Rentrée 2021

PROPOSITION DE SUJET DE THESE

Formulaire demande de financement : ARED - ISblue - ETABLISSEMENTS - ...

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Identification du projet

Acronyme du projet *(8 caractères maximum)* **: OASIS**

Intitulé du projet *en langue française* : Estimation de l'état de l'océan à partir de mesures in situ et de méthodes d'interpolation analogues.

Intitulé du projet en langue anglaise : Ocean state Analog in-SItu analyses System

Présentation de l'établissement porteur (bénéficiaire de l'aide régionale)

Établissement porteur du projet : Nicolas Kolodziejczyk (UBO, LOPS, UMR 6523)

Ecole Doctorale : EDSML X SPI ou MATHSTIC pour les projets ISblue ☐

Identification du responsable du projet (futur directeur de thèse)

Nom du laboratoire d'accueil : LOPS

Code du laboratoire (U/UMR/USR/EA/JE/...) : UMR 6523

Directeur[1] du Laboratoire : Jérôme Paillet

Nom de l'équipe de recherche : Océan & Climat

Nombre HDR dans le laboratoire : 13

Nombre de thèses en cours : 29

Nombre de post-docs en cours : 23

Nom et prénom du directeur* de thèse (HDR), porteur du projet : Bruno Blanke (CNRS/LOPS UMR 6523)

- e-mail : blanke@univ-brest.fr

- Téléphone : +33 (0) 2 90 91 55 22

- Publications récentes du directeur de thèse *(nb total et 5 références max au cours des 5 dernières années)* **:**

206 publications au total

•[JMS17] Desbiolles, F., A. Bentamy, B. Blanke, C. Roy, A.M. Mestas-Nuñez, S.A. Grodsky, S. Herbette, G. Cambon, et C. Maes, 2017: Two decades [1992-2012] of surface wind analyses based on satellite scatterometer observations. Journal of Marine Systems, 168, 38-56, doi:10.1016/j.jmarsys.2017.01.003.

•[JGR18] Laxenaire, R., S. Speich, B. Banke, A. Chaigneau, et C. Pegliasco, 2018: New insights on Agulhas Rings dynamics as inferred from altimetry. Journal of Geophysical Research, 123, 10.1029/2018JC014270

•[GRL18] Maes, C., N. Grima, B. Blanke, É. Martinez, T. Paviet-Salomon, et T. Huck, 2018: A surface "superconvergent" pathway connecting the SOutyh Indian Ocean to the subtropical South Pacific Gyre. Geophysical Research Letters, 45, 10.1002/2017GL076366.

•[OM18] Van Sebille, E., S.M Griffies, R. Abernathey, T.P. Adams, P. Berloff, A. Biastoch, B. Blanke, E.P. Chassignet, Y. Cheng, C.J. Cotter, E. Deleersnijder, K. Döös, H. Drake, S. Drijfhout, S.F. Gary, A.W. Heemink, J. Kjellsson, I.M. Koszalka, M. Lange, C. Lique, G.A. MacGilchrist, R. Marsh, G.C. Mayorga Adame, R. McAdam, F. Nencioli, C.B. Paris, M.D. Piggott, J.A. Polton, S. Rühs, S.H. Shah, M.D. Thomas, J. Wang, P.J. Wolfram, L. Zanna, et J.D. Zika, 2017: Lagrangian ocean analysis: fundamentals and practices. Ocean Modelling, 121, 49-75, 10.1016/j.ocemod.2017.11.008.

•[MPB19] Dobler, D., T. Huck, C. Maes, N. Grima, B. Blanke, É. Martinez, et F. Ardhuin, 2019: Large impact of Stokes drift on the fate of surface floating debris in the South Indian Basin. Marine Pollution Bulletin, 148, 202-209, 10.1016/j.marpolbul.2019.07.057.

- Expériences d'encadrement et co-encadrement de doctorants (passées et en cours) (nom des doctorants dirigés et en cours et antérieurement, sur les 6 années passées : sujet, financement, date de soutenance, et situation professionnelle actuelle si connue)

• Yann FRIOCOURT (thèse soutenue en décembre 2006, financement DGA) : « Cycle saisonnier du courant de pente dans le Golfe de Gascogne et ses conséquences sur le transport de masses d'eaux : simulation numérique et analyse lagrangienne »

• Héloïse MULLER (thèse soutenue en décembre 2008, financement CIFRE) : « La circulation résiduelle lagrangienne en Mer d'Iroise ».

