Extending the Validity of a One-Dimensional Coupled Bio-physical Model by Parametrization

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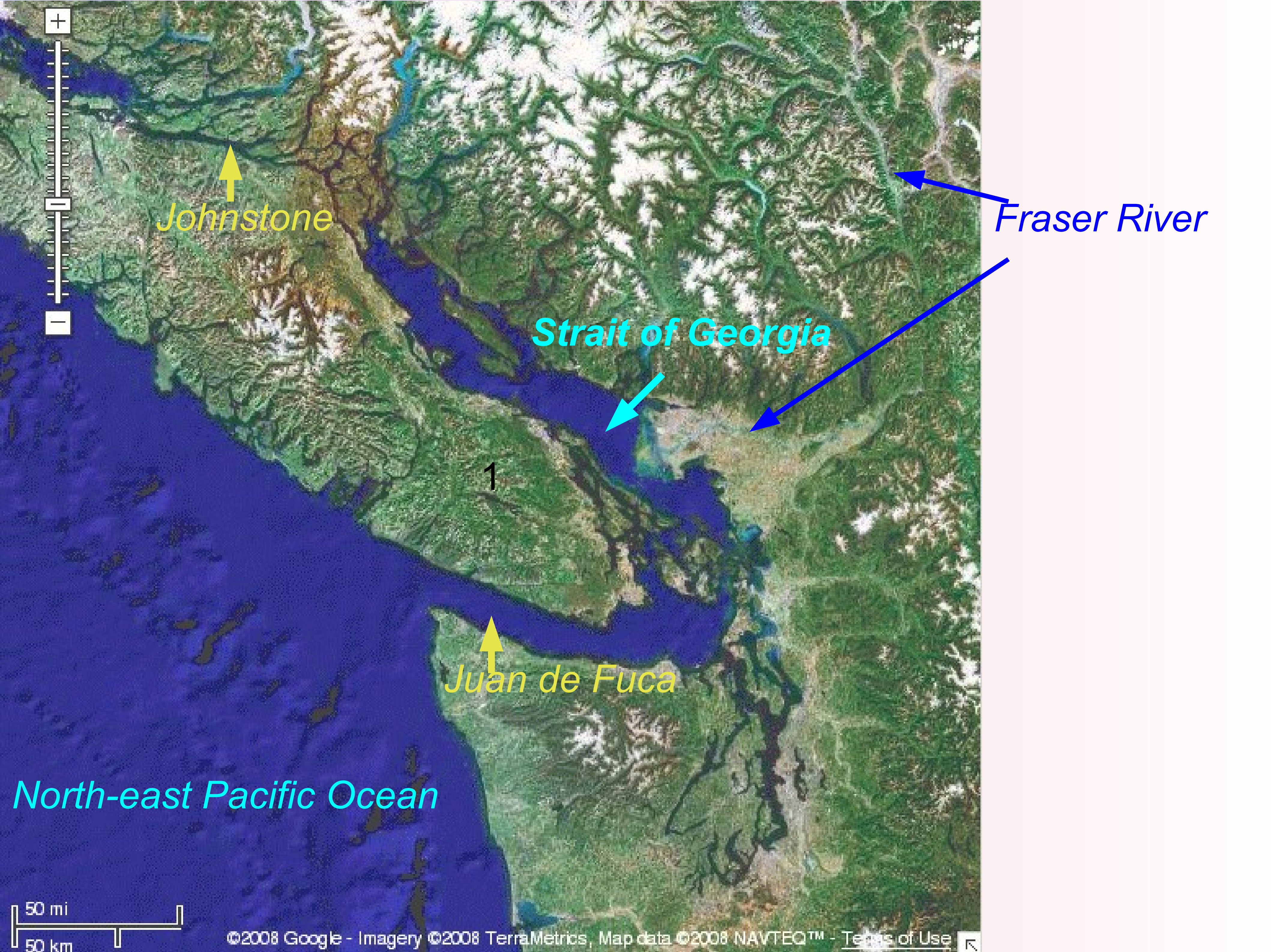
Outline

- Strait of Georgia
- Our goals
- The model
- Example parameterizations
- Conclusions



Johnstone
Fraser River
Strait of Georgia
1
Juan de Fuca
North-east Pacific Ocean
50 mi
50 km
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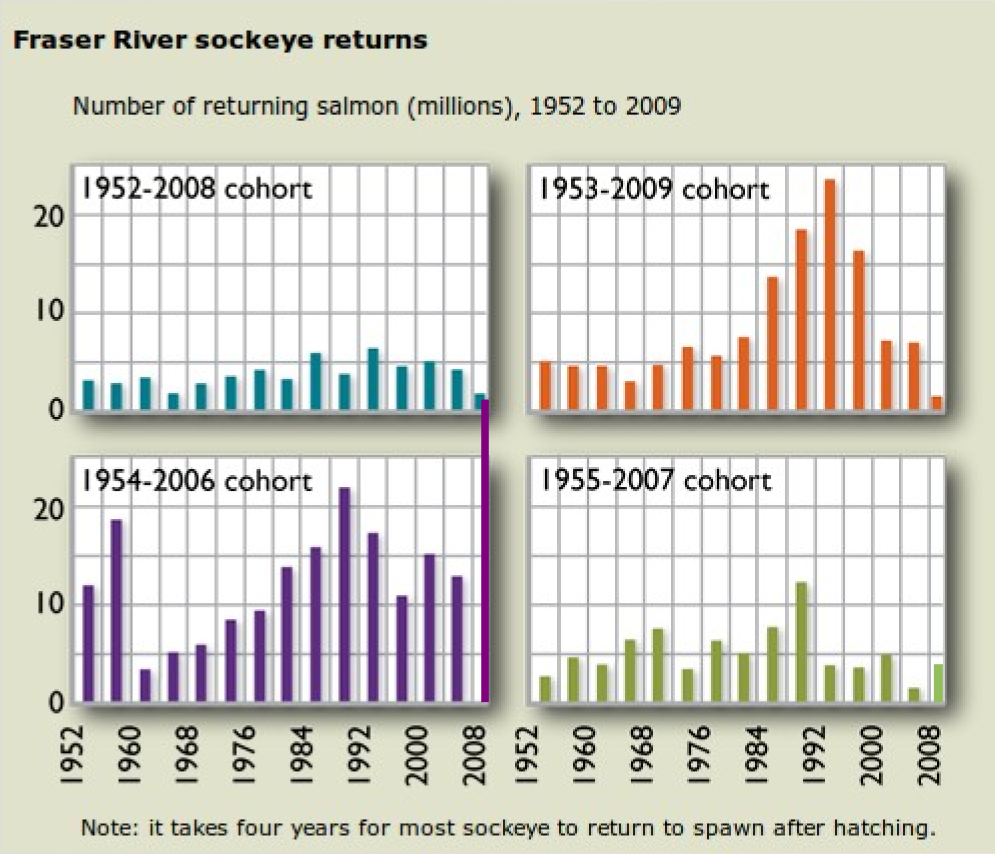
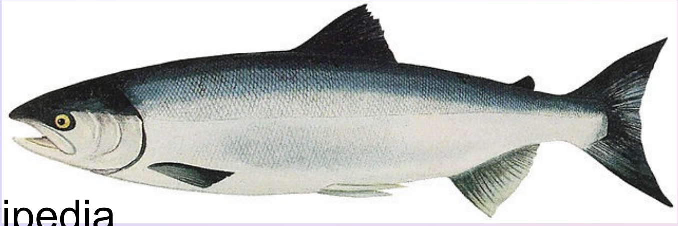
Strait of Georgia



Biodiversity Canada who adapted it from LaPointe, 2010, with 2010 and 2011 added



wikipedia

Home waters for most of the population of BC.

Important habitat for juvenile salmon.

Important aquaculture centre.

Qualicum Bay Scallops

Strait of Georgia

- 400 m deep, 120 km long, 30 km wide
- significant input of freshwater
- strongly stratified, often without a surface mixed layer
- estuarine type circulation
- biologically productive

Traffic
Map
Satellite
Hybrid
Johnstone
Northern Strait of Georgia
Fraser River
Southern Strait of Georgia
Juan de Fuca
BC
OR
50 mi
50 km
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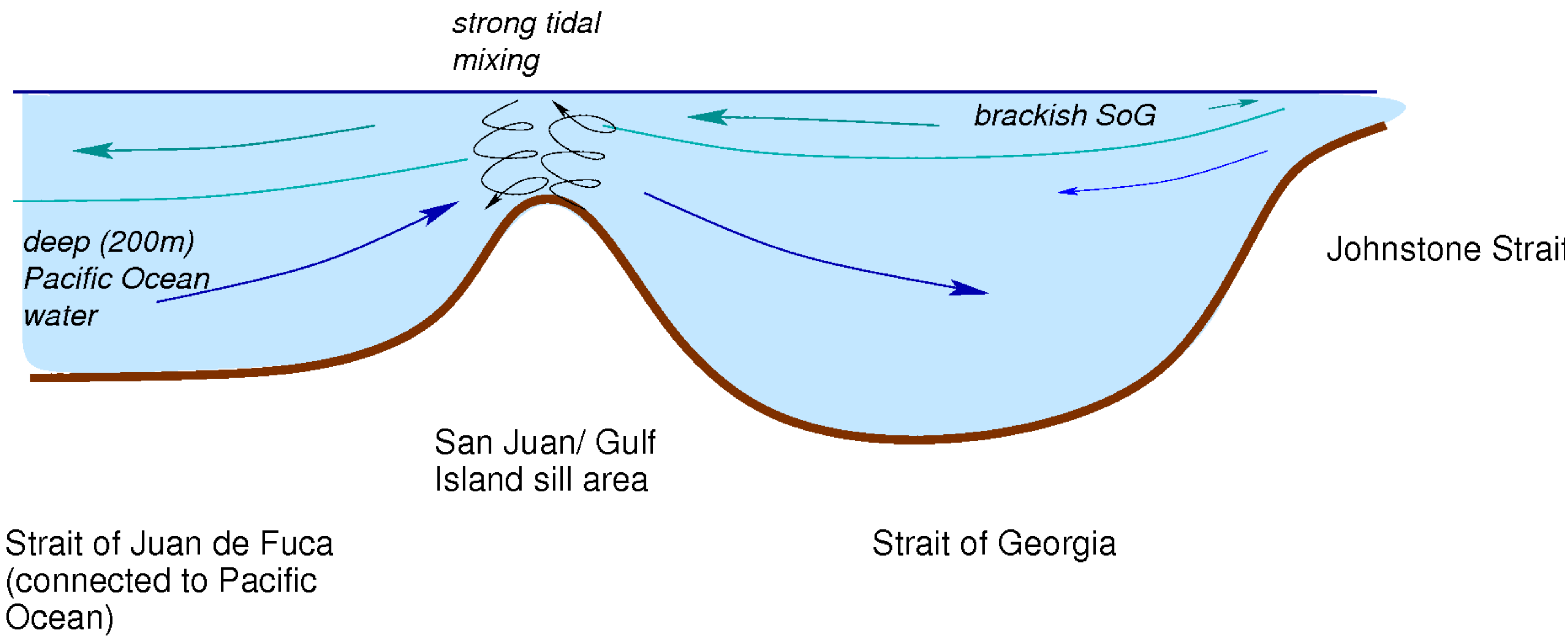
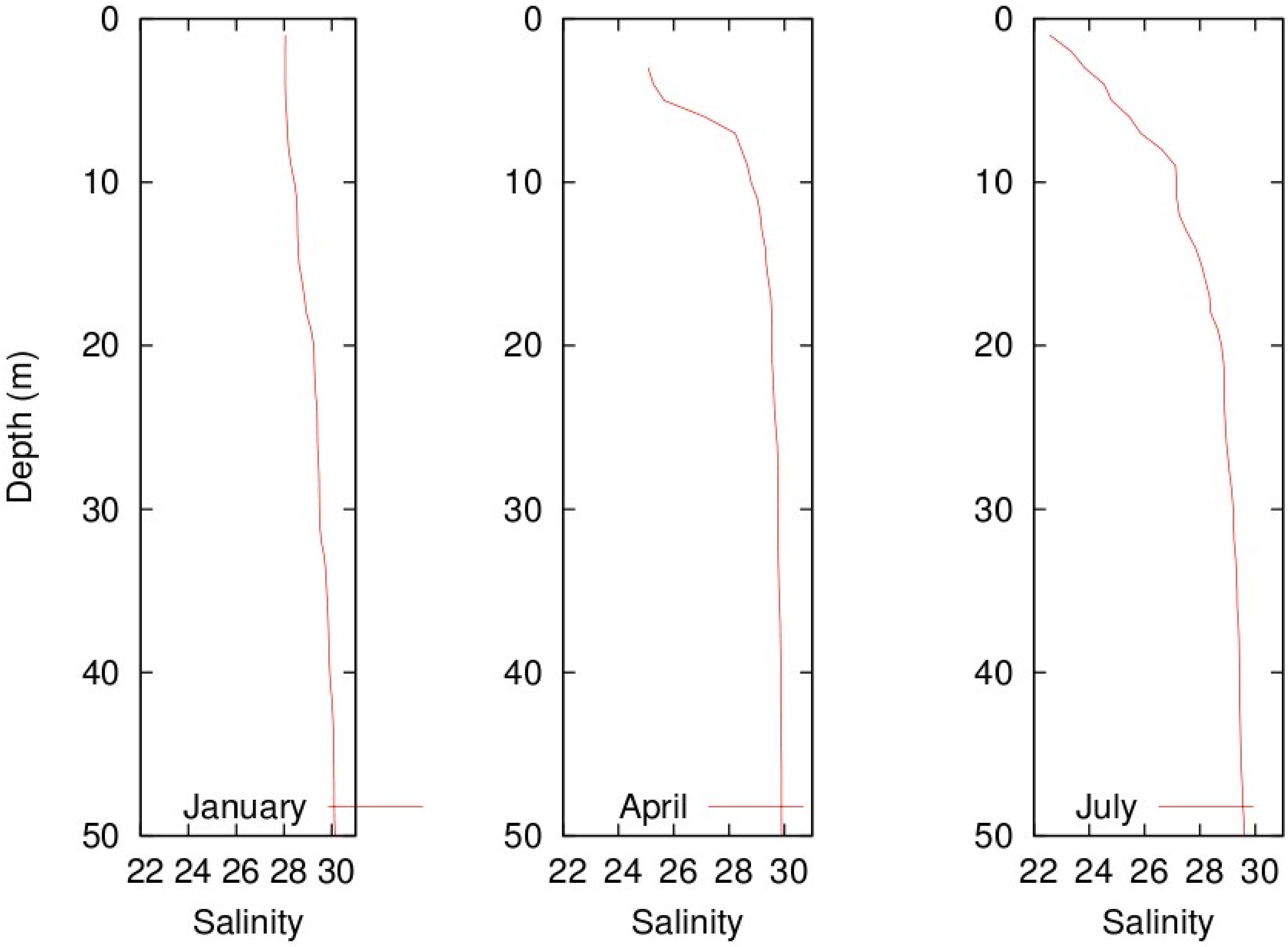
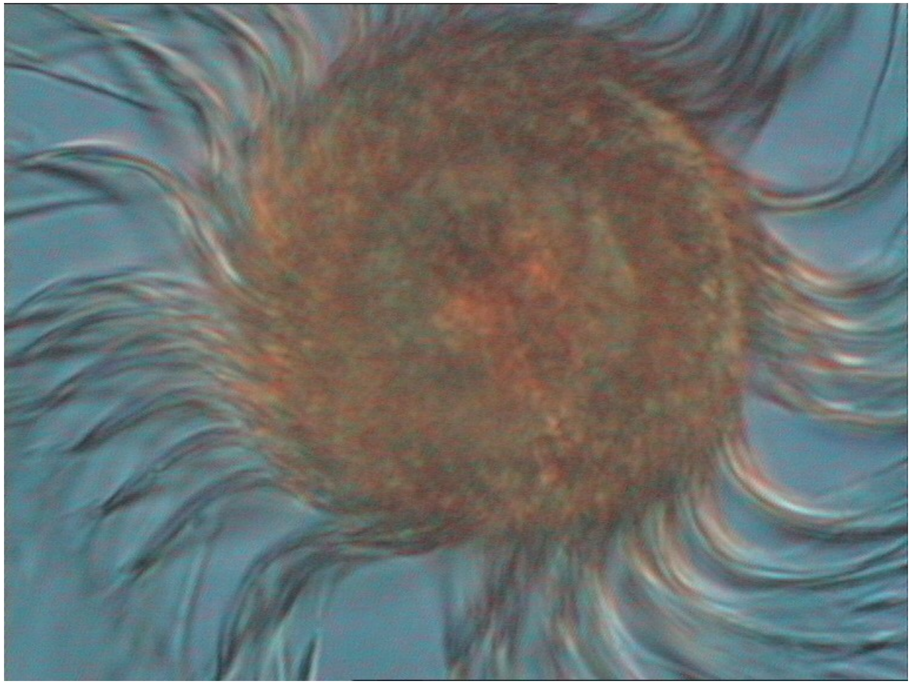


