Earth-surface Dynamics Modeling & Model Coupling

A short course

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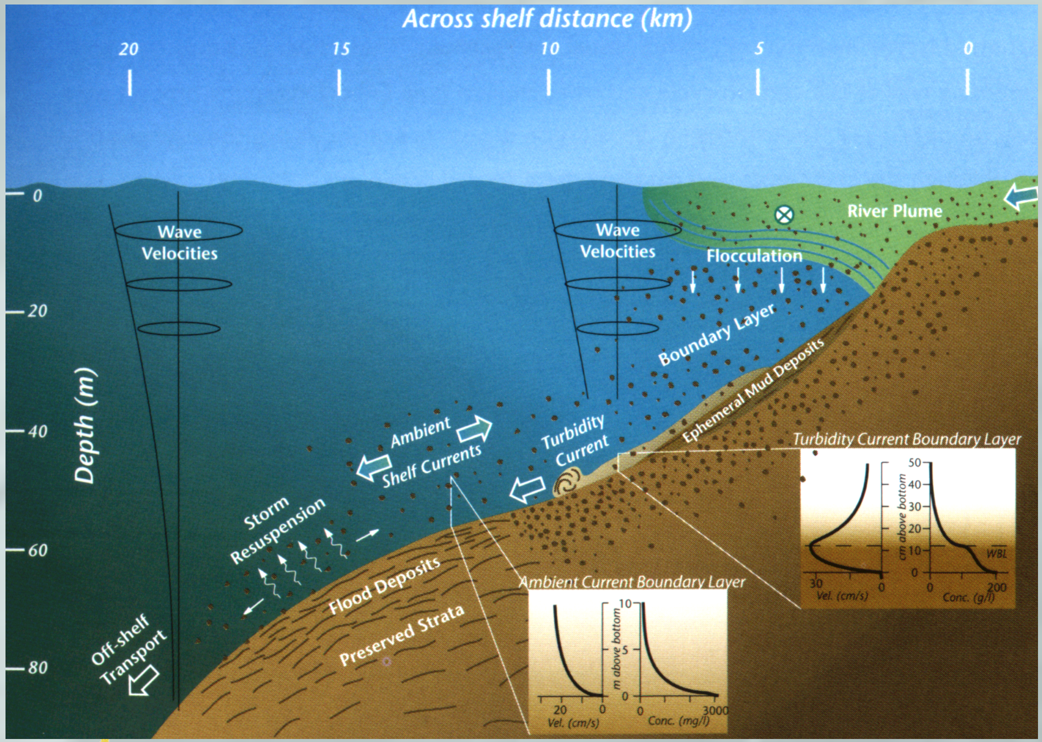
With special thanks to Pat Wiberg, Carl Friedrichs, Courtney Harris, Chris Reed, Rocky Geyer, Alan Niedoroda, Rich Signell, Chris Sherwood



COMMUNITY SURFACE DYNAMICS MODELING SYSTEM

Module 5: Shelf Sediment Transport

ref: Syvitski, J.P.M. et al., 2007. Prediction of margin stratigraphy. In: C.A. Nittrouer, et al. (Eds.) Continental-Margin Sedimentation: From Sediment Transport to Sequence Stratigraphy. IAS Spec. Publ. No. 37: 459-530.

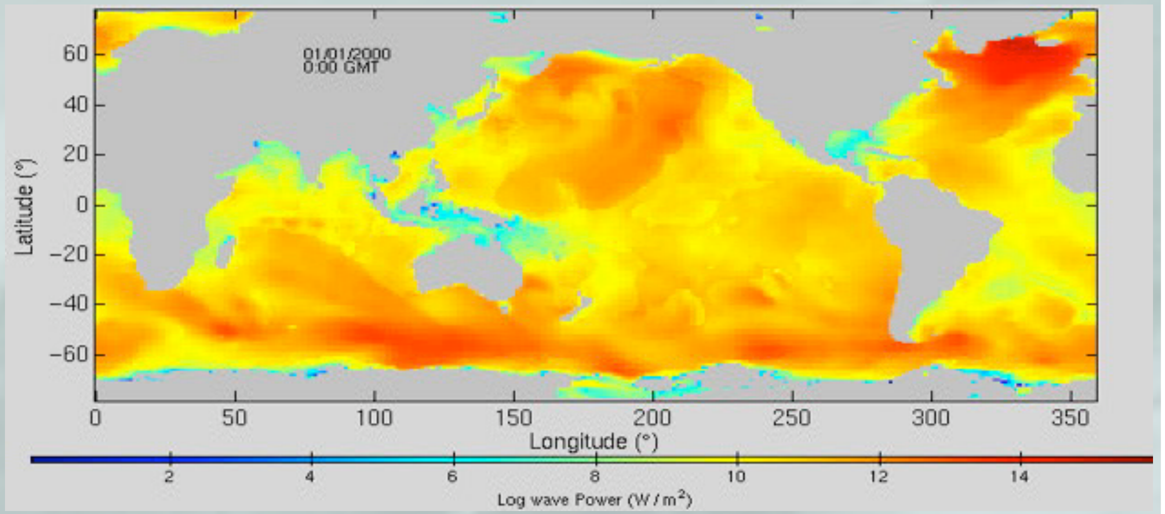
Shelf diffusivity (3)

Gravity-driven slope equilibrium (4)

Event-based models (7)

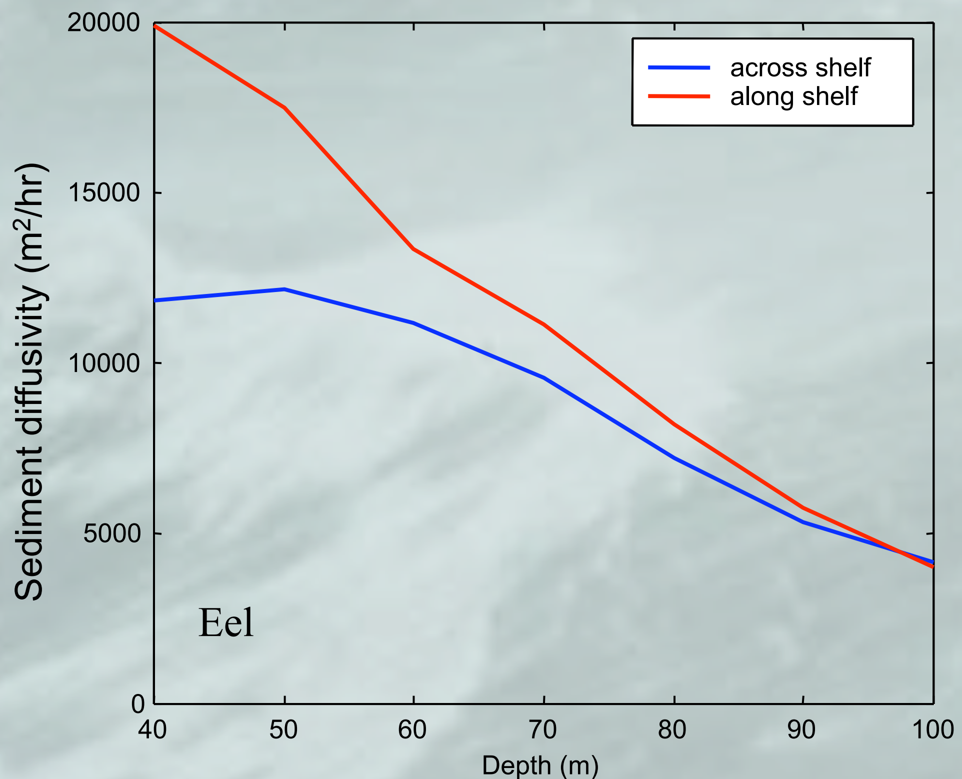
Coastal Ocean Models (4)

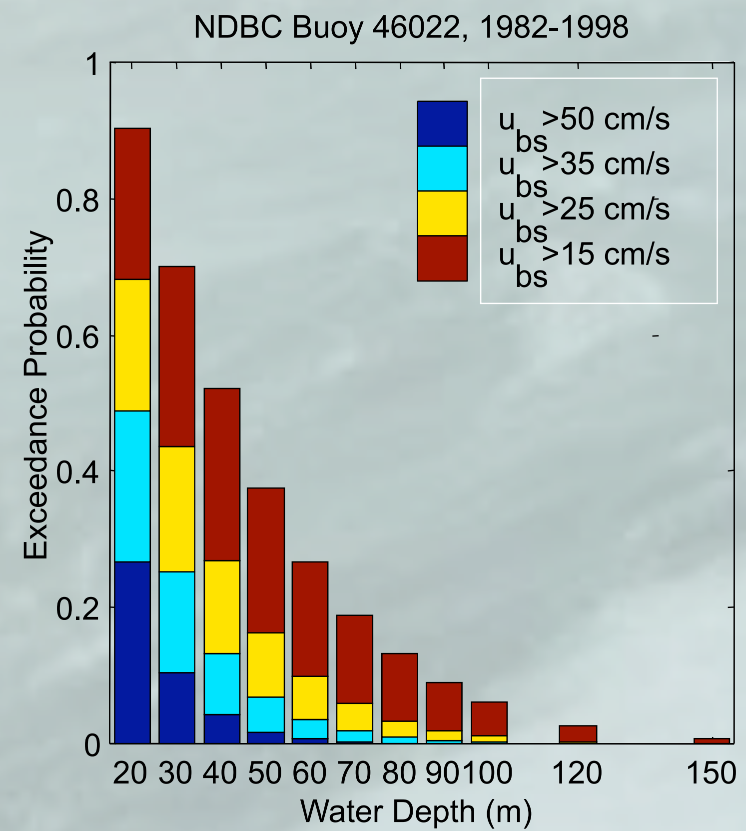
Summary (1)



Shelf diffusivity

Local transport occurs if the probability of wave resuspension is exceeded at a particle's water depth.



