The Blob and Queen Charlotte:
Predicting Ocean Properties in an Upwelling System during Anomalous Conditions

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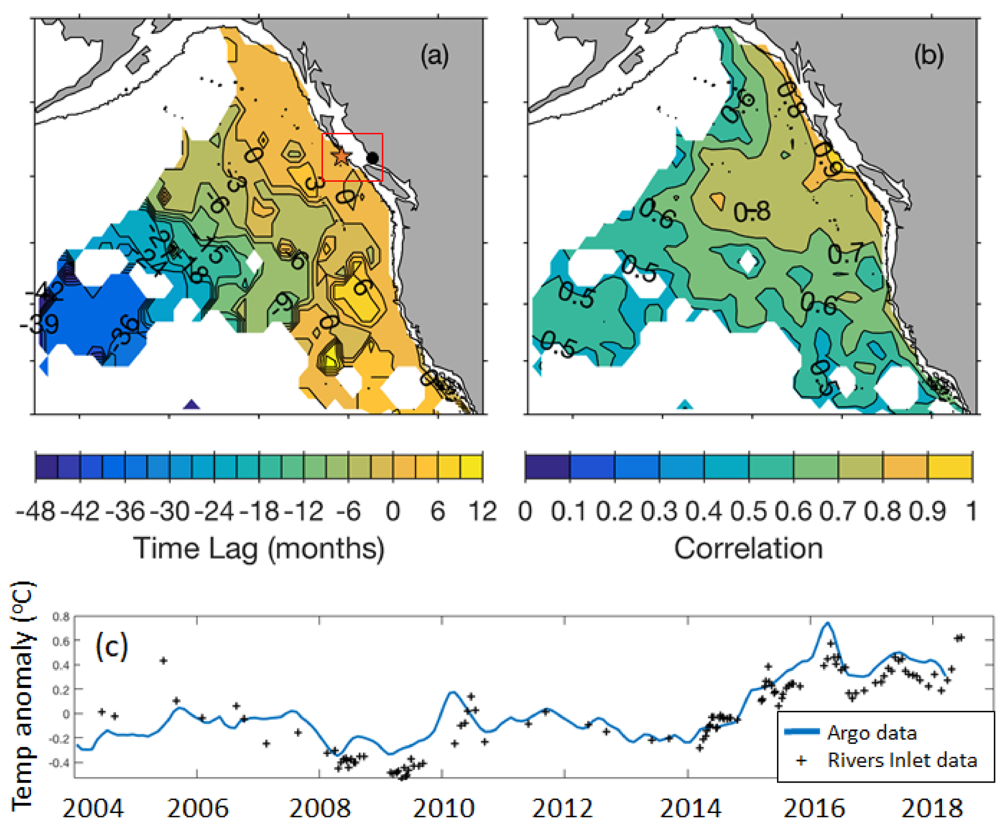
1. Goal

Understand and predict changing conditions caused by anomalous events (e.g. heatwaves) in seasonally upwelled coastal and continental shelf waters off the central coast of British Columbia, Canada.

2. Motivation: The case for predictability

From 2014 onward, ecosystems along the west coast of North America were significantly impacted by The Blob and an El Niño. In the highly productive waters of Queen Charlotte Sound (QCS), deep upwelled waters were anomalously warm through at least 2018 [1].



High correlations between open-ocean, shelf break, and deep coastal temperature anomalies suggest predictability on interannual timescales.

Figure 1: *Modified from Jackson et al. 2018, GRL.* Lagged maximum correlation (a) time lag and (b) correlation coefficient at 140 dbar in the NE Pacific with a shelf break Argo interpolation point (orange star). (c): Time series from the shelf break (orange star) compared to Rivers Inlet on the central coast (black dot on map), R^2 = 0.75.

