MODELING OF THE AFTER-EFFECTS OF OXYGENATED INFLOWS IN ANOXIC FJORDS SYSTEMS

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Anoxic conditions in the water column

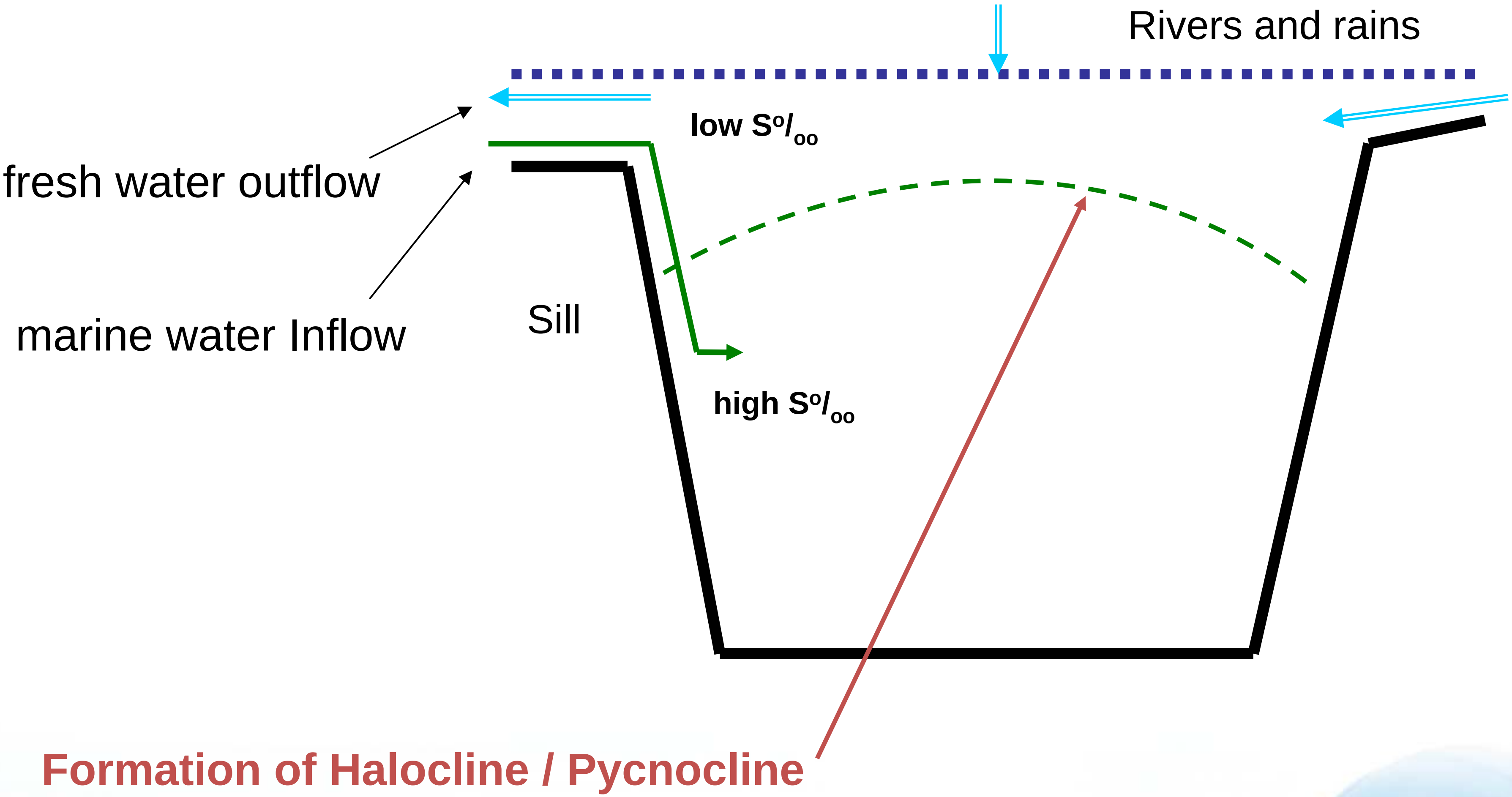
Common feature in numerous areas in coastal and marginal seas

Affected by natural and anthropogenic factors:

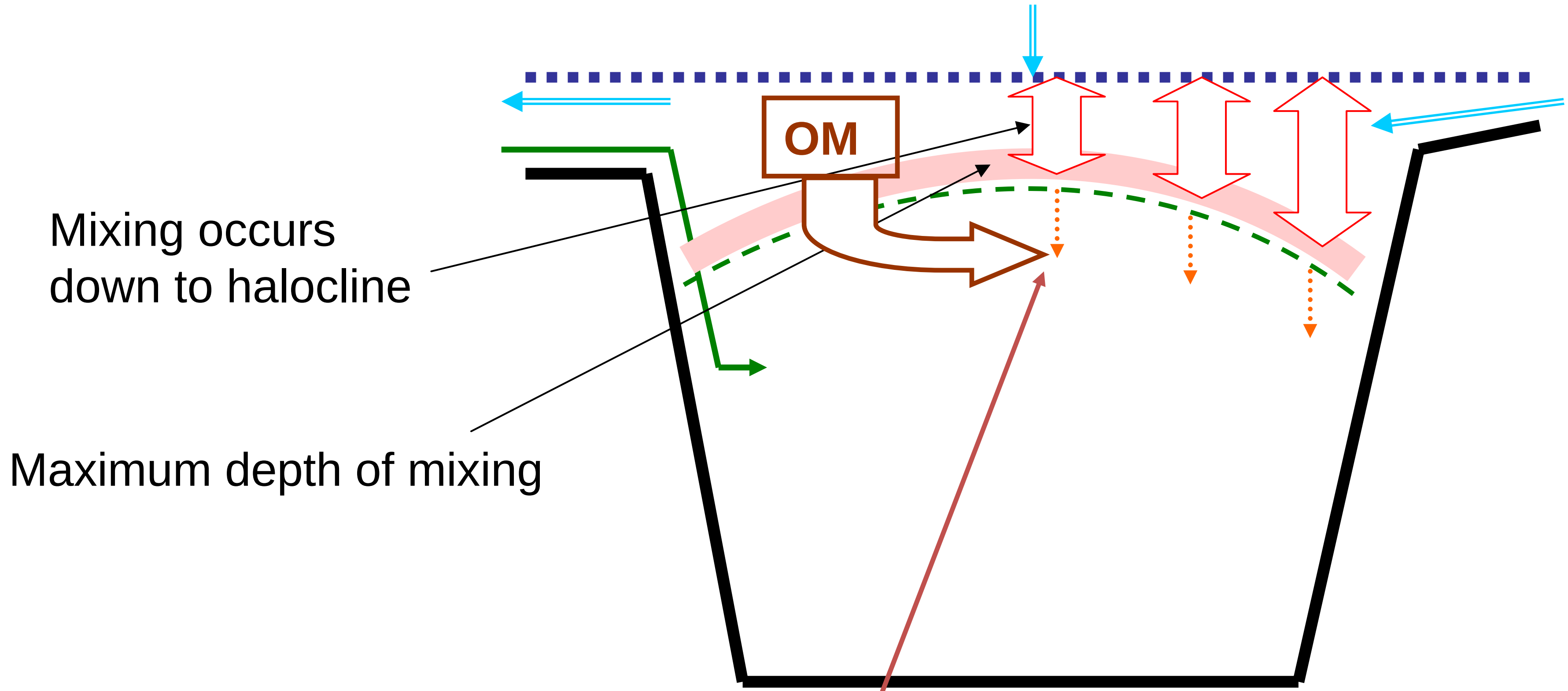
- **intensity of aeration**
- **amount of produced OM**

The appearance of water anoxia is a threat for the functioning of healthy coastal ecosystems and thereby a direct danger to human health and economic welfare of coastal societies.

Anoxic conditions in the water column



Anoxic conditions in the water column

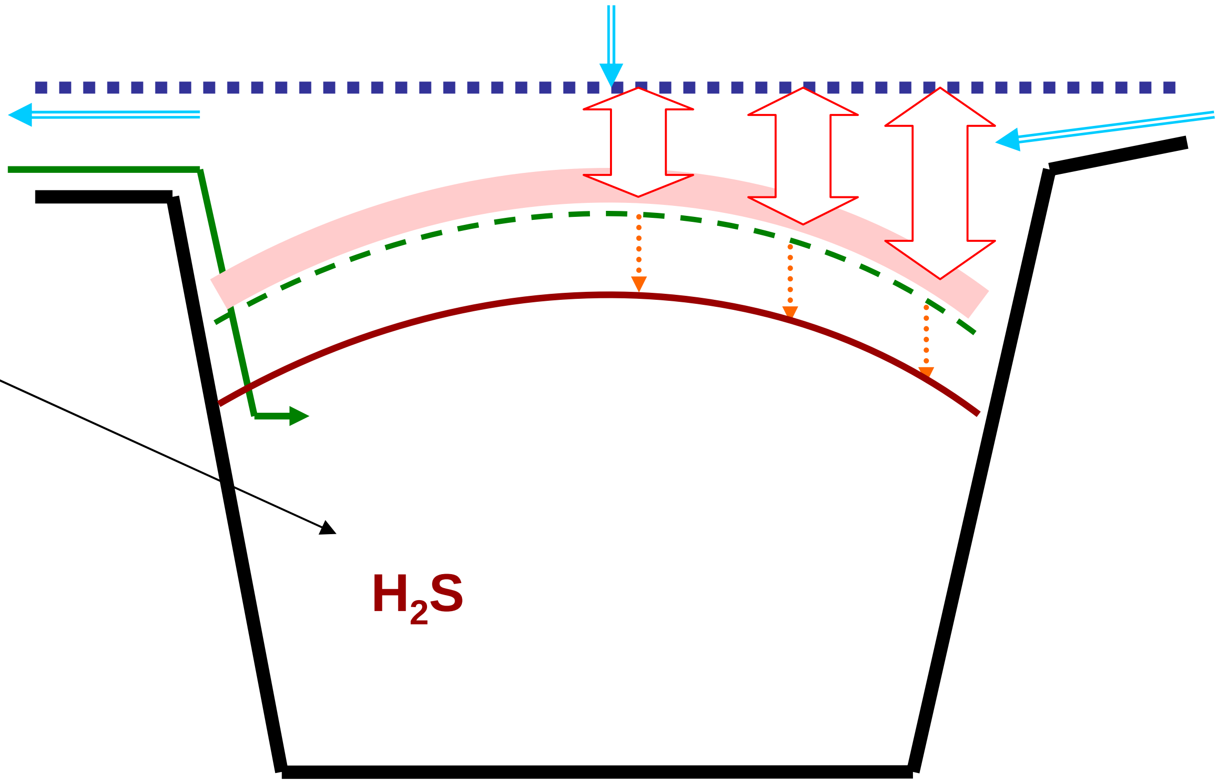


Weak turbulent transport of O_2 exists to the deeper layer

O_2 is using up for the OM decomposition

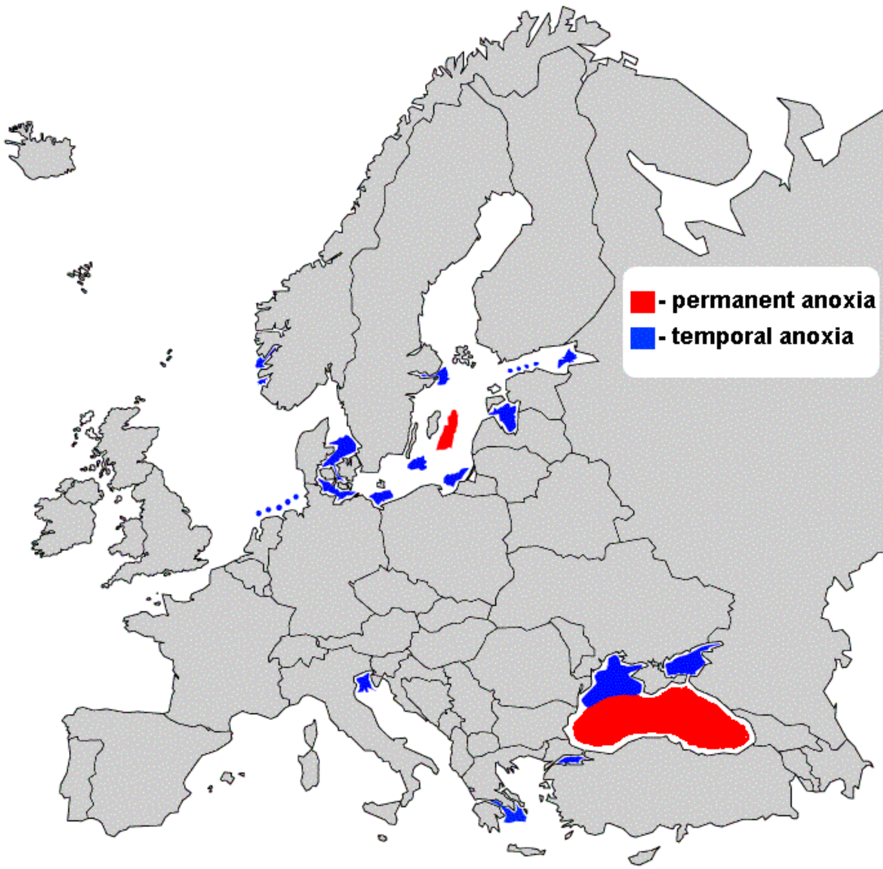
Anoxic conditions in the water column

Formation of anoxia



Flux of OM is not balanced by the flux of O_2
and OM is decomposed with other electron-acceptors.

