AGU ADVANCING EARTH AND SPACE SCIENCES

JGR Oceans

RESEARCH ARTICLE

10.1029/2023JC019685

Special Section:
Forcing, response, and impacts of coastal storms in a changing climate

Key Points:

- Pathways of land-sourced contaminants in the aftermath of Hurricane Florence are investigated with an ocean model with hydrology source
- The Cape Fear River plume had a westward coastal current and intermittent offshore storage modulated by wind direction and river discharge
- Beaches 100 km west saw river-sourced water quality hazards with delayed onset and long duration, from days to weeks after the storm

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Modeled Coastal-Ocean Pathways of Land-Sourced Contaminants in the Aftermath of Hurricane Florence

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Abstract Extreme precipitation during Hurricane Florence, which made landfall in North Carolina in September 2018, led to breaches of hog waste lagoons, coal ash pits, and wastewater facilities. In the weeks following the storm, freshwater discharge carried pollutants, sediment, organic matter, and debris to the coastal ocean, contributing to beach closures, algae blooms, hypoxia, and other ecosystem impacts. Here, the ocean pathways of land-sourced contaminants following Hurricane Florence are investigated using the Regional Ocean Modeling System (ROMS) with a river point source with fixed water properties from a hydrologic model (WRF-Hydro) of the Cape Fear River Basin, North Carolina's largest watershed. Patterns of contaminant transport in the coastal ocean are quantified with a finite duration tracer release based on observed flooding of agricultural and industrial facilities. A suite of synthetic events also was simulated to investigate the sensitivity of the river plume transport pathways to river discharge and wind direction. The simulated Hurricane Florence discharge event led to westward (downcoast) transport of contaminants in a coastal current, along with intermittent storage and release of material in an offshore (bulge) or eastward (upcoast) region near the river mouth, modulated by alternating upwelling and downwelling winds. The river plume patterns led to a delayed onset and long duration of contaminants affecting beaches 100 km to the west, days to weeks after the storm. Maps of the onset and duration of hypothetical water quality hazards for a range of weather conditions may provide guidance to managers on the timing of swimming/shellfishing advisories and water quality sampling.

Plain Language Summary Hurricane Florence hit the southeastern United States in September 2018, causing historic rainfall and flooding. Floodwaters carrying contaminants traveled down rivers to the ocean, causing harmful algal blooms, beach closures, and other impacts. In the Cape Fear River Basin, North Carolina's largest watershed, open-air lagoons used to store waste from industrial hog farming were breached, causing sewage to flow into the ocean in a coherent feature called a 'river plume' that moved in different patterns. Flooding impacts are increasing, but the movement of contaminants in river plumes following extreme events is not well understood. We used a numerical ocean model to simulate the Cape Fear River plume carrying a dye representing contaminants following Hurricane Florence. The plume initially traveled west hugging the coast due to Earth's rotation, alternately spreading east or offshore due to changes in the direction of winds blowing on the ocean. The river plume patterns led to a delayed onset and long duration of contaminants affecting beaches far down the coast, days to weeks after the storm. We also simulated several scenarios with different river discharge and winds. This information could help guide managers on when to perform water quality sampling and issue swimming or shellfishing advisories.

1. Introduction

Coastal ecosystems, infrastructure, and human health are increasingly vulnerable to storms and flooding as tropical cyclones are predicted to move more slowly and have larger total precipitation, and as populations and industries are becoming more concentrated in coastal regions (Intergovernmental Panel on Climate Change, 2021). In the United States, for example, recent large rainfall events associated with tropical cyclones include Matthew (2016) and Florence (2018) causing extreme precipitation in the southeast, Irene (2011), Sandy (2012), and Henri (2021) in the mid-Atlantic and northeast, Harvey (2017), Imelda (2019), Sally (2020), Fiona

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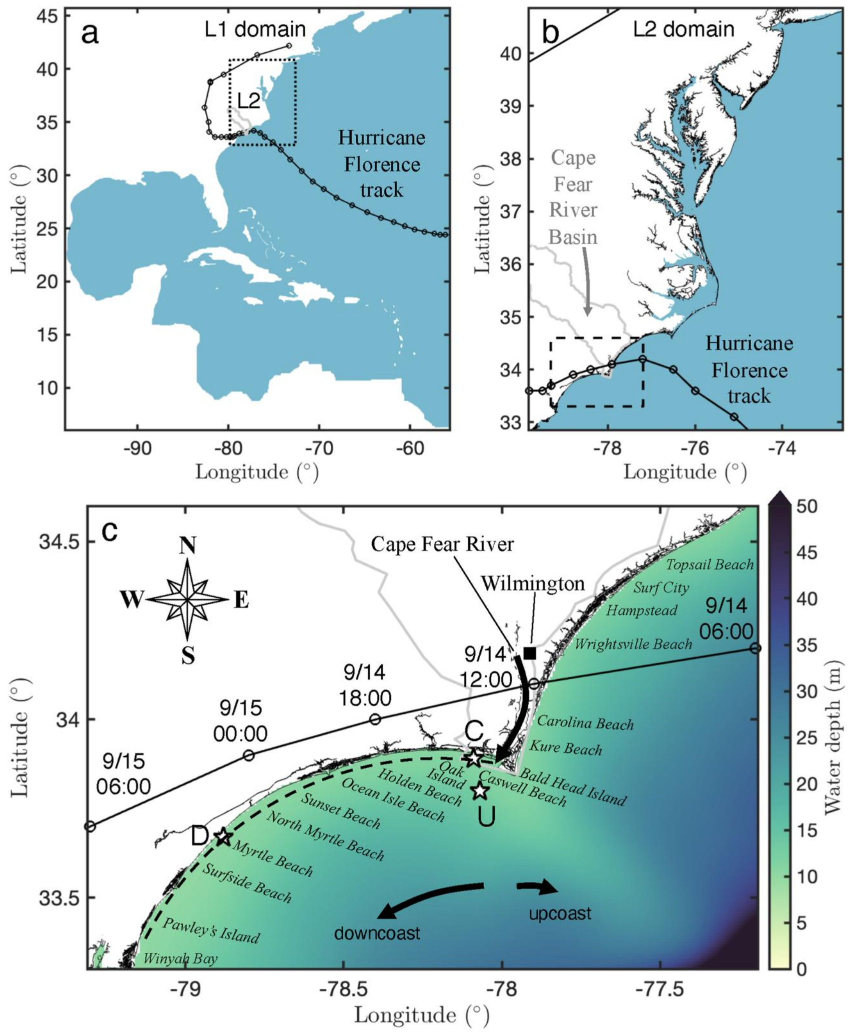