3. Study area: Why QCS? Why upwelling?

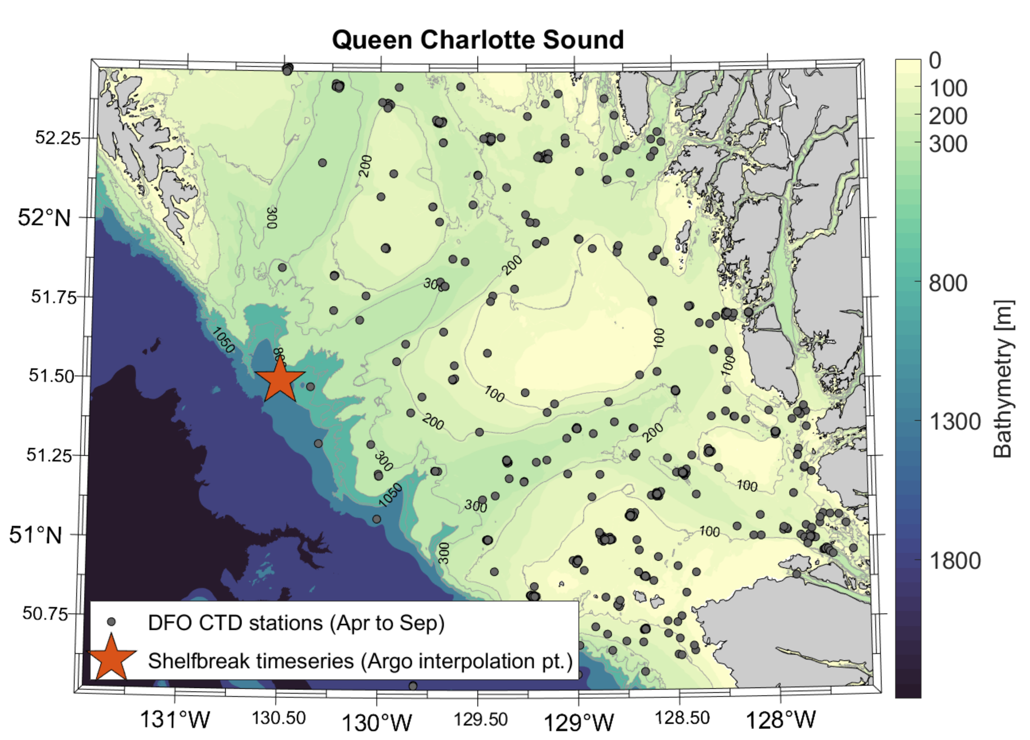


Figure 2: Study area bathymetry, location of shelf break timeseries (Argo interpolation point, orange star) and locations of QCS CTD stations used in the analysis (grey dots).

Each spring and summer, dense, cold, nutrient-rich, low-oxygen water:
- upwells onto the ∼150 km wide continental shelf in QCS.
- fuels high levels of productivity.
- dominates the seasonal cycle in much of the water column.

Anomalous events (such as heatwaves) in this deep upwelled water **cannot** be tracked using satellite data!

Data Sources	Data types used	Location	Time period used	Contact / public data access
Argo autonomous profiling float dataset	Objectively mapped T, S data product	NE Pacific (1° × 1° grid)	2004 to 2019 (Monthly)	http://sio-argo.ucsd.edu/RG_Climatology.html
Department of Fisheries and Oceans Canada	Historic CTD data archive	Queen Charlotte Sound	2004 to 2018 (Apr to Sep)	www.waterproperties.ca
NOAA climate index	Pacific Decadal Oscillation	North Pacific Ocean	2004 to 2018 (Monthly)	http://research.jisao.washington.edu/pdo/PDO.latest

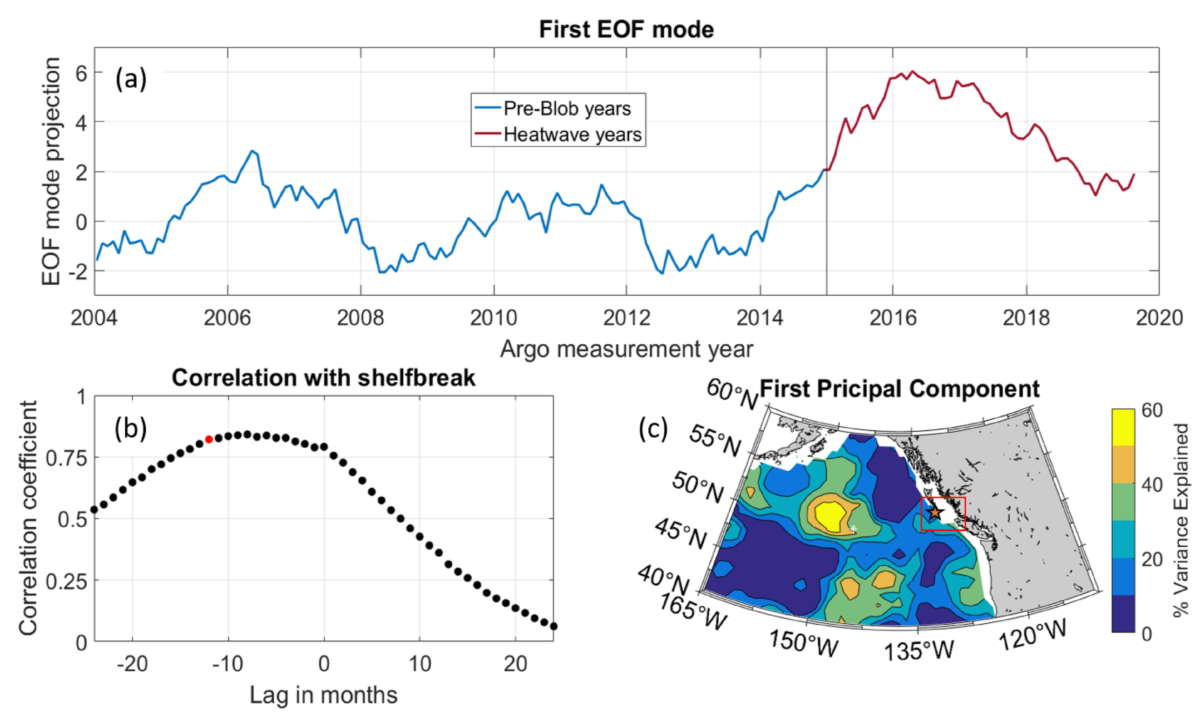
4. Methodology: Statistical predictive model setup

