Hydrodynamic models for San Francisco Bay: An overview of what we can model, when models may be useful, and why hydrodynamic models often are necessary but not sufficient

Stephen Monismith
Stanford University

Thanks to Mark Stacey, Jon Burau, Wim Kimmerer, Satoshi Inagaki, Jeremy Bricker and Jim Hench, Oliver Fringer, Ed Gross, and Jeff Koseff

Problems of interest
(why we should invest in models)

- Salinity field field response to flow (X2)
- Phytoplankton biogeochemistry (Ammonium)
- Transport of larval organisms
- Sediment dynamics:
  - Dredging effects and dredged material disposal
  - Effects of tidal wetland restoration
  - Transport of sorbed contaminants
- Contaminant fate and transport

My point: Models good for 3D scalar transport and mixing (if they have the right ingredients) – challenge is formulating and testing models for biogeochemistry etc.

What equations models solve

Transport (physics)

Equations discretized on a grid laid on the domain (SF Bay)

$$\frac{\partial C}{\partial t} + \vec{U} \bullet \nabla C = 0$$ Conservative scalar

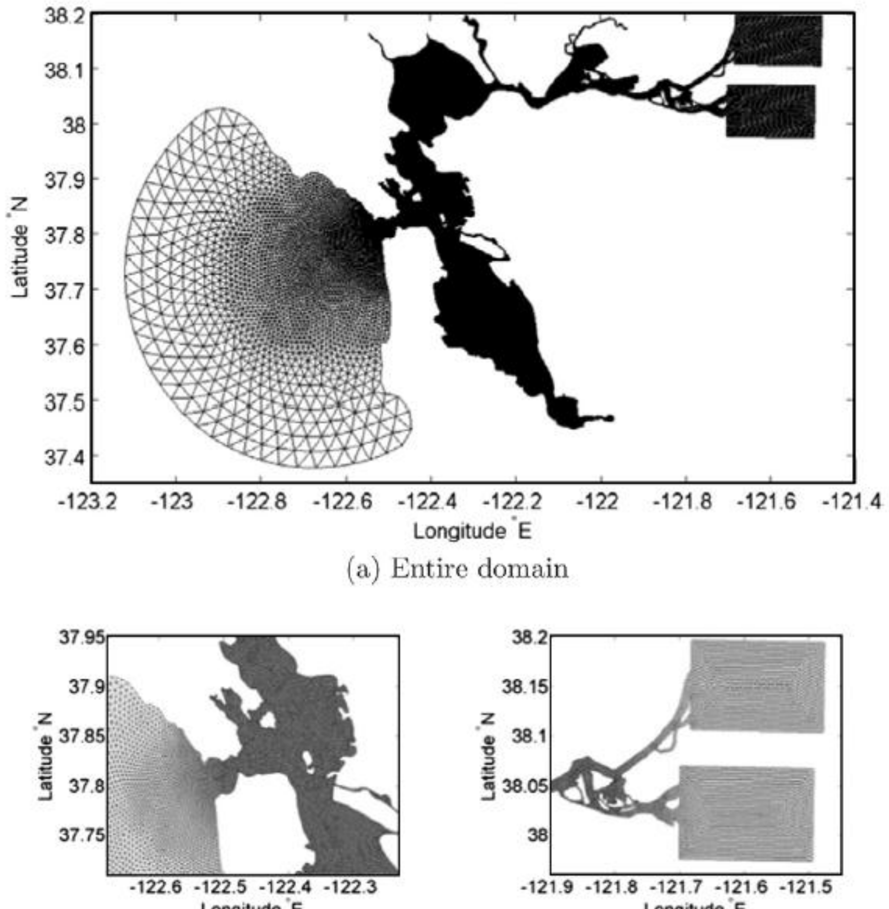
$$= \mu C$$ Scalar with growth

$$= \ldots$$

$= $ stuff General behavior

Problem dependent model

A Grid: Northern SF Bay/Golden Gate



(a) Entire domain

(b) Refinement at Golden Gate

(c) Rectangular "false deltas"

Chua and Fringer (2011)

