On the role of salinity on the water mass transformation in the central Irminger Sea between 2002 and 2011

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GLOBAL DISCOVERIES FOR TOMORROW'S WORLD

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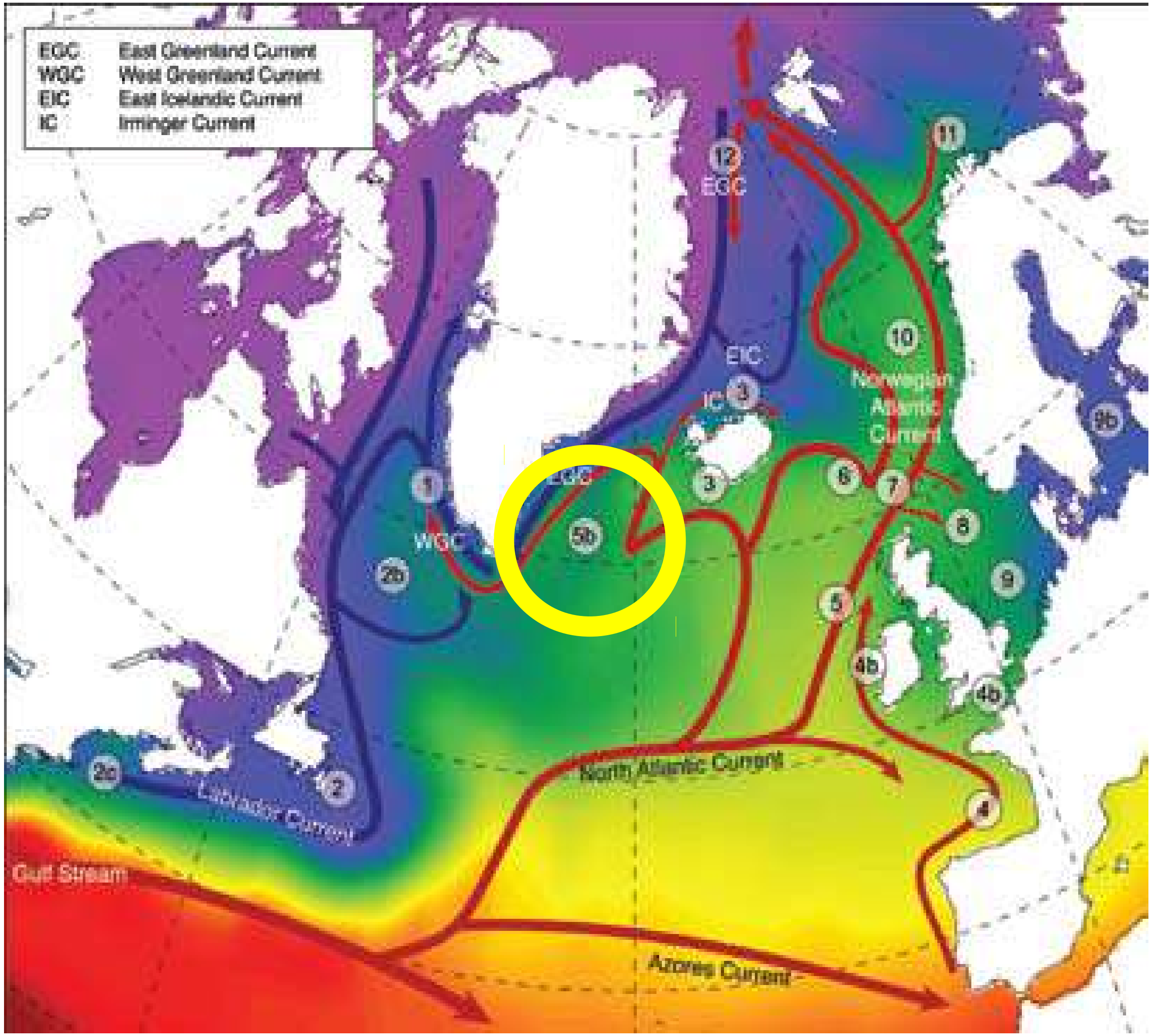

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Changes in Salinity & Temperature in ICES area (2000 to 2009) – mostly upper layer

