Seasonal and Interannual Surface Temperature Variability along the Columbia River Estuary

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Motivation

Temperature in estuaries – important for ecology: algal blooms (Ralston et al. 2015), salmon health (Gross et al., 2023), etc.

Despite importance of temperature in estuaries, little work has been done

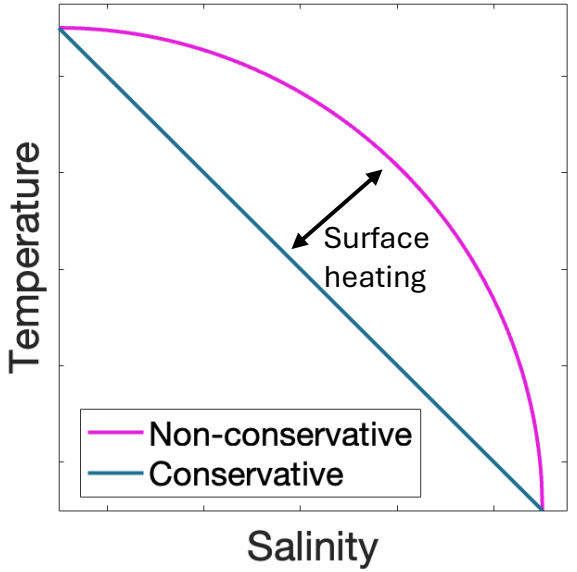
→ Most physical oceanography focuses on salinity in estuaries, since it is dominant in setting density, mixing

Multiple factors influence temperature in estuaries:

→ Time varying end members (river and ocean)

→ Non-conservative processes (surface heat flux)

→ Estuarine geometry



We need to develop a better dynamical understanding of how temperature varies in estuaries, and which drivers matter most when.

Temperature in the Columbia

Long-term warming trends in the Columbia

→ Over 2°C increase in temperature since 1850 at Bonneville (Scott et al., 2023)

Interannual variability

→ 2-4 °C of variability in average July water temperatures at Bonneville (Petersen and Kitchell, 2001)

Seasonal variability

→Maximum temperature difference between river and ocean in late summer (Roegner et al., 2011)

Sub-seasonal variability

→Temperature variability largely explained by conservative mixing on a day (Roegner et al., 2011)

How do surface temperatures vary along the Columbia River estuary?

→Interannually?
→Seasonally?
→Sub-seasonally?

To answer these questions:
Data sources:

→ Coastal Margin Observation and Prediction (CMOP) SATURN moorings

→ NOAA National Data Buoy Center (NDBC) Station 46243, Clatsop Spit

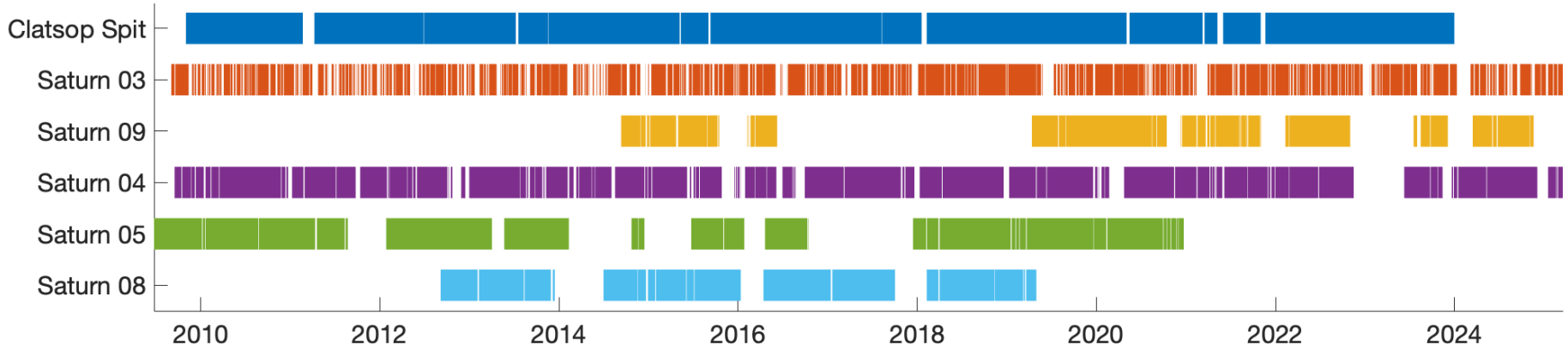
Processed and daily averaged data

Data Coverage:

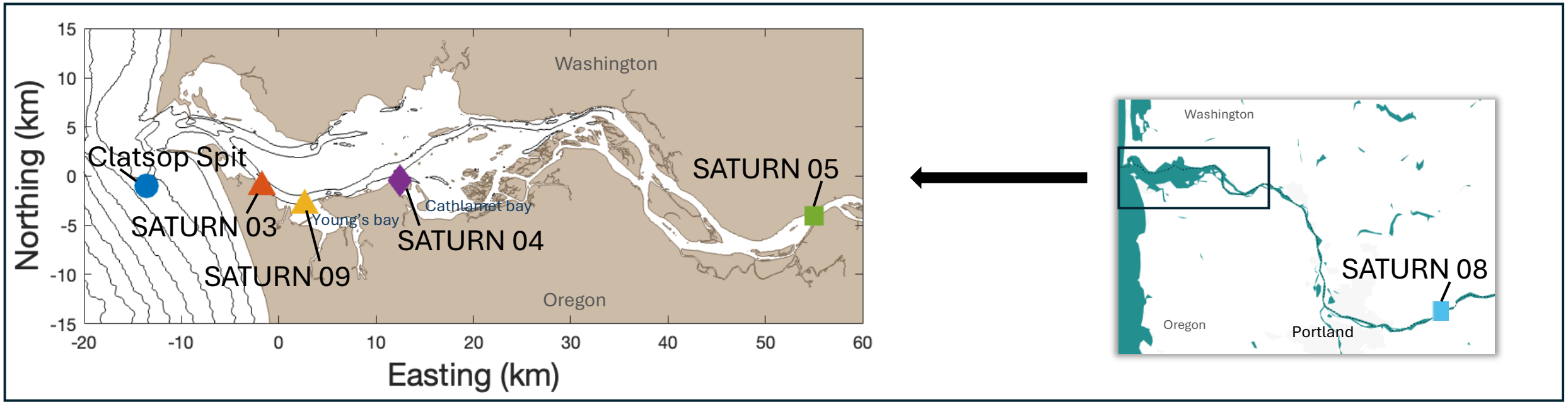
Temporal (2009-2024) →

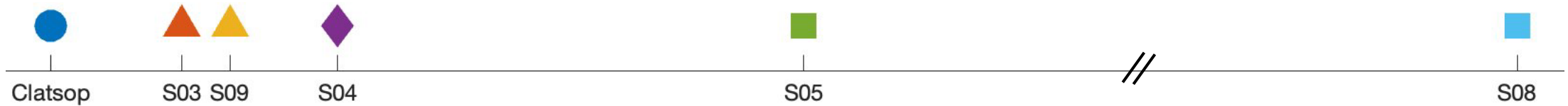
Spatial ↴

Availability of Surface Temperature Data by Site

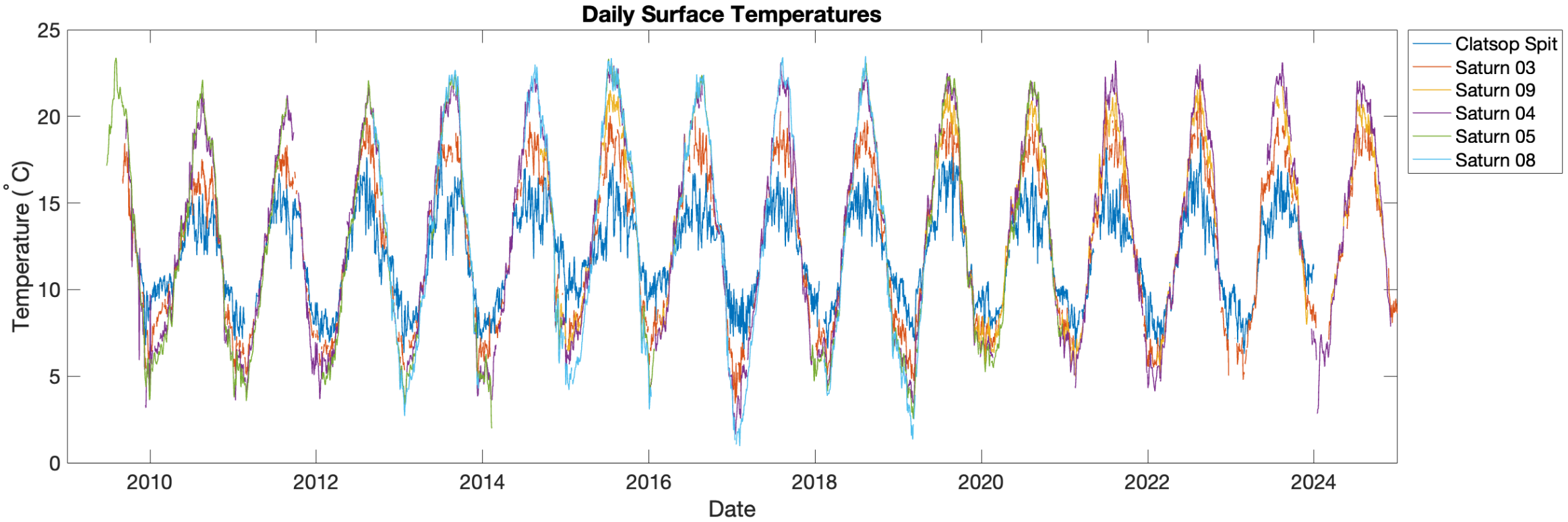


Locations of Sites

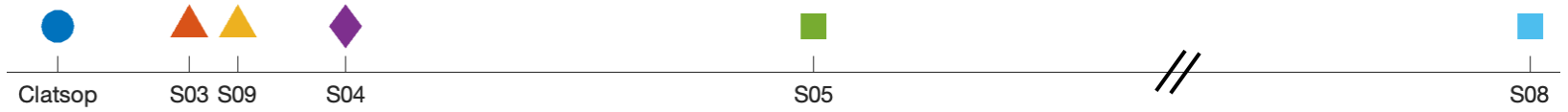




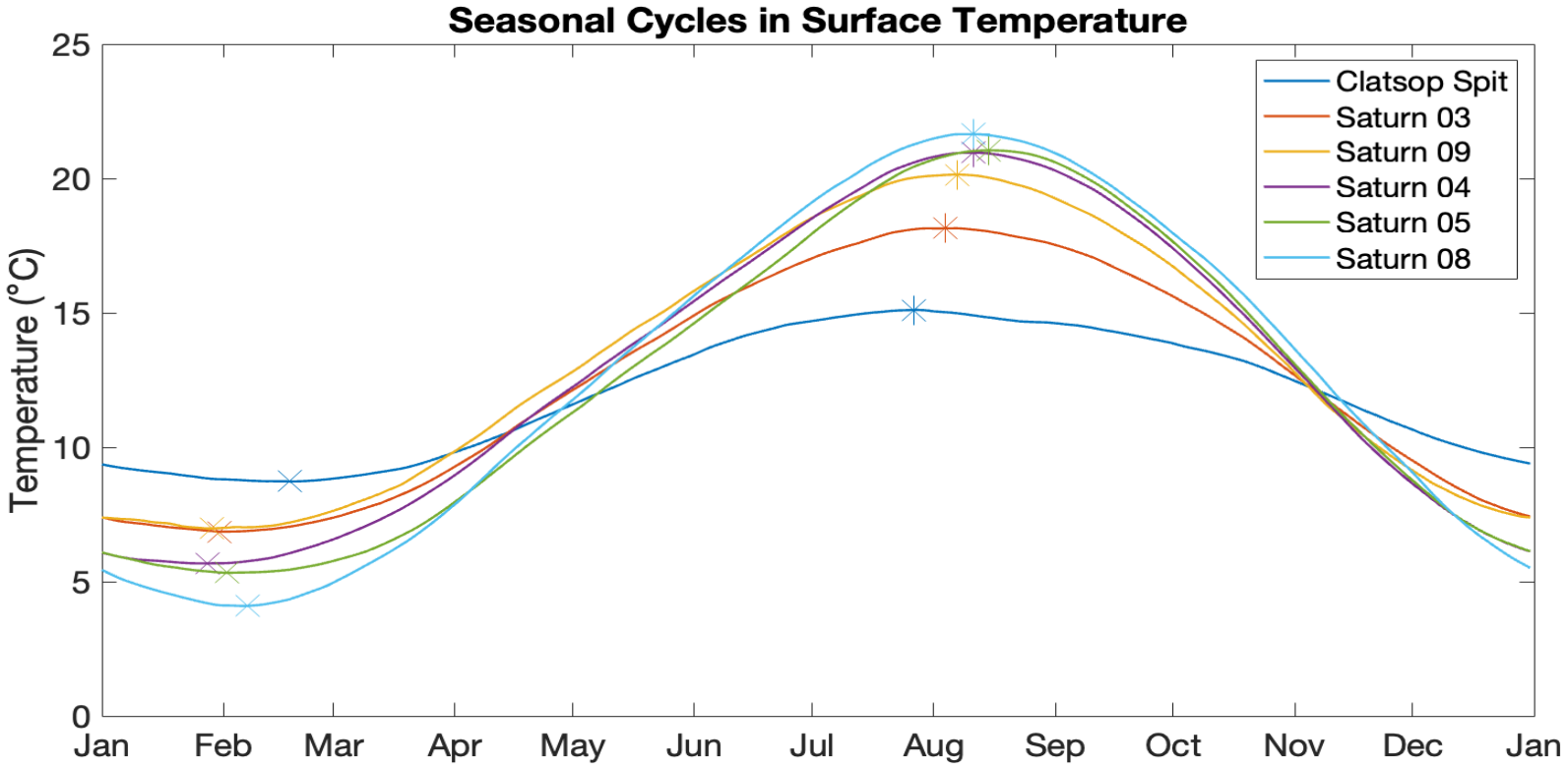
How do temperatures vary along the estuary?



- Clear seasonal cycle
  - Sites **vary in amplitude, increasing up system**
- Interannual variability – more so in winter temperatures?
- Sub-seasonal variability



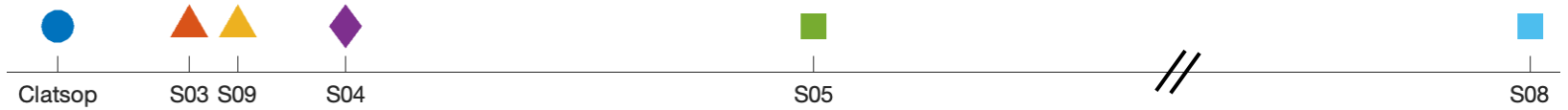
How does the seasonal cycle in surface temperature vary along the estuary?



Seasonal cycle: averaged by day over record mean, smoothed

Amplitude of seasonal cycle increases up system

Timing of summer maximum occurs later up system



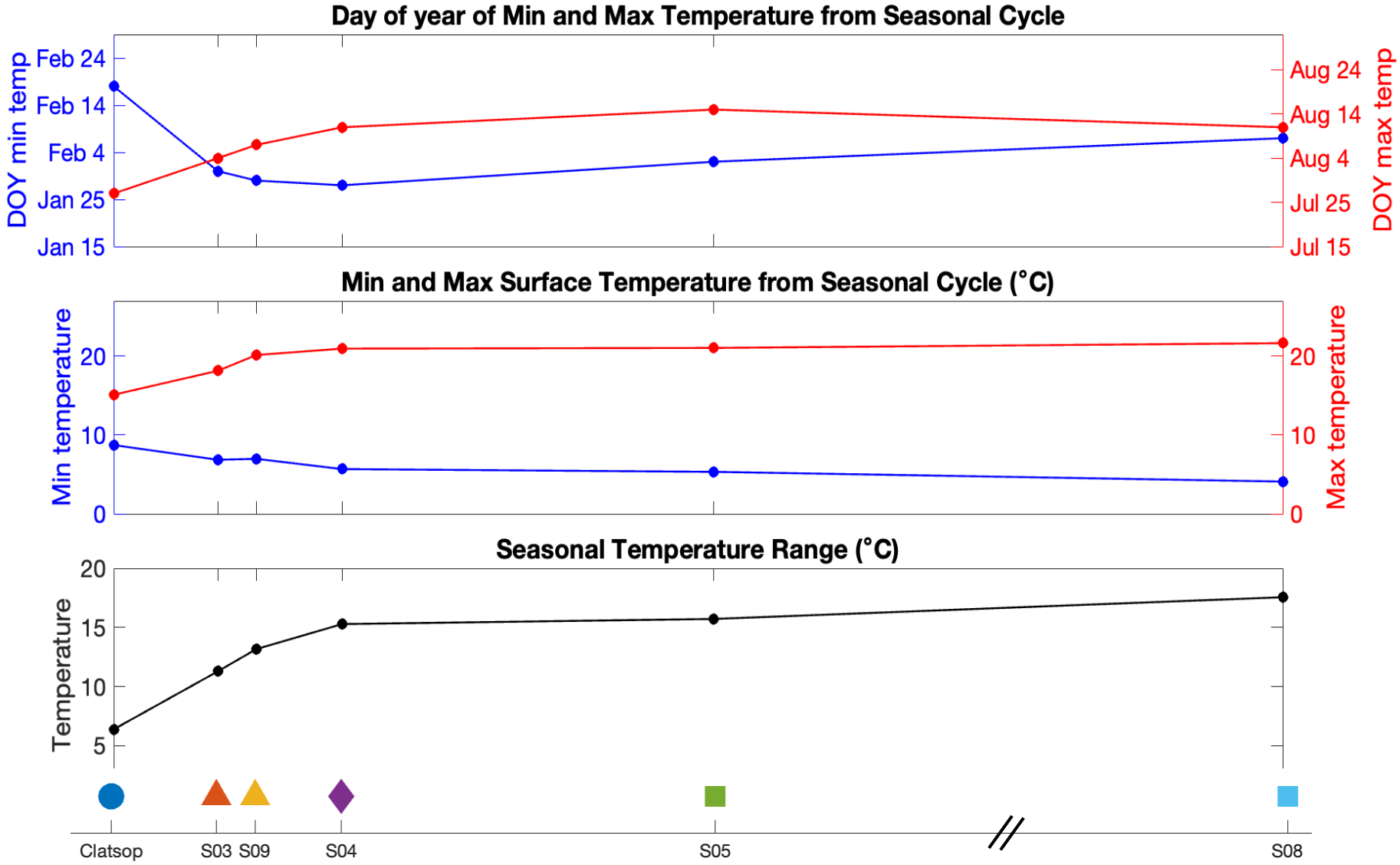
How does the seasonal cycle in surface temperature vary along the estuary in timing and amplitude ?

