Diagnostic Modeling for the 2022 South San Francisco Bay HAB Event

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Outline

- The HAB event
- Overall modeling strategy
- Steps toward diagnostic modeling

August 2022 HAB Event

- Started early August
  - First noticed around Alameda
- *Heterosigma akashiwo*
  - Causes red tide, fish kills
  - Cyst-forming
  - Mixotrophic
  - Flagellate, capable of ~10 m/day vertical migration
  - Can grow in salinity 16–36 (Kudela)
  - Nominal growth rate ~0.3 day^{-1} (Kudela)

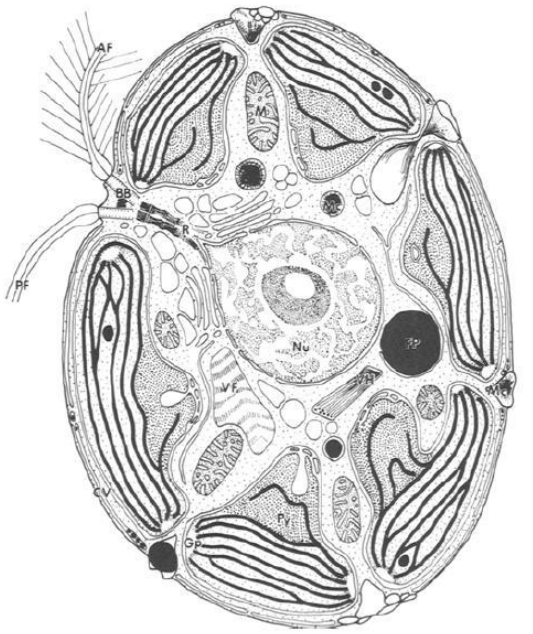


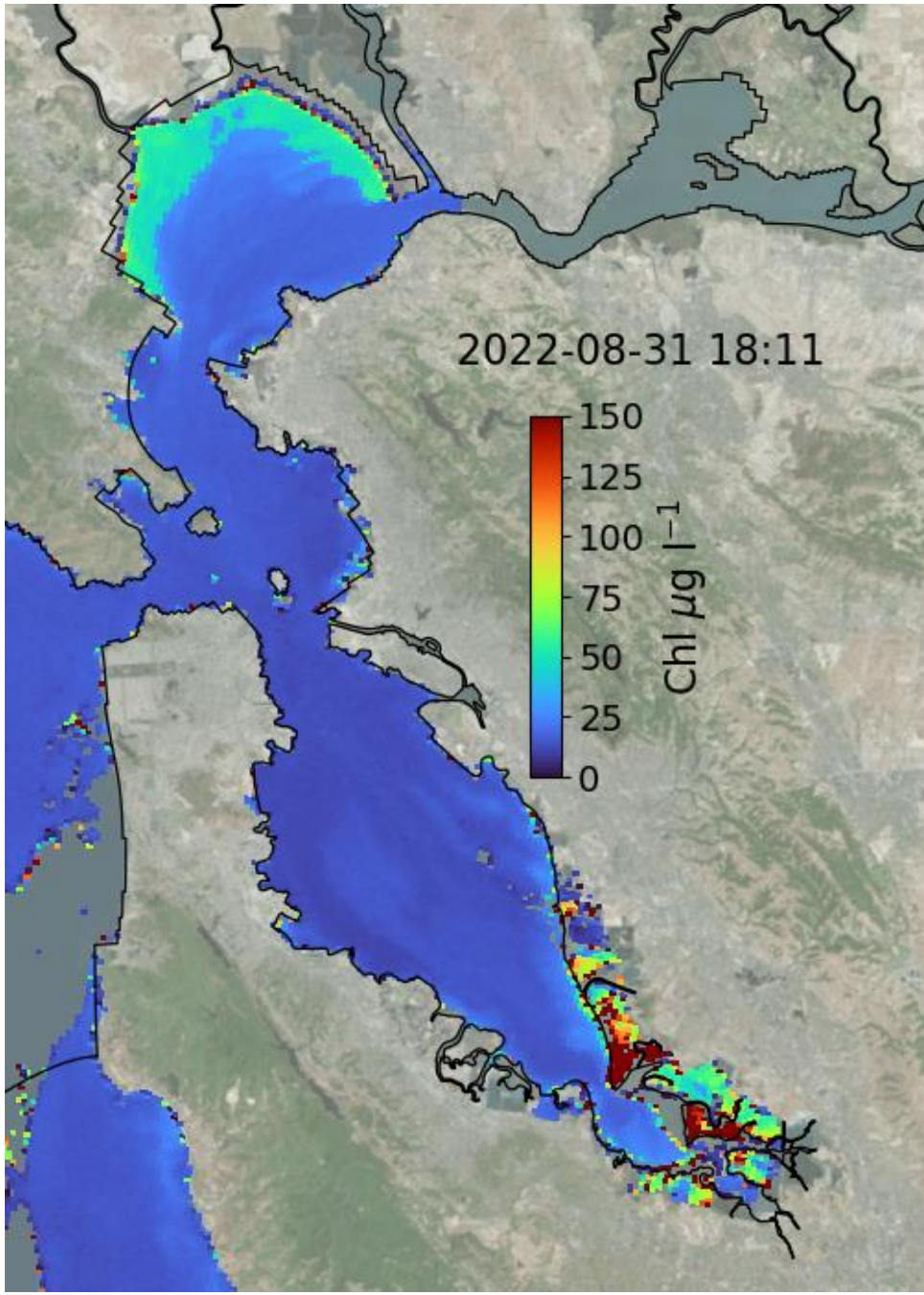
Fig. 21. *Heterosigma akashiwo*. Diagrammatic illustration of a motile cell, drawn on the basis of the strain BGN 666. AF, anterior flagellum; CV, compressed vesicle; PF, posterior flagellum; R, rhizoplast; FP, fatty particle; VF, vesicles with fine fibers; VH, vesicles with hollow fibers.

