VIMS | William & Mary
Virginia Institute of Marine Science

# Subsurface Structure and Impacts of Marine Heatwaves in the Chesapeake Bay

NATHAN P. SHUNK & PIERO MAZZINI

# Marine Heatwaves (MHW): Coastal and Global Ocean

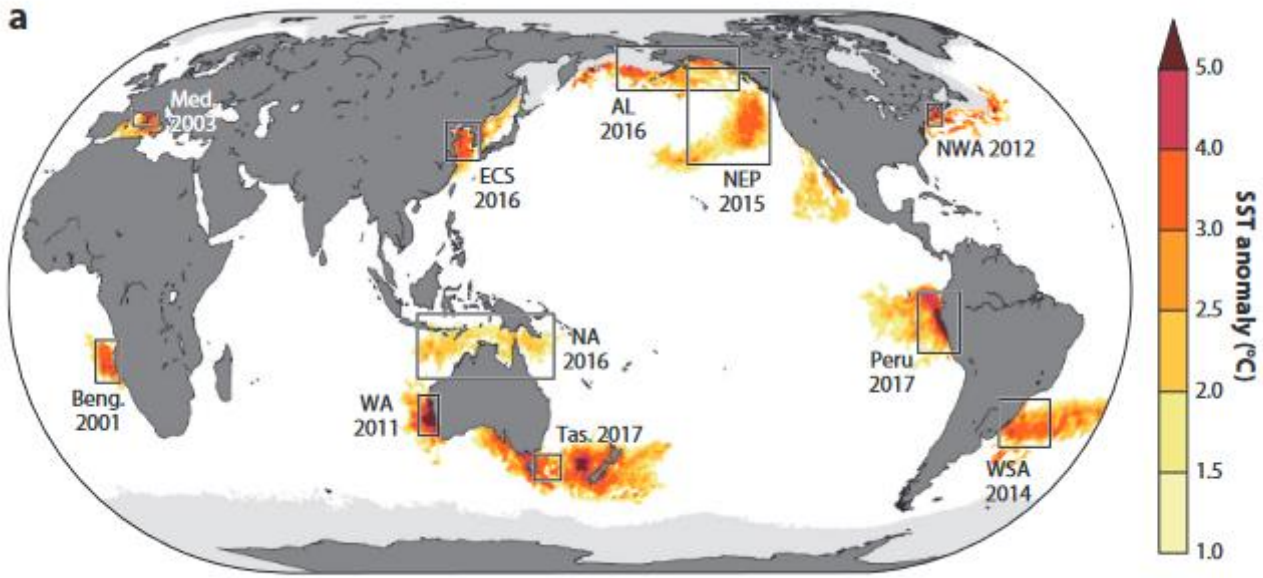
**Range in Size, Intensity, & Duration**

**Trends (Oliver, 2019)**

- Increasing Frequency, Intensity, Duration, and Spatial Extent
- Driven by atmospheric warming

- **Impacts**
  - Coral Bleaching
  - Mass Benthic Die Offs

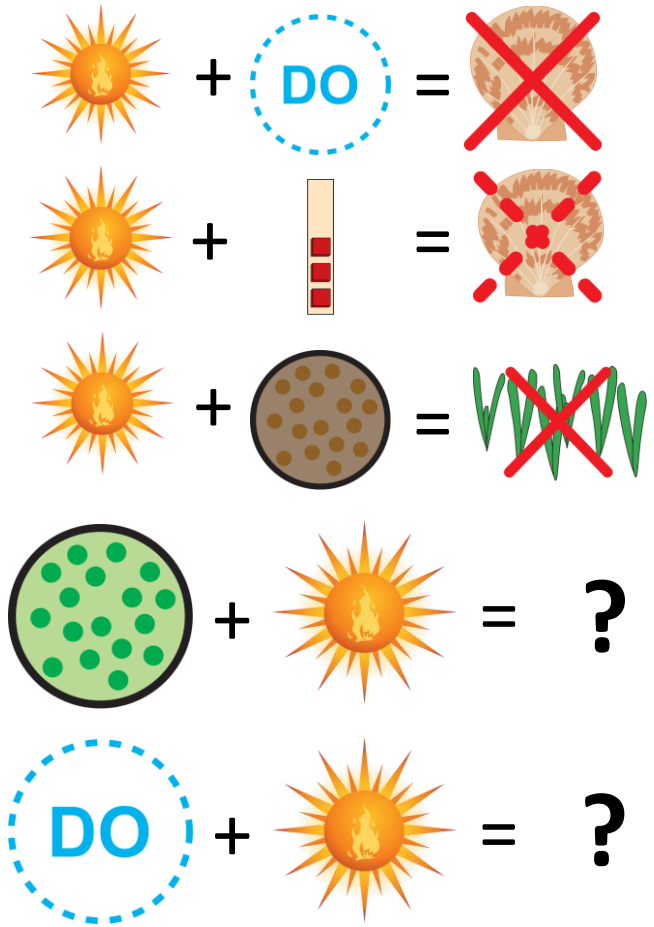
    (Submerged Aquatic Vegetation (SAV), mussels, Scallops, Crabs, etc.)
  - Biogeographic Shifts
  - Harmful Algal Blooms
  - Fishery and Aquaculture Declines




Oliver et. al., 2021

# Compound Events

- **Globally**
  - Low Dissolved Oxygen (DO)
  - Low Ph
  - Low Light
- **Chesapeake Bay**
  - Eutrophication
  - Hypoxia




(Lucey et al., 2022; Tomasetti et al., 2023)

(Tassone et al., 2021)

(Bass et al., 2023)

Symbols courtesy of the Integration and Application Network (ian.umces.edu/symbols/).

# Marine Heatwaves in the Bay

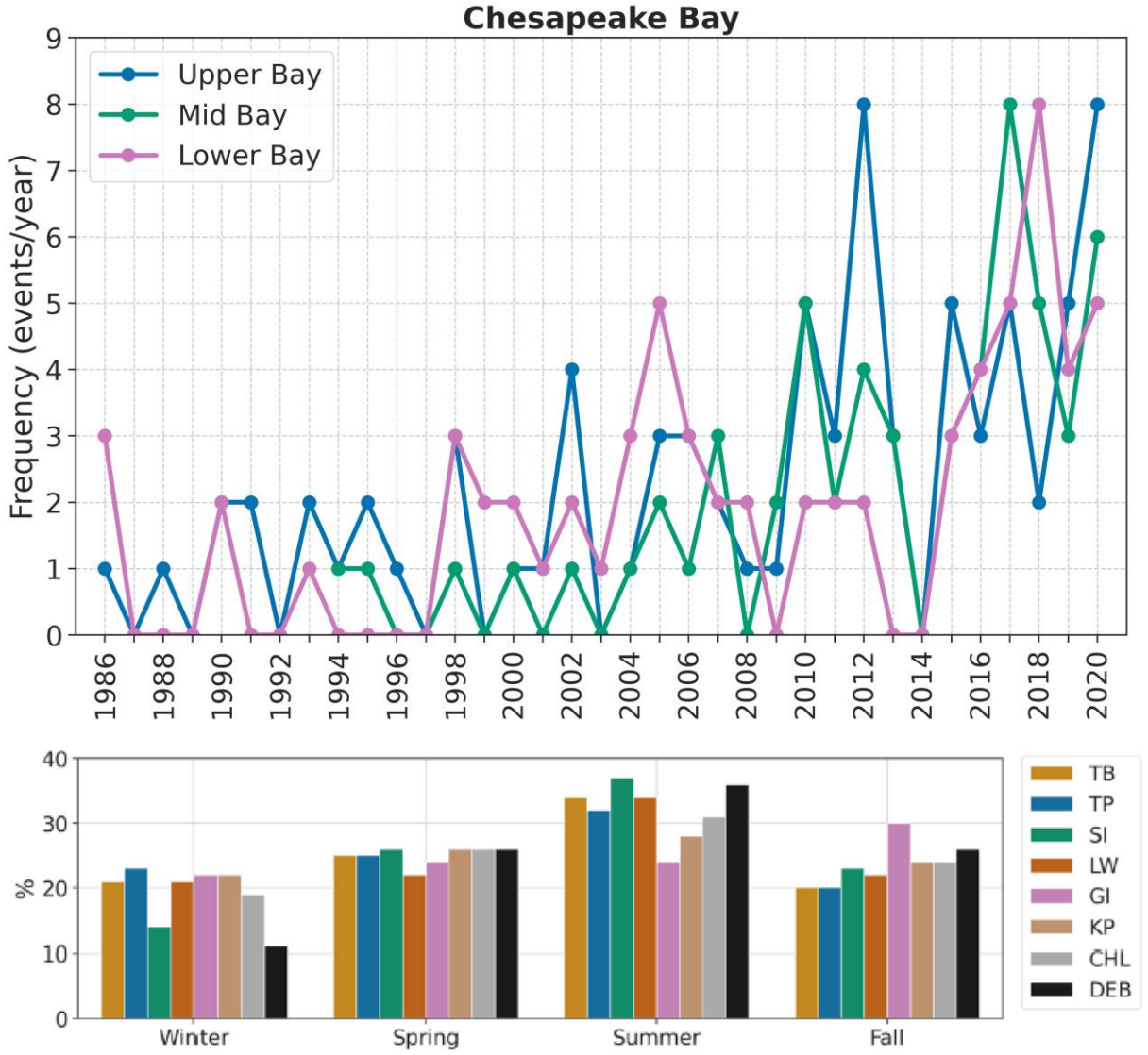
**Trends** (Mazzini & Pianca, 2022)

- Increasing Frequency of Events
  - Match Global Trends (Oliver, 2019)
  - Mean Warming in Bay (Hinson et al., 2021)
- Increasing Annual Cumulative Intensity

**Characteristics** (Mazzini & Pianca, 2022)

- Greater Percentage in Summer

- Co-occurrence Across the Bay

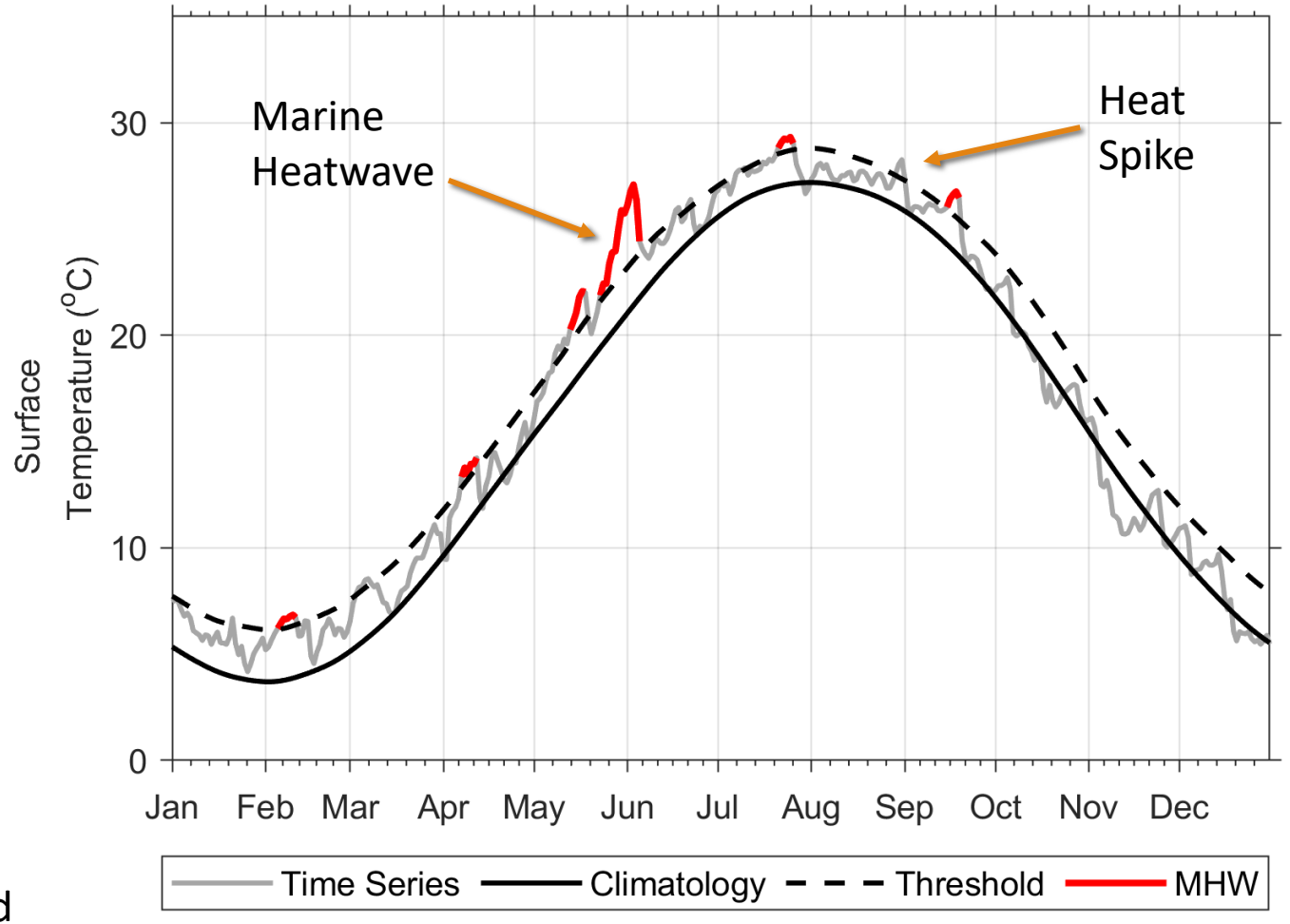



Mazzini & Pianca, 2022

# Marine Heatwave (MHW) Definition
## (Hobday etal., 2016)

"A **discrete prolonged anomalously warm** water event in a particular location"

