Marine Heatwaves as Extreme Events on the Pacific Coast of Canada

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Extreme Value Theory (EVT)

- **Goal: Estimate magnitude of events that have not yet been observed.**
- **For example, estimate the magnitude of the 100-year flood event from 25 years of data.**
- **EVT is the branch of statistics created to make these types of extrapolations.**

- **Question**: Given a *long enough* sequence of *random* measurements from a sample space, like ocean temperature, what is the likelihood that value ***Z*** is an upper bound on that sequence.
- **Answer**: Under *certain conditions*, such a distribution for ***Z*** *approaches* one of the Gumbel, Weibull and Fréchet families (*the GEV family of distributions*).
- The Generalized Pareto Distribution (GPD) is used to model the tail of *another GEV distribution,* with the random variables bigger than a *large* threshold. The extreme end of the extreme values.

Thomson and Emery. 2024. *Data analysis methods in physical oceanography*.

Goal

- **Analyze Marine Heatwave time series using Extreme Value Theory.**
  - **Characterize the marine heatwaves in terms of Magnitude (the highest temperature) and Duration (number of days).**
  - **Estimate Return Periods for both variables.**

- **Return period estimates are a standard tool for planning.**
- **The goal here is to put Marine Heatwaves into the same framework**

For extreme events like storm surge and river flooding, a useful tool is the concept of return period.

- **For example, if you are planning dikes and culverts for a city on a river, how big a flood should you expect every 10 years, every 100 years, every 500 years?**
- **If your city is a coastal one, you want to know extreme sea level heights expected from a 100-year storm event.**

Marine Heatwave Definition

Extreme Events

Consider a 30-year time series of daily temperature that contains a 50 day long marine heatwave.

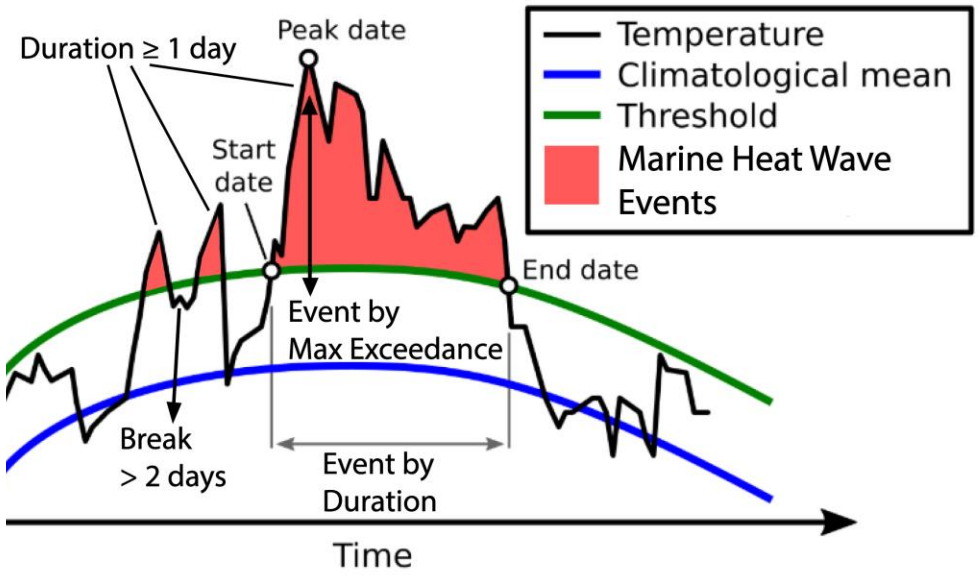
- **In that 30-year time series, each day of the year has 3 days at or above the 90th percentile.**
- **A 50-day duration MHW means that 50 consecutive days have temperatures in the top 3.**
- **That is extreme.**

Modified Definition for Our Study:

Any exceedance ≥ 1 day counts as an event
Maximum two days of break allowed for the same event

Two Metrics:

- Maximum Exceedance in °C
- Event Duration in days



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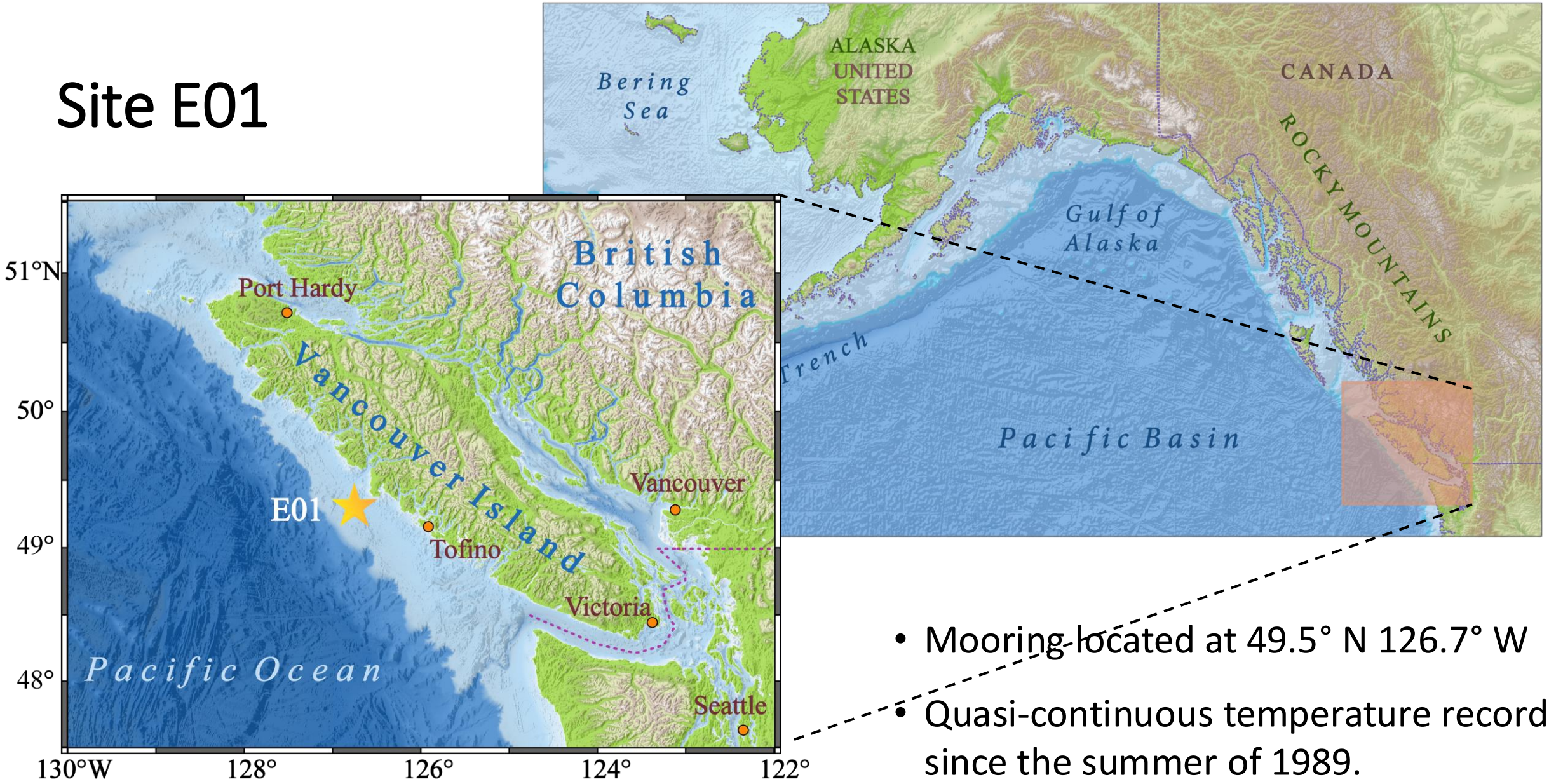
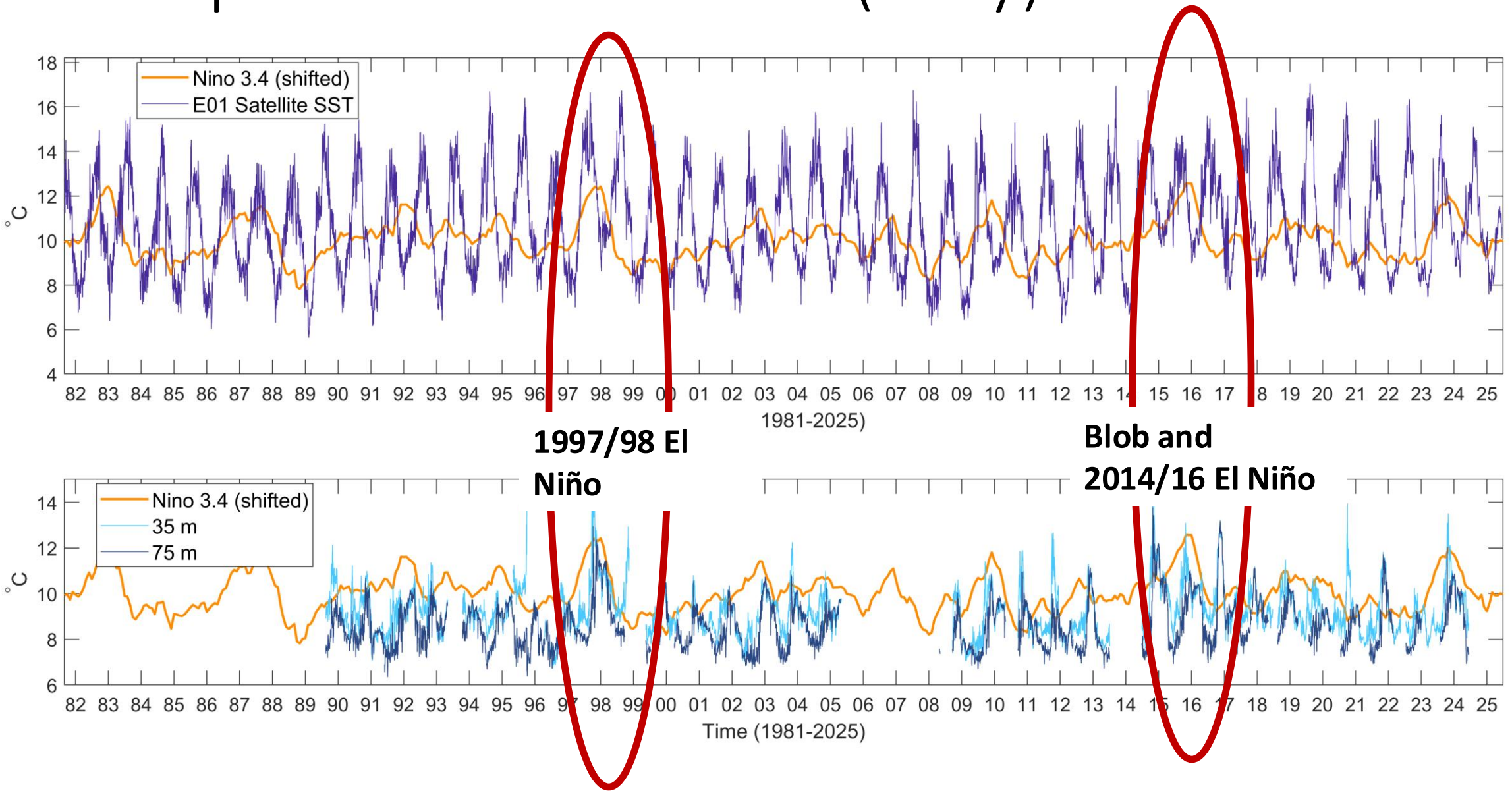
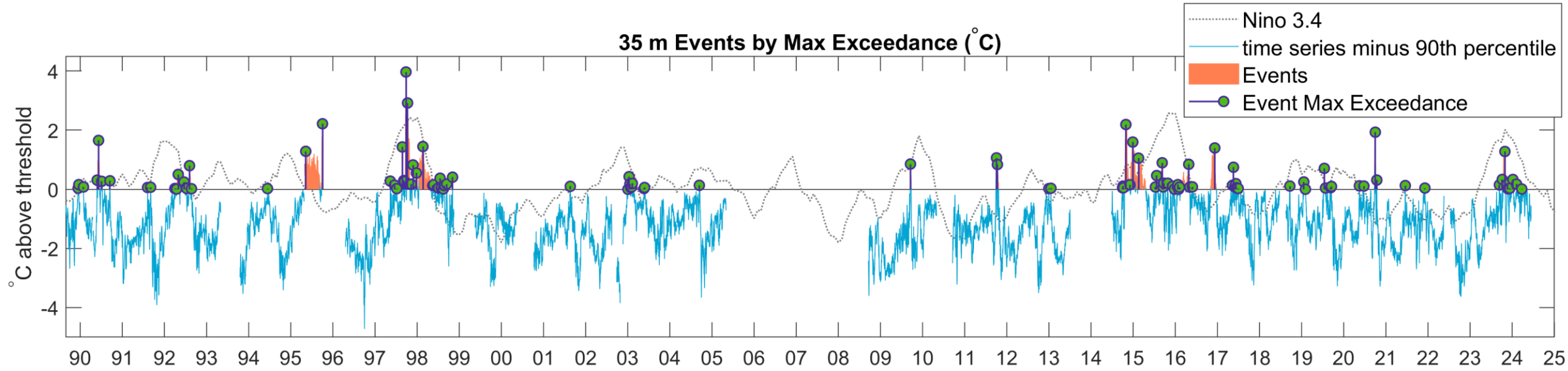