wikipedia

Remote-sensed Scenes

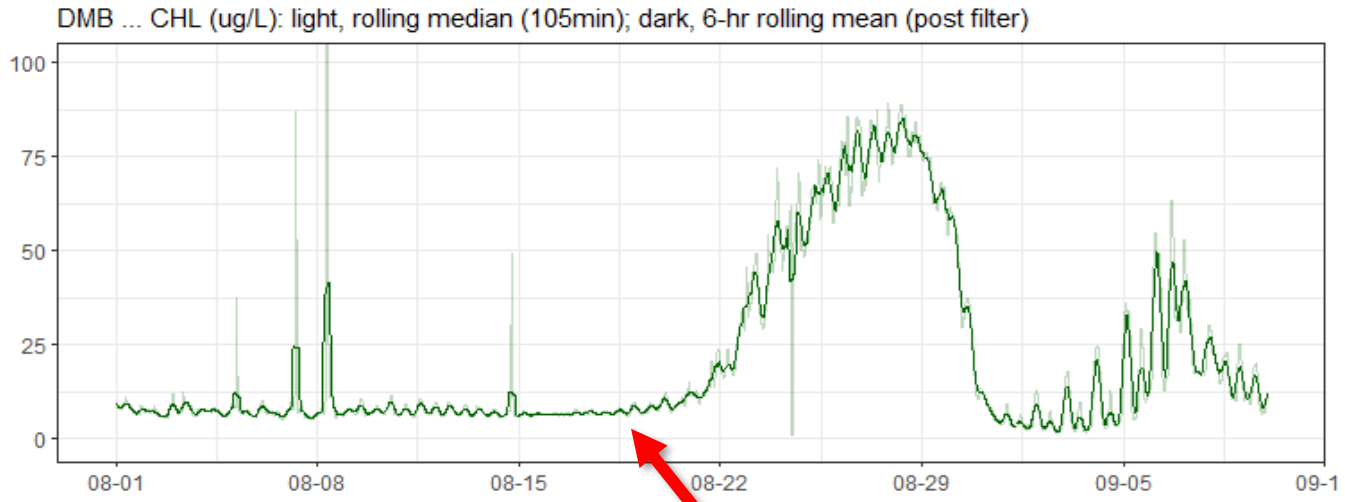
Data from Sentinel 3

Processed by Lawrence Sim at SFEI with Google Earth Engine

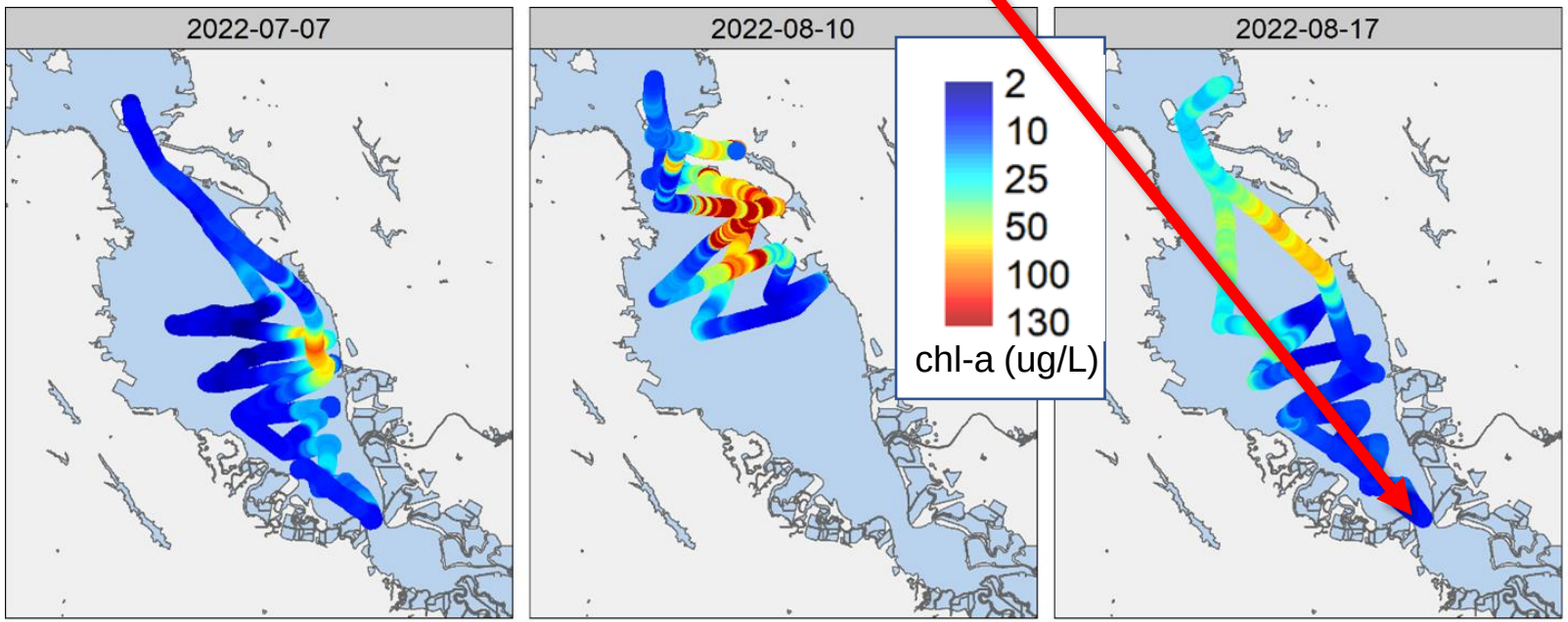


Other Data Sources

- Monitoring stations (USGS, SFEI)



- High-speed mapping (USGS)



Many questions about the event

- Why did it happen when it did?
- What aspects of the organism enabled the event?
- What long-term management options might prevent or mitigate impacts?
- What's the likelihood of something similar occurring again in 1–2 years?
- Possible to stave-off or mitigate impacts of an event in the next 1–2 years?

- Questions would benefit from a mechanistic understanding of the bloom
- Predictive mechanistic models for HABs are challenging.
  - Don't put all our eggs in this basket
  - Large parameter space to explore and constrain.
  - Hard to explore with a full-scale model

Two-Pronged Modeling Strategy

Mechanistic Modeling

- Hydrodynamic model
- Biogeochemical (BGC) model
- Predictive [eventually]
- Precise but slow

Diagnostic Modeling

- Hydrodynamic model
- Tracers
  - Conservative, age, exposure, etc.
- Isolate parts of the problem
  - Test hypotheses
  - Identify necessary ingredients for predictive model
- Infer processes or rates rather than prescribe

Questions to Address with Tracer Model

Iterative process of questions, hypotheses and analyses

Focus on a subset

1. Bloom starts near Central Bay but has minimal spread to the north
   Explained by hydrodynamics?

   Passive tracer simulation

2. Bloom fills South Bay
   Seeded solely from Alameda?

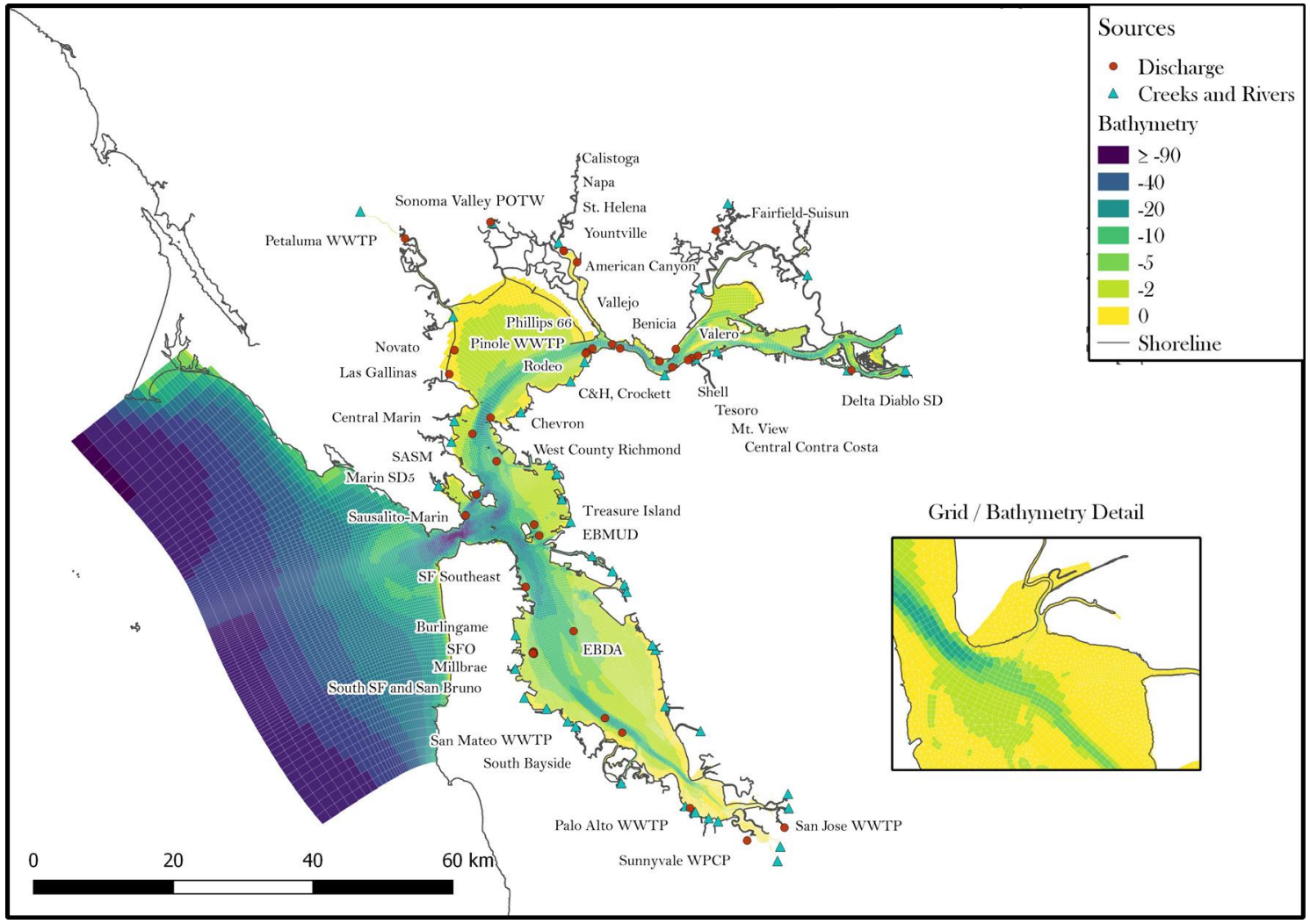
   Passive tracer with exponential growth

3. Moderate-slow-fast growth
   Depth, turbidity, light limitation?

   Maps of growth potential and inferred growth rate

Hydrodynamics

- SFEI's Full Bay model
- 3D Delft Flexible Mesh (DFM)
- River, stormwater, POTW inputs
- Tides, evaporation, wind
- Calibrated for
  - Stage
  - depth-averaged velocity
  - longitudinal salinity
  - salinity stratification
- Configuration, calibration documented in SFEI reports

