Estimating Tropical Cyclone-Induced Changes in the Upper Ocean from Argo Profiles

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Highlights

- Wind-driven vertical mixing by hurricane-strength tropical cyclones (TCs) has impacts on upper ocean stratification
- The upper ocean response to TC-induced vertical mixing depends on the salinity structure before the TC arrival:
  - Upper ocean salinity increases (decreases) in regions where before-TC salinity increases (decreases) with depth
  - Temperature decreases and density increases in both regions in the top 40 dbar (the strength of the signal depends on the before-TC salinity vertical structure)
- TC-induced changes in upper ocean stratification may have implications for air-sea exchanges

Key words

- Air-sea interactions
- Hurricane-strength tropical cyclones
- Upper ocean properties (absolute salinity, conservative temperature, potential density)
- Argo floats
- HYCOM ocean reanalysis
- Composite analysis

Motivation and Goals

- Tropical cyclones (TCs) have devastating effects on land, with strong air–sea interactions prior to landfall.
- We describe TC-induced changes in upper ocean and mixed layer (ML) properties (salinity, temperature and potential density) globally from Argo observations.
- We also describe upper ocean changes during hurricane-strength wind events from HYCOM ocean reanalysis.

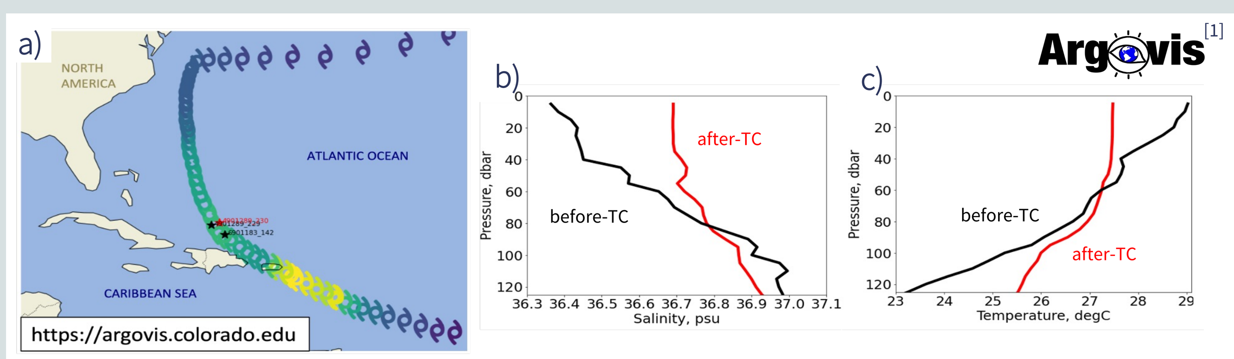

Fig. 1 As hurricane Maria moves over the ocean (panel a), TC-induced mixing along its track causes changes in (b) salinity and (c) temperature. In panel a, TC symbols are color coded by wind (increasing from blue to green to yellow).

Data

HYCOM ocean reanalysis [2]:

- Years 2011-2015
- 7 regions considered (red boxes in Fig. 2)
- Ocean salinity and temperature
- Precipitation and wind speed

Argo observations [3]:

- Years 2004-2020
- Region of study: global, i.e. where profiles co-located with TCs are available
- Temperature and salinity profiles

TC tracks [4]:

- Tropical cyclone best track data from:
  - National Hurricane Center (HURDAT2)
  - Joint Typhoon Warning Center (JTWC)
- Only hurricane-strength tropical cyclones included (i.e. wind speed > 64 knots)

Methods

HYCOM:

- Selection of hurricane-strength wind events (based on HYCOM forcing) within regions of interest (Fig. 2)
- Salinity and temperature time series co-located with hurricane-strength wind events are stored
- Composite analysis of upper ocean (salinity, temperature and potential density) changes during hurricane-strength wind events
  - Comparison between regions where before-event upper ocean salinity increases vs decreases with depth**

Argo:

