Observed Yanai Wave Trajectories in the Western Equatorial Atlantic

Alexandra Andrae*[1], Peter Brandt[1], Rebecca Hummels[1], Franz Philip Tuchen[2], and Joke Lübbecke[3]

[1]GEOMAR Helmholtz Center for Ocean Research, Kiel, Germany; [2]Rosenstiel School of Marine, Atmospheric, & Earth Science, University of Miami; [3]University of Bremen

1 Background

- The western equatorial Atlantic is characterized by a zonal equatorial current system and the North Brazil current (NBC, Fig. 1).

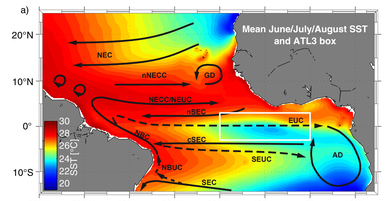

Figure 1: Surface (solid) and subsurface (dashed) tropical currents in the Atlantic with 1998-2009 mean June-August SST (in °C). Figure from [2].

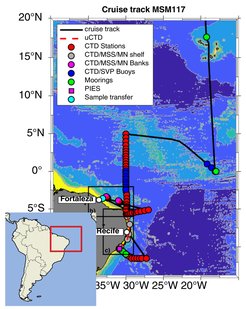

Figure 2: Cruise track of MSM117 in May-June, 2023, with stations and zoomed-out map of South America. [3]

- The NBC transports water northward across the equator as part of the Atlantic Meridional Overturning Circulation. [1]
- During cruise MSM117 in May and June, 2023, 8 surface drifters were deployed along 35°W (Fig. 2).

2 Observations

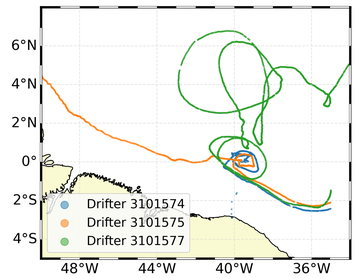

Figure 3: Trajectories of surface drifters deployed at 35°W during cruise MSM117 in May 2023 (data: [A]).

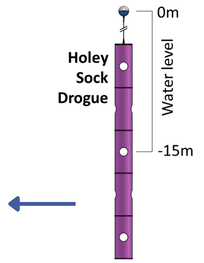

Figure 4: Sketch of a SVP drifter with head buoy and drogue (adapted from [B]).

- Surface Velocity Programm (SVP) drifters float with the upper 30m of ocean currents (Fig. 4).
- 3 drifters encountered a circular motion centered at the equator at about 40°W.
- The observed period was 14 days, with radii between 60 and 140 km (Fig. 3).

Takeaway: Drifters followed circular trajectories centered at the equator.

3 Yanai Waves

- Yanai waves are trapped around the equator propagating eastward. They are observed in all ocean basins often with periods of 10 to 30 days and long wavelengths. [4]
- Yanai waves have a non-zero meridional velocity at the equator, necessary to move the drifters northward and out of the strong NBC.

Generation mechanism

- In the ocean, Yanai waves can be generated e.g., by fluctuations in the meridional wind component. [5,6]

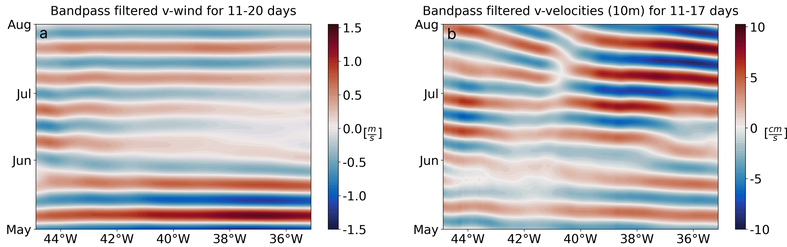

Figure 5: a) Bandpass filtered meridional wind component for 11-20 days [m/s] (data: [C]), b) upper 10m-surface currents for 11-17 days [cm/s] (data: [D]). Both panels are averaged over 1.5°N to 1.5°S.

- Biweekly fluctuations are visible in the meridional wind component (Fig. 5a) and the surface currents (Fig. 5b) consistent with a 14-day Yanai wave.

Takeaway: Yanai waves can be generated by meridional wind anomalies.

5 Discussion and Summary

- Drifters followed circular trajectories at 40°W centered at the equator with a period of 14 days.
- 14-day Yanai waves can be generated by biweekly fluctuations of the meridional wind component.
- Observed situation is reproducible in about 10% of the cases using a mean state velocity field combined with a 14-day Yanai wave velocity field.
- Most favorable conditions are amplitudes >0.6 m/s, wave phases that generate northward velocities at the equator, and deployment locations south of the equator.
- Rarely observed before: Drifters tend to leave the equator quickly due to poleward Ekman transport.
- Further investigation of mooring or ship-based velocity data could confirm the presence of a 14-day Yanai wave.

4 Reproducing the Observations with Artificial Drifter Trajectories

Drifter Trajectories

- The situation was reproduced using a simple model calculating artificial drifter trajectories (Fig. 6).
- The next position $(x(i+1), y(i+1))$ is obtained using the previous position $(x(i), y(i))$ and a velocity field (u, v) that contains a climatological background field and Yanai wave velocities:

$$x(i+1) = x(i) + [u_{Yanai}(x(i), y(i)) \cdot A + u_{Background}(x(i), y(i))] \cdot dt$$
$$y(i+1) = y(i) + [v_{Yanai}(x(i), y(i)) \cdot A + v_{Background}(x(i), y(i))] \cdot dt$$

where:
dt: time step was set to 20 min;
A: amplitude of the Yanai wave was estimated by the cross-equatorial drift velocity.