Max temp mostly occurs **later** up estuary **~ 19 days**

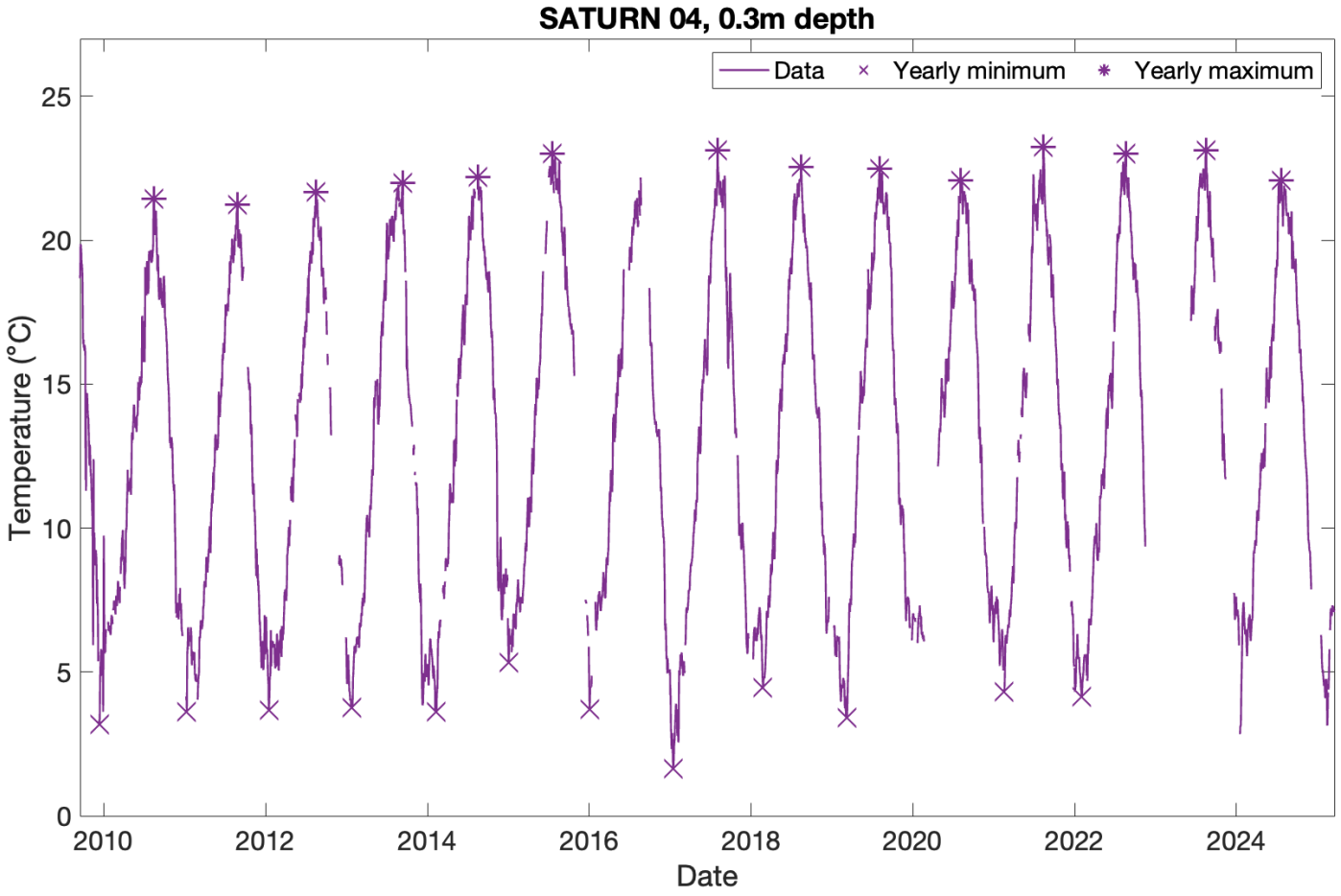
Max temperature increases up estuary by **6.5 °C**
Min temperature decreases up estuary by **4.6 °C**

Range in temp (max – min) **increases** up estuary by **~ 11 °C**

Most changes in temperature occur **down estuary**



How do the annual maximum and minimum surface temperatures vary from year to year at SATURN 04?



Summer maxima:

→ Range: 21.2 - 23.2 °C (**2 °C** difference)

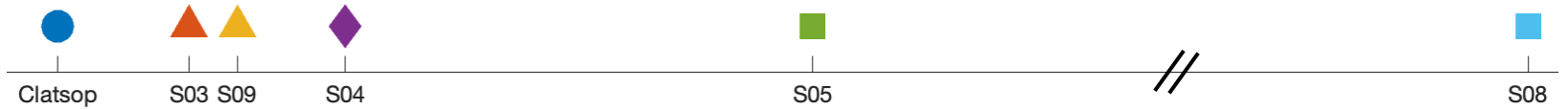
→ Mean: 22.4 ± **0.7 °C**

Winter min:

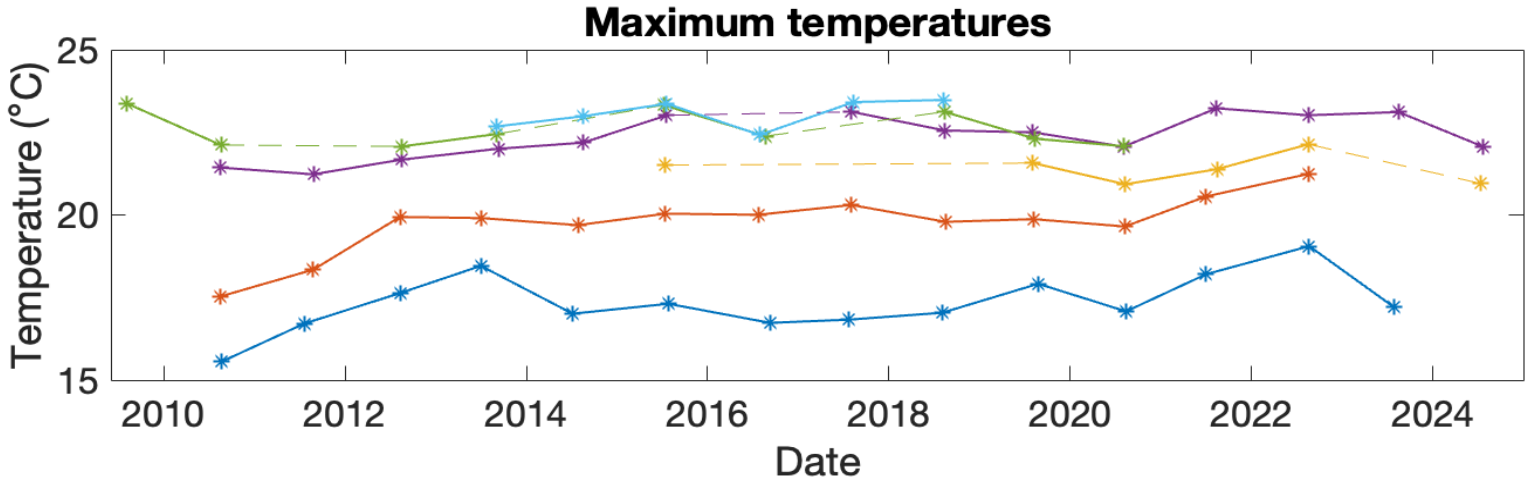
→ Range: 1.6 - 5.3 °C (**3.7 °C** difference)