- Finding TC events (one before-TC, one after-TC Argo profile are needed) [5]
- Removing seasonal signal [5]
- Estimating pointwise confidence intervals [5]
- Smoothing [5]
- Comparison between regions where before-TC upper ocean salinity increases vs decreases with depth**

** See label "increasing" vs "decreasing" in the figures

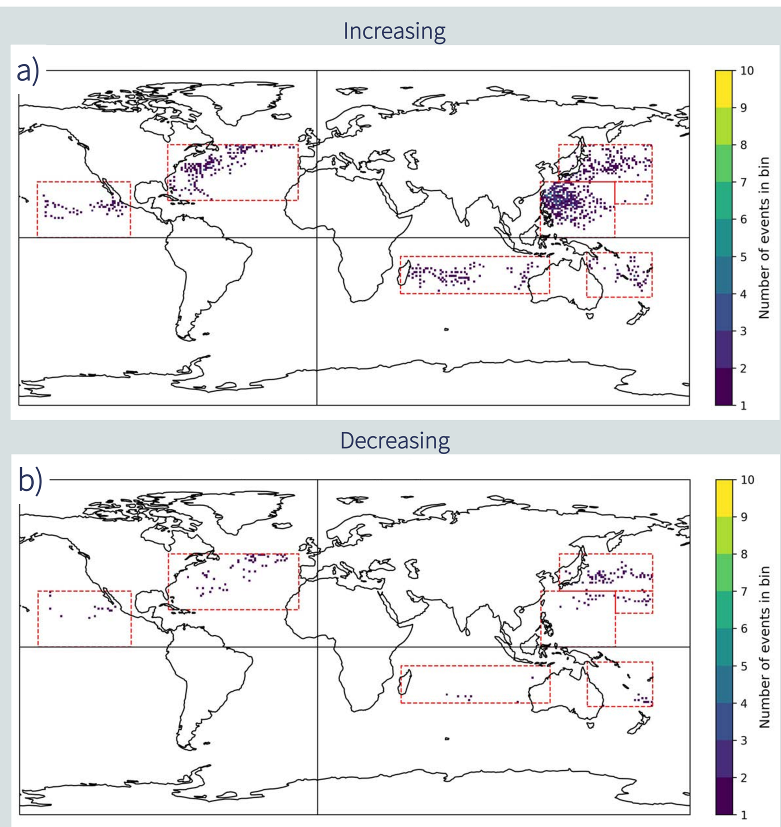

Fig. 2 Number of hurricane-strength wind events in HYCOM (in 1x1 degree bins) in regions of interest (red boxes). Maps include locations where before-event upper ocean salinity (a) increases, (b) decreases with depth.

