Impact of Warming and Sea Level Rise on Chesapeake Water Quality

Modeling Quarterly Review

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Chesapeake Bay Program
Science, Restoration, Partnership

Background and Overview

The 2010 TMDL documentation and the 2009 Executive Order call for an assessment of the impacts of a changing climate on the Chesapeake Bay water quality and living resources. The Watershed, Water Quality and Sediment Transport Model (WQSTM) and living resource models will be used to examine the impact of climate change on projected water quality. Current efforts are to frame an initial future climate-change scenario based on estimated 2050 conditions. Conditions to be described include land use, rainfall, air temperature, water temperature, sea level rise, flows and loads from the watershed, increased rainfall intensity, and wetland loss due to sea level rise and associated water quality conditions in the tidal Bay.

Background and Overview

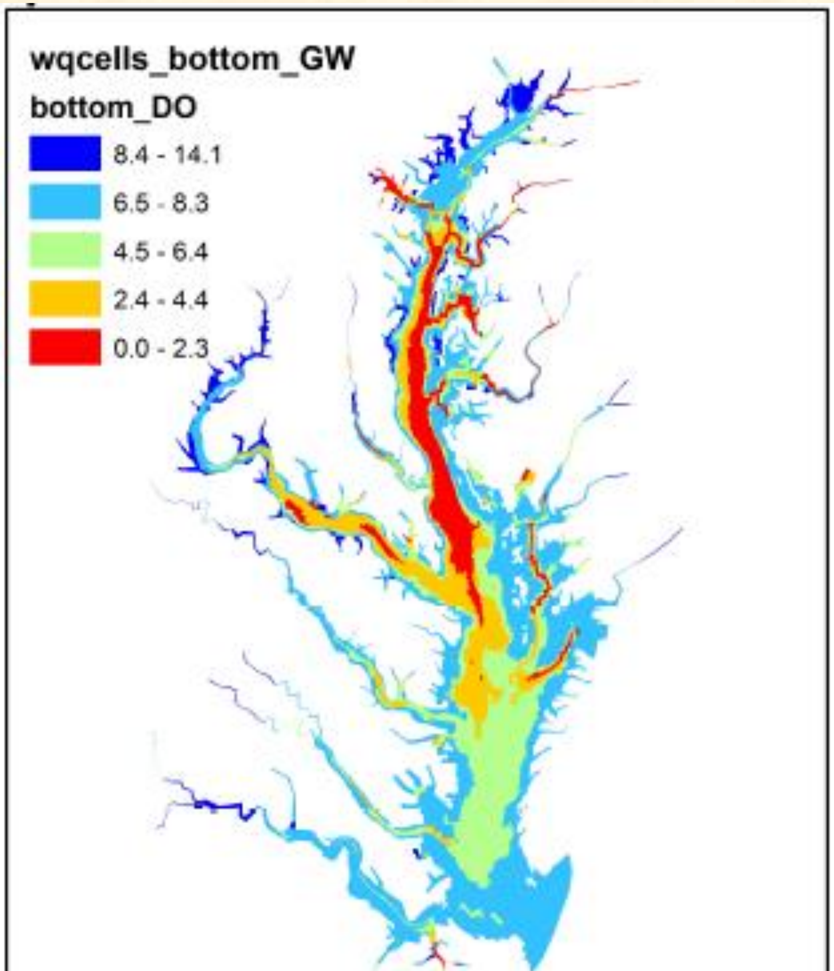
With the CBP models the various elements of climate change can be separately examined in order to understand their influence. The components we'll be examining today are the influence of an estimated 2050 condition of temperature increase (about 2˚C), sea level rise (50 cm), and rainfall intensity.

What remains to be developed and examined in 2015 are:

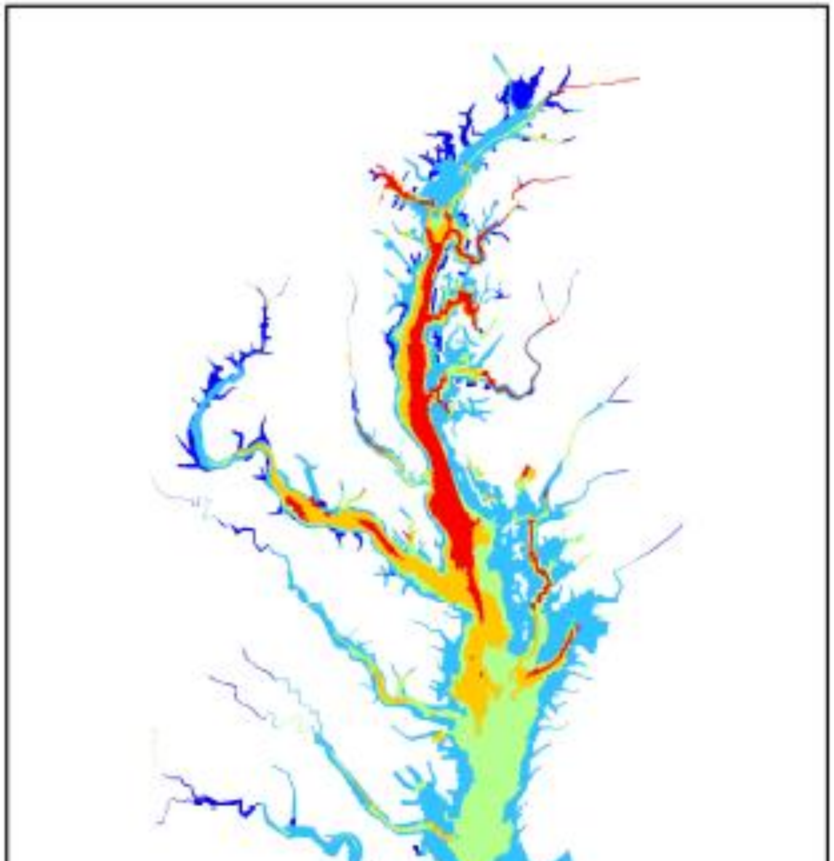
- 2050 land use.
- 2050 flows and loads using latest IPCC downscaled climate change.
- Tidal marsh loss due to sea level rise (2016 product).
- A combined scenario of all components.

2050 Estimated Temperature Increase

The Phase 6 prototype calibration was used as a basis for relative differences with scoping scenarios of 2050 temperature change and sea level rise. Average of 1991-2000 June to September bottom cell DO shown.



Phase 6 Prototype Calibration



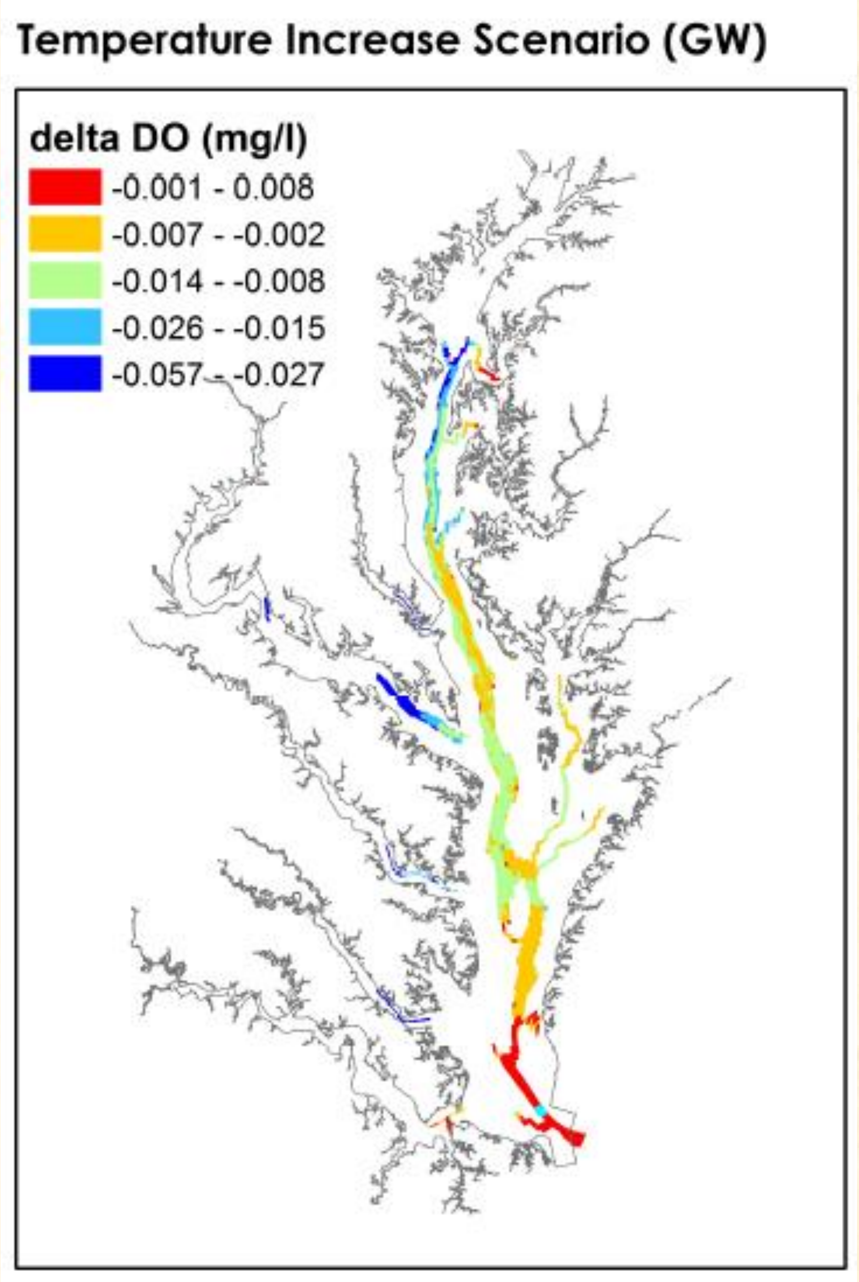
Phase 6 Prototype Calibration with 2050 Estimated Temperature Increase

2050 Estimated Temperature Increase

- **The influence of an 2050 estimated temperature increase on Chesapeake hypoxia is small.**

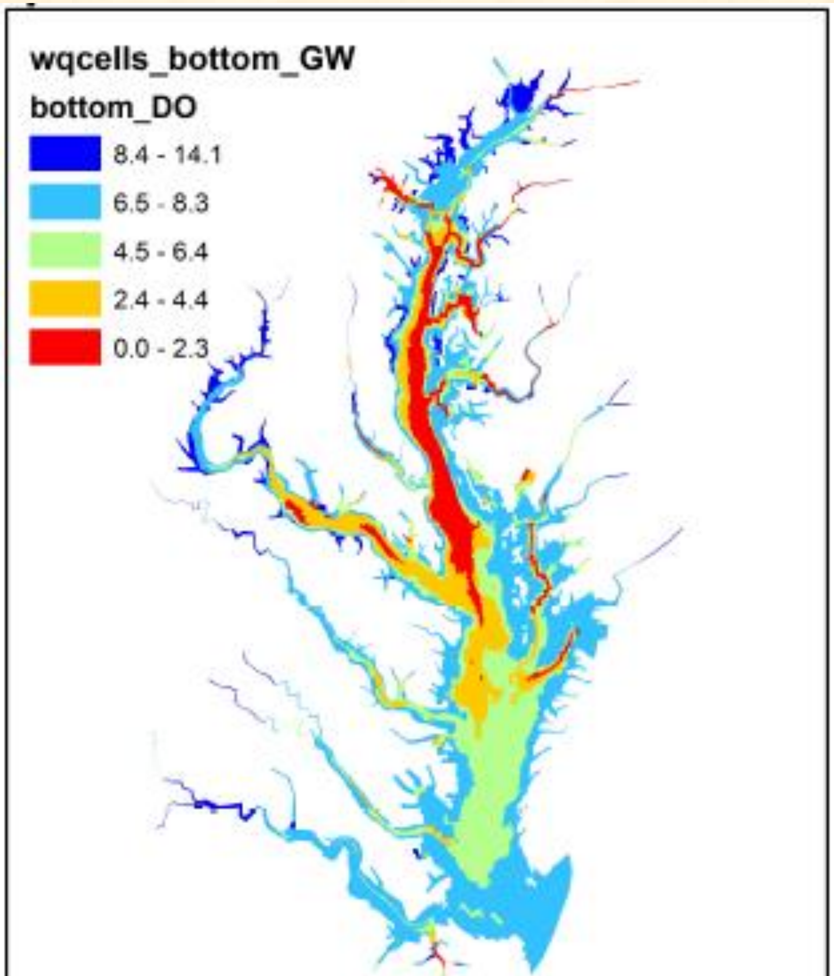
- **But, we can measure in infinitesimal with our models. The estimated delta increase in Chesapeake hypoxia due to 2050 estimated temperature increases ranges from - 0.06 to + 0.01 mg/l.**

- **Hypoxia increases are due to slight increases in vertical stratification due to the increased thermocline and because of increased respiration.**

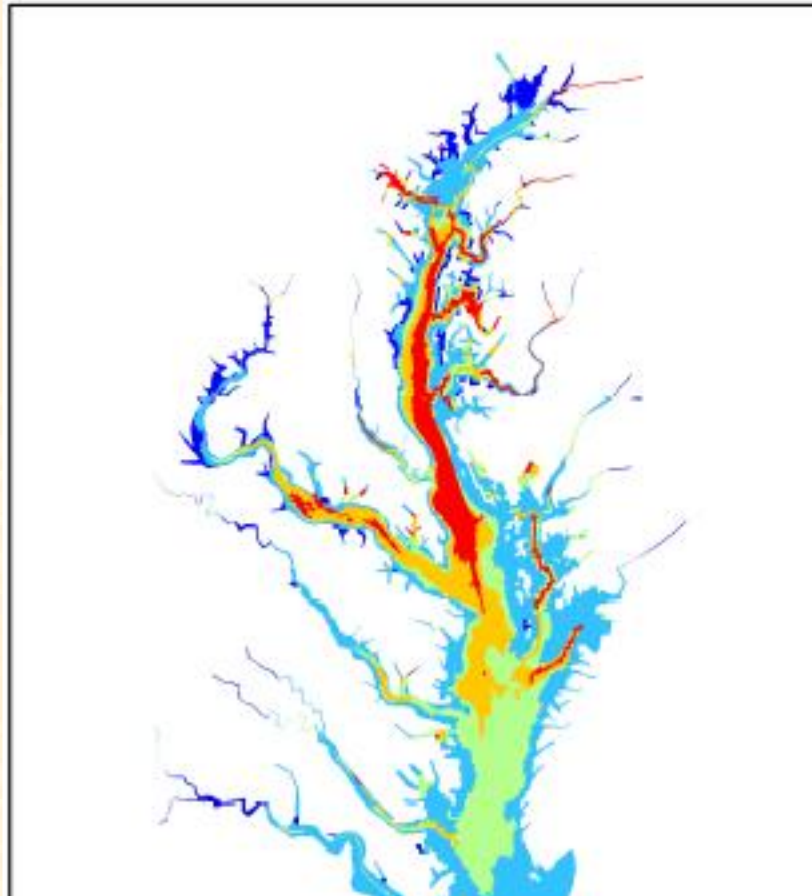


2050 Estimated Sea Level Rise

The Phase 6 prototype calibration was used as a basis for relative differences with scoping scenarios of 2050 temperature change and sea level rise. Average of 1991-2000 June-September bottom cell DO shown.



