Implementing an Estuary Mixing Parameterization in CESM

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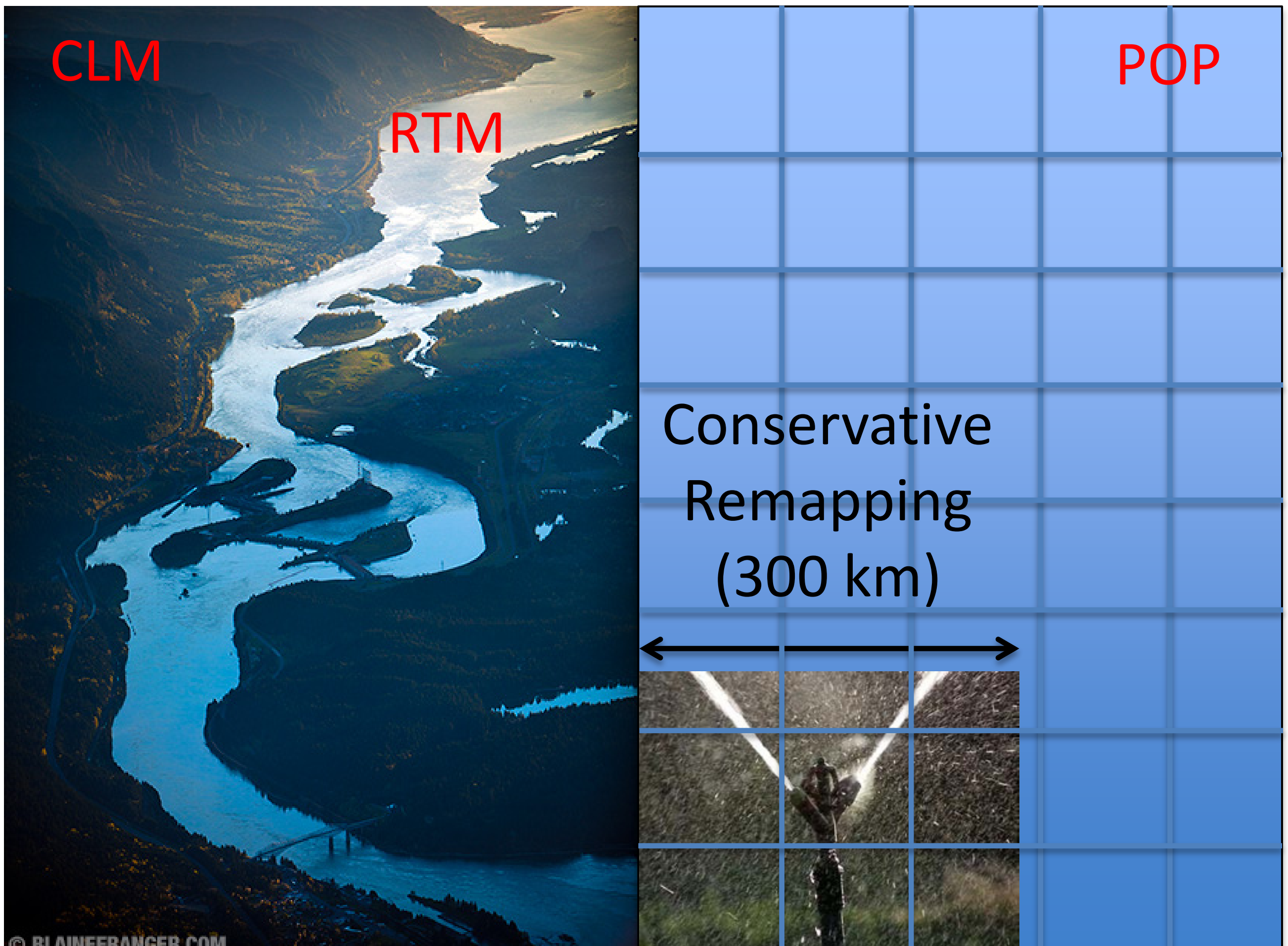
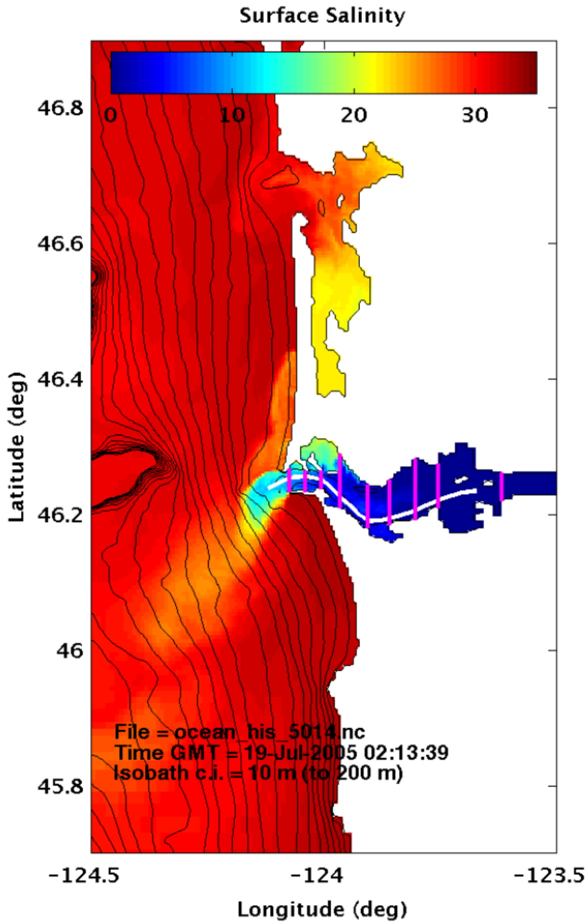
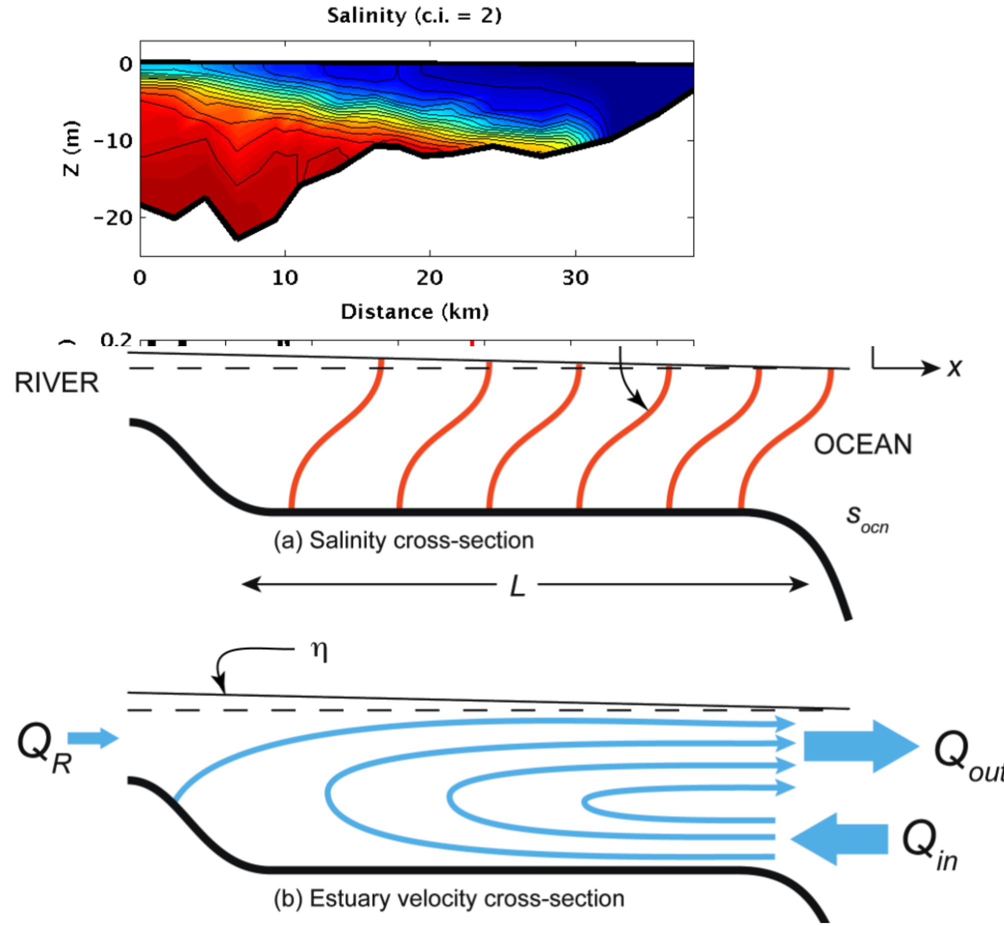
(A) Representation of Estuaries in CESM-1