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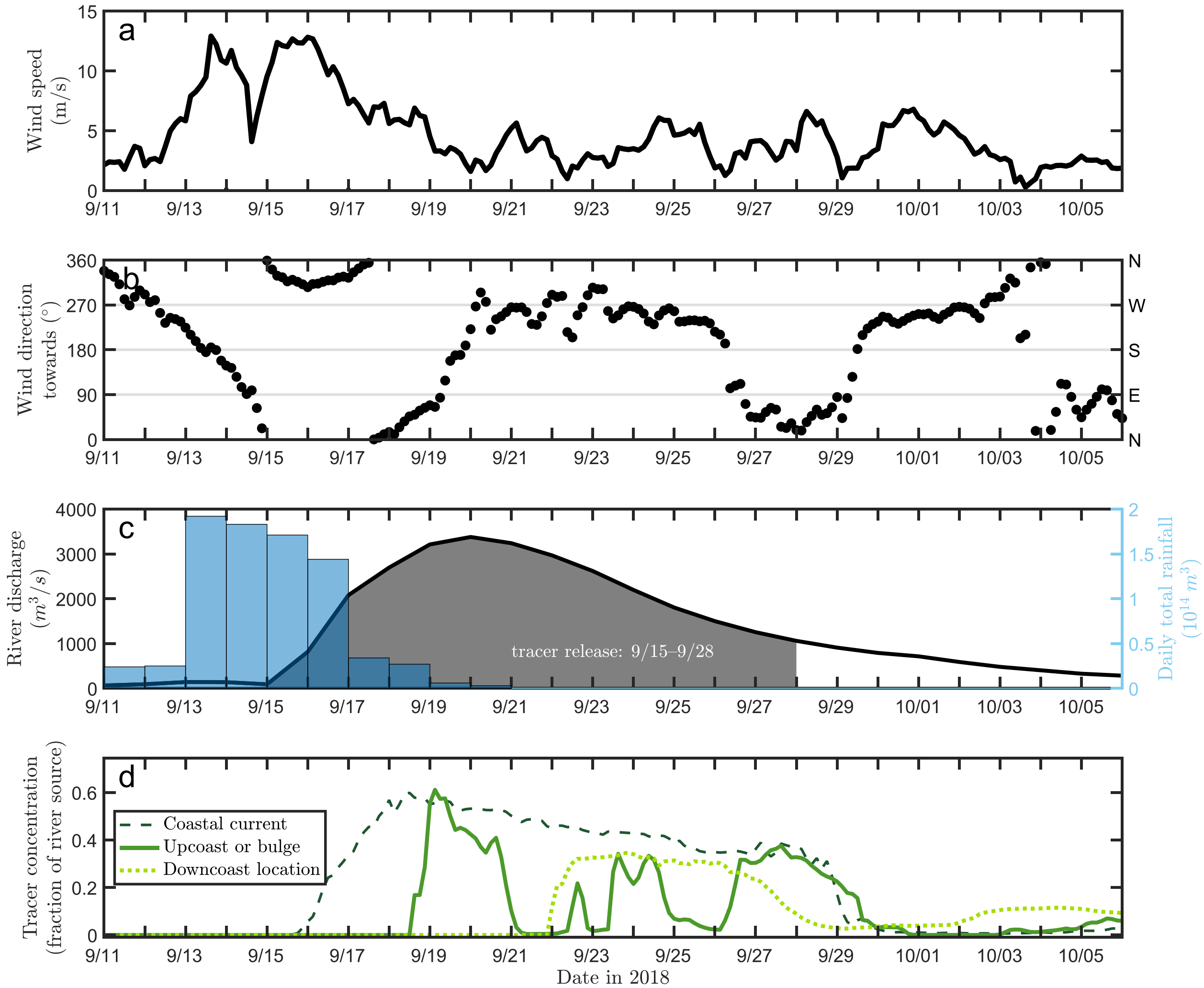

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Table 1
Summary of Regional Ocean Modeling System (ROMS) Ocean Model Runs Including Date Ranges, River Discharge, and Wind Forcing. 'Hurricane Florence' River Discharge Refers to the Detided Discharge Time Series Simulated by Coupled ROMS and WRF-Hydro Simulations for September and October 2018 Conditions, Which had a Peak of 3,377 m^3/s on 9/19–9/20 (Figure 3c). 'Hurricane Florence' Wind Forcing Refers to Gridded ERA5 Wind Forcing for September and October 2018 (Figures 3a and 3b)

