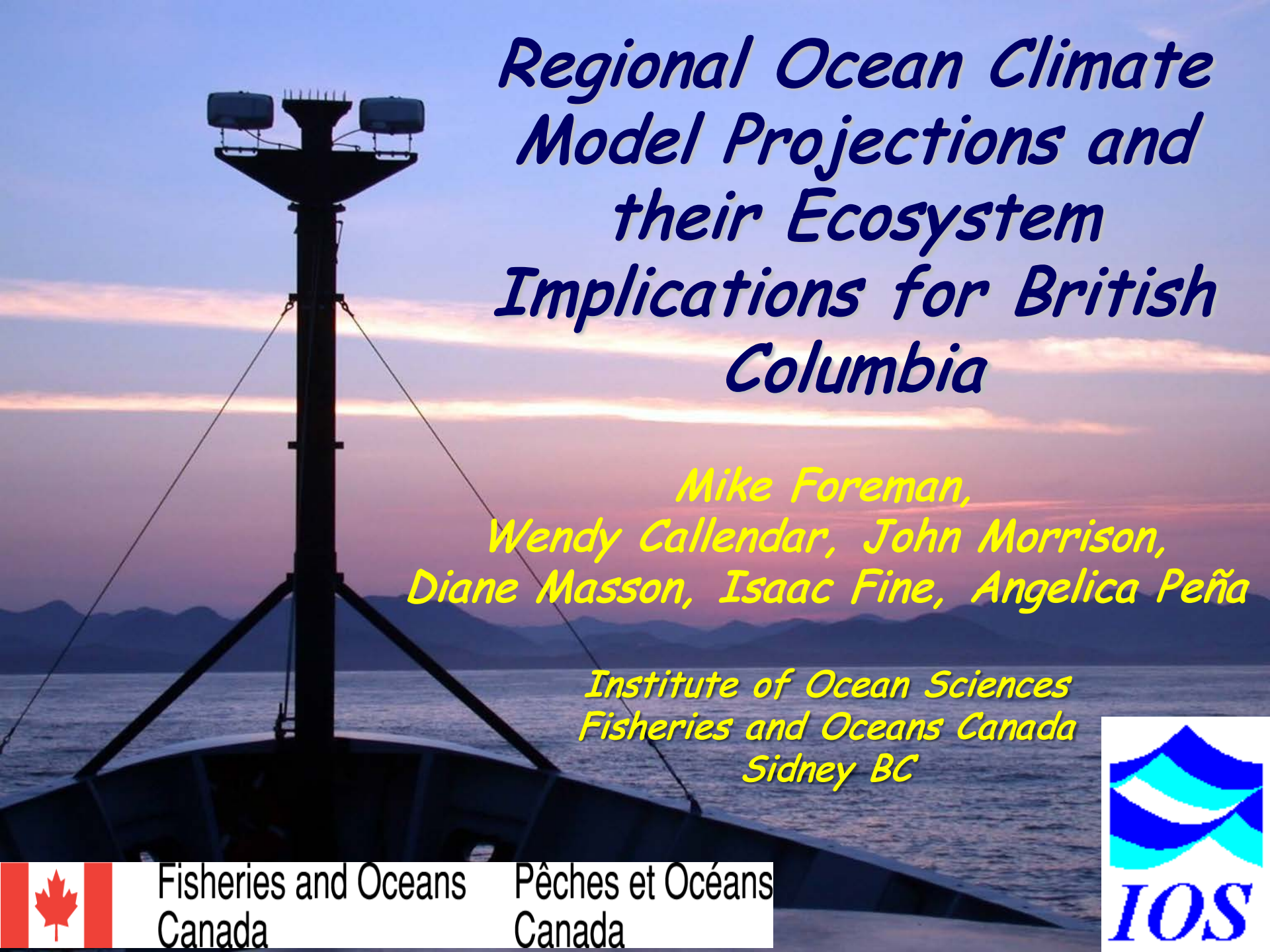


Regional Ocean Climate Model Projections and their Ecosystem Implications for British Columbia

Mike Foreman,
Wendy Callendar, John Morrison,
Diane Masson, Isaac Fine, Angelica Peña

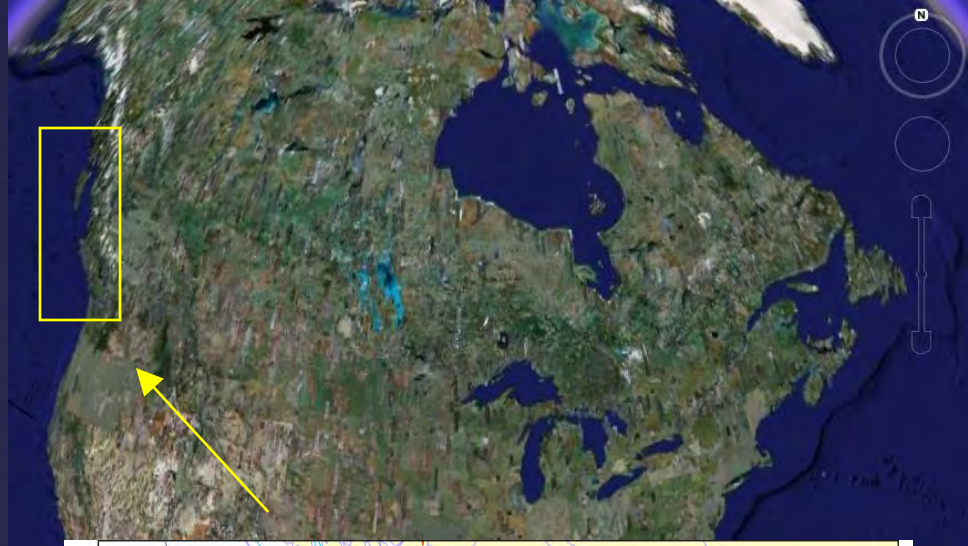
Institute of Ocean Sciences
Fisheries and Oceans Canada
Sidney BC

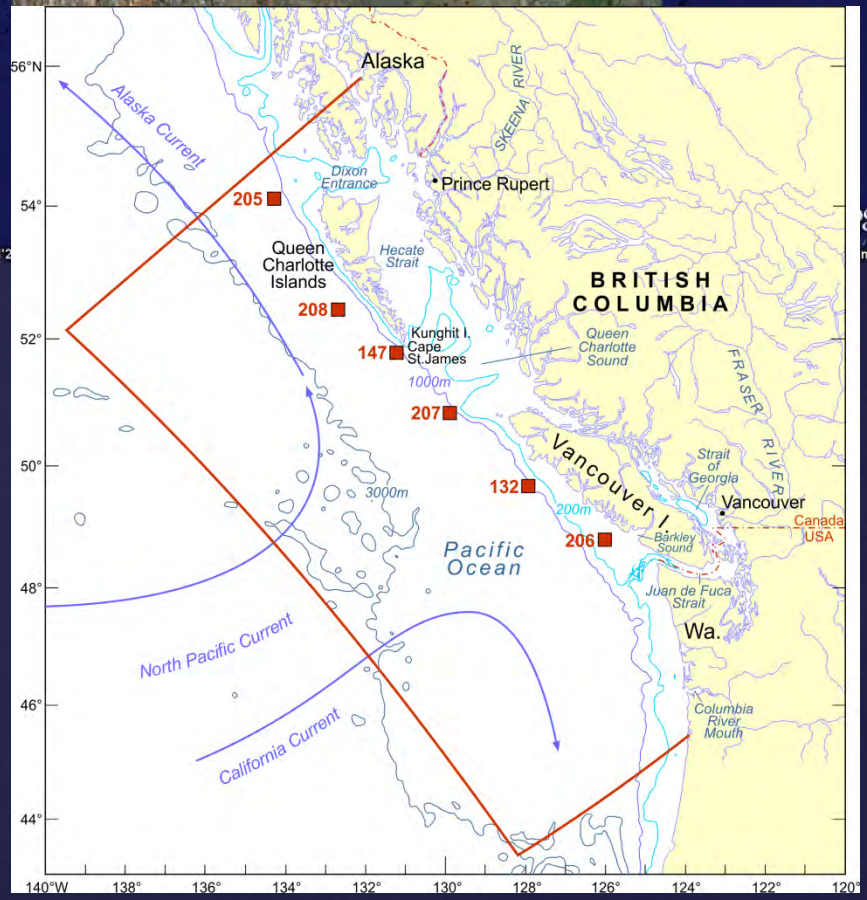
Fisheries and Oceans Canada | Pêches et Océans Canada

IOS

Outline

a) RCMs & FUTURE
b) model details
c) future projection strategy
d) forcing & initial fields
e) model projections
f) ecosystem implications
g) summary





What Role do RCMs have in FUTURE?

FUTURE Research Theme:

2. How do ecosystems respond to natural and anthropogenic forcing, and how might they change in the future?

2.1. How have the important physical, chemical and biological processes changed, how are they changing, and how might they change as a result of climate change and human activities?

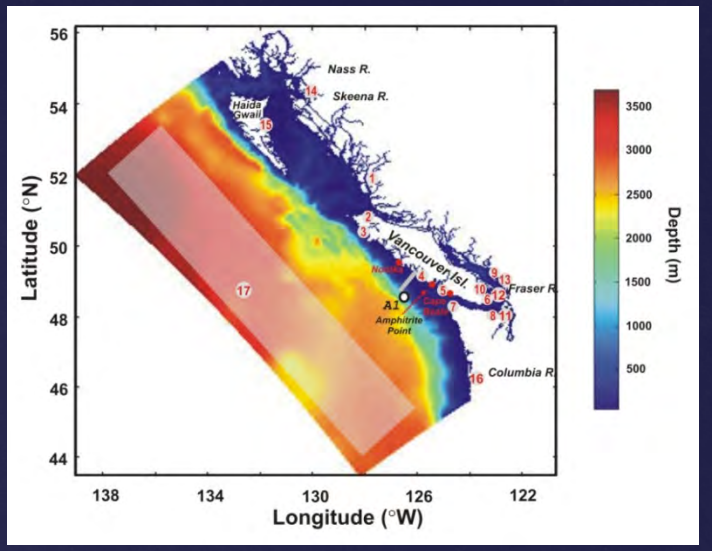
2.3. How does physical forcing, including climate variability and climate change, affect the processes underlying ecosystem structure and function?

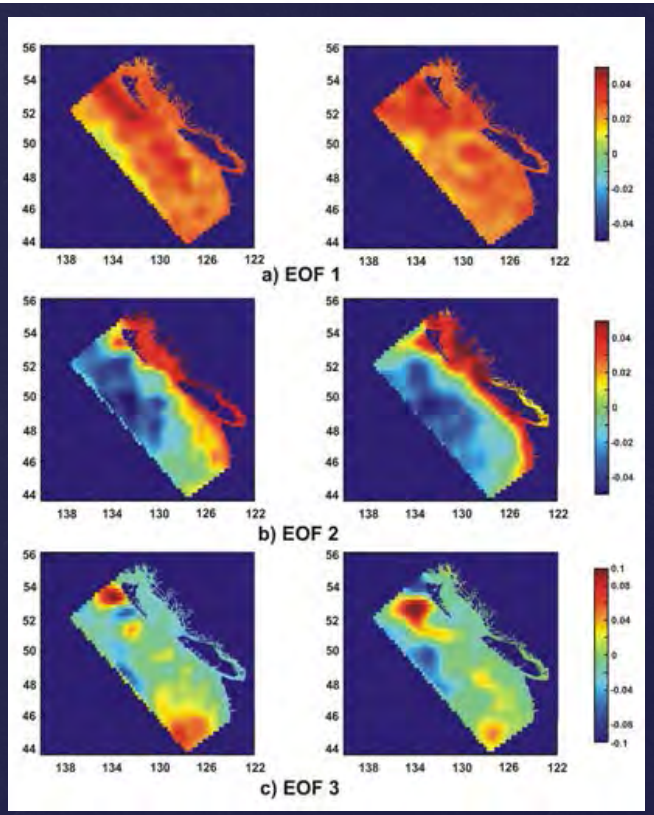
WG29 Terms of Reference:

1. Assemble a comprehensive review of existing regional climate modeling efforts;
2. Assess the requirements for regional ecosystem modeling studies (e.g., how to downscale the biogeochemistry);
3. Continue the development of RCM implementations in the North Pacific and its marginal seas;
4. Convene special sessions and inter-sessional workshops dedicated to the RCM topic;
5. Publish report and/or review paper on best practices for regional coupled modeling;
6. Establish connections between PICES and climate organizations (e.g., CLIVAR) and global climate modeling centers (e.g., NCAR, JAMSTEC, CCCMA);
7. Collaborate with other PICES expert groups such as WG-27, SICCME and the FUTURE Advisory Panels possibly by producing "Outlooks".
8. Publish a final report summarizing results.