• Fanny CHENILLAT (thèse soutenue en décembre 2011, bourse ministérielle,) : « Variabilité de structure et de fonctionnement d'un écosystème de bord est : application à l'upwelling de Californie »

• Fabien DESBIOLLES (thèse soutenue en décembre 2014, cofinancement CNES-Ifremer) : « Impact des fines échelles spatio-temporelles de l'atmosphère sur le couplage entre océan hauturier et plateau continental dans un système d'upwelling de bord est »

Et/ou co-encadrant-e scientifique: Nicolas Kolodziejczyk

Laboratoire de recherche co-encadrant : LOPS, UMR 6523

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- Expériences d'encadrement et co-encadrement de doctorants (passées et en cours)

(nom des doctorants dirigés et en cours et antérieurement, sur les 6 années passées : sujet, financement, date de soutenance, et situation professionnelle actuelle si connue)

N.B.: Nicolas Kolodziejczyk s'engage à passer son HDR avant la soutenance de l'étudiant en thèse (2024).

1) Ibrahima Camara (2012-2015) : Variabilité de la salinité et de la température dans la couche mélangée océanique en Atlantique Tropicale. Financement UCAD/LMI ECLAIR IRD. Soutenance en décembre 2015 à l'Université Cheick Anta Diop, Dakar. Encadrement 30%.
2) Odilon Houndegnonto (2018-2021): Analyse des variations thermohalines de petites échelles horizontale et verticale au sein des couches superficielles dans les plumes de rivières de l'Océan Atlantique Tropical Est. Financement IRD/MOPGA. Soutenance prévue décembre 2021 à l'UBO. Encadrement 50%.

Et/ou co-encadrant-e scientifique : Pierre Tandeo

Laboratoire de recherche co-encadrant : Lab-Sticc, UMR6285

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- Téléphone : 02 29 00 13 04

- Expériences d'encadrement et co-encadrement de doctorants (passées et en cours)

(nom des doctorants dirigés et en cours et antérieurement, sur les 6 années passées : sujet, financement, date de soutenance, et situation professionnelle actuelle si connue)

1) Chen Wang (2016-2020) : "Global Investigation of Marine Atmospheric Boundary Layer Rolls". Financement du gouvernement chinois, étudiant entre l'IMT Atlantique et IFREMER. Soutenance en juillet 2020 à l'IMT Atlantique. Encadrement 25%.
2) Paul Platzer (2017-2020), "Statistical and Dynamical Properties of Analog Forecasting Data Assimilation for Rare and Extreme Events". Financement ERC A2C2 (Pascal Yiou de l'IPSL) et ARED FEM. Soutenance en décembre 2020. Encadrement 50%.
3) Aurélien Colin (2019-2022), "On the Use of Deep learning for Ocean SAR Semantic Segmentation". Financement CLS, dans le cadre de la chaire IA OceaniX. Encadrement 25%.
4) Pierre Le Bras (2020-2023), "Analog Methods to Identify Global Oceanographic Simulations". Financement ARED. Encadrement 50%.

Le cas échéant, autres collaborations (co-en. cadrant et laboratoire concerné) :

Financement du projet de thèse

En cas de financement à 50 %, le cofinancement est-il déjà identifié *(oui/non)* **: non**

Si oui, préciser la nature du cofinancement (*ANR, partenaire privé, Ademe, etc.*) :

Si le cofinancement n'est pas encore confirmé, date prévue de réponse du cofinanceur : Co-Financement bourse doctoral UBO EDSML demandé, printemps 2021.

En cas de non-obtention du cofinancement demandé, une autre source de cofinancement est-elle identifiée *(oui/non)* **: non**

Si oui, laquelle :

Sollicitez-vous un co-financement Is-Blue (y compris ARED Is-Blue) *(oui/non)* **? oui**

Important : Veillez à bien compléter les différents co financements sollicités sur le serveur Thèses en Bretagne Loire lors du dépôt de votre dossier.

Projet de thèse en cotutelle internationale

S'agit-il d'un projet de thèse en cotutelle internationale dans le cadre d'une convention *(oui/non)* **: non**

Si oui, préciser l'établissement pressenti (*et le pays de rattachement*) :

Ce projet de thèse fera-t-il l'objet d'un cofinancement international *(oui/non)* **: non**

(Rémunération du doctorant par l'établissement implanté sur le territoire régional (18 mois sur 36 mois), et l'établissement étranger, qui s'engage également à rémunérer le doctorant dans le cadre de son séjour à l'étranger, soit durant 18 mois -a minima-)

En cas de cofinancement international, préciser -*si vous en avez connaissance***- l'organisation du calendrier des périodes de séjour :**

Préciser quel est le stade du projet international (joindre une lettre d'engagement du partenaire)

Présentation du projet (en langue française ou anglaise, 2 à 3 pages)

merci de respecter ce format maxi compatible avec extranet région

Résumé du projet *(4000 caractères maxi espaces compris) :*

The Earth system is warming under the effect of greenhouse gases emitted by human activities (IPCC, 2013). About 93% of the global heating is sequestered in the ocean, which shows an unabated, even increasing, warming trend since 1960 (e.g. Cheng et al., 2017). In this context, the global ocean exchanges with the atmosphere and redistributes physical and biogeochemical tracers such as freshwater, anthropogenic carbon dioxide, and oxygen which are critical for marine life and resources.