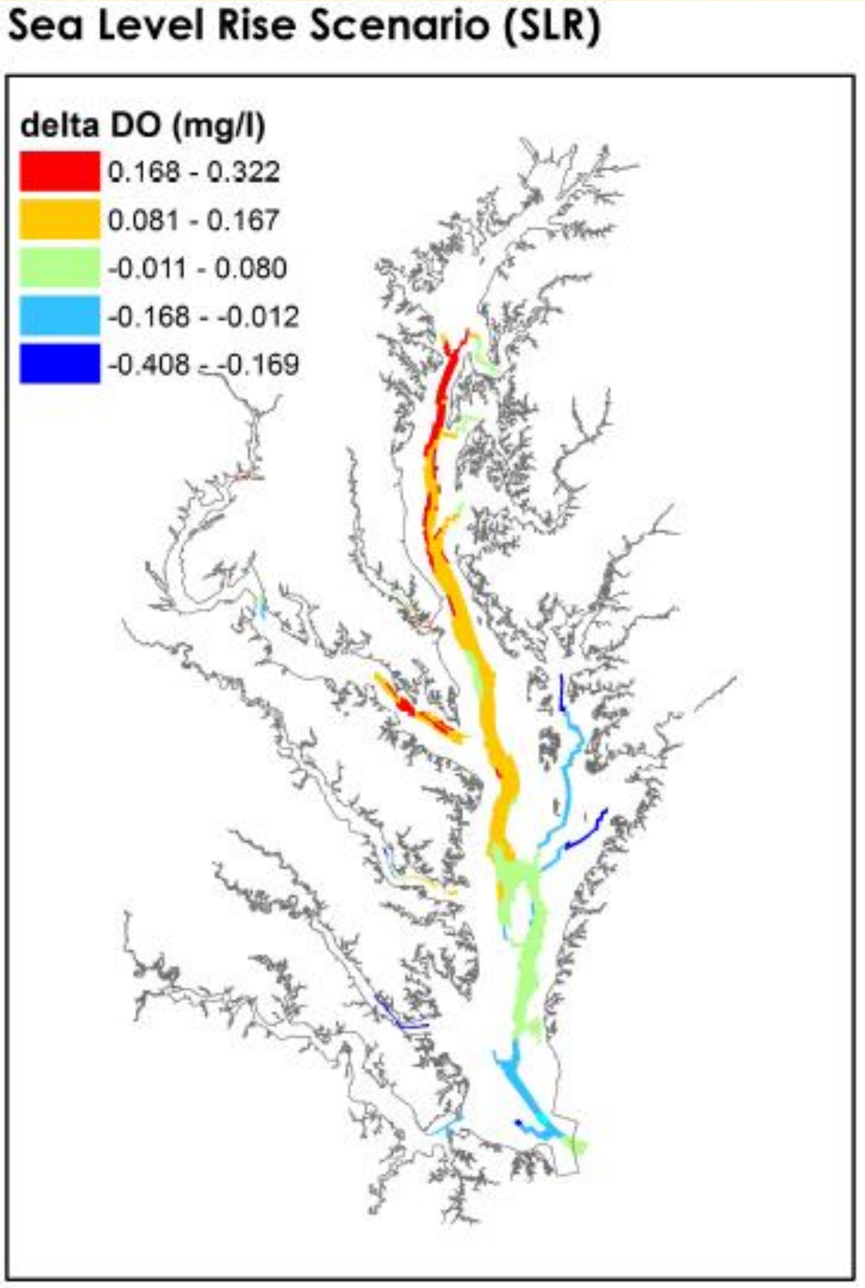
Phase 6 Prototype Calibration



Phase 6 Prototype Calibration with 2050 Estimated Sea Level Rise

2050 Estimated Sea Level Rise

- **The influence of an 2050 estimated sea level rise on Chesapeake hypoxia is small.**
- **The estimated delta increase in Chesapeake hypoxia due to 2050 estimated sea level rise ranges from + 0.3 to - 0.4 mg/l.**
- **Hypoxia decreases in the mid-Bay are due to increased ventilation of deep Chesapeake waters by high DO ocean waters and due to changes in vertical stratification.**



How the findings fit into current literature

The increase of about a 1 cm year of sea level rise (SLR) is consistent with historical and current observed rates of sea level rise in the Chesapeake.

- Boon et al., 2010. Chesapeake Bay land subsidence and sea level change: an evaluation of past and present trends and future outlook.
- Updating Maryland's Sea-level Rise Projections Report, 2013
- Kemp et al., 2011. Climate related sea-level variations over the past two millennia.
- and others.

The increase in up-estuary salinity intrusion with SLR is consistent with historical observations and with Hilton et al., 2008 and Hong and Shen, 2012.

The increase in salinity flux at the mouth of the Bay with SLR is consistent with Hong and Shen, 2012.

The increase in rainfall intensity is consistent with historical observations for the last century and with Karl and Knight, 1997 and others.

1) Sea level rise (SLR) – about 50 cm. It impacts Bay's salinity.

2) Air temperature increase – 1.5-1.9 ^{o}C. Causing Water T increase.

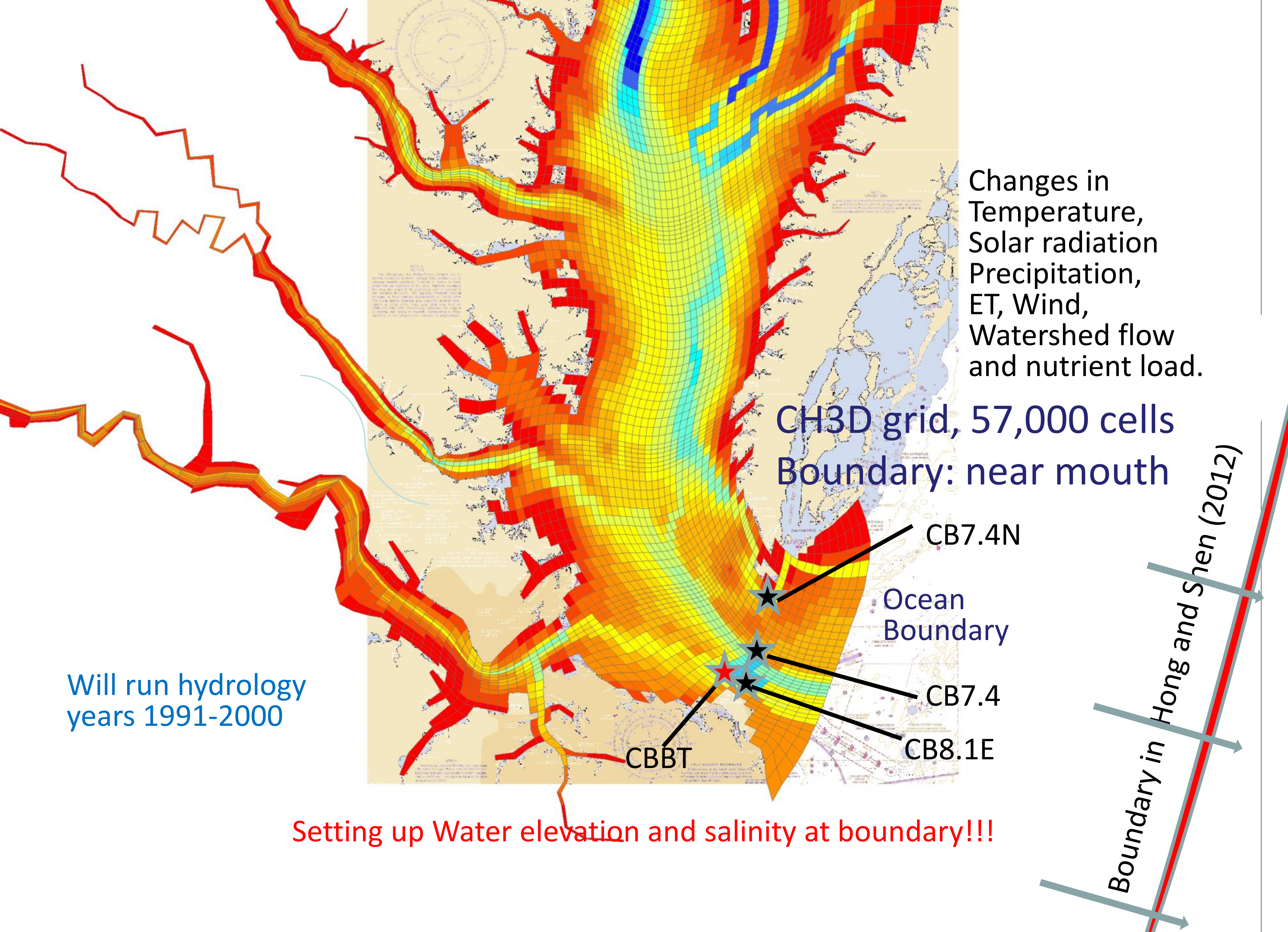
Therefore, SLR and temperature increase will modify circulation, stratification, and WQ of the Bay.

Modeling tool: WQSTM -- the regulatory model currently used in Bay's TMDL. It is a coupled CH3D hydrodynamic model and CE-QUAL-ICM water quality model.

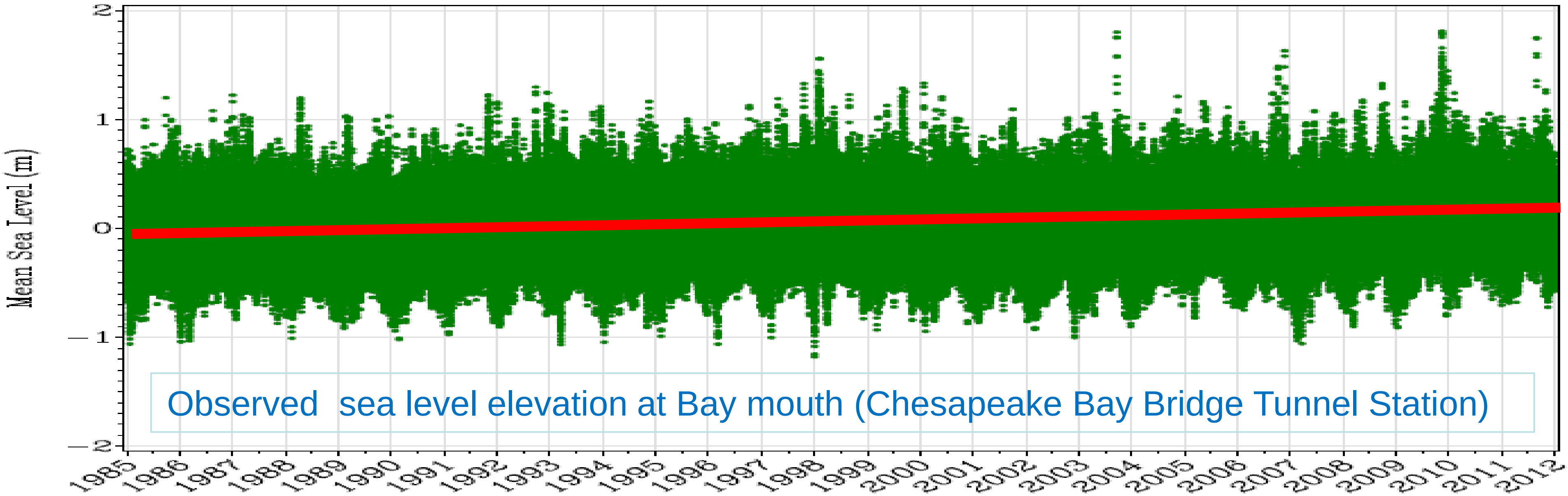
Hydrology Years: 1991-2000, which are the hydrology used in the Bay's TMDL assessment. Using hydrology from WSM P6 provisional, the prototype calibration.

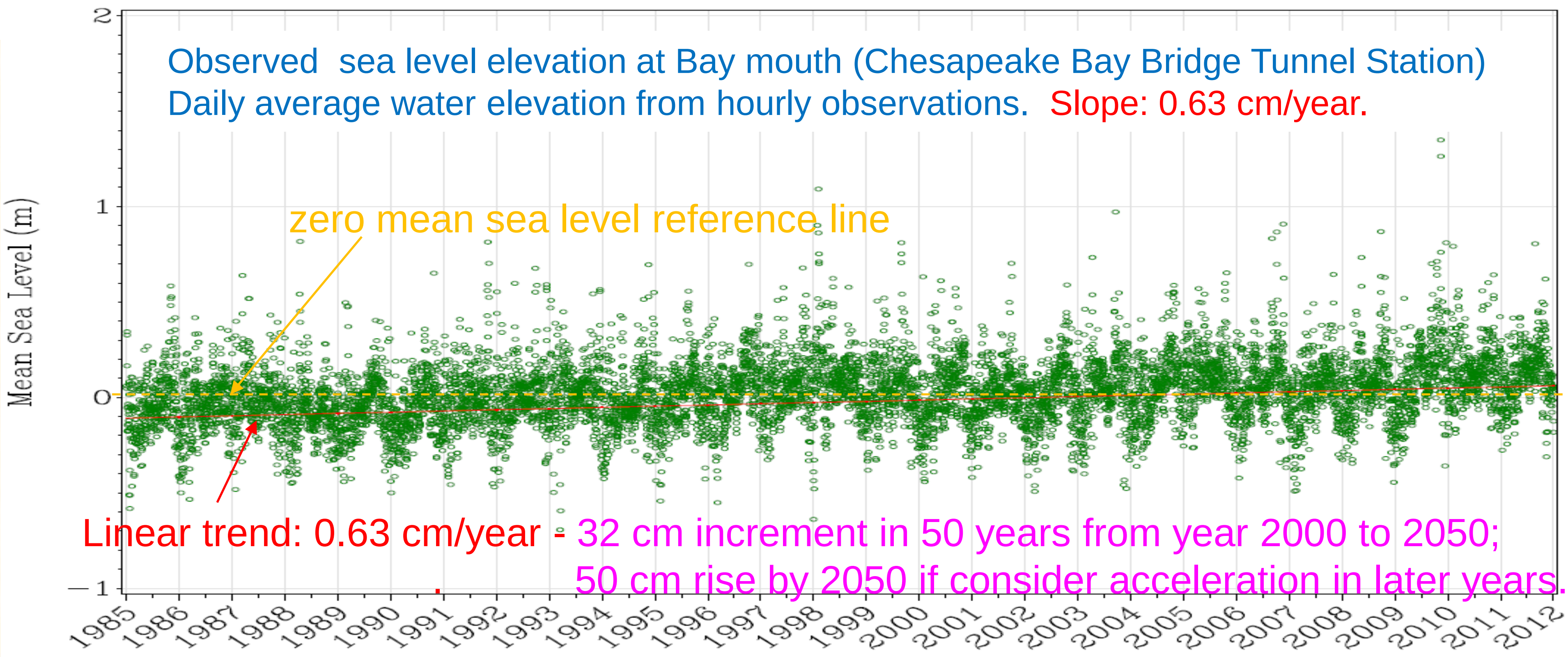
Four Model Scenarios:

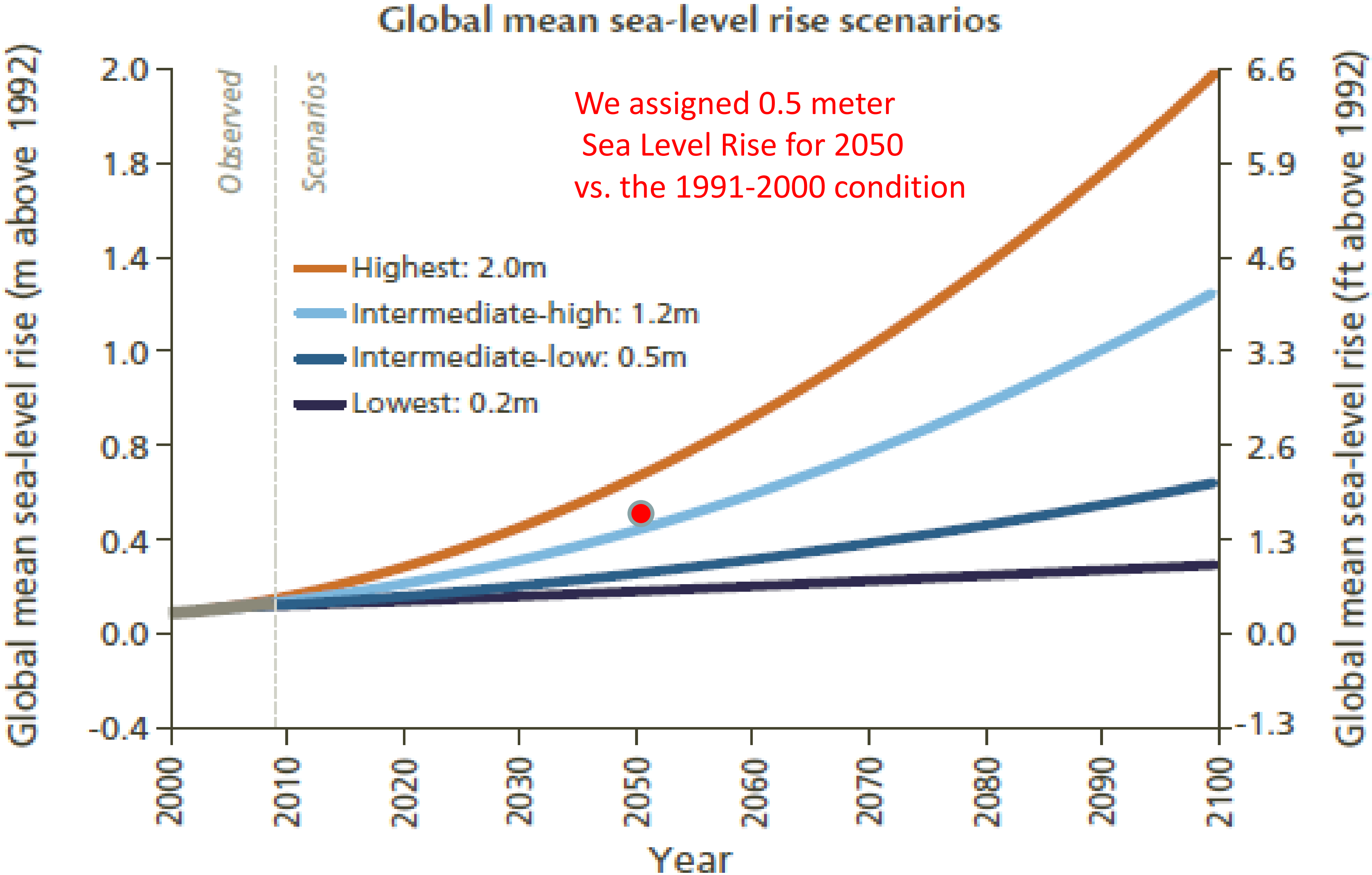
1) Base: calibration condition (1991-2000) of WSM p6 provisional.
2) SLR (Sea level rise) – 50 cm SLR.
3) GW (Global warming) – air T in 2050.
4) GW+SLR (Global warming and Sea level rise).