Yanai Wave Velocities

- Yanai waves can be described using the linearized gravity-reduced shallow water equations on an equatorial β-plane.
- Yanai wave velocities (u_{Yanai}, v_{Yanai}) can be described as solutions to the dispersion relation $\frac{\omega}{c} - k - \frac{\beta}{\omega} = 0$. [7]

$$u_{Yanai} = -\frac{\omega y}{c} e^{\frac{-\beta y^2}{2c}} sin(kx - \omega t)$$
$$v_{Yanai} = e^{\frac{-\beta y^2}{2c}} cos(kx - \omega t)$$

where:
ω: wave frequency; k: zonal wave number;
c = 1.3 m/s: gravity wave speed (2. baroclinic mode);
β: meridional gradient of the Coriolis parameter.

Artificial Drifter Experiment

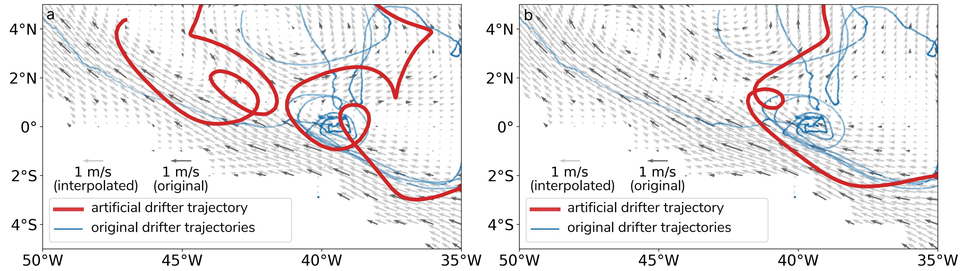

Figure 6: Examples of observed (blue) and artificial (red) drifter trajectories with an interpolated (light grey arrows) climatological background field averaged over the upper 15m (data: [E]).

Throughout the experiment, initial conditions were varied:
- amplitude of the Yanai wave 0.5-0.7 m/s
- phase of the Yanai wave 0-2π
- deployment position of the artificial drifter $x(0)$ and $y(0)$
- background field, monthly climatological fields for May, June, and July derived from drifter data.

In total, 1.447 (40°W) and 434 (35°W) artificial drifters were deployed. About 10% reproduced a scenario close to the observations.

Takeaway: In certain conditions, Yanai waves can produce circular trajectories at the surface.

Contact
*aandrae@geomar.de

GEOMAR Helmholtz Centre for Ocean Research Kiel

University of Miami Rosenstiel School of Marine, Atmospheric, & Earth Science

Universität Bremen

Data

[A] Drifter trajectories: https://osmc.noaa.gov/erddap/tabledap/OSMC_flattened.html
[B] Lagrangian Drifter Laboratory of Scripps Institution of Oceanography (https://gdp.ucsd.edu/ldl/svp/, 04/26)
[C] Wind: https://www.remss.com/measurements/ccmp/ [8]
[D] Currents: https://data.marine.copernicus.eu/product/GLOBAL_MULTIYEAR_PHY_001_030 description doi: https://doi.org/10.48670moi-00021
[E] Drifter climatology: https://www.aoml.noaa.gov/phod/gdp/mean_velocity.php [9]

References

[1] **Tuchen**, F. P., Brandt, P., Lübbecke, J. F., & Hummels, R. (2022a). Transports and pathways of the tropical AMOC return flow from argo data and shipboard velocity measurements. Journal of Geophysical Research: Oceans, 127 (2). https://doi.org/10.1029/2021JC018115
[2] **Brandt**, P., Caniaux, G., Bourlès, B., Lazar, A., Dengler, M., Funk, A., Hormann, V., Giordani, H., & Marin, F. (2011). Equatorial upper ocean dynamics and their interaction with the west african monsoon. Atmospheric Science Letters, 12 (1), 24–30. https://doi.org/10.1002/asl.287
[3] **Hummels**, R., et al (2024). Circulation, flow-topography interaction and ecosystem impact, Cruise No. MSM117, 10.05.2023 - 15.06.2023, Recife (Brazil) - Ponta Delgada (Açores, Portugal). MARIA S. MERIAN-Berichte (MSM117, 1-44). Begutachtungspanel Forschungsschiffe. https://doi.org/10.48433/cr_msm117
[4] **Shinoda**, T. (2012). Observation of first and second baroclinic mode yanai waves in the ocean. Quarterly Journal of the Royal Meteorological Society, 138 (665), 1018–1024. https://doi.org/10.1002/qj.968
[5] **Athie**, G., & **Marin**, F. (2008). Cross-equatorial structure and temporal modulation of intraseasonal variability at the surface of the tropical atlantic ocean. Journal of Geophysical Research: Oceans, 113, 2007JC004332. https://doi.org/10.1029/2007JC004332
[6] **Chatterjee**, A., Shankar, D., McCreary, J., & Vinayachandran, P. N. (2013a). Yanai waves in the western equatorial indian ocean. Journal of Geophysical Research: Oceans, 118 (3), 1556–1570. https://doi.org/10.1002/jgrc.20121
[7] **Gill**, A. E. (2006). Atmosphere-ocean dynamics (Nachdr.). Acad. Press.
[8] **Mears**, C. L., Ricciardulli, T., Wang, L., Wentz, X., & F. (2022). Rss cross-calibrated multi-platform (ccmp) 6-hourly ocean vector wind analysis on 0.25 deg grid, version 3.1. Remote Sensing System, Santa Rosa, CA. https:/doi.org/10.56236/RSS-uv6h30
[9] **Laurindo**, A. M., L., & Lumpkin, R. (2017). An improved near-surface velocity climatology for the global ocean from drifter observations. Deep-Sea Res. I, 124, 73–92. https://doi.org/10.1016/j.dsr.2017.04.009