Biogeochemical Modeling to Inform Nutrient Management Decisions in San Francisco Bay

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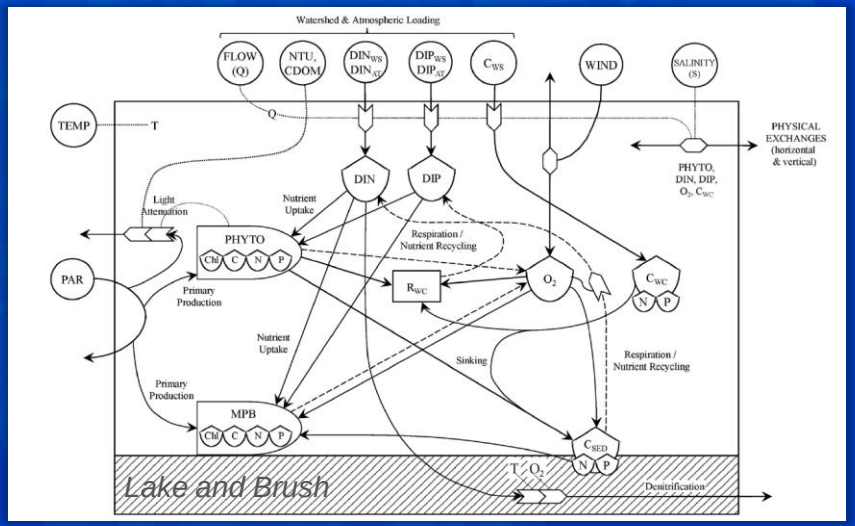
CWEMF
April 13, 2016



Nutrients in San Francisco Bay

Large loads of Nitrogen and Phosphate!

Signs of classical eutrophication are minimal
- DO in most of the Bay has been above basin standard of 5 mg/L
- No persistent harmful algal blooms within the Bay

Adverse impacts of nutrients have been warded off by:
- High turbidity / low light levels
- Benthic grazing by invasive clams (esp. Suisun Bay)
- Stratification typ. short-lived

Looking ahead
- Increasing nutrient loads
- Decreasing sediment loads
- Potential for changes in flushing rates, freshwater flows, temperature

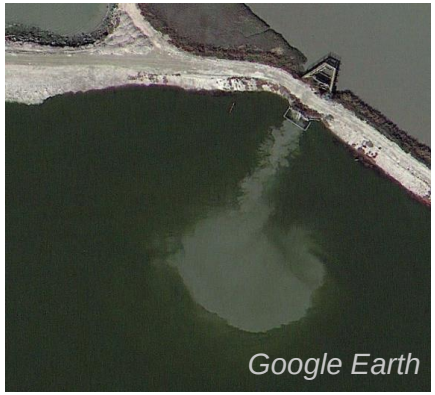
Nutrient Management Strategy

Develop scientific understanding needed to make informed decisions related to nutrients in San Francisco Bay

Observational & modeling components, aim to
- Characterize nutrient cycling
- Assess management strategies
- Explore climate/forcing scenarios
- Specific inquiries include…

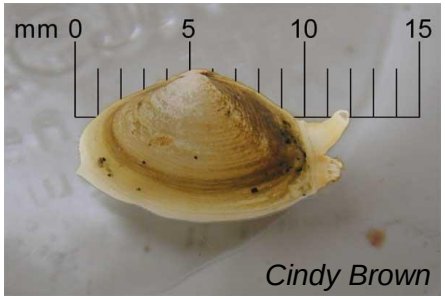
sfbaynutrients.sfei.org

Light attenuation



Ponds / sloughs

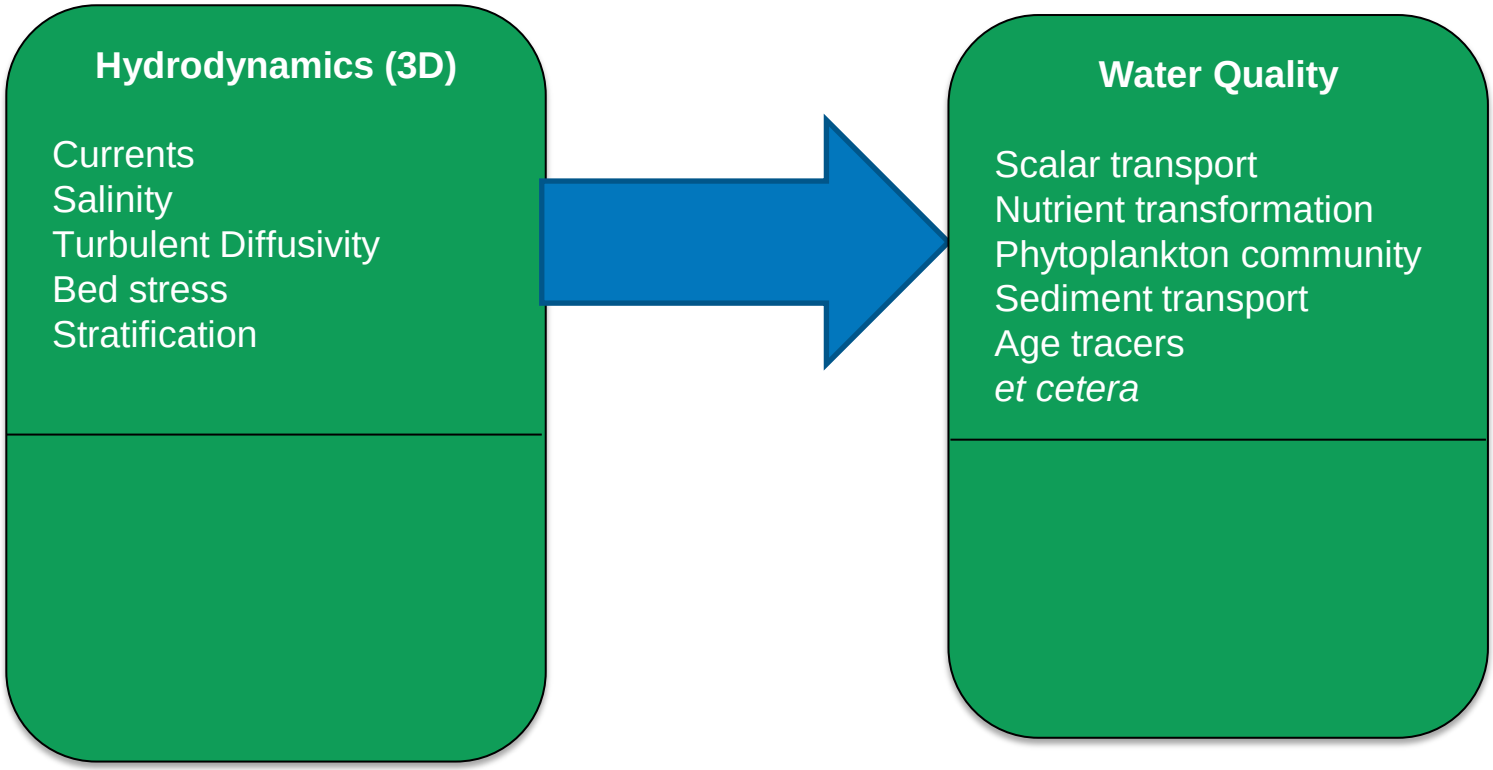
Benthic grazers



Modeling Schematic

Processes,
state variables

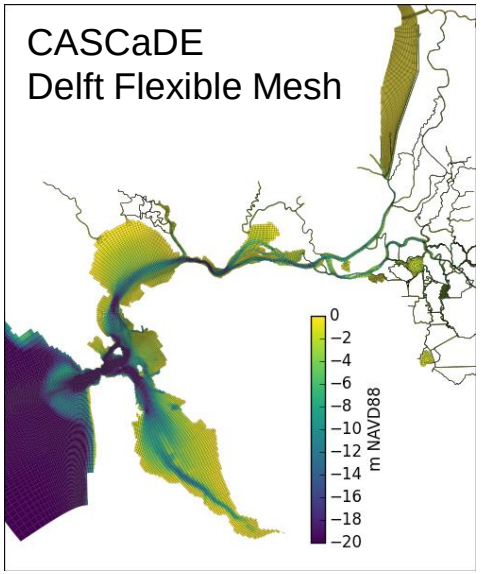
Implementations

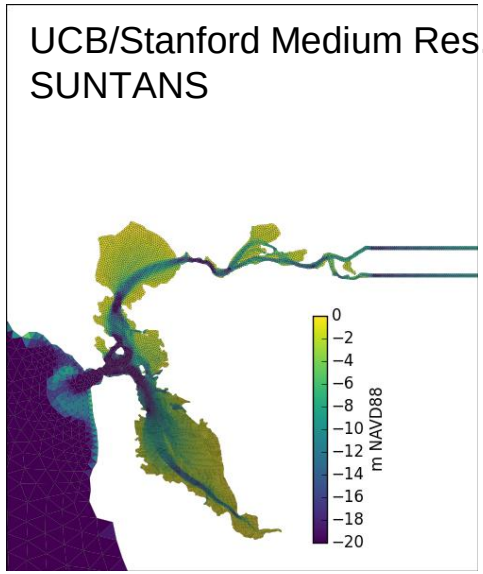


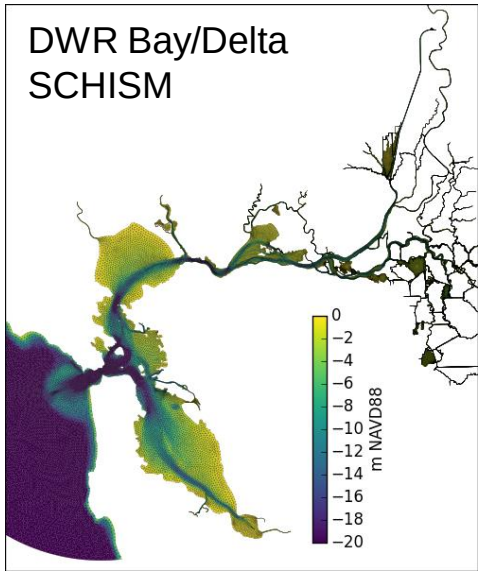
Offline, one-way coupling

Hydrodynamic Models

Multiple models / model implementations in SF Bay







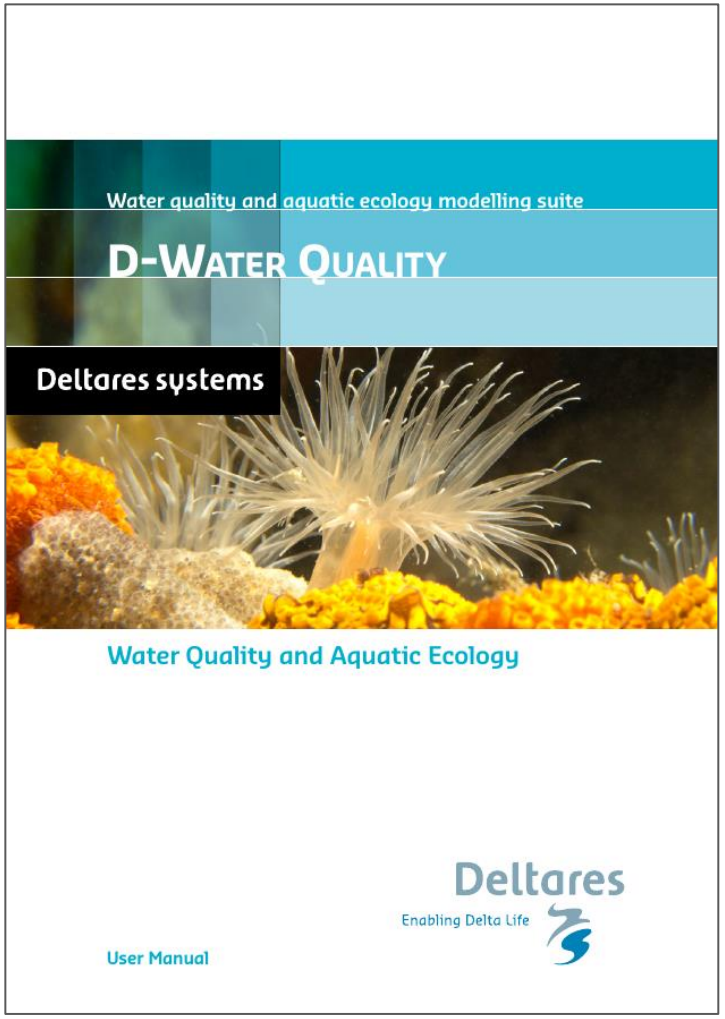
- All 3D, unstructured
- Focus in different regions, varying degrees of calibration
- Platforms have varying strengths and weaknesses

