Scaling Up Marine Sediment Transport

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The challenge: How to go from local, event-scale marine sediment transport processes to time scales associated with morphologic evolution, land-use impacts, climate change, and strata formation and at larger spatial scales?

Possible approaches

1. Extend local, event-scale models by:
   - enlarging the spatial context [e.g., CSTMS-ROMS, Delft3D]
   - increasing the time step (with appropriate model adjustments) [e.g., Xbeach]
   - running them for a series of real or synthetic events to develop a distribution of responses to a distribution of forcing [e.g., Swift et al]

Possible approaches

2. Develop simpler, time-averaged representation

   – diffusion or advection-diffusion formulation
   – solve for equilibrium shelf profile based on balance of dominant processes [e.g. Friedrichs and Scully]
   – determine an "effective storm" to represent the net effect of storms on moving sediment over some time period [e.g. Swensen]
   – geometric models of margin stratigraphy [e.g. Steckler]

Recent progress in hillslope diffusion

e.g.,Tucker and Bradley, 2010: Trouble with diffusion

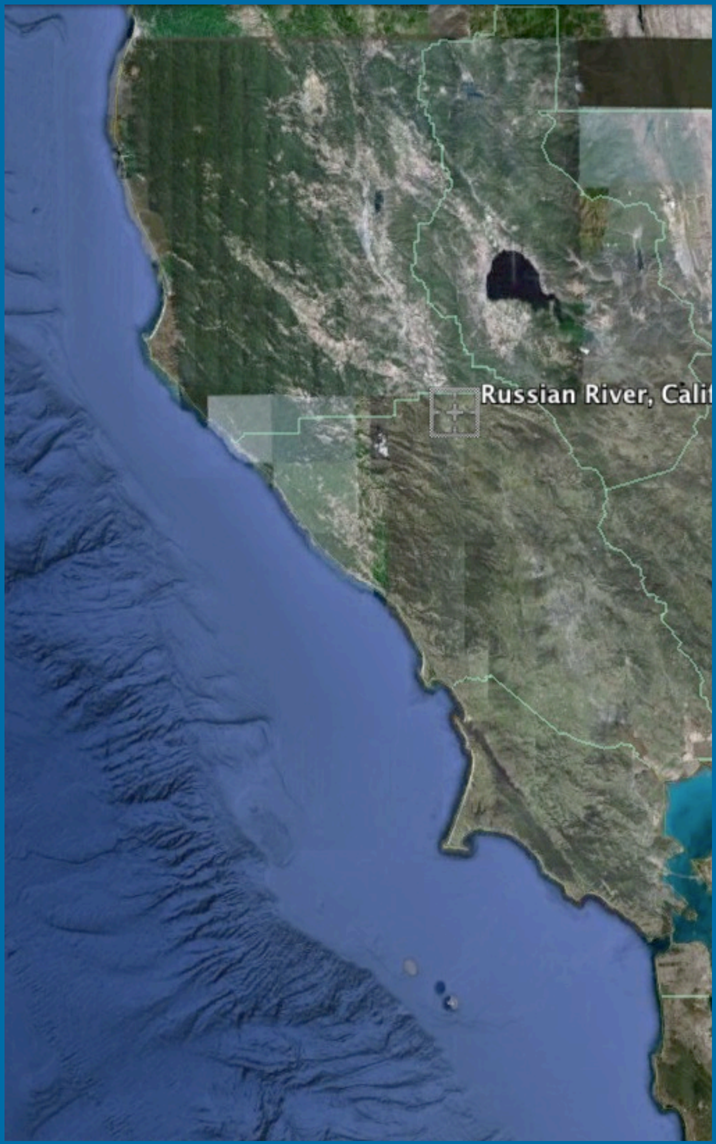
Foufoula-Georgiou et al, 2010: Non-local fluxes on hillslopes

Some conclusions:

- Most GTLs are local, but disturbances that induce transport can produce a large range of transport distances
- Connections between non-local and non-linear flux dependence on slope
- Promising alternatives to local diffusion include particle-based models and non-local transport models

Shelf vs hillslope transport

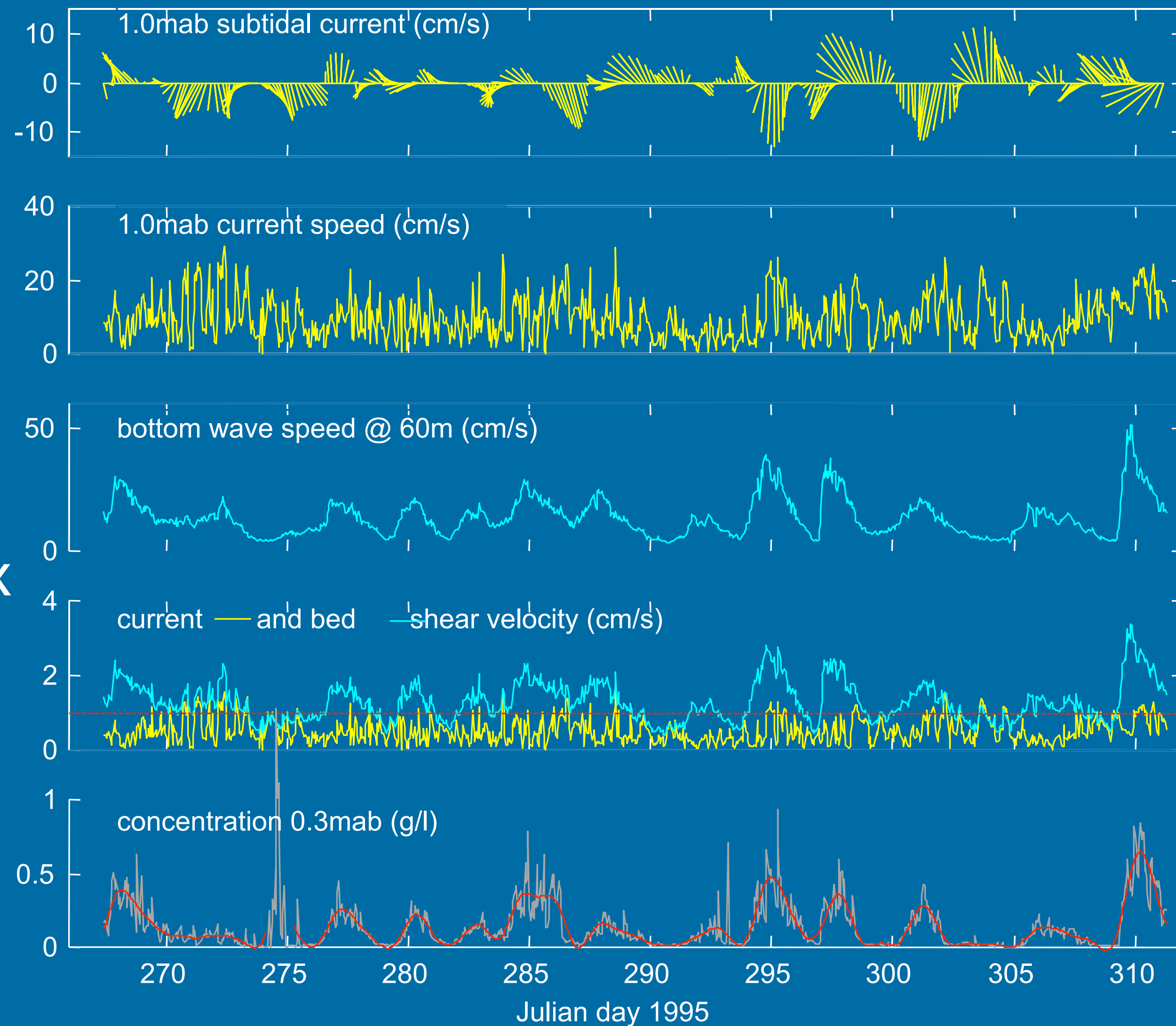
- Multidirectional vs downslope transport
- Mostly flow-driven rather than slope-driven
- Wave vs runoff response to storms; waves are inefficient mass transporters
- Response of currents to storms is limited; flow at bed can be decoupled from surface flow
- Suspended sediment mass is limited by near-bed stratification when wave >> current velocities



