A Review of Measuring Upper Ocean Responses to Hurricanes

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1. Introduction

❖ The upper ocean and hurricanes have a complex relationship:

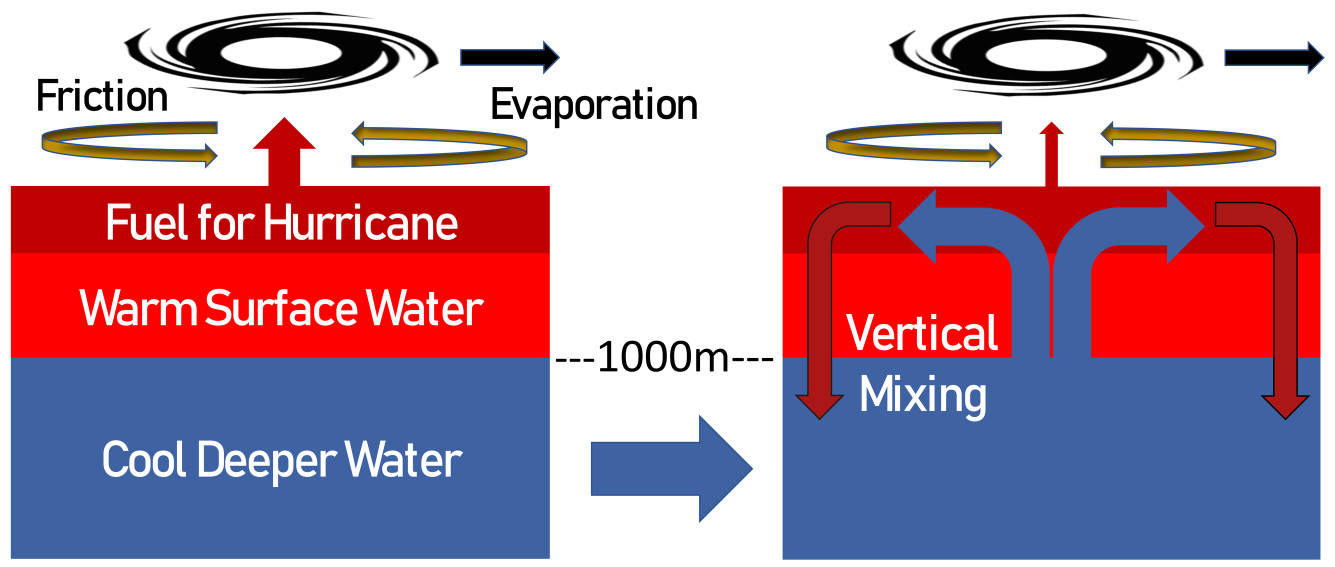

Figure 1: The left shows how the upper ocean affects hurricane intensity and development by supplying energy through frictional heat of the winds and latent heat of evaporation. The right shows how a hurricane affects the upper ocean through driving vertical mixing by upwelling of cold water to the surface and downwelling warm water from the surface.