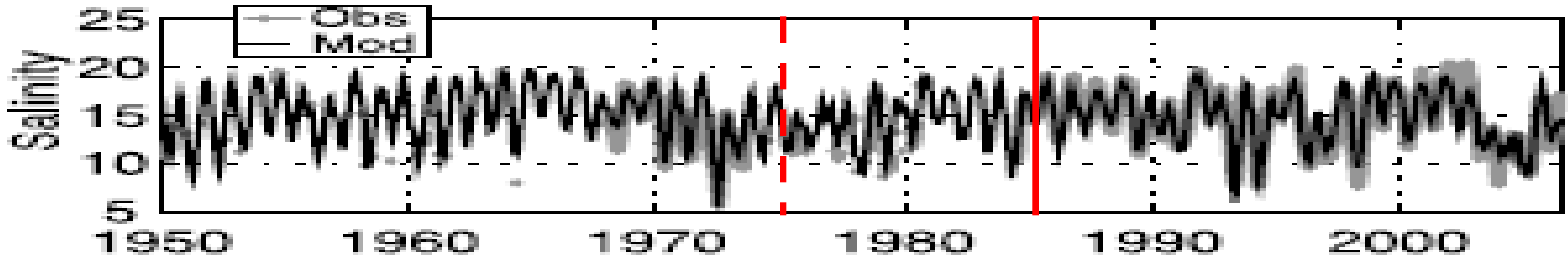
Salinity difference: Deep water DO (?) Wetland loss Expand laterally

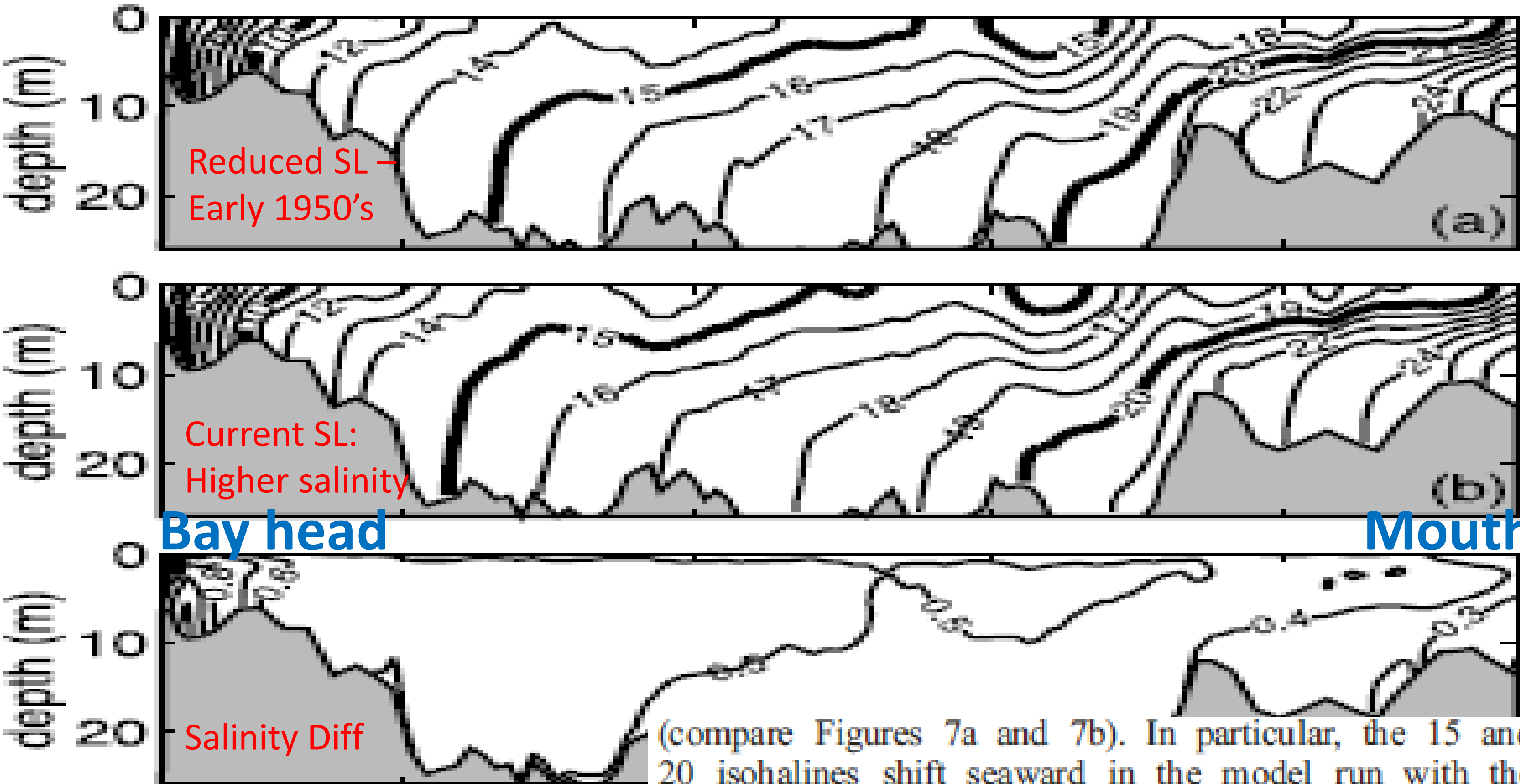

Observed sea level elevation at Bay mouth (Chesapeake Bay Bridge Tunnel Station)
Mean Sea Level (m)
2
1
0
−1
−2
1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012


Observed sea level elevation at Bay mouth (Chesapeake Bay Bridge Tunnel Station)
Daily average water elevation from hourly observations. Slope: 0.63 cm/year.
zero mean sea level reference line
Linear trend: 0.63 cm/year - 32 cm increment in 50 years from year 2000 to 2050;
50 cm rise by 2050 if consider acceleration in later years.
Mean Sea Level (m)
2
1
0
−1
1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012



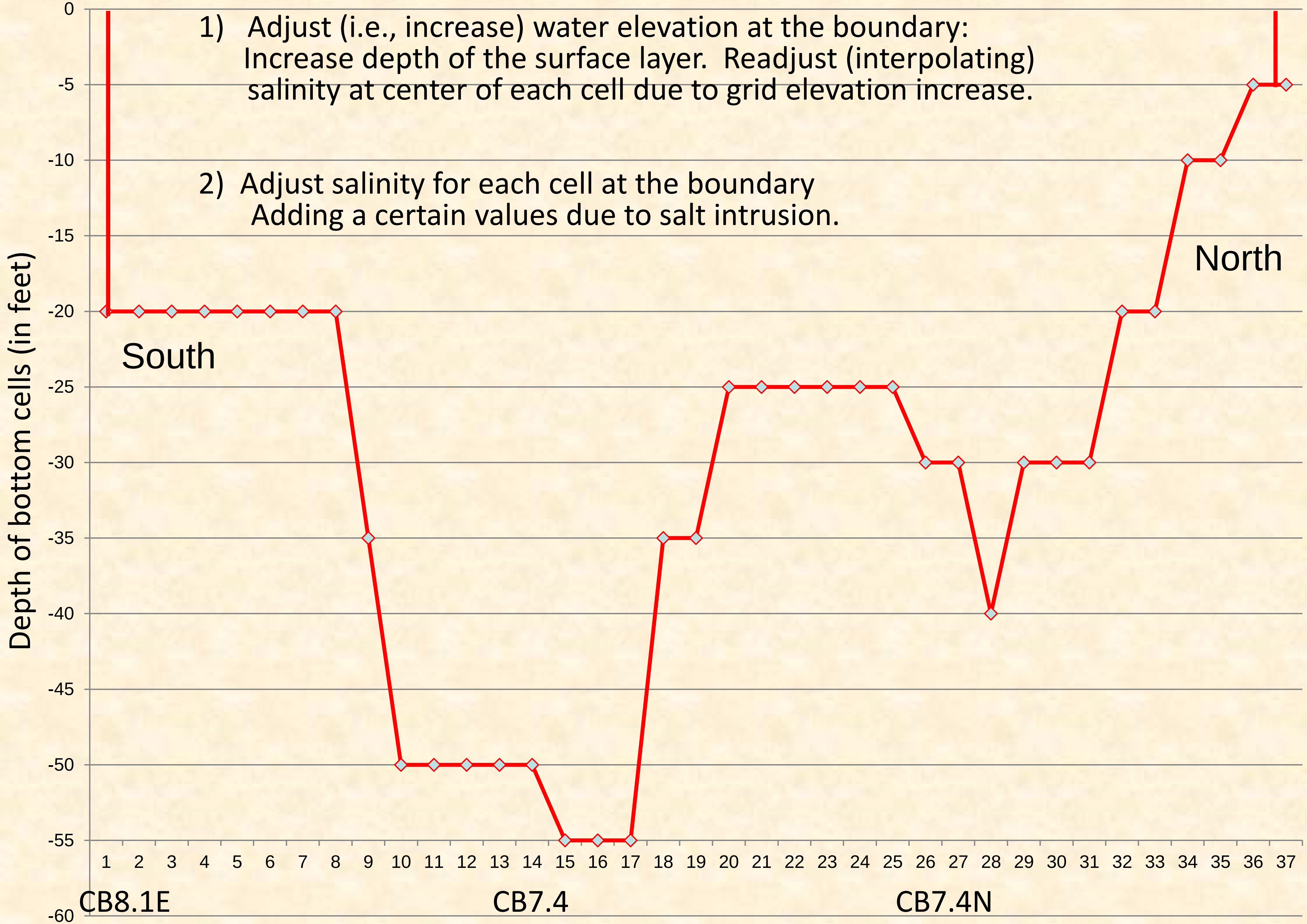
Parris, A. et al. 2012. *Global Sea Level Rise Scenarios for the United States National Climate Assessment. NOAA Technical Report OAR CPO-1. National Oceanic and Atmospheric Administration, Silver Spring, Maryland.*





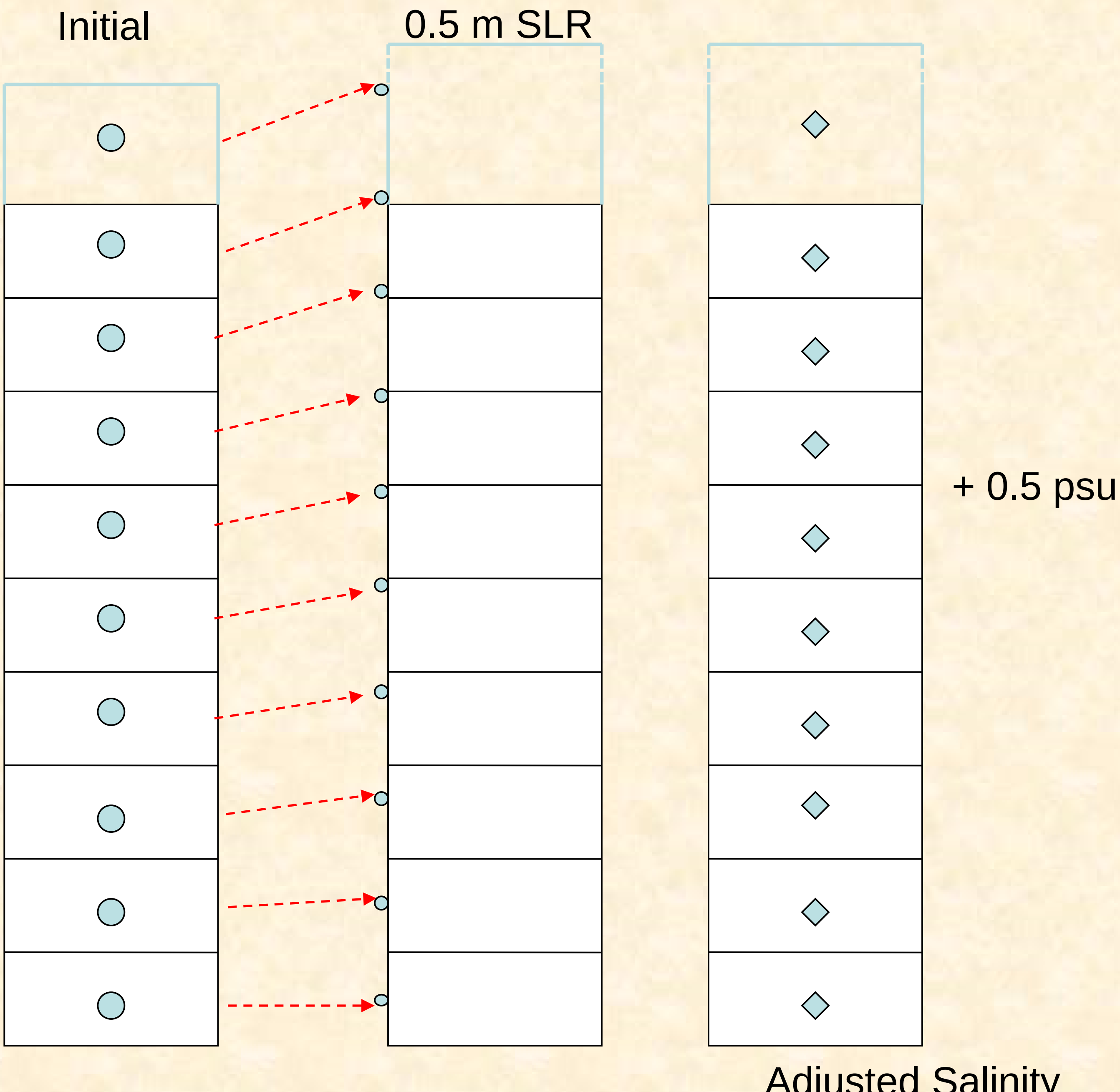
T. W. Hilton, R. G. Najjar, L. Zhong, and M. Li (2009)

(compare Figures 7a and 7b). In particular, the 15 and 20 isohalines shift seaward in the model run with the reduced sea level. In other words, the sea-level rise causes saline water to intrude further landward as expected. In