Anoxic conditions in the water column

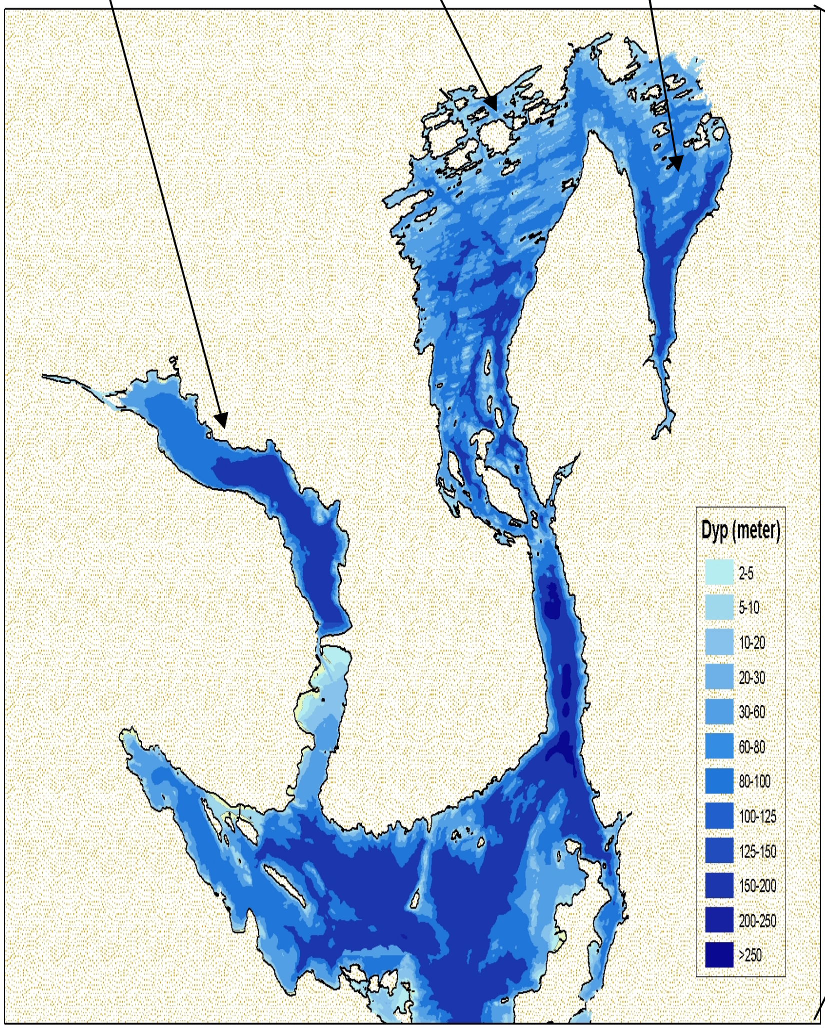


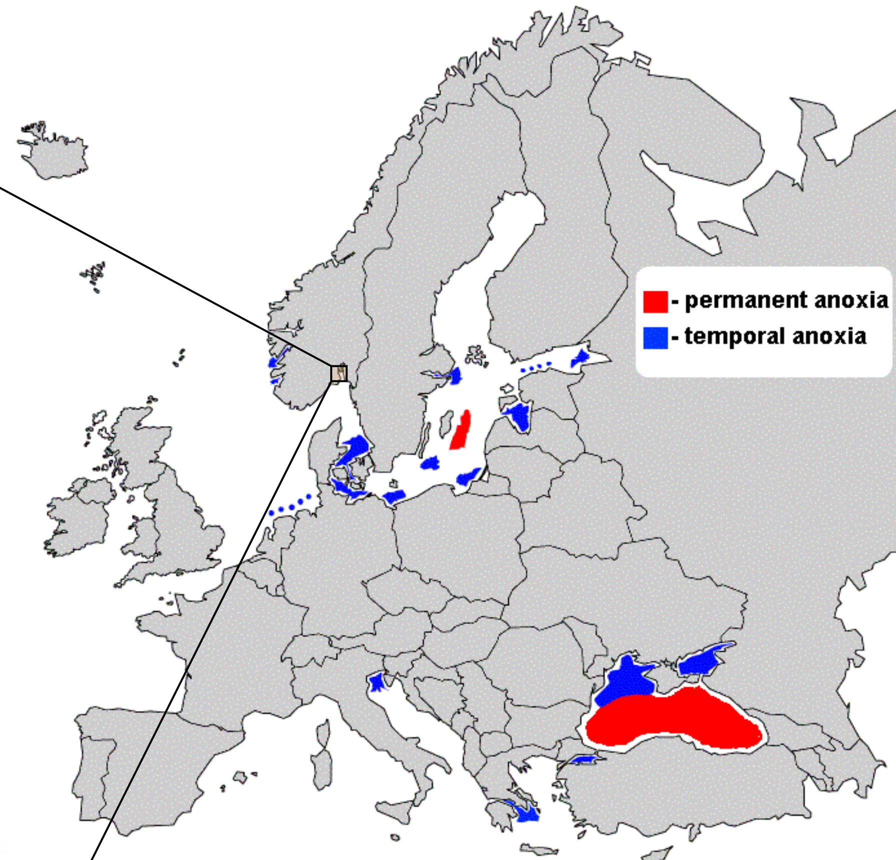
Anoxic conditions in the water column

Drammensfjord
(Richards, 1965)

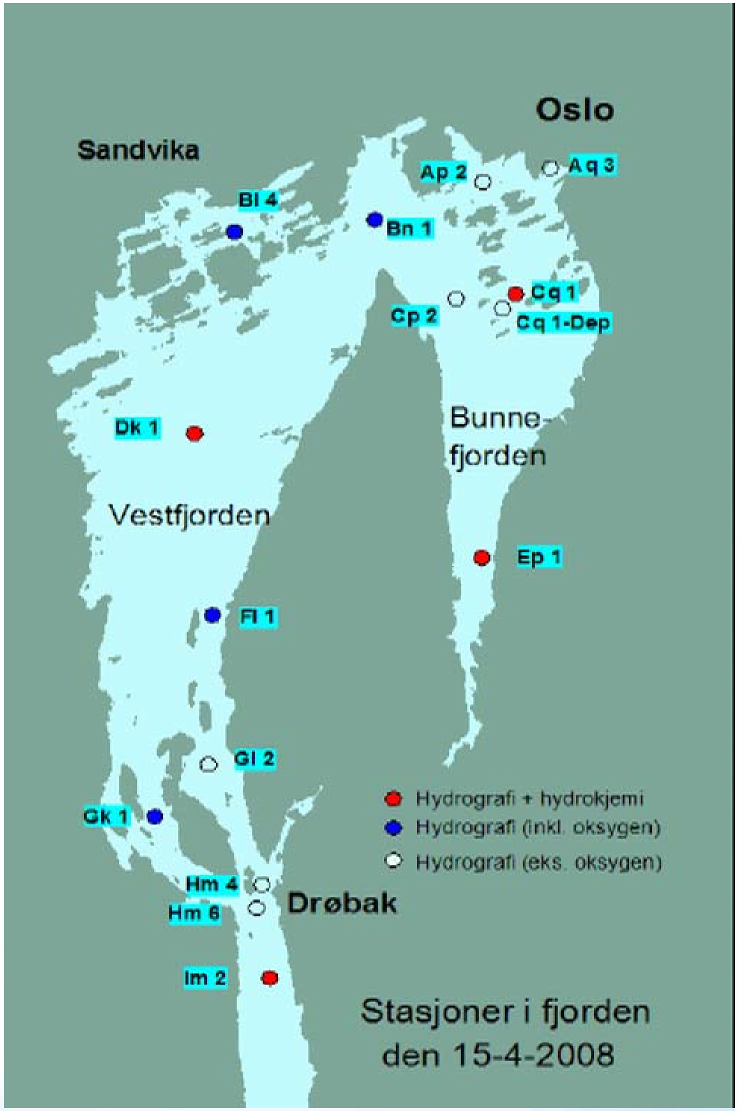
Baerumsbassenget

Bunnefjord

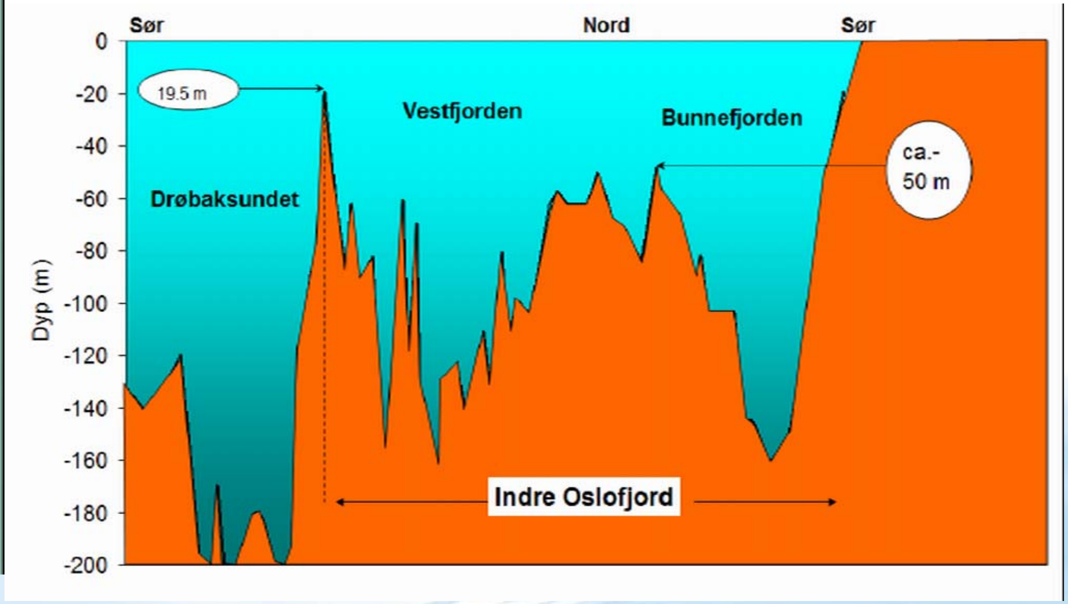




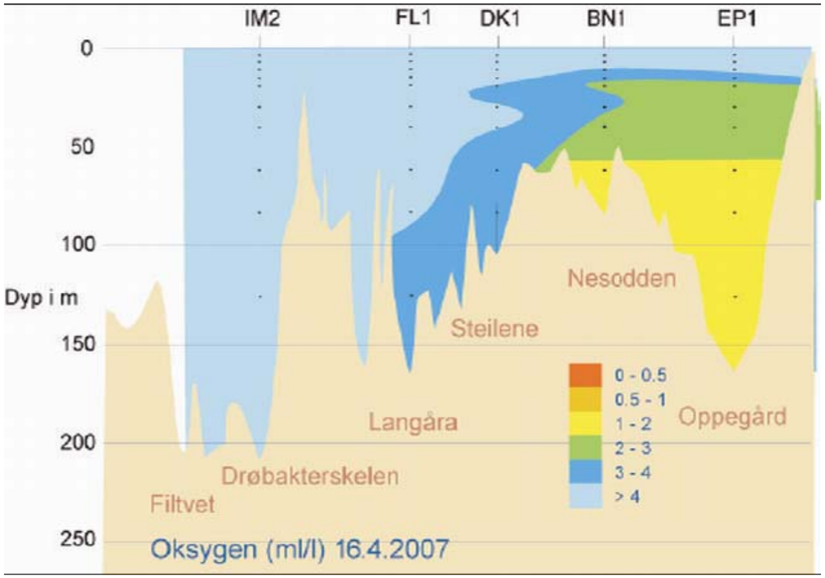
Oslofjord

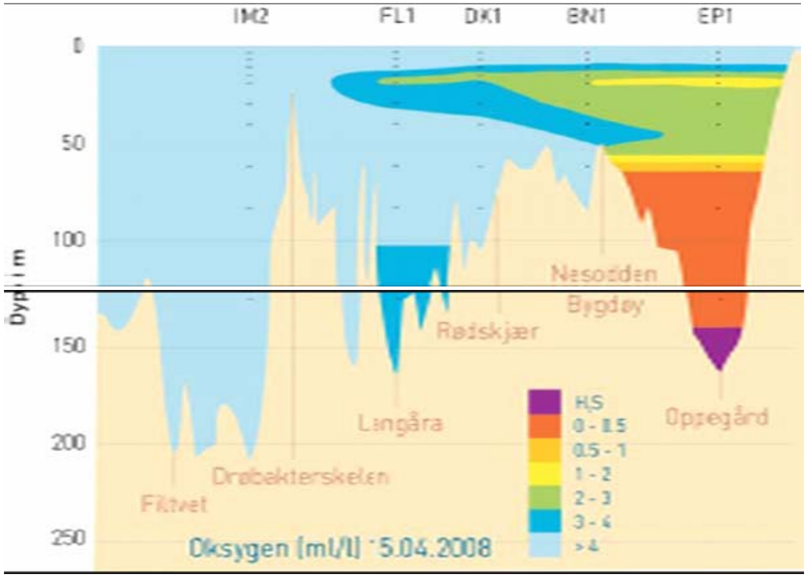


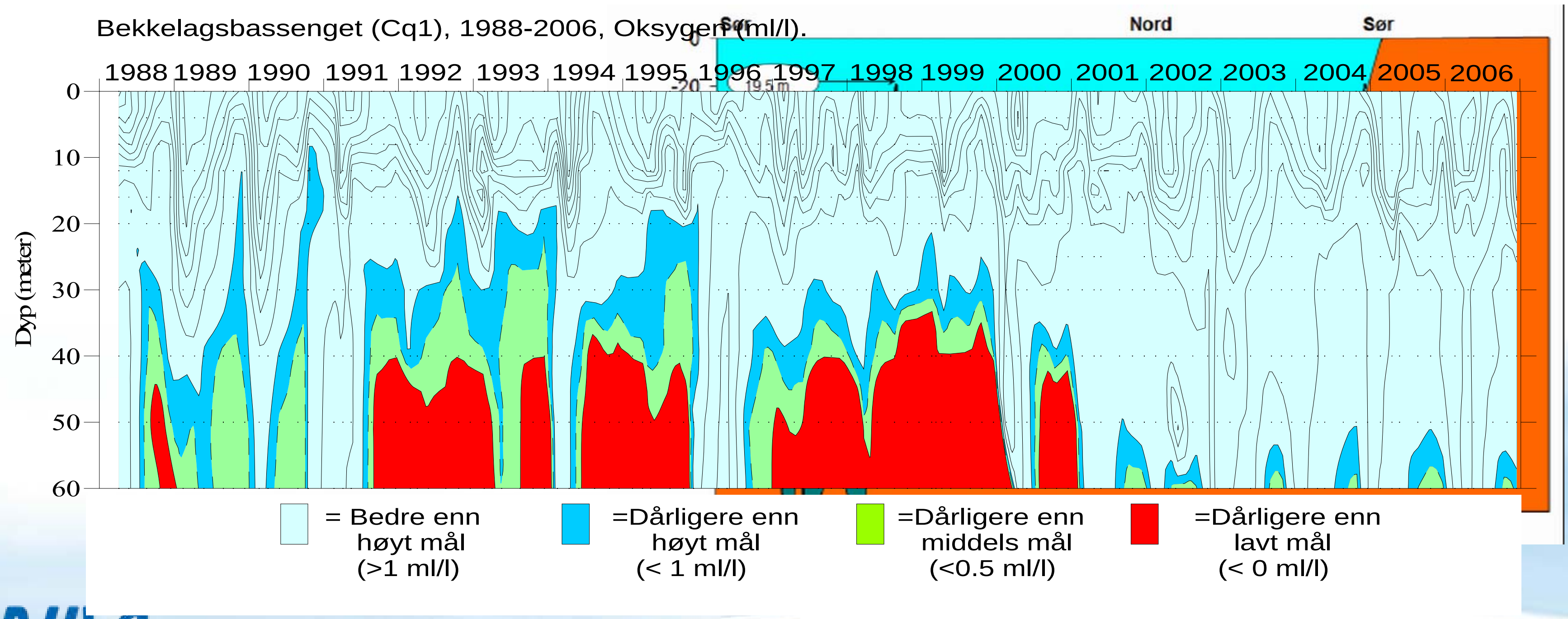
Oslo
Sandvika
Ap 2
Aq 3
Bl 4
Bn 1
Cq 1
Cp 2
Cq 1-Dep
Dk 1
Bunne-
fjorden
Vestfjorden
Ep 1
Fl 1
Gl 2
Gk 1
Hm 4
Hm 6
Drøbak
Im 2
Hydrografi + hydrokjemi
Hydrografi (inkl. oksygen)
Hydrografi (eks. oksygen)
Stasjoner i fjorden
den 15-4-2008