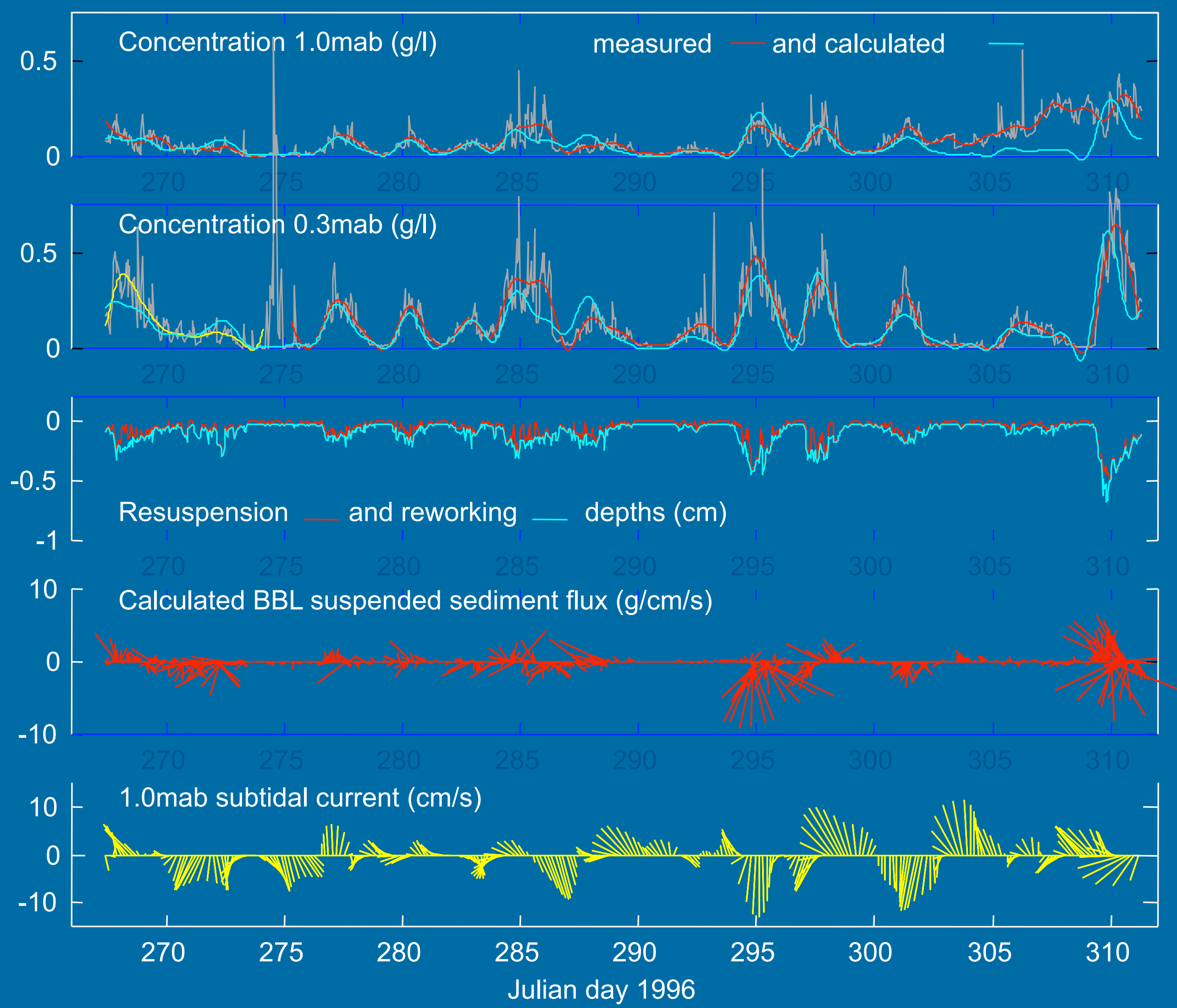
Shelf vs hillslope transport

- River mouths are upslope point sources of sediment active during floods
- Floods (-> sed delivery) and waves (-> sed mobilization) may or may not be coherent
- Sediment availability is supply limited owing to consolidation and small active layer depths
- Wave-supported gravity flows can advect large quantities of recently supplied flood sediment across the shelf

- Waves control timing and duration of transport
- Currents control direction and vertical distribution of flux
- Tides are an ever-present source of variance, turbulent mixing in the system



S60 site on the Eel shelf



- All combine to affect the magnitude of the flux
- Volume in suspension limited by availability
- Short time-scale models do a reasonably good job of predicting SSC and fluxes

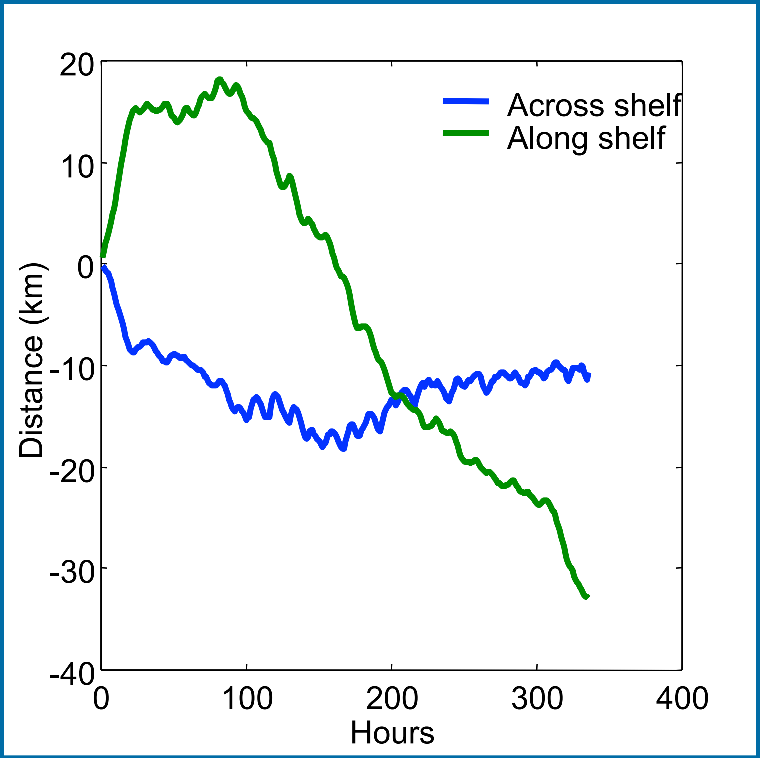
Shelf sediment diffusivity

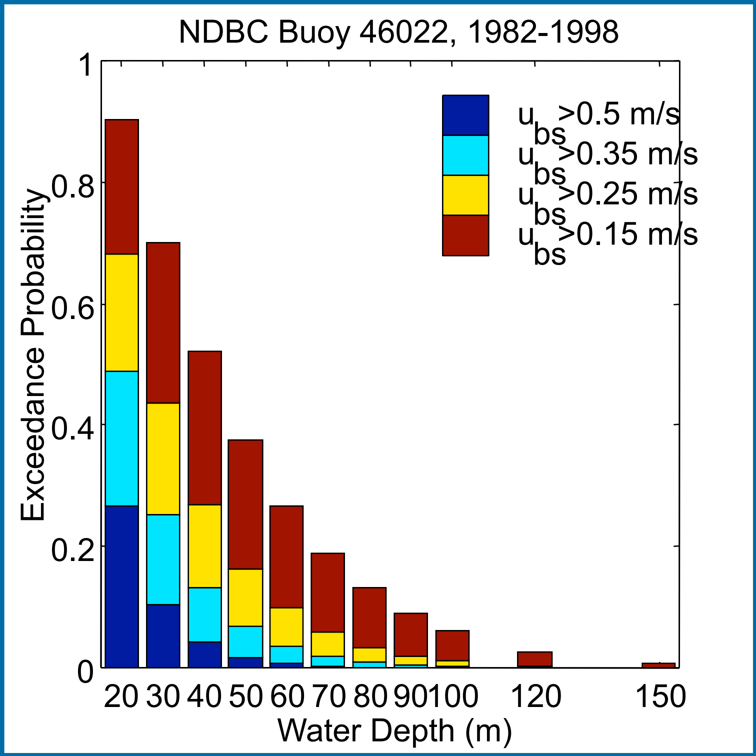
- Important to capture effects of waves, currents and tides on diffusivity
- Expect diffusivity to vary with depth and sediment conditions
- May provide a measure of sediment transport potential on the shelf
- Would need to be combined with flux due to wave-supported gravity flows

