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

Mike Foreman[1], Peter Chandler[1], Di Wan[1],
Pramod Thupaki[2], Maxim Krassovski[1],
Laura Bianucci[1], Glenn Cooper[1]

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

IOS

Fisheries and Oceans Canada Pêches et Océans Canada

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Hakai
Science on the Coastal Margin

PICES

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

ASL Environmental Sciences

Environment and Climate Change Canada
Environnement et Changement climatique Canada

Grieg Seafood

CERMAQ

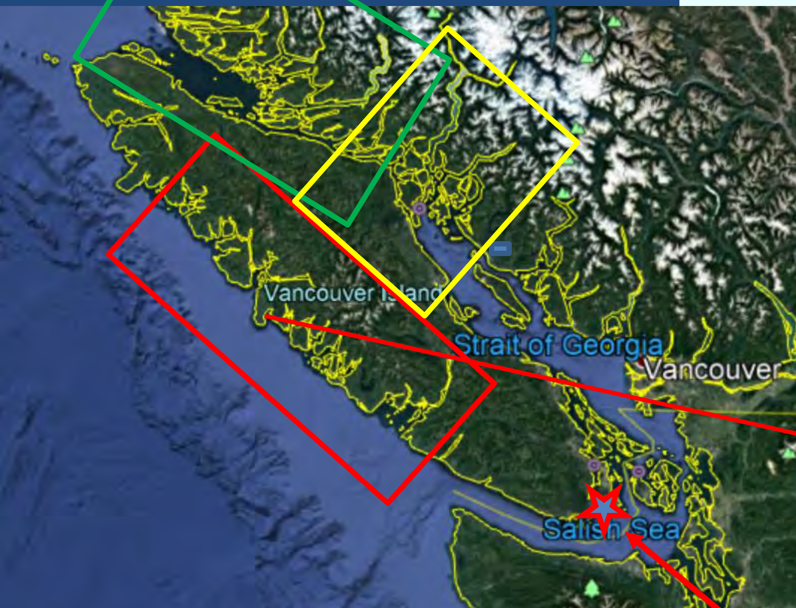
Outline:

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

Geographic Setting



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 x 60 x 20 m
  - Can hold up to 500K fish

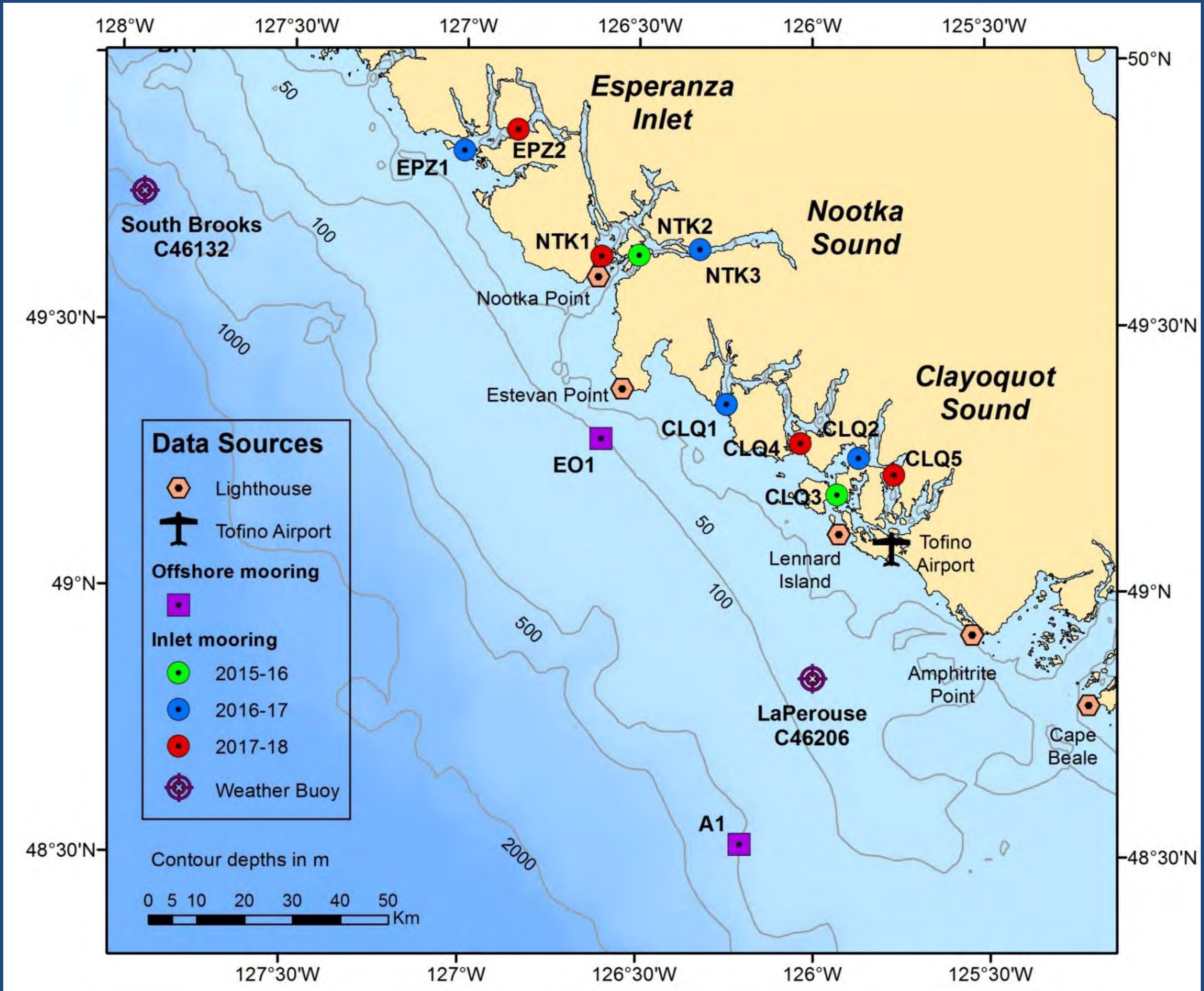
Key differences between coastal & deep ocean models

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

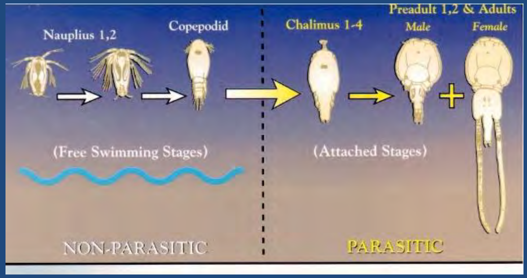
Our Biophysical Models

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)

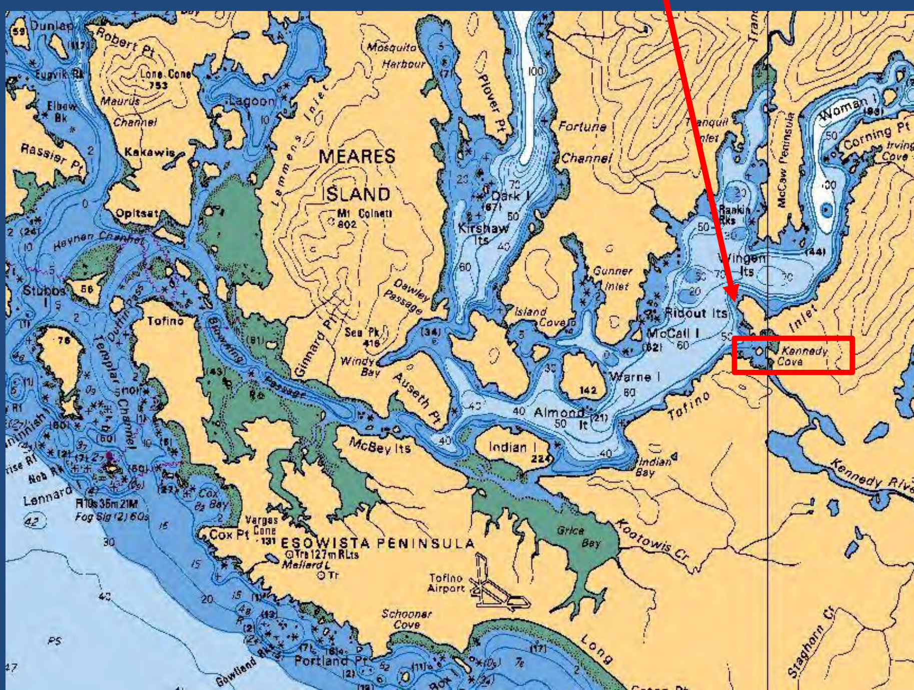


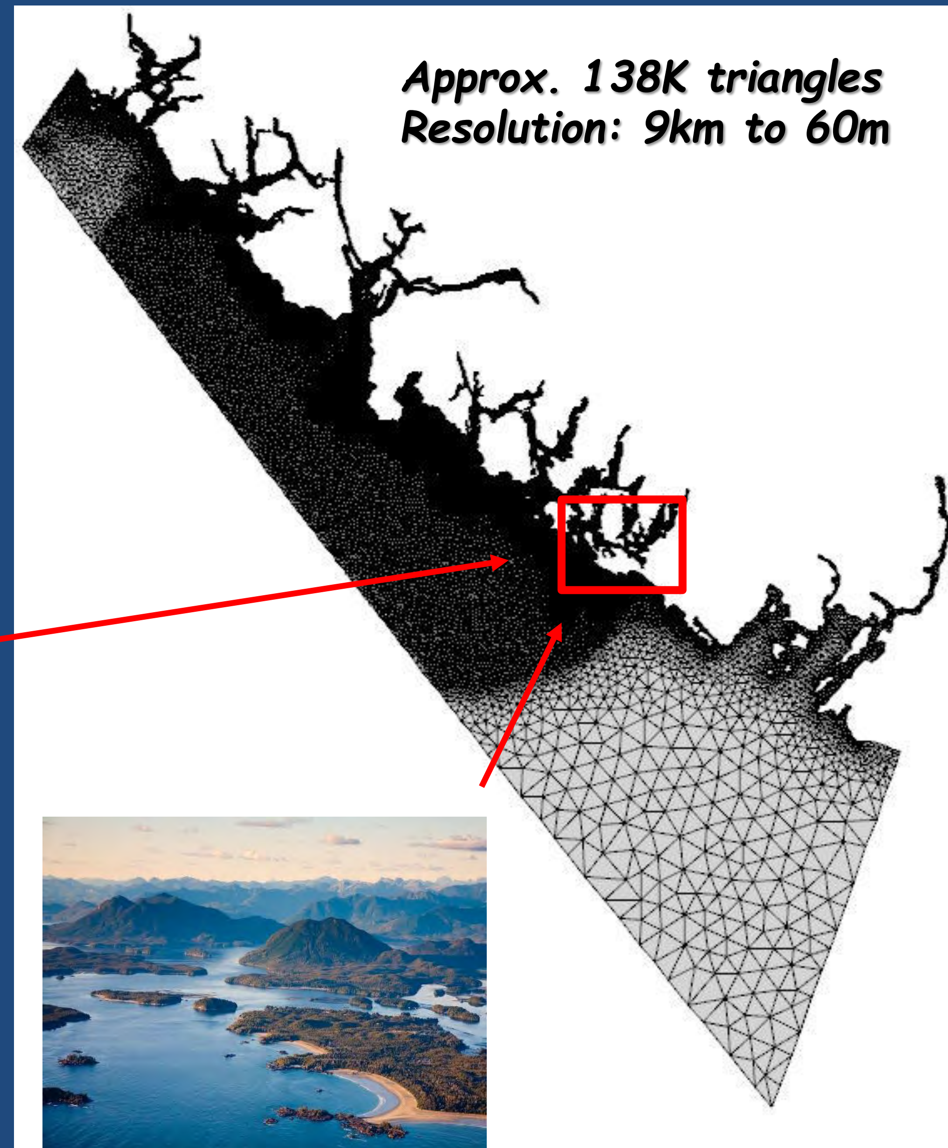
3. More complex "biological" models in S3