after LeBlond 1983 with Masson 2004 and Pawlowicz 2007

Salinity Profiles

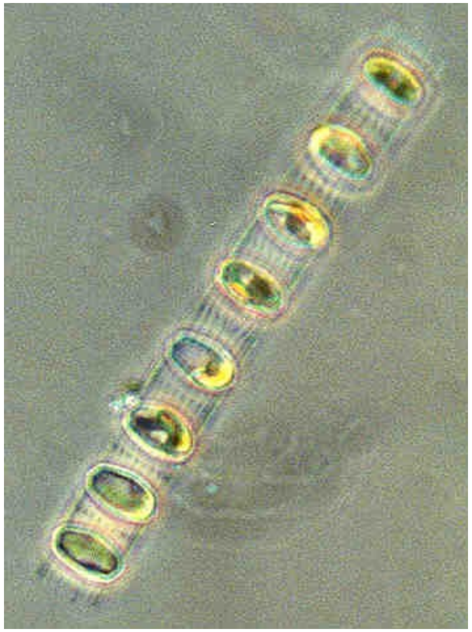


Phytoplankton



One celled organisms that form the base of the food chain in the ocean

Plankton: can't swim against the currents

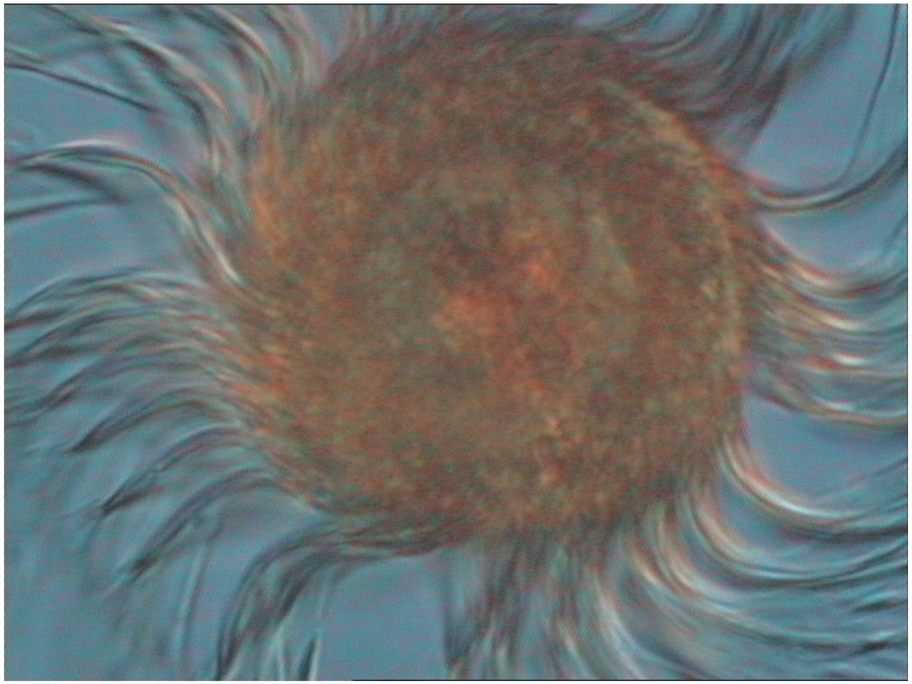


www.seriestemporales-ieo.net

www.dnr.state.md.us

www.nies.go.jp

Phytoplankton



Need light and nutrients to grow.

Limiting nutrient: Nitrogen

www.seriestemporales-ieo.net

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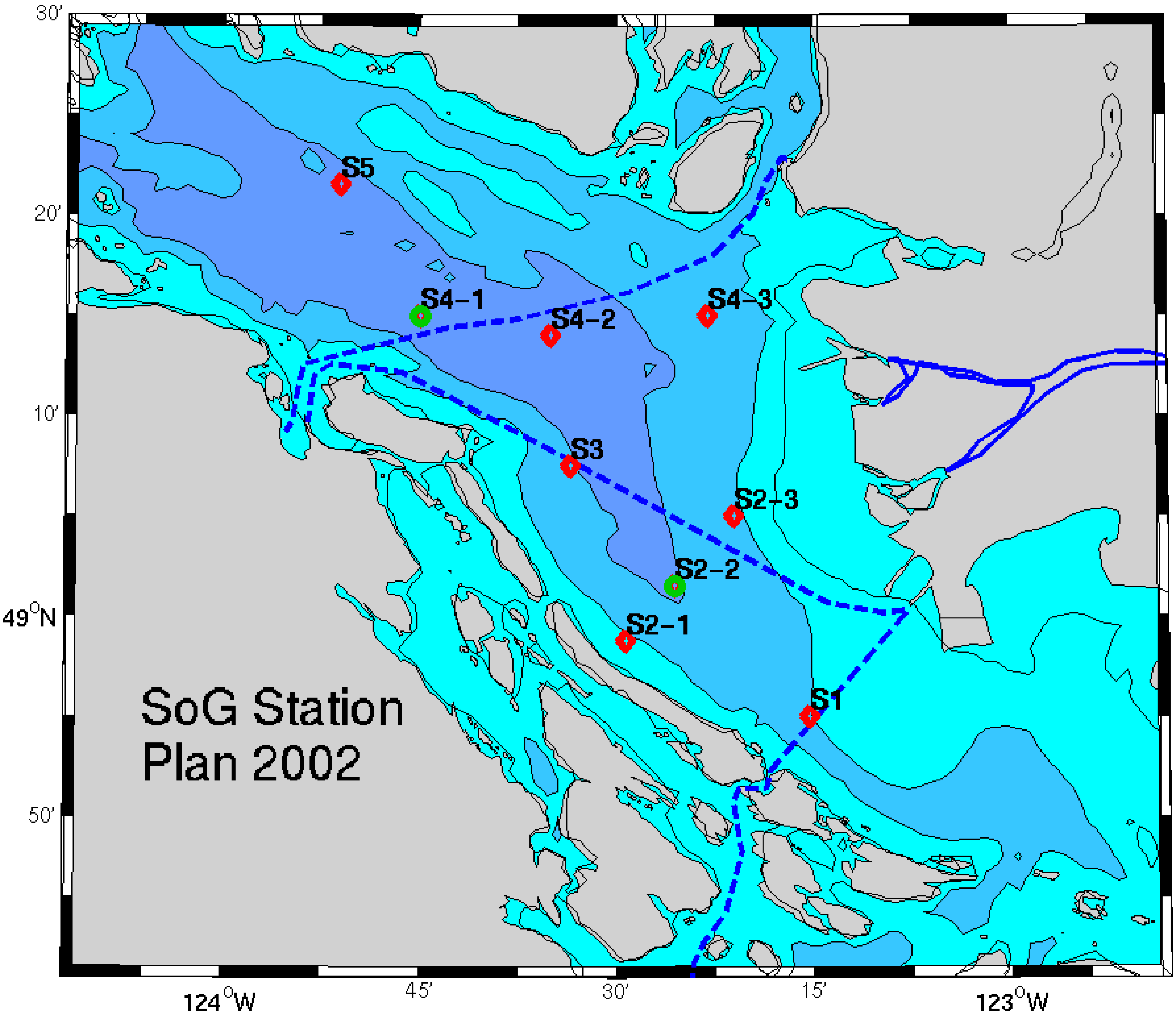
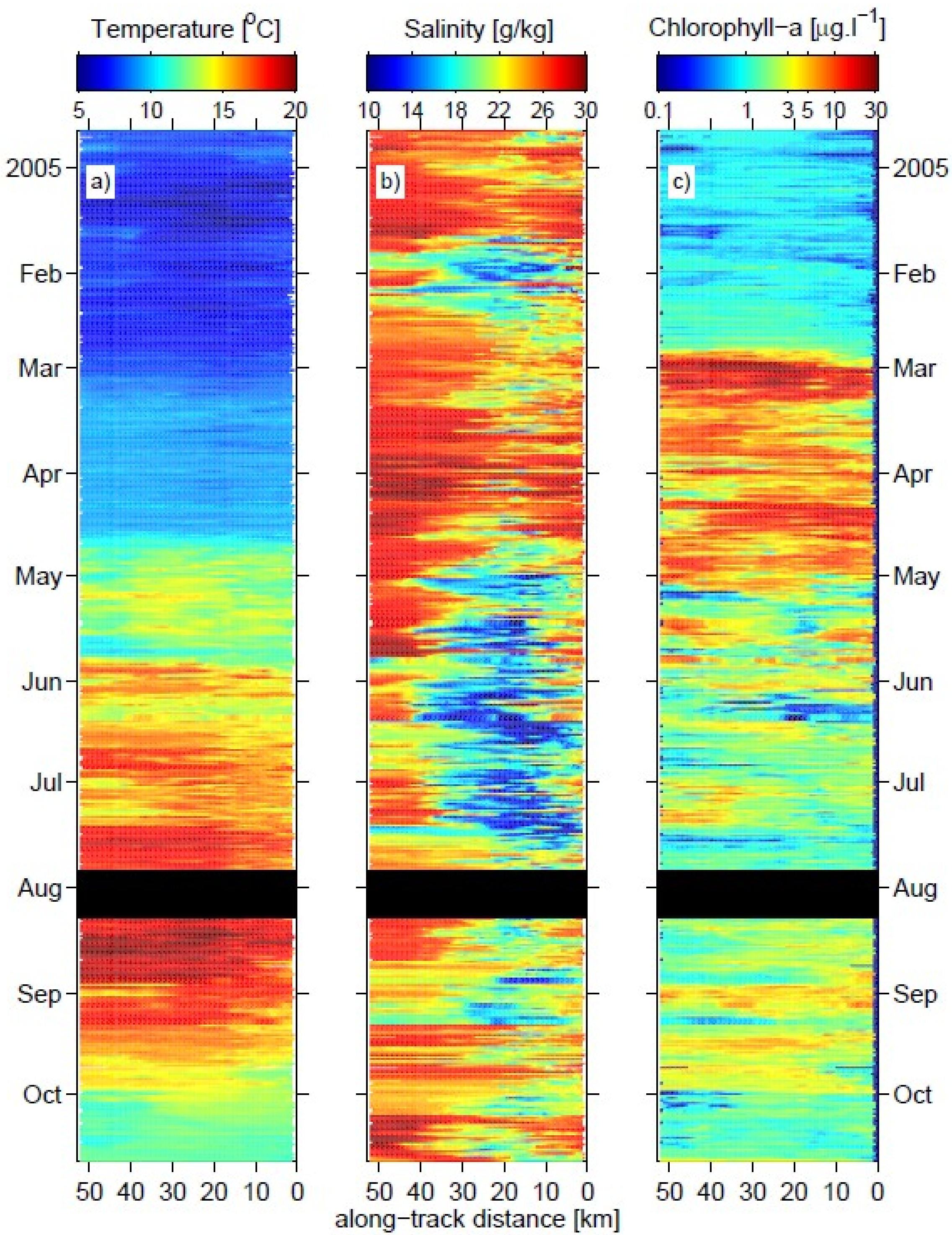
www.nies.go.jp



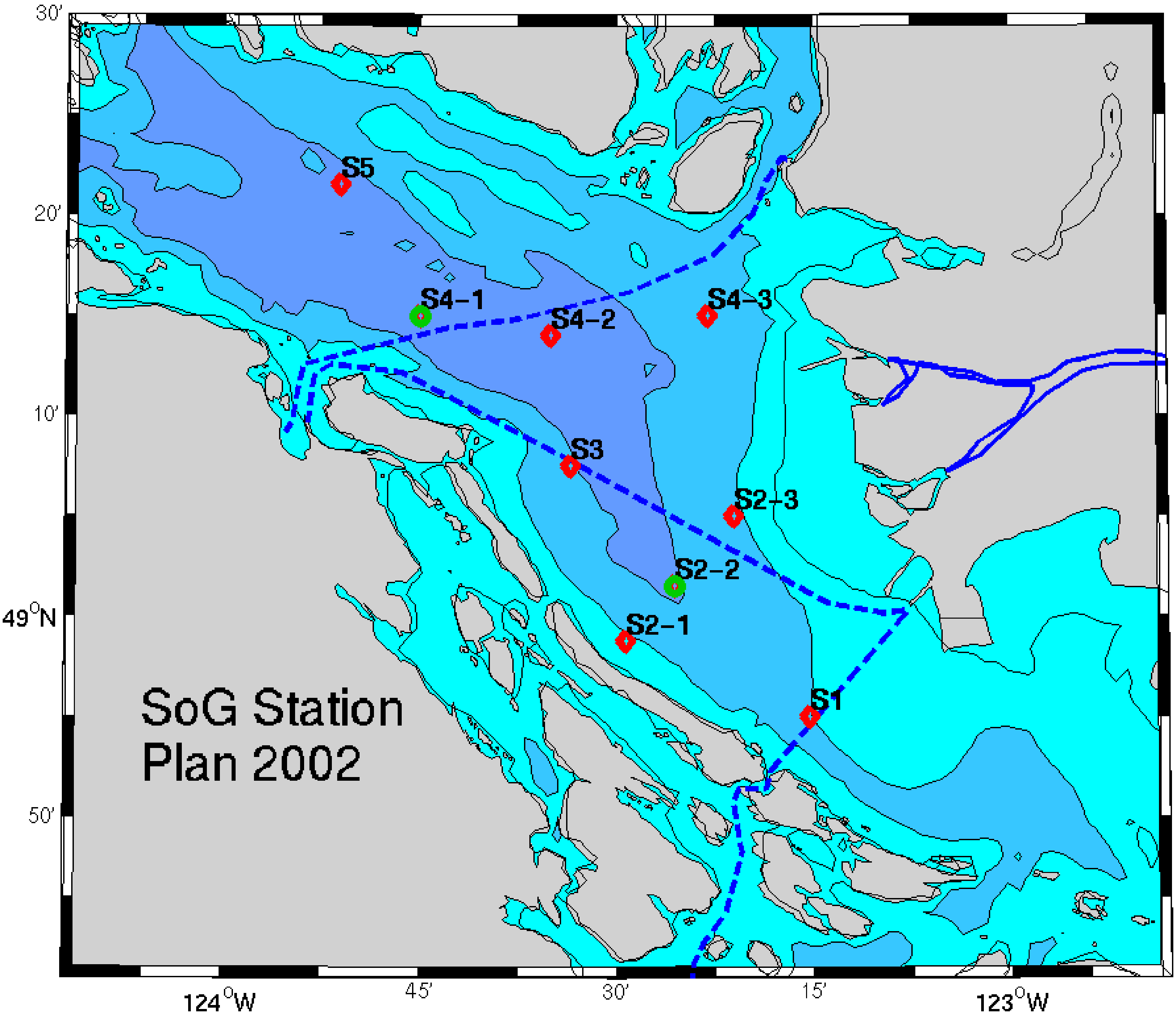
30'
20'
10'
49°N
50'
124°W
45'
30'
15'
123°W
S5
S4-1
S4-2
S4-3
S3
S2-3
S2-2
S2-1
S1
SoG Station
Plan 2002



