2014 19th Annual CESM Workshop

Implementation of Estuary-Shelf Freshwater Exchange Parameterizations in the Community Earth System Model

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- Why?
- Estuary-Shelf Freshwater Exchange Parameterizations
    - ➢ Improved "augmented precipitation" scheme
    - ➢ Estuary and shelf box models
- Conclusion and Future……

SciDAC: Collaborative project: Improving the Representation of Coastal and Estuarine Processes in Earth System Models

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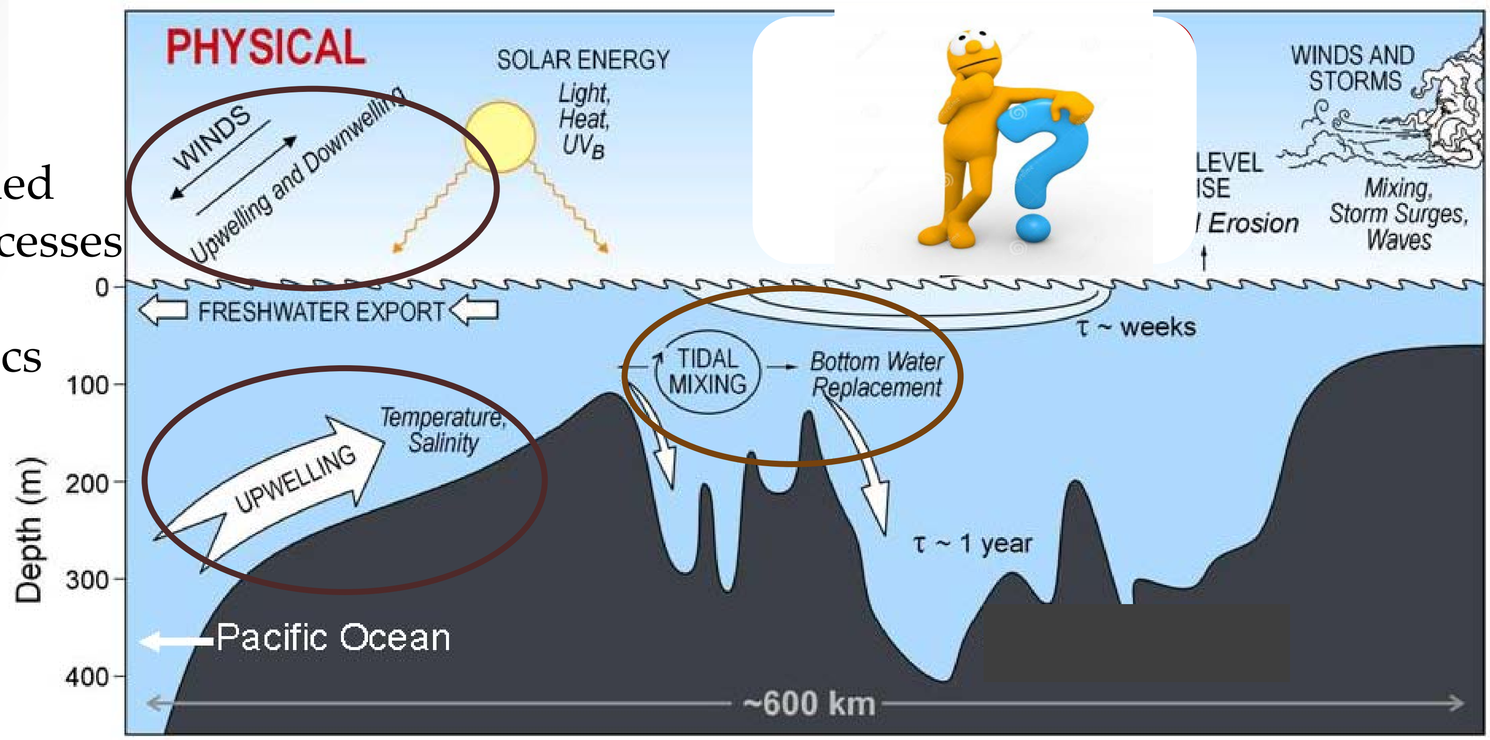
Coastal zone: coupled
Air-land-ocean processes

Multi-scale dynamics



Johannessen & Macdonald (2009)

Virtual salt flux: is it correct to consider the global water budget?
Where are the impacts of costal ocean?
Can we better represent the processes in the ESM (e.g., CESM)?

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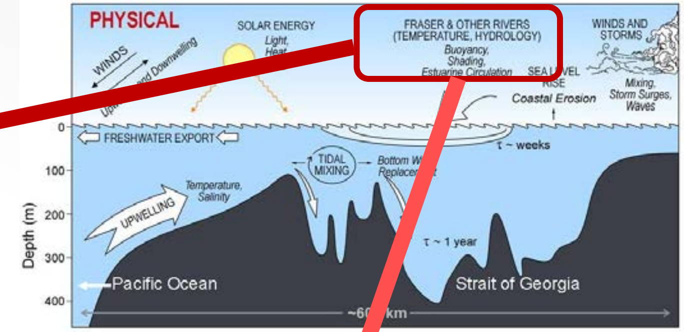
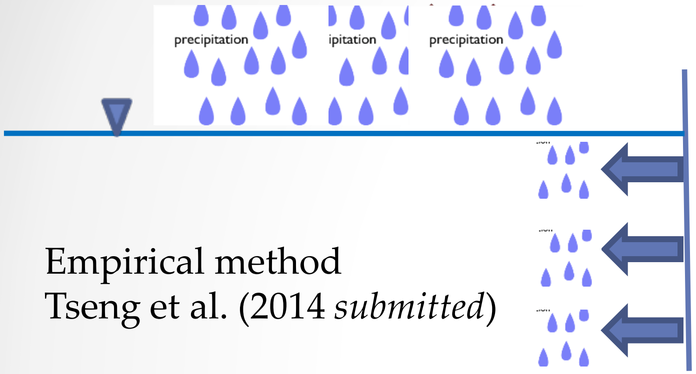
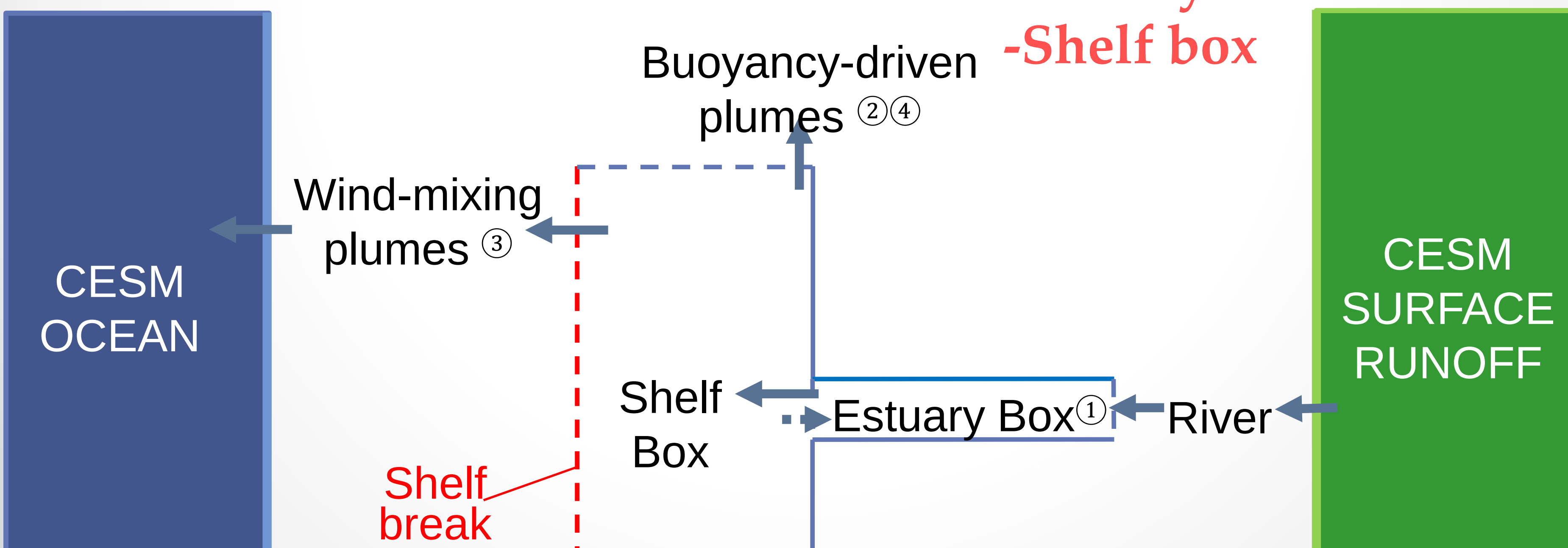


Improved "augmented precipitation" approach



Empirical method
Tseng et al. (2014 *submitted*)

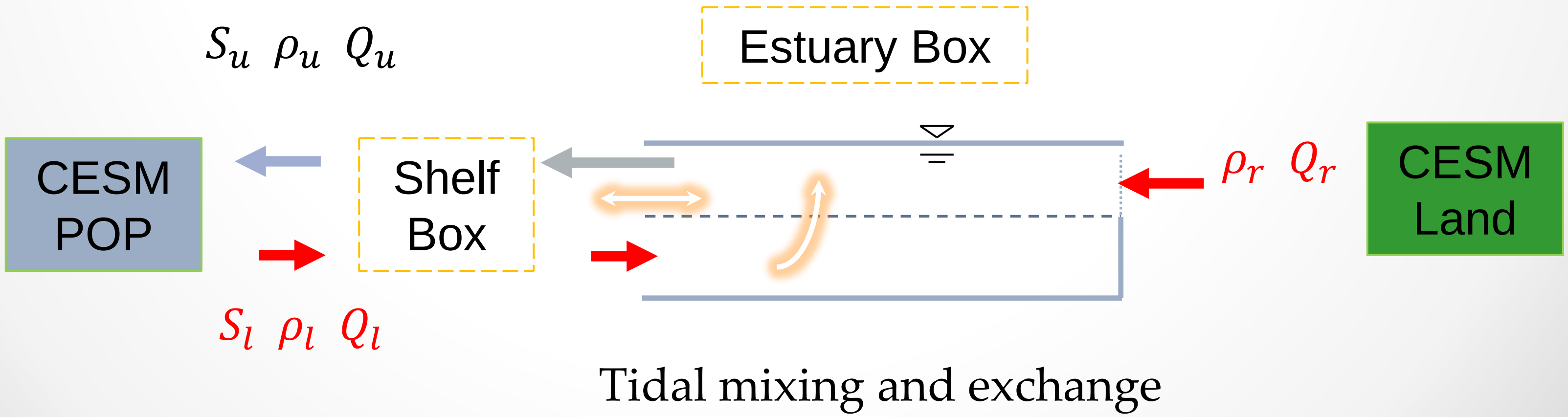
Box Model Approach
-Estuary box
-Shelf box