- Include biogeochemistry and/or lower trophic levels
- Wei, Bianucci, Peña, Holdsworth, Allen, Olson, Pilcher

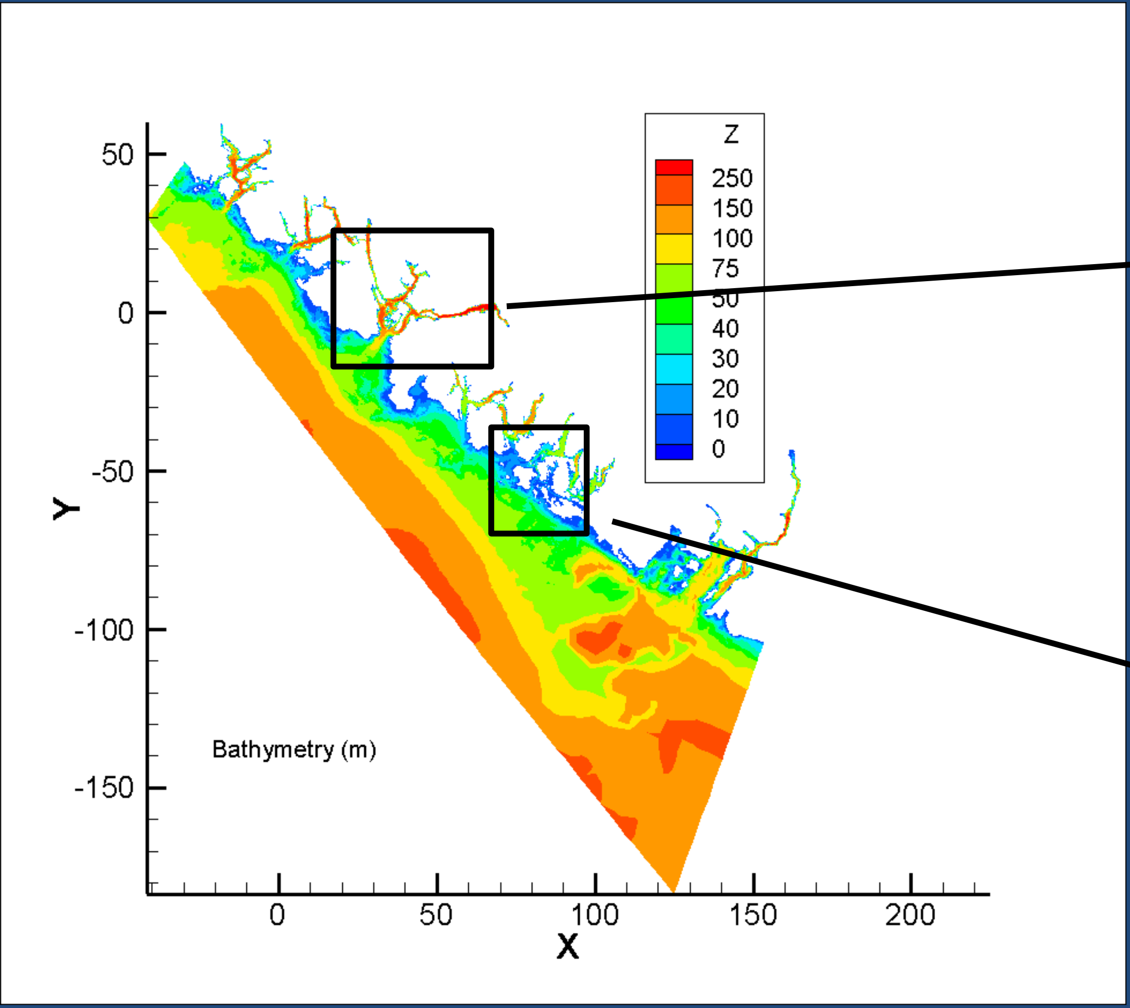
Need to capture irregular coastline, variable bathymetry with high resolution grid

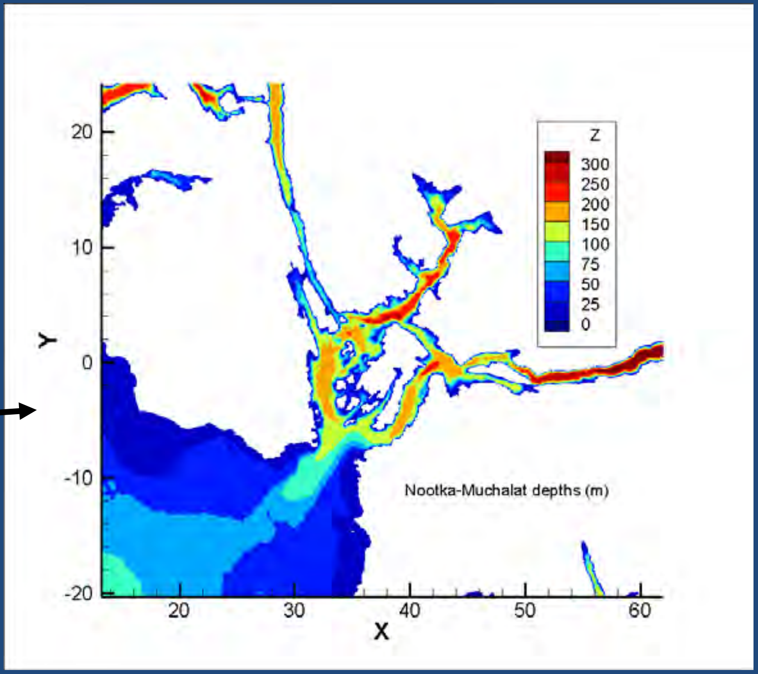
- Bathymetry from multi-beam sonar data (5m horizontal resolution)
  - if mudflats, then LIDAR data in the wetting-drying zones is desirable
    - improves tides at Kennedy Cove

