# Forcing mechanisms of sea level variations in shelf waters off the coast of British Columbia

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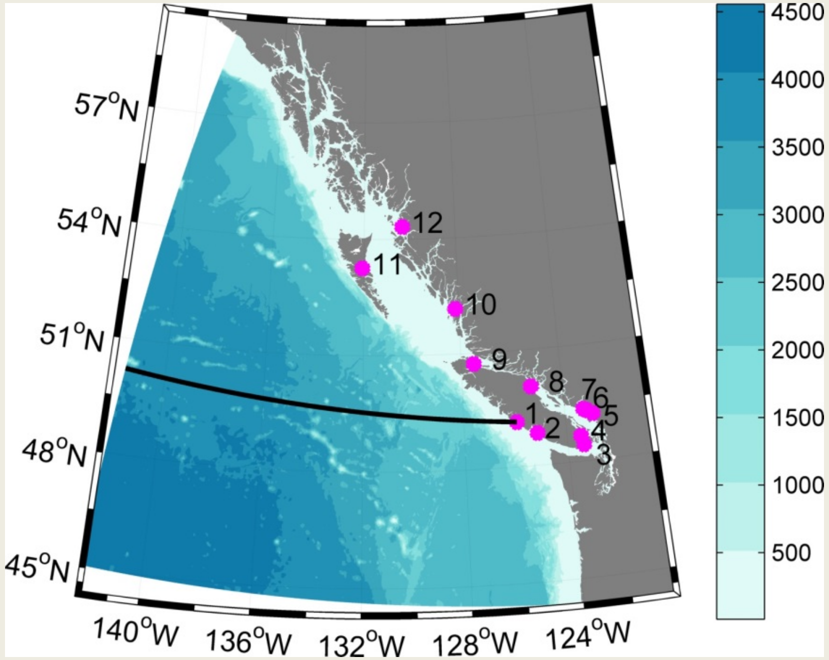
# Regional NEP36 Model

- Based on NEMO3.6
- Resolution: horizontal 1/36° lat/lon (~1.7 km), 50 vertical levels
- Initial & non-tidal conditions: T/S, U/V & SSH from daily PSY4 (global 1/12° analysis product of Mercator-Ocean, France)
- 8 tidal constituents from WebTide
- Surface atmospheric forcing: hourly NCEP CFSR product
- River runoff: monthly climatology of river (Morrison et al., 2012)
- Hindcast & “climatology OBC” test: 2007-2016



# Motivation

- **Sea levels is readily observed by tide gauges and satellite altimeters.**
- **Variations of sea level, ocean heat content and currents are closely linked**

  **e.g., Northeast Pacific (NEP) "Blob" 2012-2016**
- **Previous studies on sea level variations and forcing mechanisms in NEP, e.g.,**

  **Enfield & Allen 1980; Chelton & Davis 1982;**

  **Tabata et al. 1986;**

  **Stammer 1997; Cummins 2005;**

  **Hermann et al. 2009; Masson & Fine 2012;**

  **Thompson et al. 2014**

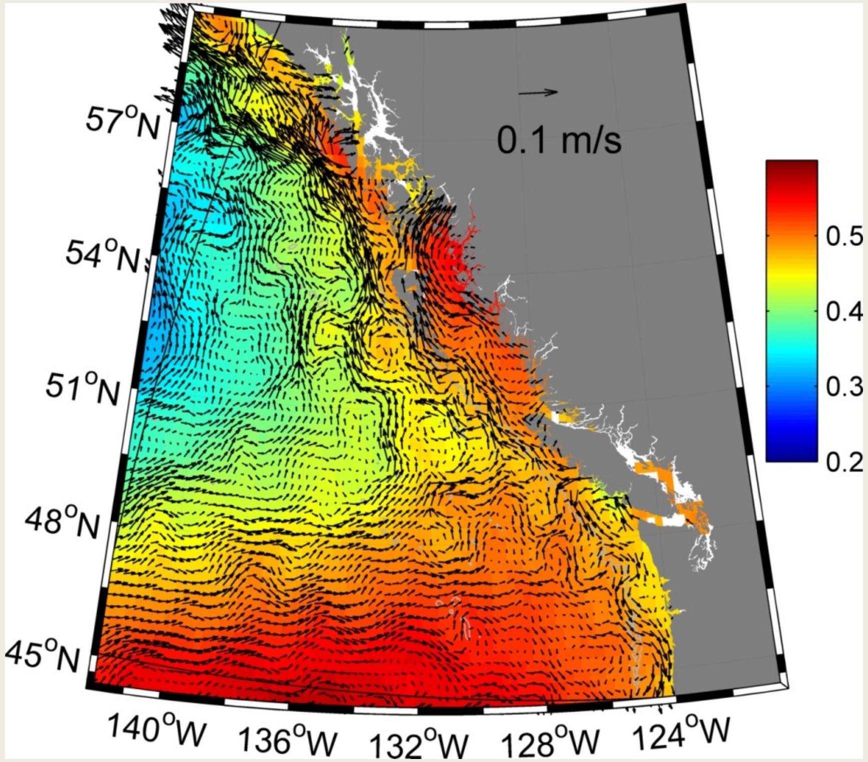
# This study

- **Objectives:**
  - **Reconcile importance of wind & halosteric contributions to seasonal variation**
  - **Clarify role of local & remote sensing**
  - **Reveal/confirm different forcing mechanisms at different time scales**

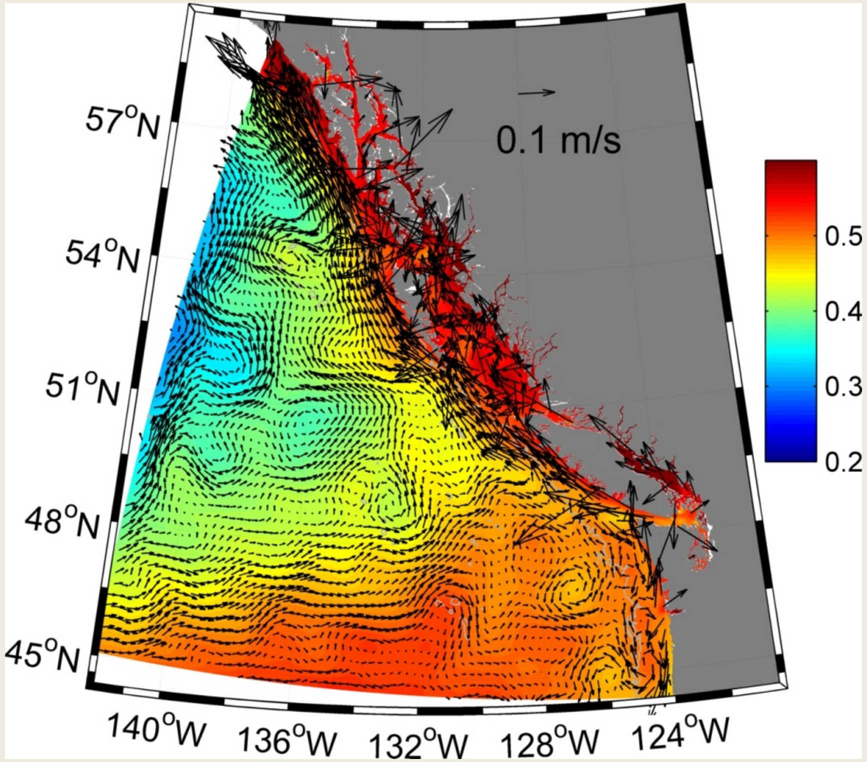
- **Approach:**
  - **Joint analysis of tide gauge & altimeter observations, high-resolution model simulations, atmospheric forcing**
  - **Compute thermal and haline components of steric height**
  - **Correlation & regression analysis**
  - **Analysis based on monthly averages.**

