since June 2008, with every single bit of data of the highest quality; Jason-2 is very much the benchmark of the altimetry constellation. Multi-mission products based on careful inter-calibration of other missions (ENVISAT, Cryosat-2, and soon HY-2A and SARAL) are routinely generated by the SALP project and made available on the AVISO server. 'AVISO maps' are synonymous with 'quality multi-mission sea surface topography maps' all over the world.

A follow-on Jason-3 program is being developed under the responsibility of EUMETSAT and NOAA: the transition towards operating agencies is now complete. However, CNES is the prime contractor on the European side, and the technical scope of CNES involvement remains unchanged from Jason-2. This means that when Jason-3 is launched (in 2014), users will continue to benefit from the same high level of continuity, accuracy and availability since the TOPEX/Poseidon launch in 1992.

The future of altimetry

Building on the strong heritage of the Jason series, CNES is preparing the next generations of altimetry missions. Delay-Doppler altimeters will improve both along-track resolution and noise: such altimeters will be on board the ESA missions Sentinel-3A and 3B, in which CNES is involved by providing the DORIS precise orbitography instrument and project support for both space and ground segments. This technology is already being used in ESA's Cryosat mission, launched in 2010 and dedicated to ice monitoring.

On ESA's behalf, CNES has set up a processing system dedicated to ocean products, so that Cryosat is now an ocean topography mission as well, with Cryosat data being routinely integrated within the AVISO multi-mission products.

AltiKa is another innovative altimeter developed by CNES, and also ready to be included on the joint CNES/ISRO SARAL mission slated for launch by the end of the year. In addition to filling the gap between ENVISAT and Sentinel-3, AltiKa will perform altimetric experiments in the Ka-band with the aim of making altimeters more compact and precise.

Last but not least, CNES and NASA are working together on the next revolution in altimetry. The SWOT mission will provide measurements of ocean topography with even greater precision, and in two dimensions: the KaRIn instrument is a high resolution Ka-band SAR interferometer for observing ocean mesoscale and sub-mesoscale processes. It is now recognized that these short-scale structures have a huge influence on ocean dynamics, and SWOT will provide the first quantitative measurement of such phenomena on a global scale. Note that SWOT is also a hydrology mission, as measurements will be made on all bodies of water such as lakes, reservoirs and rivers.

Exploring new measurements of ocean parameters

Beside traditional space-based observations (temperature, topography, etc.), scientific demand for ocean observation satellites continues to grow, with new parameters to be explored.

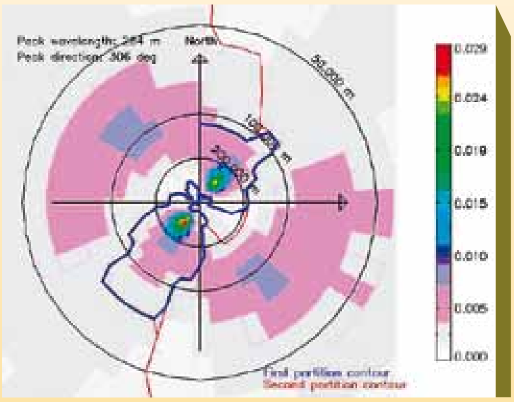
Launched in November 2009, the ESA/CNES SMOS mission is the first to measure sea surface salinity from space. Salinity is a major parameter not only in the movement and evolution of the oceans, but also in the water cycle: salinity depends on rainfall and the influx of fresh water from rivers but more importantly, on the increasing melting of the polar ice caps. SMOS incorporates sophisticated measurement techniques and complex data processing, and a strong partnership between CNES, IFREMER and CNRS/LOCEAN has been established to develop and produce the best advanced products.

Planned for the end of 2014, the CFOSAT mission is being developed in partnership with the Chinese space agency (CNSA), and will provide observations of wind at the ocean surface and spectral properties of surface ocean waves on a global scale. It will serve the operational needs for surface wind and wave forecasts (marine meteorology and climatology), as well as research needs by improving our knowledge of wave hydrodynamics, interactions between waves and near-surface atmospheric or oceanic layers, and interactions between electromagnetic signals and the sea surface.