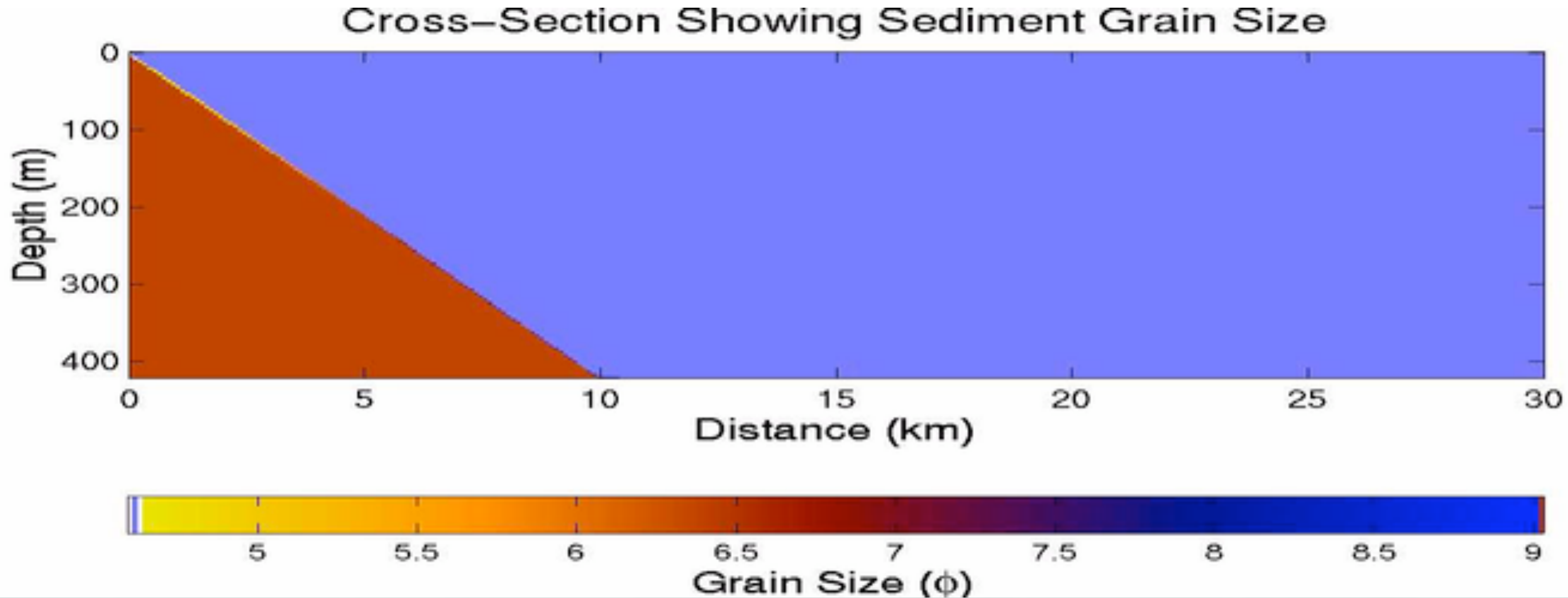


Shelf diffusivity

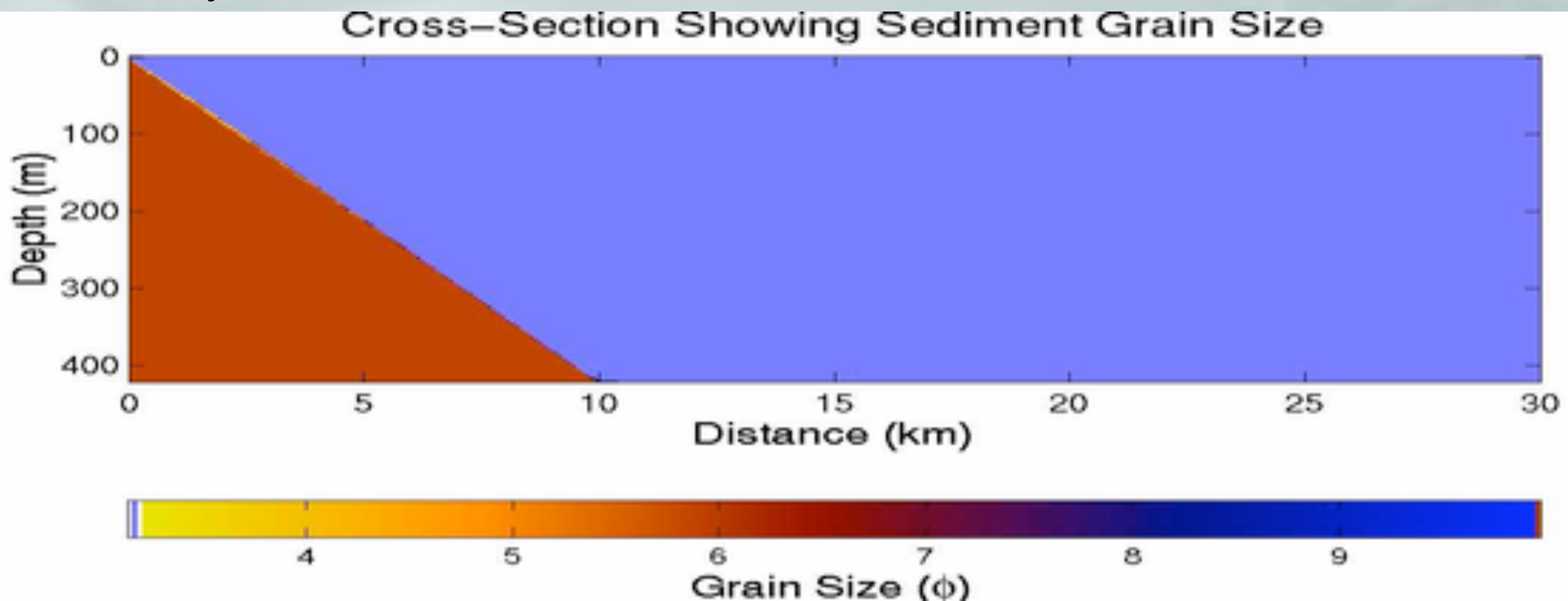
Resuspension and Advection by Bottom Boundary Energy

$$\frac{\partial h}{\partial t} = \frac{\partial}{\partial x}\left(k(t,x)\,\frac{\partial h}{\partial x} \right) \qquad \frac{\partial h_i}{\partial t} = \tilde{k}_i\,\frac{\partial h}{\partial t}$$

- $k(t,z)$ varies over time t (pdf of storms), and water depth z. Following Airy wave theory, k falls off exponentially with water depth.
- k_i is an index between 0 and 1 that reflects the ability of grain size i to be resuspended and advected.
- $k(t,z) \geq k_i$ for sediment transport



Plumes Only

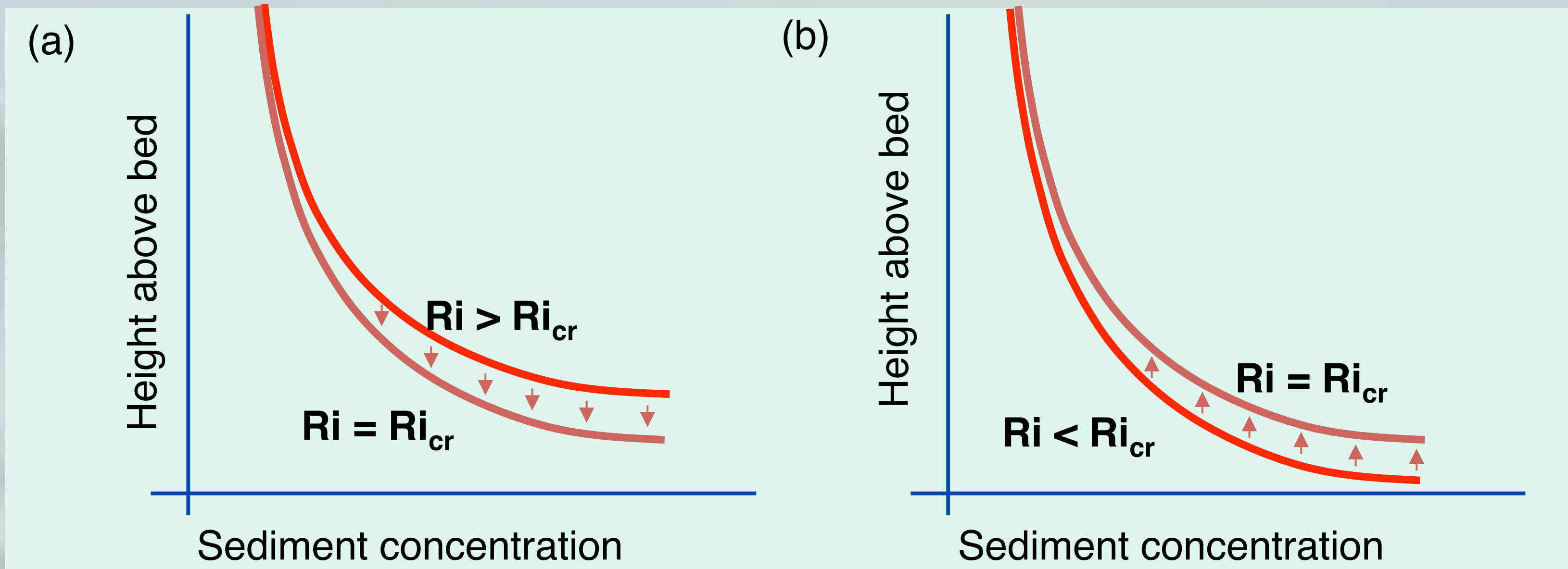


Plumes & Wave Diffusion

Gravity-driven slope equilibrium

Gradient Richardson Number (Ri) = $\frac{\textbf{density stratification}}{\textbf{velocity shear}}$