Green Douglas firs where the waters cut through.
Down her wild mountains and canyons she flew.
Canadian Northwest to the ocean so blue,
Roll on, Columbia, roll on!   *W. Guthrie (1941)*



(B) Estuaries in Nature



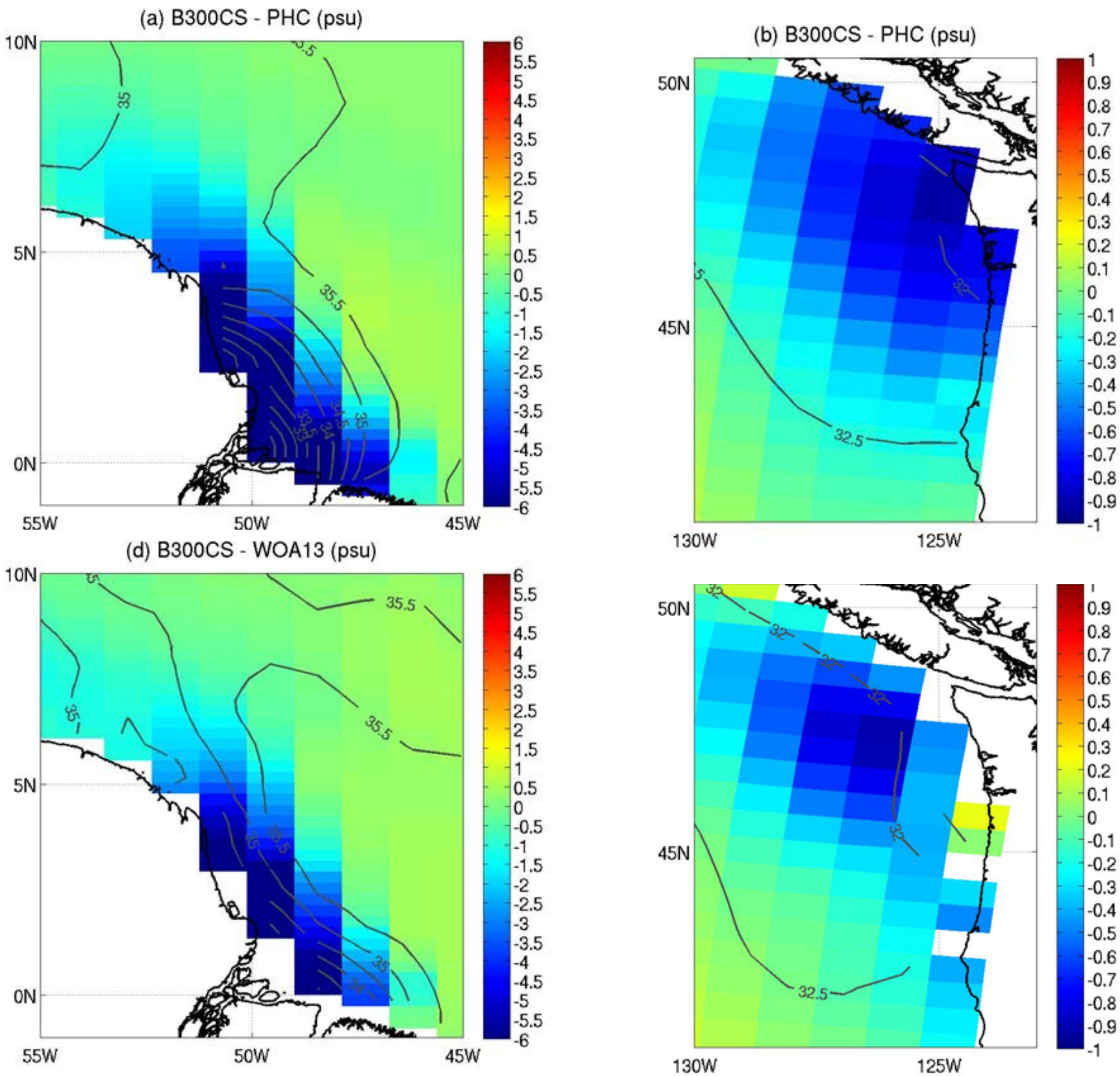


$Q_{out} > Q_R$ $S_{out} > 0$

Getting from (A) to (B)