Create an *EOF-based regression model* that uses the temperature field in the NE Pacific Ocean to predict upwelled water temperatures at the **shelf break**:

Identify and quantify interannual variability:
- Perform temporal EOF analysis on the NE Pacific Ocean Argo data.
- Modes give dominant temporal patterns in NE Pacific.
- Principal components give locations where modes explain the most variance.

Preprocessing the time series:
- Interpolate data to isopycnals (1026.4 kg/m^3 is shown).
- Remove seasonal cycle using harmonic fit.
- Standardize: mean $\mu = \mathbf{0}$ and standard deviation $\sigma = \mathbf{1}$.

Separate Argo data into model **fitting** and **testing** data:
- Use **pre-Blob years** (2004 to 2014) to create model.
- Use **heatwave years** (2015 to 2019) to test model.
- *This tests the model's ability to predict anomalous events.*



For the model, we retain only the first EOF mode. We use the PC for that mode to project the mode onto the heatwave years for model testing.

Figure 3: (a) Projection of first EOF mode calculated using pre-Blob years (blue) onto full NE Pacific Argo time series including heatwave years (red). (b) Lagged correlation for the first EOF mode projection from (a) with the shelf break time series. A lead of 12 months (red dot) has $\boldsymbol{R}$ = 0.82. (c) Principal component (PC) for first EOF mode.

5. Final model and comparison with shelf break data

To create our final model, we use the time series for the first EOF mode projection, apply a 12 month lead, return to dimensional units for temperature [^{o}C], and recombine with the seasonal cycle.

This method can create skillful predictions for:
- seasonally upwelled water in QCS, including:
- isopycnals between ∼1025.7 and ∼1026.8 kg/m^3
- depths between roughly 90 m and 260 m in summer.