Run name	Dates (2018)	River discharge	Wind forcing
Florence	09/11–10/06	Hurricane Florence, peak 3,377 m^3/s	Hurricane Florence
River-base	09/15–10/06	Baseflow condition, 100 m^3/s	Hurricane Florence
River-25%	09/15–10/06	25% Hurricane Florence, peak 884 m^3/s	Hurricane Florence
River-50%	09/15–10/06	50% Hurricane Florence, peak 1,688 m^3/s	Hurricane Florence
River-200%	09/15–10/06	200% Hurricane Florence, peak 6,754 m^3/s	Hurricane Florence
Wind-N	09/17–10/06	Hurricane Florence	constant, 5 m/s to N
Wind-E	09/17–10/06	Hurricane Florence	constant, 5 m/s to E
Wind-S	09/17–10/06	Hurricane Florence	constant, 5 m/s to S
Wind-W	09/17–10/06	Hurricane Florence	constant, 5 m/s to W

Note. Time series of synthetic forcing conditions are shown in Figures 6a and 8a.

north where the boundary grid points are all land cells (Kumar et al., 2012). Harmonic viscosity was set to 0.5 m^2/s and the GLS turbulence closure scheme was used. Atmospheric forcing was derived from a 30-km ERA5 product (Hersbach et al., 2020; Li et al., 2022) (Figures 3a and 3b), which is similar to atmospheric fields from higher resolution coupled WRF-ROMS simulations of Hurricane Florence (Zambon et al., 2021), and expected to be reasonable to simulate the bulk response of the river plume to wind forcing. The model was run with a baroclinic timestep of 30 s simulating the time period from September 11 to 6 October 2018 (Table 1). A complete description of model parameters can be found in the data archive (see Data Availability Statement).

The Cape Fear River discharge was implemented as a point source at one horizontal grid cell at the coast with uniform vertical distribution (Figure 2c) using a detided (33-hr filter) discharge timeseries extracted from a coupled ocean (ROMS) and hydrologic (WRF-Hydro) (Gochis et al., 2018) model simulation of the Hurricane Florence event (Bao et al., 2022) (Figure 3c). In contrast to using stream-gauge observations from a more inland location, using river discharge from a point near the river mouth in a hydrologic model has several potential advantages. First, the hydrologic model includes inputs from additional tributaries and overland sources near the river mouth that are not included in an upstream gauge measurement. In addition, in the work of Bao et al. (2022), WRF-Hydro was two-way coupled with a depth-averaged ROMS model configuration and was thus able to simulate the effect of interacting ocean and river processes on discharge and compound flooding. Finally, while forcing with stream-gauge data can be suitable for hindcasts, the approach here is a step towards future studies extending this work to forecast scenarios that require the simulation of rainfall-runoff process with a hydrological model. Given the model resolution and coastal river point source location, estuarine adjustment is not resolved here, which may lead to errors in the salinity and tracer concentrations and vertical structure in the river outflow. Thus, here we focus on the response of coastal plumes for given fixed water properties at the Cape Fear River mouth based on climatology (salinity: 0.5 psu, temperature: 24.5°C, tracer concentration: 1) and a constant vertically uniform distribution consistent with a strongly forced (river-dominated) system during a large discharge event. The results are not sensitive to small changes in the temperature, salinity, and vertical structure of the river source. Other rivers in the model domain were implemented as point sources from the National Water Model (Blodgett, 2019), and contributed to extreme freshwater discharge in locations such as Pamlico Sound, however interaction of these rivers with the Cape Fear River plume is not expected to significantly affect the results.

For this study of the post-storm plume behavior and the related potential for water quality hazards along the coast, we did not couple with a surface wave model. Large surface waves (wave height ~5 m) were present and drove elevated coastal water levels and ocean mixing during the storm (9/13–9/17) (Zambon et al., 2021). This was separated in time from the elevated river discharge following the storm (9/17–9/27) (Figure 3), when surface waves were observed to be small (wave height ~1 m) and thus not expected to have a substantial impact on the large-scale behavior of the river plumes. Near the beach, detailed pathways of contaminants could be modeled