Data Assimilation and Numerical Model Forecasting

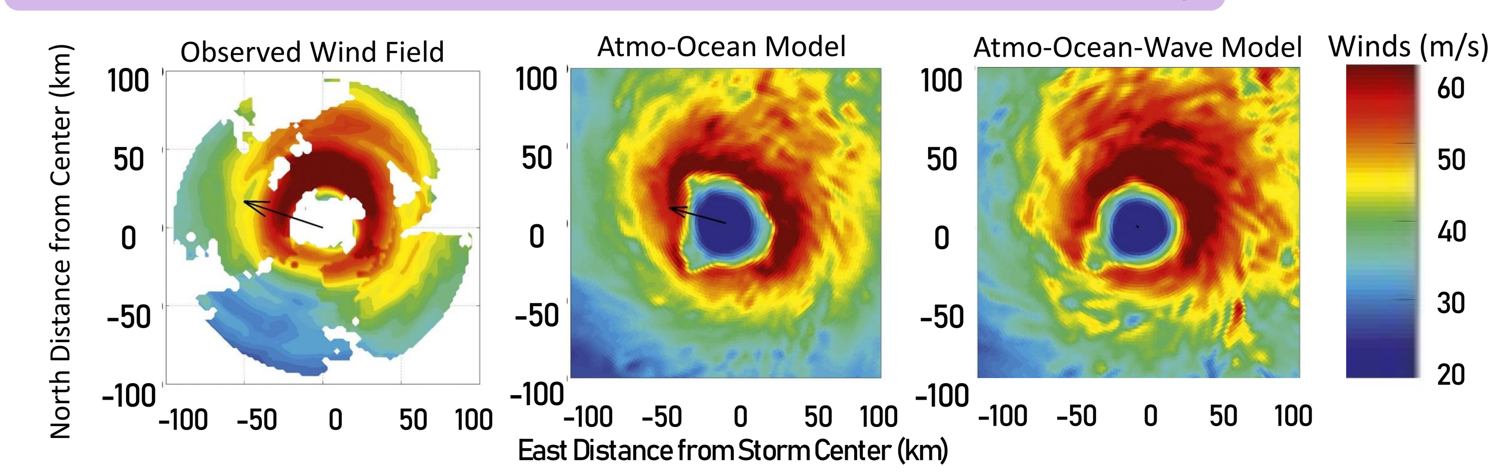

Figure 2: From Chen et al. (2013). Observed airborne Doppler radar wind field compared with a coupled atmosphere-ocean model and coupled atmosphere-ocean-wave model.

❖ Increased upper ocean data can make data assimilation more powerful in numerical models used for hurricane forecasting.

2. Early Methods

❖ In the 1960's-70's an invaluable data source came from observations aboard shipping vessels, including sea surface temperature and atmospheric conditions

Figure 3: By Karsten Petersen. The Danish cargo liner "Boribana".

Bathythermograph

Figure 4: By Tin Can Sailors. A bathythermograph (BT) used in the 1960's.

❖ BT's verified SST cooling following the passage of a hurricane that was first observed by merchant vessels at sea.

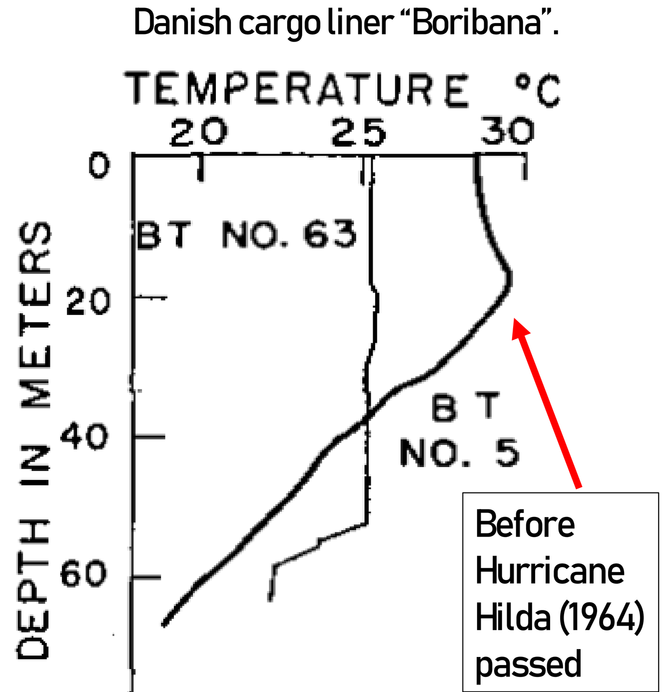

Figure 5: From Leipper (1967). Temperature vs Depth from a BT.

3. *In Situ* Instrumentation

❖ The development of *in situ* instruments greatly improved the temporal and spatial coverage of upper ocean data during and after hurricanes.

3a Gliders

Figure 6: Teledyne Marine Slocum glider.

❖ Gliders take profiles of different data along a programmed track, giving scientists control of where measurements can be taken.