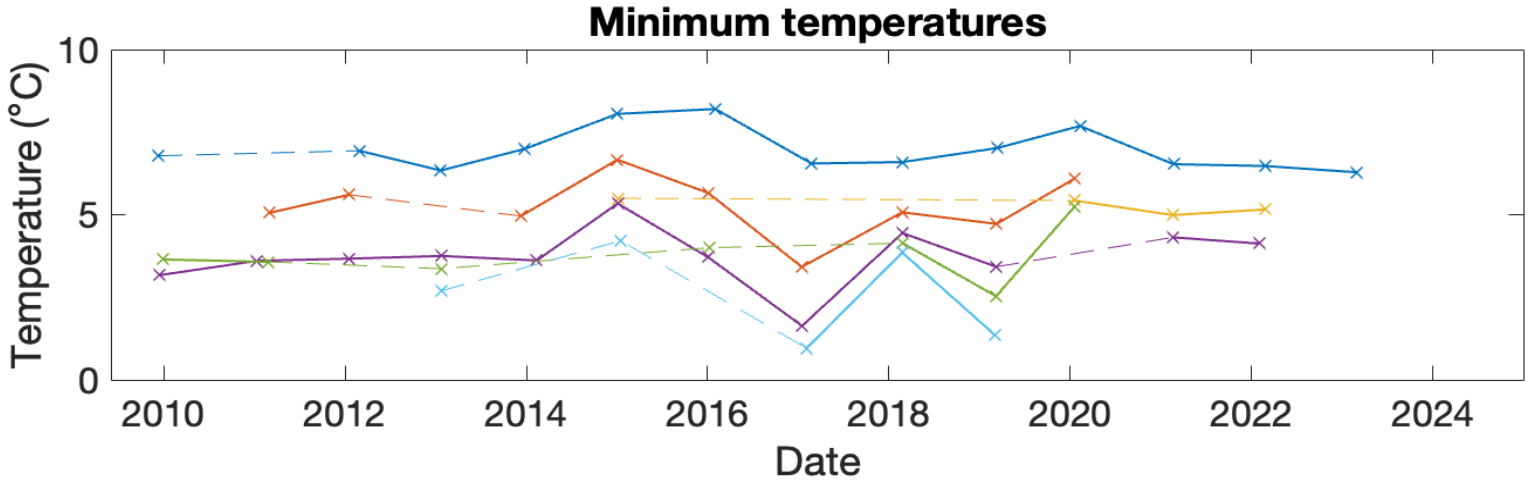
→ Mean: 3.7 ± **0.9 °C**

Slightly more/similar variability in winter minima to summer maxima at SATURN 04



How do the annual maximum and minimum surface temperatures vary year to year by site?





Maximum temperatures…

→ Are fairly constant up estuary

→ Increase over time down estuary? (~ 3 °C)

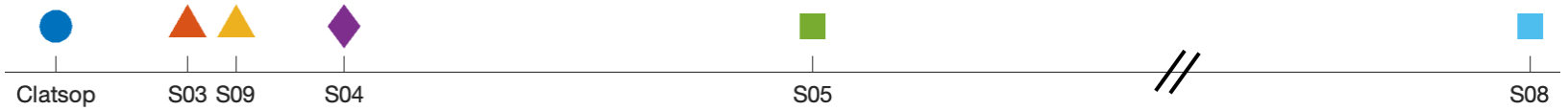
→ Are always cooler down system

Minimum temperatures…

→ Appear more variable than summer maxima

→ Co-vary

→ Are always warmer down system

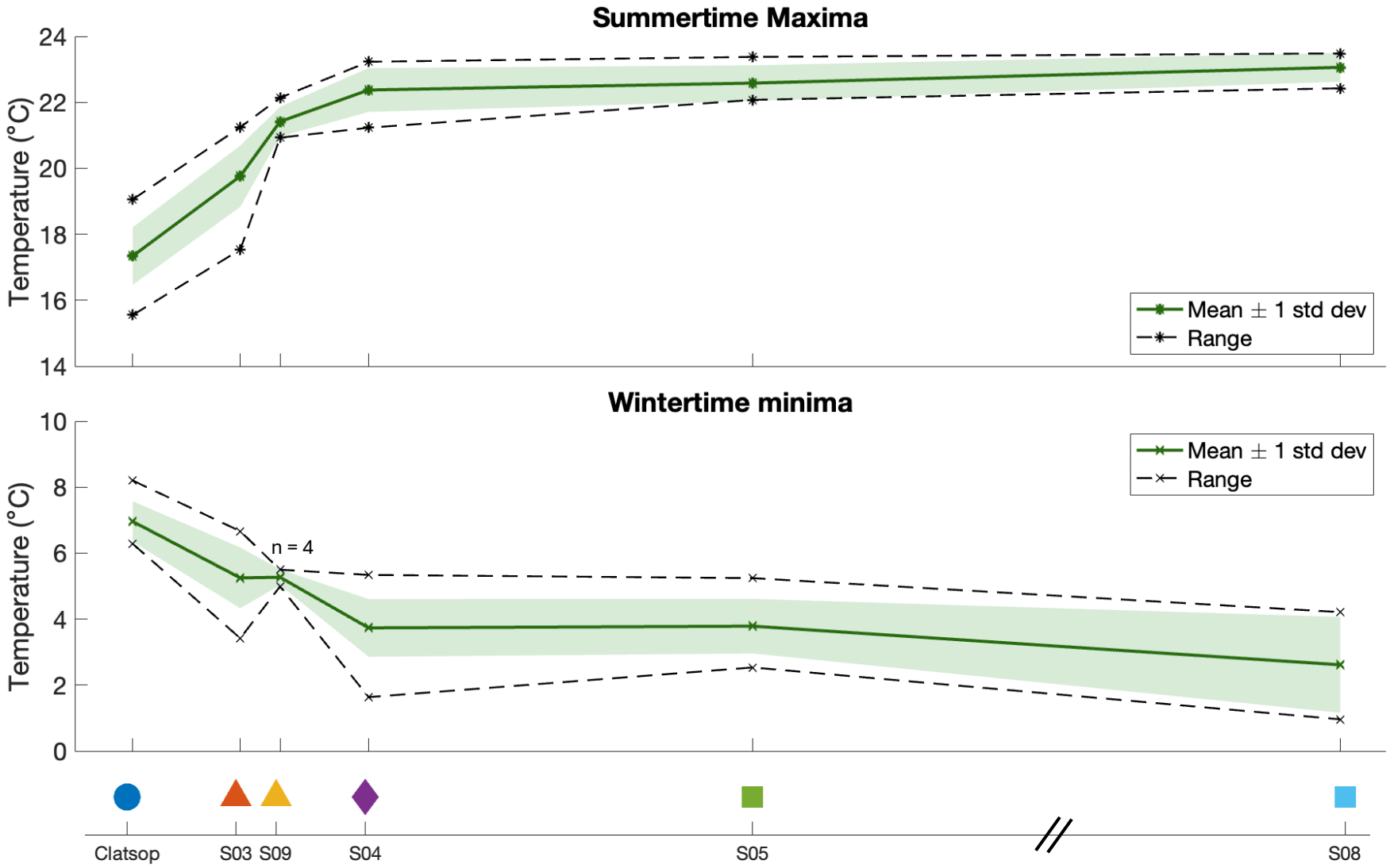


Are there spatial patterns in the interannual variability? Are there seasonal differences?

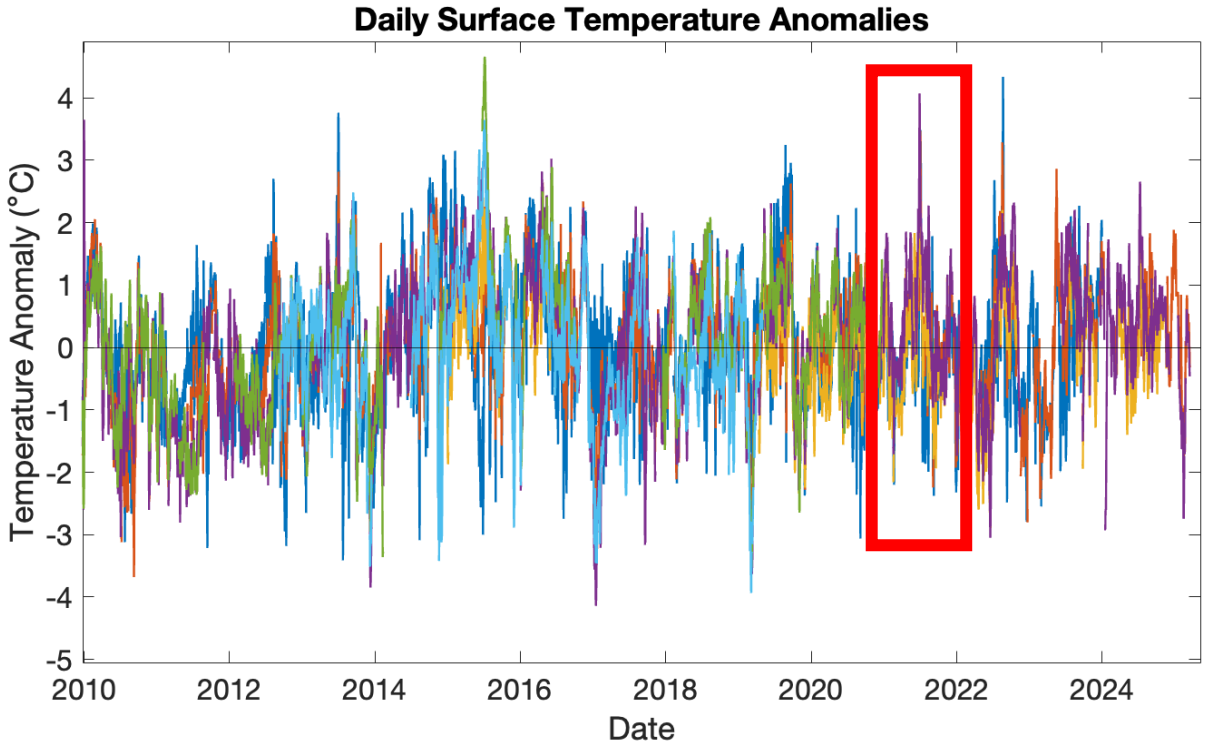
Summer: similar variability along the estuary