- **Anomalously warm**:
  90th percentile above climatology
- **Prolonged**:
  Period of at least 5 days
- **Discrete**:
  2-day gap between two 5-day intervals
- **Required Data**:
  Daily Resolution & Multidecadal Record



# Research Objectives

1. Characterize **Spatiotemporal Variability** of **Subsurface Temperatures** and **Dissolved Oxygen**

2. Identify Extent of **Warming Prior** to and **Following Events**

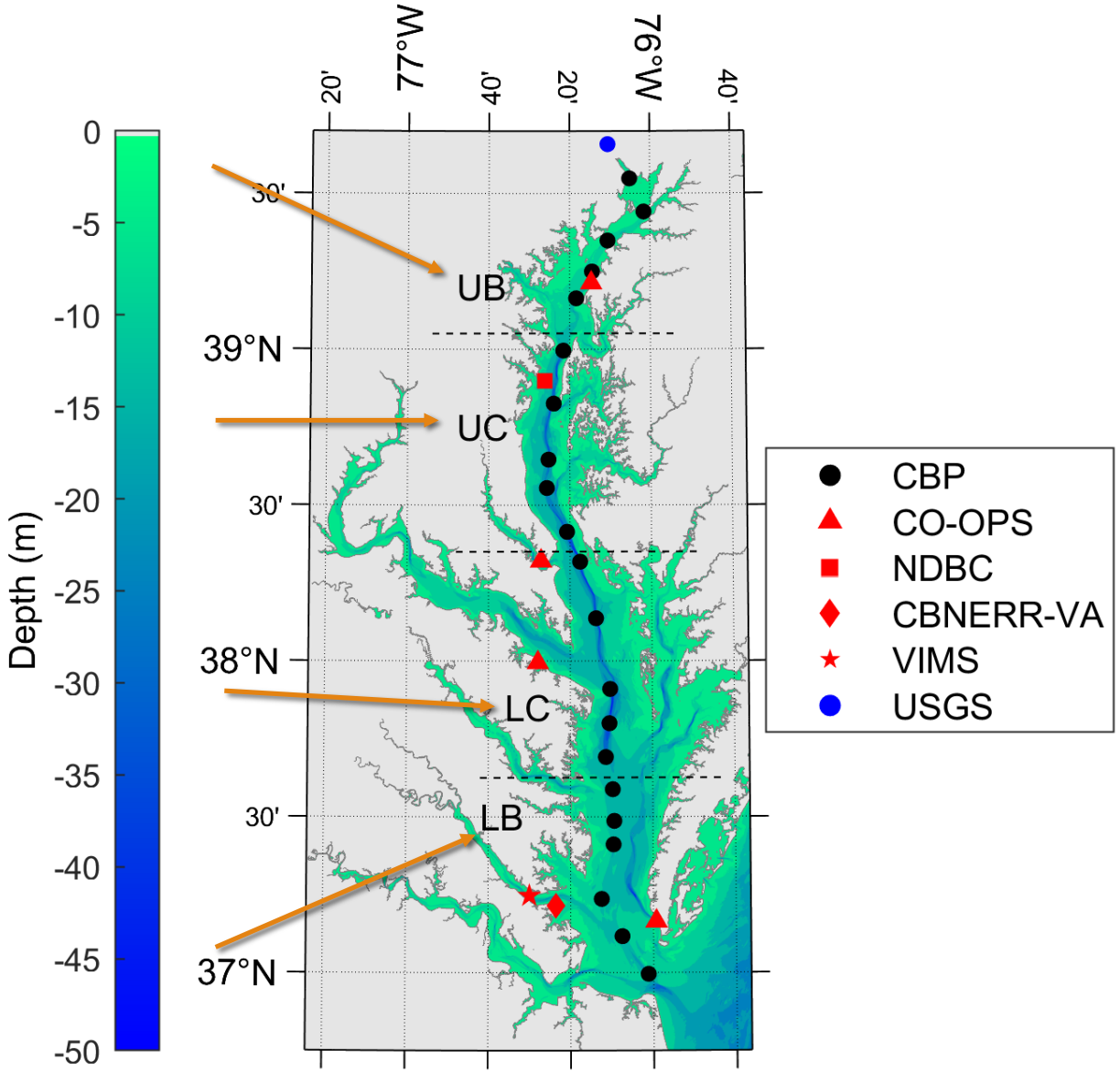
3. Evaluate **Role of Air-Sea Heat Flux** in Onset and Decline of Events

# Subsurface Analysis: Data

- **Surface Temperature (Red)**: 1986-1995 to Present
  - Center for Operational Oceanic Products and Services (CO-OPS): 4 Stations
  - National Data Buoy Center (NDBC): 1 Station
  - Chesapeake Bay National Estuarine Research Reserve VA (CBNERR-VA) & VIMS: 1 Station

(Mazzini & Pianca, 2022)

- **Subsurface Data (Black)**: 1984 to Present
  - Chesapeake Bay Program (CBP): 21 Stations
- **Susquehanna River Discharge (Blue)**: 1950 to Present
  - US Geologic Survey (USGS): 1 Station, Conowingo, Maryland



# Subsurface Analysis: Overview

**T** = Temperature
**S** = Salinity
**DO** = Dissolved Oxygen
**CHLA** = Chlorophyll-a
**ρ** = Density

$N^2$ = Buoyancy Frequency Squared
**MLD** = Mixed Layer Depth
**SST** = Sea Surface Temperature

**Surface MHWs:**

6 Surface Temperature Timeseries

**Spatially Average**

1 Surface Temperature Timeseries

**Subsurface Characteristics:**

T, S, DO, CHLA
21 Stations

**Detrend All Variables <u>Before</u> Calculating Climatologies**

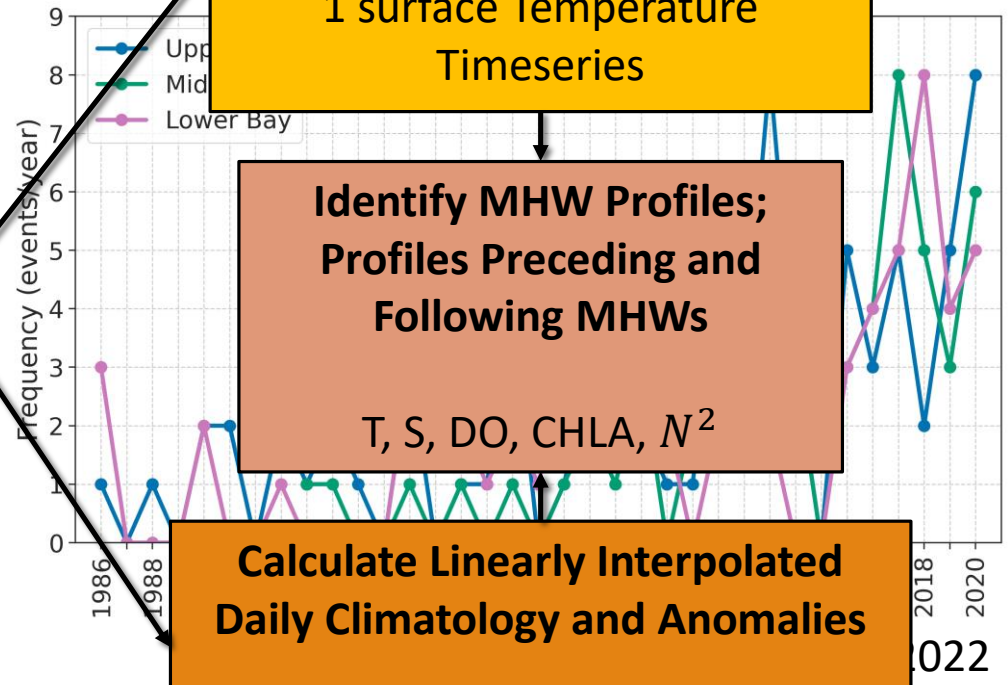
SST, T, S, DO, CHLA, $N^2$

**Calculate ρ and Interpolate**
(GSW; McDougall, T. J. & Barker, P. M., 2011)
T, S, DO, CHLA, ρ

**Calculate $N^2$ and MLD**

T, S, DO, CHLA, MLD, $N^2$

**Calculate Climatology and Threshold, then Identify MHWs**
(m_mhw; Zhao & Marin, 2019)
1 surface Temperature Timeseries




**Identify MHW Profiles; Profiles Preceding and Following MHWs**

T, S, DO, CHLA, $N^2$

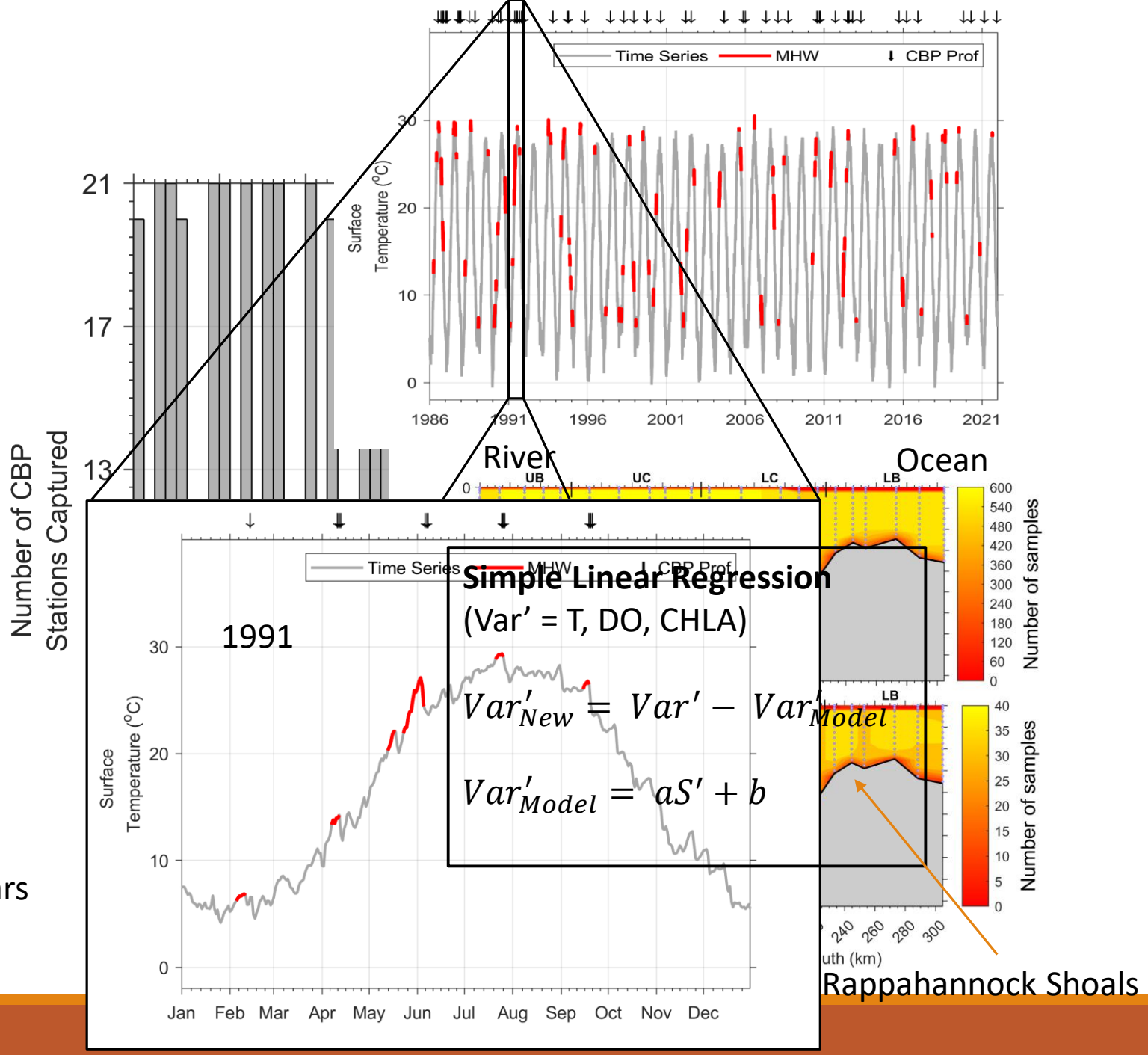
**Calculate Linearly Interpolated Daily Climatology and Anomalies**