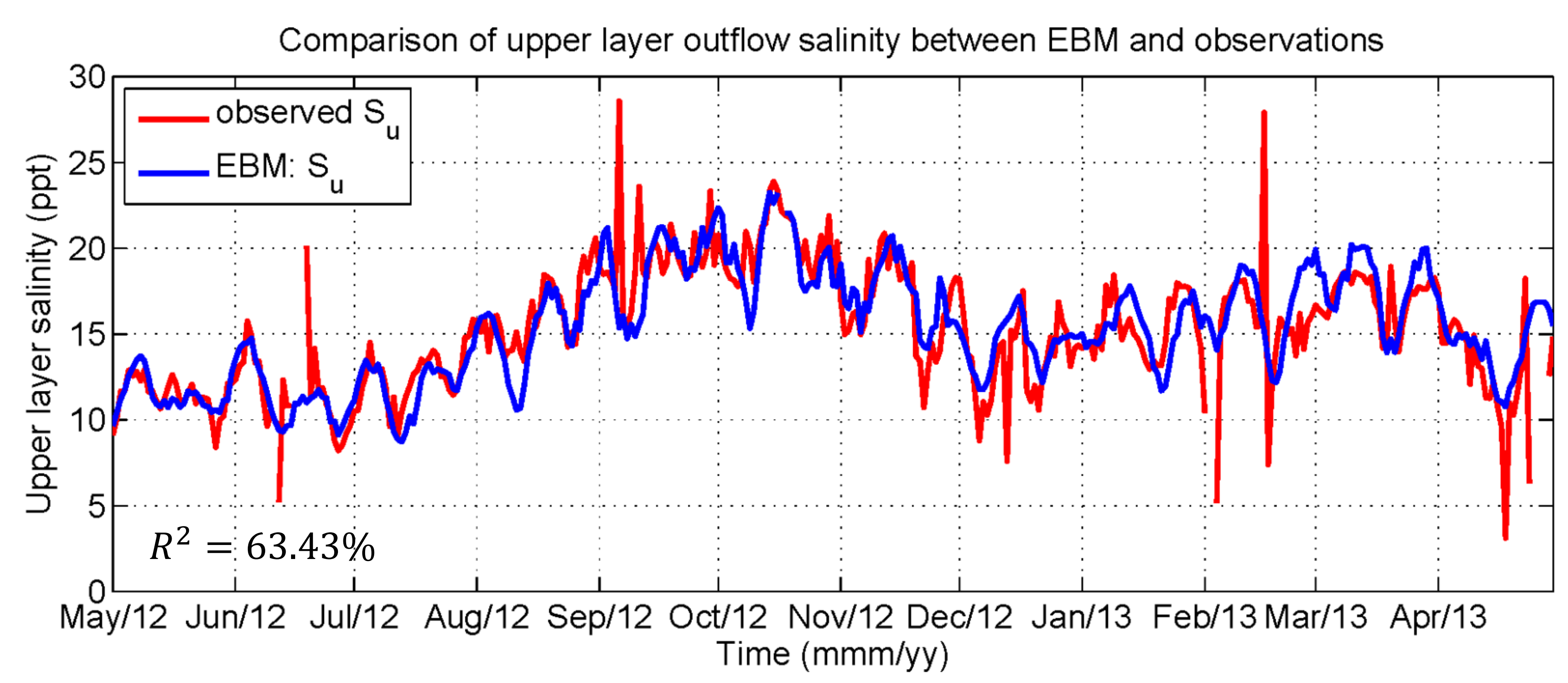
① Garvine and Whitney (2006); ② Yankovsky and Chapman (1997); ③ Lentz (2004); ④ O'Donnell (1999)

Two-layer Estuary Box Model

- Methodology
  - Steady-state Governing Equations:
    - Water mass flux conservation
    - Salt mass flux conservation
    - Potential energy flux (PEF) conservation



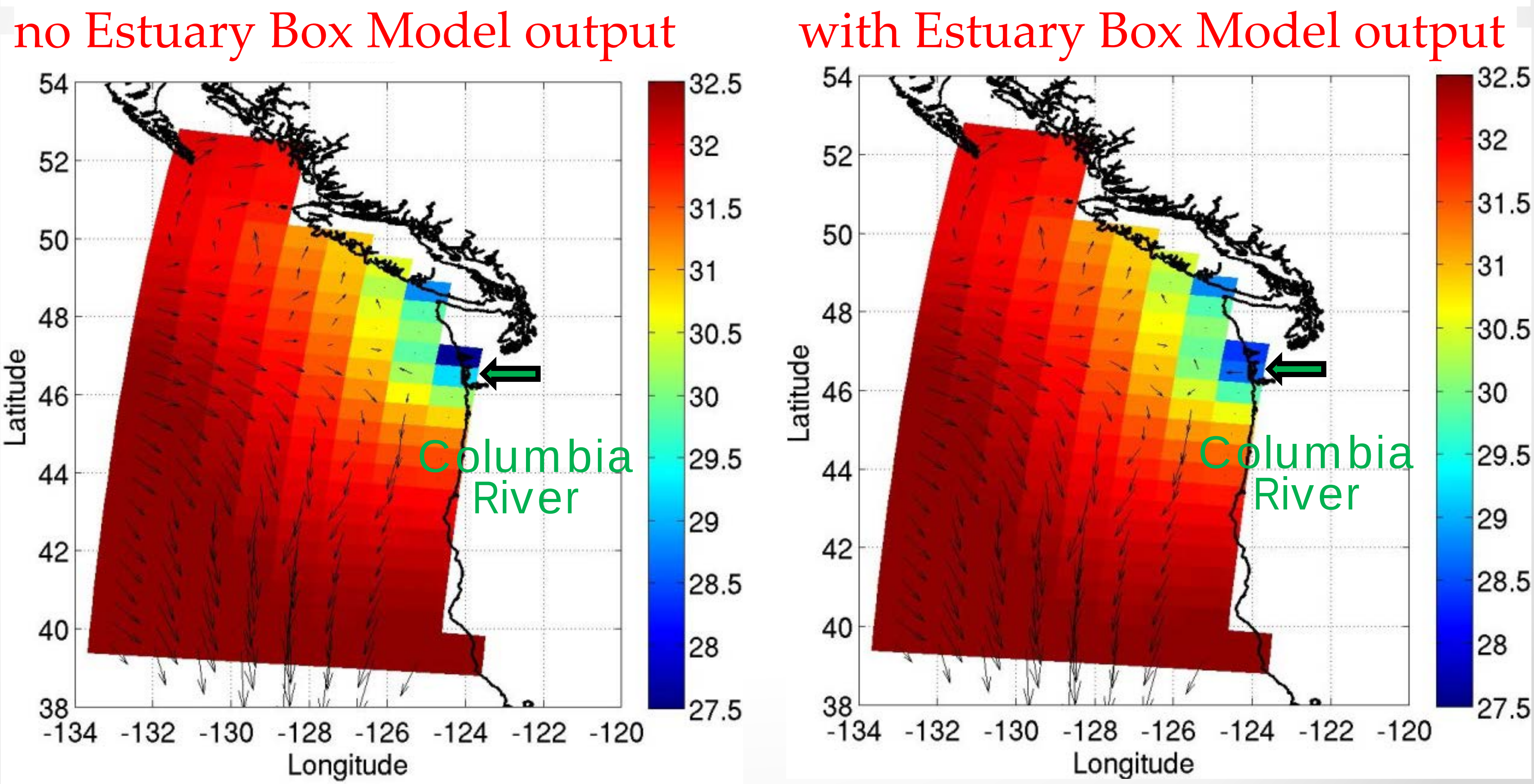
Off-line Estuary Box Model-validation with observation



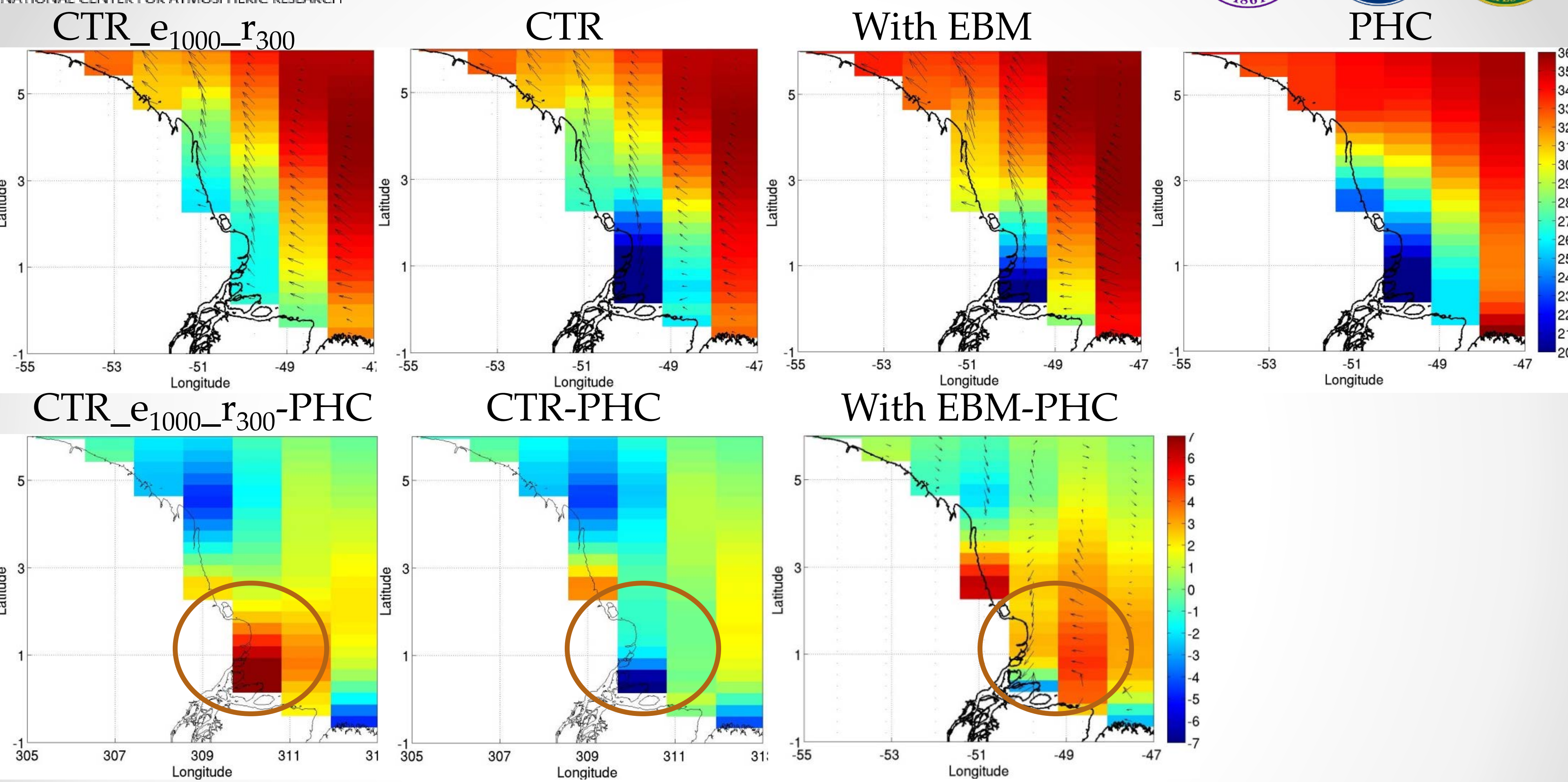
Interactive Estuary Box Model (coupled with POP)

- Apply Box Model in the CESM
  (http://www.cgd.ucar.edu/staff/ytseng/research/Salinity/main.html#ESP)

CESM surface ocean salinity and velocity vector (annual mean)