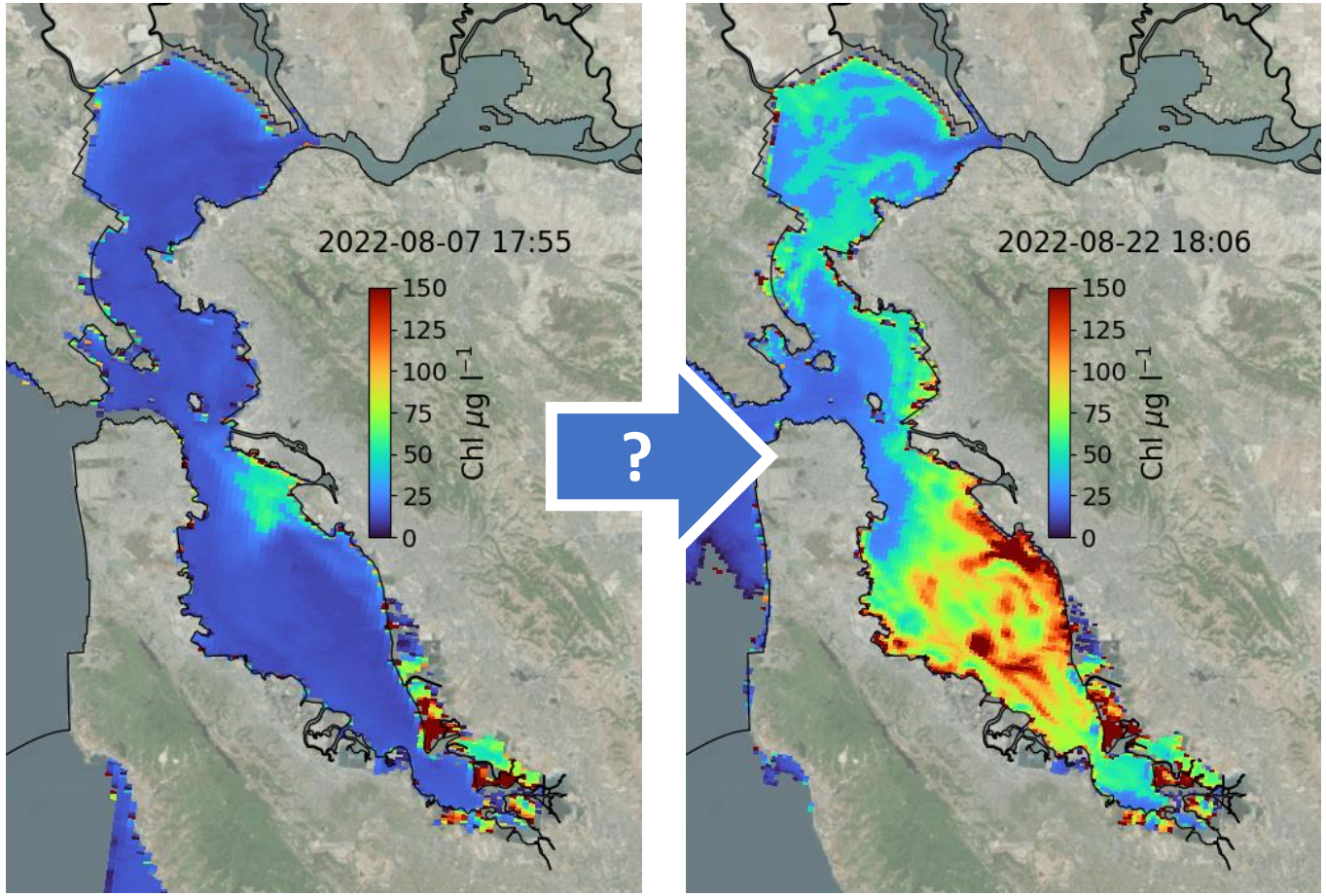


Can hydrodynamics explain bloom migration?

Elevated chlorophyll starts around Alameda

Minimal seaward expansion

Extensive landward expansion

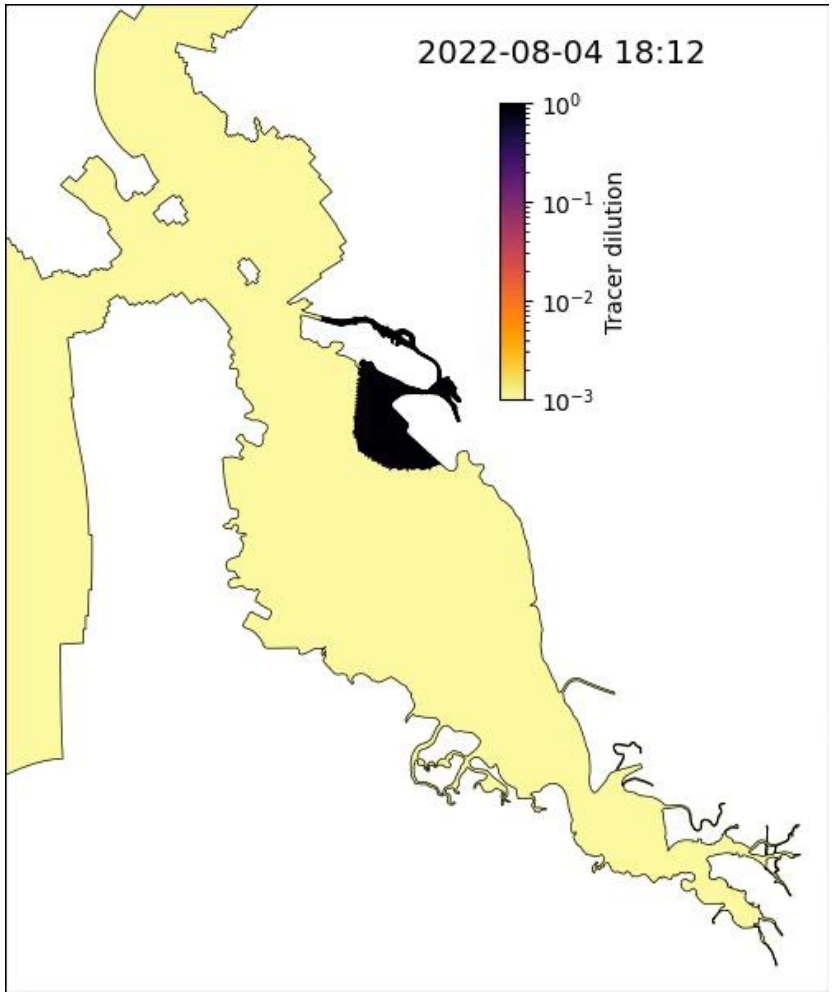


Passive and Buoyant Tracers

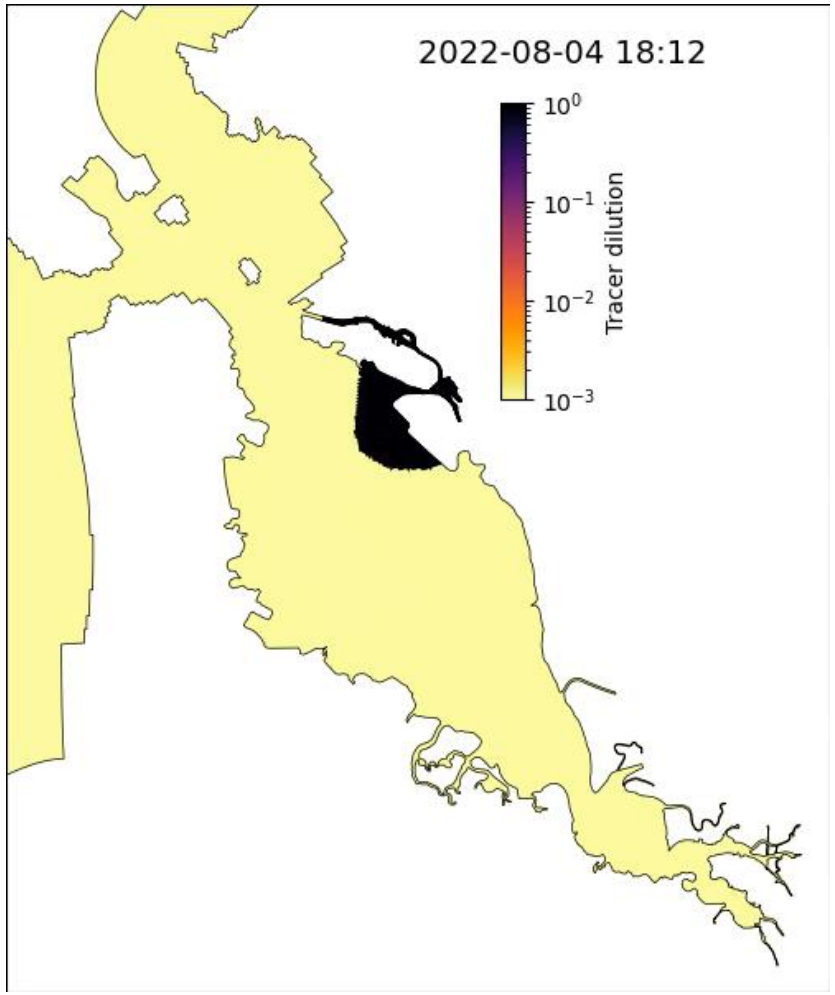
Seaward transport is present

Flushing is slow but still need some mechanism to limit growth in Central Bay.