Delft Water Quality

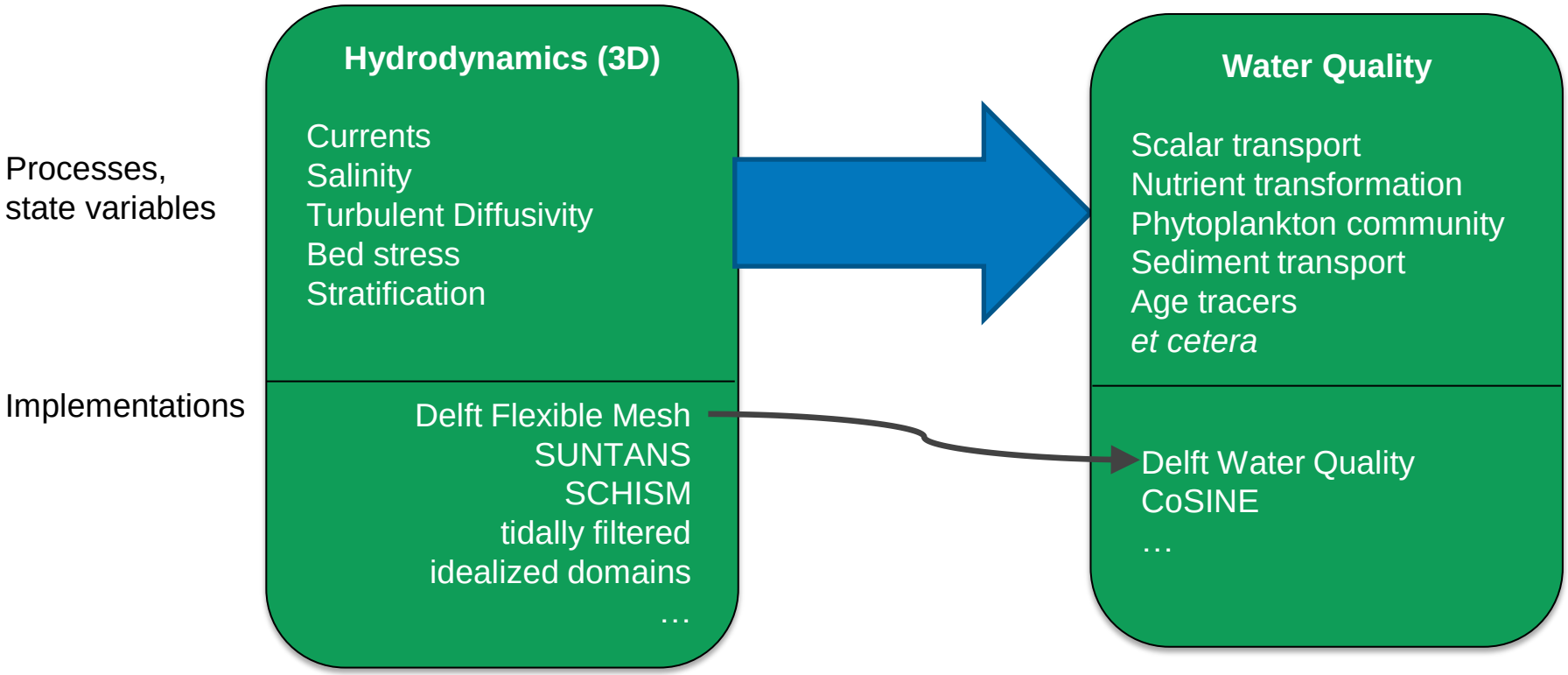
"Buffet" of reactive transport

Menu includes:

- Nutrients
- Phytoplankton speciation
- Simpler NPZ approaches
- Dissolved oxygen, forms of oxygen demand
- Sediment, sediment-water column interaction
- Light modules
- Benthic and pelagic grazing
- Age tracers, *etc*



Modeling Architecture



Offline, one-direction coupling

"Ecosystem of models" rather than *"one model to rule them all"*

SUNTANS Coupling to Delft Water Quality

Initial focus in South Bay – home to calibrated SUNTANS model

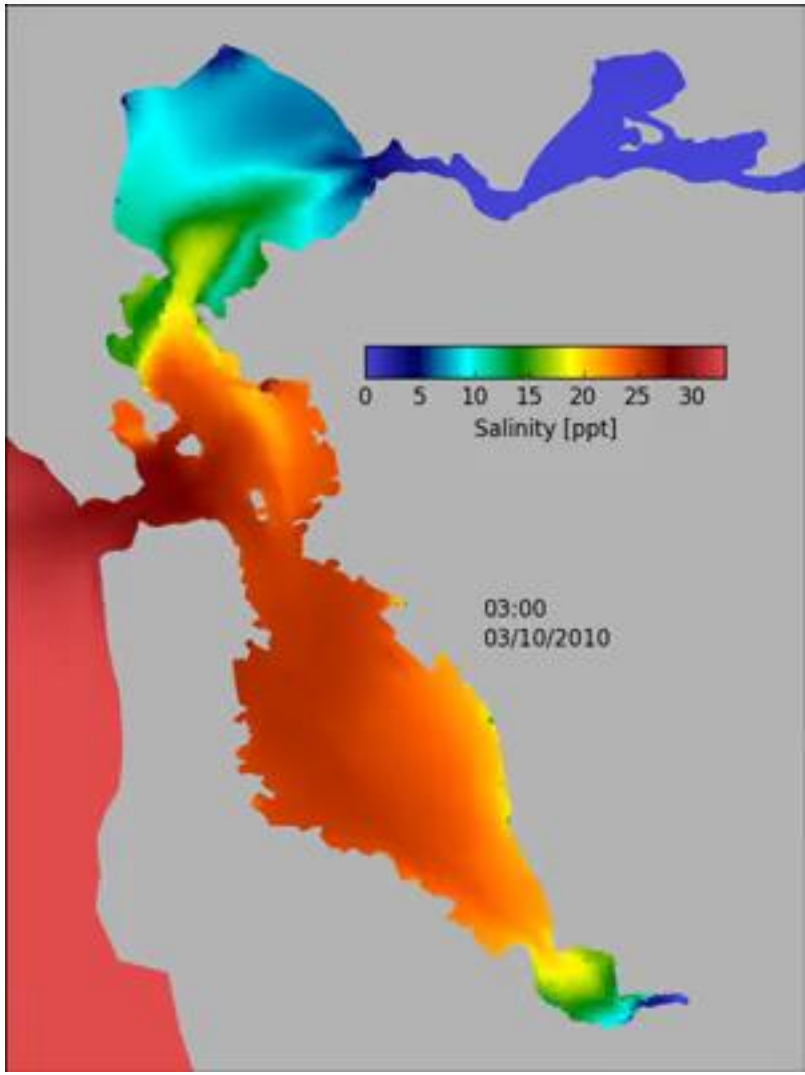
Re-purpose SUNTANS to drive water quality

C code added to SUNTANS

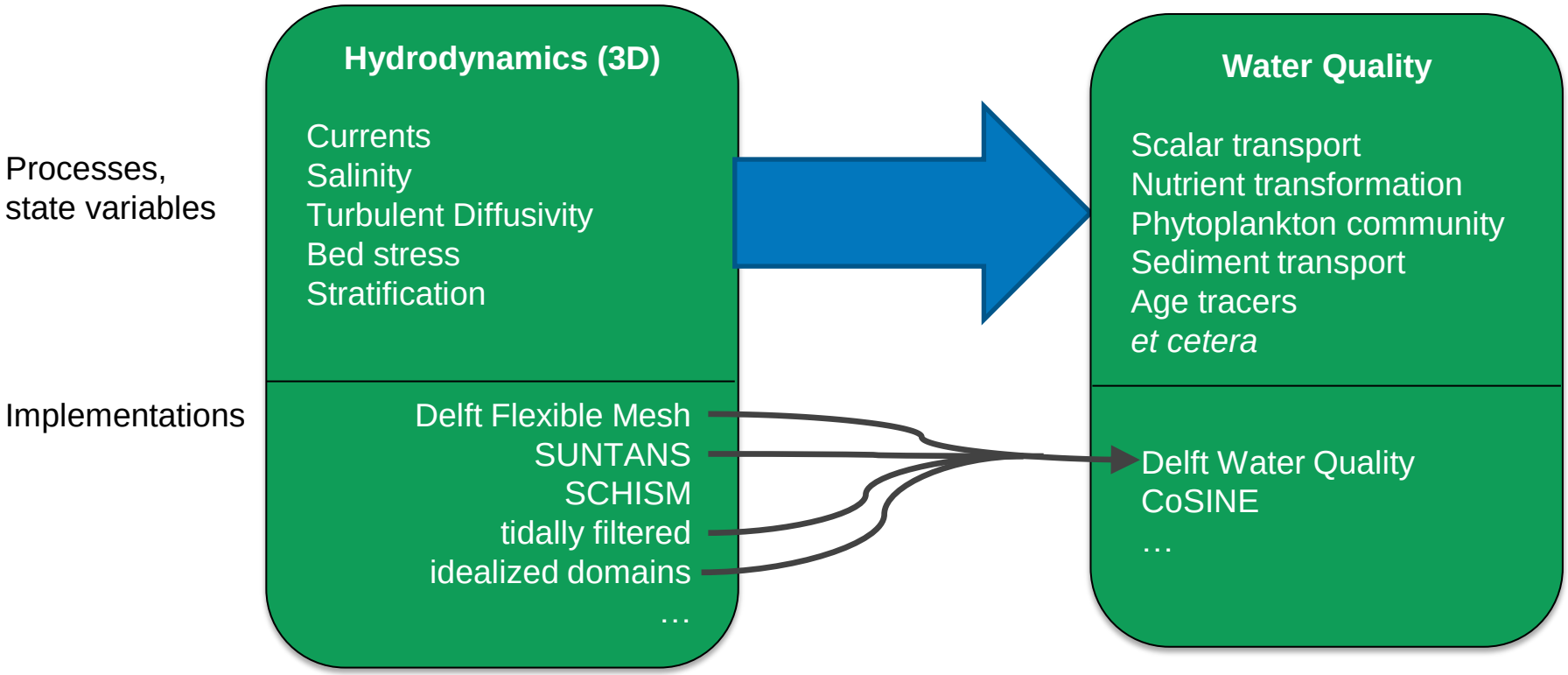
1. Integrate fluxes over output interval (30 mins)
2. Output integrated fluxes and instantaneous state variables in DWAQ format