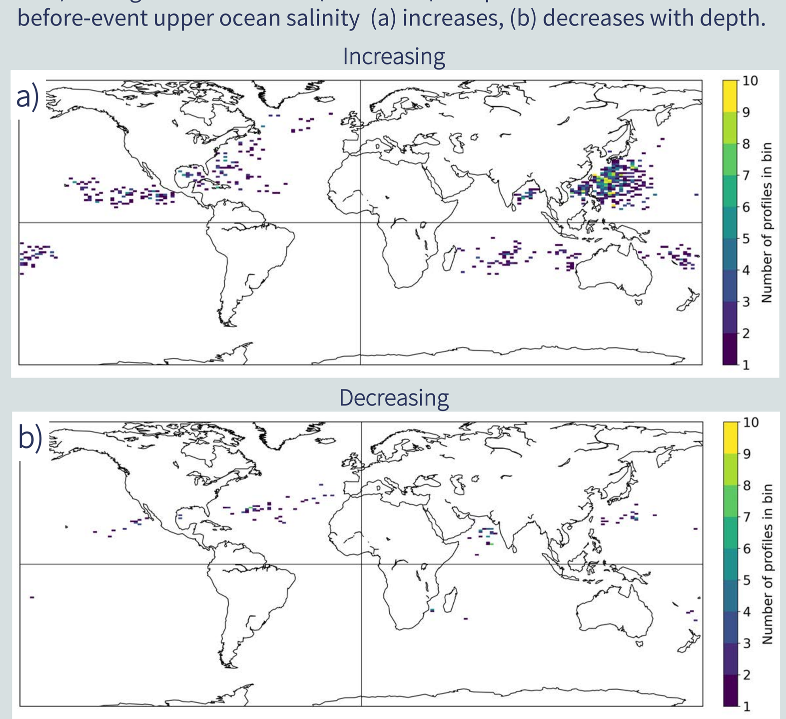

Fig 3 Number of hurricane-strength TCs (in 1x1 degree bins) co-located with Argo profiles. Maps include locations where before-TC upper ocean salinity (a) increases, (b) decreases with depth.

Upper ocean changes during hurricane-strength wind events: composites from HYCOM ocean reanalysis in regions where before-event upper ocean salinity increases vs decreases with depth