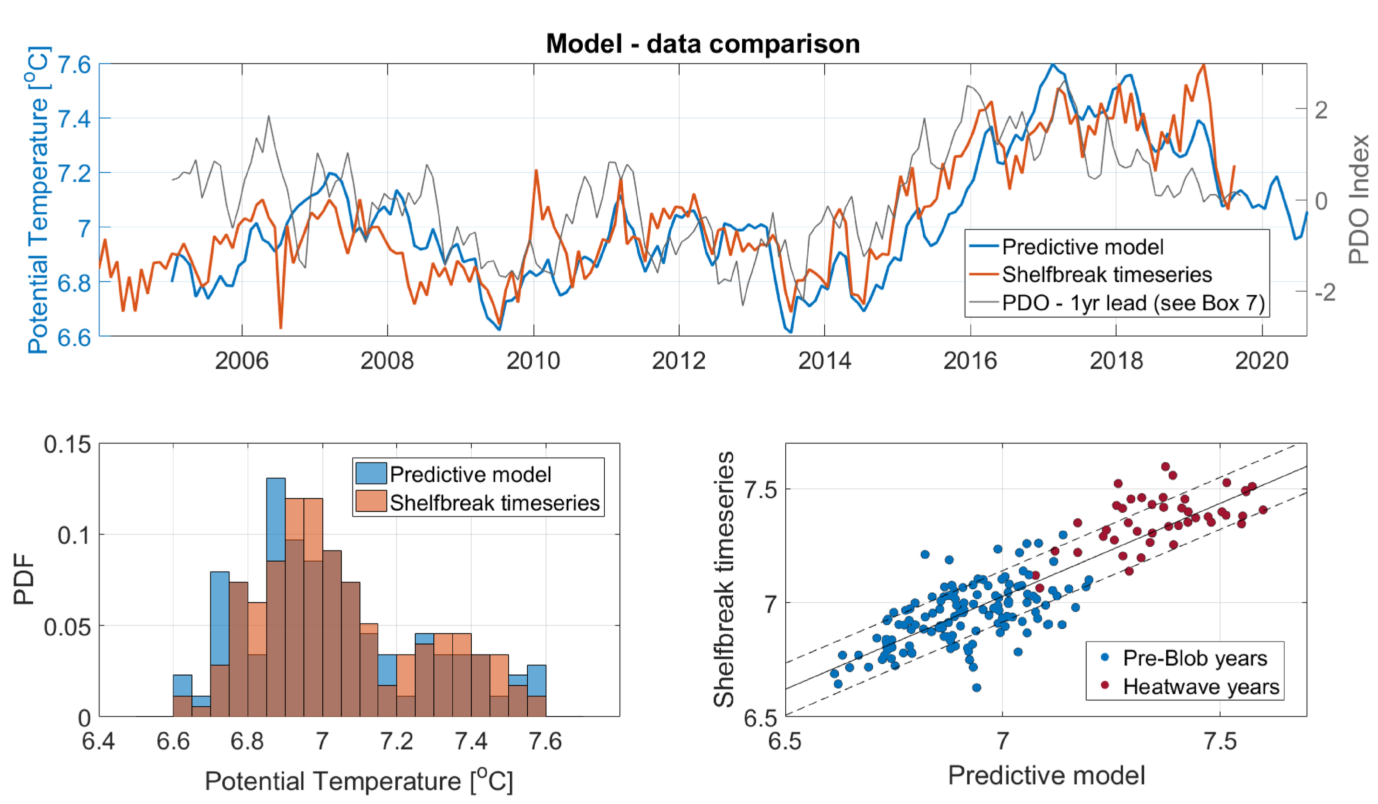


Figure 4: (a) Comparison for the final predictive model (blue) and the shelf break timeseries (orange). We note a similarity to the PDO index with a lead time of 1 year (grey, right axis), which is discussed in Box 7. (b) Histogram for the model and shelf break data. (c) Linear fit (black line) and uncertainty (dashed lines) between model and shelf break time series with the pre-Blob years used to create the model (blue dots) and heatwave years (red dots). Fit is to full time series.

The model accurately predicts The Blob and El Niño years!

6. Extending predictions across QCS (preliminary)

Model predictions for the shelf break are found to effectively provide an **upper bound** for QCS temperatures (Figure 5). To extend our predictions across QCS, we assume interannual variability in upwelled water is due only to our predicted changes in open-ocean source water.

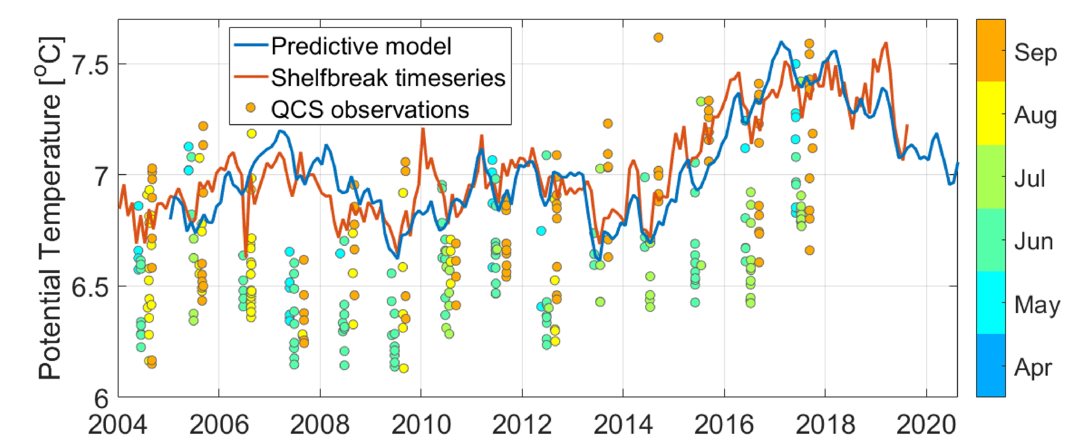


Figure 5: Predictive model (blue) and shelf break (orange) compared to data on isopycnal 1026.4 kg/m^3 in QCS (dots), for months during upwelling season.