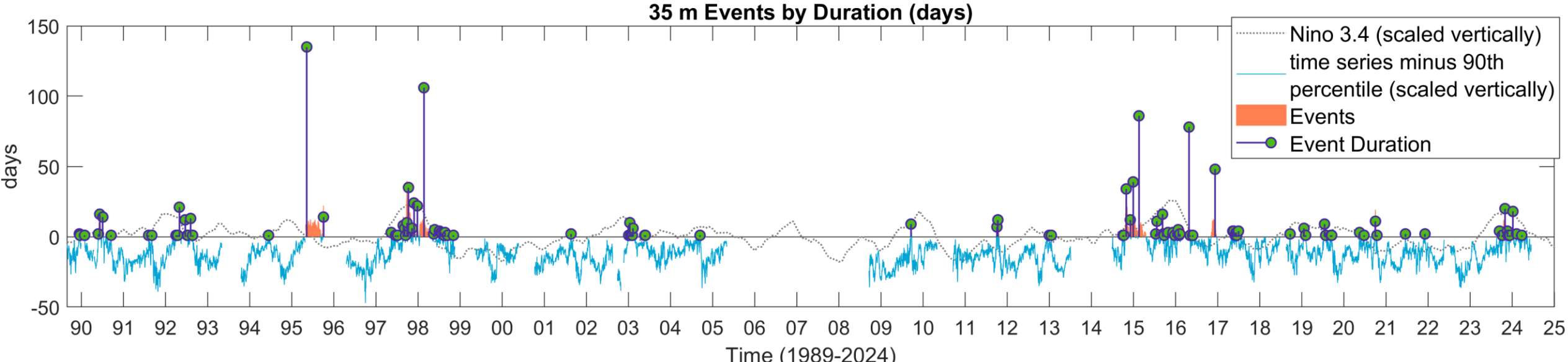
- Mooring located at 49.5° N 126.7° W
- Quasi-continuous temperature records since the summer of 1989.
- Depth: 100 m