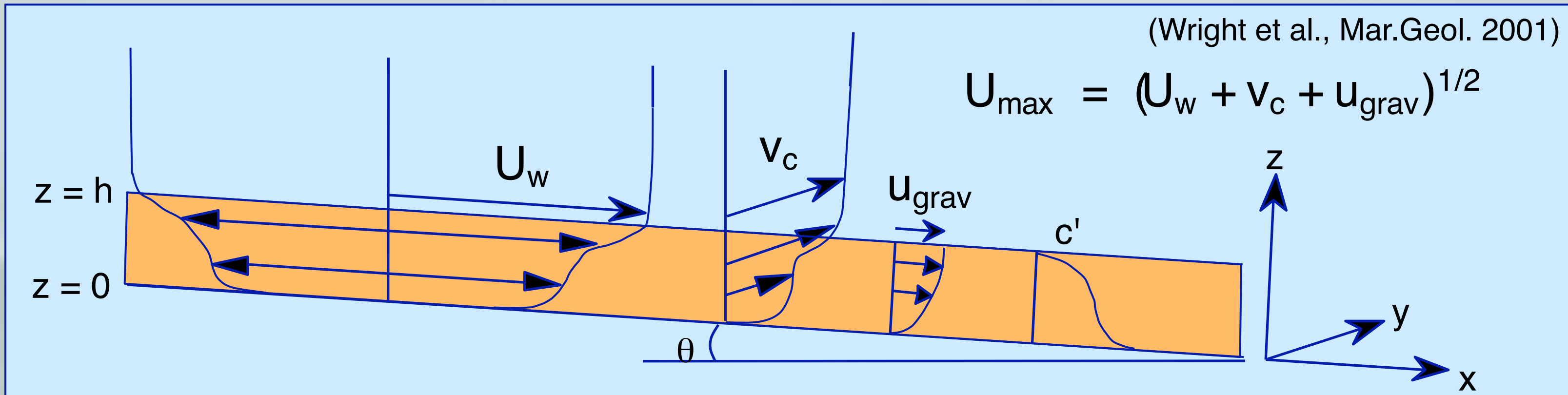
Shear instabilities occur for Ri < Ri_{cr}
" " suppressed for Ri > Ri_{cr}



(a) If excess sediment enters BBL & Ri increases beyond Ri_{cr}, then turbulence is dampened, sediment is deposited, stratification is reduced and Ri returns to Ri_{cr}

(b) If excess sediment settles out of boundary layer, or bottom stress increases & Ri decreases beyond Ri_{cr} then turbulence intensifies. Sediment re-enters base of boundary layer. Stratification is increased in boundary layer and Ri returns to $Ri_{cr.}$

Gravity-driven slope equilibrium



(i) Momentum balance: Down-slope pressure gradient = Bottom friction

total velocity = $(U_w^2 + v_c^2 + u_{grav}^2)^{1/2}$

$$\alpha B = c_d < |\vec{u}|\, u > = c_d\, U_{max}\, u_{grav}$$

- x-shelf bed slope (α)
- depth-integrated buoyancy anomaly (B)
- bottom drag coefficient (c_d)
- wave-averaged, x-shelf component of quadratic velocity
- x-shelf gravity flow velocity (u_{grav})

(ii) Maximum turbulent sediment load: (c.f. Trowbridge & Kineke, JGR 1994)

Richardson Number = Buoyancy / Shear = Critical value

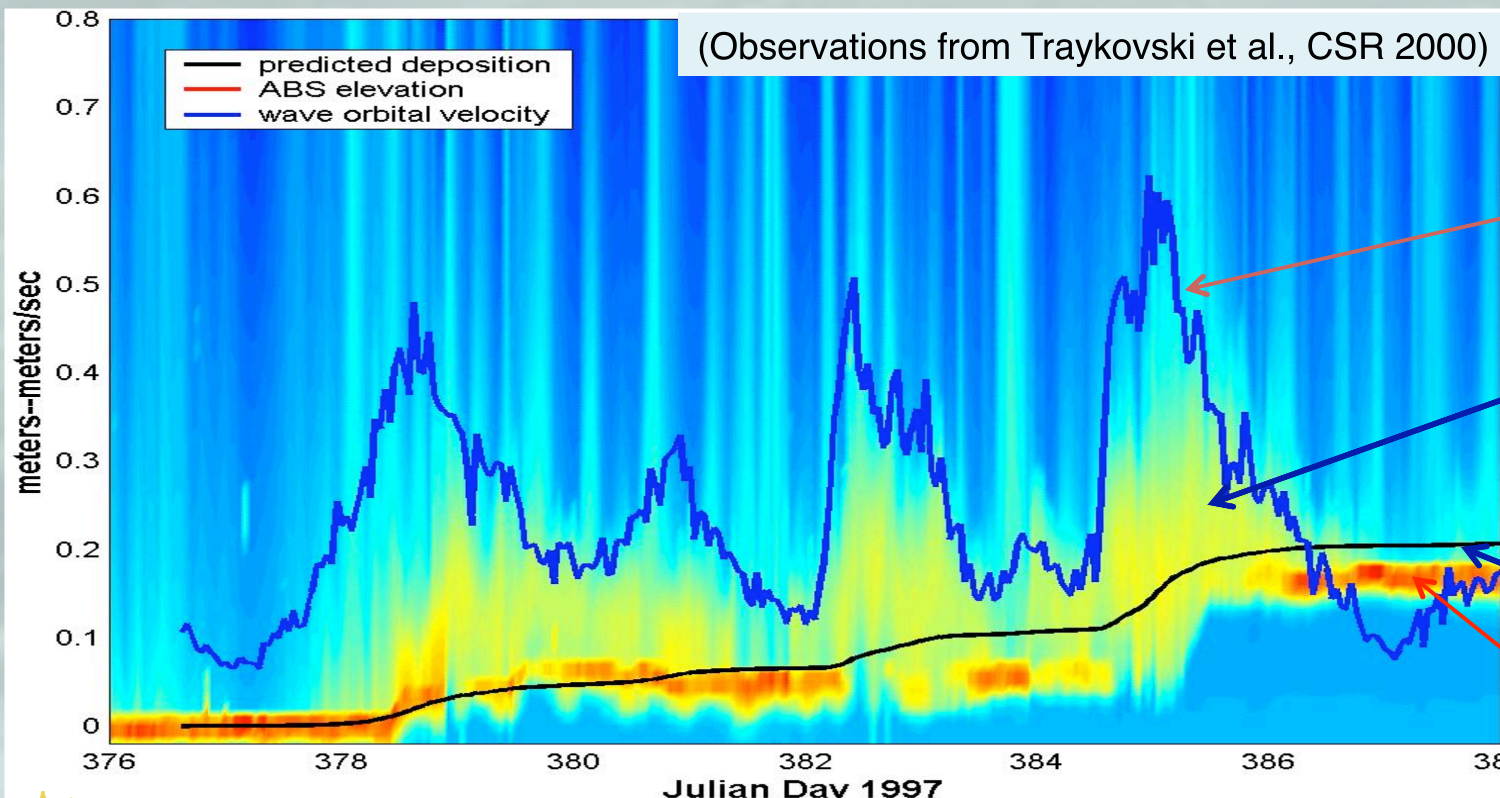
$$Ri = \frac{B}{(U_{max})^2} = Ri_{cr} = 1/4$$

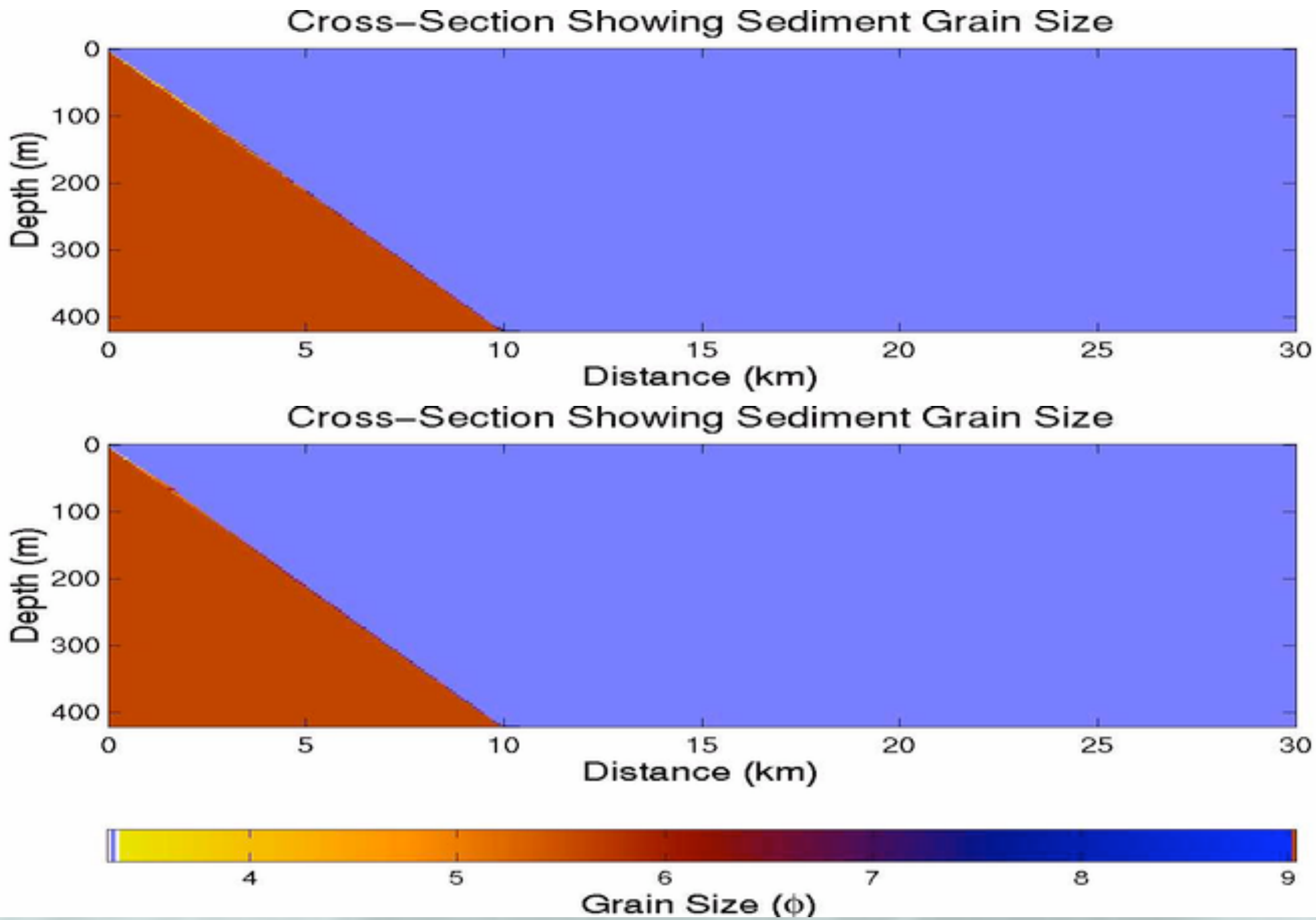
COMPARISON OF MODEL PREDICTIONS TO OBSERVED DEPOSITION

Application to 1996-97 Eel River Flood at 60-meter Site

$$\text{Deposition Rate} = -\frac{Ri_{\alpha}^{2}}{(1-P)\, c_d\, g\, s} \frac{d}{dx} (\alpha\, U_{max}^{3})$$

