Challenges and Progress in the Development of a Circulation Model for the Central West Coast of Vancouver Island

Mike Foreman¹, Peter Chandler¹, Di Wan¹, Pramod Thupaki², Maxim Krassovski¹, Laura Bianucci¹, Glenn Cooper¹

¹Institute of Ocean Sciences, Fisheries and Oceans Canada
²Hakai Institute, Calvert Island BC

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With valuable contributions from:

Michael Dunphy, David Spear, Hauke Blanken
IOS

Yuehua Lin
ASL Environmental Sciences

J.-P. Paquin, Ruping Mo
Environment & Climate Change Canada

Youyu Lu, Stephanne Taylor
Bedford Institute of Oceanography, Fisheries and Oceans Canada

Grieg Seafood & Cermaq Canada

Aquaculture Collaborative Research & Development Program
DFO
Outline:

1. Motivation for the Vancouver Island coastal model
2. Differences/challenges from ocean models
3. Model & observation details
4. Interesting (& complex) dynamics & preliminary model results
5. Summary & future work
Motivation for our Coastal Model

- Develop ocean circulation & particle-tracking models to help address aquaculture issues along the central west coast of Vancouver Island
  - Dispersion of parasites & pathogens between salmon farms & from farms to wild species
  - Advice on future farm siting to minimize connectivity & environmental impacts
- Assist industry in understanding & predicting adverse environmental conditions
Similar models have been developed in green & yellow regions & will be presented in S3

Red region is our model domain
Salmon Farms are open net cages

- Free exchange of small “particles” with neighbouring ocean
- Approx. $210 \times 60 \times 20$ m
  - Can hold up to 500K fish
Key differences between coastal & deep ocean models

1. Coastal models need
   a. Higher spatial resolution in:
      • Coastline & bathymetry
      • Atmospheric forcing fields (wind & heat flux)
   b. Accurate open boundary forcing (from a larger domain model)
   c. Fresh water discharge forcing (volume flux, temperature, salinity, biogeochemistry)
   d. Observations for model assimilation and/or evaluation
      • smaller scale spatial features

2. Numerics that
   a. Solve hydrodynamic equations on a grid incorporating 1a,b,c
   b. Accurately reproduce relevant physics (e.g., preserve freshwater plumes & near-surface stratification)
Observation Locations

12 ADCP & Microcat (CTD) moorings, 5 lighthouses, 2 Environment Canada weather buoys
1. **Physical circulation model:** FVCOM
   - *Finite Volume Community Ocean Model* (Chen et al., 2006)
   - *Standard 4D hydrodynamics & salinity/temperature advection/dispersion on an unstructured grid*
     - Approx 138K triangles; horizontal resolution: 60m to 9km
     - 21 sigma-coordinate layers in vertical; smaller thickness near surface

2. **Simple “biological” model:**
   - Non-passive offline particle tracking
   - Use saved 4D velocity, salinity, temperature & mixing fields from FVCOM + UV radiation (IHN virus)
   - transport and develop/kill viruses or sea lice (egg thru to copepodid life stages)

3. **More complex “biological” models in S3**
   - Include biogeochemistry and/or lower trophic levels
   - Wei, Bianucci, Peña, Holdsworth, Allen, Olson, Pilcher
Need to capture irregular coastline, variable bathymetry with high resolution grid

- Bathymetry from multi-beam sonar data (5m horizontal resolution)
  - if mudflats, then LIDAR data in the wetting-drying zones is desirable
- improves tides at Kennedy Cove
Highly Variable Bathymetry

- Banks & canyons on shelf
- Mudflats to over 300m in inlets
Atmospheric Forcing

Environment and Climate Change Canada LAMWEST "HRDPS" 2.5 km weather model
- sample pressure (Pascals), surface temperature (°K) & wind fields
Atmospheric Forcing

- 2.5 km horizontal resolution insufficient to resolve orographic steering winds in many coastal inlets
  - E.g., Muchalat is 1.2 to 2.0 km wide
- Need to improve by either
  - combining with weather station observations
  - or await new 1km HRDPS model (presently pre-operational)

Sample 10m winds from 1km HRDPS. Courtesy of Maher BenMansaur.
Open Boundary Forcing:
Northeast Pacific NEMO model (NEP36, DFO/ECCC)

- Rectangular grid cells with 1/36° resolution
  - approx 2km in EW at 49° N
  - Coastal inlets poorly resolved
  - Limited river discharges
  - Atmospheric forcing = 2.5km HRDPS

- Pre-operational test runs for Nov 2015 to Jan 2019

- More details in Hannah/Lu talk at 11:20 today

- Presently extracting hourly sea surface height, and 3D temperature & salinity along red open boundary of our model

- Lin (today at 11:00) nests his regional model in NEP36
  - Also takes 3D velocities

NEP36 domain & bathymetry
How accurate is NEP36 within our domain?