# Mean Sea Level & Surface Geostrophic Currents (2008-2016)

**Altimeter**




**NEP36**




**Compared to altimeter data, NEP36**

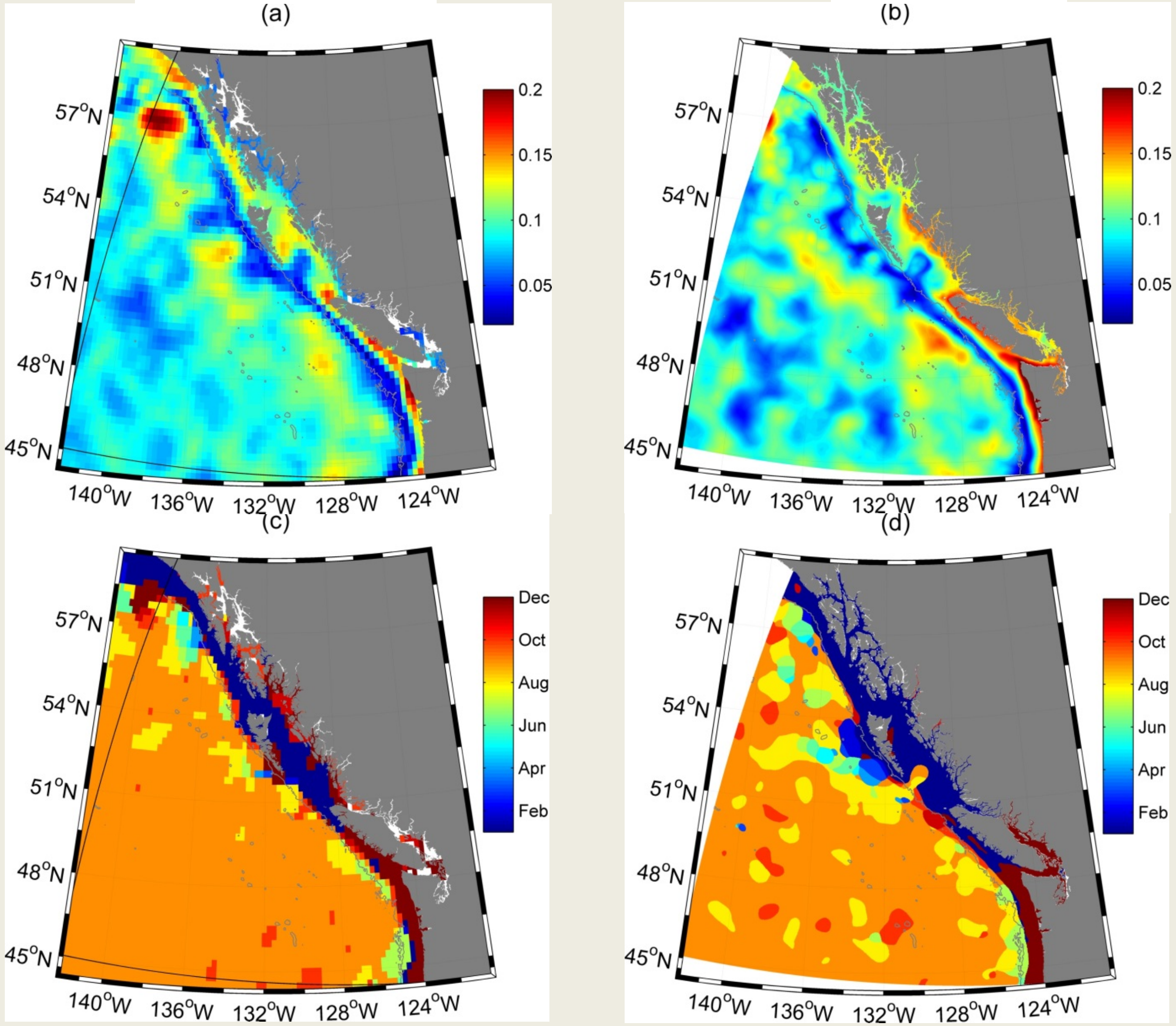
- **Captures large scale features of surface geostrophic currents**
- **Generates higher coastal sea level and stronger coastal currents**
- **Produces less small-scale eddies than altimeter data**