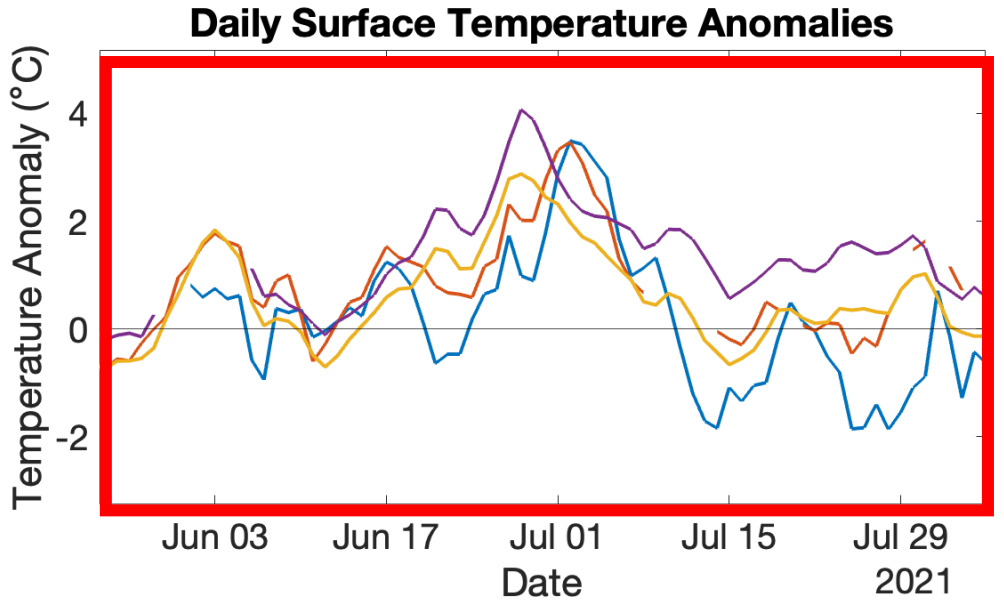
Winter: slightly more variability **up estuary**

Up estuary: more variability in winter minima than summer maxima



Ongoing work: sub-seasonal variability and extreme events



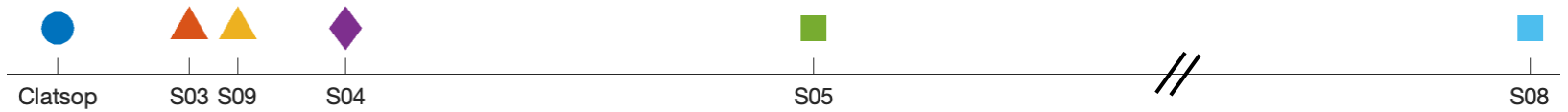


Temperature anomaly = daily surface temperature – seasonal cycle

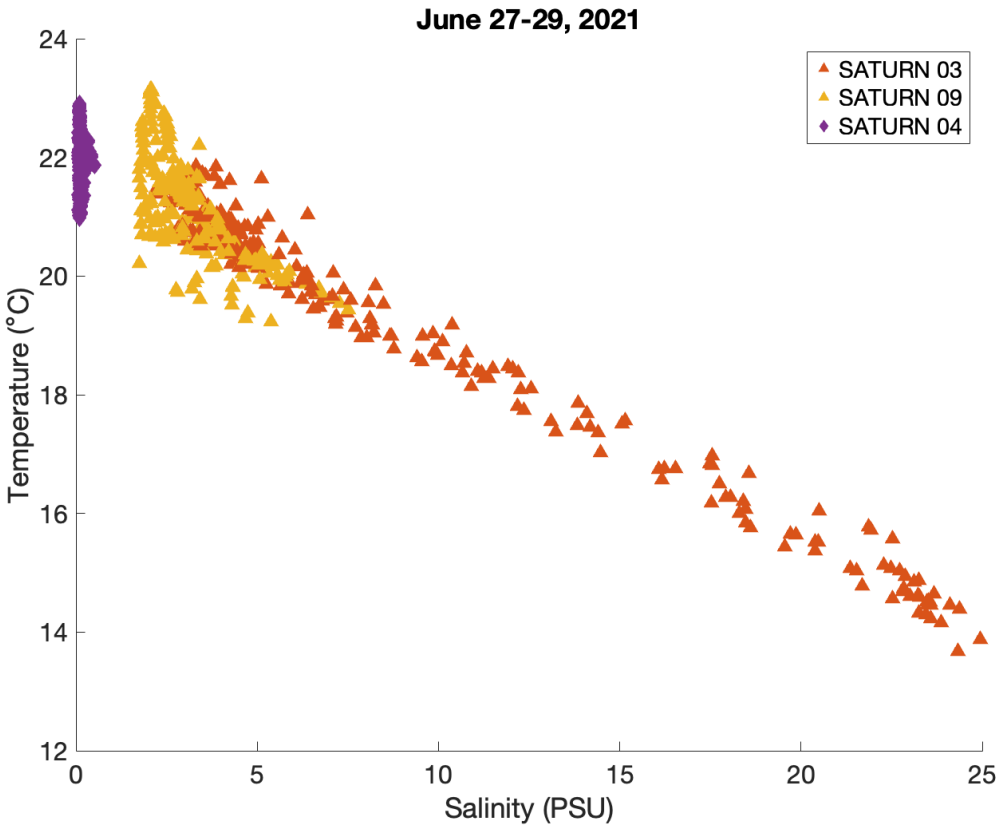
→ Positive and negative anomalies up to 4 °C
→ Anomalies last days-weeks

Summer 2021:

→ Temperature anomalies of ~3-4°C
→ Peaks in anomalies occur up-system first



Summer 2021 Atmospheric Heat event



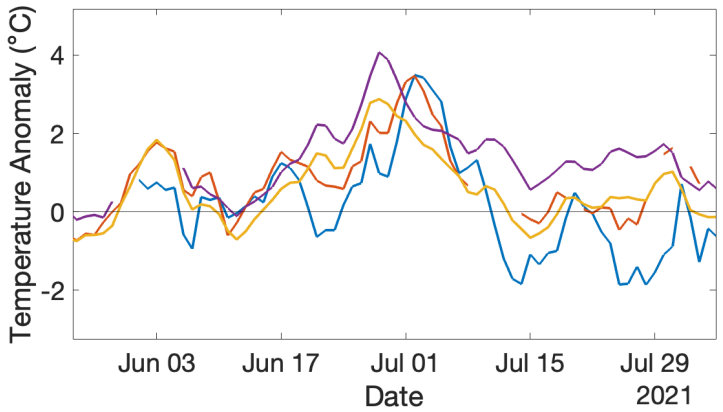
Departure from straight line between ocean and river

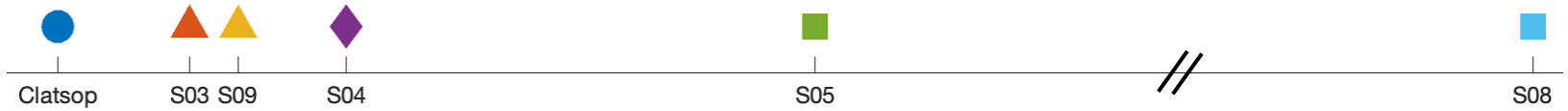
→ Temperature **variability of ~3 °C** on **timescale of a few days** at constant, **low salinity**

→ Probably surface heat flux somewhere:

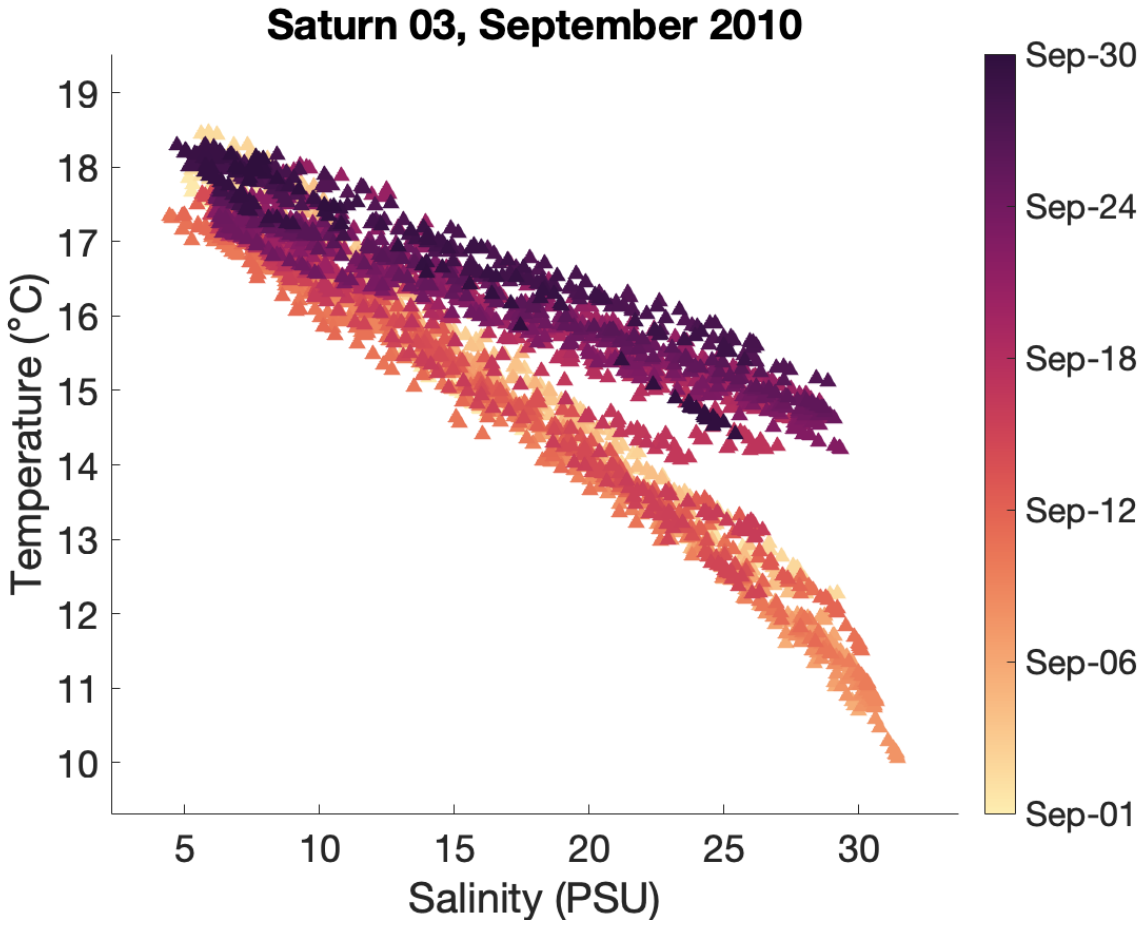
→ Heating at Saturn 09

→ Or, advection of surface heating from third end member (Young's Bay)





A different case of sub-seasonal variability



Conservative mixing between two end members

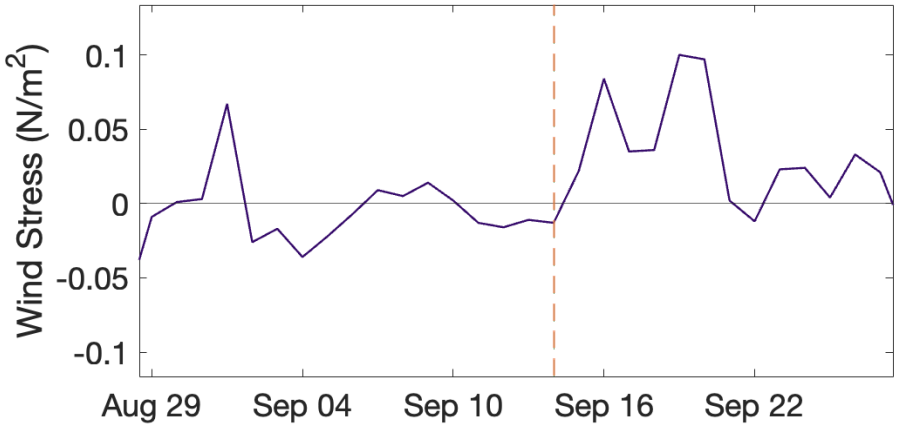
→ Consistent with Roegner et. al

→ Entire curve shifts up (warmer)

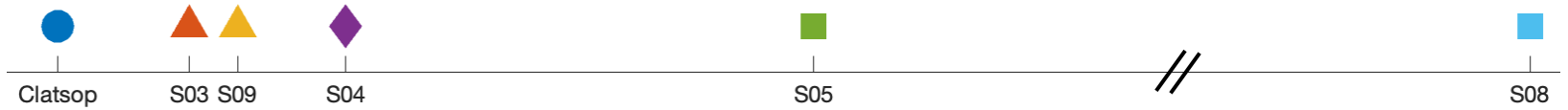
→ Temperature **variability of ~4-5 °C** on time scale of **~2 weeks** at high salinity

→ **Oceanic** end member variability

Fall transition: upwelling to downwelling favorable winds



Oregon cumulative wind stress, September 2010 (NANOOS)



Discussion

Takeaways:

- Seasonal cycle changes with location along the system
  - Greater amplitude up system (larger seasonal range)
  - Maximum temperature occurs later up system

- There is interannual variability, with differences along the estuary and seasonally
  - Up-estuary: more variability in winter minima than summer maxima
  - During winter, more interannual variability up estuary than down

- Sub-seasonal variability is apparent, through temperature anomalies and TS diagrams
  - Summer 2021 – variability of ~3°C in fresh water, departure from straight TS curve – likely surface heat flux
  - September 2010 – variability of ~5°C in salty water, shift of straight TS curve due to oceanic variability (wind driven)

Future directions:

- Further study of extreme events
  - Departures from conservative mixing, marine vs atmospheric heatwaves
- Connecting temperature and biogeochemical tracers
- Examining sources of variability
  - Heat budget analysis
  - Idealized numerical modeling

Thank you! Questions?

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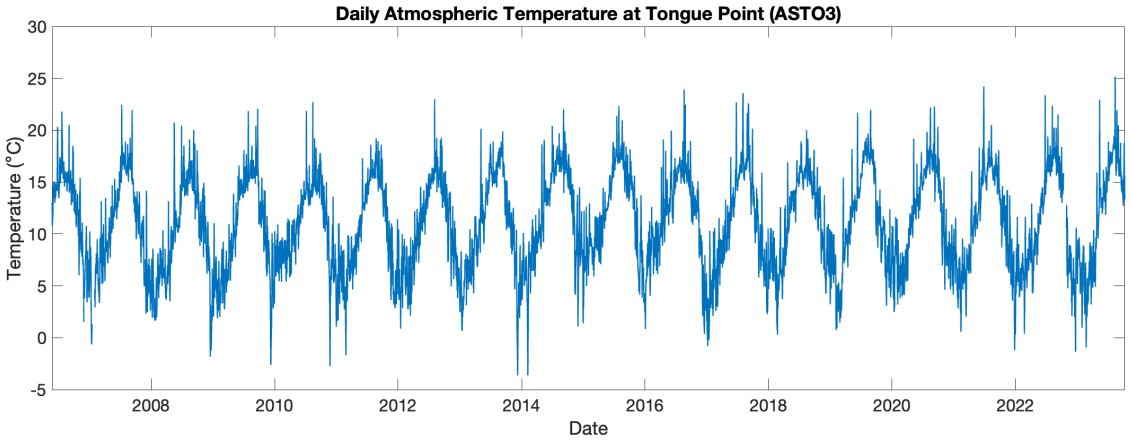
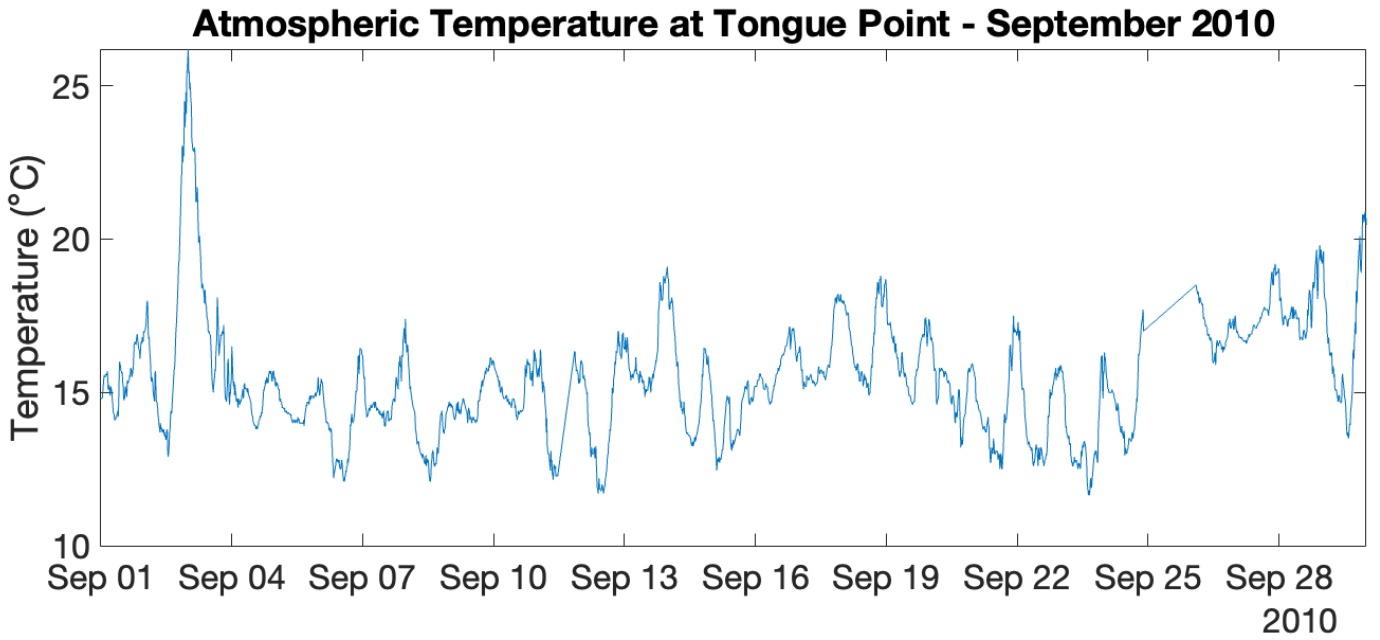
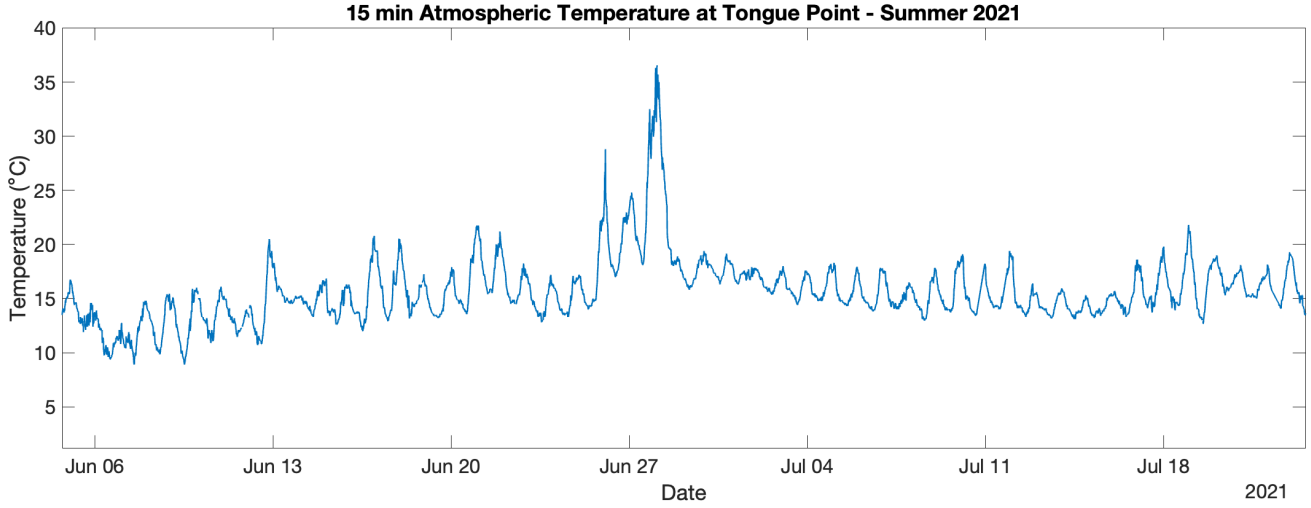
Supplemental – site depths