Compare with low-pass filtered, along shelf observed currents at mooring E01, March 1 to July 11, 2016

Top: ADCP observed
Bottom: NEP36
How accurate are the NEP36 Tidal Elevations? Compare at 4 offshore bottom pressure sites

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<th>Amp ratio</th>
<th>Phase dif°</th>
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<tr>
<td>K2</td>
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</table>

- Amplitude ratio = NEP36/observed
- Phase difference = NEP36 - observed

Conclusion:
- Diurnal amplitudes & phases pretty good!
- Semi-diurnal phases too late by 3° – 5° (6 – 10 minutes)
  - We may replace with our own tidal forcing?
Discharges primarily rainfall dominated
  - Episodic storms in winter; dry in summer

More on role of rivers in Miyama S3 talk at 12:00

- 29 rivers included but only 5 had their discharges measured by WSC in 2016
- estimate others based on historical discharge ratios (if possible) or ratios of watershed areas
- also need discharge temperature & salinity
  - seldom measured so estimate either from observations
    - in inlet near river mouth, or
    - a nearby fish farm
Using watershed area ratios assumes similar runoff characteristics
  • E.g., elevations, ground water storage, precipitation in rainfall vs snowfall, ...

To improve, we need more discharge observations or a hydrology model
Clayoquot region has much stronger tidal currents than Nootka-Esperanza.

- Spring-neap cycle important in mixing & regulating estuarine flow?
- Model not right yet!

Low-pass filtered ADCP profile (top), model (middle), & near surface observed currents (bottom).
• **CYP1 low pass filtered**
• **Positive velocity is eastward**
  • *x*-axis tick separation is 7 days
• **Some spring-neap modulation of estuarine flow?**
  • **Freshwater from Bedwell Inlet**
ZUC1 bottom temperature & salinity show sharp changes on May 9, 2016

Spike in low-pass filtered up-channel bottom currents

Compensating near surface flows
- 2 days of sustained winds around 15 m/s from the NW
  - decrease quickly to approx no wind
  - precede the ZUC1 bottom intrusion

- WDIR is direction from where wind is blowing, clockwise from north
ZUC1 low-pass filtered bottom pressures (proxy for SSH)

- "surge" of water moving by ZUC1 starting 000 May 9
  - 29cm SSH rise (low-pass) over 2 days; another 8cm by May 15
- **Hypothesis:**
  - Sustained strong winds to SE bring upwelled water onto the shelf & create a depression in SSH adjacent the coast
  - If the winds shut-off quickly, water flows coastward to adjust & "surge" moves up Nootka Sound & (probably?) into Muchalat Inlet
  - Yet to be replicated with model simulations ...
Interesting Dynamics 3: River Plume Simulations

Surface salinity March 1-8, 2016
3 hour intervals

Gold River discharge (WSC)
March 2016

SALINITY

28
26
24
22
20
18
16
14
12
10
8
6
4

Muchalat Inlet

Burman River
How accurate are the model plumes? Compare with near-surface TS observations at 16 farms

Average March 6–30, 2016 observed and model temperatures (°C) and salinities (psu) at 1m depth.
- Average abs(differences) are 0.4° and 3.3 psu
- Model temperatures good but model salinities are generally too salty
  - Combination of too much mixing, inaccurate river discharges, missing rivers,… ?

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<tr>
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</table>
• Eastward daily sea breeze causes daily oscillations in 5m temperatures
  • June 21 range: 15.5° to 10°
  • Twice daily temp observations (aliased) suggest 10° water came from below
  • Similar large oscillations in dissolved oxygen

• on June 27-30, wind changes
  • 5m temp reaches minimum on 27\(^{th}\) & stays there for 3-4 days before resuming daily pattern by Jul 1\(^{st}\)
  • 1m temp doesn’t show this drop

• Yet to be reproduced with model simulations
Summary & Future Work

- Coastal ocean modelling has unique challenges/needs:
  a) Grid that resolves irregular coastlines & variable bathymetry
  b) High resolution atmospheric forcing
  c) Accurate open boundary forcing
  d) Freshwater water discharges (volume flux, temperature, salinity, biogeochemistry)
  e) Numerics that can
     i. incorporate a) & preferably mudflats
     ii. accurately reproduce relevant physics

- Interesting (& complex) dynamics:
  a) Spring-neap variations in estuarine flow,
  b) Density intrusions,
  c) Freshwater plumes,
  d) Internal waves.

- Future work:
  a) Complete FVCOM simulations for March to July 2016
  b) Better simulate & understand "interesting physics" features
Thanks for your interest!

Session S3 starts at 10:50 in Saanich 1