Python post processing

3. Reformat grid geometry to match DWAQ conventions
4. Translate SUNTANS metadata to DWAQ format



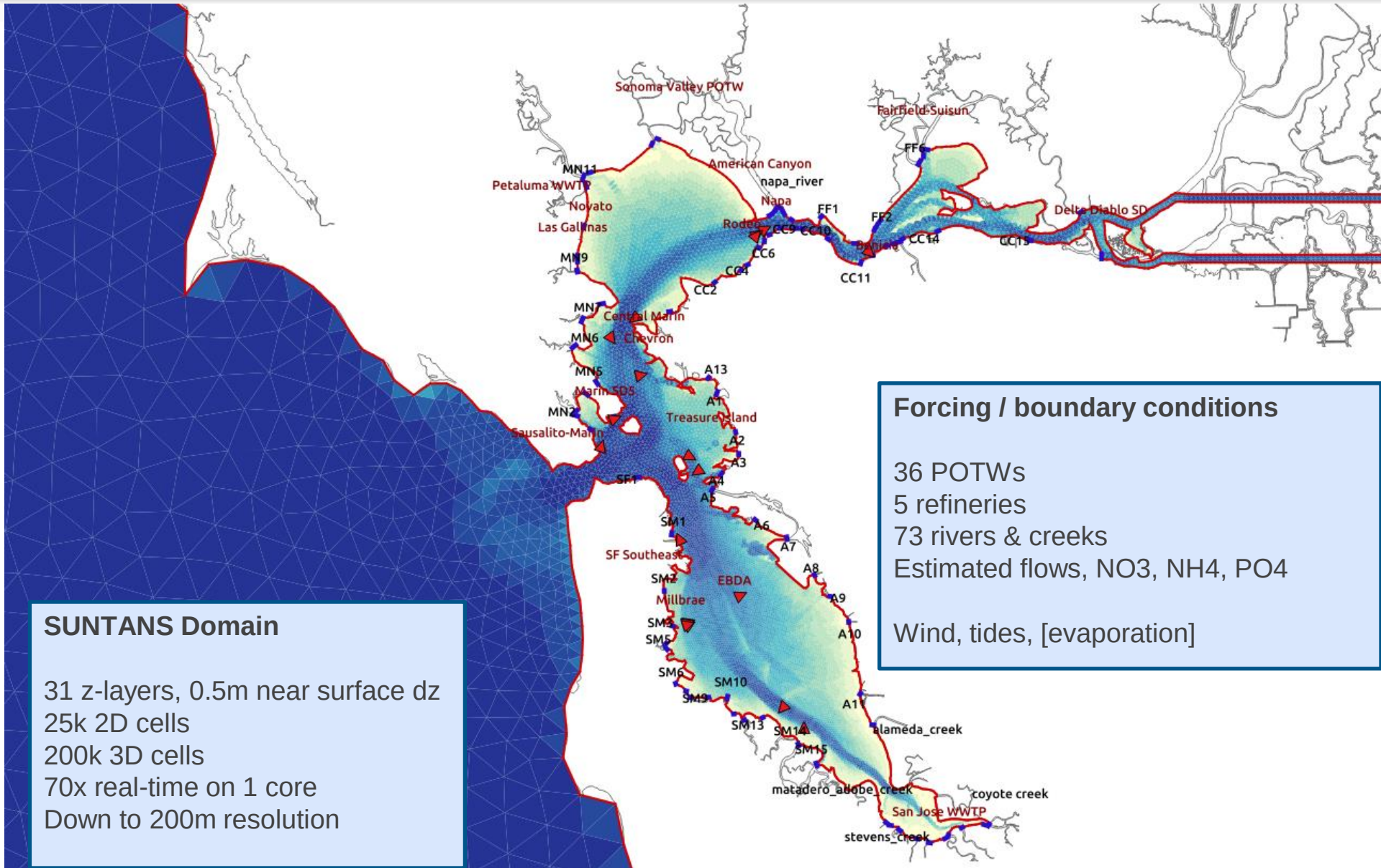
Modeling Architecture



Offline, one-direction coupling

"Ecosystem of models" rather than *"one model to rule them all"*

Hydrodynamics: Flows, POTWs, Nutrients



SUNTANS Domain

31 z-layers, 0.5m near surface dz
25k 2D cells
200k 3D cells
70x real-time on 1 core
Down to 200m resolution

Forcing / boundary conditions

36 POTWs
5 refineries
73 rivers & creeks
Estimated flows, NO3, NH4, PO4

Wind, tides, [evaporation]

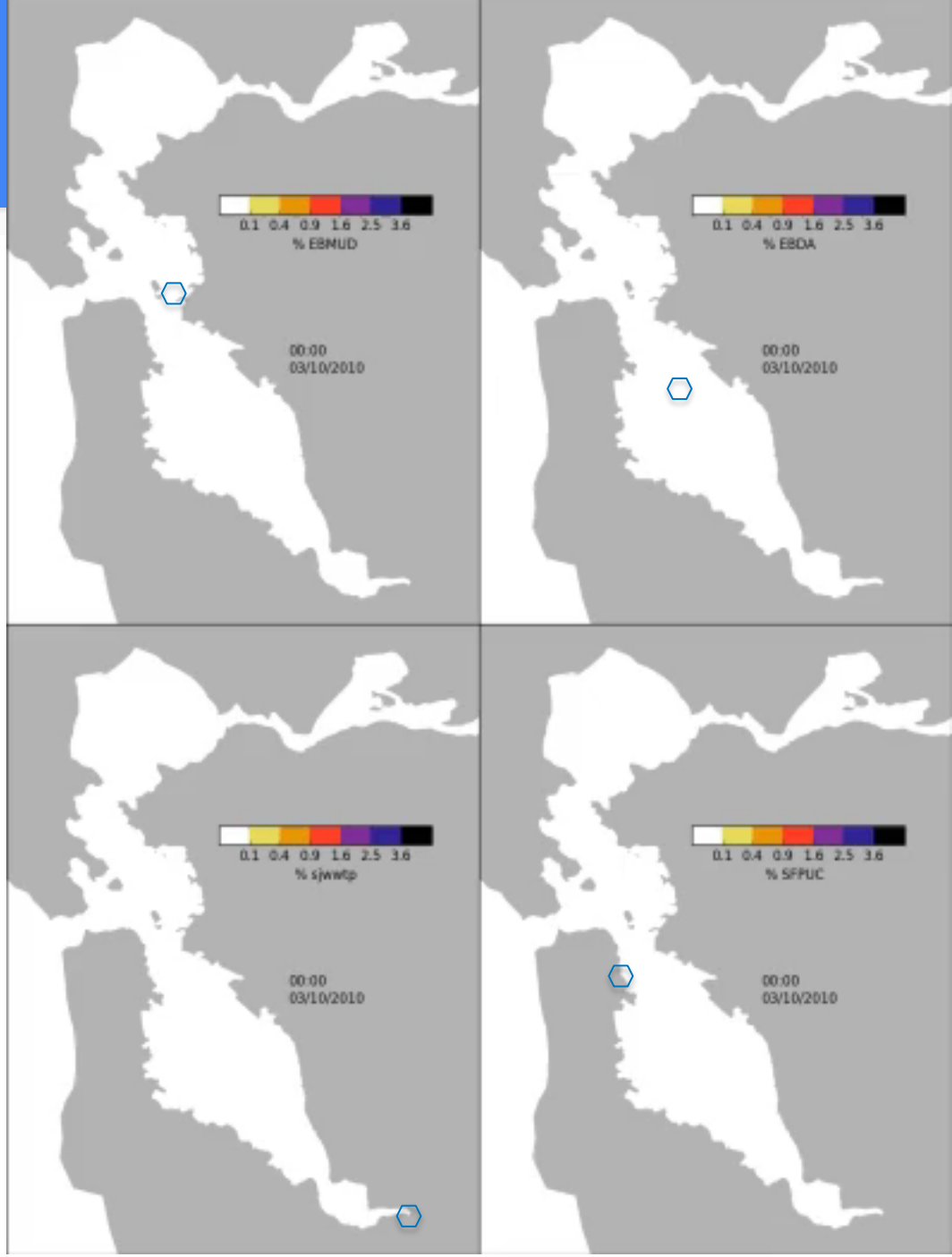
Tracer Study

One hydro run supports wide range of applications, e.g.:

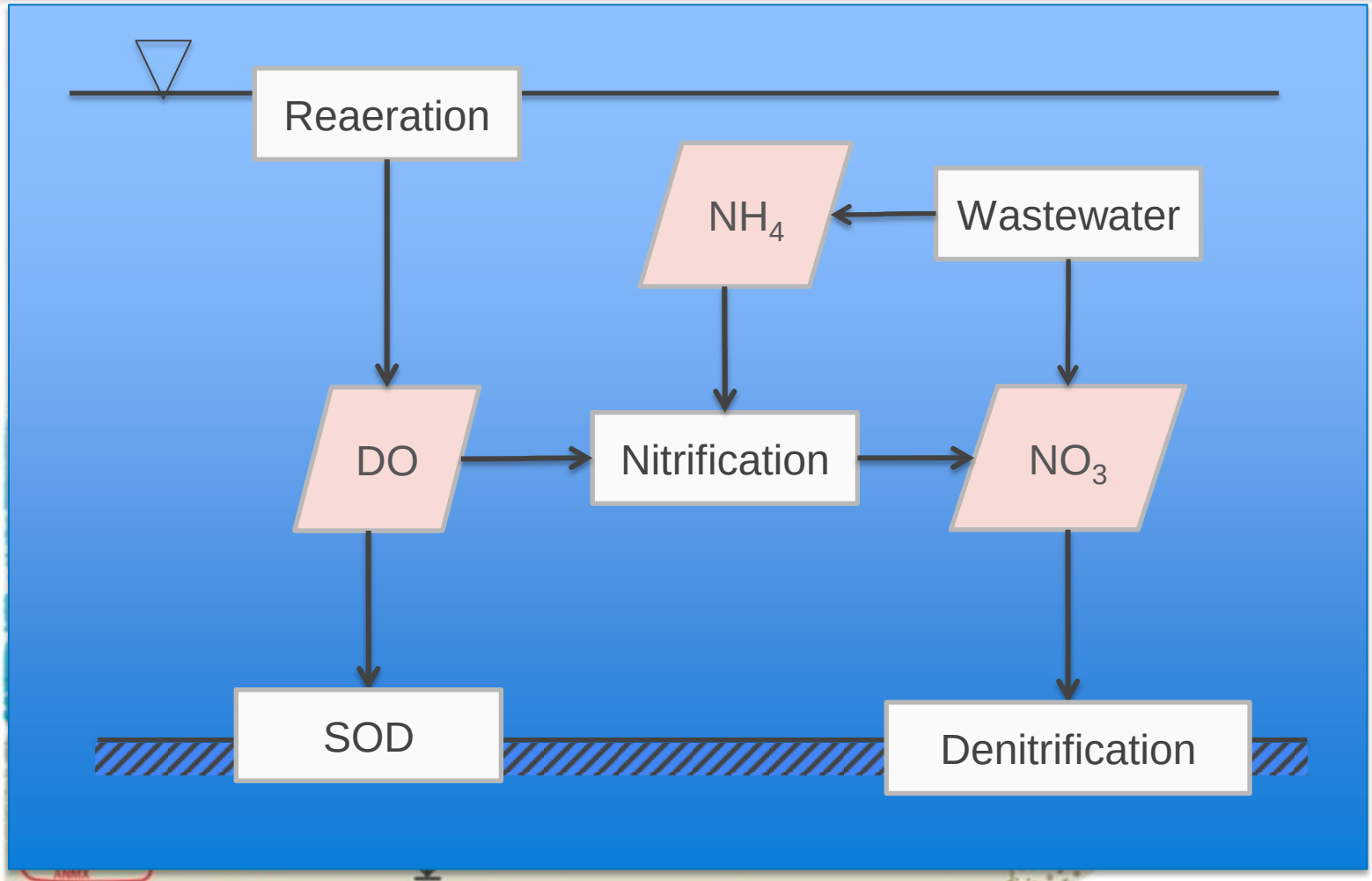
Conservative tracer study from major discharges.

Showing depth-averaged fraction from 4 specific dischargers

Starting to use these results to assess MDL for contaminant studies.