ΔS

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1 (12)	-0.94	0.69	-1.40	0.42	0.51	1.78	1.69	2.01	-1.54	
2 (1)	0.80	1.02	-1.54	1.85	1.15	1.62	1.10	0.90	-1.06	1.20
3 (2b)	0.25	-0.24	0.27	0.17	0.92	0.71	0.24	0.46	1.04	1.17
4 (2)	0.38	[illegible]	[illegible]	0.50	0.88	0.92	0.85	0.92	1.35	0.31
5 (2c)										
6 (2c)	[illegible]	[illegible]	[illegible]	-0.59	-1.96	-2.30	-1.08	-0.48	-0.13	-0.13
7 (2)	0.44	0.25	-0.22	0.74	0.17	0.34	0.44	-1.12	-0.67	-0.81
8 (2)	-0.97	0.12	-0.70	-1.15	-1.16	-1.73	-0.29	0.06	-0.50	-0.69
9 (3)	0.56	0.61	-0.48	1.14	0.81	0.02	-0.09	-0.09	-0.04	0.82
10 (3)	0.59	0.34	-0.12	0.29	0.35	0.18	0.70	0.69	0.75	0.55
11 (3)	0.99	0.83	0.97	2.54	2.37	3.40	2.37	2.46	2.08	3.17
12 (4b)										
13 (5)	1.17	0.74		2.57	2.52	2.19	2.13	2.34	2.71	2.82
14 (5b)	0.10	0.70	1.37	0.54	2.45	1.84	1.53	1.72	0.76	0.89
15 (6)	0.70	0.54	0.57	2.16	2.37	1.92	1.41	1.62	2.53	2.20
16 (6)	0.68	0.63	0.83	2.02	1.73	2.15	1.46	1.58	1.92	2.32
17 (7)	0.09	0.09	1.27	1.59	1.64	1.34	0.93	1.14	1.41	1.46
18 (7)	0.97	1.23	1.86	2.20	2.09	2.06	1.89	1.37	1.89	2.80
19 (10)	0.77	0.55	0.89	1.73	1.71	1.24	1.26	1.11	0.22	1.89
20 (10)	0.41	0.06	0.78	0.96	0.99	0.77	0.75	0.95	0.60	1.77
21 (10)	0.18	0.20	0.18	1.17	1.20	1.60	1.57	0.63	0.20	1.60
22 (11)	0.16	0.06	0.33	0.71	1.52	1.49	1.96	1.61	1.34	0.72
23 (11)	0.12	-0.72	-0.22	0.95	1.95	0.95	0.95	1.45	0.28	0.62
24 (12)	-0.33	0.12	0.16	-0.19	0.49	1.40	1.88	1.54	0.67	0.93
25 (10)	0.06	-0.22	0.40	0.14	0.74	1.48	1.70	1.30	0.90	0.80
26 (12)	0.38	1.89	1.51	1.51	1.89	3.40	4.15	2.23	1.17	2.30
27 (4)	-0.53	-1.94	-0.49	-1.02	-0.77	-0.23	0.76	0.77	0.94	0.02
28 (89)	-1.56	-1.93	-0.40	1.14	1.50	0.79	-0.43	-0.74	0.33	-0.07
29 (89)										
30 (89)	0.08	-1.65	-0.50	-0.39	0.52	0.18	0.72	-0.03	0.73	0.58
31 (89)	0.04	-0.95	-0.27	0.60	0.44	0.27	1.01		0.94	1.20
32 (9b)	-1.12	-1.98	-1.48	-1.79	-1.40	-0.98	-1.70	-0.94	-1.07	-0.81

