Impact of a storm induced downwelling along the New Jersey inner shelf

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Background

- The New Jersey coast, included in the Mid Atlantic Bight (MAB), is characterized by a broad shelf, where the 200 meter isobath (Figure 1, in grey) is located approximately 70 and 100 nautical miles offshore from Cape May and New York Harbor, respectively (Bigelow, 1933).
- The MAB experiences seasonal warming, freshwater river inputs and along shelf transport from the north that result in a strong pycnocline; this strong stratification, characteristic of late spring and summer, is subsequently destroyed in the fall and early winter by storms and surface cooling (Bigelow, 1933; Bigellow & Sears, 1935).
- Historical atmospheric observations for the MAB indicate that the wind over the shelf is mostly from the northwest through most of the year and southwest winds during the summer (Moores *et al*., 1976).
- The distribution of hourly average winds during the summer stratified season is bimodal, with alongshore winds dominating both from the southwest (upwelling favorable) and from the northeast (downwelling favorable) (Kohut *et al*., 2004).
- The sediment transport response in summer and winter storms may be different due to the differences in stratification. For example, the strength of the seasonal pycnocline limits turbulent transport across the layer in summer months (Beardsley & Boicourt, 1981).

Data Source

Data was collected from different sources:

- Meteorological data from three buoys near the New Jersey coast (National Data Buoy Center);
- Real-time surface currents from HF Radars (CODAR);
- Satellite images of Sea Surface Temperature and Ocean Color from AVHRR (NOAA series Satellites) and MODIS (Aqua), respectively;
- Glider – ru05 deployment along the NJ coast from the 20th of August to the 6th of September. The glider was recovered on the 24th August and redeployed on the 26th August.

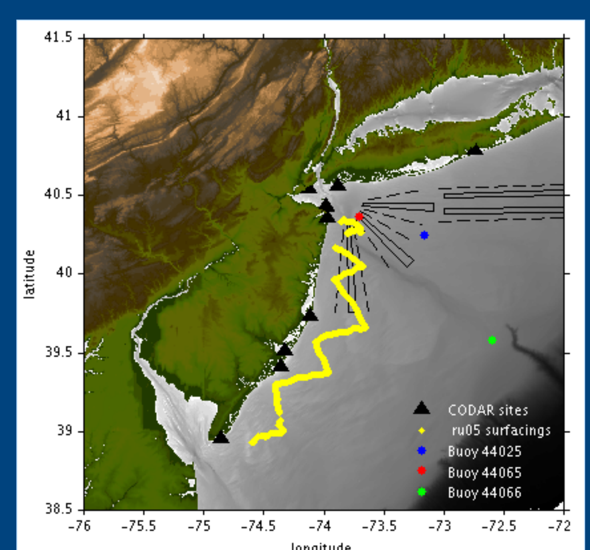

Figure 1: Map of the New York Bight, showing the continental shelf above 200 m depth (highlighted inn grey), the CODAR sites (▲), NDBC buoys (●●●), and the glider flight track (ru05), with two deployments (◆).