Nutrients Conceptual Model



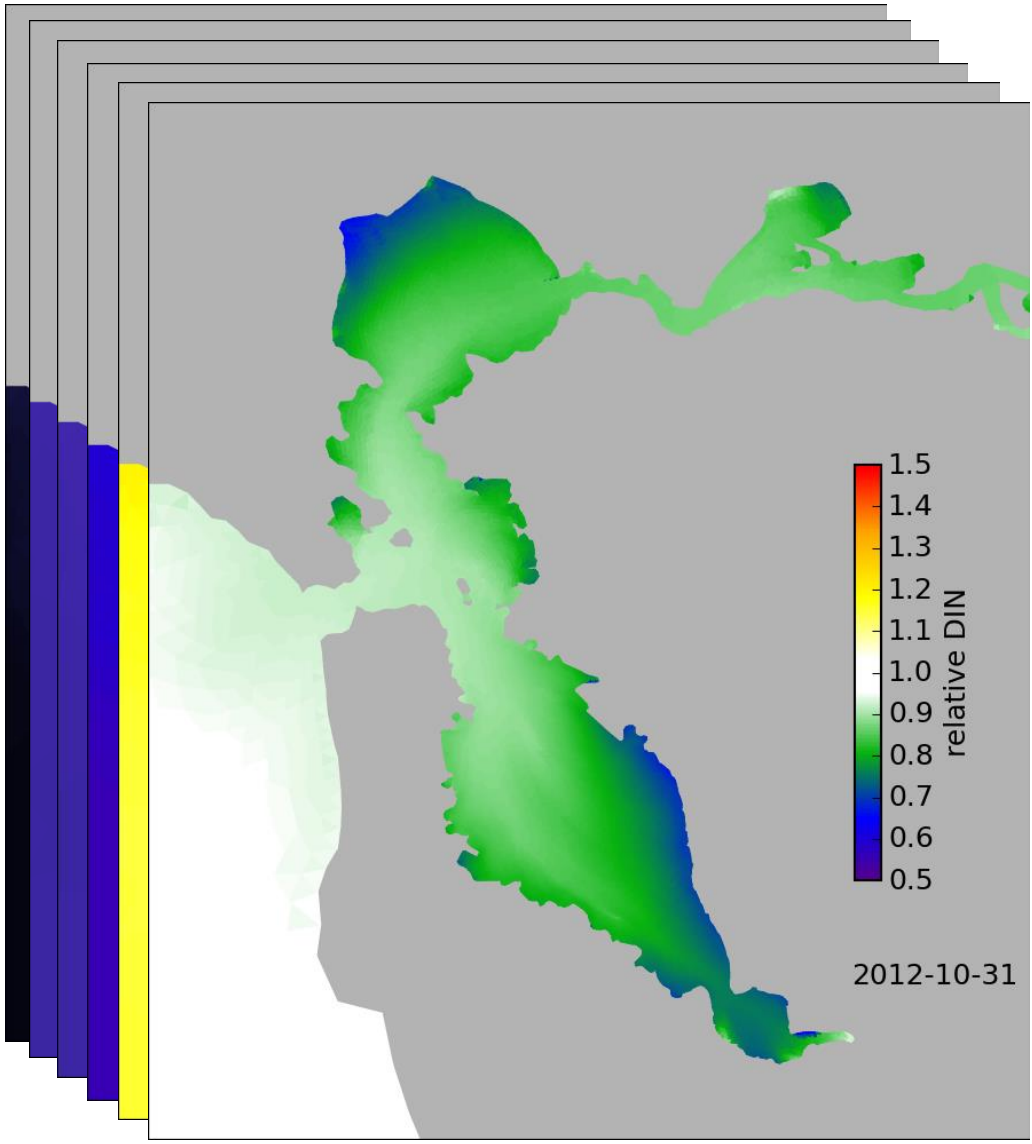
Nutrients: Spatial View

Best-guess loads of NO3 and NH4 from POTWs and Delta

Processes:
- nitrification
- denitrification
- SOD, reaeration

Uncalibrated

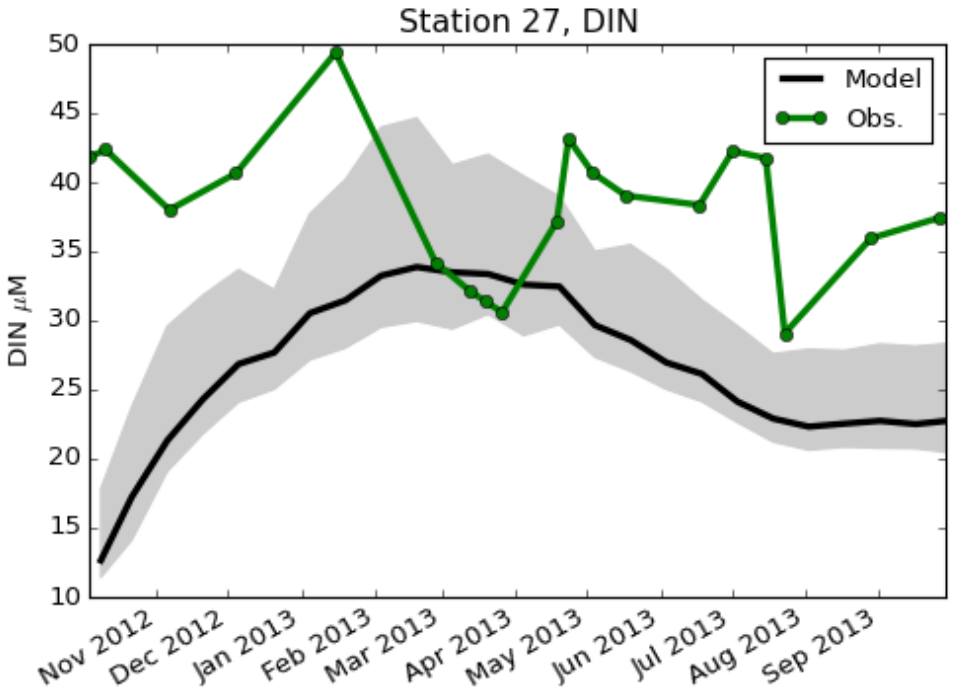
Units µM N (70x mg/l N)

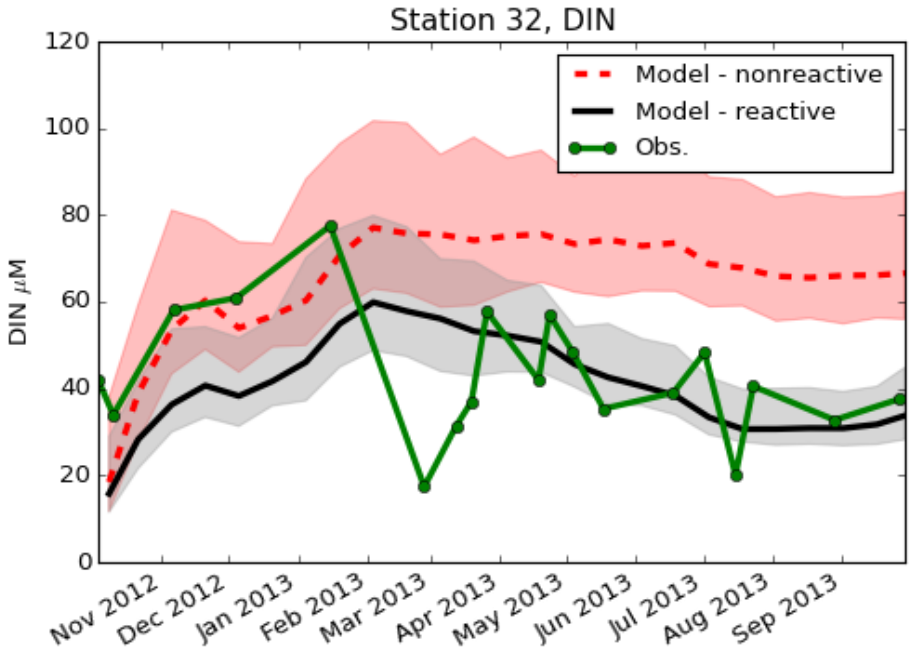


Nutrients: Temporal View

Nutrients runs with evaporation are underway, expected to improve seasonal cycle.

Comparison between reactive tracers and conserved tracers suggests reaction rates are reasonable.

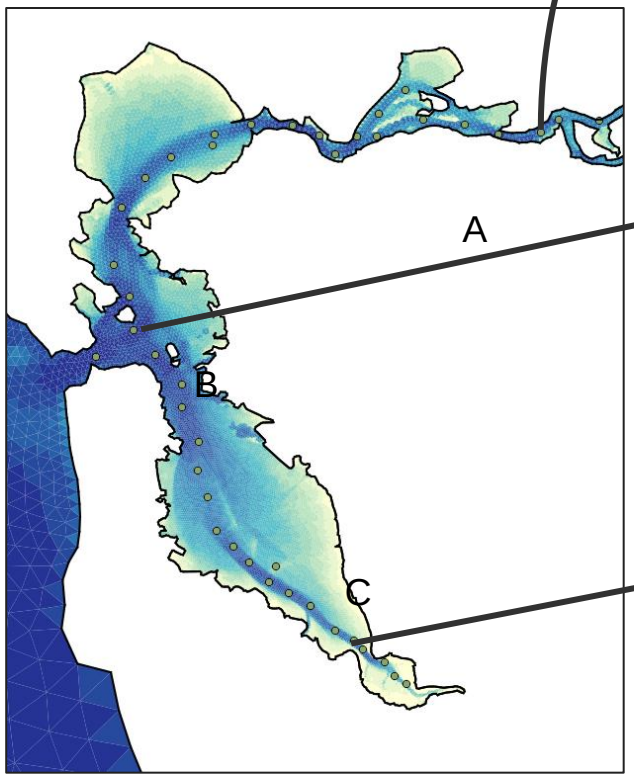


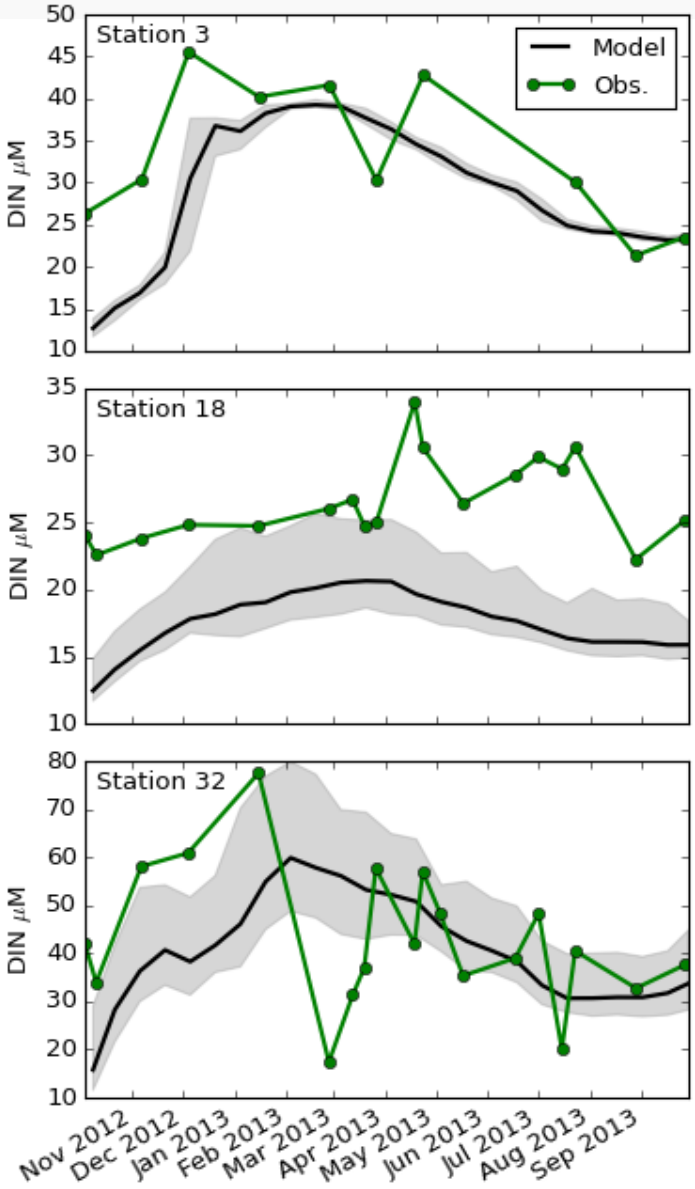


Width of model output curves due to tidal variation

Modeled vs. Observed Nutrients

With no calibration to rate constants, N species are captured relatively well.





Summary, Next Steps

Offline coupling hydro-biogeochemical:

- Proof of concept bringing in SUNTANS hydro, could be applied to others
- Facilitate interoperability, enable multiple models approach
- Cons: large intermediate files, not necessarily faster
- Pros: more flexible for re-use, separation of concerns, faster for small problems and short runs (no hydro spinup)

Promising initial results from nutrient modeling in the Bay

- Adding evaporation, resolved Delta, suspended sediment, mechanistic temperature, phytoplankton, ocean nutrients, etc.
- With small subset of processes get relatively close to observations

Looking into ways of sharing model inputs, outputs, configuration. Any thoughts?