Porosity	$(\rho_{sed}/\rho_{water} -1)$	Bed slope	Richardson #	Drag coeff.
$P = 0.9$	$s = 1.6$	$\alpha = 0.004$	$Ri_{cr} = 0.25$	$c_d = 0.003$

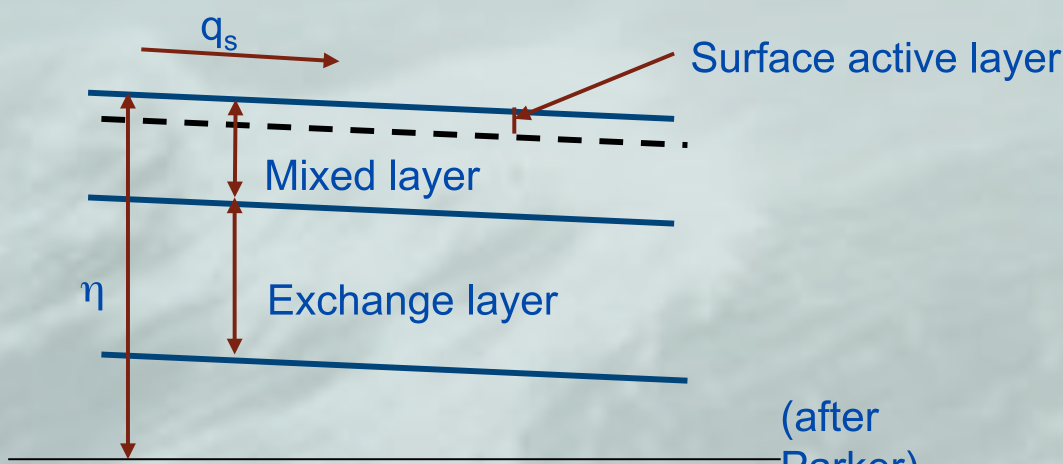




Top: Plumes & Wave Diffusion; Bottom: Plumes, Waves & Fluid Muds

Event-based transport model

Calculate suspended sediment flux (by grain size) using a 1-D shelf sediment transport model at a cross-shelf grid of nodes of specified depth and sediment characteristics. For each event (set of wave & current conditions), the net flux is calculated at each node. The divergence of the flux gives the change in bed elevation.



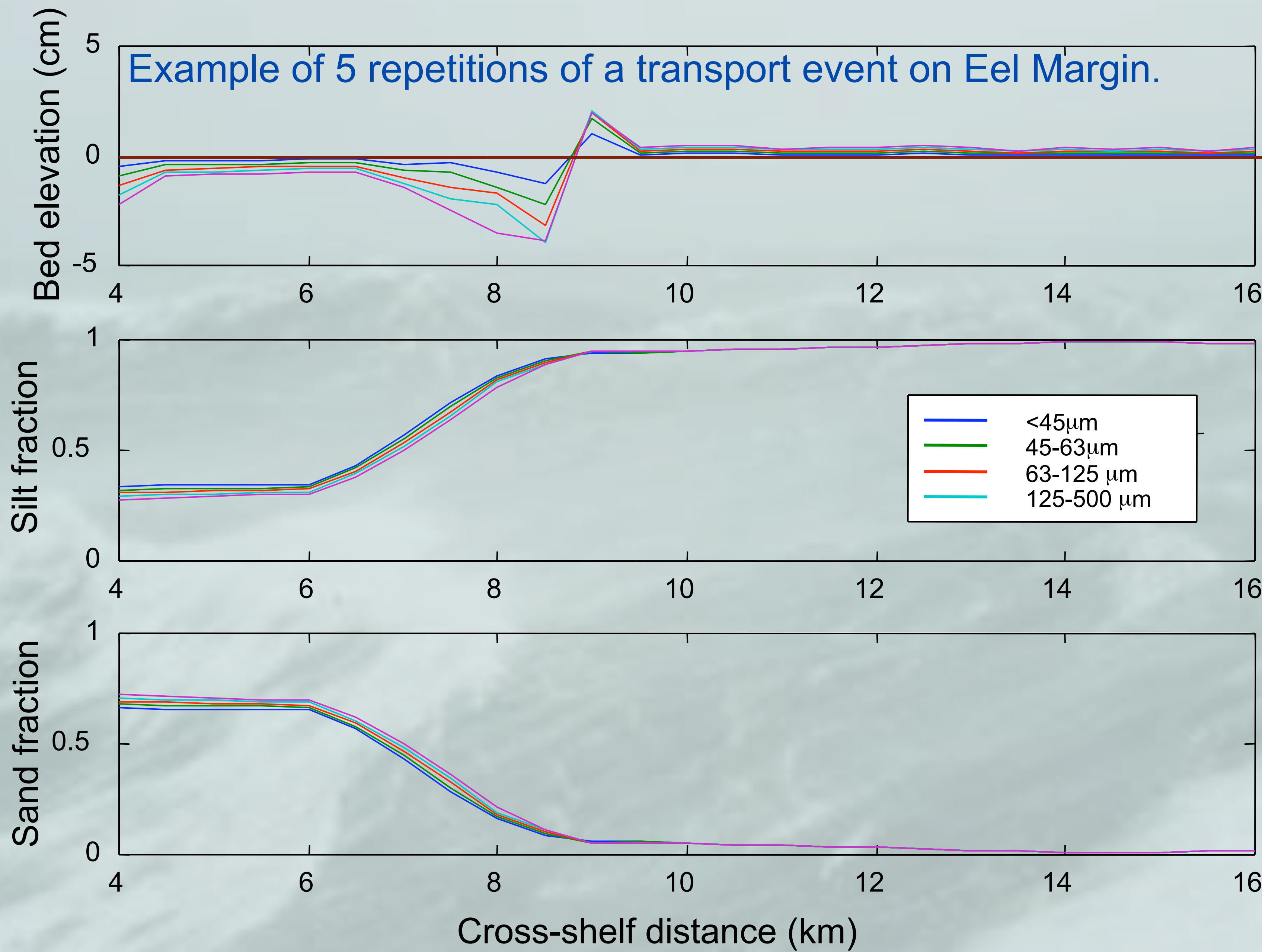
(after Parker)

$$q_{xi} = -D_{cx}\frac{\partial c_i}{\partial x} \qquad q_{yi} = -D_{cy}\frac{\partial c_i}{\partial y}$$

$$\frac{\partial \eta_i}{\partial t} = -\frac{1}{c_b}\left(\frac{\partial}{\partial x}D_{cx}\frac{\partial c_i}{\partial x} + \frac{\partial}{\partial y}D_{cy}\frac{\partial c_i}{\partial y}\right)$$

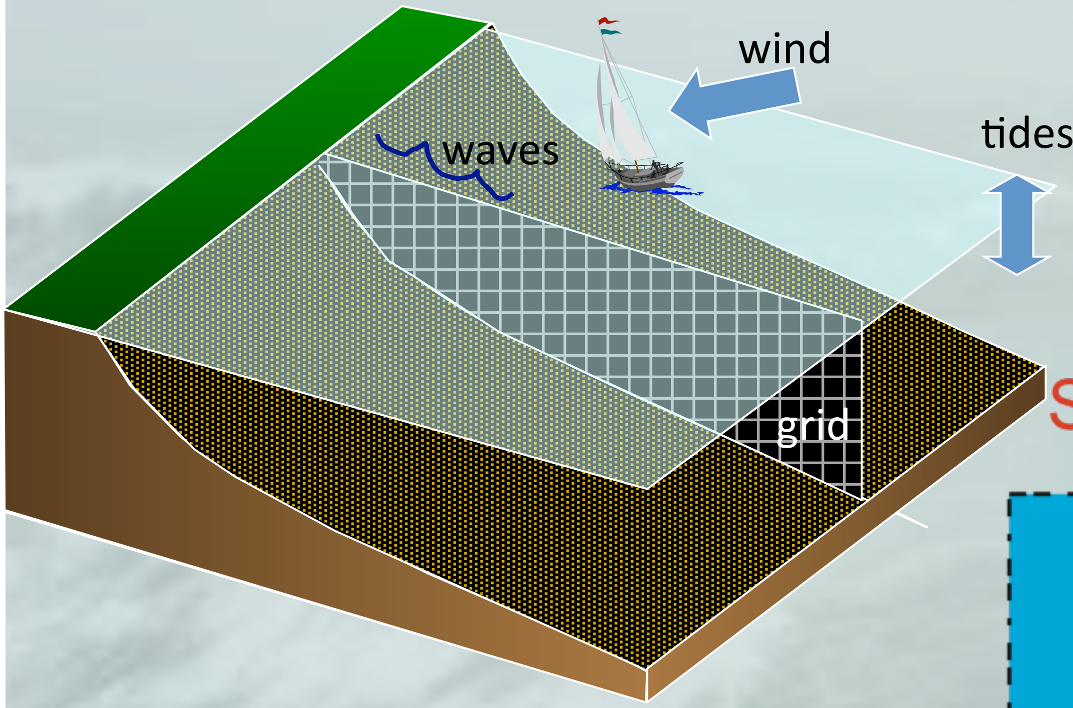
$$\frac{\partial \eta}{\partial t} = \sum_{i=1}^{N}\frac{\partial \eta_i}{\partial t}$$

