Analysis of Sea Breeze Types using WRF and Lagrangian methods

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June 2019

1. INTRODUCTION

A new Lagrangian method that had not yet been readily used to study the sea breeze, called relative dispersion (RD), was applied to validated Weather Research and Forecasting (WRF) model simulations for two pure sea breezes in New Jersey (NJ) in 2012 and 2013 (Seroka et al. 2018). The purpose of the study was to characterize the onshore and offshore components of the sea breeze, and test their sensitivities to large-scale atmospheric flow and oceanic coastal upwelling. RD especially enabled clarification of the offshore sea breeze component, which is normally more difficult to distinguish and define (and less observed) than the onshore component, which often includes a front visible on weather radar.

In their two cases, Seroka et al. (2018) found that synoptic flow impacted the sea breeze onshore extent more than offshore extent, and that coastal upwelling did not affect either the onshore or offshore extents of the sea breeze. Upwelling, however, did produce an earlier, sharper, and stronger sea breeze; and the offshore side of the sea breeze cell crossed the NJ Wind Energy Area (WEA) at ~1900 UTC, regardless of large-scale flow and upwelling tested.

These results certainly were limited to the two pure sea breeze cases that were studied. Therefore, this paper describes an extension of Seroka et al. (2018) to include all four types of sea breezes: pure, corkscrew, backdoor, and synoptic. We will describe the methods employed, and explain some results, focusing especially on the offshore components of the four different sea breeze type cases.

The National Renewable Energy Laboratory (NREL) was recently tasked to assess and recommend improvements to the RU-WRF model for characterizing the NJ offshore wind resource (NREL 2019). The recommendations from this report will be used to update the WRF model configuration used in ongoing and future advanced sea breeze studies.

2. METHODS

Data from the 116-meter meteorological tower located at the now decommissioned Oyster Creek Nuclear Generating Station (at Forked River) were thoroughly analyzed. The analysis included wind speed and direction, air temperature, and wind speed and direction shear. Along with this analysis, weather radar imagery from KDIX (central NJ) was analyzed, and 2-3 cases of each of the sea breeze types were selected for 2017 (see Dunk 2018 for data and details).

One case for each of the sea breeze types was then selected, and the sea breeze type classification was validated by using 12-km North American Mesoscale (NAM) model winds at 925 mb based on Seroka et al. (2018) sea breeze classification methods. The following lists the four different sea breeze type cases chosen:

- Pure: April 5, 2017
- Backdoor: April 14, 2017
- Corkscrew: June 22, 2017 (with coastal upwelling)
- Synoptic: August 4, 2017

See Miller et al. (2003) and Steele et al. (2015) for graphic displays of the sea breeze types.

Next, the most recent WRF version available, WRF v 4.0, was run using the same model setup as Seroka et al. (2018), which included a 3-km resolution parent nest and 600-m resolution inner nest. The sea breeze type classifications of the four different cases were re-validated using the 925 mb wind output from both the 3-km and 600-m WRF simulations. See Seroka (2019) for results of the validation of the four different sea breeze types using NAM and WRF 3-km/600-m simulated 925 mb winds.

The two-dimensional Lagrangian methods were then performed on the four sea breeze type cases, using the same exact setup as Seroka et al. (2018). First, particles were placed on a 10-km resolution grid within the 3-km WRF wind fields. The particles were advected within each horizontal layer by the horizontal components of the winds every 10 min over 1 hr. These 1-hr trajectories were performed for 1700–1800, 1800–1900, 1900–2000, 2000–2100, 2100–2200, 2200–2300, and 2300–0000 UTC, as determined by peak sea breeze time for the cases studied.

Relative dispersion (RD) was then calculated to map Lagrangian Coherent Structures (LCSs) from the trajectories. RD minus the initial 10-km separation distance of the particles at 100 m hub height was then plotted for 1700, 2000, and 2300 UTC, to show a speed (km/hr) of divergence and convergence.