While the Global Ocean Heat Content (OHC) shows unabated increasing trend (Fig.1), the Global Mean Surface Temperature (GMST) and Sea Surface Temperature (SST) records exhibit a more fluctuating global and regional pattern on interannual to decadal time scales (Cheng et al., 2018). One of the reason is that the large part of the oceanic global absorption of heat (but also freshwater and biogeochemical tracers) is regionally localized and distributed in specific water masses (Meehl et al., 2011, Wijffels et al., 2016; Kolodziejczyk et al., 2019). This has the effect of modulating the global and regional GMST change (Hu and Fedorov, 2017; Drijfhout et al., 2014). In the context of anthropogenic forcing, it is still difficult to disentangle the natural/internal variability of ocean heat and freshwater at regional and interannual time scales. Indeed, in the presence of mesoscale turbulence, large-scale low-frequency chaotic internal ocean variability emerges and may hamper the detection of underlying climate signals (Sérazin et al, 2017; Llovel et al., 2018). Therefore, the first step in understanding and predicting the long-term oceanic physical (Temperature and Salinity, T/S) evolution is to estimate accurately past and present global and regional ocean variability from available in situ measurements.

However, historical ocean observations also suffer from sparse or/and uneven sampling of the ocean observing system in some key regions, such as the Southern Ocean and High latitudes, especially for the period before 2000, i.e. prior to the 'golden age' of the global sampling of the Argo observing system (Riser et al., 2016; Durack et al., 2014). Indeed, as a consequence of small constraints on ocean reanalysis systems, larger uncertainties are still pending on many regional interannual ocean variabilities (Palmer et al. 2017).

In the context of multi-scale ocean variability, the reconstruction of long-term time series from sparse and noisy oceanographic observations is one of the major challenges (Figure 1). To tackle these issues, statistical tools using observations alone (e.g., optimal interpolation) or based on numerical models (i.e., data assimilation) have been widely used to fill the gap of missing data in oceanographic time series and in higher resolution fields of consistent T/S. The first approach relies on simple statistical models and has limited skill in accurate error estimation. The second approach relies on complex and costly numerical models that suffer from biases and drifts, preventing the assessment of realistic ocean states on the long-term.

Despite these difficulties, novel methods resulting from recent advances in applied mathematics can help tackle some issues and limitations of state-of-the-art interpolation methods. Taking advantage of the increasing mass of environmental data made available by the global ocean observing system, innovative approaches have been developed relying on advanced data-driven methods for data assimilation and climate forecasting (Tandeo et al., 2015; Sévellec et al., 2018). In this context, the recent development of assimilation methods based on 'Analog strategy' (Lguensat et al., 2017; Zhen et al., 2020) shows promising results for the potential improvement of state-of-the-art ocean data

statistic assimilation schemes. The objective of the project is to set up a new generation of in situ analysis systems using Analog strategy.

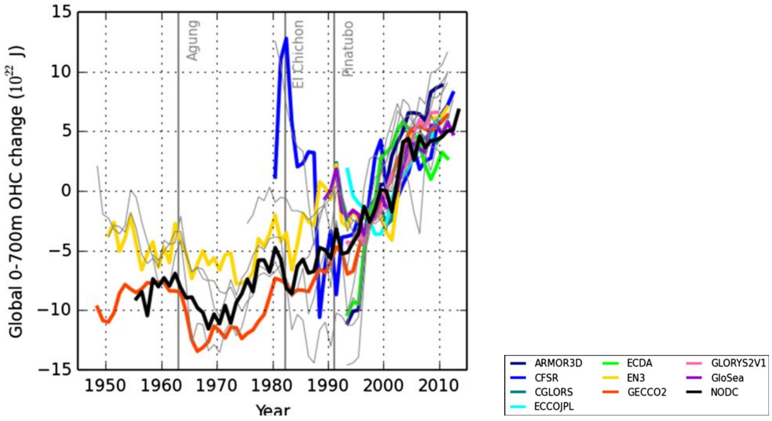

Figure 1: Time series of ocean global integrated heat content change, relative to a 1993–2007 baseline.The curves correspond to different products using different analysis methods. The spread among the different curves results from the different ability of each product to interpolate the temperautre in unsampled areas espacially before the 2000's and Argo array (from Palmer et al., 2017).

Présentation détaillée du projet :

1 - Hypothèse et questions posées, état de l'art, identification des points de blocages scientifiques (4000 caractères maxi espaces compris)

The driving scientific question advocating for a novel approach in ocean state reconstruction is related to the role of the ocean in climate variability at regional and decadal time scales. In the context of anthropogenic forcing, it is still a major challenge to disentangle the natural/internal variability of the ocean heat and freshwater on regional and interannual to decadal time scales (Palmer et al., 2019). This is due to major gaps in ocean sampling before the Argo period (before the 2000's; Durack et al., 2014; Riser et al., 2016). Although the unprecedented Argo global time series is currently 20 years long, it is still too short to consistently explore natureal variability at lower frequencies. Also, the Argo network nominal sampling (3°x3°) does not sample mesoscale features that are ubiquitous in the ocean. However, **this huge source of information is still to be exploited with new approaches using advanced statistical methods in order to better extract and project ocean variability over long time series and with proper error estimates**.