Seaward transport stronger with buoyant tracer.



Passive



15 m/d upward

Seeded solely from Alameda?

Exponential growth, 0.25 d^{-1}

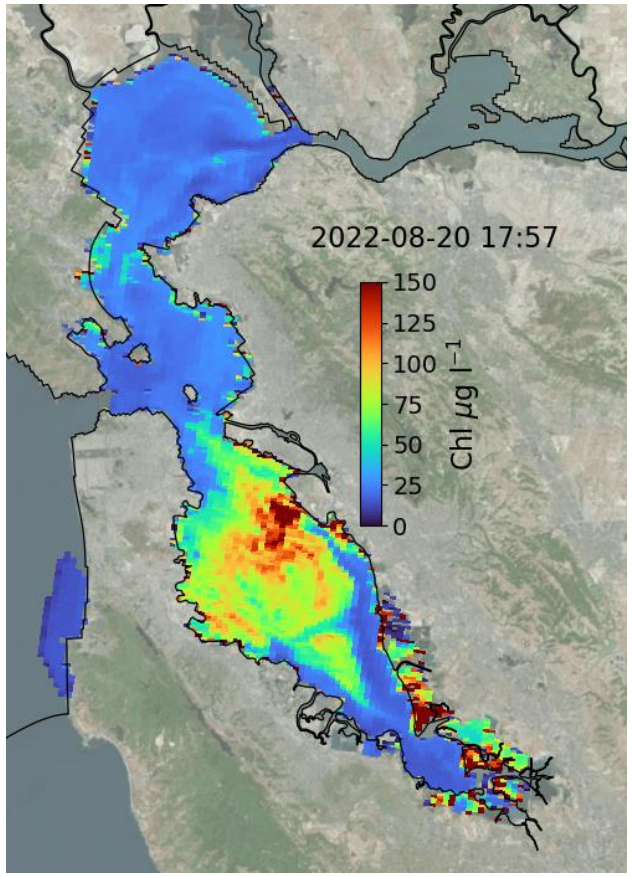
Transport from Alameda can reach a majority of the bloom but not all.

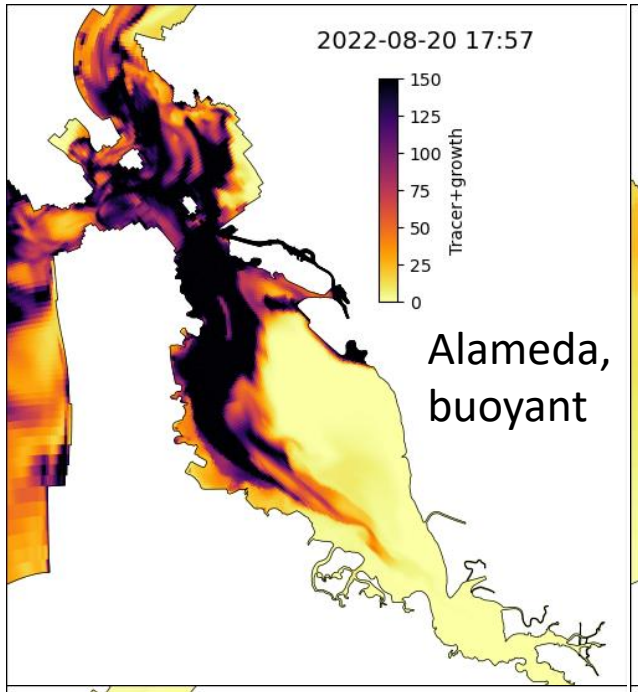
Inconclusive.

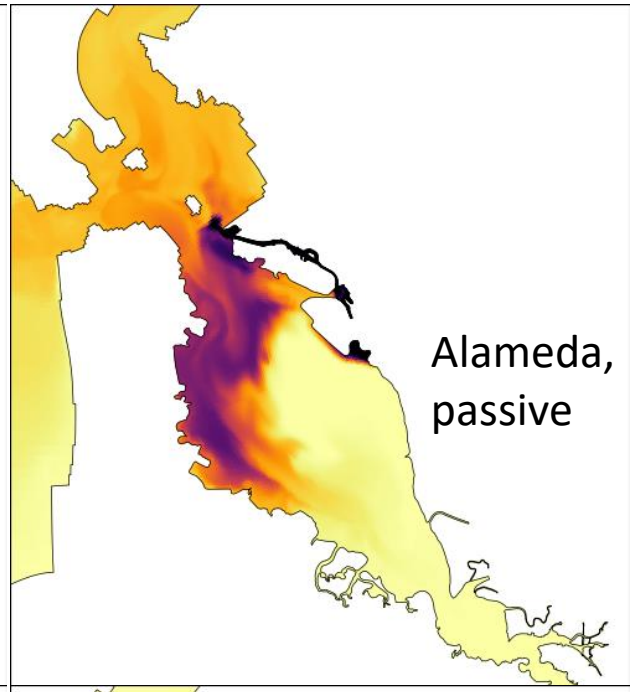
Under-diffusive model?

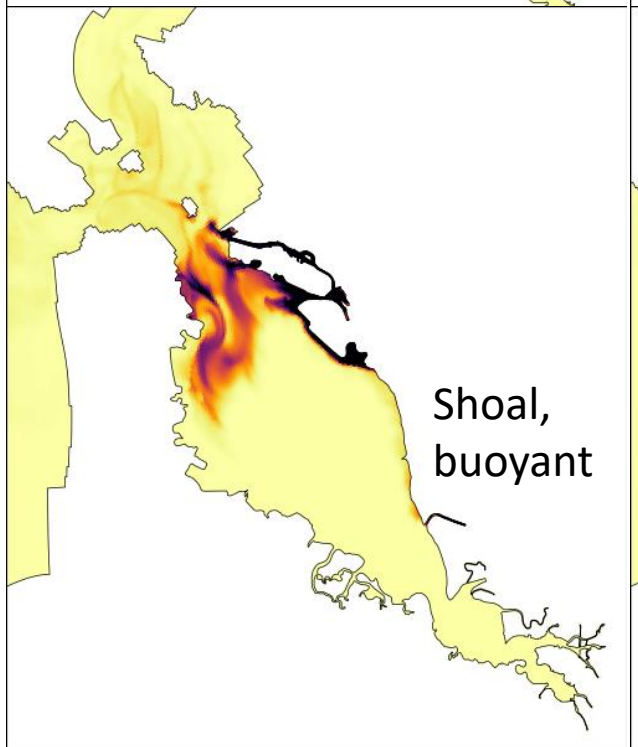
Under-represented wind-driven transport

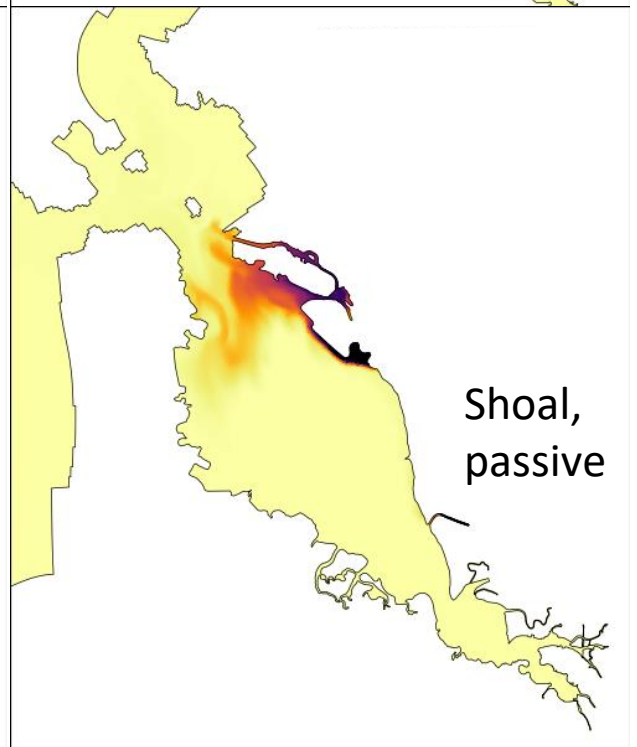
Or need distributed initial conditions.