# Seasonal Cycle of Sea Level

**Amplitude**
= maximum minus minimum

**Phase**
= month when maximum occurs

**Altimeter** | **NEP36**

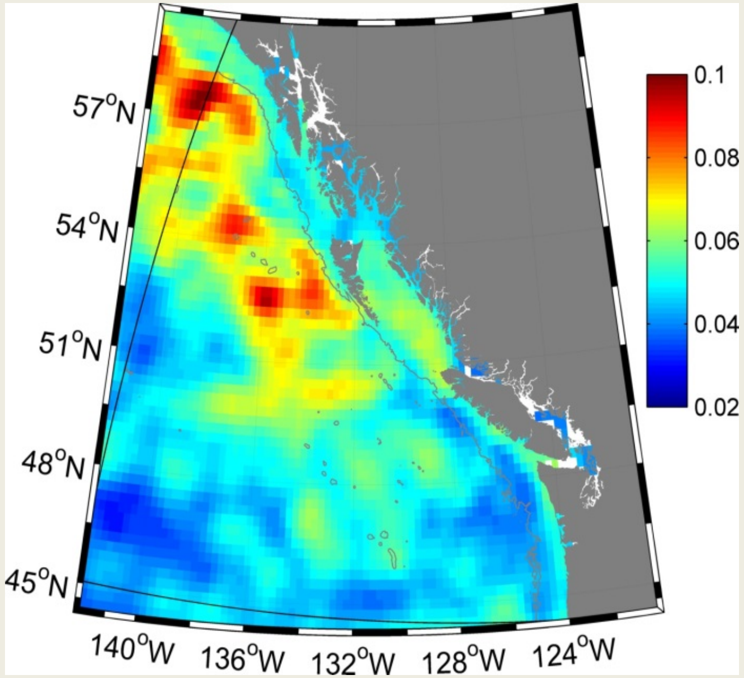



**NB: Weak signal over shelf break**

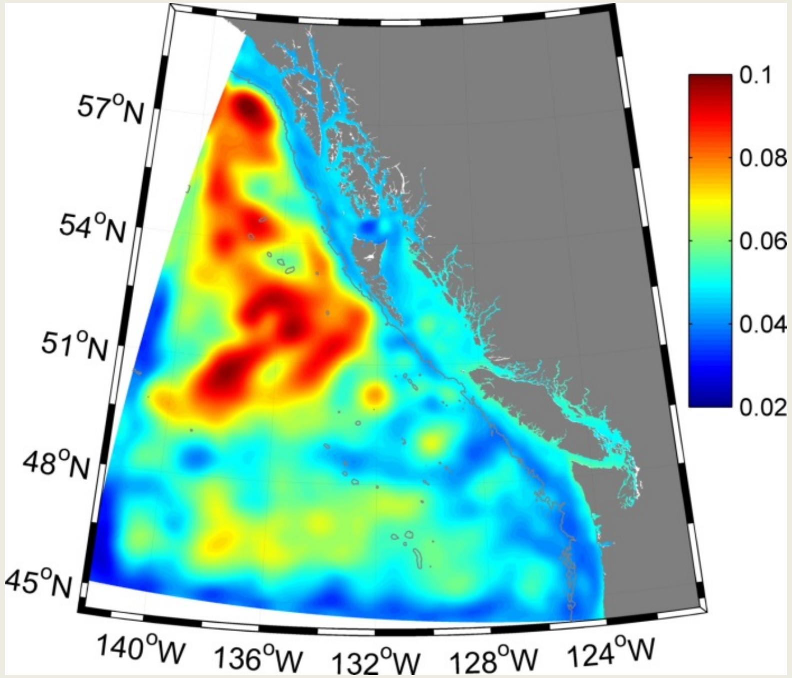
**NB: Out of phase between shelf & deep waters**

