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Supporting Information for

Observed diurnal cycles of near-surface shear and stratification in the equatorial Atlantic and their wind dependence

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Introduction

The data sets of the TRATLEQ drifter experiments are described in more detail, focussing on the characteristics of the three types of drifters, on the processing of the raw data, and on the performed collocation of drifter pairs. An estimate of the Stokes drift during the two drifter experiments is given to allow comparison with Eulerian velocity measurements. The IDs of the used SVP drifters are listed so that these drifters can be found in the SVP database. Furthermore, mean diurnal cycles of along-wind shear in the upper 15 m of the ocean are shown as a function of wind speed for the combined drifter experiments and for the EMP at the PIRATA site at 0°N, 23°W. The analysis performed for near-surface stratification at the PIRATA site at 0°N, 23°W is also repeated for the site at 0°N, 10°W.

Text S1.

During the TRATLEQ cruises (M158 and M181) with the RV Meteor, three types of surface drifters (CARTHE, SVP, and Hereon drifters, see Figure S1) were deployed to monitor velocity differences between about 0.5 m and 15 m depth. All velocities derived from drifters are affected by wind slip, i.e., direct wind drag on the portion of the drifter above the water and surface wave rectification with the extent depending on the shape of the respective drifter. CARTHE drifters have been designed to be compact and quasi-biodegradable and to follow currents extending from the surface to a depth of 0.6 m. The drifters include a donut-shaped top component, carrying the GPS and batteries, which is attached via a flexible chain to a 38 cm long rigid cross-shaped drogue centred at 0.4 m depth. They present minimal wave rectification issues and their wind-induced slip velocity is less than 0.5% of the neutral wind speed at 10 m height (Novelli et al., 2017).

However, in the presence of large waves, the error of the CARTHE velocities can increase to a few cm s^{-1} (Poulain et al., 2022). For wind speeds above 8.1 m s^{-1}, the absolute slip velocity during laboratory testing was found to decrease with increasing wind speed, likely caused by wind separation from the sea surface due to the presence of surface gravity waves (Novelli et al., 2017). The drag area ratio of CARTHE drifters is about 12 (Poulain et al., 2022). SVP drifters are the standard drifters of the Global Drifter Program, track currents at a depth of around 15 m, and can be upgraded with various sensors. All SVP drifters consist of a spherical surface buoy tethered to a weighted holey-sock drogue of 720 cm length that is centred at 15 m depth. They have a slip bias of less than 1 cm s^{-1} in 10 m s^{-1} winds according to observations. This bias results from the direct action of the wind on the surface floating buoy as well as from the vertical shear of the horizontal velocities across the vertical extent of the drogue. The drag area ratio is larger than 40 (Niiler et al., 1995). When comparing the slip for CARTHE and SVP drifters, it should be noted that SVPs have more direct wind drag above the sea surface compared to CARTHE drifters (Poulain et al., 2022). The so-called Hereon drifters were designed and built at Hereon Helmholtz Centre in Geesthacht, Germany, and follow currents extending from the surface to a depth of 0.7 m. They consist of a tube-shaped top component, containing GPS and batteries, that is attached to a 35 cm long cross-shaped drogue via a flexible cord of 20 cm length. When deployed, about 5 cm of the top element remain above the sea surface, resulting in a ratio of drag area inside to drag area outside the water of 21 (Horstmann et al., 2023). Based on this information, we assume a mean wind slip of maximum 3 cm s^{-1} for the CARTHE drifters, a similar wind slip for the Hereon drifters, and a mean wind slip of maximum 1 cm s^{-1} for the SVP drifters during the two drifter experiments. These wind slips lead to uncertainties in the mean velocity difference between drifters with drogues at 0.5 m and 15 m depth. In particular, the higher wind slip for drifters with a drogue at 0.5 m depth compared to drifters with a drogue at 15 m depth yields an overestimation of the background shear stated in Table 1 of up to 3 cm s^{-1}.