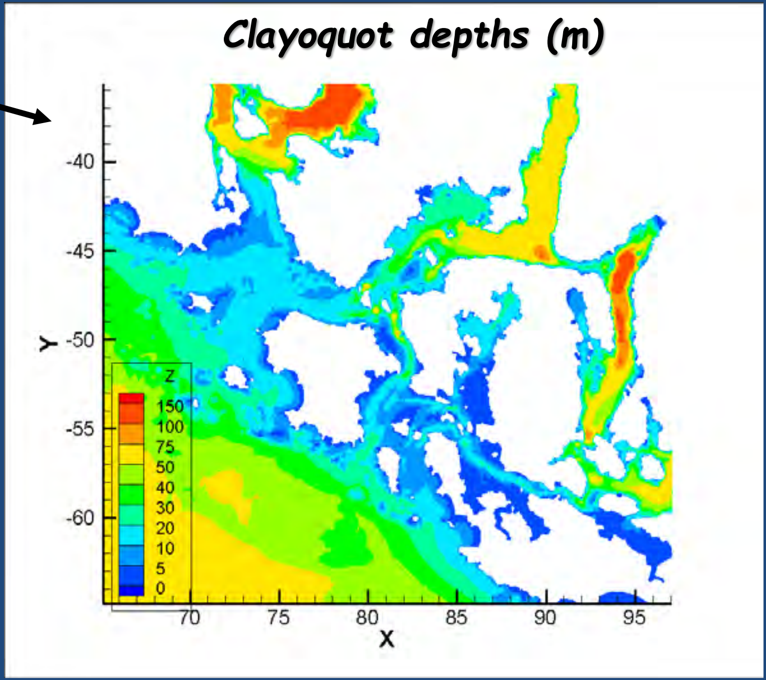




Highly Variable Bathymetry

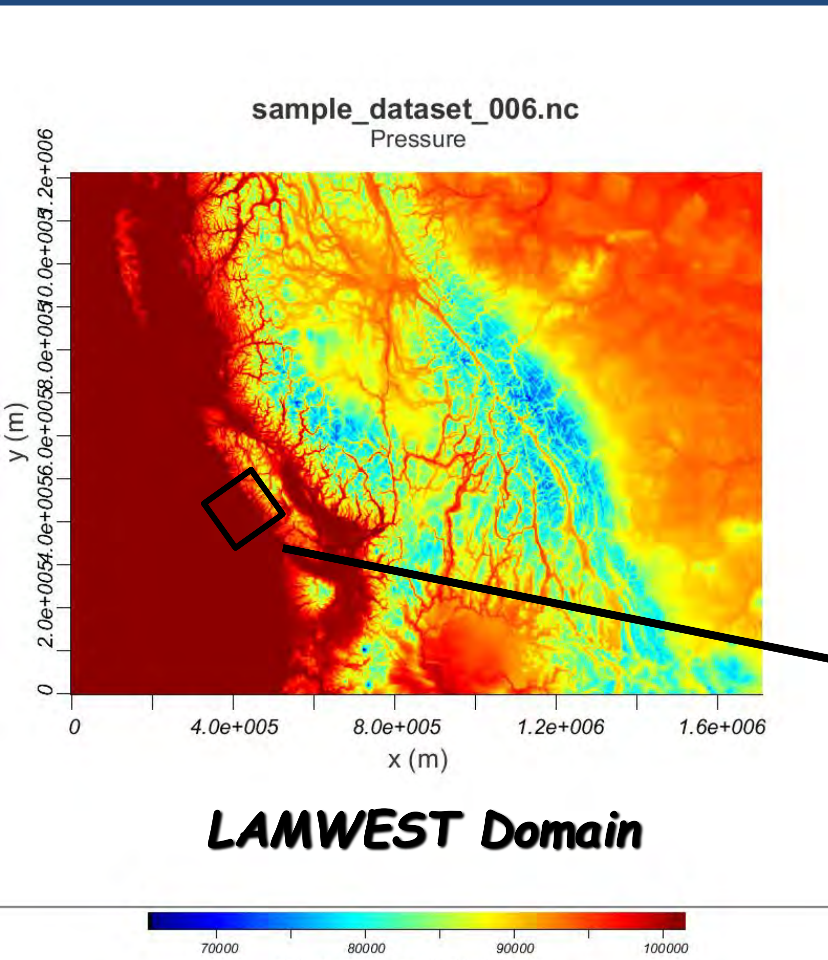


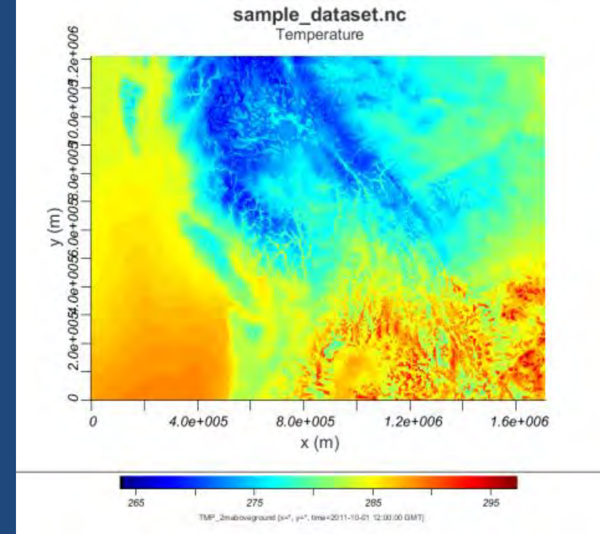


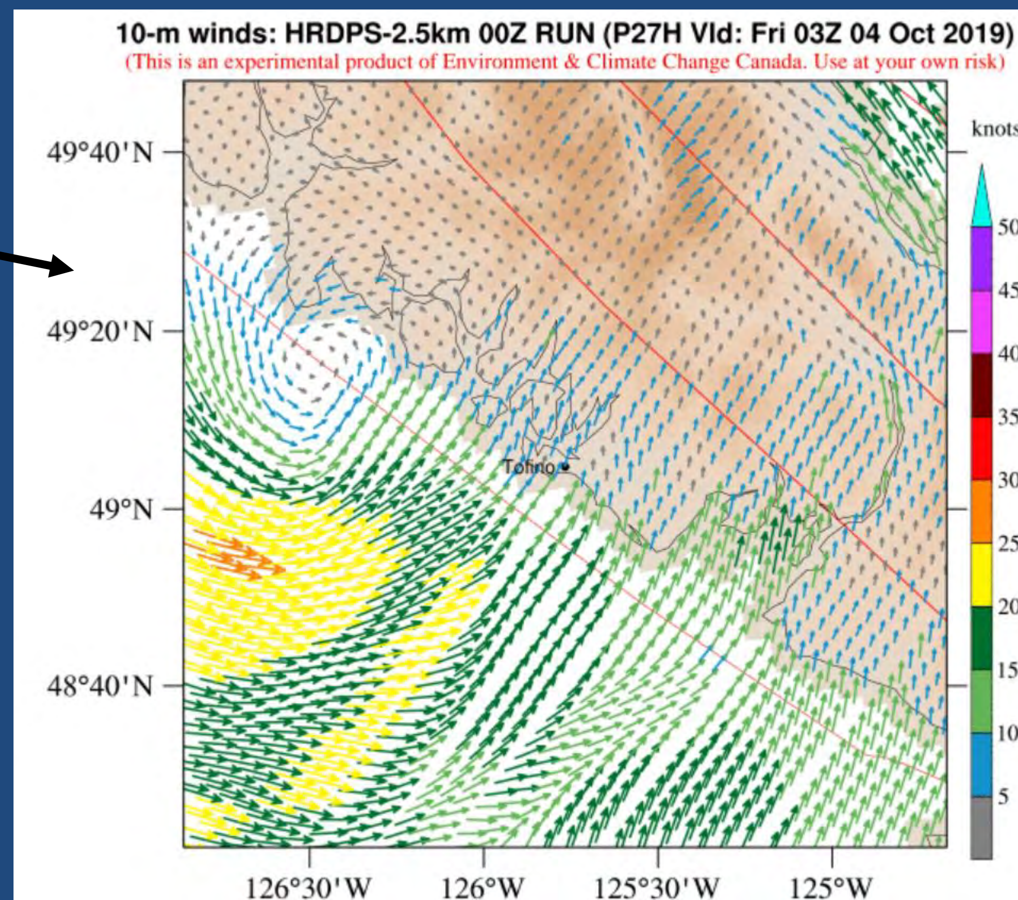


- Banks & canyons on shelf
- Mudflats to over 300m in inlets

Atmospheric Forcing



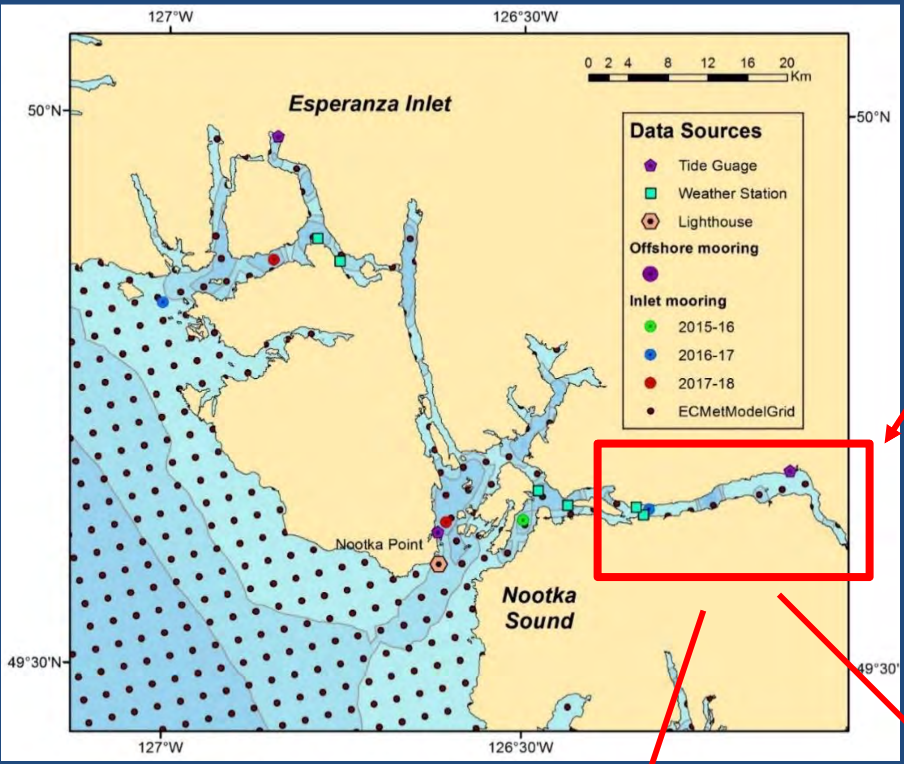


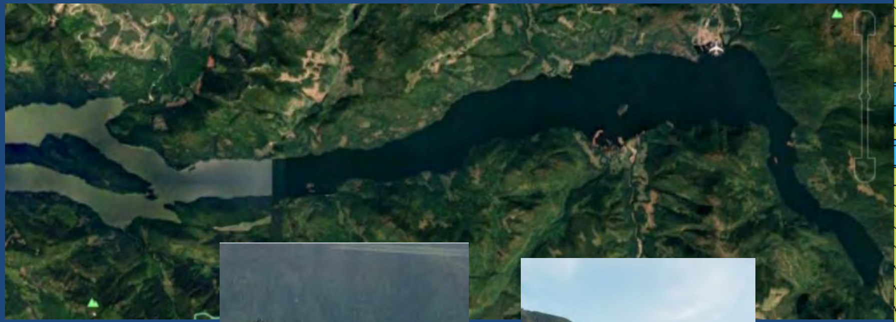


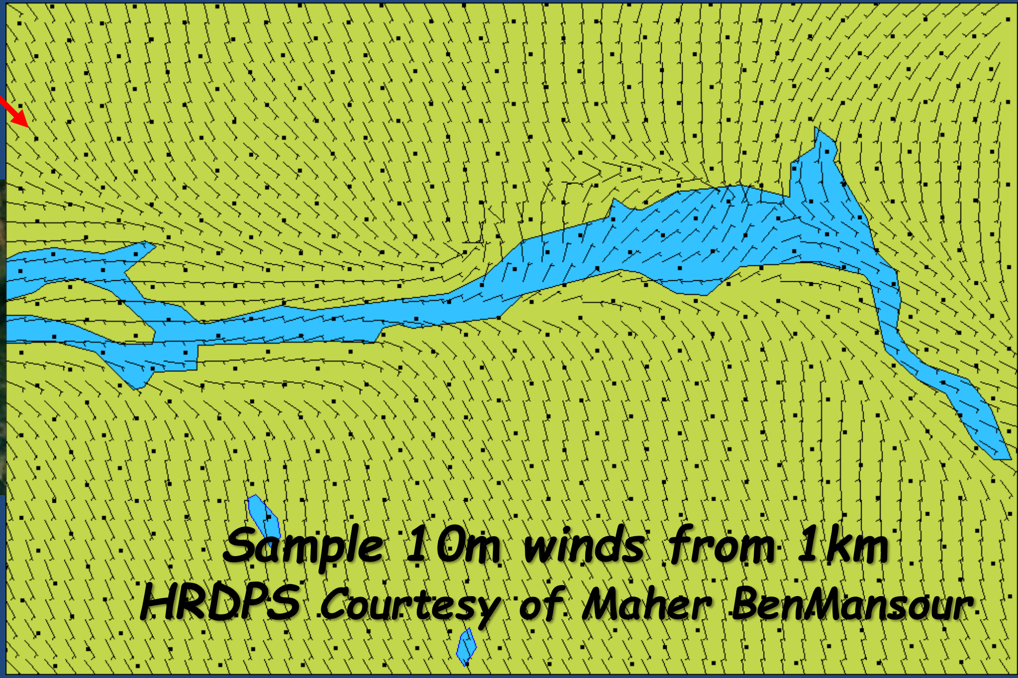
- *Environment and Climate Change Canada LAMWEST "HRDPS" 2.5 km weather model*
  - *sample pressure (Pascals) , surface temperature (°K) & wind fields*

Atmospheric Forcing

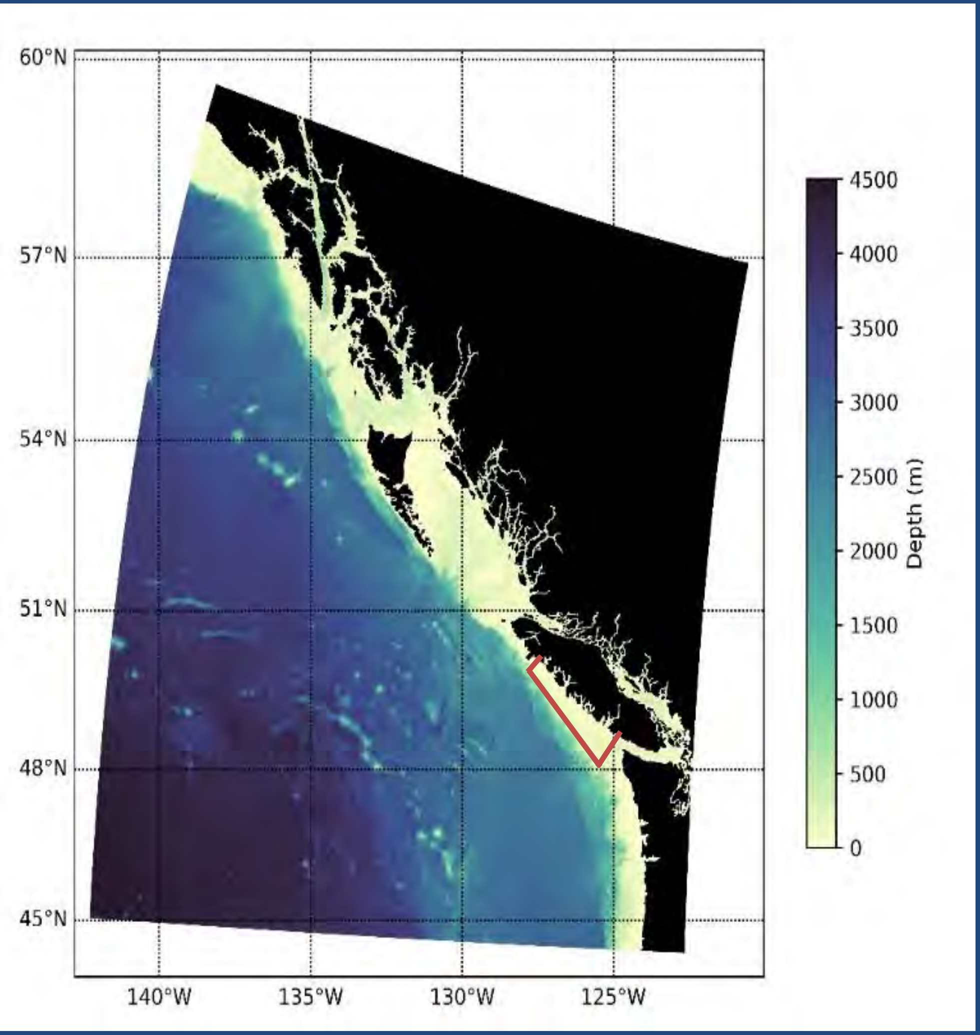
- *2.5 km horizontal resolution insufficient to resolve orographic steering winds in many coastal inlets*
  - *E.g., Muchalat is 1.2 to 2.0 km wide*
- *Need to improve by either*
  - *combining with weather station observations*
  - *or await new 1km HRDPS model (presently pre-operational)*





