This call is for PhD topics due to start in 2021, and concerns only the PhD projects fully financed by the Institute.

Proposal Form

PhD's title:	Tropical Cyclone classification and prediction using multimodal physics-informed artificial intelligence methods
PhD supervisor *(accredited to supervise research)*: Ifremer Dpt./Unit/Lab:	Alexis Mouche ODE/LOPS/SIAM
PhD co-supervisor: Organisation, laboratory (Ifremer Dpt./Unit/Lab):	Pierre Tandeo IMT Atlantique, Lab-STICC, France John Knaff NOAA/NESDIS, USA
Laboratory/host structure, location:	LOPS/ IFREMER Centre Bretagne Brest
Doctoral School:	
Two suggested referees' names and contact details for the international evaluation of this proposed PhD project:	- Patrick Gallinari (Prof. Sorbonne Univ.) patrick.gallinari@lip6.fr - V. Kudryavstev (Prof. Russian State Hydrometeorological University). kudr@rshu.ru

Résumé en Français – *1200 caractères*

Aujourd'hui, les modèles numériques, même contraints par de nombreuses observations, ne parviennent toujours pas à résoudre complètement la nature non linéaire et intermittente de la dynamique complexe sous-jacente des systèmes météorologiques extrêmes. De même, et malgré les capacités d'observation toujours croissantes, les méthodes statistiques basées sur les données semblent également rapidement inefficaces en cas d'événements extrêmes et rares. En lien avec les objectifs du projet de la Chaire ANR Oceanix, ce sujet de thèse propose de développer un nouveau cadre pour extraire et apprendre des informations cruciales à partir d'observations satellitaires multimodales existantes et de sorties numériques grâce à des approches d'apprentissage profond contraintes par la physique du phénomène d'intérêt.

La recherche proposée se concentre sur les cyclones tropicaux et utilisera les données d'observation de la Terre de la NASA et de l'ESA déjà existantes, y compris des données non locales dans le temps et dans l'espace. L'objectif principal est de développer de nouvelles méthodologies pour exploiter pleinement les données de mission en orbite basse existantes qui sont sensibles aux caractéristiques de la surface de l'océan ainsi que les mesures in situ et les sorties des modèles numériques pour compléter, contraindre et aider à l'interprétation des différentes observations satellitaires.
Le premier objectif est de caractériser les principales propriétés des cyclones tropicaux (trajectoire, intensité, structure) à partir des archives de données. Une méthode objective pour ré-analyser les données, y compris les observations de l'océan qui peuvent être utilisées comme pré conditionneurs (par exemple les vagues générées par les tempêtes) ou comme post-contrainte (par exemple les propriétés des sillages laissés par les cyclones tropicaux) doit être développée. Le deuxième objectif vise à proposer une méthode d'estimation de la dynamique du cyclone tropical à partir d'observations antérieures pour fournir des prévisions à court terme de son évolution. Le dernier objectif s'appuie sur les deux premiers pour concevoir un réseau optimal de capteurs qui fournirait les observations requises pour la surveillance et la prévision des cyclones tropicaux.
La thèse se déroulera dans le cadre du projet ANR Chair OceaniX (https://cia-oceanix.github.io/) et le doctorant travaillera au sein d'une équipe d'experts en télédétection océanique et en mathématiques appliquées. Dans le cadre de la Chair Oceanix, le doctorant recevra une bourse complémentaire pour sa participation à des activités d'enseignement et d'animation menées par OceaniX, ainsi qu'une bourse de visite pour passer jusqu'à 6 mois dans des équipes partenaires à l'étranger.

Mots-clés : Cyclones Tropicaux, interactions océan-atmosphère, évènements extrêmes, observations multi modales (satellite, in-situ, modélisation), apprentissage profond avec contraintes physiques

Profil de candidature souhaité – *400 caractères*

Nous recherchons un.e étudiant.e master ou un.e ingénieur en data science, apprentissage statistique et/ou en géosciences (dynamique océanique ou atmosphérique).

Le ou la candidate devra avoir un bagage théorique solide et des connaissances fortes en data science, avec si possible de l'expérience dans les méthodes de machine learning classiques ou en deep learning. La personne devra également avoir de solides connaissances dans les environnements de programmation (par exemple, Python, Git) et dans la manipulation des données satellitaires.