The accuracy of the reported location is 0.00001° = 0.001 km for Hereon, 0.0001° = 0.01 km for CARTHE and Copernicus BRST SVP, and 0.001° = 0.1 km for the remaining SVP drifters. The temporal resolution is irregular for CARTHE and Hereon and mostly hourly for SVP drifters. Therefore, the original data were linearly interpolated to an hourly grid for values less than 4 h apart. Further, the quality of data was validated to account for GPS errors and other failures. The following criteria were considered:

1. The drogue still had to be attached to the drifter. For SVP drifters, the drogue status is given by the quality-controlled drifter metadata provided by NOAA AOML (https://www.aoml.noaa.gov/phod/dac/dirall.html). Note that for CARTHE and Hereon drifters the drogue status is unknown and a drogue loss cannot be ruled out, which would result in higher velocities (Lodise et al., 2019). However, as there were no large storm and wave events during the deployment period, a drogue loss is unlikely (cf., Haza et al., 2018).
2. A maximum velocity criterion of $3 \text{ m s}^{-1} \approx 10.8 \text{ km h}^{-1}$ was applied (cf., Lumpkin & Pazos, 2007).
3. A maximum acceleration criterion of 1 km h^{-2} was used.
4. Drifters with constant velocities for more than 5 h were removed as they are considered grounded.
5. Drifters fetched by ships were manually removed.

The validated and gridded trajectories of SVP and CARTHE drifters from the first drifter experiment and of SVP and Hereon drifters from the second drifter experiment were then collocated using a maximum distance criterion of 100 km (slightly less than 1° in longitude/latitude) and a temporal criterion of 1 h. The positions of the collocated values are depicted in Figure S2. The sensitivity of both criterions was tested. Increasing the temporal criterion to 3 h did not significantly increase the number of pairs. The maximum distance of 100 km was chosen to allow enough pairs for statistics but to avoid an impact of other processes. Furthermore, no criterion is used to eliminate possible outliers as a criterion of three standard deviations off the median removes unproportionally more values in the afternoon where the vertical shear of horizontal velocities is strongest. Hence, this criterion removes ‘true’ velocity peaks and yields a bias. For a better comparison with shipboard observations and to focus on the equatorial region, only drifter pairs between 1°S and 1°N are considered in the study.

Text S2.

Stokes drift is the difference between Lagrangian and Eulerian average flow velocities. It is created by wave motion which induces a net drift of particles in the direction of surface wave propagation. Accordingly, the surface drifter velocity measurements are affected by Stokes drift.

Using surface Stokes drift data from the global wave reanalysis WAVERYS from Copernicus Marine Service (CMEMS, 2019), there is a mean surface Stokes drift in the region of the drifter deployment of 0.06 m s^{-1} for the periods of both the October experiment and the May experiment. The mean amplitude of a supposed diurnal cycle (difference between the maximum and the minimum of a diurnal composite) of the Stokes drift amounts to < 0.01 m s^{-1} for both experiments. Using surface Stokes drift data from ERA5 reanalysis by the Copernicus Climate Change Service (C3S, 2018), there is a mean surface Stokes drift in the region of the drifter deployment of 0.07 m s^{-1} for the October experiment and 0.06 m s^{-1} for the May experiment. The mean amplitude of a supposed diurnal cycle of the Stokes drift amounts to < 0.01 m s^{-1} for both experiments. Hence, the Stokes drift leads to a relatively constant displacement of the drifters in the course of a day and has no influence on the diurnal jet amplitudes obtained by the drifters. Since the Stokes drift decreases exponentially with depth, the drifters with a drogue at 0.5 m depth are affected by Stokes drift, while the effect is negligible for the drifters with a drogue at 15 m depth (cf., Kenyon, 1969; Carrasco et al., 2014). This dependence of the Stokes drift on depth leads to an increase of the mean velocity differences between drifter measurements at 0.5 m and 15 m depth. Note that the above stated mean Stokes drifts are calculated at the surface and will be reduced when referencing to the depth of the drifter's drogue. Furthermore, the Stokes drift is likely overestimated in the used reanalysis product due to uncertainties in the tropics (cf., Sterl & Caires, 2005; Carrasco et al., 2014). Nevertheless, a substantial part of the background shear of the drifter measurements could be explained by the presence of Stokes drift.