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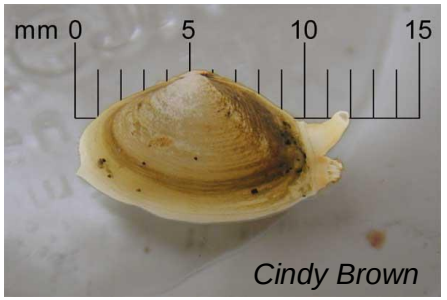
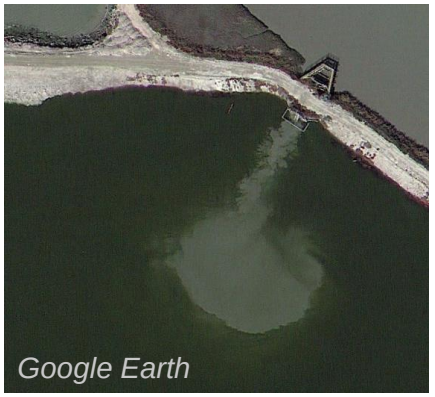
Priority Scientific Questions

1. Importance of clams vs. sediment for controlling blooms in South Bay



2. Dose:response relationships in South Bay
   - *Dose:* nutrients, temperature, light extinction, freshwater
   - *Response:* transformation rates, chl-a, productivity, DO, HABs



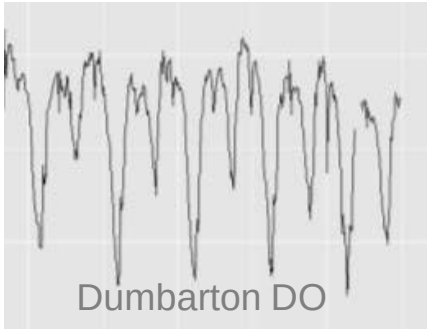
3. Role of sloughs and ponds in nutrient transformations

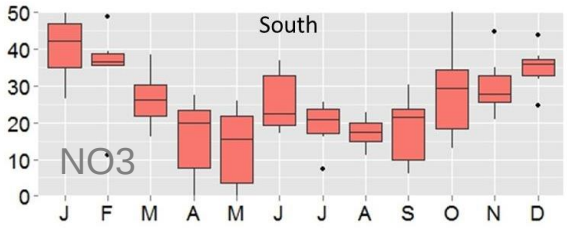
Priority Technical Questions

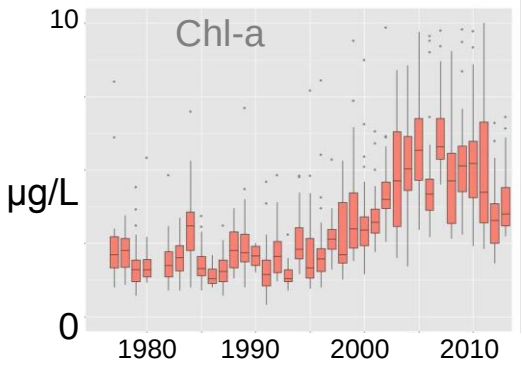
What model complexity is sufficient to reproduce distinct events & trends, such as:

- Spatial, seasonal trends in NH4, NO3
- South Bay bloom of 2003
- Depression of DO at Dumbarton Bridge on tidal time scales
- Decadal trends in chl-a

Identify necessary / sufficient …
- constituents, processes, coupling
- spatial and temporal resolution



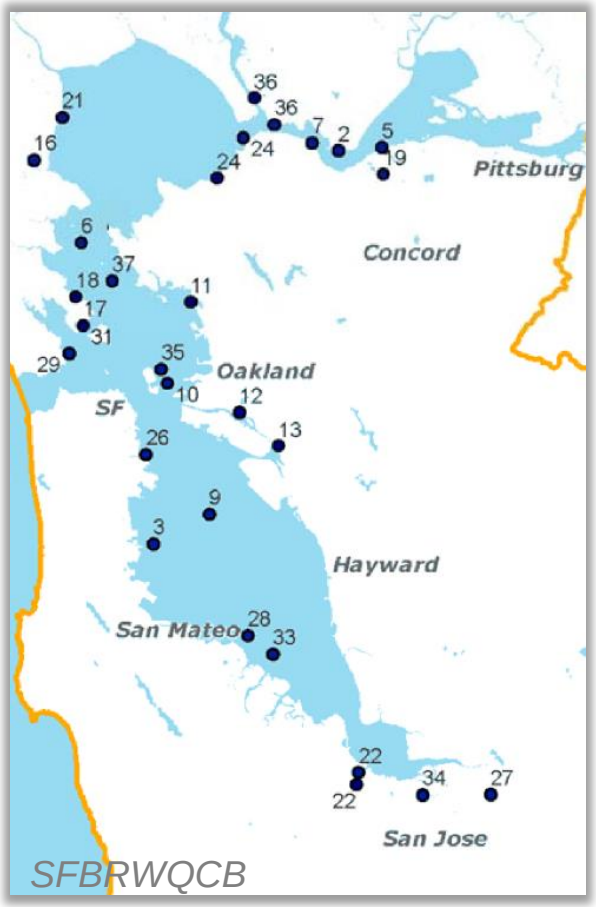




Priority Management Questions

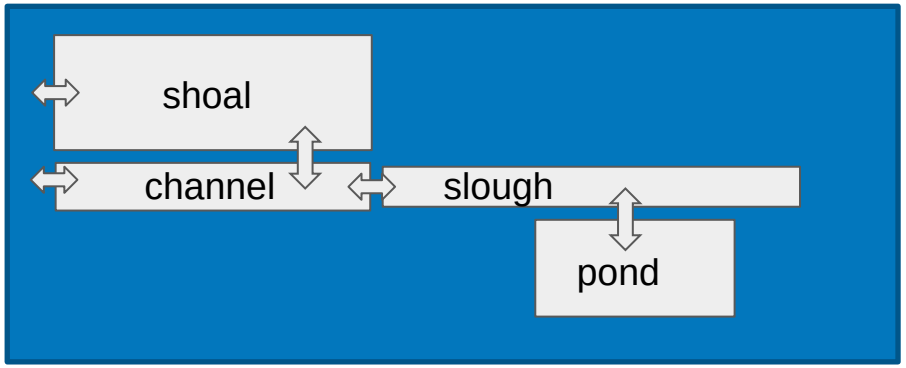
Quantify spatial region of influence of POTW discharges.

- Include **seasonal variability** of discharges, freshwater flows, winds
- Produce tools to estimate discharge **contributions at an arbitrary time/place** in the Bay
- **Inform decisions** relevant to load reductions, CEC distributions, etc.



Hydrodynamic-ish Models

Synthetic / idealized flows:

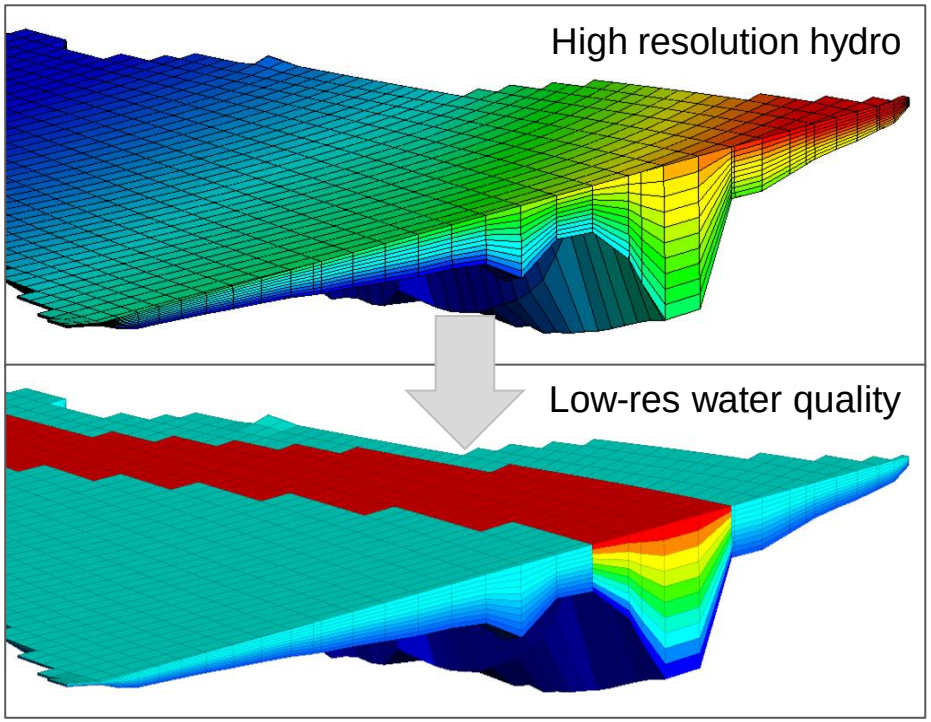


Aggregated/filtered Flows:

Aggregate horizontally (shown)

Lump layers

Aggregate “in time” – filter fluxes to get subtidal transport



Summary, Next Steps

Parallel efforts to balance near-term and long-term hydrodynamics needs

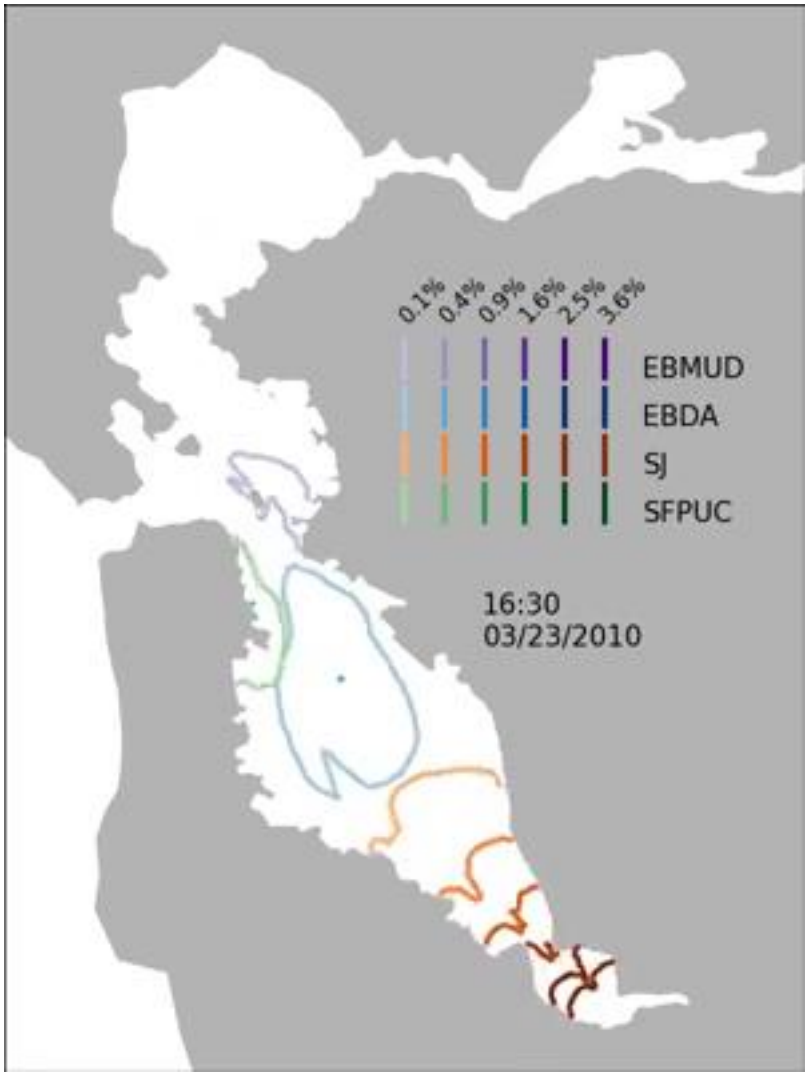
Basic water quality runs successful

Ready to add realistic nutrient loads

Evaluating sensitivity to forcing, parameters

Reproduce spatial and seasonal trends in nutrients at scale of South Bay

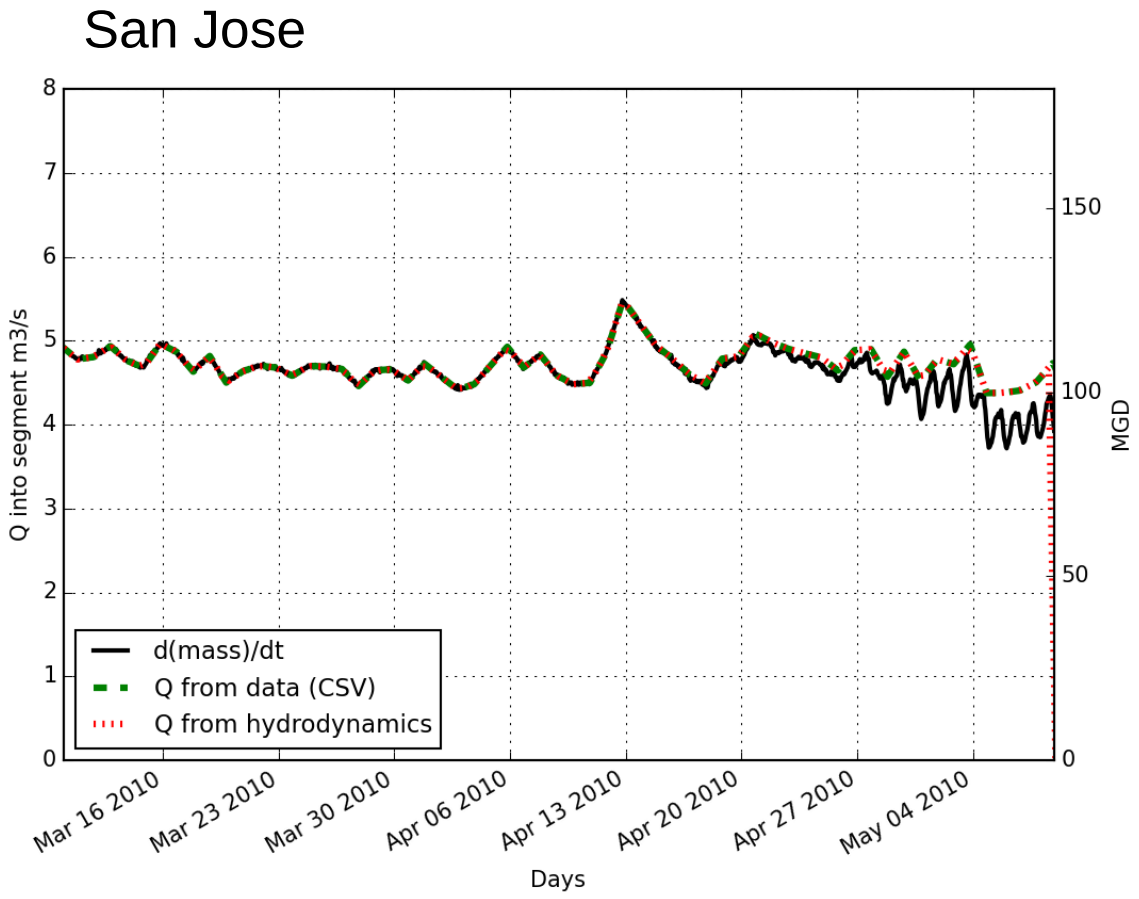
Ongoing conversations about additional applications for
- emerging contaminants
- wet weather sampling
- sea level rise