BC Shelf Model

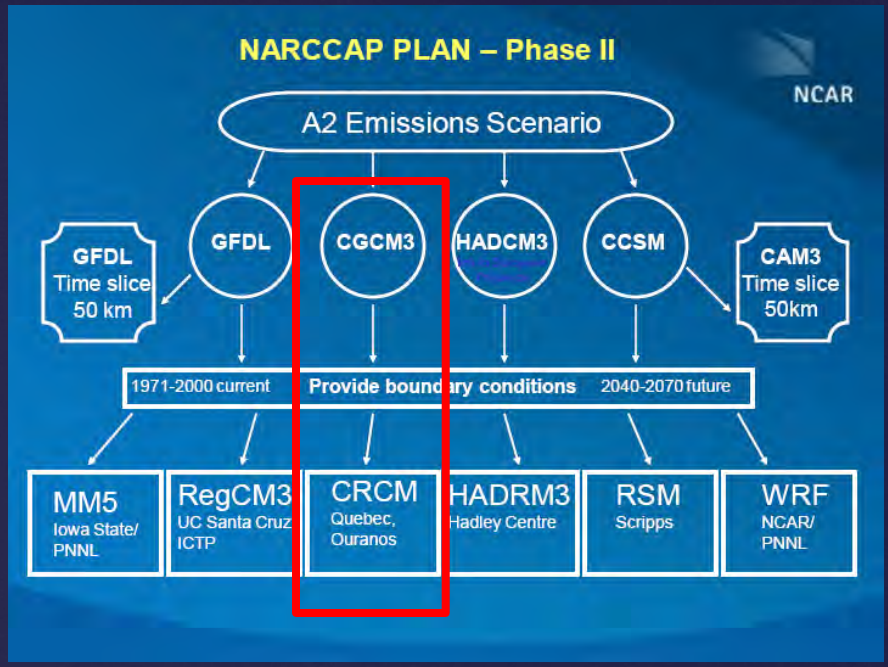
- Masson & Fine, 'Modeling seasonal to interannual ocean variability of coastal British Columbia', JGR, 2012
- Hindcast: 1995-2008
  - Evaluated against various observations
- ROMS application with resolution
  - Horizontal: 3km
  - Vertical: 30 sigma levels
- Forcing:
  - 8 tidal constituents
  - 3 hourly winds (NARR)
  - bulk formula heat flux (NARR)
  - monthly discharge from 21 main rivers
  - monthly open boundary forcing (SODA)
- Could be used for future simulations with appropriate changes to initial & forcing fields





ROMS & AVISO SSH EOFs

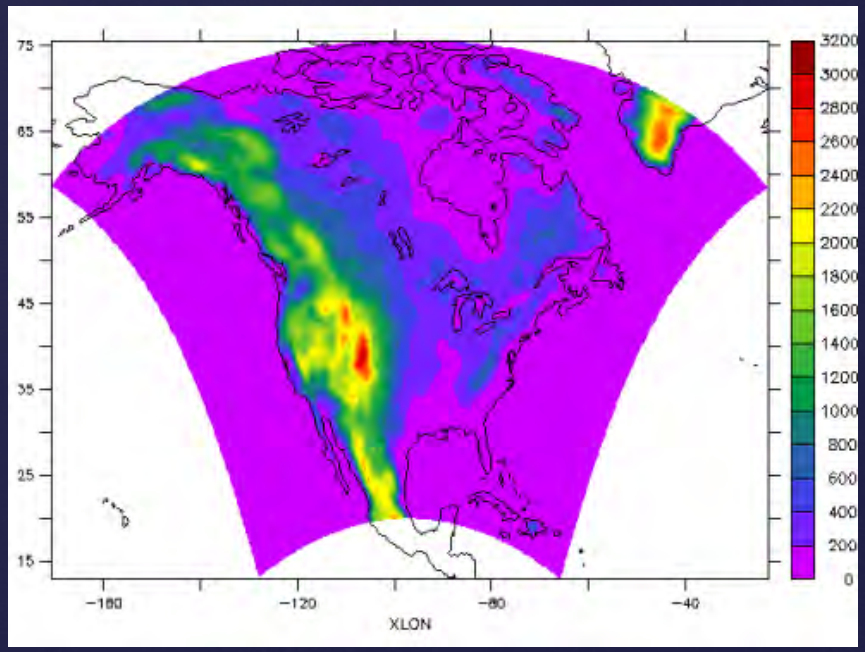
Future Projections from North American Regional Climate Change Assessment Program (NARCCAP)



- 4 GCMs forcing 6 RCMs
- 24 possible combinations for ensemble statistics & uncertainty estimates
- IPCC AR4 A2 scenario

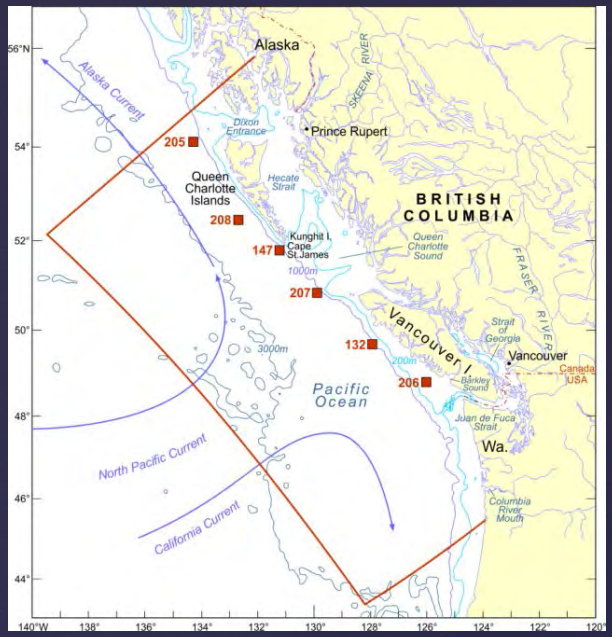
RCMs:

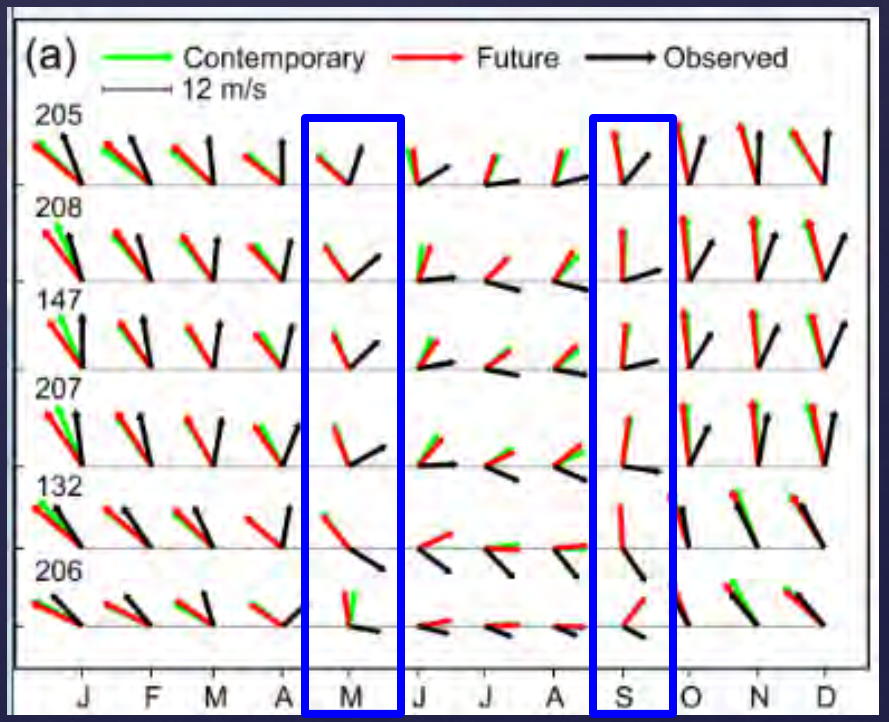
- ~50 km resolution vs >1° for GCMs
- atmospheric only; no active ocean
- periods: 1970-1999 & 2040-2069



RCM Wind Accuracy

- RCMs don't capture contemporary offshore downwelling/upwelling winds & transitions accurately
  - E.g., May to Sept differences between observed & RCM monthly averages
- Upwelling & timing of spring/fall transitions critical for marine ecosystems
  - Direct use of RCM forcing could generate misleading conclusions
- Adopted an anomaly approach





CRCM/CGCM3

Future Forcing Strategy

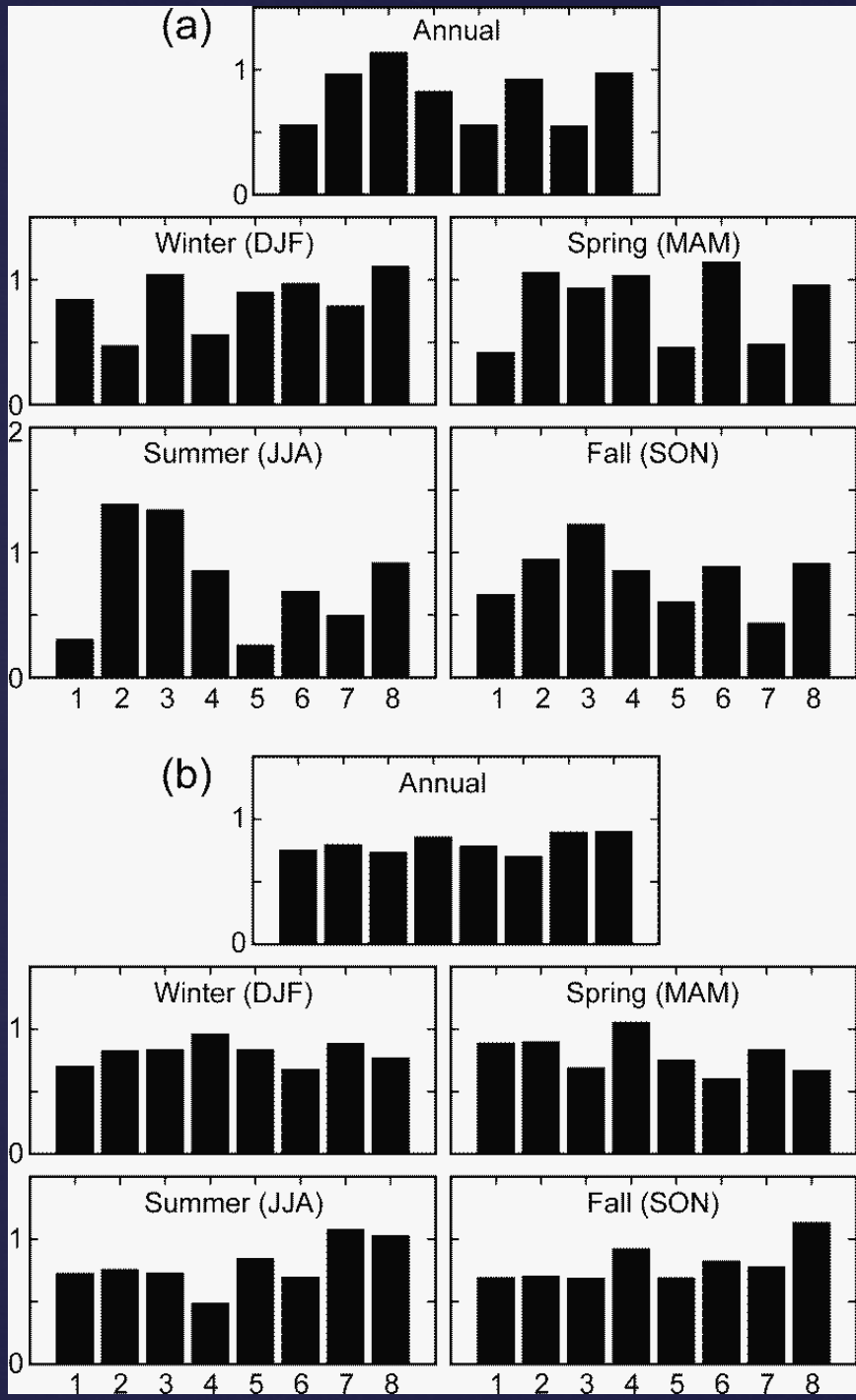
- Add NARCCAP RCM or GCM monthly average anomalies (2040-2069 minus 1970-1999) to the Masson & Fine forcing & initial fields
  - "Pseudo global warming" (Kimura and Kitoh, 2007; Sato et al., 2007; Hara et al., 2008)
- Only CRCM/CGCM3 combination so far
- Wind & heat flux components from CRCM/CGCM3
- Oceanic initial conditions & boundary forcing from CGCM3
- Freshwater runoff from Morrison et al. (2011) hydrology model that uses CRCM/CGCM3 precipitation & temperature

Representativenes of CRCM/CGCM3

- *11 RCM/GCM combinations but 3 had large data gaps*
  - *8 member ensemble*

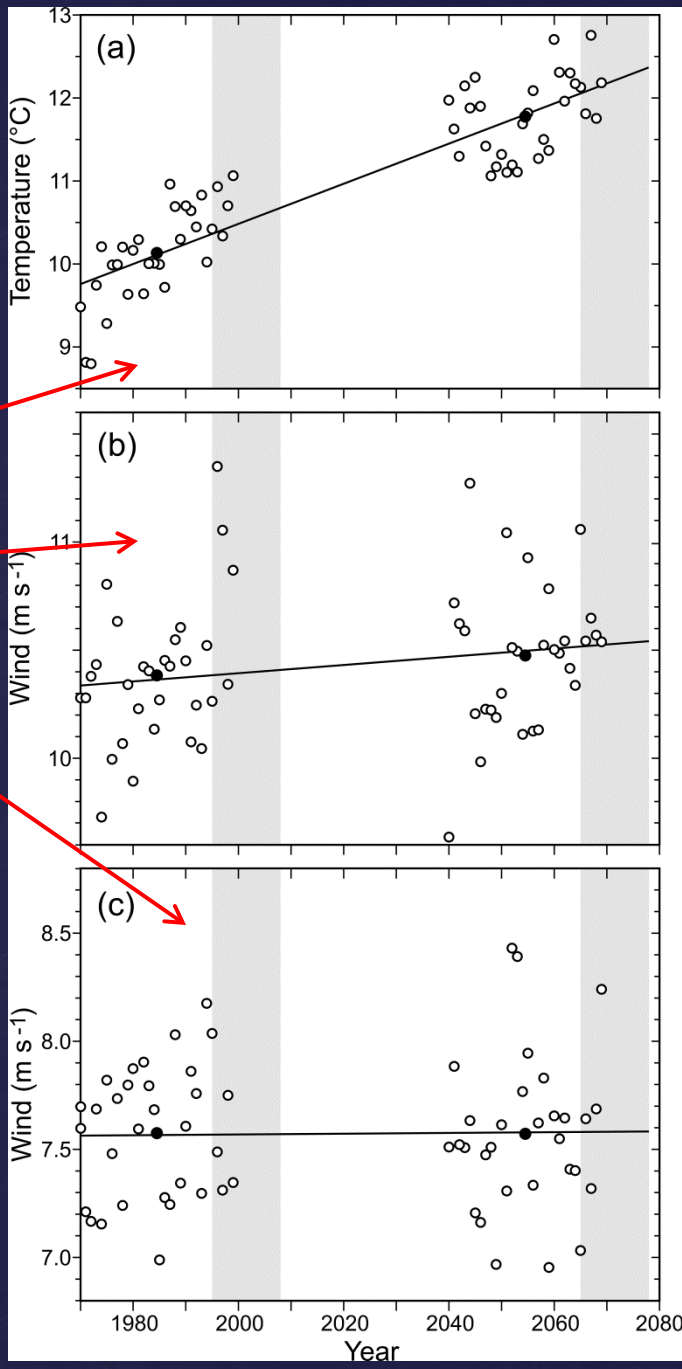
1. *For each of 8 combinations, computed annual & seasonal domain-averaged mean anomalies (future - contemporary) of*
   a) surface air temperature
   b) precipitation
2. *computed ensemble means & standard deviations*
3. *Scaled difference between individual & ensemble means by ensemble SD: "studentizing" or "standardizing"*