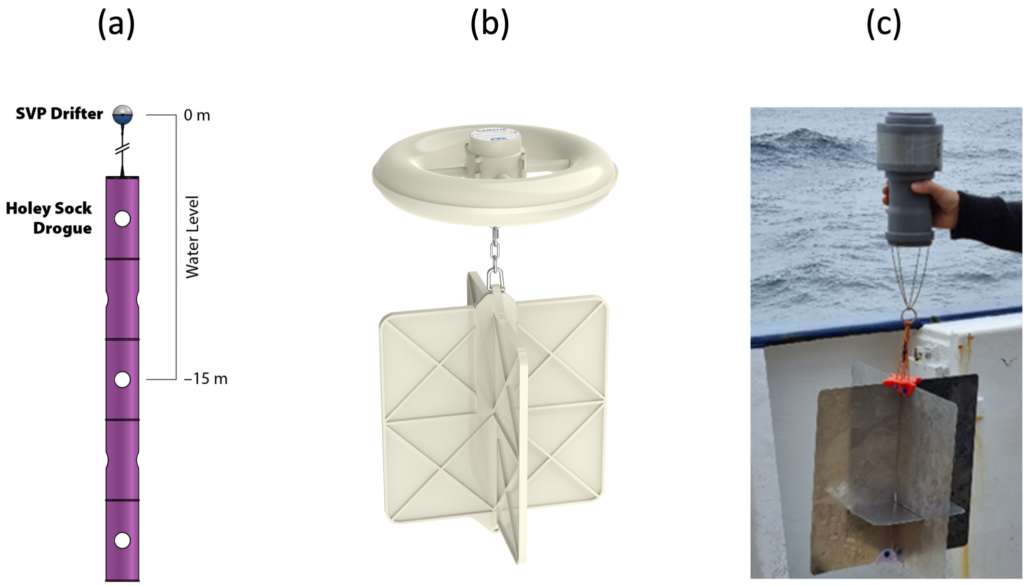

Figure S1. Pictures of the three types of surface drifters used with (a) SVP (image used with permission from the Lagrangian Drifter Laboratory at the Scripps Institution of Oceanography), (b) CARTHE, and (c) Hereon drifters.

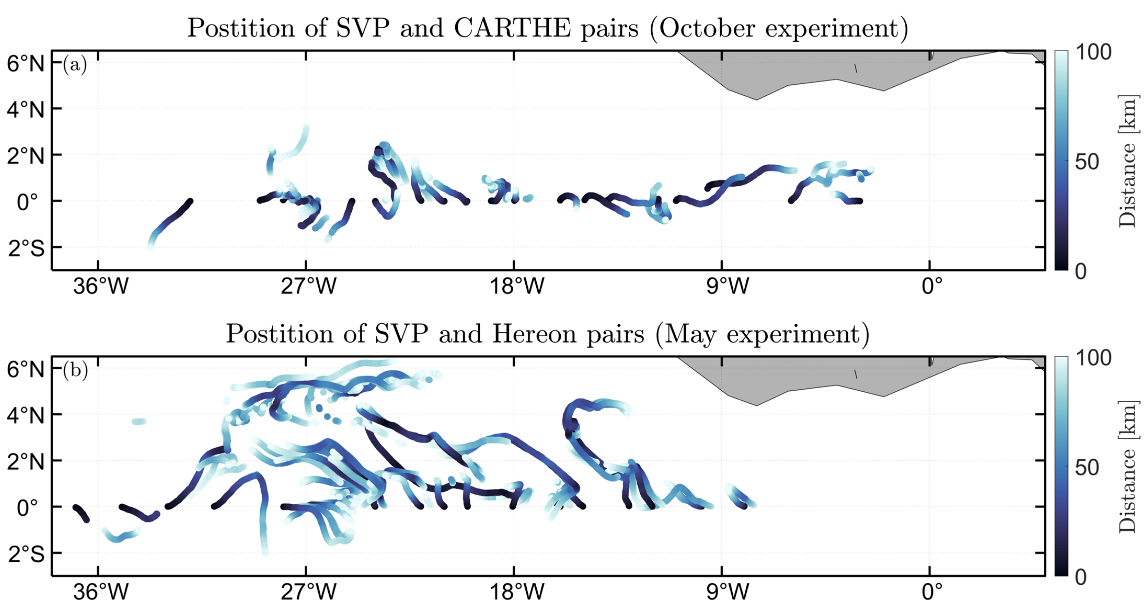

Figure S2. Positions of the collocated drifter pairs. The collocation is performed for (a) SVP and CARTHE drifters deployed during the October drifter experiment and for (b) SVP and Hereon drifters deployed during the May drifter experiment with the mean distance between the paired drifters shown in colour.