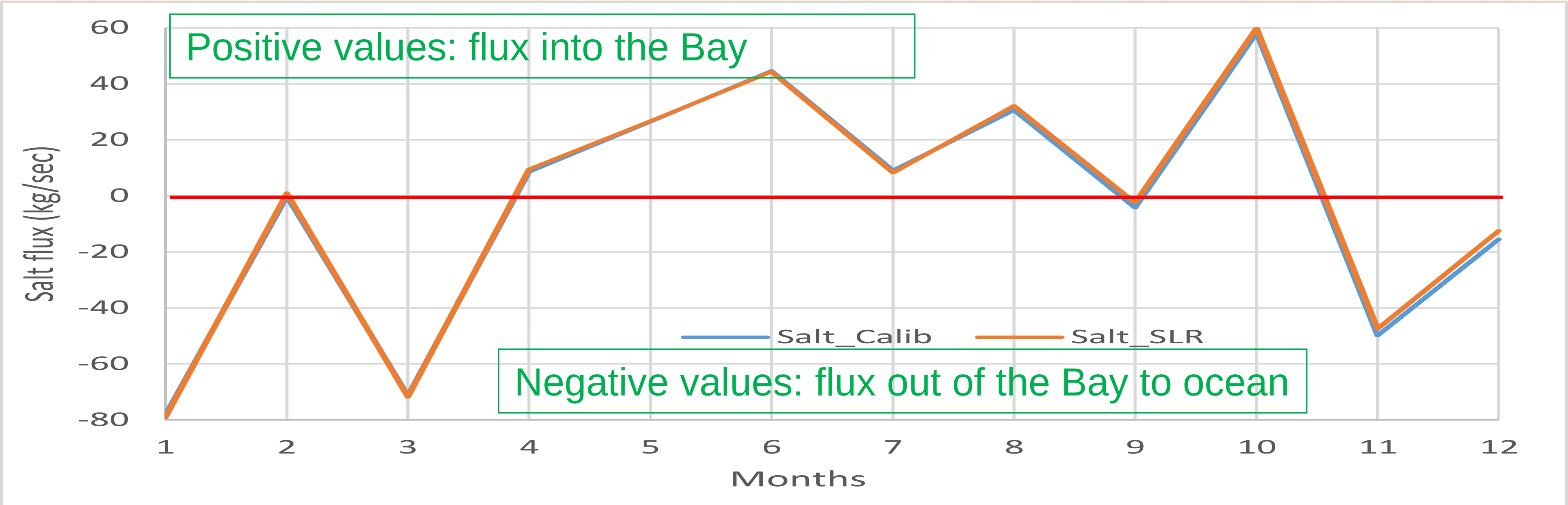


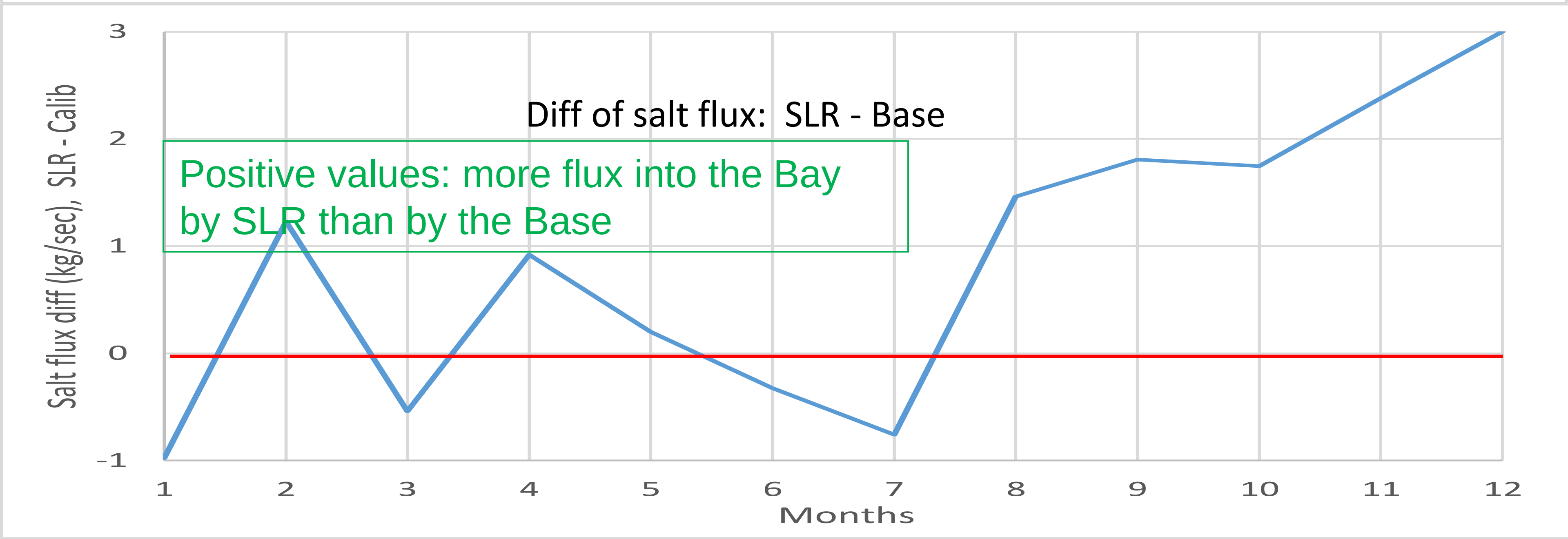
1) Adjust (i.e., increase) water elevation at the boundary:
Increase depth of the surface layer. Readjust (interpolating) salinity at center of each cell due to grid elevation increase.
2) Adjust salinity for each cell at the boundary
Adding a certain values due to salt intrusion.
North
South
Depth of bottom cells (in feet)
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
-60
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37
CB8.1E
CB7.4
CB7.4N

Boundary salinity setting

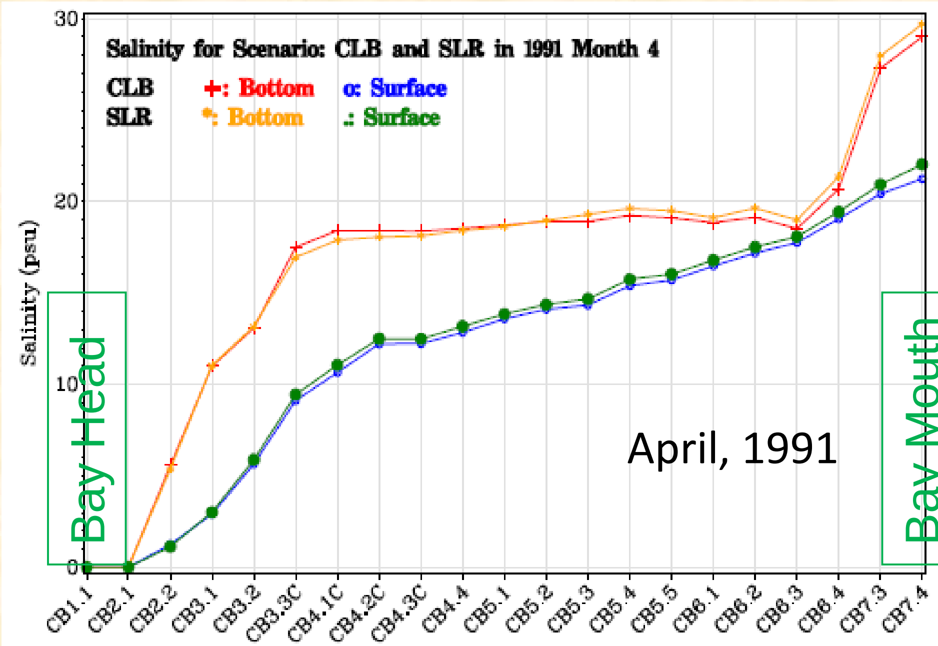


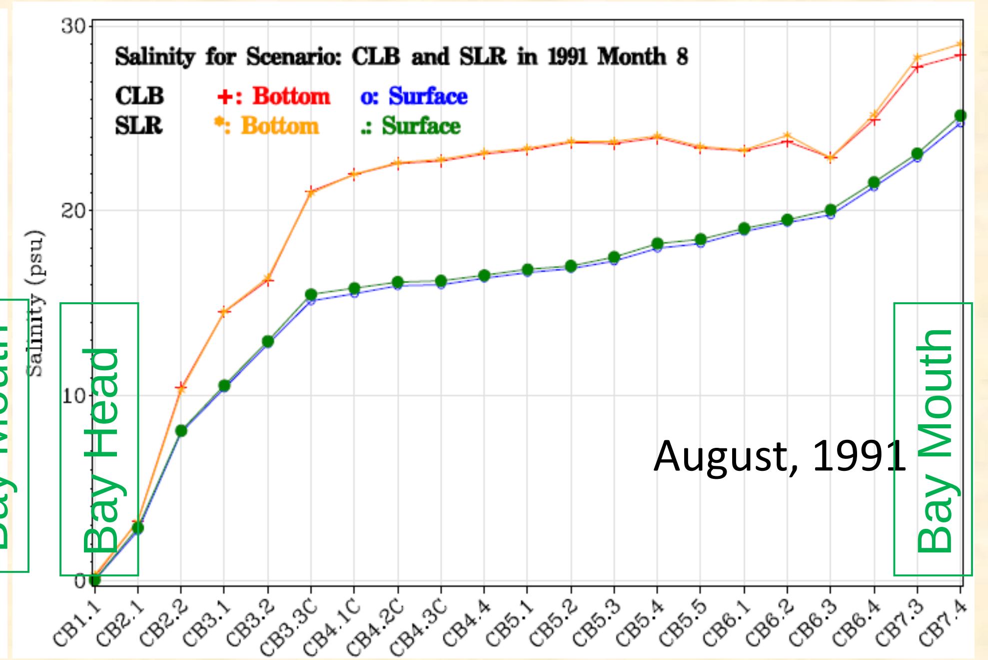
Monthly average salt flux at the boundary