Travel distance distributions

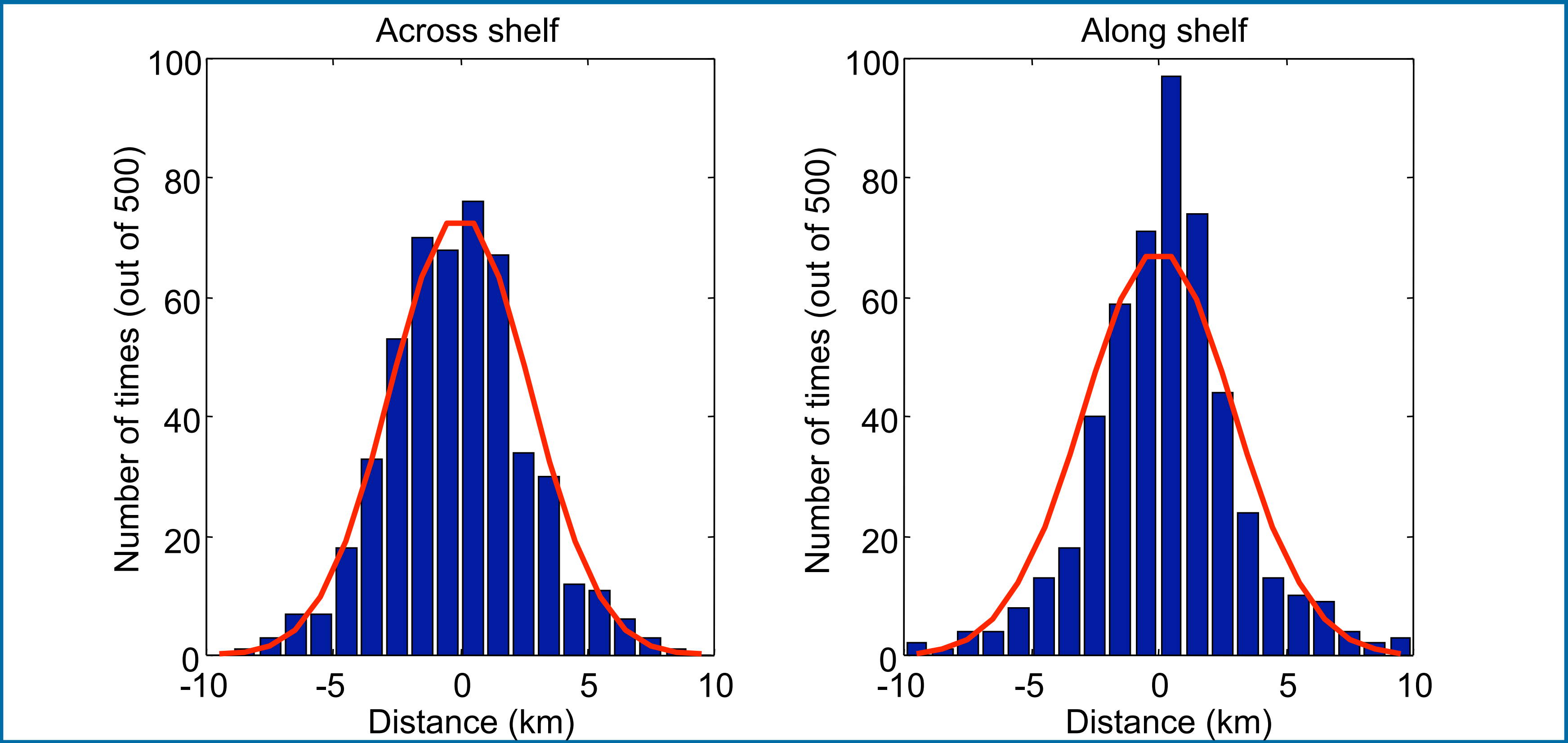
Random 14-day section of hourly currents; mean removed.

A “particle” moves with the current if the probability of wave resuspension is exceeded at its current location.