Controls on Growth

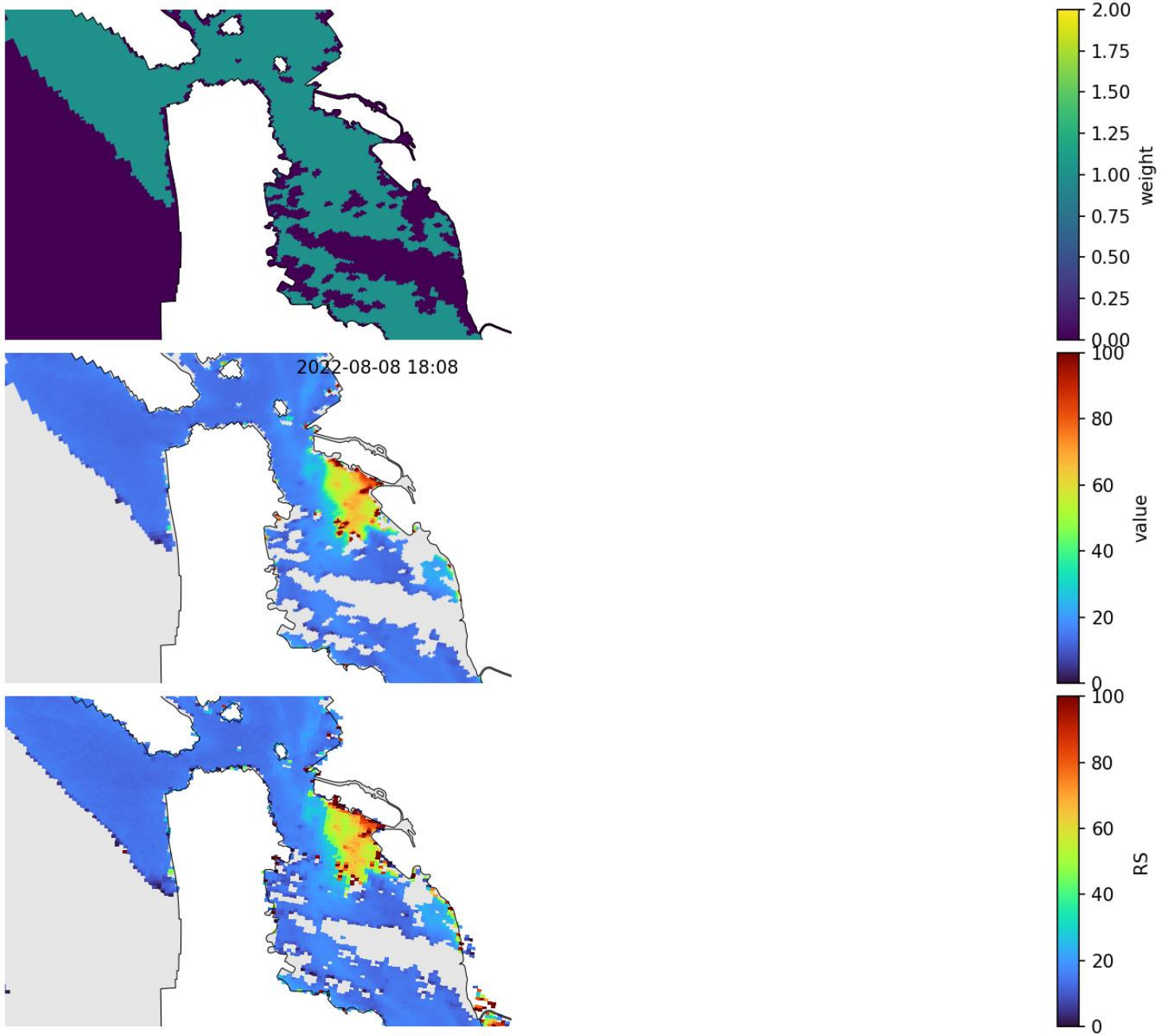
1. Estimate from Remote-sensing

Concepts based on partial age tracers.

A pair of tracers label presence/absence of data and value of data where present:

`weight`
`weight·chlorophyll`

Recover chlorophyll from ratio



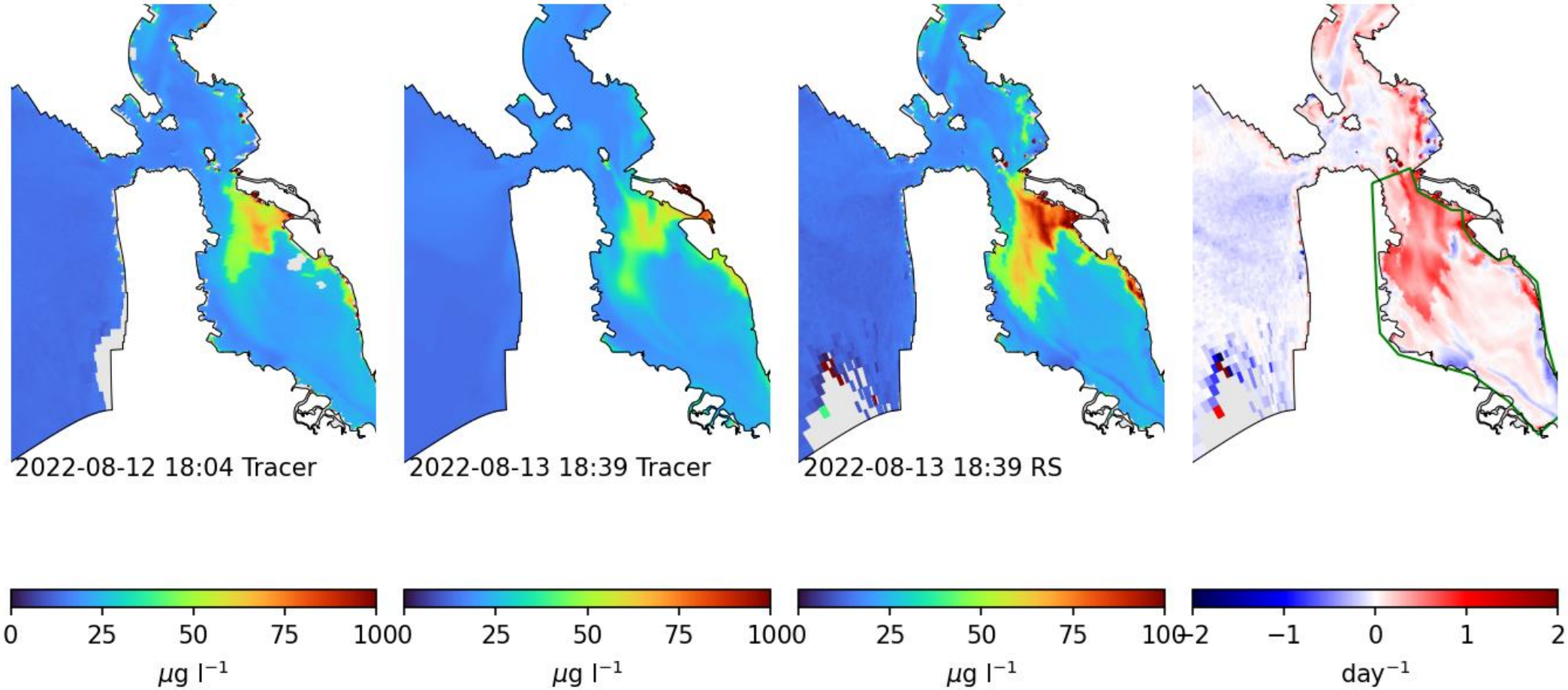
Scene-to-Scene Growth

Set tracer field from imagery, with weight=0 for missing data.