T, S, DO, CHLA, $N^2$

# Subsurface Analysis: MHW Profiles

- Evenly Distributed Through Time
- Eliminates Bias due to Trends
- 84 Events: ~36% Partially & ~24% Fully Represented
- 30-40 Marine Heatwave (MHW) profiles per station
- Data Availability Seasonally Variable
  - Most in June and July
  - Least in Nov, Dec, Feb

- 6.5% (51/790) MHW Profiles in Wet/Dry Years
  - 59.3% (19/32) Profiles in May
  - 44.4% (16/36) Profiles in December



# Temperature

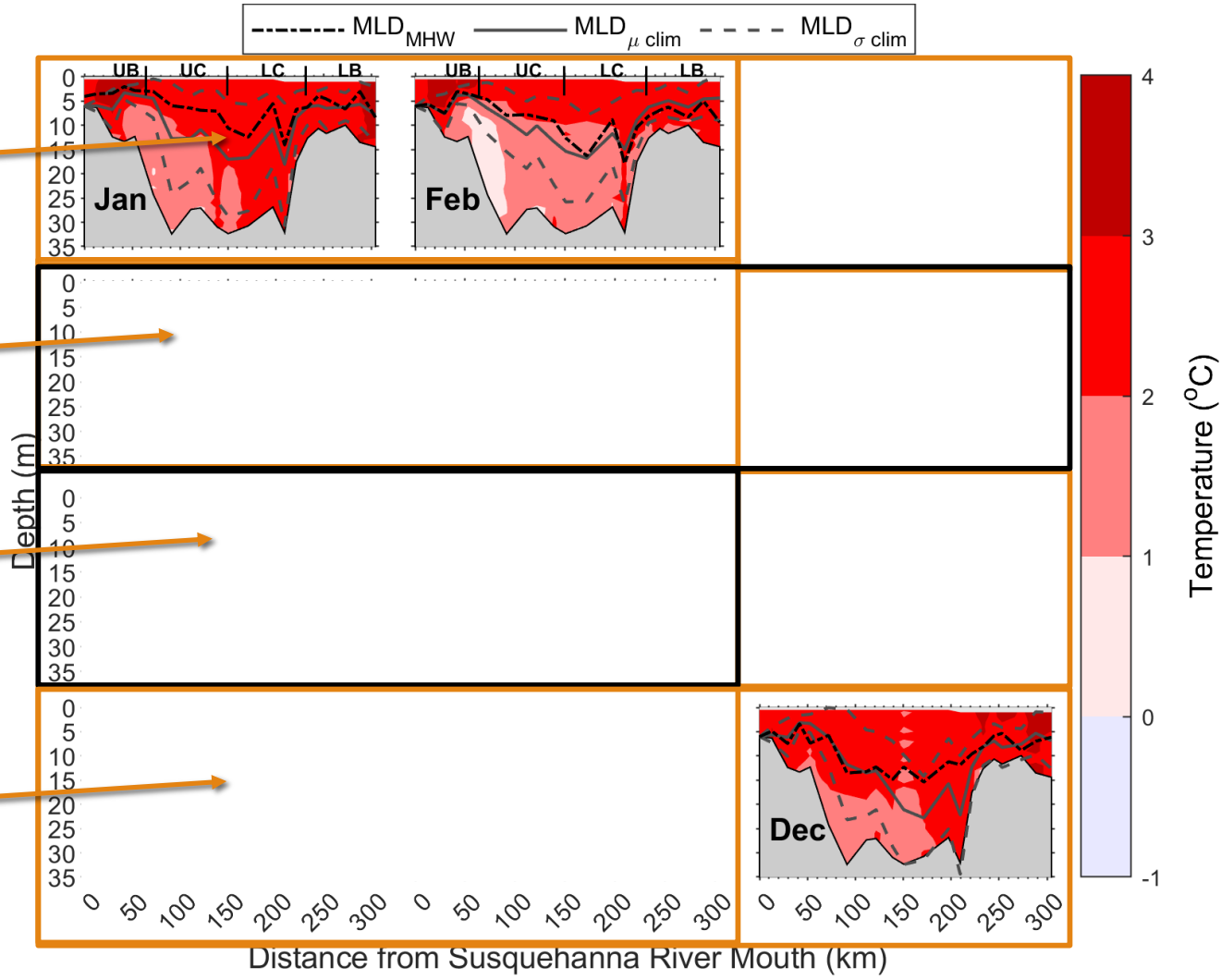
SPATIOTEMPORAL CHARACTERISTICS

# Temperature: Seasonal Variability

- **Winter**
  - Anomalies Penetrate to Bottom
  - Larger Anomalies
- **Summer**
  - Thermal Stratification in Channel
  - Horizontally Consistent
  - Smaller Anomalies
- **Spring**
  - Late Spring Consistent with Summer Patterns
  - Large Anomalies in UB & UC
  - March: Stratified in UC; Homogeneous in LC
- **Fall**
  - Consistent with Winter Anomaly Patterns
- **Shoaled Mixed Layer Depth**

**2 Seasonal Regimes**

- Stratified Season (April-August)
- Homogeneous Season (October-February)
- Surface Source of Heat (Horizontally Consistent Anomalies)