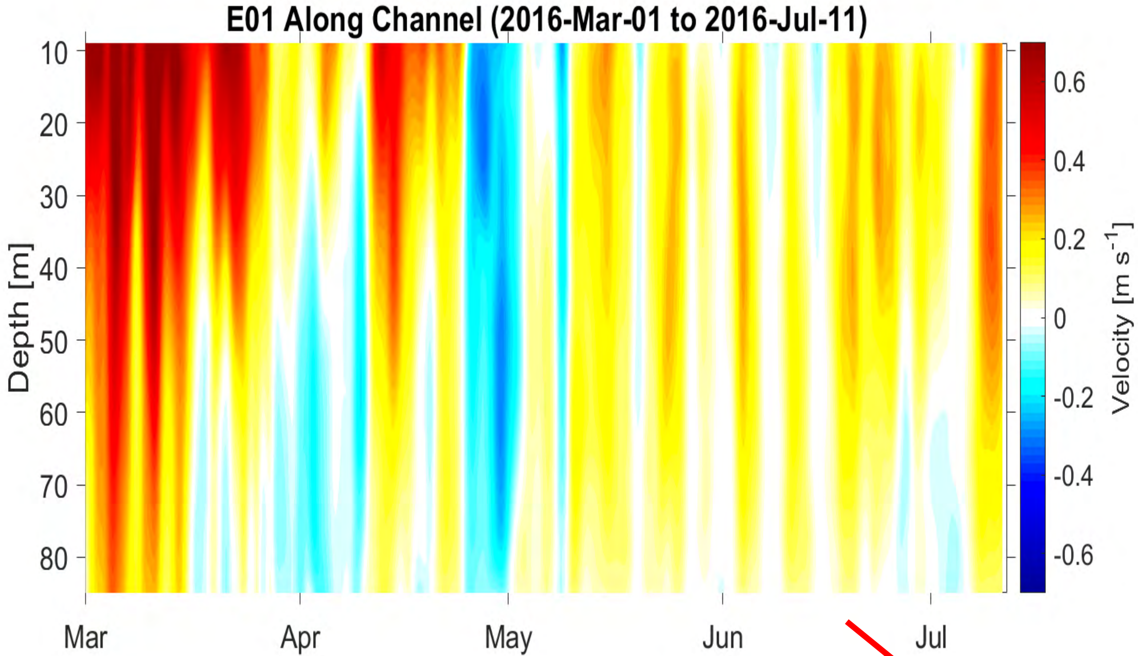


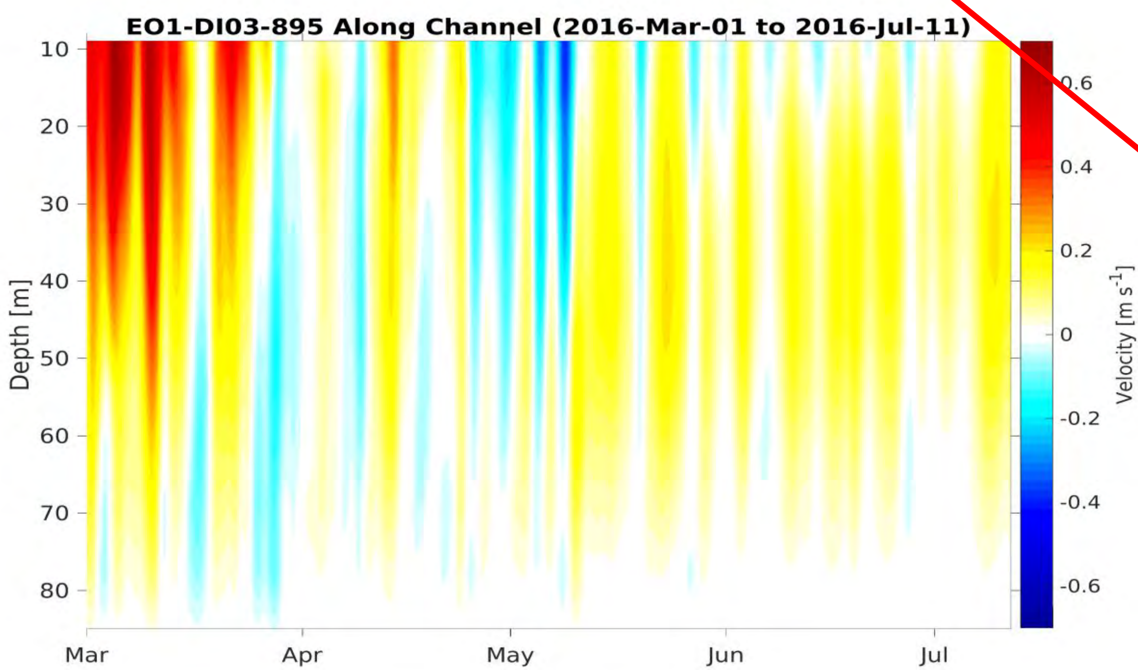
Open Boundary Forcing:
Northeast Pacific NEMO model (NEP36, DFO/ECCC)



NEP36 domain & bathymetry

- *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*

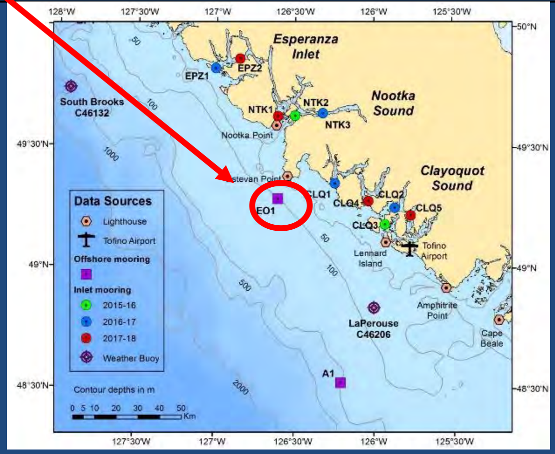




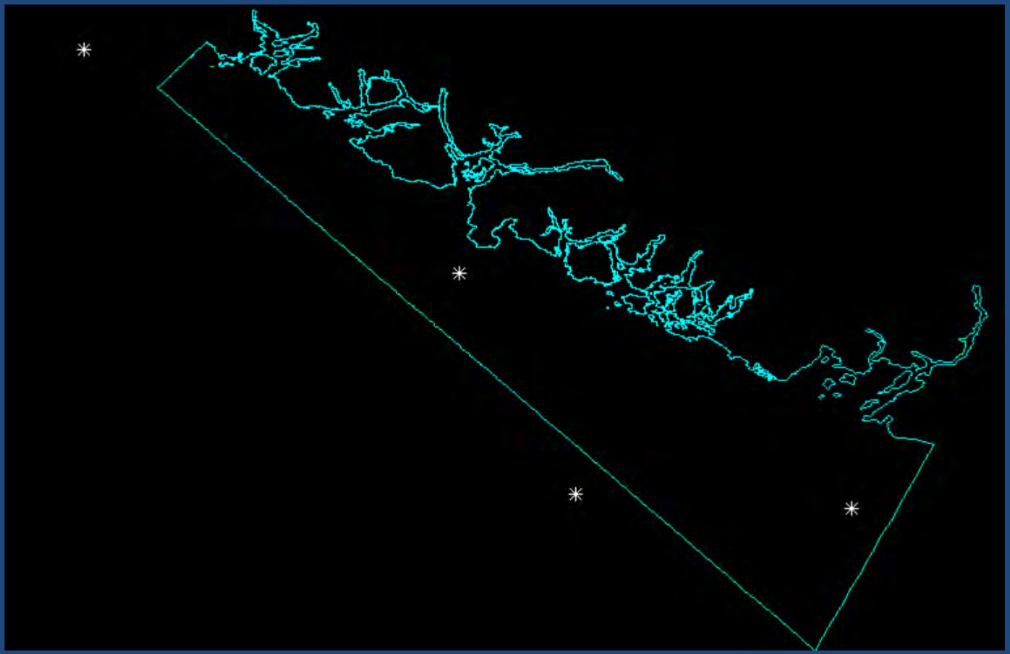
How accurate is NEP36 within our domain?

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



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

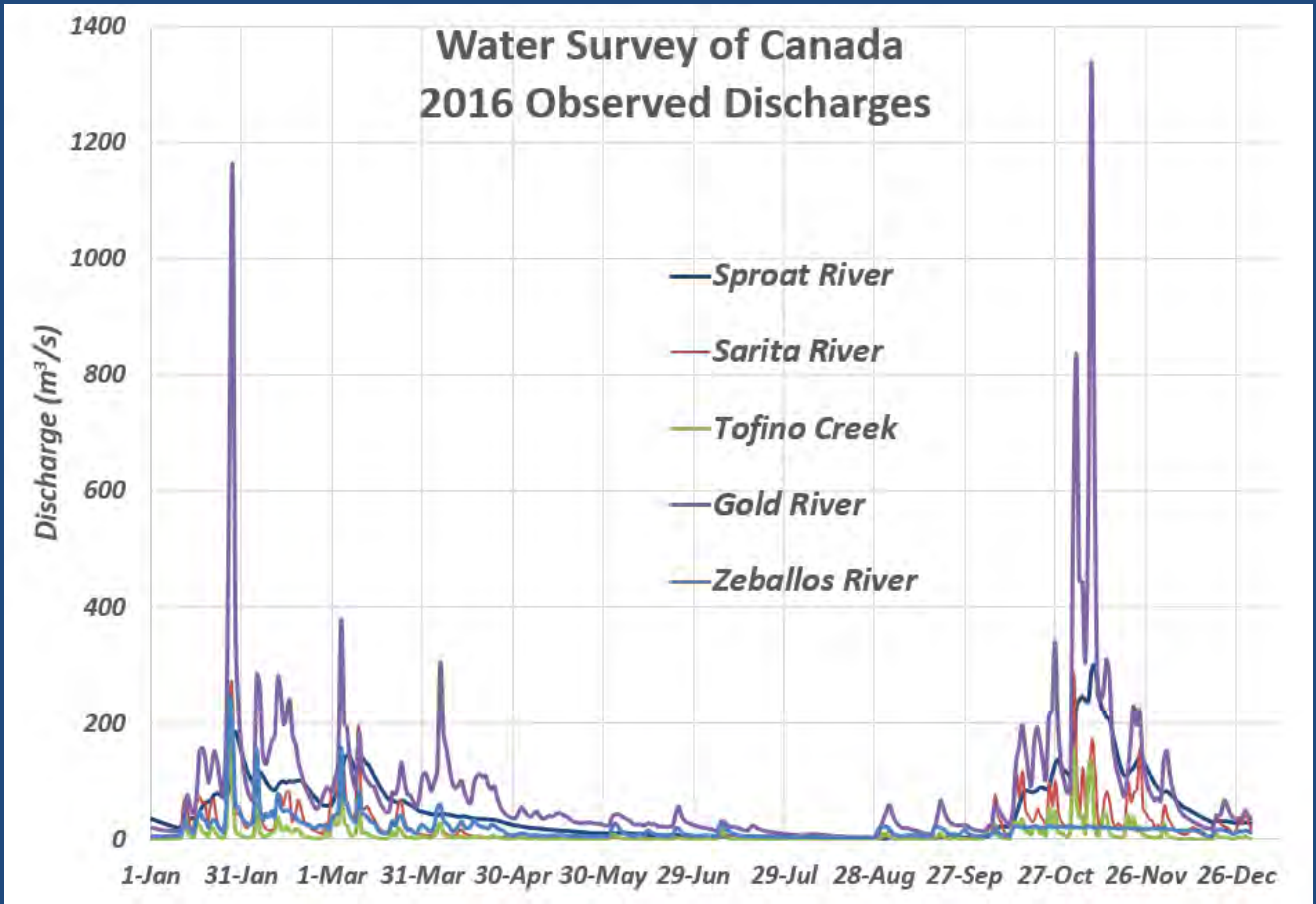
constituent	Amp ratio	Phase dif°
Q1	0.984	0.08
O1	0.994	0.30
P1	1.012	-0.20
K1	1.008	0.83
N2	1.020	4.48
M2	1.005	3.70
S2	1.002	5.10
K2	0.985	2.95