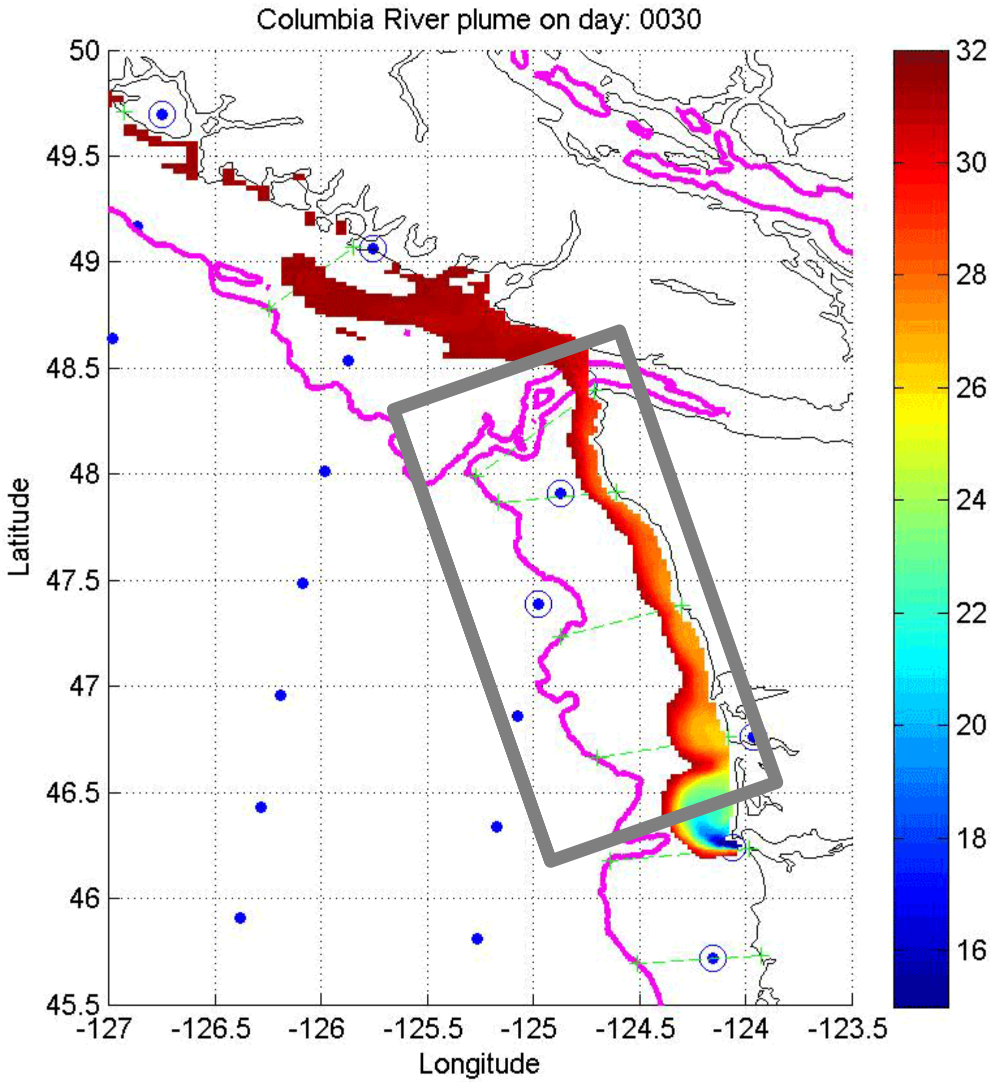
Amazon

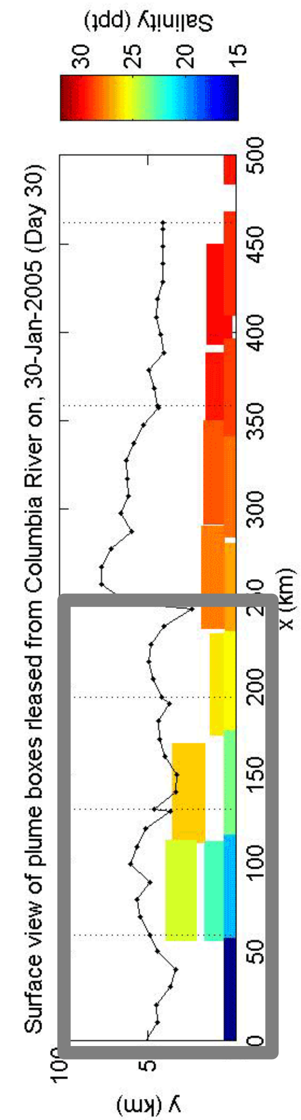


Summary of the estuary box model

- The estuary Box Model agrees well with observation in the Columbia River estuary.
- Surface salinity distribution at river mouth is obviously improved with estuary Box Model, but we need to introduce the shelf Box Model for more realistic salinity distributions on the shelf ocean.

Off-line Shelf Box Model-validation with ROMS



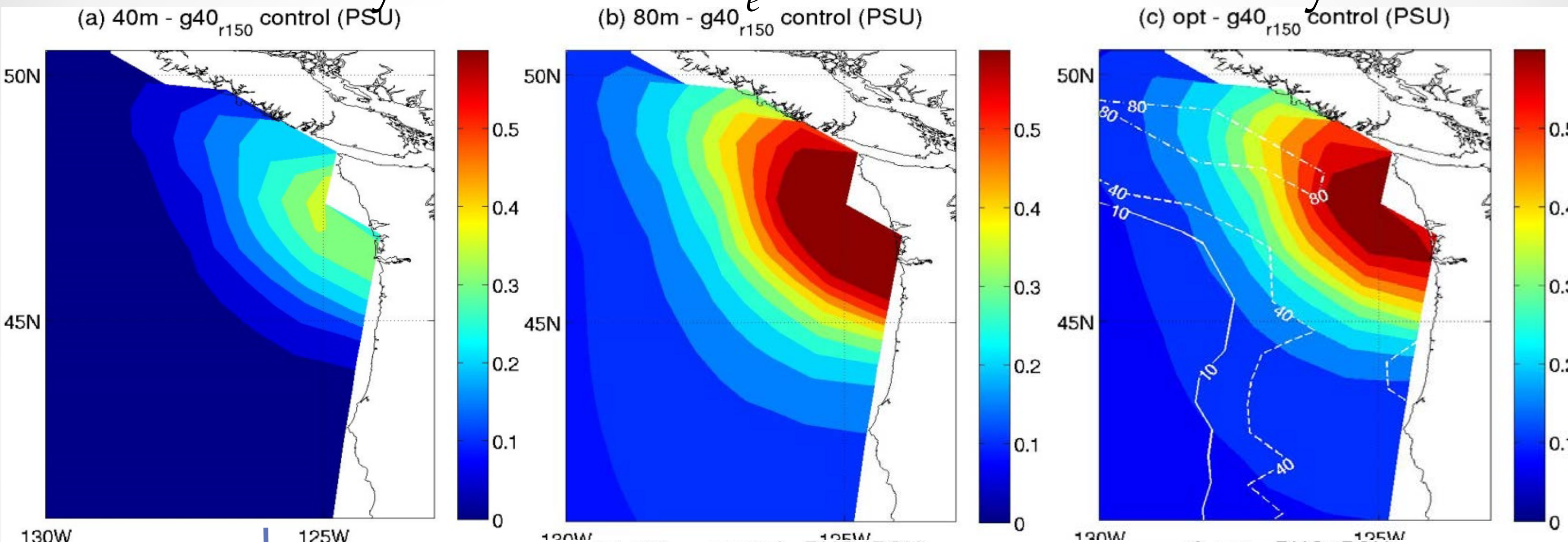


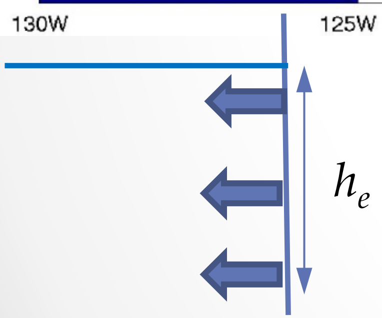
Conclusion and future……

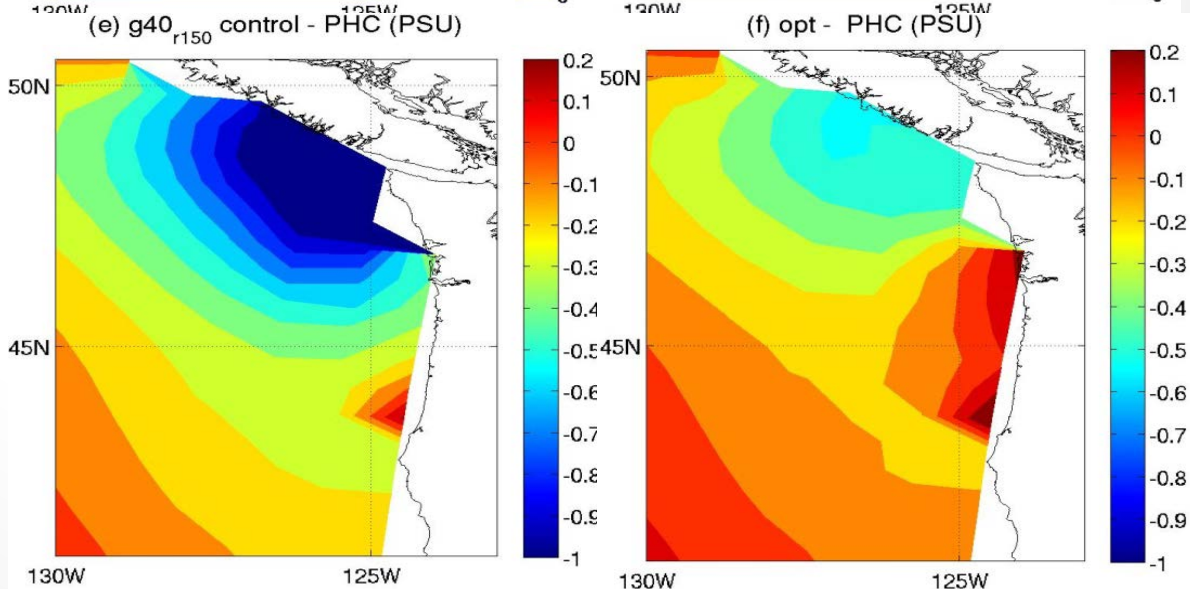
- The estuary box model is implemented and tested for Amazon and Columbia (offline and online coupled with POP)
- Parameters for different rivers are being estimated and examined (Congo and Mississippi rivers are done!)
- Top 20 rivers will be included and analyzed/compared
- The model framework of shelf box model is completed. It will be included and tested soon after the offline validation is completed (2014 summer)
- Validation/generalization ready for CESM2 (2014 winter)

Improved "augmented precipitation"

Sensitivity of different h_e on the surface salinity







30-year g40 average surface salinity.

- **Columbia**

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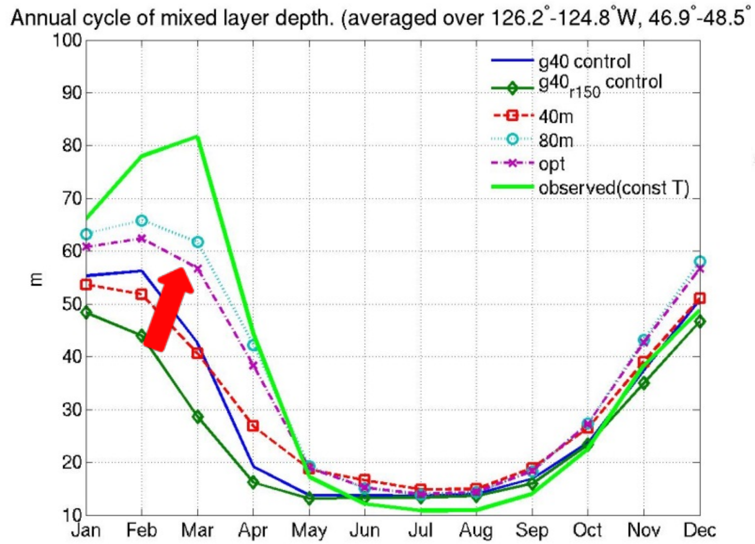
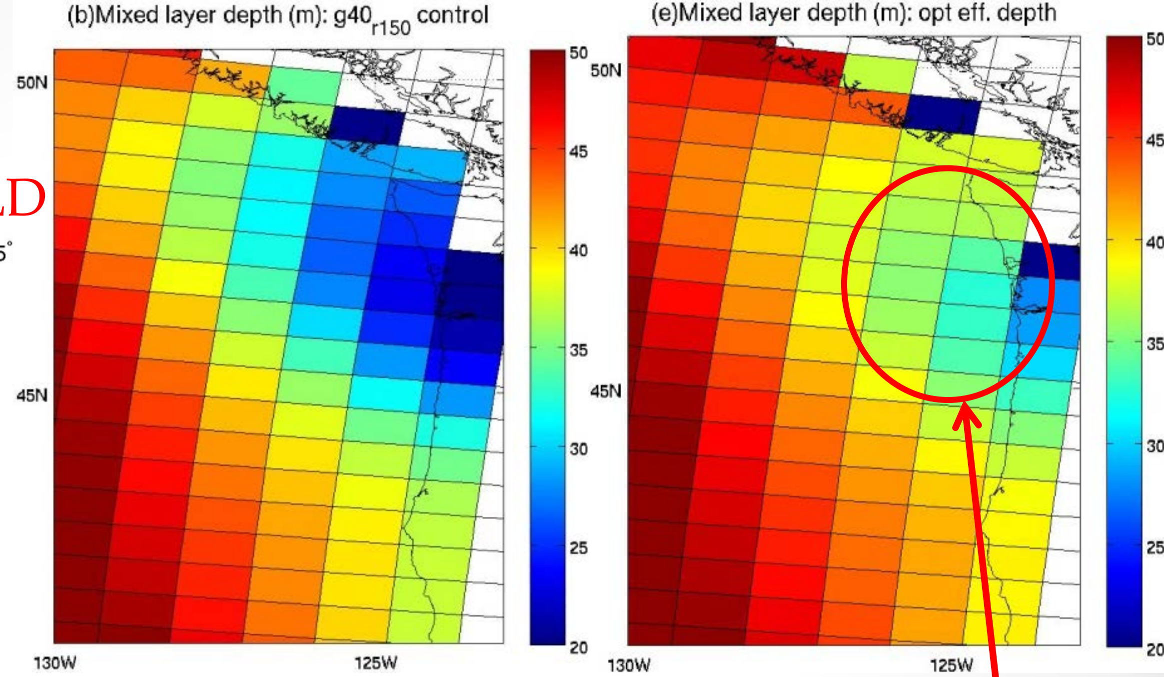
Significant improvement in MLD





mixed layer depth (MLD)