1. Distributed Source → Point Source
2. Runoff ≠ Surface Buoyancy Flux
3. Errors associated with virtual salt flux (VSF)
4. Derivation of Estuary Box Model (EBM)
5. VSF compatible implementation of EBM
6. Vertical distribution of riverine freshwater input
7. Global deployment of EBM

Salinity Biases in Standard Model



Amazon

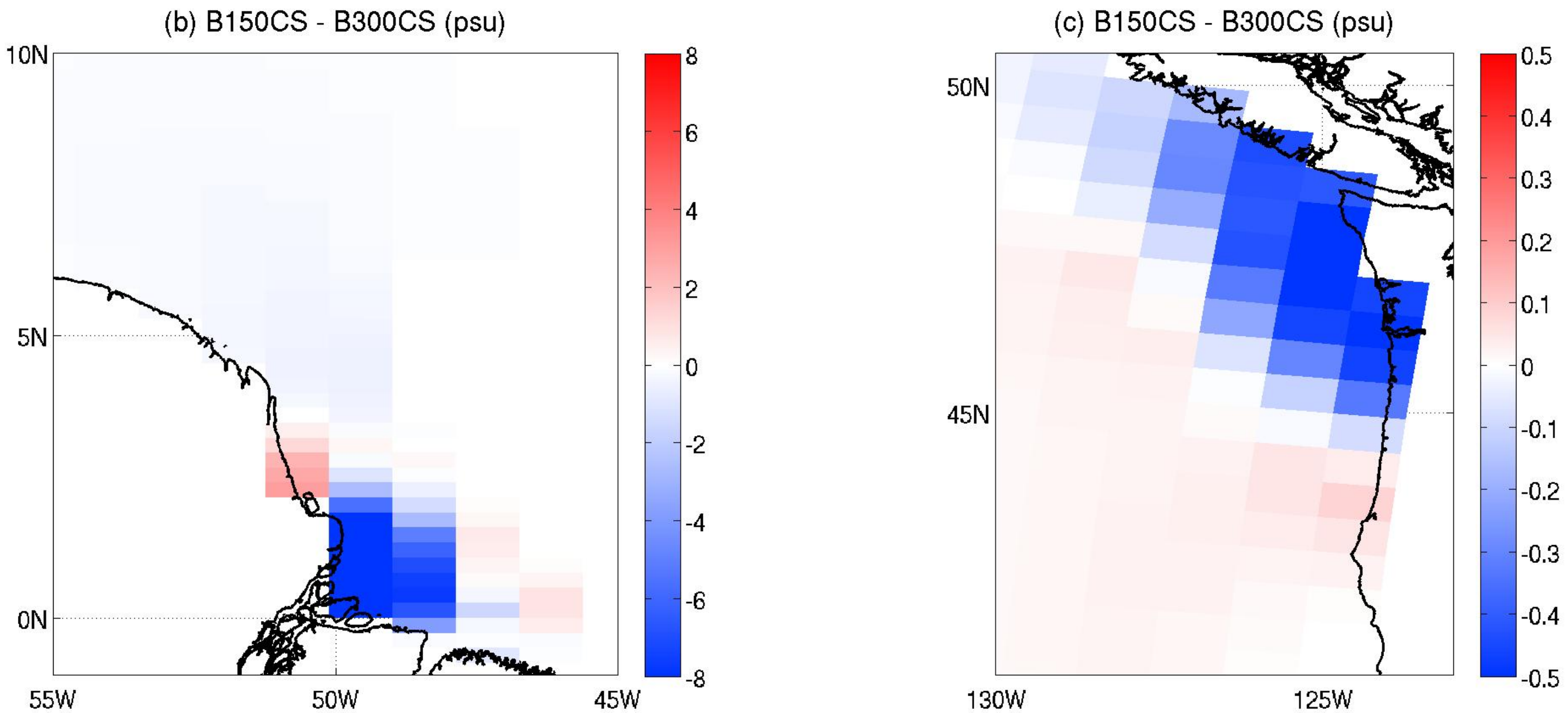
Columbia/Fraser

CORE-II IAF Run
Annual Mean
vs.