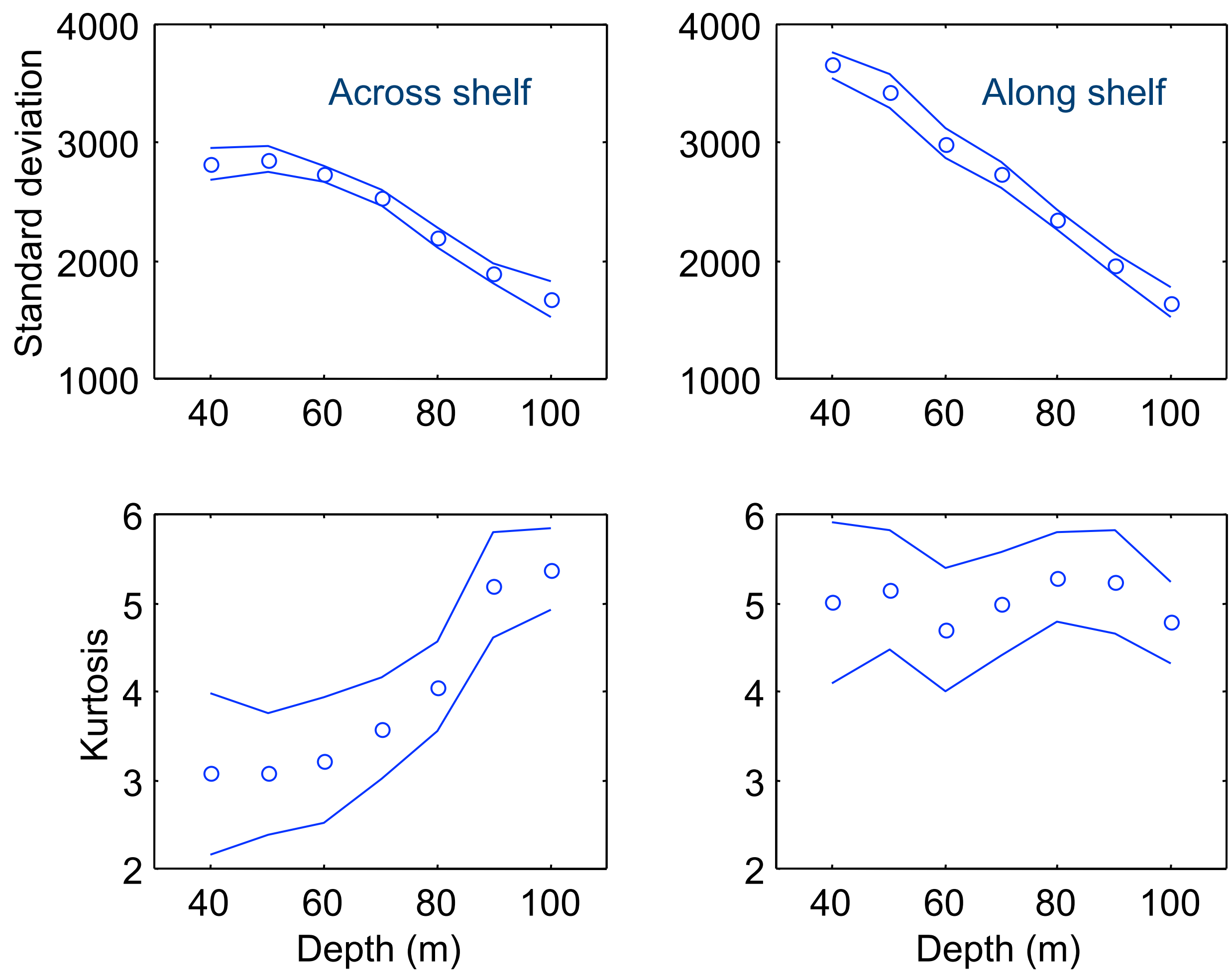


Example distribution from Eel shelf

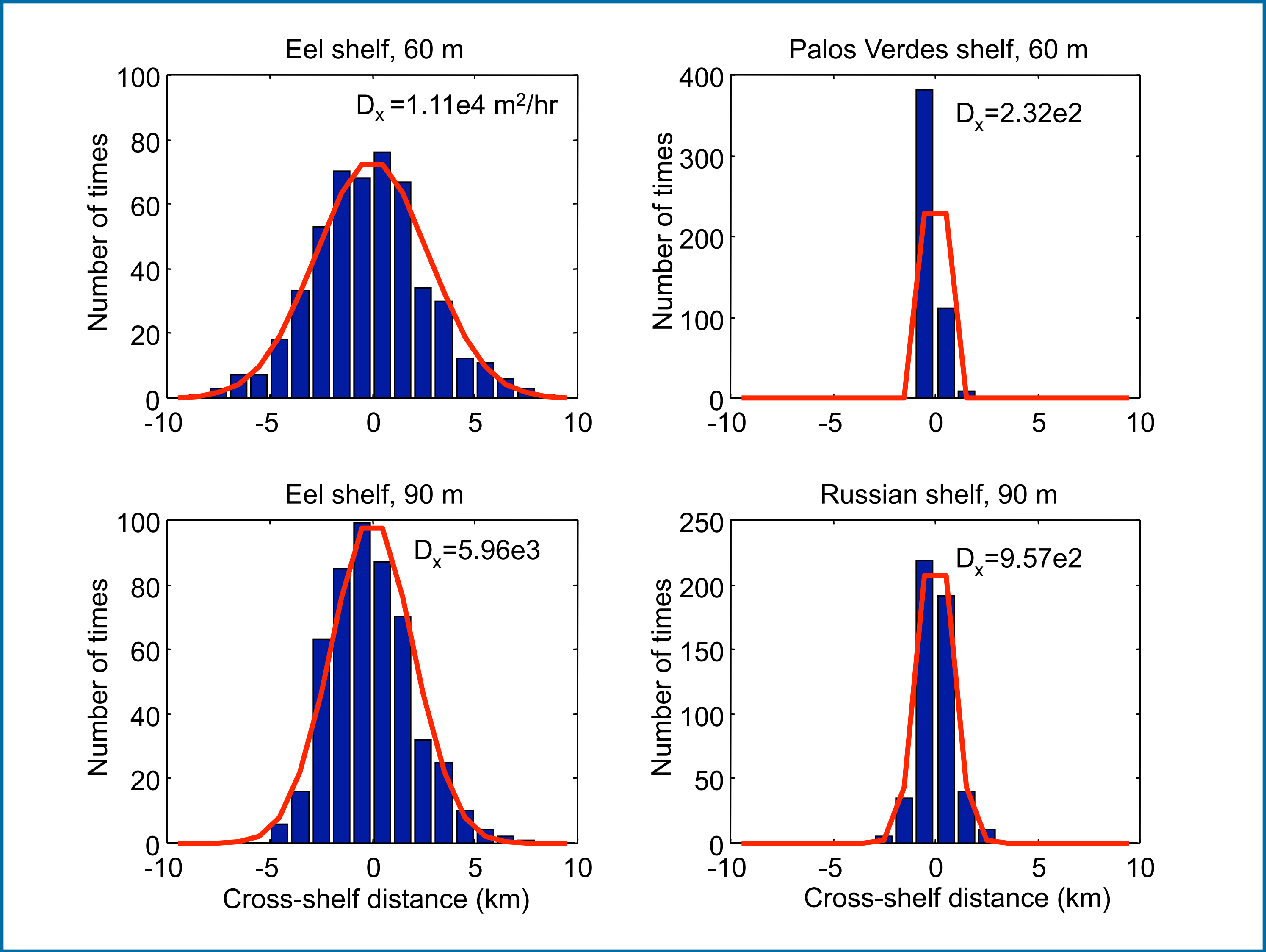


500 particles, initially at a depth of 60 m, moving across and along the shelf for a period of 14 days.

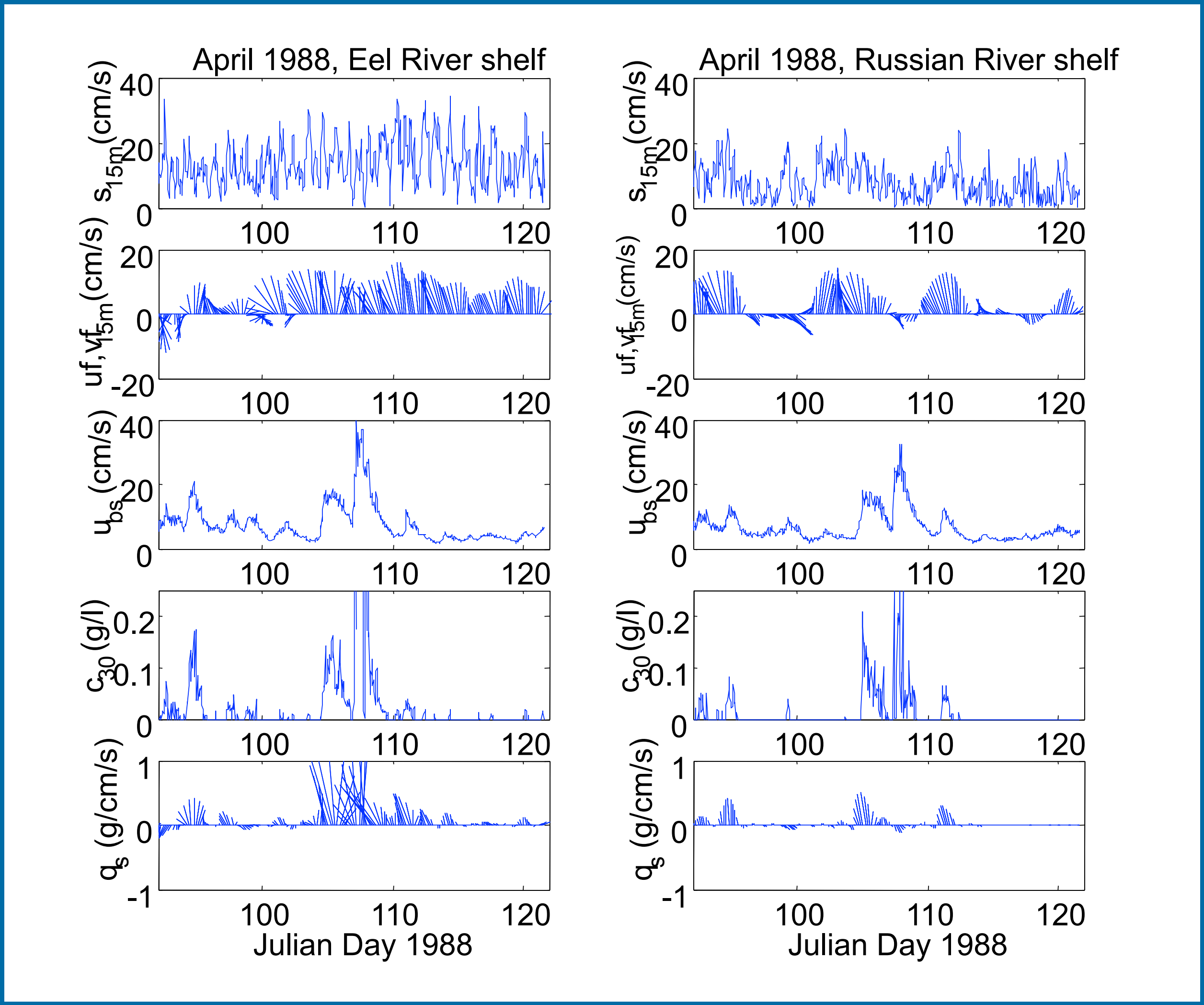
Statistics of distributions calculated along a cross-shelf transect based on 10 runs at each depth across the shelf