English summary – *1200 characters*

Today, numerical models, even constrained by copious amounts of observations, still fail to fully unveil the nonlinear and intermittent nature of underlying complex dynamics of extreme weather systems. Similarly, and in spite of the ever growing observational capabilities, data-driven statistical methods also rapidly appear ineffective in case of extreme and rare events. In line with the ANR Chair Oceanix project objectives, this PhD topic proposes to develop a new framework to extract and learn crucial information from existing multi-modal satellite observations and numerical outputs with physics informed deep learning approaches.
The proposed research focuses on Tropical Cyclones and shall make use of the existing Earth observations data from NASA and ESA, including non-local data in time and space. The overarching goal is to develop new methodologies to fully exploit existing low-orbit mission data that is sensitive to the ocean surface characteristics as well as in-situ and model outputs to complement, constrain, and aid the different satellite observations.
The first objective is to characterize Tropical Cyclone main characteristics (trajectory, intensity, structure) from data archive. An objective method to re-analyse the data including observations of the ocean that can be used as pre-conditioners (e.g. waves generated by storms) or as post-constrain (e.g.

tropical cyclone wakes properties) shall be developed. The second objective aims at developing a method to estimate the dynamic of the Tropical Cyclone based on previous observations to provide short-term forecasts of its evolution. The last objective elaborates on the two first to design an optimal network of sensors for providing the required observations for Tropical Cyclone monitoring.
The thesis will take place in the framework of the ANR Chair OceaniX project (https://cia-oceanix.github.io/) and the PhD student will work within a team with experts in Ocean remote sensing and in applied mathematics. In the framework of AI Chair Oceanix, the PhD candidate will receive a complementary scholarship for his/her participation to teaching and animation activities led by OceaniX as well as a visiting scholarship for spending up to 6 months in partner teams abroad.

Key-words: Tropical Cyclone, air-sea interactions, extreme events, multi-modal observations (satellite, in-situ, model), physics informed deep learning

Preferred profile of the PhD student– 400 characters

MSc. and/or Engineer degree in data science, statistical learning and/or geosciences (ocean or atmospheric dynamics).

Besides a strong theoretical background, computer skills, including first experience in using state-of-the-art classic machine learning methods or recent deep learning frameworks, programming environment (e.g., python, git server) and managing real satellite data is expected.

Detailled Research Project *(3 pages)*

1- Background and scientific/ technological context

Main literature references, potential collaborative projects …

Today, numerical models, even constrained by copious amounts of observations, still fail to fully unveil the nonlinear and intermittent nature of underlying complex dynamics of extreme weather systems. Similarly, and in spite of the ever growing observational capabilities, data-driven statistical methods also rapidly appear ineffective due to the typical high dimensionality of extreme events. A lack of a dedicated observation network to monitor extreme events further challenges their predictive reliability. Therefore, fundamental limitations in existing missions/sensor capabilities are inevitable, notwithstanding their different space-time resolutions. In that context, several issues remain including how to organize, combine and optimally use all available data, retrieved geophysical parameters, and initialize numerical models. Specifically, present capabilities prevent a precise characterisation of the key precursors controlling the rapid intensification of Tropical Cyclones, whereas they are likely to become more frequent in context of global warming [Elsner et al., 2008].

Recent work has been done to demonstrate the feasibility to merge satellite information using classic statistical methods [Knaff et al., 2011] and more recently deep learning approaches [Wimmers et al., 2019]. Moreover, recent advances have been made to monitor and characterize the Tropical Cyclone with low-orbit platforms, including microwave passive [Reul et al., 2017] or active [Mouche et al., 2019] sensors with different resolution measurements (low resolution from radiometers, medium resolution from scatterometers, and ultra-high resolution synthetic aperture radar).

The use of wind speed estimates from these sensors has already resulted in significant changes in how real-time TC intensity estimates are created by operational Tropical Cyclone centers. Ocean surface wind speed estimates from the suite of ESA and NASA sensors are now often used for improving the operational intensity estimates (Buck Sampson, personal communication 2020) that traditionally have heavily relied on a subjective technique developed by Dvorak [Dvorak et al., 1975] based on subjectively determined patterns observed in geostationary (very high orbit) satellite imagery (visible and infrared window) and a number of intensity change constraints or rules.

Finally it shall be emphasized that non-local information related to the ocean that can be used as pre-conditioners (e.g. waves generated by storms) or in post analysis (e.g. tropical cyclone wakes [Balaguru et al., 2020, Combot et al., 2020]) are rarely used to guide the analysis of storms evolution.

