Water temperature in estuaries
Proposal to NSF PO August 2019, PI Melanie Fewings, Co-PI Jim Lerczak

PROJECT SUMMARY

Abstract

Estuaries are biologically productive systems that support important fisheries and coastal ecosystems, but many estuaries are under stress from pollution and changing river flows and weather patterns. Water temperature strongly affects the biogeochemical rates and ecology of estuaries. What controls water temperature in estuaries, however, has received little attention in comparison to salinity, which controls the density field and drives the estuarine circulation. Temperature is typically assumed to be a dynamically passive tracer in estuaries. In rapidly flushed estuaries, the water temperature is determined by conservative mixing of the river and ocean water masses, so temperature can be predicted from the salinity field and the river and ocean temperatures. In slowly flushed estuaries, however, these river and ocean 'end member' temperatures vary on time scales shorter than the transit time of water parcels passing through the estuary, making conservative mixing less useful for predicting temperature. Further, in slowly flushed estuaries, air-sea heat fluxes cause the water temperature to depart from the conservative mixing prediction. There has been little work on the processes that control water temperature in slowly flushed systems. The major influences on the water temperature in estuaries are (1) conservative mixing of ocean and river waters with different temperatures, (2) advection of heat by the estuarine circulation, which is to first order salinity-controlled and independent of the temperature, and (3) air-sea heat exchange. We propose to develop a new analytical framework and non-dimensional parameters that govern temperature structure in estuaries. We will test this analytical theory using existing long time series observations of six estuaries that span the relevant parameter space: the Connecticut, Delaware, Hudson, Merrimack, Columbia, and Guadalquivir. We will determine the range of natural variability in estuarine temperatures and forcing, and relate to estuary depth and transit time. We will use idealized numerical model experiments to determine the effects of air-sea heat fluxes and time-varying end members, guide the separation of these effects in observations, and determine whether temperature can have strong effects on estuarine circulation through affecting vertical mixing.

Intellectual Merit

Although temperature is as important as salinity in its effects on the ecology of estuaries, the literature provides no framework for understanding the temperature structure, variability, and dynamics of estuaries. Without this understanding, we have no way other than direct simulation of predicting which estuaries will be sensitive to the increases in precipitation and river runoff forecast for the coming decades. The proposed project will determine what controls the structure and evolution of water temperature in six estuaries across a range of parameter space. We hypothesize that in estuaries where the residence time is long, the maximum water temperature in summer is determined by a negative feedback between the air-sea heat exchange and the advective heat loss carried by the estuarine circulation.

Broader Impacts

Estuaries are under stress from nutrient loading, hypoxia, and harmful algal blooms. Water temperature is a major influence on physiological processes of the plankton that cause harmful algal blooms. Oysters become more susceptible to disease, and have less ability to tolerate freshening of the water column, at higher temperatures. Fish and crustaceans have thermal tolerance limits, and some species of fish already experience thermal stress during current heat waves. This project will determine how water temperature in estuaries is dynamically controlled, as a precursor to being able to predict which species in which estuaries are likely to experience increased thermal stress in coming decades, when precipitation and river flow are forecast to increase.

Our objectives are to answer the following 3 **research questions** and test **hypotheses (H)**:

Q1. What is the range of natural variability in estuarine temperature and its forcing, and how does T depend on estuary depth and transit time?

Hypotheses:

H1a: Along-channel structure: estuaries that display an along-channel maximum in water temperature in summer, or minimum in winter, are shallow estuaries with a long transit time.

H1b: Estuaries that depart from a straight line in T-S space are ones for which the forcing (either end member temperature or air-sea flux) changes rapidly compared to the transit time.

Approach: Use existing long time series to characterize ~3-6 estuaries that span the range of the parameter space (water depth, transit time). The mid-latitude seasonal cycles in air-sea fluxes and river and ocean temperatures will allow the analysis to span that parameter range.

Q2. How is the estuarine water temperature affected by **surface fluxes** and by time-varying **river and ocean temperatures** (end members)?

Hypotheses:

H2a: Surface fluxes and time-varying end members can both cause the estuary T-S curve to depart from a straight line.

H2b: Because the river is forced by the same surface fluxes as the estuary, when surface fluxes are important, the riverine end member will be time-varying.

Approach: Use idealized (along-channel uniform) numerical model experiments in ROMS to understand the separate and combined effects of surface fluxes and time-varying end members across parameter space, and use to interpret existing observations from ~3-6 estuaries.

Q3. What are the dynamical effects of water temperature in the estuary?

Hypotheses:

H3: In regions of marginal stability, **vertical thermal stratification is dynamically important via suppressing or enhancing shear-driven vertical mixing**.

Approach: Use paired idealized numerical model experiments with temperature as a dynamically active or passive variable; compare results to each other and to existing observations. Assess effects of diurnal heating on stratification and shear in the observations by comparing cloudy and clear periods that have otherwise similar conditions and forcing.