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Project Acronym: **PREFACE**

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Instrument: Collaborative Project

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Deliverable reference number and full title: *D3.3 "Report on Near Inertial Waves"*

Lead beneficiary for this deliverable: UCPH

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Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the Consortium (including the Commission Services)	
CO	Confidential, only for members of the Consortium (including the Commission Services)	

Contribution to project objectives – with this deliverable, the project has contributed to the achievement of the following objectives (from Annex I / DOW, Section B1.1.):

N.º	Objective	Yes	No
1	Reduce uncertainties in our knowledge of the functioning of Tropical Atlantic (TA) climate, particularly climate-related ocean processes (including stratification) and dynamics, coupled ocean, atmosphere, and land interactions; and internal and externally forced climate variability.	x	
2	Better understand the impact of model systematic error and its reduction on seasonal-to-decadal climate predictions and on climate change projections.	x	
3	Improve the simulation and prediction TA climate on seasonal and longer time scales, and contribute to better quantification of climate change impacts in the region.	x	
4	Improve understanding of the cumulative effects of the multiple stressors of climate variability, greenhouse-gas induced climate change (including warming and deoxygenation), and fisheries on marine ecosystems, functional diversity, and ecosystem services (e.g., fisheries) in the TA.		x
5	Assess the socio-economic vulnerabilities and evaluate the resilience of the welfare of West African fishing communities to climate-driven ecosystem shifts and global markets.		x

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Deviation from planned efforts for this deliverable: None.

Executive Summary:

This report is Deliverable 3.3 of the PREFACE project, produced by the work package WP3. WP3 focuses on improving the understanding of the physical processes controlling the mixed layer heat and freshwater balances in the eastern boundary upwelling regions of the tropical Atlantic and in the Gulf of Guinea, by performing observational and model process studies, extending the Atlantic observing system and providing datasets to evaluate regional ocean and atmospheric, and global climate models.

This report focuses on near inertial waves (NIWs), a process that is not represented in climate models but has recently been shown to exert control over the position of Intertropical Convergence Zone (ITCZ), a band of convective systems in the atmosphere which overlies the tropics' warmest water. Jochum et al. (2013) shows that NIW induced mixing brings cool subsurface water to the surface, and thereby modifies the tropical SST gradient and ITCZ position. However, NIW strength is sensitive to details of atmospheric forcing, and there are only few observational constraints. Thus, there are three NIW related goals in PREFACE: Firstly, use the PIRATA mooring array to quantify the NIW strength; secondly, develop a NIW parameterization for a European climate model, tune it with PIRATA data and corroborate the

results of Jochum et al. (2013); and thirdly, show that including NIWs in climate models leads to higher fidelity on seasonal to decadal scale forecast. The analysis of the PIRATA data has been described in D3.2, the impact on predictability will be assessed in a forthcoming report, and the implementation and testing of the NIW parameterization is the focus of the present report.

Main results can be summarized as follows:

- accounting for NIWs in NorESM leads to significant improvements in the distribution of tropical SST and precipitation;
- although NorESM has a very different mixed layer model than CESM, pattern and magnitude of the NIW impact are similar in both;
- we could show that long term averages of NIW activities at PIRATA moorings is consistent with available drifter data (see previous report D3.2), and these values were used to tune the parameterization. Essentially, this tuning compensated for shortcomings for the representation of storms in the atmospheric model. It was not possible, however, to verify observationally the connection between NIW activity and mixing. This is what links the storms to changes in SST, and *our recommendation is to enhance one of the safer, off-equatorial PIRATA moorings with high vertical resolution temperature, if not velocity instruments as was done successfully in the Bay of Bengal* (Johnston et al. 2016). This allows to quantify the connection between wind bursts, ocean mixing and SST.

Impact of Oceanic Inertial Mixing on SST and precipitation in a global climate model

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NIWs are free modes of oceanic motion and are generated by any perturbation of the equilibrium flow; in particular travelling atmospheric storms can create oscillatory wind stress which is in resonance with the flow of NIWs, and thereby create strong ocean velocities and mixing (d'Asaro 1985). In current climate models the temporal and spatial resolution is typically not sufficient to resolve them, and they need to be parameterized. For NorESM, this required the following steps, some of them being necessary because for numerical reasons the NorESM ocean model does not allow for coupling frequencies higher than daily:

1. take hourly winds from the atmospheric model, pass them on to the coupler, and then drive the newly included slab ocean mixed layer model;

2. take the inertial velocity from the slab model, modify it with the PIRATA and drifter based tuning, and pass the resulting inertial kinetic energy to the ocean mixed layer model. **Figure 1** shows the values of speed used to calculate the inertial energy;

3. add this energy to the turbulent kinetic energy budget of the mixed layer, which will use this additional energy to entrain more water from the below the mixed layer, thereby deepening the mixed layer and lowering the SST.