Buoy data

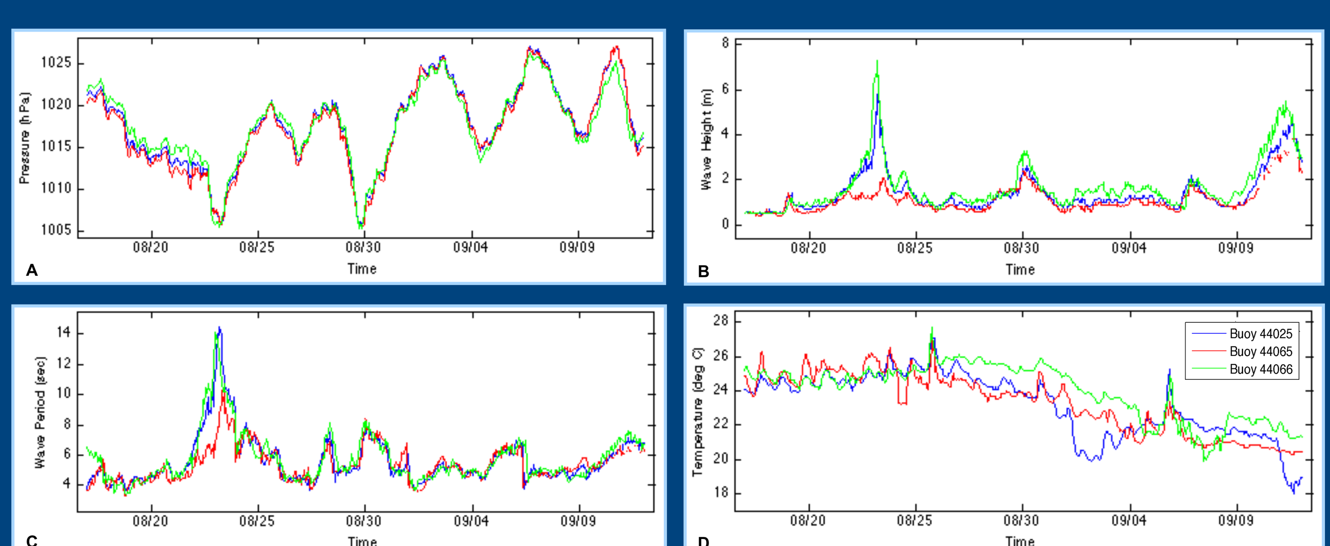

Figure 2: Data collected from 3 NDBC buoys: A) Significant Wave height; B) Sea Level Pressure; C) Average Wave period; D) Sea Surface Temperature (SST).

- Two storms can be identified by the two low pressure systems, on the 23rd August and 30th August (Figure 2A), and coincide with the two increases in significant wave height and wave period (Figure 2B and 2C);
- The largest temperature response in the surface layer is seen with the second storm (figure 2D), especially noticed at the 44025 buoy;

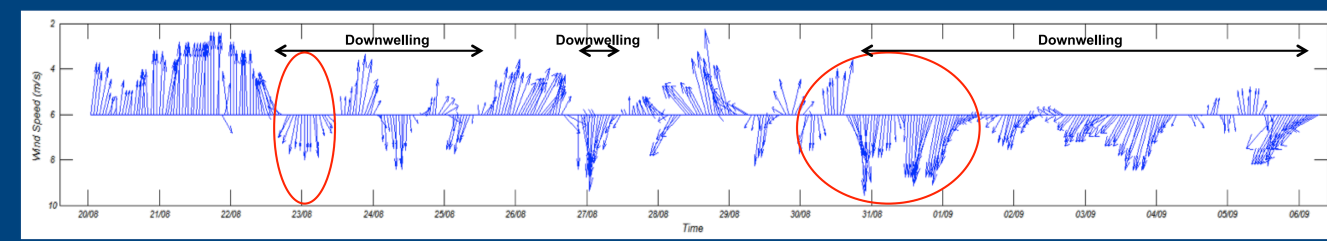

Figure 3: Wind speed and direction (arrows pointing to where the wind is going). The period of the storms are marked in red and the downwelling favorable winds are marked in black.

- During the first storm, the wind rotated from South to North (Figure 3; 4).
- During the second storm, due to the wind direction change and increased intensities, the winds are consistently downwelling favorable. Evidence of this downwelling event is seen in the surface currents (CODAR), satellite SST and glider profiles (Figures 6, 7, 9 and 11) discussed below.