- *Figure shows absolute values*
- *CRCM/CGCM3 (#1) is representative*

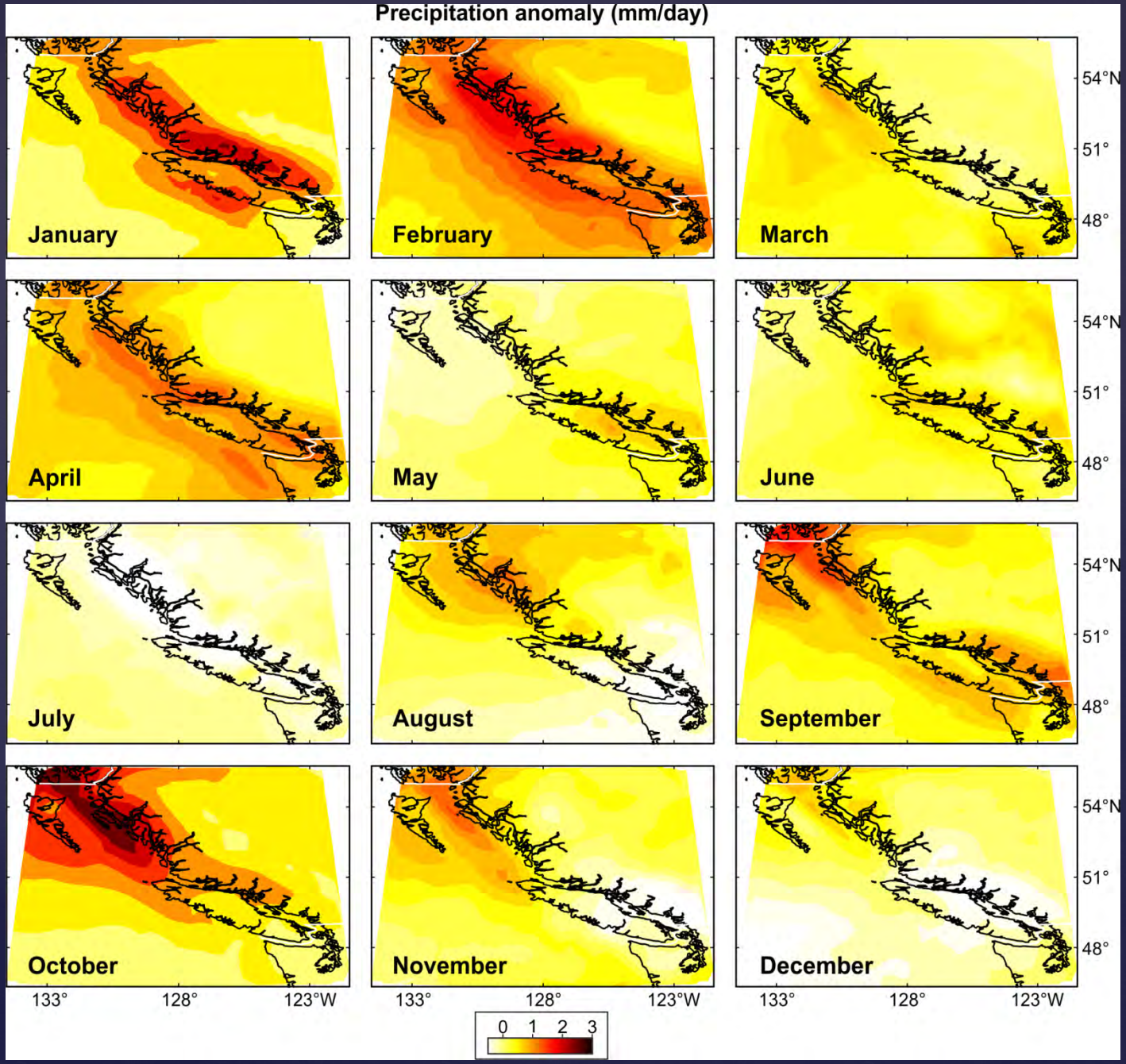


Timing Mismatch?

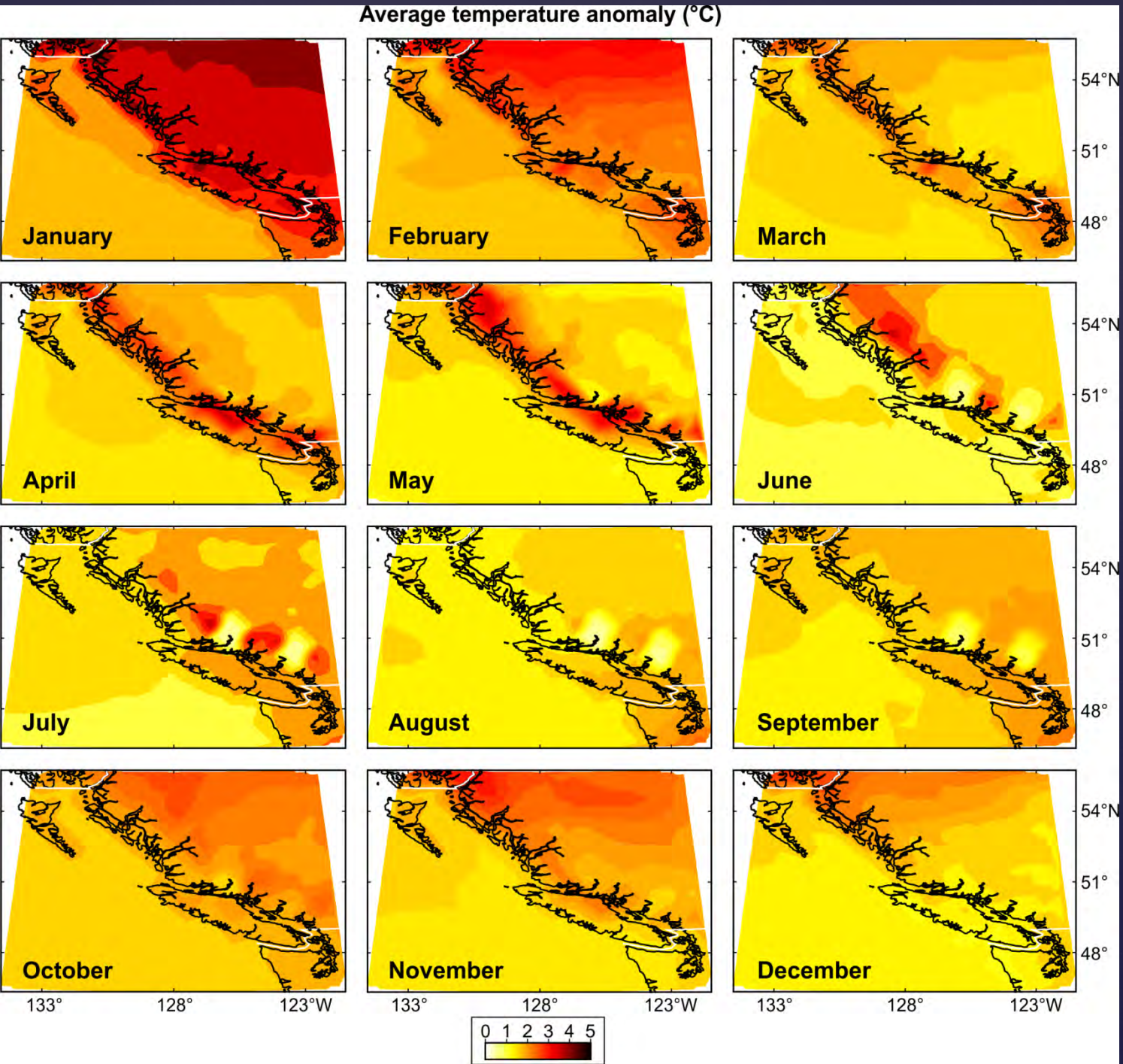
- Masson & Fine hindcast for 1995-2008 while NARCCAP periods are 1970-1999 and 2040-2069
- Figure shows CRCM/CGCM3 model domain averaged
  a) Annual air temperatures
  b) winter (Oct-Apr) wind speeds
  c) summer (May -Sep) wind speeds
  covering NARCCAP contemporary & future periods
- 100-yr trend (solid line) for a) essentially same as future 30-yr trend so reasonable to extrapolate
- b) & c) trends not significantly different from zero
- Future run may be considered for 2065-2078; 70 years ahead of hindcast



Precipitation Anomalies



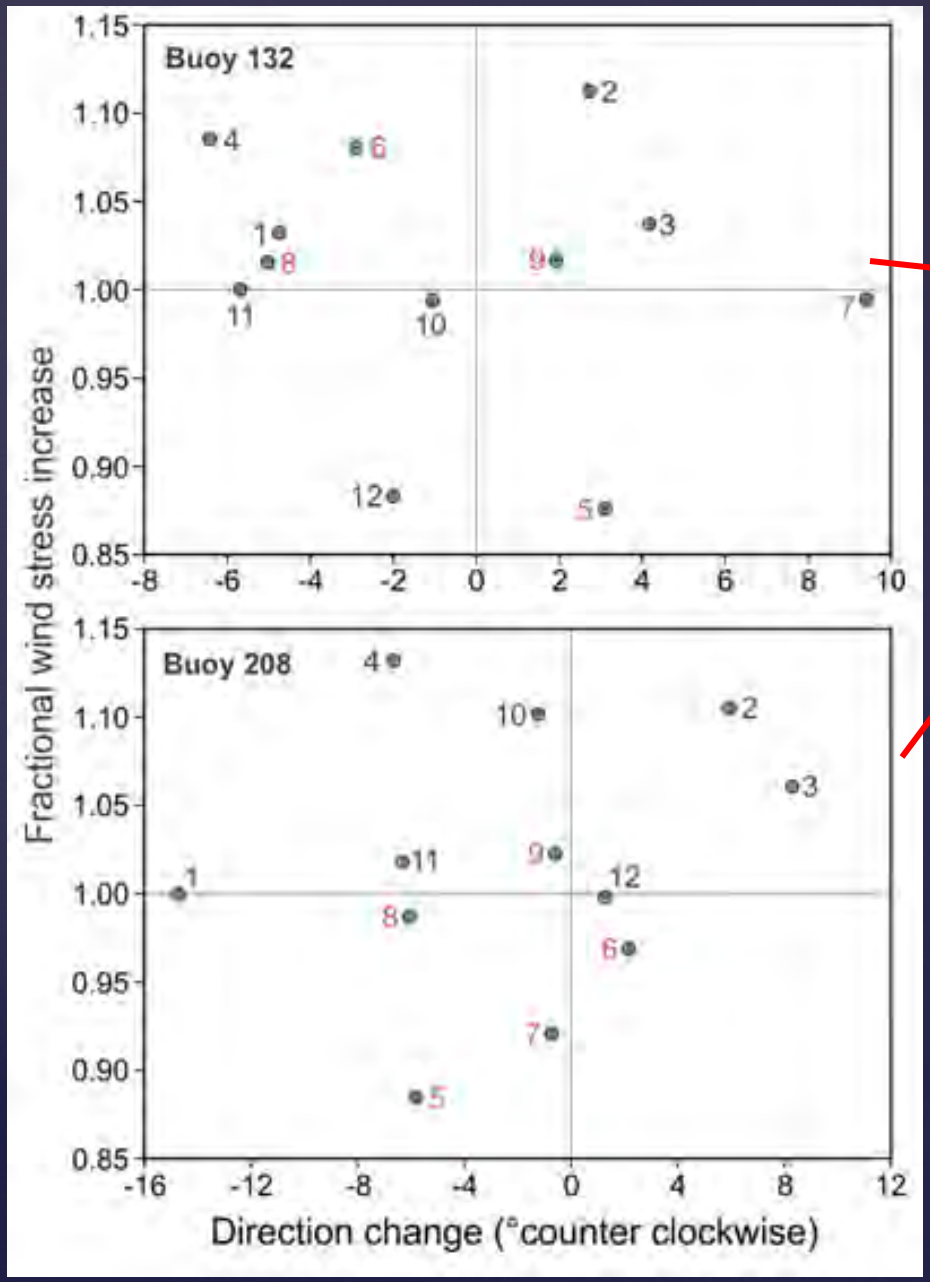
- Monthly-averaged differences 2040-2069 minus 1970-1999
- Generally wetter in winter & dryer in summer
- Average annual anomaly ~ +0.5mm/day