# Standard Deviation of Sea Level Anomaly (SLA)
# (Seasonal Cycle Removed)

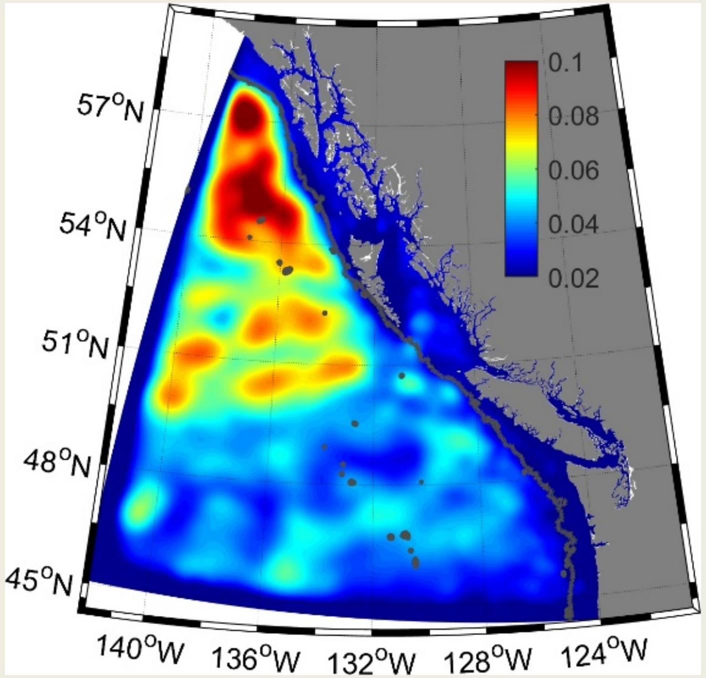
**Altimeter**




**Hindcast**

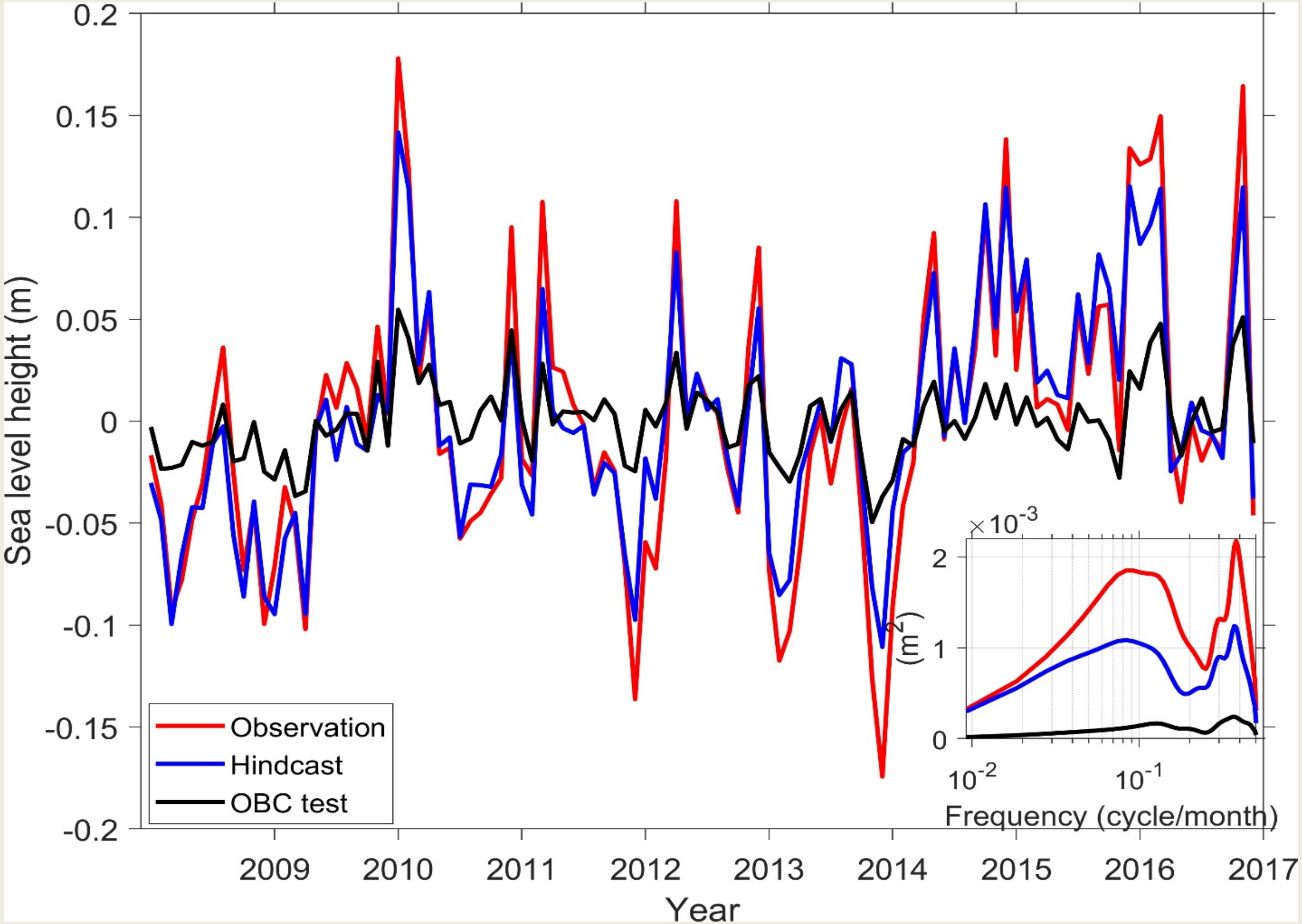



**Obc Test**



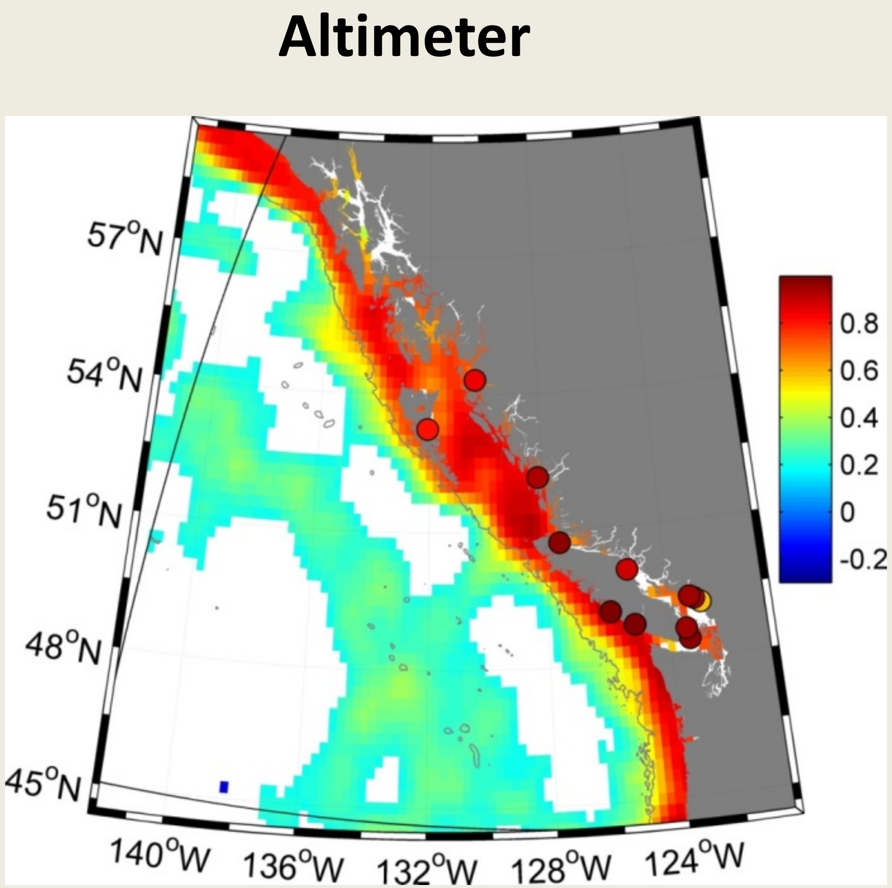

- **Minimal amplitude near shelf break: different dynamics between shelf & deep waters**
- **Interior eddies: model too strong or altimeter too weak?**

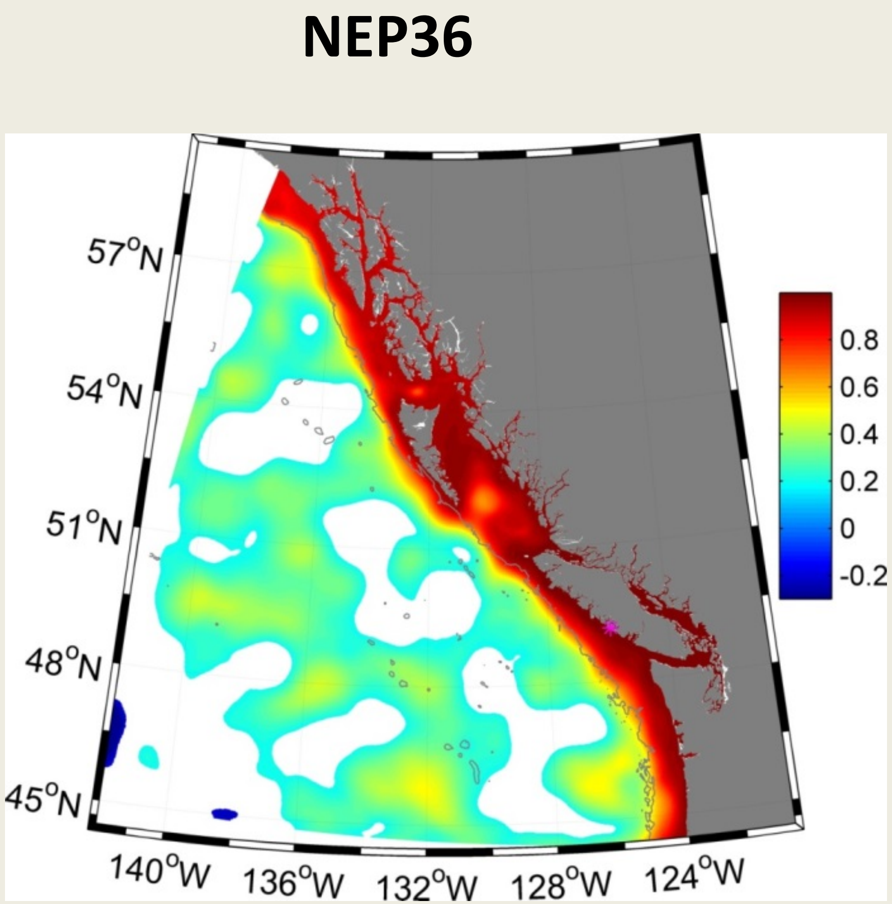
# Sea Level Anomaly at Tide Gauge Tofino




- **Hindcast obtains sub-seasonal & inter-annual variations similar with observations**
- **“Climatology OBC” produces much weaker variations: Remote forcing important!**