Temperature time series (daily)

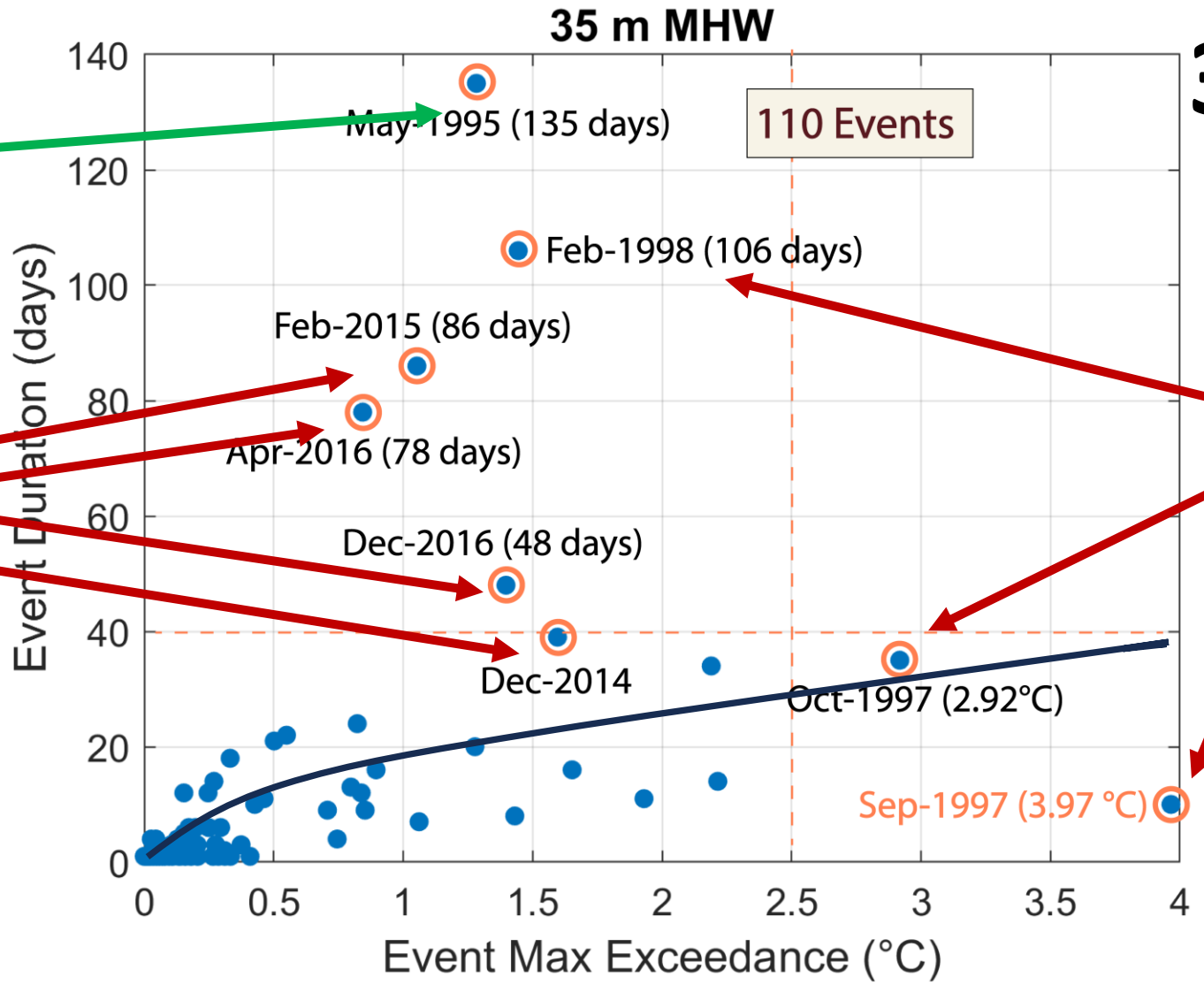


Marine Heatwaves at 35 m





Distribution of MHW Events: Duration vs Magnitude

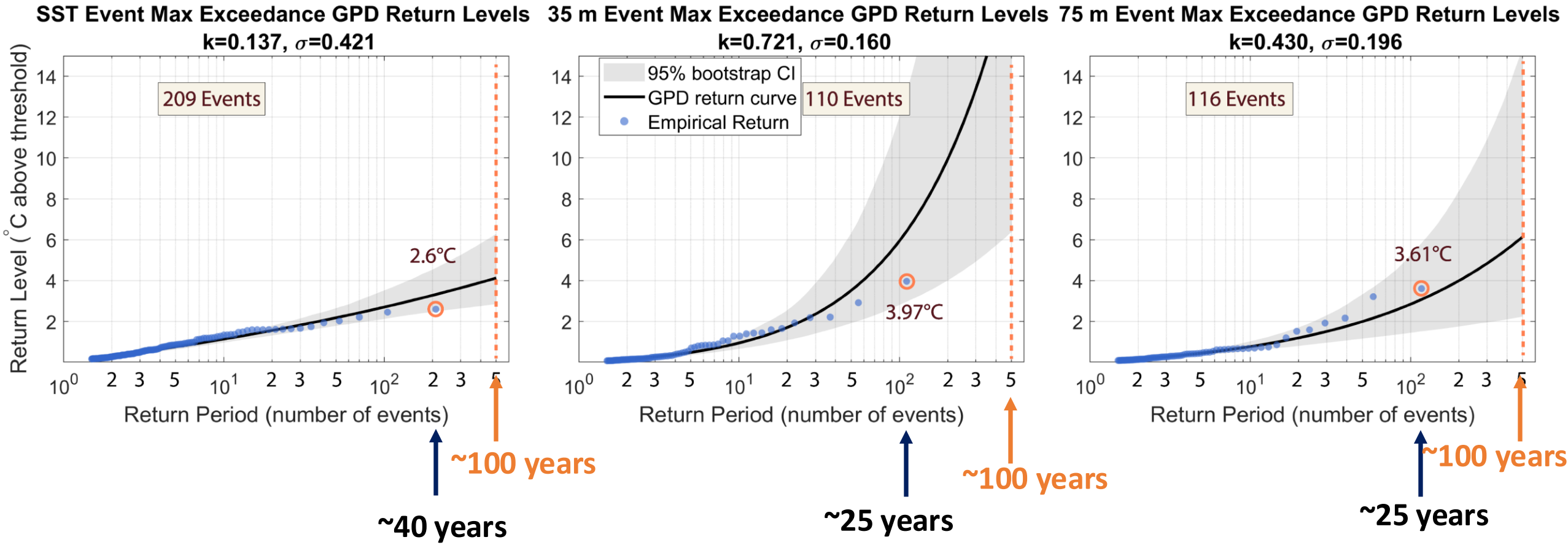


May 1995

2014-16 Blob and El Niño

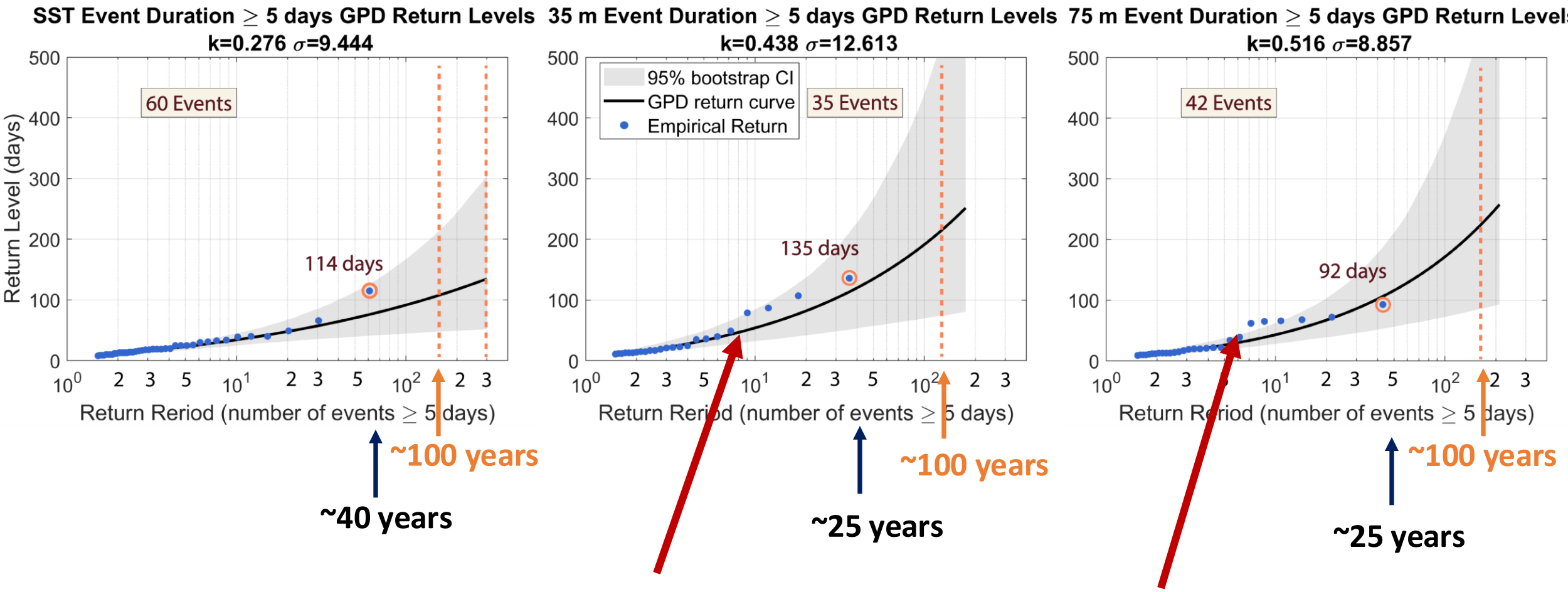
1997/98 El Niño

GPD Return Plots for Magntiude



Are the empirical curves flattening out while the GPD curves are increasing? Not clear

GPD Return Plots for Event Duration ≥ 5 days



What is happening here? A jump in the empirical return level and then flattening out?

Summary 1/2

- The temperature records at the E01 mooring off Vancouver Island are dominated by sustained MHW events.
- A duration of 100 days means 100 consecutive days where each day the temperature is in the top 3 of a 30-year time series for that day.