ΔT

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1 (12)	0.06	0.60	-1.52	0.32	1.22	0.04	0.04	3.50	-0.75	
2 (1)	1.02	0.93	-0.80	2.27	1.26	0.99	0.56	0.76	-0.55	0.91
3 (2b)	-0.23	[illegible]	0.06	1.86	0.49	0.96	0.88	0.50	1.19	-0.16
4 (2)	0.94	1.03	0.56	0.97	2.41	1.62	2.68	0.01	0.62	0.29
5 (2c)	1.59	[illegible]	0.54	-0.13	-0.56	-0.83				
6 (2c)	[illegible]	[illegible]	2.72	1.21	0.86	0.45	1.17	1.48	0.89	0.11
7 (2)	0.22	0.04	0.09	0.07	0.35	0.10	0.33	-1.55	-0.73	-1.06
8 (2)	3.55	-0.31	0.14	-1.77	-1.01	-0.02	0.88	-0.62	-0.31	0.38
9 (3)	1.02	0.07	-1.19	2.11	0.94	0.44	0.05	0.61	-0.02	-0.02
10 (3)	-0.44	-0.49	-1.04	1.54	0.39	-0.16	0.14	-0.44	0.38	0.27
11 (3)	0.52	0.73	0.47	2.22	2.15	3.34	1.95	1.89	1.19	2.07
12 (4b)	1.38	0.50	1.38	1.82	2.69	2.48	2.26	3.13		
13 (5)	0.74	0.14		2.34	2.88	3.24	4.38	3.48	3.34	2.38
14 (5b)	0.26	1.24	1.04	1.11	2.72	1.58	1.22	2.01	0.33	-0.07
15 (6)	0.34	0.86	0.89	2.75	2.43	1.53	2.58	2.34	2.62	2.02
16 (6)	0.49	0.45	0.74	2.37	1.96	1.50	1.59	1.92	1.71	2.00
17 (7)	0.73	0.40	3.47	4.33	2.80	2.80	3.60	4.40	3.40	2.20
18 (7)	1.20	1.64	2.84	3.24	2.84	2.36	2.64	2.92	3.00	3.52
19 (10)	2.88	0.80	1.94	2.27	2.20	0.85	2.14	1.90	0.49	2.57
20 (10)	0.88	0.67	2.08	1.70	0.78	0.55	1.49	2.11	0.39	1.93
21 (10)	0.54	1.02	0.46	1.49	1.35	1.46	2.01	0.64	0.32	2.05
22 (11)	0.59	0.27	0.77	0.58	1.21	1.10	1.99	1.79	0.96	1.55
23 (11)	1.47	1.16	1.04	0.48	1.80	1.86	2.39	2.10	1.49	1.59
24 (12)	0.12	0.13	-0.08	-0.68	0.50	1.10	2.13	1.14	1.08	0.67
25 (10)	0.14	-0.20	0.35	-0.07	0.58	1.32	1.50	0.78	0.35	0.62
26 (12)	0.34	1.45	0.95	1.03	2.29	2.33	3.71	2.74	0.24	1.18
27 (4)	-0.47	-0.48	-0.37	0.21	-0.31	-2.10	-0.61	1.50	0.76	-1.57
28 (89)	1.53	1.53	2.65	3.79	3.00	1.85	2.71	2.29	1.38	2.00
29 (89)	0.60	0.49	0.69	0.84	0.68	0.17				
30 (89)	0.99	0.82	1.25	0.43	0.64	0.18	0.29	1.04	0.48	0.62
31 (89)	0.97	0.95	1.66	1.17	0.95	1.15	1.43		1.21	0.82
32 (9b)		1.20	2.84	0.29	0.98	1.76	2.23	2.23	2.06	1.64

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Area 5b – Irminger Sea

Warming / salinity increase in middle of 2000's

Abrupt cooling in 2008 & 2009 –

Return of deep convection to NA (Våge et al. 2009, Nature Geoscience)