2- Strategic positioning within the Department/Institute

Such a dilemma is in line with IFREMER objectives aiming at building a Digital Twin Earth System with a realistic Ocean and at improving our understanding of the Ocean by the year 2100. Such objectives can only be attained by mastering the wealth of observations available at hands and preparing the future network of observations. LOPS is actively working on these challenges (cf. HCERES LOPS 2020) and is considered as a leader team in the field of Ocean Remote Sensing. However, the heterogeneity of the data to explore, the high dimensionality of extreme events and the limitations of existing models require new methods to further assess the interactions between ocean and extremes at the air-sea interface. Developing such a new approach and structuring the research and education on this topic is the aim of ANR Chair Oceanix project, the framework of this PhD thesis.

3- Scientific objectives

In line with the ANR Chair Oceanix project objectives, this PhD topic proposes to develop a new framework to extract and learn crucial information from existing multi-modal satellite observations and numerical outputs. These efforts shall be applied to Tropical Cyclones in order to develop a physics-informed model architecture based on artificial intelligence methods, including three main objectives

Objective 1: Tropical cyclone characterization
It aims at better characterizing tropical cyclone evolution from formation to dissipation. The PhD candidate shall develop an objective method to re-analyse the data to describe the wind forcing over the ocean for any tropical cyclone observed from space on regular space and time domain.

Objective 2: Extreme events dynamics
The goal is to provide short-term forecasting of tropical cyclone trajectories, structures and intensities, including the challenge of Tropical Cyclone rapid intensification. The PhD candidate will rely on observations and numerical model outputs to develop a semi-physic model to predict the dynamics of tropical cyclones from key controlling parameters.

Objective 3: Preparing the future of observations
The previous two objectives will allow the PhD candidate to define the most suitable interpretation framework, guiding the development, design and use of future generations of observation networks for Tropical Cyclones.

4- Methodology

We aim to develop a comprehensive and generic methodology based on AI tools and frameworks to address these scientific objectives and make the best use of the available observation and simulation datasets and physical knowledge. While purely data-driven schemes may be considered as direct applications of off-the-shelf deep learning architectures, we envision the design of physics-informed deep learning frameworks. In this respect, variational deep learning models [e.g., Fablet et al., 2020] or analog forecasting coupled with data assimilation [e.g., Zhen et al., 2020] provide an appealing framework to bridge deep learning and physics for solving inverse problems (e.g., reconstruction and forecasting issues). Here, the specific focus will be given to accounting (i) for the irregular space-time sampling of the observation data as well as multimodal observation/simulation data, possibly at different space/time scales, (ii) the intrinsic stochasticity of the underlying processes, both in the learning and evaluation phases.
The proposed research shall make use of the existing data from NASA and ESA, including non-local data in time and space. The overarching goal is to fully exploit existing low-orbit mission data that is sensitive to the ocean surface characteristics. Another aspect that will be investigated in this project is the definition of methodologies to use model outputs to complement, constrain, and aid the different satellite observations. More specifically, the information of the ensemble members (e.g., as in the ECMWF product) will be used to physically constraint physical parameter estimates made in the tropical cyclones, and to get an a priori estimate of forecast variability.

5- Resources at disposal for the PhD student for the duration of the research project (human, technological…)

The thesis will take place in the framework of the ANR Chair OceaniX project (https://cia-oceanix.github.io/). The PhD student will work within a team with experts in Ocean remote sensing and in applied mathematics. The PhD will be co-supervised by Dr. A. Mouche (Ifremer/LOPS) and Dr. J.

Knaff (NOAA), Dr. P. Tandeo and with the additional expertise of Dr. R. Fablet (IMT Atlantique/Lab-STICC) and Dr. B Chapron (IFREMER).
In the framework of AI Chair Oceanix, the PhD candidate will receive a complementary scholarship for his/her participation to teaching and animation activities led by OceaniX (e.g., MSc. courses in data science and ocean science, co-working sessions,...) as well as a visiting scholarship for spending up to 6 months in partner teams abroad (e.g., NOAA). Dr. J. Knaff already proposed to host the PhD student for a multi-month scientific visit to his institution at Forth Collins, Colorado, USA.
Through AI Chair OceaniX and joint INRIA/Ifremer/IMT Atlantique team, this PhD will benefit from state-of-the-art AI-oriented computational resources (eg, GPU cluster) to run significant numerical experiments and exploit the available datasets.