For this purpose, the CFOSAT satellite will carry two active microwave instruments: a wave scatterometer spectrometer (SWIM: Surface Waves Investigation and Monitoring) supplied by CNES and a scatterometer (SCAT) supplied by CNSA for measuring winds over the ocean.

The future certainly holds yet more prospects. Some are under phase 0 study at CNES and await flight opportunity: such examples are GEOCAPI, dedicated to ocean colour monitoring from geostationary orbit, providing access to biogeochemical parameters, or SWIM Evolution which is already preparing the post-CFOSAT era.

[Fig. 2]



[Fig. 3]

[Fig. 1]
Map of sea level trends measured over the "reference altimetry" period (1993-2010), thanks to the continuity of missions from TOPEX/Poseidon, Jason-1 and Jason-2.
Careful intercalibration of missions and continuous improvement in processing made this data an exemplary 'essential climate variable' for global change studies.
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[Fig. 2]
Directional wave spectrum simulated during performance studies for the instrument SWIM onboard CFOSAT. From 2015, CFOSAT will continuously and globally measure amplitude, wavelength and orientation of wind seas and swell waves. The simulator tool, SimuSWIM, was developed in cooperation with LATMOS as a tool for the processing chain development.
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[Fig. 3]
The altimetry constellation.
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Oceanography

Laboratory contribution

Sea surface salinity observations from Space and wind speed monitoring under Tropical Cyclones with SMOS

SMOS : un nouvel outil pour estimer la salinité de surface des océans et les vents surfaciques dans les cyclones tropicaux

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Abstract

SMOS sensor is the first orbiting interferometric radiometer, providing brightness temperature images of the Earth at a low microwave frequency of 1.4 GHz. Intricacies of these new datasets are deciphered by researchers from several French laboratories to provide first-time satellite estimates of the sea surface salinity, a key oceanographic variable. The peculiar properties of the SMOS signal also proved to be very useful to better infer surface wind speed information under Tropical cyclones.

Résumé

Le capteur du satellite SMOS est le premier radiomètre interférométrique en orbite permettant une mesure de la température de brillance de la Terre à la fréquence de 1,4 GHz. Des chercheurs de plusieurs laboratoires français analysent ces nouvelles données afin d'estimer pour la première fois la salinité de surface océanique depuis l'espace. Les propriétés particulières du signal mesuré permettent également une meilleure restitution du vent de surface dans les cyclones tropicaux.

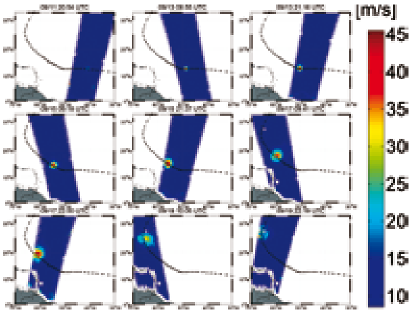
Sea Surface Salinity remote sensing with SMOS

Sea surface salinity (SSS) is known to play an important role in the dynamics of the ocean circulation and is the key tracer for the marine branch of the global hydrological cycle. Our basic knowledge about the global SSS distribution is derived from the compilations of all the available oceanographic data collected over time. The SSS in situ observing system has expanded significantly during the last decade (e.g., Argo array), providing an average of one sample every 300-400 km square every 10 days. Notwithstanding these recent gains, the in situ sample density remains sparse to resolve climatologically important seasonal to interannual signals at the spatial scales over which SSS is known to vary significantly (~100 km).

While sea surface temperature, sea level, sea ice, ocean color properties and sea states are routinely monitored using satellite data, SSS observations from space were not available until the recent launches of ESA SMOS (Soil Moisture and Ocean Salinity) and NASA/Aquarius missions. Salinity remote sensing is based on the microwave emission properties of the sea surface. They depend partly on the dielectric constant of sea water, which in turn is partly related to salinity and temperature. The strength of the emission can be measured remotely with a microwave radiometer and given coincident sea surface temperature data, SSS can be restituted. SMOS and Aquarius sensors are operating at a frequency of ~1.4 GHz (wavelength 21 cm), chosen because it belongs to a protected band, maximizes the sensitivity to changes in salinity and minimizes atmospheric contributions to the signal.