Finally, KDIX weather radar imagery was gathered for the four cases, and comparisons with the WRF/Lagrangian analyses were completed.

3. RESULTS

Figure 1 shows the results from the pure sea breeze case on April 5, 2017. There is good agreement between what the KDIX weather radar imagery depicts as the location of the sea breeze front, and what the relative dispersion (RD) depicts as the location of the same inland front. The front is depicted as a linear collection of higher returns on the weather radar image, nearly parallel to the NJ coastline and just inland at 1700 UTC; on the right panel, the blue shading where convergence occurs indicates the frontal zone, again along and just inland of the NJ coast. The front propagates onshore to around central NJ (extending southwest to northeast) (left center panel), and the blue shading onshore in the right center panel is consistent (slightly east) with what the weather radar depicts at 2000 UTC. Finally, the front is past Philadelphia on the weather radar (bottom left panel), and right around Philadelphia in the blue shading (bottom right panel) at 2300 UTC.

Offshore, a strong fanning out of red shading (divergence) from New York (NY) Harbor/Raritan Bay and Delaware (DE) Bay occurs and extends offshore and to the southeast, and there is also red divergence over the NJ WEA (blue convergence in between the NJ WEA and coast) at 1700 UTC. The red shading moves a bit offshore and weakens by 2000 UTC (right center panel), and is replaced by a bit of blue convergence over the southern portion of the NJ WEA at 2300 UTC (bottom right panel). Blue convergence also is occurring in and offshore of the Raritan Bay.