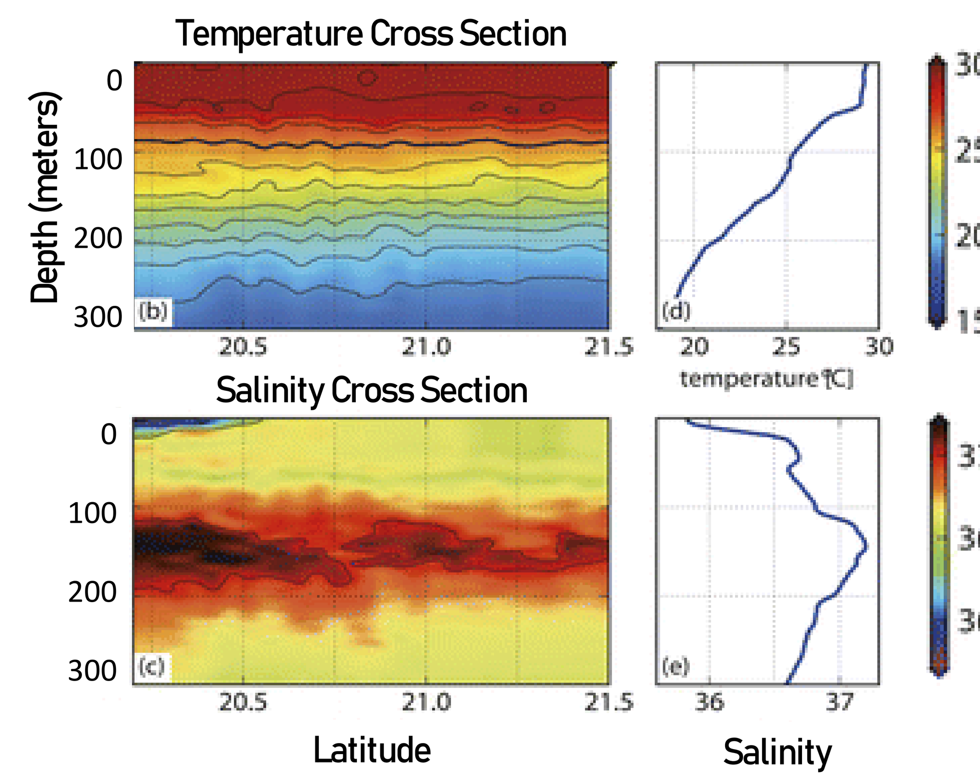

Figure 7: From Dong et al. (2017). pre-storm conditions in North Atlantic in Oct. 2014, before Hurricane Gonzalo.

3b. Floats & Drifters

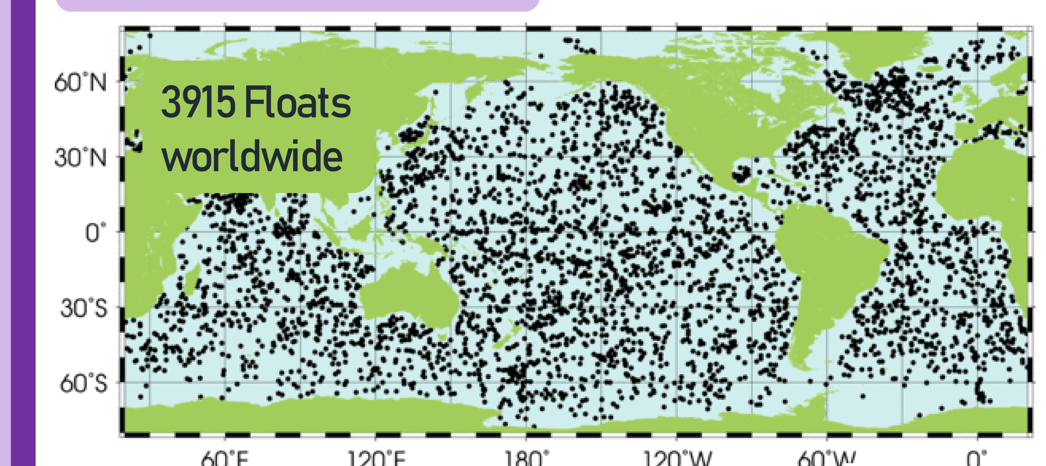

Figure 9: From the Argo official website showing the number of deployed floats as of 3/10/19.