Finest resolution: 10 m

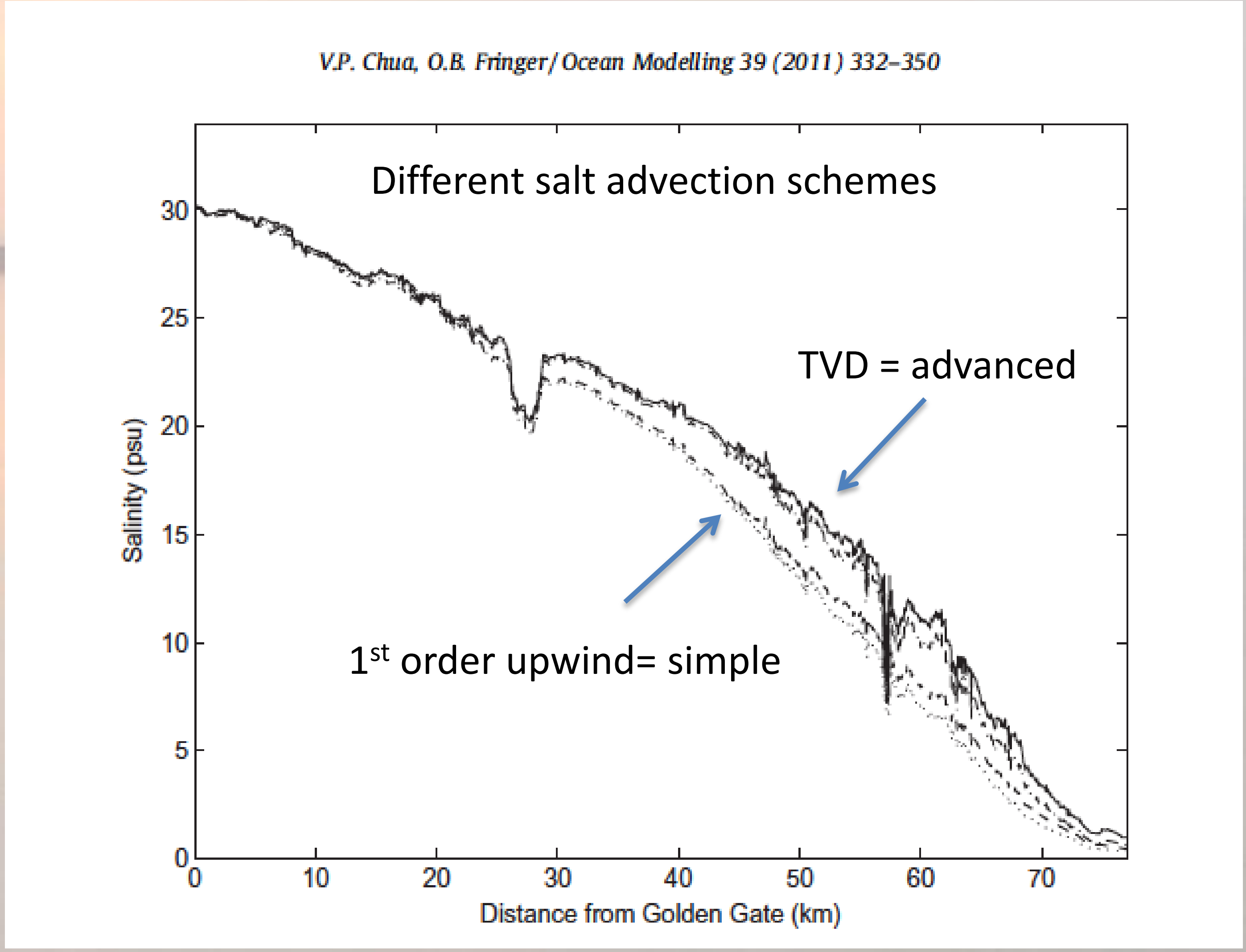
Total number of 3D cells: 2.5 million

Time step size: 10 s

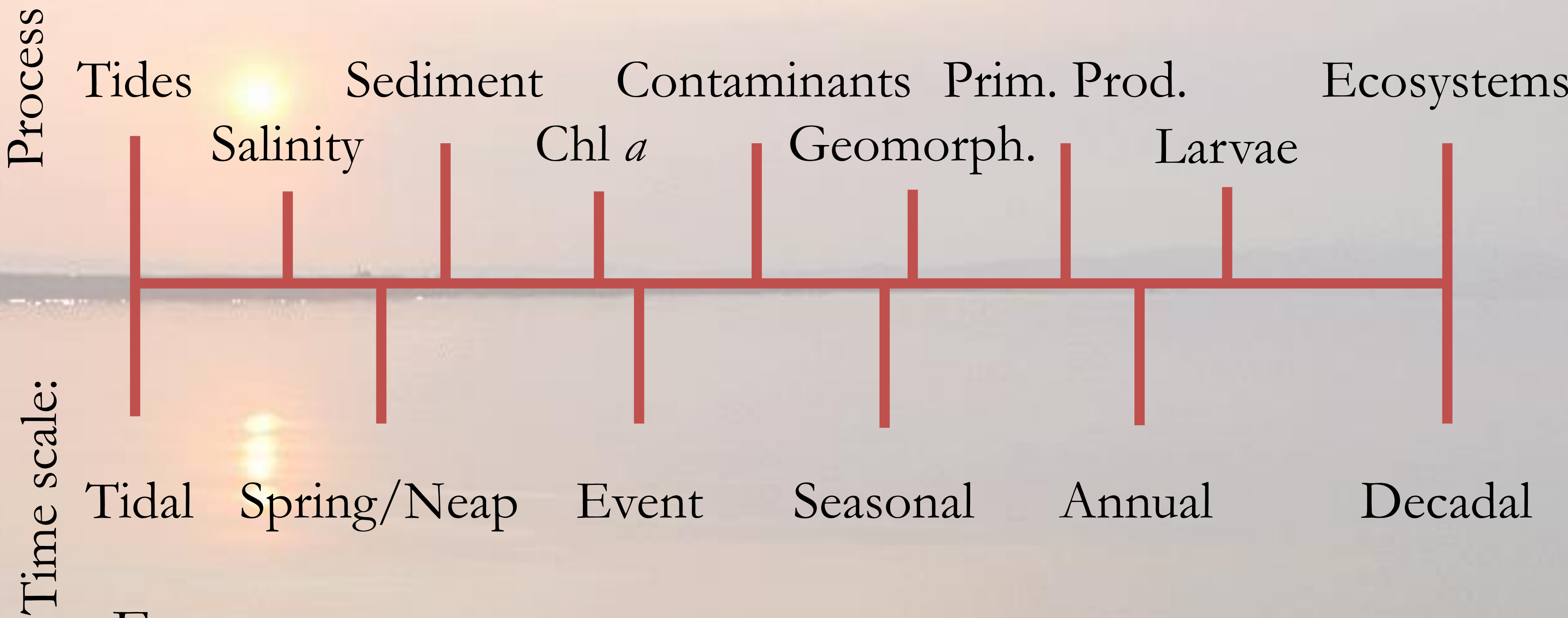
Speedup: 10X faster than real time

Number of processors: 32

A reminder: Numerical schemes can affect results



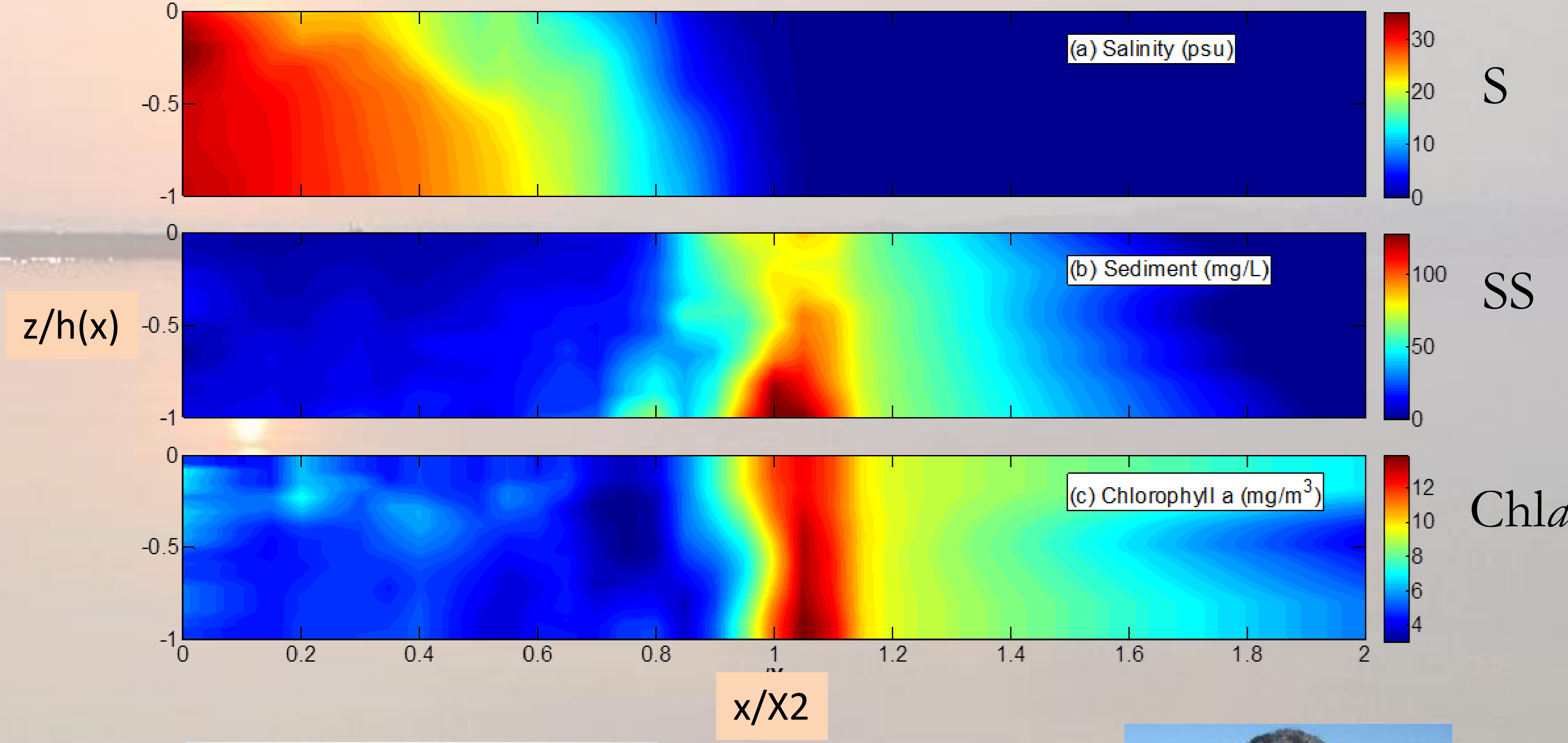
The range of difficulty



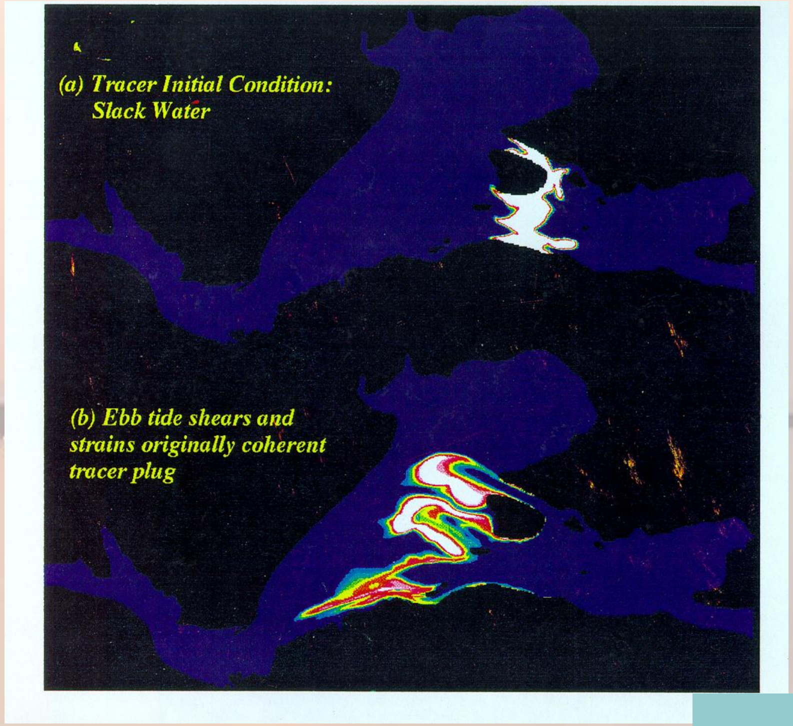
Easy

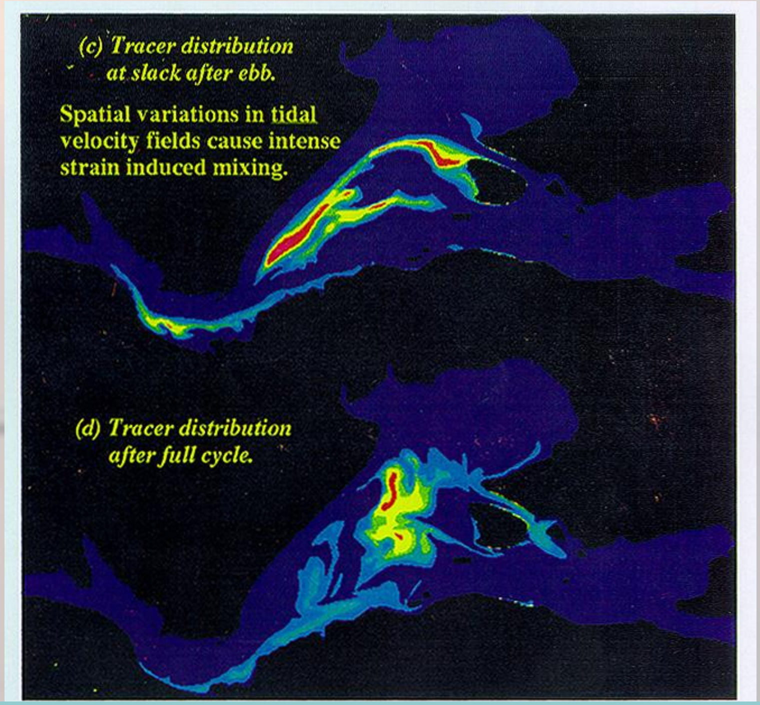
Hard

A point of reference: Good data describing system is critical – e.g. USGS transects

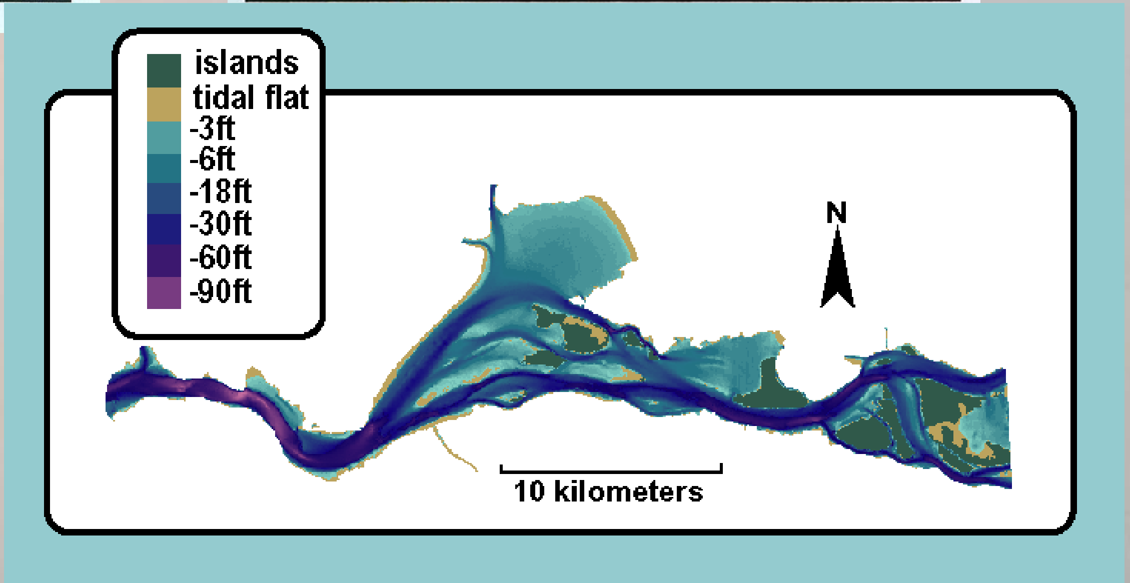


Models can influence policy: Mixing in the LSZ (1993)

