2015 CESM Ocean Model Working Group Meeting
Boulder, CO

Box Model Approach for Improving the Representation of Riverine Freshwater Inputs in Climate Models

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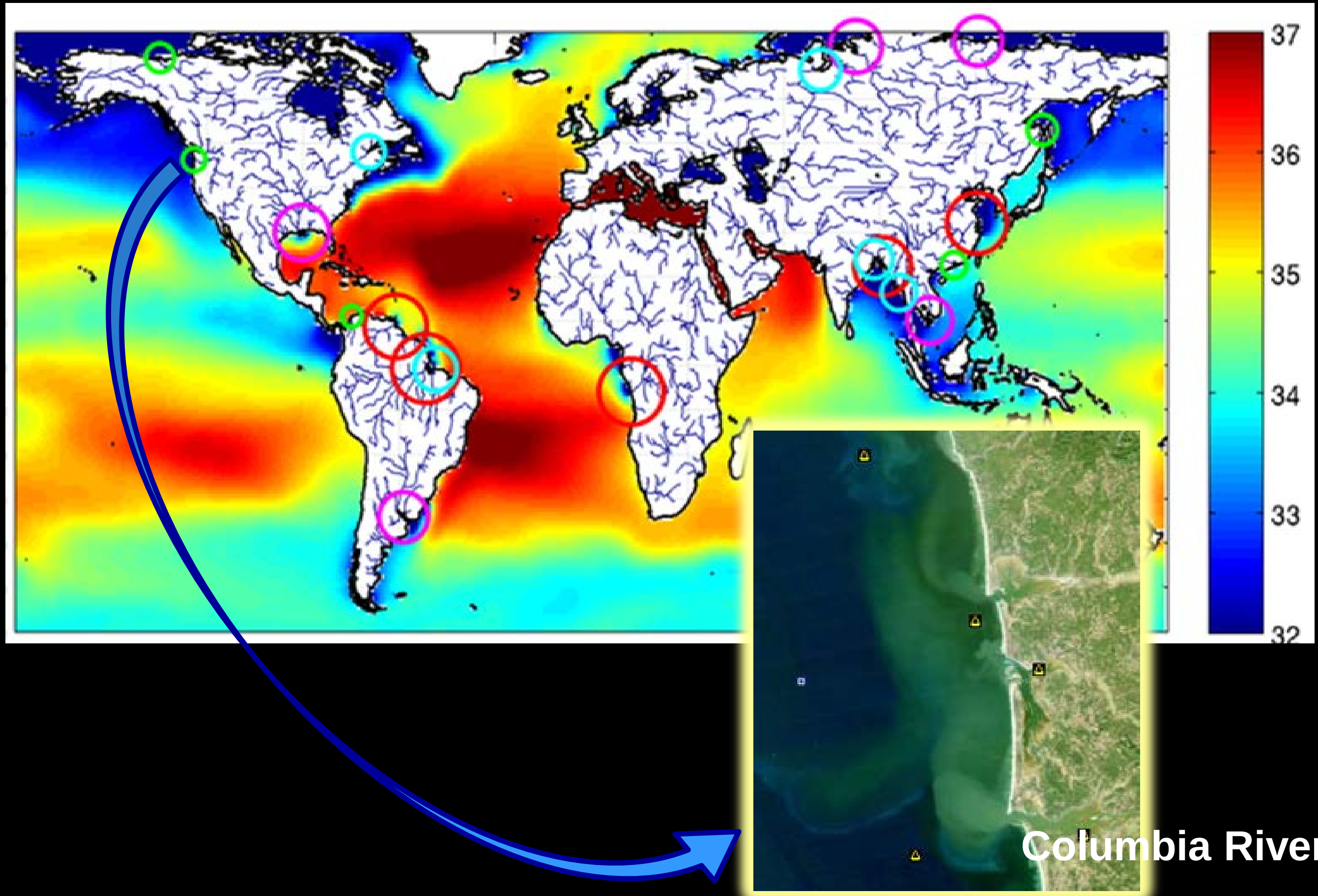
Sun, Q.; Whitney, M. M.; Bryan, F. O.; Tseng, Y. H. and MacCready, P.

Motivation: **Develop physically-based parameterizations to better represent estuary and shelf processes influencing the salinity, location, and timing of riverine freshwater delivery in CESM**

Overview

- Introduction
- Estuary Box Model (EBM)
- Shelf Plume Box Model (SPBM)
- Conclusions



Box Model Approach for Improving the Representation of Riverine Freshwater Inputs in Climate Models

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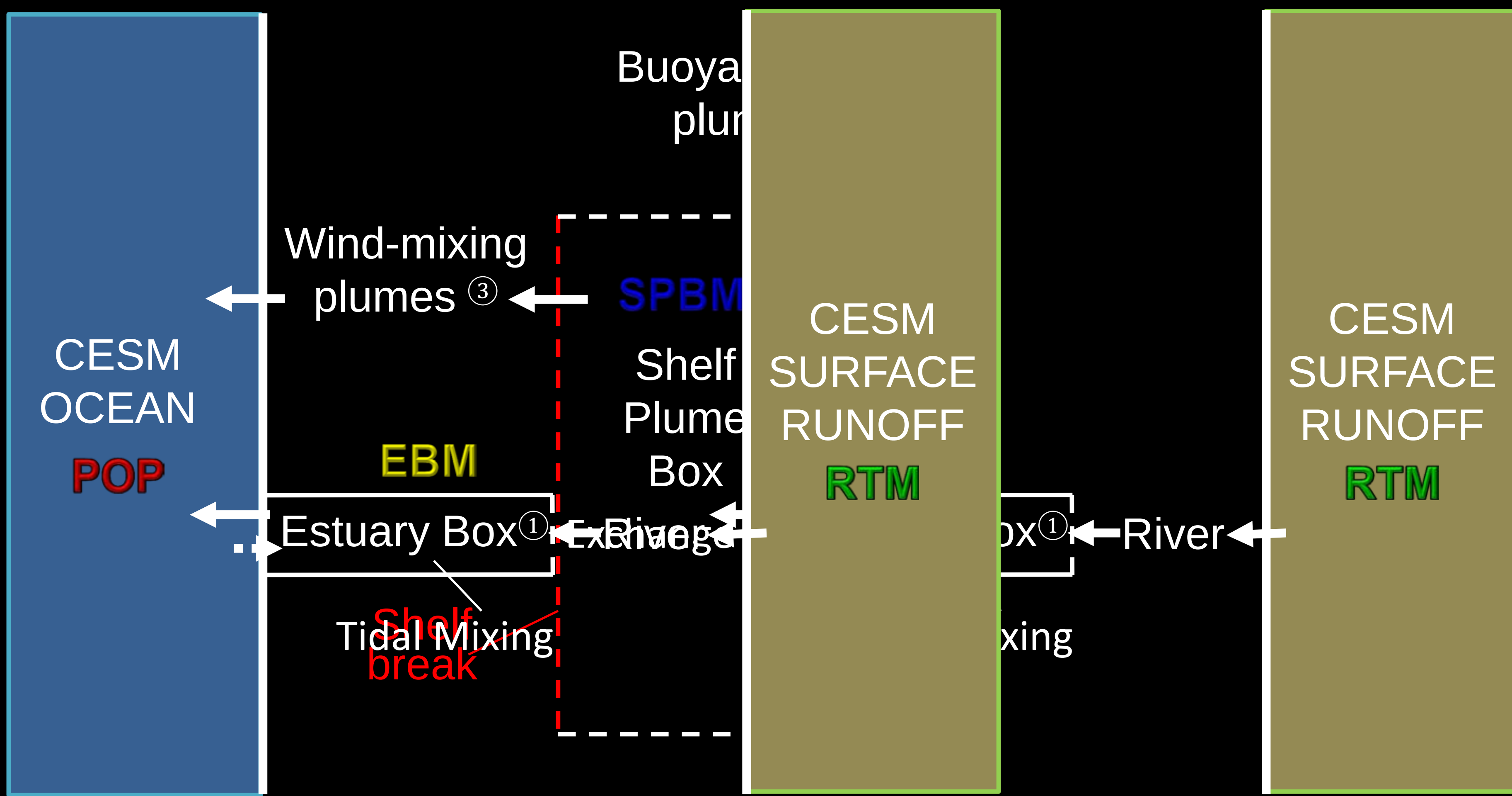
Estuary Box Model (EBM) and Plume Box Model (PBM)