Enhanced MLD

Summary of the global impacts

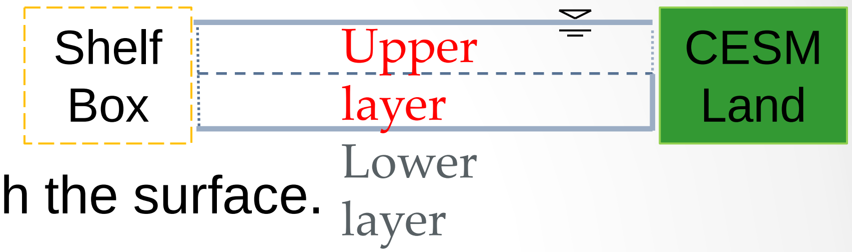
- A reduction of ~8% of the surface salinity biases in coastal region
- Main improvement occurs in April-June (~12% in g40 simulation)
- Similar improvement in the coupled b40 simulation than the g40 simulation but the magnitude is larger (due to a larger bias)
- Impacts are mostly local and influenced by the nearshore circulation (largest when h_e is comparable with the MLD), except the Arctic

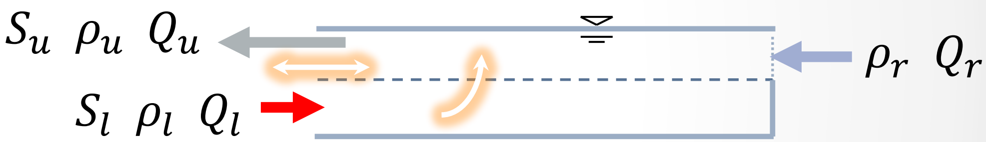
Detail in Poster 189 Whitney

Estuary Box Model

➢ Methodology

- A two-layer box with assumptions:
  Steady state and zeros net flux through the surface.





- Governing equations:

  Water mass flux conservation:

  $$\rho_r \cdot Q_r + \rho_l \cdot Q_l - \rho_u \cdot Q_u + m_t \cdot Q_{ut} \cdot (\rho_l - \rho_u) = 0$$

  Salt mass flux conservation:

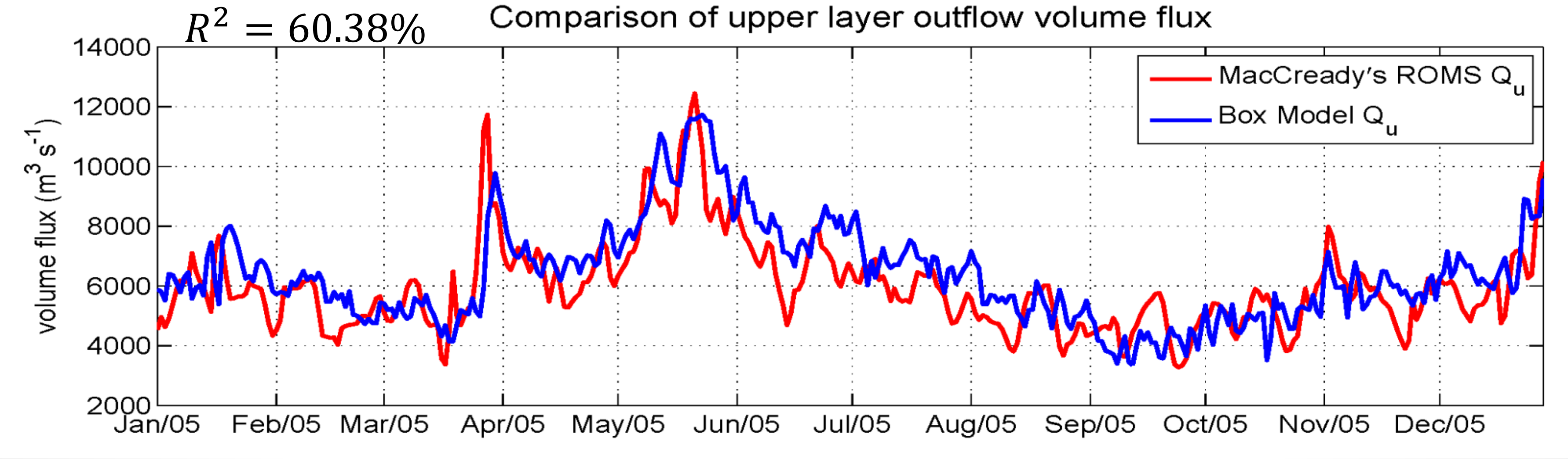
  $$S_l \cdot \rho_l \cdot Q_l - S_u \cdot \rho_u \cdot Q_u + m_t \cdot Q_{ut} \cdot (S_l \cdot \rho_l - S_l \cdot \rho_u) = 0$$

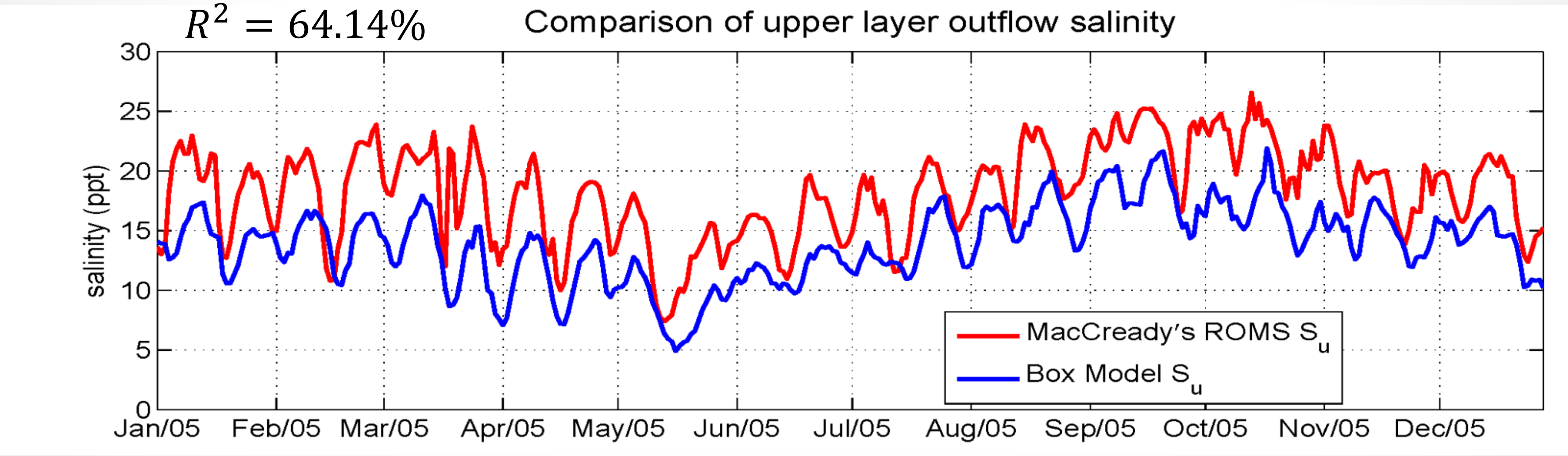
  Potential energy flux (PEF) conservation:

  $$PEF_r + PEF_l - PEF_u + PEF_t + PEF_{tp} = 0$$

Color:
Riverine water
Oceanic water
Estuarine water
Mixing & exchanging

Off-line Estuary Box Model-validation with ROMS





Conclusion and future……

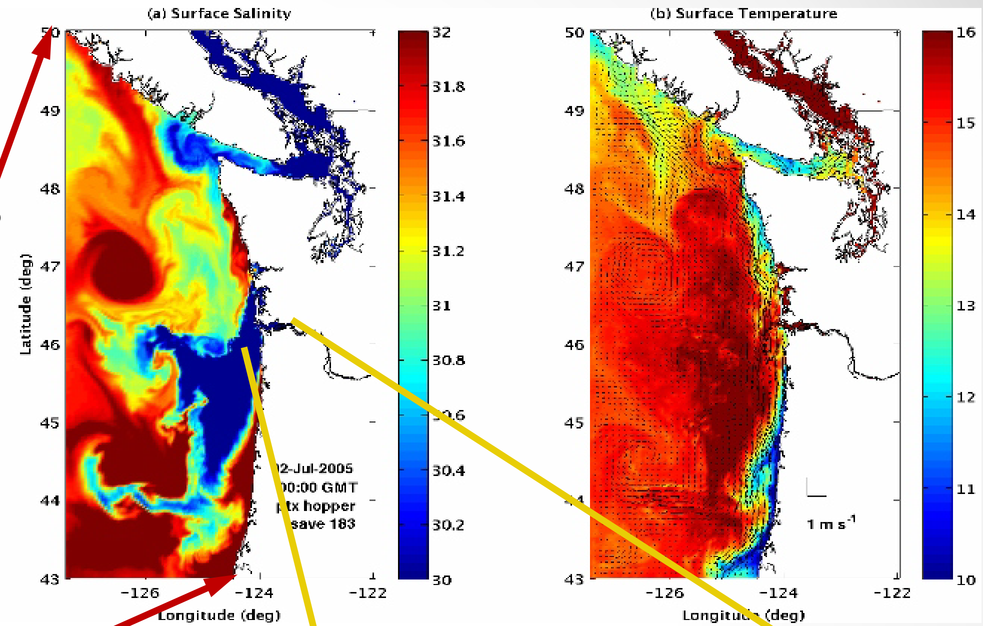
- A simplified estuary-shelf freshwater exchange parameterization is developed based on an augmented precipitation method (i.e., the optimal Runoff effective depth, h_R)
- Locally improved simulation due to vertical mixing with little difference in a global view
- Further complicated parameterization based on Estuary and shelf box models

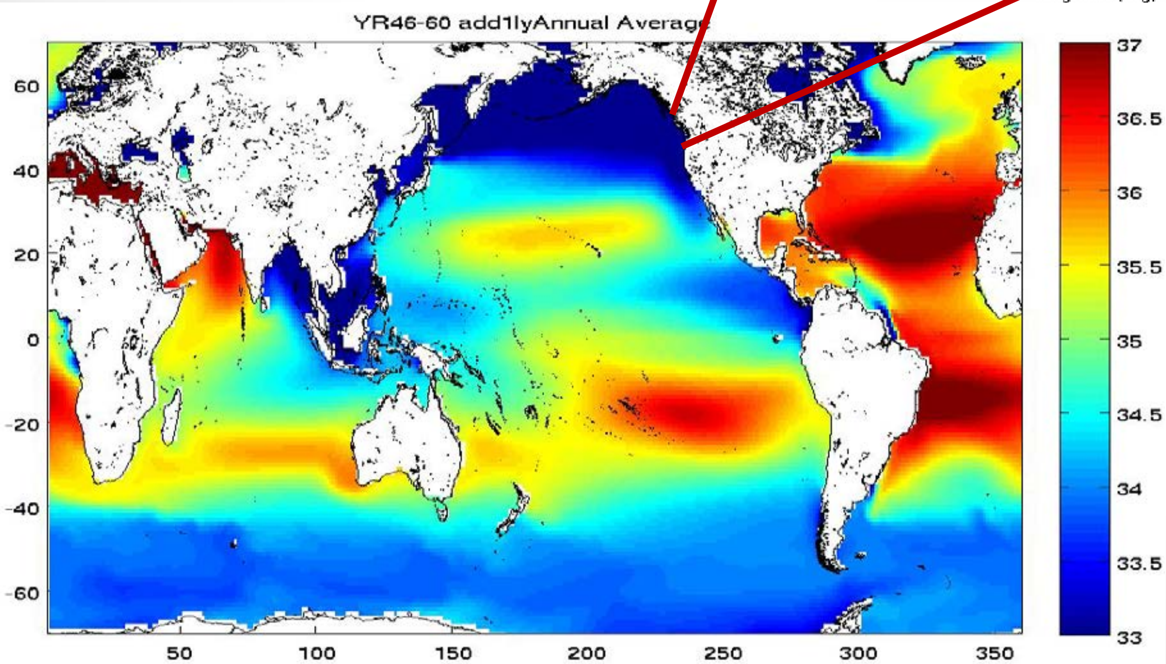
Why?