Currently, reconstructions of long term time series from sparse and noisy observed oceanographic parameters (T/S) rely on two approaches: statistical tools using observations alone (e.g., optimal interpolation) or numerical models (i.e., data assimilation) are used to interpolate long time series and higher resolution fields of consistent T/S.

The first family, mainly using optimal interpolation methods (OI, Bretherthon et al., 1976), consists in statistically filling in unsampled regions using a linear combination of observations, from surrounding data-rich regions and climatology. OI methods account for 'a priori' statistics that rely on covariance amplitude and scale of a parameter assumed and/or computed from historical data or ancillary data or models (e.g. Gaillard et al., 2016, Domingues et al., 2008, Roemmich and Gilson, 2009, Cheng and Zhu, 2016). However, the tuning of 'a priori' statistics has several limitations. Firstly, the fields analyzed by OI are strongly dependent on a first guess, which is generally based on a mean state climatology or the analysis of previous time steps. This procedure forces the estimates towards a mean state, thus in regions far from well-sampled area, ocean variability is missed. Secondly, the 'a priori' statistics are used "statically", i.e. the covariance model (amplitude and scales) is prescribed before the analyses by the 'a priori' statistics. The shortcoming for this approach is the incompleteness or miss representativity of the derived covariance compared to true variance. A consequence is that the error estimate is more an evaluation of the sampling error, than an evaluation of the skill of the OI method to reconstruct time series. This is a major issue when estimating time series from sparse data, because the long-term ocean variability may be masked by unpredictable turbulent features (Llovel et al., 2018). Interpolation methods and error estimates need to take into account such turbulent behavior in error estimates.

The second family of ocean state reconstruction relies on a numerical ocean model (OGCM) and data assimilation methods to fill in the data gap with consistent forced ocean dynamics prescribed by an OGCM. OGCMs are more and more costly in memory and CPU as they integrate primitive equations at smaller time steps and higher resolution. Also, this approach suffers from inherent biases, drift and caveats due to imperfection in the numerical models: i.e. parametrization of subgrid physics and atmospheric forcing products; but also due to the low observation constraint on the OGCM trajectory. This leads to large uncertainties quantifying errors from model and associated assimilated data (Palmer et al., 2017).

2 - Approche méthodologique et techniques envisagées : (4000 caractères maxi espaces compris)

Taking advantage of the increasing amount of environmental data available from the global ocean observing system and of recent progress in Applied Mathematics, innovative approaches have been developed relying on fully data-driven methods for data assimilation and climate forecasting (Tandeo et al., 2015; Sévellec et al., 2018). In this context, **the recent development of assimilation methods based on Analog strategy** (Lguensat et al., 2017; Zhen et al., 2020) **shows promising results for the potential improvement of state-of-the-art ocean data statistic assimilation scheme**. By constructing an analog catalog based on “similar” states of the dynamical system, analog data assimilation is able to reconstruct the complex and nonlinear evolution of a dynamical system from partial and noisy observations (Fig. 2). The catalog will be provided by the parameters time series themselves, or an ensemble of pre-computed simulations (Tandeo et al., 2015; Hamilton et al., 2016, Lguensat et al. 2017).

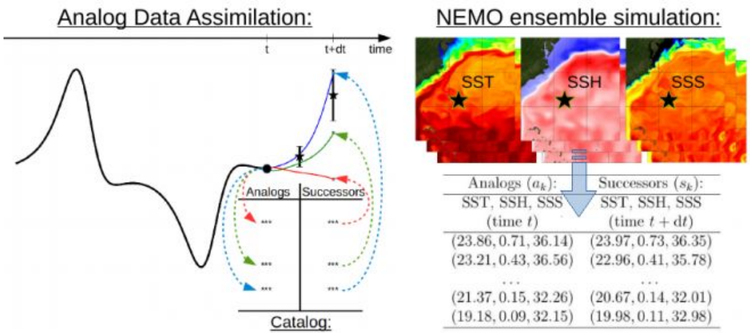

Figure 2: The evolution in time of one particle or member. The catalog implicitly represents the dynamics of the system from examples of historical datasets. The observations are shown by black asterisks, and their variance is shown by the corresponding error bar (from *Lguensat et al.*, 2017).