# Correlation of Sea Level Anomaly at Tofino with Large Scale

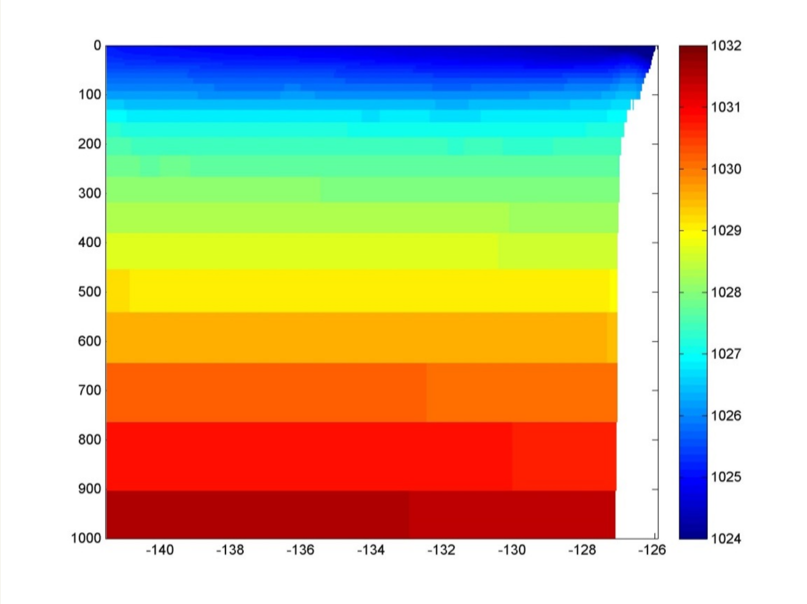


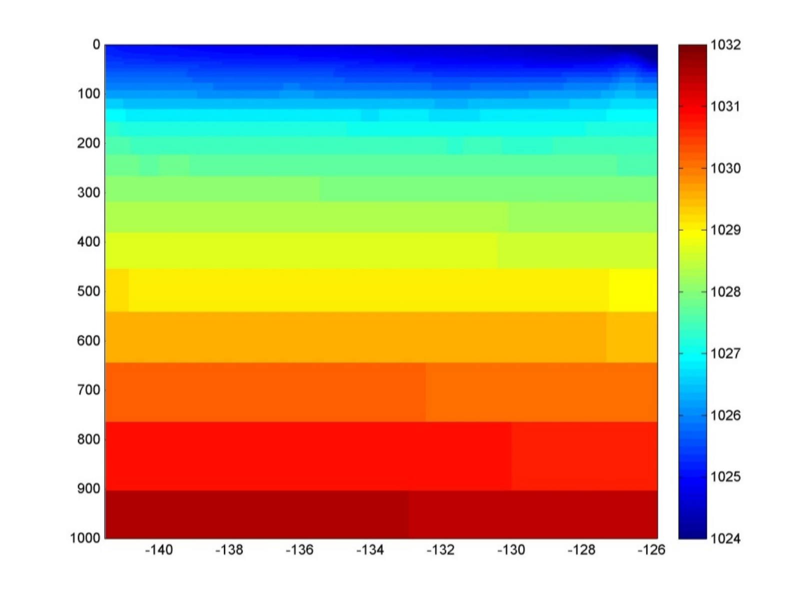

- **Large-scale coherence on shelf – SLA at Tofino well represents variability on shelf.**
- **Correlations significantly decrease in deep water.**

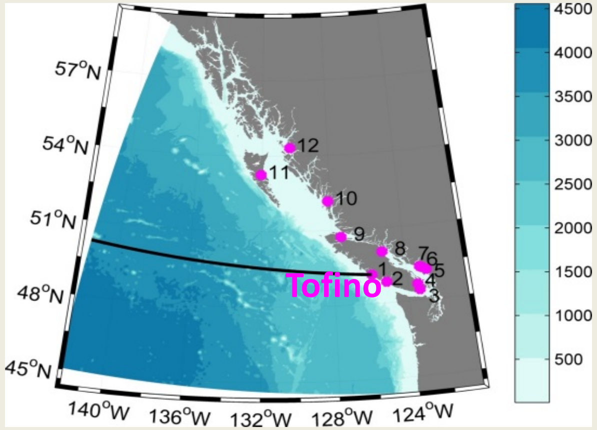
# Calculation of Steric Height at Tofino