Averages over 4 sites

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?*

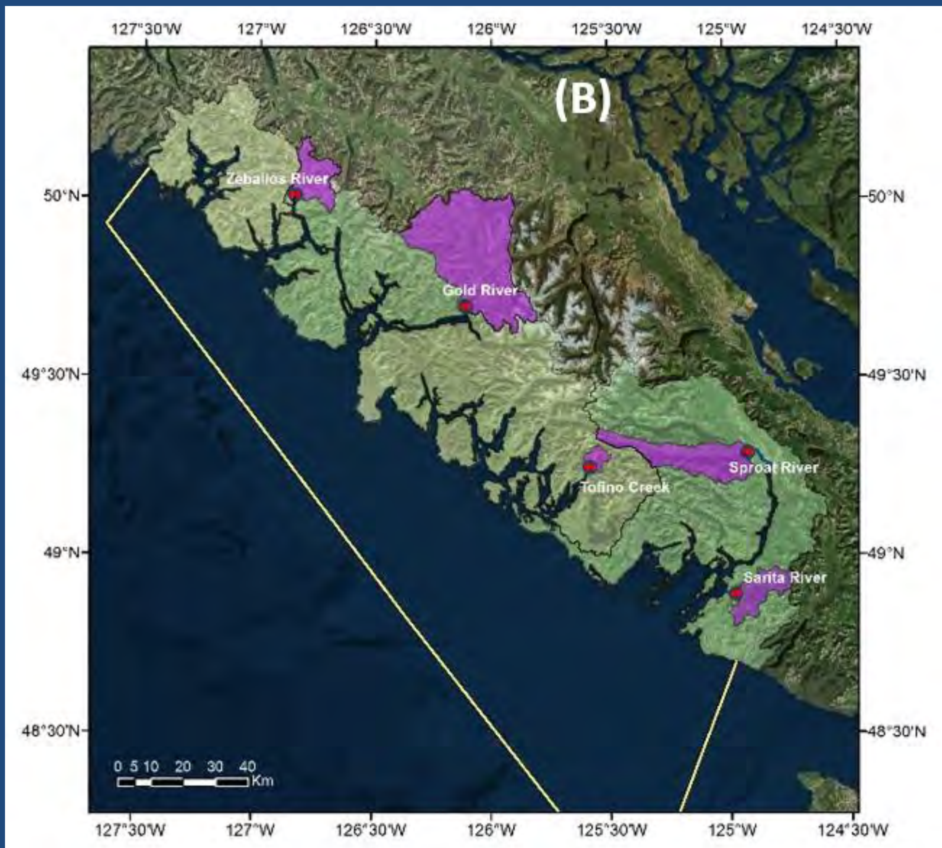
Freshwater Discharge Forcing

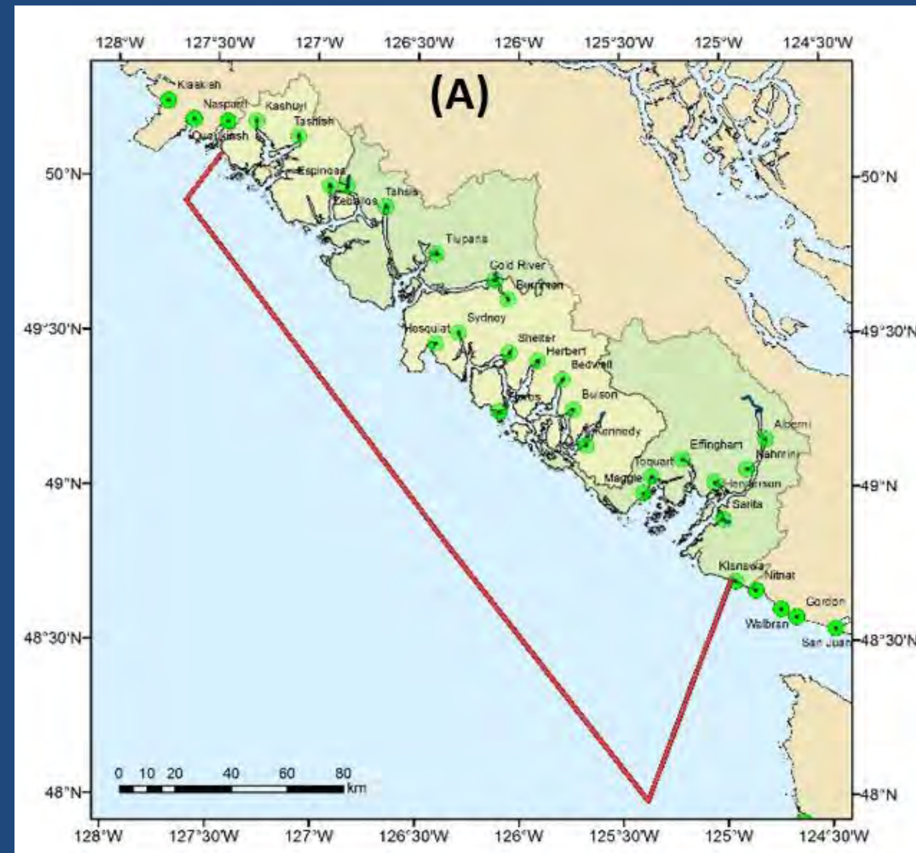


- *29 rivers included but only 5 had their discharges measured by WSC in 2016*
- *estimate others based on historical discharge ratios (if possible) or ratios of watershed areas*
- *also need discharge temperature & salinity*
  - *seldom measured so estimate either from observations*
    - *in inlet near river mouth, or*
    - *a nearby fish farm*

- *Discharges primarily rainfall dominated*
  - *Episodic storms in winter; dry in summer*
- *More on role of rivers in Miyama S3 talk at 12:00*

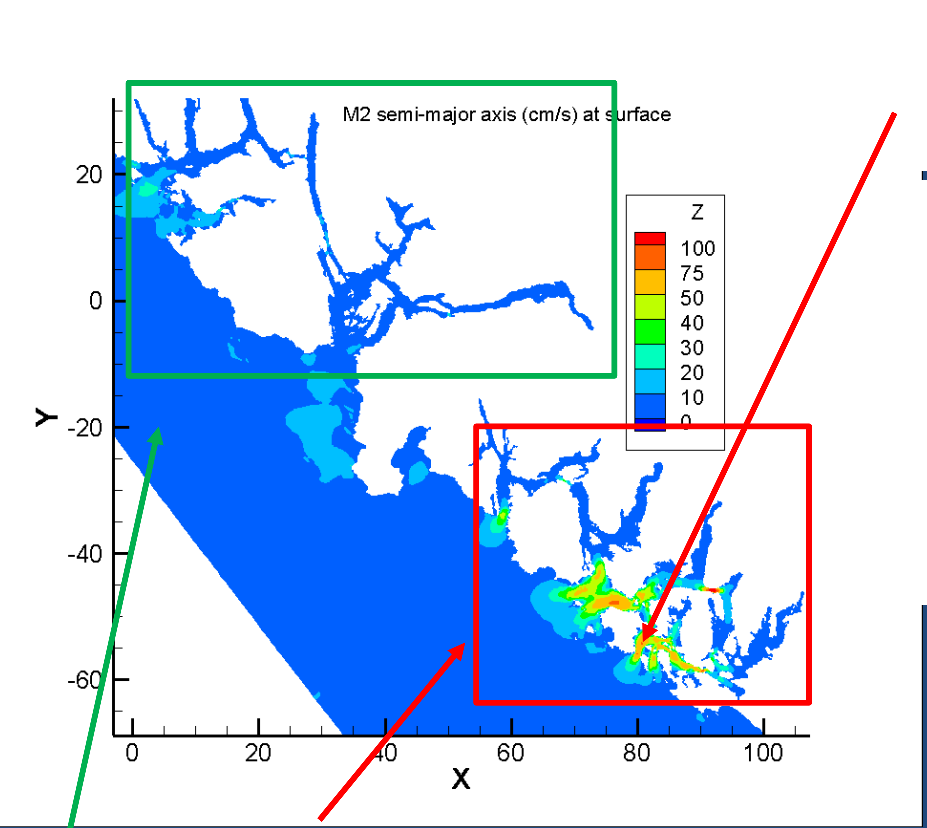
Fresh water sources within the FVCOM domain

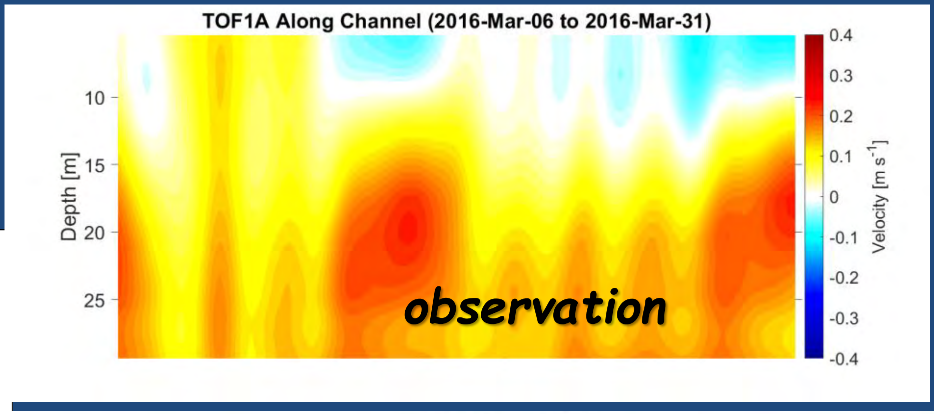


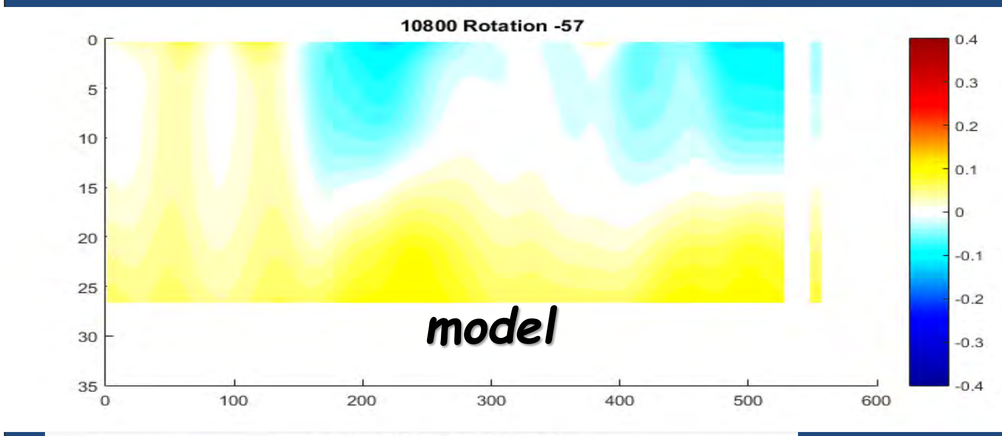


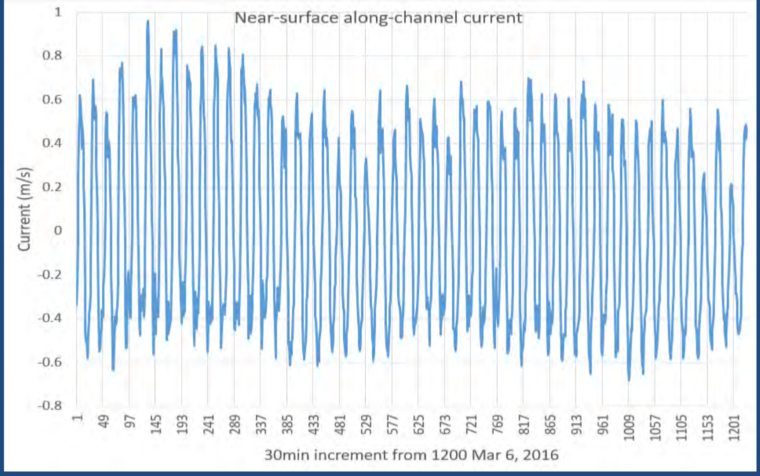
- *Using watershed area ratios assumes similar runoff characteristics*
    - *E.g., elevations, ground water storage, precipitation in rainfall vs snowfall, …*
- *To improve, we need more discharge observations or a hydrology model*