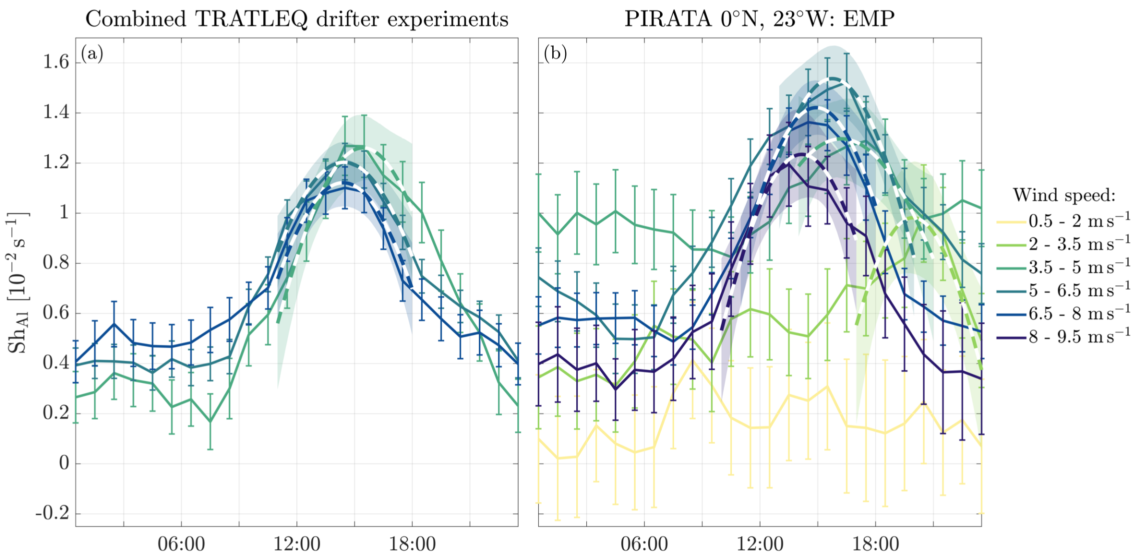

Figure S3. Mean diurnal cycles of along-wind shear (Sh_{Al}) as a function of LST and wind speed. Sh_{Al} is derived (a) between 0.5 m and 15 m depth for both drifter experiments and (b) between 4.3 m and 14.8 m depth for the EMP at the PIRATA site at 0°N, 23°W. The colours correspond to different wind speed ranges. Wind speeds at 10 m height are taken from (a) CCMP and (b) PIRATA. If a robust diurnal pattern is present, the associated diurnal peak is fitted to a sinusoidal function which is displayed by the dashed line. The error bars represent the standard error, and the shading marks the 95% CIs to estimate the fitted peak. Note that during the TRATLEQ drifter experiments, 98% of the observed daily-mean wind speeds ranged from 3.4 m s^{-1} to 7.7 m s^{-1} and during the EMP at the PIRATA buoy at 0°N, 23°W from 0.4 m s^{-1} to 9.3 m s^{-1}.