6- Expected results and valorization (publications and public dissemination)

The PhD candidate shall target publications in peer-review journals within the 3 years. Dataset useful for the science and/or applicative communities will be published as well.

7- Originality and innovation

Use of machine learning approach to take the most of multi-modal and local/non-local (space and time) observations in combination with numerical model outputs for improving our understanding of extreme events dynamics.

8- Does the project come under the ABS Nagoya Protocol and/or does it involve the use of genetic resources?

No

9- Potential partnerships

This project is a partnership between IFREMER, INRIA and IMT Atlantique at national level and with NOAA at international level. Most of the questions we shall address here are also included in the framework MAXSS ESA project. MAXXS gathers a European consortium (KNMI, ICM, PML, NESRC) and shall start in November 2020.

10- Provisional schedule

M01 - M03: Bibliography and creation of observational and model datasets
M03 - M15: Characterization of tropical cyclones evolution, from formation to dissipation
M15 - M27: Forecast of tropical cyclones (including trajectory, structure, intensity, and rapid intensification)
M27 - M33: Definition of the optimal observational network for tracking tropical cyclones
M33 - M36: Preparation of the PhD manuscript, publication and defense

PhD supervision

⚠ **Warning, at closure date, PhD supervisors and co-supervisors shall have no more than 2 other PhD supervisions ongoing.**

⚠ **The PhD supervisor must be an Ifremer employee and accredited to supervise research (HDR).**

⚠ Ifremer employees in position since 1st January 2017 with more than 5 years experience as researcher, may submit a topic proposal but must commit to obtain research supervision accreditation (HDR) within 3 years.

1- PhD Supervisor (accredited to supervise research)

Full name:	Mouche Alexis
Professional Position and Speciality:	Cadre de recherche (C1) / Ocean Remote Sensing
Ifremer Dpt./unit/ Lab:	ODE/LOPS
Address:	IFREMER Centre de Bretagne 1625 Route de Sainte-Anne 29280 Plouzané
e-mail:	alexis.mouche@ifremer.fr
Phone nbr.:	+33 (0)2 98 22 49 29

Experience in postgraduate student supervision

Names of postgraduates currently or previously supervised *(Ifremer grants and others)* from the past 7 years; PhD topic and defence date; Current employment situation *(if known)*

Huimin Li, PhD (2019), 4-year, CSC Scholarship. Co-supervised with J. Tournadre and B. Chapron from IFREMER. Now assistant professor at Nanjing University of Information Science and Technology. PhD Thesis title: "Global observations of ocean surface winds and waves using spaceborne synthetic aperture radar measurements"

Chen Wang, PhD (2020), 4-year CSC Scholarship. Co-supervised with J. Tournadre and B. Chapron from IFREMER and R. Garello and P. Tandeo from IMT Atlantique. Now assistant professor at Nanjing University of Information Science and Technology. PhD Thesis title: "Global Investigation of Marine Atmospheric Boundary Layer Rolls Using Sentinel-1 SAR data"

Gressani Victor, CNES/CLS scholarship. Co-supervised with J. Tournadre and F. Nouguier from IFREMER, and F. Soulat from CLS. PhD defense planned on December 14th 2020.

Combot Clément, IFREMER scholarship. Co-supervised with J. Tournadre, Y. Quilfen and B. Chapron from IFREMER. PhD defense planned in December 2020. Exact date to be confirmed.

Léo Vinour, IFREMER scholarship. Co-supervised with C. Roy from IRD and S. Jullien from IFREMER. PhD defense planned in 2021.

PhD supervisor signature

Alexis Mouche

2- PhD Co-Supervisor

Full name:	Pierre Tandeo
Professional Position and Speciality:	Enseignant chercheur à IMT Atlantique / Mathématiques appliquées à l'environnement
Structure, Laboratory (Ifremer Dpt./Unit/Lab):	Lab-STICC, équipe TOMS "Traitement, observations et méthodes statistiques"
Address:	IMT Atlantique Département SC 655 Avenue du Technopôle, 29280 Plouzané
email:	pierre.tandeo@imt-atlantique.fr
Phone nbr.:	+33 (0)2 29 00 13 04