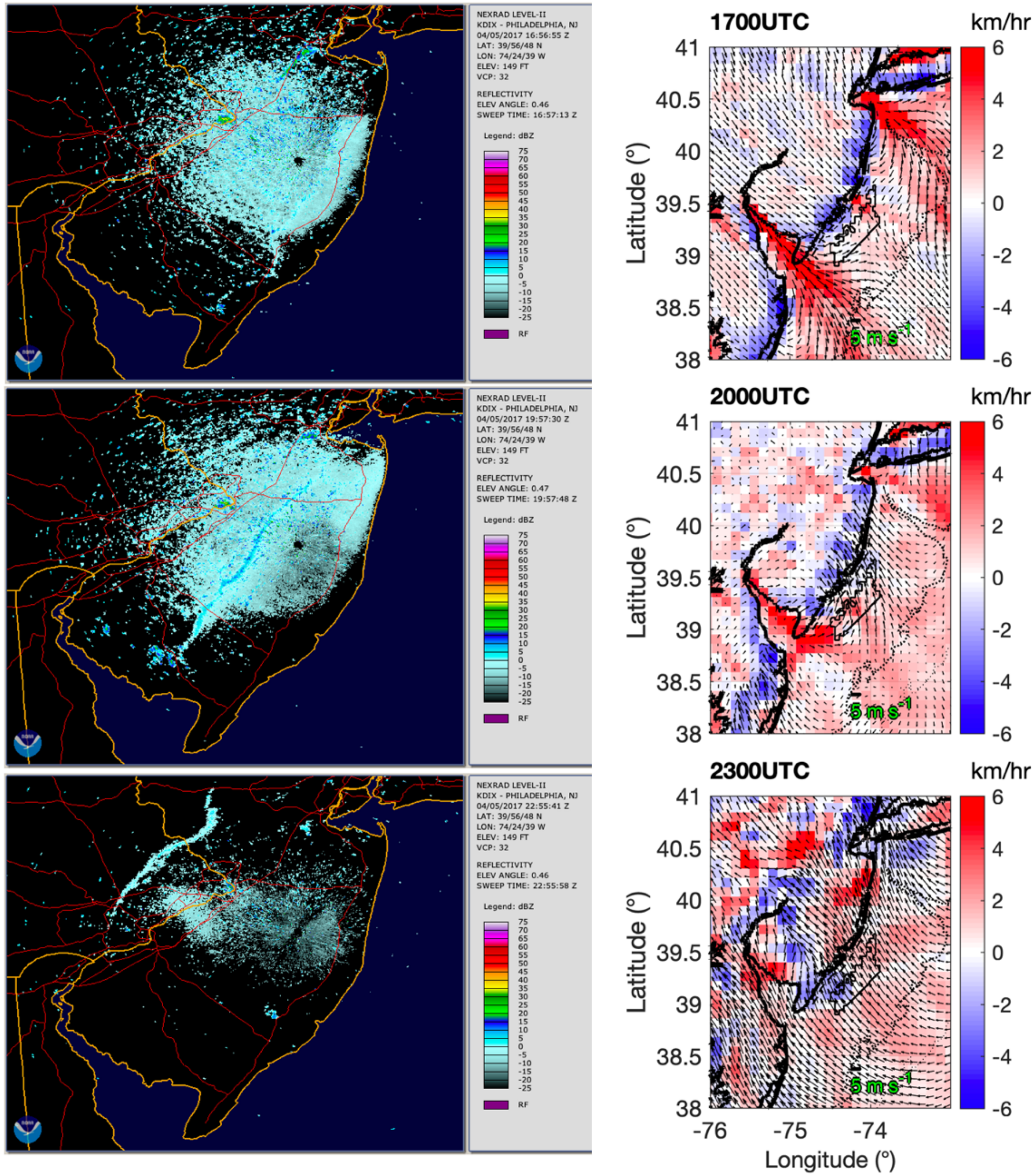

Figure 1: Pure sea breeze case on April 5, 2017. Left panel is KDIX weather radar imagery base elevation clear air mode at 1700, 2000, and 2300 UTC, and right panel is shaded RD-10km (km/hr) at 100 m from WRF/2-D trajectory/RD calculations at the same three times. In right panel, NJ WEA marked in black boxed contour, 50-m isobath in thick dotted black contour, 200-m isobath in thin dotted black contour, and green 5 m/s legend scale vector for black WRF 100-m wind vectors averaged across the hour beginning at time indicated on panel.

Figure 2 shows the results for the backdoor sea breeze case on April 14, 2017. The inland sea breeze front propagation is similar to the pure sea breeze in Figure 1, with the weather radar front (left panel) propagating to around/just west of Philadelphia by 2300 UTC (bottom left).

Onshore, the blue convergence (right panel) propagates similarly to Figure 1 and the weather radar in Figure 2. Offshore, a similar extending out of red divergence occurs again out of Raritan Bay and DE Bay, and over the NJ WEA red divergence at 1700 UTC is replaced by weak blue convergence at 2000 and back to weak red divergence at 2300 UTC.