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

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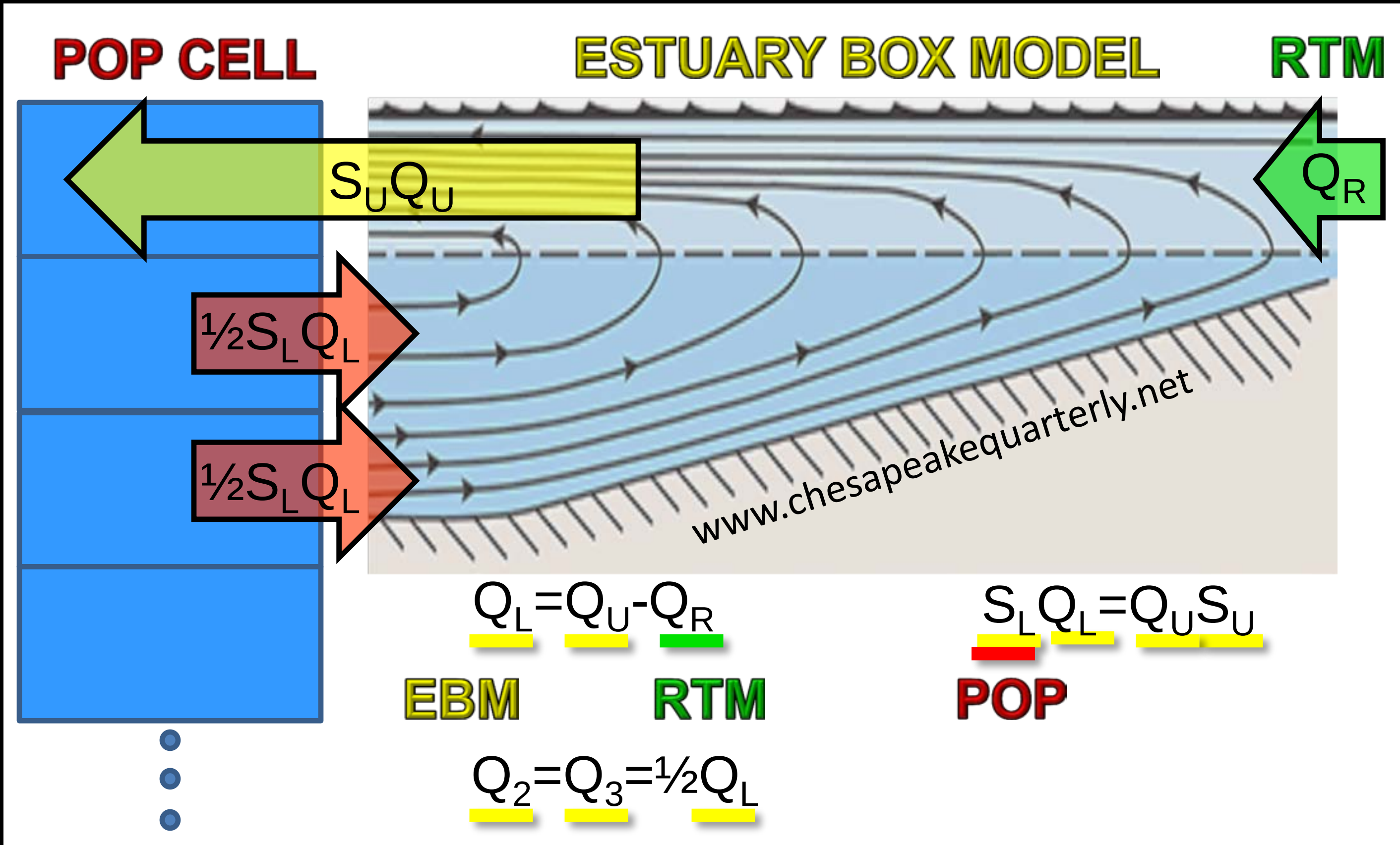
Coupling the Estuary Box Model (EBM)

- Zero net salt flux, net volume flux equals river discharge
- Box model introduces exchange flow and vertically redistributes salt
- Inputs: RTM discharge, POP salinity, estuary dimensions, tidal information, mixing coeffs.
- EBM solves polynomial for Q_L (fast)
- Added to POP advection routine



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EBM Governing Equations and Solution

- Simple case: river inflow, vertical tidal mixing, layer interface at half depth
- Governing equations:
  - **Volume and salinity conservation:** $Q_U = Q_R + Q_L$ $S_U = S_L \cdot Q_L / Q_u$
  - **Potential energy conservation** (from density advection-diffusion):
    $-gh(\rho_L Q_L - 3\rho_U Q_U + 3\rho_R Q_R) = 2gWLK(\rho_L - \rho_U) + ½gh(\rho_U + 2\rho_R + \rho_L)Q_L$

- **Solution** (need to set ε):

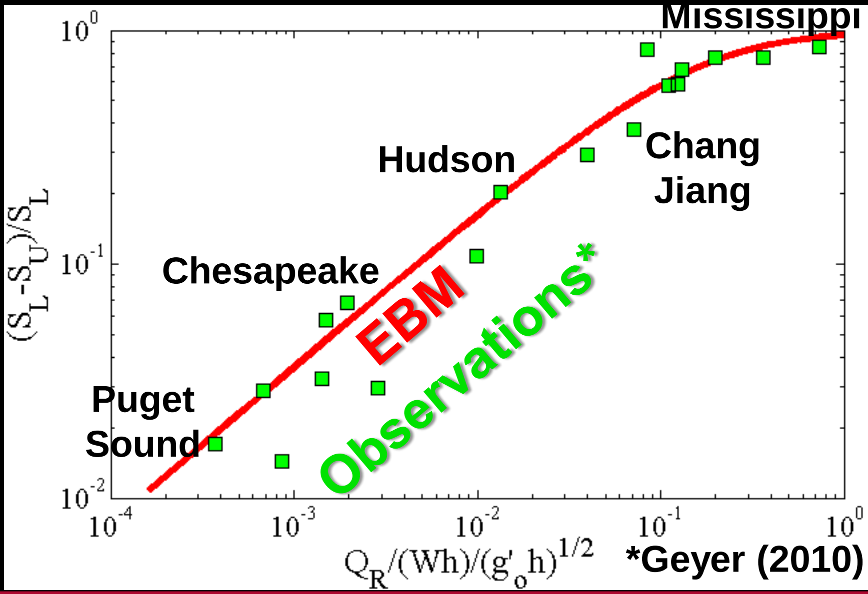
$\mathbf{Q_L}^2 + (3/2)Q_R\mathbf{Q_L} - 2WLK/(hQ_R) = 0$

$K = \varepsilon C_D u_{tide} h/Sc$ $C_D = 0.0025$ $Sc = 2.2$

- Fully-adjusted solution (need to set λ):

$$\mathbf{Q_L}^2 + (3/2)Q_R\mathbf{Q_L} - 2\lambda[g'_o h^3 W^2 Q_R/Sc]^{2/3} = 0$$