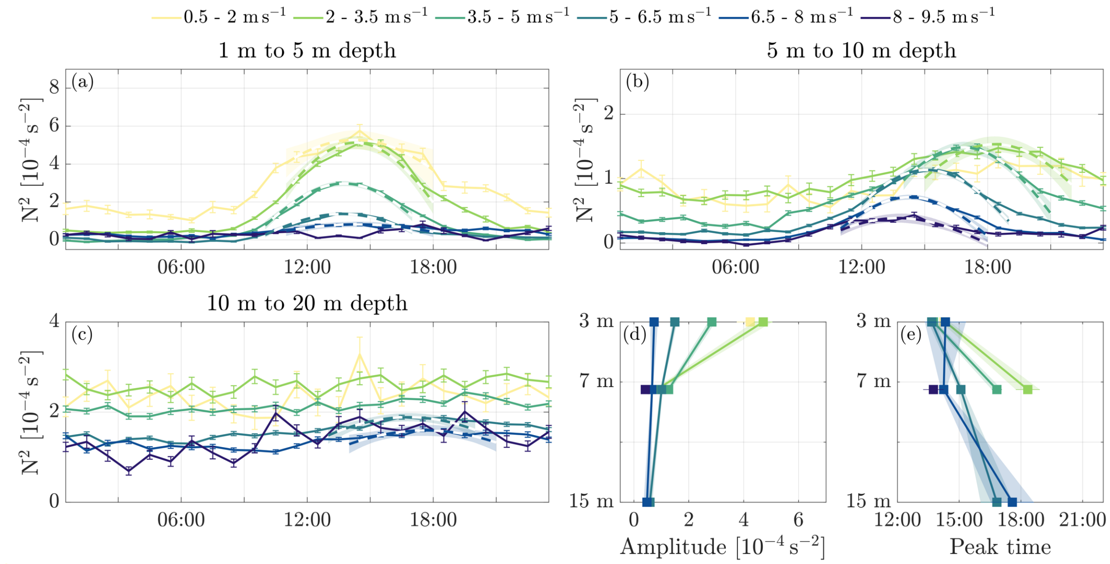

Figure S4. Same as Figure 6 in the paper, but for the PIRATA site at 0°N, 10°W.

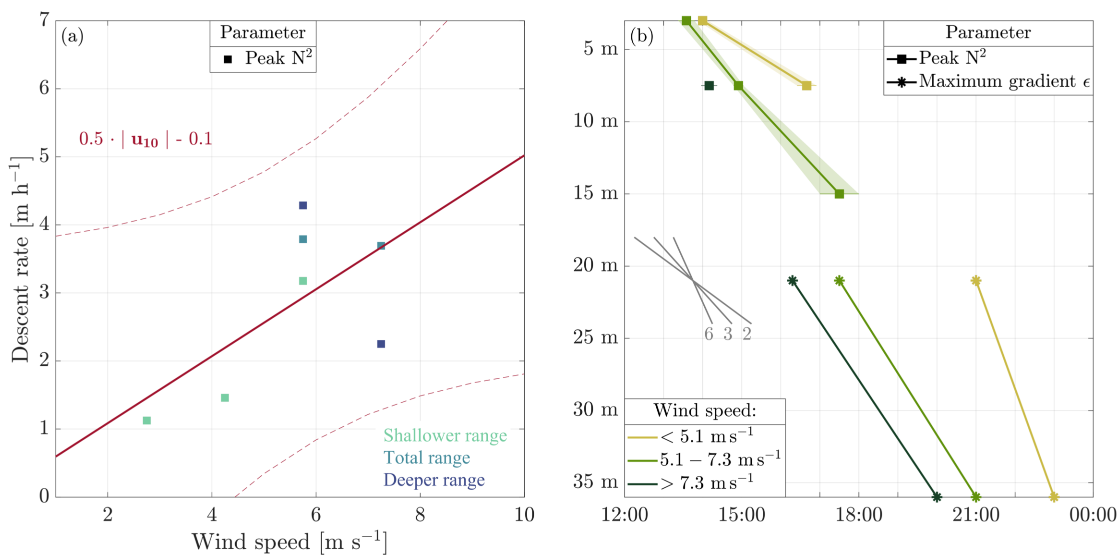

Figure S5. Same as Figure 7 in the paper, but for the PIRATA site at 0°N, 10°W.

IMEI number	WMO number
300234066438030	4401868
300234066025240	1501669
300234067112260	1501663
300234066513790	4402502
300234067112280	1501664
300234066438020	4401867
300234067112240	1501661
300234066025220	1501667
300234066518820	4402500
300234067112180	1501660
300234067112250	1501662
300234066438040	4401869
300234066519790	4402503
300234067111290	1501659
300234066025230	1501668
300234067111280	1501658
300234066838680	4401859
300234066514830	4402501
300234067110240	1501655
300234066025210	1501666
300234064909760	1501654
300234066514800	4101773
300234067110300	1501657
300234066837700	4401858
300234067110280	1501656
300234066025100	1501665

Table S1. IMEI and corresponding WMO numbers of the SVP drifters deployed during the October drifter experiment.

IMEI number	WMO number
300534062125180	1501765
300534062123870	1501761
300534062124880	1501764
300534062123380	1501760
300534062122880	1501758
300534062123370	1501759
300534062023990	1501768
300534062023750	1501766
300534062123880	1501762
300534062024550	1501769
300534062024720	1501770
300534062023970	1501767
300534062124870	1501763
300534062024940	1501774
300534062024800	1501773
300534062024960	1501775
300534062024730	1501771
300534062024770	1501772

Table S2. IMEI and corresponding WMO numbers of the SVP drifters deployed during the May drifter experiment.