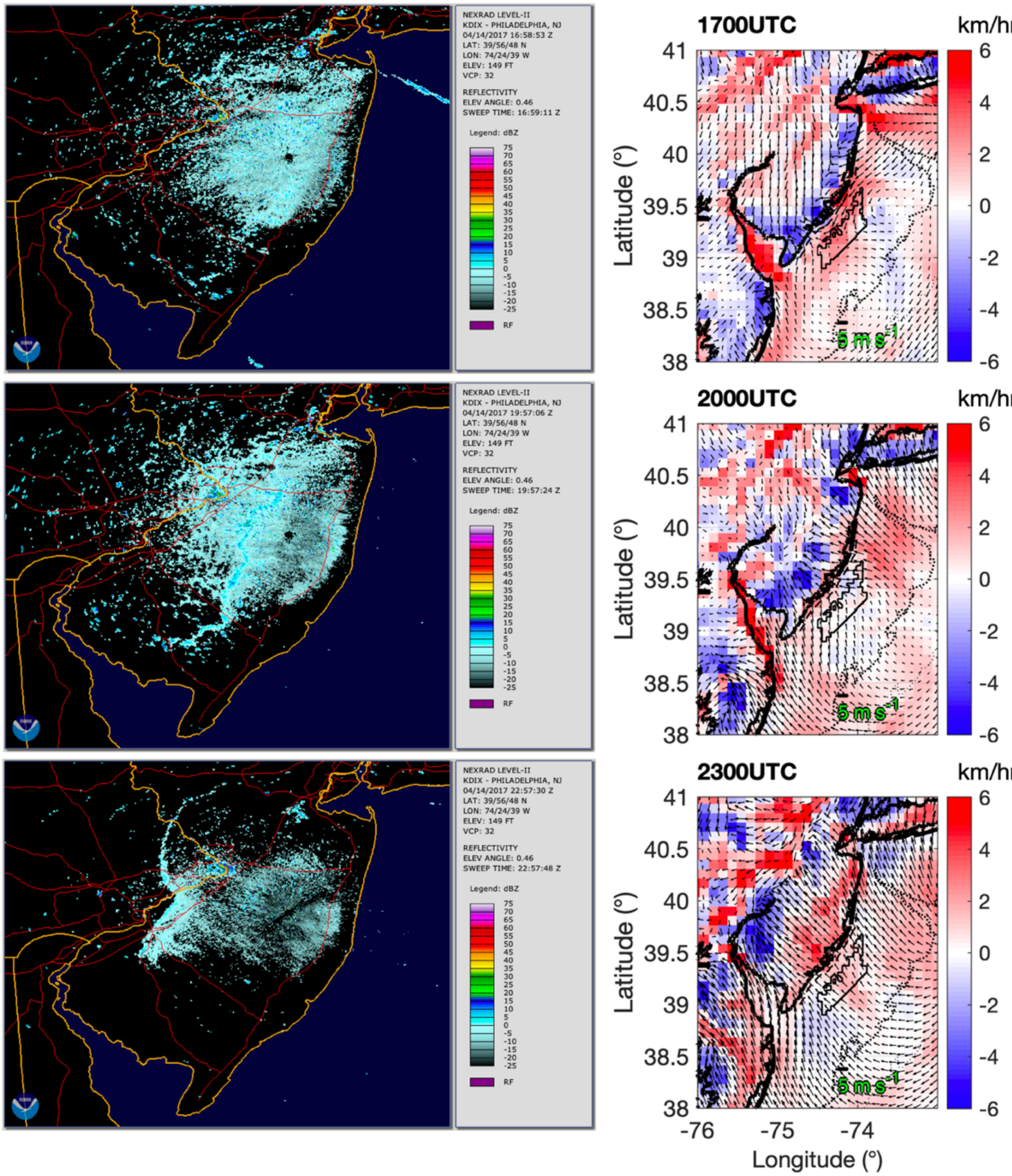

Figure 2: Same as Figure 1, but for backdoor sea breeze case on April 14, 2017.

Figure 3 shows the results for the corkscrew sea breeze case on June 22, 2017. The inland sea breeze front is not as apparent in the weather radar (left panel), but can faintly be seen bowing out westward just to the southwest of Sandy Hook, NJ at 2000 UTC (left center panel). The front is also faint near Fort Dix, NJ (location of KDIX weather radar) at 2300 UTC, indicating the inland front is more stationary and does not propagate as far inland as the pure and backdoor sea breeze cases in Figures 1 and 2. Offshore, general red divergence occurs with some blue convergence just north of the NJ WEA at 1700 UTC (top right). Again, red divergence extends offshore from NY Harbor and DE Bay. At 2000 UTC, faint blue convergence occurs in the center of the NJ WEA and red divergence in the northern section of the NJ WEA. Finally at 2300 UTC, red divergence occurs across the NJ WEA with blue convergence to the north toward Raritan Bay.