The analog strategy differs from the linear OI approach:

i) The dynamical information relating the past and future states of the dynamical system is adaptatively extracted from a catalog and introduced at each step of the assimilation (Fig. 2). This provides a more realistic reconstruction of the parameters trajectories, even non-linear ones, provided that the analog catalog is rich enough (Tandeo et al., 2015)

ii) Better estimation of the interpolation error since adaptive posterior variance allows to better characterize the analyses (Fig. 3; the error analyses in OI only quantify the sampling error, see Zhen et al., 2020)

iii) Depending on the richness and resolution of the analog catalog (availability of high-resolution model) an upscaling/downscaling approach is possible to reconstruct a higher resolution and frequency (Schenk and Zorita, 2012)

iv) Since a catalog of analog situations for constraining and projecting the assimilation, the analog catalog could be used as a forecasting system for the probabilistic determination of the evolution of the ocean as given time and space scales (Yiou and Deandreis, 2019).

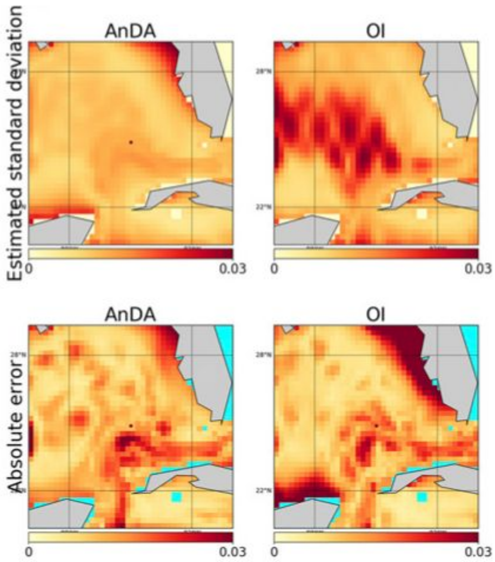

Figure 3: Example of comparison of the variance and error resulting from Analog interpolation (left) versus conventional OI (right) for satellite altimetry data. Monthly averages of (top) the estimated standard deviation and (bottom) absolute error centered on 8 Mar in the Gulf of Mexico. The a posteriori covariance, i.e. the skill produced by conventional OI (top-right panel) only depends on the tracks of satellite altimetry and the background covariance. Therefore, the estimated standard deviation does not seem relevant to approximate the absolute error. On the other hand, the estimated standard deviation produced by AnDA is flow-dependent (top-left panel) and closer to the absolute error (from *Zhen et al.*, 2020).

Analog assimilation methods and tools (Lguensat et al., 2017) are freely available online (https://gitub.com/ptandeo/AnDa). They have been successfully tested on various Lorenz chaotic systems and satellite 2D surface data (Zhen et al., 2020). **The novelty of the present project is to adapt the method for the assimilation of in situ observation of T/S profiles**. **Then, the objective is to set up a new generation of in situ analysis systems using Analog strategy.** The analog catalog will be constructed from Argo and historical in situ profiles over the period 1950-2019.

Implementation : The first step will be to produce a set of standardized profiles (on standard z and sigma levels). Then, from these profiles, in a given grid cell, the analog catalog will be constructed: ensemble of pairs of profiles separated by a given time lag depending on the spatio-temporal resolution of the sampling. The optimal grid cell and time step resolution for the analysis will be discussed. Different strategies for reducing the spactial degree of freedom using kernel Gaussian function, EOF functions or profile classification will be tested. The tuned analog in situ analysis will be compared to existing state-of-the-art OI tools and products, including ISAS OI (Kolodziejczyk et al., 2017), to benchmark and validate the analog reconstruction.

Synthetic Experiments: An ensemble (50 members, 50 years) of global ocean/sea-ice simulations based on the NEMO 1/4° eddy-permitting OGCM, and the associated ensemble of synthetic T/S profiles generated at the same locations/dates as real profiles (OCCIPUT project; Penduff et al., 2015; see https://meom-group.github.io/projects/occiput/) provide a huge and modular source of data to : i) test the sensitivity to the catalog size and to the ocean sampling; ii) test the optimal space reduction scales and strategy; iii) evaluate the optimal time step of integration for accurate reconstruction as a function of sampling and time span of the reconstruction; iv) test the capacity of analog strategy for downscaling/upscaling the unsampled and unresolved scales with in situ sampling

Developing 1D and 2D indicators: Since the analog strategy has been first developed for 1D and 2D time series, the analog reconstruction could also be directly performed on a 2D field of integrated quantities such as OHC, freshwater content, total or thermosteric Sea Level.

3 - Positionnement et environnement scientifique dans le contexte régional, national et international :

Estimating the ocean state from in situ historical measurements to disentangle the ocean anthropogenic change from ocean variability on interannual and regional scales remains an outstanding challenge (Palmer et al., 2019, OceanObs'19 White Paper). Also, better estimating (and then reducing) the associated error on global and regional ocean variability is an ongoing work within the international community (International GDAP EEI GEWEX assessment, Meyssignac et al. 2019). This challenge and these issues can be tackled by future instrumental developpement, but also by the development of new methods for data analysis and error handling. Considerable advances have been made during the two last decades with the development of Argo that greatly helps to fill the sampling gap and provide more quantitative information on changes in ocean heat and freshwater storage of the ocean at regional scale. The news methods and products will notably build on unprecedented historical Argo data set. This data set includes the Argo measurements from floats that have been funded by the CPER Argo and CPER ObsOcean funded as part of the contribution to the TGIR Argo France fleat. This new huge source of information is still to be exploited **with new approaches using advanced statistical methods** in order to better extract and project ocean variability along with proper error estimates. Also, **using synthetic data sets derived from ensemble numerical simulations is a promising approach** that will help to further explore, feed and validate these new advanced methods.