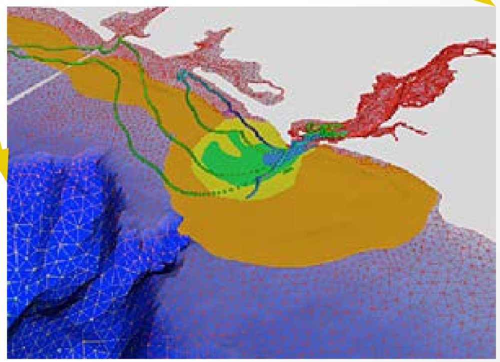
How are these features affected by climate?

Impacts of the nutrients and carbon from the river mouth

Require better representation of transport and mixing processes along the coast ->help the global simulation





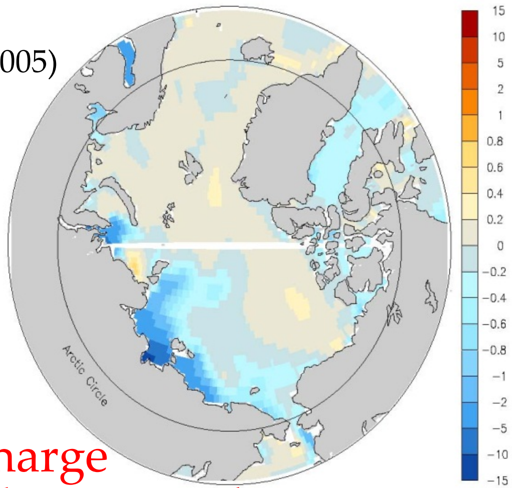


Human impacts: 40% population lives along the coast

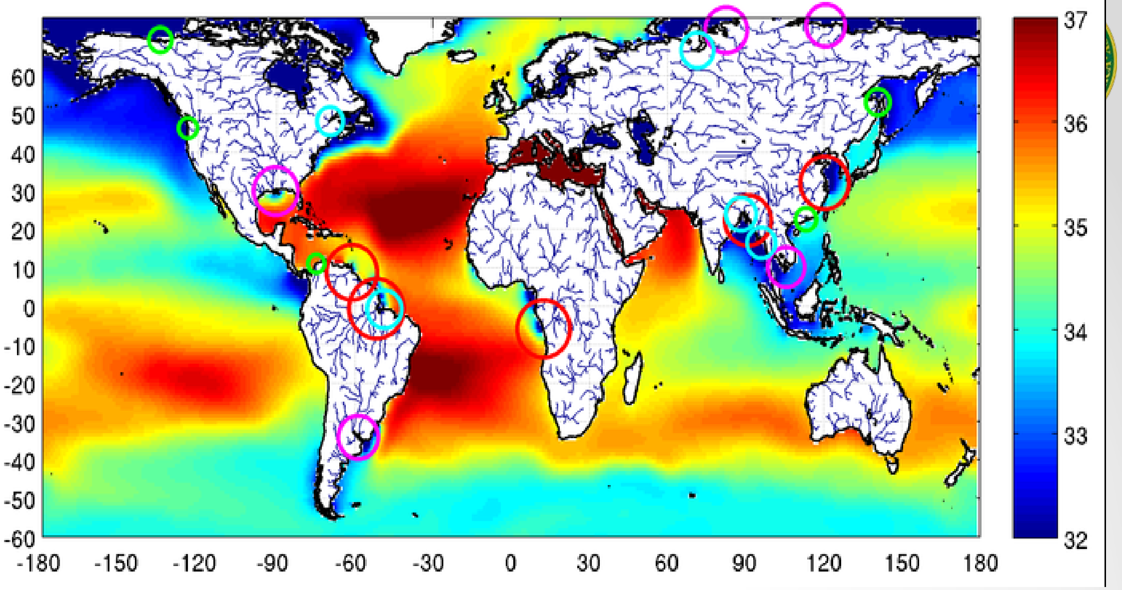
Why?

Salinity bias

Griffies et al. (2005)

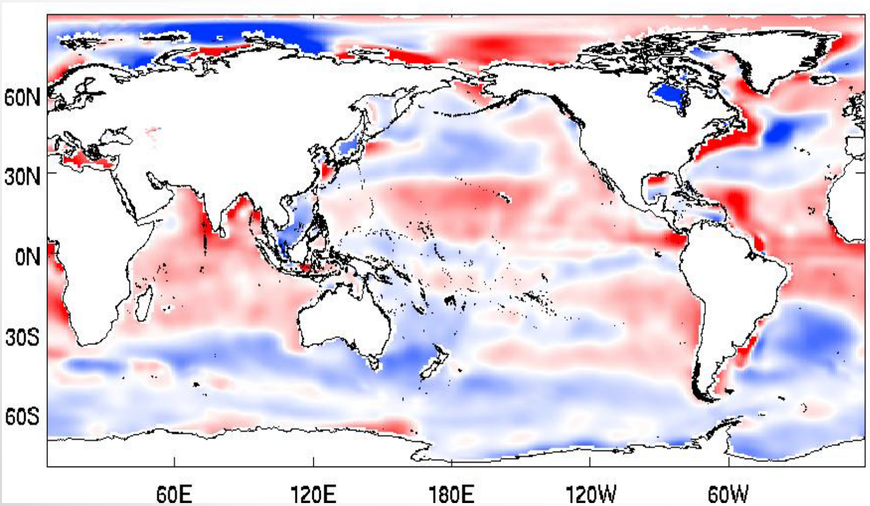


river discharge thickness h_r=40 m -> h_r=10m

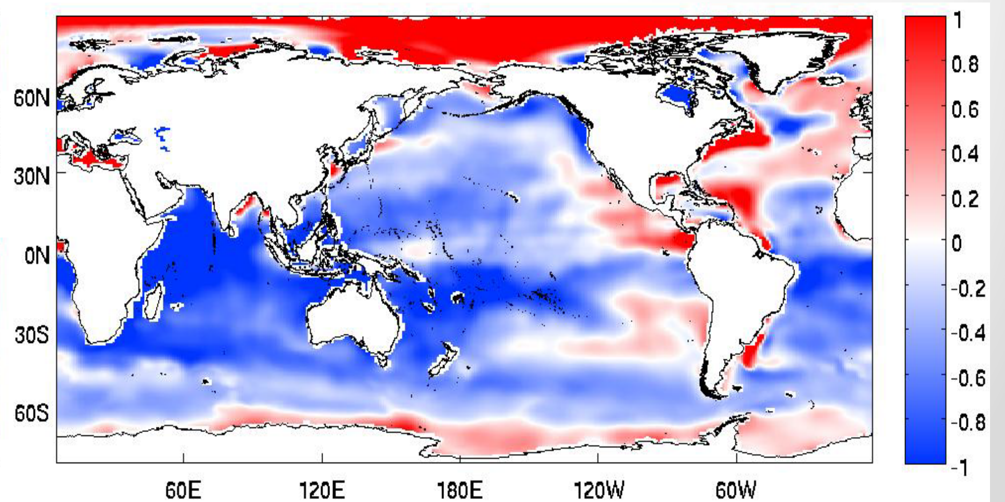


Salinity (WOA09 annual mean)

Larger bias in CCSM4



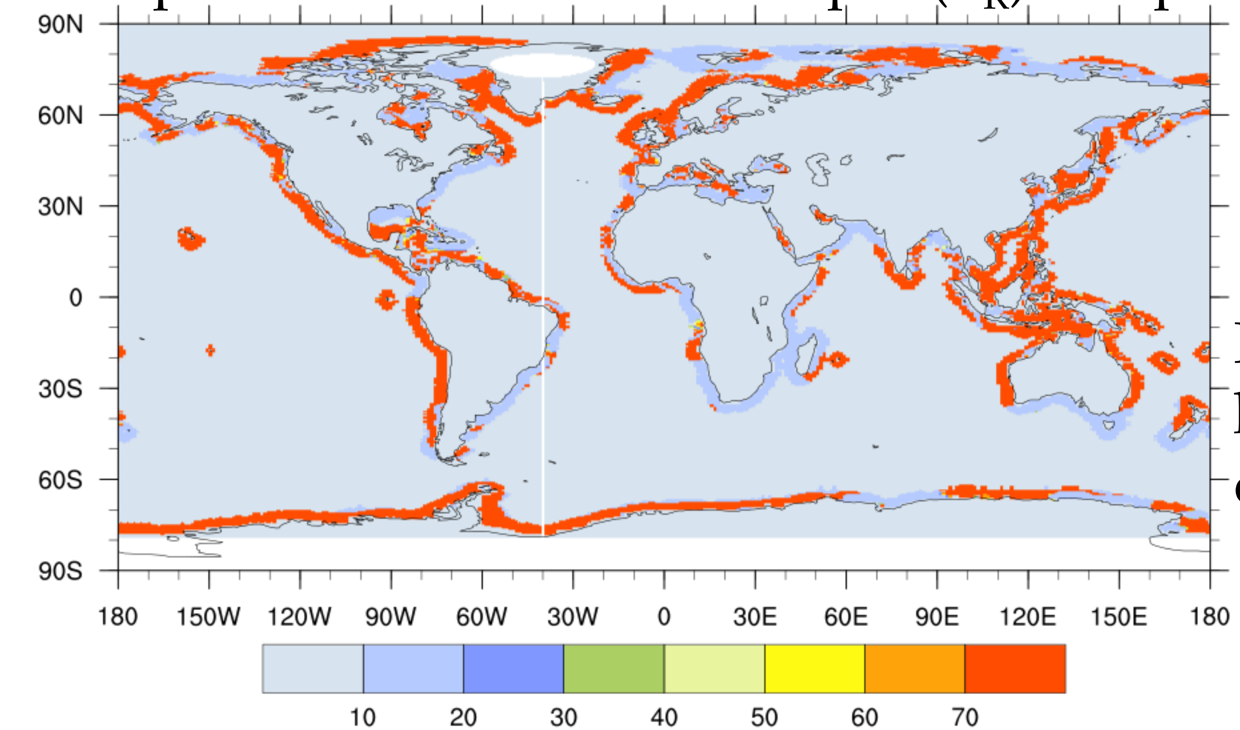
COREII forc. 1˚ POP



CCSM4 1˚ 20th Century Ens. #1 (1990-2005)

➢ Improved "augmented precipitation" scheme

- Actual river PE inputs often form slender coastal currents/plumes.
- Redistribute the runoff flux as a source term vertically by considering the change of available potential energy (APE)=$\Delta \varrho g z$
- Optimal Runoff effective depth (h_R) comparing with the PHC3



Runoff effective depth h_R can be determined by observation

- A reduction of ~8% of the surface salinity biases in coastal region
- main improvement occurs in April-June (~12% in g40 simulation)
- Impacts are mostly local and influenced by the nearshore circulation.