PHC

WOA13

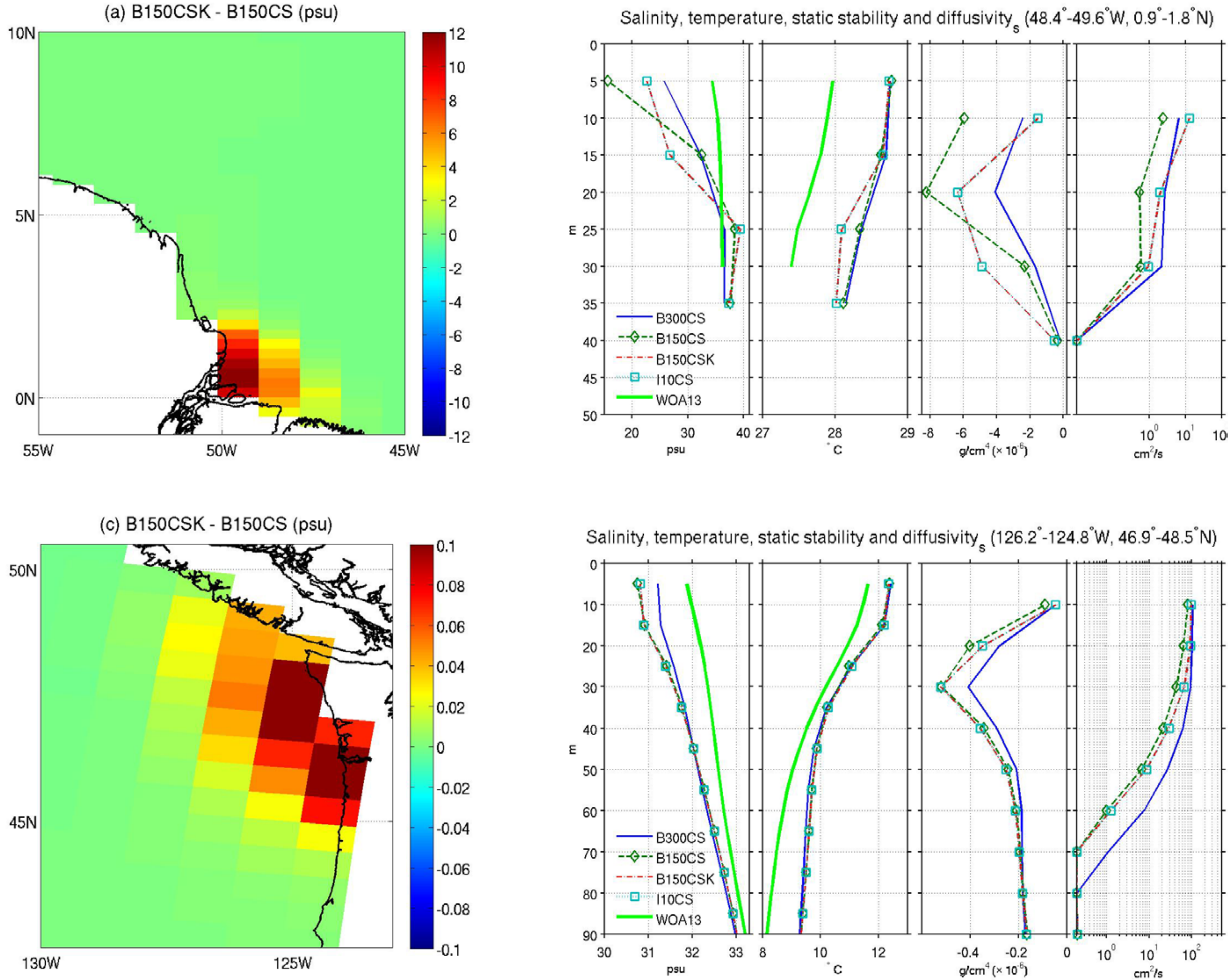
Reduced Spreading Radius
300 km ➔ 150 km



Fresh Bias Worsened

Impact of Including River Runoff in Surface Buoyancy Flux in KPP

- Boundary layer depth and mixing coefficients depend on surface buoyancy flux B_f through the Monin-Obukhov length scale and the convective velocity scale
- In standard CESM/POP runoff is included in the freshwater contribution to B_f
- In an estuary parameterization runoff is no longer considered a surface flux, so is excluded from B_f within KPP


(a) B150CSK - B150CS (psu)
10N
5N
0N
55W
50W
45W
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
Salinity, temperature, static stability and diffusivity$_s$ (48.4°-49.6°W, 0.9°-1.8°N)
m
psu
°C
g/cm^4 (× 10^{-6})
cm^2/s
B300CS
B150CS
B150CSK
I10CS
WOA13
(c) B150CSK - B150CS (psu)
50N
45N
130W
125W
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
Salinity, temperature, static stability and diffusivity$_s$ (126.2°-124.8°W, 46.9°-48.5°N)
m
psu
°C
g/cm^4 (× 10^{-6})
cm^2/s
B300CS
B150CS
B150CSK
I10CS
WOA13

Virtual Salt Flux and Global Salt Balance

Virtual Salt Flux:

$$\Delta S = -\frac{\Delta h}{h} S = -\frac{S_1}{dz_1}\left(P - E + R\right)$$

For global salt balance must take $S_1 = S_{ref}$ =const.=34.7:

$$\iint_{globe} \left(P - E + R\right) S_1 \, dA = S_{ref} \iint_{globe} \left(P - E + R\right) dA \simeq 0$$