# Temperature: Seasonal Stratification

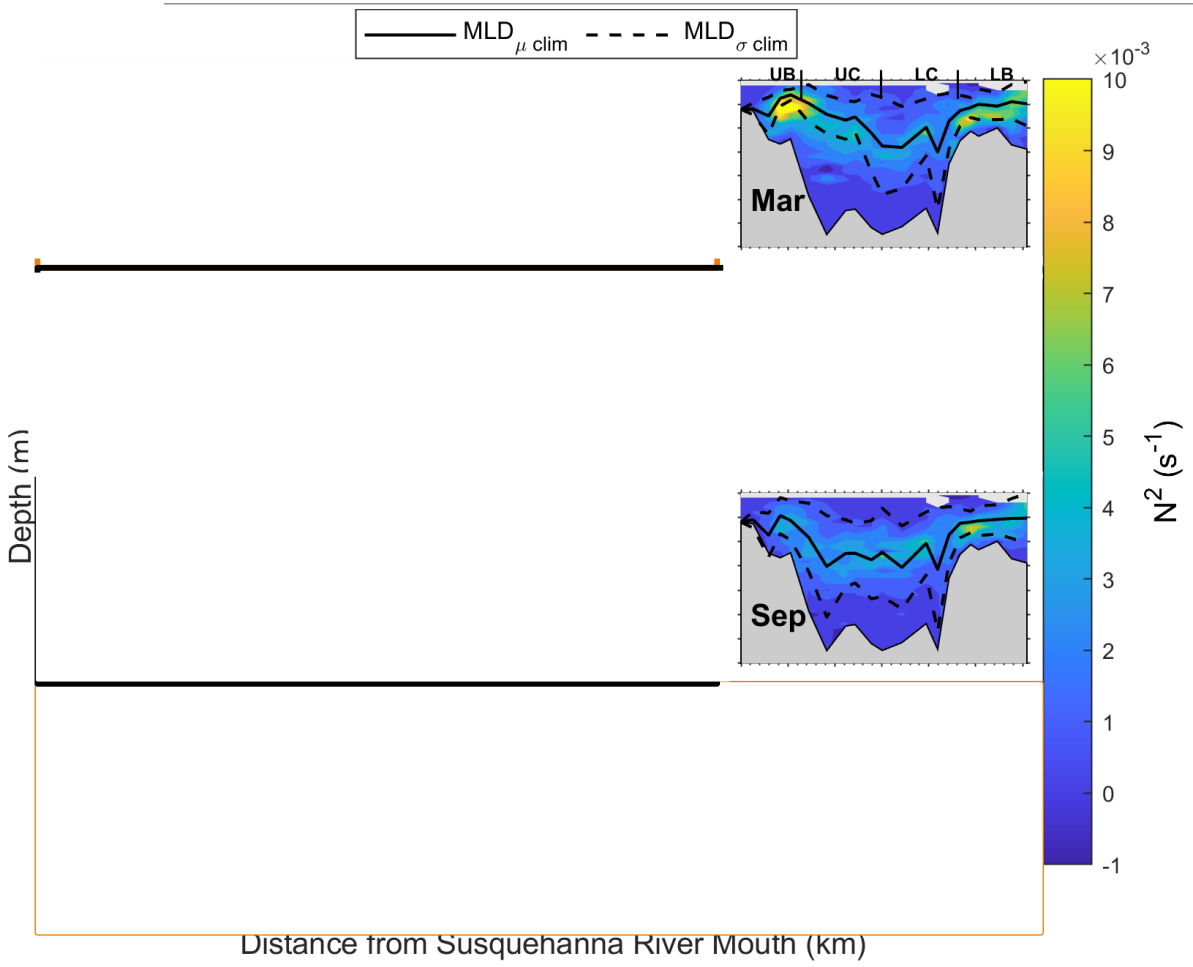
**Stratified Season:**

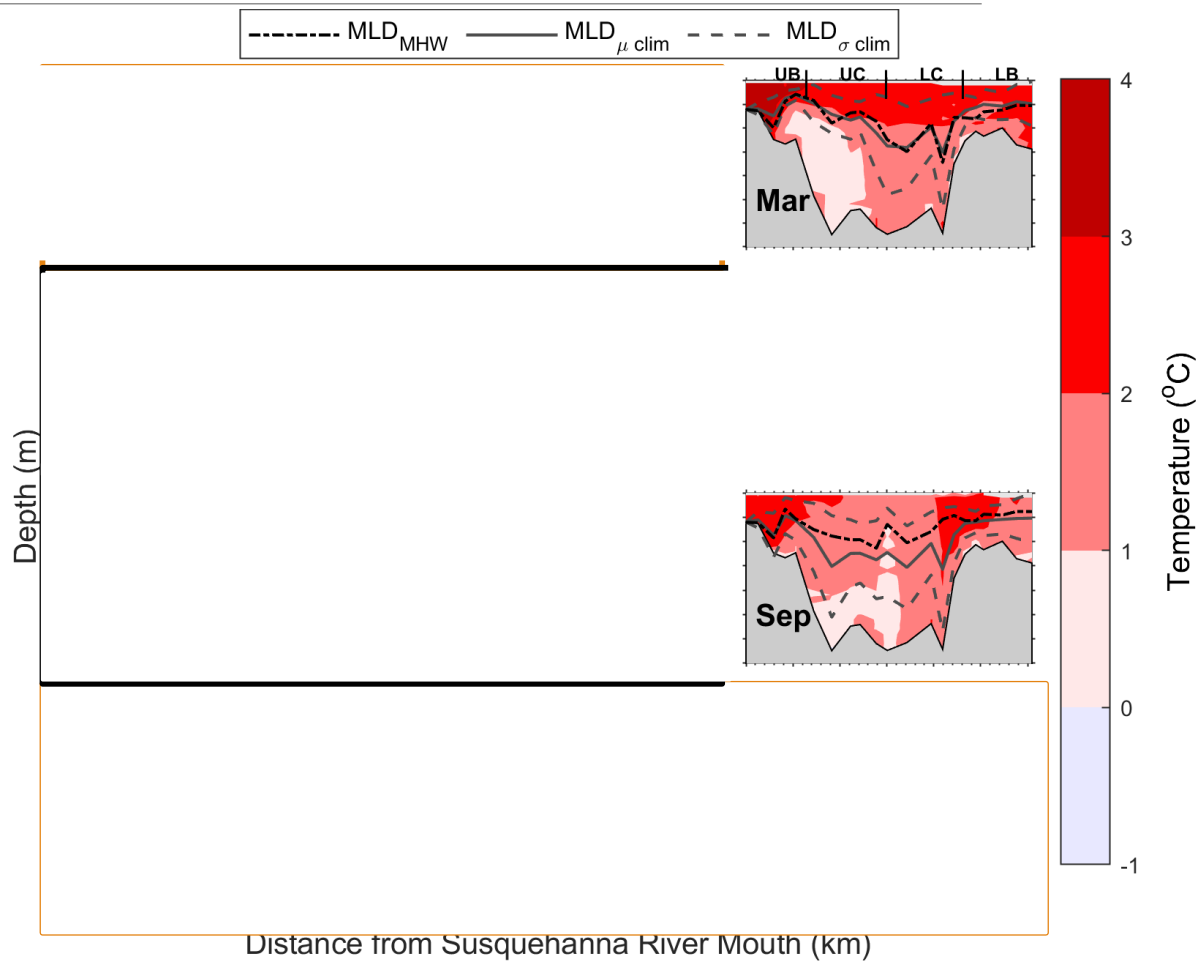
Strong Stratification; Stable Mixed Layer Depth

**Homogeneous Season:**

Weak Stratification; Variable Mixed Layer Depth

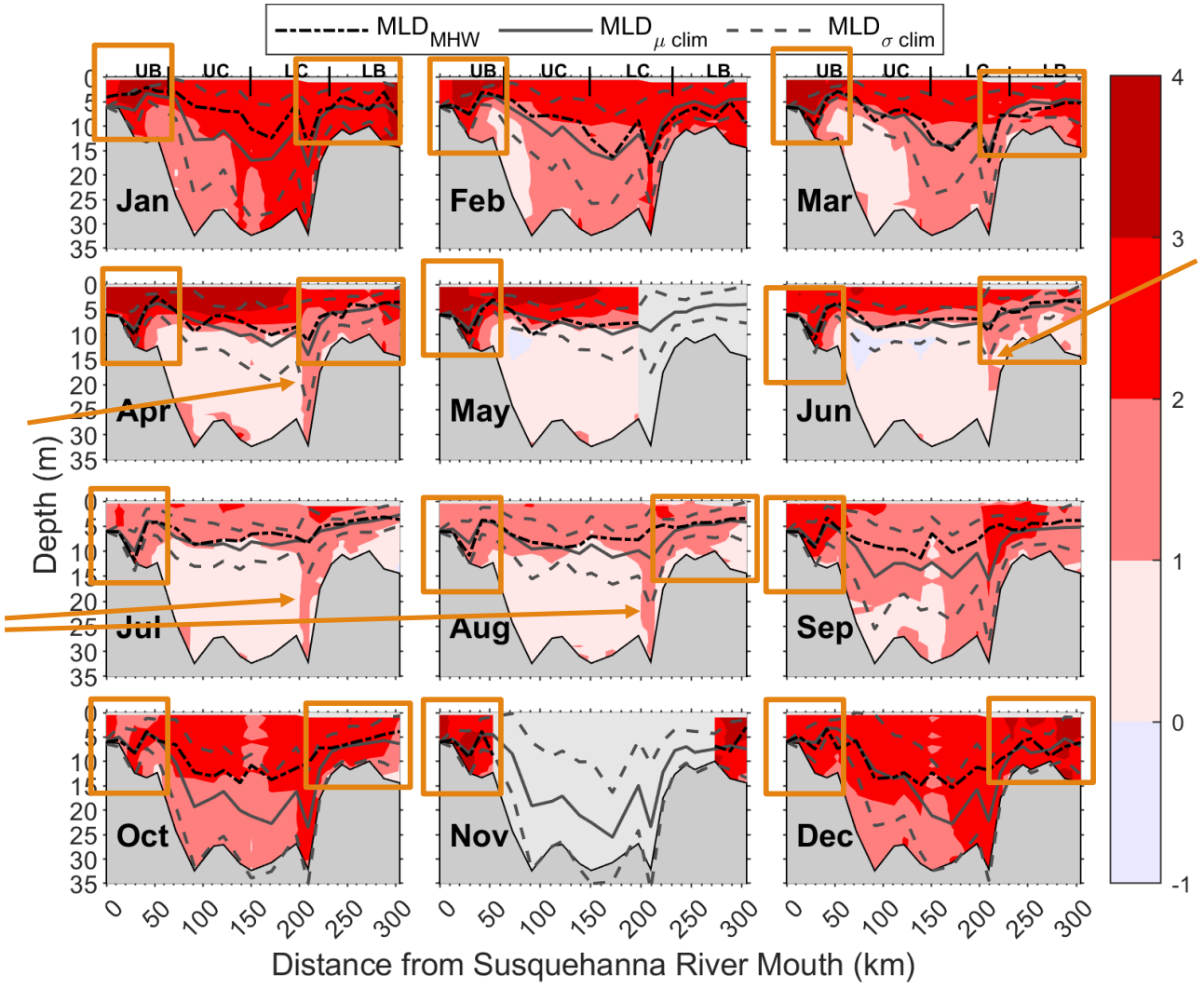
**Delayed response to Discharge: ~6 Months**



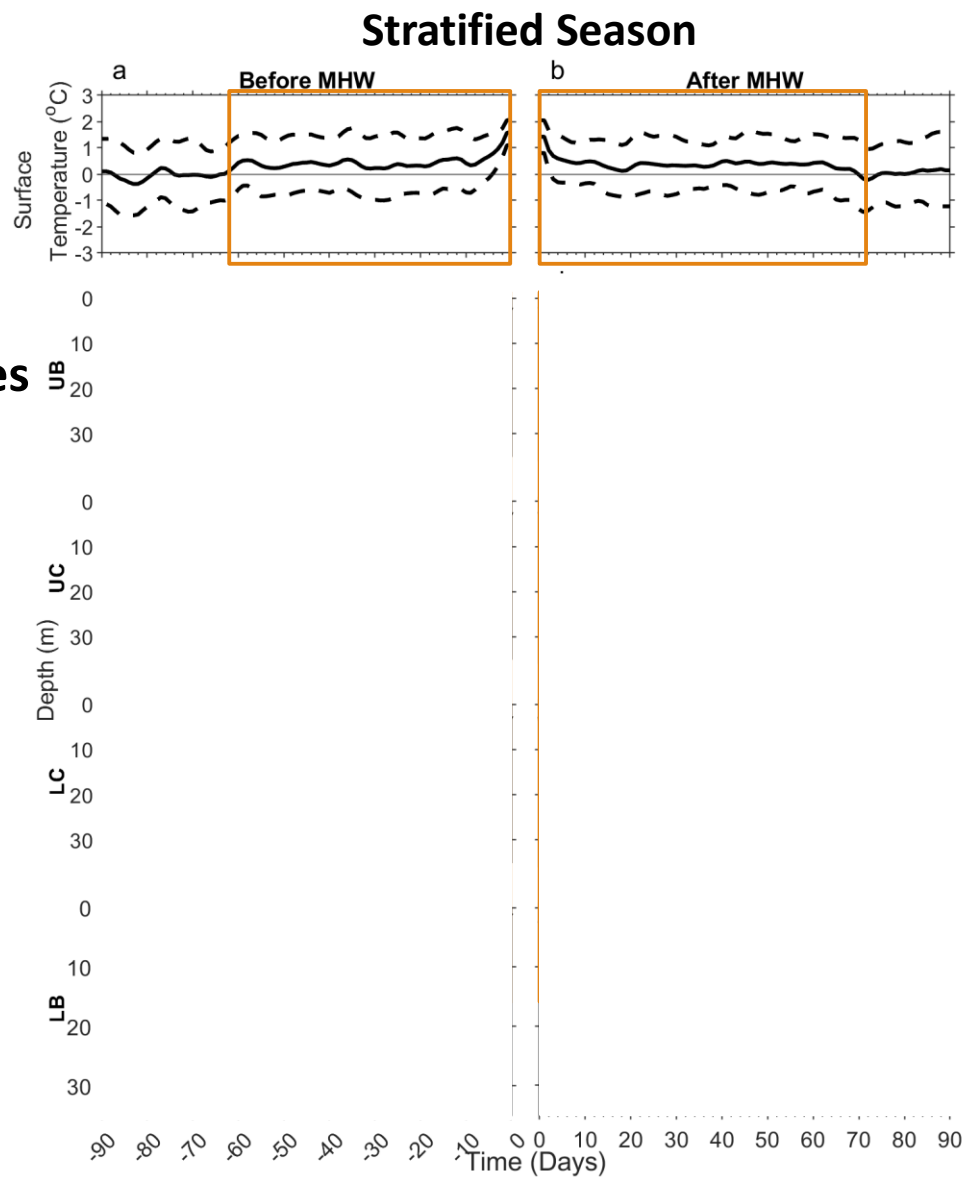
# Temperature: Exceptions

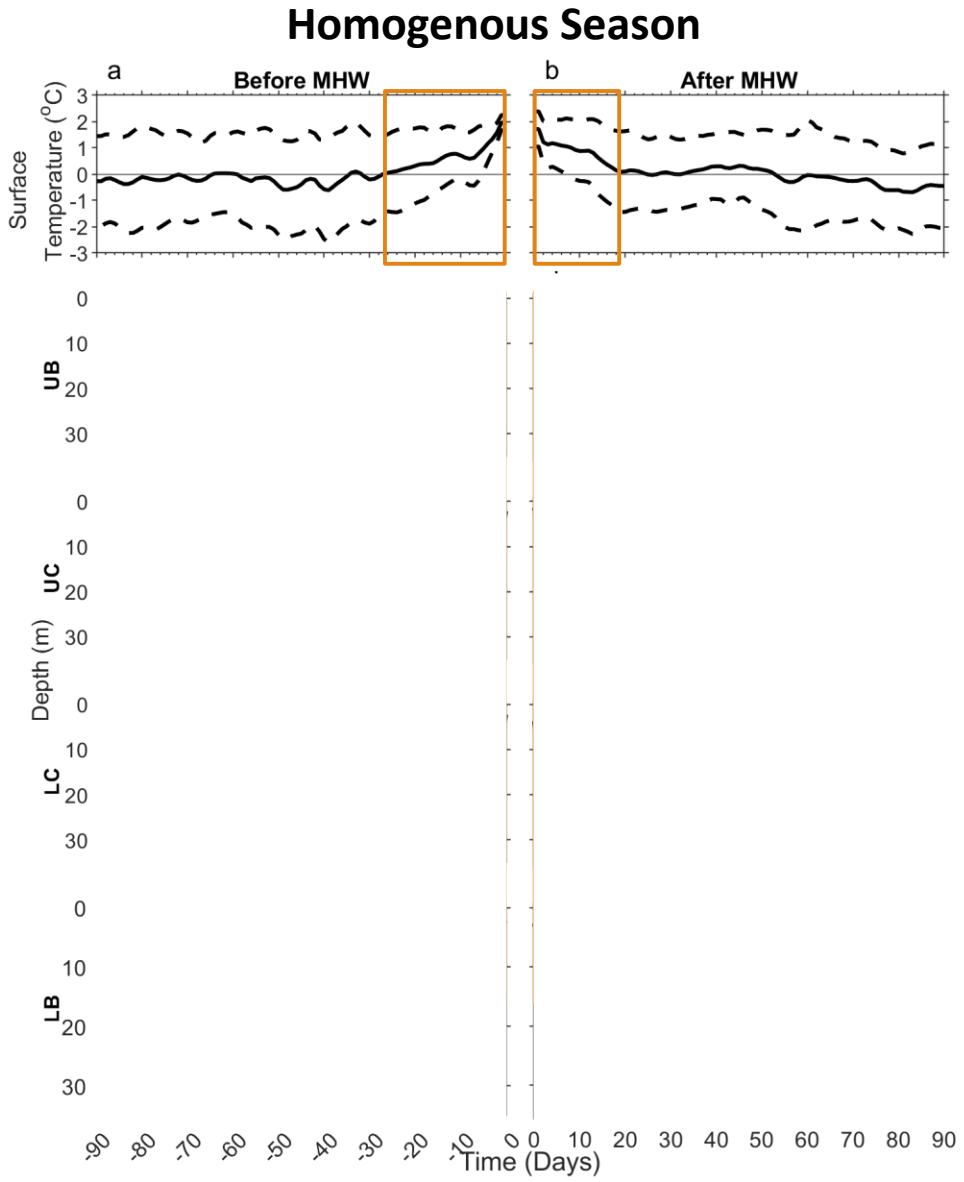
- **Upper Bay (UB)**
  - Homogeneous Year Round
  - Influence of Susquehanna
- **Lower Channel (LC)**
  - Penetrates to Bottom Year Round
  - Convergence and Wind Mixing
- **Lower Bay (LB)**
  - Muted Seasonal Cycle (Note April & June)
  - Seasonal Tidal and Saltwater Intrusion Dynamics