$g'_o = 0.25$



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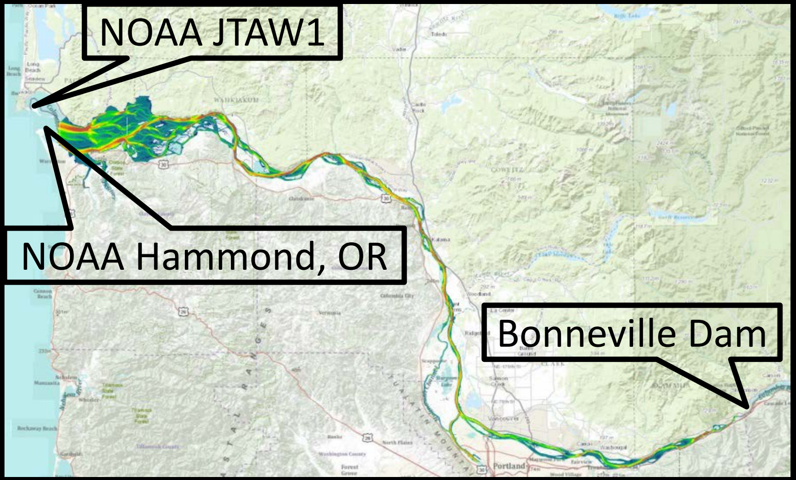
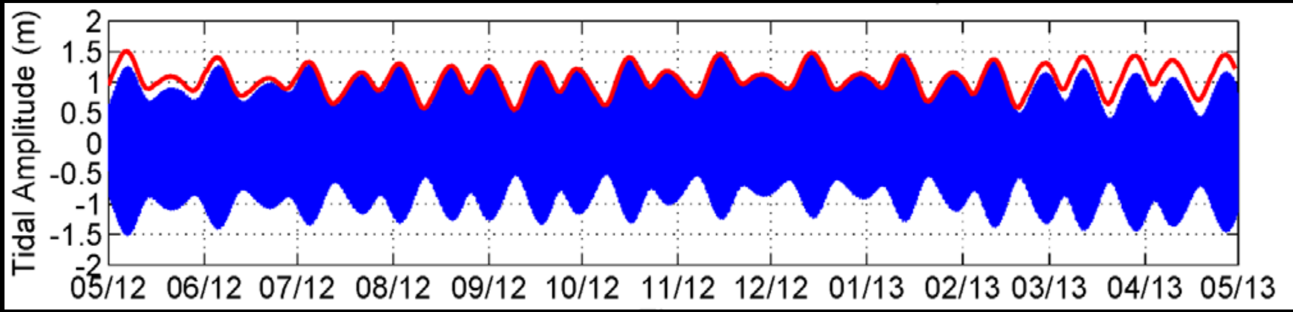
EBM Test: Columbia River



- Estuary dimensions:
  L=50 km, W=3.7 km, H=11 m
- Fixed inflow salinity (S_L=32)
- Forcing terms:
  - ✓ USGS observed discharge at Bonneville Dam
  - ✓ Daily tidal amplitude at Hammond, OR (includes spring-neap variations)



- Compared to near-surface salinity observations at mouth (NOAA buoy JTAW1 for 2012) and mixing coefficients set to minimize model error

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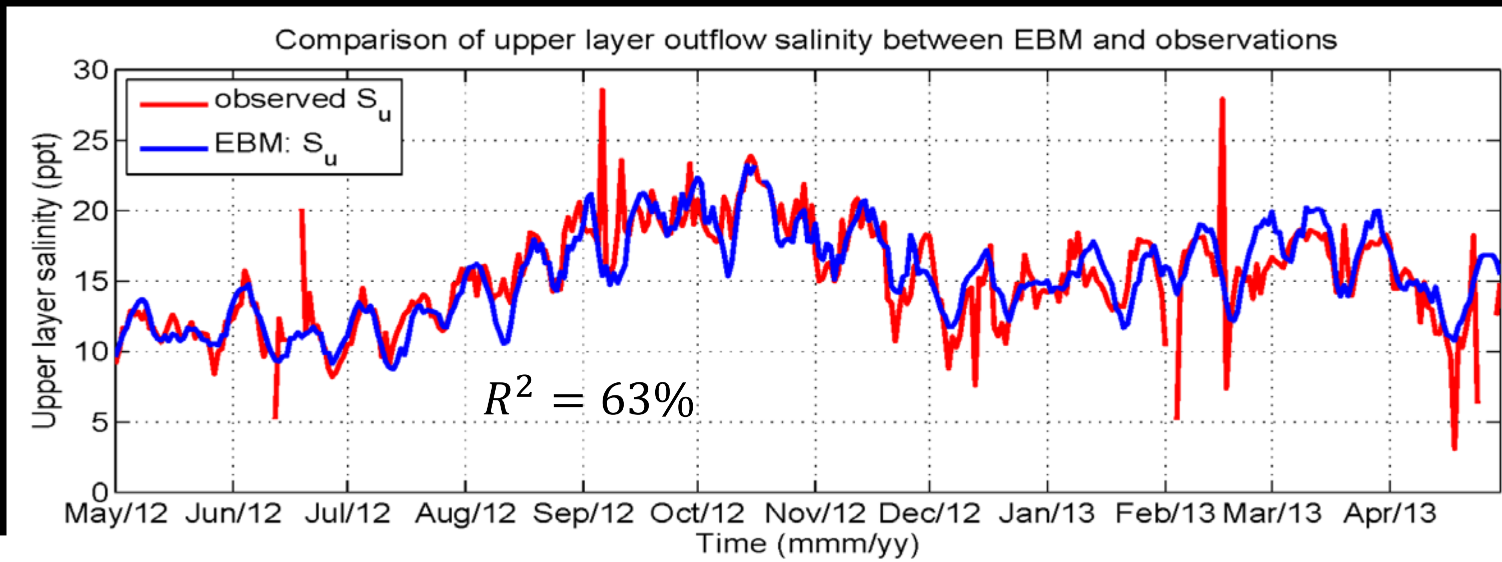
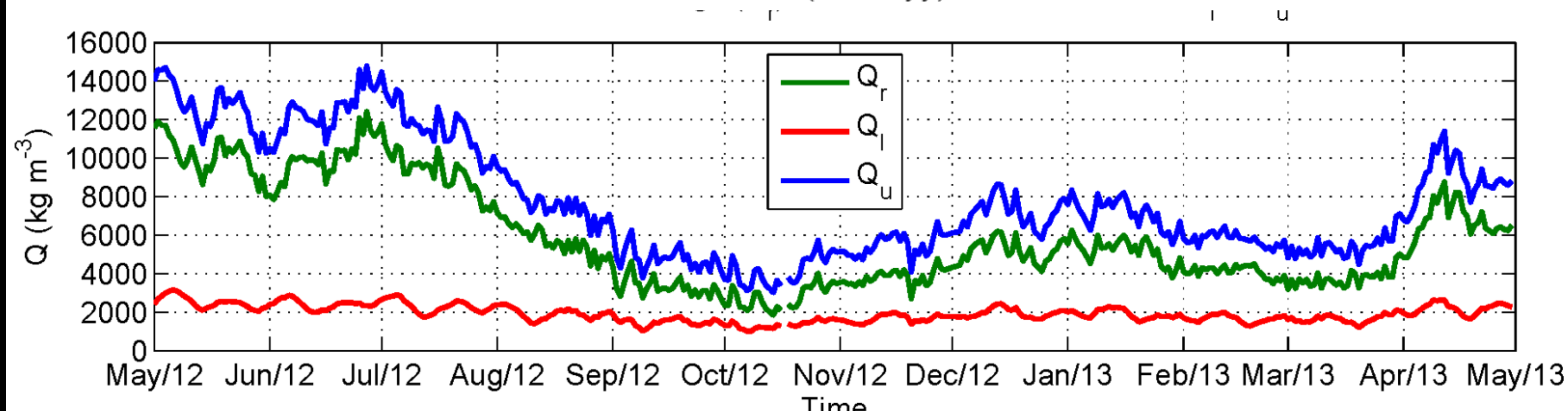
EBM Test: Columbia River (Comparison with Observations)