Load / Mass Comparison

Comparison of
1. Tracer mass
2. POTW flow data
3. Flow in hydrodynamics

Divergence comes from tracer mass exiting the model domain



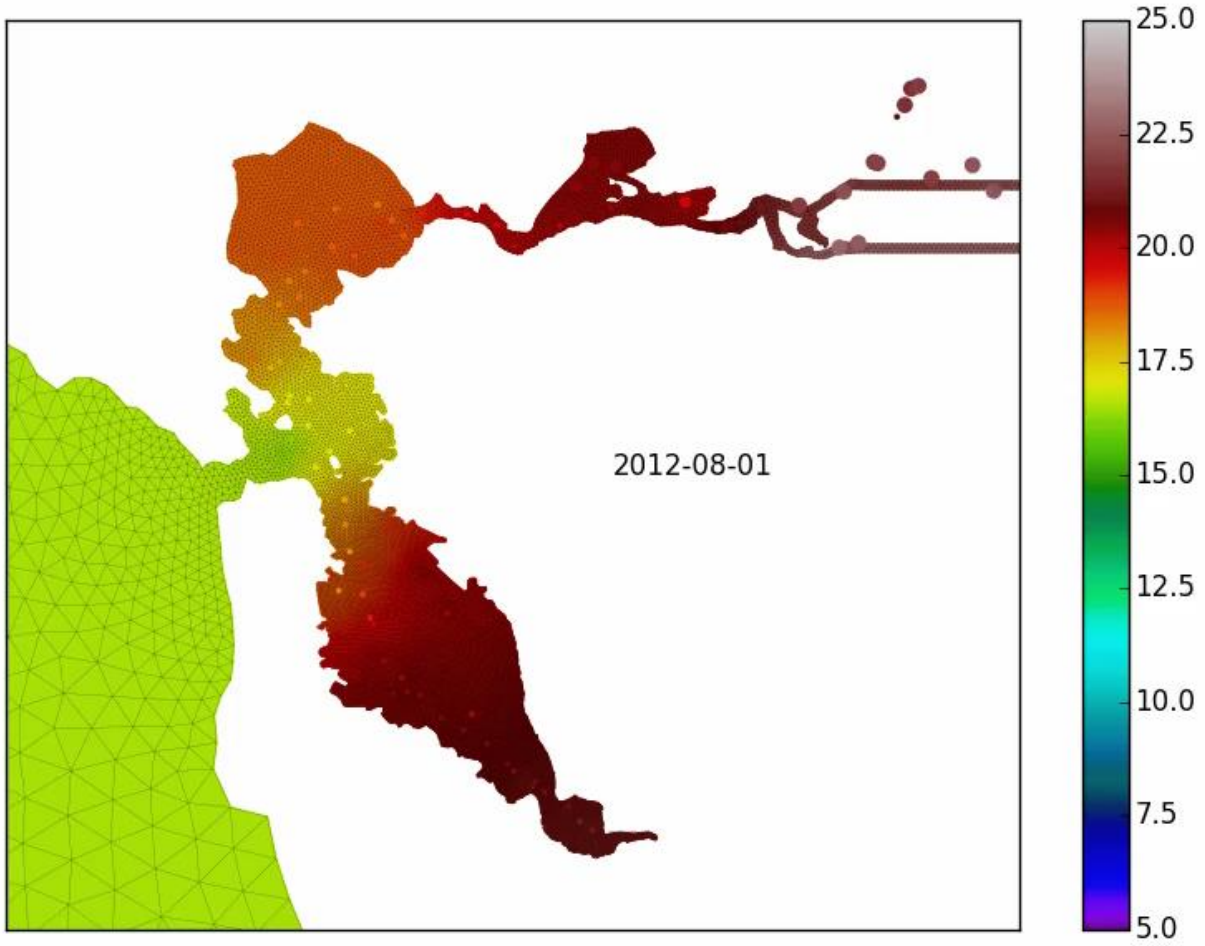
Extrapolated Temperature Field

Temperature is essential for water quality.

Observational network is dense relative to temperature variation.

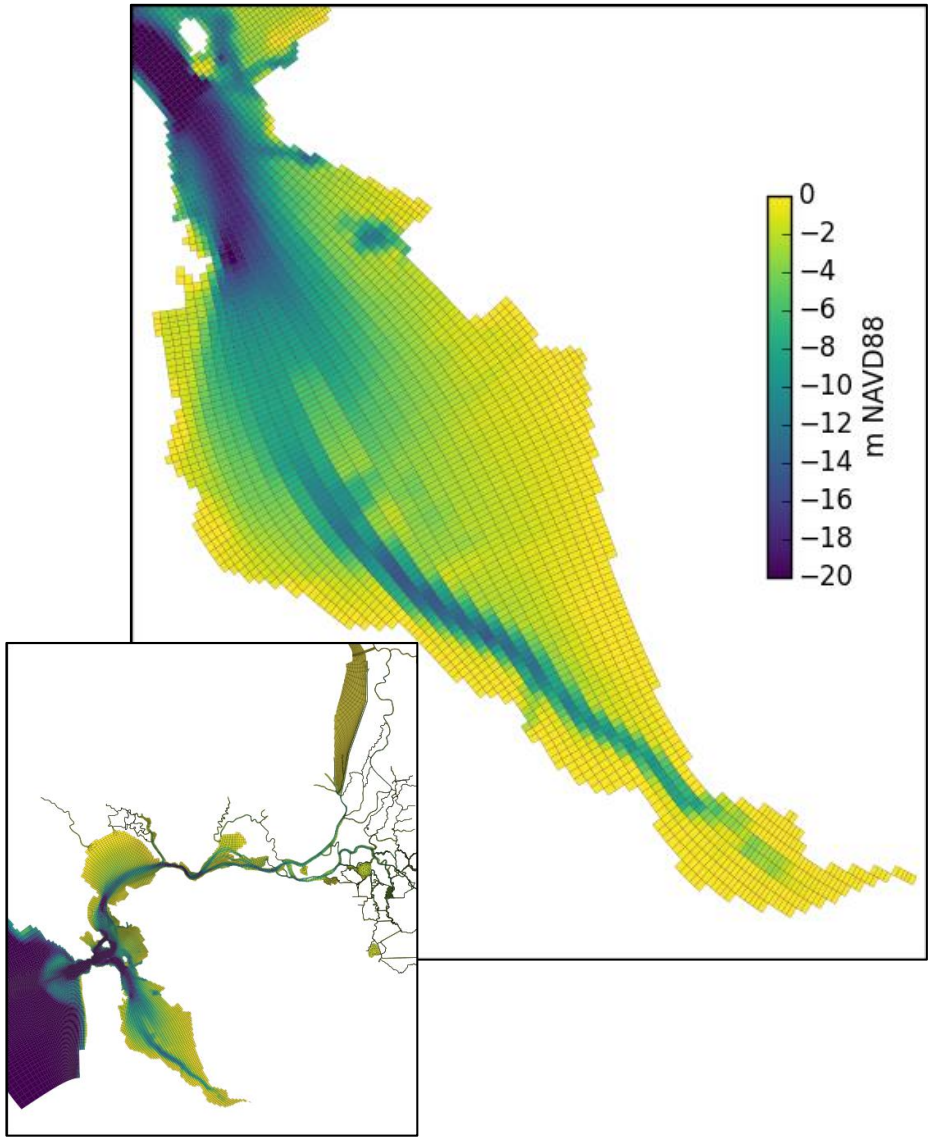
Can extrapolate rather than model.

Extrapolation honors shorelines, similar to DIVA.



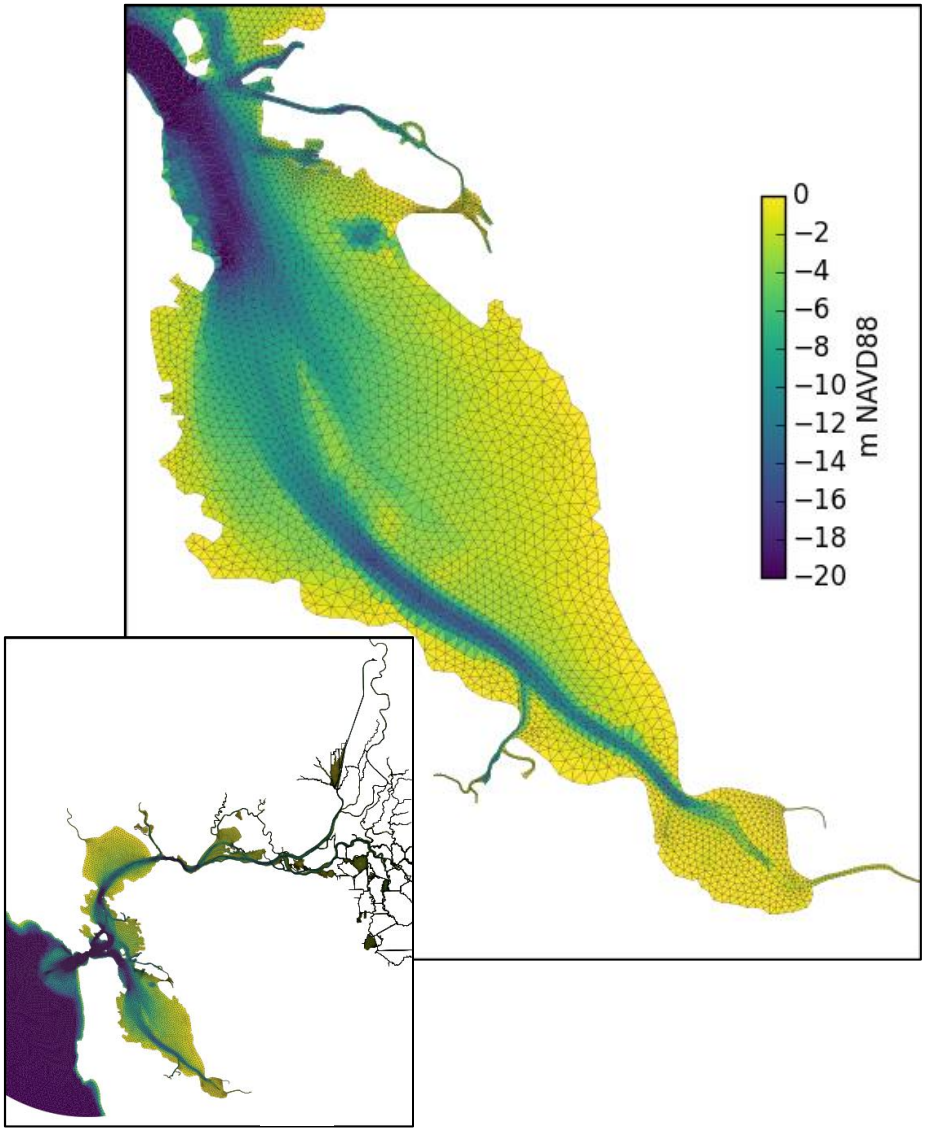
CASCaDE / Delft Flexible Mesh

- Collaboration with USGS, Deltares
- Promising validation of salinity, flow in North Bay
- SFEI working on South Bay, better resolution, freshwater inputs
- Newest model in Deltares stable
- Awaiting updates on open source status
- Seamless integration with water quality model
- Good candidate for the long-term