Comparison of 3 California shelf sites: $D = \frac{1}{2}\frac{\sigma^2}{T_{diff}}$



Transport rates on the Eel shelf are higher than on the Russian shelf



Flux difference

55-60% tidal

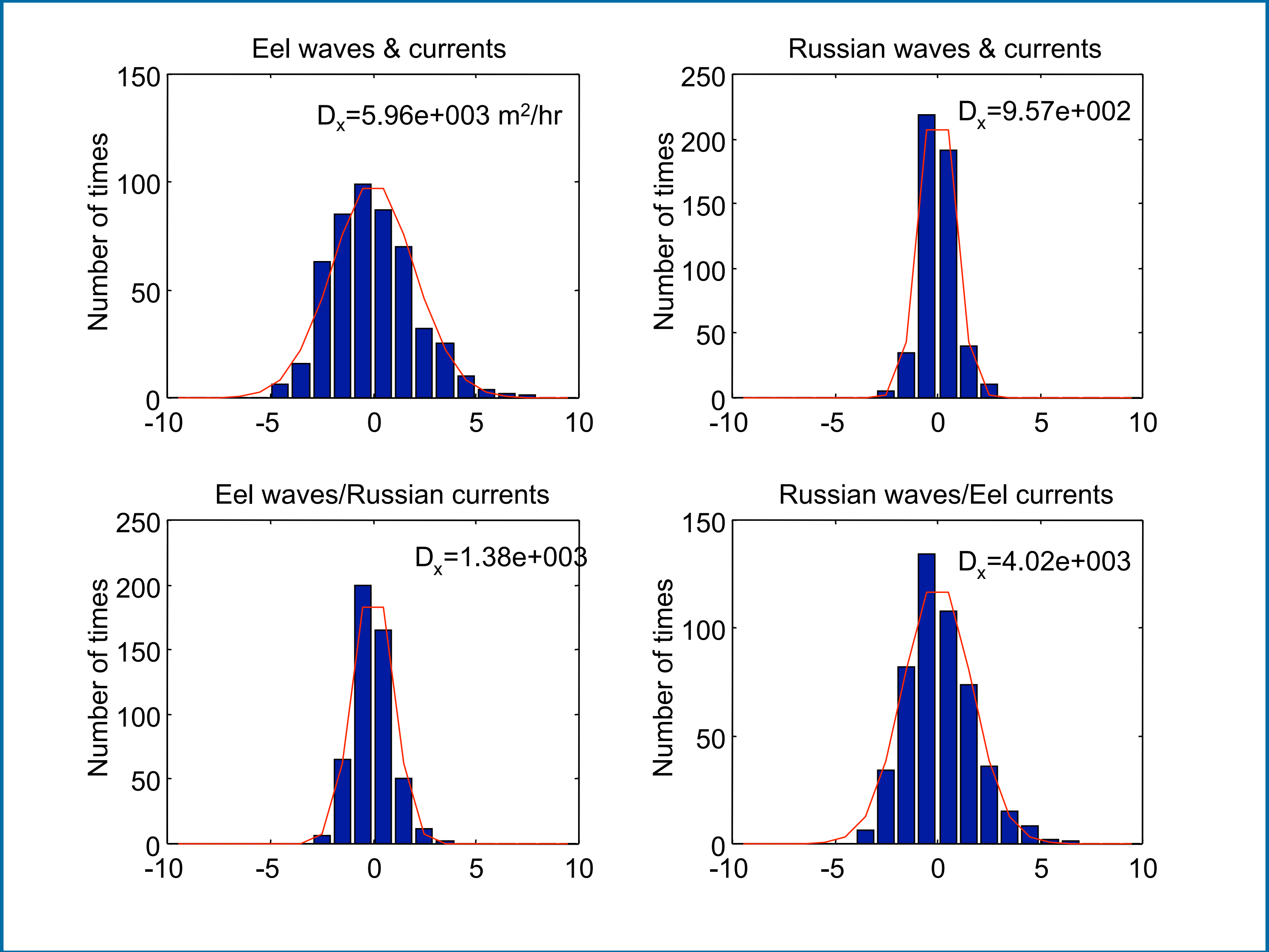
15-20% subtidal currents

15-20% waves

5-10% sediment

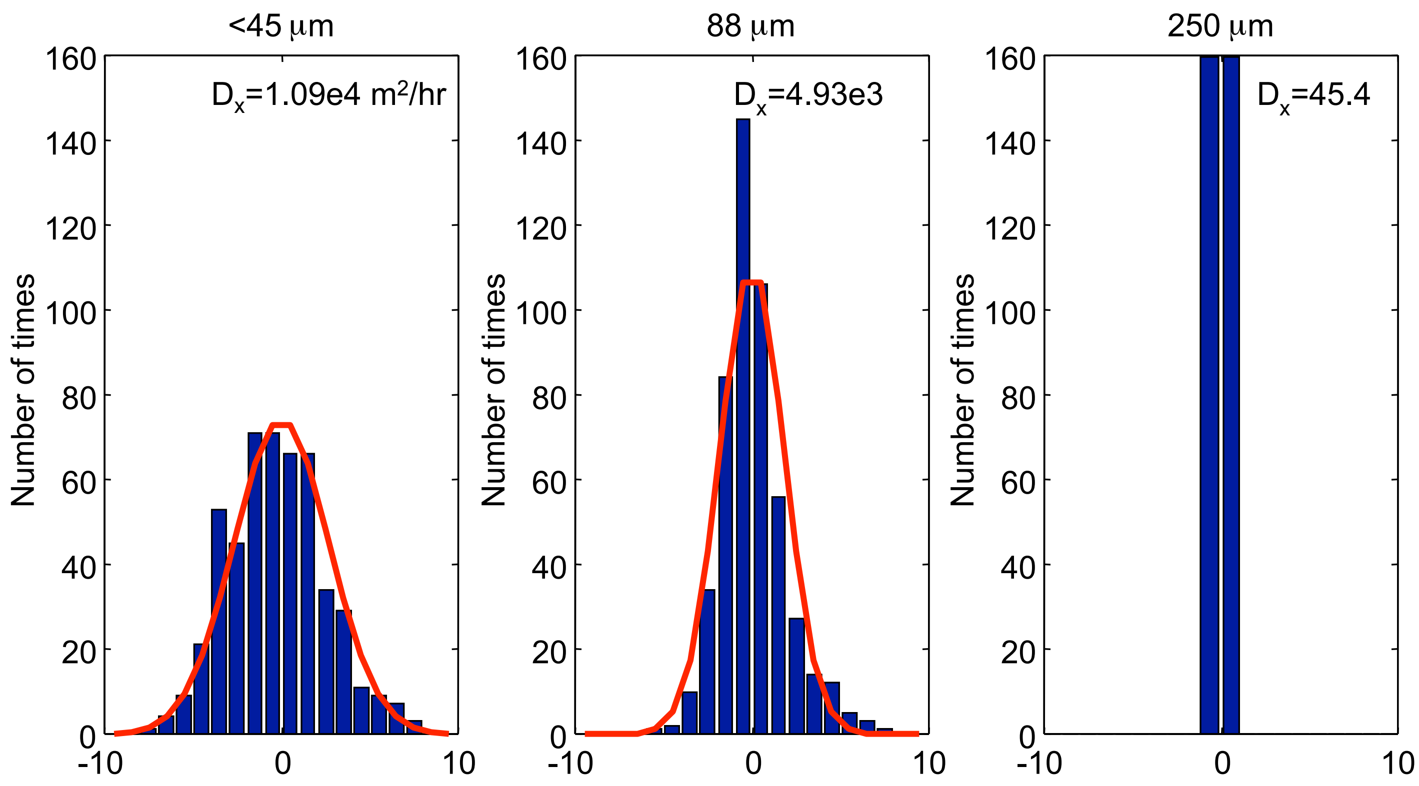
Total flux on Eel shelf 4.6 x total flux on Russian shelf