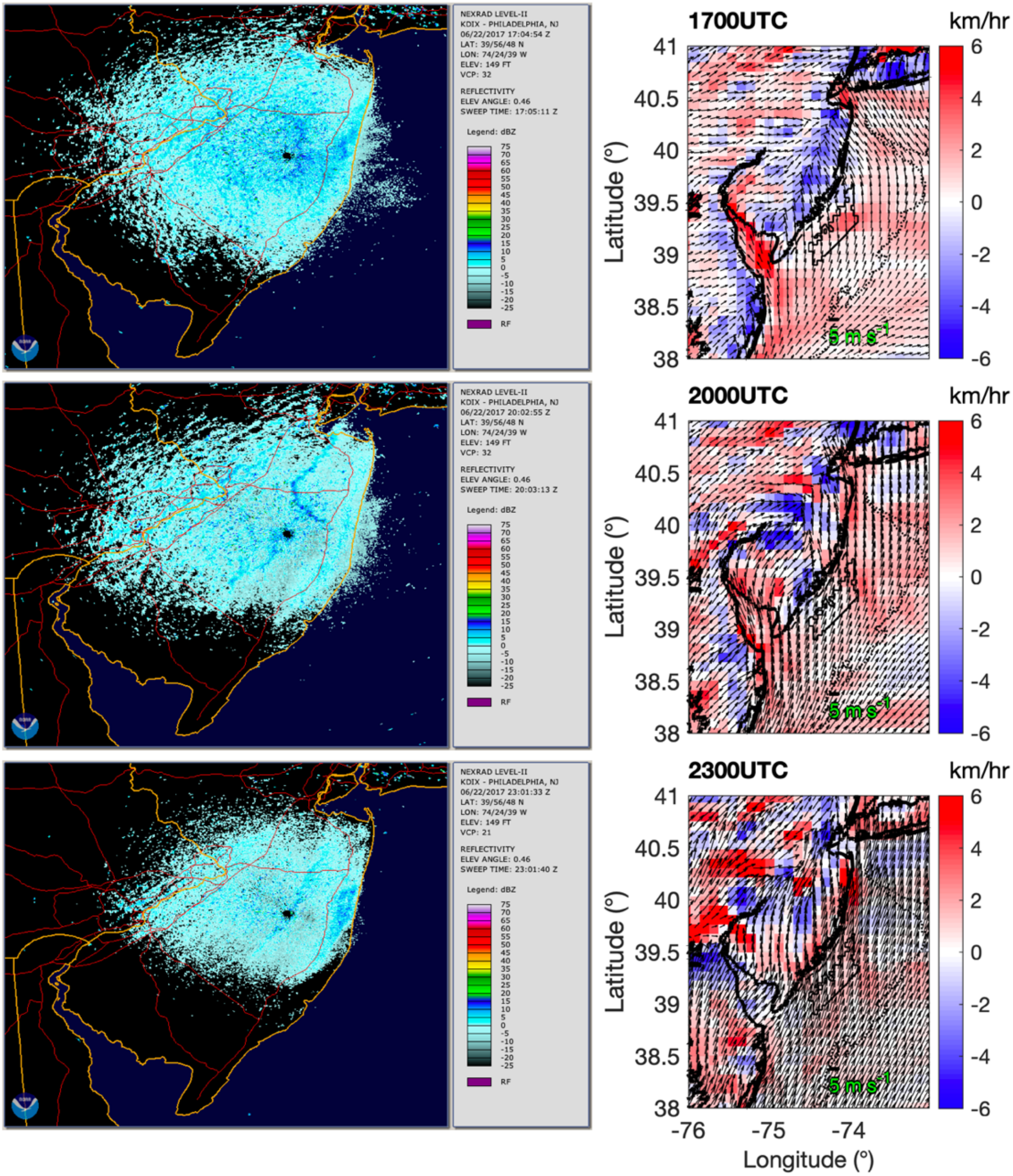

Figure 3: Same as Figure 1, but for corkscrew sea breeze case on June 22, 2017.

