Supporting Information for "Towards comprehensive understanding of air-sea interactions under tropical cyclones: On the importance of high resolution and multi-modal observations"

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Introduction

This document provides further details on the methodology for analysing SAR images and collecting Argo data. Two figures illustrate the sampling method and extraction of stratification parameters from Argo floats. A third one, on sea surface temperature anomalies, completes the discussion and perspectives raised in the article.

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1. SAR Methodology.

The extraction of Tropical Cyclones parameters follows exactly the same strategy presented in (Combot et al., 2020):

a) TC center positioning: Best-track positions are linearly interpolated to match SAR acquisition time, and provide a first guess to guide the center analysis. Using both polarization mode of the SAR backscattered signal, we search, in the vicinity of this first guess center (100 km), the area with the largest average difference in contrast, corresponding to the eye region. In this area, we select the lowest intensity point as the second guess center. The spatial grid is then converted into polar coordinates. From the location of this new center, we derived radiometric gradients for each azimuth, and the maximum values delineate the eye extent. The final center is then defined from the barycenter of the eye structure.

b) The geographical coordinates are converted into final polar coordinates.

c) A progressive azimuthal decomposition of the wind profiles is then performed to extract the ring of the highest winds for each azimuth, following the exhaustive description of (Combot et al., 2020).

d) The maximum value of this ring is taken as Vmax, and its location gives Rmax.

e) To provide a sampling domain for Argo collection, we also derived for each azimuth direction, the contour of r17 m.s^{-1}. The 90th percentile values is then used to determine its maximum extent.

2. Argo Methodology.

2.1. Temporal Sampling and Quality Flag.

For each case, we then collect Argo floats located in the limit of the maximum extent of r17, given by the SAR observation. A sampling period of 15 days is applied going from T-20:T-5 days before the storm, to obtain a representative view of the pre-storm ocean stratification state. A threshold of 5 days before the TC has been chosen to ensure this estimate undisturbed by the coming tropical cyclone. A quality control is then made to remove ambiguities or bad-quality data, following the quality control flag description.

For each ocean variable (Pressure, Salinity and Temperature), we examine the quality control flag associated to each vertical point of each profile. Vertical measurements with a flag value of 3 or 4 (=bad data), or 9 (=missing data) are not considered (NaN values). A profile quality flag is also provided to indicate the ratio of accurate data along the vertical structure. A letter from (A) to (F) is attributed according to the overall quality, (A) corresponding to 100% good data along the profile while (F) stands for 0%. When less than half of the vertical structure is considered as relevant (D, E F flag), the complete Argo profile is removed from the analysis.

The life-cycle of the selected Argo is split into three stages: a fast descending path, until it reaches a parking level where it drifts 9 days, then ascending to the surface to transmit data. Measurements are essentially conducted during this ascending stage, and we only kept ascending path data for consistency.

2.2. Extraction of the Vertical Stratification Parameters.

Once the in-situ data gathered, the analytical scheme, described in (Kudryavtsev et al., 2019), is followed to analyze each collected density profile. It provides an averaged Brunt-Väisälä frequency of the seasonal Thermocline, which is assumed to be the main ocean modulator of the baroclinic response. A simple decomposition of the vertical profile is used to infer the seasonal Thermocline depth and its gradient, by approximating the ocean stratification as a three-layer structure (see Fig S1). The seasonal and permanent Thermocline are adjusted with a linear approximation, and the abyssal layer with a constant density. Upper and lower boundaries correspond to the mixed layer depth and the top of the abyss. For the mixed layer depth, the maximum of the second derivative of the profile is considered. For the top of the abyss, the depth containing 95% of the density drop is considered. A least square method is then performed to derive the depth of the seasonal Thermocline from the two linear trends (see dashed lines in Fig S1 a & b). Mixed layer depth is independently reassessed, by simply taking the depth of 0.2°C difference from Sea Surface Temperature. The associated density values at the mixed layer depth and at seasonal Thermocline depth are then extracted, from which can be deduced the averaged Brunt-Väisälä frequency (see Fig S1).