	Global (65N south) ERR/RMS ERR (Annual mean)	Arctic (65N north) ERR/RMS ERR (Annual mean)	Coastal ERR/RMS ERR (Annual mean)	Coastal ERR/RMS ERR (Jan-Mar)	Coastal ERR/RMS ERR (Apr-Jun)	Coastal ERR/RMS ERR (Jul-Sep)	Coastal ERR/RMS ERR (Oct-Dec)
g40 control	0.068/0.365	-0.040/0.656	0.041/0.709	-0.018/0.742	0.019/0.720	0.072/0.932	0.090/0.819
$g40_{r150}$ control	-0.016/0.366	-0.103/0.647	-0.054/0.732	-0.109/0.741	-0.075/0.796	-0.029/0.940	-0.003/0.841
g40 opt.	0.068/0.355	-0.037/0.625	0.041/0.676	-0.026/0.706	-0.025/0.702	-0.084/0.866	-0.081/0.813
b40 control	-0.393/0.769	0.382/1.090	-0.247/1.307	-0.275/1.268	-0.287/1.306	-0.22/1.559	-0.204/1.345
$b40_{r150}$ control	-0.392/0.764	0.328/1.068	-0.285/1.311	-0.305/1.262	-0.330/1.349	-0.271/1.574	-0.236/1.353
b40 opt.	-0.387/0.766	0.355/1.011	-0.237/1.271	-0.280/1.253	-0.282/1.275	-0.189/1.500	-0.198/1.333

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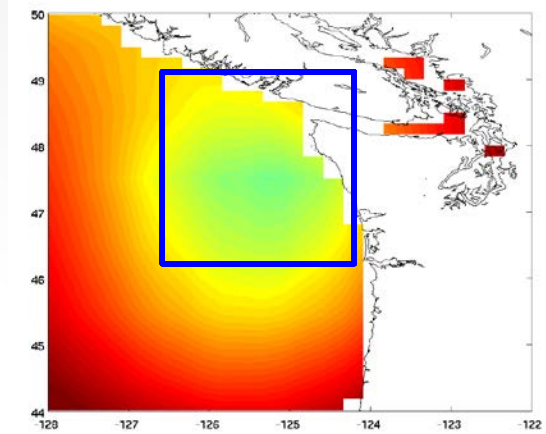
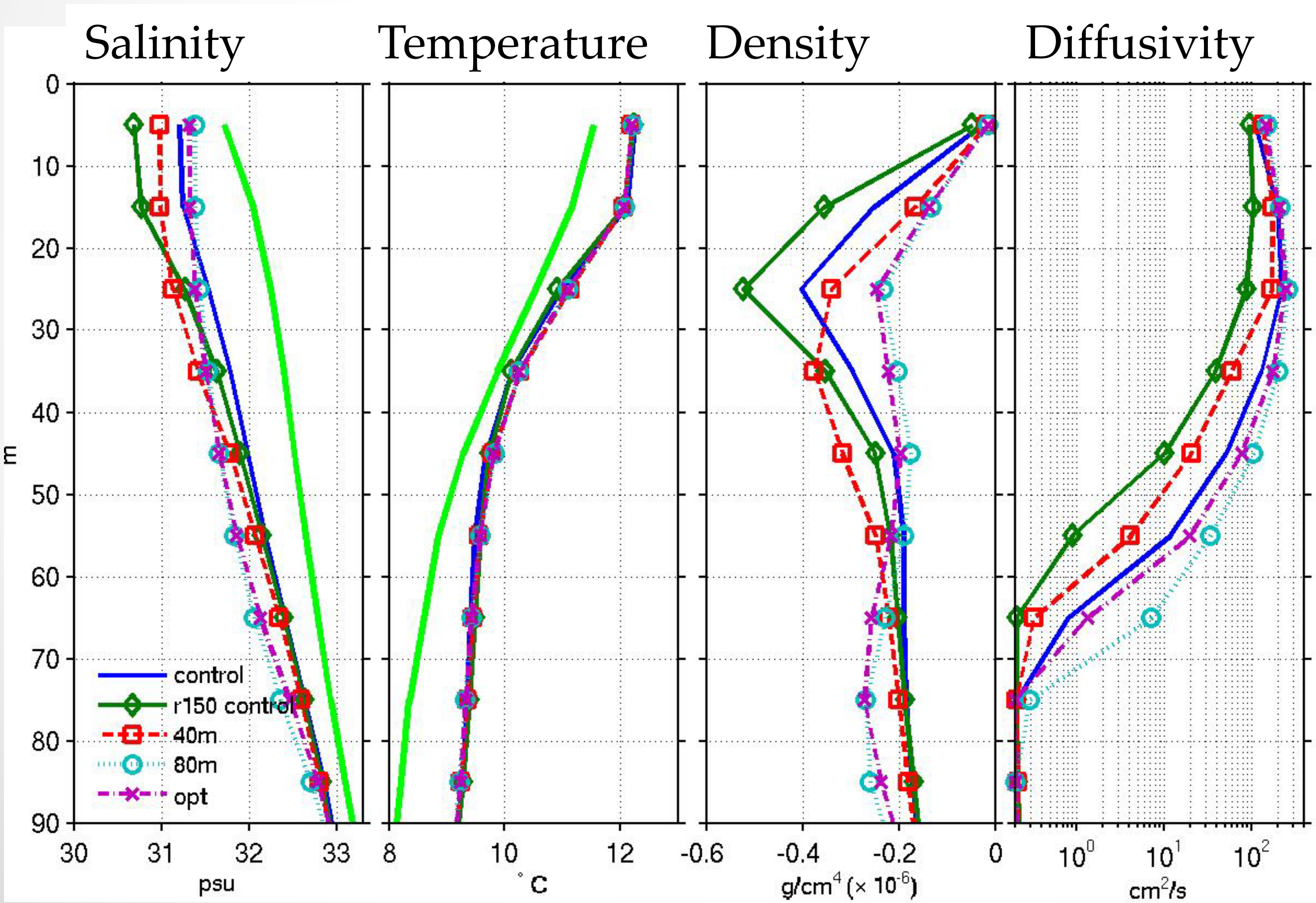


Vertical profiles averaged over 126.2-124.8W, 46.9-48.5N



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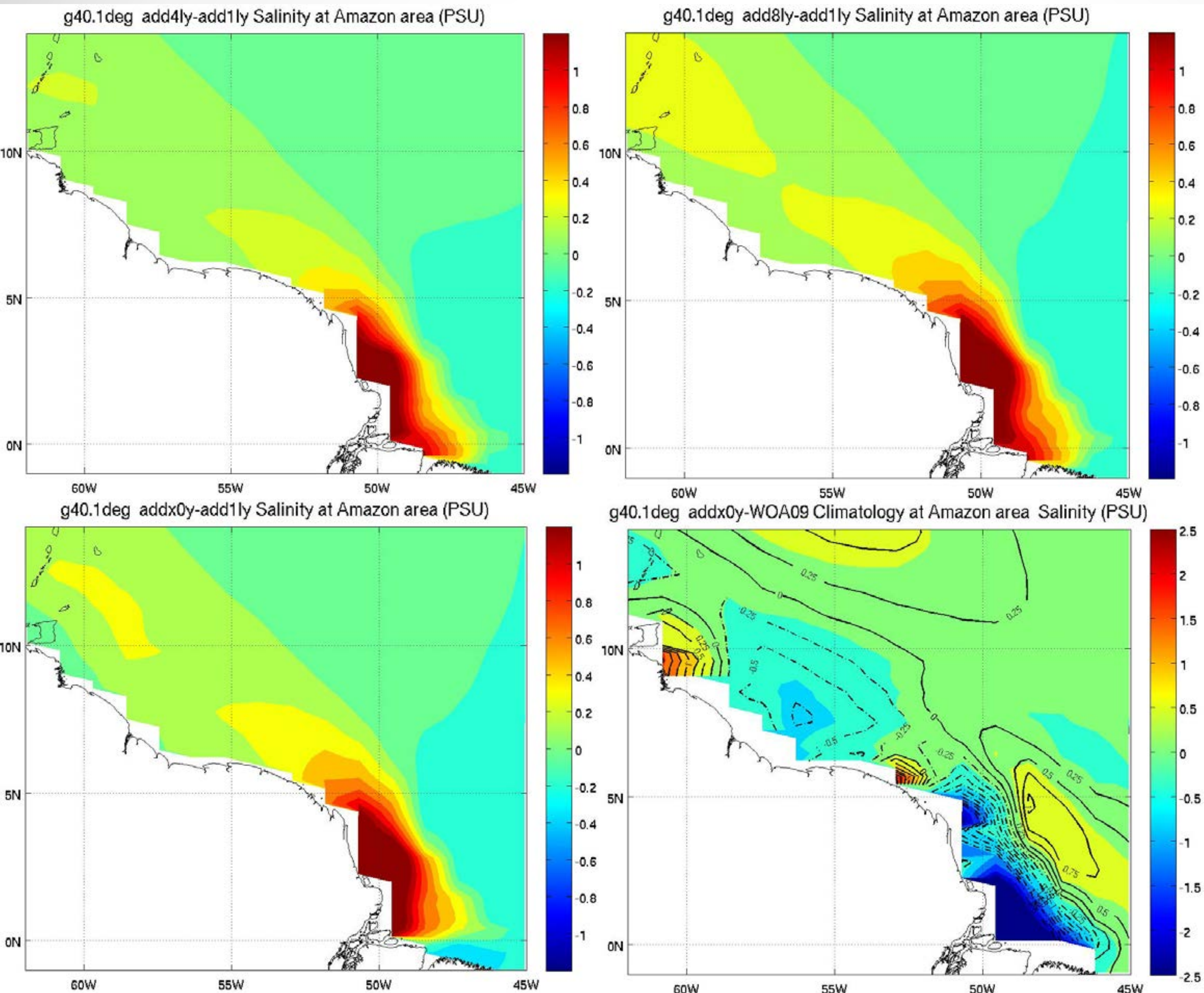
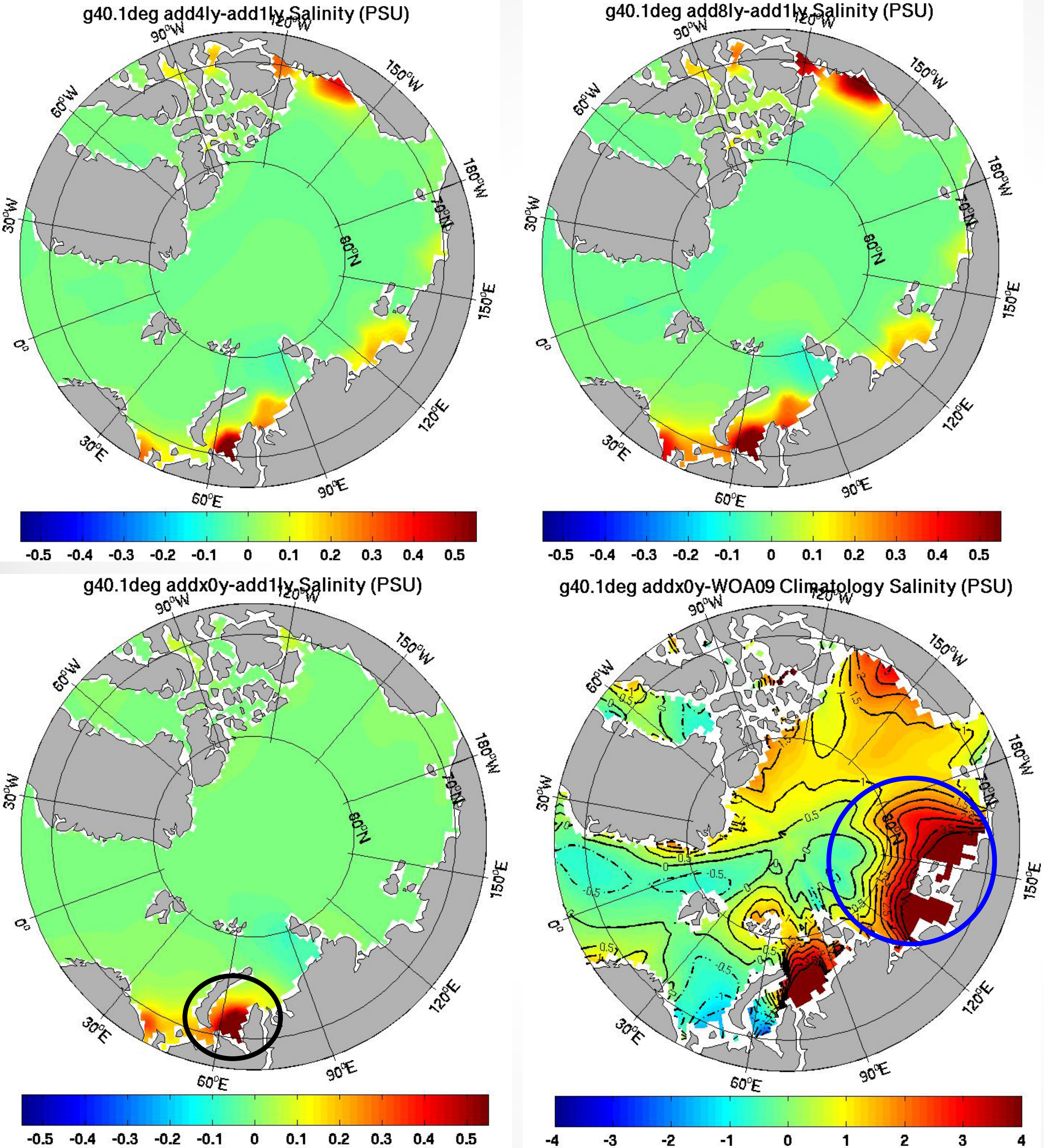
Sensitivity of different h_R on the surface salinity