Relative importance of waves and currents



Effects of grain size

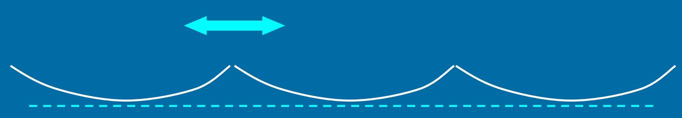
D (μm)	τ_{cr} (dy/cm^2)	w_s (cm/s)	f
<45	1.0	0.1	0.79
45-63	1.0	0.2	0.11
63-125	1.3	0.4	0.07
125-500	2.2	2.2	0.03



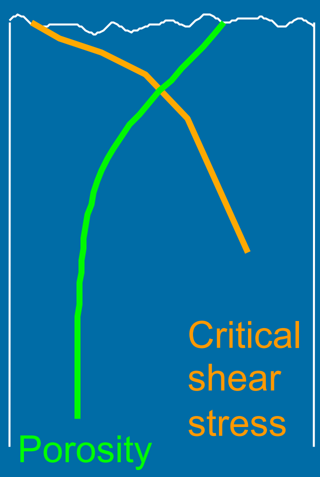
Concentration gradient on which diffusion acts is defined by the depth of the active layer of the bed

Active layer depth (ALD) controlled by

- ripple geometry and transport rate (sand beds)

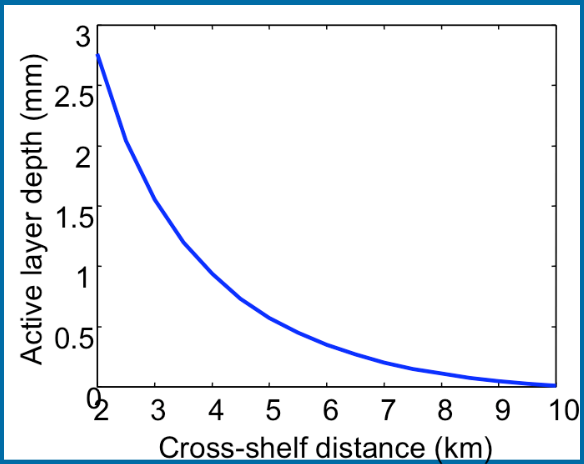


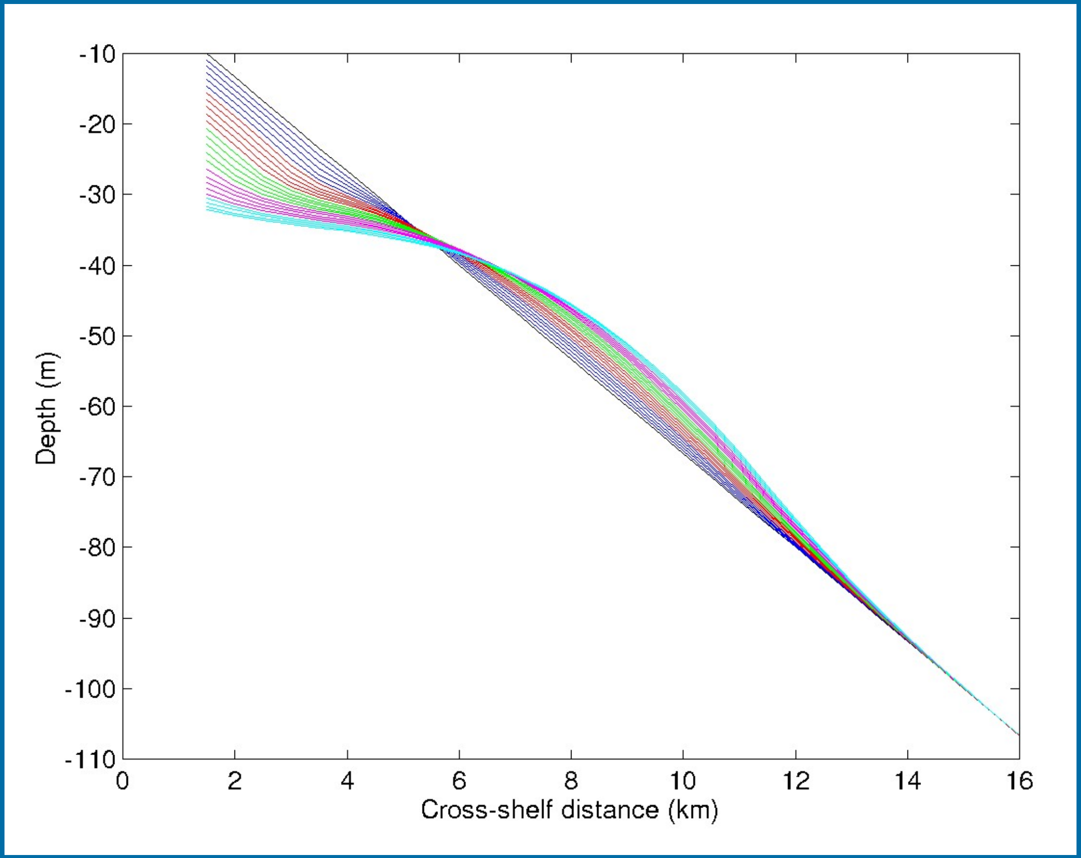
- consolidation state of bed (mud beds)