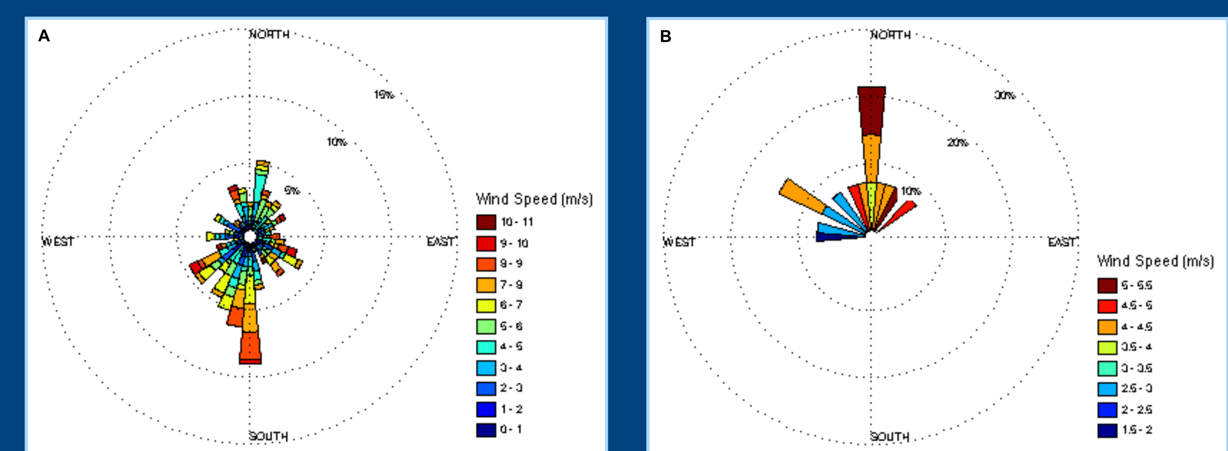

Figure 4: Wind rose. A) Wind speed and directions during the ru05 deployment; B) wind speed and direction during the first storm on 23rd August

- The predominant summer winds come from the Southwest, which was also observed during the ru05 deployment (Figure 4B).
- During the first storm, the winds shifted and came from the North (downwelling favorable); however there were no increase in the wind intensities.

Surface currents (CODAR)

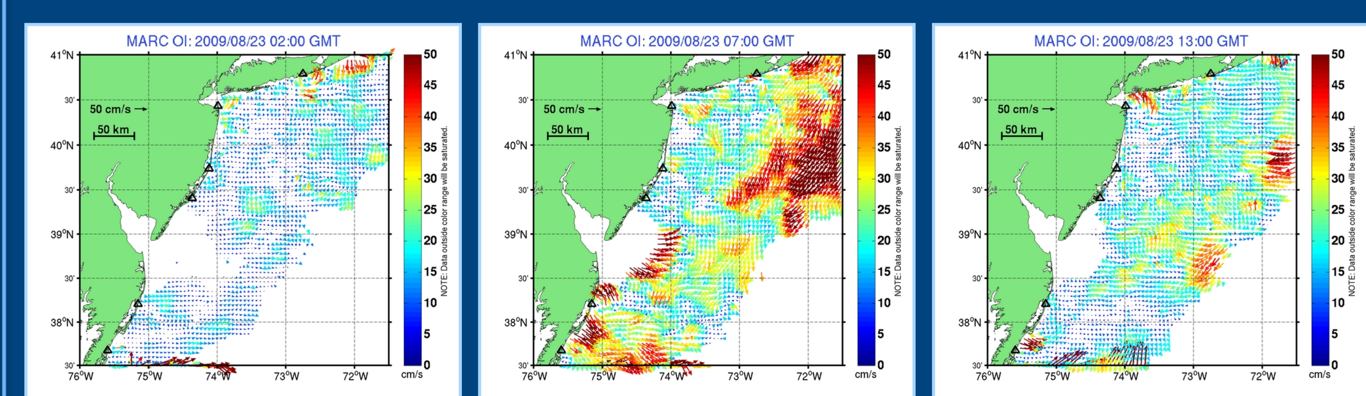

Figure 5: Real-time surface currents before (left), during (middle) and after (right) the first storm.

- The first storm, which caused higher waves with longer period, shown in the buoy data, was short in duration and the effects were felt more off-shore. The winds weren't stronger than usual, so apparently the higher waves were caused by a sudden change in wind direction (Figure 3; 4C).