Finally, Figure 4 shows the results for the synoptic-enhanced sea breeze case on August 4, 2017. No real sea breeze front is captured by the weather radar imagery (left panel) or RD (right panel) except for perhaps some higher radar returns along the coastline at 2000 UTC (left center panel) and some blue convergence onshore and to the south at 1700 UTC (top right panel). Cloud streaks are apparent in the weather radar imagery, stretching from SSE to NNW especially at 2000 and 2300 UTC (left center and left bottom panels). On the right panel, weaker blue convergence over the NJ WEA and red divergence extending offshore from the NY Harbor and DE Bay (again) at 1700 UTC is replaced by general weak red divergence at 2000 UTC across the entire offshore region except well offshore to the southeast. Finally, at 2300 UTC, a mix of red divergence and blue convergence occurs offshore and over the NJ WEA.

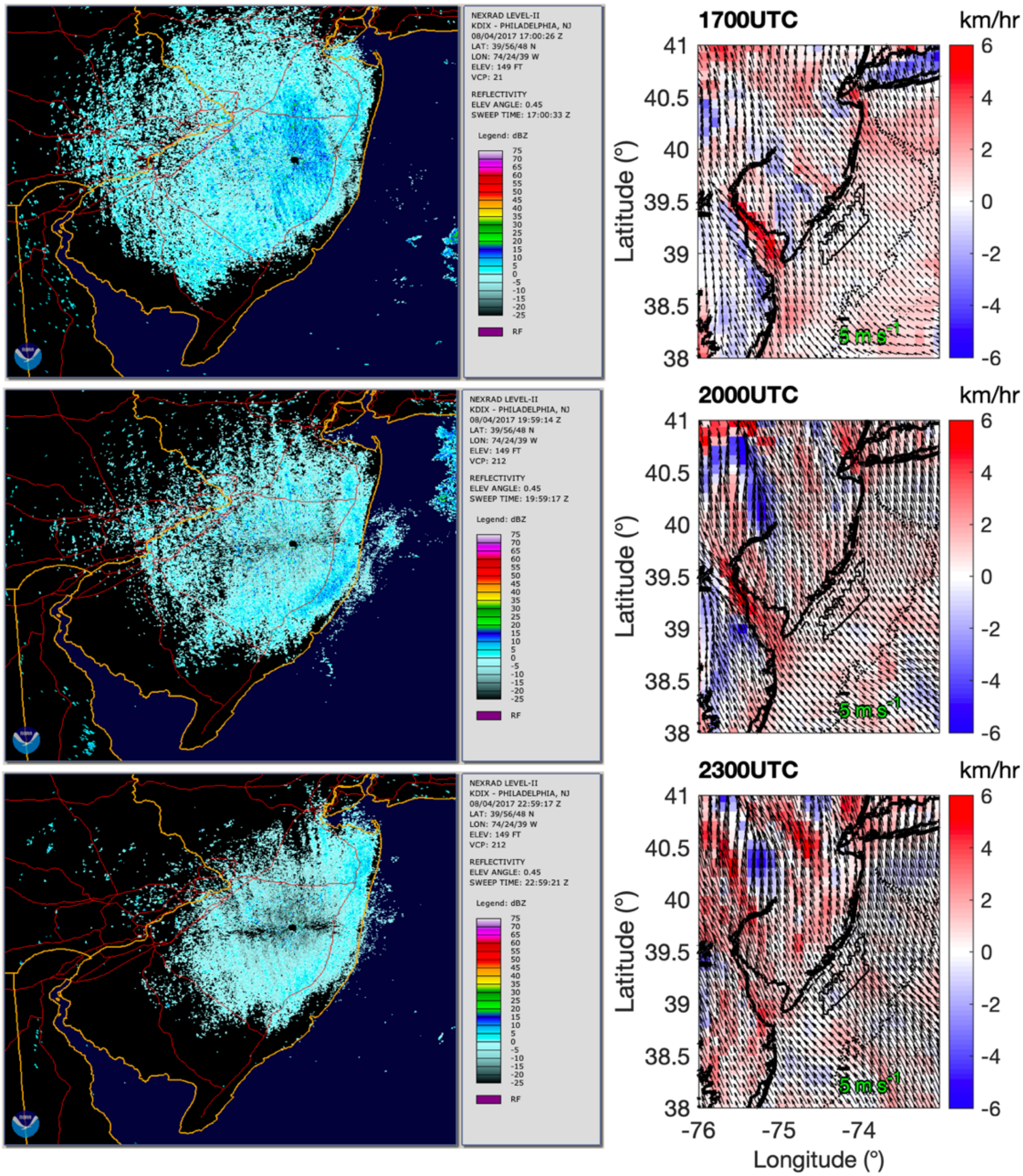

Figure 4: Same as Figure 1, but for synoptic sea breeze case on August 4, 2017.

4. CONCLUSIONS AND ONGOING/FUTURE WORK

It seems that strong divergence emanates from the NY Harbor/Raritan Bay and DE Bay offshore across all sea breeze types studied here. This is especially true at 1700 UTC for each case, regardless of flow out of the bays (pure sea breeze, Fig. 1) or flow into the bays (backdoor, corkscrew, and synoptic sea breezes, Figs. 2-4). Also, over the NJ WEA, general divergence at 100 m hub height is slowly replaced by a mix of convergence and divergence by 2000 and 2300 UTC for the pure, backdoor, and corkscrew sea breeze cases, which is consistent with sea breeze theory (divergence at surface offshore and convergence at surface onshore is slowly replaced by convergence at surface offshore and divergence at surface onshore as sea breeze develops and dissipates). For the synoptic-enhanced sea breeze case studied (Figure 4), a mix of convergence and divergence over the NJ WEA occurs throughout the 1700-2300 UTC period. It is also possible that blue convergence propagates offshore with time in Figure 4, which would possibly indicate a sort of frontal convergence that propagates offshore in that sea breeze type (a new result).