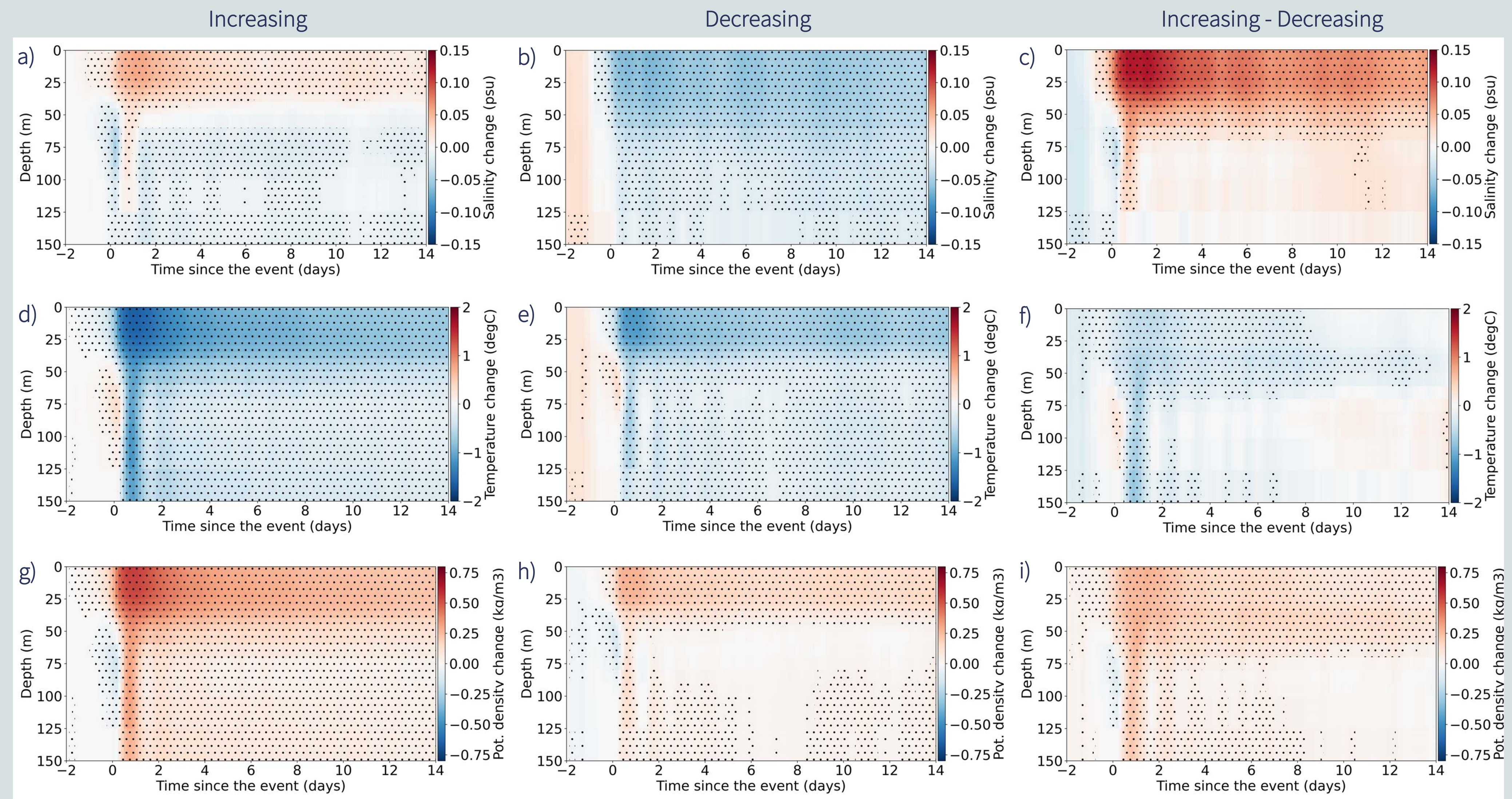

Fig. 4 Upper ocean changes during hurricane-strength wind events: HYCOM salinity (a-c), temperature (d-f), and potential density (g-i). Changes are estimated as differences (at the event location) from the profile two days before the event and are shown as composites in regions where before-event upper ocean salinity increases (a, d, g) vs decreases (b, e, h) with depth. Panels (c, f, i) show the difference between the "increasing" case (i.e. panels a, d, g) and the "decreasing" case (i.e. panels b, e, h), e.g. panel c) is a) minus b). Dots indicate statistically significant values (95% confidence limit).

- Upper ocean salinity
  - ↑ where before-event salinity ↑ with depth (Fig. 4a, "increasing" case)
  - ↓ where before-event salinity ↓ with depth (Fig. 4b, "decreasing")
- Upper ocean temperature
  - ↓ regardless of before-event salinity vertical structure (Fig. 4d, e)
  - ↓ more in "increasing" case (Fig. 4f)
- Upper ocean potential density
  - ↑ regardless of before-event salinity vertical structure (Fig. 4g, h)
  - ↑ more in "increasing" case (Fig. 4i)

Statistically significant differences between "increasing" and "decreasing" case, for all the variables (Fig. 4c, f, i)

Upper ocean changes during hurricane-strength tropical cyclones (TCs): results from Argo observations in regions where before-TC upper ocean salinity increases vs decreases with depth