Halverson & Pawlowicz, 2012

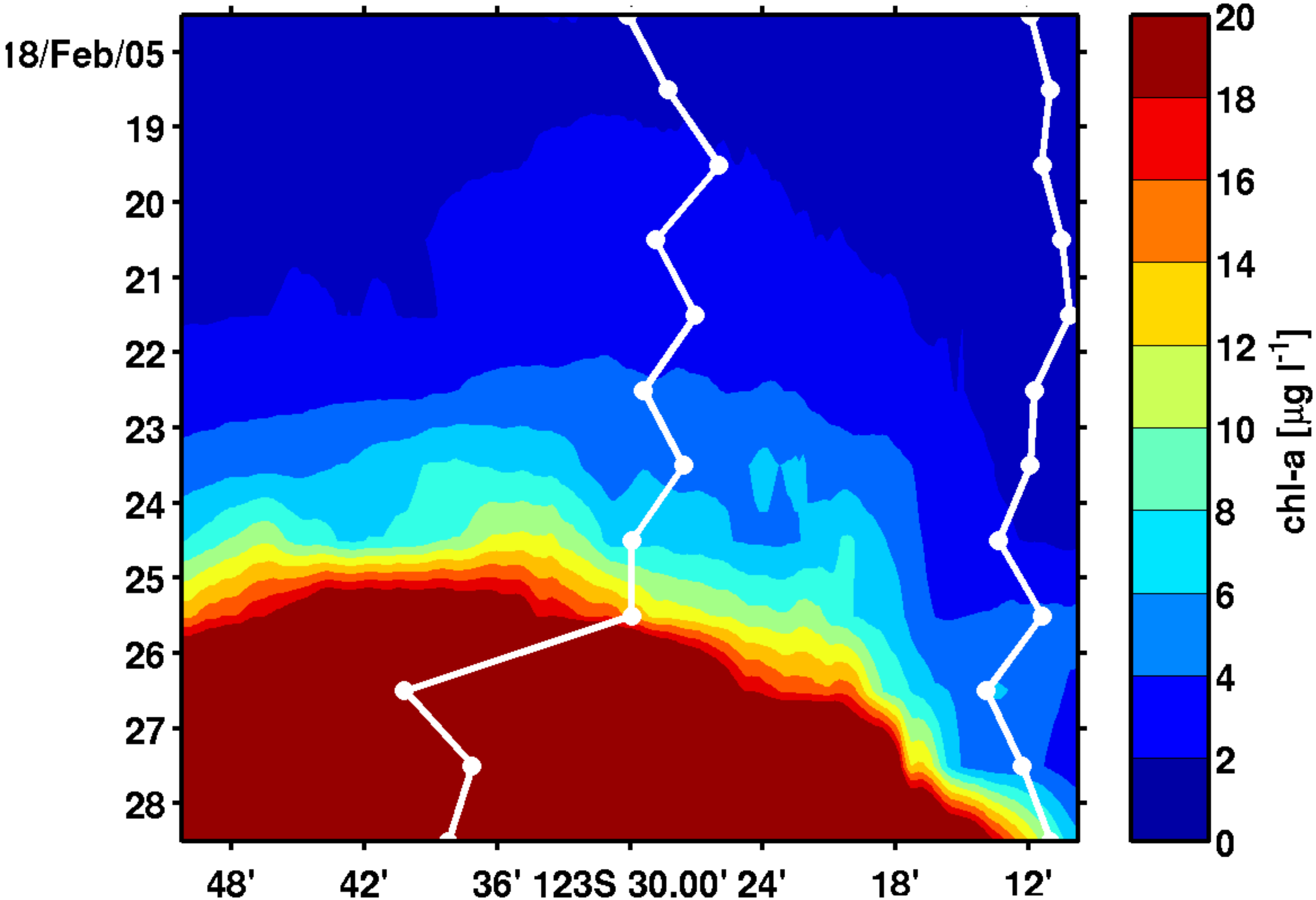
Goal

- **An accurate physical model** to provide a foundation for lower trophic layer models (questions of primary productivity, timing and interannual variability) and for a carbon model (questions of pH values and processes)

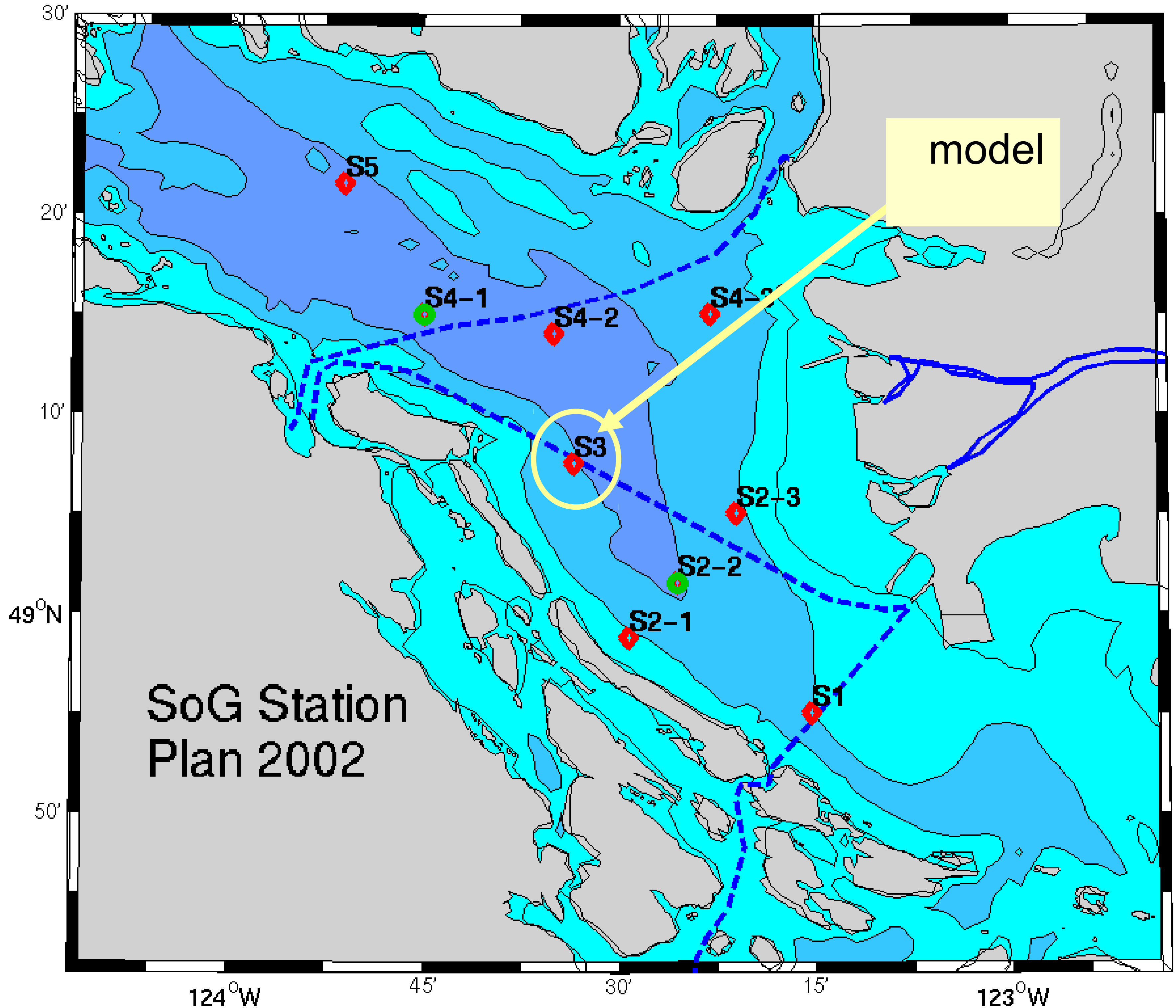


S5
S4-1
S4-2
S4-3
S3
S2-3
S2-2
S2-1
S1
SoG Station
Plan 2002
30'
20'
10'
49°N
50'
124°W
45'
30'
15'
123°W

Spring Bloom along the Ferry Route



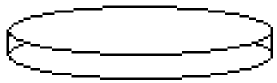
Mark Halverson



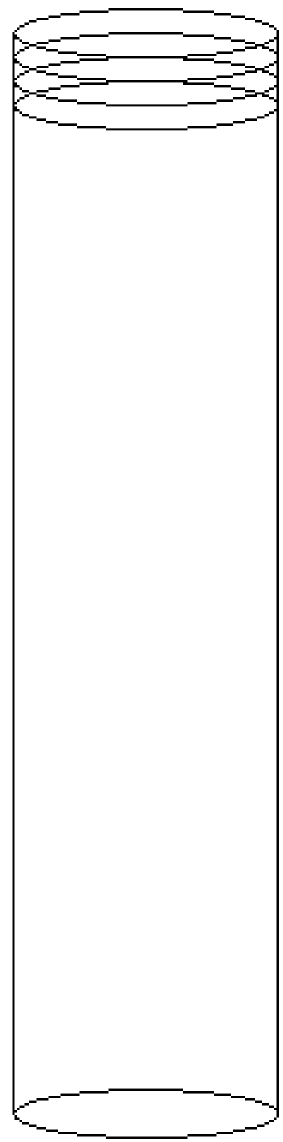
model
S5
S4-1
S4-2
S4-3
S3
S2-3
S2-2
S2-1
S1
SoG Station
Plan 2002
30′
20′
10′
49°N
50′
124°W
45′
30′
15′
123°W

One-dimensional Mixing Model plus

- ✓ Using a 1-dimensional model allows detailed vertical resolution and runs quickly; allows multiple parameter tests, grad-student friendly
- ✗ All two-dimensional processes must be parameterized
- Use a standard, well supported mixing layer model (KPP)
- Add baroclinic pressure gradients (due to finite size of the Strait)
- Add estuarine circulation