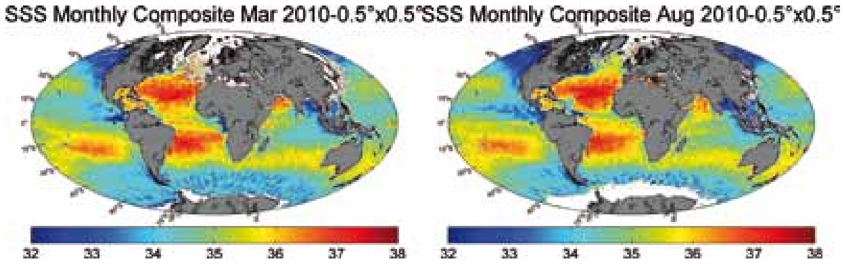
Based on the known SSS variability, the satellite missions aim at producing global maps of sea surface salinity with an accuracy of 0.1–0.2 over a time scale of 1 month and at a spatial resolution of ~100 km. This is a challenging objective for several major reasons. First, the sensitivity of L-band brightness temperatures to variations in SSS is relatively weak with respect open-ocean SSS variability.

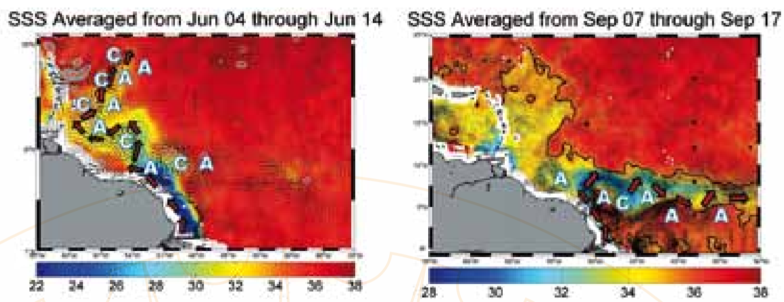
Second, there are many geophysical sources of brightness at L-band that corrupt the salinity signal, and the scene brightness models used to account for these sources have uncertain accuracy.



[Fig. 1]

[Fig. 2]





[Fig. 3]

[Fig.1]
Monthly composites of the sea surface salinity at a spatial resolution of 0.5 x 0.5° deduced from SMOS data for the months of march (left) and August (right) 2010.

[Fig. 2]
SMOS swath intercepts with Hurricane Igor from September 11 to 19, 2010 as the storm intensity evolved from Category 1 (11th) to Category 4 (13-16th) and then progressively weakened (17th onward). The color maps are indicating the values expressed in m/s of the surface wind speed retrieved from SMOS data. Black dots indicate the storm track

[Fig. 3]
Major pathways for the freshwater Amazon-Orinoco river plume detected by SMOS in 2010. SSS fields are superimposed with surface currents from altimetry. Northwestward pathway in June by North Brazil current advection (left) and eastward path following the North Equatorial Counter Current in september (right).

Moreover, the technical approach developed for the SMOS satellite is polarimetric interferometric radiometry: this ambitious technique is used for the first time in the context of Earth observation from space. The complex raw data processing is not error-free and induces residual inaccuracies in the retrieved SSS. Finally, man-made radio frequency interferences emanating from the world coasts contaminate the data in many key ocean areas (North Atlantic, Bay of Bengal,..). Researchers involved in the Centre Aval de Traitement des Données SMOS (CATDS) nevertheless deciphered intricacies of these new data set and developed algorithms to generate first-time satellite estimates of the sea surface salinity. Two example of these monthly maps are shown in Fig. 1. The maps show the salient basin scale features, such as the elevated SSS in the Atlantic relative to the other basins, and the general correspondence of lower SSS with climatologically high precipitation or river runoff zones and higher SSS in high evaporation zones. Comparison of the satellite estimates with in situ observations reveal an overall accuracy on the order of 0.3 [1], with a degraded quality at high latitudes partly because of reduced sensitivity in cold seas. While clear progresses are still needed to reach the mission requirements, many interesting results were already evidenced. These data thus proved to be very useful to monitor the seasonal cycle and advection pathways of the major freshwaterpools of the world ocean (e.g. Amazon and Congo river plumes, Far Eastern Pacific Fresh Pool [2],..). SSS freshening events detected under high rain zones is also very promising to better constraint precipitation estimates over the oceans. Impact of these data sets on improving ocean circulation modeling through assimilation is an undergoing activity.