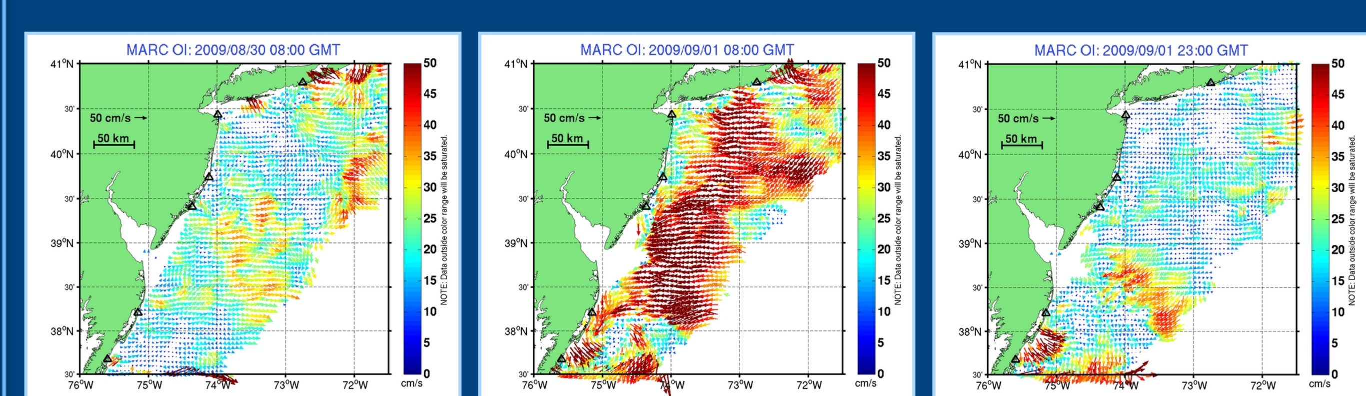

Figure 6: Real-time surface currents before (left), during (middle) and after (right) the second storm.

- In comparison, the second storm, which has a faster decrease in pressure (Figure 2A), lasted for almost two days and the surface currents were stronger and directed onshore (Figure 6), supporting the hypothesis that the second storm coincides with a downwelling event.

Sea Surface Temperature and Ocean Color (Satellites)