- Clatsop spit – 0.46m
- SATURN 03 – 2.4m (Point Adams Station)
- SATURN 09 – 0.5m (Young’s bay buoy)
- SATURN 04 – 0.3m (Tongue Point Station)
- SATURN 05 – 2.5m (Point westward station)
- SATURN 08 – 0.8m

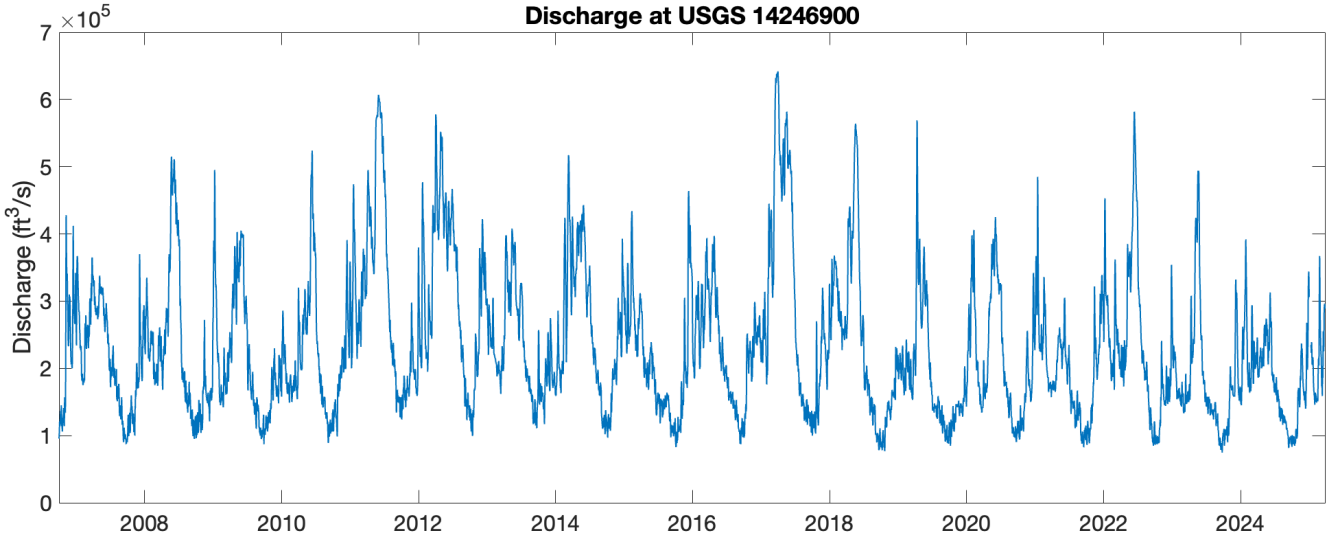
Supplemental – Atmospheric temperature