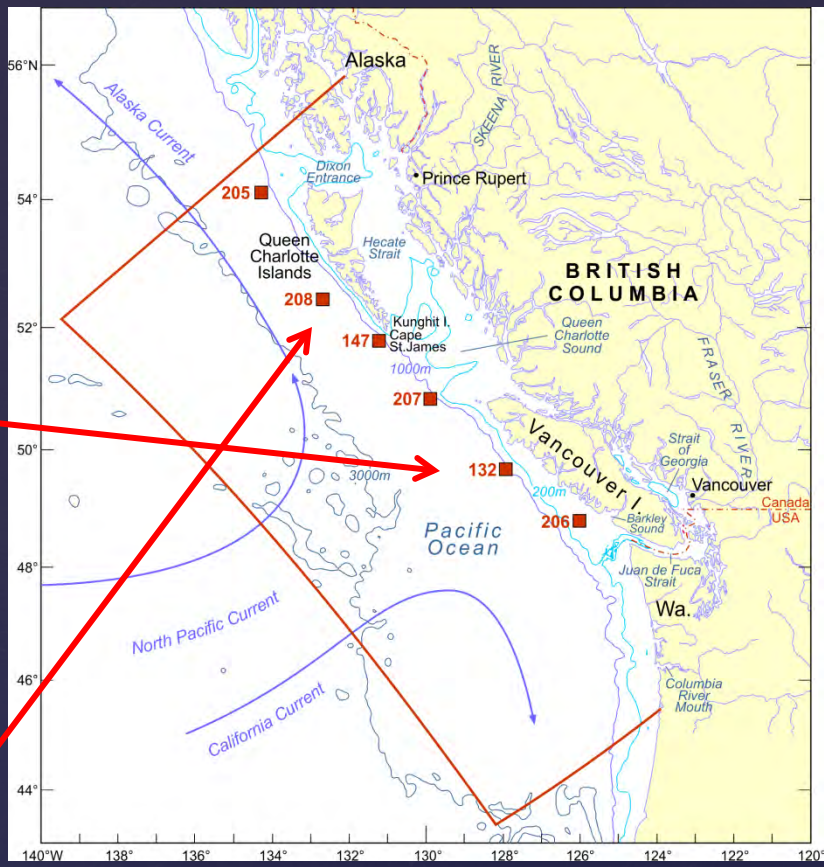


Surface Air Temperature Anomalies

- Monthly-averaged differences 2040-2069 minus 1970-1999
- Warmer everywhere
  - Slightly different patterns for day and night

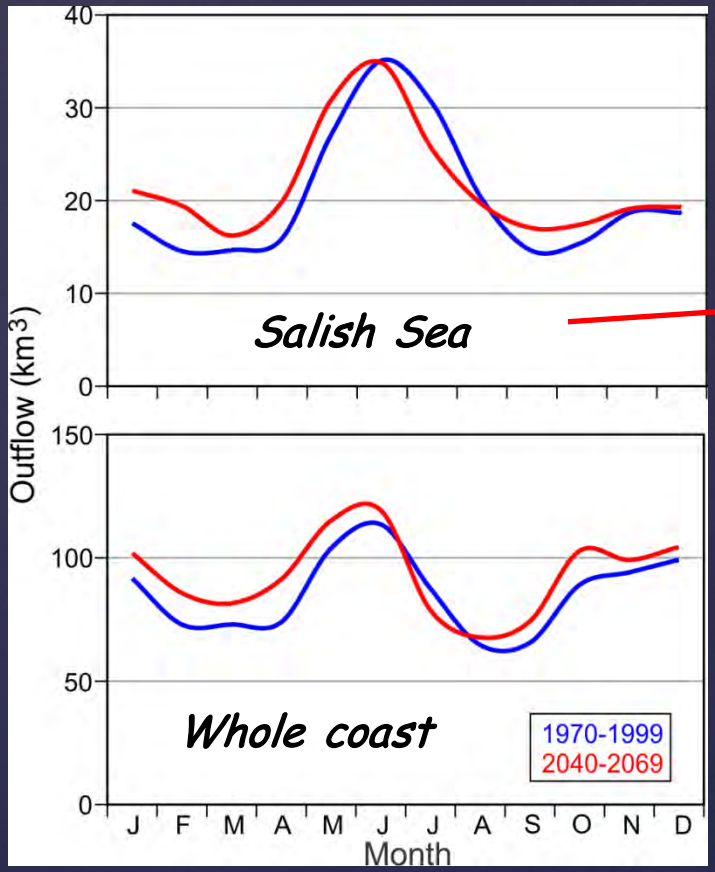
Wind Anomalies

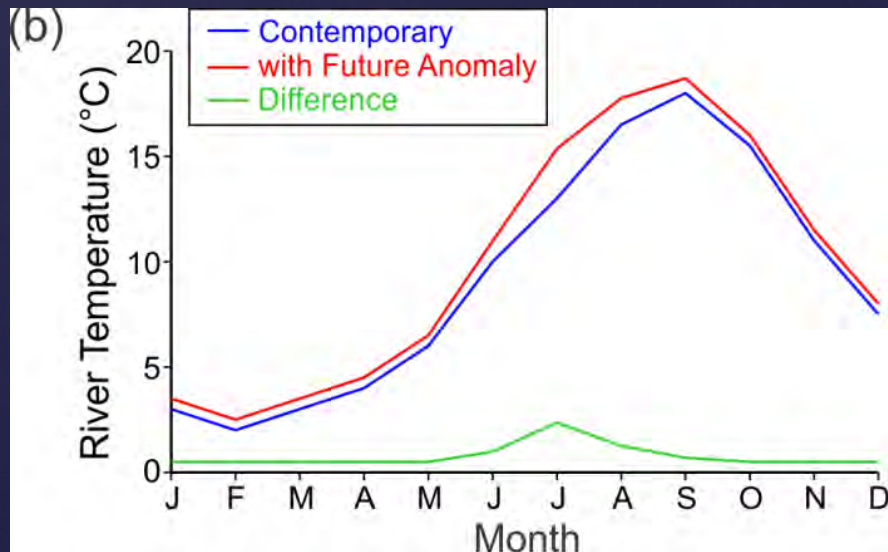




- *Numbered dots = months*
  - *Red = upwelling months*
- *Generally stronger winter winds*
- *Perhaps, stronger summer upwelling winds at buoy 132*

Contemporary & Future Freshwater Discharges

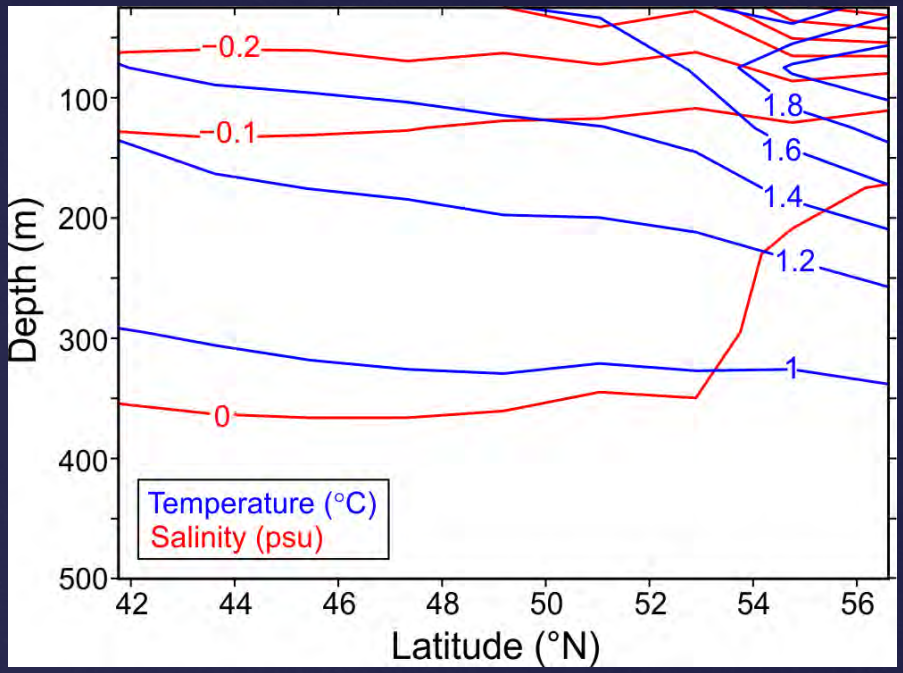




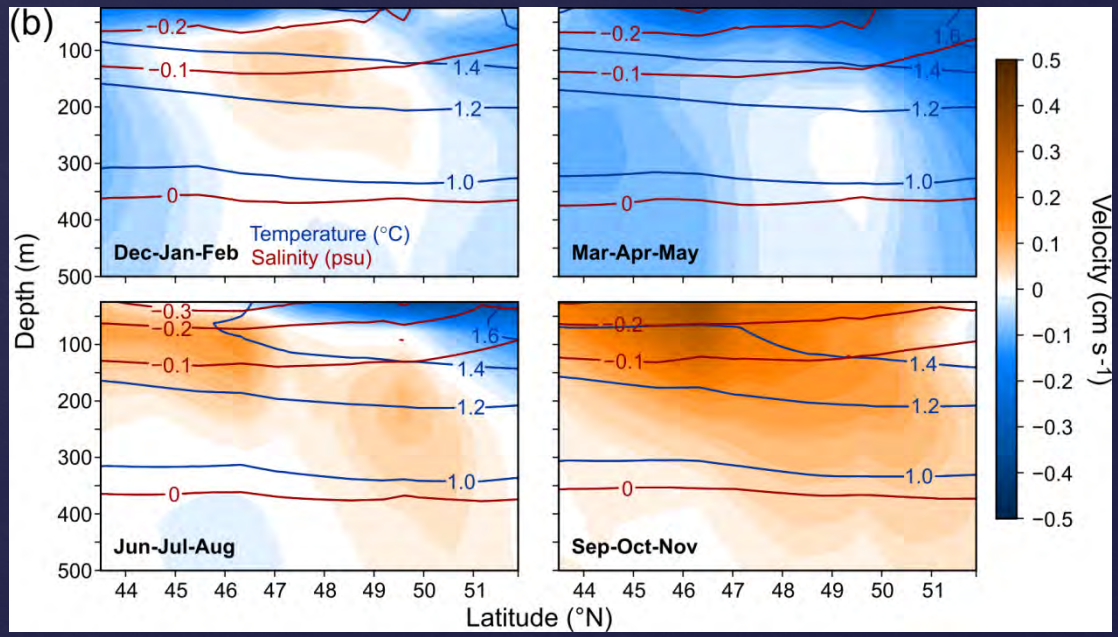
- *21 sub-basins*
- *Except for June-August, more discharge*
- *Warmer river temperatures*

Initial and Lateral Boundary Ocean Condition Anomalies

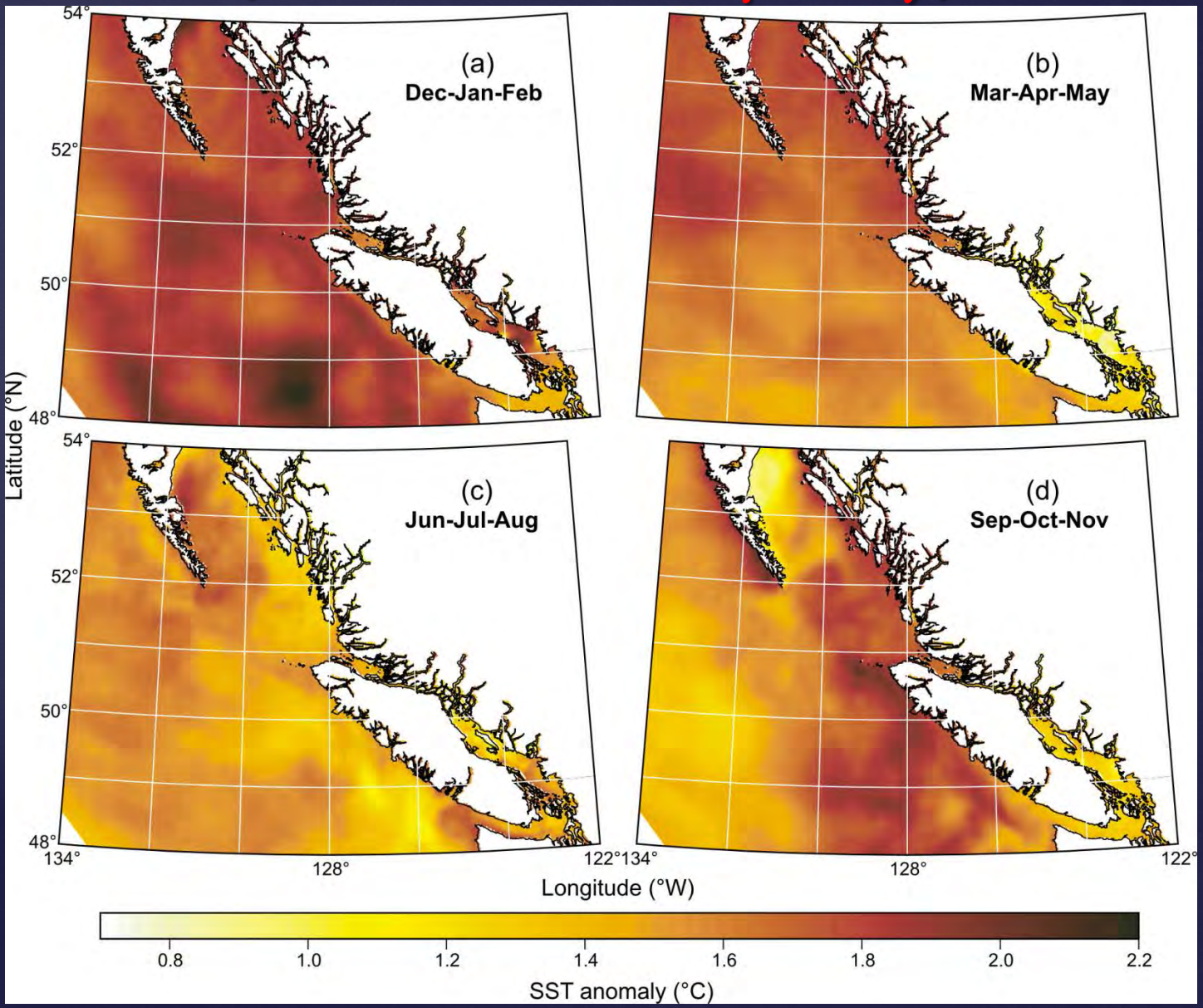
- 3D temperature/salinity initial anomalies from CGCM3
  - no active ocean in CRCM
  - Only latitudinal anomalies
  - future will be warmer and fresher



