Improving the representation of estuarine processes in CESM

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Overview

- Introduction
- Development of Estuary Box Model (EBM) and results
- Implementation of EBM in POP2 and results
- Current work: Tracking riverine freshwater globally
- Summary
The role of river in global hydrological cycle
Sea surface salinity bias: model (CESM) – climatology (WOA13)
River runoff treatment in standard CESM
- Applied as extra precipitation at sea surface.
- Spreading around river mouth (300KM radius).
- Discharge into ocean with ZERO salinity.
- Using global reference salinity for VSF formula.

Improving river runoff by:
- Remapping runoff as point source.
- Introducing in the estuary mixing.
- Local salinity for VSF formula.

(Tseng et al, Ocean Modelling, 2016)
Estuarine mixing in nature

- Salty sea water intrusions along bottom.
- Non-ZERO outflow at shallow depth.
- Mixing depends on both of runoff and tides.

Columbia River high discharge season

Columbia River low discharge season

http://www.ldeo.columbia.edu/~orton/salt_intrusion.html
Estuary Box Model (EBM): Two layer box

- Ocean model
- Land model

Salinity

(Low) [  ] (High)

Estuary Box Model (EBM): Control equations

**Continuity:** \( \frac{\partial u}{\partial x} + \frac{\partial w}{\partial z} = 0 \)

**Salinity balance:** \( \frac{\partial (uS)}{\partial x} + \frac{\partial (wS)}{\partial z} = \frac{\partial}{\partial x} \left( K_H \frac{\partial S}{\partial x} \right) - \frac{\partial}{\partial z} \left( K_V \frac{\partial S}{\partial z} \right) \)

**Potential energy (PE) balance:** \( \frac{\partial (uPE)}{\partial x} + \frac{\partial (wPE)}{\partial z} = \frac{\partial}{\partial x} \left[ K_H \frac{\partial (PE)}{\partial x} \right] + \frac{\partial}{\partial z} \left[ K_V \frac{\partial (PE)}{\partial z} \right] \)

\[ PE = \rho \ast g \ast z \text{ with } \rho = \rho_0 \ast (1 + \beta \ast S) \]

\[ -K_V g \frac{\partial \rho}{\partial z} - g \frac{\partial K_V \rho}{\partial z} + w g \rho \]
Estuary Box Model (EBM): Algebraic solutions

\[ Q_U = Q_R - Q_L \]

\[ S_U = S_L \frac{a_0 a_t Q_t - 2Q_L}{a_0 a_t Q_t + 2Q_U} \]

\[ \lambda_3 Q_L^3 + \lambda_2 Q_L^2 + \lambda_1 Q_L + \lambda_0 = 0 \]

\[ \lambda_3 = -H \]

\[ \lambda_1 = 0.096a_1 \left( \frac{W H c^4}{Q_R S c^2} \right)^{1/3} \]

\[ \lambda_2 = 2Q_R (2H - h) + a_2 Q_t H \]

\[ \lambda_0 = -0.048a_1 \left( \frac{W H c^4}{Q_R S c^2} \right)^{1/3} \]

\[ H^2 W Q_R - Q_R (2H - h)(Q_R + a_2 Q_t) - a_2^2 \frac{Q_t^2}{4} H \]

Estuary Box Model (EBM): Parameters and forcing

2 Mixing parameters: \( a_1 \) \( a_2 \); 3 dimensional parameters: \( W \) \( H \) \( h \)

3 Forcing terms: \( Q_R \), \( Q_t \) and \( S_L \)
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➢ EBM compared with observations and ROMS in Columbia River

EBM outflow salinity vs. observations

- RMSE=1.7 PSU, $R^2=70\%$

EBM volume fluxes vs. ROMS

- RMSE=513 m$^3$/s, $R^2=89\%$

(Sun et al, Ocean Modelling, 2017)
Estuary Box Model (EBM) global parameterization specification

Estuary stratification-circulation diagram

- Hudson
- Chesapeake
- Puget Sound
- Mississippi
- Chang Jiang

$Q_R/(Wh)/(g' h)^{1/2}$

*Geyer (2010)
Sun et al, Ocean Modelling, 2017
Result (G-case): SSS difference with EBM – control case

31st to 60th year averaged sea surface salinity difference
improved runoff – control run without improvement
Result (G-case): global assessment with salinity skill scores

Coastal ocean bands mask

\[ SS = 1 - \frac{\text{mean}[(\text{EBM case} - \text{WOD})^2]}{\text{mean}[(\text{ctrl. case} - \text{WOD})^2]} \times 100\% \]

Upper 150m ocean integrated salinity SS, with or without high latitude ocean.

Sun et al, JAMES, 2018 (in review)
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Future work: global riverine freshwater pathway and influences

Riverine FW fraction fraction [%] at sea surface, in month: 1

North Atlantic zonal
Riverine FW fraction fraction [%], in month: 1

Atlantic meridional
Riverine FW fraction [%] in month: 1
Summary

- The Estuary Box Model is a physically based parameterization of unresolved estuarine mixing processes in the CESM.
- The offline tests of EBM show very good agreement with direct observations of outflow salinity and high-resolution simulations of exchange flow volume fluxes.
- A reduced set of parameters allows the parameterization to be practically applied to every river inflow point in global Earth system models at negligible cost.
- The global CESM simulations with the EBM show it can have significant impacts on the salinity field of the coastal oceans, with non-negligible impacts in some open ocean areas.
- The EBM can further imply in river borne nutrient and contaminants.
THANK YOU FOR YOUR ATTENTION
Estuary Box Model (EBM): **Implementation in POP2**

\[
\frac{DS}{Dt} = \nabla (K \nabla S) + \frac{\partial}{\partial Z} \left[ \kappa \left( \frac{\partial S}{\partial Z} - \gamma_s \right) \right] - \frac{\partial F^R}{\partial Z} - \frac{\partial F^{REX}}{\partial Z}
\]

with

\[
\kappa \left. \frac{\partial S}{\partial Z} \right|_{z=0} = -F_s(0) \quad \text{and} \quad F_s(0) = (q_w^p + q_w^E + q_w^l)S_{ref}
\]

Salt flux taken out of ocean: \( F^R \) with local reference salinity

Salt flux taken from deeper to shallower: \( F^{REX} \) with local reference salinity