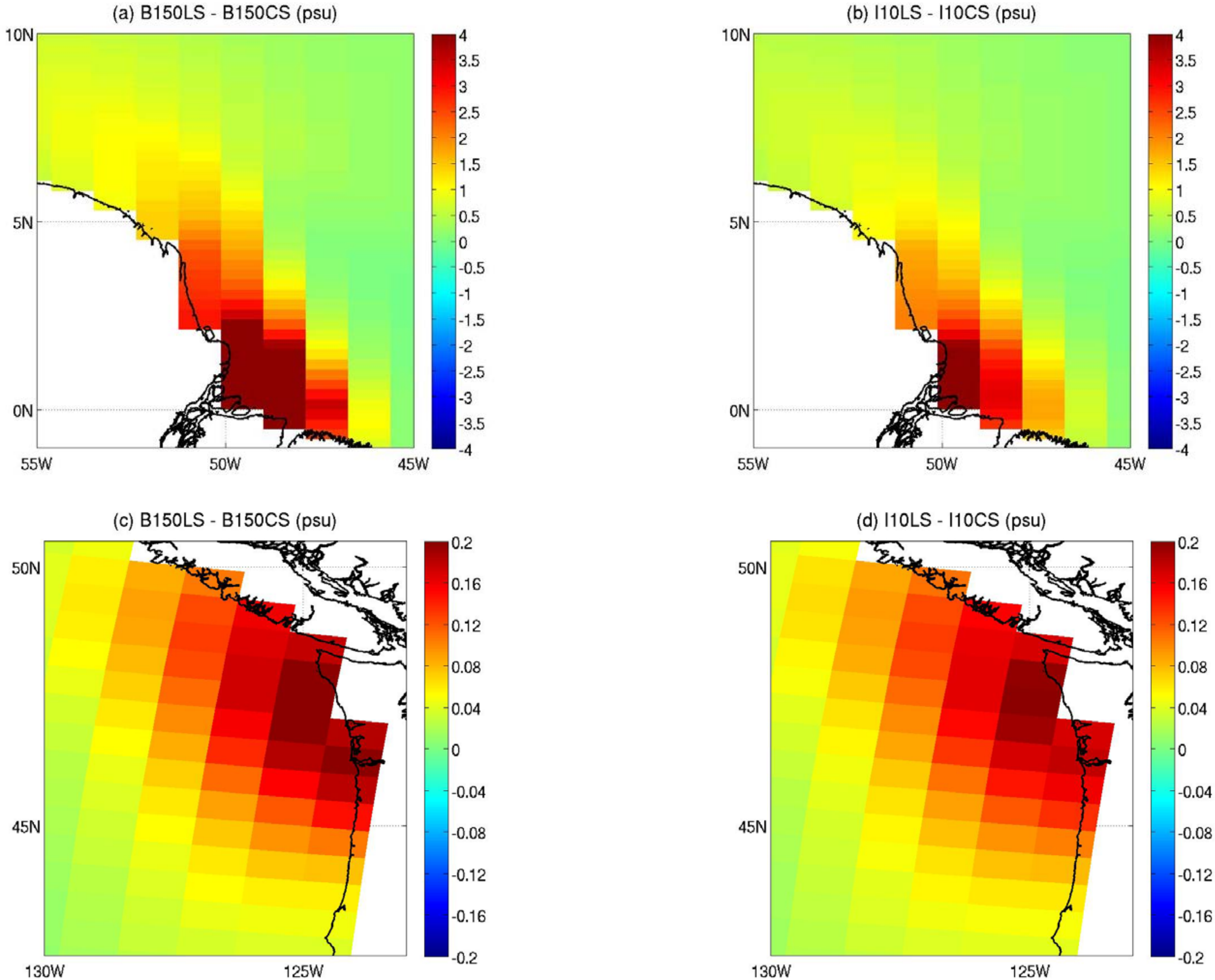
Open Ocean Error ~ 2 psu/35 psu = 6%

River Plume Error ~ 20 psu/35psu = 60%

Modified Global Balance w/ Locally referenced runoff salinity:

$$\iint_{globe} \left[(P - E) S_{ref} + R S_1 + \varepsilon\right] dA \simeq 0$$

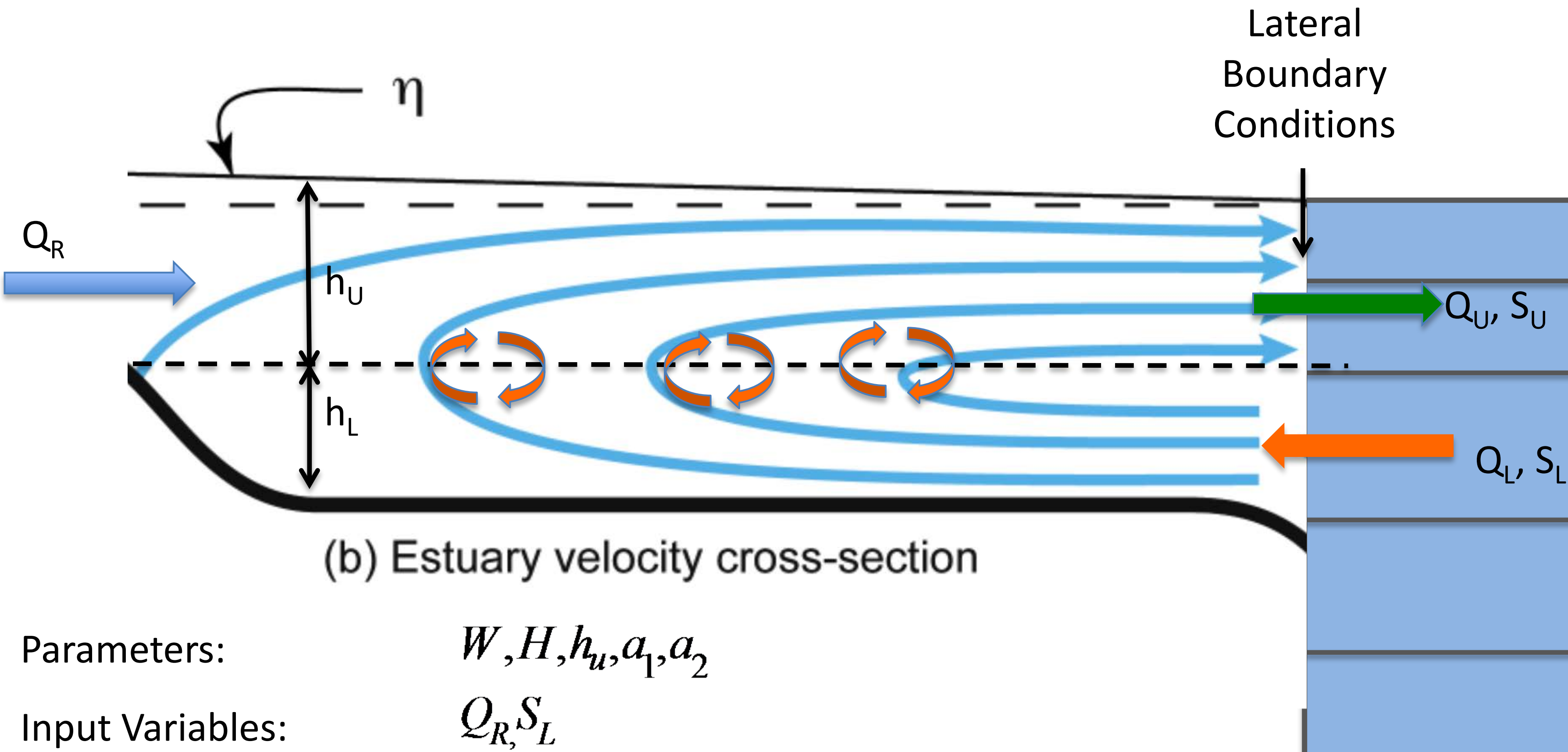
$$\varepsilon = \iint_{globe} R(S_{ref} - S_1) dA \Big/ \iint_{globe} dA$$