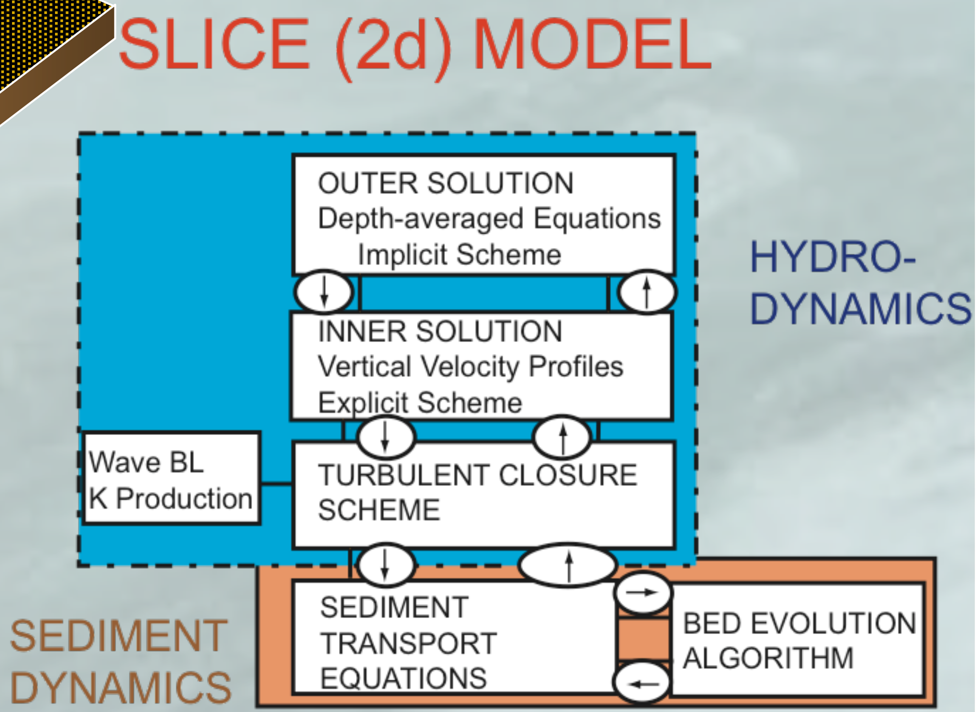
$$\frac{\partial F}{\partial t} = -\frac{1}{c_b L_a}\left(\frac{\partial q_i}{\partial x}\right) - \left(F_{ei}\frac{\partial \eta}{\partial t} + \sigma\right)$$


Example of 5 repetitions of a transport event on Eel Margin.
Bed elevation (cm)
5
0
-5
4
6
8
10
12
14
16
Silt fraction
1
0.5
0
<45µm
45-63µm
63-125 µm
125-500 µm
Sand fraction
Cross-shelf distance (km)

SLICE Description

Neidoroda & Reed





$$\frac{\partial c_i}{\partial t} + \frac{\partial u c_i}{\partial x} + \frac{\partial (w - w_{is}) c_i}{\partial z} = \frac{\partial}{\partial x} D_x \frac{\partial c_i}{\partial x} + \frac{\partial}{\partial z} D_z \frac{\partial c_i}{\partial z} + s_i - \lambda_i c_i$$

$$(w - w_{is}) c_i - D_z \frac{\partial c_i}{\partial z} = 0$$

Neidoroda & Reed

$$(w - w_{is}) c_i - D_z \frac{\partial c_i}{\partial z} = F_i$$

SLICE Description

$$Fi = M(\tau_{ic}, \tau_b, \alpha_j)$$

$$\frac{\partial k}{\partial t} + \frac{\partial u k}{\partial x} + \frac{\partial w k}{\partial z} = \frac{\partial}{\partial x} \frac{K_x}{\sigma_x} \frac{\partial k}{\partial x} + \frac{\partial}{\partial z} \frac{K_z}{\sigma_z} \frac{\partial k}{\partial z} + P_k + G_k + P_{wc} - \frac{Cu''}{2} \frac{k^{3/2}}{\ell}$$

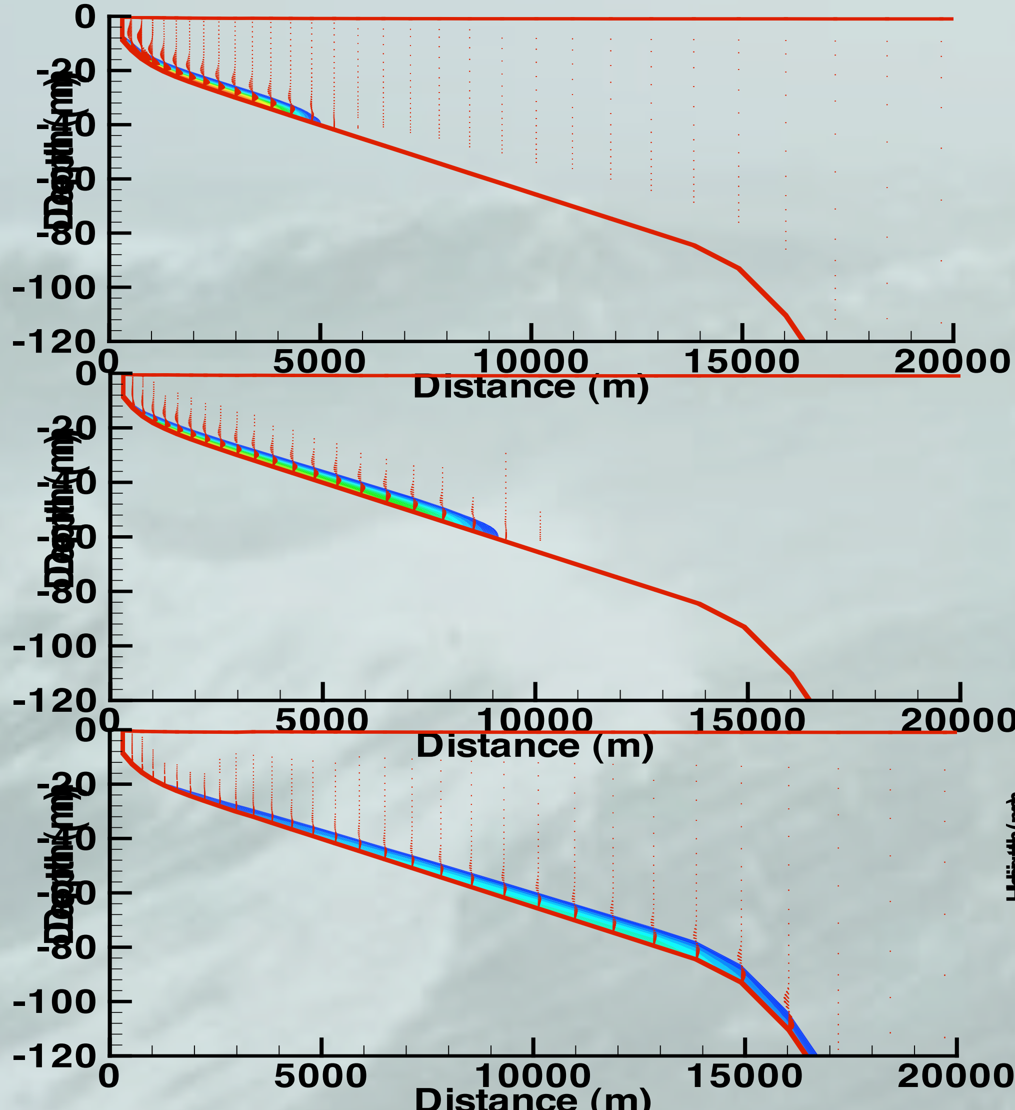
$$\ell = \frac{\alpha h_\ell \kappa z}{\alpha h_\ell + \kappa z} \qquad v_T = Cu' \sqrt{k}\, \ell$$