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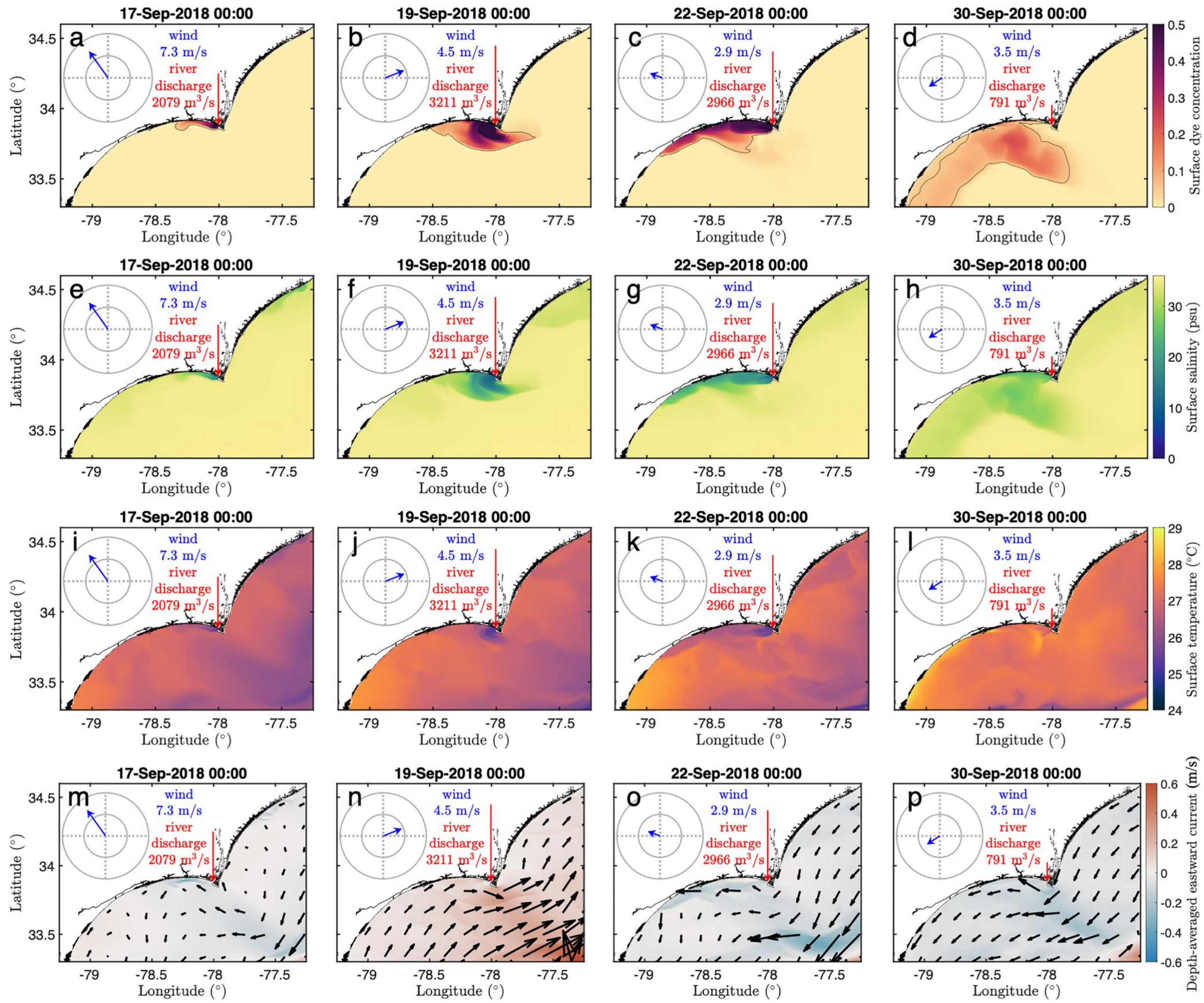

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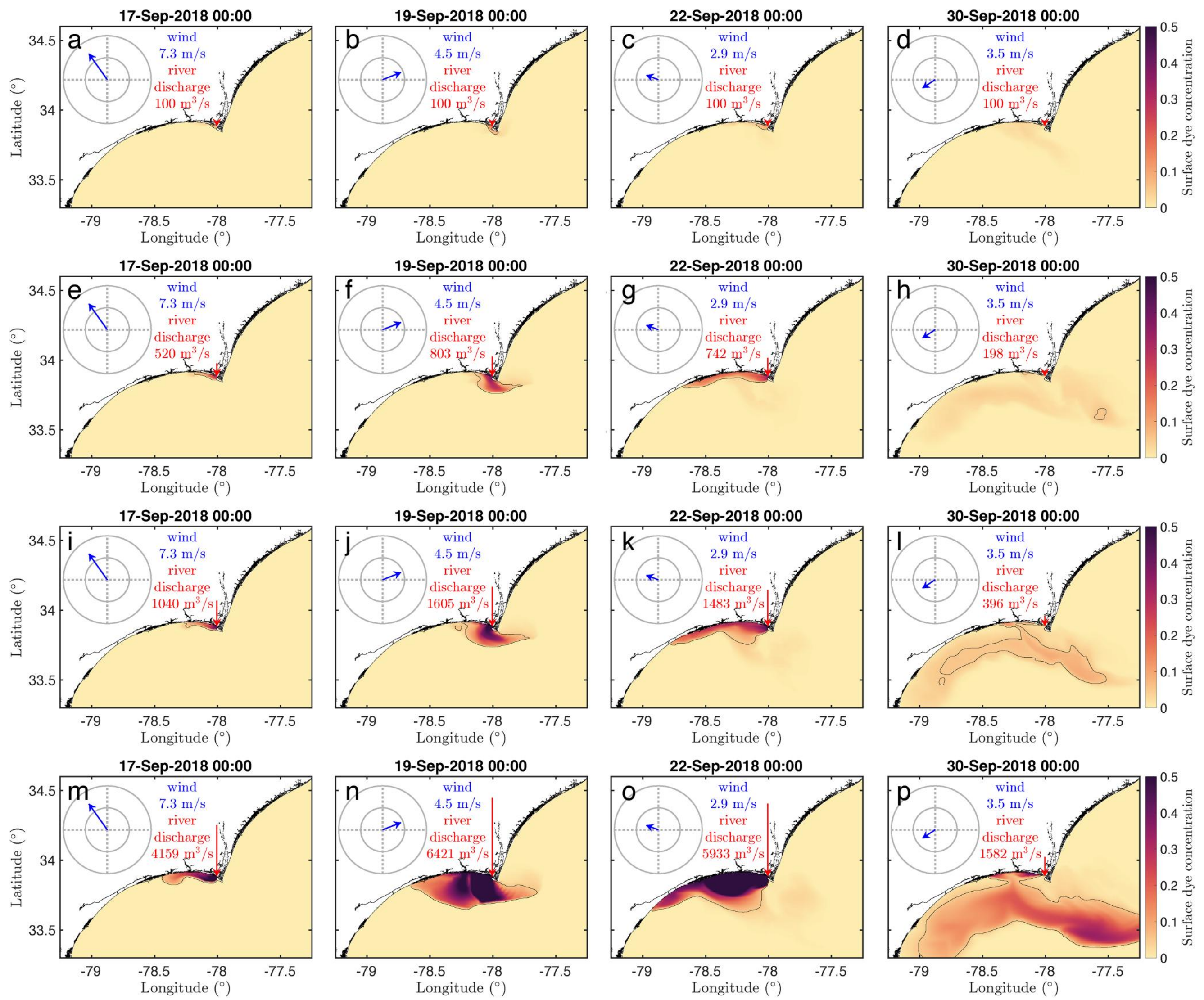