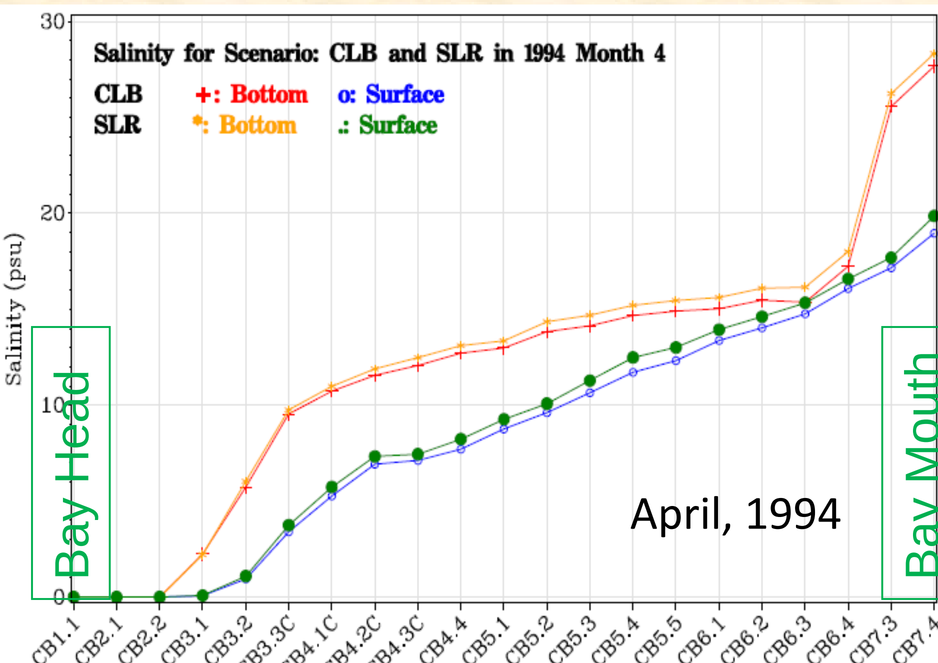


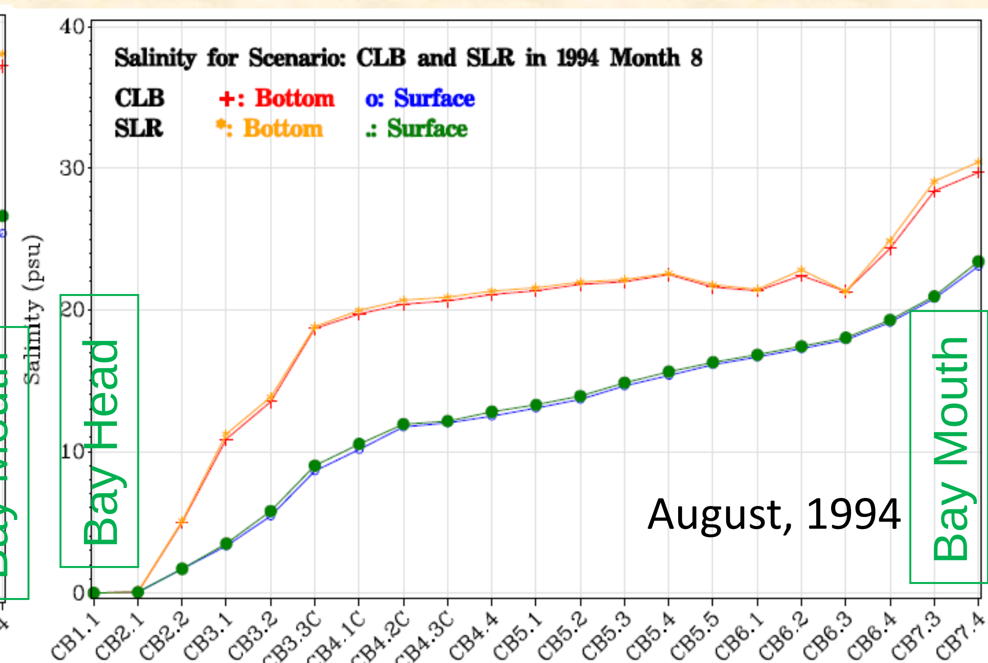


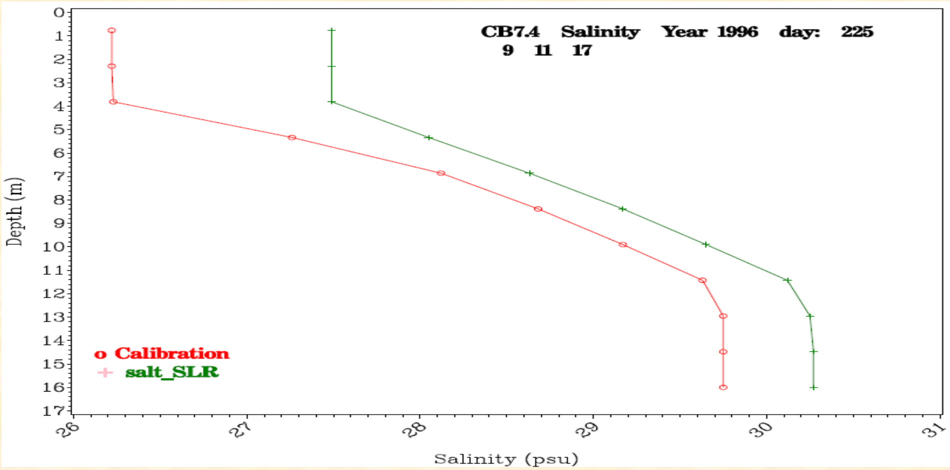
Average Bottom and Surface salinity

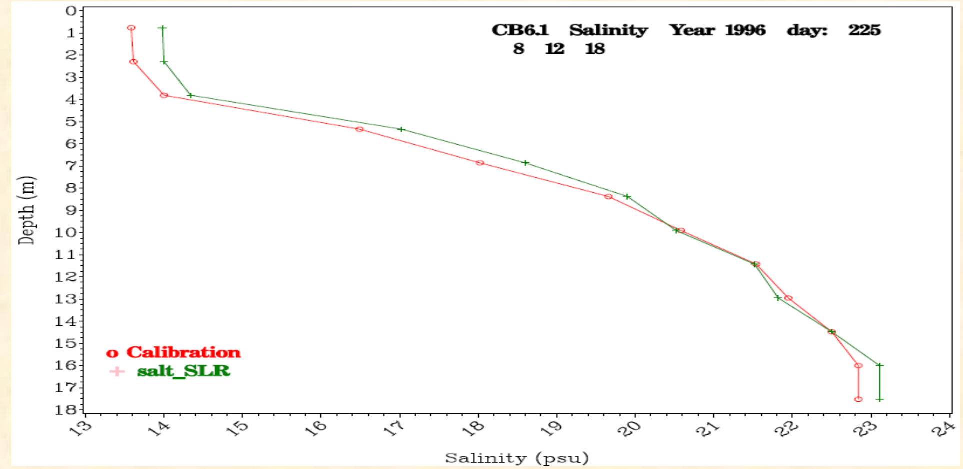


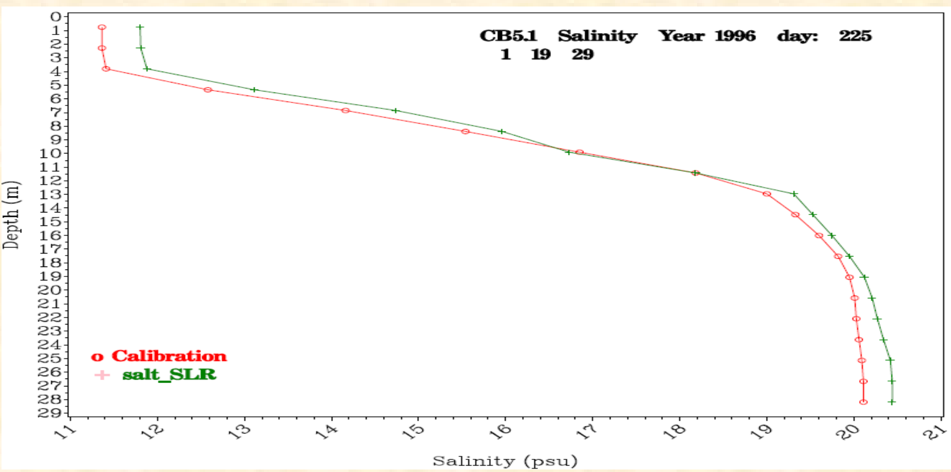


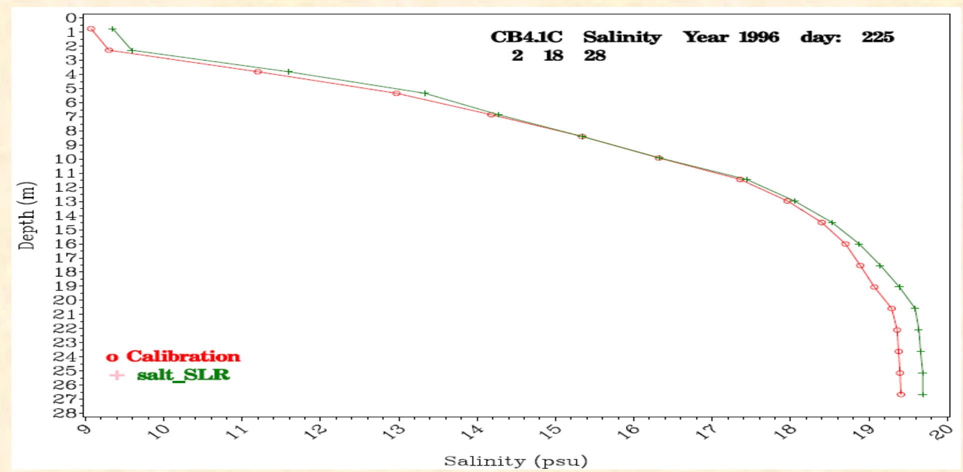


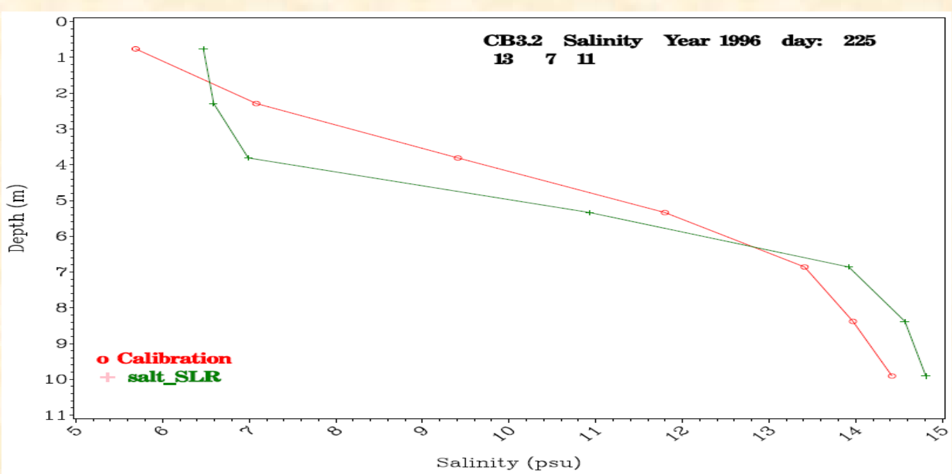


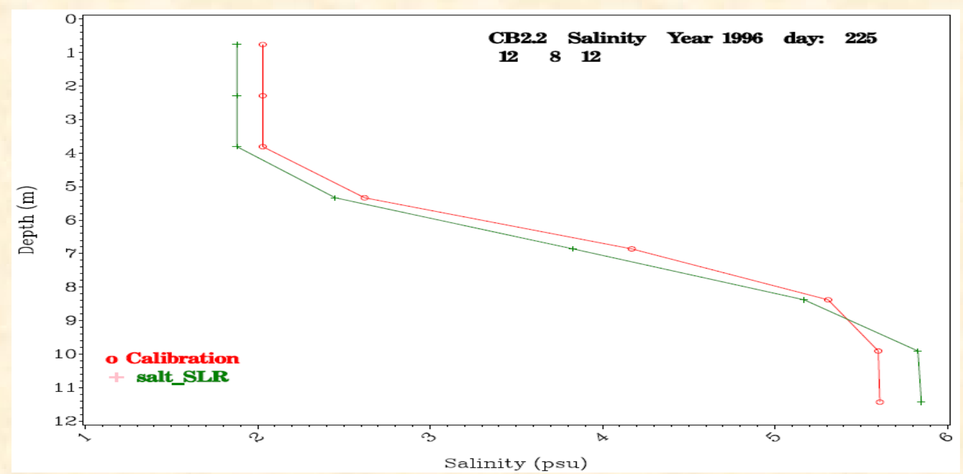

CB7.4 Salinity Year 1996 day: 225
9 11 17
o Calibration
+ salt_SLR
Depth (m)
Salinity (psu)


CB6.1 Salinity Year 1996 day: 225
8 12 18
o Calibration
+ salt_SLR
Depth (m)
Salinity (psu)

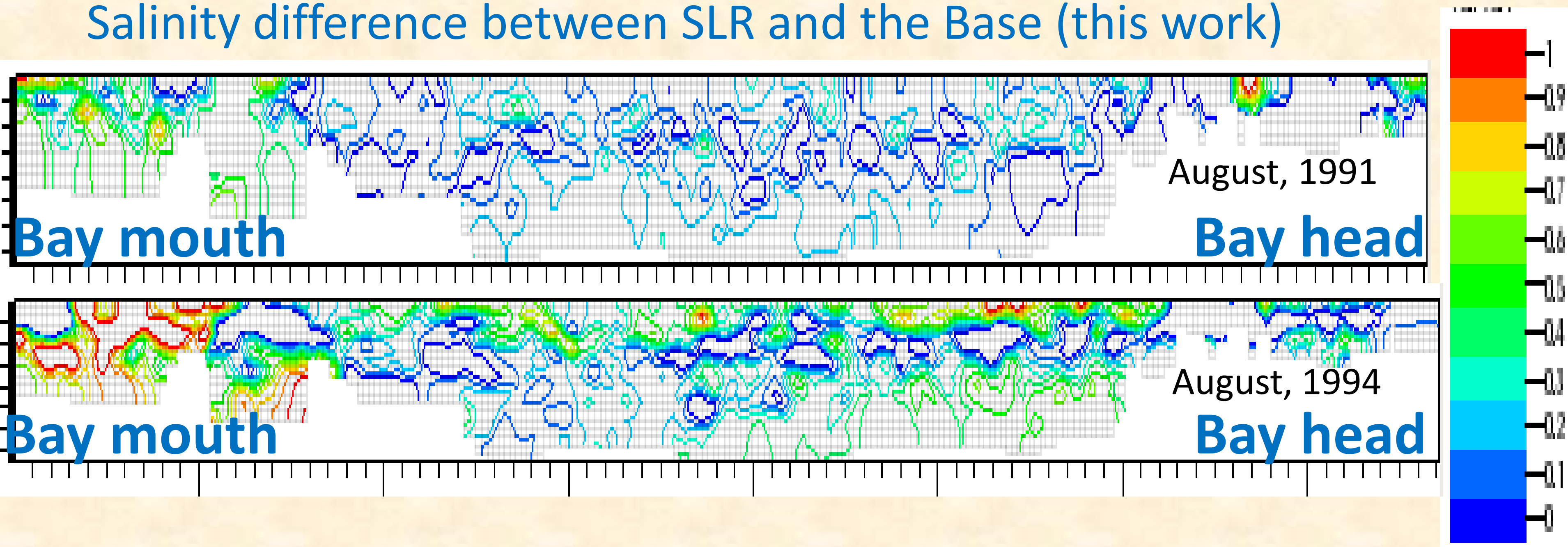

CB5.1 Salinity Year 1996 day: 225
1 19 29
o Calibration
+ salt_SLR
Depth (m)
Salinity (psu)


CB4.1C Salinity Year 1996 day: 225
2 18 28
o Calibration
+ salt_SLR
Depth (m)
Salinity (psu)

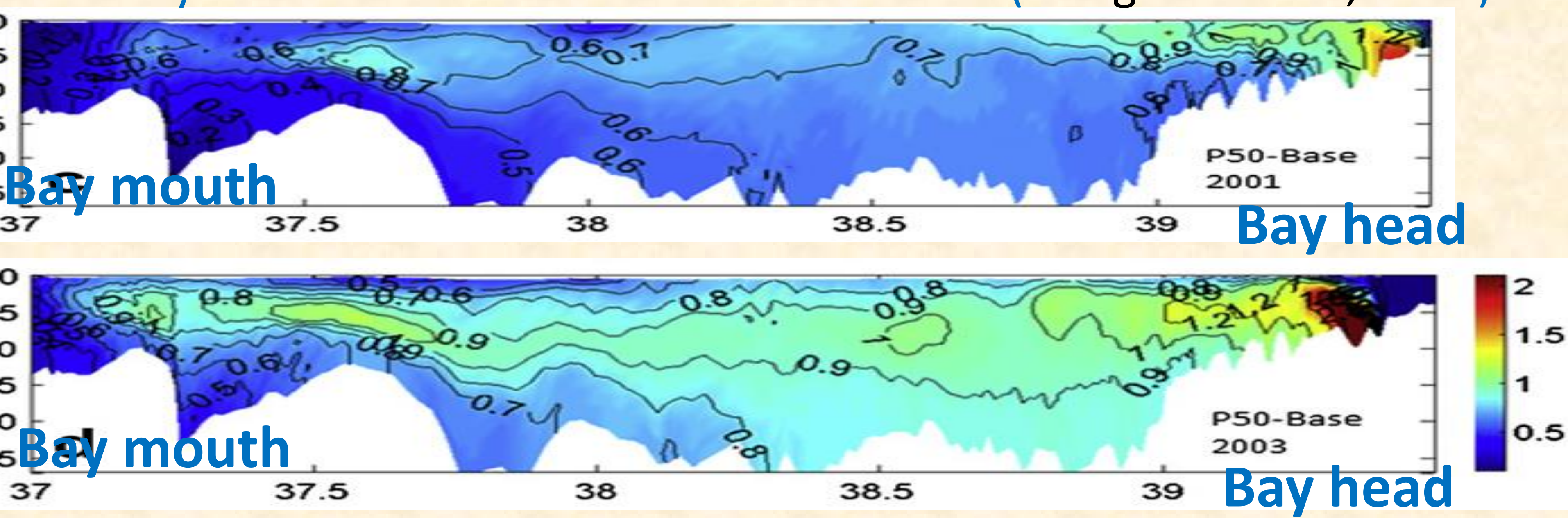

CB3.2 Salinity Year 1996 day: 225
13 7 11
o Calibration
+ salt_SLR
Depth (m)
Salinity (psu)

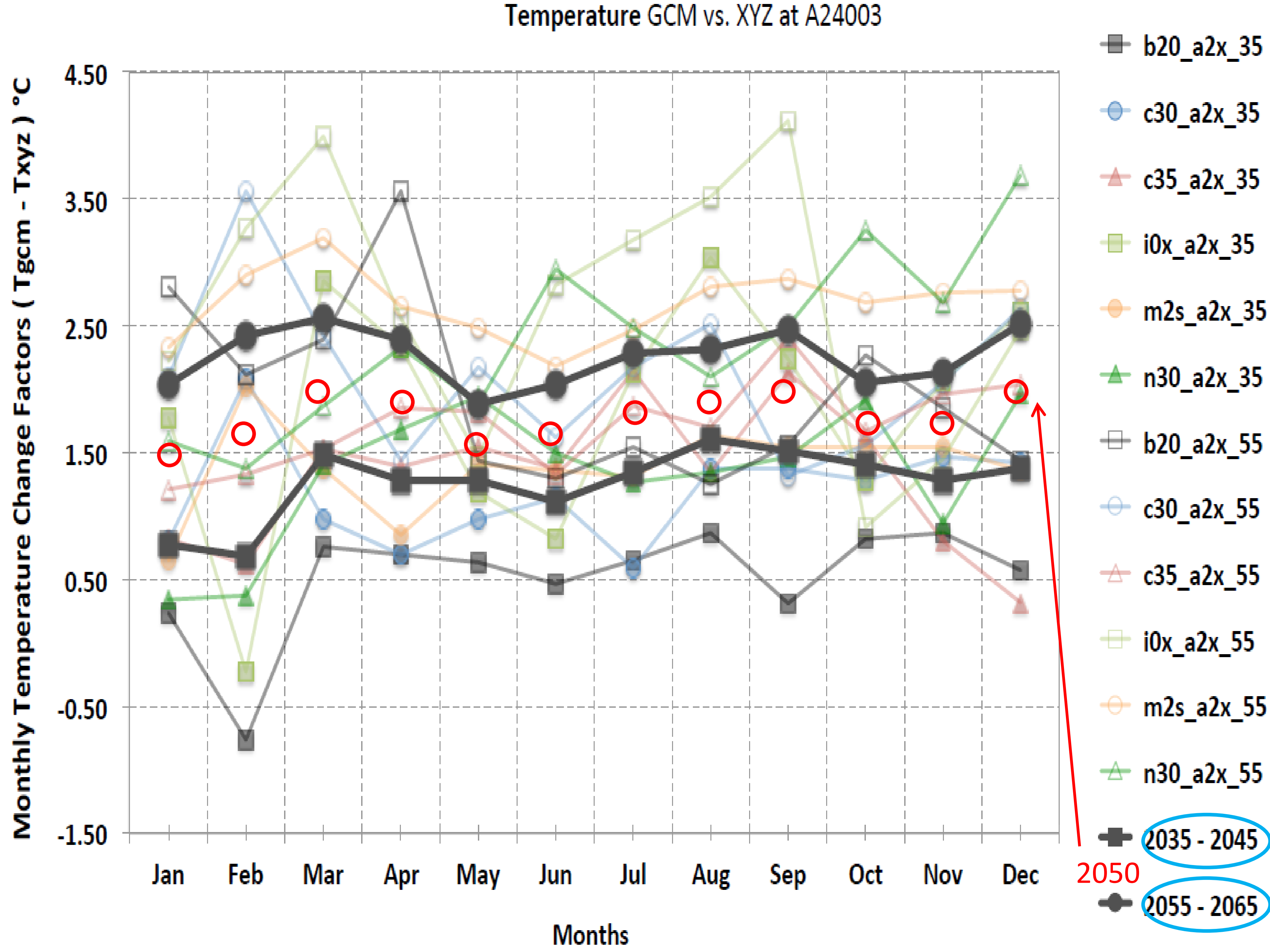

CB2.2 Salinity Year 1996 day: 225
12 8 12
o Calibration
+ salt_SLR
Depth (m)
Salinity (psu)

Salinity difference between SLR and the Base (this work)