R included in B_f

R excluded from B_f

EBM and Natural BC Implementation



Parameters: W, H, h_u, a_1, a_2

Input Variables: Q_R, S_L

Potential Energy: $\lambda_3 Q_L^3 + \lambda_2 Q_L^2 + \lambda_1 Q_L + \lambda_0 = 0$

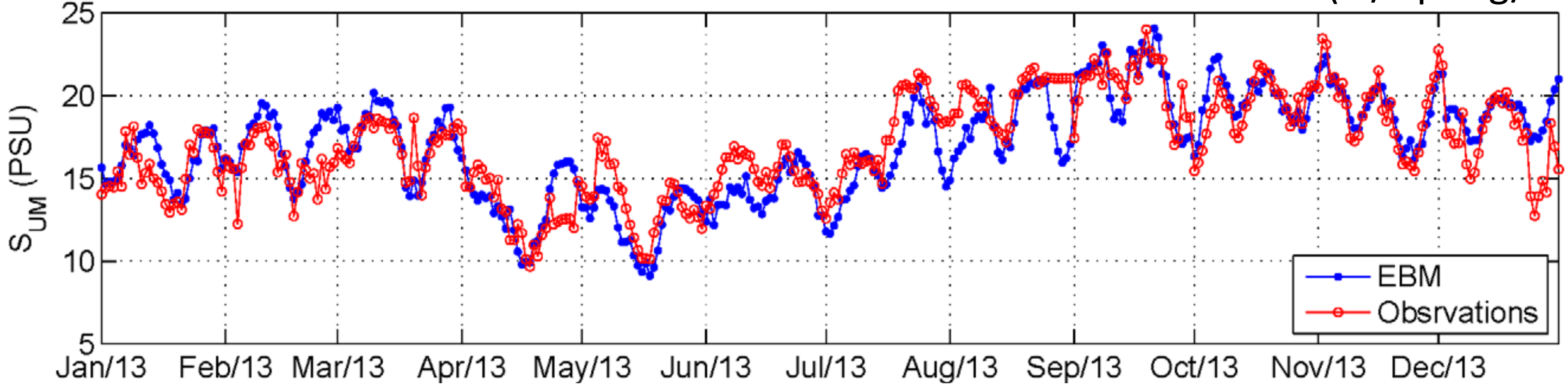
Volume Eq: $Q_U = Q_R + Q_L$

Salinity Eq: $Q_U S_U = Q_L S_L$

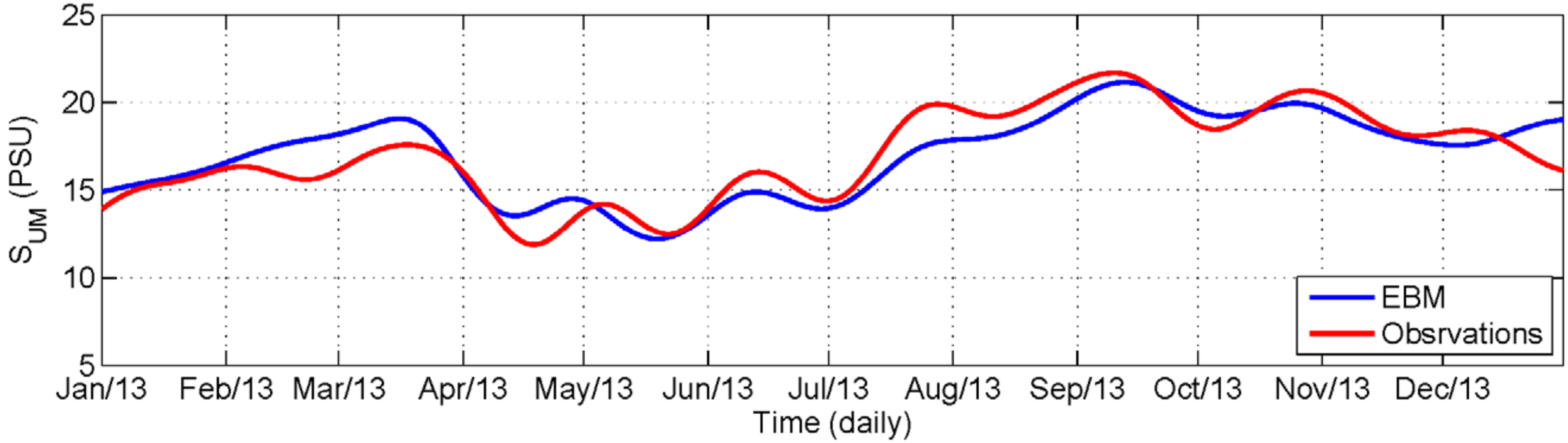
EBM Calibration & Validation

- Driven with observed $Q_R(t)$ and mean S_L

(w/ spring/neap a_1)