Transport until time of next image

Surface concentration from next image

Implied growth rate

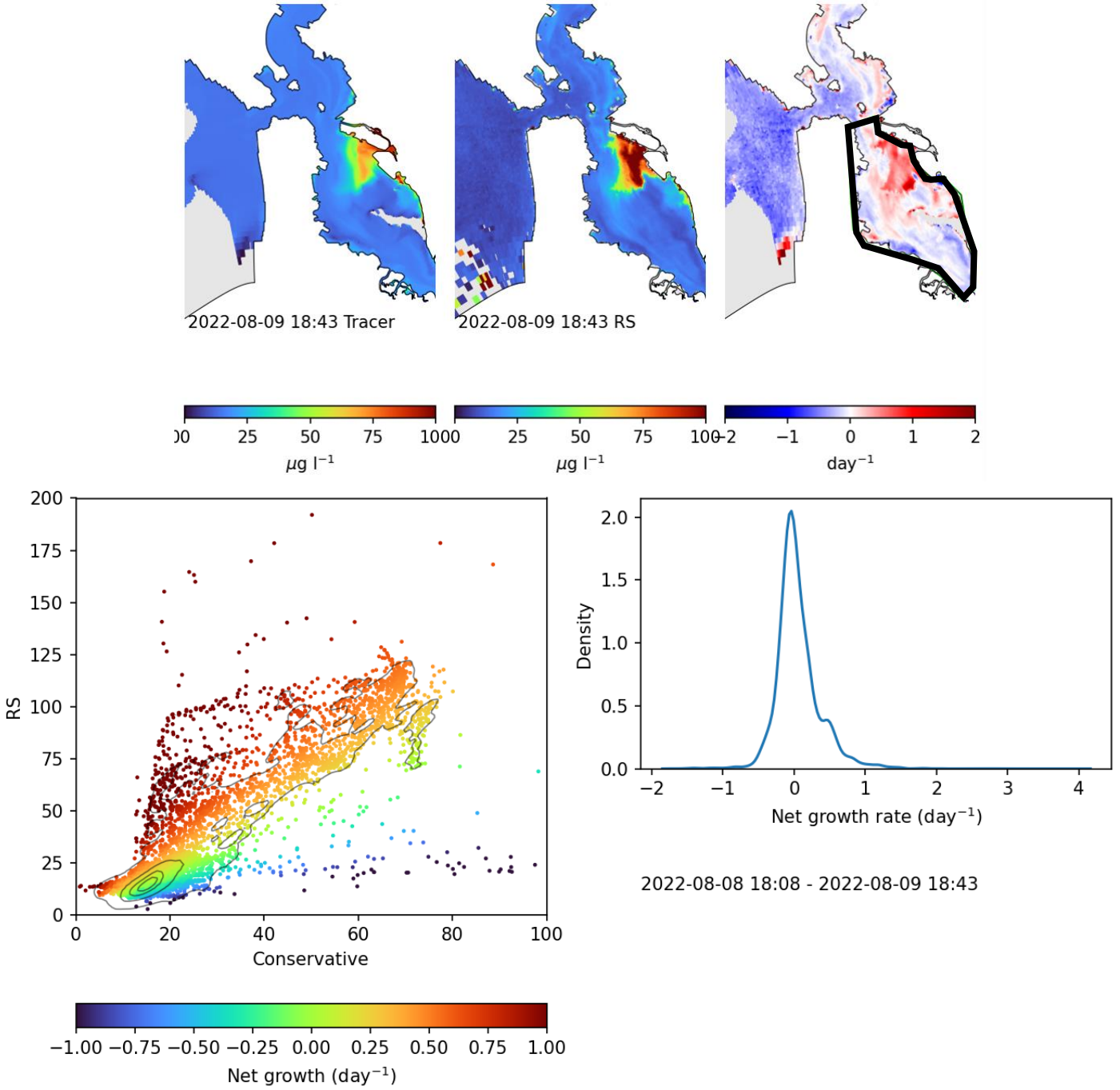


Aggregate Rates over South Bay

For each cell with valid imagery and tracer data.

Normalized by cell area.

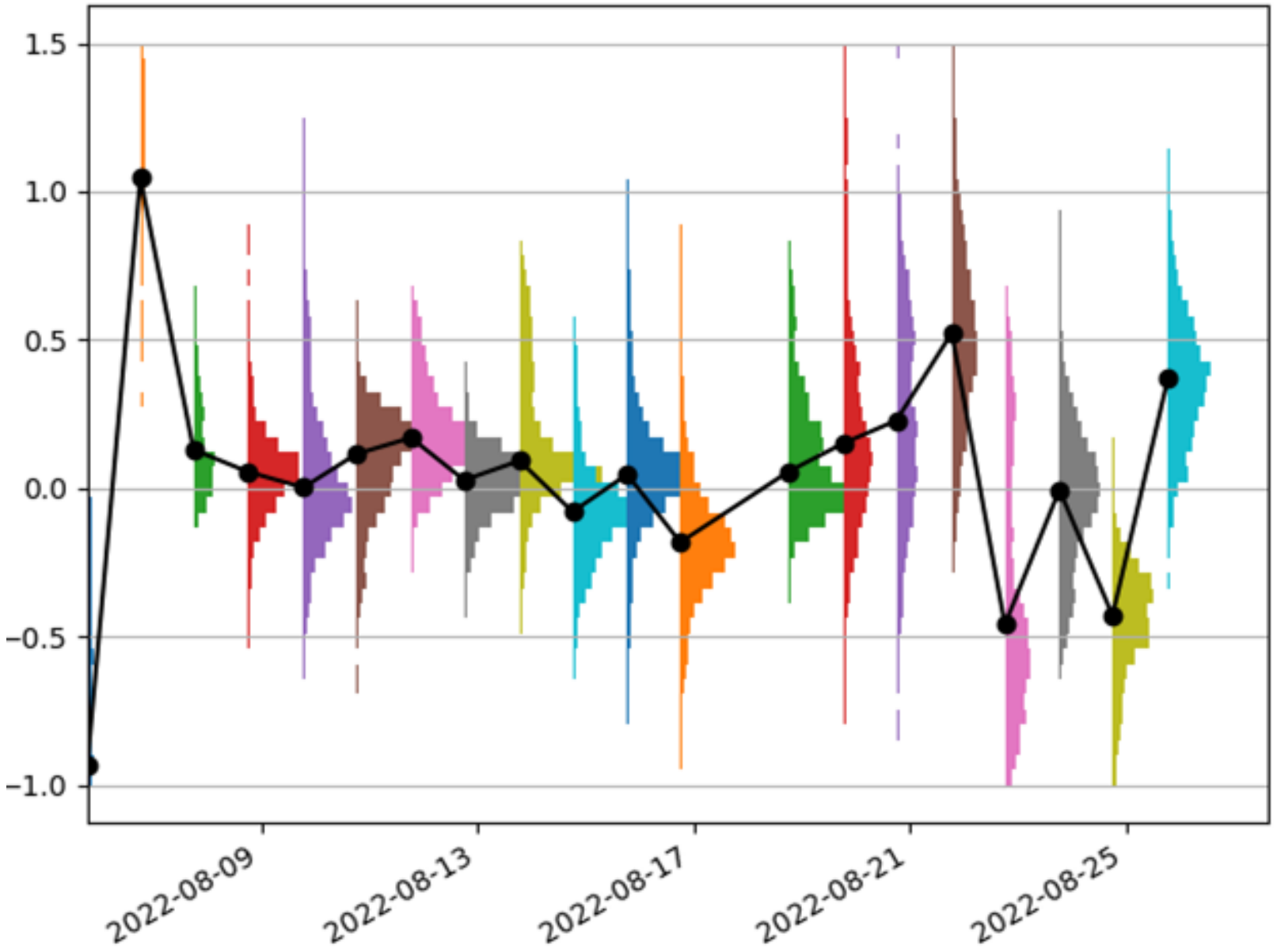
Aggregate over open areas of South Bay



RS-based Growth

Noisy

Random bias in scenes?



Controls on Growth

2. Predicting Rates

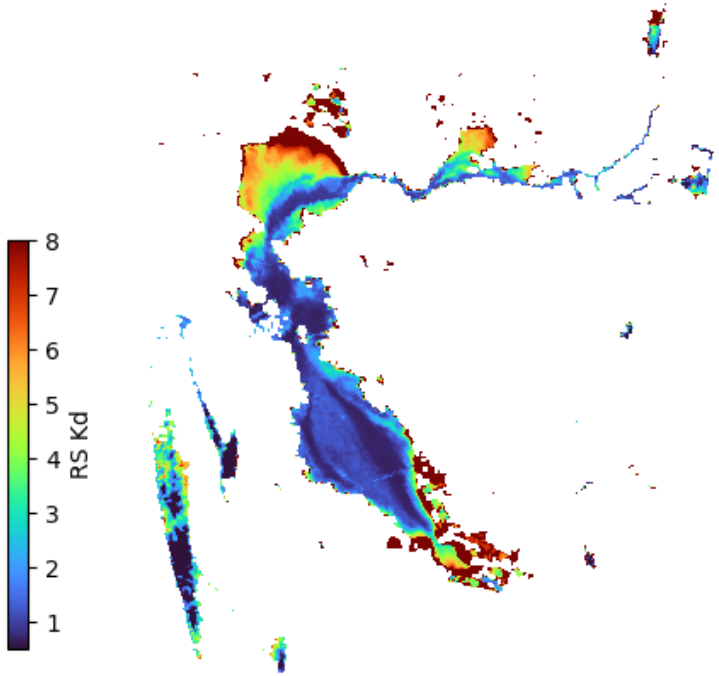
- Light
  - Vertical mixing
  - Turbidity
  - Vertical migration
- Nutrients
  - Ambient DIN >30 µmol/l
- Grazing
- Viruses(!)