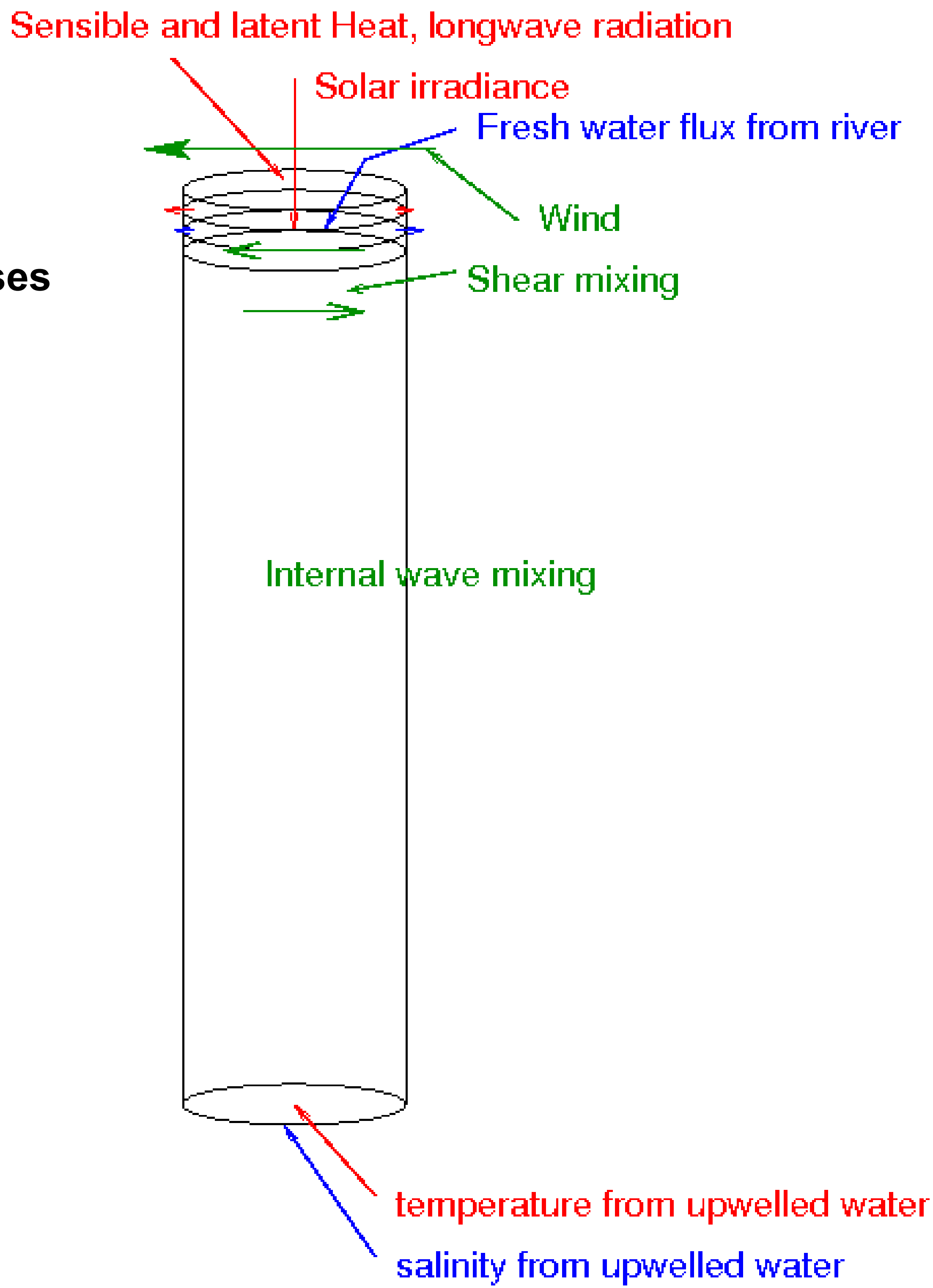


40 m deep, 10 km diameter



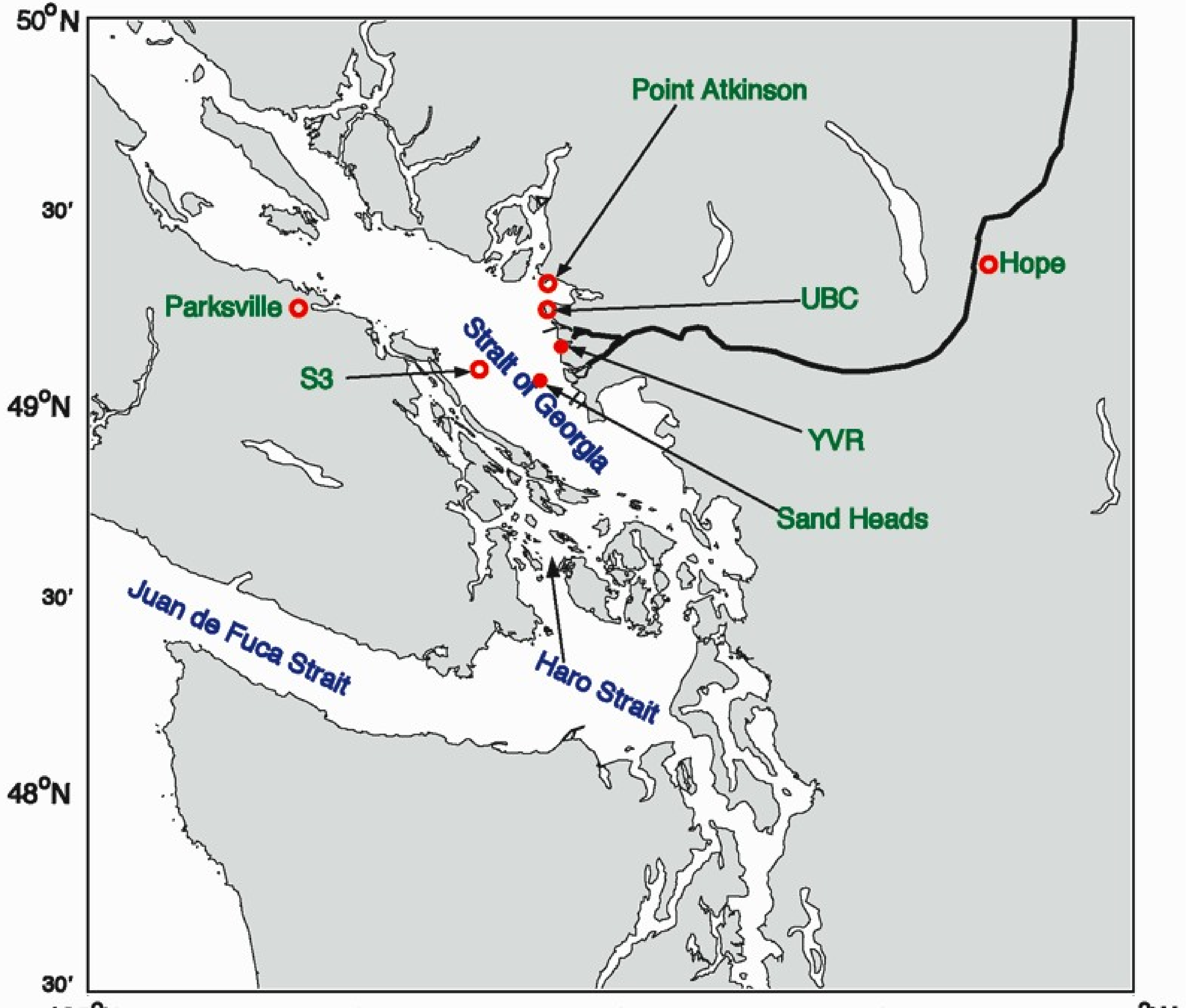
Vertically exaggerated.
40 m deep separated into 0.5 m disks
(all the way down)

Physical Model
Resolved processes



Physical Model

- Initialized with a temperature and salinity profile in Sep/Oct
- Forced with hourly wind, temperature, humidity, cloud fraction and daily Fraser River and Englishman River flows
- Bottom boundary condition: seasonal cycle of salinity and temperature and observed temperature increase over time



50°N
30'
49°N
30'
48°N
30'
125°W
124°W
123°W
122°W
121°W
Point Atkinson
UBC
Hope
Parksville
Strait of Georgia
S3
YVR
Sand Heads
Juan de Fuca Strait
Haro Strait

Estuarine Circulation

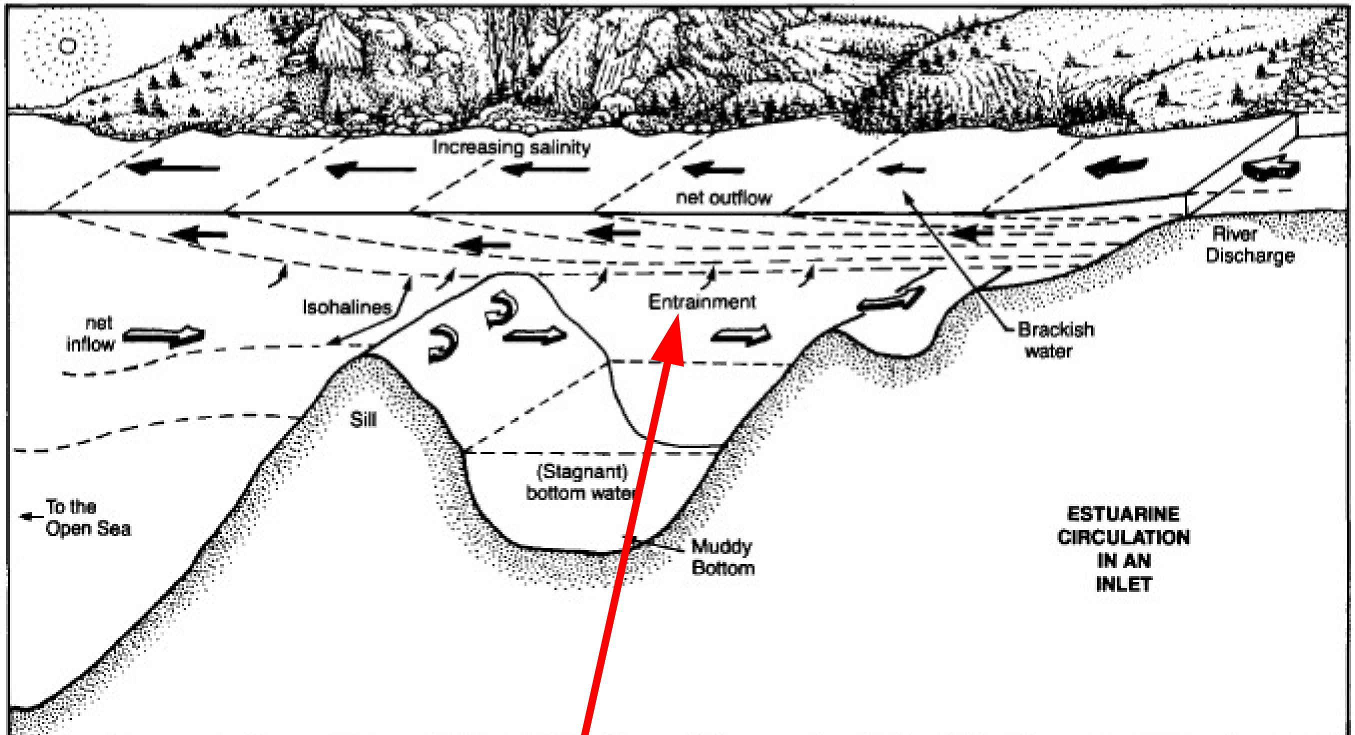
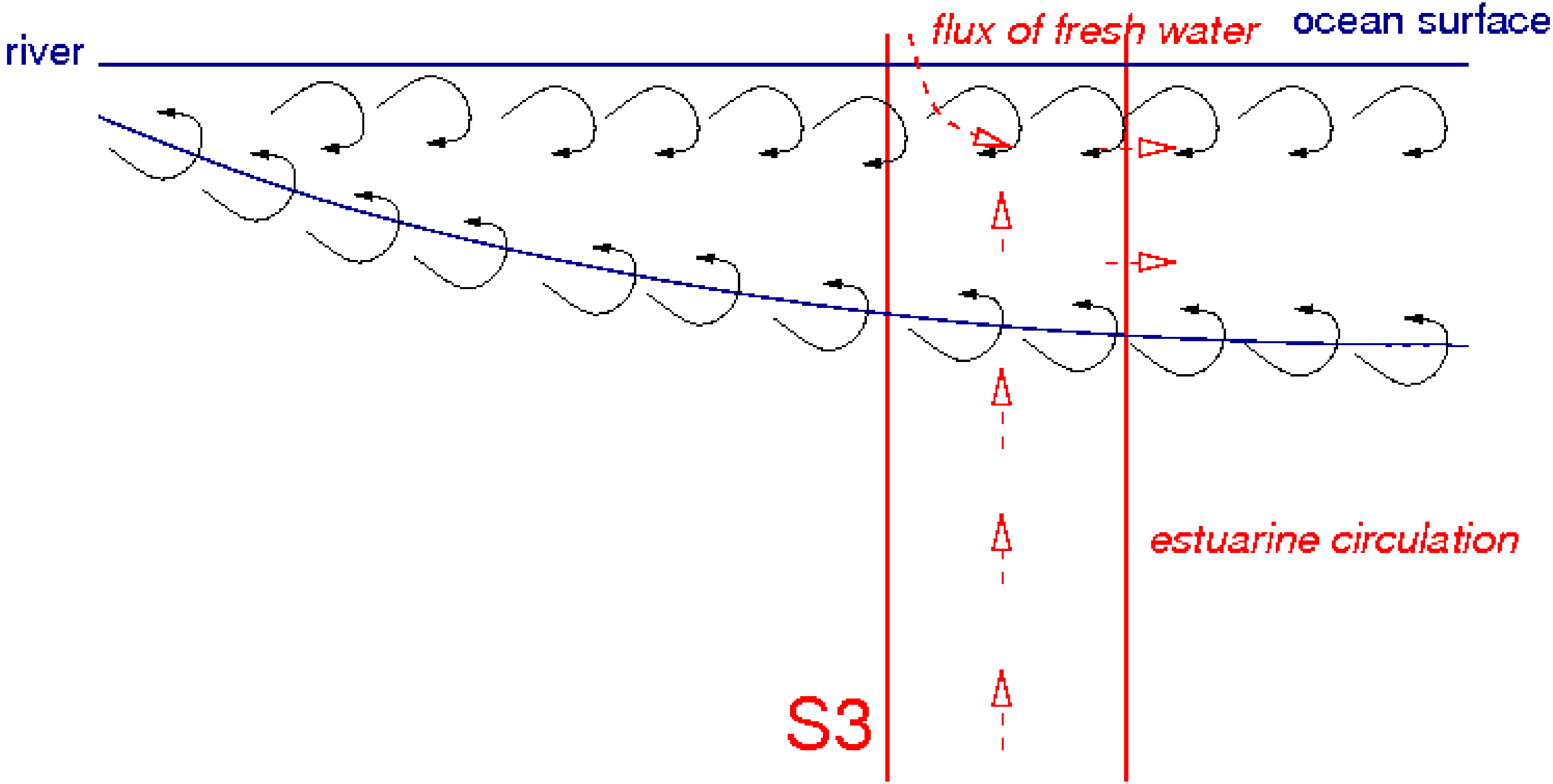


FIG. 2.7. Estuarine circulation in a typical British Columbia inlet. Salt water entrained and carried seaward by river outflow is replenished by a net inflow at depth. Sloping isohalines (lines of equal salinity) indicate a down-inlet increase in salinity in surface brackish layer. Turbulent mixing occurs in vicinity of sill.

Entrainment of deeper, nutrient-rich, water into the surface outflowing circulation is the most important source of nutrients to the system.

Physical Model
Major unresolved process:
Estuarine Circulation



Amount of vertical entrainment set by conservation of mass and salt using data.

Parameterization Philosophy

- Only uses information available, either from the incoming forcing data (e.g. river flow) or from the core model (e.g. mixing layer depth)
- Is physically based
- Matches the observations
- Is numerically appropriate (i.e. No pathological behaviour at extrema)

Needed:

- Amount of freshwater to add
- Depth to add freshwater
- Vertical velocity rate

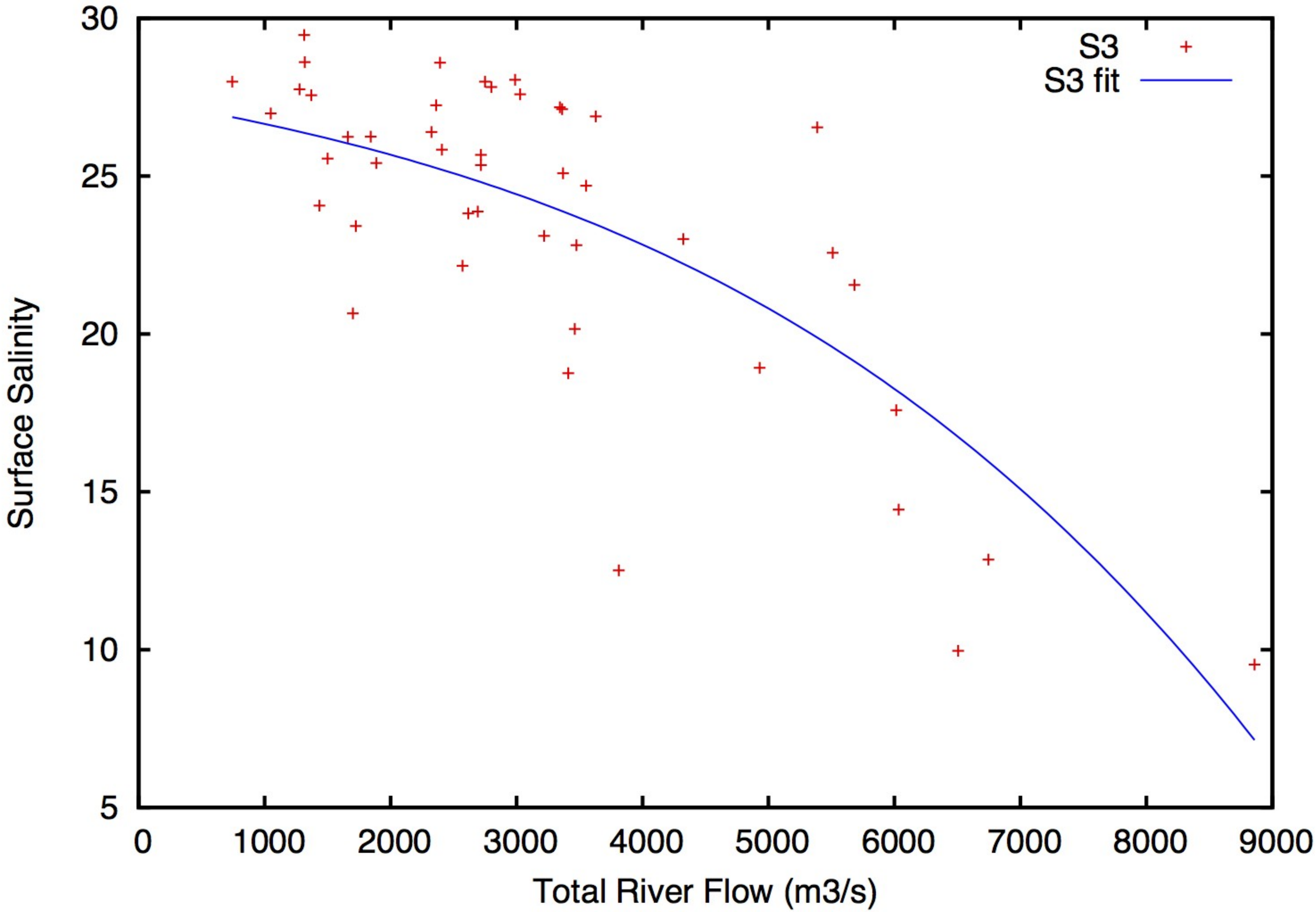
Mechanism:

- Salinity fit
- Freshwater fit
- Entrainment calculation

Parameterize Based on Data #1 Amount of Freshwater

- 48 cruises to the SoG
- Surface salinity is related to total freshwater input to the SoG (fit 1)
- Amount of freshwater is tuned to give the fitted surface salinity