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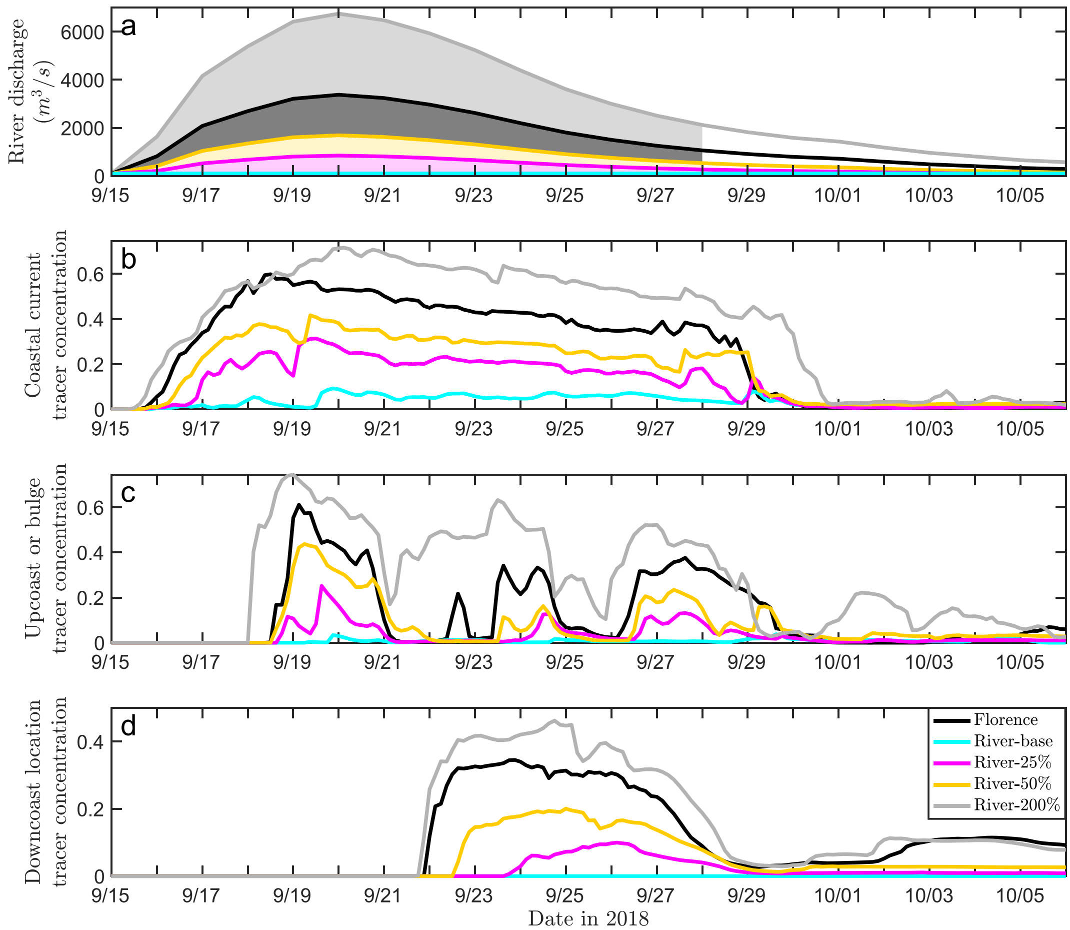