- Estimate space- and time-varying growth rates

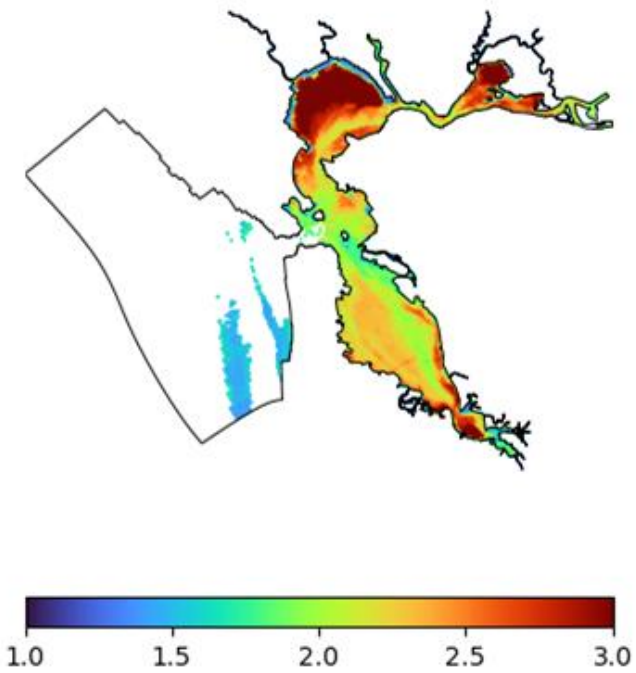
$$G(t) = G_0 \frac{1}{H\, C_{avg}} \int_0^H C(z) \frac{I_0 \exp(-K_d z)}{I_{sat} + I_0 \exp(-K_d z)} dz$$

- $G_0\ I_{sat}$ from lab measurements
- $C(z)$ from buoyant tracers
- K_D from remote-sensing

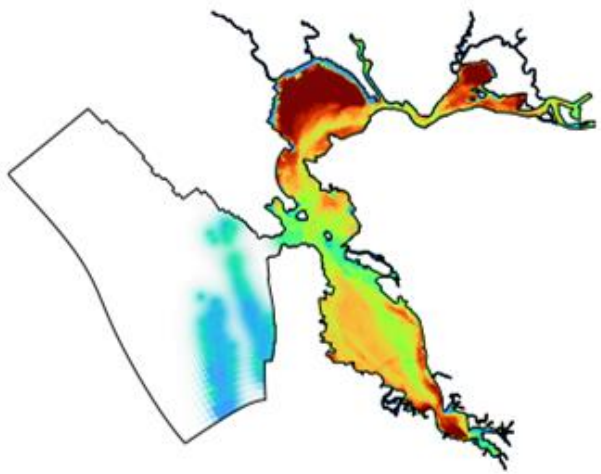
Space- and time-varying light attenuation



Original RS scene



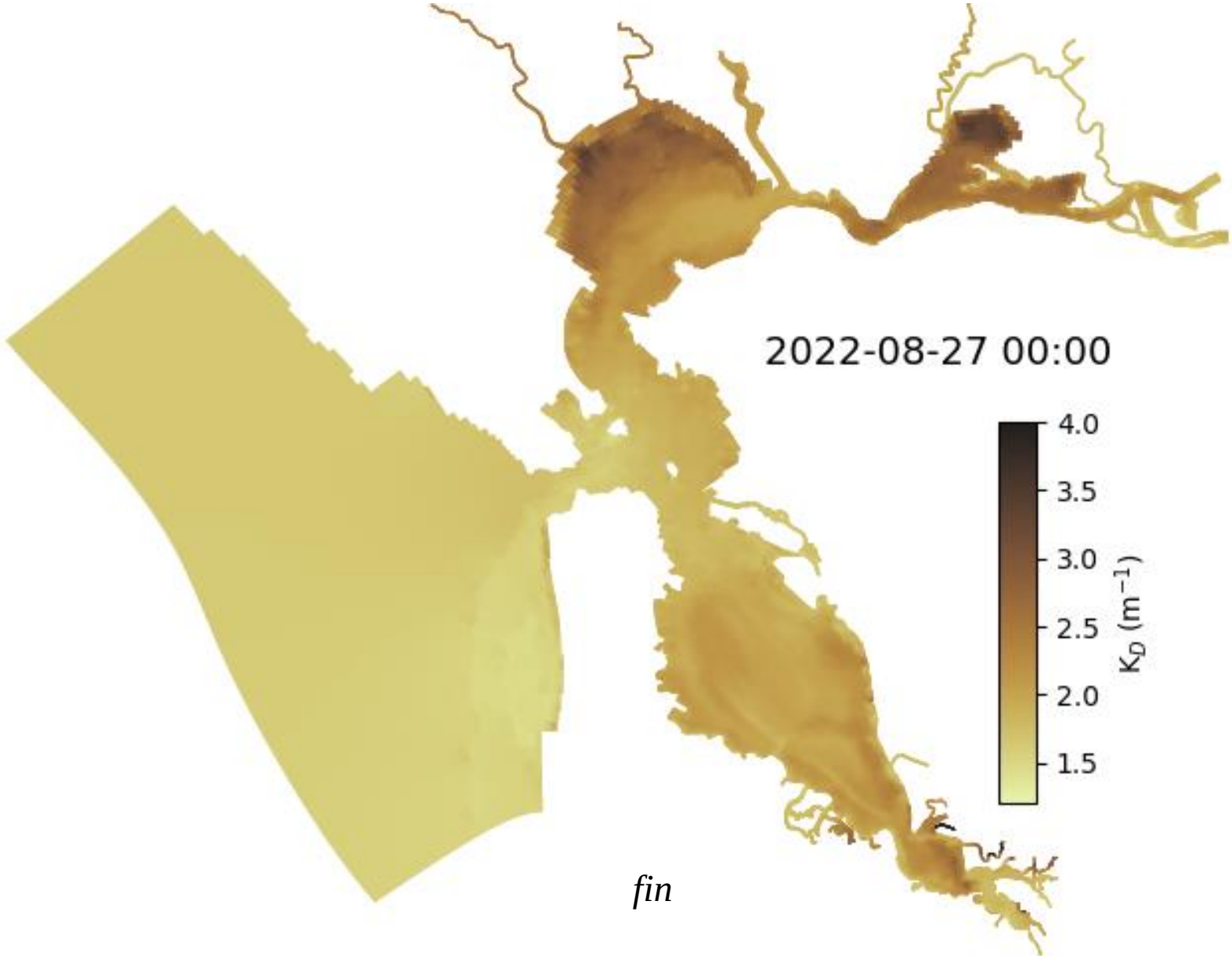
“Calibrated” and mapped to grid



Extrapolated with weights

Interpolating in time

Along the lines of inverse distance weighting, using both time offset and the weight from the extrapolation.



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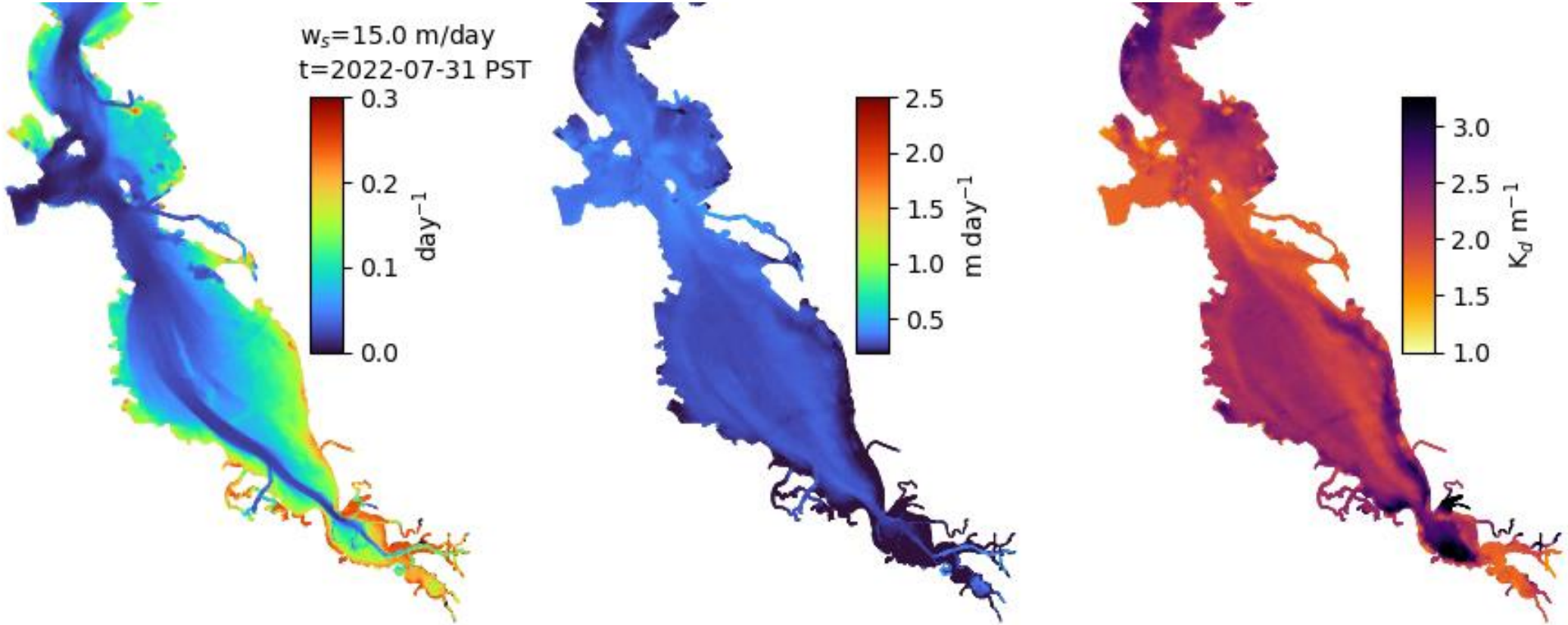
15 m/d Swimming