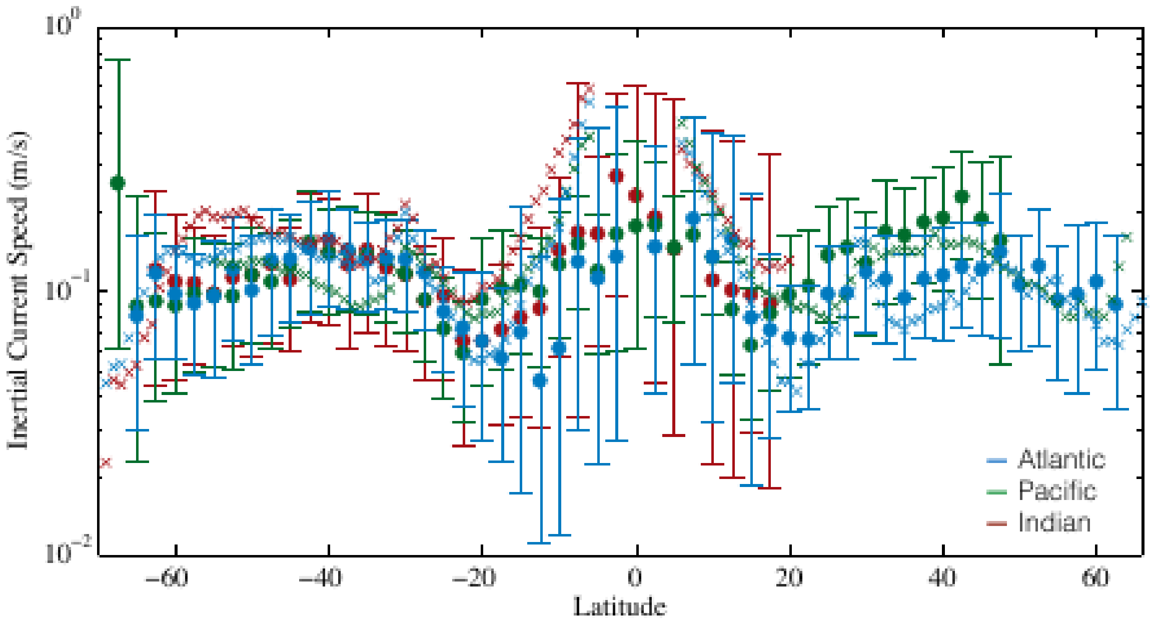

Figure 1: Observations of zonally averaged near inertial velocities from drifter data (provided by S. Elipot and R. Lumpkin, AOML); color denotes the basin, dots the mean value, and lines one standard deviation. The model means are shown as crosses (negligible standard deviation because of large amount of model output).

It should be noted that most of the literature and observations of NIWs focus on the ocean under the mid-latitude storm tracks, although NIWs are of similar strength in the tropics

(**Figure 1**). Most importantly, however, only in the tropics do NIWs have a feedback on the atmospheric circulation. The averages of the last 40 years of 100 year integrations of NorESM are used to assess the impact of NIWs. In general the impact on SST should be negative definite, since NIWs mix up colder water from below. Thus, the areas in **Figure 2** that show warming have additional feedbacks, like weaker winds, or in the case of the equatorial cold tongue in the Pacific, upwelling of warmer water because NIWs mix more heat downward in the subduction zones, which returns to the surface along the equator (see Jochum et al. 2013).

While the SST differences are of similar magnitude across the globe, they really matter in the tropics because they shift the rainfall patterns; precipitation becomes more focused on the equator in the Pacific, and shifts northward in the Atlantic (**Figure 2**). Both features can also be seen in CESM, which point to this being a robust feature of climate.

In the context of PREFACE it is encouraging to note that the changes project on some long standing biases, some of which have been the motivation for the present proposal: the warm bias off Peru and Namibia are now reduced (**Figure 2**, left), and the precipitation in the Atlantic has shifted north (**Figure 2**, right) in response to the strengthened cross-equatorial SST gradient. Interestingly, the AMOC too is much improved; it is reduced from a maximum of 26 Sv to a more realistic 21 Sv (not shown). This is the one NIW impact that is different from CESM, and something that we do not understand yet.

The results are currently being written up for publication in the Journal of Climate. One additional experiment is currently being carried out, the completion of which will allow us to complete the manuscript: masking out the effect of NIWs outside the tropics. With this, we can test the idea put forward by Jochum et al. (2013) that the changes in the mid-latitude westerlies caused by NIWs are solely due to tropical NIWs, and not due to local mid-latitude feedbacks.

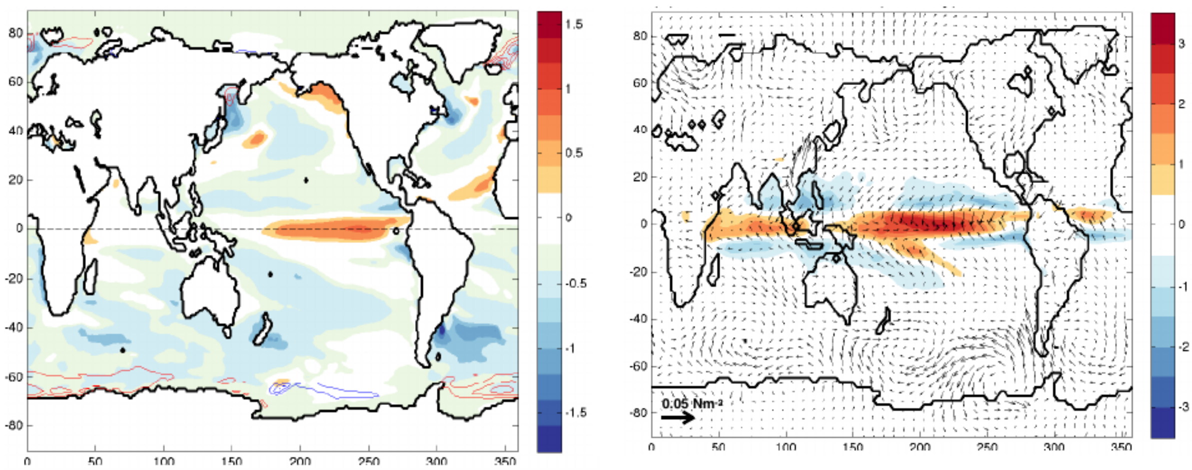

Figure 2: Differences in SST, sea ice concentration (contour interval 5%, **left**) and precipitation (mm/day) and wind stress (**right**).

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