The resutling method and ocean state products will provide a new generation of statistical fully 'data-driven' analysis system tools and products for in situ T/S profiles, which will be widely used within the ocean and climate scientific community. It will offer material for new scientific studies to reassess ocean warming, freshwater budgets and the sea-level budget at global and regional scales; and to better understand their governing processes. Analog tools and products will also be valuable to oceanographic operational centers in order to upgrade present linear OI tools and products used to reanalyze historical databases, and provide improved Ocean State indicators for marine services such as CMEMS-Copernicus.

4 - Contexte scientifique et partenarial : éléments généraux (ERC, CPER, FEDER, Breizhcop ...)

(4000 caractères maxi espaces compris)

In the supporting context of EUR ISBLUE, the project will be carried out in close collaboration with LOPS (6523) and Lab-Sticc (UMR 6285) by Nicolas Kolodziejczyk (40%; LOPS/UBO), Pierre Tandeo (30%; Lab-STICC/IMT Atlantique), Bruno Blanke (10%; LOPS/CNRS, HDR) and Florian Sevellec (20%; LOPS/CNRS). N.K. has expertise in in situ reanalysis systems. In particular, he is responsible for ocean state estimate tools and products wihtin the labellised CNRS/INSU 'Service National d'Observation' Argo-France (coordinator) which is part of Argo France TGIR currently supported by the CPER Bretagne ObsOcean project, the A+ ranked Argo2030 ANR PIA3 project and the Ifremer PIANO project. His research focuses on understanding the processes of interannual variability of ocean water masses and their formation using observations. P.T is an expert in applied mathematics, data-driven assimilation and satellite interpolations. He has worked on the analog forecasting method and its coupling with ensemble data assimilation. He is also actively working on the quantification of uncertainties, coming both from observations and models, in data assimilation. B. B. has a wide expertise in eddy resolving ocean modeling. F.S is an expert on analog forecast on decadal climate variability.

The wide collaborative framework will include Pierre Ailliot (Laboratoire de mathématiques de Brest, UMR 6205, UBO) as an expert in applied mathematics and statistical methods. William Llovel (LOPS/CNRS) is an expert in Sea-level change and chaotic/intrinsic ocean variability. Sally Close

(LOPS/UBO) is an expert in statistics and chaotic/intrinsic ocean variability using OCCIPUT. Thierry Penduff (IGE/CNRS) provides the OCCIPUT outputs (ensemble of 50 forced ocean simulations) and is an expert in chaotic/forced variability.

The collaborative framework already exists. N.K. and P.T. are superving M2 training on analog interpolation using satellite SSS, SST and SSH data. P.A, T.P. and P.T. (as PI) have been working on the CMEMS R&D project 3DA that developed the analog tools for the interpolation of satellite SSH. P.T. and F.S. are collaborating in the AMIGOS PhD project using analog methods for reducing uncertainty on ensemble climate models. W.L., T.P. and N.K. are part of the IMOTHEP TOSCA project that will investigate chaotic ocean variability using ensemble simulations and building on the outcomes from the OCCIPUT project.

Bibliography reference of OASIS project:

Bretherton, F., R. Davis, and C. Fandry, 1976: Technique for objective analysis and design of oceanographic experiment applied to MODE-73. Deep-Sea Res. Oceanogr., 23, 559–582, doi:10.1016/0011-7471(76)90001-2.

Cheng, L., and J. Zhu, 2016: Benefits of CMIP5 Multimodel Ensemble in Reconstructing Historical Ocean Subsurface Temperature Variations. Journal of Climate. doi: 10.1175/JCLI-D-15-0730.1

Cheng, L., K. E. Trenberth, J. Fasullo, T. Boyer, J. Abraham and J. Zhu, 2017 : Improved estimates of ocean heat content from 1960 to 2015. Science Advances, doi: 10.1126/sciadv.1601545.

Cheng, L. G. Wang, J. P. Abraham and G. Huang, 2018 : Decadal ocean Heat redistribution since the late 1990s ad its associated with key climate modes. Climate. 6, 91; doi:10.3390/cli6040091.

Domingues, C. M., J. A. Church, N. J. White, P. J. Gleckler, S. E. Wijffels, P. M. Barker, and J. R. Dunn, 2008: Improved estimates of upper-ocean warming and multi-decadal sea-level rise. Nature, 453, 1090–1093, doi:10.1038/nature07080.