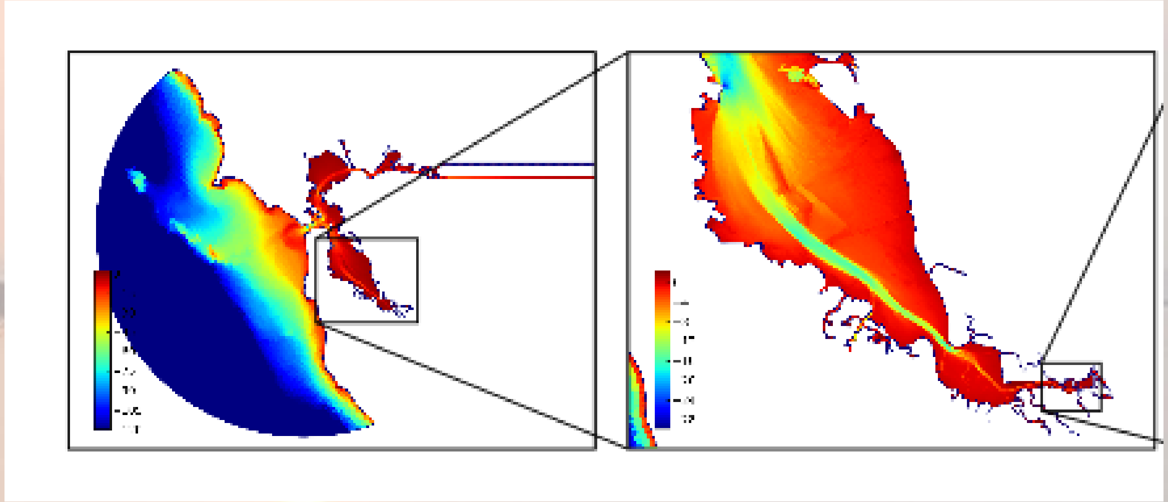


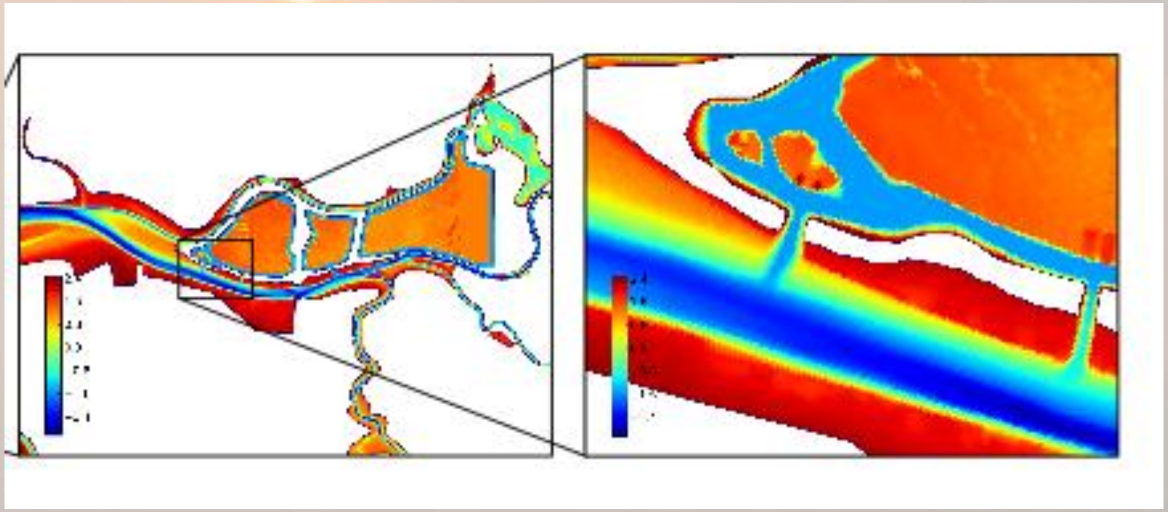


Dispersion via tidal shear in Suisun Bay
(2D calculations by Jon Burau)



Current models: South Bay Salt Pond sediment dynamics (SUNTANS - Hollerman et al)





Finest resolution: 1 m

Total number of 3D cells: 5 million

Time step size: 5 s

Speedup: 2X faster than real time

Number of processors: 48

3D simulations (Gross et al 2010)

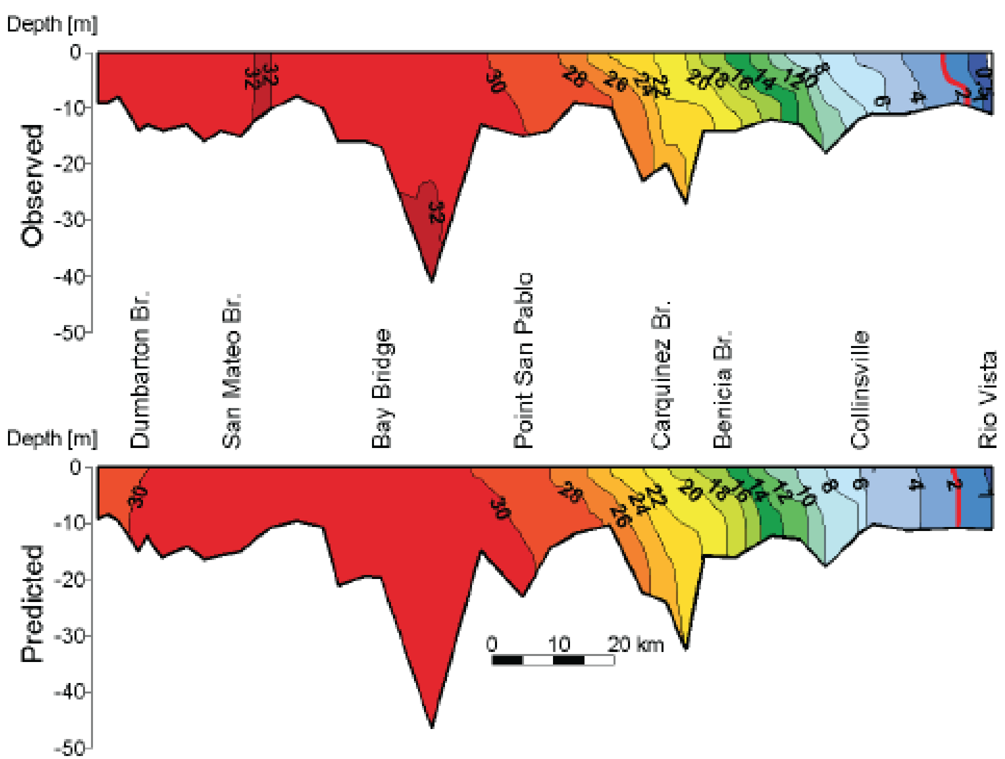
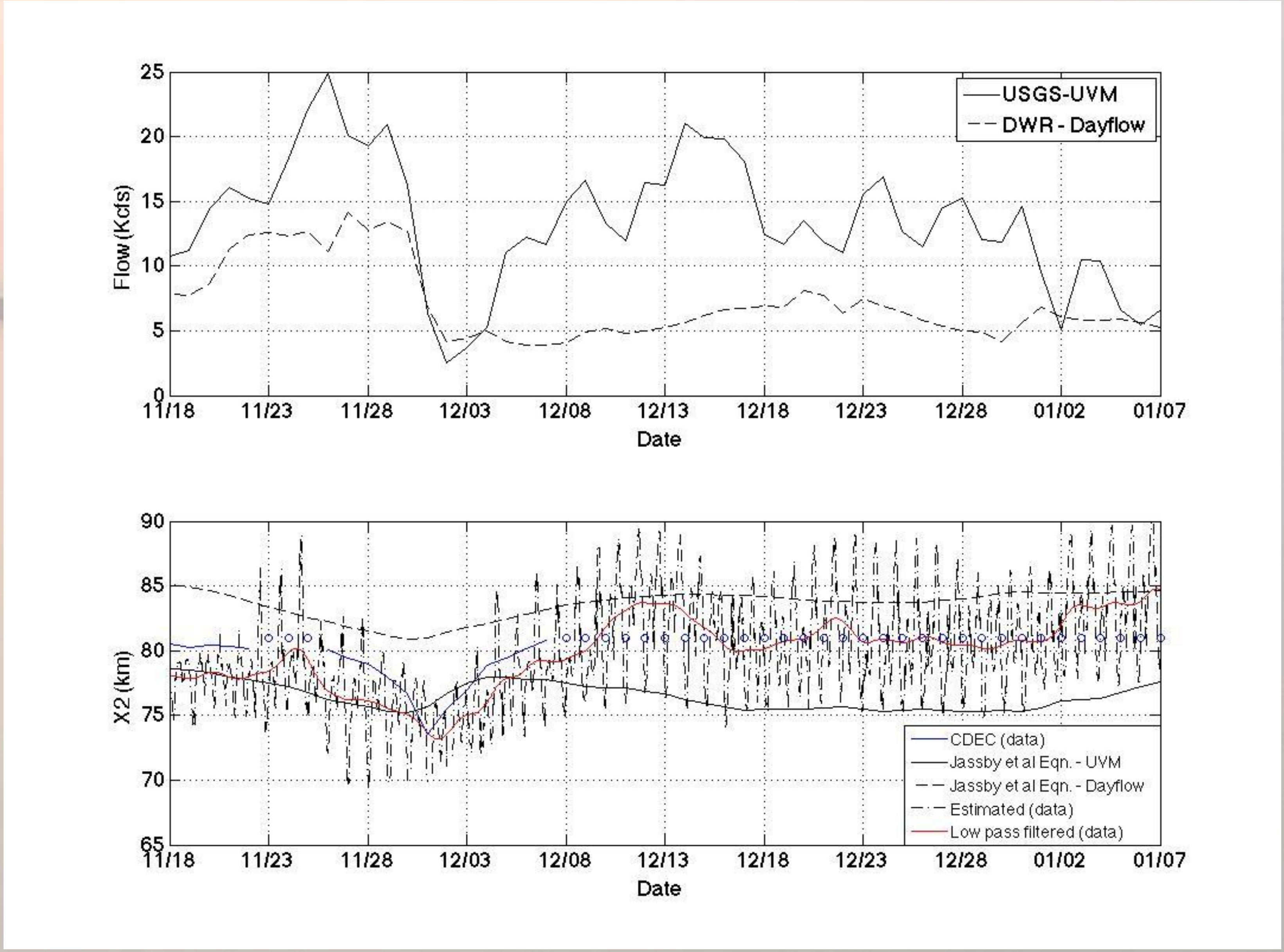