- Seasonal anomalies in temperature, salinity, normal velocity forcing along northern, western, southern boundaries
  - Brown/orange shading denotes flow into domain

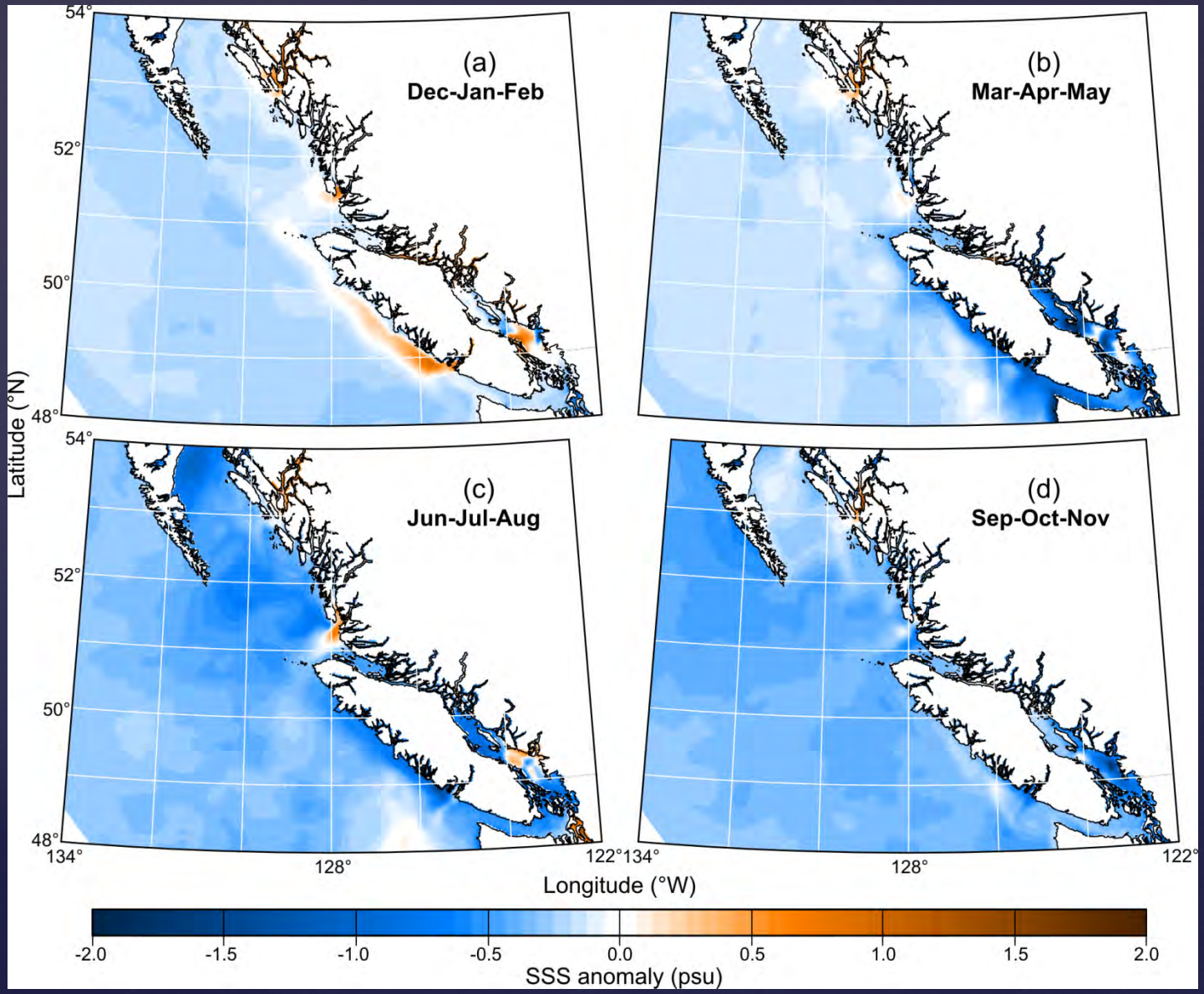


Model Projections: SST Anomalies (Future - contemporary)



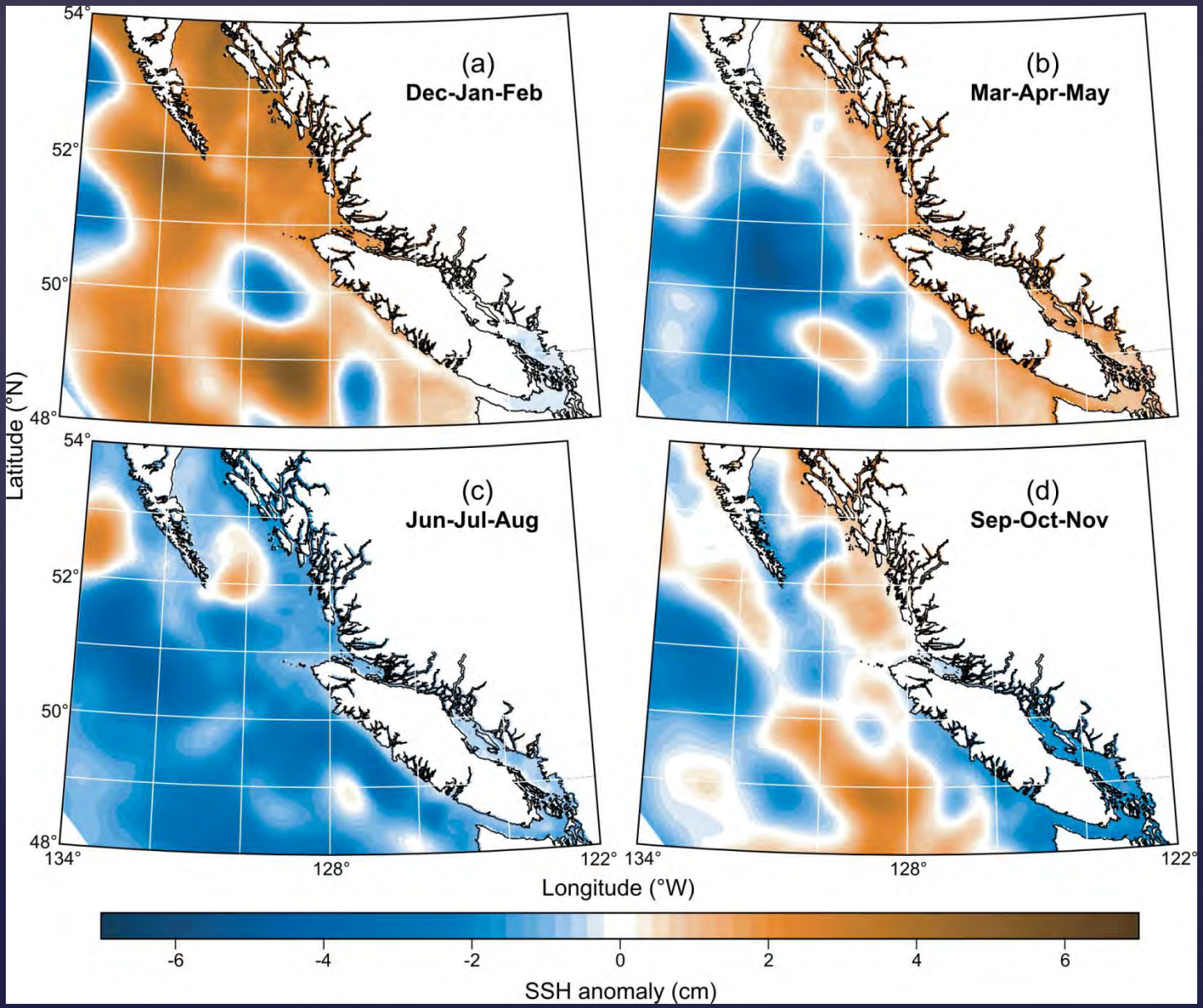
- *Warmer everywhere*
- *Larger in winter*

Model Projections: SSS Anomalies (Future - Present)



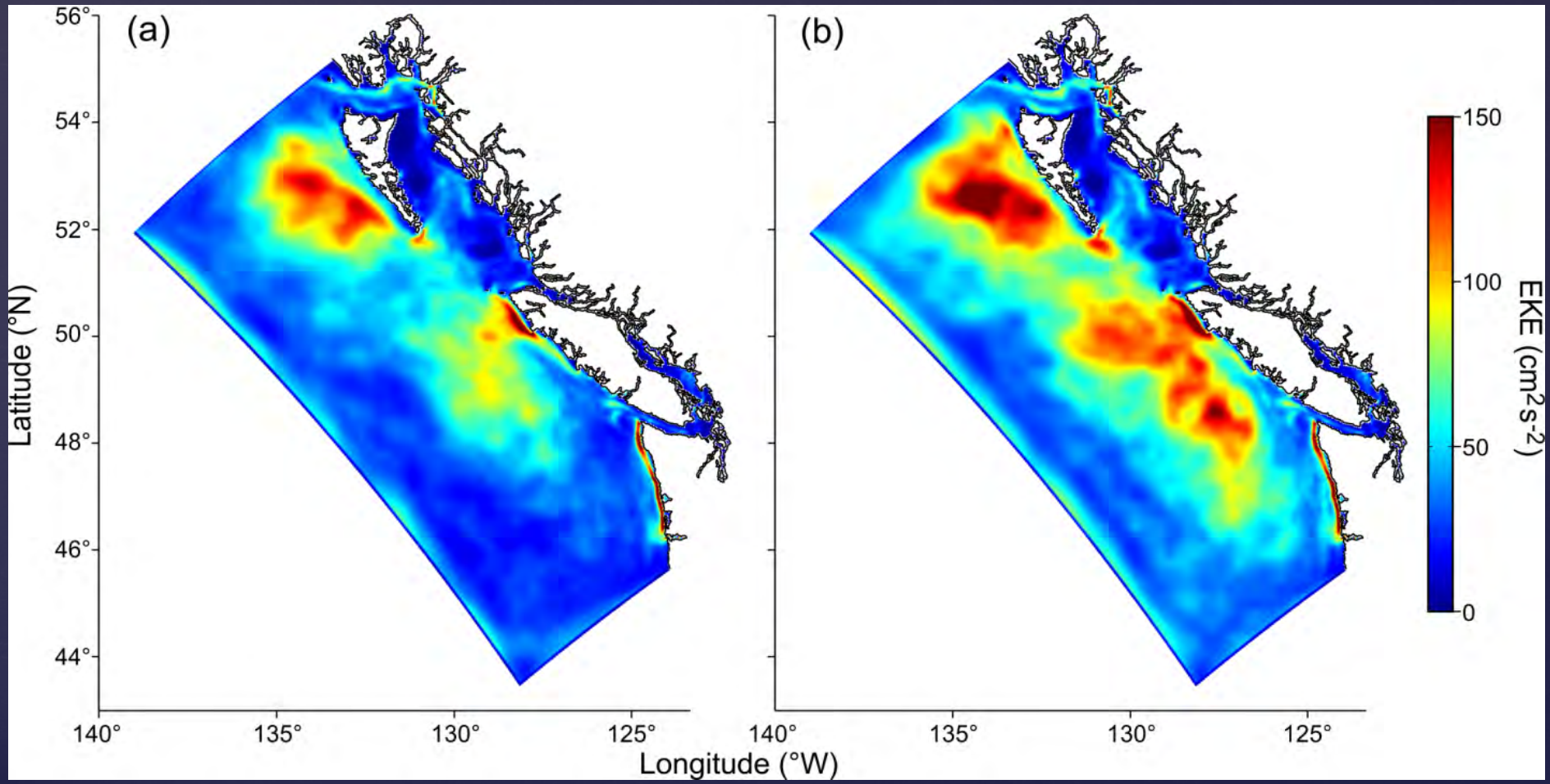
- Generally fresher
- But timing changes result in a few saltier regions

SSH (height) Anomalies



- Generally higher in winter & lower in summer
- Changes from winds (set-up, set-down) & density (dynamic height)
- ROMS is Boussinesq; no volume expansion