Sør
Nord
Sør
19.5 m
Vestfjorden
Bunnefjorden
ca.-
50 m
Drøbaksundet
Indre Oslofjord
Dyp (m)
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200


IM2
FL1
DK1
BN1
EP1
0
50
100
150
200
250
Dyp i m
Nesodden
Steilene
Langåra
Oppegård
Drøbakterskelen
Filtvet
0 - 0.5
0.5 - 1
1 - 2
2 - 3
3 - 4
> 4
Oksygen (ml/l) 16.4.2007


IM2
FL1
DK1
BN1
EP1
0
50
100
150
200
250
Dyp i m
Nesodden
Bygdøy
Rødskjær
Langåra
Oppegård
Drøbakterskelen
Filtvet
H2S
0 - 0.5
0.5 - 1
1 - 2
2 - 3
3 - 4
> 4
Oksygen (ml/l) 5.04.2008


Bekkelagsbassenget (Cq1), 1988-2006, Oksygen (ml/l).
Sør
Nord
Sør
1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006
0
10
20
30
40
50
60
Dyp (meter)
= Bedre enn høyt mål (>1 ml/l)
=Dårligere enn høyt mål (< 1 ml/l)
=Dårligere enn middels mål (<0.5 ml/l)
=Dårligere enn lavt mål (< 0 ml/l)

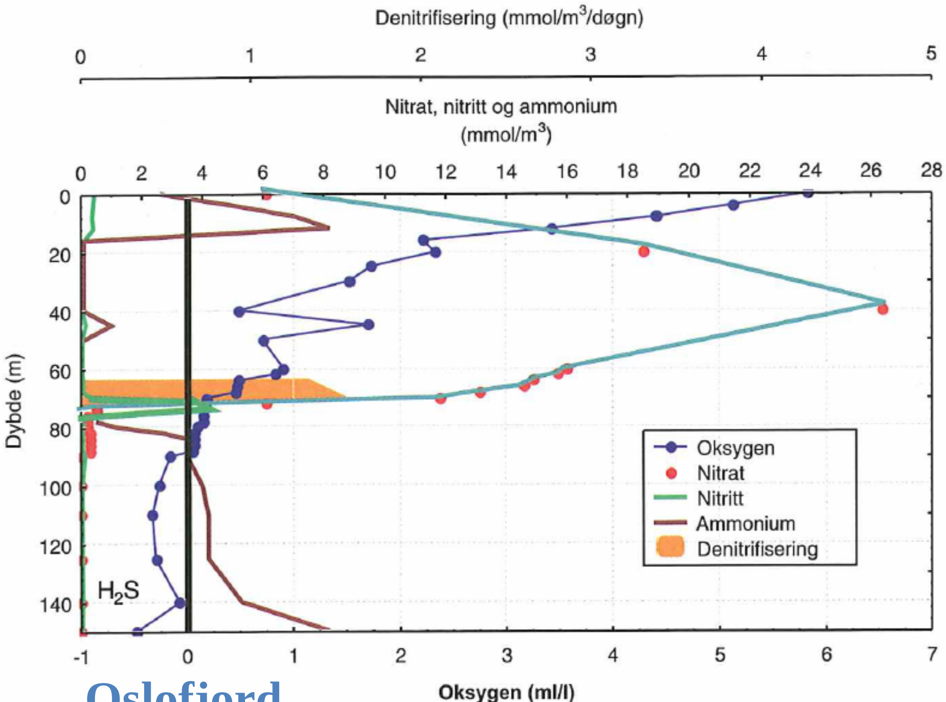
Questions:

What happens during the periods of stagnation and flushing:

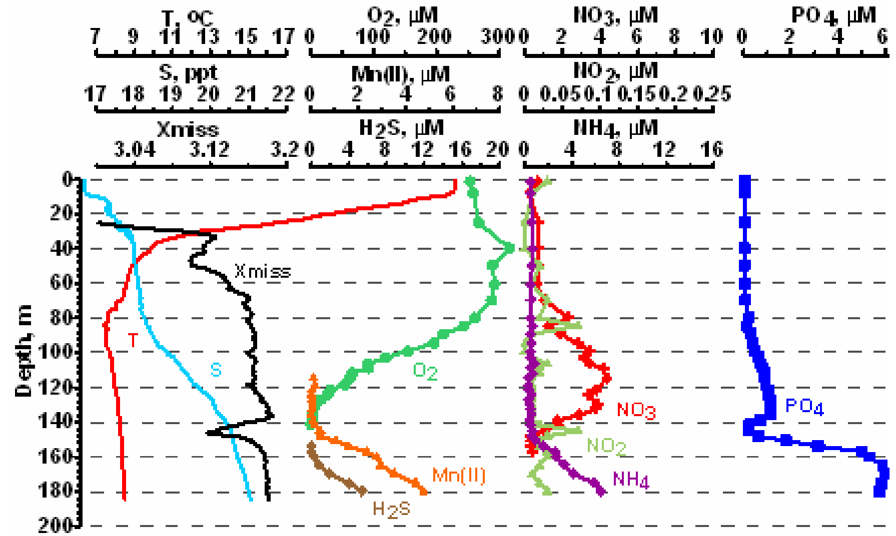
– Are the main processes at the redox interface in equilibrium?

– Is the redox interface characterized by the same chemical structure?