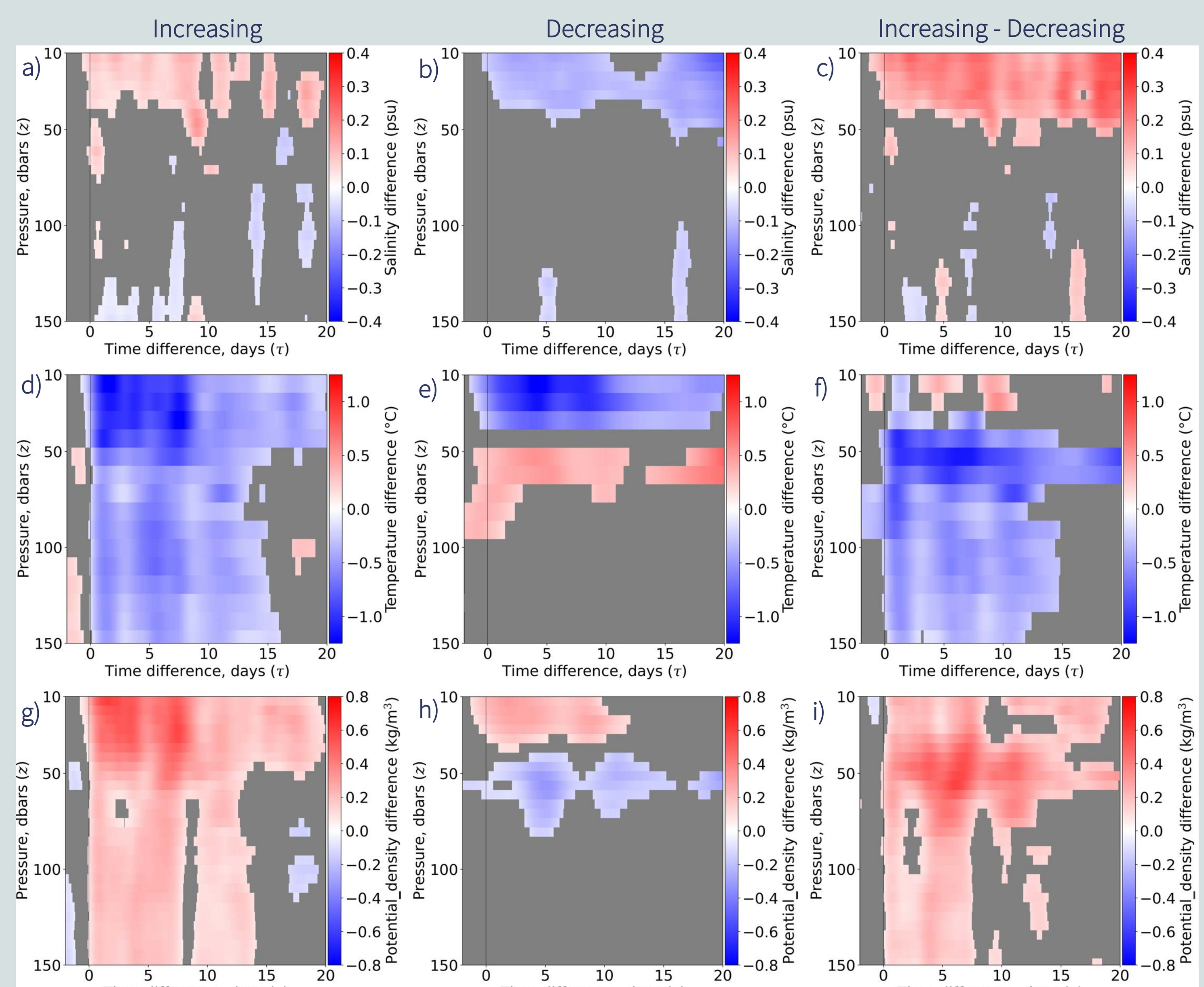

Fig. 5 Upper ocean changes during hurricanes-strength tropical cyclones: Argo salinity (a-c), temperature (d-f), and potential density (g-i). Changes are estimated as differences between after-TC profile and before-TC profile and are shown in regions where before-TC upper ocean salinity increases (a, d, g) vs decreases (b, e, h) with depth. Panels (c, f, i) show the difference between the "increasing" case (i.e. panels a, d, g) and the "decreasing" case (i.e. panels b, e, h), e.g. panel c) is a) minus b). In all the panels, a pointwise α = 0.05 hypothesis test is performed and used to mask areas where we fail to reject the null hypothesis.

- Upper ocean salinity
  - ↑ where before-TC salinity ↑ with depth (Fig. 5a, "increasing" case)
  - ↓ where before-TC salinity ↓ with depth (Fig. 5b, "decreasing")
- Ocean temperature above 40 dbar
  - ↓ for both cases (Fig. 5d, e)
  - ↓ more in "decreasing" case (Fig. 5e)
- Below 40 dbar, temperature
  - ↓ for "increasing" case (Fig. 5d)
  - ↑ for "decreasing" case (Fig. 5e)
- Ocean potential density above 40 dbar
  - ↑ for both cases (Fig. 5g, h)
  - ↑ more in "increasing" case (Fig. 5g)
- Below 40 dbar, potential density
  - ↑ for "increasing" case (Fig. 5g)
  - ↓ for "decreasing" case (Fig. 5h)