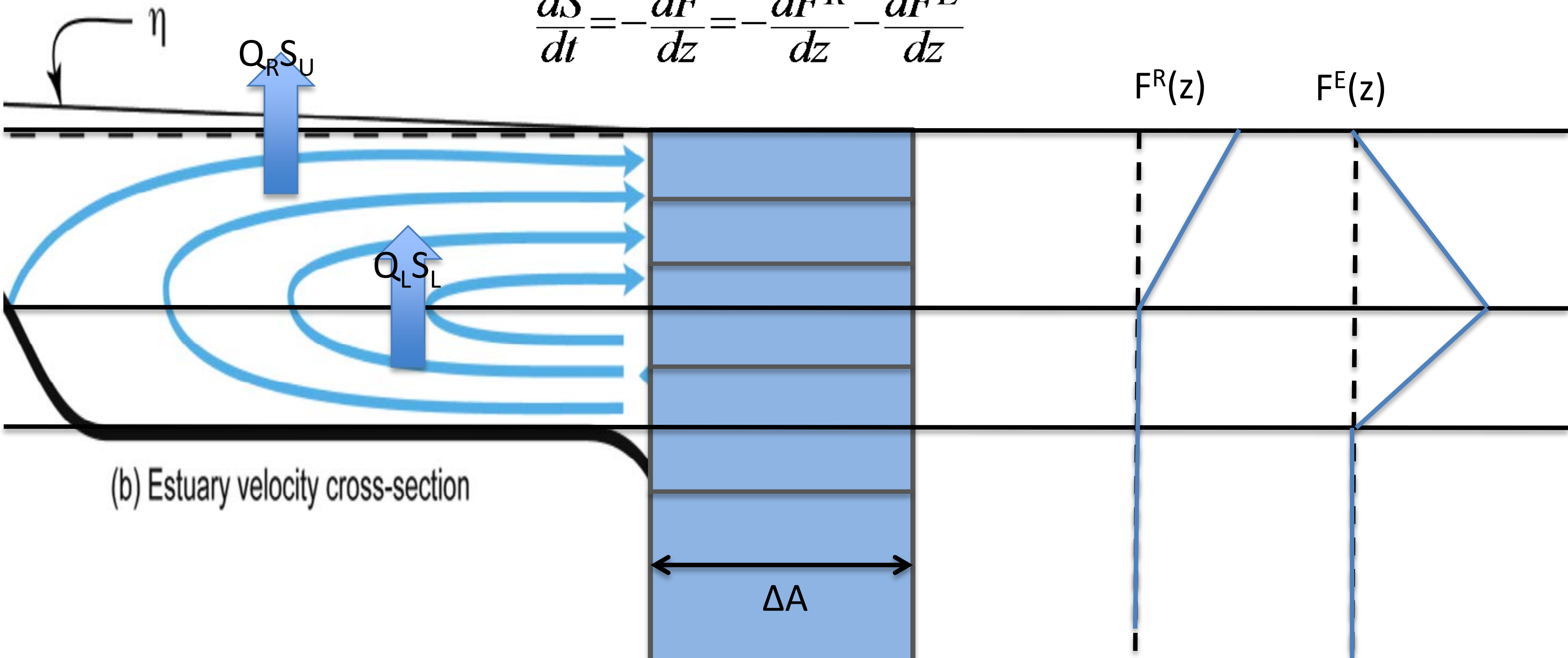


(w/o spring/neap a_1)



Virtual Salt Flux Implementation

$$\frac{dS}{dt} = -\frac{dF}{dz} = -\frac{dF^R}{dz} - \frac{dF^E}{dz}$$



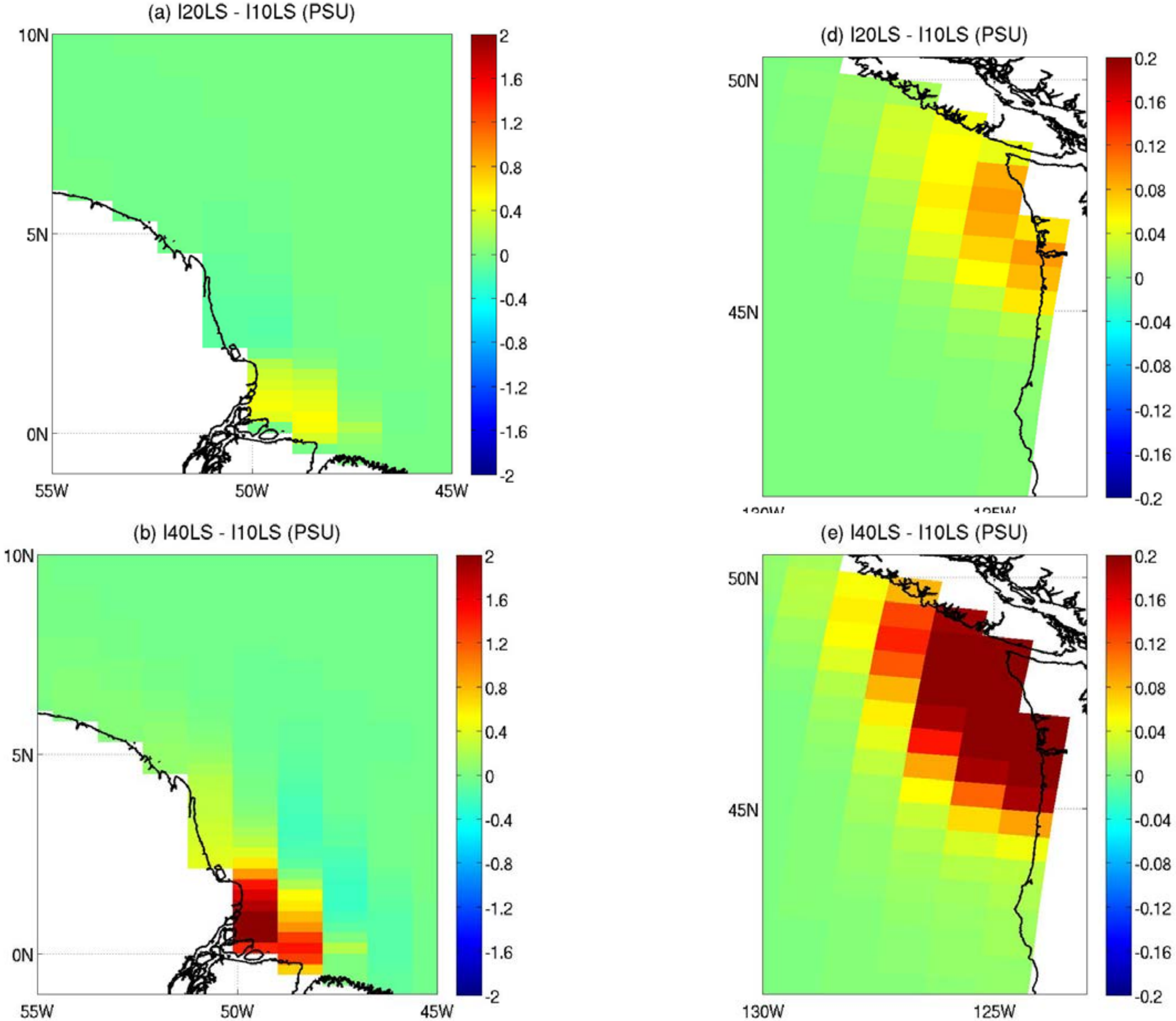
$$F^R(z) = F_0^R\left(1 - z/h_U\right)$$

$$F_0^R = Q_R S_U / \Delta A$$

$$F^E(z) = F_I^E \begin{cases} z/h_U & z \le h_U \\ (h_U + h_L - z)/h_L & h_U \le z \le h_U + h_L \end{cases}$$

$$F_I^E = Q_L S_L / \Delta A$$

Vertically Distributed VSF
(no exchange Flow)