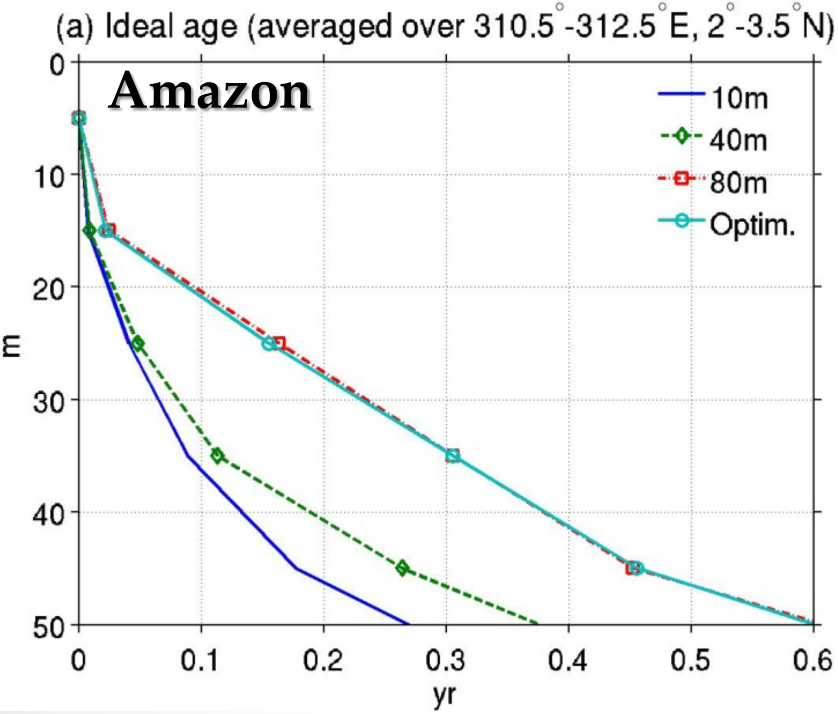


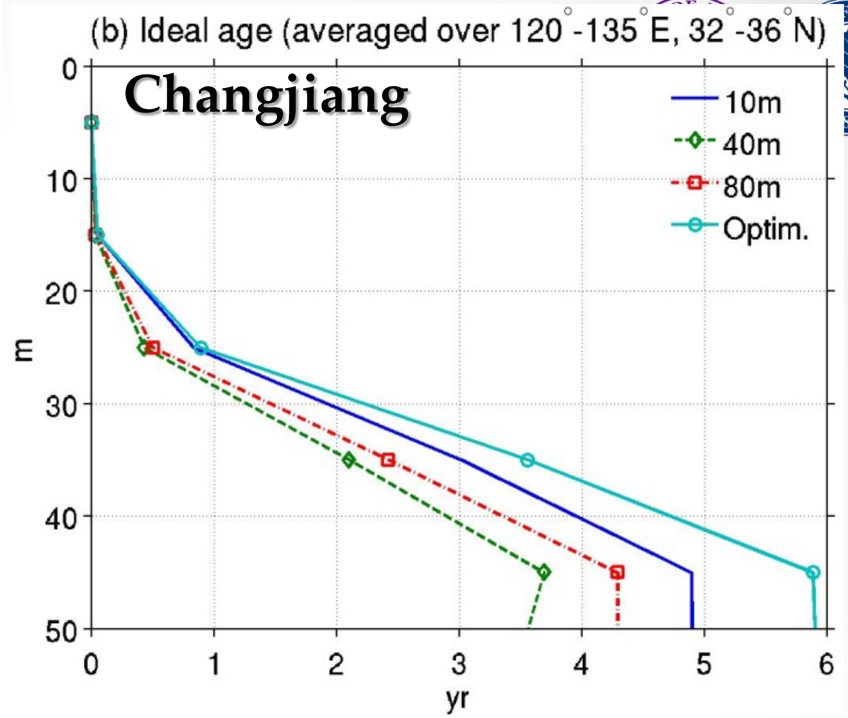
Amazon

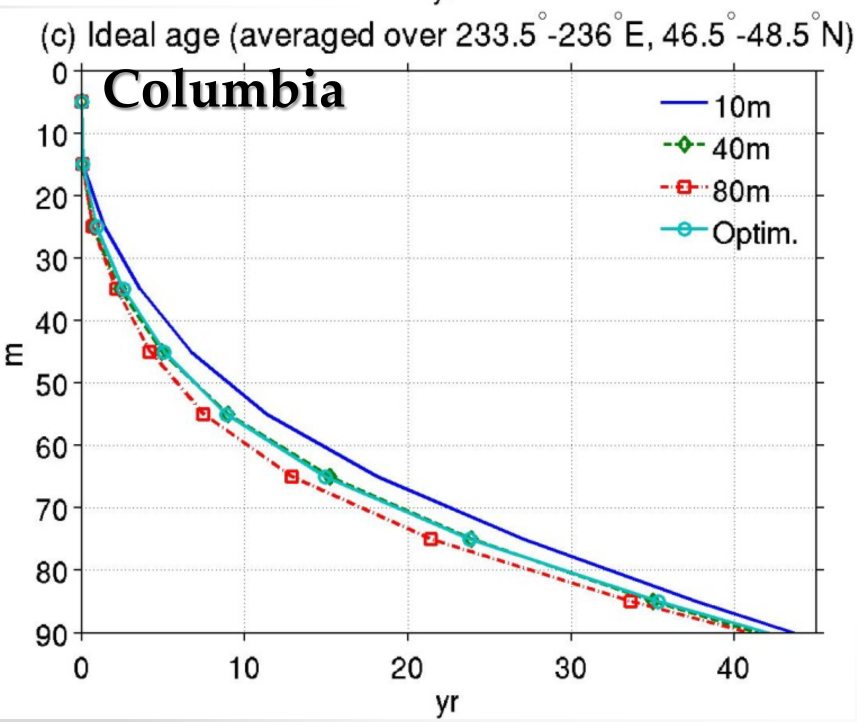


Arctic

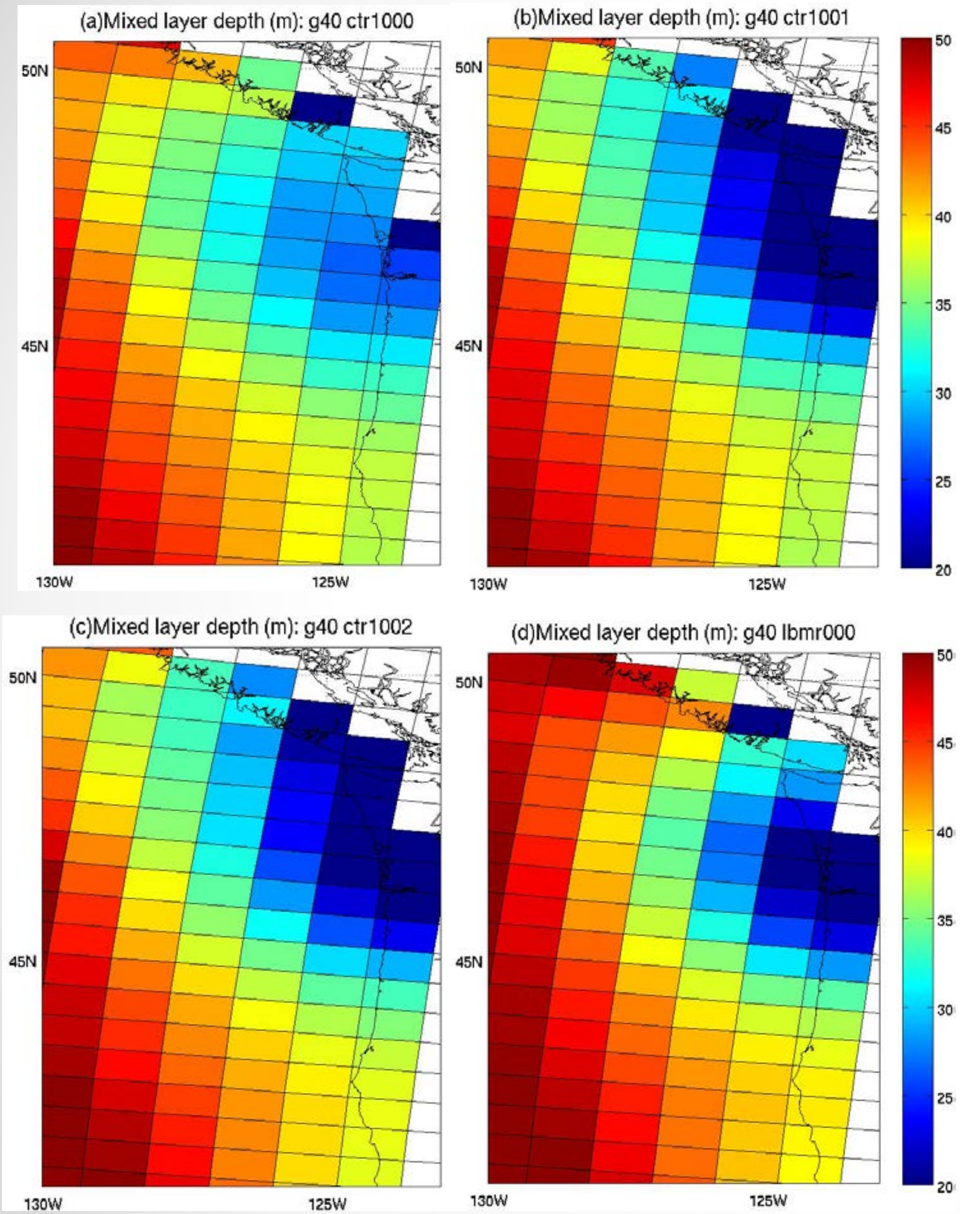
Large warm bias cannot be corrected

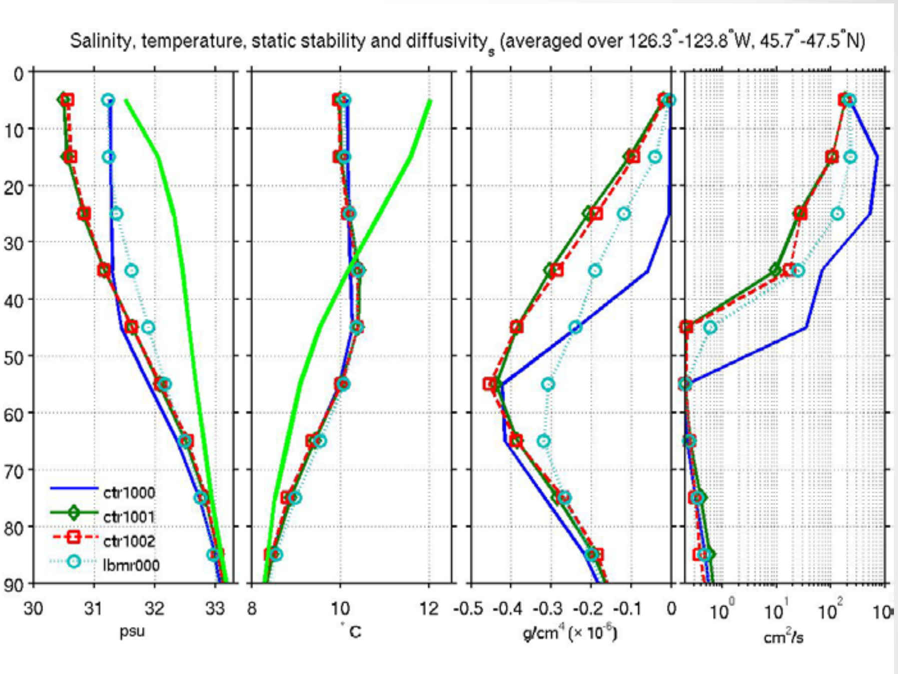






Ideal age in the coupled simulations

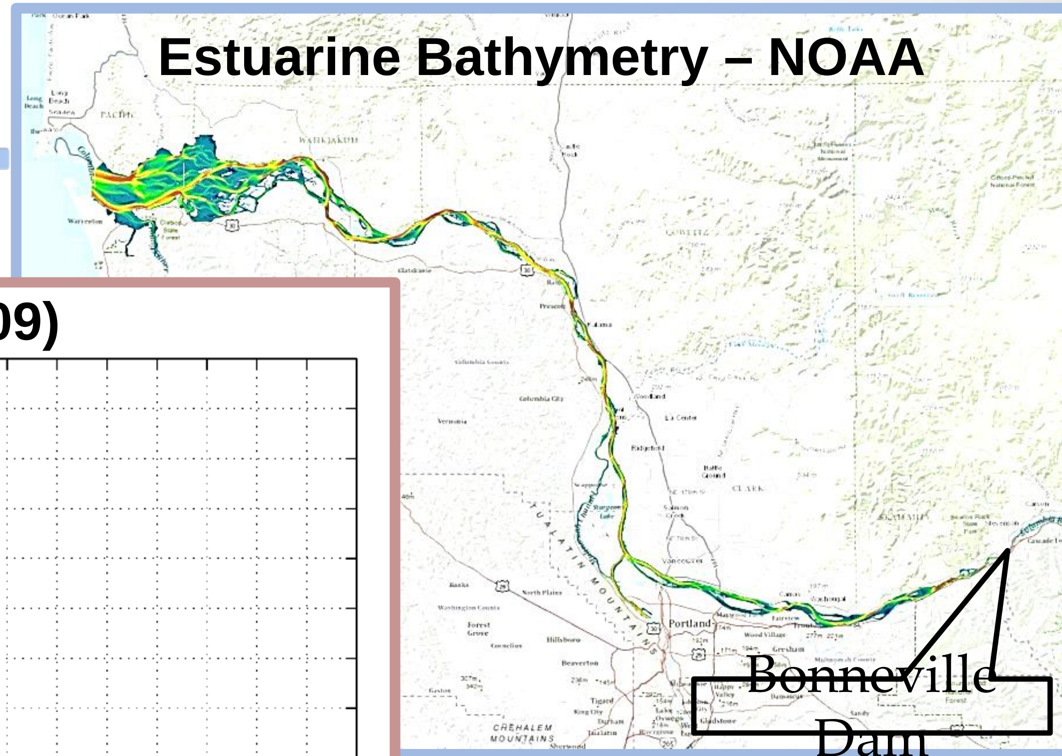

(a)Mixed layer depth (m): g40 ctr1000
(b)Mixed layer depth (m): g40 ctr1001
(c)Mixed layer depth (m): g40 ctr1002
(d)Mixed layer depth (m): g40 lbmr000
50N
45N
130W
125W
50
45
40
35
30
25
20

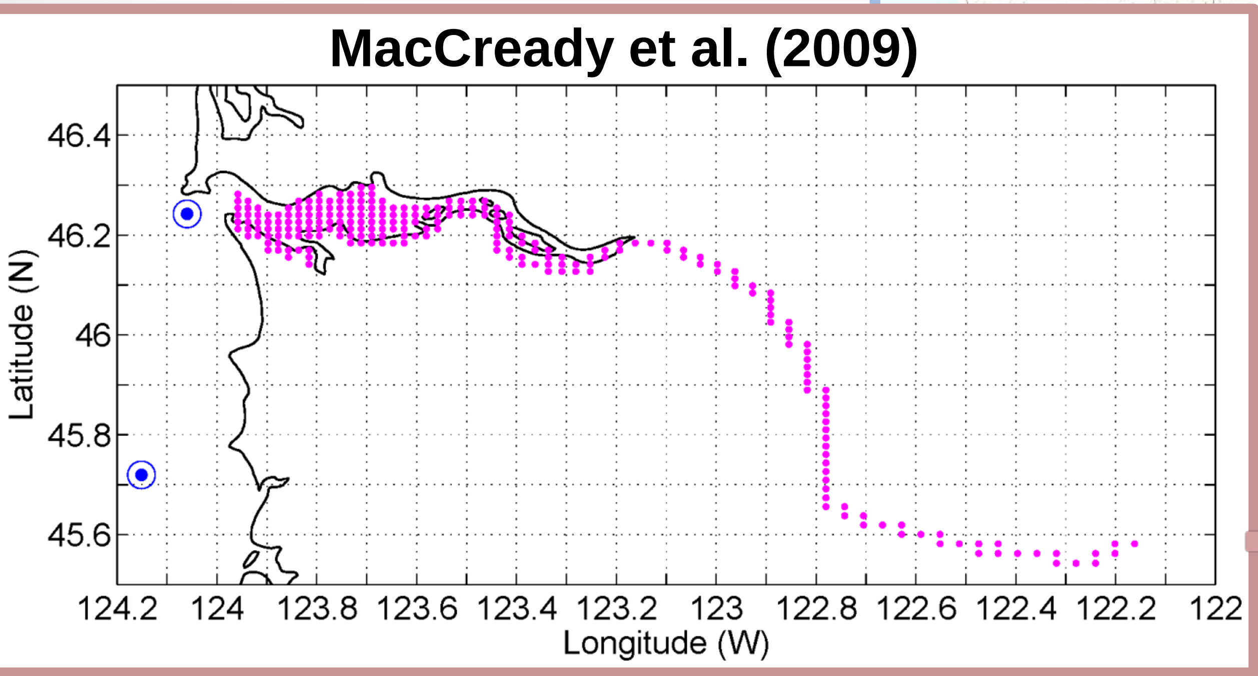

Salinity, temperature, static stability and diffusivity$_s$ (averaged over 126.3°-123.8°W, 45.7°-47.5°N)