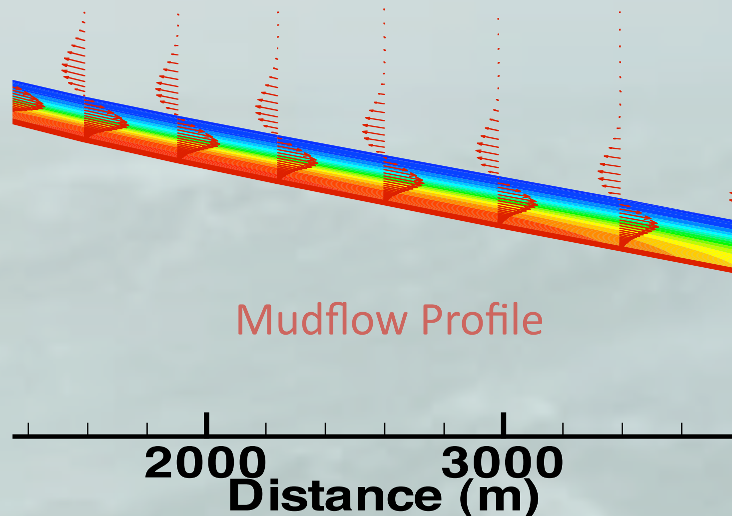
$$K_x = constant$$

$$K_z = \nu + \nu_T$$

Neidoroda & Reed

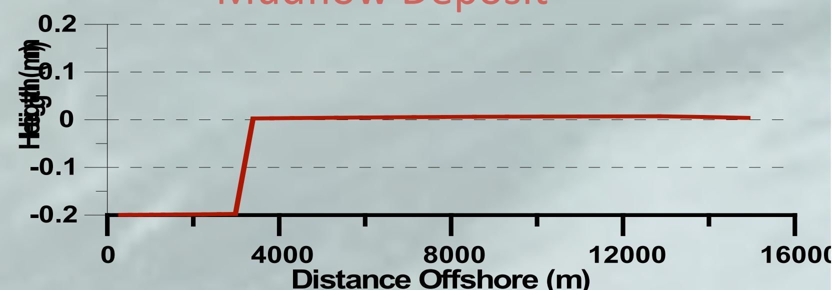
SLICE Density Flows

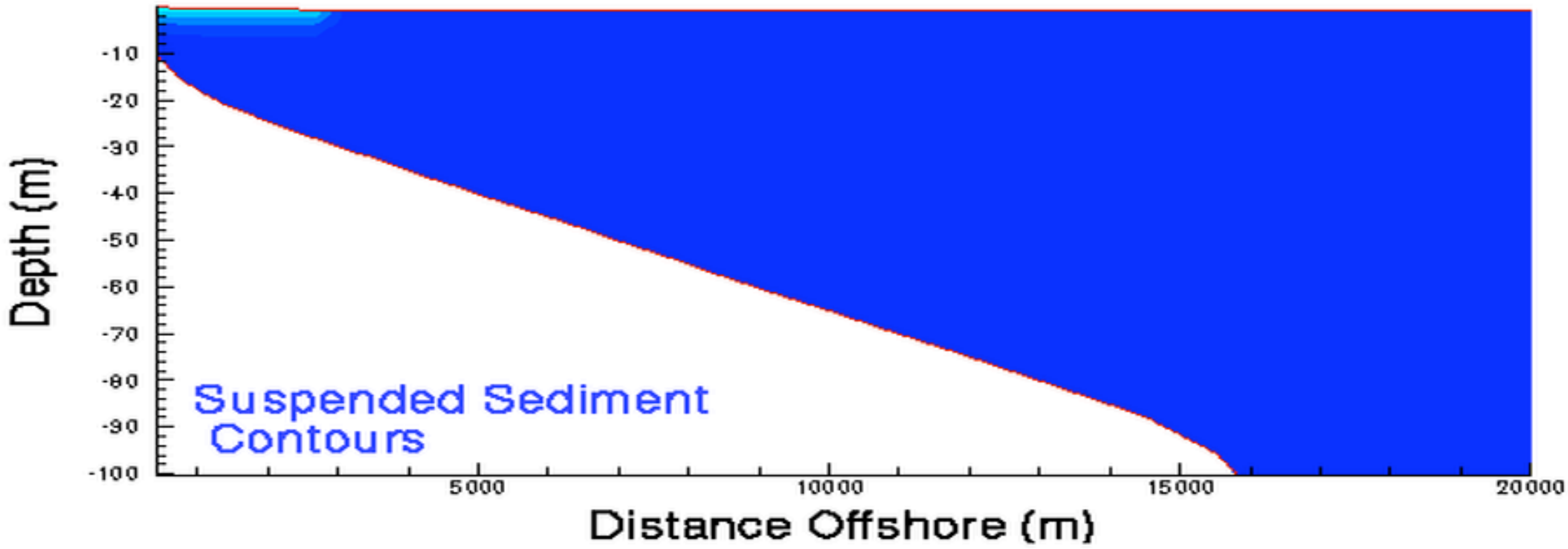


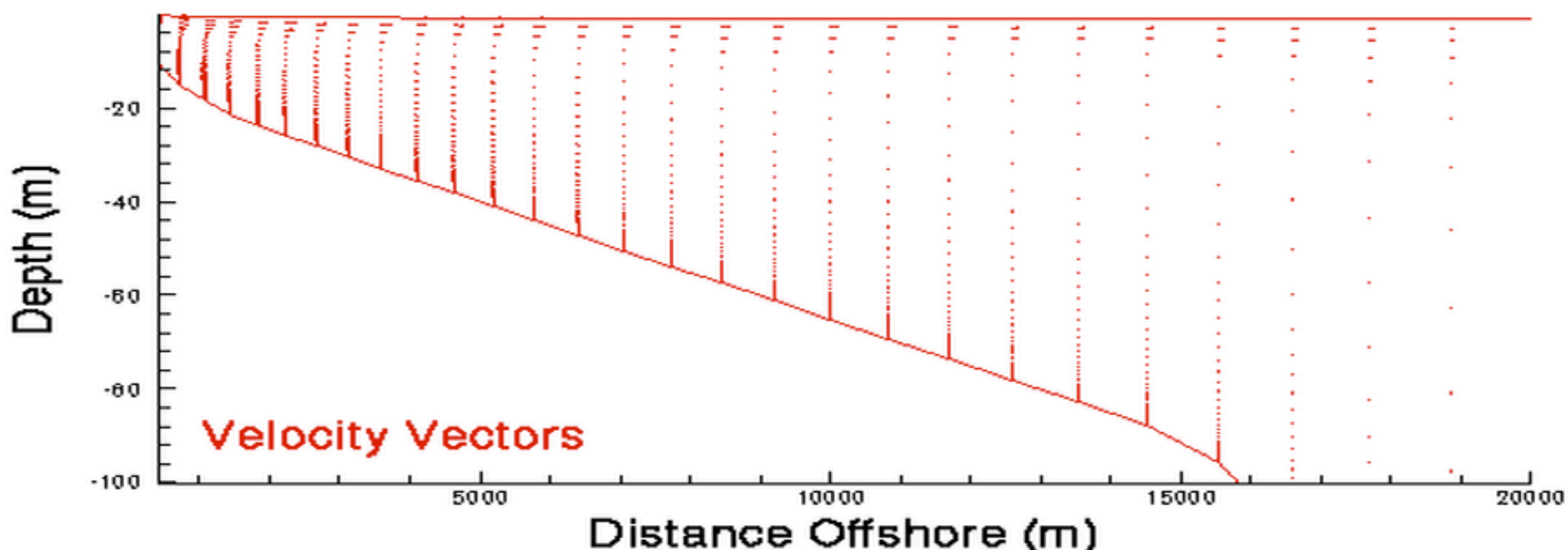


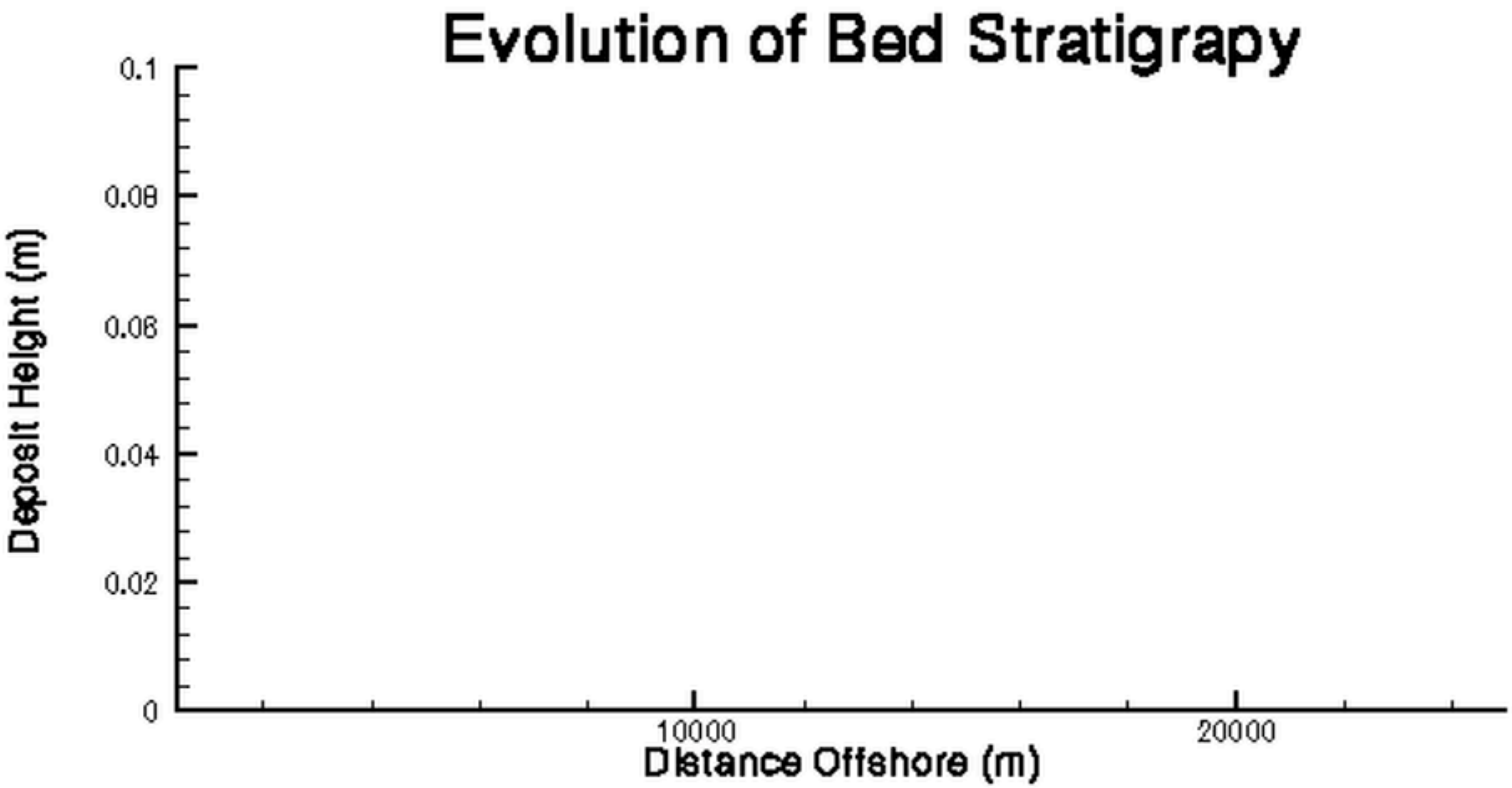
Mudflow Profile

Mudflow Deposit

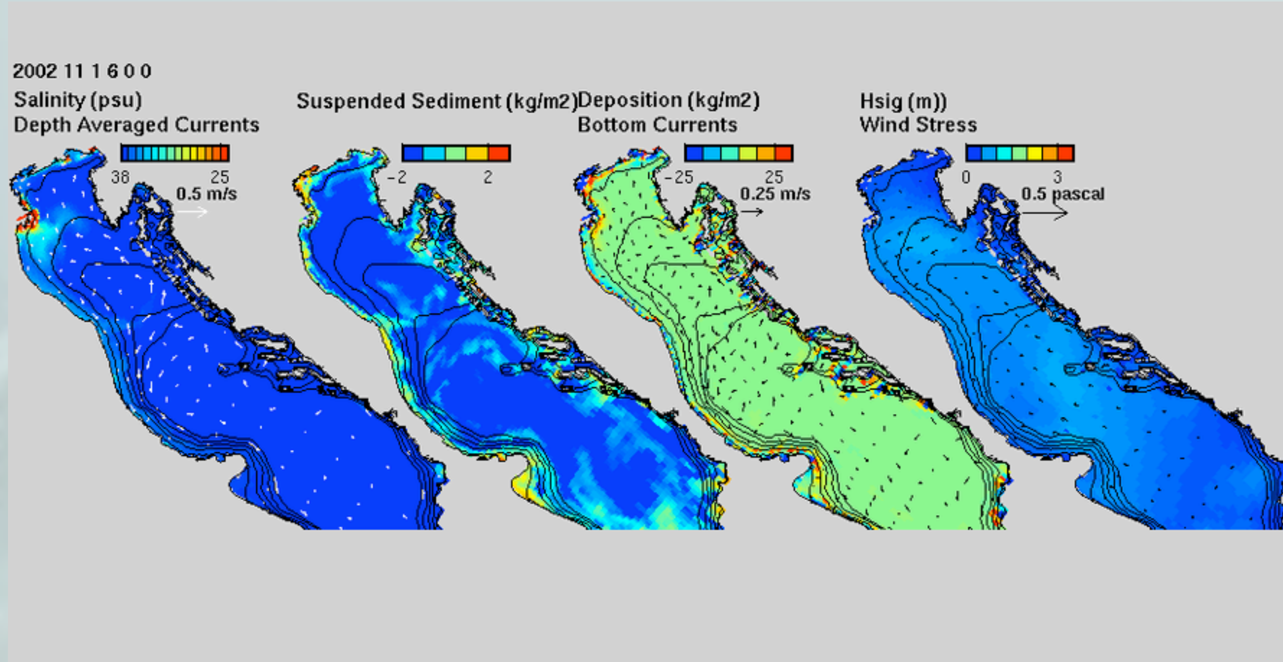


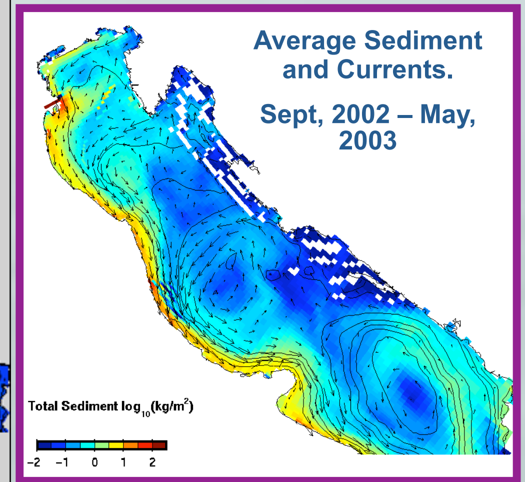

Depth (m)
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
Suspended Sediment
Contours
5000
10000
15000
20000
Distance Offshore (m)


Depth (m)
-20
-40
-60
-80
-100
Velocity Vectors
5000
10000
15000
20000
Distance Offshore (m)


Evolution of Bed Stratigrapy
Deposit Height (m)
0.1
0.08
0.06
0.04
0.02
0
10000
20000