Interesting Dynamics 1: Estuarine Flow Modulation & Preliminary Model Results



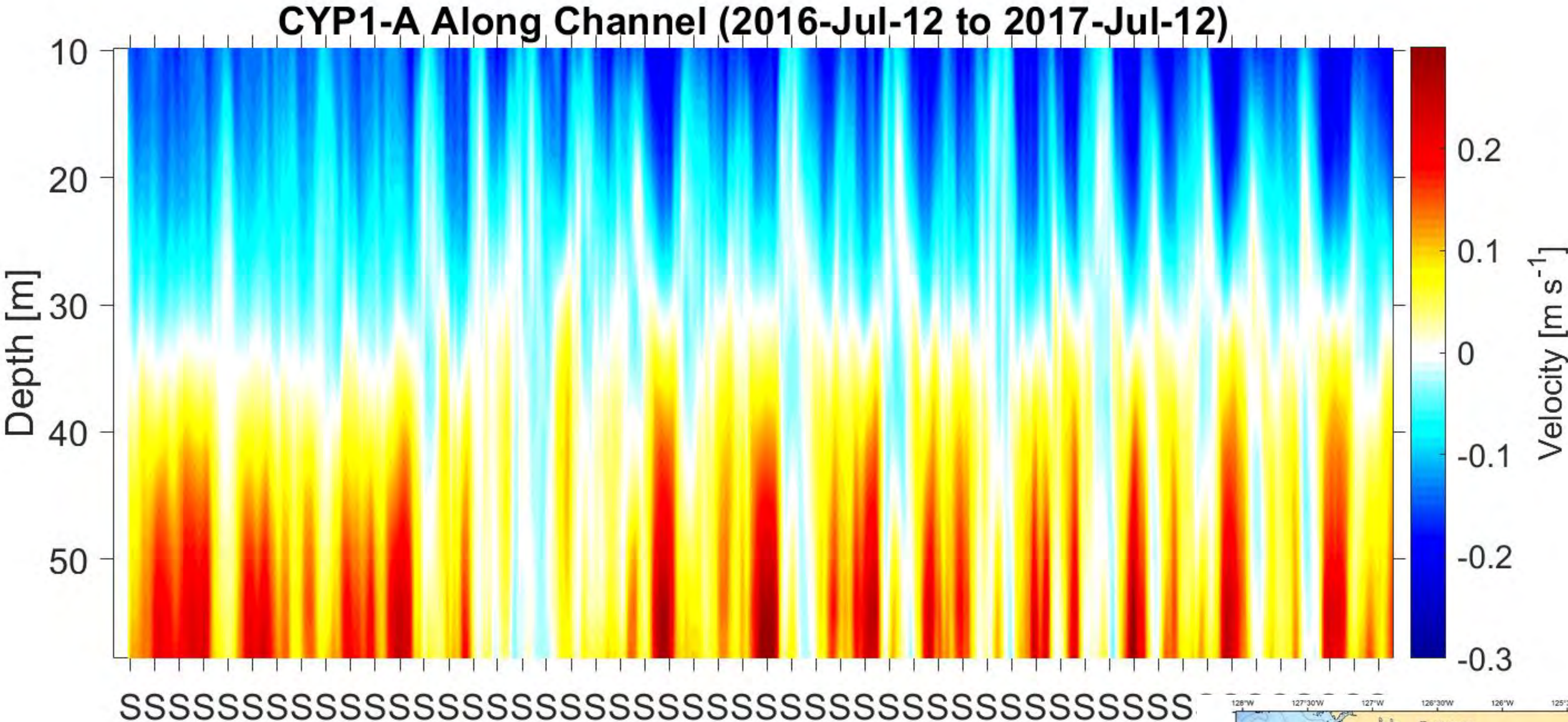


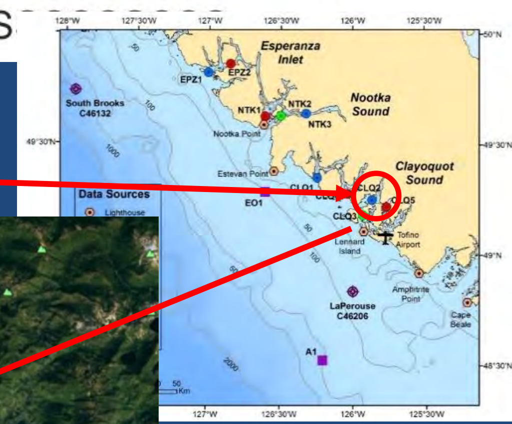




- Clayoquot region has much stronger tidal currents than Nootka-Esperanza
  - Spring-neap cycle important in mixing & regulating estuarine flow ?
  - Model not right yet !

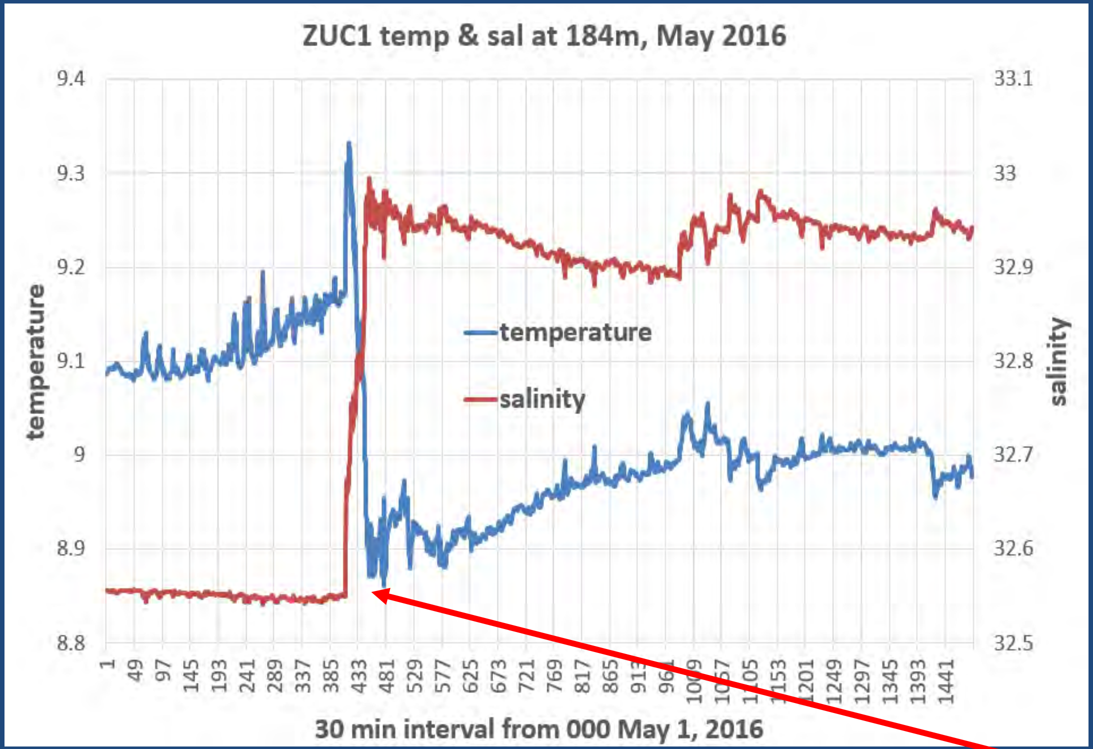
Low-pass filtered ADCP profile (top), model (middle), & near surface observed currents (bottom)

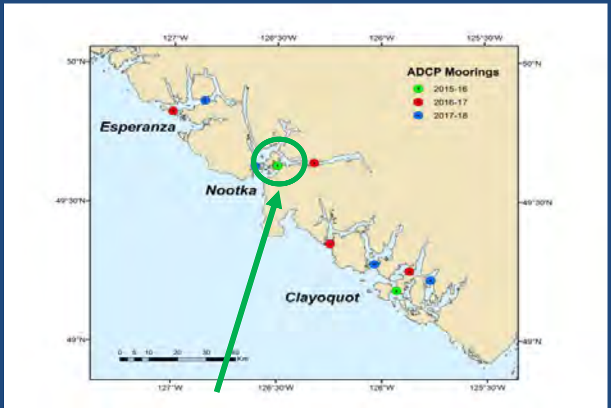


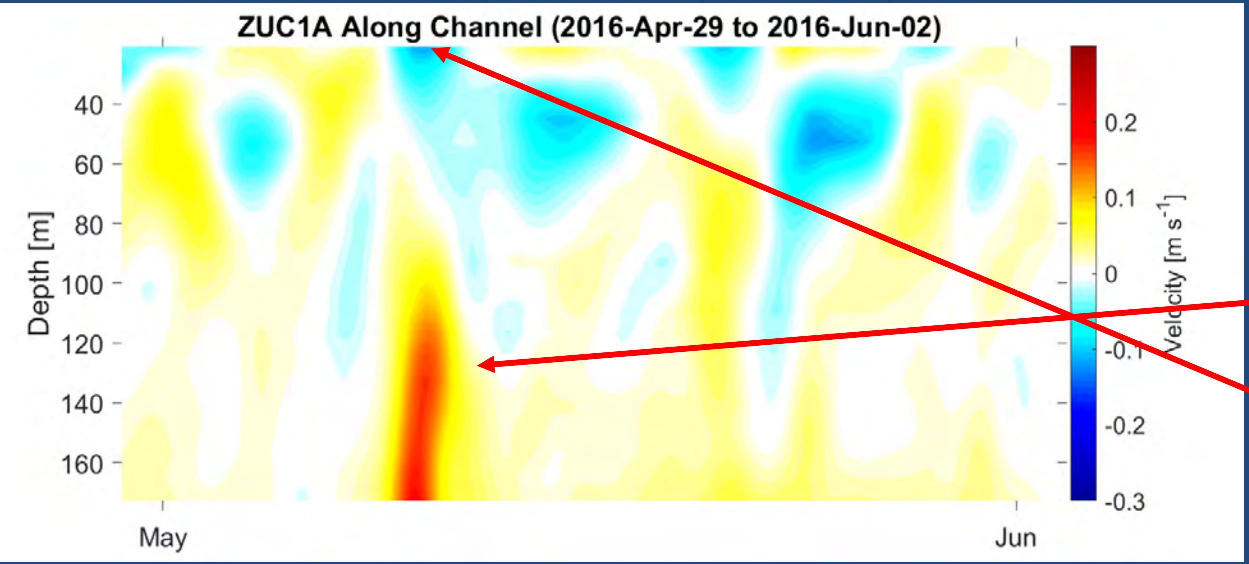


- *CYP1 low pass filtered*
- *Positive velocity is eastward*
  - *x-axis tick separation is 7 days*
- *Some spring-neap modulation of estuarine flow?*
  - *Freshwater from Bedwell Inlet*