Two dimensionless numbers can then be computed to describe the dominant regime of the ocean response. The Froude number, defined as the ratio between the translation speed with the first mode of the baroclinic speed, is derived from the density stratification: $c1 = g' * h1h2/(h1 + h2)$, with g' the reduced gravity, defined as $g' = g * (\rho_2 - \rho_1)/\rho_2$. The pair $h1/\rho_1$ and $h2/\rho_2$ represents respectively the depth and density of the mixed layer and of the seasonal Thermocline. This parameter is indicative of a strong near-inertial response for Fr>1, or rather a dominant barotropic response for Fr<1.

Non-linear response stemming from a strong Ekman upwelling, can also be triggered not only for steady systems, but also for very large cases. A dimensionless translation speed is computed taking into account both size and translation speed, corresponding to the ratio of the local inertial period to the residence time of the cyclone : $S = \pi * V_{fm}/(4Rmax * f)$ (Reul et al., 2021). Cases for which S 1 (resonant) or >1 have strong near-inertial wake signature, while for cases $S << 1$, an important Ekman circulation can be set into the shape of circular pattern (no wake). Most of diverging scenarios has been found for a threshold $S <= 0.5$ (residence time at least two time larger than inertial periods).

These two criteria, as well as the ocean depth, are used to point out barotropic responses that are limiting for our analysis.

2.3. Spatial Selection of Argo Floats.

From the collection of Argo floats, many vertical profile measurements can be co-located to a single SAR observation. In order to associate specific stratification parameters to each case, we select a vertical profile following three main rules:

1) If several Argo floats are located within the TC center region [0-2Rmax], we chose the closest profile in time and space. In the situation of only one in-situ measurement, it is taken as reference (float at -9 days in Fig S2a).

2) If many floats are gravitating around TC center but outside the central region, we chose vertical profiles of similar latitude [± 1°C] (see red box in Fig S2b).

3) Without any in-situ measurements located at the same latitude, we used an averaged value of N1, given by the different packs of floats. (see Fig S2c)

From these three main steps, each SAR acquisition has been associated with pre-storm stratification parameters from Argo profilers. In the absence of Argo data, we used the climatological monthly product of ISAS-15. The closest profile in term of space and time is chosen and the step 2 is applied.