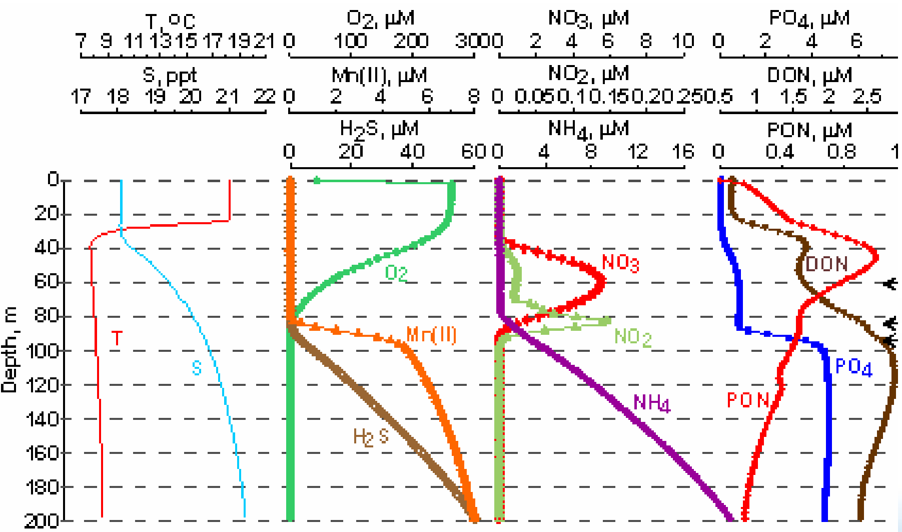
Redox interface structure



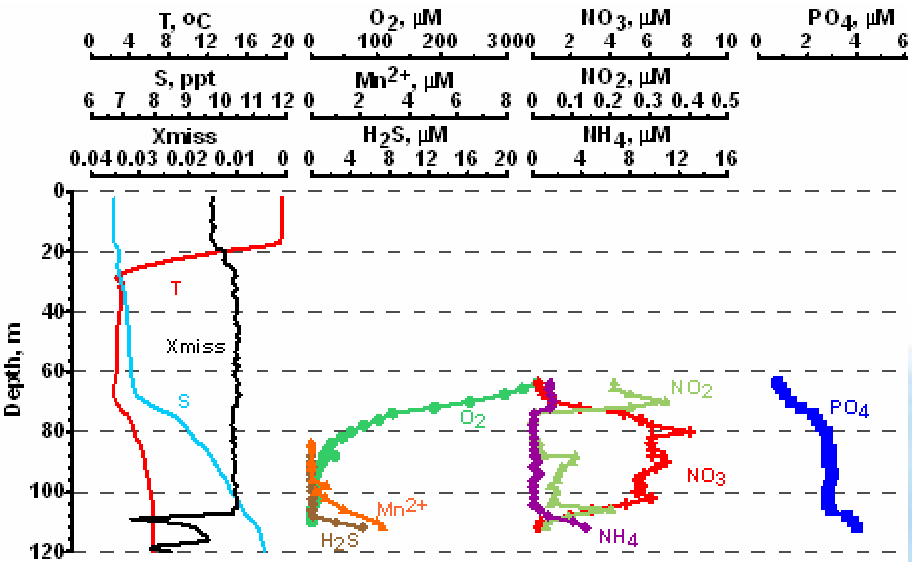
Oslofjord



Black Sea

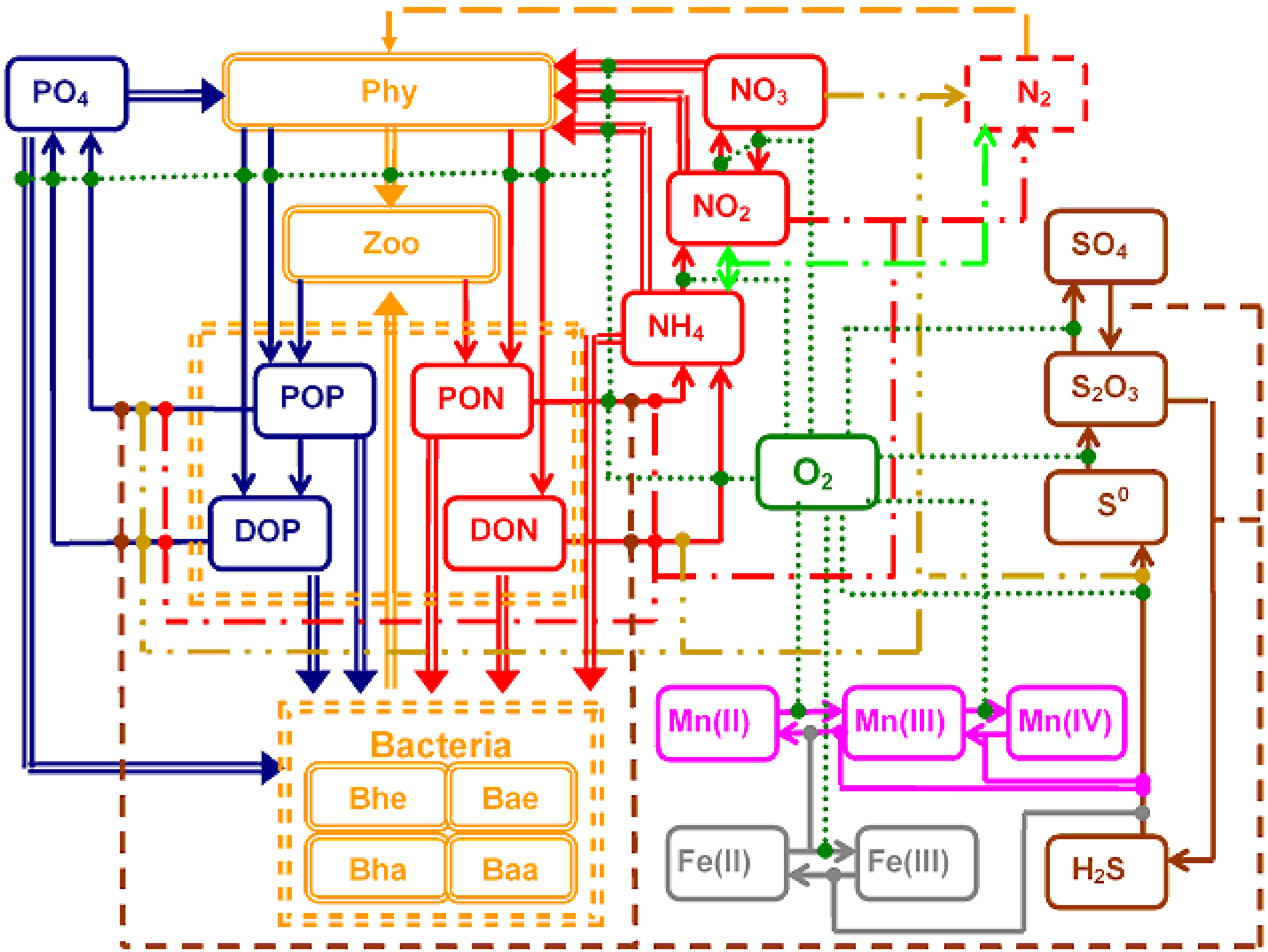


Model



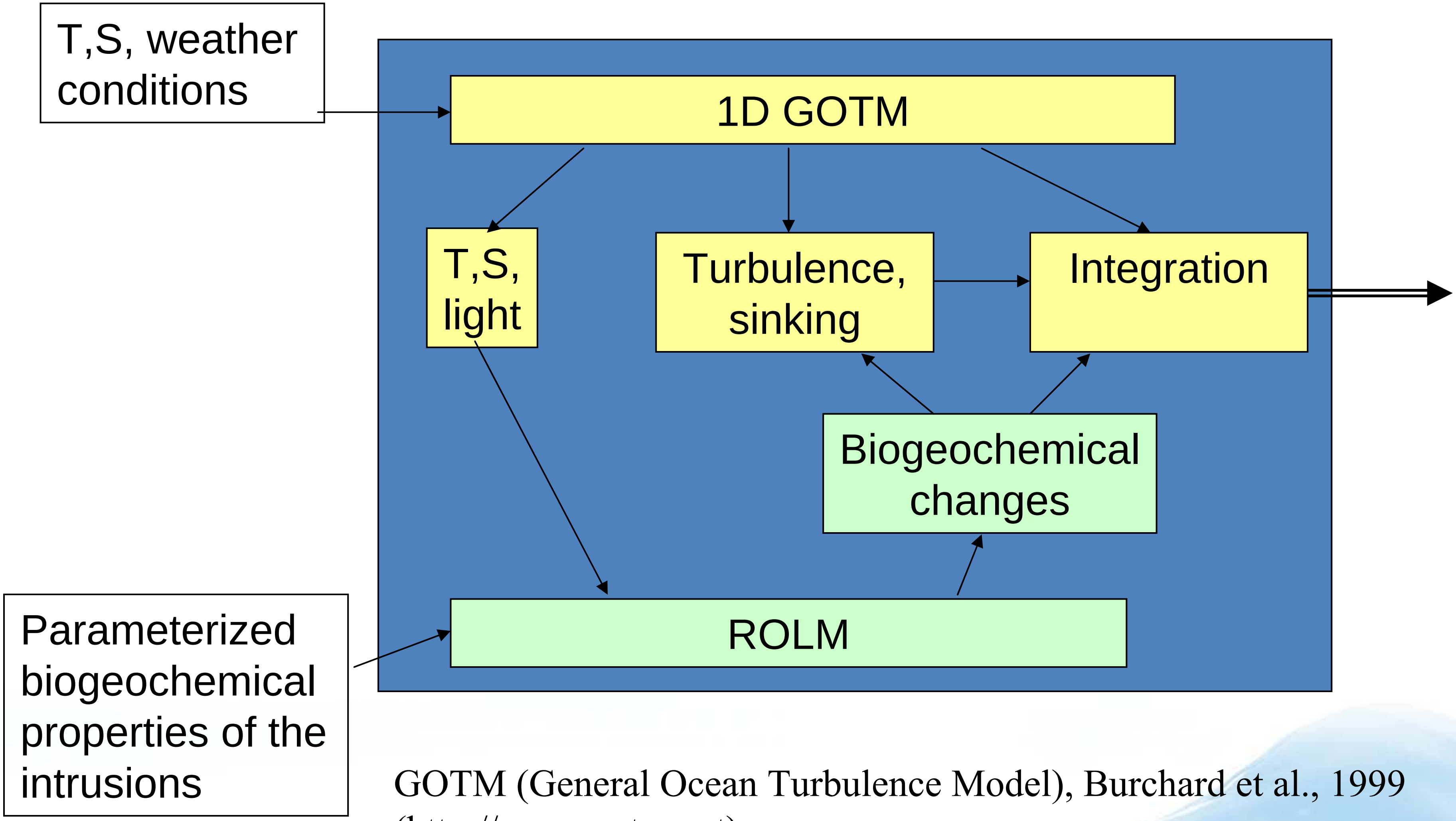
Gotland

ROLM biogeochemical model



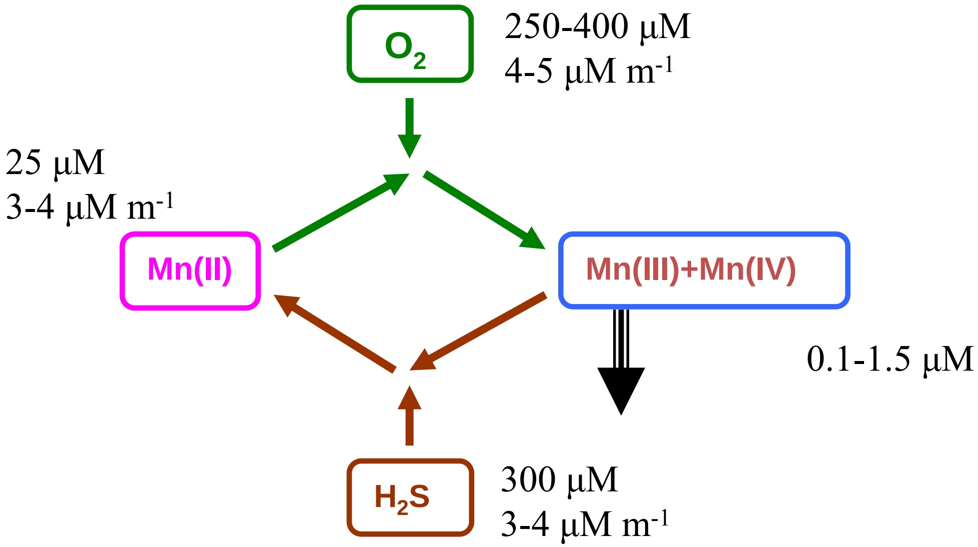
ROLM (Redox Layer Model). Yakushev et al., 2007.
http://www.io-warnemuende.de/documents/mebe68_2007-yakushev.pdf

Scheme of calculations:

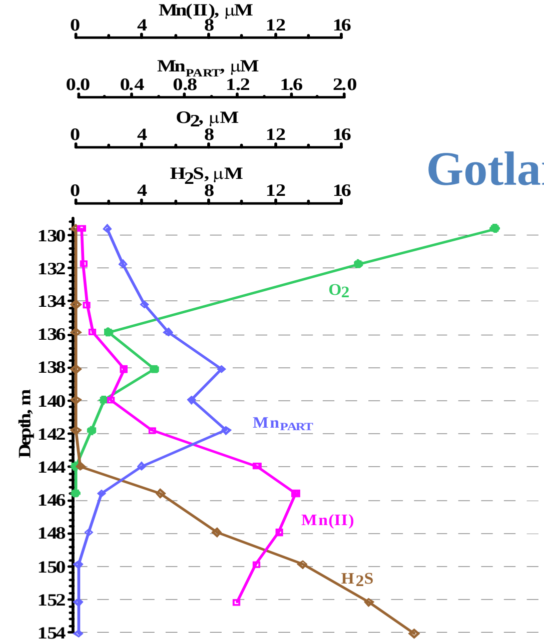


GOTM (General Ocean Turbulence Model), Burchard et al., 1999 (http://www.gotm.net).

Vertically balanced structure:

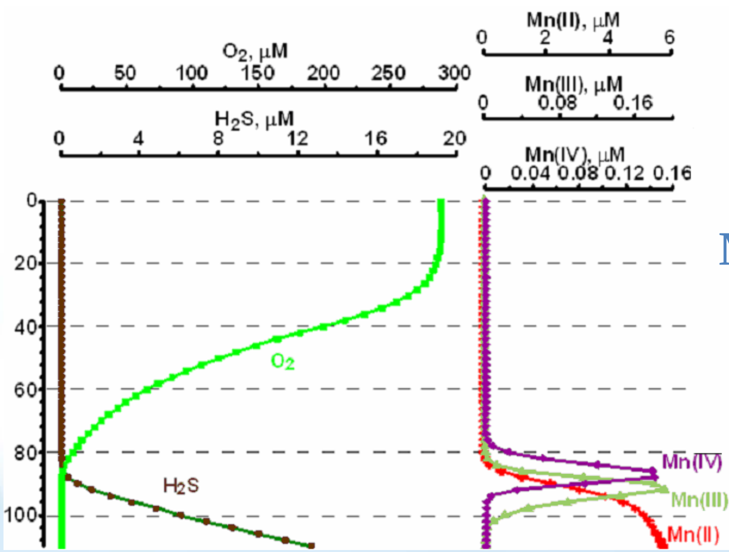


Gotland

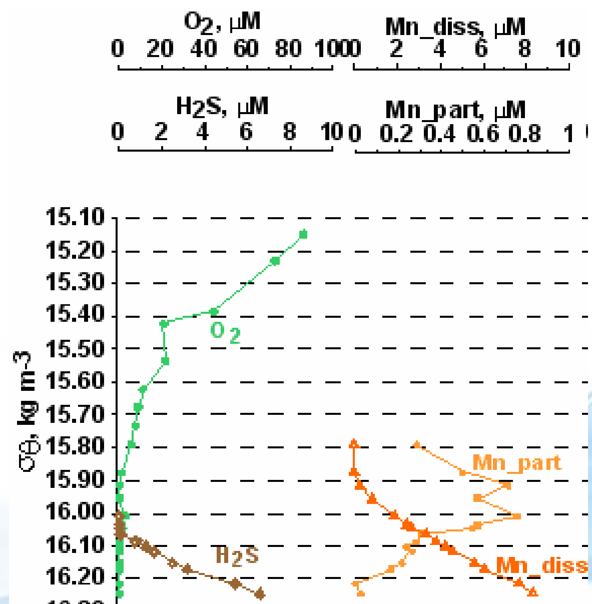


FS "Professor Albrecht Penck"
14.07.2006, St. 0011F05

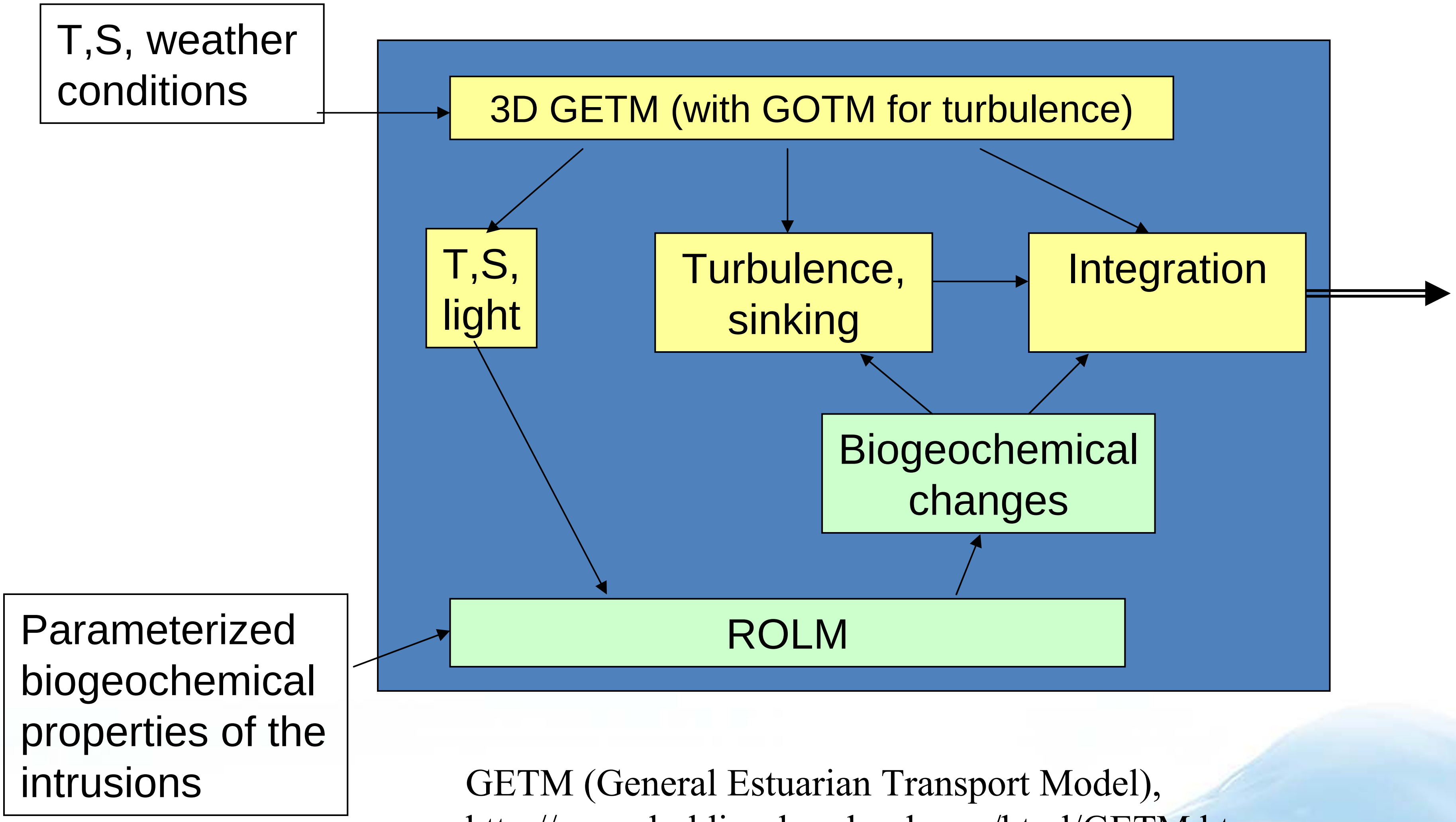
Model



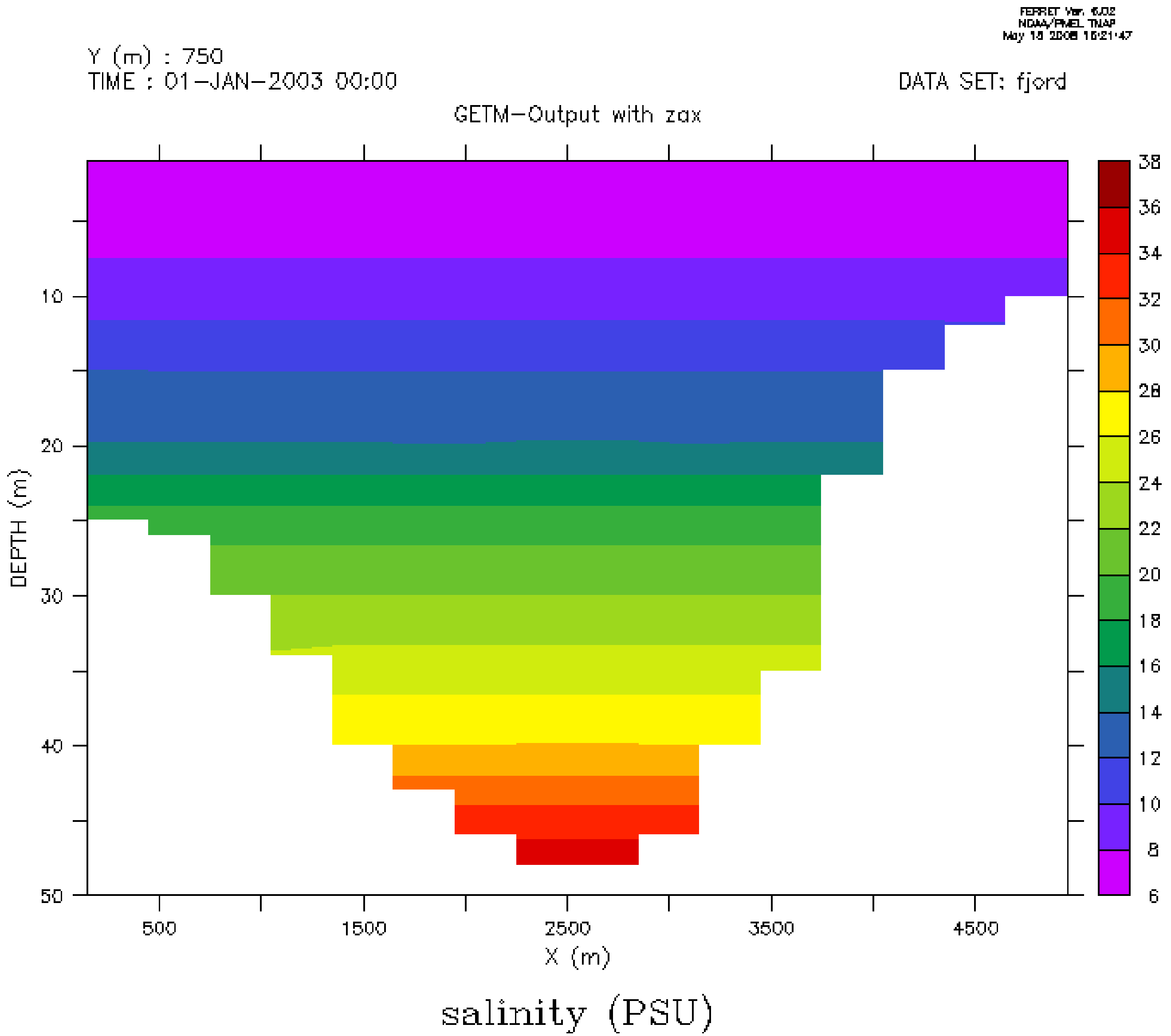
Black Sea

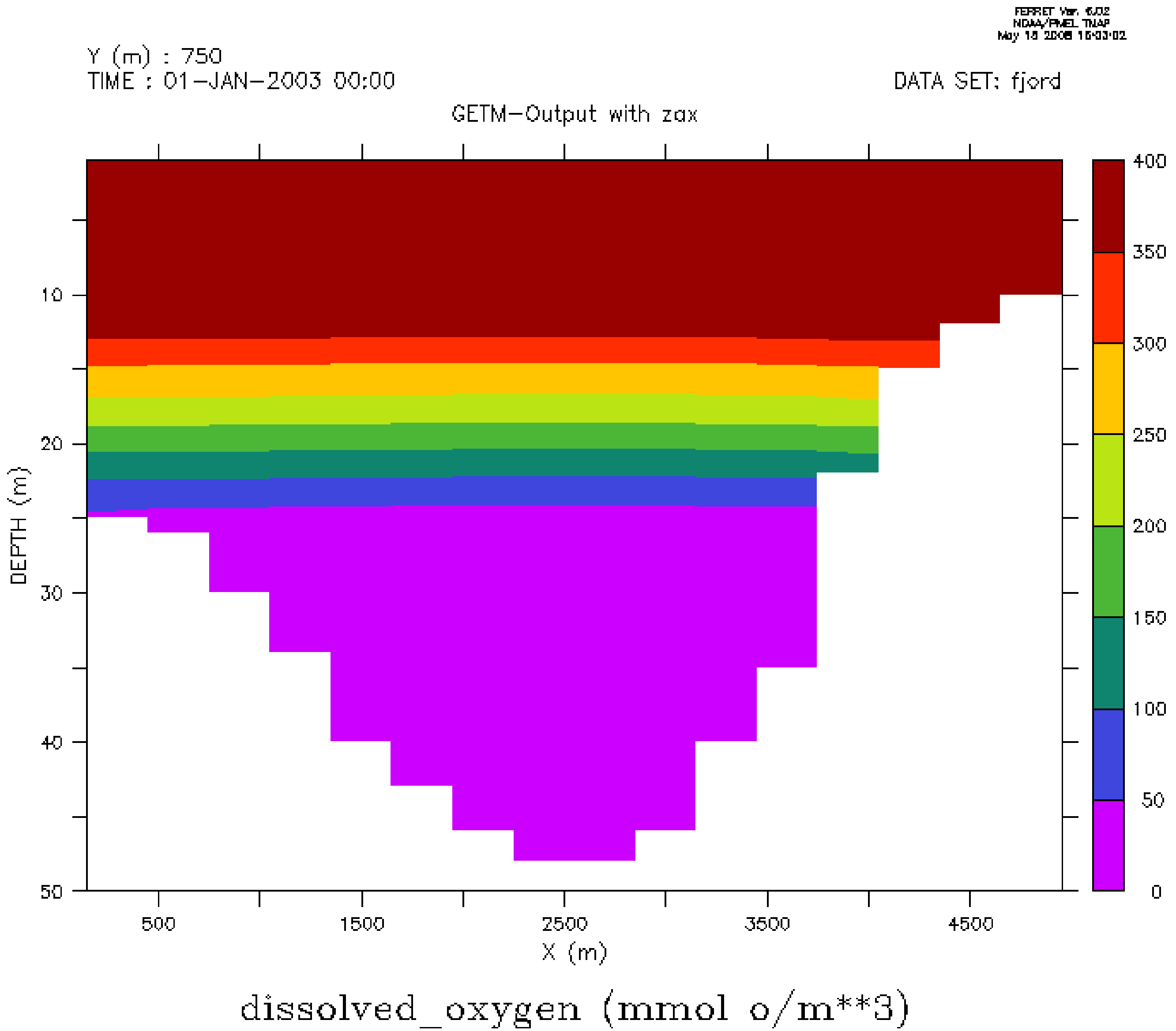


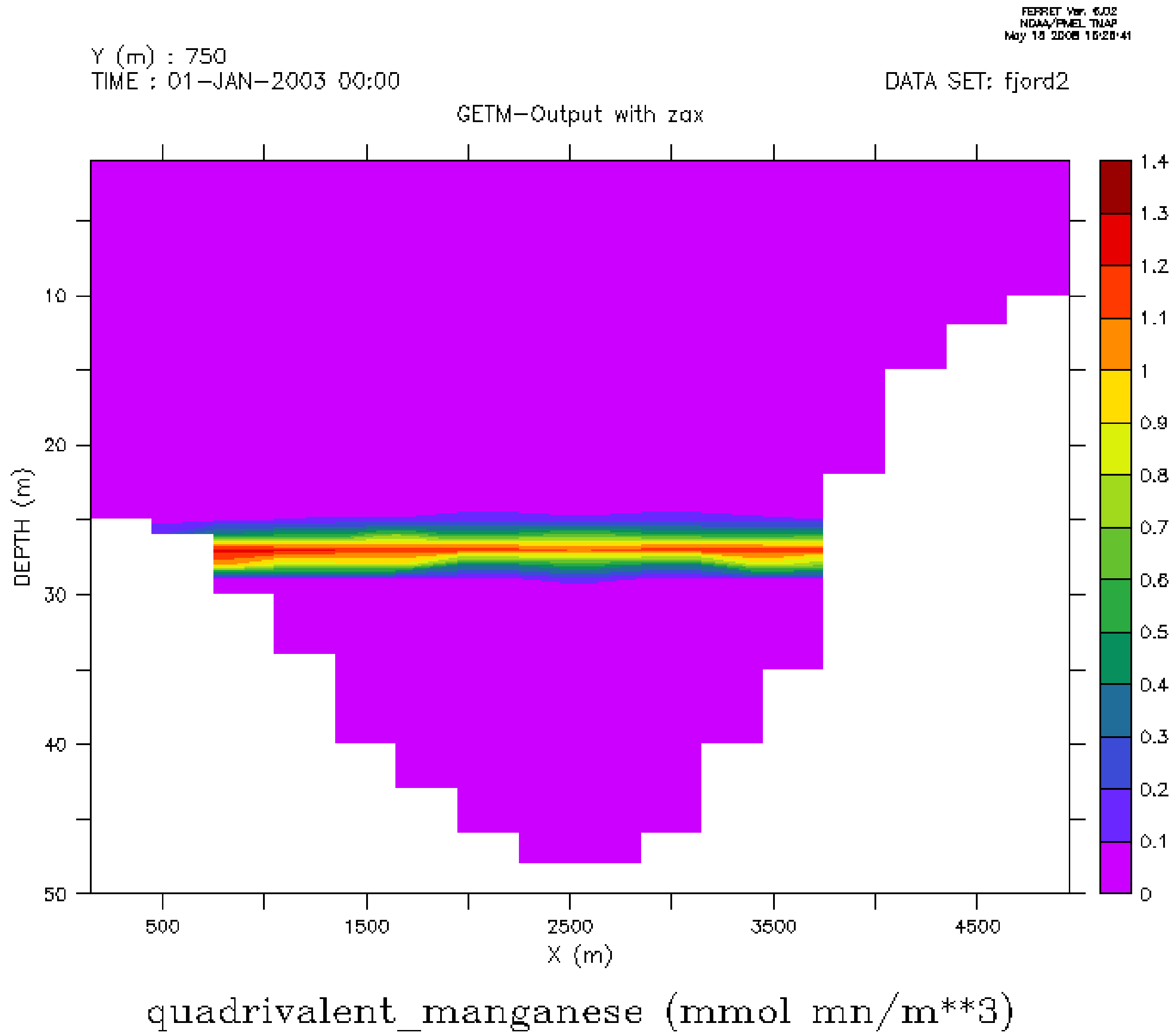
Scheme of calculations:

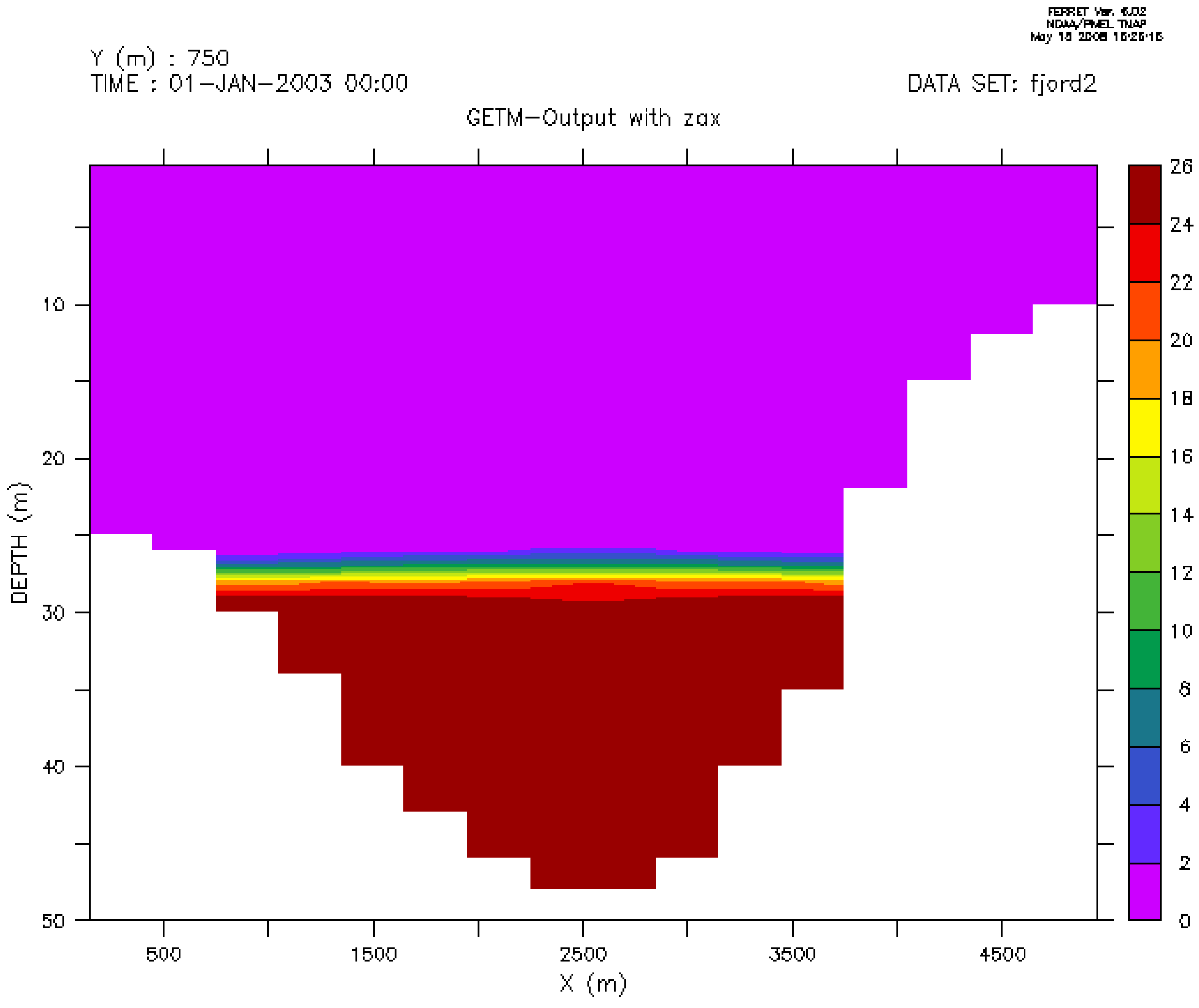


GETM (General Estuarian Transport Model), http://www.bolding-burchard.com/html/GETM.htm