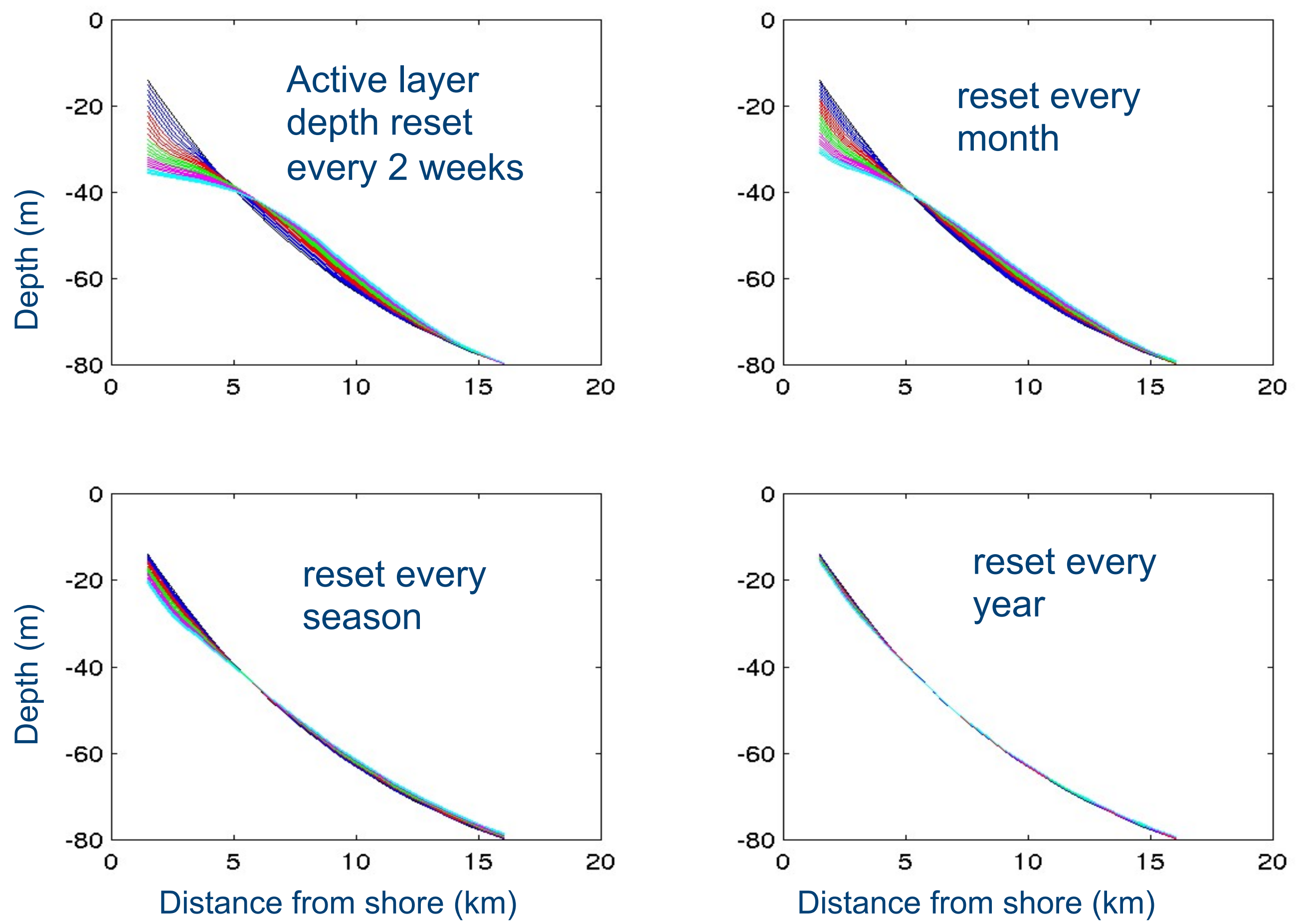
Five-year calculation of bed-level change by diffusive transport

Depths of erosion and deposition depend on active layer thickness and the time scale for resetting the active layer once exhausted



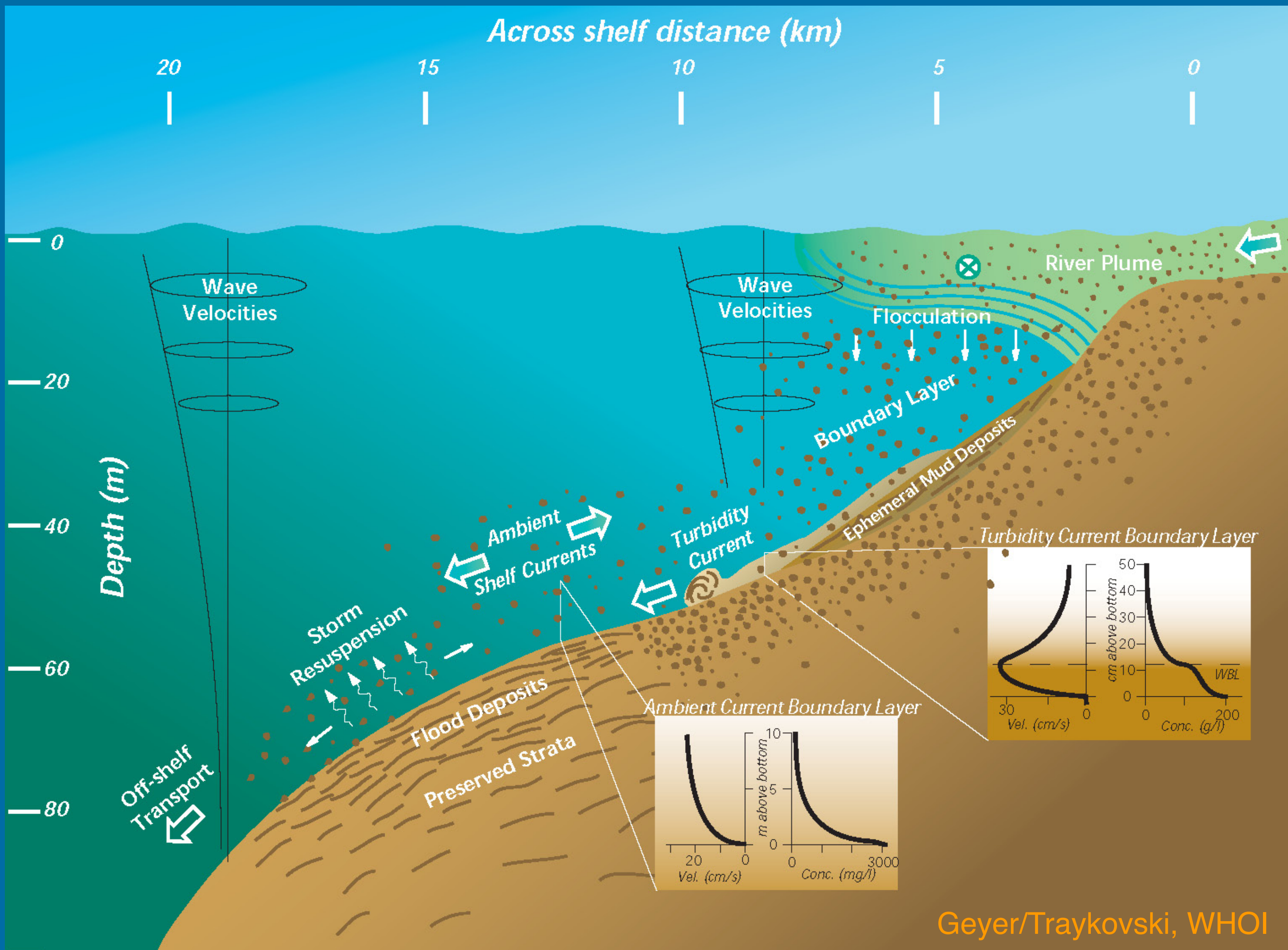


Effect of active-layer recovery time on depths of erosion and deposition.