Figure 8: By NOAA Research News. An Argo float being deployed from a boat.

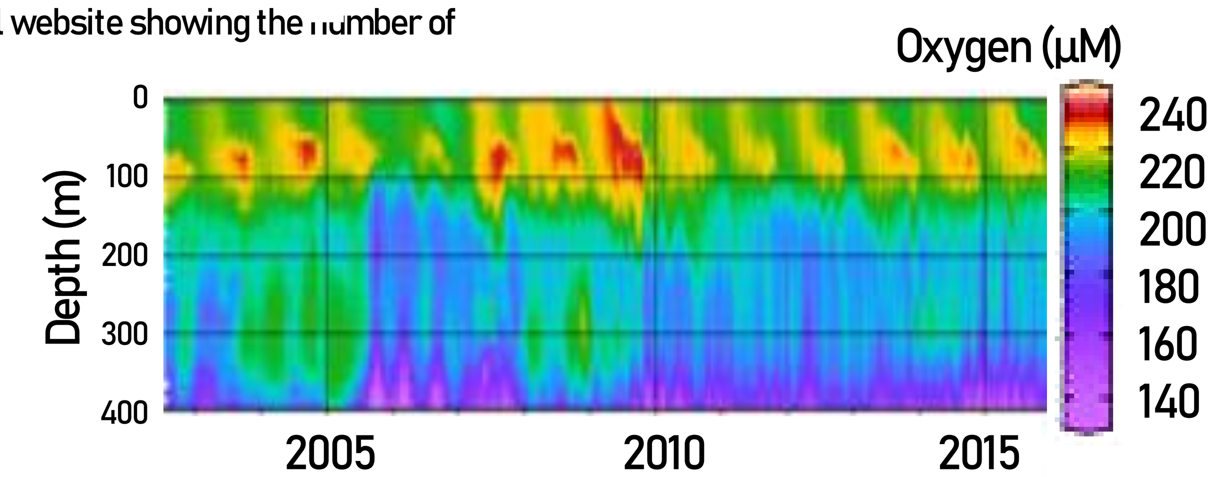

Figure 10: Modified from the Argo official website. Data is demonstrating new innovative biogeochemical sensors that have been added to some floats.

❖ Argo floats have greatly increased the spatial coverage of ocean data and the chance to measure near hurricane events.

3c. Moored Systems

Figure 11: Buoy from National Data Buoy Center

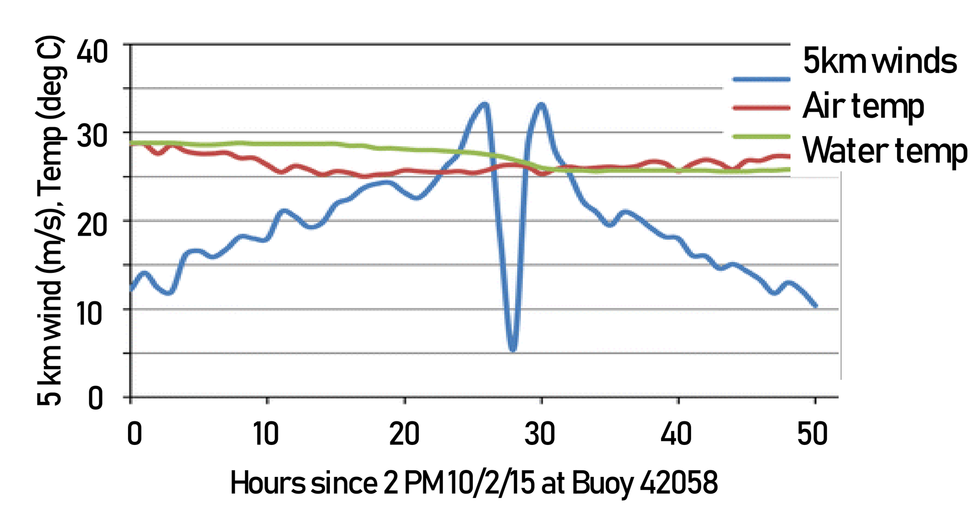

Figure 12: From Hsu (2017). 5-km wind speed, air temperature and water temp. during the time of Hurricane Matthew (2016).