Eddy Kinetic Energy



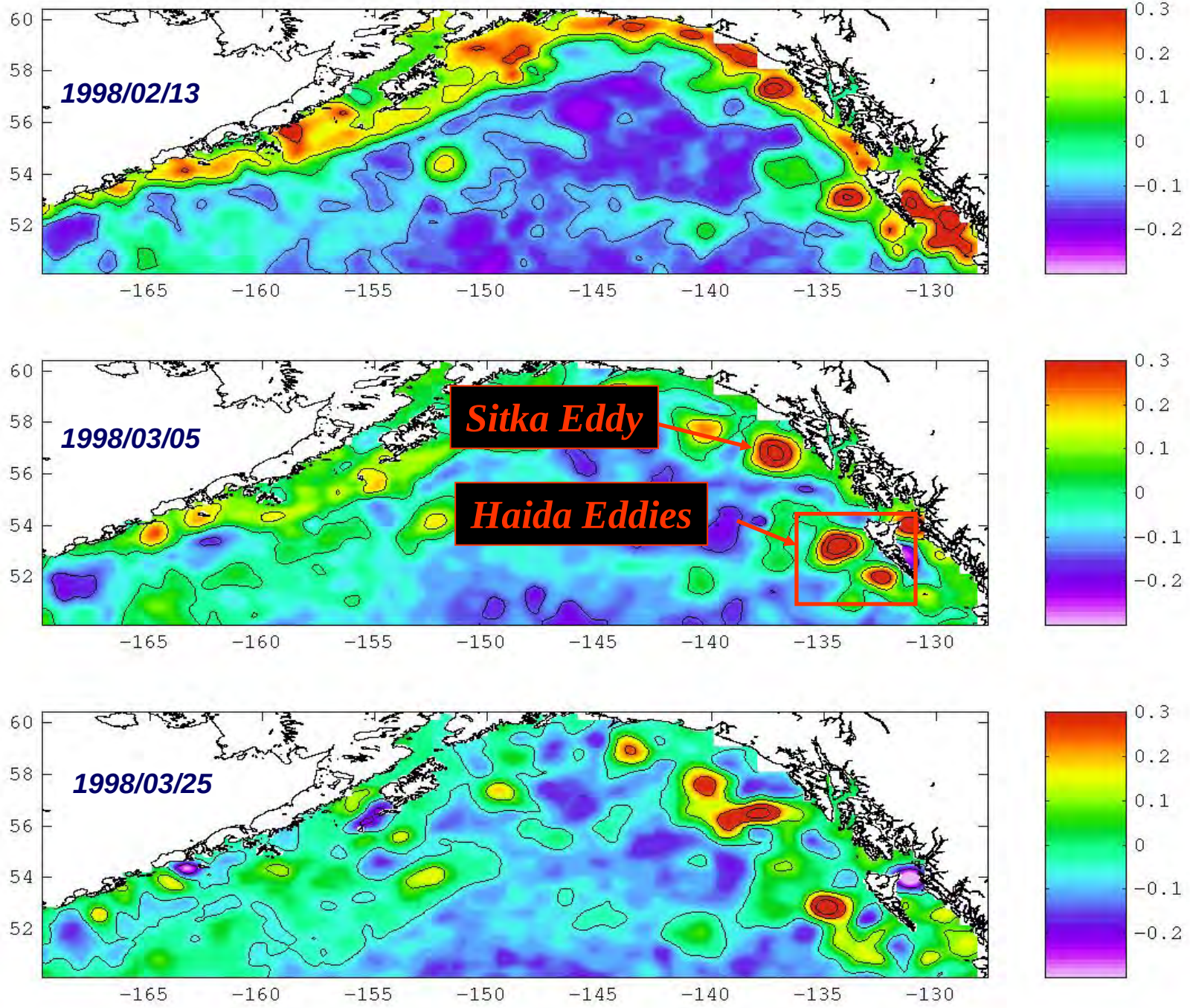
contemporary

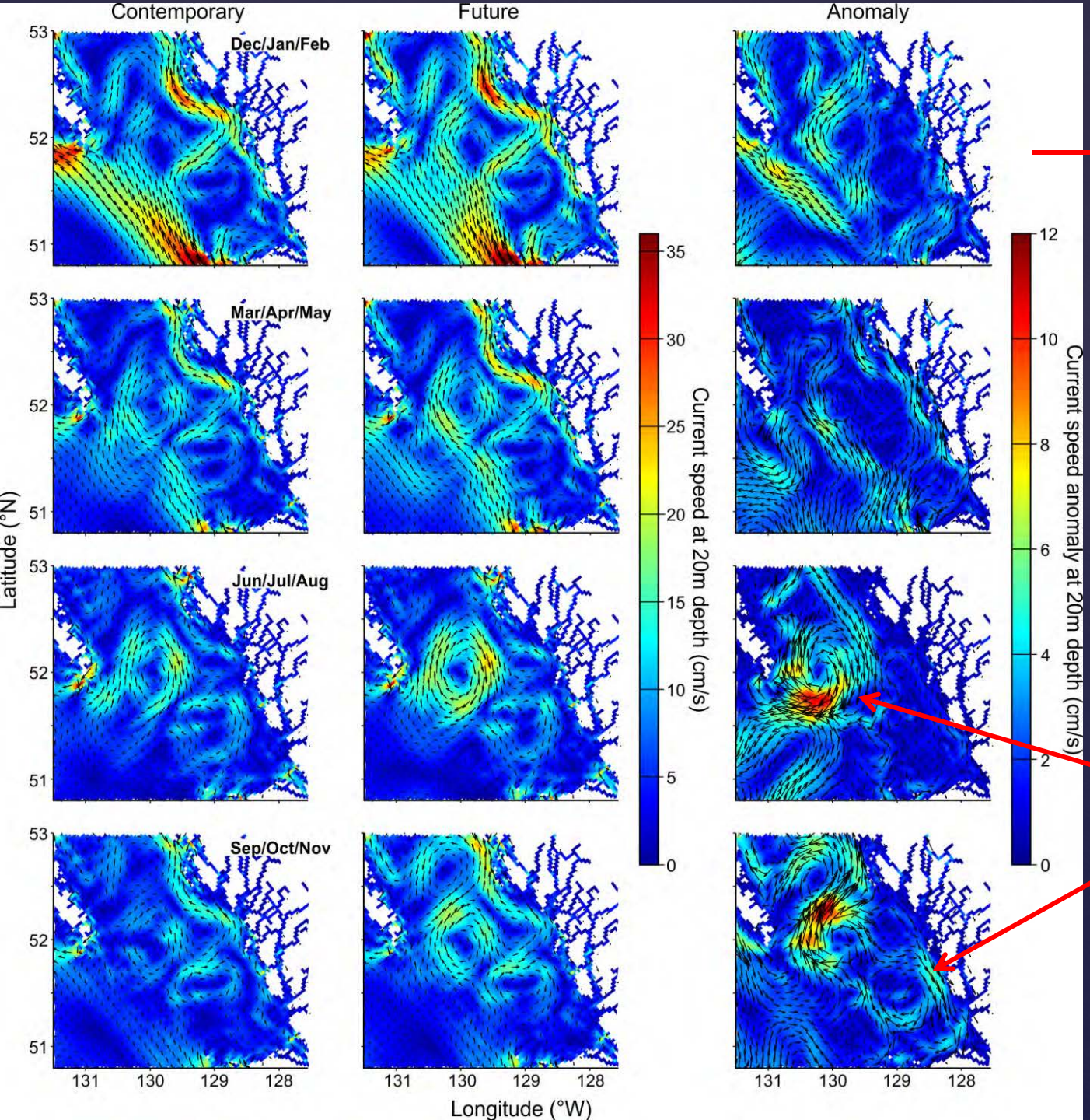
future

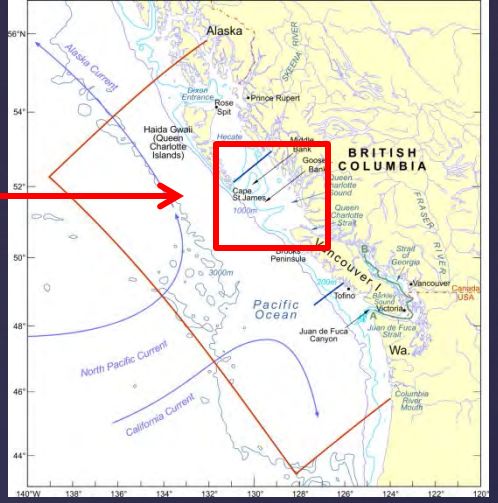
- Stronger, not more, Haida Eddies due to stronger winter winds

SSHa

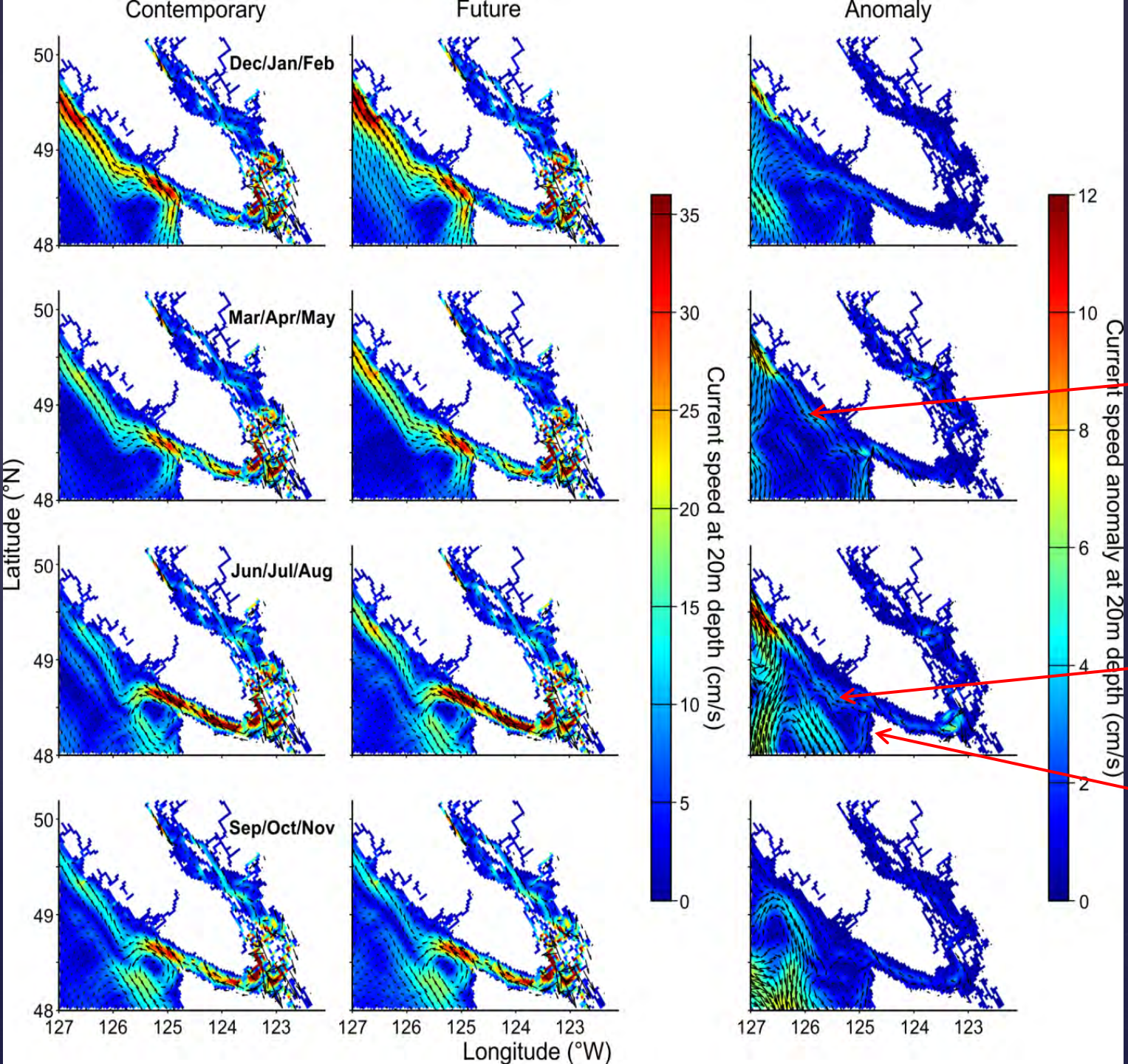
TOPEX/ERS



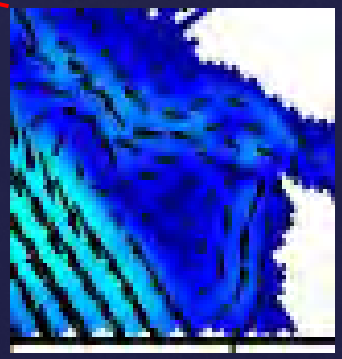




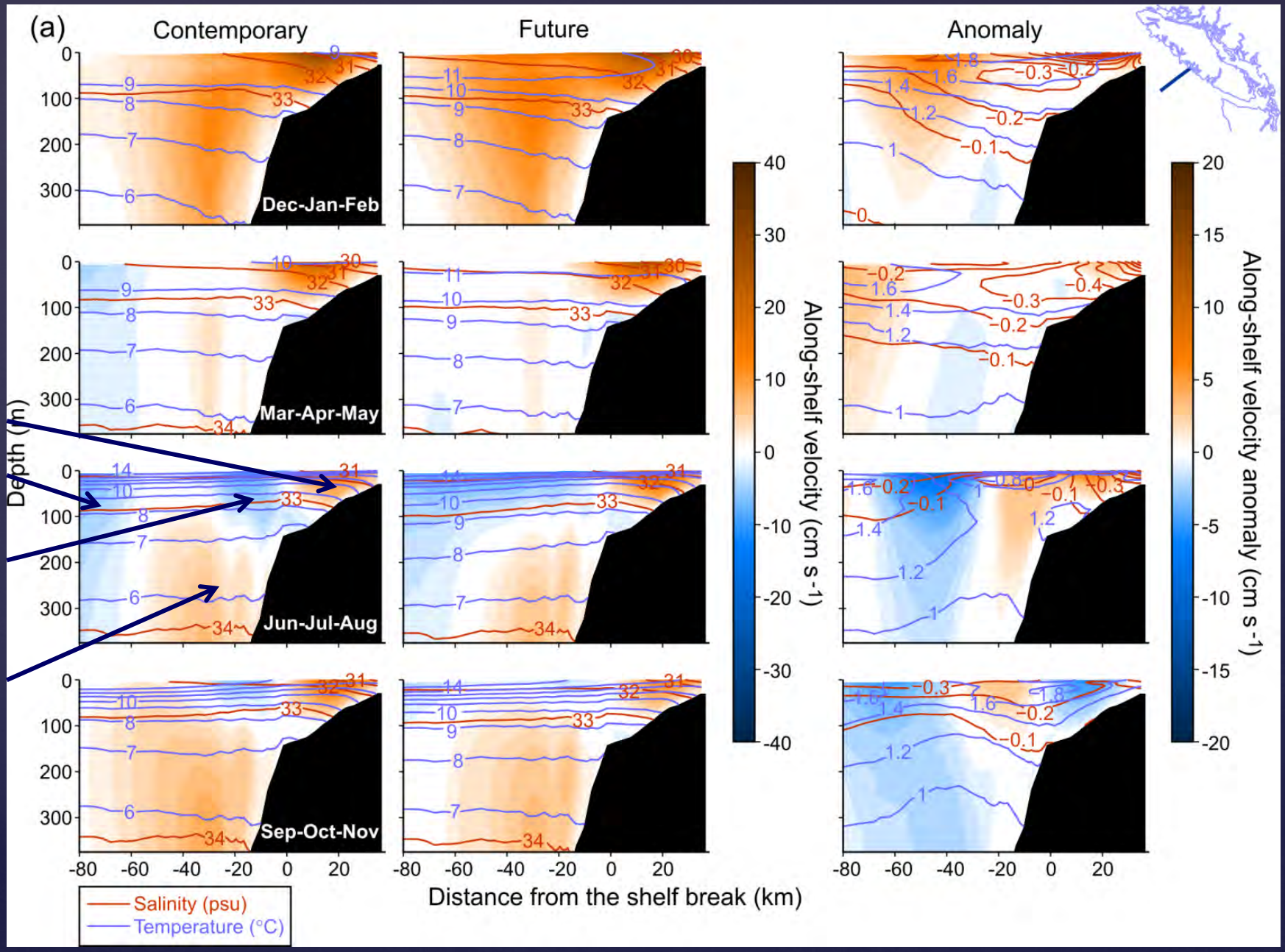
- *20m flows*
- *Stronger eddies around Middle & Goose Island Banks in some seasons*