Ongoing and future work includes upgrading the WRF configuration for these sea breeze simulations based on NREL's feedback and more closely matching the real-time RU-WRF configuration which will also be updated based on NREL feedback (NREL 2019). Also, 3D trajectories and Lagrangian analysis will be performed and visualized, to compare to the 2D trajectories and Lagrangian analysis that were performed here. A short-term sea breeze climatology for NJ will be developed in order to potentially develop a Lagrangian prediction parameter for sea breeze. These sea breeze analyses will also be compared to other adjacent regions' sea breezes. Finally, further in the future, WRF wind turbine parameterizations (e.g. Fitch, EWP) will be utilized to simulate the effect of wind turbines on the boundary layer wind resource, and Lagrangian analyses could be performed on those simulation results to enhance understanding of wake effect during sea breeze events.

REFERENCES

Dunk, R. (2018). "AW NJ 2017 Sea Breeze Discussion", "AW Sea Breeze Physical Parameters", and supporting documents.

Miller, S. T. K., Keim, B. D., Talbot, R. W., & Mao, H. (2003). Sea breeze: Structure, forecasting, and impacts. *Reviews of geophysics*, *41*(3).

National Renewable Energy Laboratory (NREL) (2019). "Validation of RU-WRF, the Custom Atmospheric Mesoscale Model of the Rutgers Center for Ocean Observing Leadership".

Seroka, G., Fredj, E., Kohut, J., Dunk, R., Miles, T., & Glenn, S. (2018). Sea Breeze Sensitivity to Coastal Upwelling and Synoptic Flow Using Lagrangian Methods. *Journal of Geophysical Research: Atmospheres*, *123*(17), 9443-9461.

Seroka, G. (2019). "2017 Sea Breeze Cases Final.xlsx"

Steele, C. J., Dorling, S. R., von Glasow, R., & Bacon, J. (2015). Modelling sea-breeze climatologies and interactions on coasts in the southern North Sea: implications for offshore wind energy. *Quarterly Journal of the Royal Meteorological Society*, *141*(690), 1821-1835.