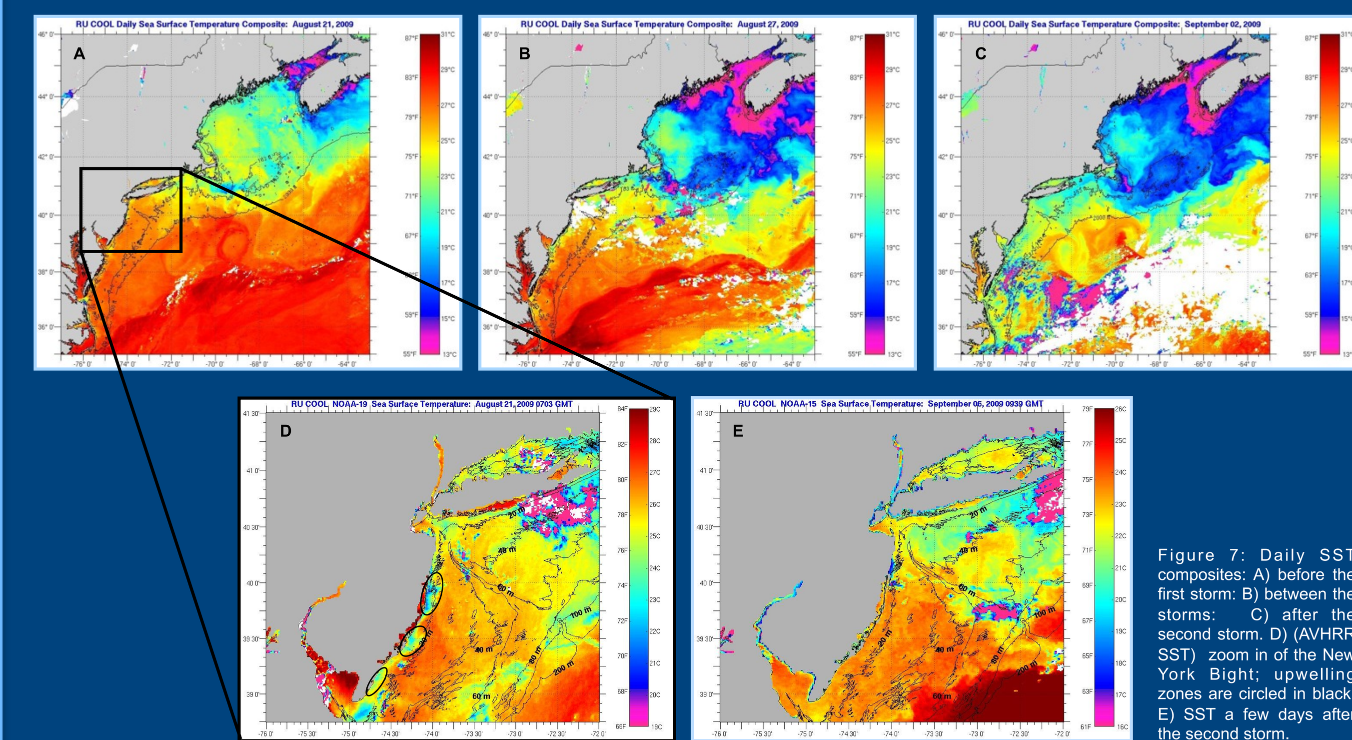

Figure 7: Daily SST composites: A) before the first storm: B) between the storms: C) after the second storm. D) (AVHRR SST) zoom in of the New York Bight; upwelling zones are circled in black. E) SST a few days after the second storm.

- The black circles on Figure 7D show recurring upwelling centers due to topographic variations associated with ancient river deltas (from North to South, offshore of Barnegat Inlet, the Mullica River Estuary, and Townsend/Hereford Inlets). Prior to the storms there is evidence of upwelling in these regions.
- In Figure 7E, while there is an overall decrease in surface temperature following the storms, near shore the upwelling event was disrupted by the onset of downwelling favorable winds (Figure 3). This results are in accordance with Glenn (2004) where during the summer of 1998 there were a series of low-pressure storms that effectively mixed near shore waters.

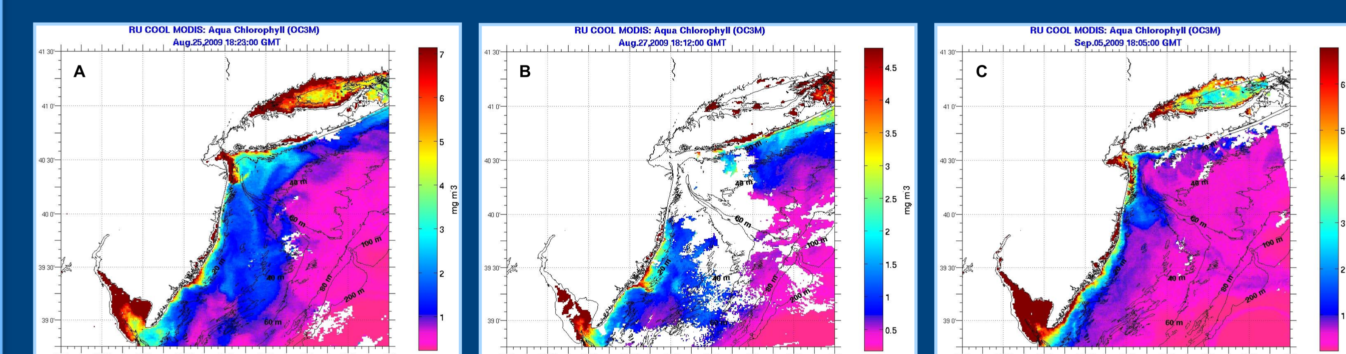

Figure 8: MODIS Aqua Chlorophyll Images: A) before the first storm: B) between storms: C) after the second storm.