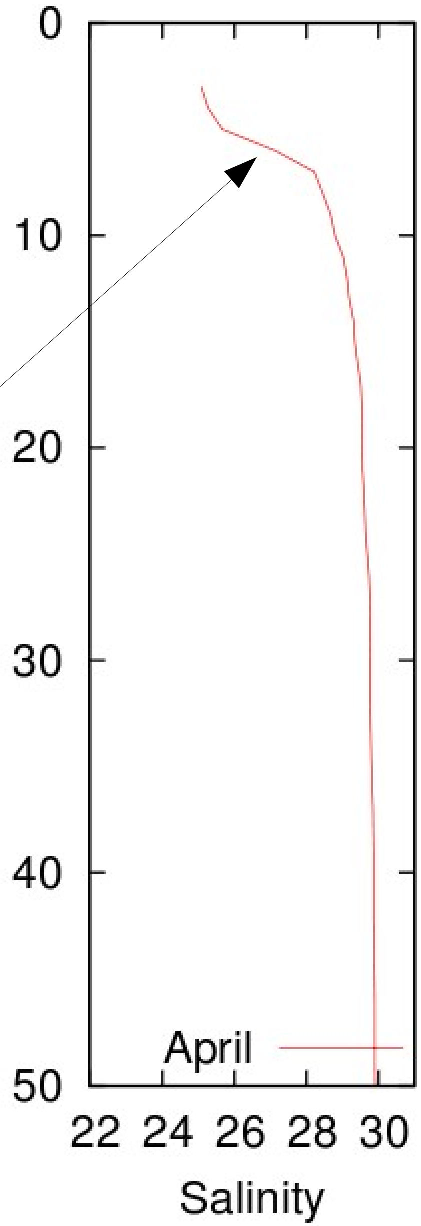
Fit 1



S3
S3 fit
Surface Salinity
Total River Flow (m3/s)
30
25
20
15
10
5
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

Parameterize Based on Data #2 Depth of Freshwater

- Model calculates the mixing layer depth
- Freshwater is introduced (exponential) over a depth proportional to the mixing layer depth
- Proportionality is tuned to match the halocline depth between model and observations

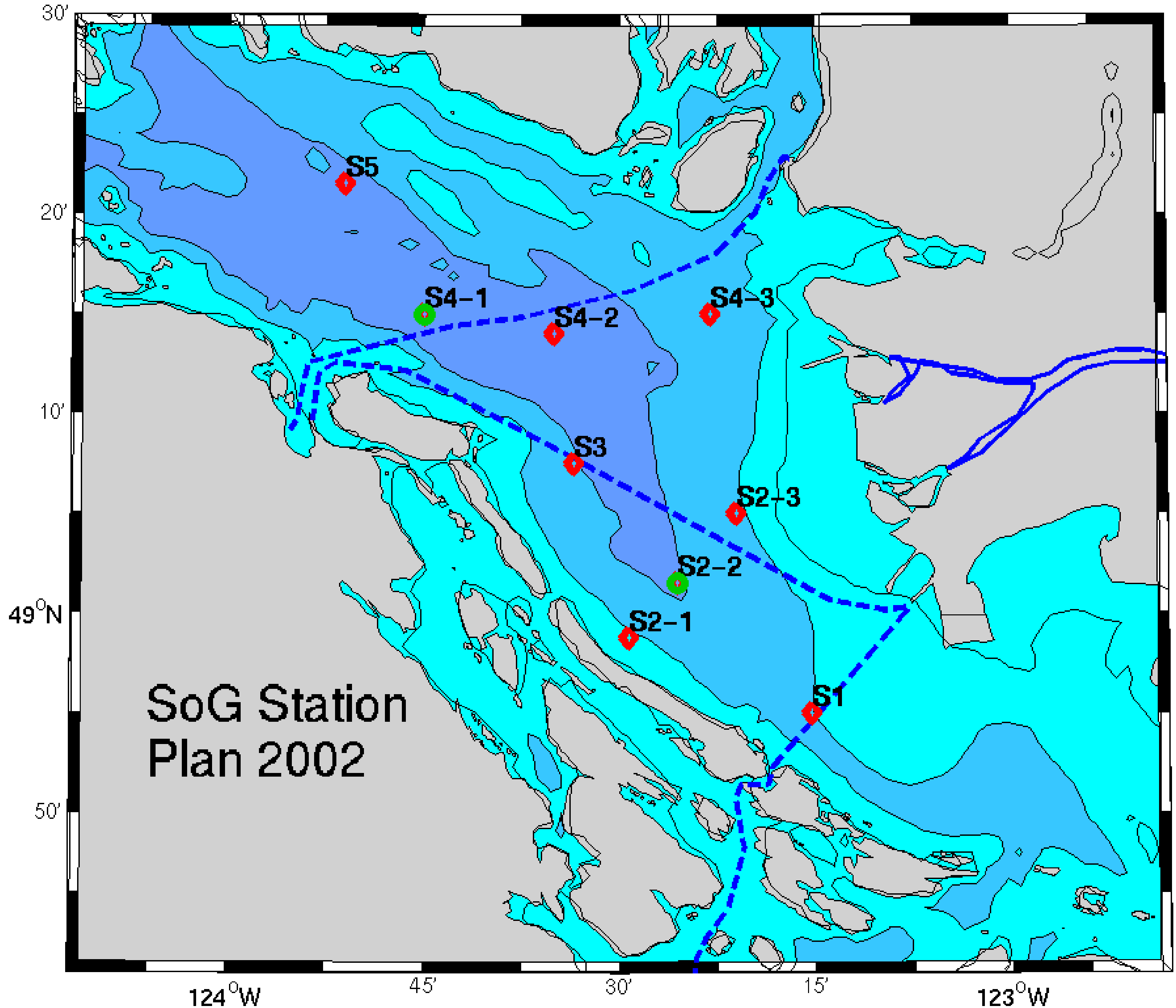


A Salinity Similarity Solution

- Freshness ($F = S_D - S$) almost has a similarity solution with depth S_D is deep salinity, S is in-situ salinity
- Freshness varies with distance from the river mouth and with the amount of freshwater
- We assume these dependencies are partially separable
- Integrated freshness

$$I_F = \int F dz = F_* \mathcal{F}\left(\frac{z}{d}\right) \mathcal{F}_r\left(\frac{r}{r_3}\right) \mathcal{F}_T\left(\frac{T}{\bar{T}}\right)$$

where $d(r, T)$, r_3 and $\bar{T}$ are relevant scales for the depth, lateral distance and freshwater input, respectively.



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S5
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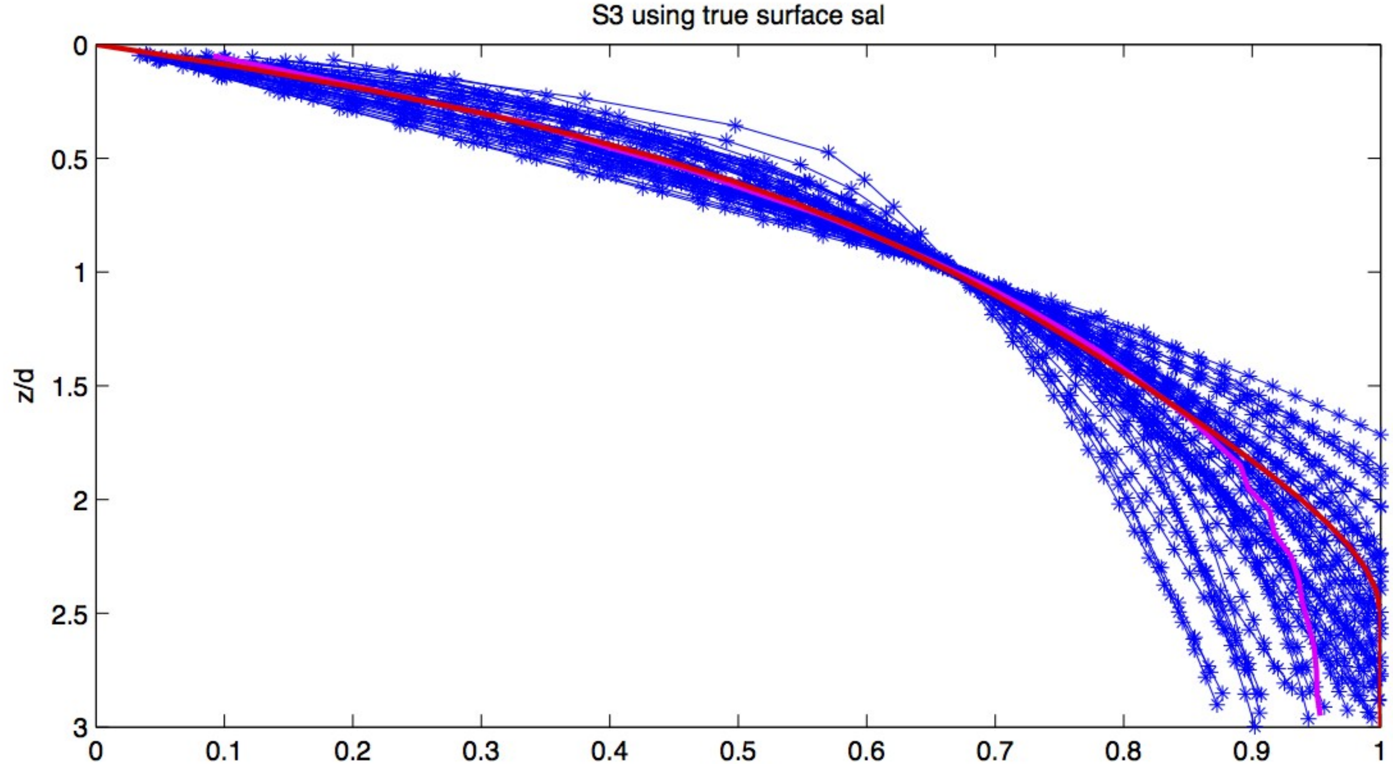
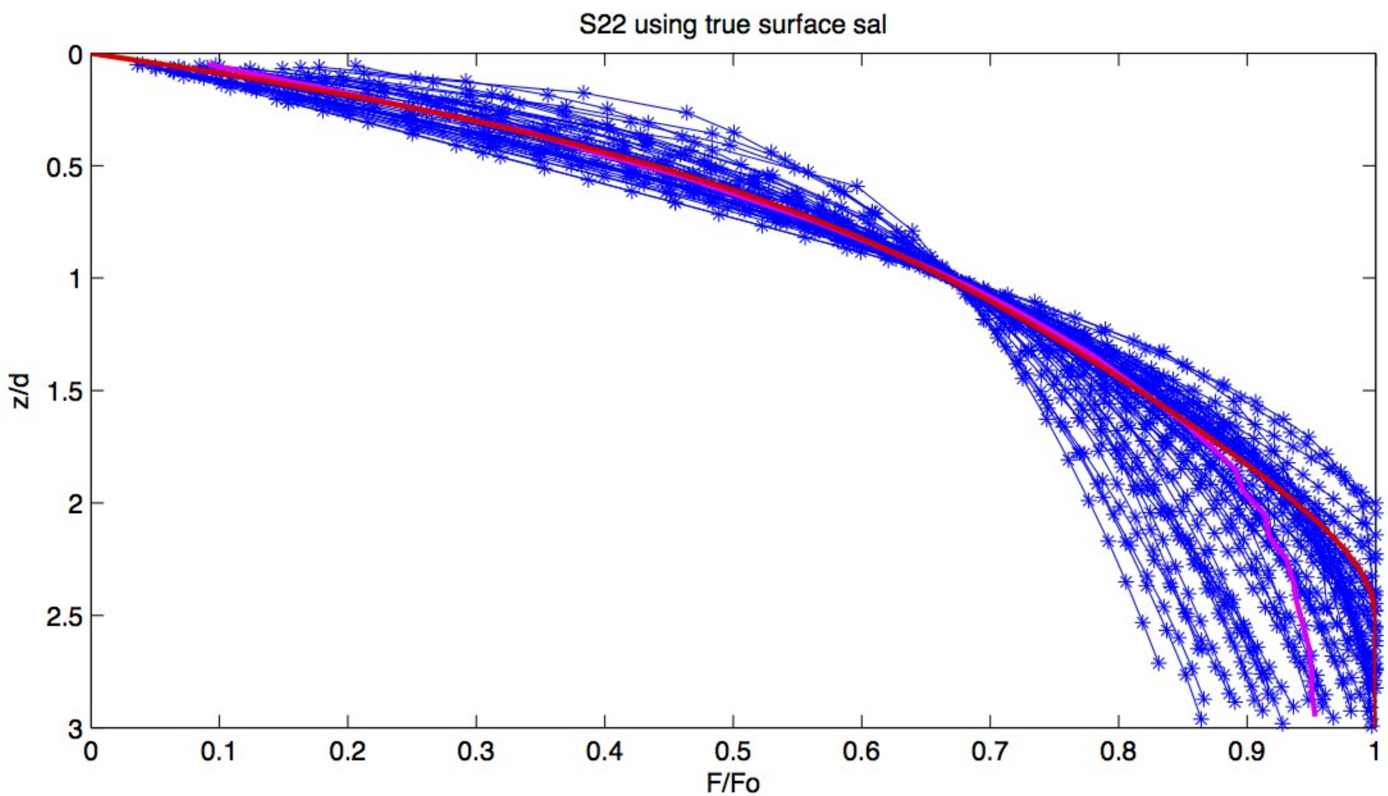
S4-2
S4-3
S3
S2-3
S2-2
S2-1
S1
SoG Station
Plan 2002

Similarity solution with depth. Two different stations, same function.





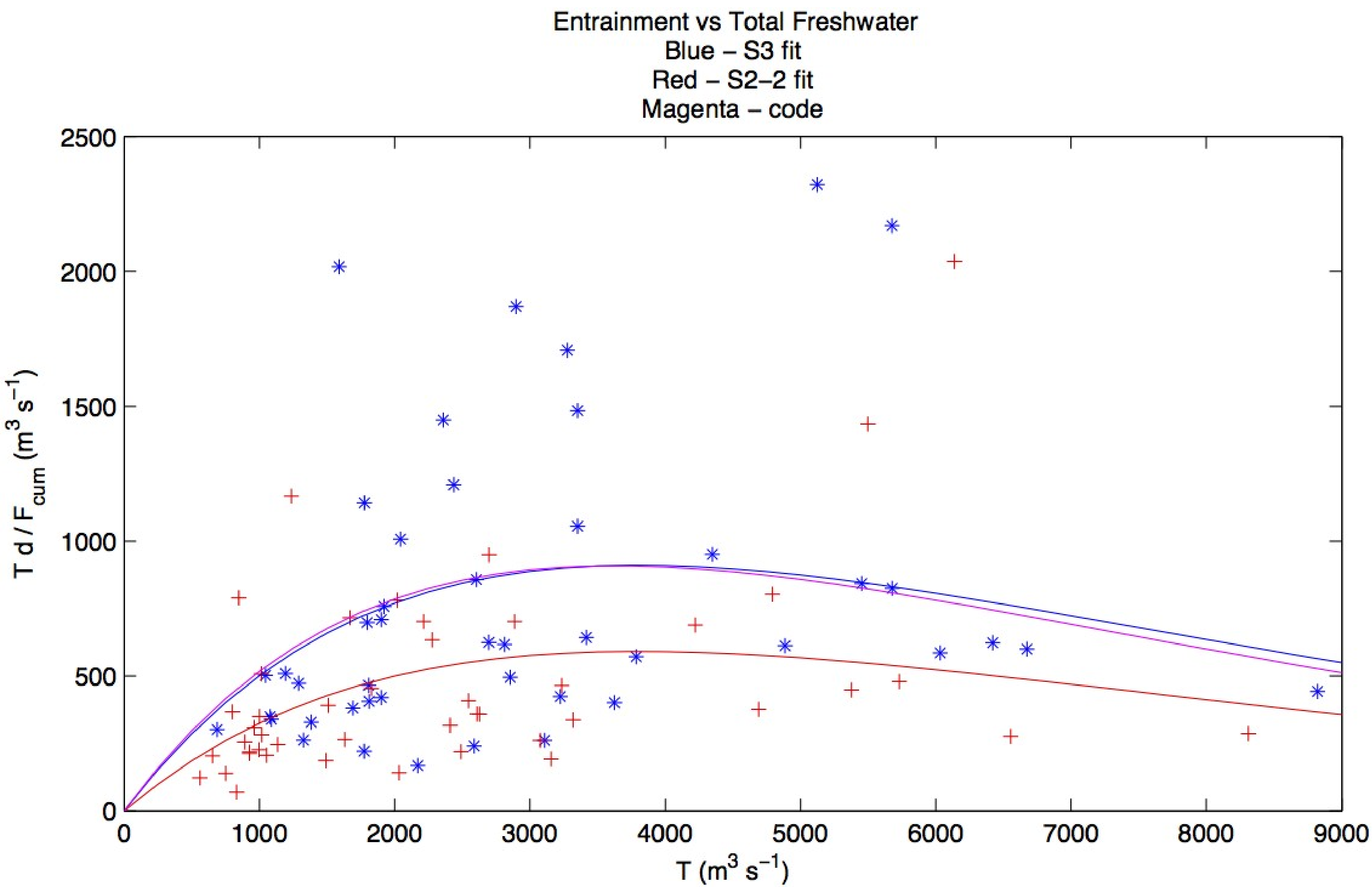
Vertical Velocity

- Can use Knudsen's relations (conservation of mass and salinity) to relate I_F to the entrainment velocity at depth
- By matching freshwater variation, one can show that the vertical velocity must vary with

$$\left(\frac{T}{\overline{T}}\right) \mathcal{F}_{\mathcal{T}}{}^{-1} \mathcal{D}_{\mathcal{T}}$$

  where $\mathcal{D}_{\mathcal{T}}$ is the variation of the depth d with freshwater flow.
- I have no measurements of vertical velocity, but do have salinity profiles and can thus determine the freshness solution and can calculate this function versus total freshwater, T.