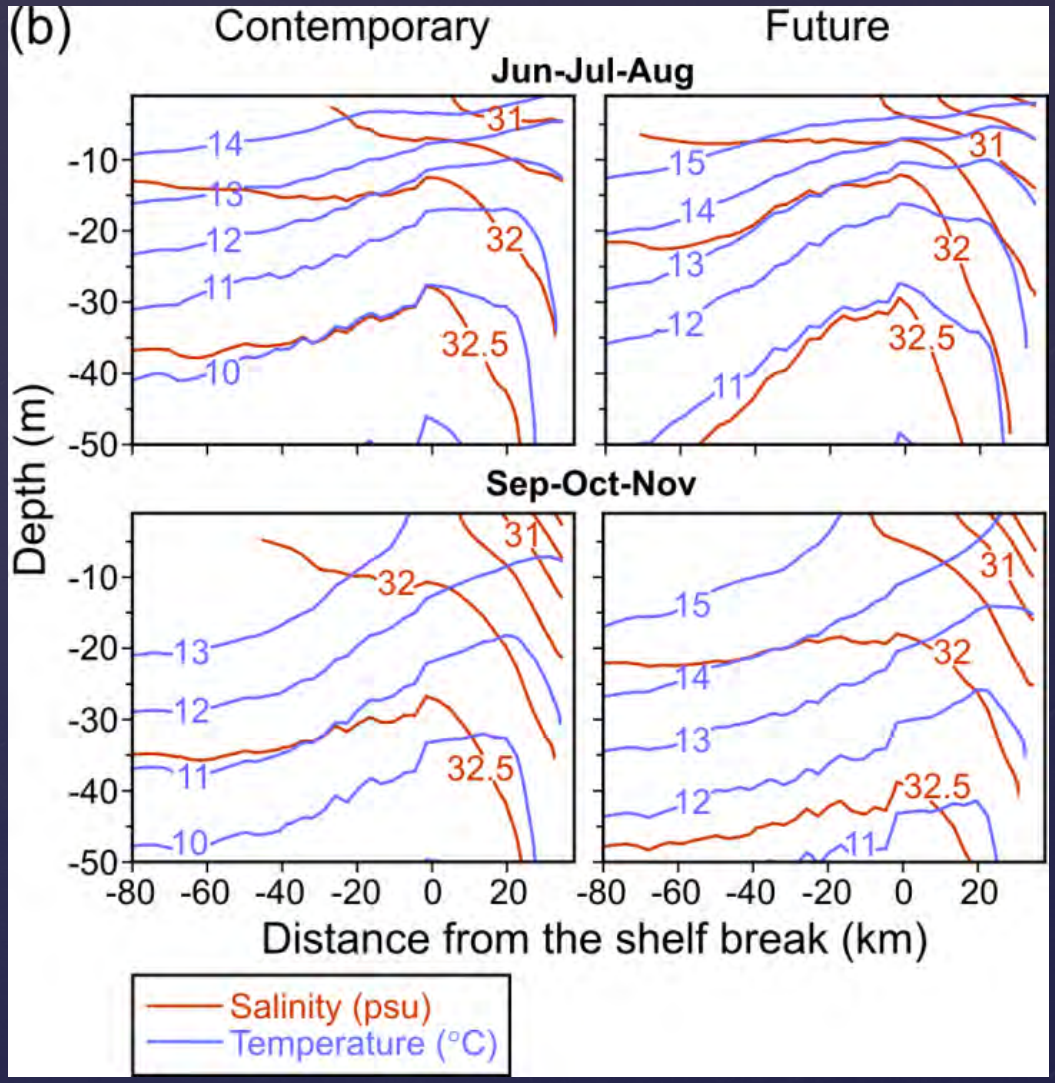
- *20m flows*
- *Stronger Vancouver Island Coastal Current*
- *Slight increase in Juan de Fuca Eddy amplitude (timing ?)*



Flows, temperatures, salinities off Vancouver Island



Is there more upwelling?

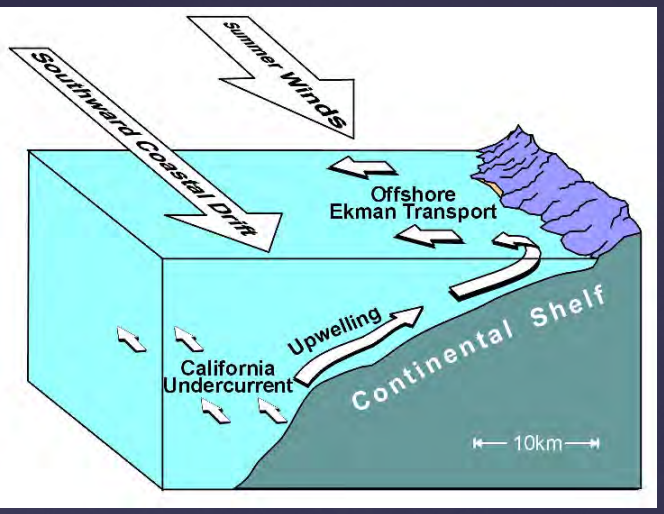


Not conclusive: T is warmer & coastal current is fresher but isotherms & isohalines not much steeper

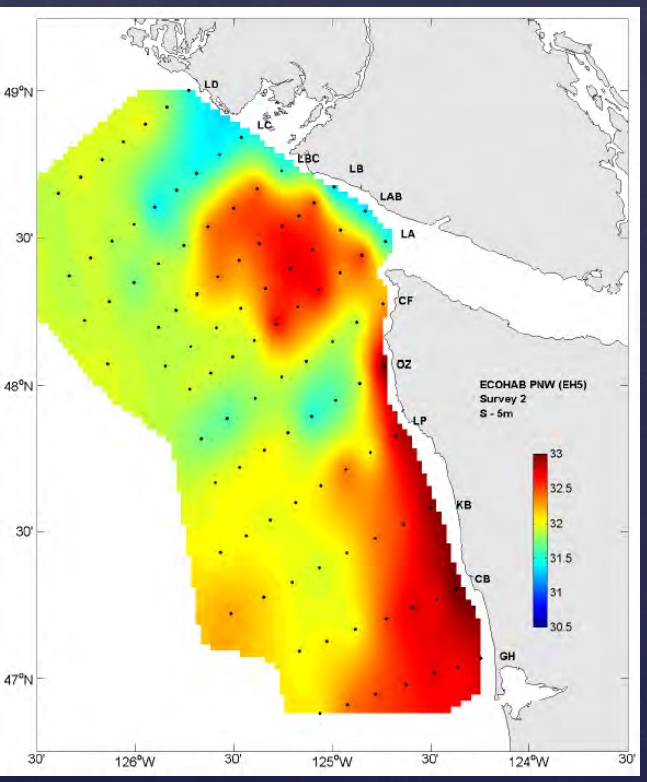
Ecosystem Implications:

1. Juan de Fuca Eddy

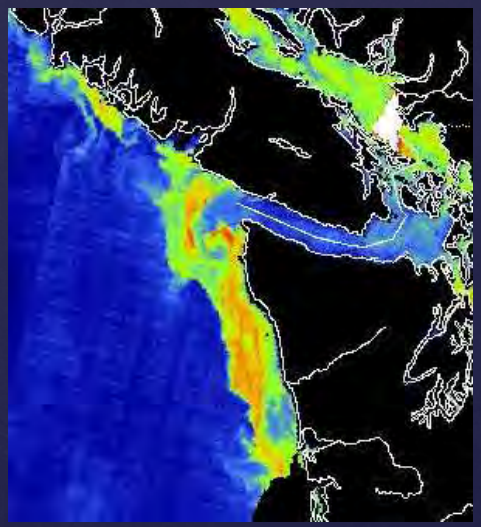
- summer upwelling feature off the entrance to Juan de Fuca Strait
  - Not classical upwelling, as off Washington, Oregon, California
  - nutrient-rich California Undercurrent water moves up the Juan de Fuca and Tully Canyons onto the shelf
- Makes the SW Vancouver Island & northern Washington shelves one of most productive fishing regions in the NE Pacific (Ware & Thomson, 2005)
- Little indication of change in magnitude & timing

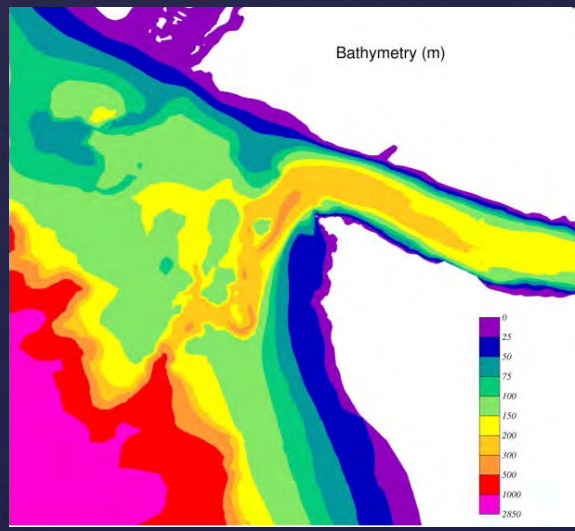


Courtesy of Rick Thomson



Sept 2005 salinity at 5m depth



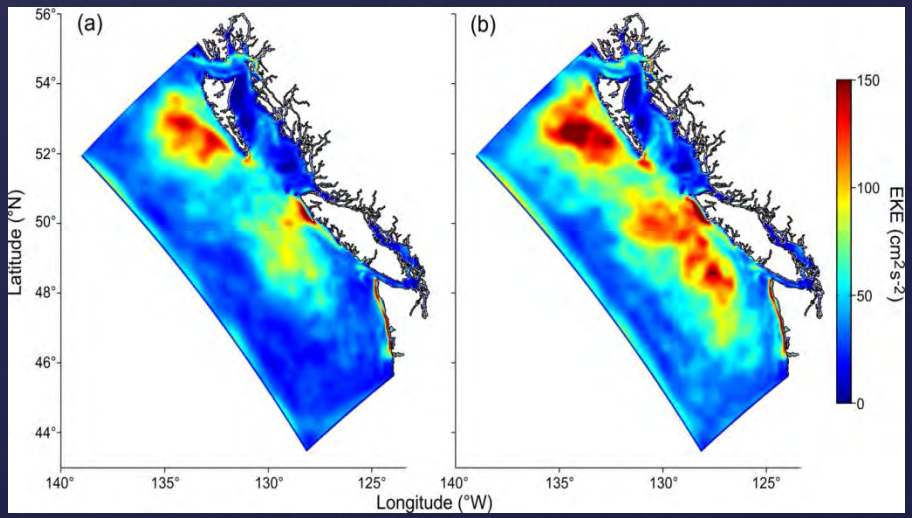


Ecosystem Implications:

2. Haida Eddies

- carry plankton, larvae, & nutrients offshore (Whitney & Robert, 2002)
  - reduce productivity on shelf but increase productivity offshore
  - Pacific cod recruitment in Hecate Strait shows strong negative correlation with mean sea level (high ➡ bigger eddy) previous winter
  - re-stock fish populations around seamounts

- Projected to become stronger



Ecosystem Implications:

3. Sea lice

- Lice from salmon farms have impacted wild migrating juvenile salmon in Broughton Archipelago
- Faster progression through planktonic life stages with warmer temperatures
- Planktonic mortality increases with fresher water

- Copepodids can swim to avoid low salinity water but eggs & nauplii are passive
- More study needed to determine if projected warmer & fresher waters will increase/decrease lice numbers