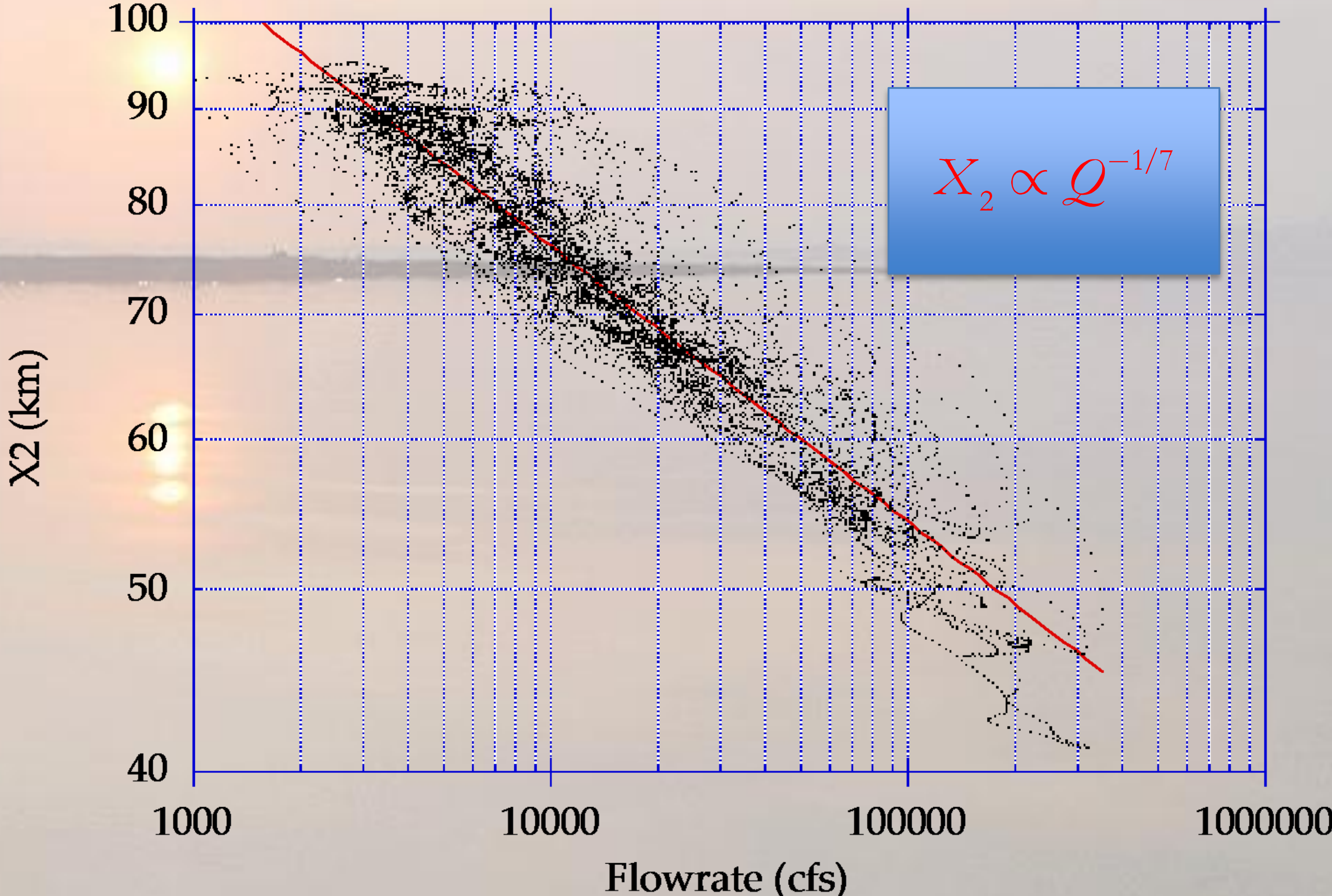
Figure 13 Observed and predicted salinity profiles at synoptic sampling stations, interpolated along the axis of the San Francisco Estuary on October 26, 1994

Conservative scalar transport can be done with reasonable accuracy

Boundary Conditions? Flow and X2 (FLaSH 2011)

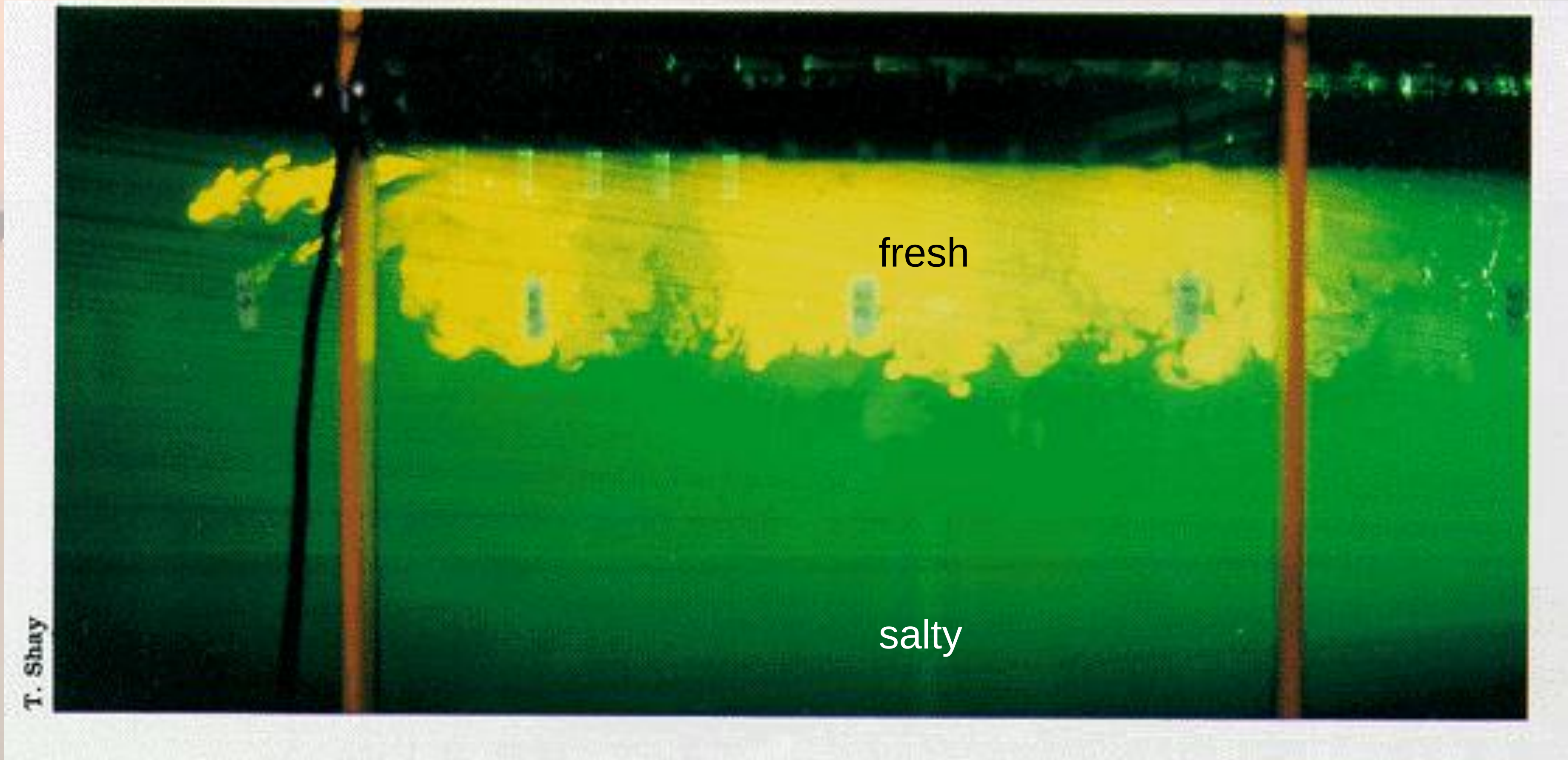


Models can help with understanding system response (E. Gross and W. Kimmerer)



Monismith et al 2002

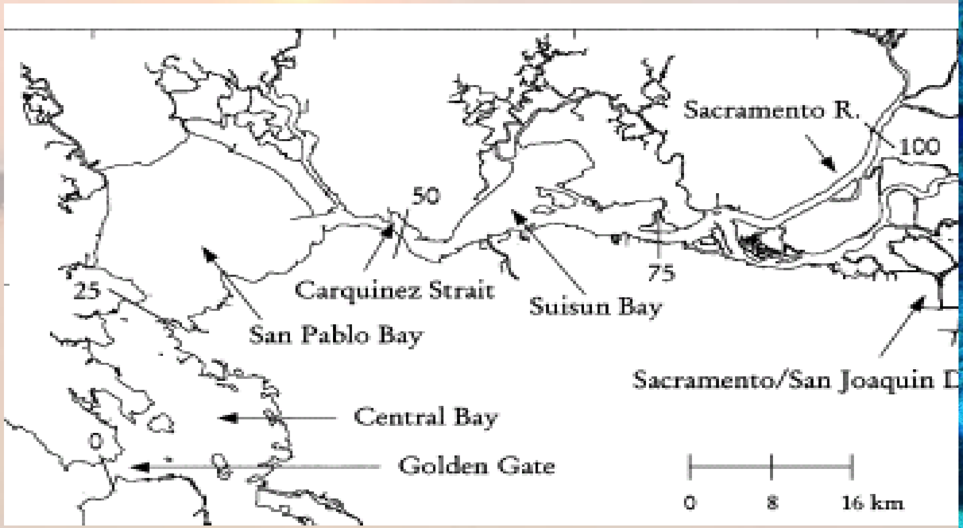
Modeling challenge: Stratification (Stratification kills turbulence)



Monismith/Shay

Mixing front in a stratified fluid (turbulence from oscillating grid)

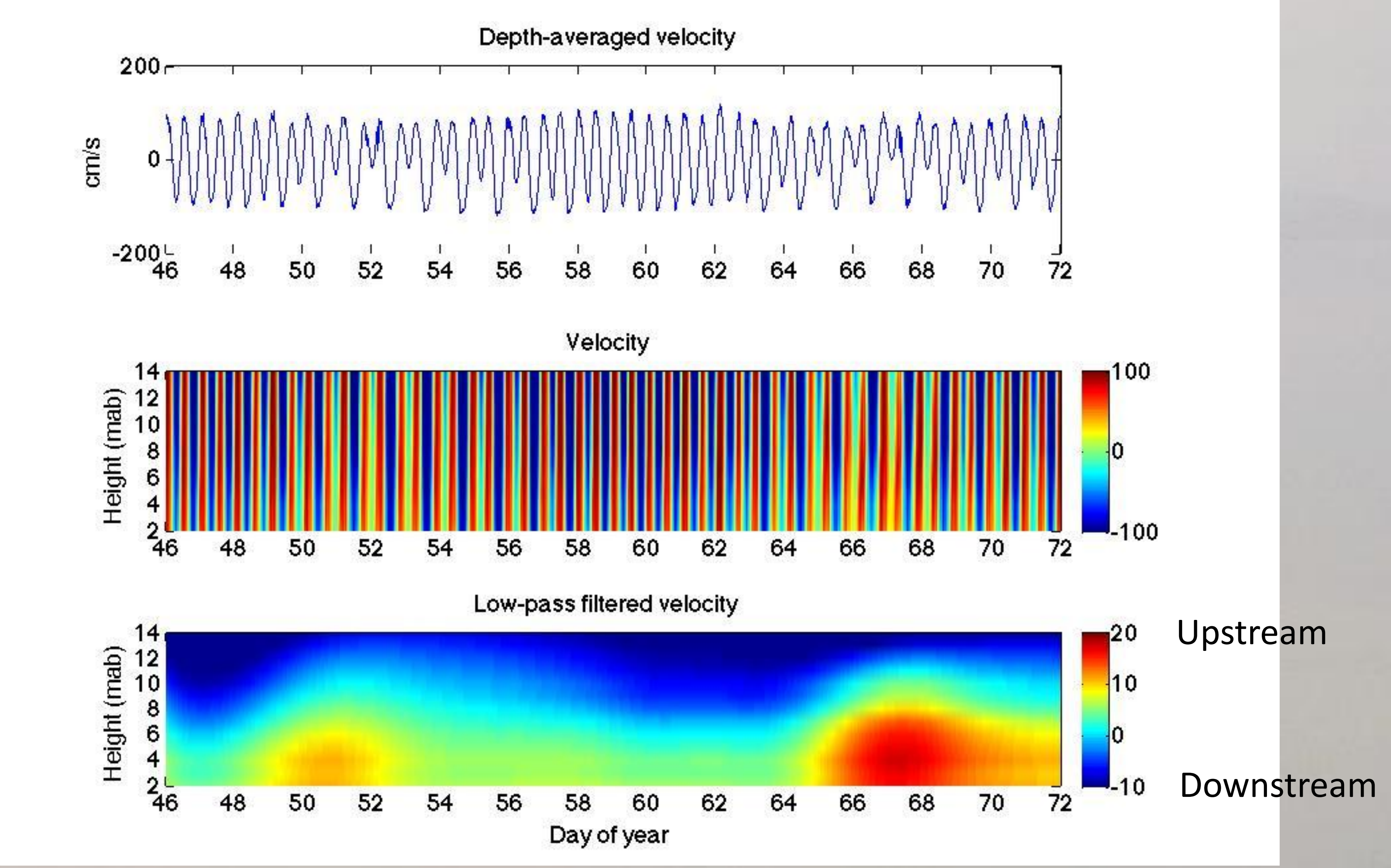
An example of ADCP measurements in Carquinez Strait (northern SF Bay)