# Temperature: Synoptic Timescale

- **Surface Anomalies**
  - Present 1-2 Months Before and After Events
  - **Preconditioning of Bay Waters**
- **Subsurface Anomalies**
  - Before
    - Stratified: 5-18 days
    - Homogenous: ~10 days
    - **Warming Begins Before Events**
  - After
    - Stratified: 5-10 days
    - Homogenous: 10-20 days
    - **Persistent Warming Afterwards**
- **Mixed Layer Depth**
  - Shoals 5 days Before and Recedes 5 days Afterwards



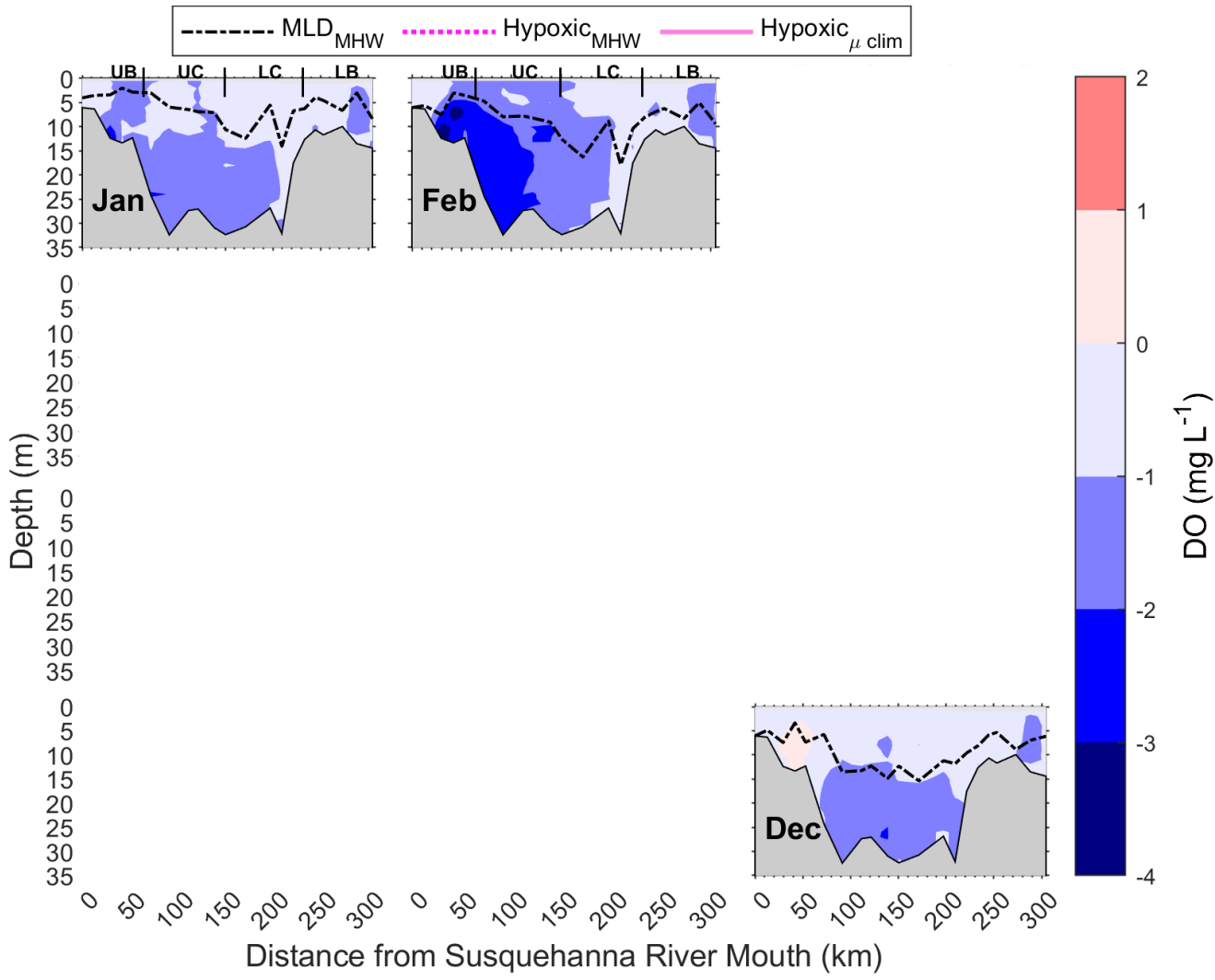
# Dissolved Oxygen

SPATIOTEMPORAL CHARACTERISTICS

# Dissolved Oxygen (DO): Seasonal Variability

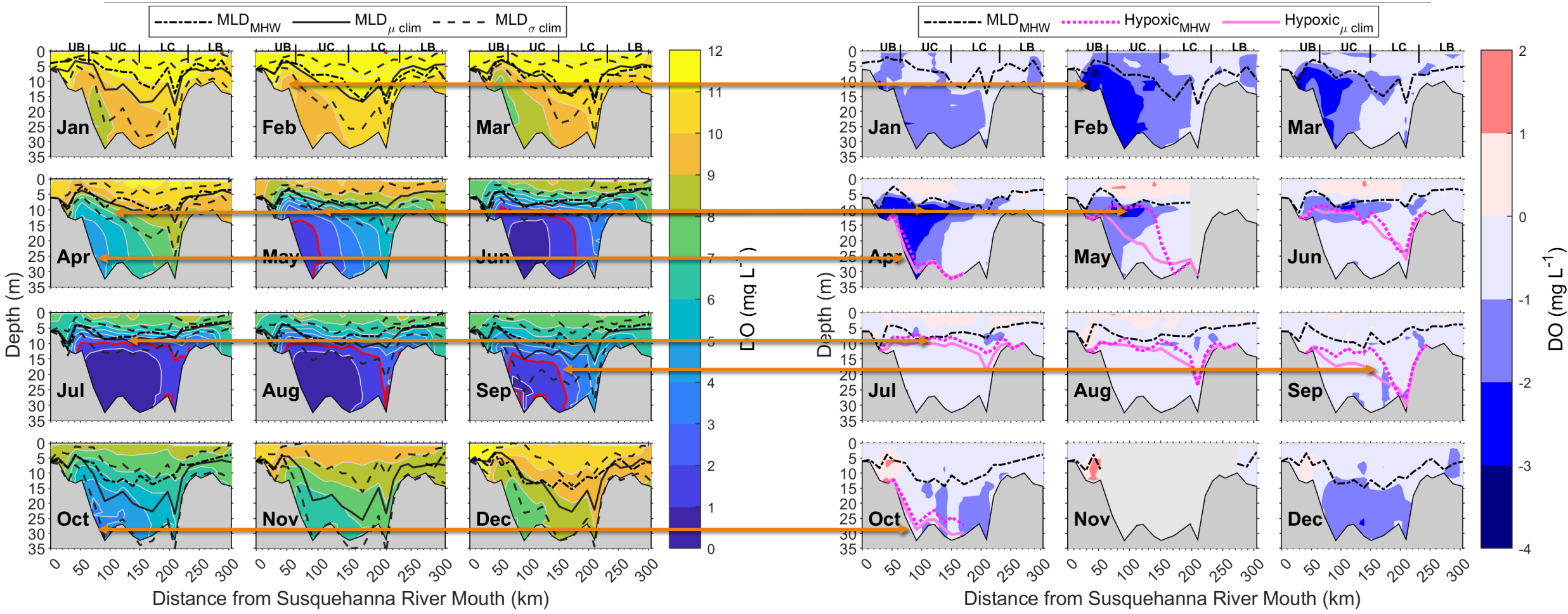
- **Winter**
  - Low DO Concentrated In Deep Channel
  - Greatest Negative Anomalies in UC and UB
- **Spring**
  - Notable Negative Anomalies in UC and UB
  - Slight Positive Anomalies in Surface
- **Summer**
  - Absence of Notable Anomalies
  - Slightly Positive Anomalies in Surface
- **Fall**
  - Few Notable Anomalies
- Anomalies Capped by Mixed Layer Depth
- Hypoxic Zone Expands April-October

**DO Anomalies Spatial Variability Greater**



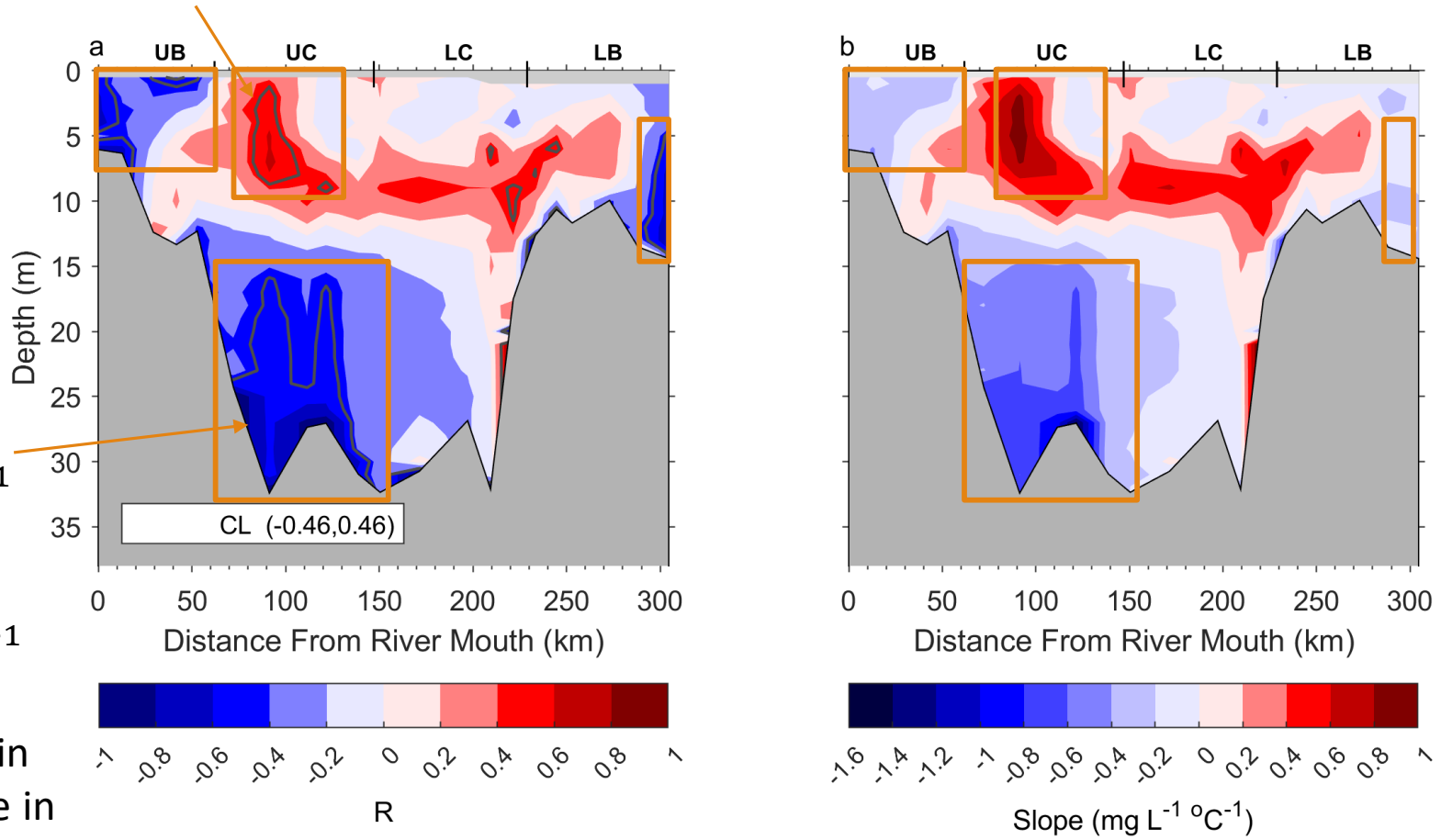
# Dissolved Oxygen (DO): Seasonal Variability cont.