- Chlorophyll concentration on the surface diminished after the second storm due to the possible downwelling event that occurred with the wind turn (figure 3, 4, 6)

Sub-surface Data – RU05 Glider Deployment

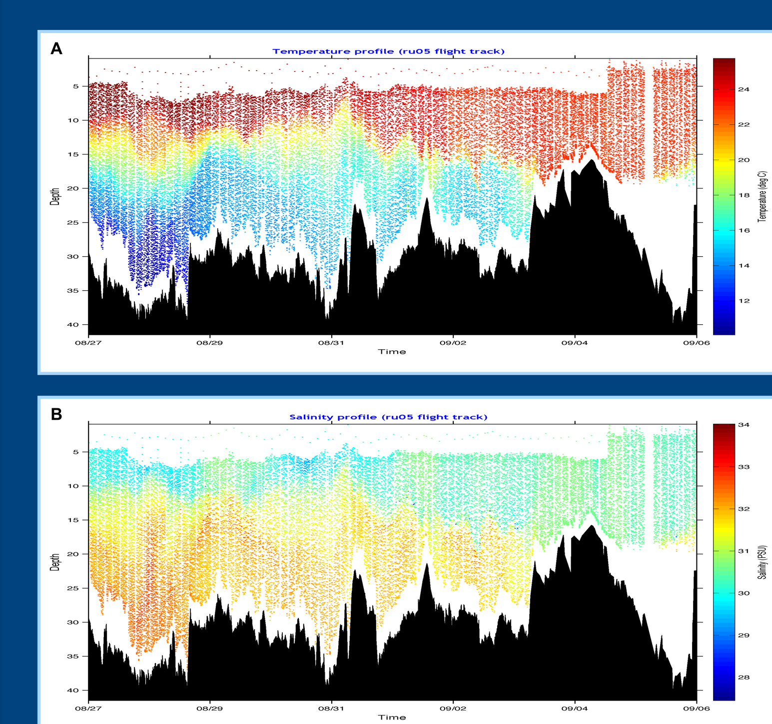

Figure 9: Profile Cross-sections: A) Temperature: B) Salinity

- Temperature of the surface layer decreased approximately 4 °C which is also supported by the SST from the buoys and the satellite images.
- After the second storm, the surface layer gets mixed and the thickness of the thermocline decreases (Figure 9A; 10A).
- The pycnocline also gets sharper (Figure 10B).
- The surface layer deepens; in 10 days, it almost doubles the depth of the water above 20 °C.
- The salinity follows the same pattern as the temperature.

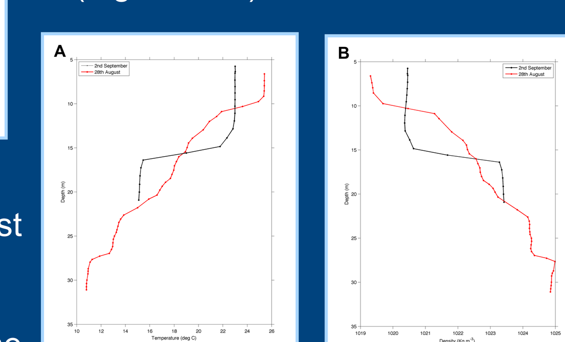

Figure 10: Single profile from before (red) and after the storm (black) for: A) Thermocline: B) Pycnocline

- The highest values of backscatter were found near the bottom, between the 29th and 31st of August and on the 4th of September (Figure 11A).
- Comparing backscatter data with chlorophyll concentration (Figure 11B) and oxygen saturation (Figure 11C), the first period mentioned is probably just the nepheloid layer with suspended sediment. During the summer, this sediment resuspension is limited to below the pycnocline, due to the strong stratification (Glenn *et al.*, 2008).
- In the second time period with high backscatter values (Figure 11A), the concentration of chlorophyll (Figure 11B) is also high. This is most likely higher concentrations seen nearshore (Figure 8C).