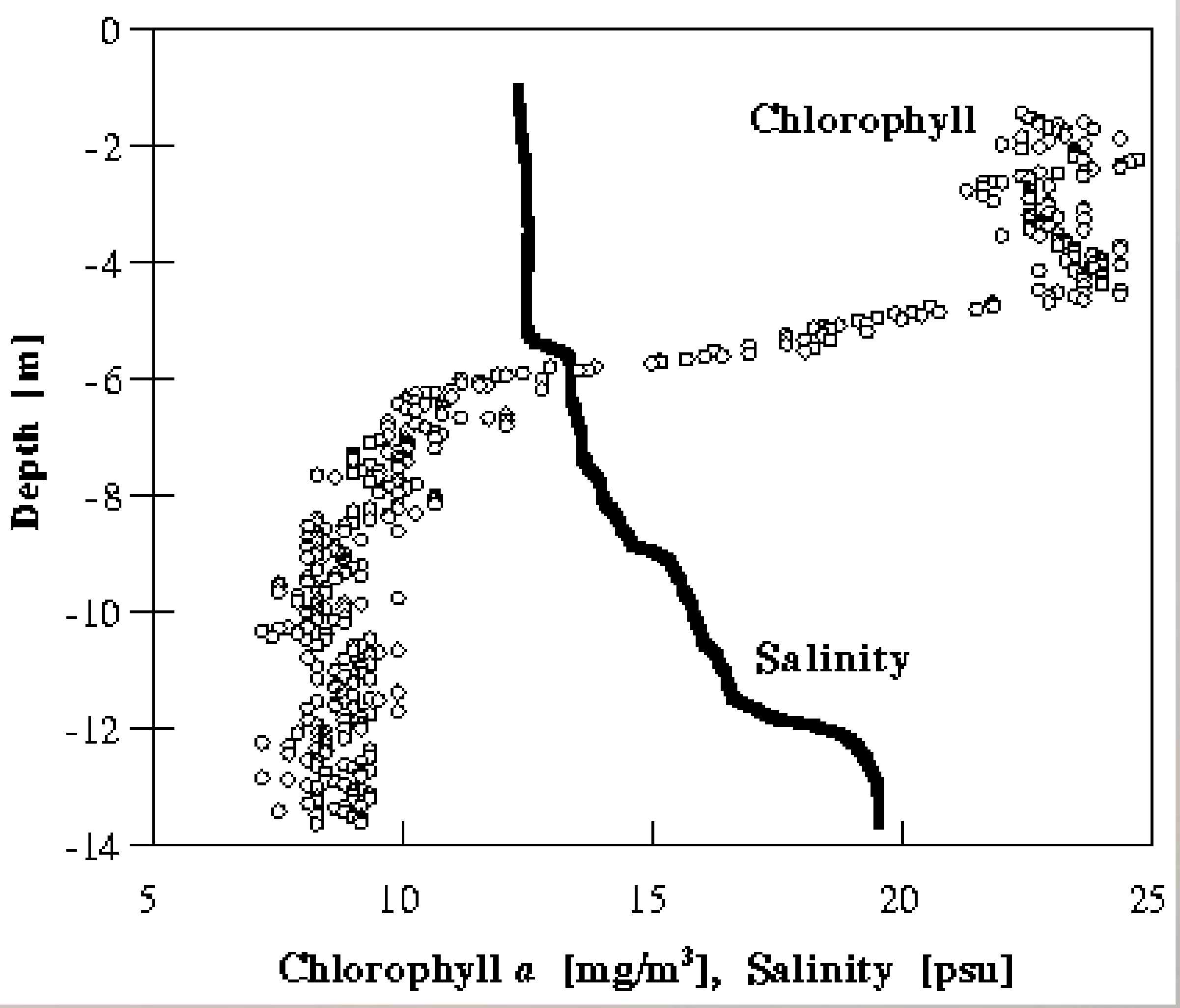
ADCP offshore of Moorea, FP

ADCP = Acoustic Doppler Current Profiler: measures velocities at many heights above instrument using Doppler shift of sound scattered off small things in water.

Stratification affects residual flows: ADCP in Carquinez Strait Feb-April 1992 (USGS (R. Cheng)

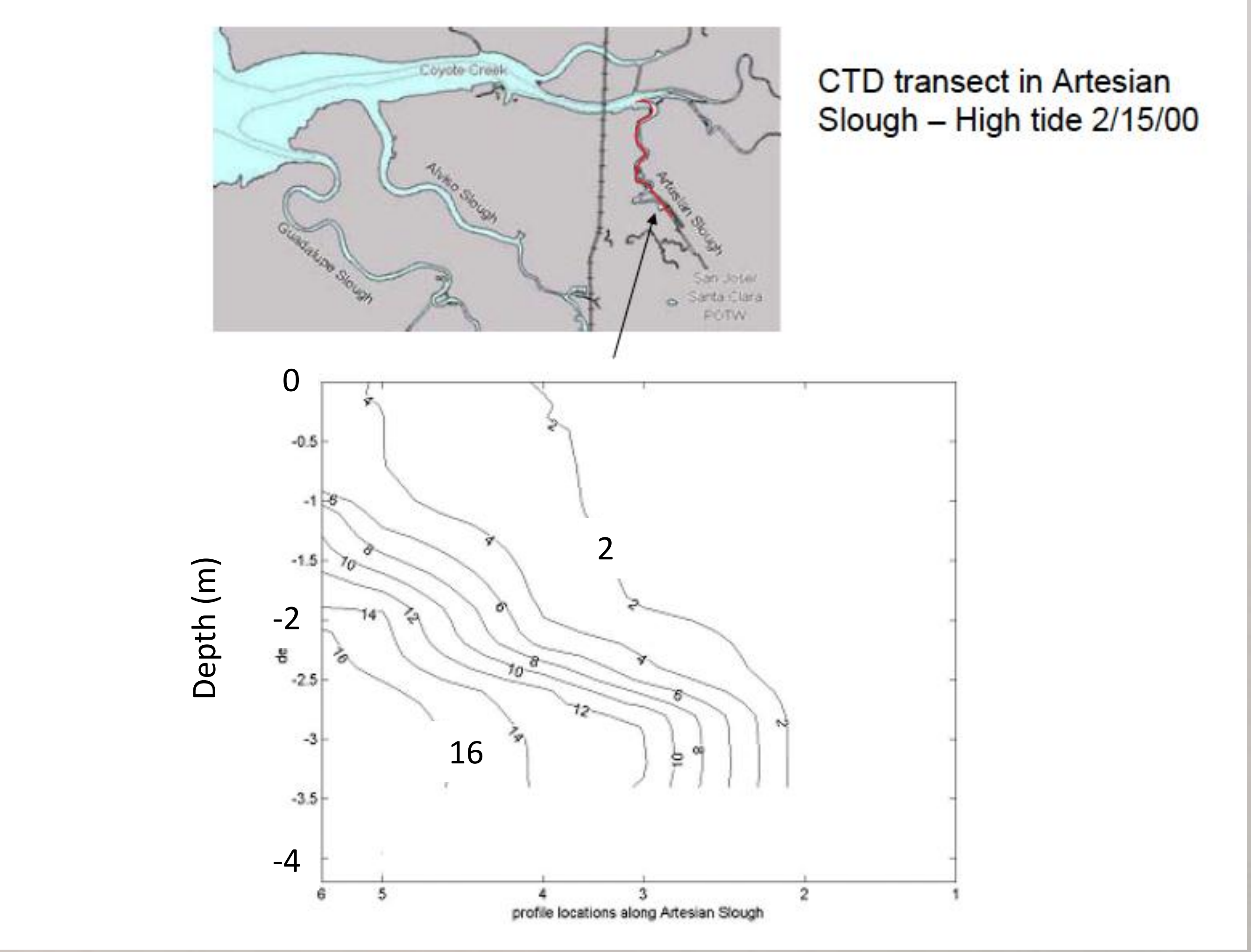


Stratification is important to primary production

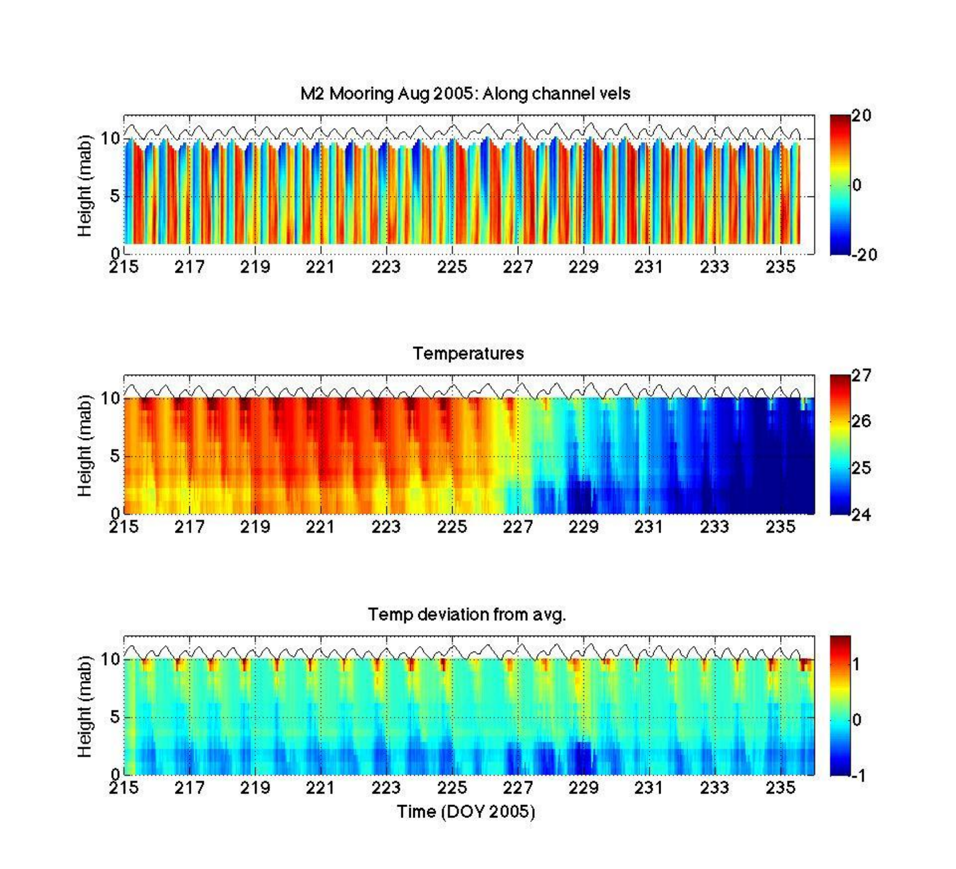


Lucas et al JMR 1999

Even small channels can be stratified (Simons unpub.)