Entrainment Velocity vs T



Comparison to Riche & Pawlowicz

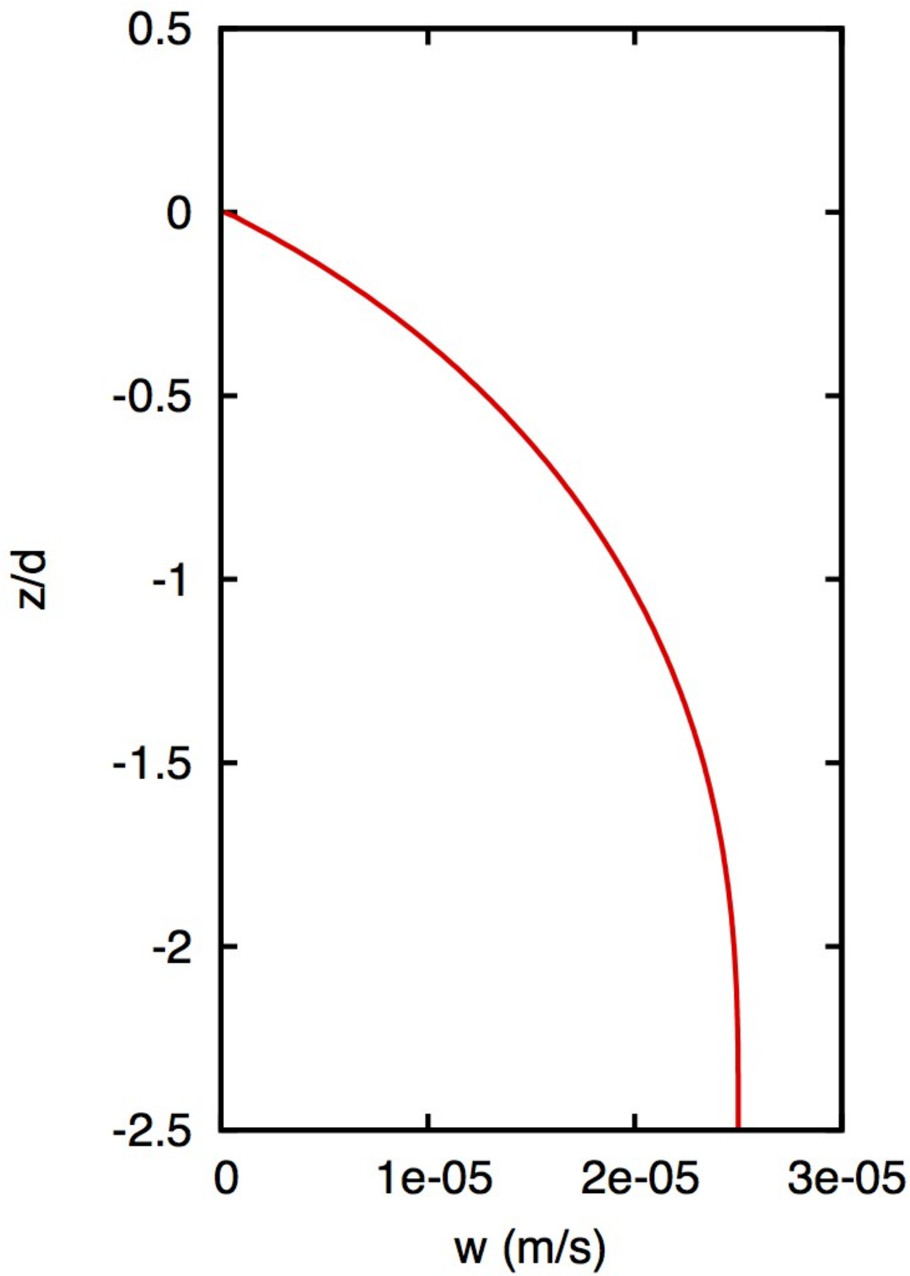
- Observation analysis shows entrainment almost independent of river flow
- This is consistent with the fit
- A constant value is wrong at large and small river flow, fit is forced to zero

Parameterize Based on Data #3 Entrainment Magnitude

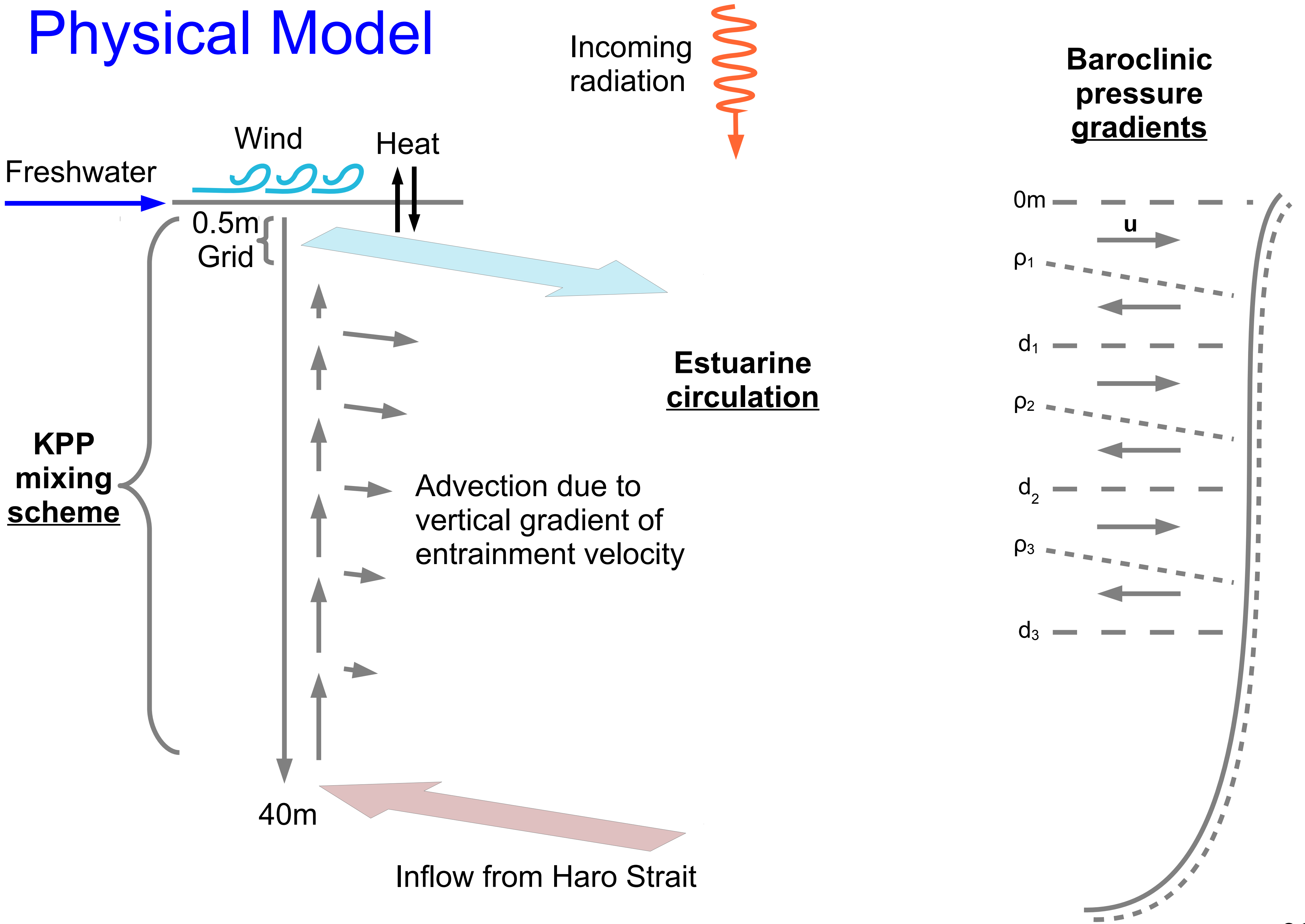
- Using
  - the variation of entrainment with depth
  - the salinity fit (fit 1)
  - assumptions on the spreading shape of the plume = cone (1/3 to 1/4 of full circle) plus extra $r^{0.2}$ (Hetland and MacDonald, 2008)
- One gets a magnitude of entrainment from 0.5-1.5 x 10^{-4} m s^{-1}
- Agrees with box model of Riche & Pawlowicz

Parameterize Based on Data
#3 Entrainment Depth Variation

- Assume a balance between the pressure gradient force and mixing of momentum
- Assume parabolic form for 1/eddy viscosity
- Gives a cubic form for the entrainment.