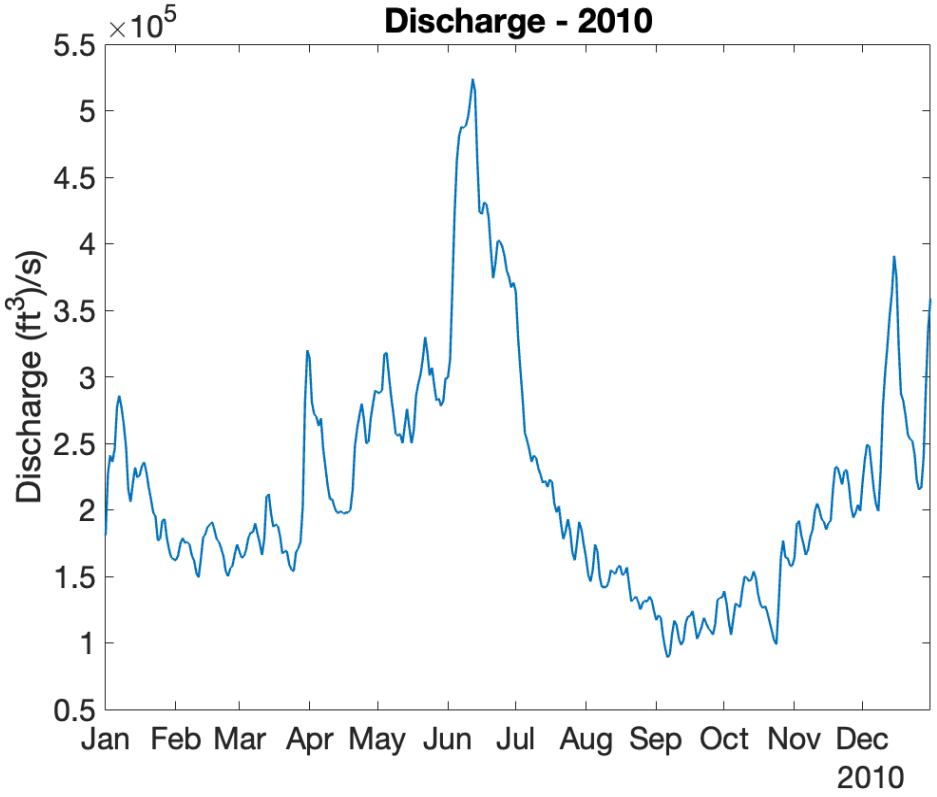


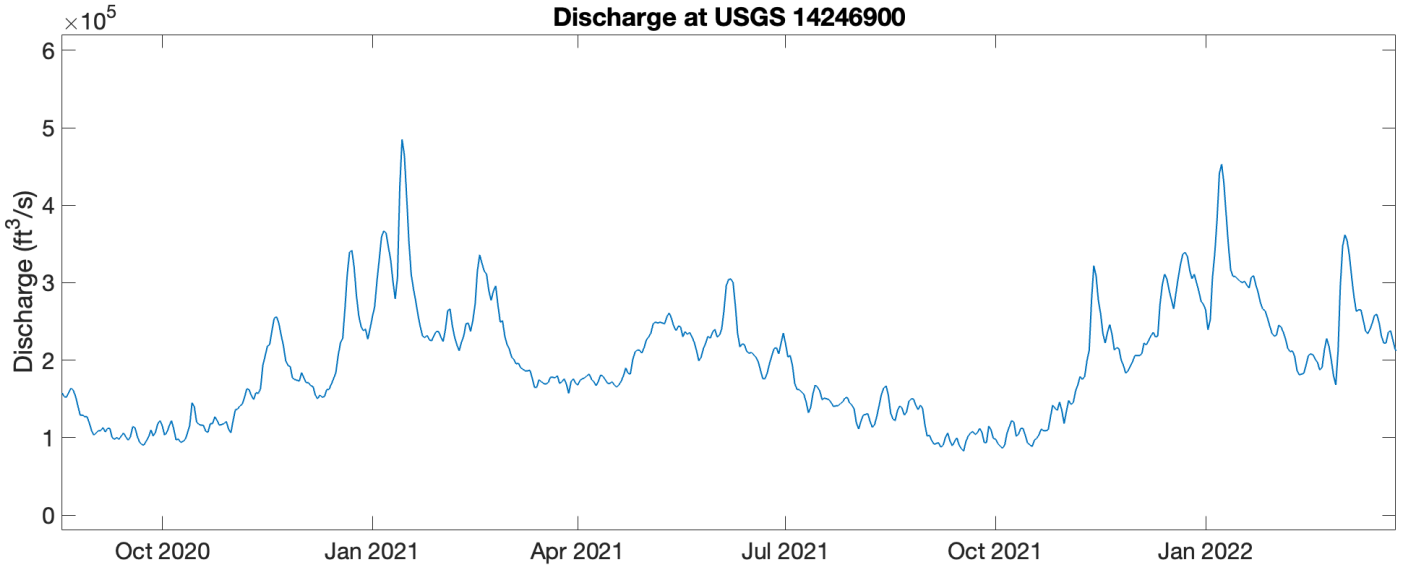




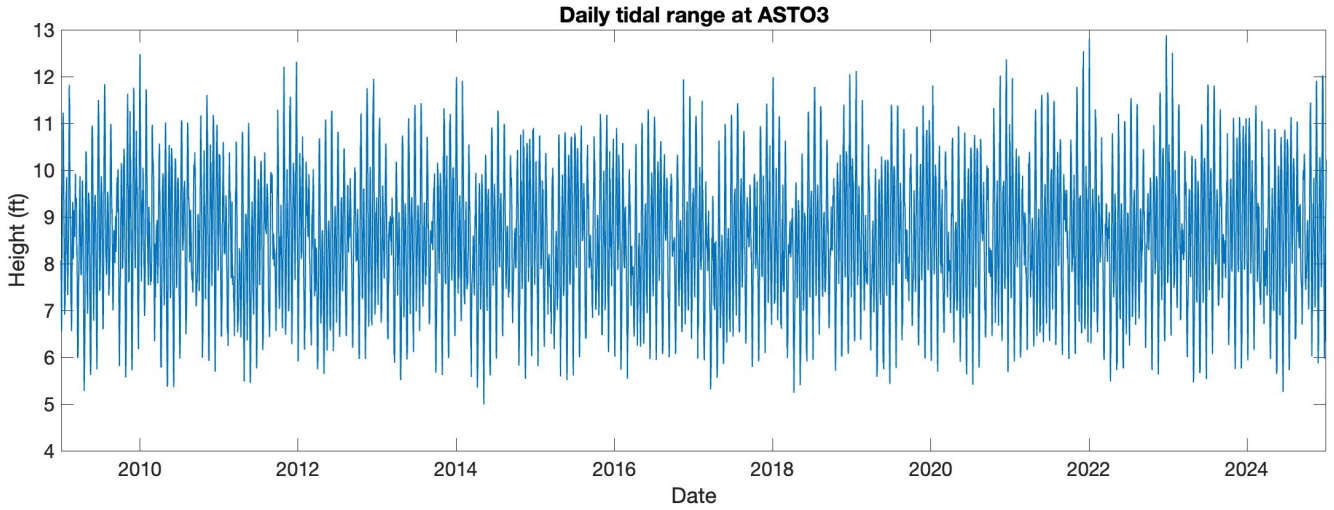
Supplemental – River discharge

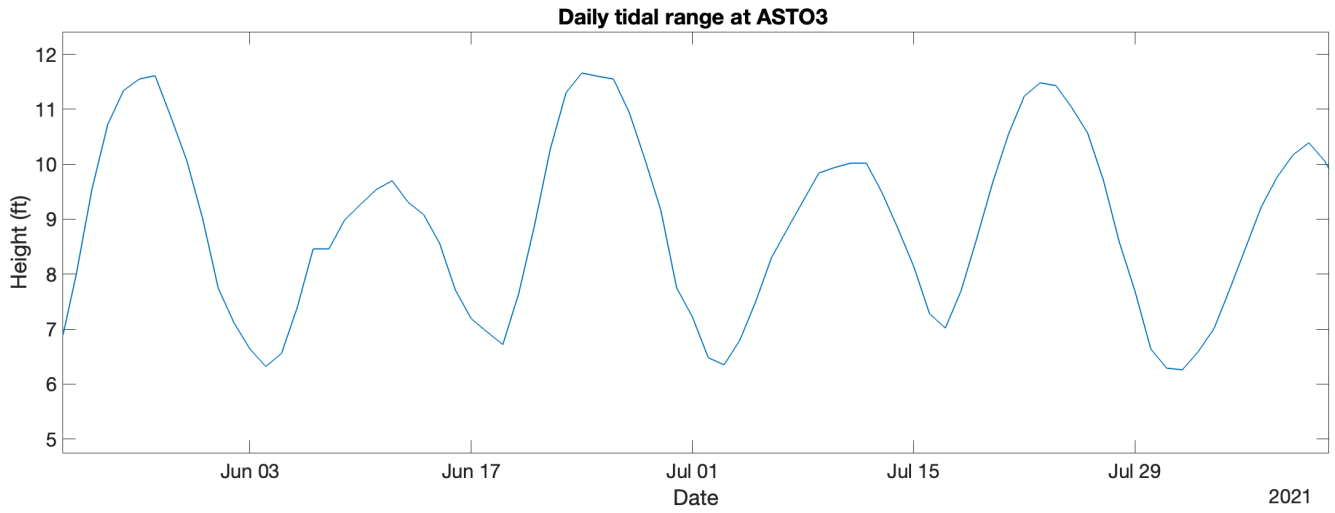


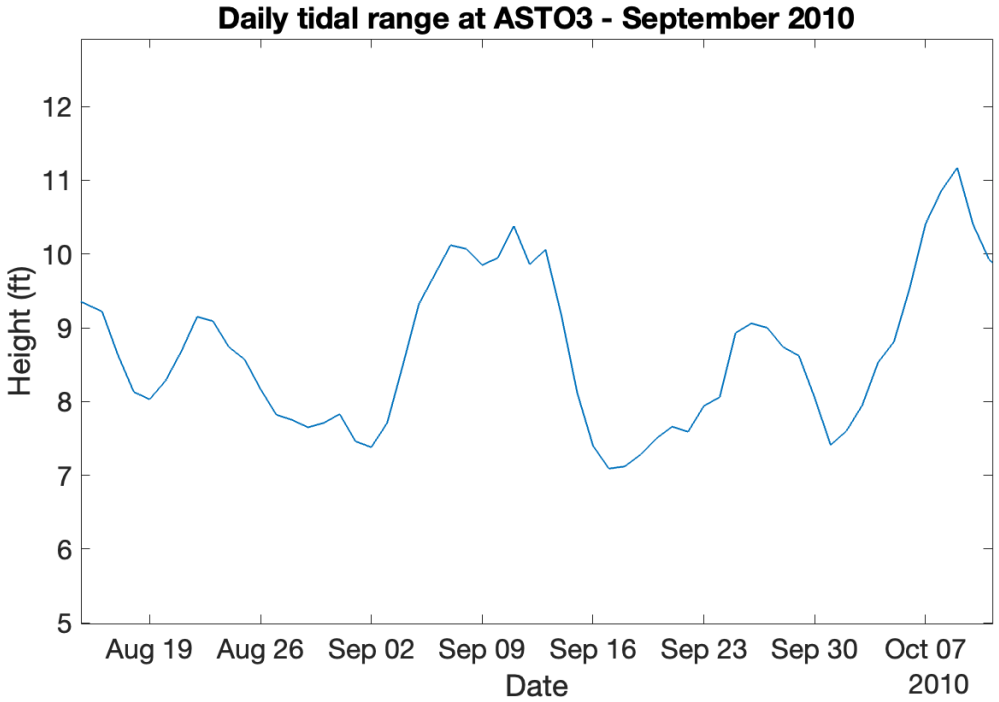




Supplemental – Spring/neap







Supplemental – September 2010