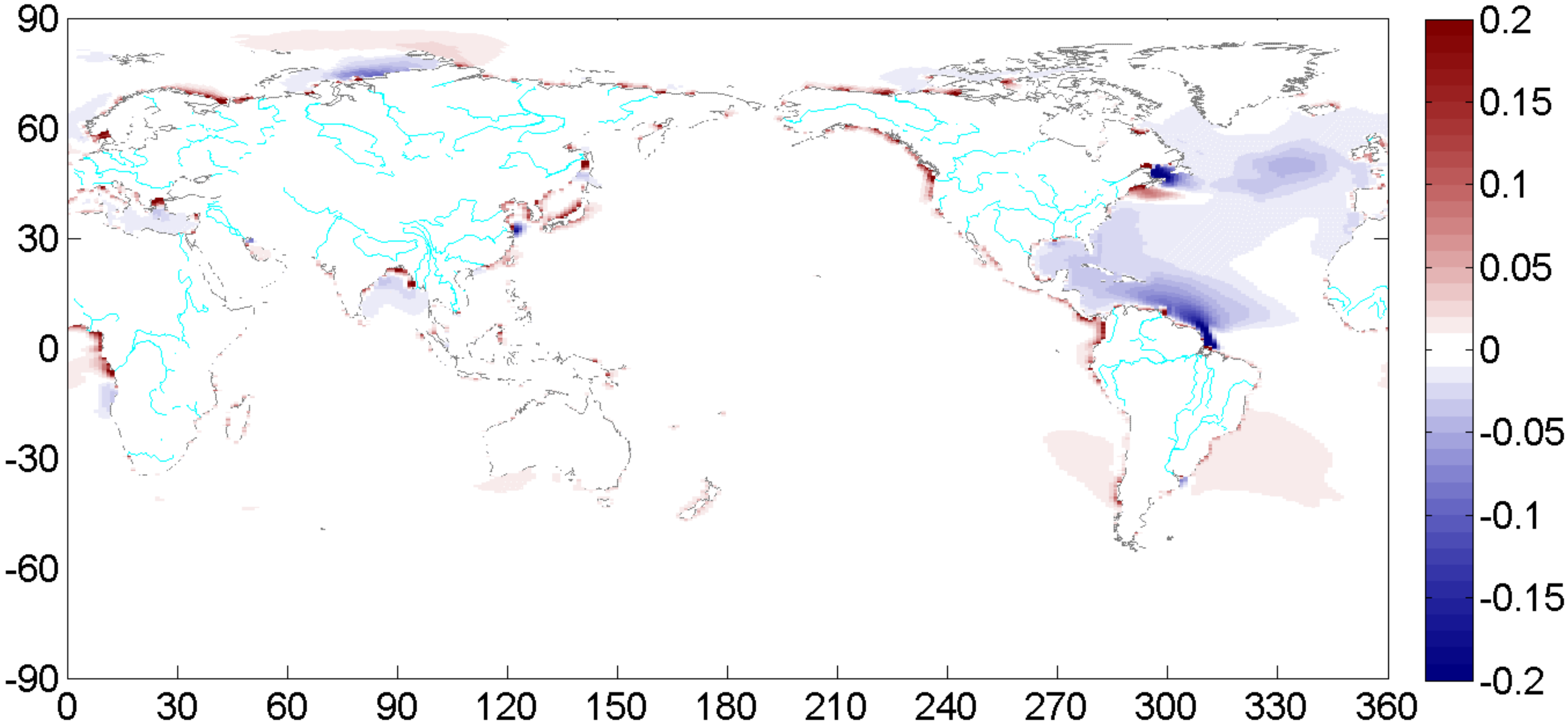
h_U=20m

h_U=40m

Global Implementation of Full EBM

- Need 5 parameters for each river mouth
- Top 20 rivers account for 2/3 of global runoff
- Providing parameters specific to the top 20 rivers
  - Mixing parameters tuned to fit observed S_U
- All remaining rivers prescribed as "generic" small estuary
- NB: further reduction of input to single gridpoint

Global Impact of EBM vs. VSF Only



Status & Prospects

- Reducing spreading area of runoff input exacerbates existing fresh bias in coastal SSS
  - Reducing to single point VSF alone produces unphysical solutions
- All other additions and changes including the EBM act to ameliorate fresh bias
- Changes in treatment of runoff to accommodate the EBM have as large or larger of an impact on the solution as the EBM itself
- The poor quality of the hydrographic climatologies near river mouths makes it difficult to measure change in solution skill
- The EBM has no measurable impact on computational performance and minimal impact on code structure
- The stronger physical basis of the EBM and physically reasonable solutions argue for including it in CESM-2
- Work continues on developing a parameterization of mixing in river plumes on the shelf and assessing the impact of the exchange circulation on other tracers

POP Implementation
estuary_vsf_mod.F90

….
call pop_init_phase2
    call init_estuary

…
advance: do
    …
  if (coupling time step)
        call ocn_import_mct (receive Q_R)
        call pop_set_coupled_forcing
            call set_estuary_vsf_forcing (computes F_0^R)
            call set_estuary_exchange_circ (computes F_l^E)
    endif
    …
    call step
        call baroclinic_driver
            call tracer_update
                …
                call add_sw_absorption
                call add_estuary_vsf_tracer_tend (computes $\frac{dF}{dz}$)

ts-loop

k-loop