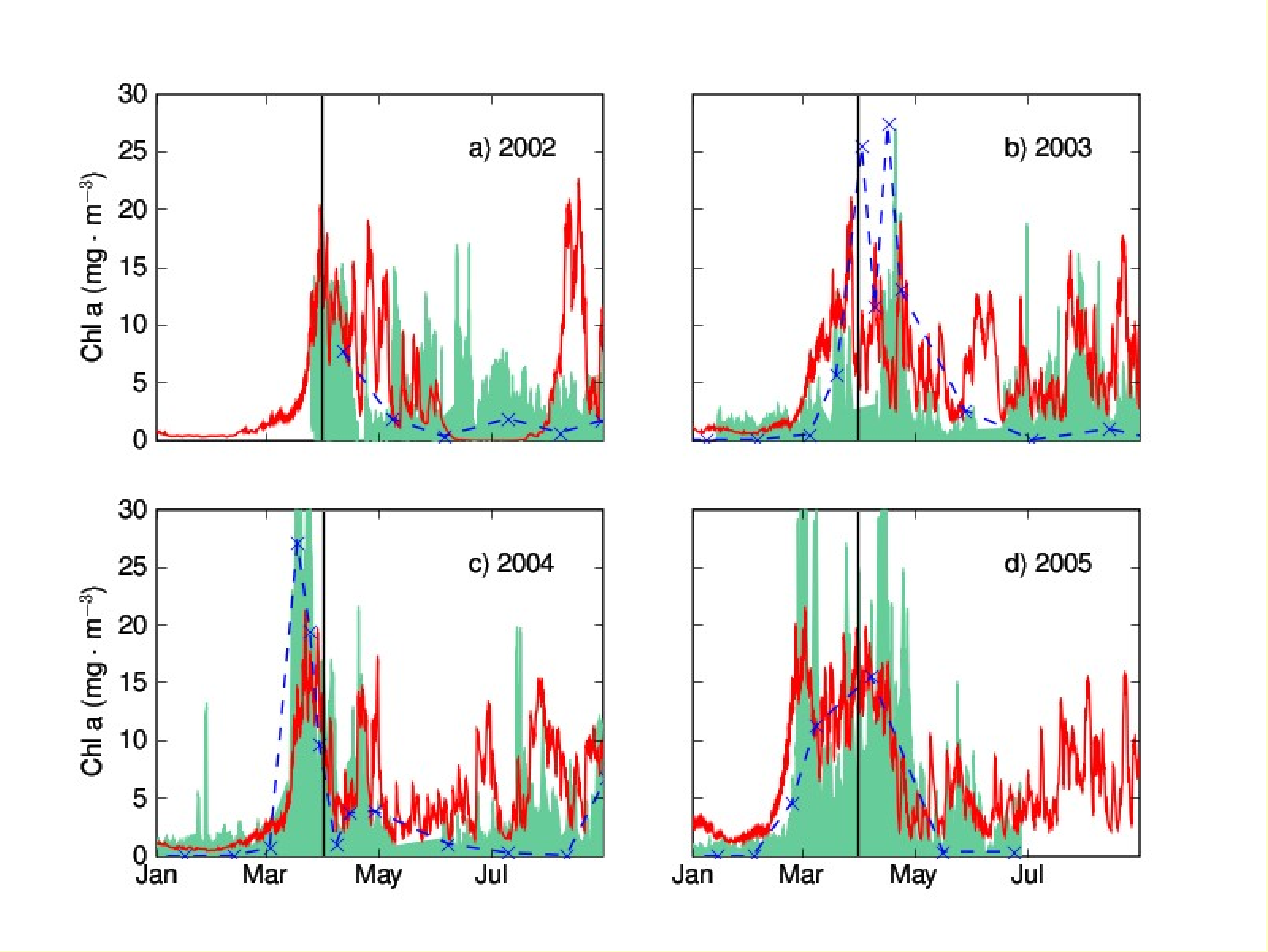


Physical Model



Ben Moore-Maley

Ferry chl fluor., Surface chl > 20 m, Surface model chl

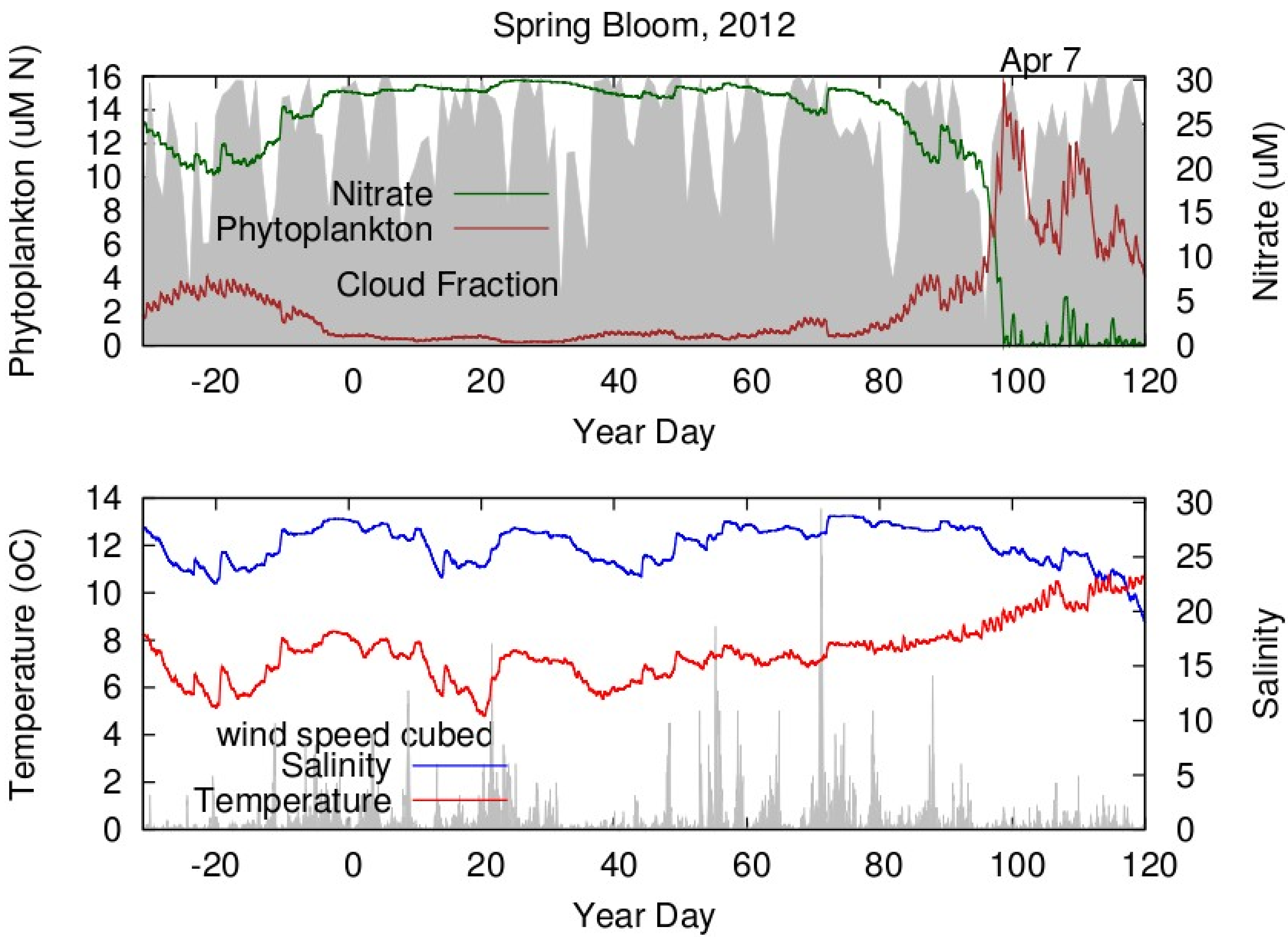


Ferry chl unscaled between years

Results: Freshwater and Entrainment

- Adding the freshwater flow and entrainment allowed the simulation of the physical structure of the flow
- Biological code has been successfully used to hindcast and forecast the spring bloom timing in the Strait of Georgia.

2012 Spring Bloom

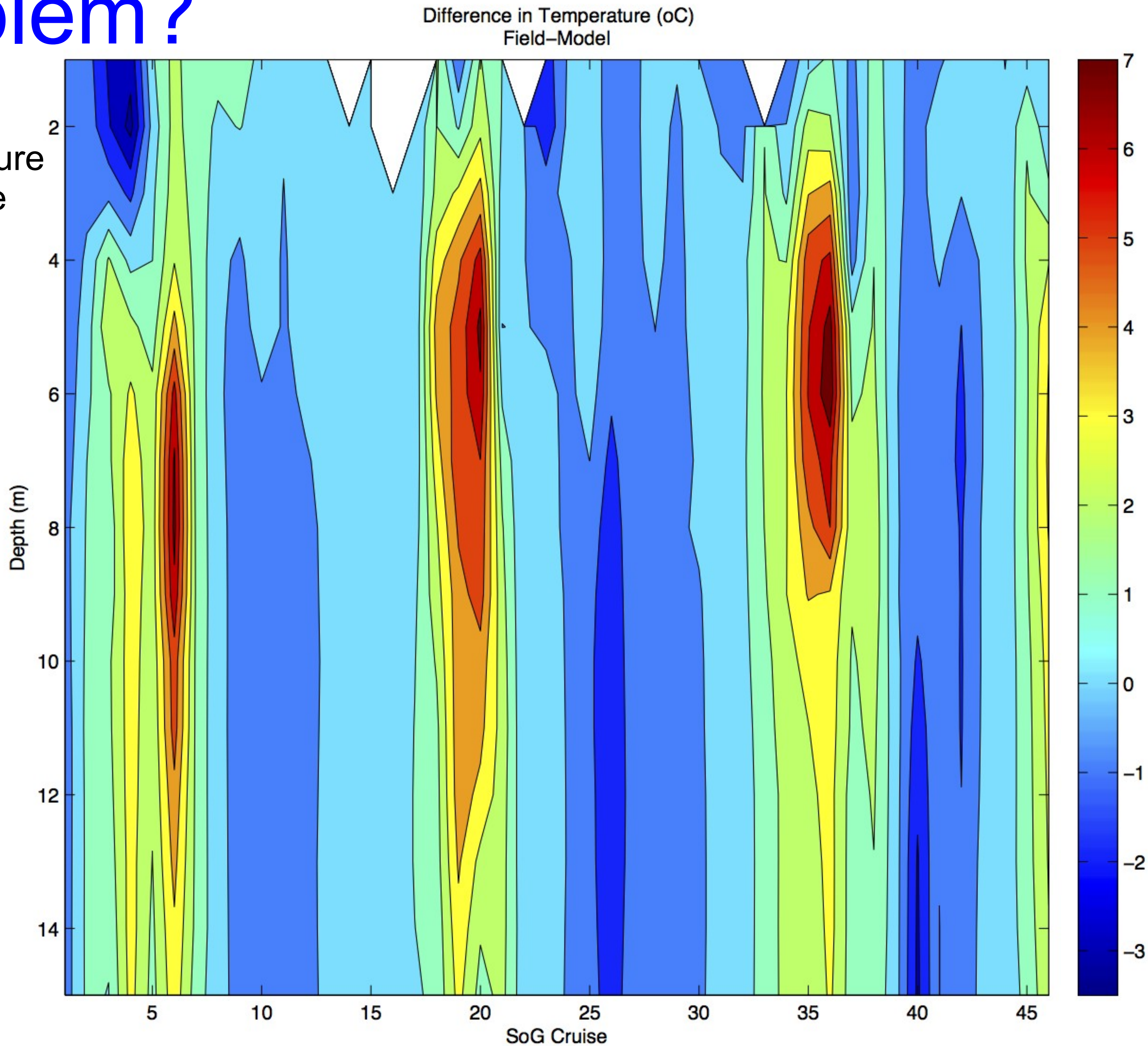


Conclusions

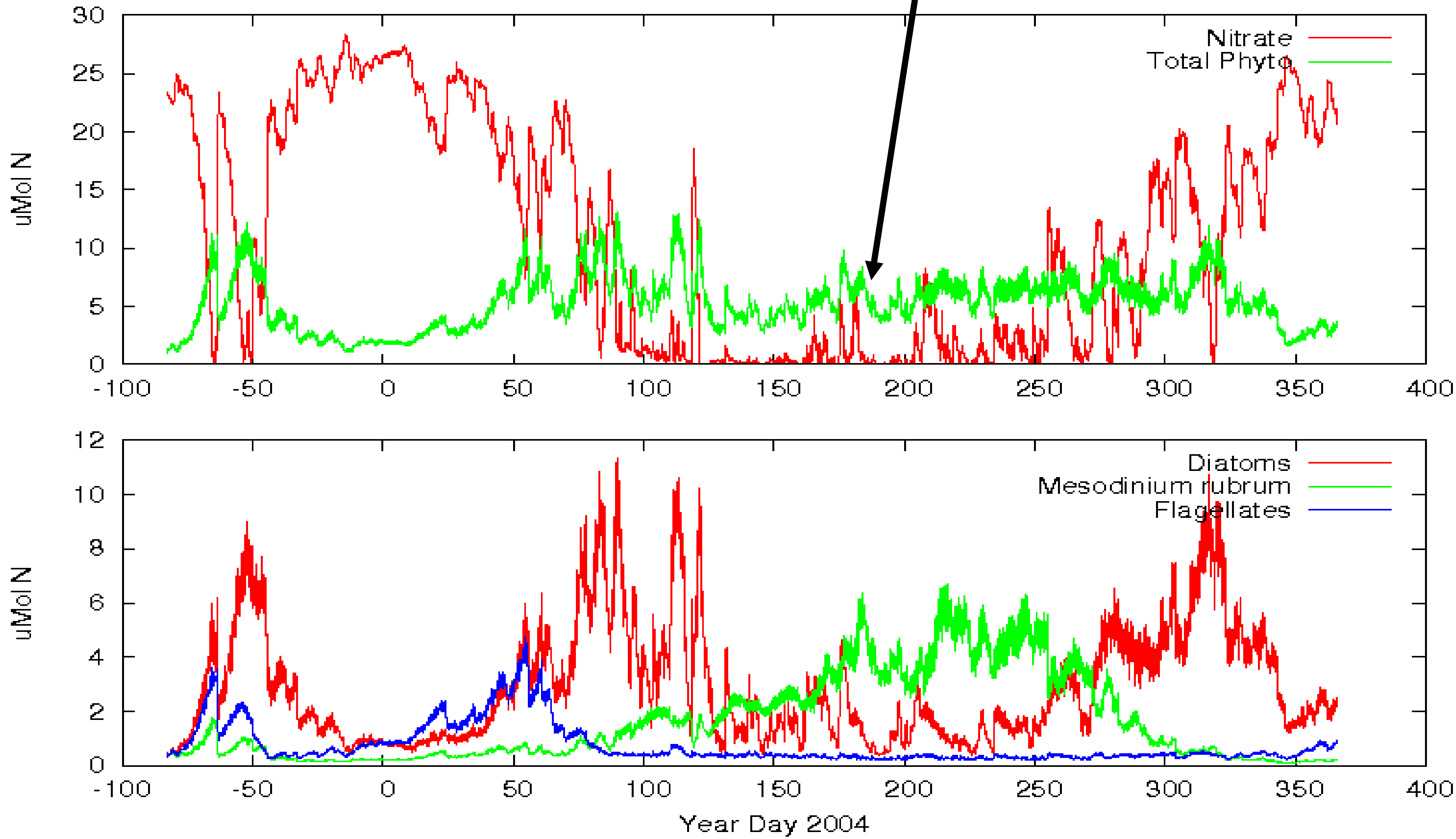
- Most models cannot resolve all important details
- We can “correct” these models by inserting our knowledge of processes but this requires:
  - Good knowledge of the processes
  - Careful thought for extremes
  - Lots of data to accurately tune parameterizations

Problem?

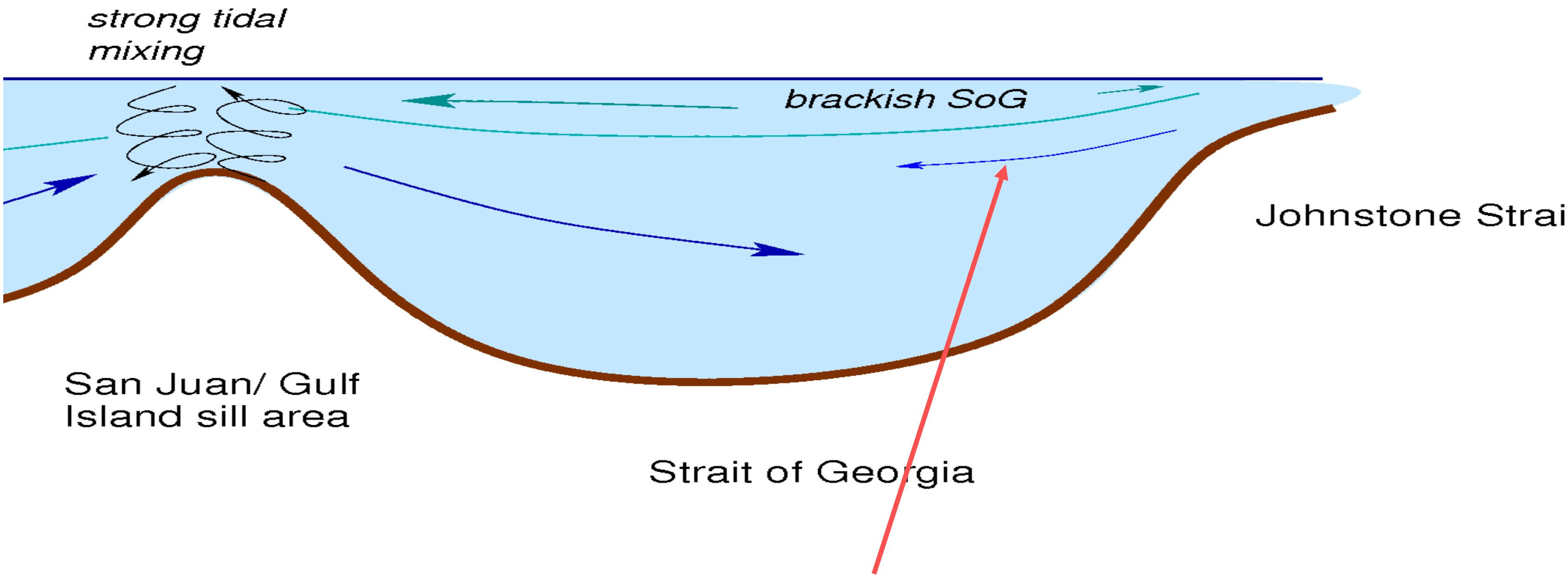
Temperature Difference Between Field and Model