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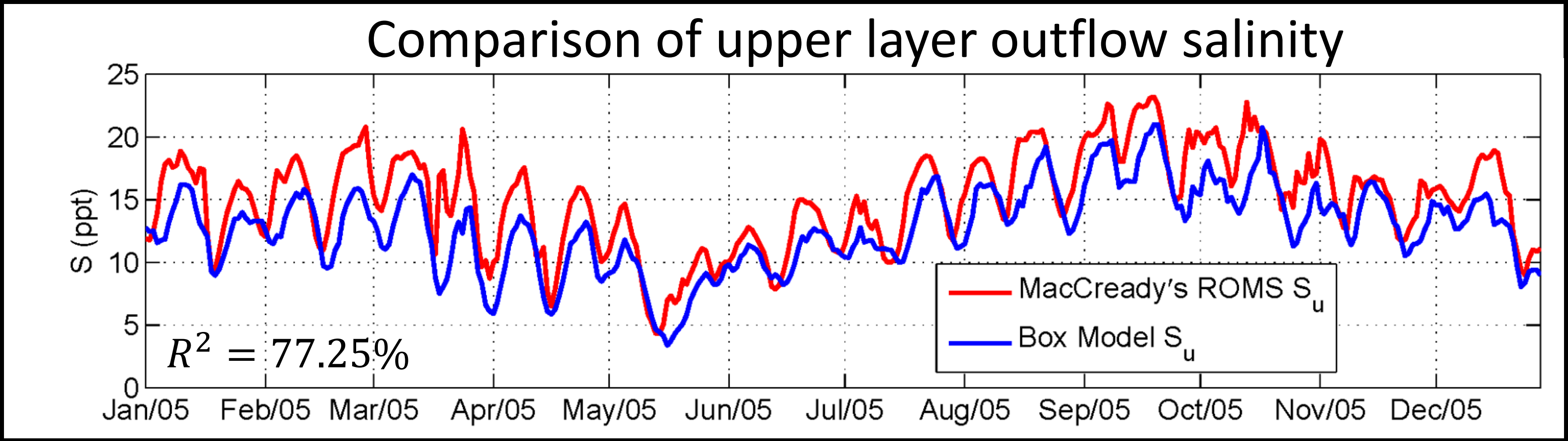
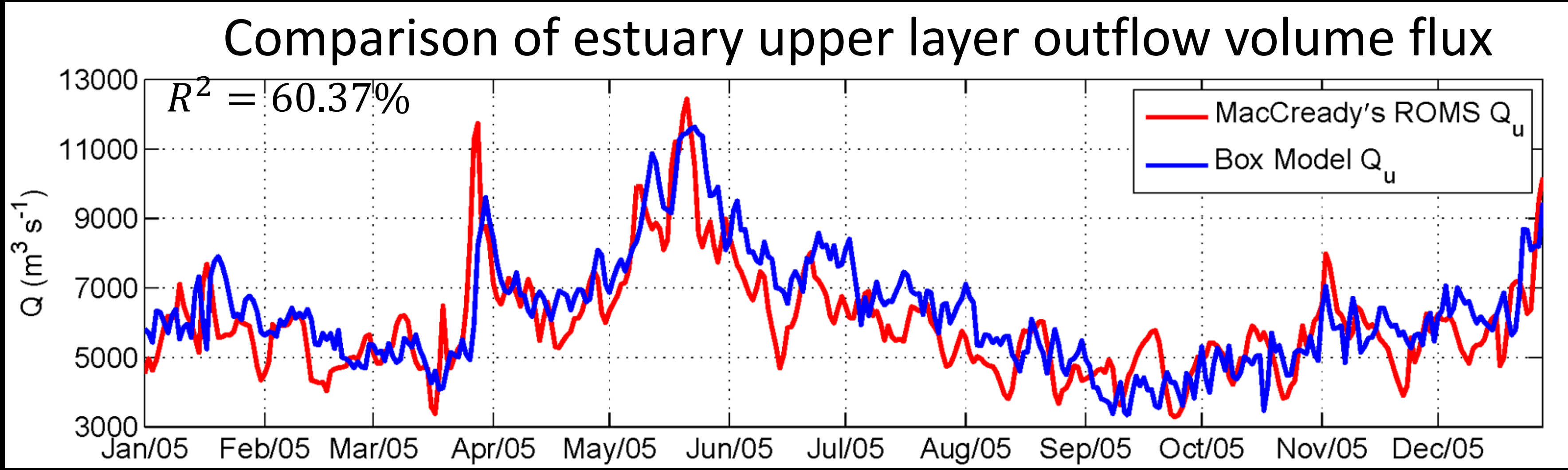
EBM Test: Columbia River (Comparison with Regional Model)





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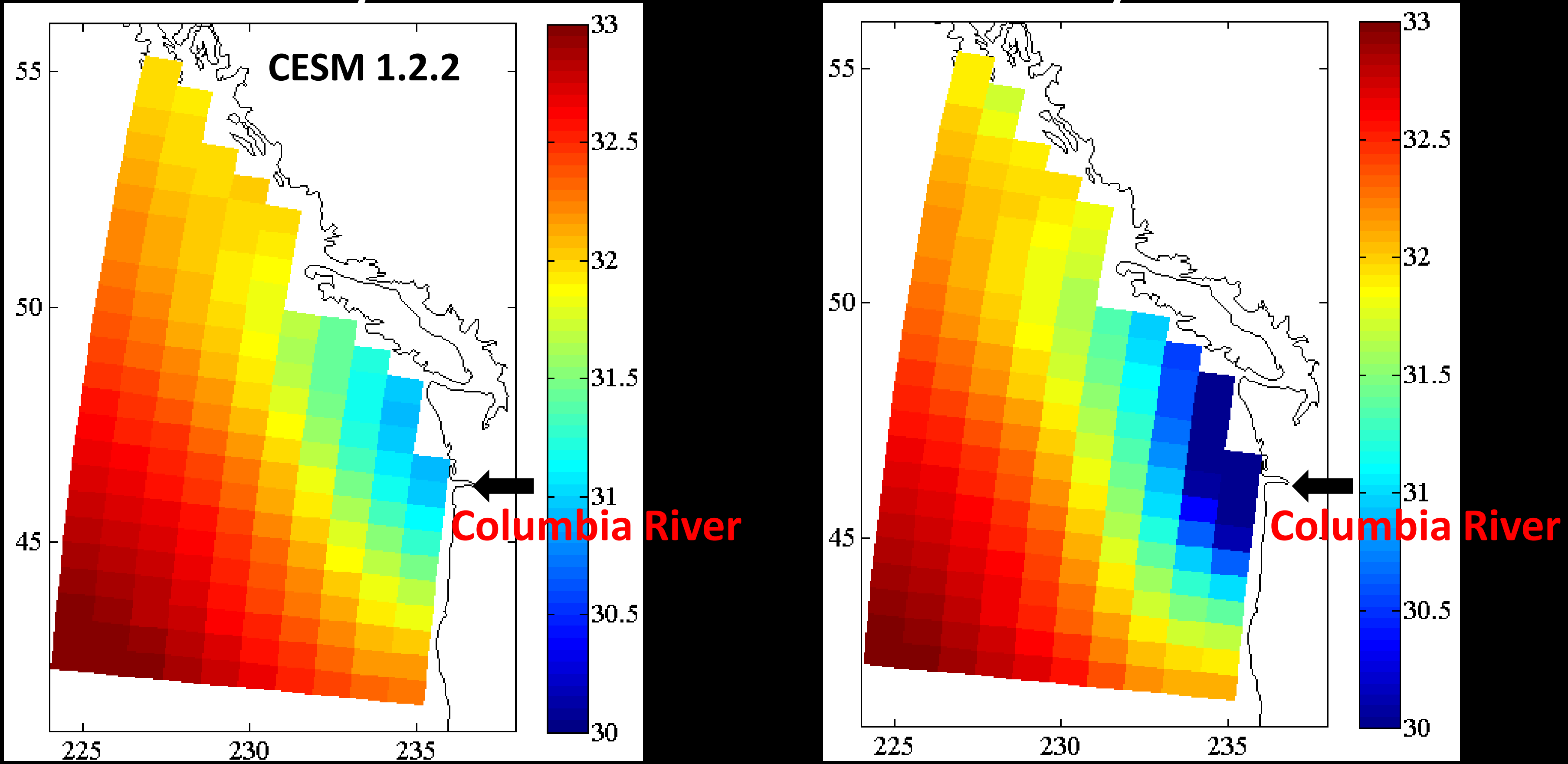
Sun, Q.; Whitney, M. M.; Bryan, F. O.; Tseng, Y. H. and MacCready, P.