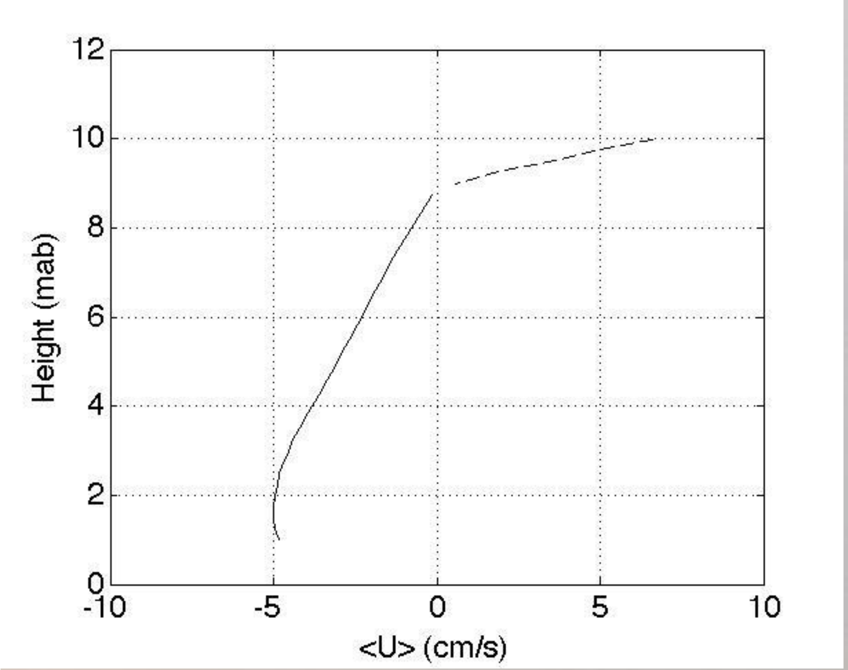
The Delta can be stratified by heating



Velocities and temperature

Downstream

Upstream



Mean Velocity

San Joaquin River near Stockton

Modelling challenge: The effects of fronts

Models are typically formulated as

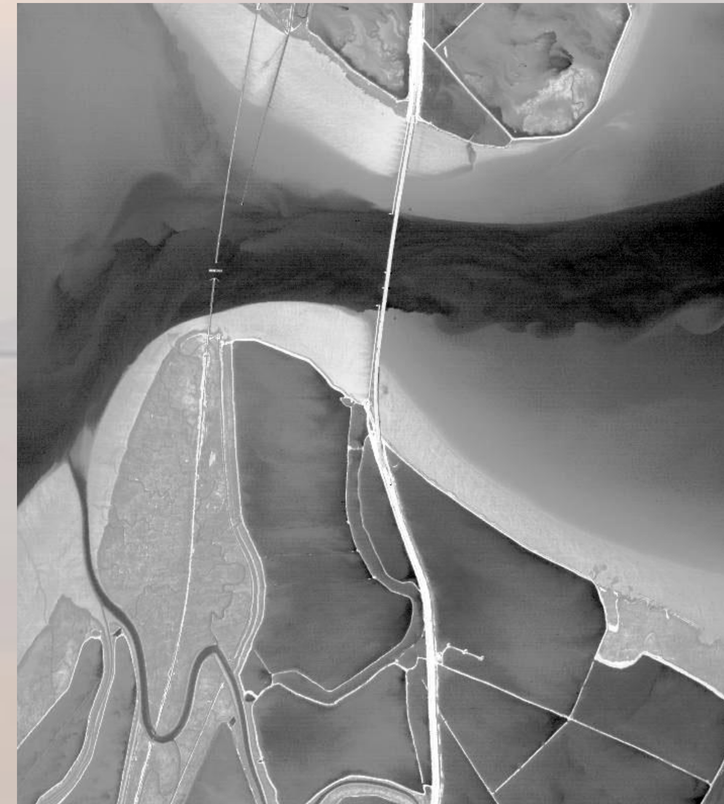
$$\frac{dA}{dt} = F + \beta AB$$

What the model calculates is average (overbar) concentrations

$$\frac{d\overline{A}}{dt} = F + \beta\overline{A}\,\overline{B} \neq F + \beta\overline{AB}$$

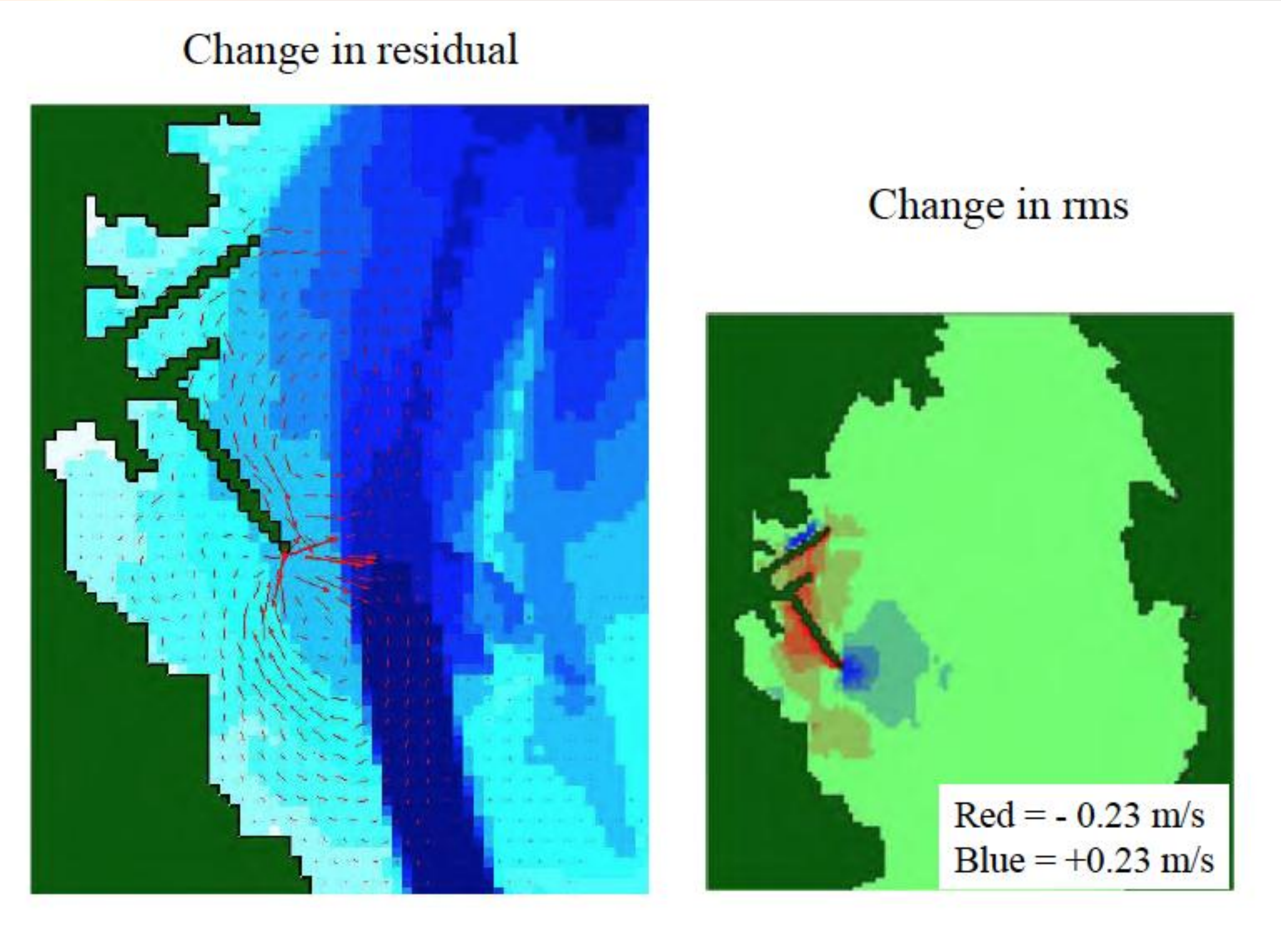
$$\overline{AB} = \overline{\left(\overline{A} + A'\right)\left(\overline{B} + B'\right)} = \overline{A}\,\overline{B} + \overline{A'B'}$$