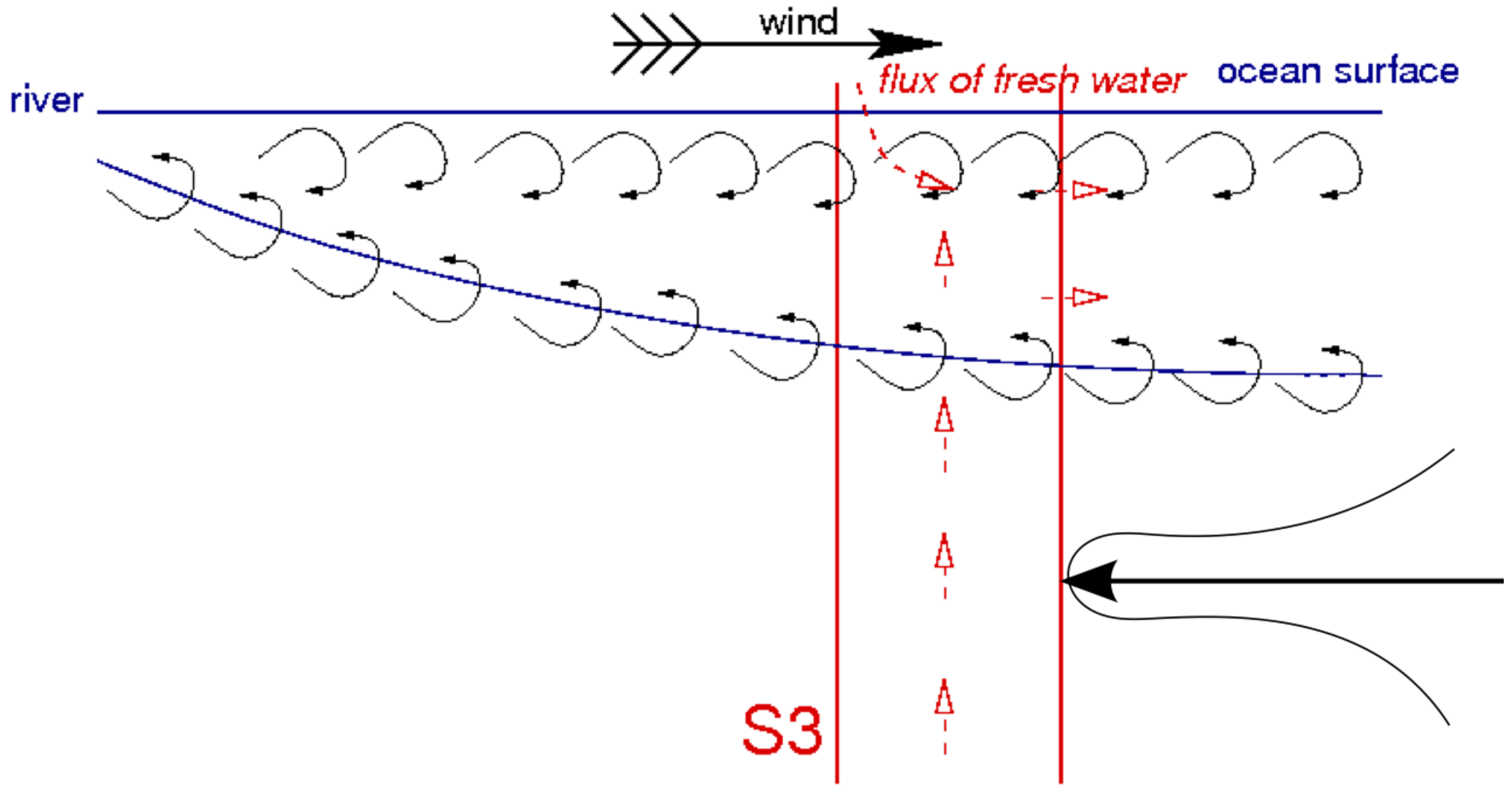
Too much summer productivity



Another Water Mass



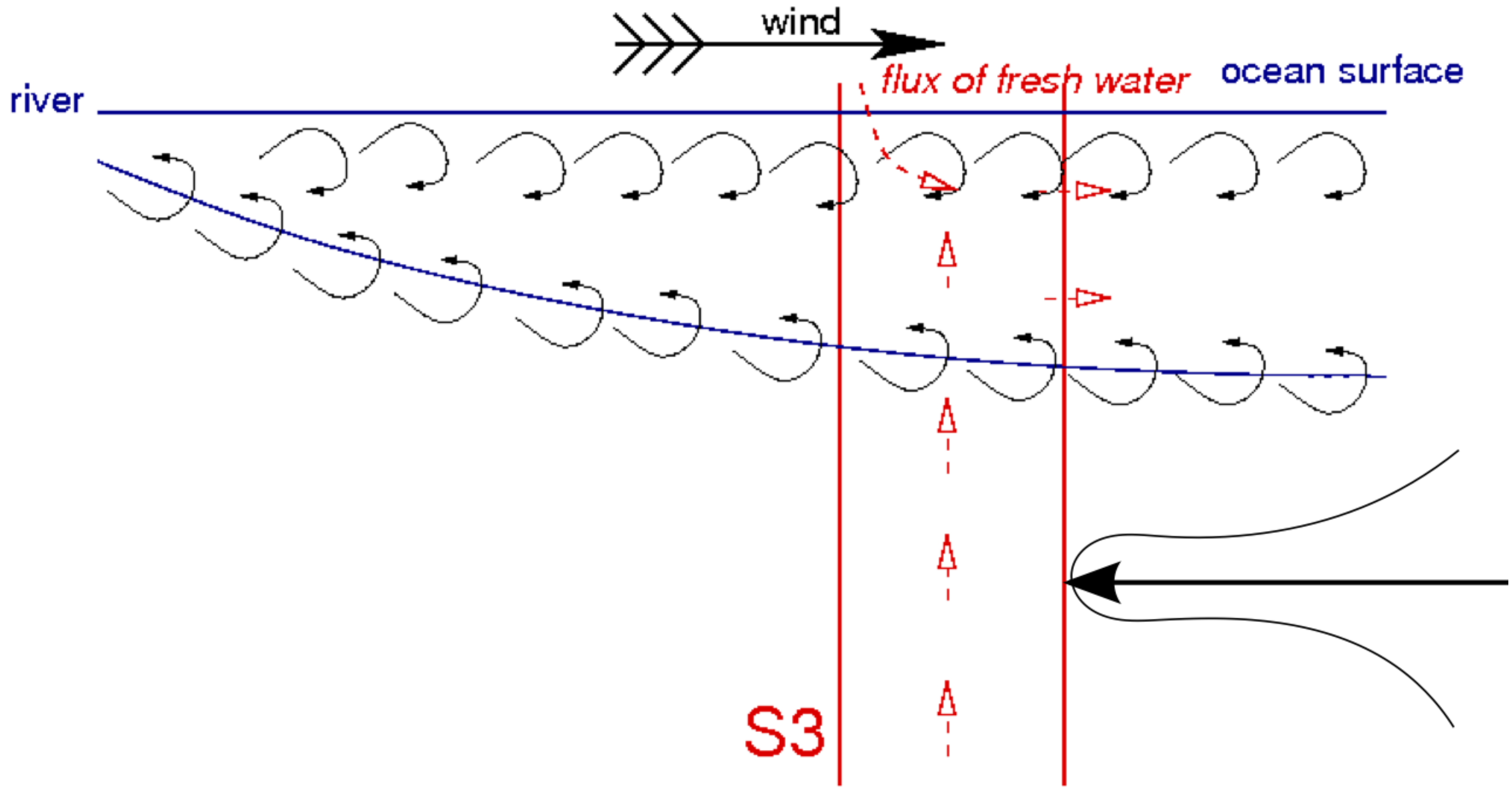
- Summer water mass advected from northern Strait has been near surface and so warm and low in nitrate
- Process probably happens throughout the year but has the greatest impact in the summer



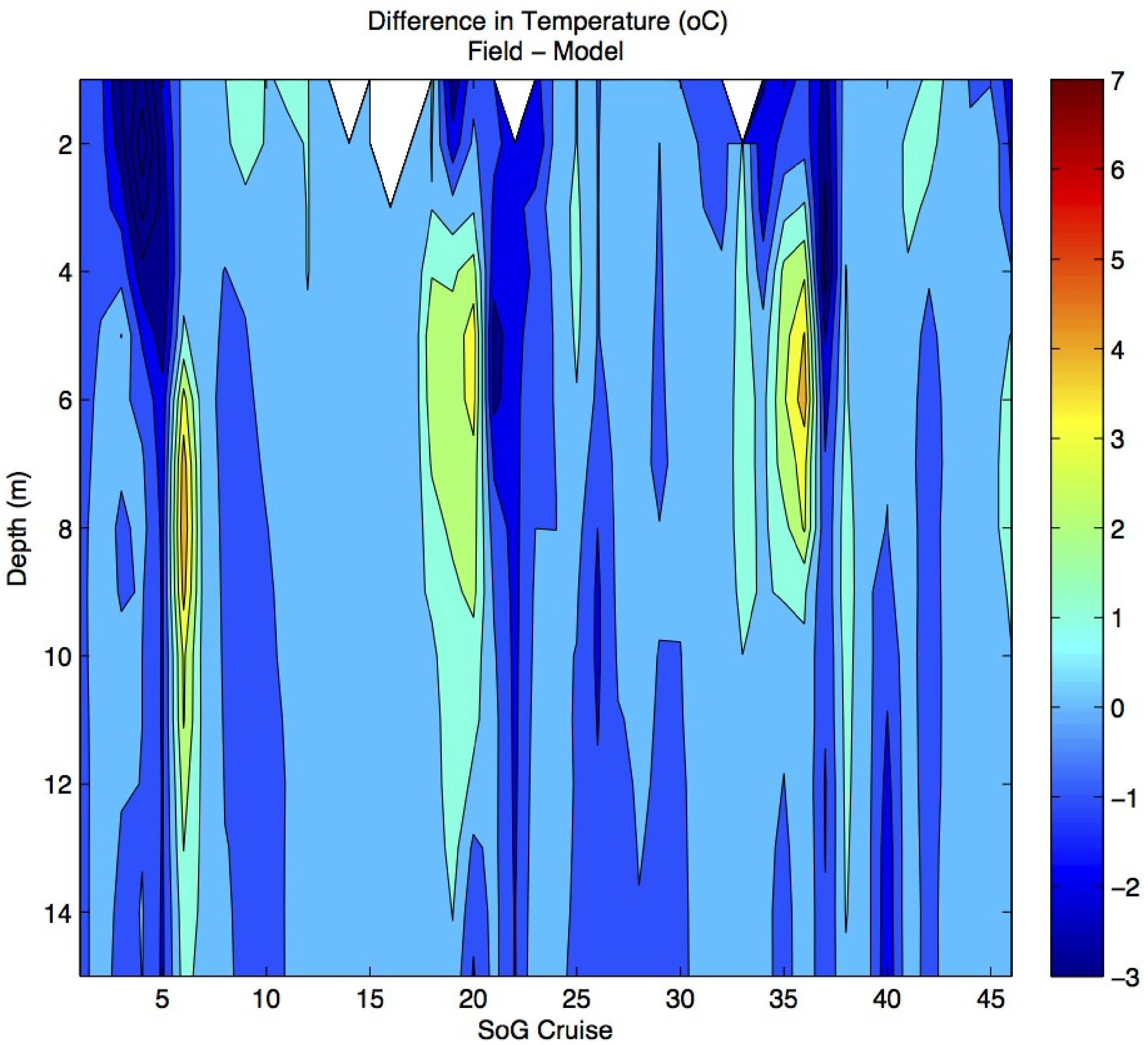
- Amount of horizontal advection proportional to upwelling by Knudsen's relations
- Five fitting parameters: strength, time from surface, depth, width upward, width downward

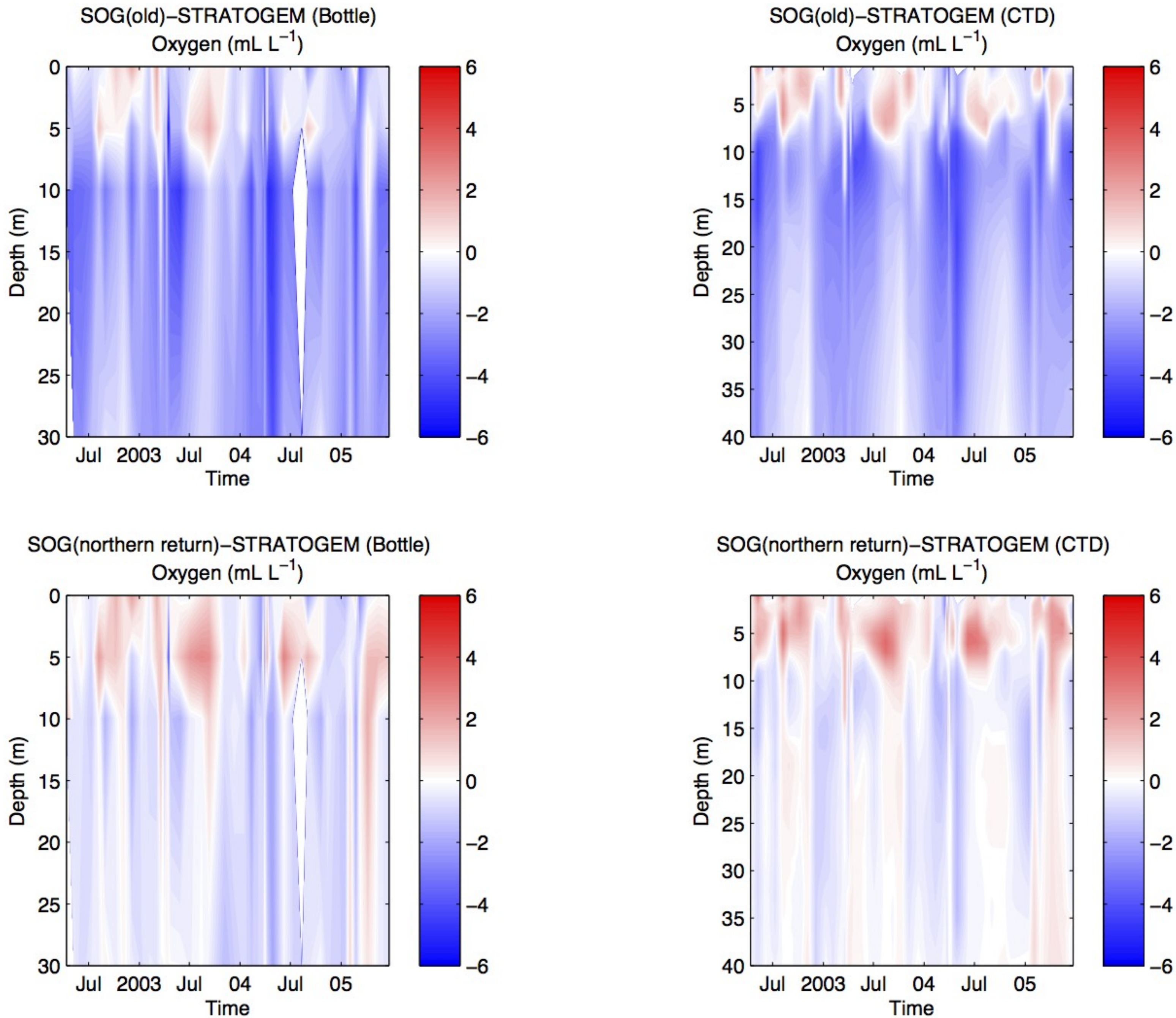
Tuning Northern Advection

- Use temperature data from STRATOGEM to evaluate a given set of parameters (root mean square distance)
- Choose ranges for each parameter based on science
- Randomly choose 20-sets of parameters within the range
- Evaluate, choose top 6, combine & mutate, repeat



- Strength = 0.83 x Knudsen's scaling estimate
- Time from surface = 4 day back average
- Depth = 26 m
- Width Upward = 13 m
- Width Downward = 8 m


Difference in Temperature (oC)
Field – Model
Depth (m)
SoG Cruise
2
4
6
8
10
12
14
5
10
15
20
25
30
35
40
45
7
6
5
4
3
2
1
0
−1
−2
−3


SOG(old)–STRATOGEM (Bottle)
Oxygen (mL L^{-1})
Depth (m)
Time
Jul 2003 Jul 04 Jul 05
SOG(old)–STRATOGEM (CTD)
Oxygen (mL L^{-1})
Depth (m)
Time
SOG(northern return)–STRATOGEM (Bottle)
Oxygen (mL L^{-1})
Depth (m)
Time
SOG(northern return)–STRATOGEM (CTD)
Oxygen (mL L^{-1})
Depth (m)
Time

Results: Northern Return Flow

- Summer productivity and probably carbon cycle estimates require accounting for water mass entering at 20-30 m depth
- This water mass probably comes from the north and carries water that has been near the surface and is thus warm and low in nutrients
- Including this water mass, and tuning, reduces the temperature, nitrate, oxygen and carbon error between the model and the observations.

Conclusions

- Most models cannot resolve all important details
- We can “correct” these models by inserting our knowledge of processes but this requires:
  - Good knowledge of the processes
  - Lots of data to accurately tune parameterizations
- With biology included in the model, there are more cross-checks possible which both
  - Expose missing processes
  - Confirm parameterizations