High Surface Wind speed estimates from SMOS

Because upwelling radiation at 1.4 GHz is significantly less affected by rain and atmospheric effects than at higher microwave frequencies, the SMOS measurements were also proved [3] to offer unique opportunities to complement existing ocean satellite high wind observations, often erroneous in these extreme conditions. As illustrated in Fig. 2, SMOS large spatial swath and frequent revisit time intercepted the 2010 category 4 hurricane Igor 9 times during its most intense phases. Much less affected by rain, SMOS data can provide improved estimates of the evolution of the surface wind speed and its structure under severe conditions: this is of great interest for operational Hurricane intensity forecasts.

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Oceanography

Laboratory contribution

Joint use of altimetry and ocean color for the control of ocean circulations

Utilisation conjointe de l'altimétrie et de la couleur de l'océan pour le contrôle des circulations océaniques

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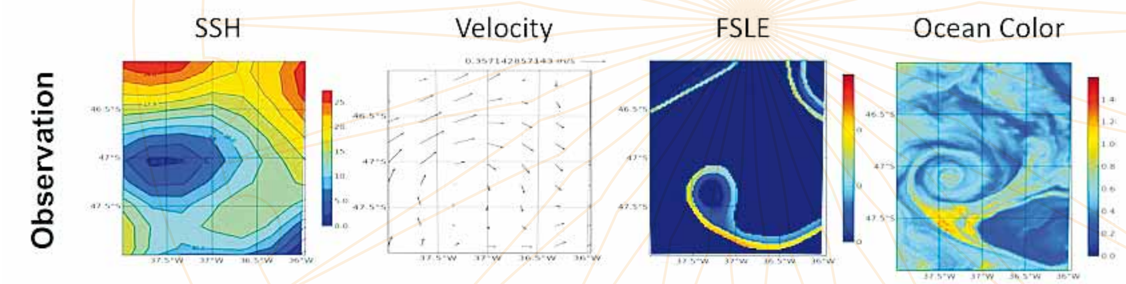
Abstract

In this work, we show it is possible to invert the information contained in oceanic submesoscales, such as evidenced in tracer observations of ocean color, to improve mesoscale dynamics provided by altimetry. An example of application is given for a region of the South Atlantic ocean. The inverse problem is defined by a cost function measuring the misfit between two images, one from Ocean Color and the other one from altimetry-derived Lyapunov exponent map.

Résumé

Nous démontrons ici qu'il est possible d'inverser l'information contenue dans les sous-mésoéchelles océaniques, par exemple celles vues dans les données couleur de l'océan, pour améliorer la dynamique observée par l'altimétrie. Un exemple d'application est présenté dans l'Atlantique sud. Le problème inverse est exprimé avec une fonction coût qui mesure l'écart entre deux types d'images. L'une venant de la couleur de l'océan, l'autre des cartes d'exposants de Lyapunov dérivées de l'altimétrie.



[Fig. 1]

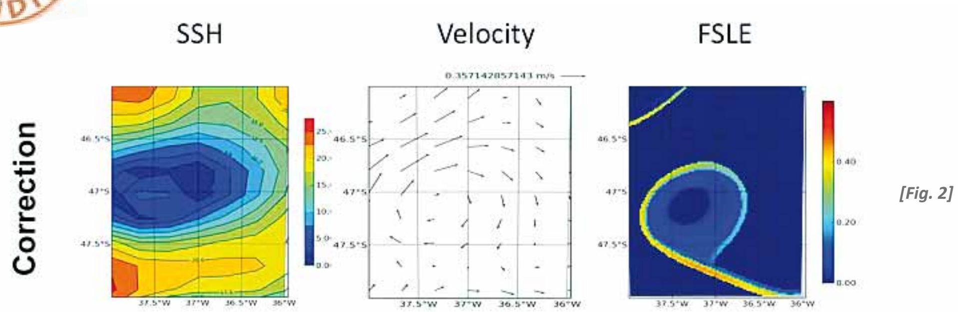
[Fig. 1] - Observations that are used in the data assimilation process: successively the original Aviso SSH data, the derived geostrophic velocity field, the corresponding FSLE field and the Ocean color image. Note that the two last images are the ones under consideration in the minimization process.