**Marine Heatwaves Associated with modulation of Low DO**



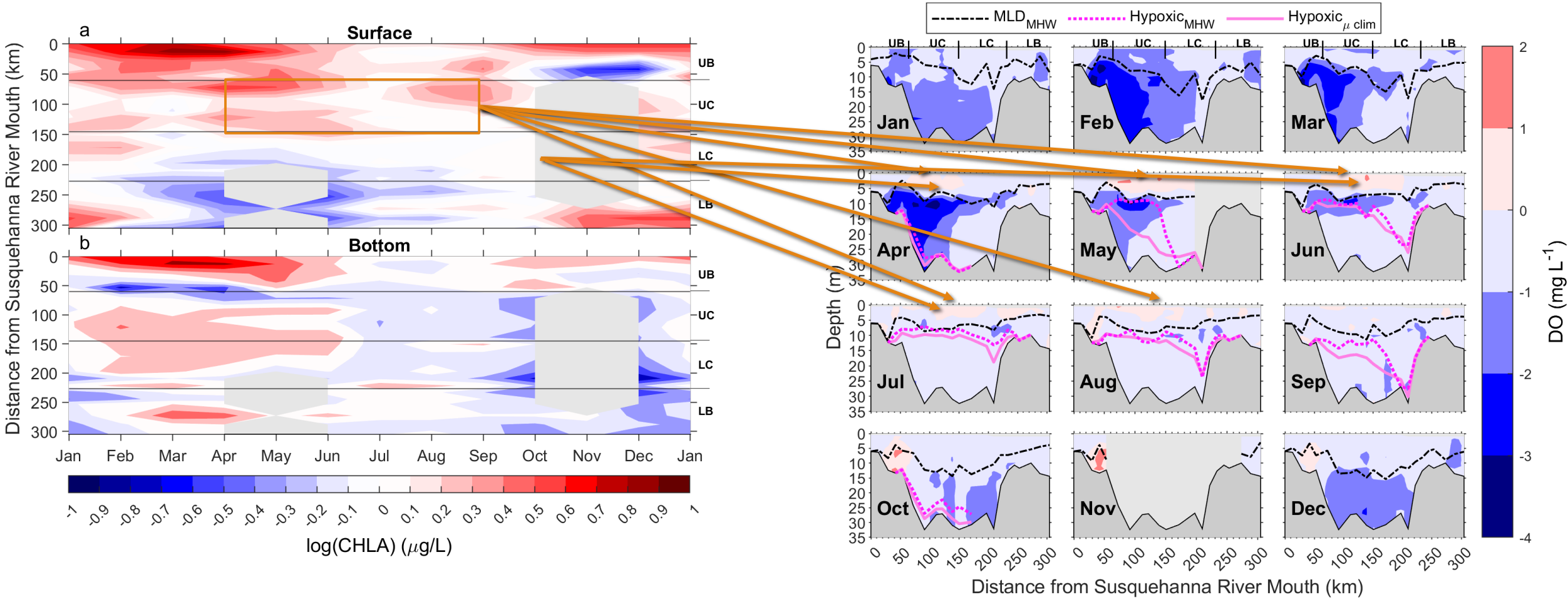
# Dissolved Oxygen: Correlation Analysis

- **UB**
  - Negative R
  - Small Slope
- **LB**
  - Negative R
  - Small Slope
- **UC**
  - **Surface**
    - Positive R
    - 0.4-1 mg $L^{-1}$ °$C^{-1}$
  - **Bottom**
    - Negative R
    - -1.6 to -0.4 mg $L^{-1}$ °$C^{-1}$
    - ~10-20% Change in DO due to Change in Solubility



# Dissolved Oxygen: Positive Correlation

**Positive Correlation Possibly Due to Enhanced Rates of Photosynthesis, NOT Solubility Changes**



# Potential Ecosystem Impacts

- **Seasonal Effects on Organisms**
  - Exceed Heat Tolerances (Summer)

(Caputi et al., 2016; Shields et al., 2018; Cheung and Frölicher, 2020; Tomasetti et al., 2023)

  - Impact Vulnerable Larval Life Stages (Fall-Spring)

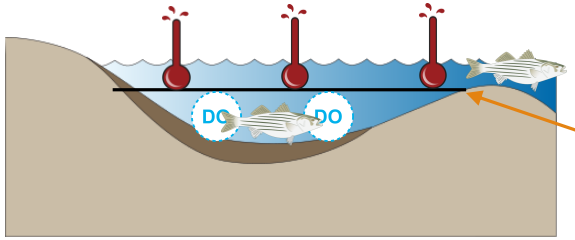
(Colombano et al., 2022)

  - Change Migration Patterns (Fall-Winter)

(Aguilar et al., 2005)

- **Limited Thermal Refuges**

  (Tassone et al., 2022)




- **Cumulative Heat Stress**
  - MHWs Last ~11 days
  - 22-55 days of Total Anomalous Warming

**Contact Information:**
Nathan Shunk: npshunk@vims.edu
Piero Mazzini: pmazzini@vims.edu

# Conclusions

## Temperature

- **Seasonal Temperature Regimes**
  - Stratified Spring-Summer
  - Homogenous Fall-Winter
- **Air-Sea Heat Flux Primary Driver**
- **Persistent Anomalies**
  - Preconditioning: 1-2 Months Surface, 5-20 Days Subsurface
  - Persistence: ~10 Days to Months Surface, 5-20 Days Subsurface
  - Total Heat Stress: 22-55 Days

## Dissolved Oxygen

- **Decreased Dissolved Oxygen**
  - Greatest in Upper Bay & Upper Channel
  - Winter & Spring
- **Expansion of Hypoxic Zone**: April-October

**Contact Information:**
Nathan Shunk: npshunk@vims.edu
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# Future Work

**Temperatures**

- **Mainstem Structure**
  - Cross Stem Structure
  - Connection with Tributaries & Plume
- **Other Forcing**
  - Local: Winds, River Discharge, etc.
  - Regional: NAO, BHI, and ENSO
  - Especially Wet/Dry Years

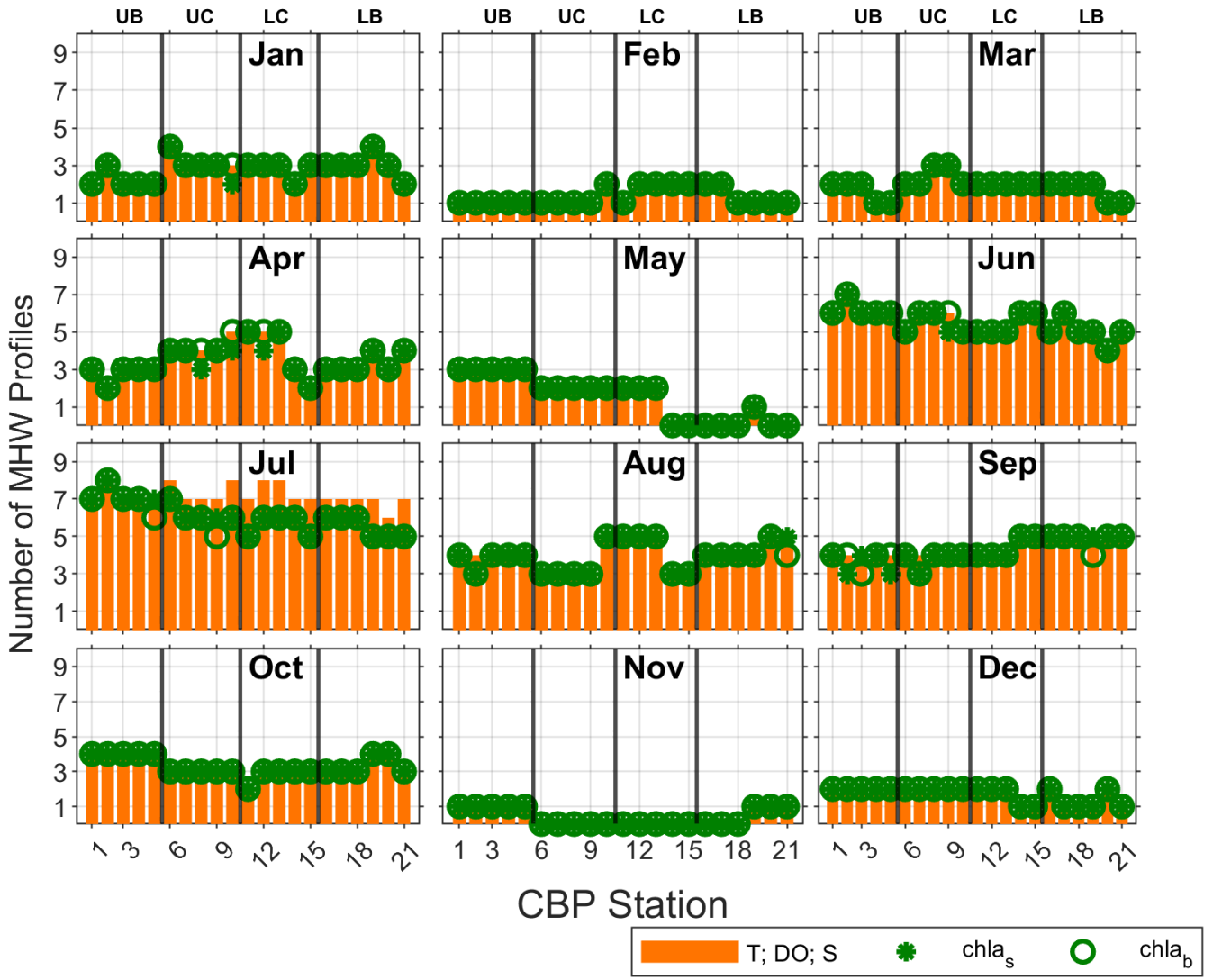
**Water Quality**

- **Dissolved Oxygen**
  - Cumulative Impact on Dissolved Oxygen
  - Mechanisms
- **Other Biogeochemical Parameters**