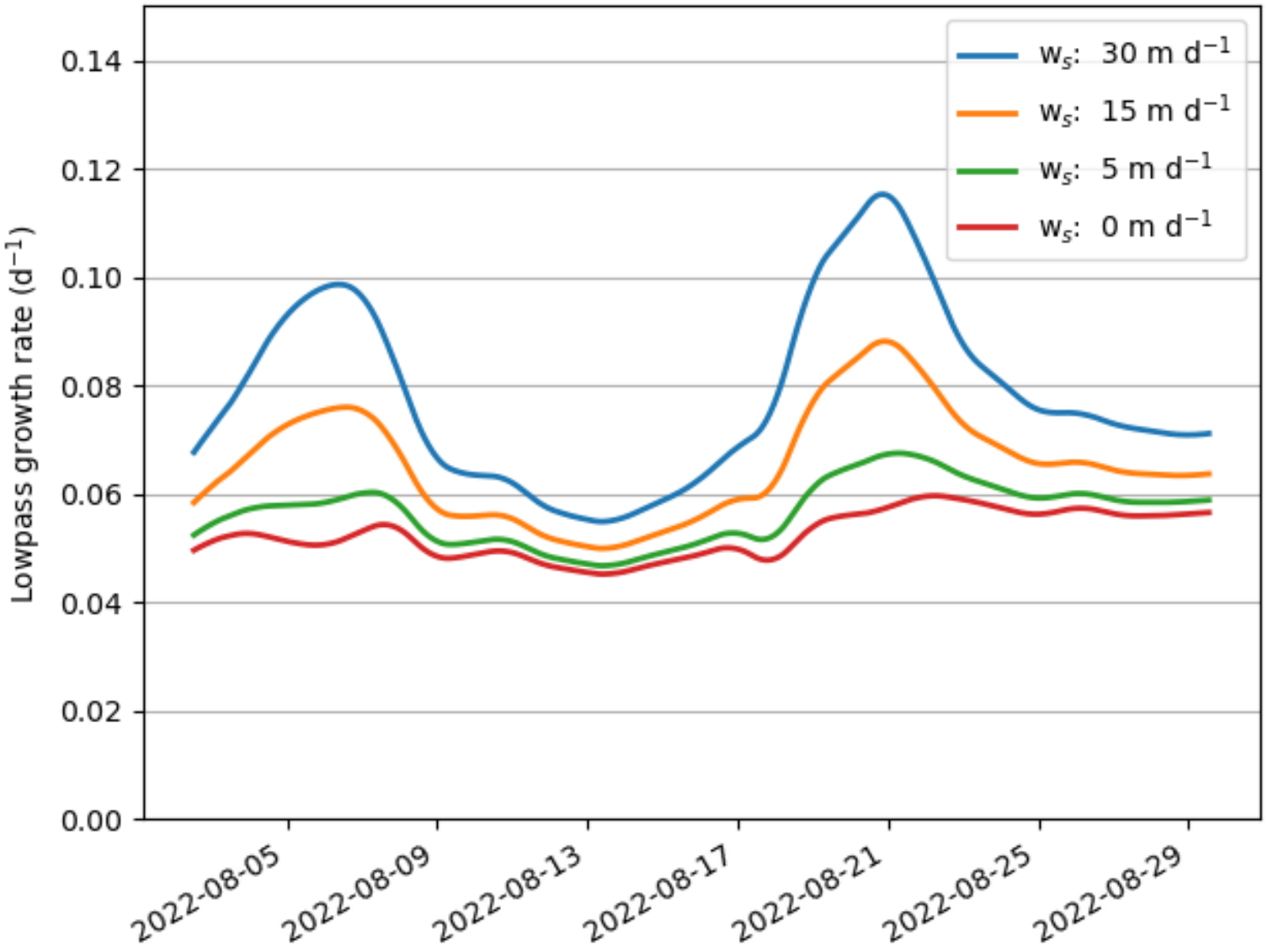


Predicted Growth Rate

- Volumetric average over South Bay
- Godin filtered (daily and tidal)
- 30 m/d not physical, but good to bracket possibilities esp. if model is mixing too much in the vertical

Growth rates are too low

Vertical migration boosts both mean and temporal variance

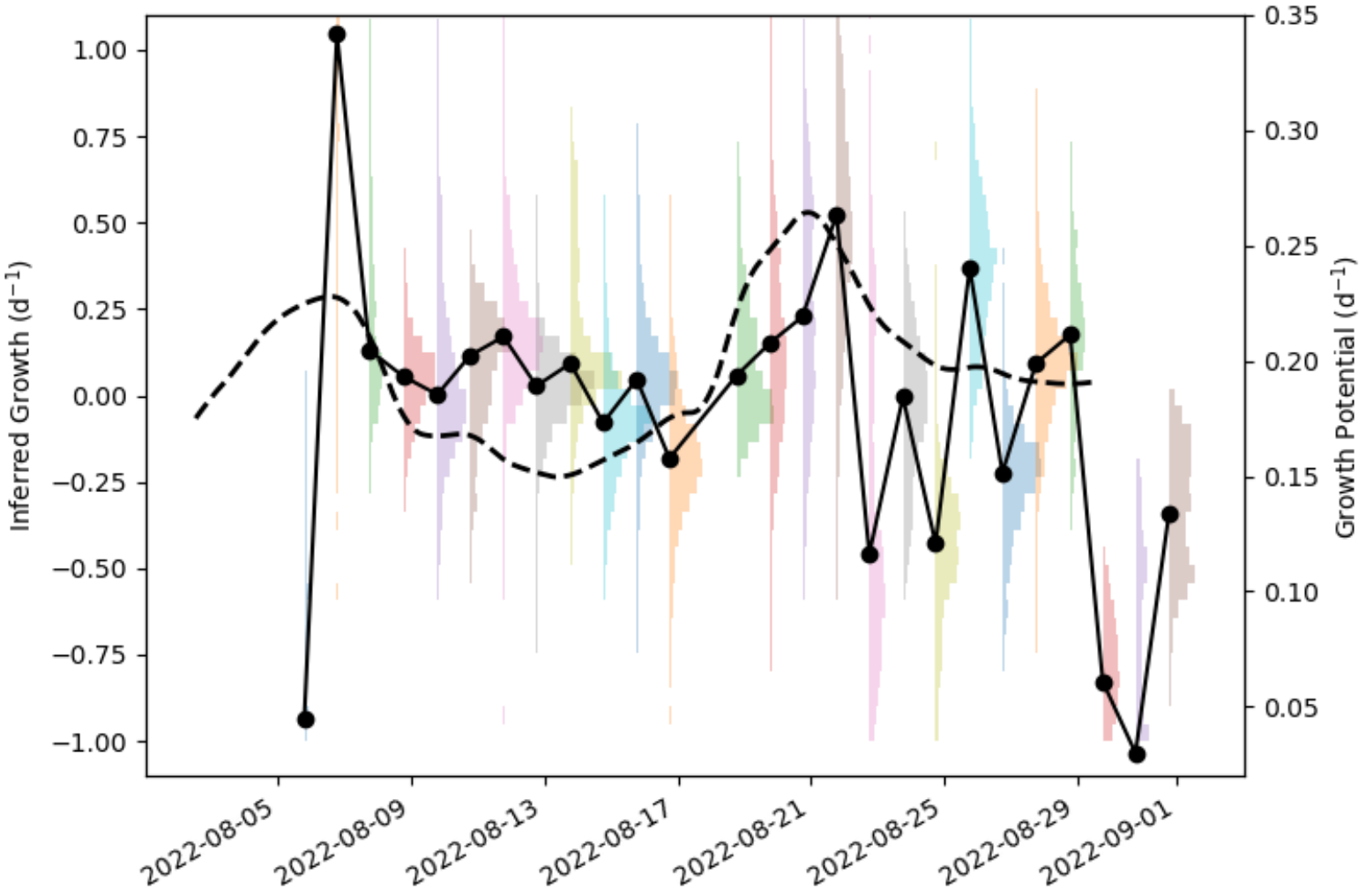


Predicted vs Inferred Growth

Scales are off, for good & bad reasons

- Predicted excludes mortality, grazing
- Uncertainty in baseline growth rates, light limitation curve

Get some of the temporal patterns, but predicted leads inferred.



Summary

Many ways to include transport in HAB studies

Ultimately want predictive models, but it’s a long road to get there.

Tracer approaches can constrain our understanding of specific water quality processes

We’re not done! But it’s promising enough to continue looking.