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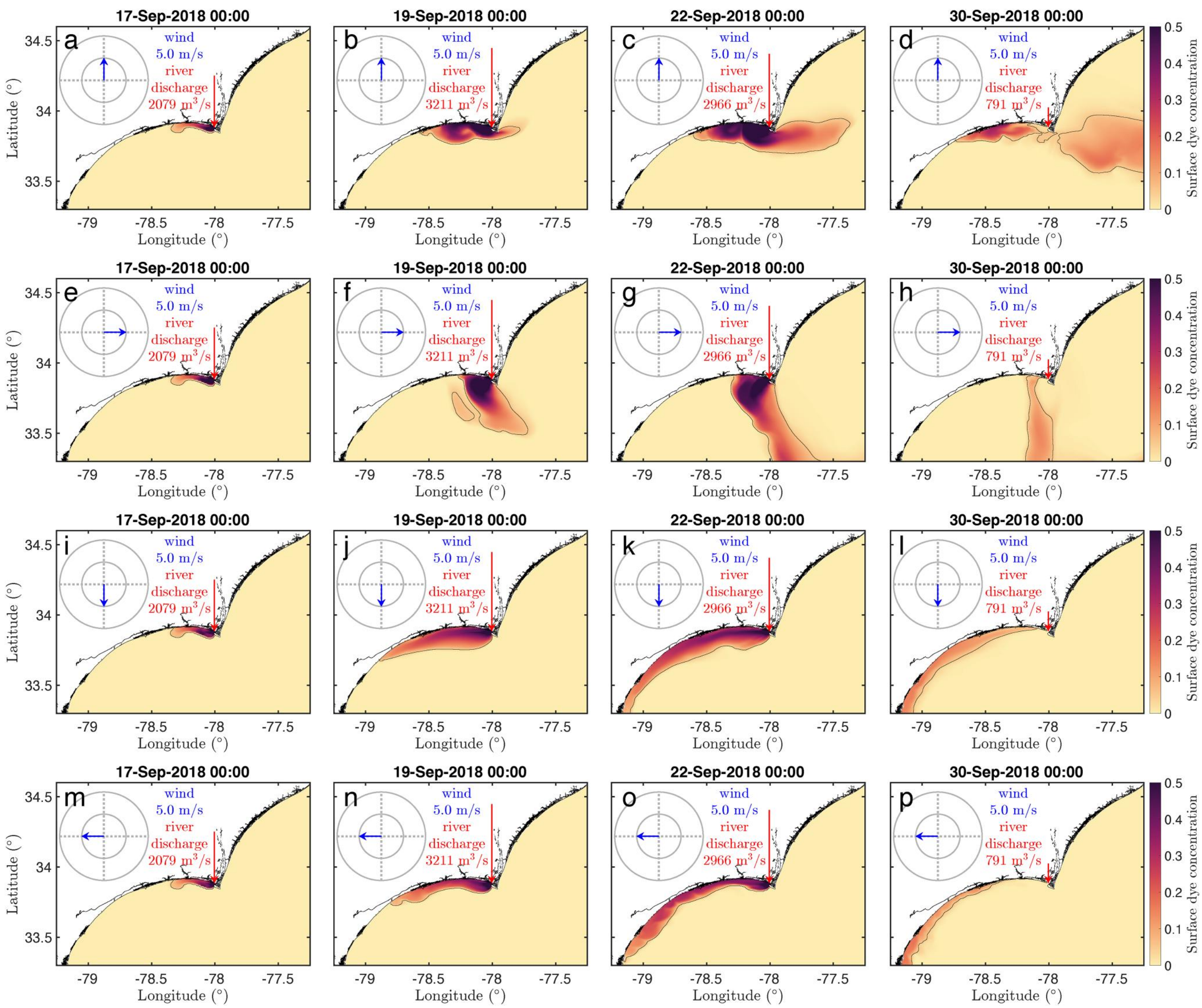