**Questions?**

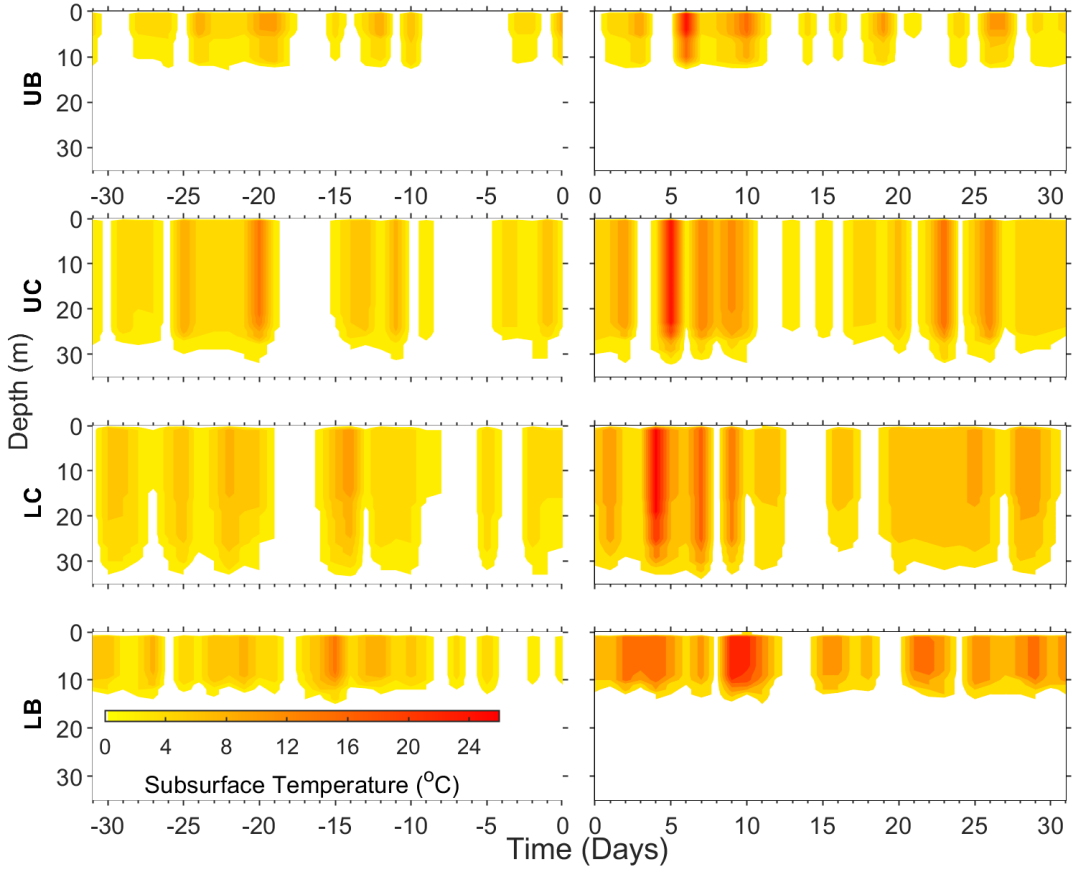
# Appendix

# Marine Heatwave Profile: Data Availability

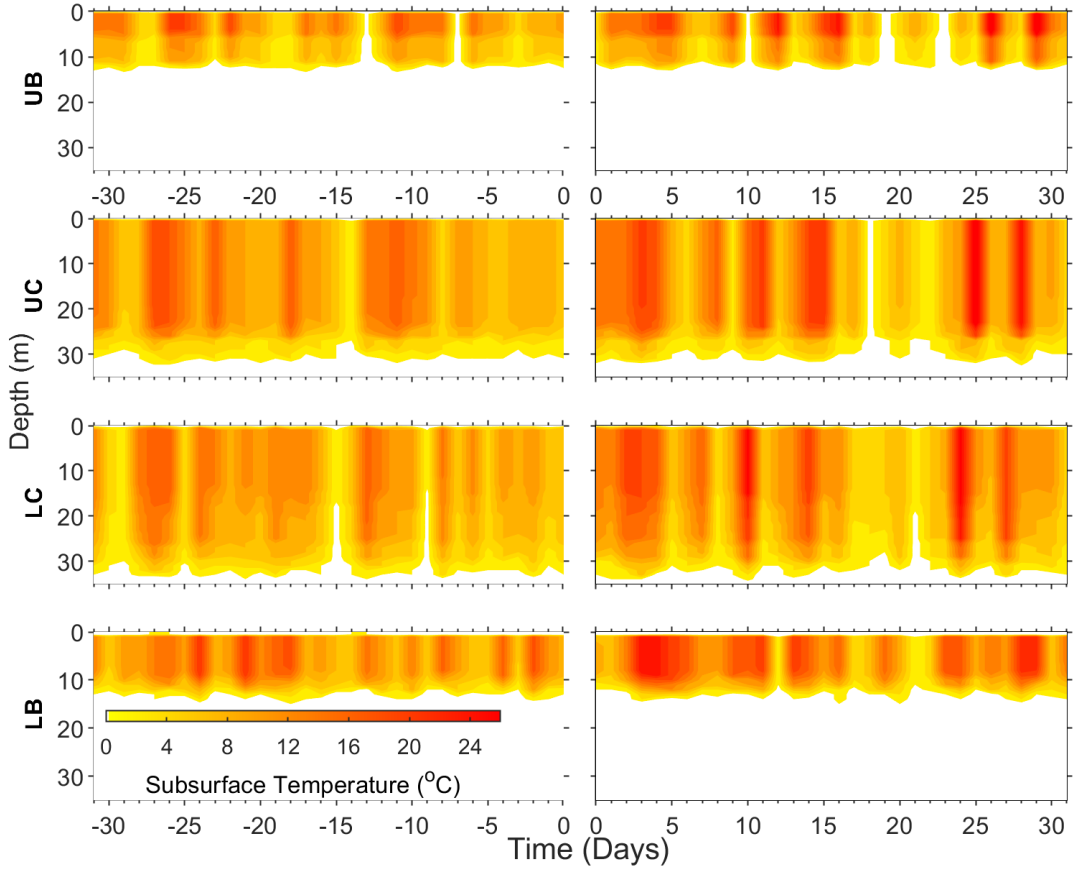


# Synoptic Profile Data Availability

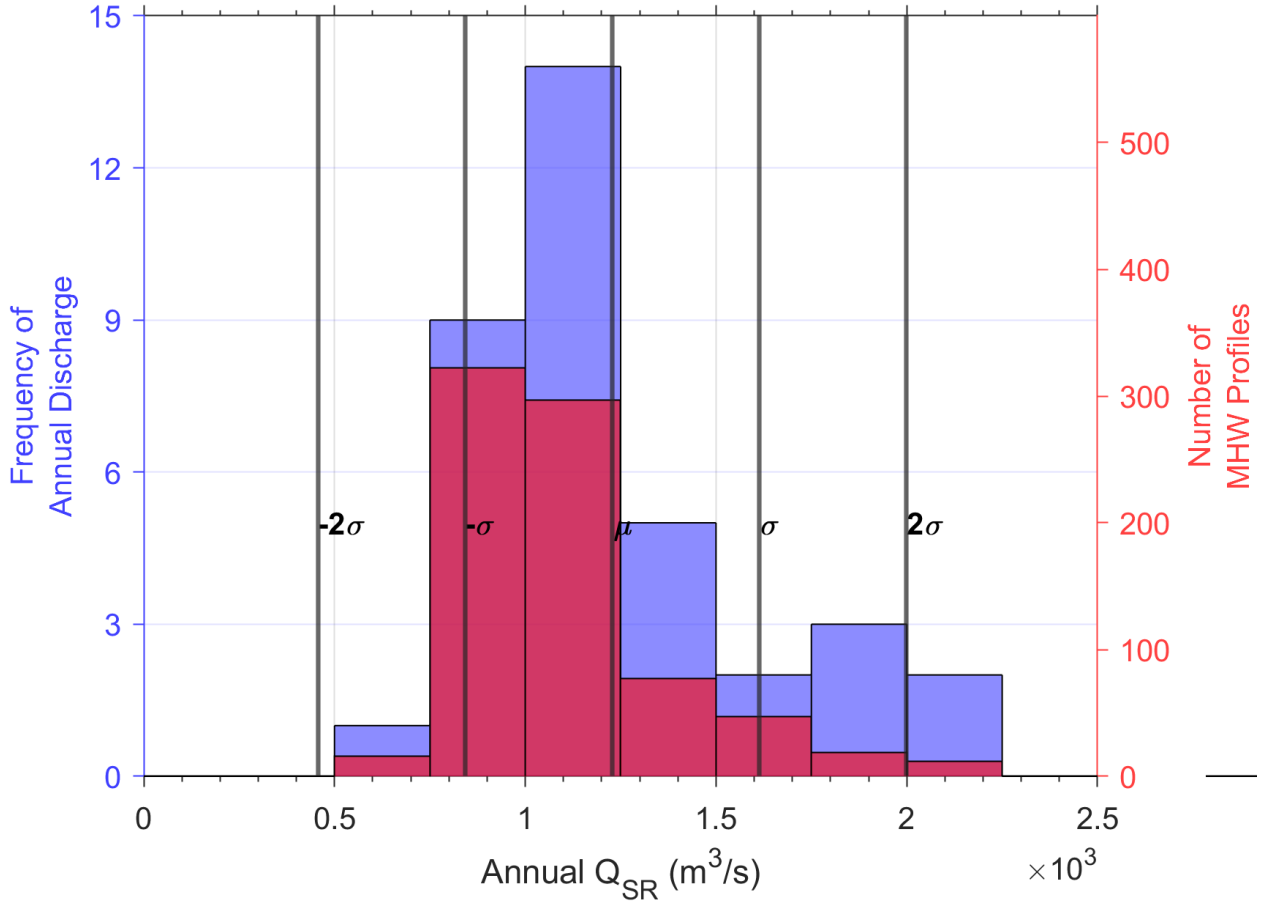
Homogenous Season



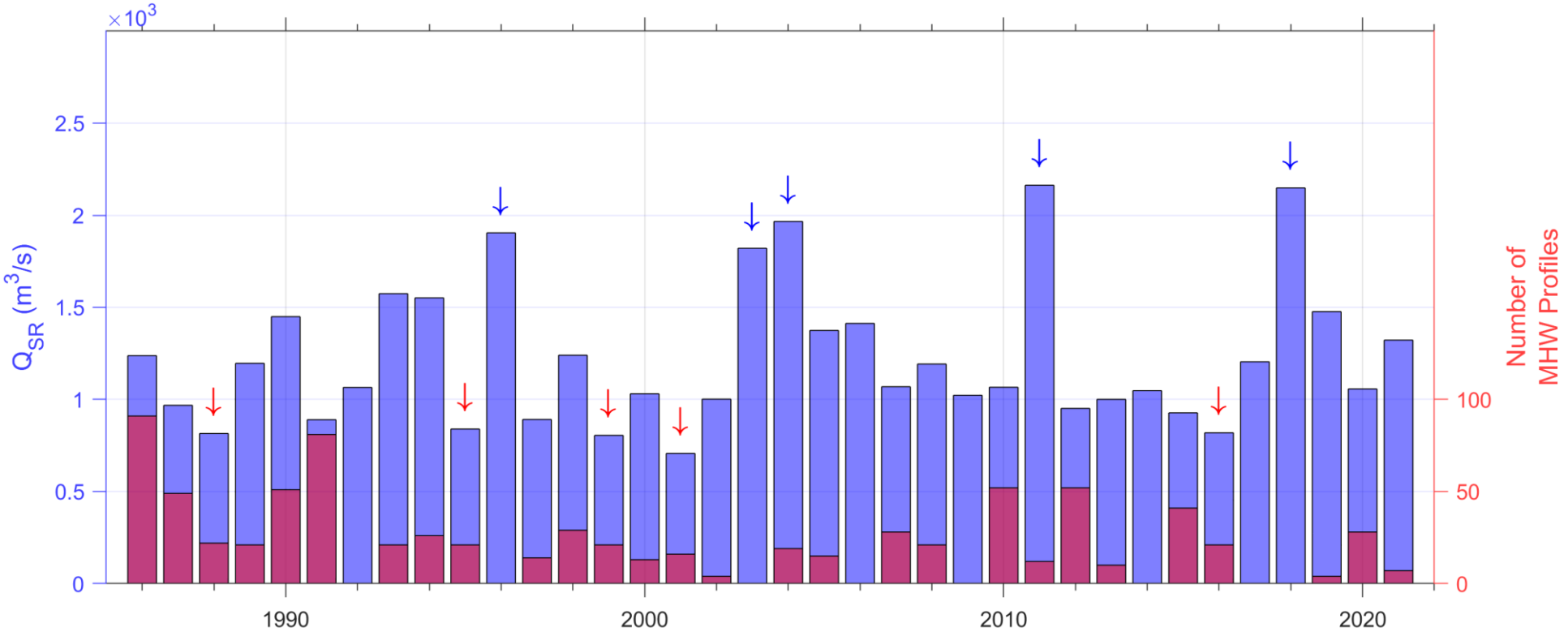

Stratified Season