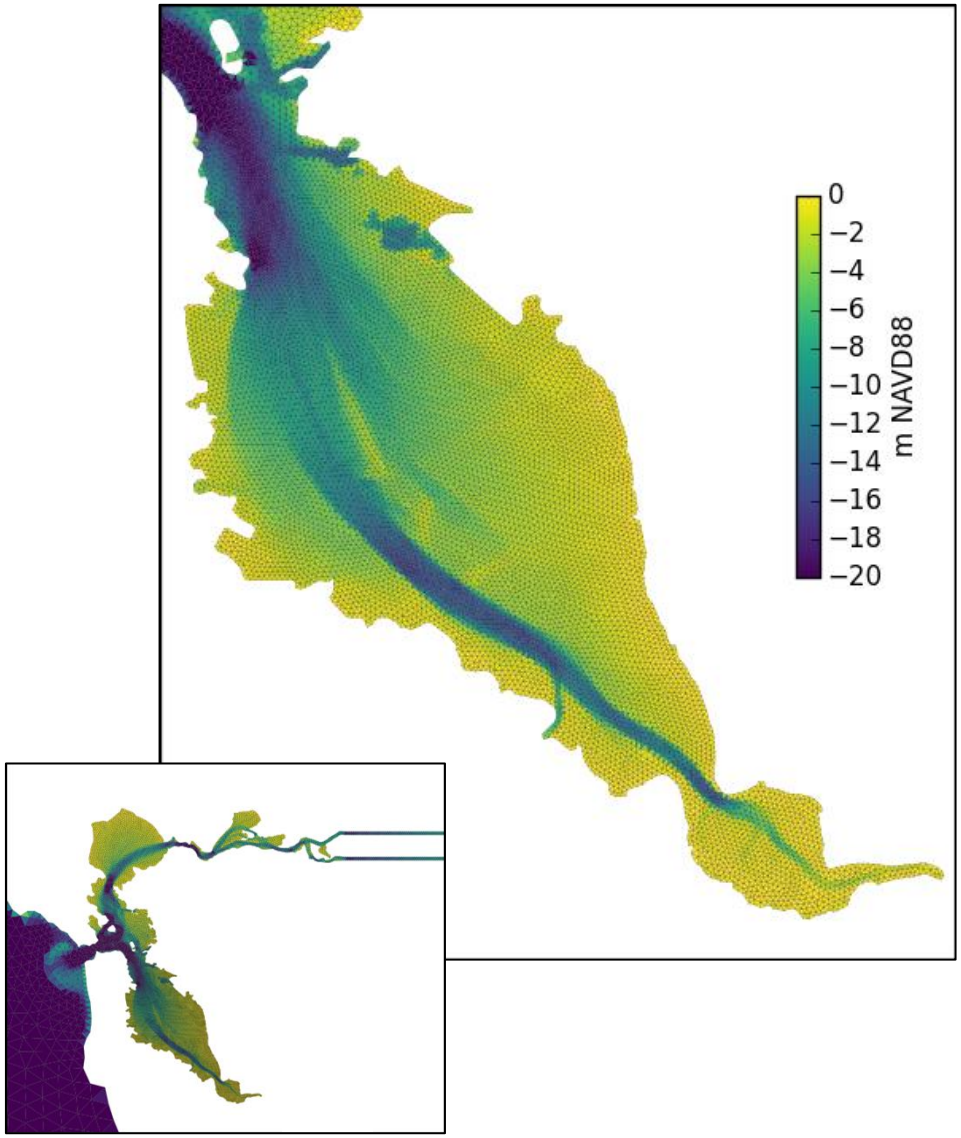
DWR / SCHISM

- Significant investment and commitment from DWR
- Delta-focused, though willingness to improve South Bay
- Finite-element model – significantly different method than Delft, SUNTANS, UnTRIM
- Possibility of integrating SCHISM hydrodynamics into water quality model
- Candidate hydrodynamics for Suisun Bay



SUNTANS: Medium Resolution

- Existing model setups calibrated for South Bay and San Pablo Bay (tides, currents, salinity)
- No Delta, and not robust in Suisun
- No temperature

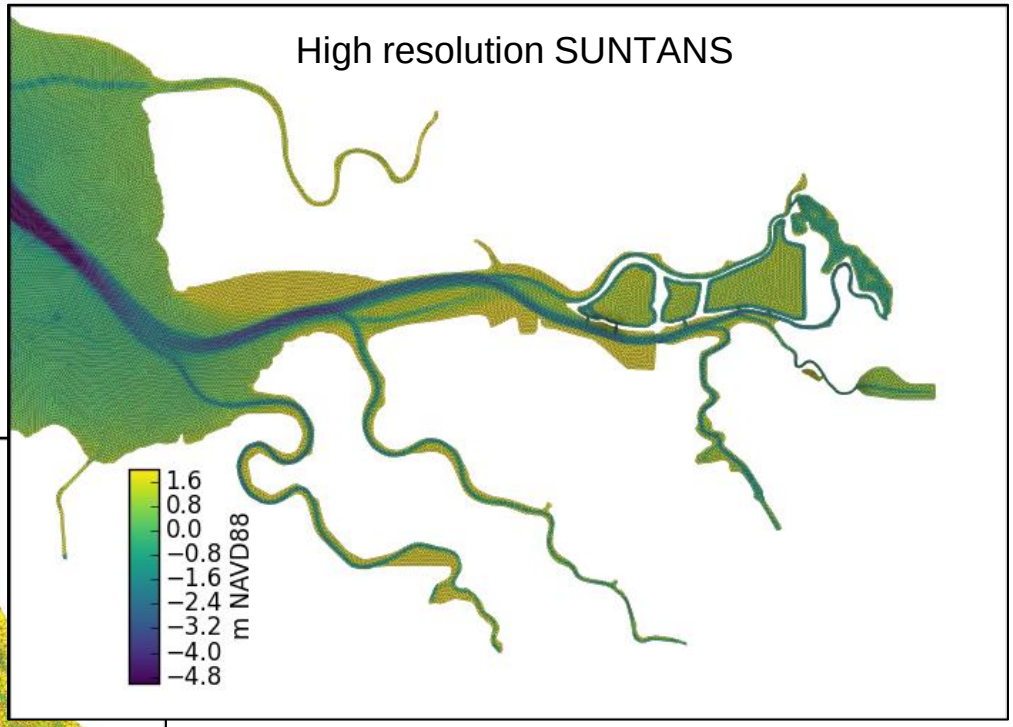


LSB Slough and Ponds Models

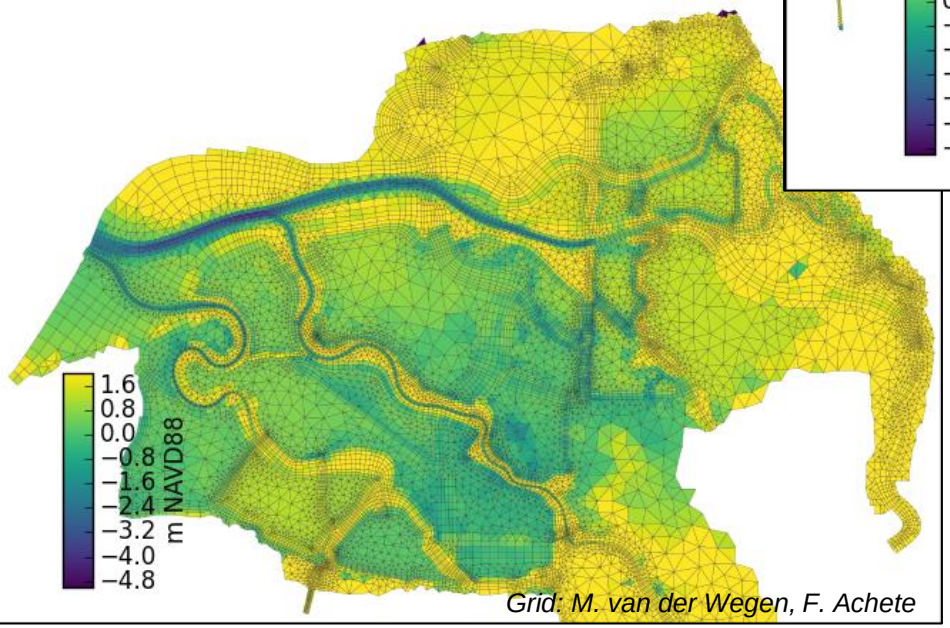
Future plans include investigating the role of sloughs and salt ponds.

Potential models include high resolution SUNTANS and a Delft model designed for an Alviso sediment/Hg transport

High resolution SUNTANS



Alviso-focused Delft (USGS/Deltares)



Grid: M. van der Wegen, F. Achete

Both partially calibrated in Lower South Bay and sloughs

Limited validation of pond exchange

Too slow for present exploratory work

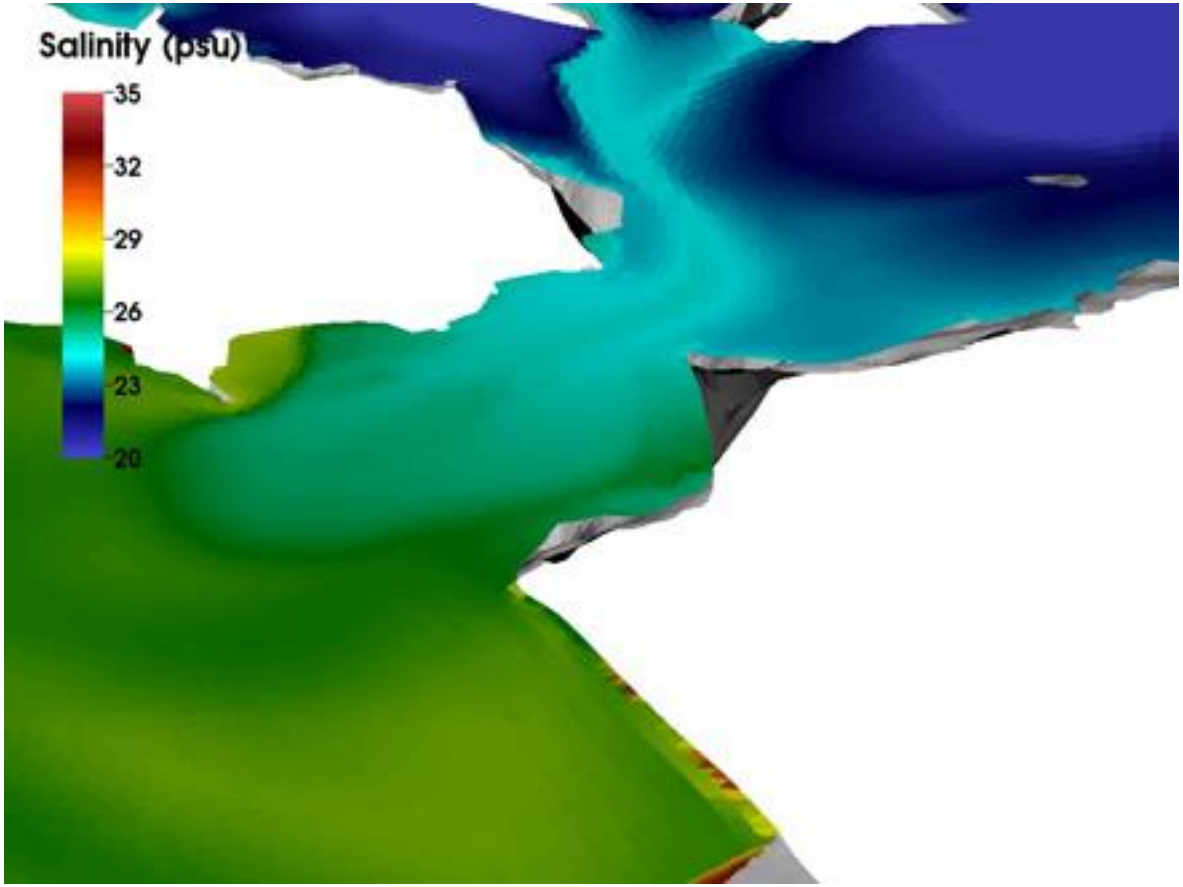
Example: Wet Weather Sampling

Aid in interpretation of wet weather sampling data

High-resolution SUNTANS

Surface and vertical slice through Golden Gate

High-flow conditions (3000 m^3/s)