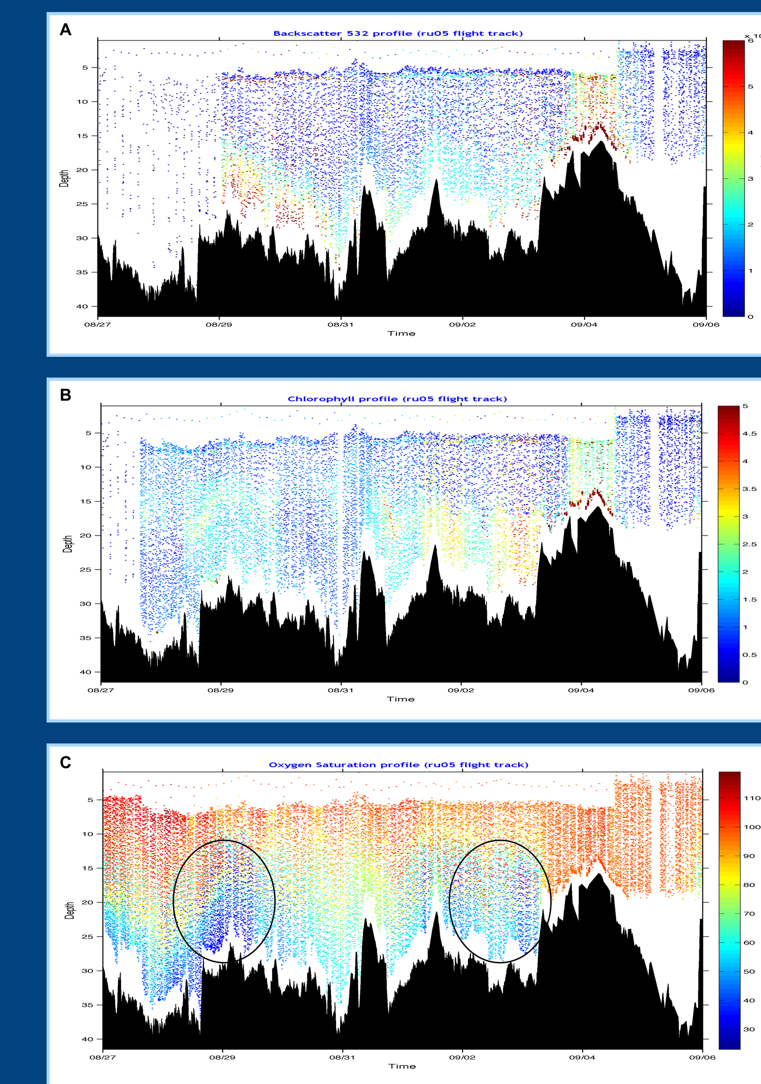

Figure 11: Profile Cross-sections: A) Back-scatter 532: B) Chlorophyll: C) Oxygen Saturation

- The highest chlorophyll values can be found beneath the thermocline (Figure 9A; 10A; 11B).
- The two circles on Figure 11C coincide precisely with two of the three recurrent upwelling centers on the NJ coast that are also co-located with historical regions of low dissolved oxygen (Figure 7D). The fact that there is a higher concentration of chlorophyll at these depths (beneath the thermocline) is an indication that there is probably phytoplankton trapped beneath the pycnocline and therefore, the processes of respiration and decomposition are higher, resulting in decreased oxygen values.

Conclusions

- Storms forcing and water column stratification play an important role in defining the ocean structure.
- Despite the intense mixing during the storm, the surface layer remained distinct from the bottom waters due to the strong pycnocline still present from the summer months.
- The pycnocline also limited the resuspension of sediments on the bottom layer and trapped phytoplankton below creating a low oxygen zone.
- The duration of the storm as well as the wind speed and direction may influence the amount of mixing of the surface layer.

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