Interesting Dynamics 2: Nootka-Muchalat density intrusion May 9, 2016

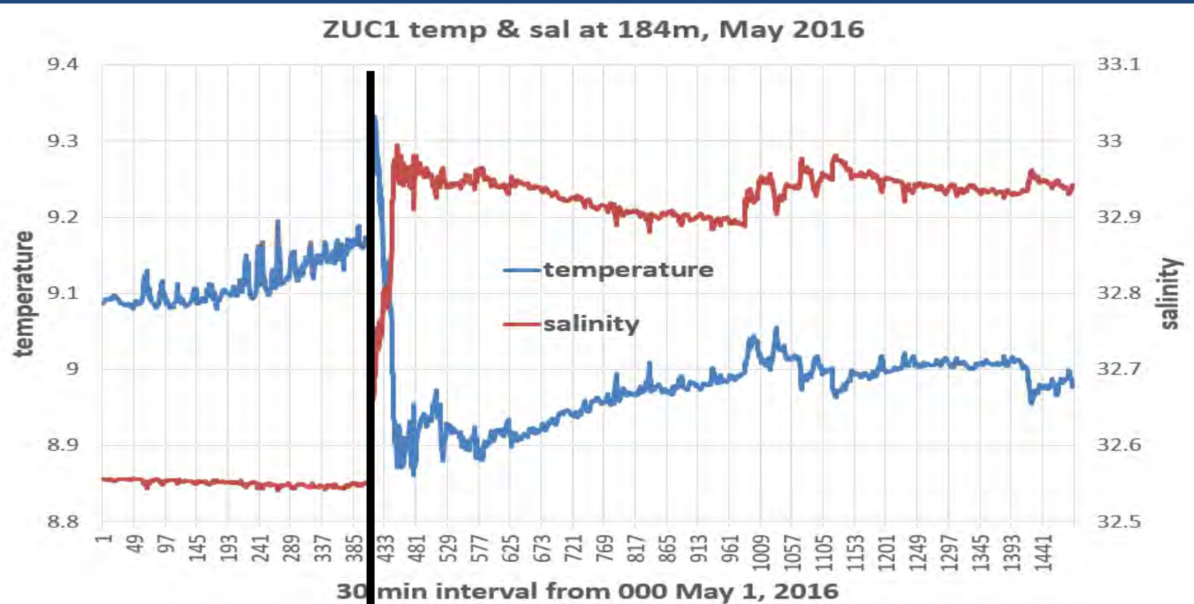


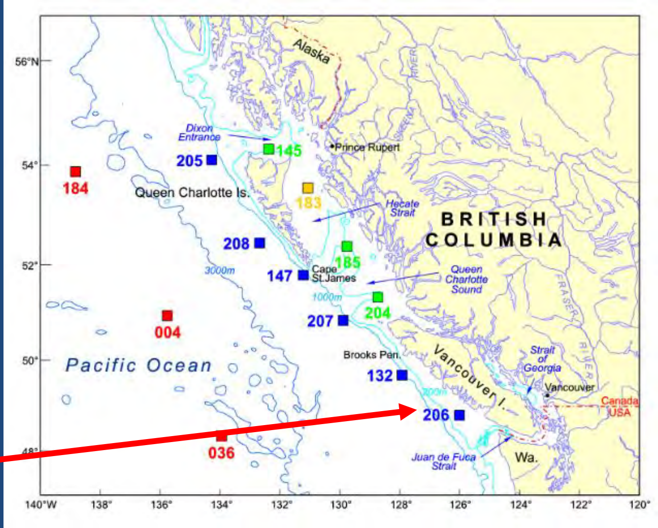


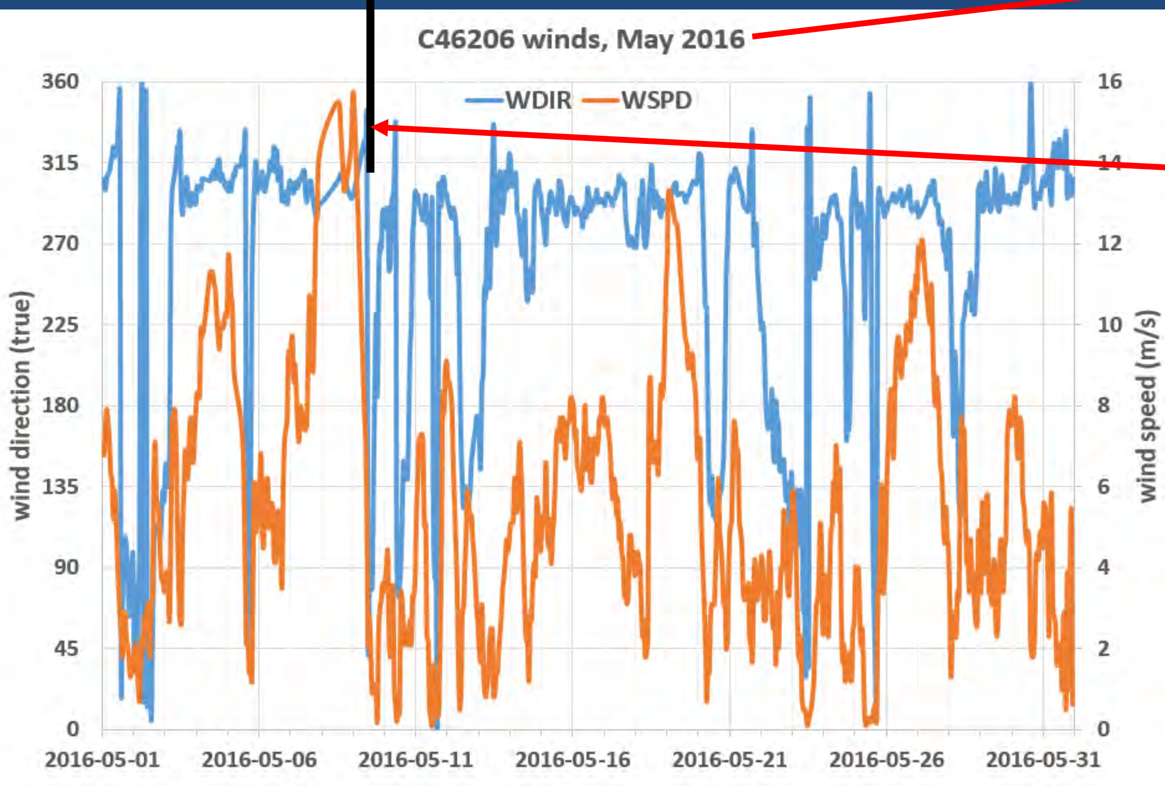


- ZUC1 bottom temperature & salinity show sharp changes on May 9, 2016
  - Spike in low-pass filtered up-channel bottom currents
  - Compensating near surface flows

ZUC1 bottom TS vs C46206 observed winds

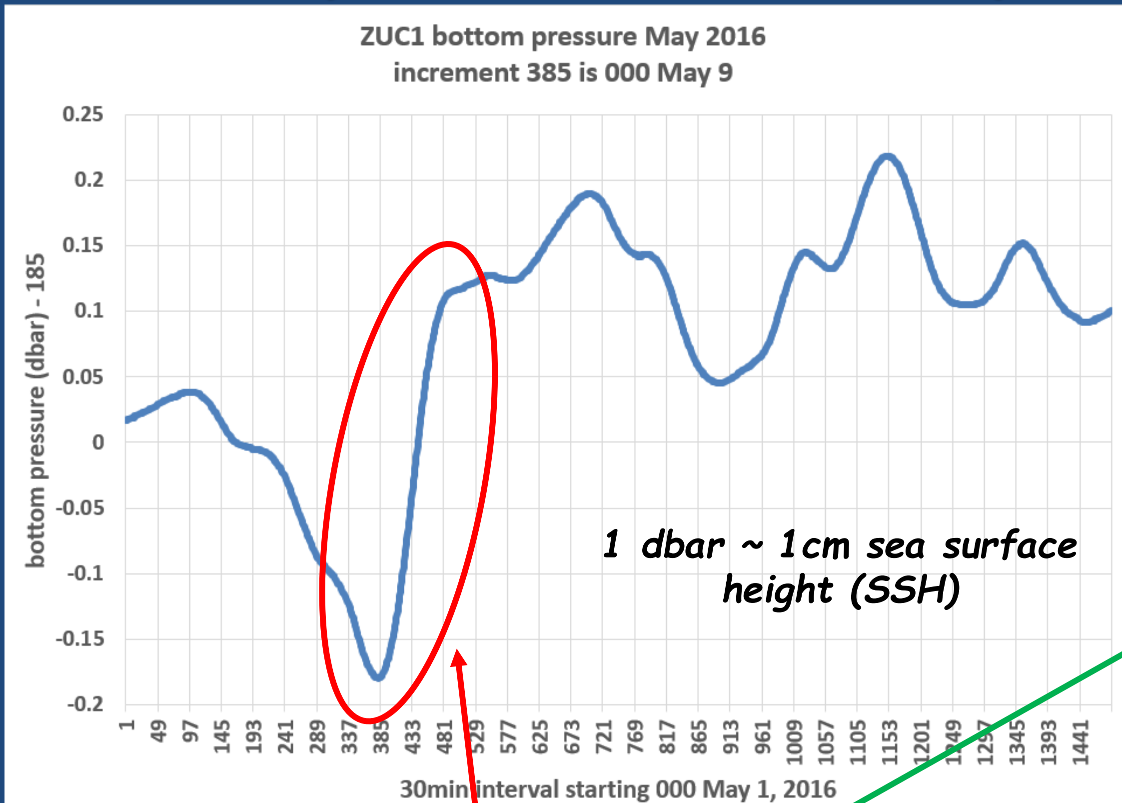


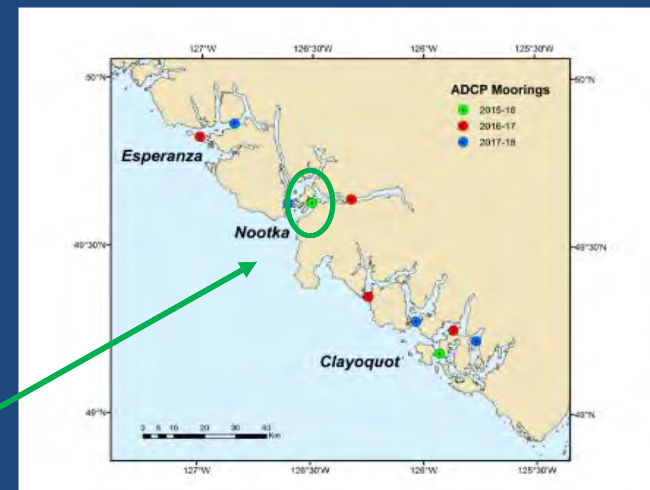




- *2 days of sustained winds around 15 m/s from the NW*
  - *decrease quickly to approx no wind*
  - *precede the ZUC1 bottom intrusion*
- *WDIR is direction from where wind is blowing, clockwise from north*