Experience in postgraduate student supervision

Names of postgraduates currently or previously supervised *(Ifremer grants and others)* from the past 7 years; PhD topic and defence date; Current employment situation *(if known)*

Pierre Le Bras (2020-2023, PhD student):
- With IUEM and LOPS (Brest, France)
- Regional fundings (ARED)
- "Analog Methods to Identify Global Oceanographic Simulations"

Aurélien Colin (2019-2022, PhD student):
- With CLS (Brest, France) and IFREMER (Brest, France)
- OceaniX AI chair program
- "On the Use of Deep learning for Ocean SAR Semantic Segmentation"

Yicun Zhen (2018-2020, postdoc):
- With OceanNext (Grenoble, France) and Univ. Grenoble Alpes (Grenoble, France)
- European CMEMS funding
- "Data-Driven Data Assimilation: Application to the Interpolation of Satellite Data in Oceanography"
- Now postdoc at IFREMER and LOPS (SIAM) with Bertrand Chapron

Paul Platzer (2017-2020, PhD student):
- With France Energies Marines (Brest, France) and Institut Pierre Simon Laplace (Paris, France)
- French ANR + European ERC grants
- "Statistical and Dynamical Properties of Analogue Data Assimilation for Extreme and Rare Events"
- PhD defense planned in December 2020

Chen Wang (2016-2020, PhD student):

- With IFREMER (Brest, France) and Univ. Washington (Seattle, US)
- Chinese scholarship
- “Global Investigation of Marine Atmospheric Boundary Layer Rolls Using Sentinel-1 SAR data”

PhD co-supervisor signature

Pierre Tandeo

3- PhD Co-Supervisor

Full name:	John Knaff
Professional Position and Speciality:	Senior scientist
Structure, Laboratory (Ifremer Dpt./Unit/Lab):	*NESDIS/STAR* *CIRA/ Colorado State University*
Address:	*Colorado State University* *Campus Delivery 1375* *Fort Collins, CO 80523-1375*
email:	*John.Knaff@noaa.gov*
Phone nbr.:	*970 491-8881*

Experience in postgraduate student supervision

Names of postgraduates currently or previously supervised *(Ifremer grants and others)* from the past 7 years; PhD topic and defence date; Current employment situation *(if known)*

PhD co-supervisor signature

Evaluation by Host (Ifremer Department, Unit and Laboratory)

(service committed to accommodating and supplying the candidate with the resources and assistance necessary for completion of the proposed project)

Estimated accommodation period:

Name of Head of Laboratory:
Comments:

Head of Laboratory signature

Name of Head of Unit:
Comments:

Head of Unit signature

Evaluation by External Unit/Laboratory (University, Research Institute, Technical College…) *(service committed to accommodating and supplying the candidate with the resources and assistance necessary for completion of the proposed project)*

Name of supervisor 1:
Host structure, Unit/Laboratory/Department:
Address:
email:
Phone nbr.:

Estimated accommodation period:
Comments:

External supervisor 1 signature

Name of supervisor 2:
Host structure, Unit/Laboratory/Department:
Address:
email:
Phone nbr.:

Estimated accommodation period:
Comments:

External supervisor 2 signature

Evaluation by Project Manager/coordinator *(if the PhD project is subject to contractual obligations)*

Project title:
Full name:
Structure, Unit/Laboratory/Department:
email:

Comments:

Project manager/coordinator signature

References

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Fablet, R., B. Chapron, L. Drumetz, E. Memin, O. Pannekoucke. F. Rousseau. Learning Variational Data Assimilation Models and Solvers. arXiv preprint, 2020.

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Wimmers Anthony, Christopher Velden and Joshua H. Cossuth Using Deep Learning to Estimate Tropical Cyclone Intensity from Satellite Passive Microwave Imagery, Monthly Weather Review. DOI 10.1175/MWR-D-18-0391.1. 2019 American Meteorological Society

Knaff, J. A., DeMaria, M., Molenar, D. A., Sampson, C. R., & Seybold, M. G. (2011). An automated, objective, multiple-satellite-platform tropical cyclone surface wind analysis. Journal of applied meteorology and climatology, 50(10), 2149-2166.

Zhen, Y., Tandeo, P., Leroux, S., Metref, S., Penduff, T., & Le Sommer, J. (2020). An adaptive optimal interpolation based on analog forecasting: application to SSH in the Gulf of Mexico. Journal of Atmospheric and Oceanic Technology, 37(9), 1697-1711.