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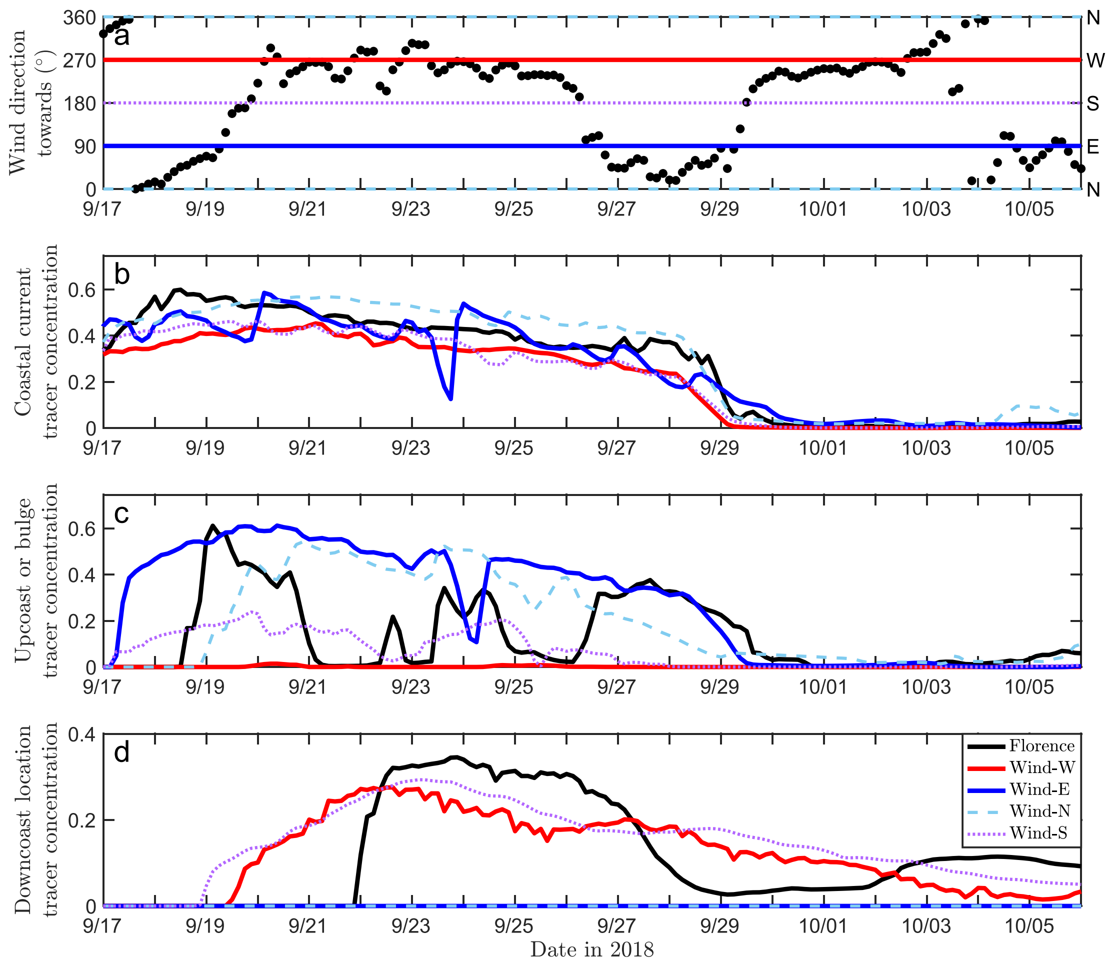
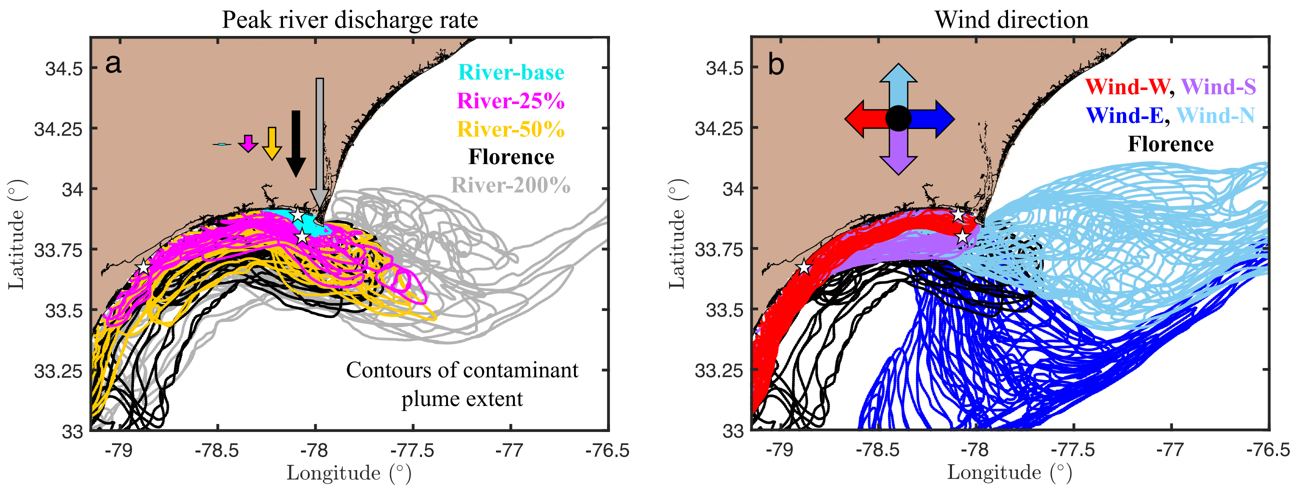
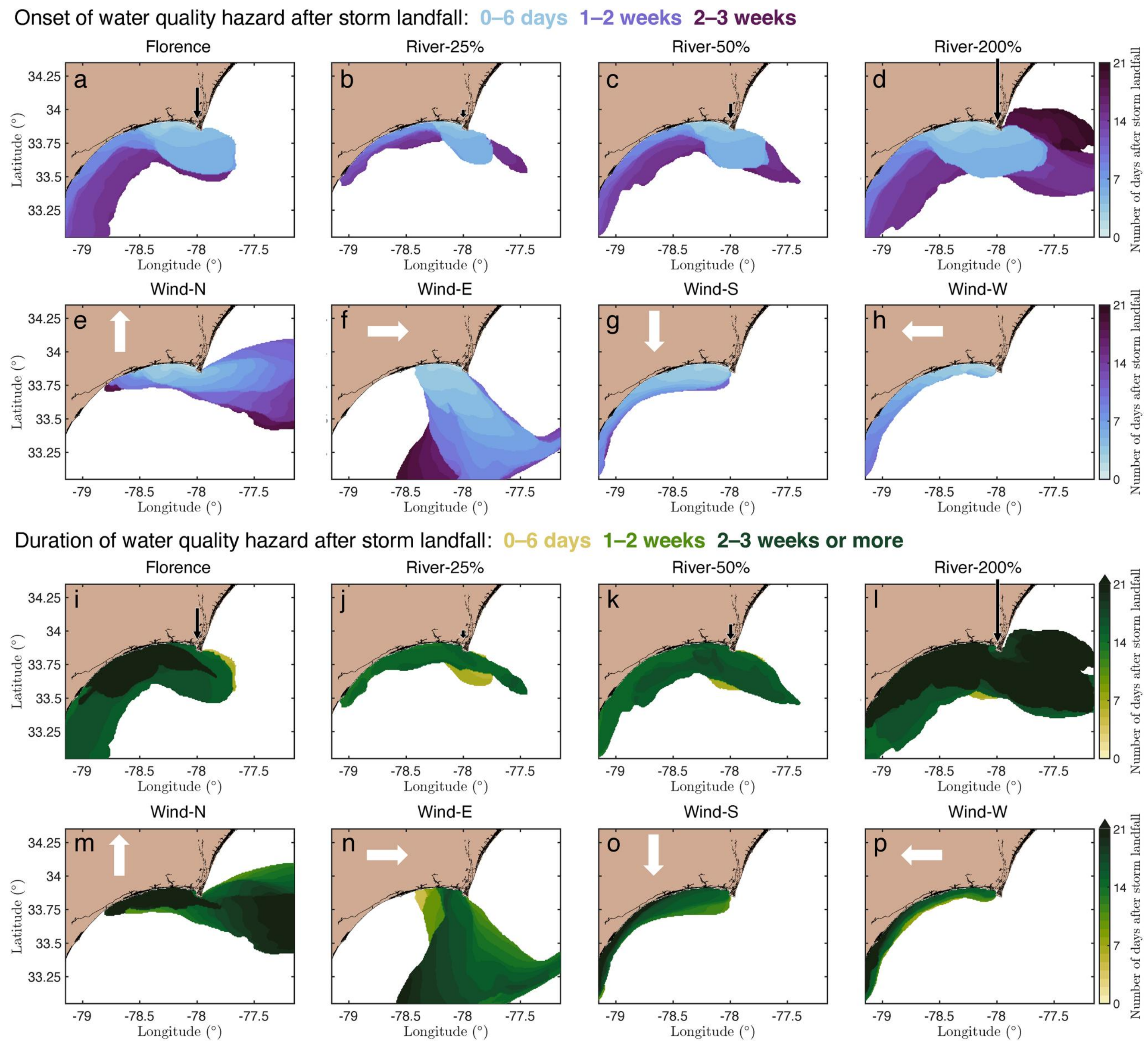