- Two 100+ day events were observed at 35 m and one was observed in the SST. A 92-day day event was observed at 75 m.
- These long events are not due to warming over the 30+ year record – big events happen near the beginning.
- The very large events (Magnitude or Duration) are dominated by events in fall/winter/spring. Suggests links to El Niño and the summer upwelling regime.

- The 2014-2016 Blob plus El Niño event was a large event but does not dominate the MHW record.
- The 1997 El Nino was a very big event, as was an unheralded 1995 event.

Summary 2/2

- Extreme Value Theory is a useful way to explore the statistics of MHW events.
  - We are still working our way towards Return Period estimates that we trust.
  - The differences between the GPD return period curves and the empirical ones is a measure of what we don't know.
- Questions that have arisen
  - Are the extreme MHWs from a different population than the 'less extreme' ones?
  - Should the Return Period curve for Duration increase or level off?
  - Do we expect Duration to increase or decrease with Magnitude?
  - Is it foolish to say that the Magnitude of the 50-year MHW at 35 m is 10C at our location?

Final questions

- **How representative are our findings? Do other shelf regions see similar return period statistics for Magnitude and Duration?**
- **Can we assess whether the large MHWs can be closely linked to climate indices like Nino3.4 or others?**
- **Can we show that the ‘small’ MHW are linked to the overlying atmosphere while the ‘extreme’ ones are linked to heat redistribution in the ocean?**