## Density




## Extended Density

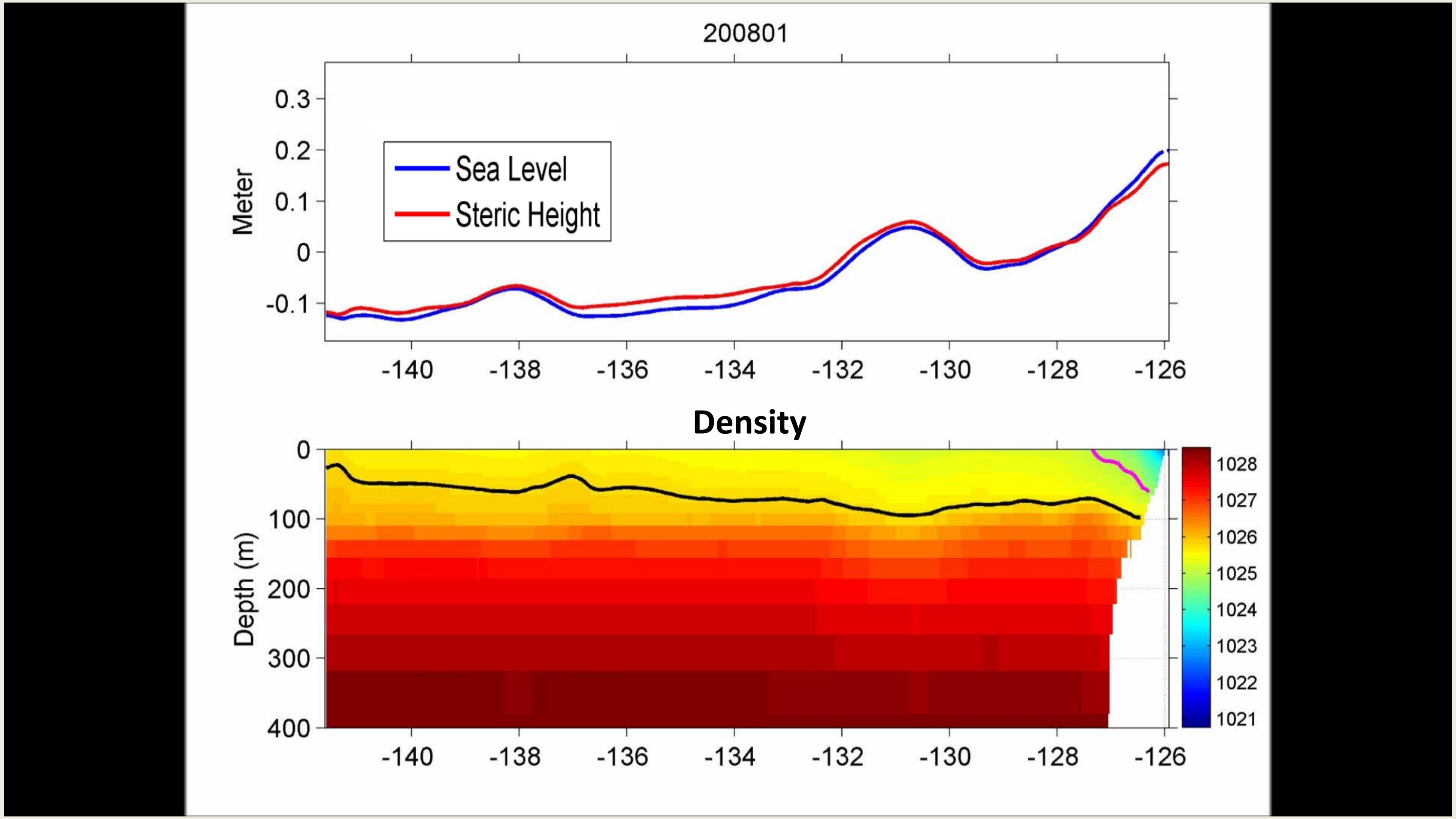



**"Bottom density" method first introduced by Helland-Hansen (1934):**

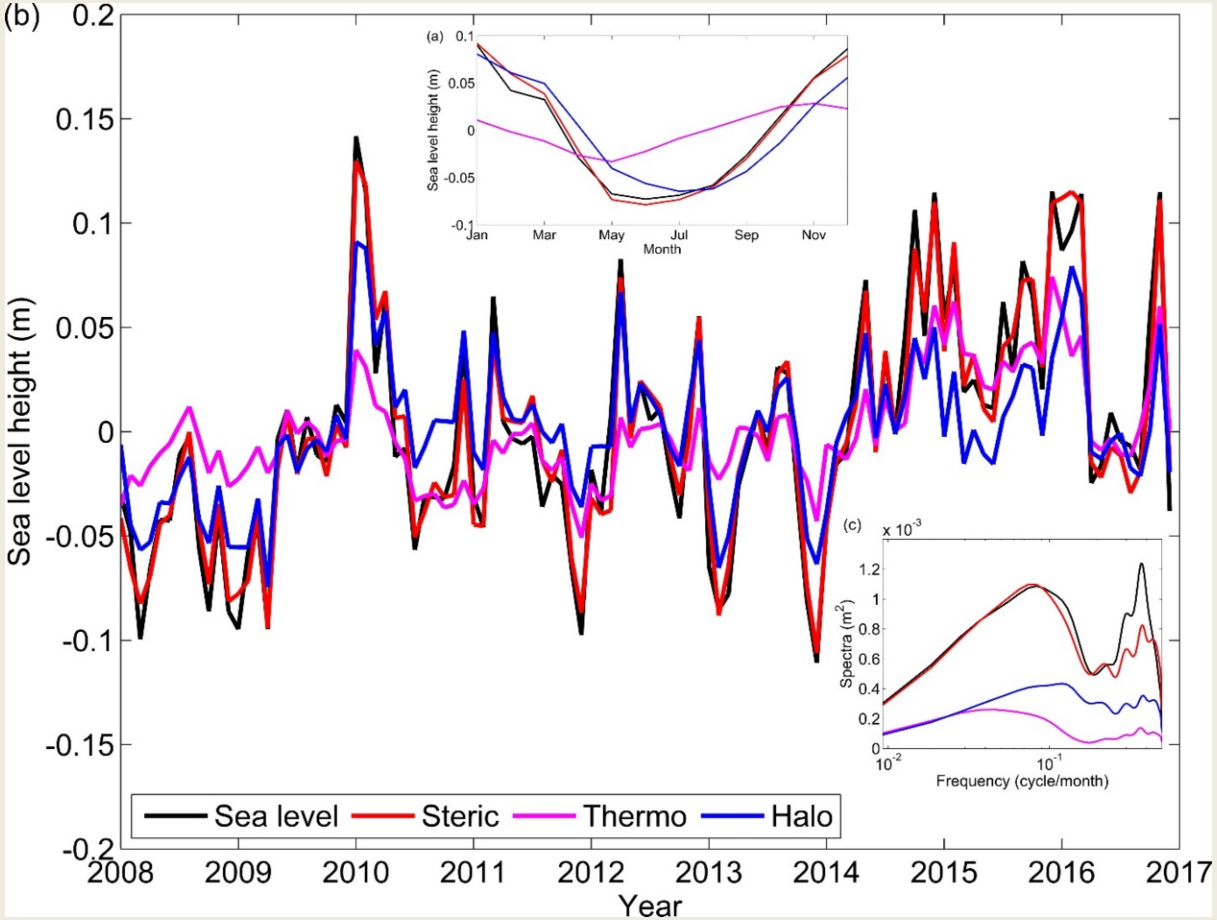
- **Extend bottom T/S along section horizontally under sea floor from their point of intersection to coast**
- **Assume zero cross-shelf gradient of dynamic height, hence zero along-slope geostrophic flow at bottom.**

# Animation: Sea Level, Steric Height & Density Variations




- **Steric height accounts for most sea level variations;**
- **Strong T-S variability in upper 200 m.**

# Tofino – Sea Level and Steric Height




## Seasonal cycle

- Steric height accounts for seasonal sea level & haline effect dominant; consistent with Tabata et al. (1986) based on observations.
- Importance of seasonal wind is well known, but influence of wind is through baroclinic process!

## Sea level anomaly (seasonal cycle removed)

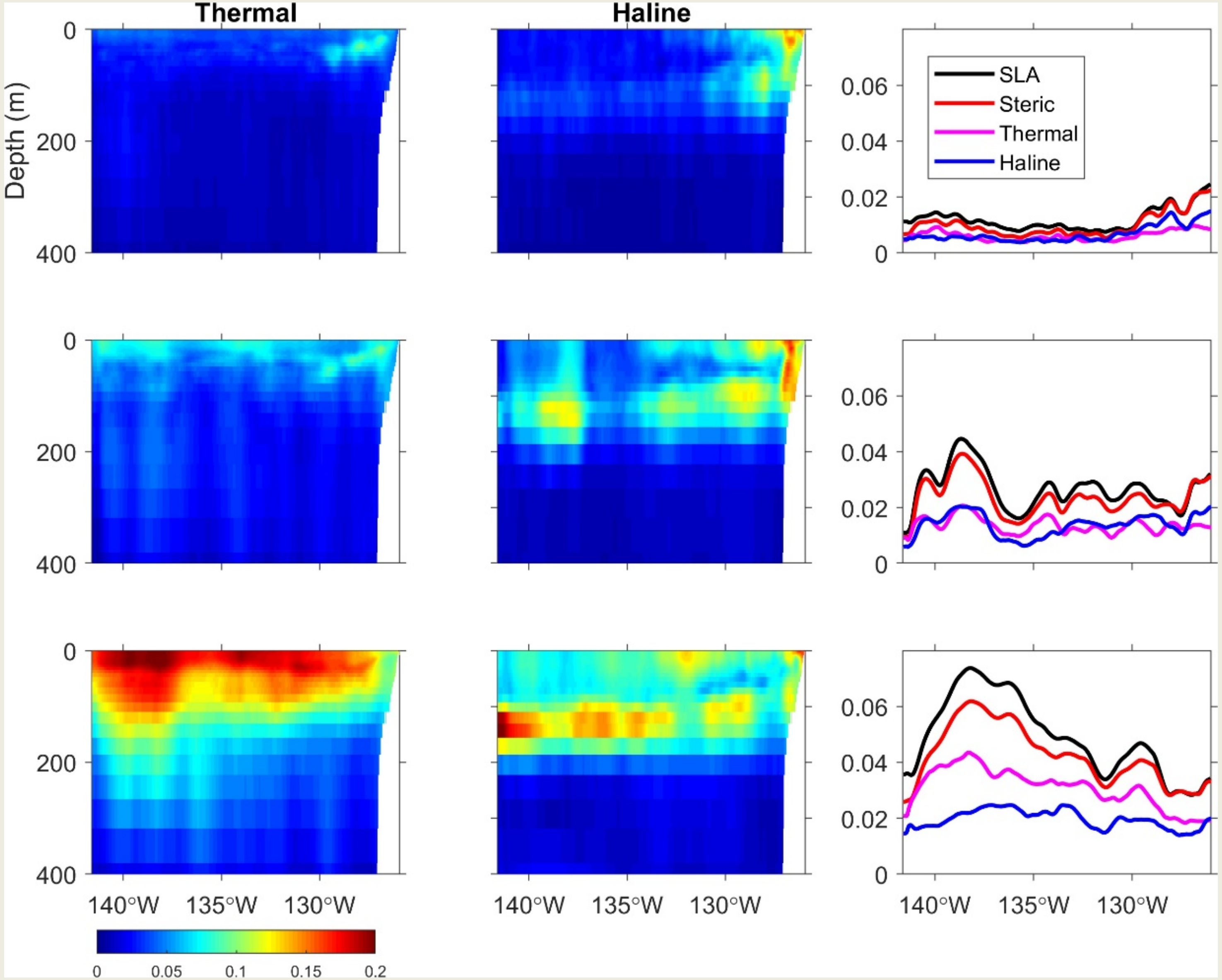
- Steric accounts for SLA variations.
- Significant haline effect even with climatology runoff!
- Two spectral peaks centered at 14 & 2.5 months.