❖ Moored systems combine multiple sensors to provide many detailed data of both the atmosphere and the ocean.

❖ These systems reveal the limitation of *in situ* instruments— they can only measure data at one location at a time.

4. Remote Sensing

❖ Remote sensing by geostationary (GOES) and polar orbiting satellites gives a bigger, detailed picture of changes occurring in the upper ocean following hurricanes.

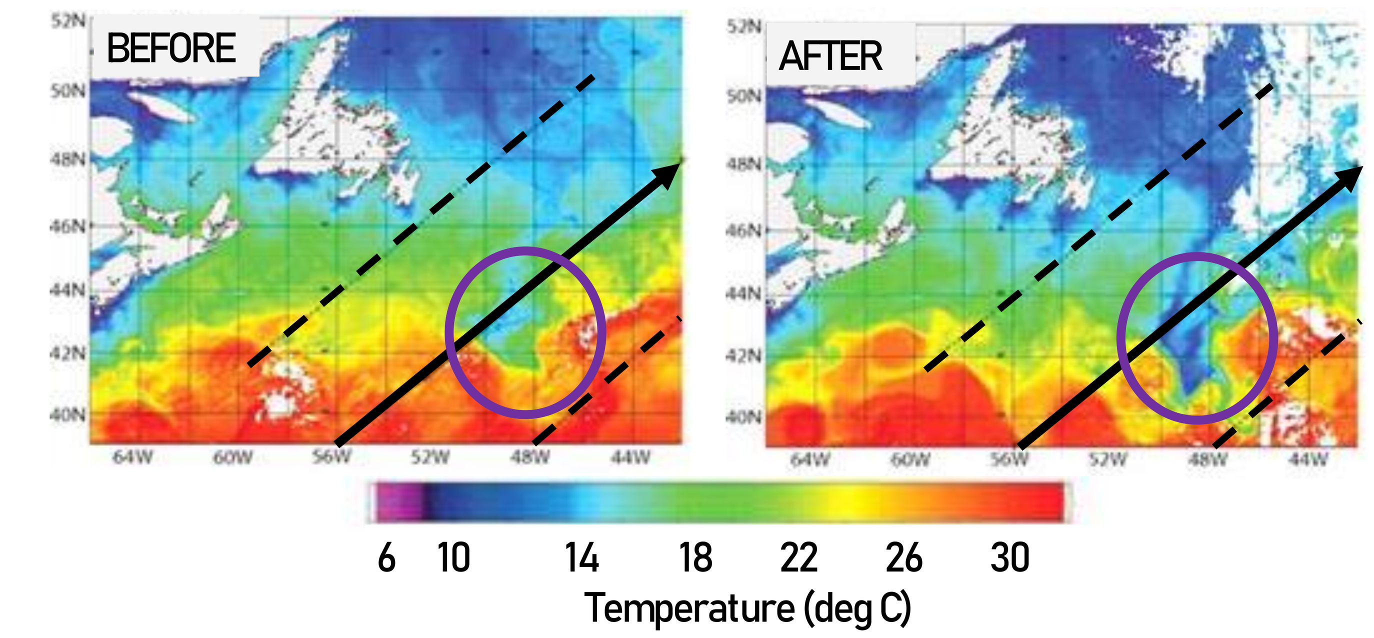

Figure 13: Modified from Son et al. (2007). Composite satellite images of sea surface temp before and after the passage of Hurricane Fabian (2004). Black arrows are storm track. Dashed lines are 350 km from storm center. Circles show regions of SST cooling after the