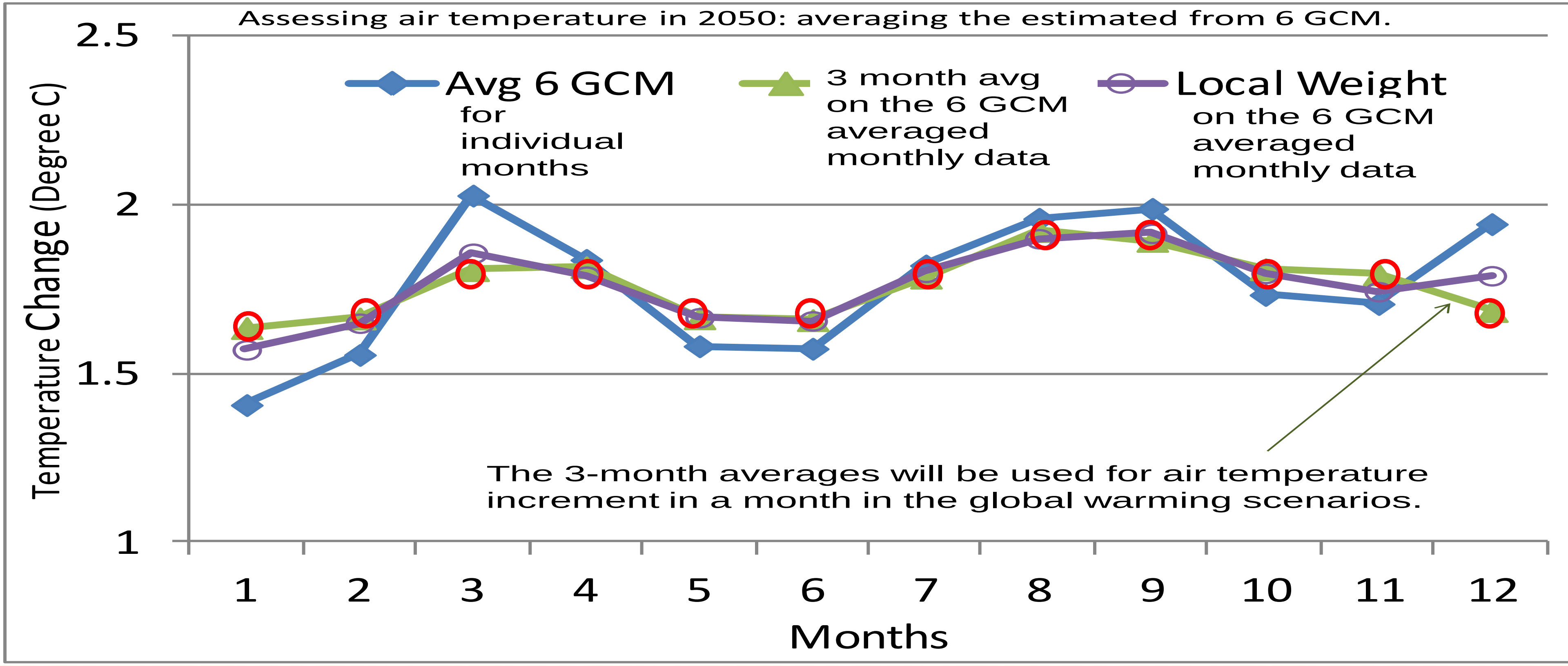


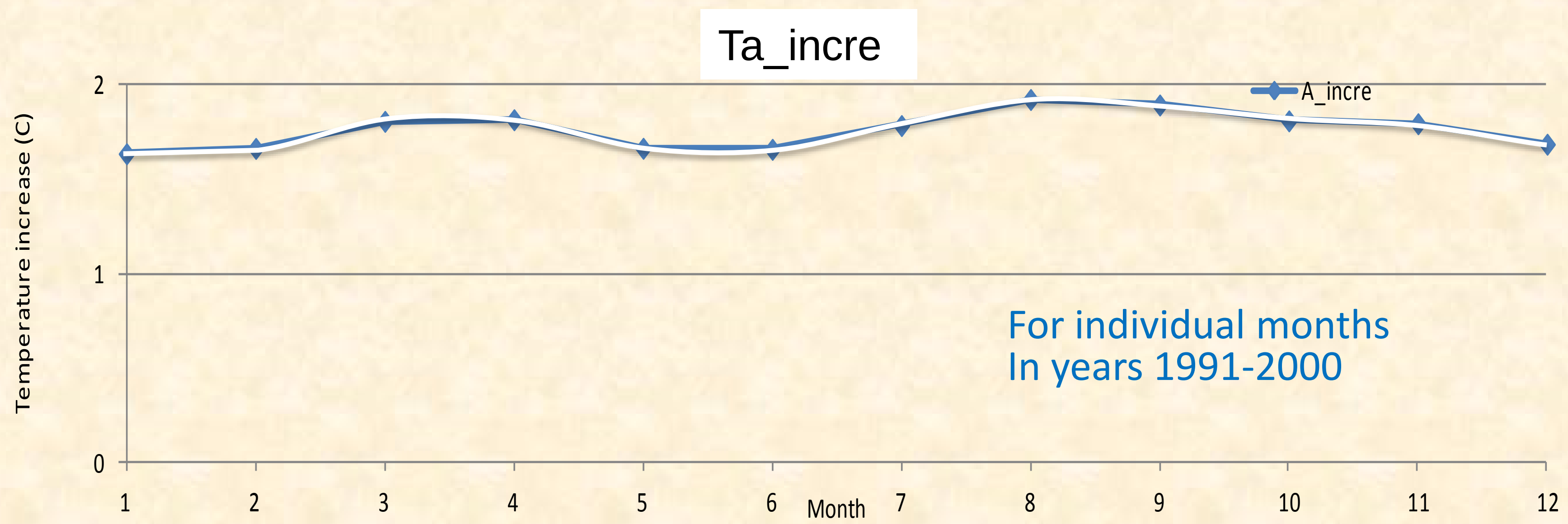
Salinity difference between SLR and the Base (Hong and Shen, 2012)





Temperature GCM vs. XYZ at A24003
Monthly Temperature Change Factors (Tgcm - Txyz) °C
4.50
3.50
2.50
1.50
0.50
-0.50
-1.50
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months
b20_a2x_35
c30_a2x_35
c35_a2x_35
i0x_a2x_35
m2s_a2x_35
n30_a2x_35
b20_a2x_55
c30_a2x_55
c35_a2x_55
i0x_a2x_55
m2s_a2x_55
n30_a2x_55
2035 - 2045
2050
2055 - 2065


Assessing air temperature in 2050: averaging the estimated from 6 GCM.
Avg 6 GCM for individual months
3 month avg on the 6 GCM averaged monthly data
Local Weight on the 6 GCM averaged monthly data
The 3-month averages will be used for air temperature increment in a month in the global warming scenarios.
Temperature Change (Degree C)
2.5
2
1.5
1
1 2 3 4 5 6 7 8 9 10 11 12
Months


Ta_incre
A_incre
For individual months
In years 1991-2000
Temperature increase (C)
2
1
0
1 2 3 4 5 6 7 8 9 10 11 12
Month

2. Simulation of Water Temperature due to Global Warming

A) Water temperature will increase due to air temperature increase: through heat exchange between air and the water, as simulated in CH3D:

$$\partial Tw / \partial z = Pr / Ev \times K (Ta - Te)$$

Where, Tw: water temperature;

Ta: air temperature

Z: depth

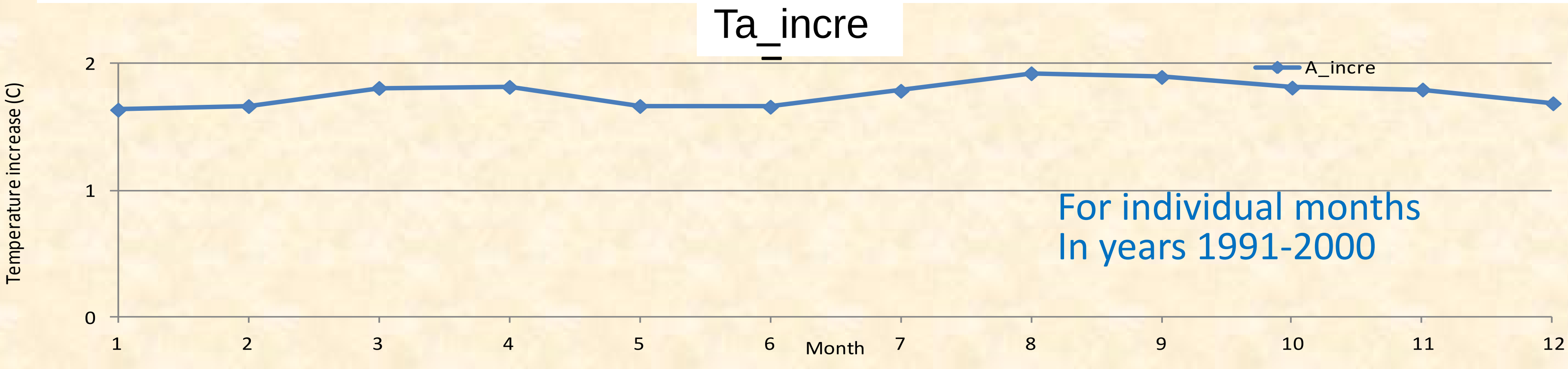
Te: Equilibrium temperature

K: surface heat exchange coefficient

Ev: vertical Ekman number

Pr: Prandtl number

In order to simulate Tw in 2050, we calculated Te and K in 2050 which is a function of Ta in 2050, assuming no change in humidity and wind.



2. Simulation of Water Temperature due to Global Warming

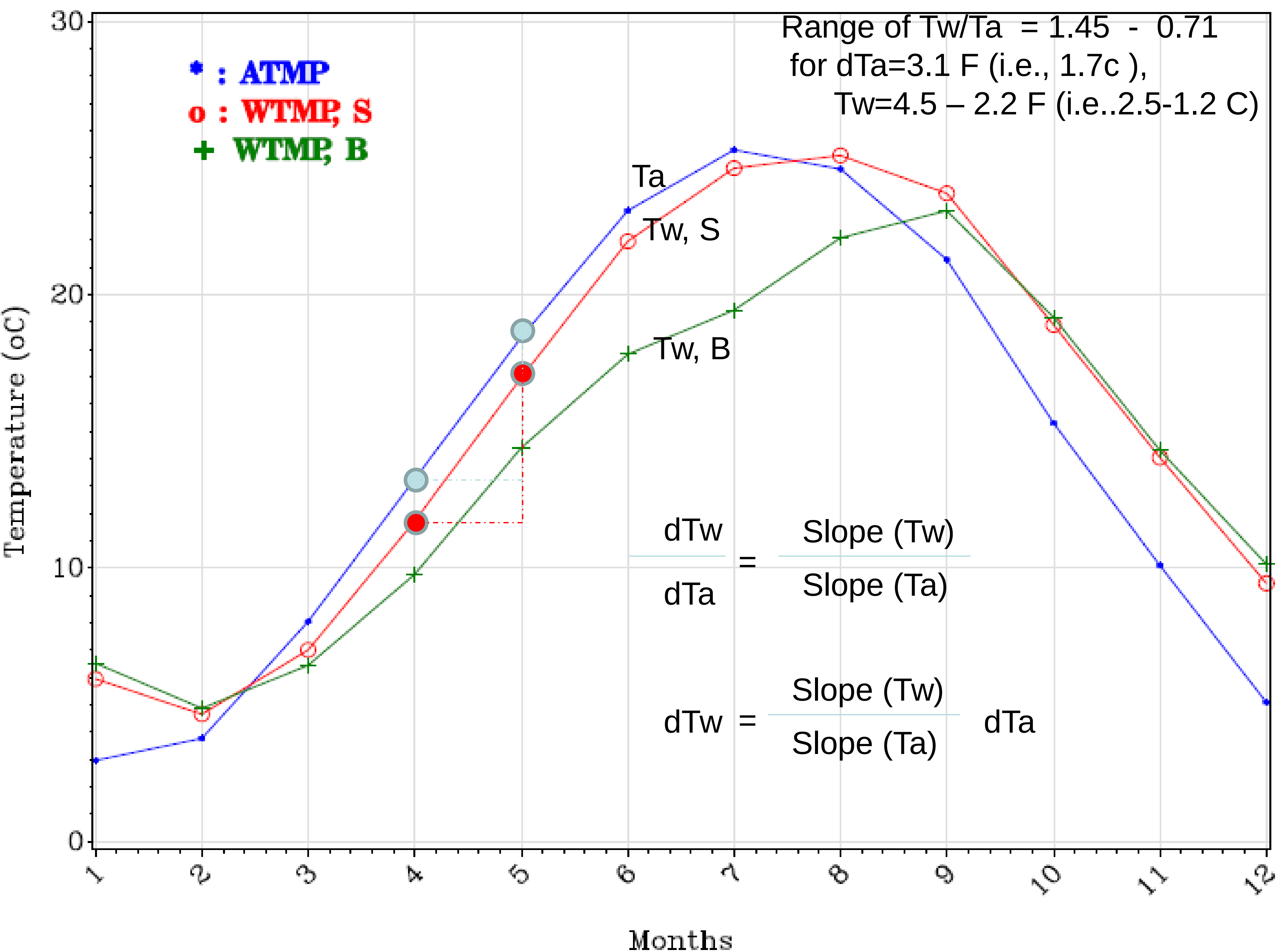
A) Water temperature will increase due to air temperature increase: through heat exchange between air and the water, as simulated in CH3D:

dTw / dz = Pr /Ev x K (T – Te)

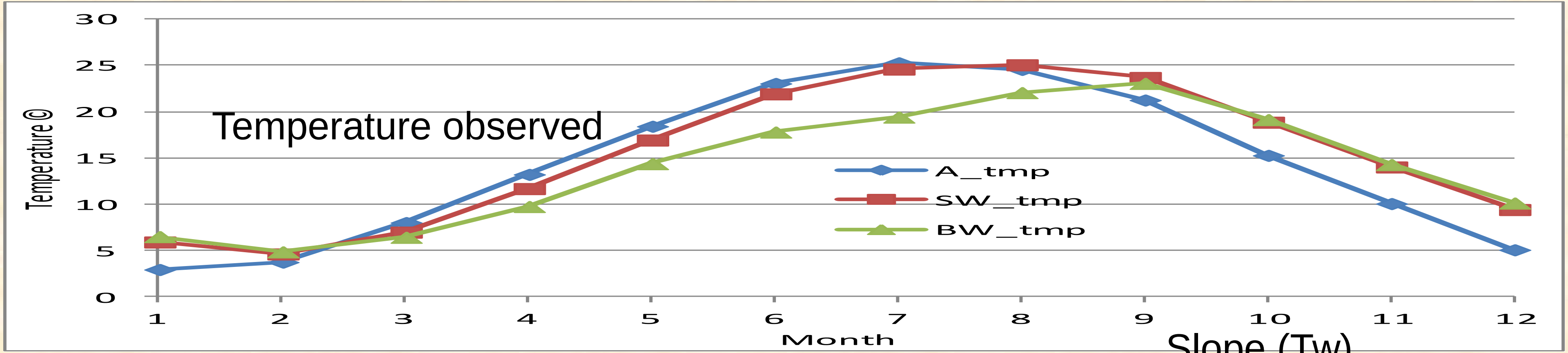
Where, Tw: water temperature, Ta: air temperature
Z: depth
Te: Equilibrium temperature
K: surface heat exchange coefficient
Ev: vertical Ekman number
Pr: Prandtl number

In order to simulate Tw in 2050, we calculated Te and K in 2050 which is a function of Ta in 2050, assuming no changes in humidity and wind.

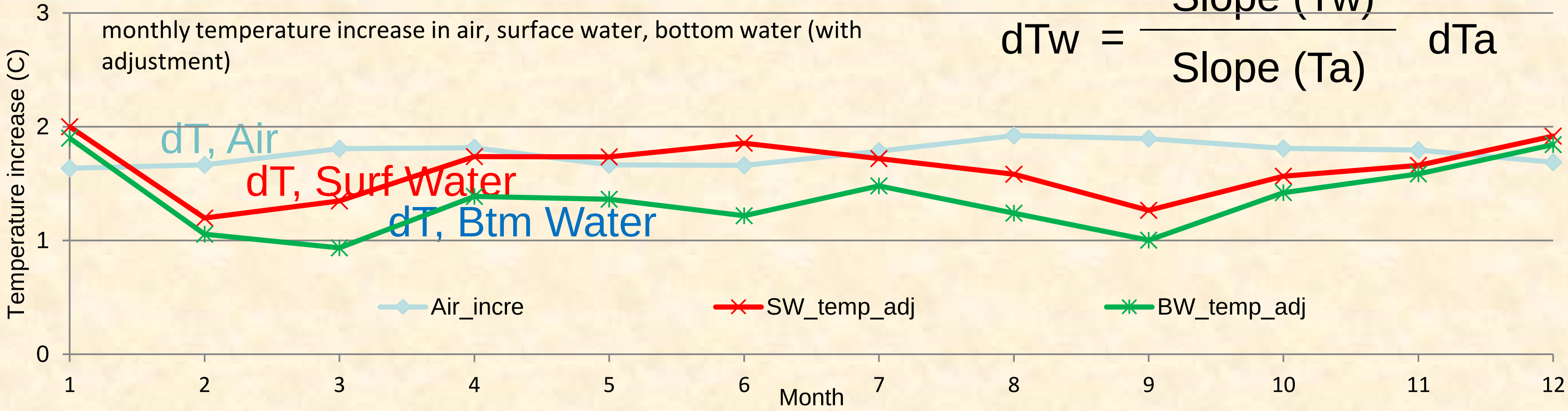
B) The Tw at the boundary also influence the Bay’s Tw.
* it is better to estimate and set Tw at the boundary in 2050 condition.