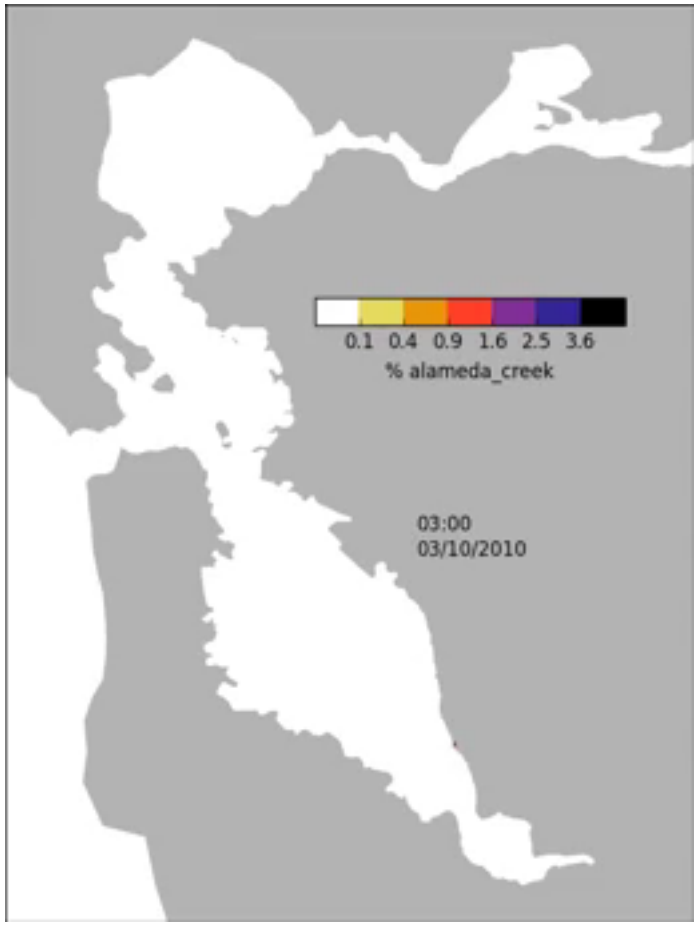
Applications Beyond Nutrients

Flexible framework for broad range of applications:

- Passive tracer studies
- Support of field efforts
- Sea level rise
- Contaminants with decay, sorption, reaction

DelWaq functionality:

- Add new processes – reaction, settling, layering in the bed
- Particle tracking – model sediment, larvae, particulates, surfactant, oil, …
- Sediment modeling including bed model



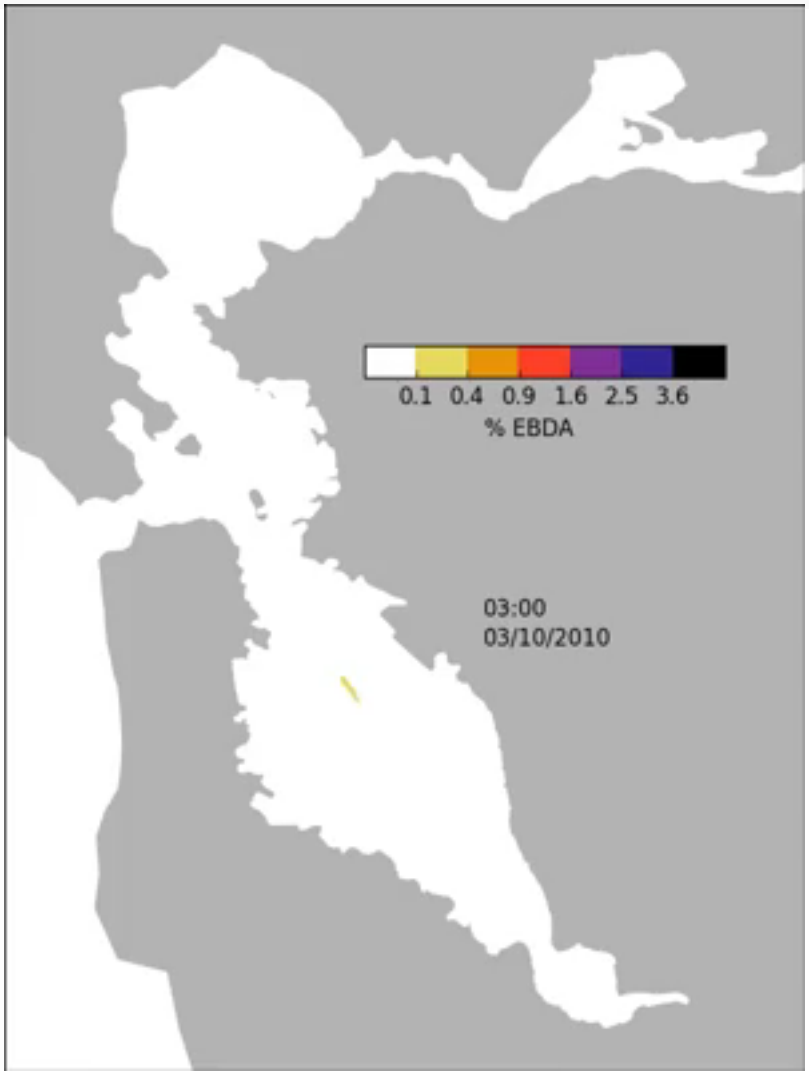
Tracer Study Preview

Depth-averaged EBDA Fraction

Discharge is active in hydrodynamics

In DelWaq: tracers “attached” to discharge:
- NO3
- NH4
- EBDA-specific tracer

Caveats:
- near-field outfall representation
- updates coming for flow and load

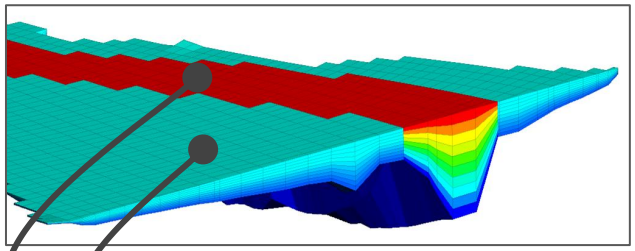


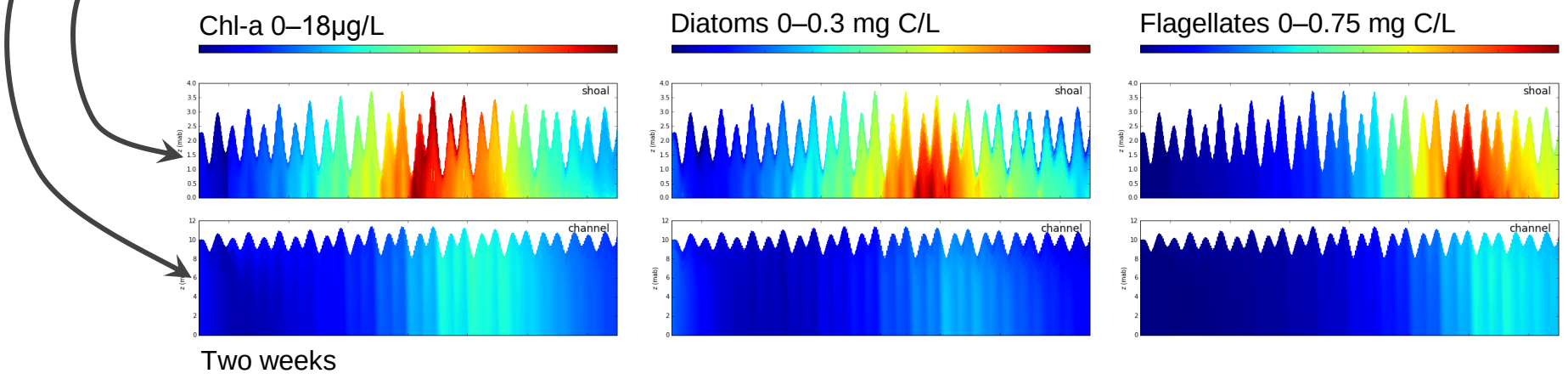
DelWaq with Aggregated/Filtered Hydro

Non-physical flushing in two-box model ➔ tidal filtering at boundary

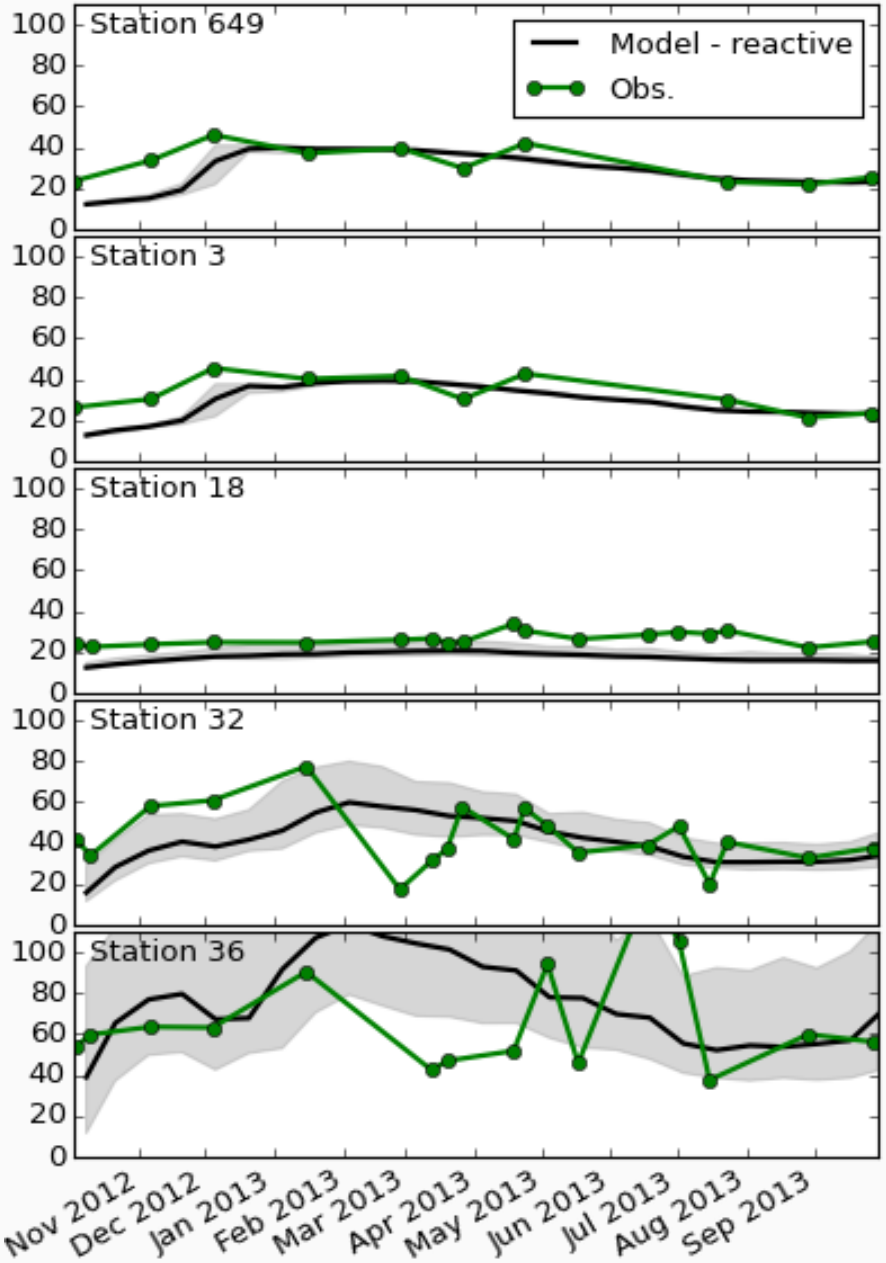
Utilized in proof of concept phytoplankton model: N, P, Si, nutrient limitation, multiple phytoplankton species

Can form blooms in shoals, disperse into channel





Add'l DIN Comparison



Conclusions - Coupling

Coupled biogeochemical modeling in the Bay for nutrient studies

Multiple hydrodynamic models, one-way coupling to water quality model

Proof of concept bringing in SUNTANS hydro, could be applied to others

Offline coupling:
- large intermediate files
- more flexible for re-use
- separation of concerns
- faster for small problems, short runs (no hydro spinup)

Looking into ways of sharing model inputs, outputs, configuration.

Conclusions - Nutrients

Without calibration, reasonable fidelity of spatial distribution of N

Seasonal pattern likely improved by adding evaporation

Lack of phytoplankton not a problem (except when it is?)

To-do list is long:
- evaporation
- phytoplankton
- resolved Delta

Conclusions – Modeling SF Bay

Many modeling efforts in the SF Bay/Delta system

Opportunities for re-use of inputs, outputs, configurations

Looking for ways to increase data & knowledge sharing

-