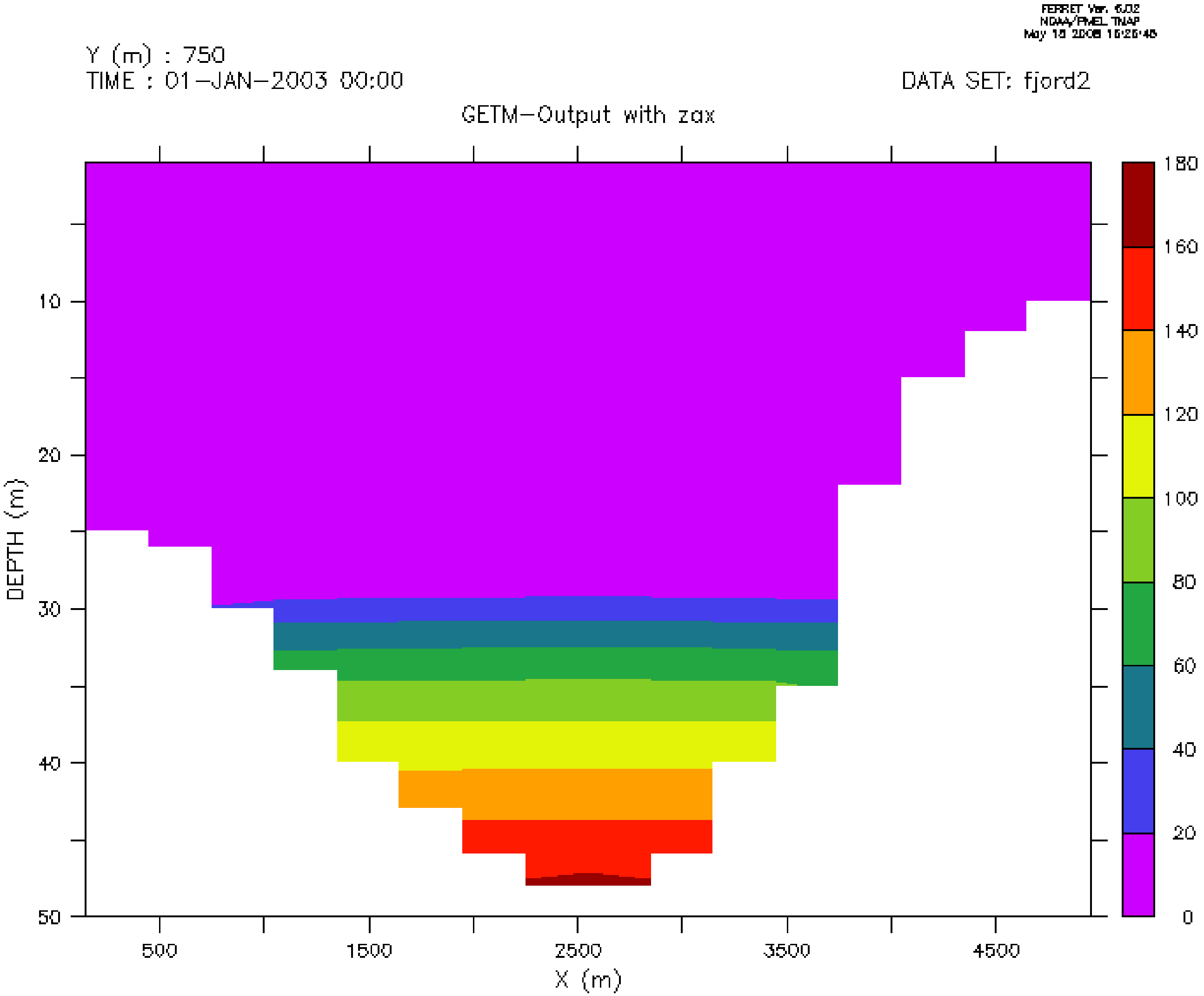

FERRET Ver. 6.02
NOAA/PMEL TMAP
May 15 2008 15:21:47
Y (m) : 750
TIME : 01-JAN-2003 00:00
DATA SET: fjord
GETM-Output with zax
DEPTH (m)
10
20
30
40
50
500
1500
2500
3500
4500
X (m)
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
salinity (PSU)


FERRET Ver. 6.02
NOAA/PMEL TMAP
Y (m) : 750
TIME : 01-JAN-2003 00:00
DATA SET: fjord
GETM-Output with zax
DEPTH (m)
10
20
30
40
50
500
1500
2500
3500
4500
X (m)
400
350
300
250
200
150
100
50
0
dissolved_oxygen (mmol o/m**3)

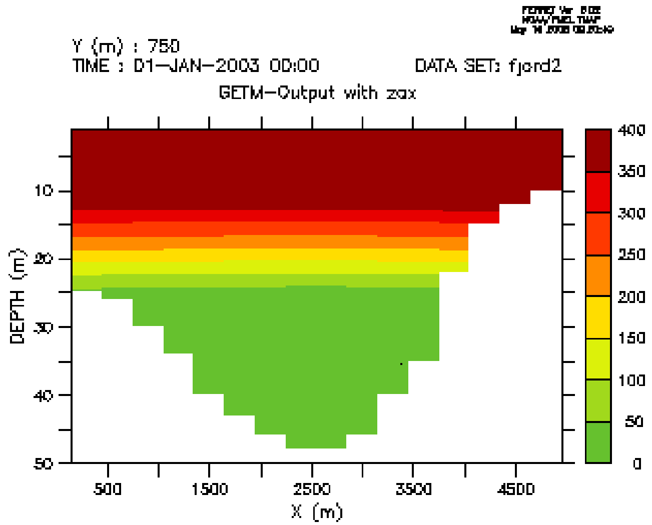

FERRET Ver. 6.02
NOAA/PMEL TMAP
May 15 2008 15:20:41
Y (m) : 750
TIME : 01-JAN-2003 00:00
DATA SET: fjord2
GETM-Output with zax
DEPTH (m)
10
20
30
40
50
500
1500
2500
3500
4500
X (m)
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
quadrivalent_manganese (mmol mn/m**3)



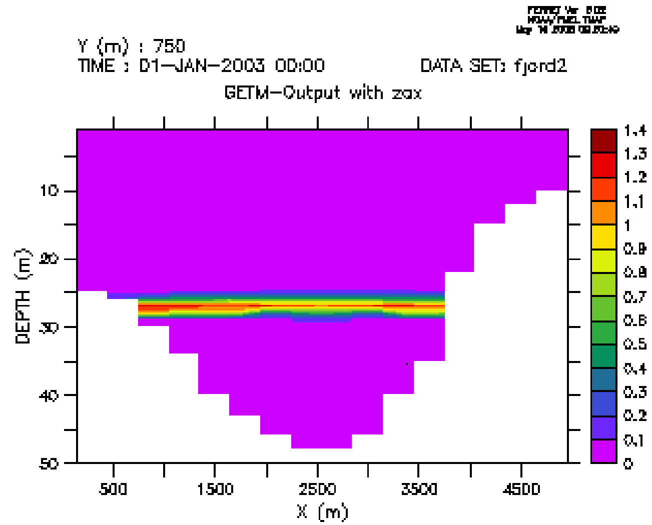
bivalent_manganese (mmol mn/m**3)



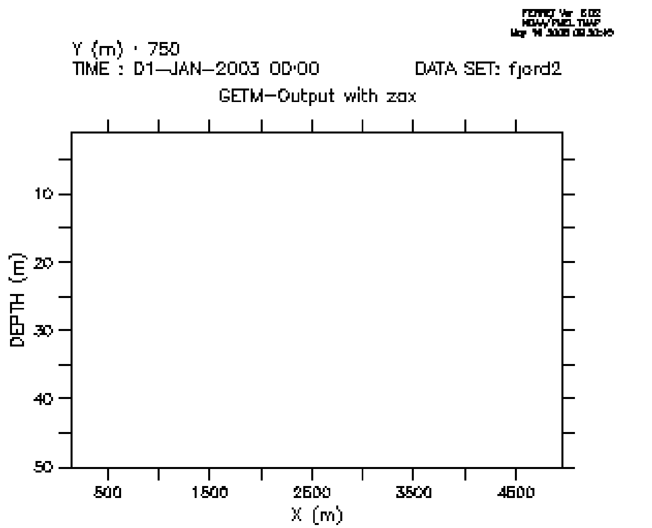
hydrogen_sulfide (mmol s/m**3)



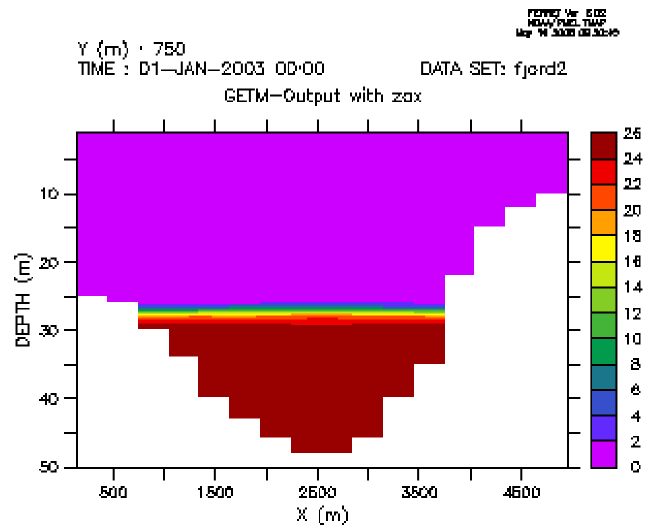
dissolved_oxygen (mmol o/m**3)



quadrivalent_manganese (mmol mn/m**3)



zonal vel. (m/s)

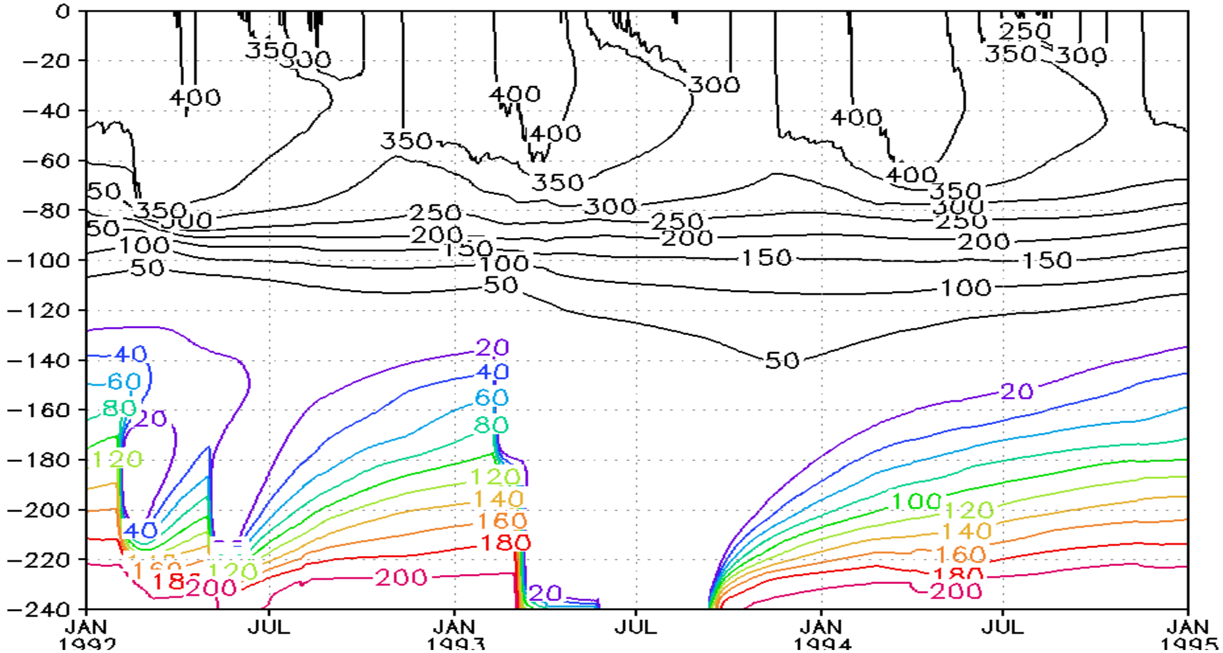


bivalent_manganese (mmol mn/m**3)

1D modeling of temporal variability:

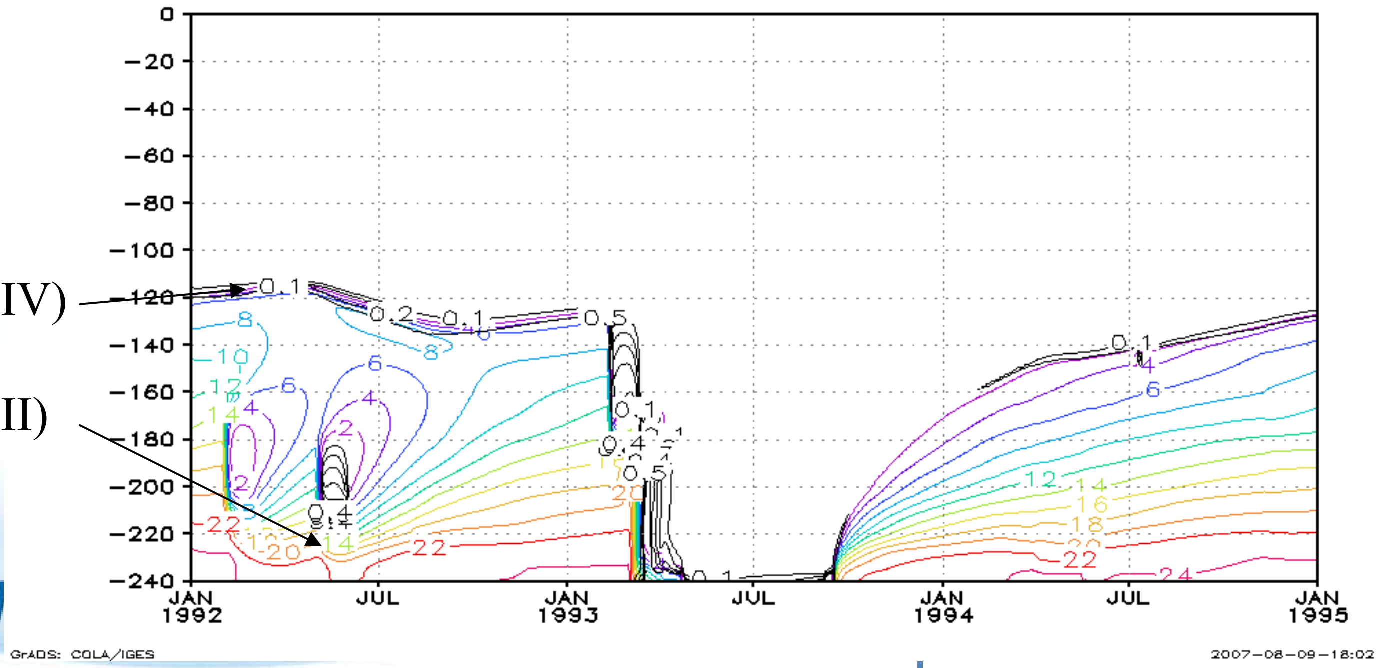
O_2

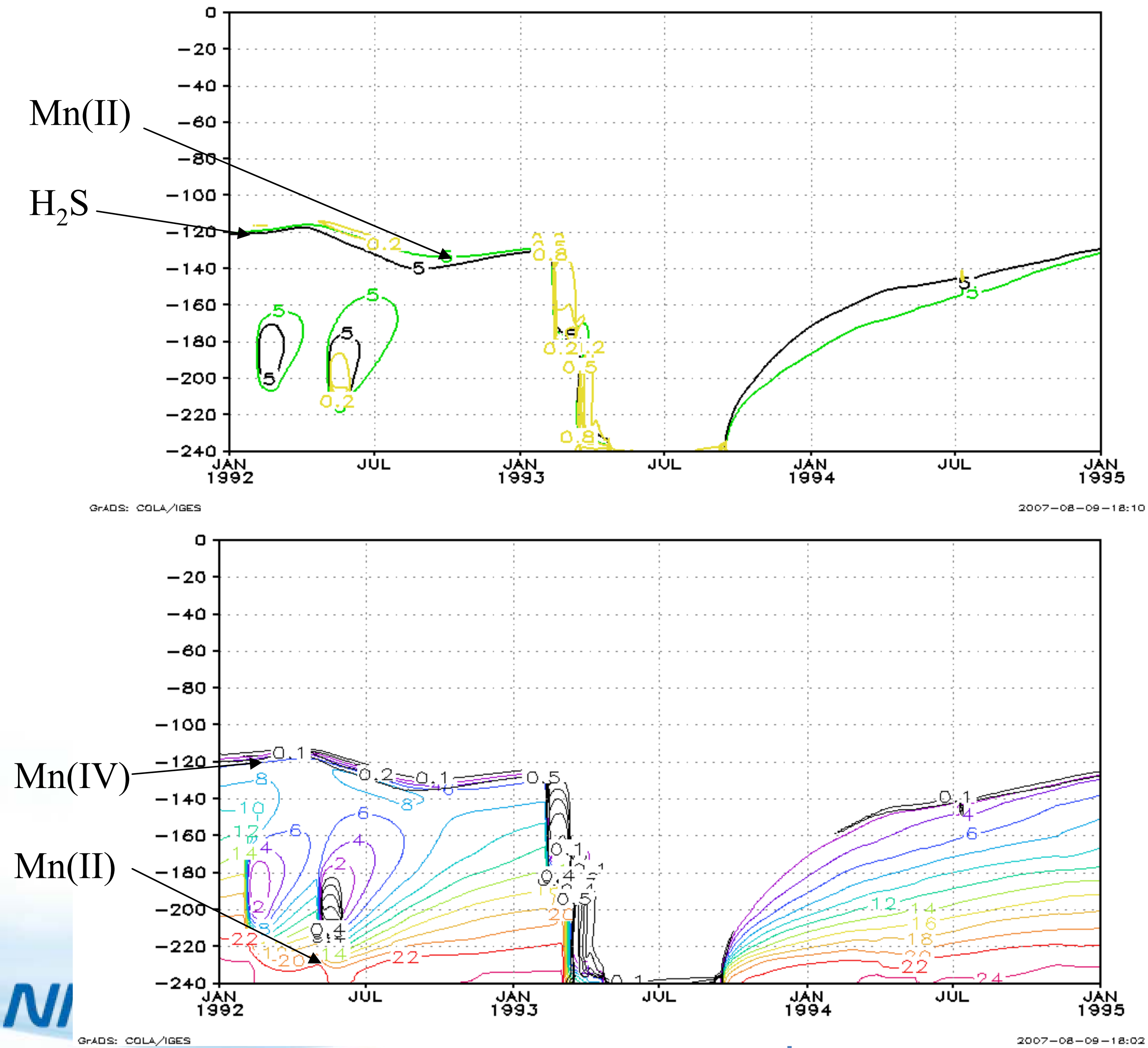
H_2S

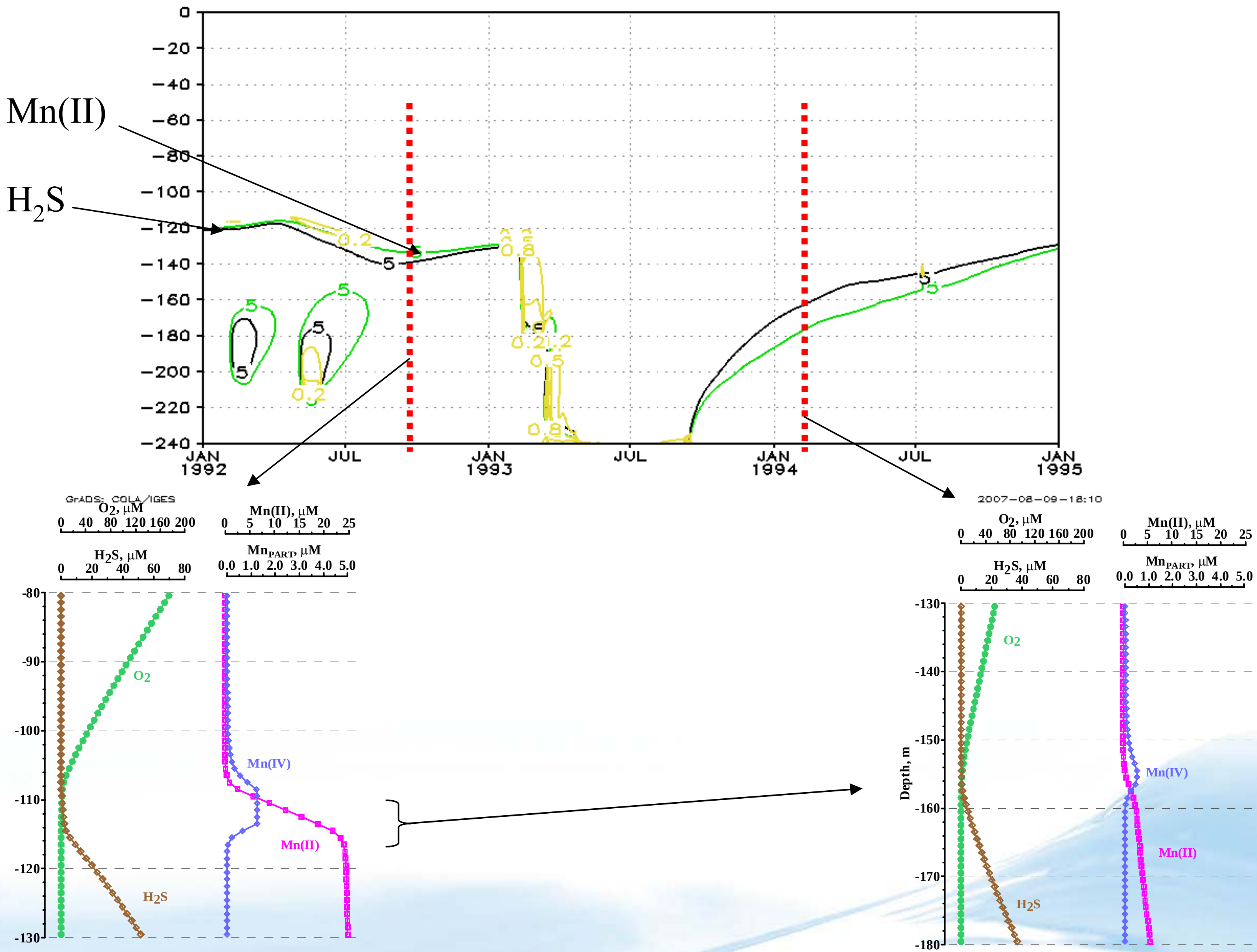


Mn(IV)

Mn(II)

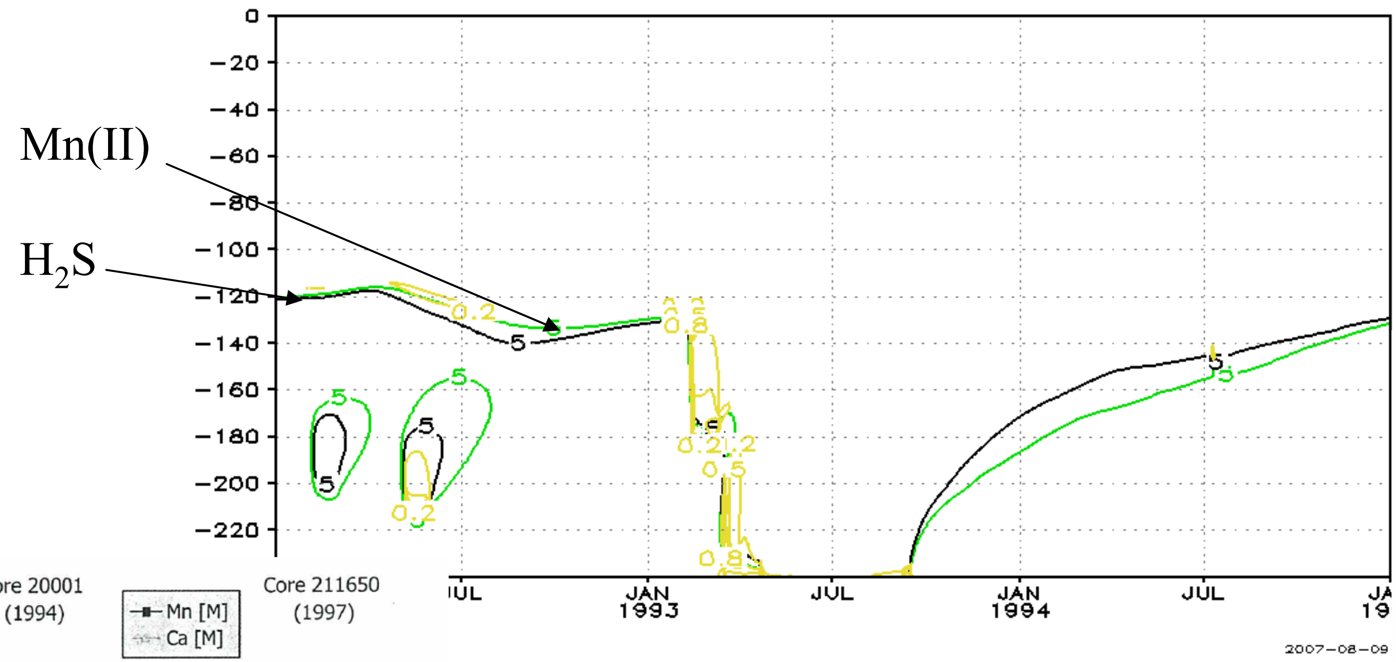



Mn(II)
H$_2$S
JAN 1992
JUL
JAN 1993
JUL
JAN 1994
JUL
JAN 1995
GrADS: COLA/IGES
2007-08-09-18:10
Mn(IV)
Mn(II)
GrADS: COLA/IGES
2007-08-09-18:02



01.01.1991

01.01.1991



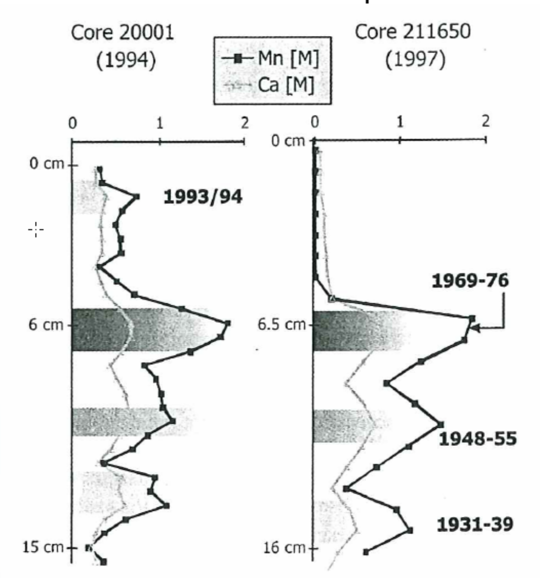
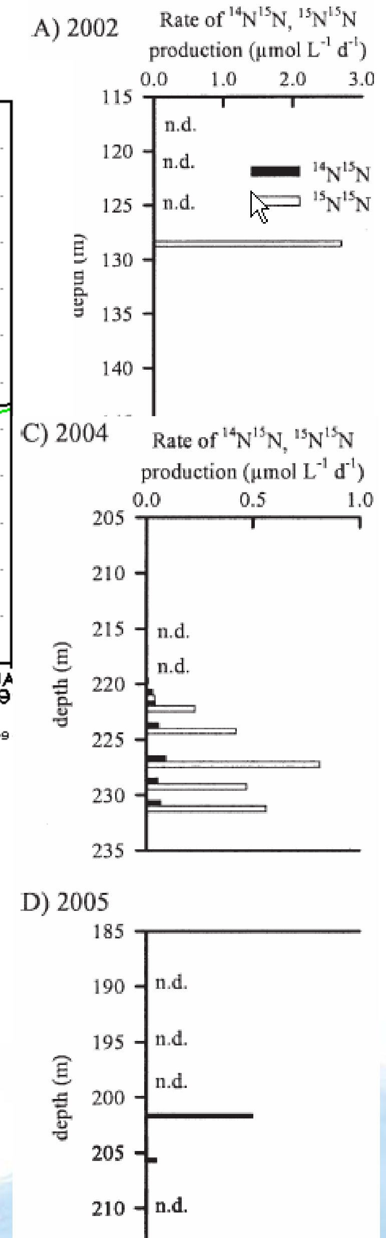


Fig. 8. Solid phase profiles of core 211650 (July 1997) and 20001 (August 1994, Neumann et al., 1997).