References

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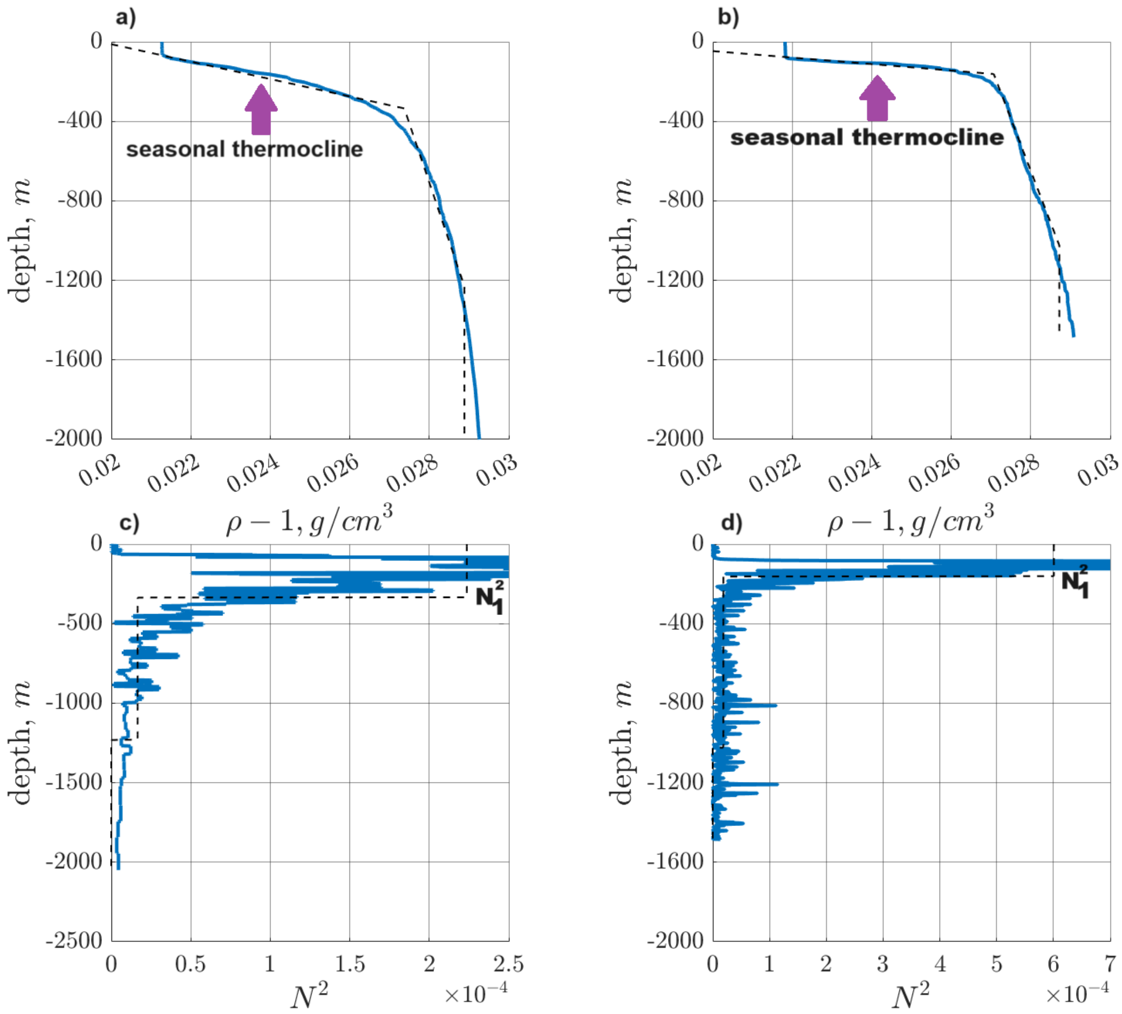

Figure S1. Example of two differently stratified vertical density profiles (upper panels). a) averaged tropical stratification, b) strong stratification. The density gradient is used to calculate the vertical distribution of the Brunt-Väisälä frequency associated with each density profile (lower panels). The gradient along the seasonal Thermocline is used to estimate the associated mean value of the Brunt-Väisälä frequency (N_1^2), as shown in panels c) and d).