EBM: Apply in CESM (Columbia River)

CESM surface ocean salinity (2nd simulation year, July)

without Estuary Box Model | **with Estuary Box Model**



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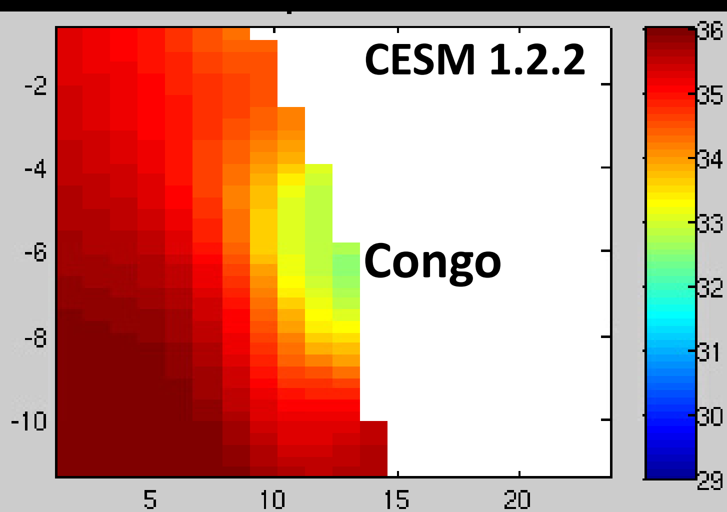
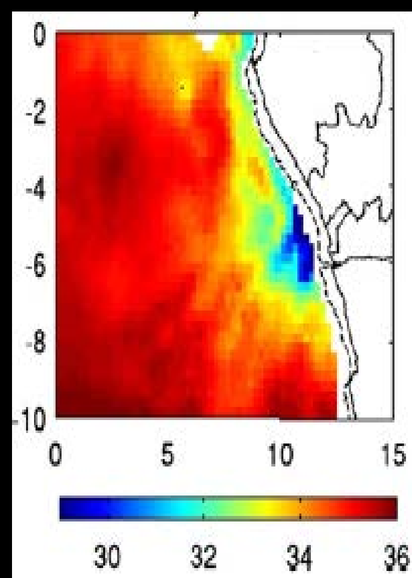
EBM: Apply in CESM (Congo River)

- Standard run: less stratified than observations
- With EBM: more stratified than observations
- Suggests the need for the shelf plume box model

without EBM

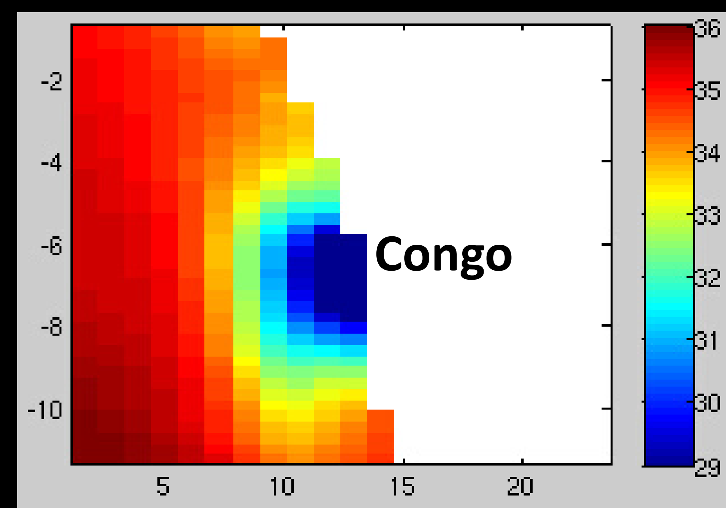


SSS observations*



Hopkins (2013)

with EBM



*10-day satellite mean, 2010

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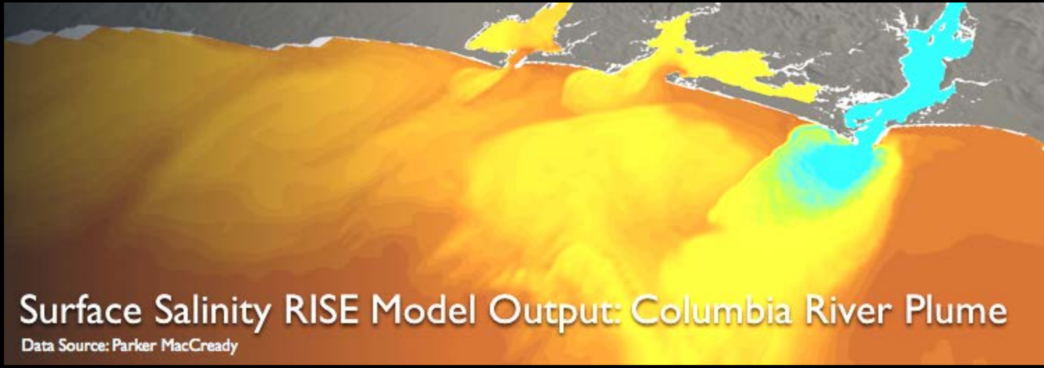
River plumes on the shelf

- **Change location, timing, and salinity of riverine freshwater delivery**
- Alongshelf propagation of slender plumes (W~10 km)
- Shear-driven mixing
- Offshore wind-driven transport
- Represent dynamics with shelf plume box model (SPBM)



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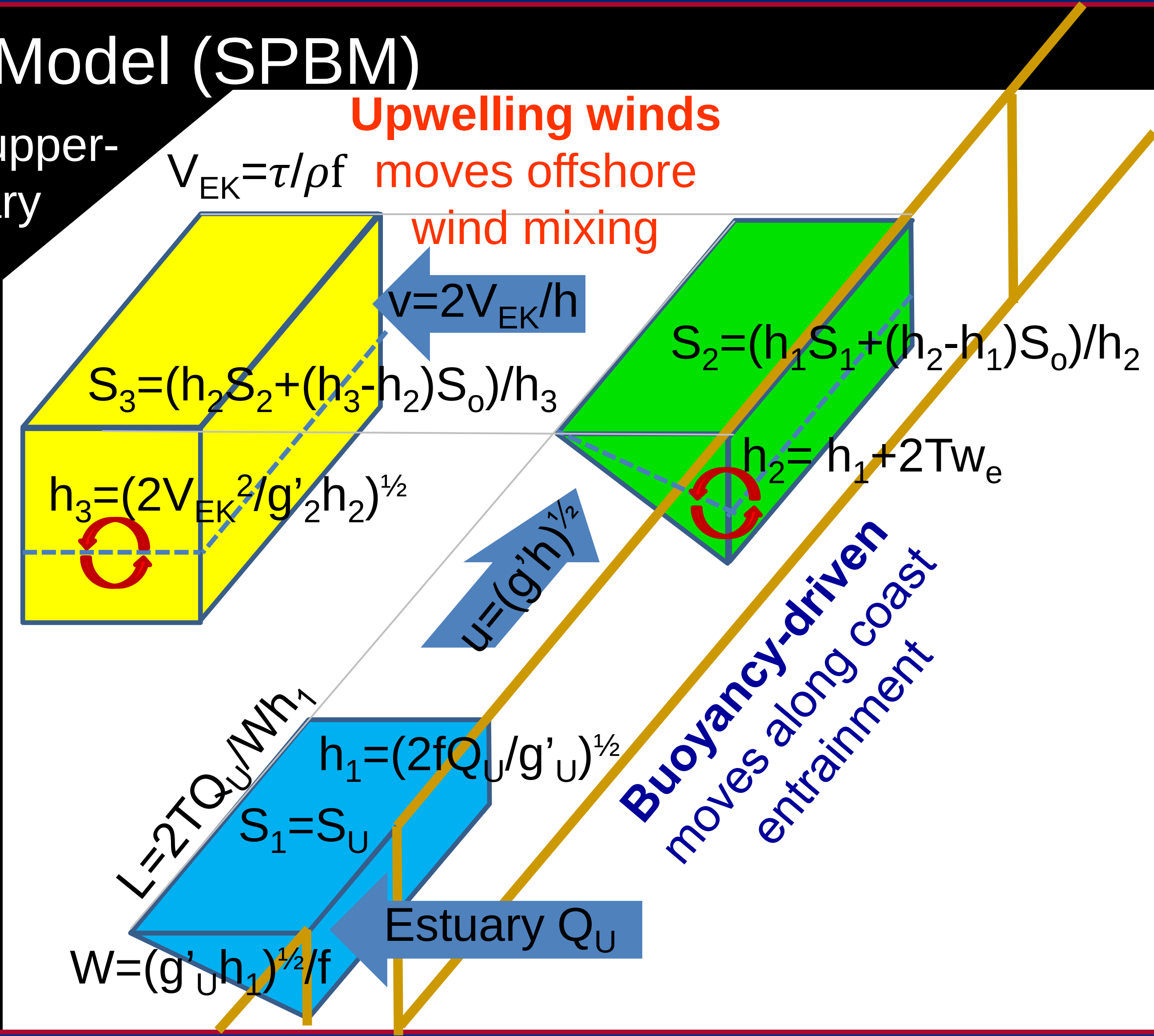
Shelf Plume Box Model (SPBM)