Context and objectives

Mesoscale dynamics has been shown to be a key ingredient of the ocean circulation. The ubiquitous presence of mesoscale eddies in the world ocean has been evidenced by satellites altimetry. Today, there is an increasing interest for even smaller sub-mesoscale activity at scales of O (1km) [1]. High resolution satellite images of tracer fields -such as Chlorophyll or Sea Surface Temperature- clearly evidence filaments and frontal structures at these sub-mesoscales. Interestingly, submesoscale dynamics is also viewed as a key element of the biogeochemical behavior of the ocean (e.g. [2]). The observational prospects, especially from space, offer wide possibilities for actually observing those features (e. g. SWOT mission). Our general objective here is to explore how, with data assimilation, one can use the submesoscale information that is contained in satellite ocean color (OC) fields to better describe ocean dynamics at meso-and larger scales. The overall problem is complex and as a preliminary step we made a number of choices:

- Nowadays, submesoscales are synoptically observed only by tracers and in particular through OC observations. In parallel, altimetry provides a relatively faithful access to mesoscale dynamics and in particular velocity field through the geostrophic derivation of the SSH. We have thus decided as a first step, to explore the capability of OC information at the submesoscales to correct for the dynamics as described by altimetry.

- To perform data assimilation we used the Finite-Size Lyapunov Exponents (FSLE) as the proxy variable for the velocity field to be compared to the OC image.



[Fig. 2]

[Fig. 2] - Corrections that result from the minimization/inversion process: successively, the backward SSH field derived from the corrected velocity field, the corrected velocity field itself and the corresponding corrected FSLE field.

Then, the goal of this work is to demonstrate that the submesoscales from the OC field are invertible to improve the description of the altimetric velocity.

Data

The founding breakthrough for the present study lies in the observations that mesoscale flow stirring can be characterized quite faithfully by Lyapunov exponents [3][4]. Therefore frontal structures obtained from the binarization of the OC normalized gradients can be compared to the maximum lines obtained from the binarization of the FSLE maps. In this study, two satellite observation data are therefore considered: Ocean Color and Altimetry. The domain under consideration is a small region of the South Atlantic ocean (45-49°S, 32-39°W). The surface velocity field is inferred from AVISO SSH products using the geostrophic hypothesis. The velocity resolution is 1/3°. The resolution of FSLE images are 1/48°. OC images are provided by MODIS sensor at a resolution 1/100°. These OC products are filtered at 1/48° to correspond to FSLE.

Method and results

The details of the methodology developed to tackle this problem are explained in [5] and [6]. It is based essentially on the minimisation of a cost function that measures the misfits between two types of images. One originated from the altimetry-derived geostrophic velocity field through Lyapunov exponents. The second image directly derived from ocean color data. To define images, the FSLE and OC fields are simply binarized. This is a crude approach and more work is underway to refine the definition of appropriate images. Fig. 1 shows the observations that are used in the image data assimilation process. And Fig. 2 shows the corrections brought to the velocity field.

At this stage, the extent to which the corrections to the velocity field are accurate is uncertain. However, our methodological approach brings us some elements to assess the error bar resulting from the minimization processes. In addition, several assessments have been made that give some confidence into the process [6].

Conclusion

In this work, a test case has been presented that demonstrates the feasibility to correct a SSH derived velocity field with Ocean Color data. This is a first interesting result pointing out that indeed information from the submesoscales is invertible and useful for the control of larger scales. Interesting either is the fact that biogeochemical information (OC data) are useful to correct for physical information (velocity). Another important dimension of this work relates to the resolution scales. Sub-mesoscale Ocean Color images can compensate for the lack of SSH resolution in time and space. This can be seen also as a way of parametrizing the difficult problem of the inverse cascade from the submesoscales towards larger scales.

Although the results are clearly positive about the feasibility of submesoscale inversion a number of uncertainties remains about the effective control of the flow field. More work is necessary to provide a more precise assessment of the efficiency of the control.

That is why, we think for the near future of the setting of a fully coupled high-resolution physico-biogeochemical model that will allow to perform twin-experiments in which the errors will be perfectly known. This is seen as a necessary step for setting up a complete data assimilation system for the submesoscale data.

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