Possible next steps

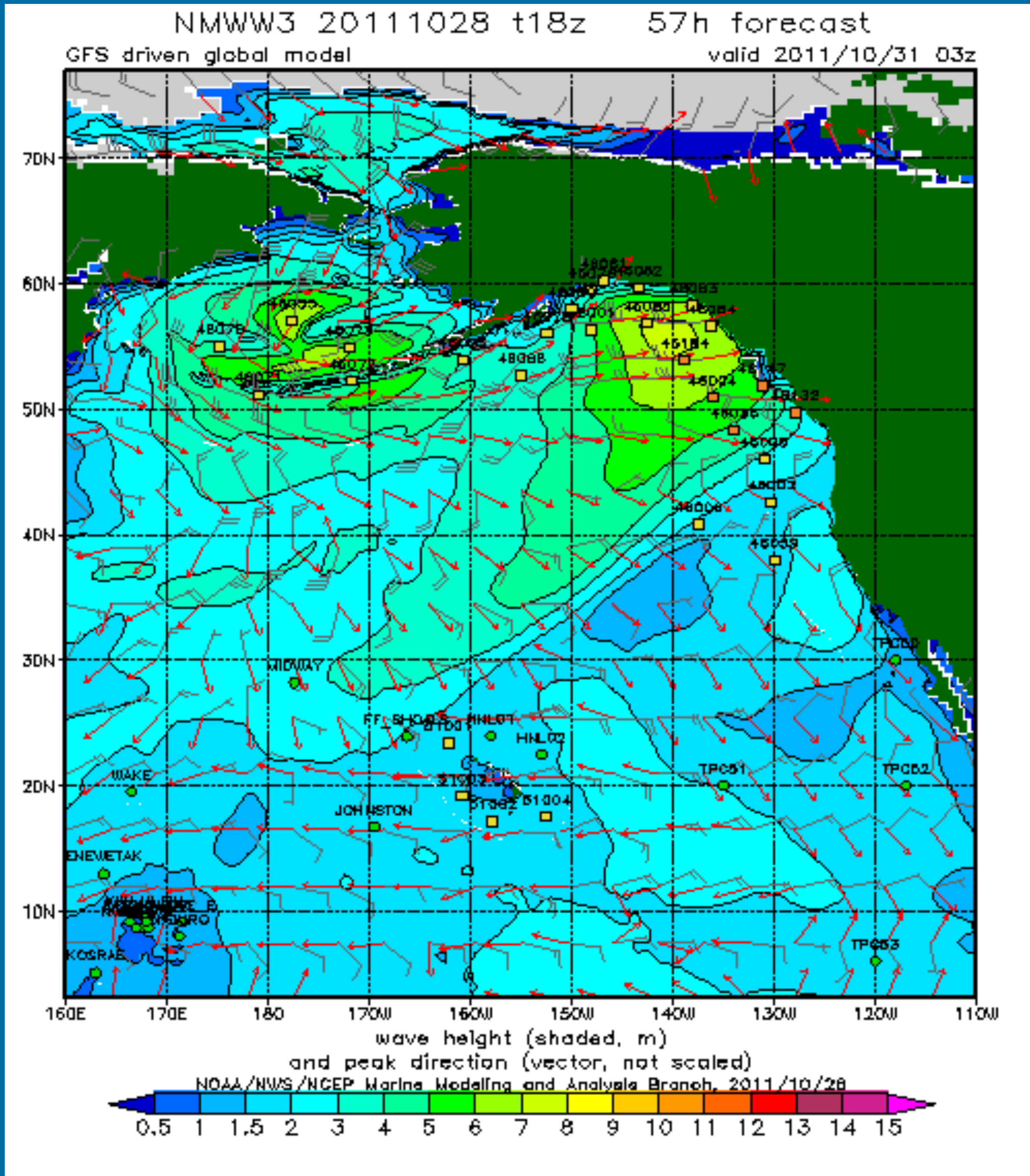
- Extend the random walk calculations to include sediment fluxes directly -> particle-based model
  - Could build in triggers for cross-shelf advection by wave-supported gravity flows



Across shelf distance (km)
20
15
10
5
0
0
20
40
60
80
Depth (m)
Wave Velocities
Wave Velocities
River Plume
Flocculation
Boundary Layer
Ephemeral Mud Deposits
Turbidity Current
Ambient Shelf Currents
Storm Resuspension
Flood Deposits
Preserved Strata
Off-shelf Transport
Turbidity Current Boundary Layer
cm above bottom
WBL
Vel. (cm/s)
Conc. (g/l)
Ambient Current Boundary Layer
m above bottom
Vel. (cm/s)
Conc. (mg/l)
Geyer/Traykovski, WHOI

Possible next steps

- Extend the random walk calculations to include sediment fluxes directly -> particle-based model
- Map shelf diffusivity as a measure of sediment transport potential (requires spatial wave, current and tide time series)
  - How do spatial variations in diffusivity affect sediment redistribution on the shelf?

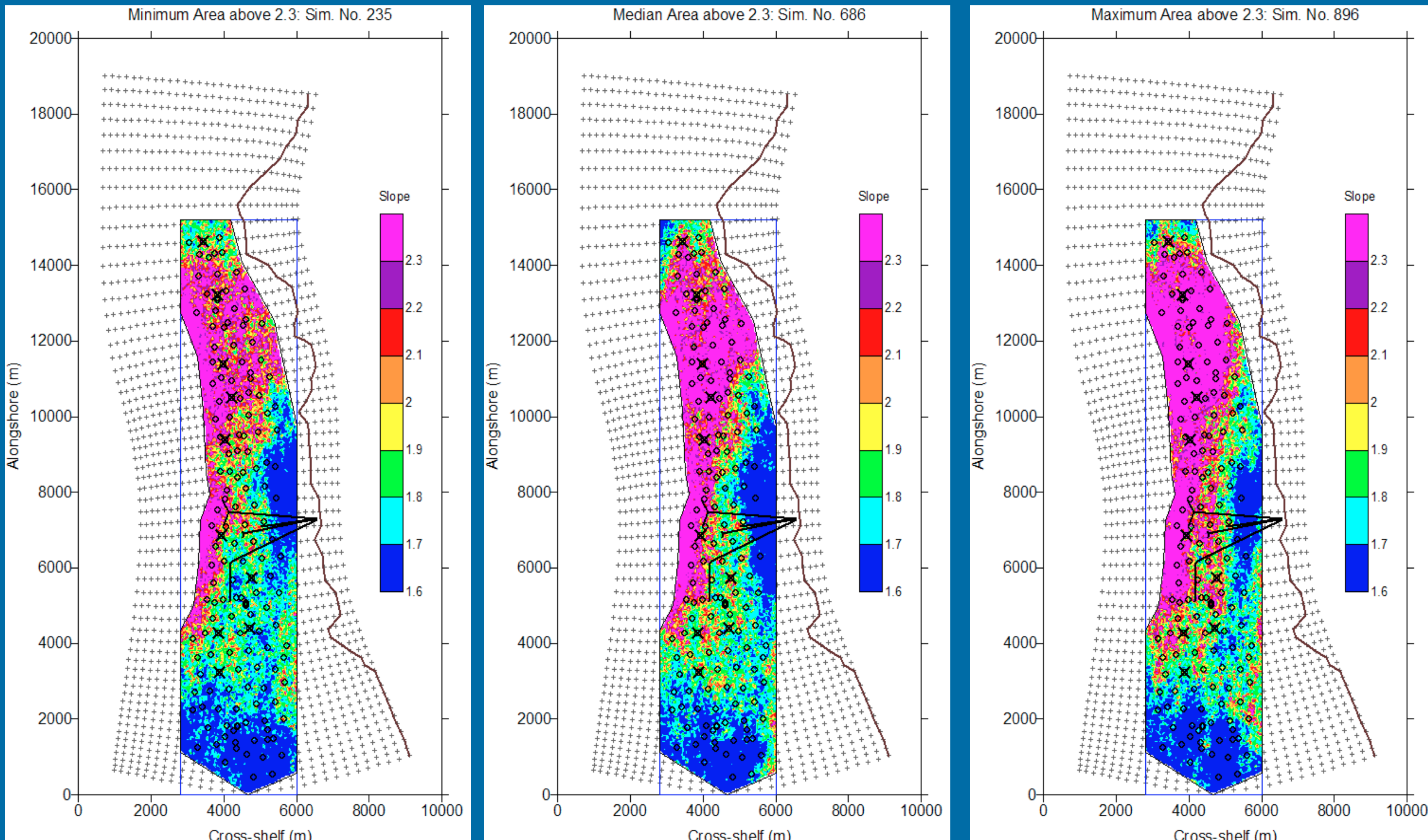


NOAA's WaveWatch III operational wave model

Possible next steps

- Extend the random walk calculations to include sediment fluxes directly -> particle-based model
- Map shelf diffusivity as a measure of sediment transport potential (requires spatial wave, current and tide time series)
- Investigate effects of textural variations, flood deposition, consolidation times on fluxes

Geostatistical simulations of erodibilty on the Palos Verdes shelf, CA



Conclusions

- A range of problems need long-term, regional characterizations of marine sediment transport
- Variety of approaches -- suitable for different problems or time scales
- Simple random-walk diffusion characterization captures important variability on shelf
- Limited by the shortness of available forcing records. Global models or downscaling from long-term climate indicators may help
- Still need a better understanding of the small-scale sediment processes

Comparison of measured and calculated fluxes at 60-m on the Eel shelf in fall 1995