# Thermal & Haline Contributions to Steric Height

< 5 months

5-20 months

> 20 months




**Deep ocean:**

- **Higher energy at lower frequencies**

**Shelf:**

- **< 20 months haline effect is higher**
- **> 20 months thermal effect is higher**

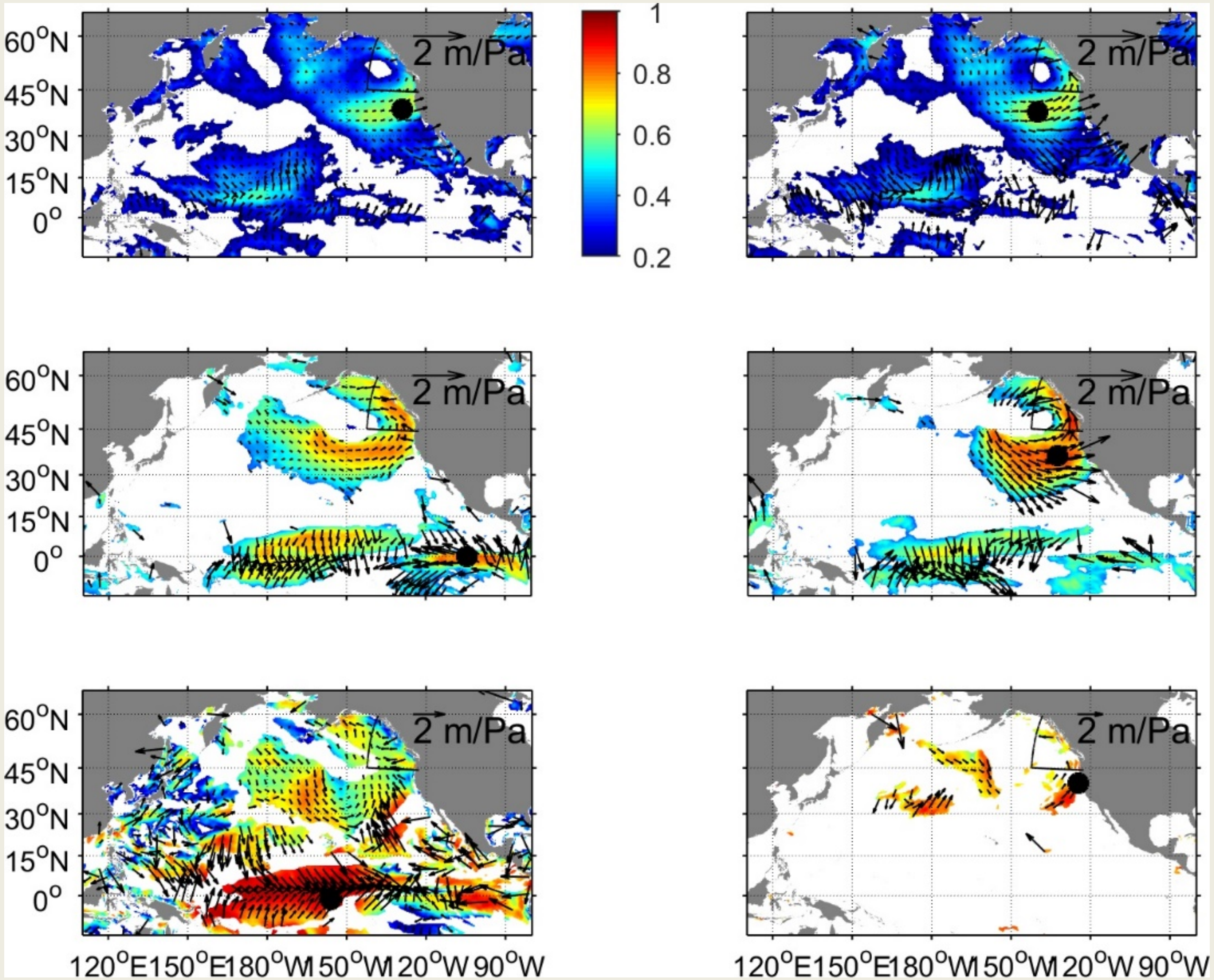
# Regression of Steric Height at Tofino onto Wind Stress

**Thermosteric** | **Halosteric**

< 5 months

5-20 months

> 20 months




Importance of remote winds:

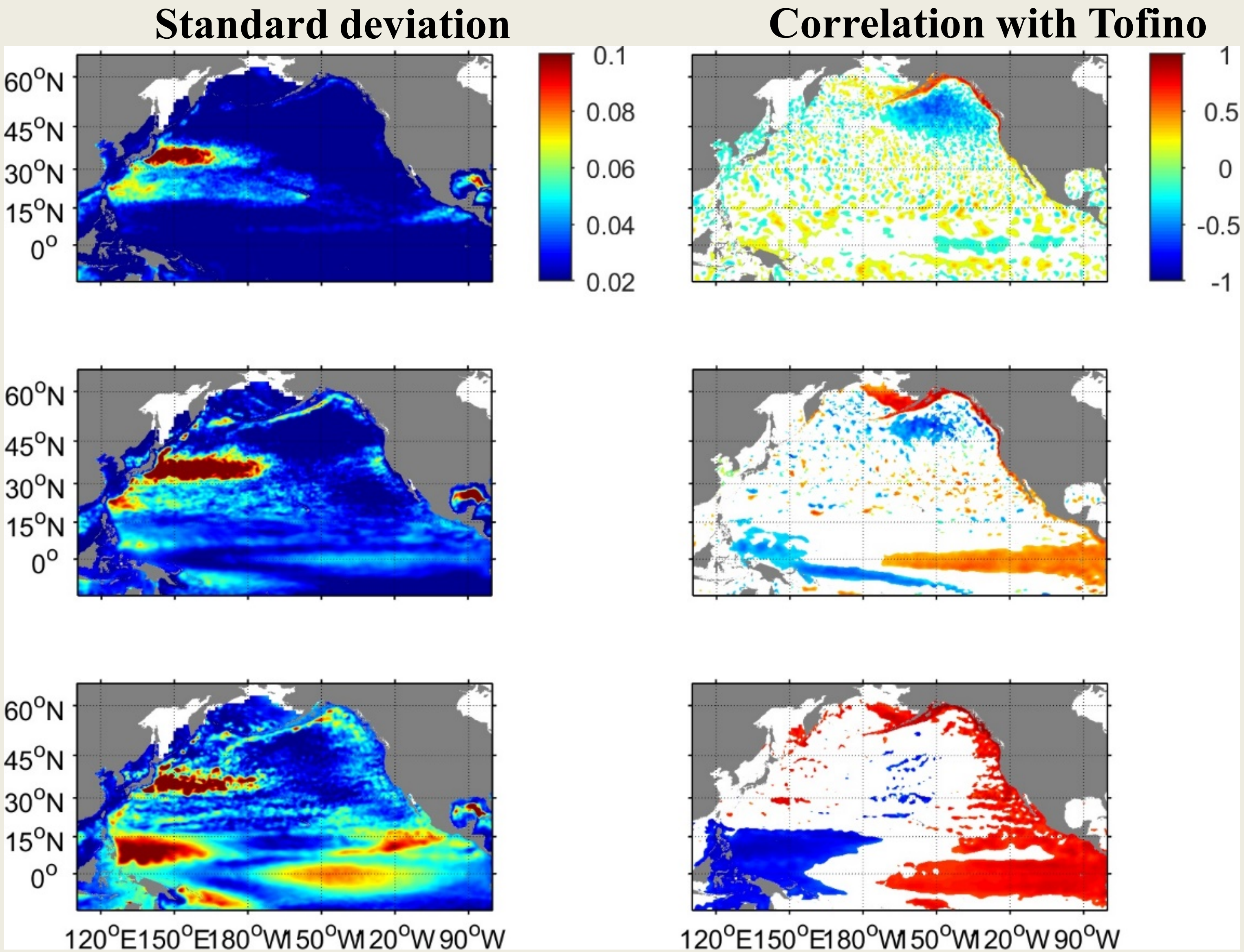
- < 5 months: mid-latitude winds onto coast of Washington & Oregon states
- 5-20 months: mid-latitude & equatorial winds
- > 20 months: equatorial wind drives thermal component

# Relationship of SLA at Tofino with Pacific SLA

< 5 months

5-20 months

> 20 months

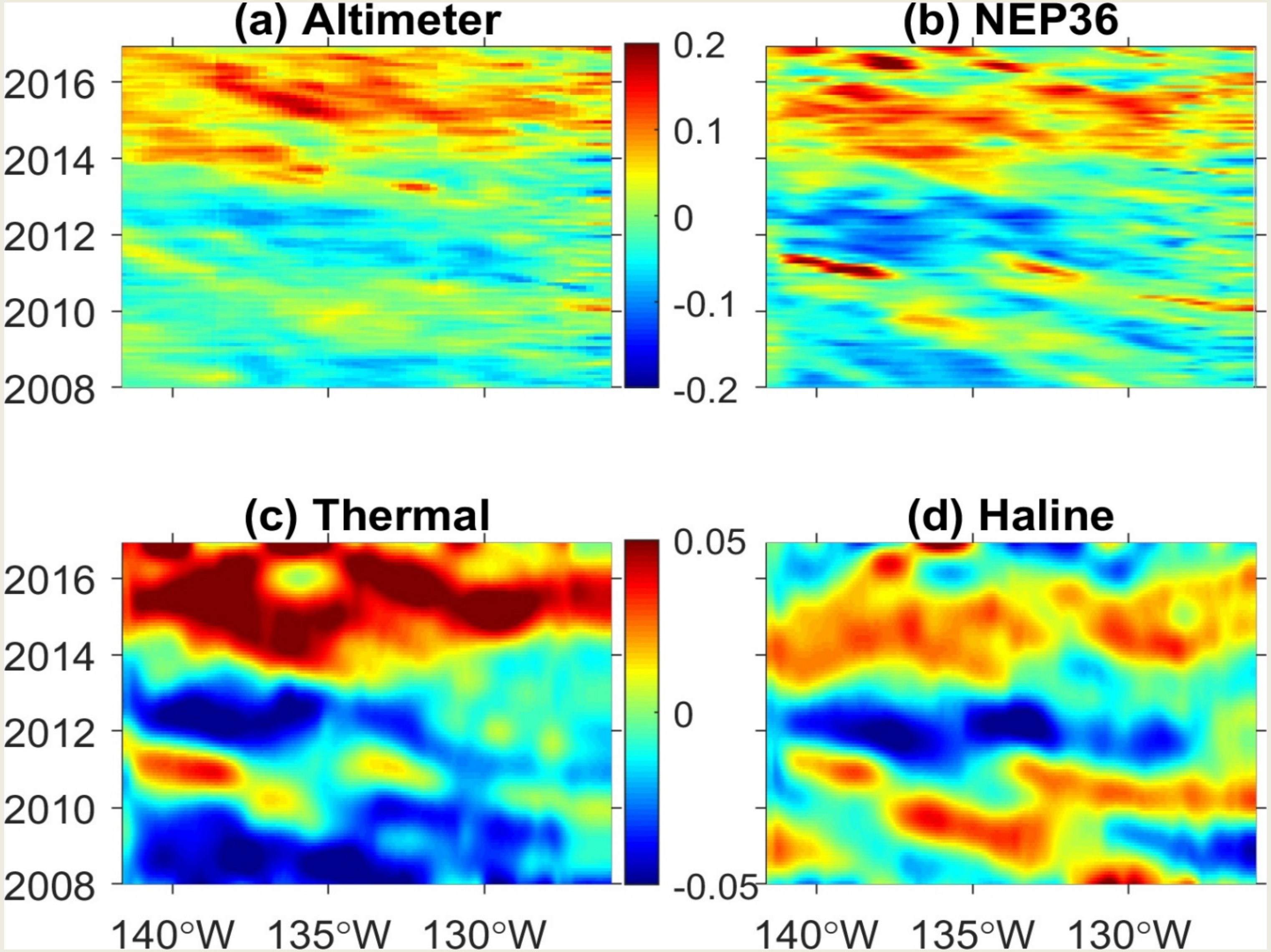



- < 5 months: positive (negative) correlation on shelf (deep ocean) are due to mid-latitude wind
- 5-20 months: effects of mid-latitude & equatorial winds
- > 20 months: equatorial & mid-latitude winds

# Linkage between SLA Variations on Shelf and in Deep NEP

Monthly data

> 20 months




- "Blob" signal extends from deep ocean onto shelf
- Mid-latitude winds drive thermal steric
- Consistent with Bond et al (2016).

# Conclusions

- **On shelf, seasonal sea level maximum in winter is caused by down-welling wind pushing upper layer freshwater downward – a baroclinic process.**
- **At time scales < 20 months, shelf sea levels are driven by remote winds at mid-latitudes.**
- **At 5-20 months & > 20 months, shelf sea levels are linked to Trade Winds in central tropical Pacific.**
- **Overall, remote wind is a key driver of sea level variations in shelf waters off British Columbia.**