Hypothesis: low temperatures in QCS are caused by mixing with cooler deep water.

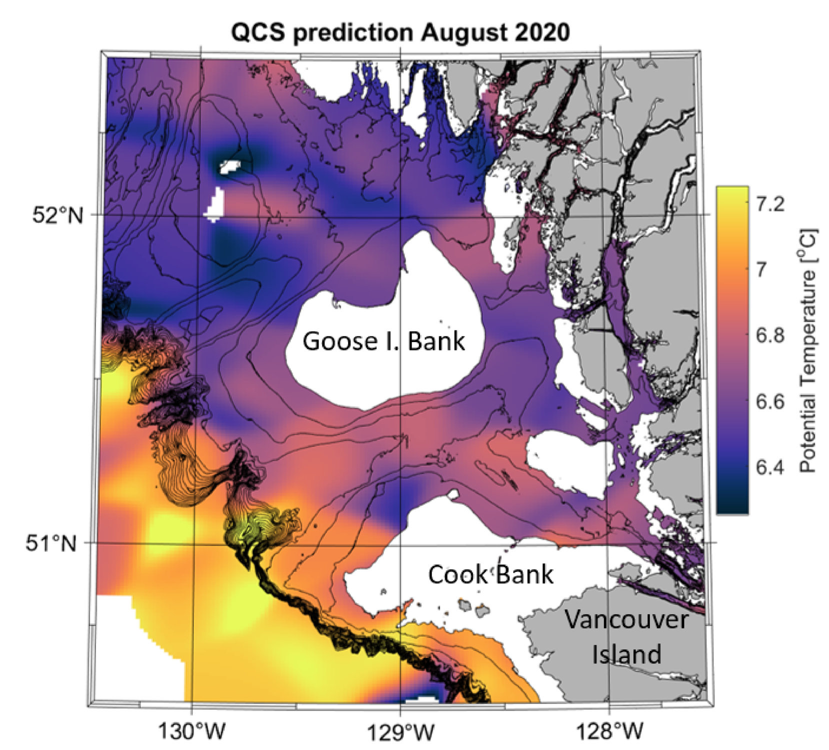


Figure 6: Prediction for temperature on 1026.4 kg/m^3 isopycnal for August 2020.

Creating a 'best-guess' map of spatial variability in QCS:
- Use CTD data from 2004-2018 (Apr to Sep).
- Subtract the monthly shelf break temperatures.
- Objectively map the temperature anomalies.

QCS Prediction = resulting spatial map + shelf break prediction.

August 2020 shelf break prediction is 7.1±0.2^{o}C (95% confidence).

7. Model skill and interpretation

Accuracy & error statistics show our EOF-based regression model is skillful.

Model accuracy and error statistics	
R^2 (fraction of variance explained by model)	0.74
± 2 (standard error) (95% confidence interval for linear fit accuracy)	±0.2
± 2 (RMSE) (95% confidence interval for prediction accuracy)	±0.2

Why an EOF-based model?
A linear regression model is not able to predict the heatwave years using only data from the pre-Blob years!

Interpretation - Why does this method work?
- EOF modes are not physics – interpret with care!
- Our model's accurate predictions at the shelfbreak for The Blob and El Niño show that interannual variability during both **anomalous events** and 'normal' years is driven by the same physical processes.
- The Pacific Decadal Oscillation (see Figure 4(a)) correlates with the shelfbreak timeseries at $\boldsymbol{R}$ = 0.64 ($\boldsymbol{R}$ = 0.86 for the predictive model) → some of the interannual varibility is driven by the PDO.

8. Summary and next steps

We are able to skillfully predict the temperature of upwelled water at the shelf break in Queen Charlotte Sound a **year** into the future using a readily available Argo data product. **The slow post-Blob cooling will continue in summer 2020!**

Next steps: To accurately map and interpret spatial variability in QCS, we need to estimate water mass modification. This summer, we will deploy an autonomous ocean glider with a microstructure turbulence sensor to measure mixing rates.

Ref: 1. Jackson, J. M., Johnson, G. C., Dosser, H. V., Ross, T. (2018). Warming from recent marine heatwave lingers in deep British Columbia fjord. Geophysical Research Letters. doi:10.1029/2018GL078971

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