Deviation inside cell from cell average

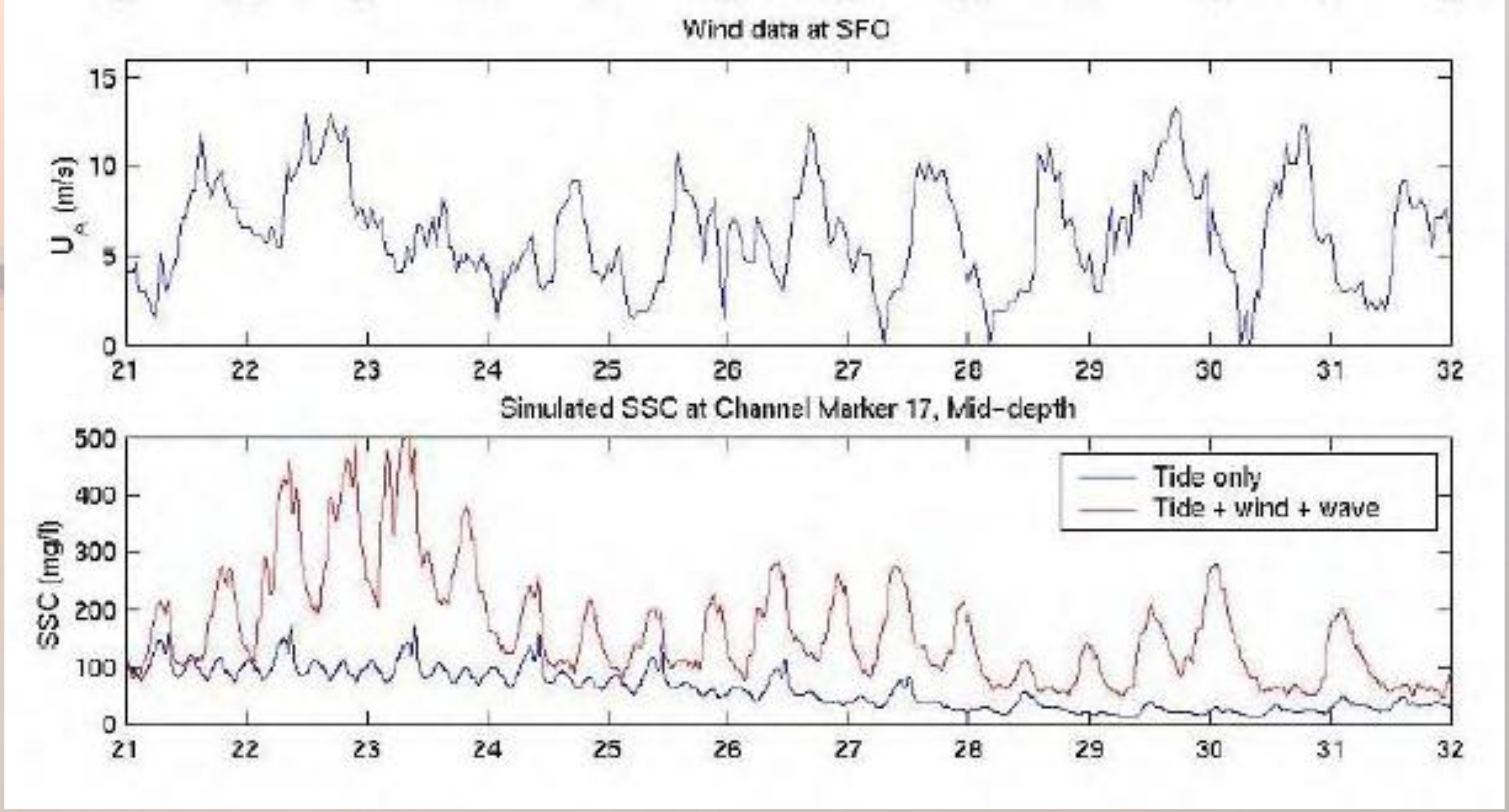


Thermal front near Dumbarton Bridge

More complicated models: Sediment transport in South SF Bay and the SFO Runways (Inagaki 2000)

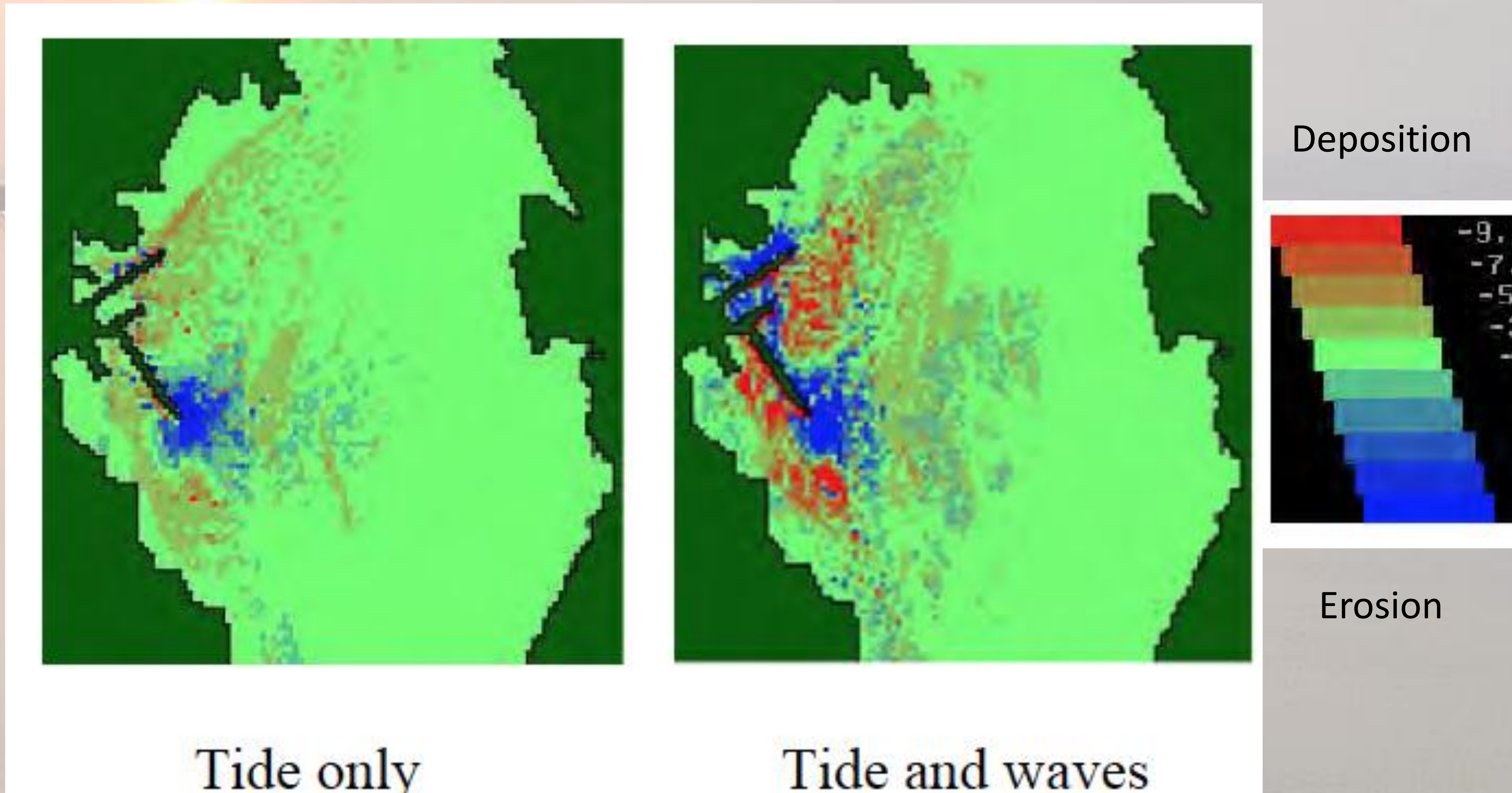


Important to include relevant processes: Example: Wind waves are important to sediments

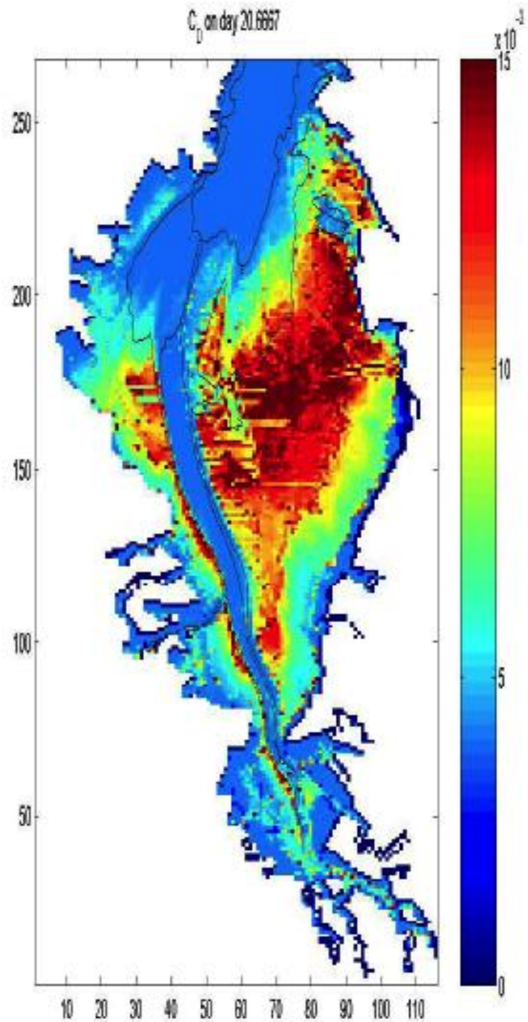


Note: Model uses sediment parameters from Krone (1962) thesis

Wind waves are important to estimating runway effects on sediments



Wind waves effect the basic physics of bottom stress (Bricker)



15×10^{-3}

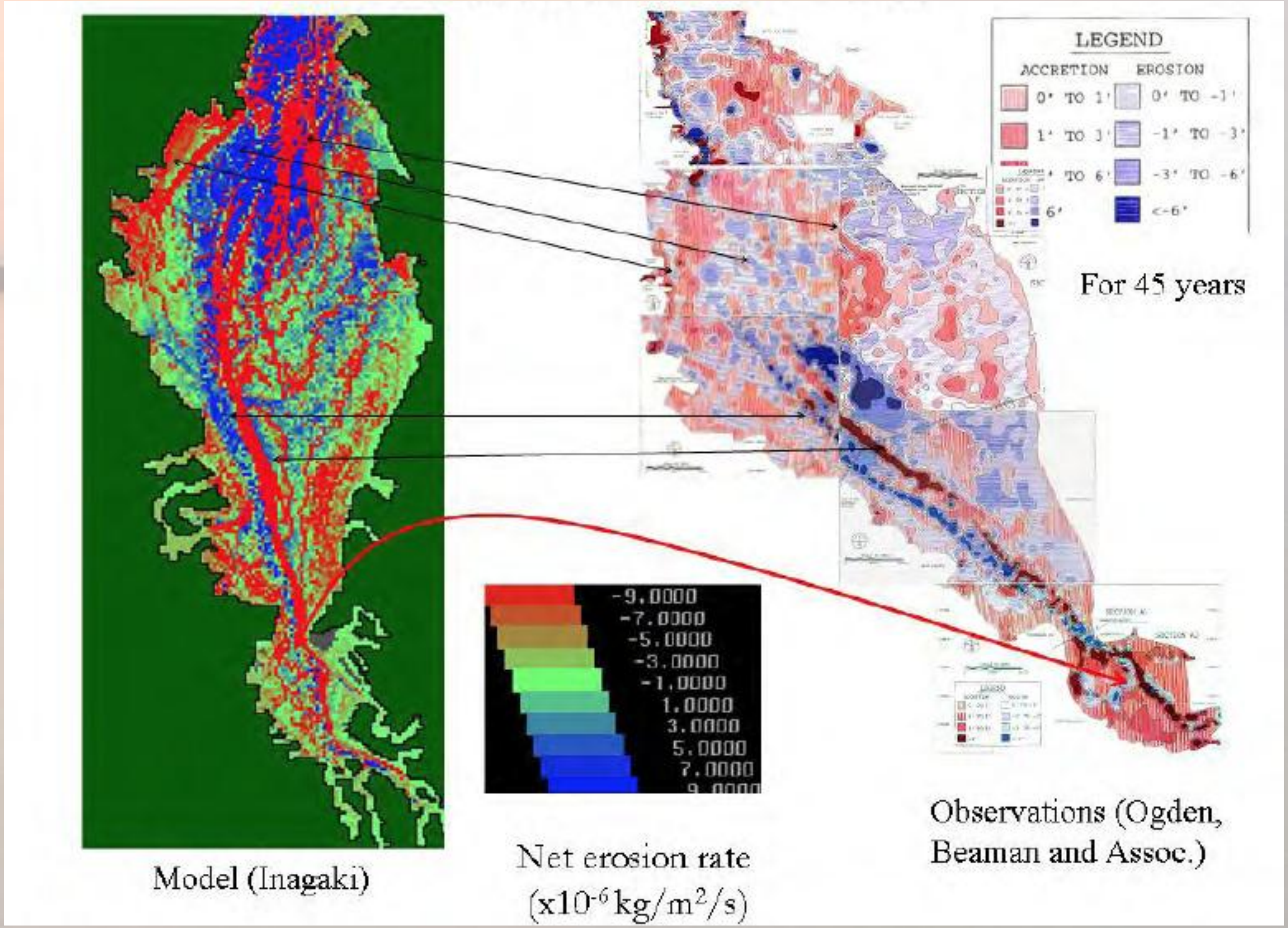
10×10^{-3}

5×10^{-3}

"canonical"