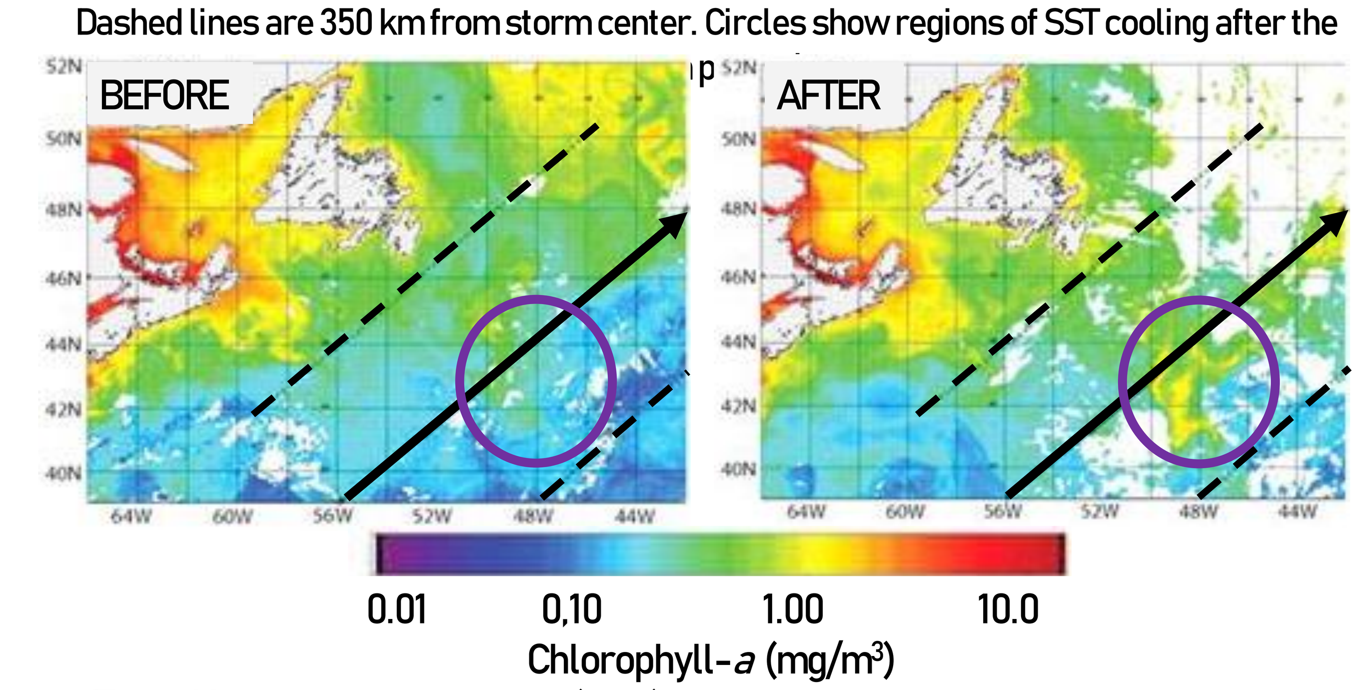

Figure 14: Modified from Son et al. (2007). Composite satellite images of chlorophyll-*a* concentration before and after Hurricane Fabian (2004). Lines are the same as **Figure 13**. Circles show location of a large phytoplankton bloom.

❖ New innovations in remote sensing for ocean color have led to leaps in understanding the biological response to hurricanes.

5. Outstanding Research

❖ How can we better understand and model hurricane interactions with warm and cold core ocean eddies?

❖ What microbes are present in post-storm phytoplankton blooms in various oceans?

❖ Can bloom size and location be predicted from hurricanes to take direct samples?

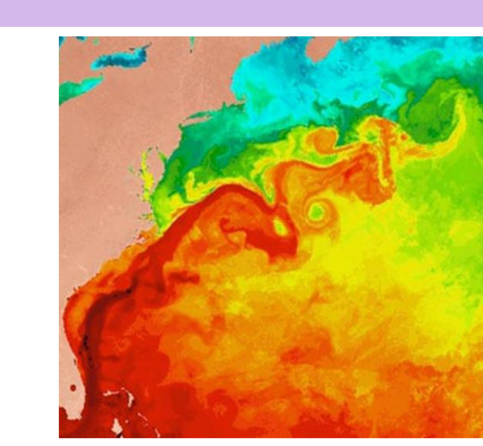

Figure 15: NASA image of eddies in North Atlantic.

6. Conclusion

❖ By combining these different data collection methods, fuller understanding and measurements of upper ocean and hurricane interactions are possible.

❖ Better data will improve modelling and hurricane forecasting.