- Plume box starts with upper-layer salinity and estuary outflow (over T=1 day), geostrophically adjusts
- Propagates downshelf when buoyancy-driven
- Upwelling winds can transport plume across shelfbreak
- A new plume box is made every day
- Boxes exist until delivered to open ocean (POP)



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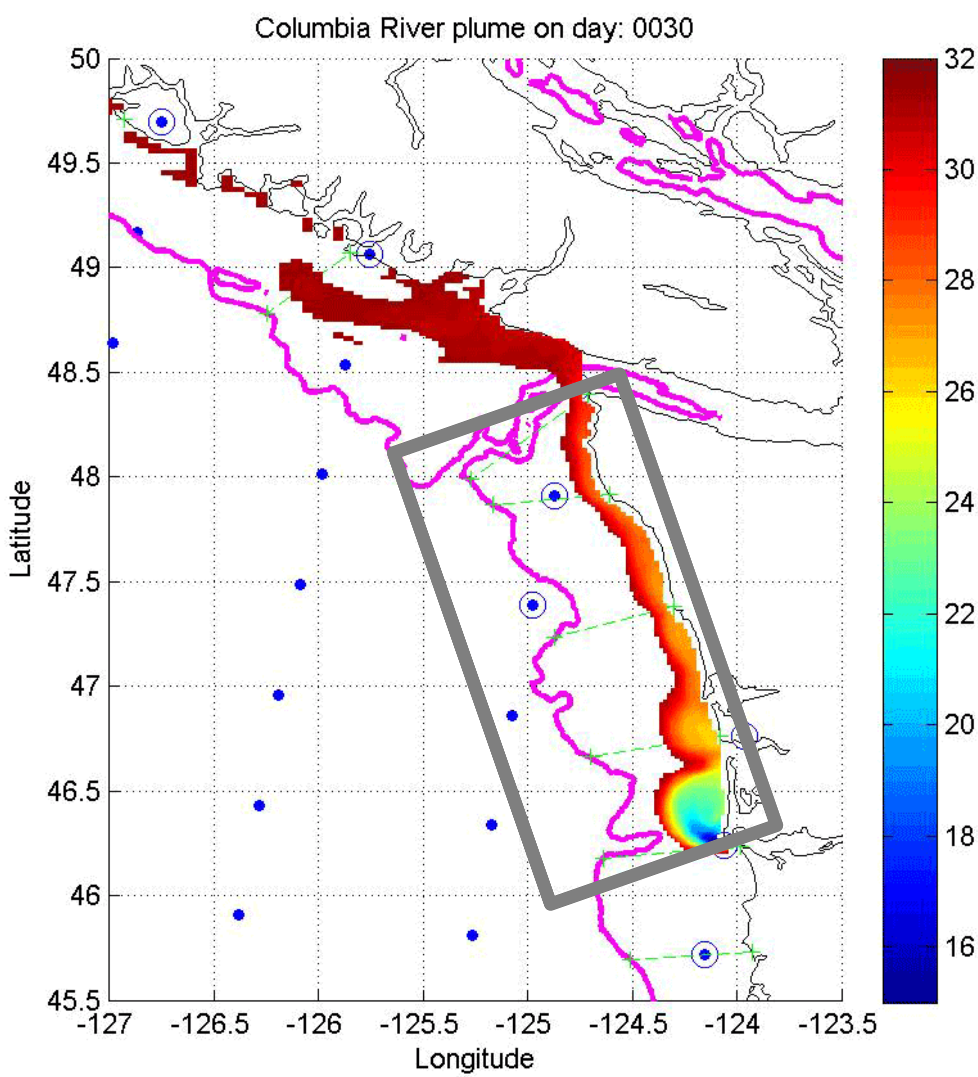

