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)
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.
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
Amplitude = maximum minus minimum

Phase = month when maximum occurs

NB: Out of phase between shelf & deep waters

NB: Weak signal over shelf break
Standard Deviation of Sea Level Anomaly (SLA) (Seasonal Cycle Removed)

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

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

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:** 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

- “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.