m
ctr1000
ctr1001
ctr1002
lbmr000
psu
°C
g/cm^4 (× 10^{-6})
cm^2/s

Estuary Box Mo

- Comparison

Box Model:
Length=220 (km)
Width=2.41 (km)
height=4(m)

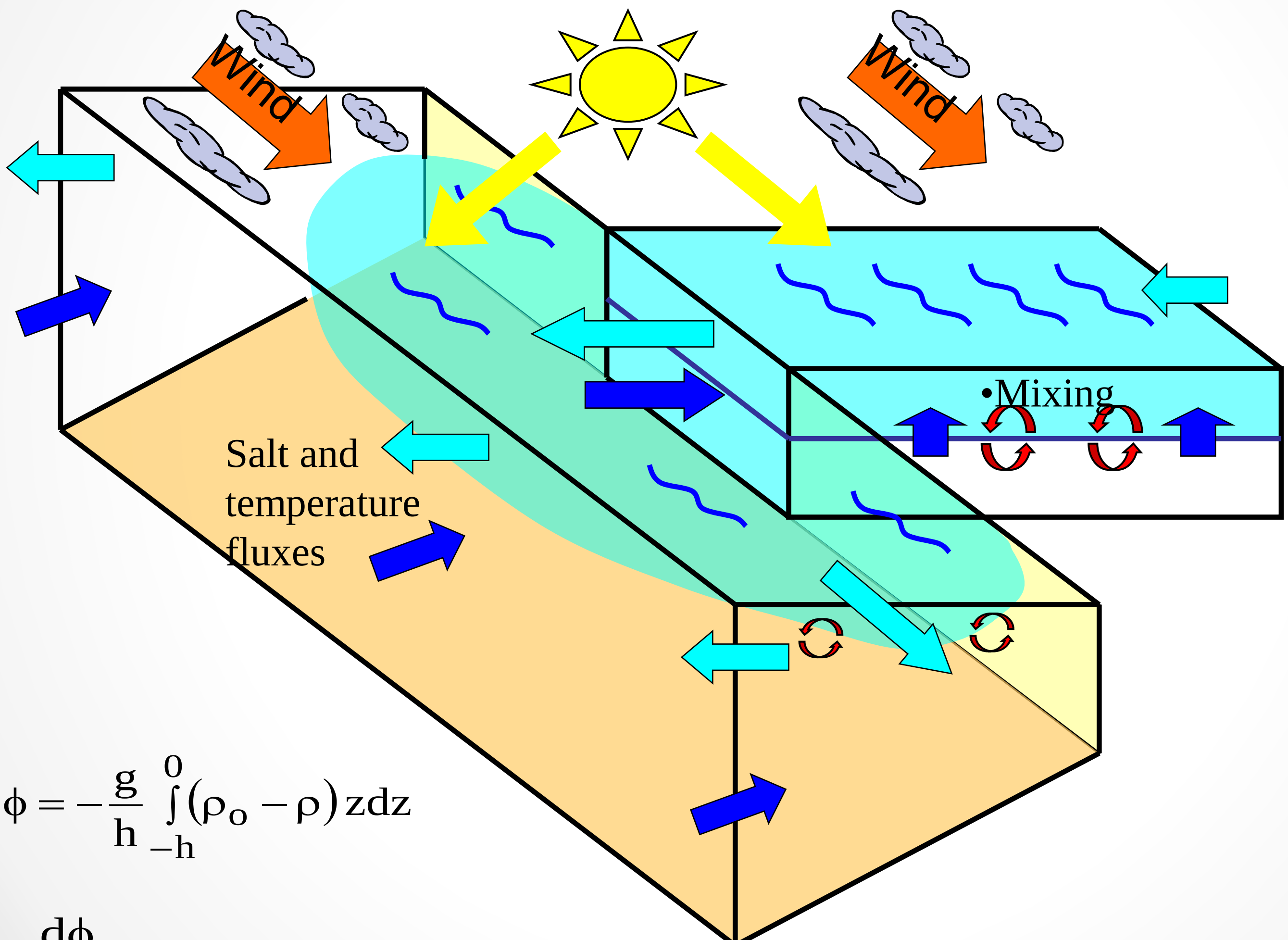




ROMS:
246 horizontal grids
40 vertical layers

How?

Estuary and shelf box model



$$\phi = -\frac{g}{h}\int_{-h}^{0}(\rho_o - \rho)\,z\,dz$$

$$A\frac{d\phi}{dt} = \Omega_{Buoyant} + \Omega_{Heatflux} + \Omega_{Tidal} + \Omega_{Wind}$$

Approach by Garvine and Whitney (2006), Hordoir et al. (2008)

Shelf Box Model

- Methodology
  - Buoyancy-driven situation
  - Upwelling wind driven situation
  - Wind relaxed situation