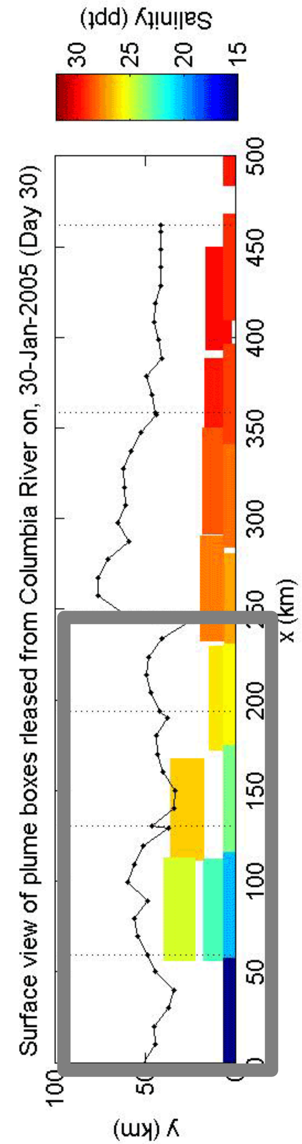

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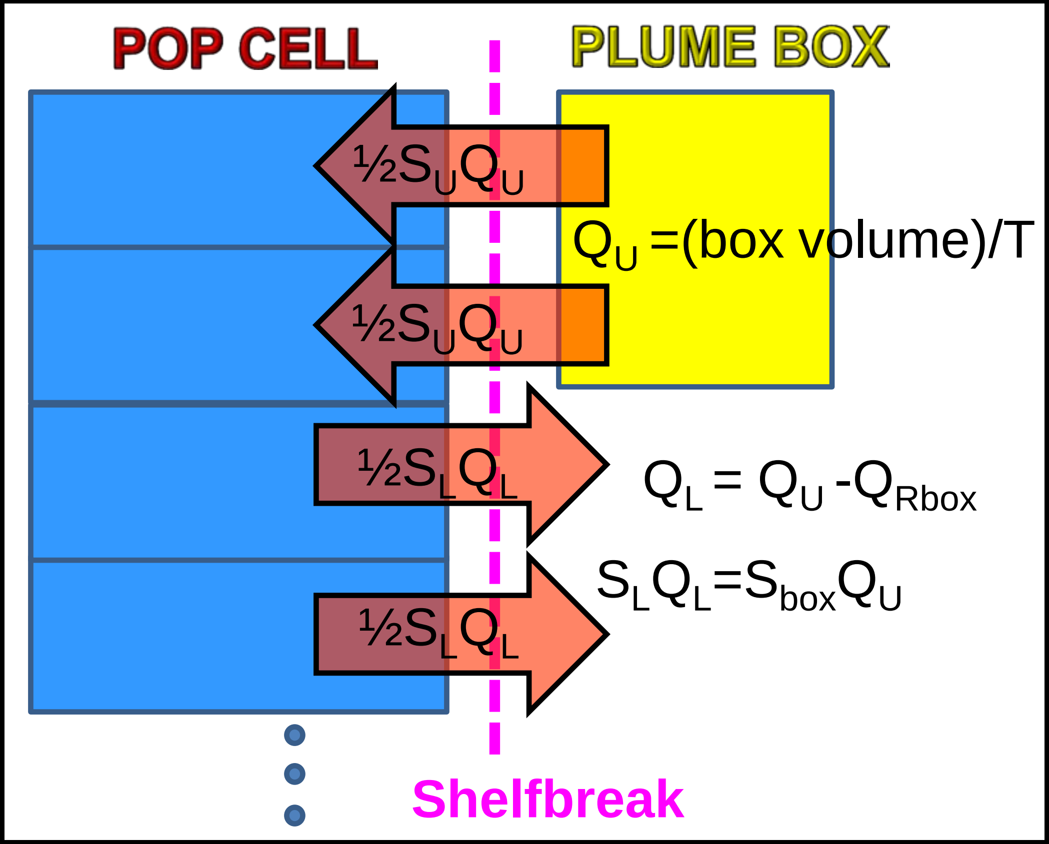
Coupling the Shelf Plume Box Model (SPBM)

- At POP cell where freshwater delivery occurs, the SPBM introduces zero net salt flux and net volume flux equals river discharge in plume box
- Coupled like the EBM would be (like a moving estuary)
- Introduces exchange flow and vertically redistributes salt
- Inputs:
  EBM output, shelf width, POP salinity, CESM winds, entrainment coefficient
- Added to POP advection routine (EBM to SPBM to POP)



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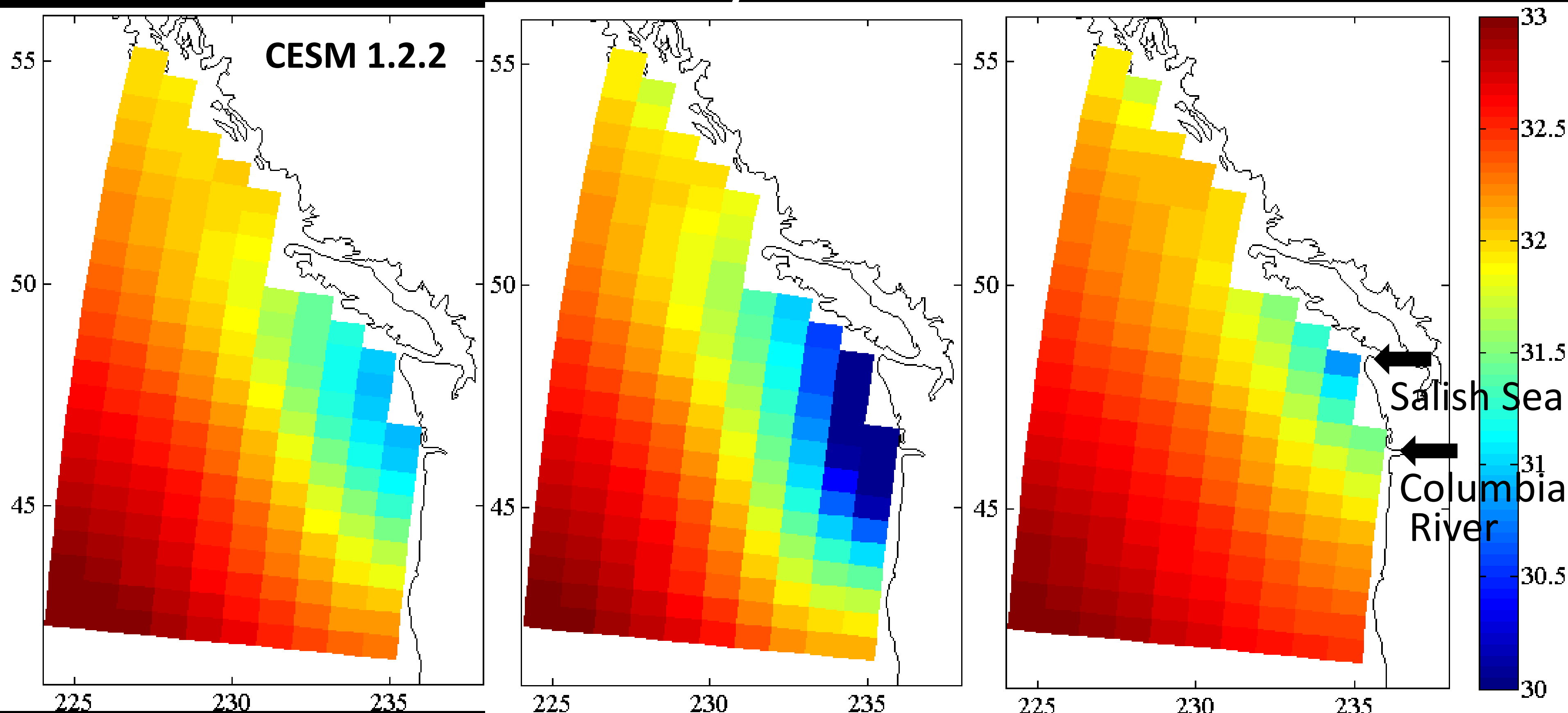
SPBM: Apply in CESM (Columbia River)

CESM surface ocean salinity (2nd simulation year, July)

no box models **with Estuary Box Model** **with Shelf Plume Box Model**



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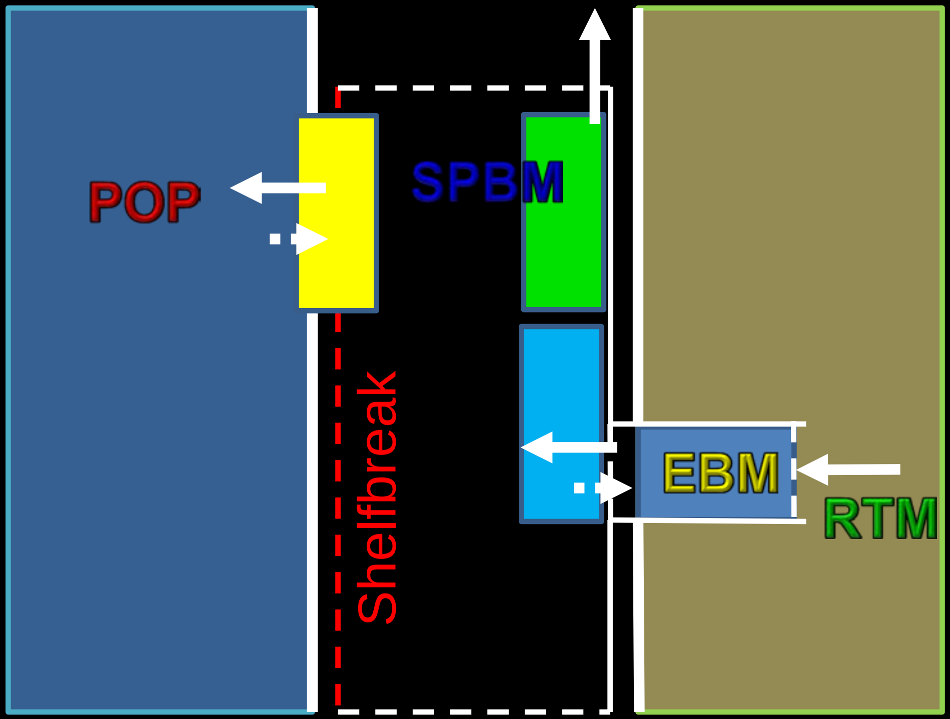
Conclusions