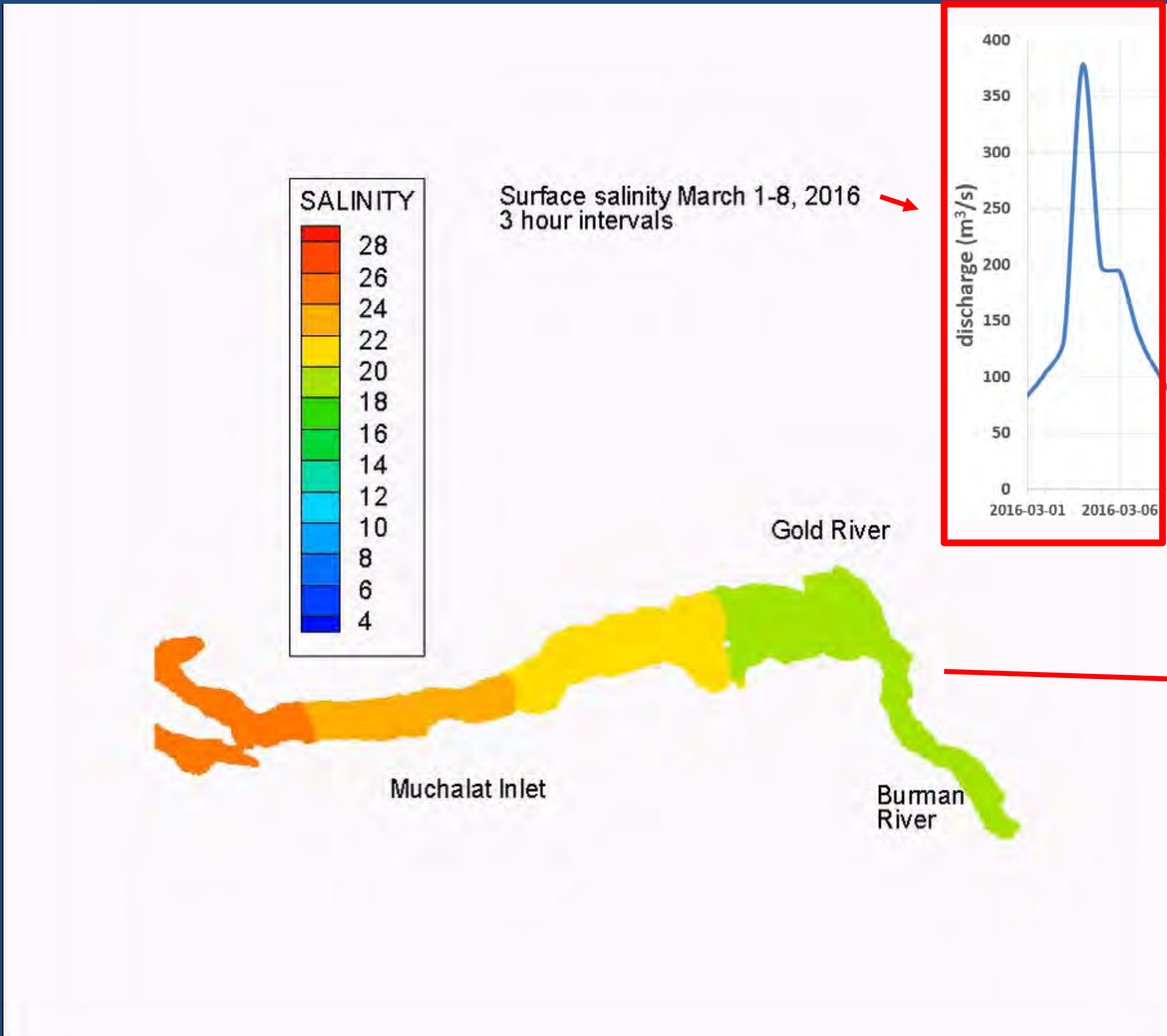
ZUC1 low-pass filtered bottom pressures (proxy for SSH)

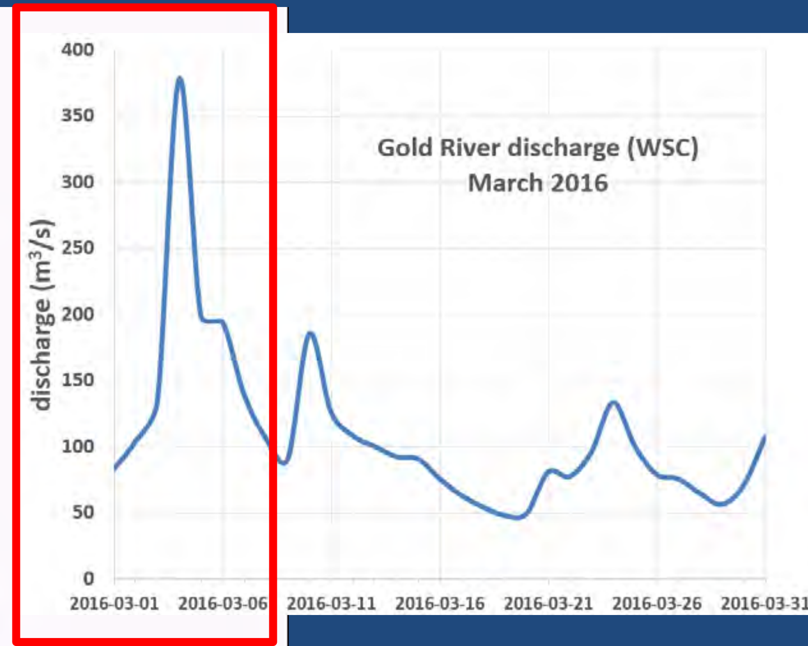


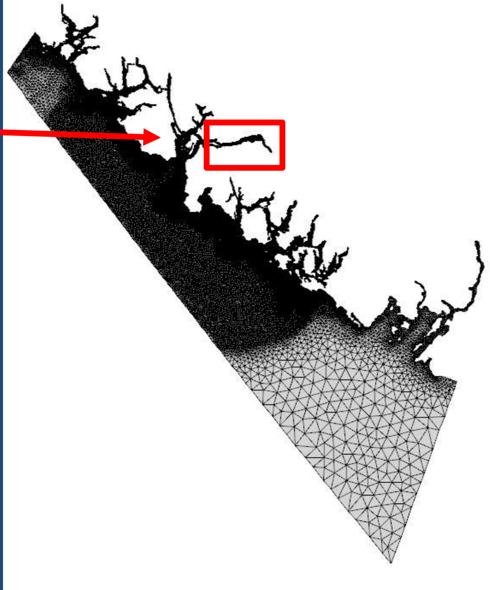


- "surge" of water moving by ZUC1 starting 000 May 9
    - 29cm SSH rise (low-pass) over 2 days; another 8cm by May 15
- **Hypothesis:**
    - Sustained strong winds to SE bring upwelled water onto the shelf & create a depression in SSH adjacent the coast
    - If the winds shut-off quickly, water flows 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





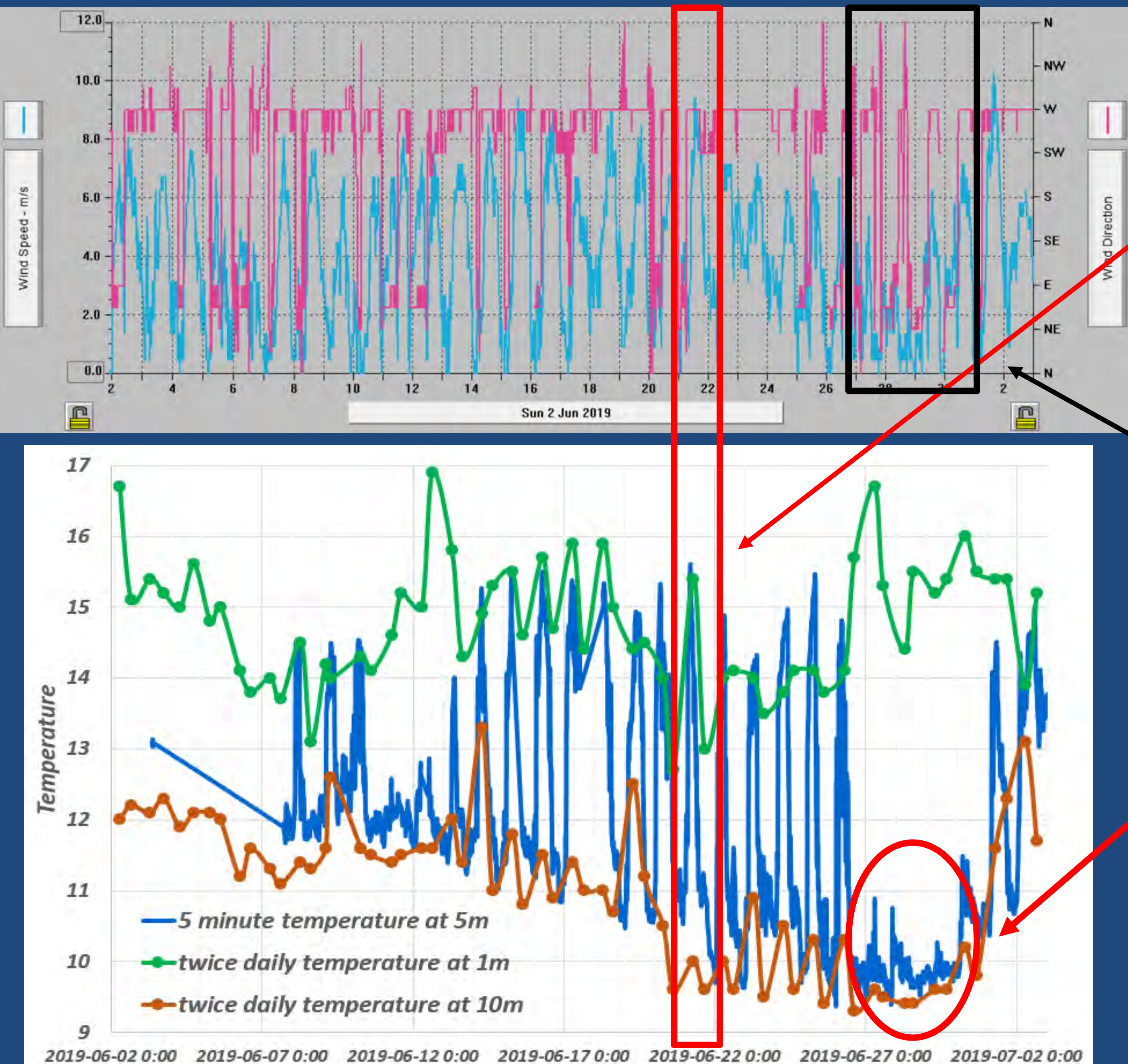


How accurate are the model plumes?
Compare with near-surface TS observations at 16 farms

Farm	Temperature			Salinity		
#	observed	model	difference	observed	model	difference
1	8.6	9.1	-0.5	21.3	19.8	1.5
2	9.3	8.8	0.5	22.0	24.7	-2.7
3	9.1	9.0	0.1	21.8	20.7	1.2
4	9.2	8.8	0.4	22.1	23.6	-1.5
5	9.3	8.8	0.5	19.8	23.0	-3.2
6	10.3	9.0	1.3	20.3	21.3	-1.0
7	9.3	8.7	0.6	24.7	25.7	-1.0
8	8.6	8.9	-0.3	21.3	22.8	-1.5
9	9.1	8.9	0.2	23.4	21.2	2.0
10	9.1	8.8	0.3	21.6	25.4	-3.8
11	9.0	8.9	0.1	23.1	22.4	0.7
12	8.9	9.0	-0.1	21.4	18.9	2.5
13	8.6	8.5	0.1	17.1	28.9	-11.8
14	8.5	8.5	0.0	16.3	28.9	-12.6
15	9.2	8.6	0.6	23.2	27.7	-4.5
16	9.2	8.6	0.6	26.4	25.8	0.6

- *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,… ?*

Interesting Dynamics 4: Internal Waves in June 2019?



- *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 27th & stays there for 3-4 days before resuming daily pattern by Jul 1st*
  - *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