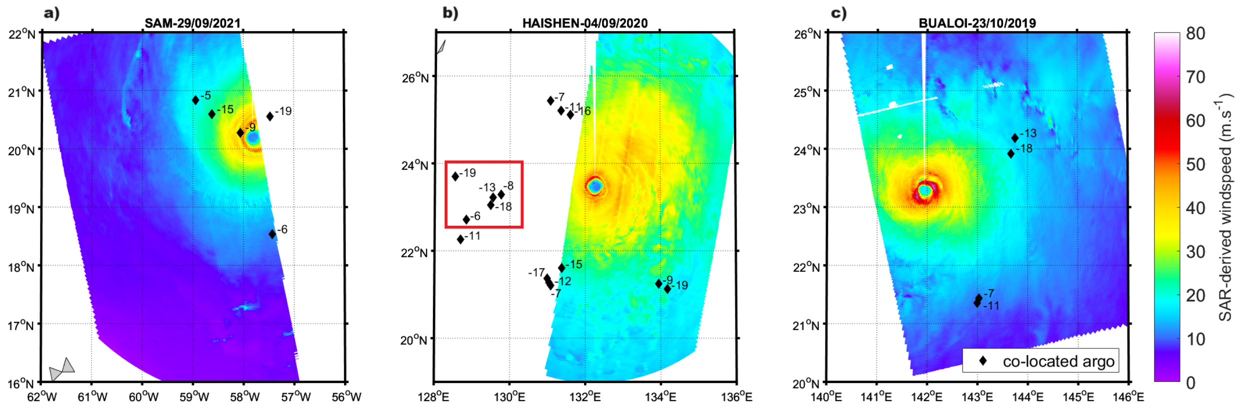

Figure S2. The three typical Argo sampling scenarios. a) Case with several floats near the inner core. b) Constellation of floats within the outer core (the red box shows the floats within a radius of 1° latitude around the TC centre), and c) at the edge of the TC (none at the same latitude). The date of the TC passage is used as a reference to indicate the dates of the float measurements. Thus, negative numbers represent the number of days prior to the storm.

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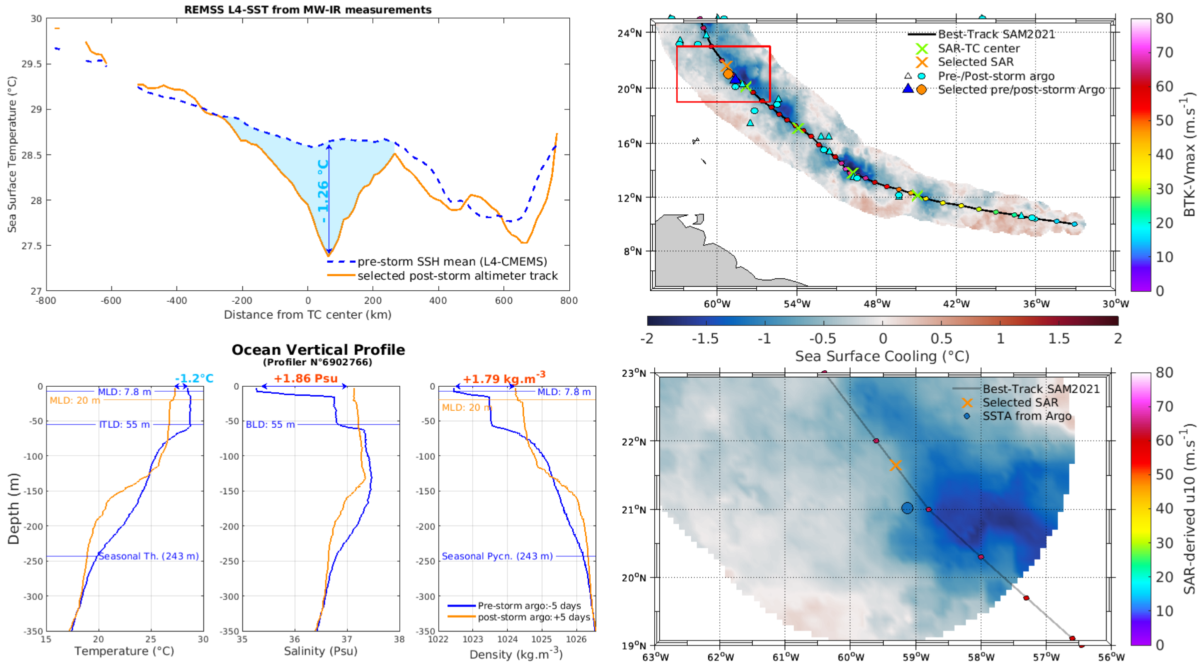

Figure S3. Illustration of the multimodal analysis of the cold wake of hurricane SAM, with a) the averaged cross-track measurements of the SSTA from daily-interpolated MW/IR observations from REMSS. The location is given by the red box b) within the synoptic view of the Sam wake, which displays the Argo and SAR data collected at each BTK position. Two illustrative in-situ measurements, located at the positions of the orange markers, are displayed: with c) the Pre- & Post-storm ocean vertical profiles of sea surface temperature, d) salinity and e) density within the cold wake. MLD: mixed layer depth, ITLD: isothermal layer depth, BLD: Barrier layer depth. f) SSTA inside the red box is zoomed.