- Estuary Box Model (EBM) estimates estuary exchange flow and upper-layer salinity ***(location and timing of river discharge same as RTM)***

- Shelf Plume Box Model (SPBM) represents buoyancy-driven and wind-driven plume behavior ***(changes location, timing, and salinity of freshwater delivery)***

- It is best to use the EBM and SPBM at 1^{o} POP resolution

- Results from test cases are encouraging



THANK YOU

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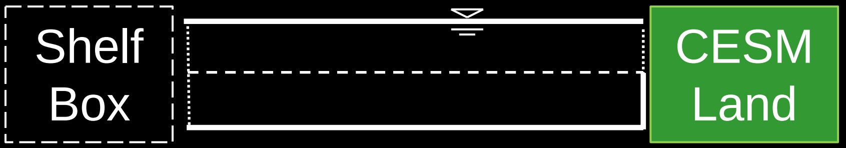
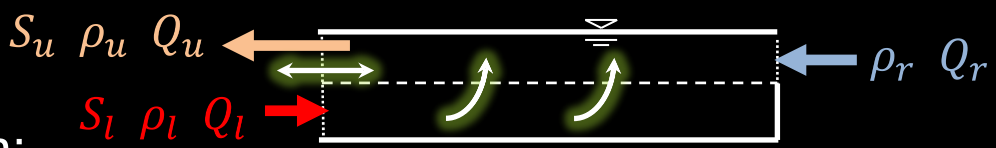
Estuary Box Model

➢ Methodology



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



- Governing equations:
  Water volume flux conservation:

$$Q_r + Q_l - Q_u = 0$$

Salinity flux conservation:

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

Potential energy flux (PEF) conservation (from density advection/diffusion equation):

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

Color:
Riverine water
Oceanic water
Estuarine water
Mixing & exchanging

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A box model approach for improving the representation of riverine freshwater inputs in climate models

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Estuary Box Model

- Potential energy flux in the Estuary Box Model:

  River inflow:

  $$PEF_r = \frac{g}{2} \cdot (H + h) \cdot \rho_r \cdot Q_r > 0$$

  Upper layer outflow at mouth:

  $$PEF_u = -\frac{g}{2} \cdot (H + h) \cdot \rho_u \cdot Q_u < 0$$

  Lower layer inflow at mouth:

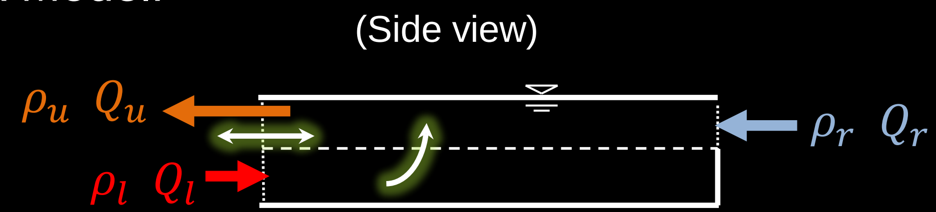
  $$PEF_l = \frac{g}{2} \cdot h \cdot \rho_l \cdot Q_l > 0$$

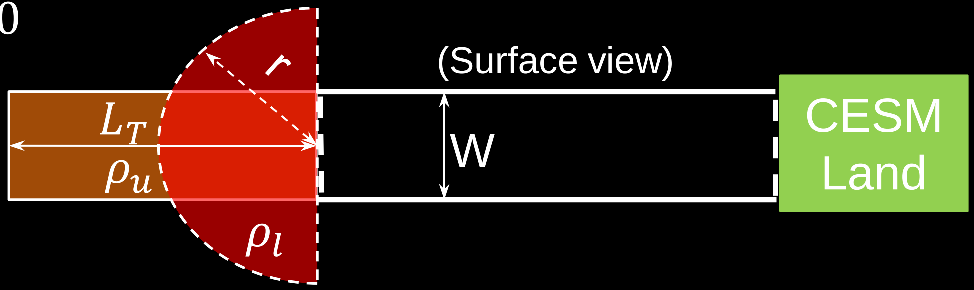
  Tidal mixing in estuary:

  $$PEF_{TM} = \frac{g}{2} \cdot W \cdot L \cdot K_V \cdot (\rho_l - \rho_u) \cdot \frac{H}{h} > 0 \text{ with } K_V = \frac{\epsilon \cdot C_d \cdot U_T \cdot H}{Sc} \ ①$$

  Tidal pumping at mouth:

  $$PEF_{TP} = \frac{g}{2} \cdot (H + h) \cdot (\rho_l - \rho_u) \cdot m_T \cdot Q_{uT} > 0 \text{ with } \begin{cases} m_T = 1 - \frac{r}{L_T} \\ Q_{uT} = 2\frac{(H-h) \cdot W \cdot U_T}{\pi} \end{cases}$$





① Ralston et al. (2008)

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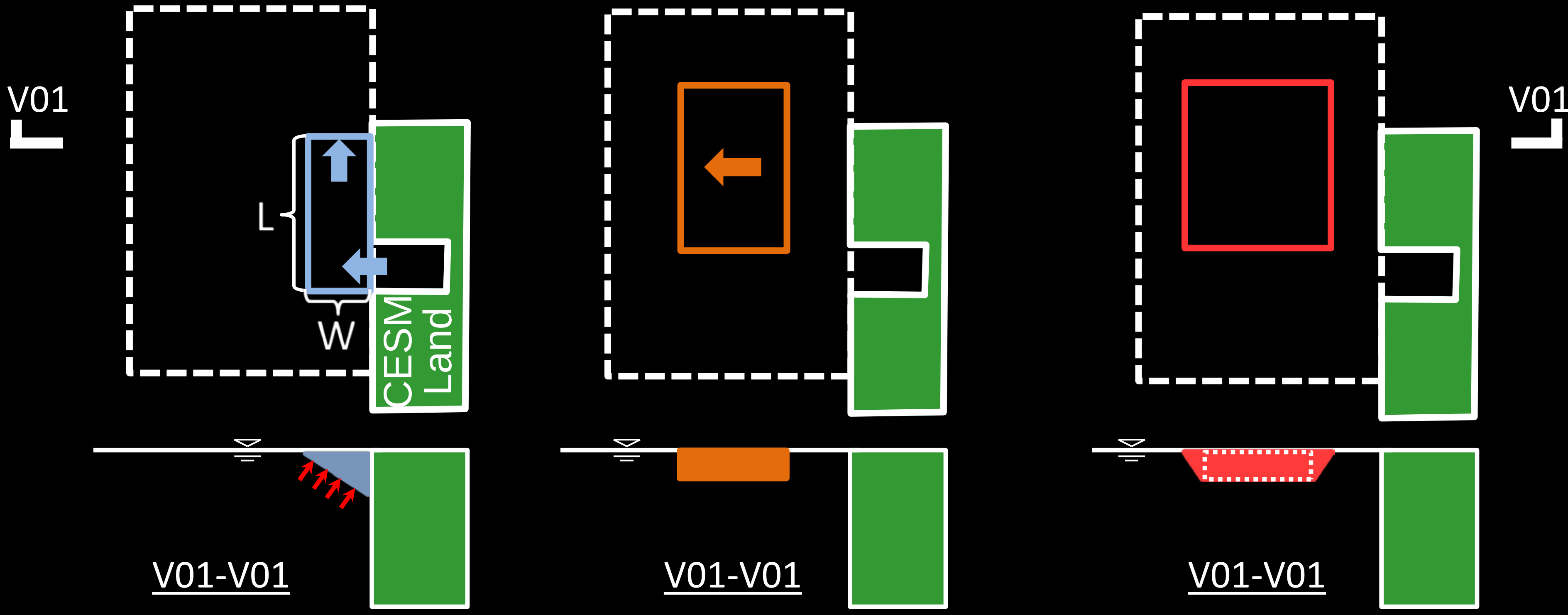
Shelf Box Model

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



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Shelf Box Model

- Methodology