Drijfhout, S. S., A. T. Blaker, S. A. Josey, A. J. G. Nurser, B. Sinha, and M. A. Balmaseda (2014), Surface warming hiatus caused by increased heat uptake across multiple ocean basins, Geophys. Res. Lett., 41, 7868–7874, doi:10.1002/2014GL061456.

Durack P., P. J. Gleckler, F. W. Landerer and Kalr E. Taylor, 2014:Quantifying underestimates of long-term upper-ocean warming. Nature Climate Change. doi: 10.1038/NCLIMATE2389.

Durack P., J., S. E. Wijffels, and R.J. Matear, 2012, Ocean salinity reveal strong global water cycle intensification during 1950-2000. Science 336, 455-458. doi:10.1126/science.1212222.

Hamilton F., T. Berry, and T. Sauer, 2016: Ensemble Kalman Filtering without a Model. Physical Review X, 6, 011021. doi: 10.1103/PhysRevX.6.011021

Hu, S., and A. V. Fedorov (2017), The extreme El Niño of 2015–2016 and the end of global warming hiatus, Geophys. Res. Lett., 44, 3816–3824, doi:10.1002/2017GL072908.

IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp, doi:10.1017/CBO9781107415324.

Gaillard, F., Reynaud, T., Thierry, V., Kolodziejczyk, N., & von Schuckman, K., 2016: ISAS-13 re-analysis: Climatology and inter-annual variability deduced from Global Ocean Observing Systems. Journal of Climate, 29(4), 1305–1323. https://doi.org/10.1175/JCLI-D-15-0028.1

Lguensat, R., P. Tandeo, P. Ailliot, M. Pulido, and R. Fablet, 2017: The analog data assimilation. Mon. Wea. Rev., 145, 4093–4107,https://doi.org/10.1175/MWR-D-16-0441.1.

Llovel, W., Penduff, T., Meyssignac, B., Molines, J.-M., Terray, L., Bessières, L., & Barnier, B. (2018). Contributions of atmospheric forcing and chaotic ocean variability to regional sea level trends over 1993–2015. Geophysical Research Letters, 45, 13,405–13,413. https://doi.org/10.1029/2018GL080838

Kolodziejczyk, N., Llovel, W., & Portela, E., 2019: Interannual variability of upper ocean water masses as inferred from Argo Array. Journal of Geophysical Research: Oceans, 124. https://doi.org/10.1029/2018JC014866

Kolodziejczyk Nicolas, Prigent-Mazella Annaig, Gaillard Fabienne (2017). ISAS-15 temperature and salinity gridded fields. SEANOE. https://doi.org/10.17882/52367

Meehl, G. A., Arblaster, J. M. Fasullo, A. Hu and K. E. Trenberth, 2011 : Model-based evidence of deep-ocean heat uptake during surfac temperature hiatus periods. Nat. Clim. Change. 1, 360-364, doi : 10.1038/nclimate1229.

Meyssignac B., Boyer T., Zhao Z., Hakuba M.Z., Landerer F., Stammer D., Köhl A., Kato S., L'Ecuyer T., Ablain M., Abraham J.P., Blazquez A., Cazenave A., Church J., Cowley R., Cheng L.J., Domingues C., Giglio D., Gouretski V., Ishii M., Johnson G., Killick R., Legler D., Llovel W., Lyman J., Palmer M., Piotrowicz S., Purkey S.G., Roemmich D., Roca R., Savita A., von Schuckmann k., Stephens G., Wang G.J., Wijffels S., Zilberman N. (2019). Measuring Global Ocean Heat Content to estimate the Earth Energy Imbalance. Frontiers in Marine Science. doi: 10.3389/fmars.2019.00432

Palmer MD, Durack PJ, Chidichimo MP, Church JA, Cravatte S, Hill K, Johannessen JA, Karstensen J, Lee T, Legler D, Mazloff M, Oka E, Purkey S, Rabe B, Sallée J-B, Sloyan BM, Speich S, von Schuckmann K, Willis J and Wijffels S (2019) Adequacy of the Ocean Observation System for Quantifying Regional Heat and Freshwater Storage and Change. Front. Mar. Sci. 6:416. doi: 10.3389/fmars.2019.00416

Palmer, M. D., Roberts, C. D., Balmaseda, M., Chang, Y-S., Chepurin, G., Ferry, N., et al., 2017: Ocean heat content variability and change in an ensemble of ocean reanalyses. Clim. Dyn. 49, 909–930. doi: 10.1007/s00382-015-2801-0

Riser, S. C., Freeland, H. J., Roemmich, D., Wijffels, S., Troisi, A., Belbéoch, M., et al.,2016: Fifteen years of ocean observations with the global argo array. Nat. Clim. Chang. 6, 145–153. doi: 10.1038/nclimate2872

Roemmich, D., J. Gilson, 2009: The 2004–2008 mean and annual cycle of temperature, salinity, and steric height in the global ocean from the Argo Program. Progress in Oceanography, 82(2), 81–100. https://doi.org/10.1016/j.pocean.2009.03.004

Schenk, F., and E. Zorita, 2012: Reconstruction of high resolution atmospheric fields for northern Europe using analog-upscaling. Climate Past, 8, 1681–1703, doi:10.5194/cp-8-1681-2012.