Distance Offshore (m)

Nested Modeling





C.Harris, VIMS

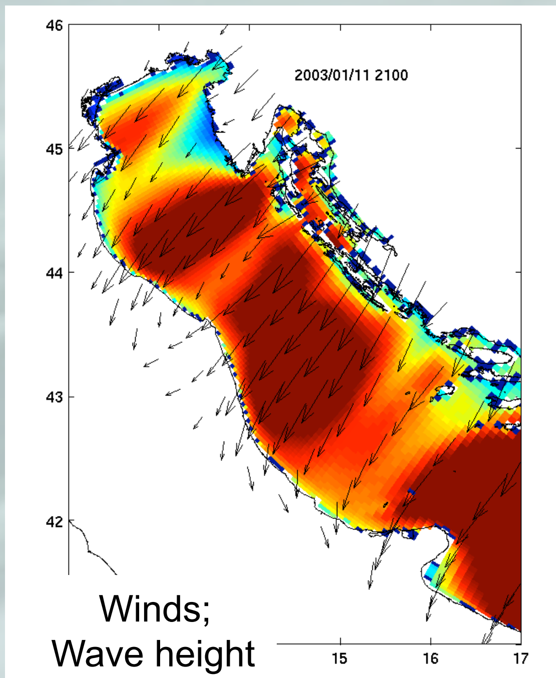
Regional Hydrological Model
(HydroTrend)
(atm-landsurface model)
to
Regional Ocean Model (ROMS)
for
Sediment Supply, Buoyancy,
Sediment Plumes

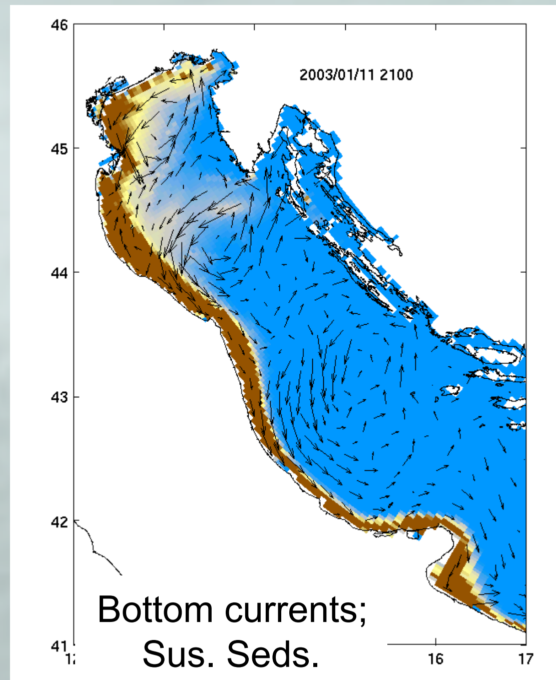
Global Ocean Model
(NOGAPS)
(coupled ocean-atm model)
to
Regional Ocean Model (ROMS)
(coupled ocean-atm model)
for
Regional Circulation and
Current Shear

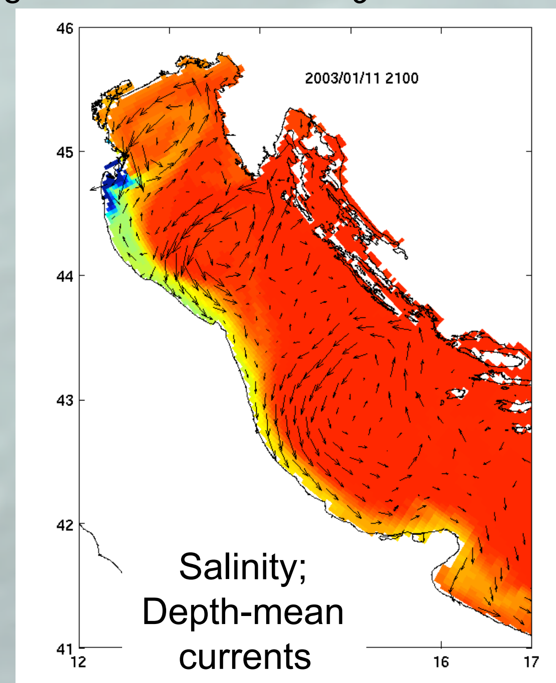
Global Met. Model (NOGAPS)
(coupled ocean-atm model)
to
Regional Met. Model (COAMPS)
(coupled ocean-atm model)
to
Wave Model (SWAN)
for
Sediment Resuspension (ROMS)

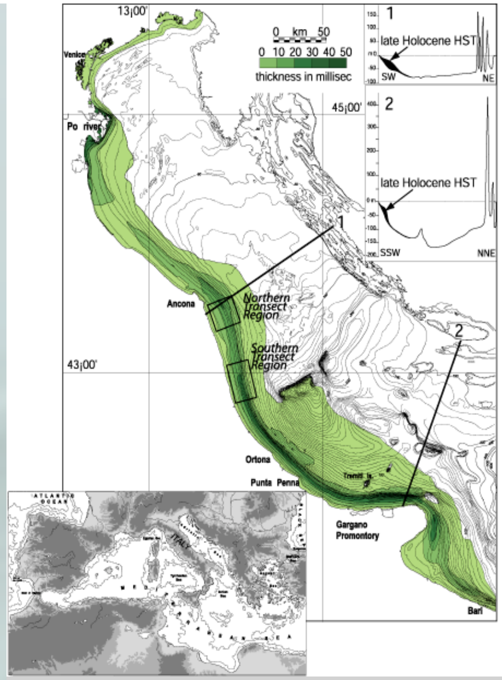
Circulation and Sediment-Transport Modeling