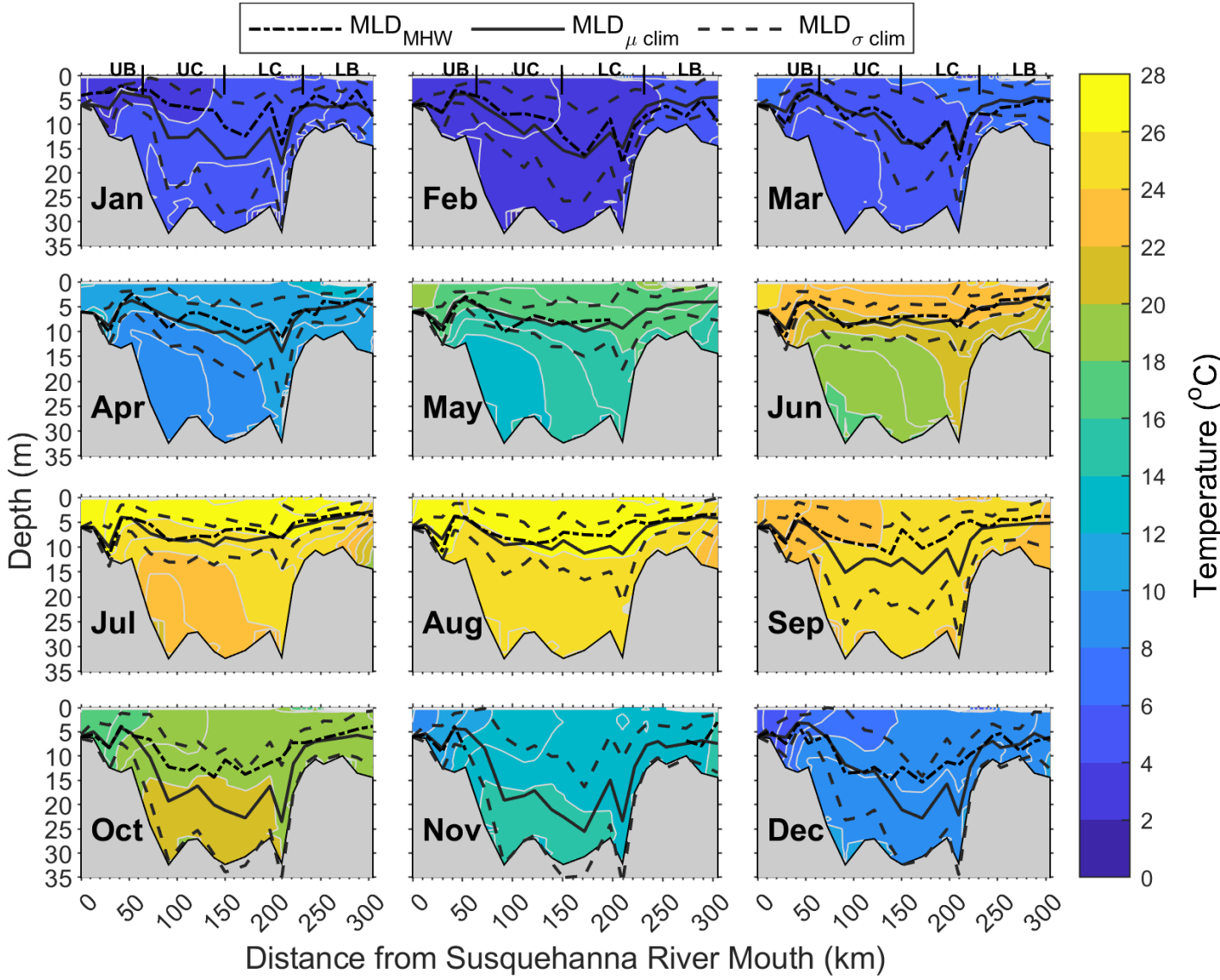
# Data Distribution by Discharge Bins



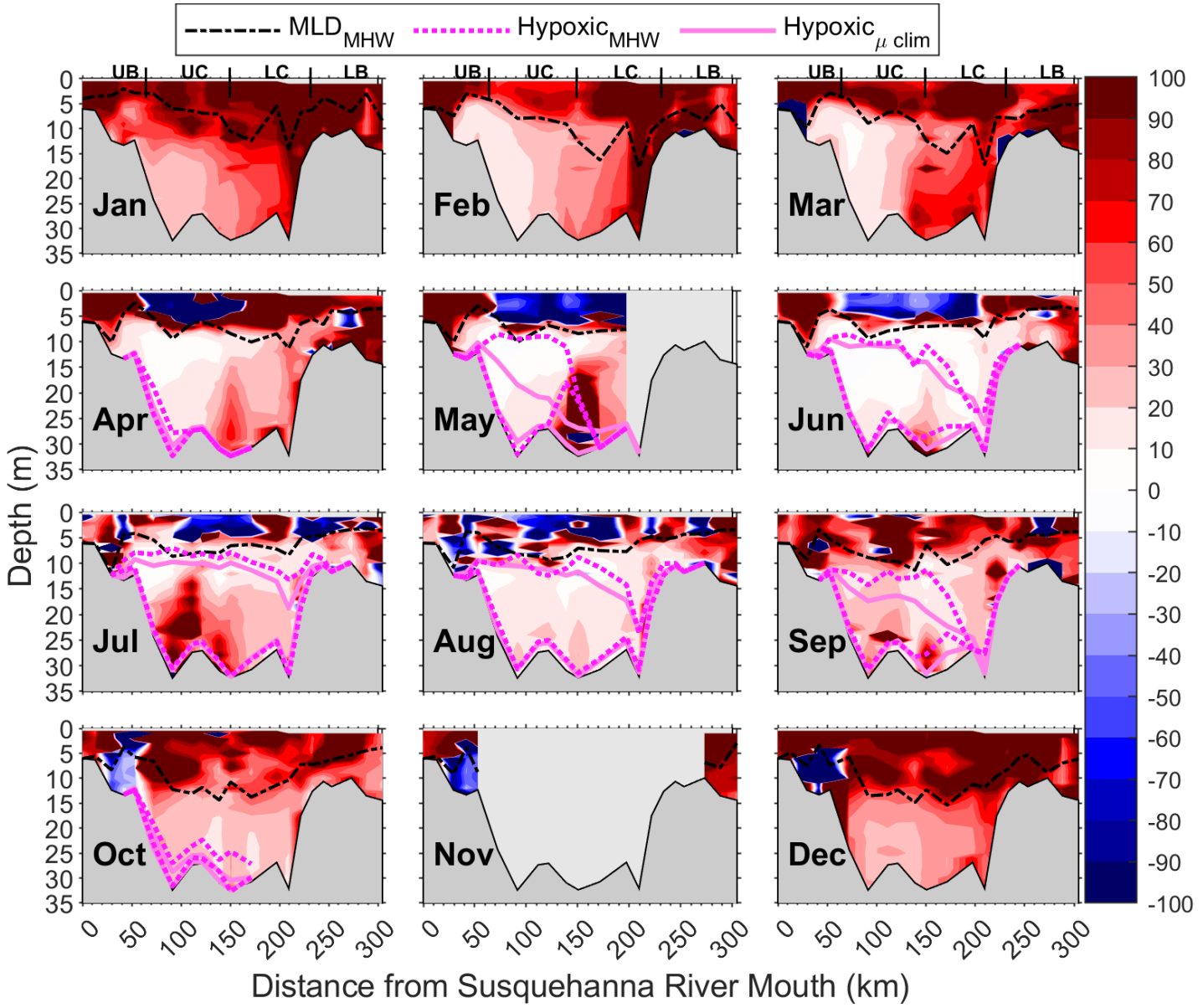
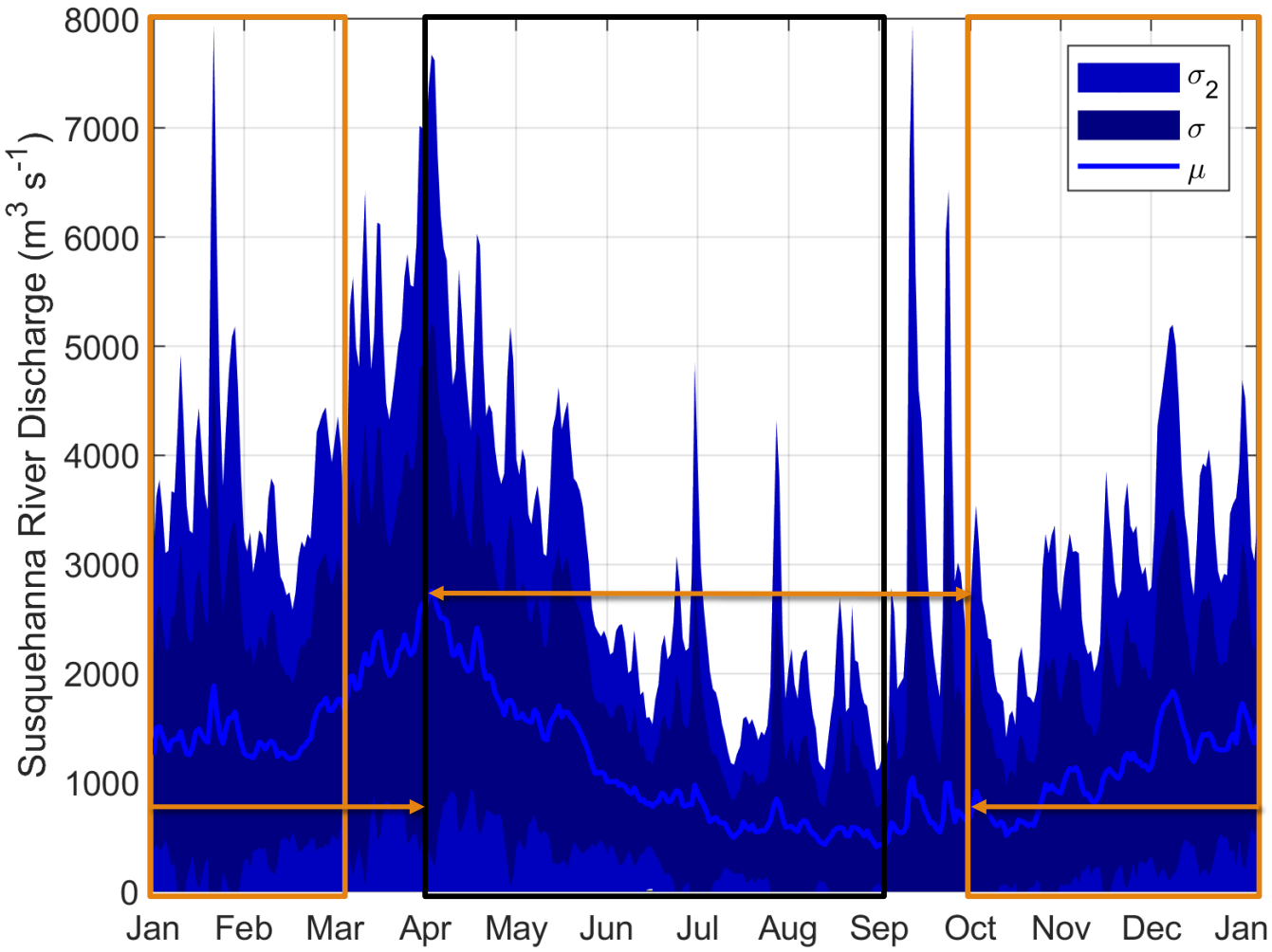
# Annual River Discharge



# Climatological Temperatures



# Percent Change in DO Due to Solubility



# Climatological River Discharge