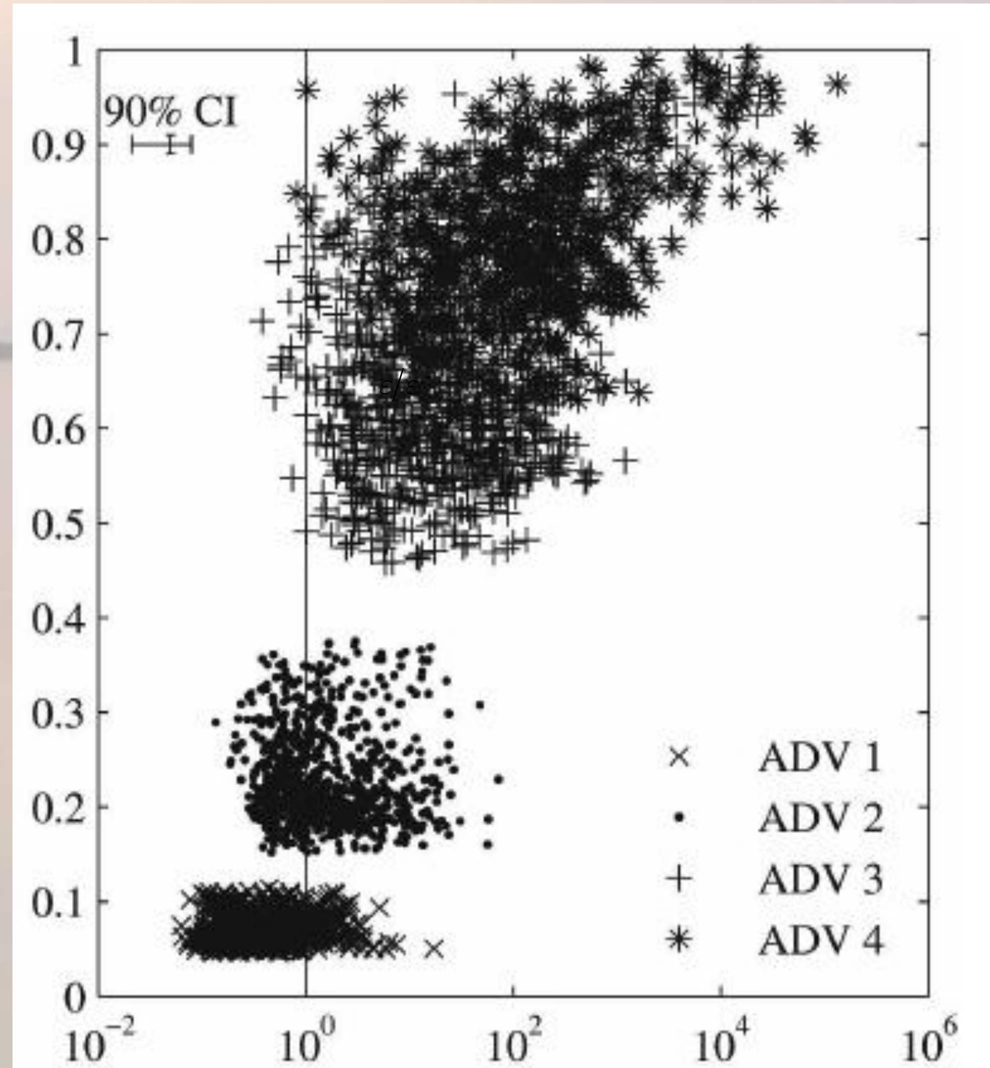
$$C_D = \frac{\tau_b}{\rho U^2}$$

The comparison to long-term data isn't bad



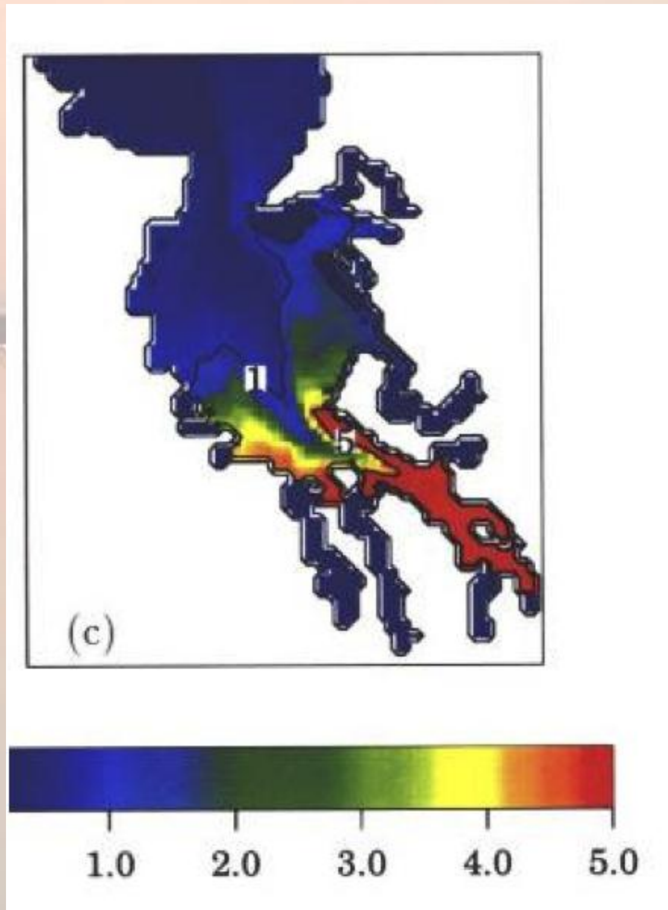
Turbulence due to wave breaking breaking (Jones)

$\frac{z}{h}$



ε/ε (no waves)

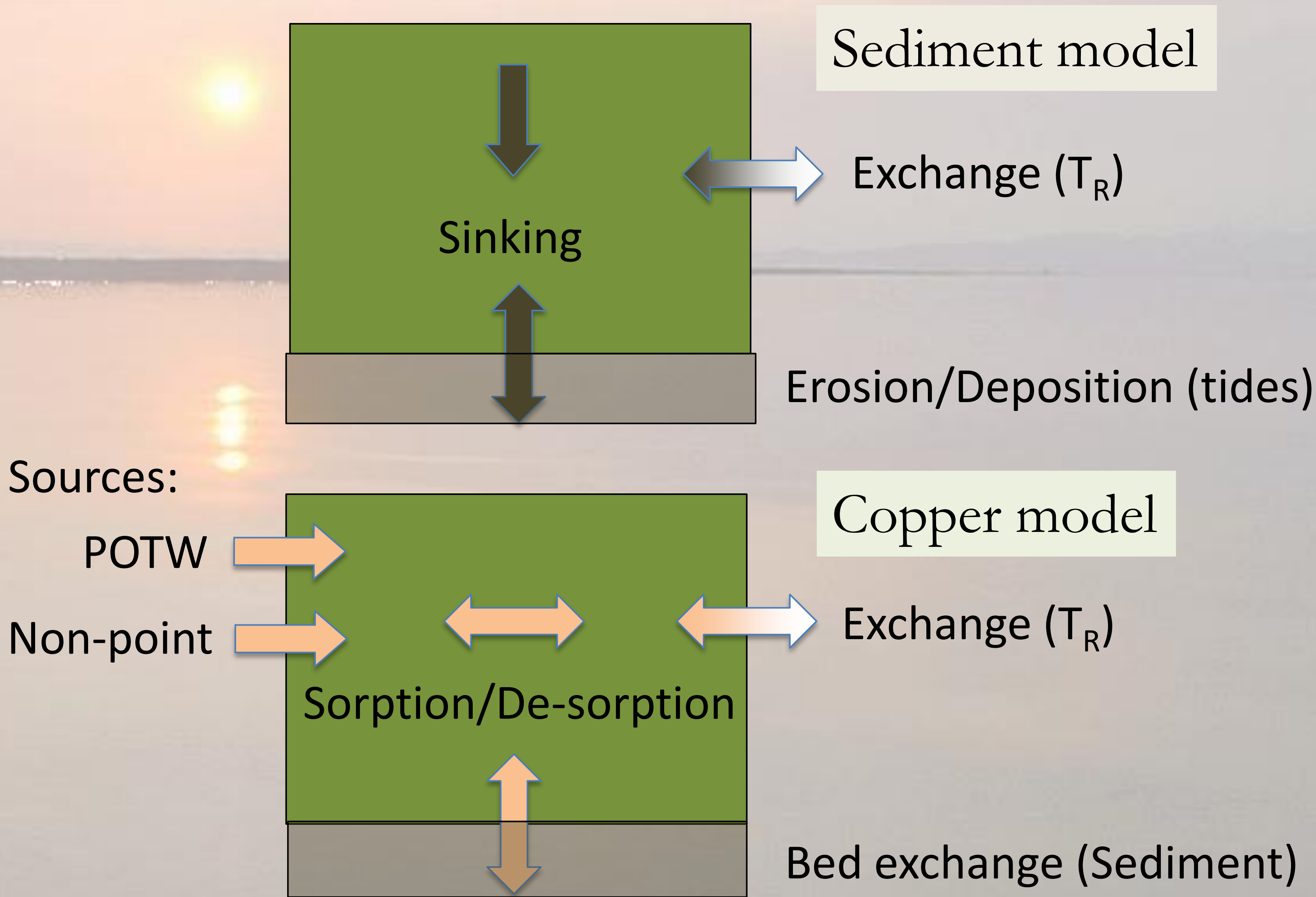
Using a 3D model: South Bay Copper (ca. 1999)



3D model: Depth-averaged scalar concentration from SJ POTW (E. Gross)

Control Volume with Residence Time from 3D model

Zero-D (Box) Sediment-Copper Model



Model results and parameter sensitivity

T_f (days)	10	20 (base)	40	RMP data
Median total Cu (ppb)	4.5	5.2	5.7	5.1
Median dissolved Cu (ppb)	2.7	3.3	3.6	3.1

w_s	base	x 2	x 0.5
Median total Cu (ppb)	5.2	3.7	8.9
Median dissolved Cu (ppb)	3.3	3.3	3.5

POTW	yes	no
Median total Cu (ppb)	5.2	4.8
Median dissolved Cu (ppb)	3.3	3.0

Even larger effects on computations of structure of bed model for Cu

Summary

- 3D models can do a good job predicting currents, salinity and (by inference) transport of conservative scalars
- Hydrodynamic model needs to include all important processes (e.g., stratification, wind waves)
- Sediment models more challenging (data is harder to obtain as well)
- Model technology has significantly advanced in last decade
- Accuracy of hydrodynamic model may not be the most critical aspect of overall modeling exercise
- Good observational data is critical


Thanks