Wind direction towards (°)
360
270
180
90
0
N
W
S
E
N
a
b
c
d
Coastal current tracer concentration
Upcoast or bulge tracer concentration
Downcoast location tracer concentration
0.6
0.4
0.2
0
9/17
9/19
9/21
9/23
9/25
9/27
9/29
10/01
10/03
10/05
Florence
Wind-W
Wind-E
Wind-N
Wind-S
Date in 2018



Peak river discharge rate
a
River-base
River-25%
River-50%
Florence
River-200%
Contours of contaminant
plume extent
Latitude (°)
Longitude (°)
34.5
34.25
34
33.75
33.5
33.25
33
-79
-78.5
-78
-77.5
-77
-76.5
Wind direction
b
Wind-W, Wind-S
Wind-E, Wind-N
Florence



Onset of water quality hazard after storm landfall: 0–6 days 1–2 weeks 2–3 weeks
Florence
River-25%
River-50%
River-200%
Wind-N
Wind-E
Wind-S
Wind-W
a
b
c
d
e
f
g
h
34.25
34
33.75
33.5
33.25
Latitude (°)
-79
-78.5
-78
-77.5
Longitude (°)
21
14
7
0
Number of days after storm landfall
Duration of water quality hazard after storm landfall: 0–6 days 1–2 weeks 2–3 weeks or more
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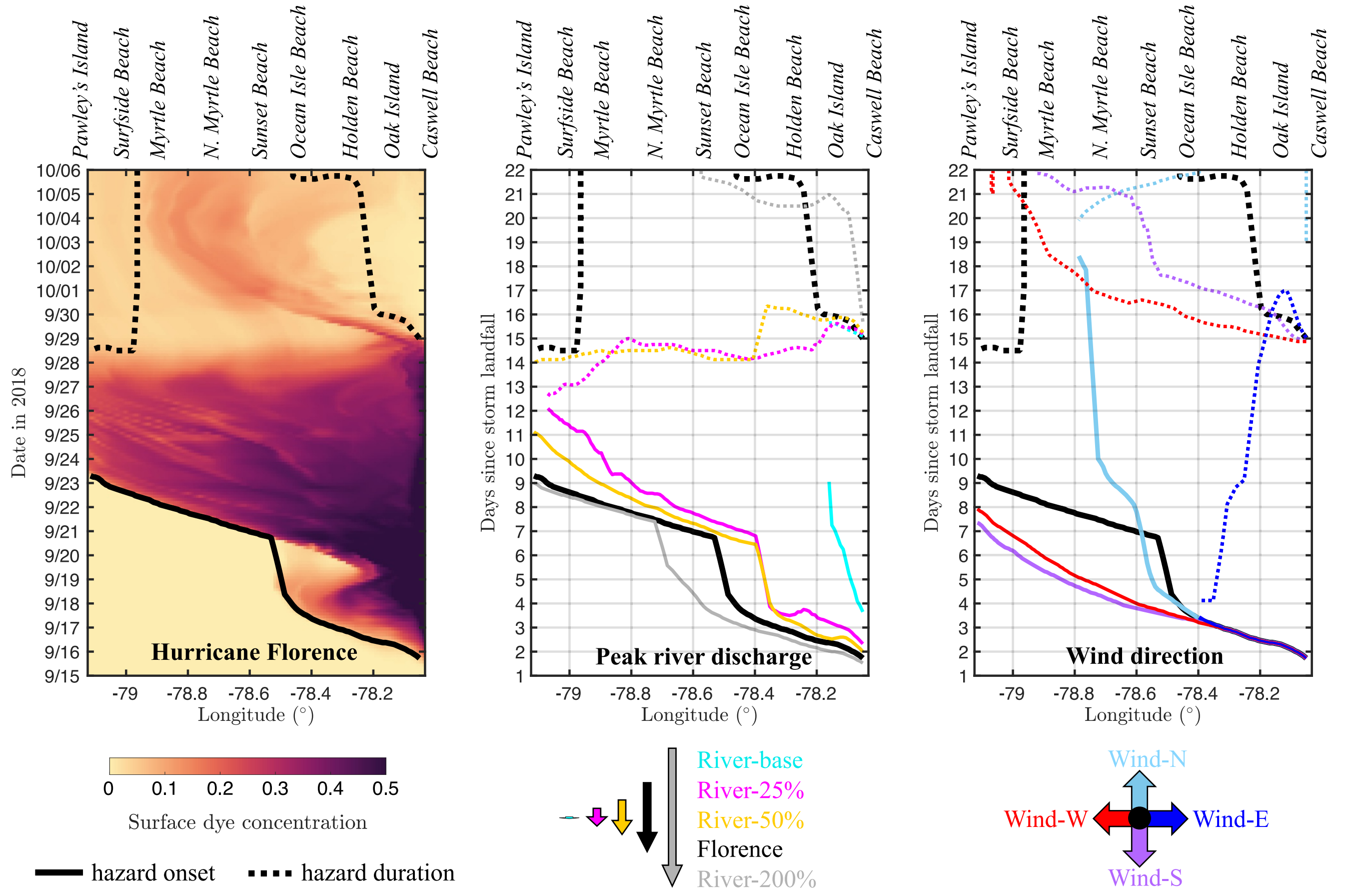

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U.S. Geological Survey data release (Tech. Rep.)

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