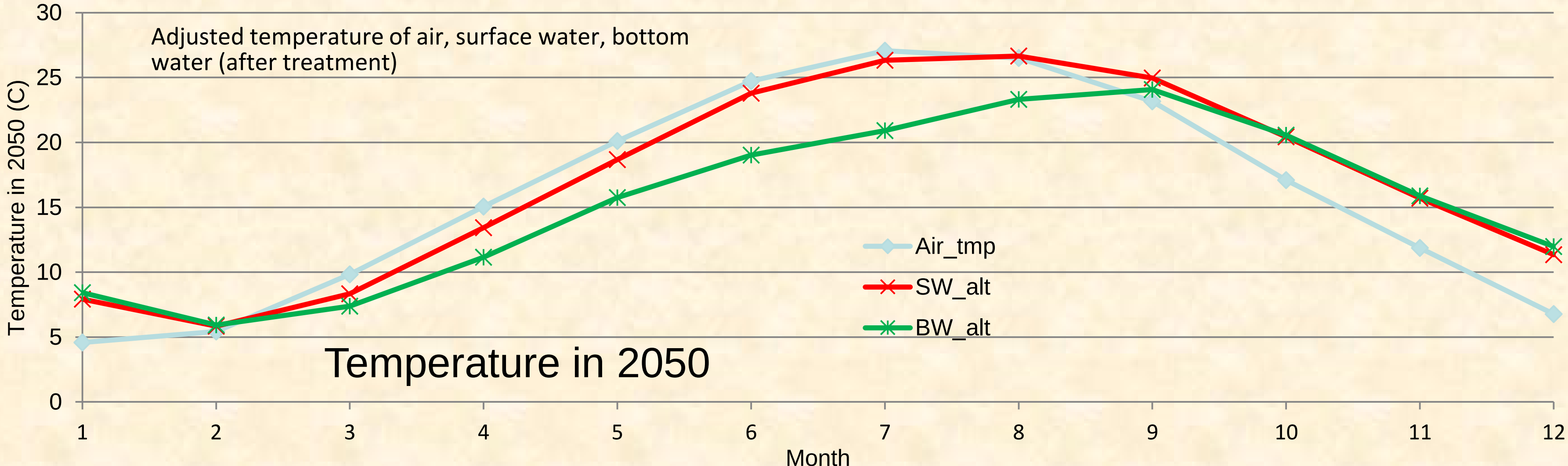


Range of Tw/Ta = 1.45 - 0.71
for dTa=3.1 F (i.e., 1.7c),
Tw=4.5 – 2.2 F (i.e..2.5-1.2 C)
* : ATMP
o : WTMP, S
+ WTMP, B
Ta
Tw, S
Tw, B
dTw / dTa = Slope (Tw) / Slope (Ta)
dTw = Slope (Tw) / Slope (Ta) dTa
Temperature (oC)
Months
0
10
20
30
1
2
3
4
5
6
7
8
9
10
11
12

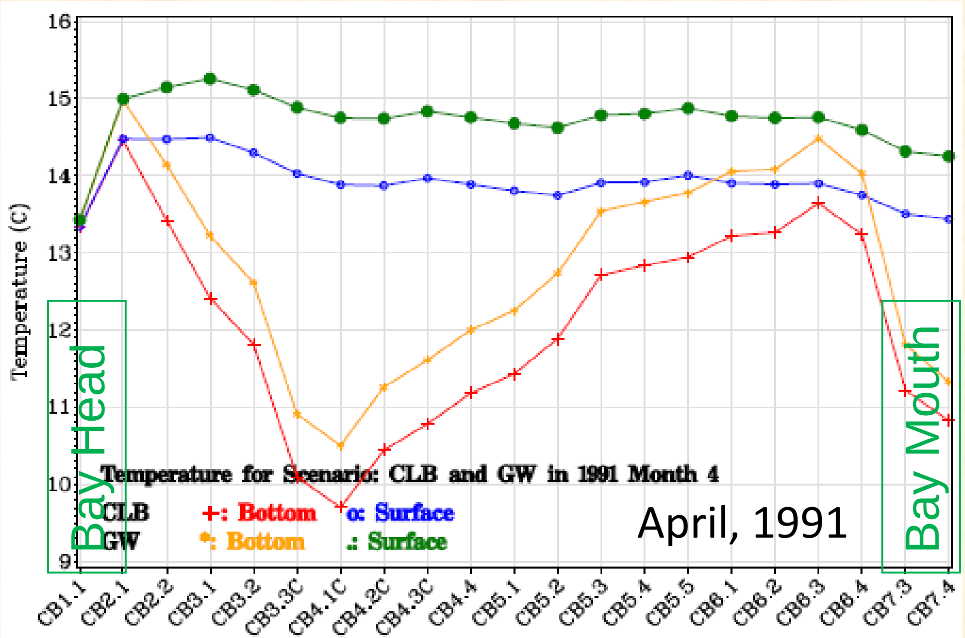


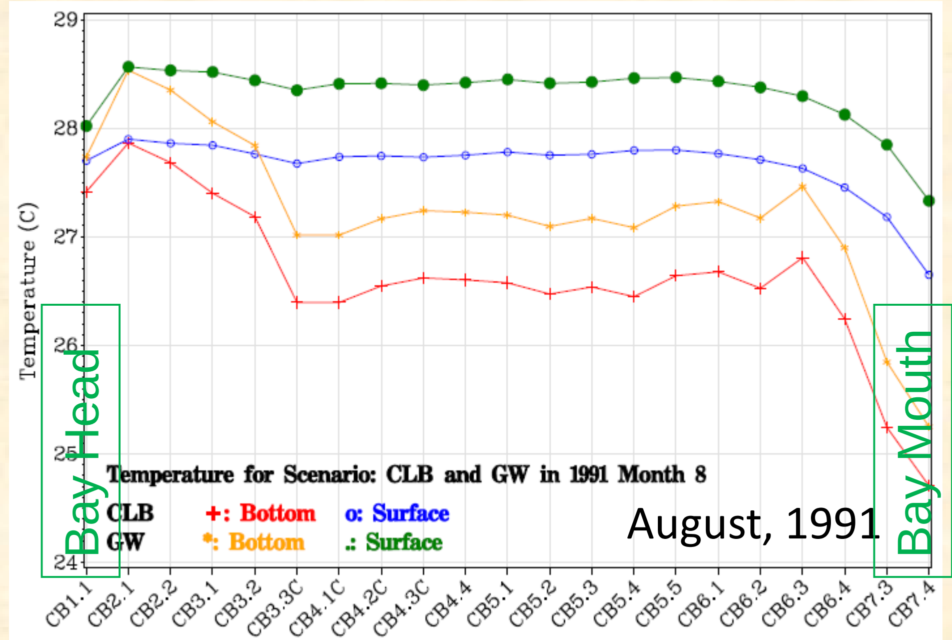
$$dTw = \frac{\text{Slope (Tw)}}{\text{Slope (Ta)}} dTa$$