- ROMS: Regional Ocean Modeling System — RANS for heat & momentum fluxes
- 3-8 km grid, 21 vertical “S” levels
- Initialized with ship data
- Zero-gradient b.c. near Otronto, seven tidal components
- LAMI forcing every 3 hours, SWAN waves, Po River discharge
- *k*-ω turbulence model, Styles & Glenn wave-current boundary layer
- Resuspension & transport of single grain size, w_s = 0.1 mm/s, τ_c =0.08Pa

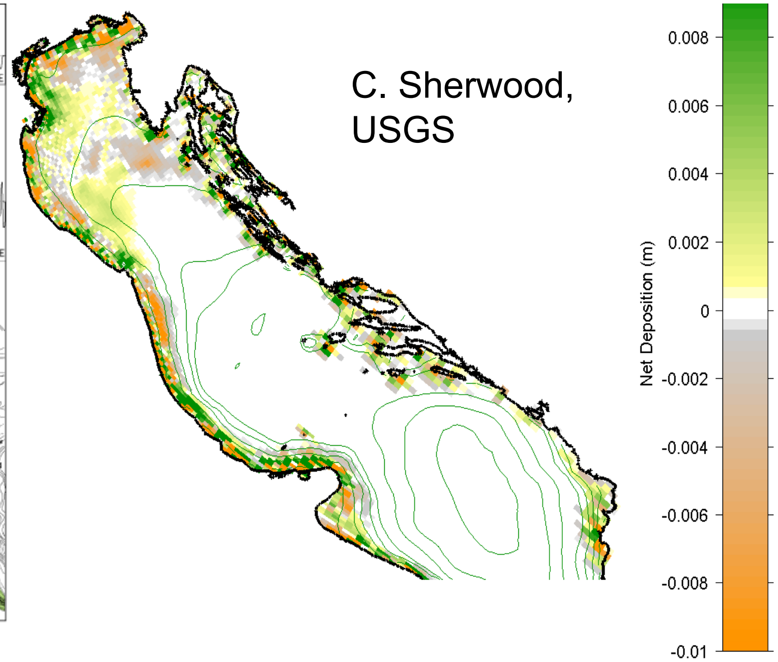




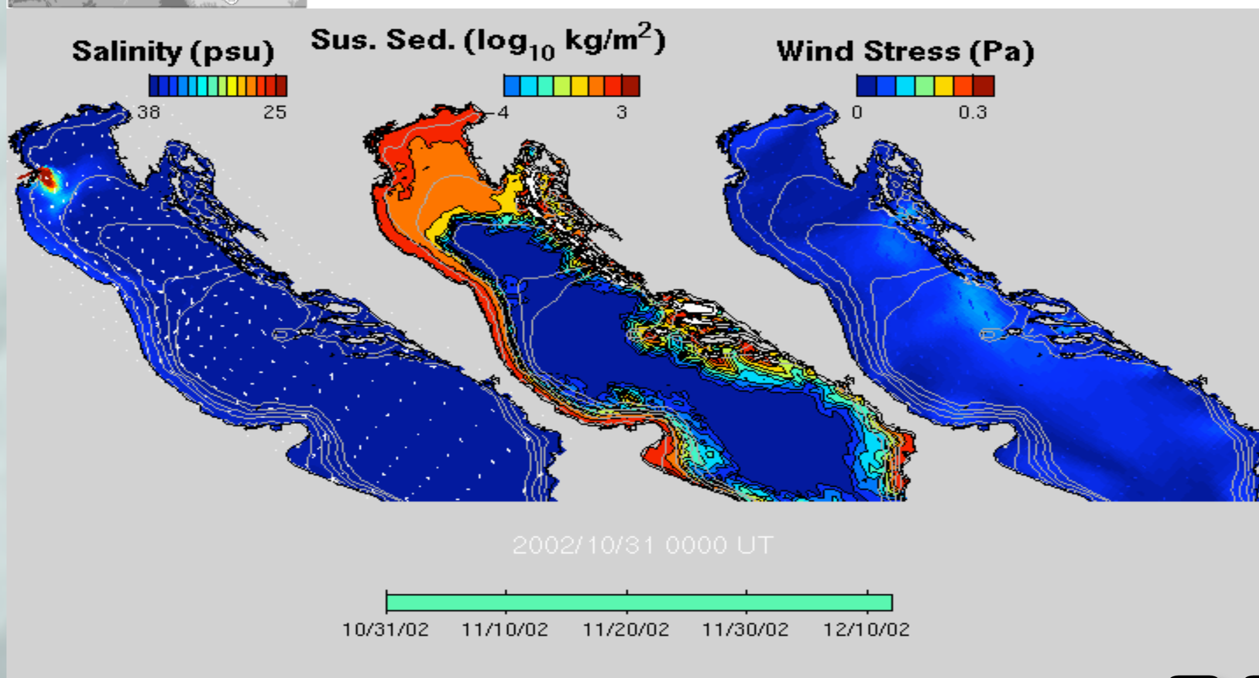




13¡00'
Venice
Po river
0 km 50
0 10 20 30 40 50
thickness in millisec
45¡00'
1
late Holocene HST
SW
NE
2
late Holocene HST
SSW
NNE
Ancona
Northern Transect Region
Southern Transect Region
43¡00'
Ortona
Punta Penna
Gargano Promontory
Bari

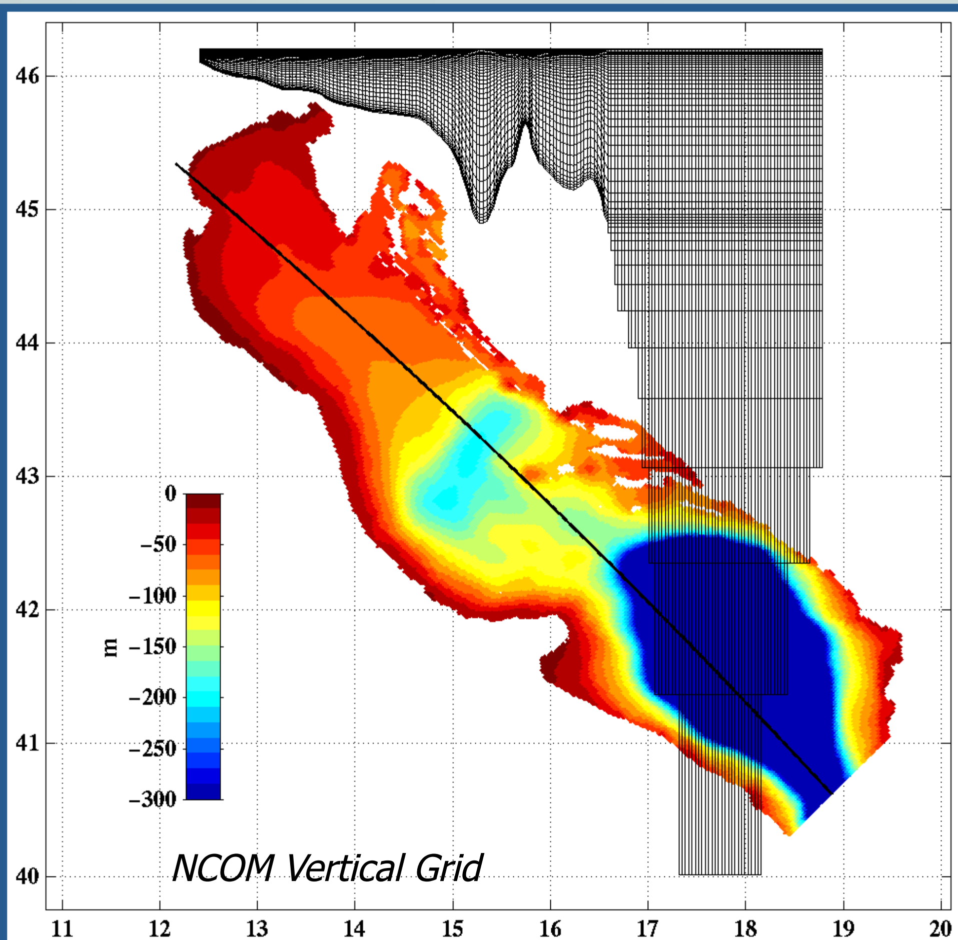


C. Sherwood, USGS
Net Deposition (m)
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
-0.01



Salinity (psu)
38
25
Sus. Sed. (log10 kg/m2)
-4
3
Wind Stress (Pa)
0
0.3
2002/10/31 0000 UT
10/31/02
11/10/02
11/20/02
11/30/02
12/10/02

VIMS-NCOM 3D Transport Model

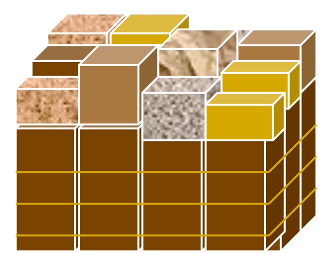


Currents, Bed Shear

2 km Sediment Model

Inputs: sediment sources, sizes, critical shear stress, settling velocity.

Calculates: flux, concentration, erosion / deposition.



Sea Floor Grid

Conclusions:

Shelf diffusivity

Advantages: uses daily *pdf* of regional ocean energy, simple and robust; compatible with landscape evolution models

Disadvantages: depends wave energy *pdf* -- how variable is diffusion in response to decadal and longer term variability?

Gravity-driven slope equilibrium

Advantages: uses daily *pdf* of local total velocity, simple and robust; can be tested against field data

Disadvantages: Needs pdf for wave energy and sediment discharge from rivers, to calculate Richardson number

Event-based Approach

Advantages: uses wave, current, and sediment information available for a site, preserving all correlations, can be tested against field data

Disadvantages: time scales short, data needs intensive for long-term simulations, inshore boundary condition difficult to specify

Coastal Ocean Model

Advantages: Can get it right if all terms are included & appropriate resolution is used.

Disadvantage: Computationally intensive: data needs intensive