Schmidtko, S., L. Stramma, and M. Visbeck, 2017 : Decline in global oceanic oxygen content during the past five decades. doi:10.1038/nature21399.
Sérazin, G., A. Jaymond, S. Leroux, T. Penduff, L. Bessières, W. Llovel, B. Barnier, J.-M. Molines, and L. Terray (2017), A global probabilistic study of the ocean heat content low-frequency variability: Atmospheric forcing versus oceanic chaos, Geophys. Res. Lett., 44, 5580–5589, doi:10.1002/2017GL073026.
Sévellec, F.and S. S. Drijfhout, 2018: A Novel Probabilistic Forecast System Predicting Anomalously Warm 2018-2022 Reinforcing the Long-Term Global Warming Trend, Nature Communications, 9, 3024.
Tandeo, P., P. Ailliot, J. J. Ruiz, A. Hannart, B. Chapron, R. Easton, and R. Fablet, 2015: Combining analog method and ensemble data assimilation: Application to the Lorenz-63 chaotic system. Machine Learning and Data Mining Approaches to Climate Science, Springer, 3–12.
Wijffels, S. E., D. Roemmich, D. Monsalesan, J. Church and J. Gislon, 2016 : Ocean temperature chronicle the ongoing warming of earth. Nature Climate Change. 6. Opinion and Comments.
Yiou, P. and C. Déandréis, 2019: Stochastic ensemble climate forecast with an analogue model Geosci. Model Dev., 12, 723–734, https://doi.org/10.5194/gmd-12-723-2019, 2019
Zhen, Y., P. Tandeo, S. Leroux, S. Metref, T. Penduff, and J. Le Sommer, 2020: An Adaptive Optimal Interpolation Based on Analog Forecasting: Application to SSH in the Gulf of Mexico, Journal of Atmospheric and Ocean Technology. doi: 10.1175/JTECH-D-20-0001.1

Vous sollicitez un financement ISblue, ou une ARED ISblue :

Précisez le lien du sujet avec les thèmes ISblue

Thème ISblue	**Thème principal**	**Thème secondaire (si nécessaire)**	**Autre (si nécessaire)**
la régulation du climat par l'océan		x	

les interactions entre la Terre et l'océan			
la durabilité des systèmes côtiers			
l'océan vivant et les services écosystémiques			
les systèmes d'observation à long terme	x		

Expliquez/précisez <u>en quelques lignes</u> dans quelle mesure votre demande correspond à l'un ou plusieurs des critères ISblue ci-dessous :

1- Originalité, impact potentiel du projet (4 lignes maxi)

The expected outcome of the project is to produce a new generation of statistical fully 'data-driven' analysis system tools and products for in situ T/S profiles, which will be widely used within the ocean and climate scientific community. The analog tools and products will be provided to operational centers in order to upgrade present linear OI tools and products used to reanalyze historical database, and provide Ocean State products and indicators to CMEMS-Copernicus.

2- Positionnement international du sujet, cotutelle ou co-encadrement international (4 lignes maxi)

None

3- Effet intégrateur entre unités de recherche et / ou interdisciplinarités (4 lignes maxi)

In the context of the EUR ISBLUE, the project rely on and foster the interdisciplinarity and synergy between Lab-Sticc (UMR6285), laboratory of applied mathematics at IMT Atlantic and UBO and LOPS (UMR 6523) laboratory of physical oceanography, climate and remote sensing at UBO. The three main collaborators (NK, PT, FS), are teaching in the master program "Physique, Ocean, Climat" inside ISblue. This OASIS collaborative project will be the opportunity to present to the students of this master, in practice sessions, the different interpolation techniques used in oceanography.

4- Potentiel d'insertion à un haut niveau dans la communauté académique ou non académique du docteur (4 lignes maxi)

For the PhD student, the outcomes of the PhD will be an improved high level knowledge in ocean and climate sciences. Overall she/he will master the advanced methodology of data analysis based on data driven and artificial intelligence that are coming up in various scientific fields beyond the ocean and climate sciences.

Le candidat

Profil souhaité du candidat (spécialité/discipline principale, compétences scientifiques et techniques requises):

Le candidat devra:

- Être titulaire d'un solide background en mathématiques appliquées et/ou en science de l'océan et du climat.

- Maîtriser le codage en python

- La manipulation des grands jeux de données in situ.

- Savoir échanger, lire et rédiger en anglais

- Savoir travailler en équipe

ATTENTION :

Tout dossier non déposé sur le serveur dans les délais indiqués, ne pourra être pris en compte notamment par les instances ISblue, conseil de l'EDSML.

1 Ce formulaire est rédigé en style épicène