Intensive precipitation during the inflow (Pollehne, p.c. 2007)

Formation of the Mn-rich sediment layers after the inflows (Heiser et al., 2001)

Denitrification/anammox change in 1 year after an iflow (Hannig et al., 2007)

> 2 years required for the reestablishment of the stable redox interface structure…

NIVA

Conclusions

- Periods of oxygenated inflows are characterized by sudden increase of particulate Mn(IV) and vanishing of the total Mn from the water column.

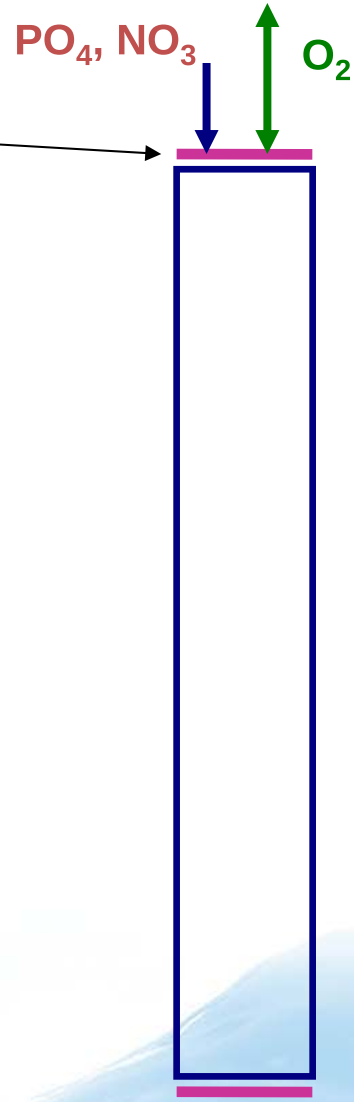
- Periods of reestablishing of the anoxic conditions are characterized my inbalanced redox structure with absence of Mn(IV) maximum between O_2 and H_2S.

- Application of the models (2D, 3D) can be usefull for analysing and prediction of the reactions of the oxygen-deficient and anoxic systems on the possible changes of climatic (mixing events) and anthropogenic factors (eutrophication).

Thank you !

Boundary conditions

Upper boundary:



PO_4, NO_3: $Q_P{}^u = 0.0085$ mmol m^{-2} d^{-1}

$Q_{NO3}{}^u = 0.46$ mmol m^{-2} d^{-1} (HELCOM, 2002)

O_2:

$$Q_{O_2} = k_{660}\,(Sc/660)^{-0.5}\,(Oxsat\text{-}O_2)$$

$$k_{660} = 0.365\ u^2 + 0.46\,u$$

Oxsat (T,S) is the O_2 saturation concentration (UNESCO,1986);

Sc is the Schmidt number

C_i: $Q_{Ci}{}^u = 0.$

Boundary conditions

Lower boundary:

Phy,Zoo,Bact,PON,POP: $$Q_{C_i} = -(B_u w^{Sink} \frac{\partial}{\partial z} C)/H_{bot}$$

H_{bot} Is the thickness of the box next to the bottom

B_u=0.8 – burial coefficient

Mn(IV),Fe(III): $$Q_{C_i} = 0$$

NH_4, PO_4: $$Q_{C_i} = \tau_L^{-1}(C_{Li} - C_i)$$

τ_L^{-1} =6000 s, is the relaxation time scale

$C_{NH4}=10\ \mu M$, $C_{PO4}=4.5\ \mu M$

H_2S,Mn(II), Fe(II) : $$Q_{C_i} = F_{bf}(O_2)\tau_L^{-1}(C_{Li} - C_i)$$

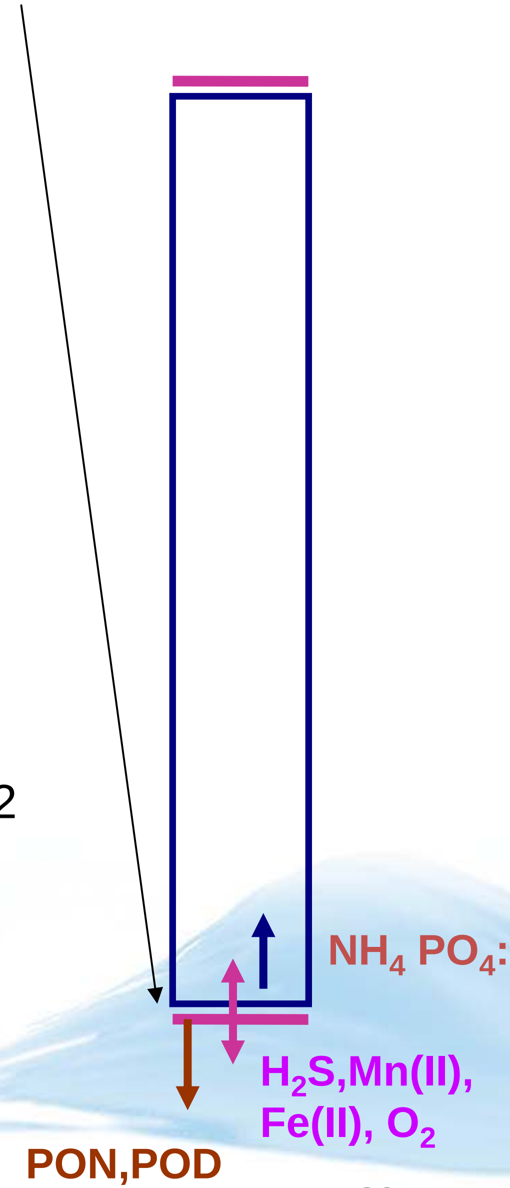
$F_{bf}(O_2) = (1 - 0.5(1 - \tanh(O_2^{bf} - O_2))$ is the dependence on O2

$C_{H2S}=40\ \mu M$, $C_{Mn(II)}= 10\ \mu M$, $C_{Fe(II)}=0.4\ \mu M$

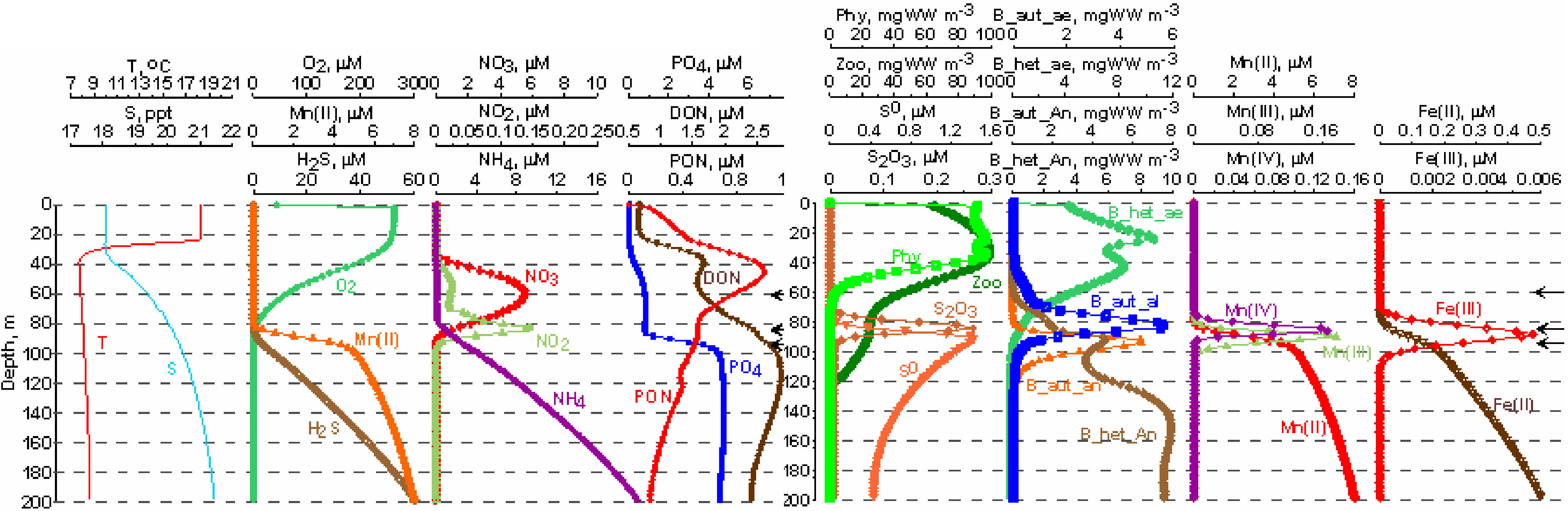
O_2: $$Q_{C_i} = F_{bf}'(O_2)\tau_L^{-1}(C_{Li} - C_i)$$

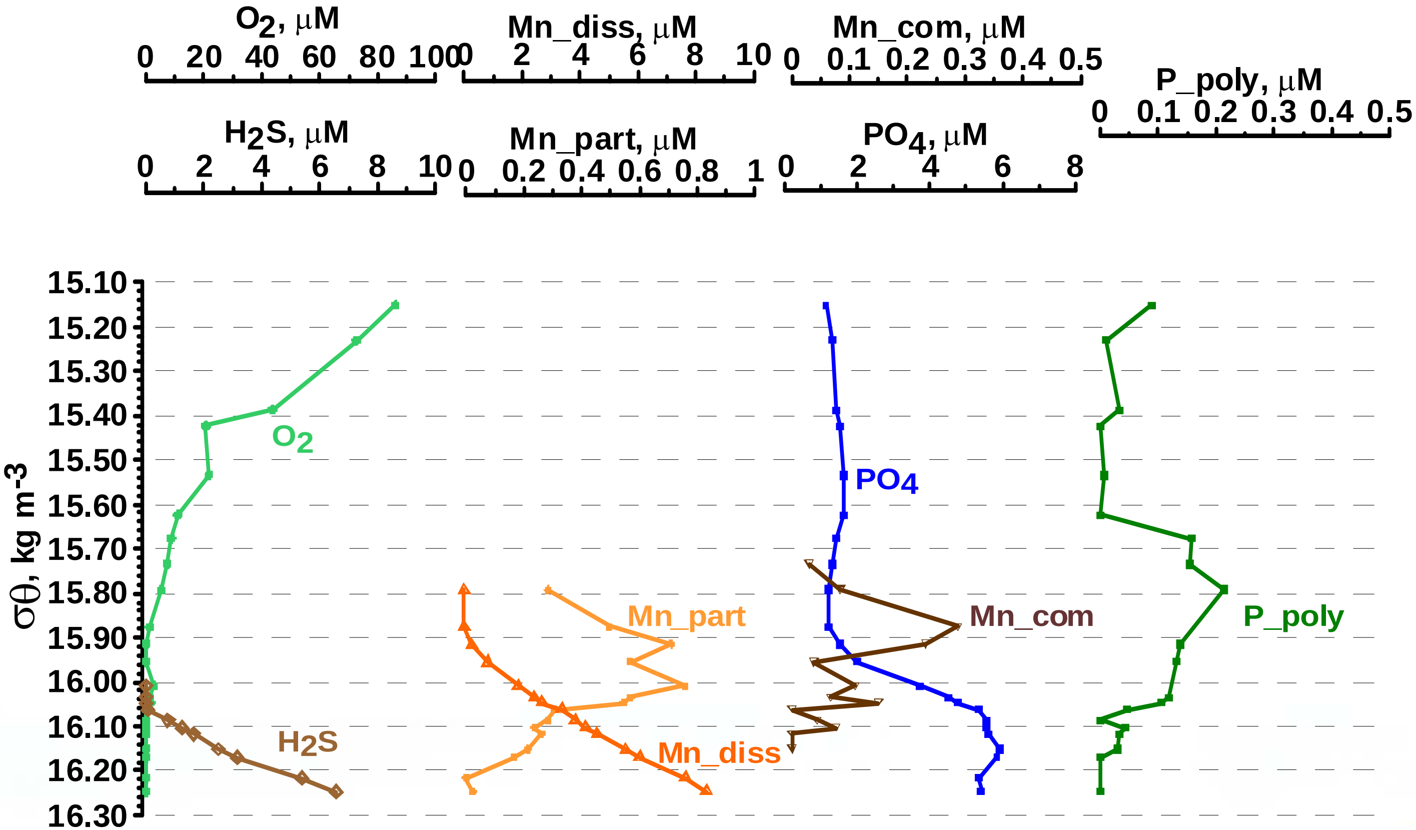
$F_{bf}'(O_2) = 0.5(1 - \tanh(O_2^{bf} - O_2)$ is the dependence on O2

$C_{O2}=0\ \mu M$



Stable balanced situation:





O2, µM
0 20 40 60 80 100
H2S, µM
0 2 4 6 8 10
Mn_diss, µM
0 2 4 6 8 10
Mn_part, µM
0 0.2 0.4 0.6 0.8 1
Mn_com, µM
0 0.1 0.2 0.3 0.4 0.5
PO4, µM
0 2 4 6 8
P_poly, µM
0 0.1 0.2 0.3 0.4 0.5
σθ, kg m-3
15.10
15.20
15.30
15.40
15.50
15.60
15.70
15.80
15.90
16.00
16.10
16.20
16.30
O2
H2S
Mn_part
Mn_diss
PO4
Mn_com
P_poly