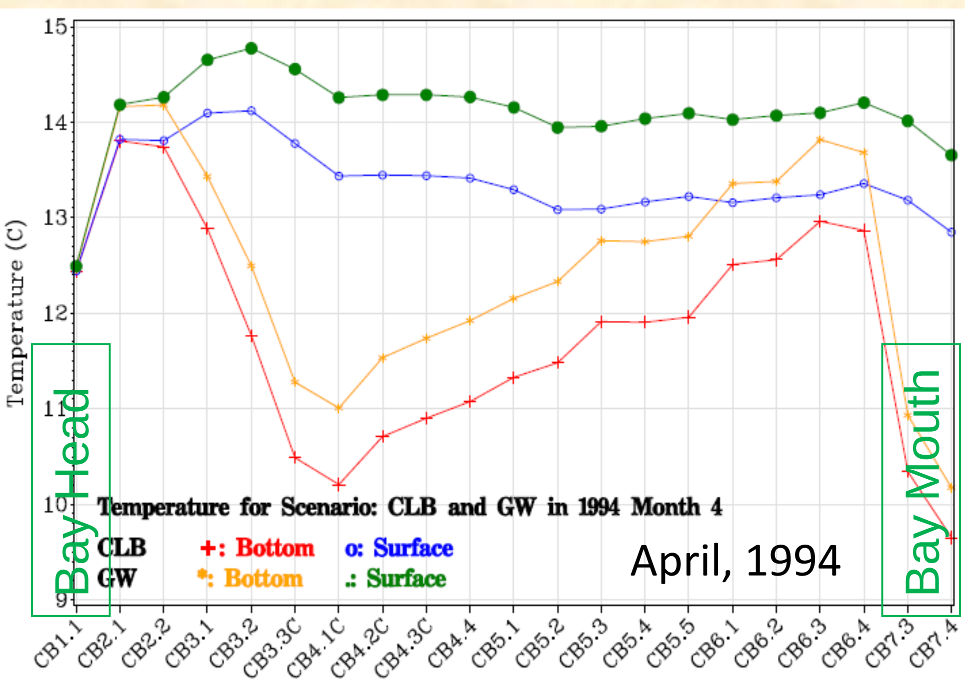


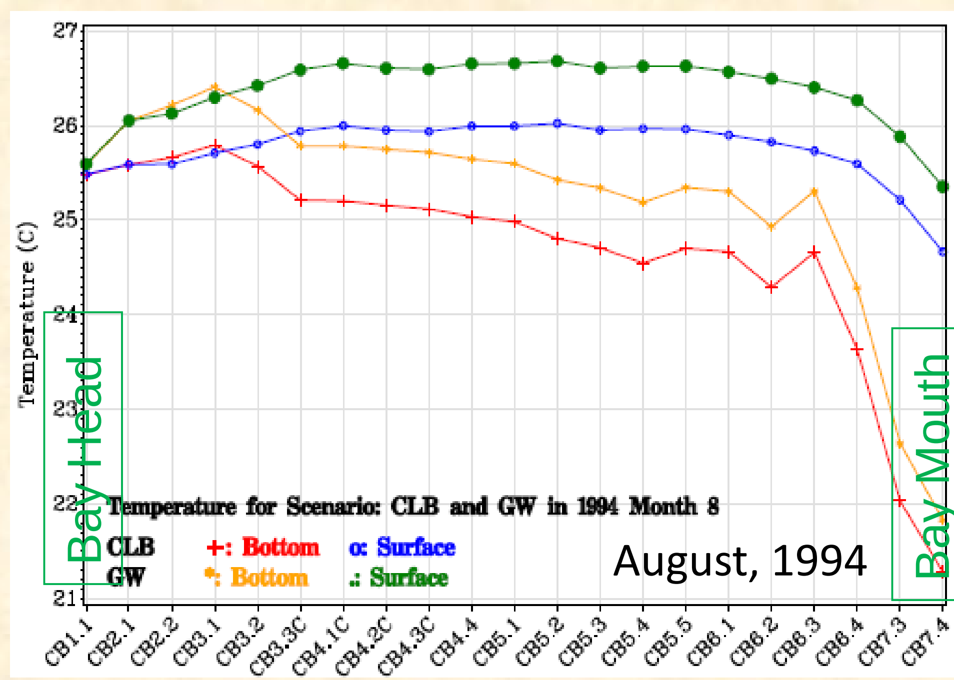


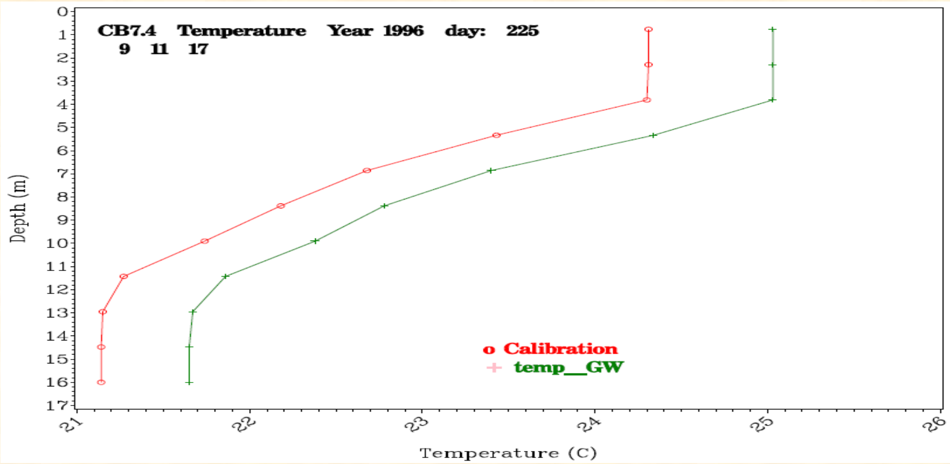
Average Bottom and Surface temperature

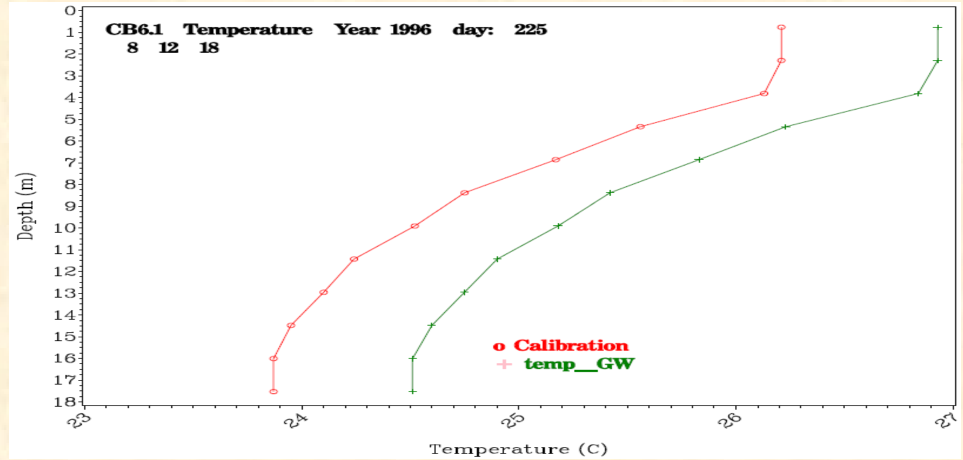


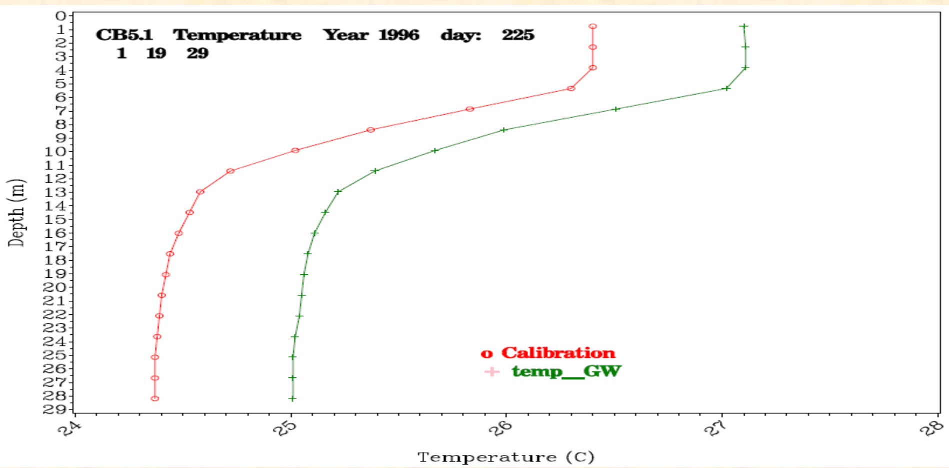


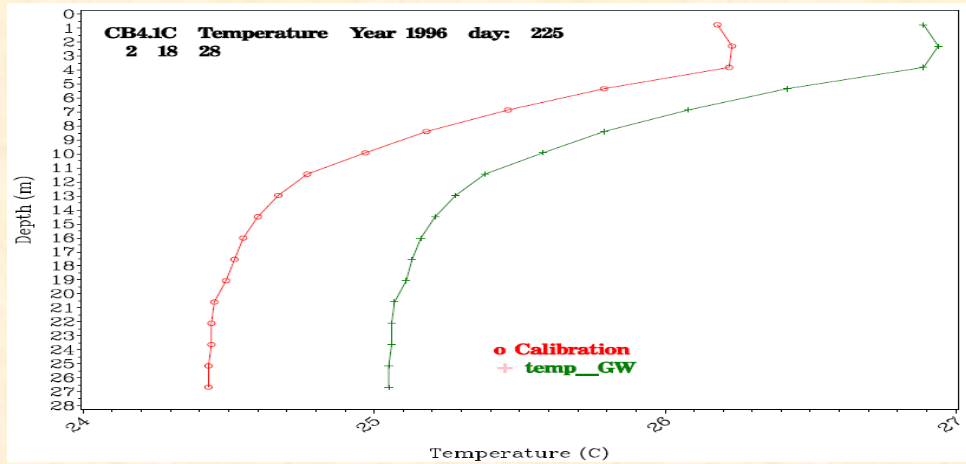


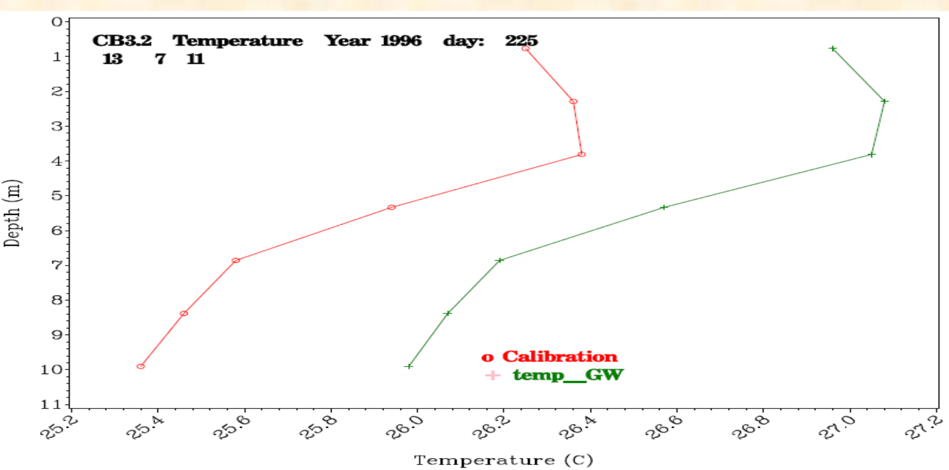


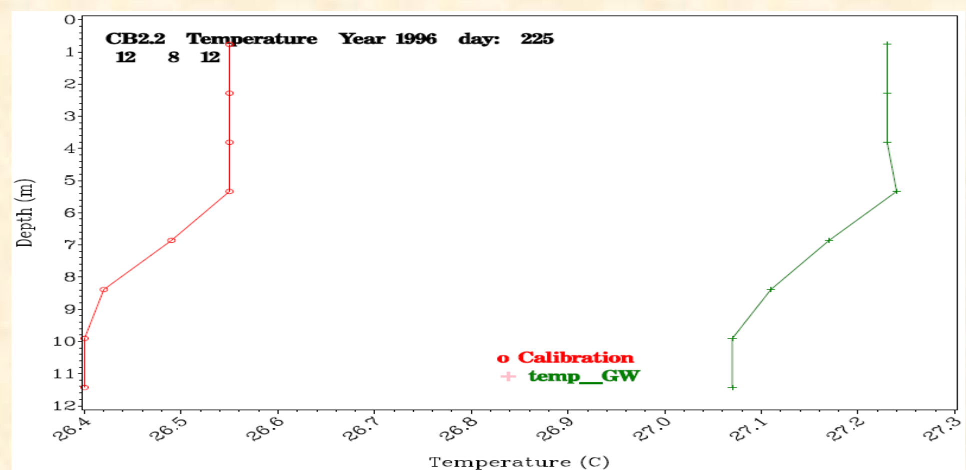

CB7.4 Temperature Year 1996 day: 225
9 11 17
o Calibration
+ temp__GW
Depth (m)
Temperature (C)

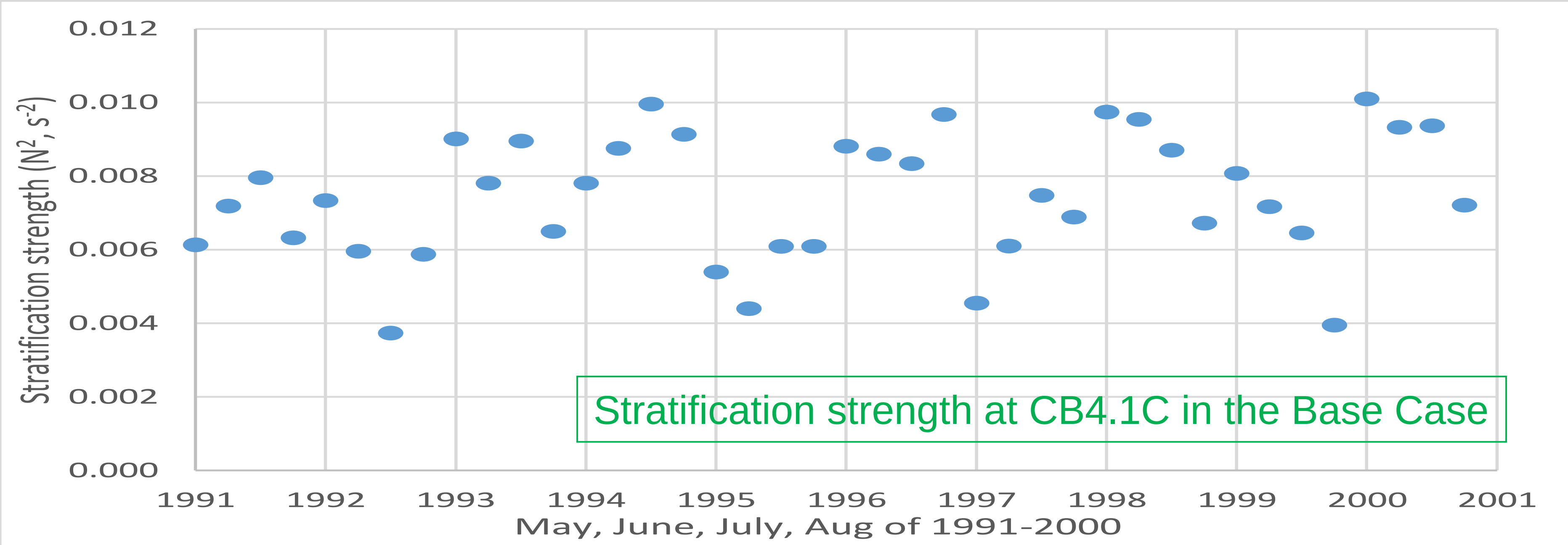

CB6.1 Temperature Year 1996 day: 225
8 12 18
o Calibration
+ temp__GW
Depth (m)
Temperature (C)


CB5.1 Temperature Year 1996 day: 225
1 19 29
o Calibration
+ temp__GW
Depth (m)
Temperature (C)

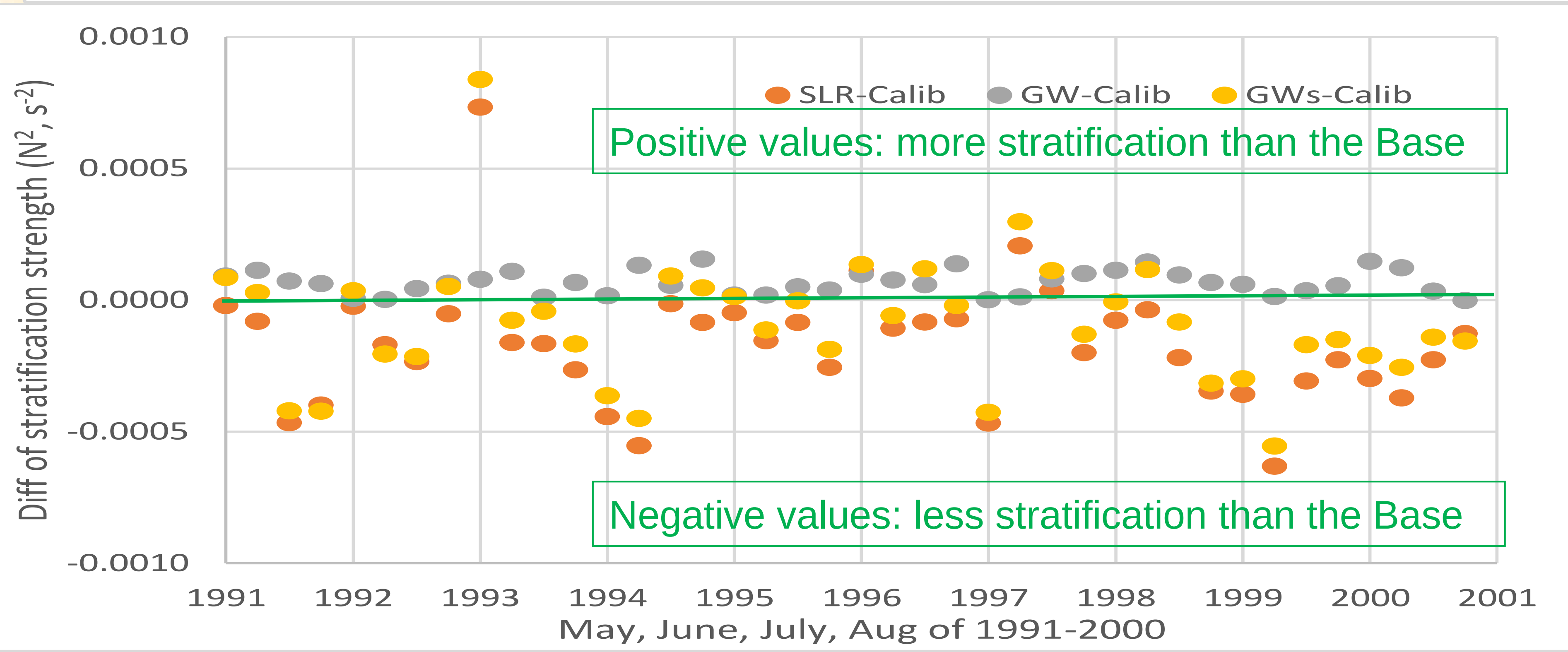

CB4.1C Temperature Year 1996 day: 225
2 18 28
o Calibration
+ temp__GW
Depth (m)
Temperature (C)


CB3.2 Temperature Year 1996 day: 225
13 7 11
o Calibration
+ temp__GW
Depth (m)
Temperature (C)


CB2.2 Temperature Year 1996 day: 225
12 8 12
o Calibration
+ temp__GW
Depth (m)
Temperature (C)



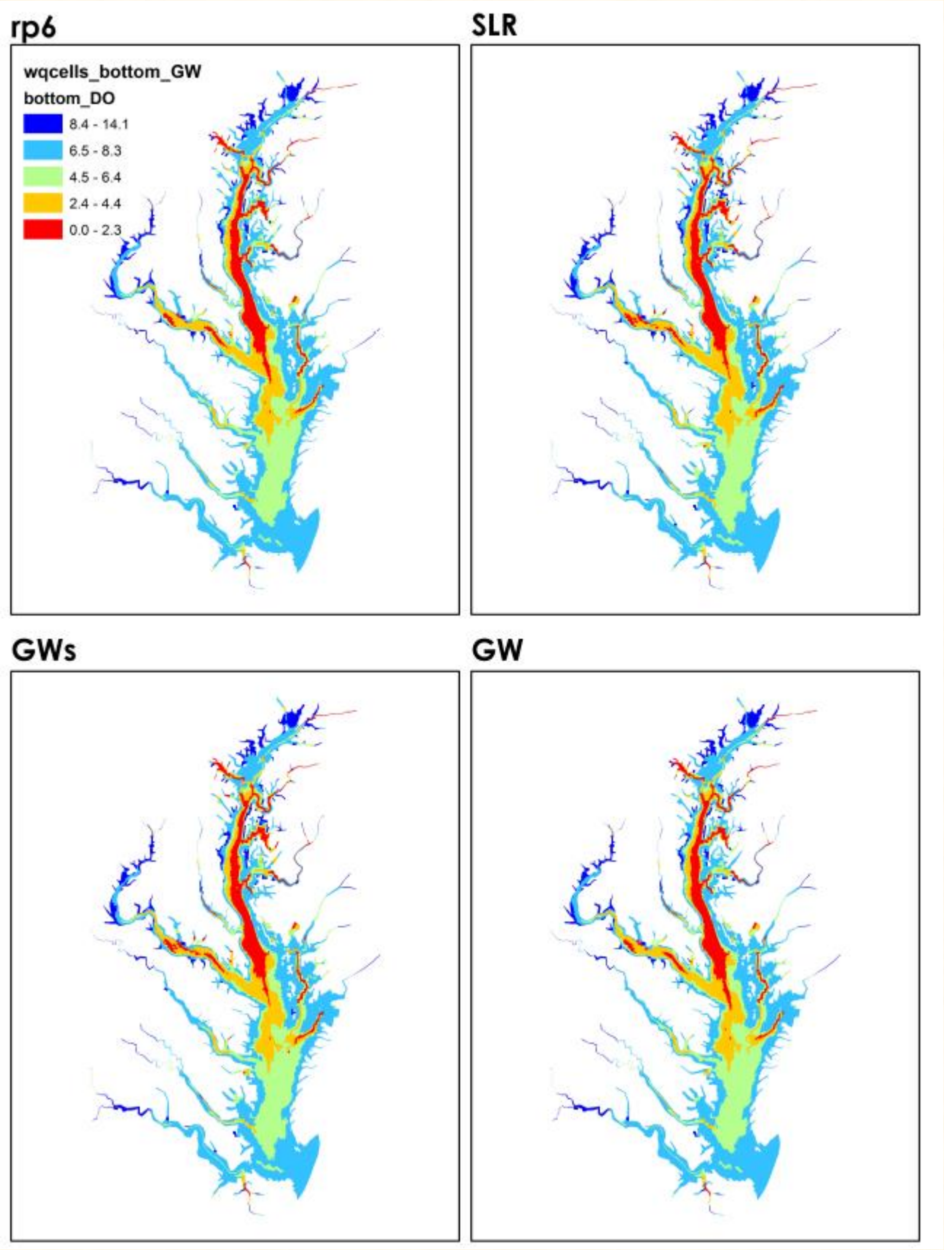
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Stratification strength (N^2, s^{-2})
Stratification strength at CB4.1C in the Base Case
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001
May, June, July, Aug of 1991-2000



0.0010
0.0005
0.0000
-0.0005
-0.0010
Diff of stratification strength (N^2, s^{-2})
SLR-Calib
GW-Calib
GWs-Calib
Positive values: more stratification than the Base
Negative values: less stratification than the Base
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001
May, June, July, Aug of 1991-2000

Conclusions:

- A measurable but small effect on hypoxia due to 2050 warming and sea level rise is estimated.
- Combined, the influence of the two tend to slightly reduce deep water and deep channel hypoxia in mid-Bay by about 0.1 mg/l.
- The influence of estimated increased precipitation intensity in 2050, 2050 land use, 2050 watershed loads, and 2050 tidal marsh loss by sea level rise are all expected to have greater detrimental impacts on Chesapeake water quality.



Conclusions:

- Now the Modeling Team would like to focus on the climate change elements not yet completed for the 2050 assessment while continuing to examine the 2050 temperature increase and sea level rise scoping scenarios.
- Timelines are short for developing the entire climate change analysis by the close of 2015.