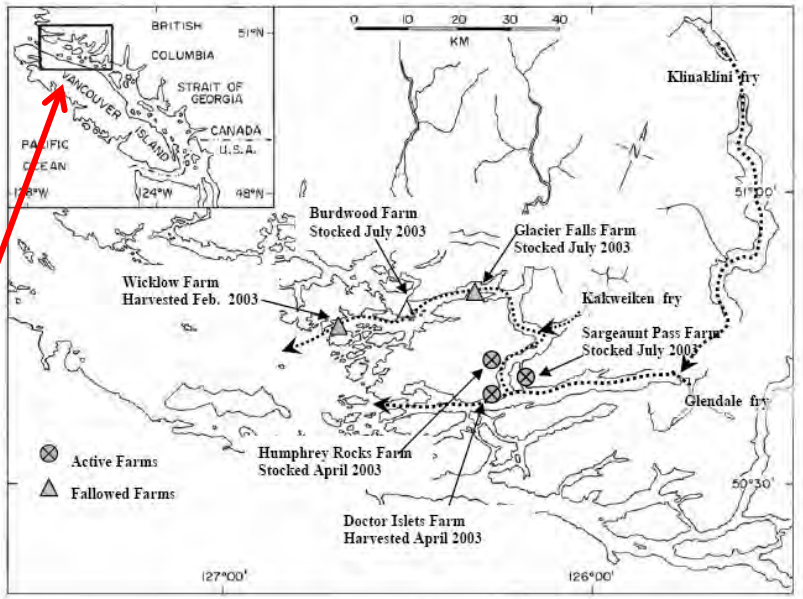
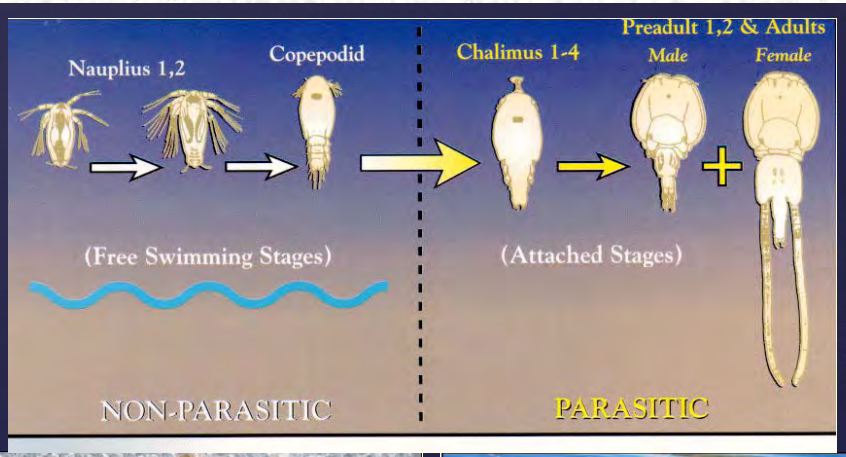
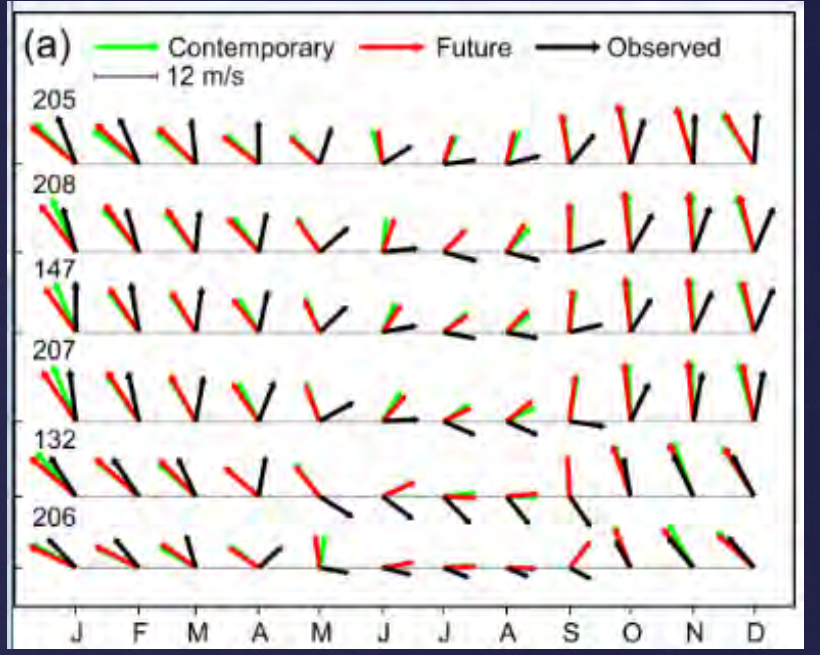


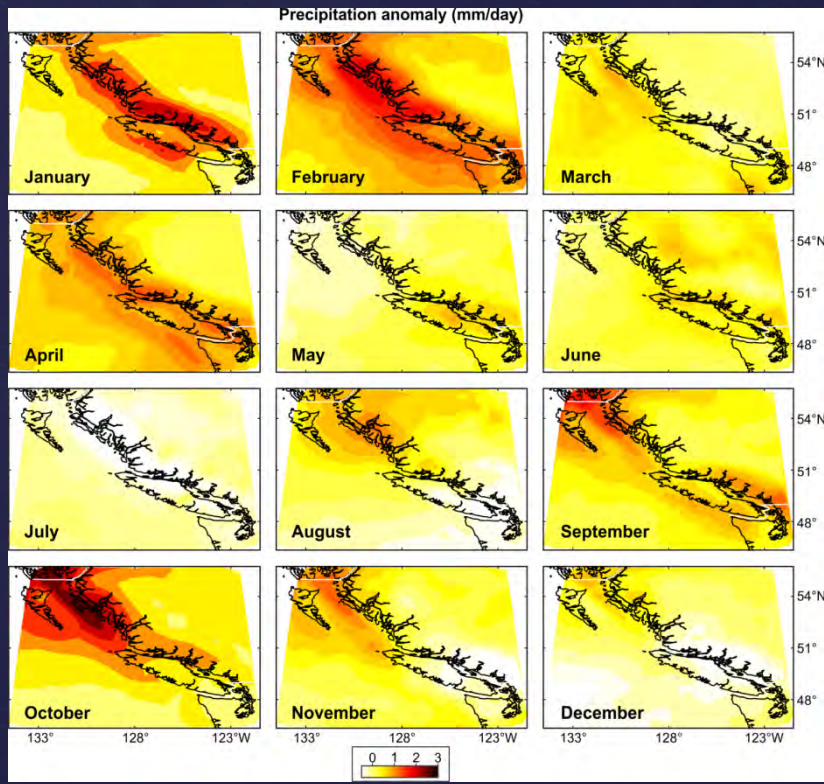
Figure 5. Broughton Archipelago showing two possible migration paths taken by pink salmon fry (dashed lines) and the location of three active salmon farms (Doctor Islets, Sargeaunt Pass and Humphrey Rocks) together with three inactive farms (Glacier Falls, Burdwood and Wicklow).



Summary

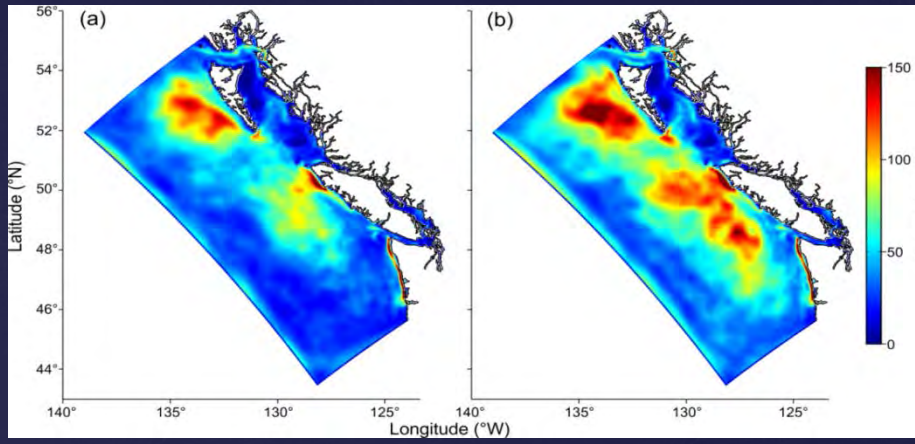
- Reran Masson & Fine (2012) hindcast for 2065-2078
- Inaccurate RCM winds → future forcing & initial fields computed by adding NARCCAP anomalies to Masson & Fine fields
- Representativeness of CRCM/CGCM3 within ensemble
- Timing mismatch justified
- General forcing field differences:
  - Warmer air temperatures
  - More river discharge

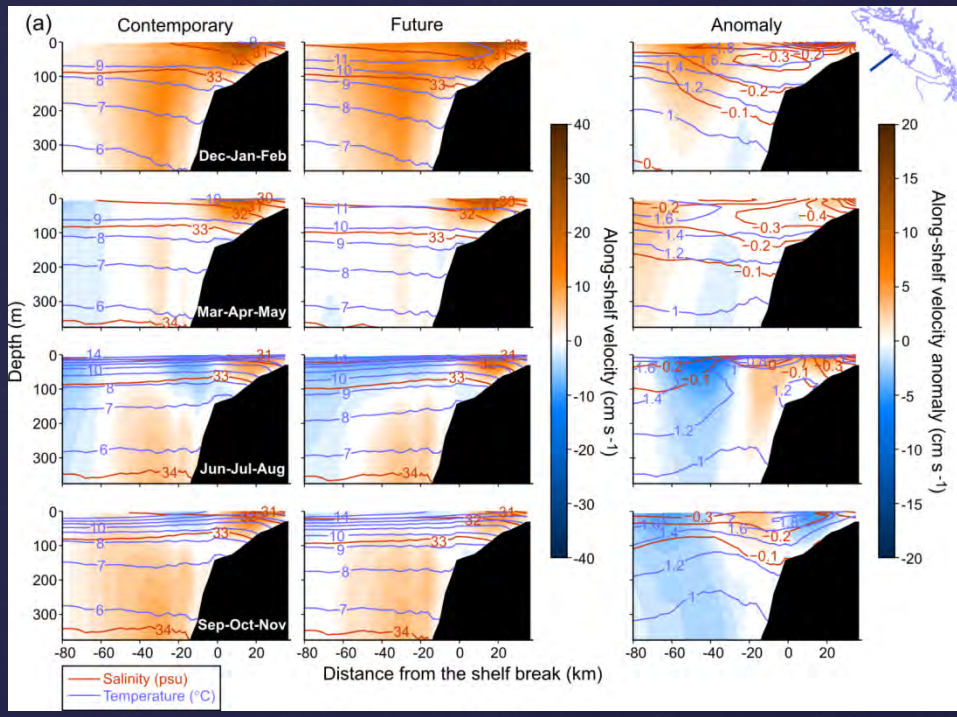




Summary

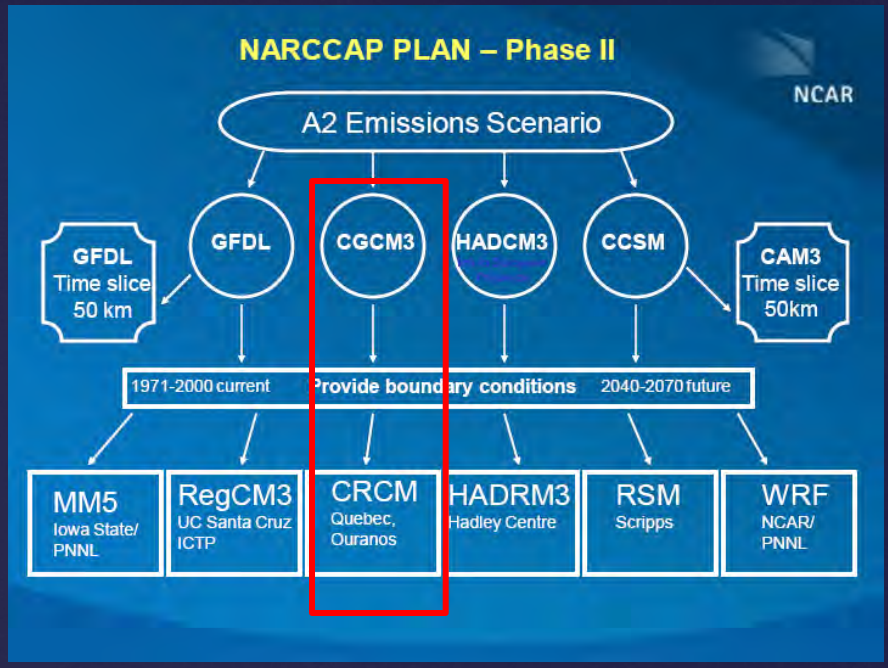
- Model projections:
  - More EKE (winter)
  - Stonger Haida, Goose Island Bank, Middle Bank, Rose Spit Eddies in some seasons
  - Stronger Vancouver Island coastal current
  - Little (if any) change in upwelling & JdF Eddy
  - Can't comment on California Undercurrent
- More details in 2 recent Atmosphere-Ocean papers

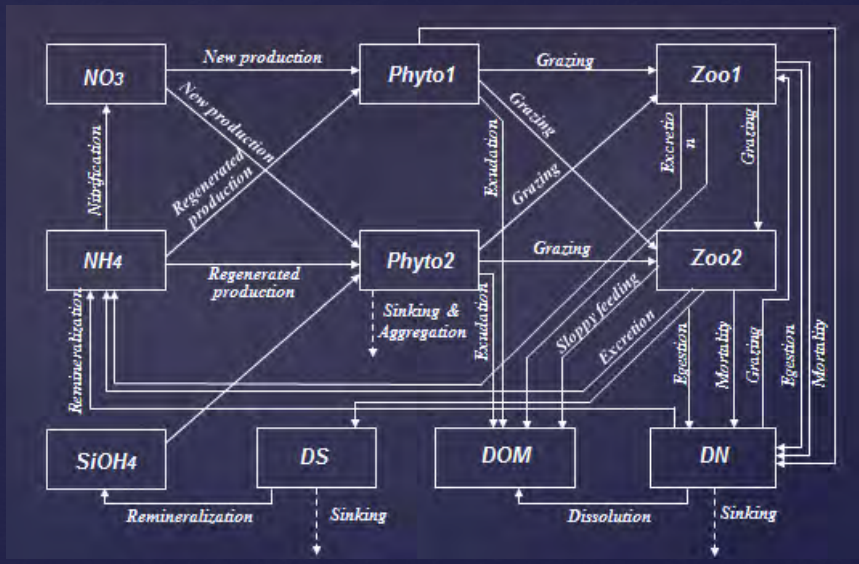




Ongoing & Future Work

- Other NARCCAP AR4 RCM/GCM combinations
  - Ensemble stats & uncertainty estimates
- AR5 RCM results
- Provide boundary forcing for 1km Salish Sea model projections
- Couple to NPZD & marine geochemical ecosystem model
  - Angelica Peña, S2 this afternoon @ 16:10





Acknowledgements

- Fisheries and Ocean Canada:
  - Climate Change Science Initiative (CCSI)
  - Ecosystem Research Initiative (ERI)
  - Aquatic Climate Change Adaptation Services Program (ACCASP)
  - Centre for Ocean Model Development for Application (COMDA)
- Environment Canada, Ouranos
- North American Regional Climate Change Assessment Program (NARCCAP)
- PICES WG20 and WG29
- Ministry of Oceans and Fisheries, Korea
- Research Institute of Oceanography, Seoul National University