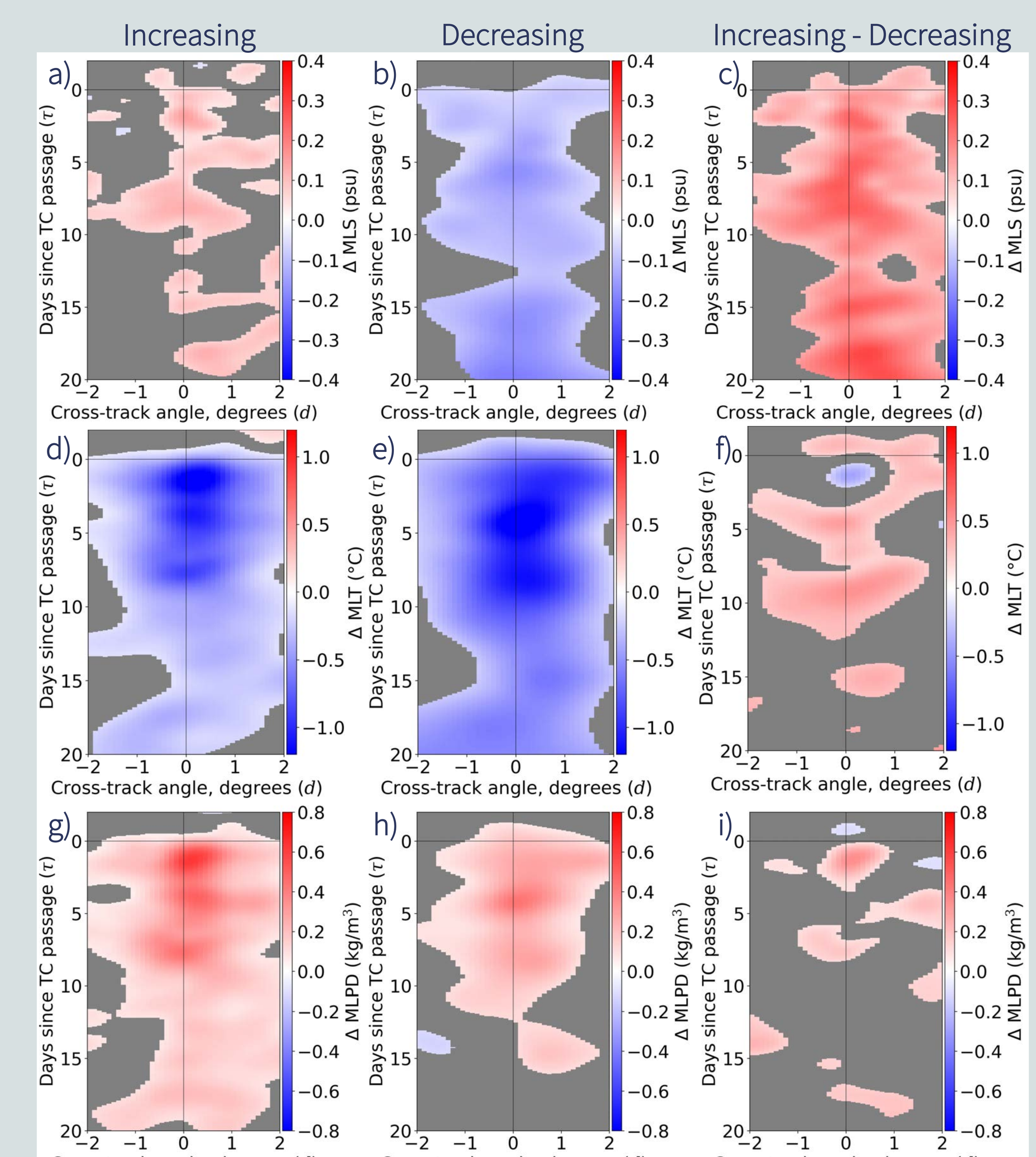

Fig. 6 Upper ocean changes during hurricanes-strength tropical cyclones: Argo mixed layer salinity (a-c), temperature (d-f), and potential density (g-i). Changes are shown in a cross track angle-time reference system (cross-track angle equal zero corresponds to the center of the TC track), for regions where before-TC salinity increases (a, d, g) vs decreases (b, e, h) with depth. Panels (c, f, i) show the difference between the "increasing" case (i.e. panels a, d, g) and the "decreasing" case (i.e. panels b, e, h), e.g. panel (c) is (a) minus (b). All the panels are masked as in Fig. 5.

Changes in mixed layer properties are consistent with changes in the top part of the water column (Fig. 5)

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