ΔS

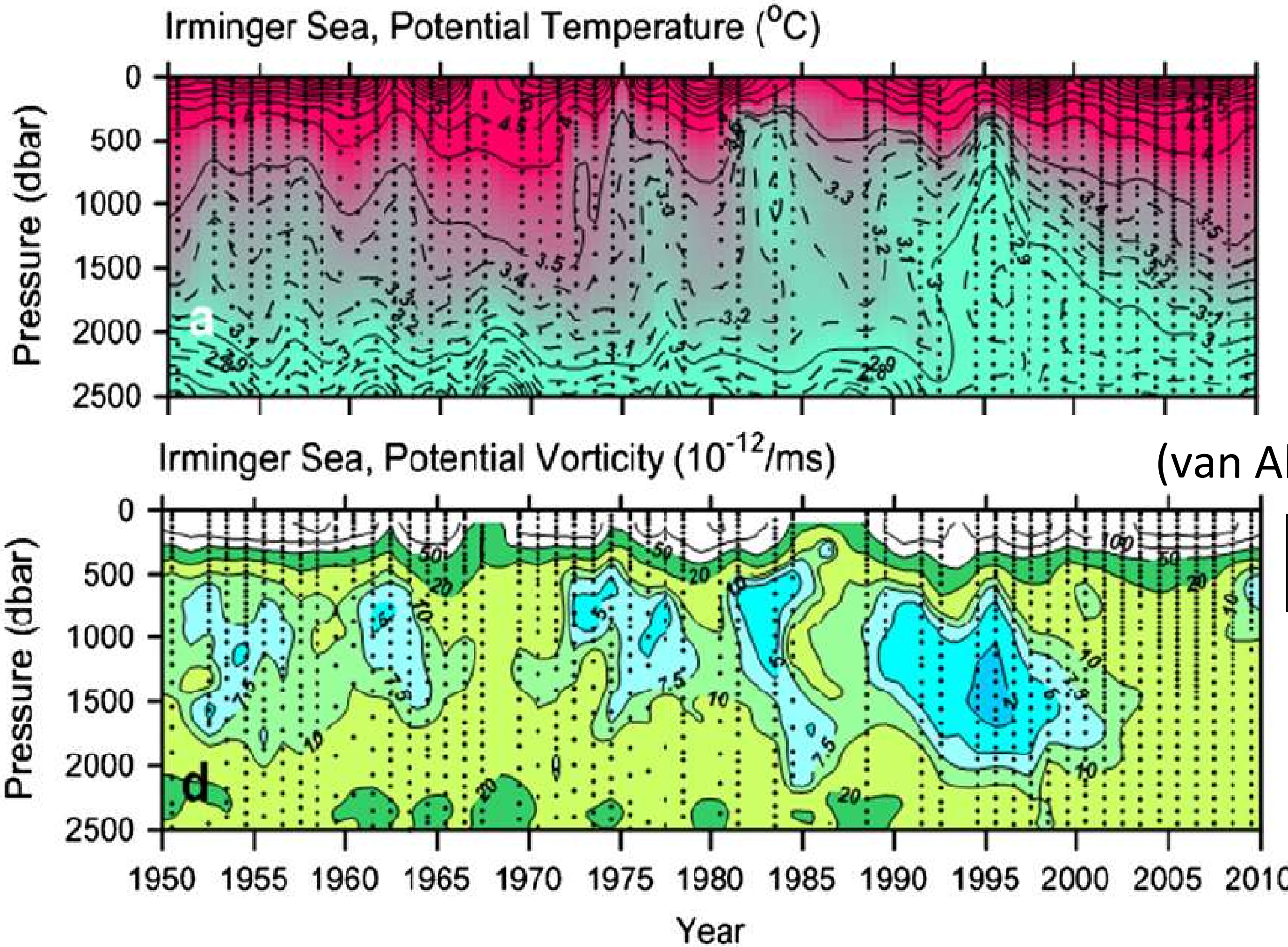
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1 (12)	-0.94	0.69	-1.40	0.42	0.51	1.78	1.69	2.01	-1.54	
2 (1)	0.80	1.02	-1.54	1.85	1.15	1.62	1.10	0.90	-1.06	1.20
3 (2b)	0.25	-0.24	0.27	0.17	0.92	0.71	0.24	0.46	1.04	1.17
4 (2)	0.38	[illegible]	[illegible]	0.50	0.88	0.92	0.85	0.92	1.35	0.31
5 (2c)										
6 (2c)	[illegible]	[illegible]	[illegible]	-0.59	-1.96	-2.30	-1.08	-0.48	-0.13	-0.13
7 (2)	0.44	0.25	-0.22	0.74	0.17	0.34	0.44	-1.12	-0.67	-0.81
8 (2)	-0.97	0.12	-0.70	-1.15	-1.16	-1.73	-0.29	0.06	-0.50	-0.69
9 (3)	0.56	0.61	-0.48	1.14	0.81	0.02	-0.09	-0.09	-0.04	0.82
10 (3)	0.59	0.34	-0.12	0.29	0.35	0.18	0.70	0.69	0.75	0.55
11 (3)	0.99	0.83	0.97	2.54	2.37	3.40	2.37	2.46	2.08	3.17
12 (4b)										
[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14 (5b)	0.10	0.70	1.37	0.54	2.45	1.84	1.53	1.72	0.76	0.89
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16 (6)	0.68	0.63	0.83	2.02	1.73	2.15	1.46	1.58	1.92	2.32
17 (7)	0.09	0.09	1.27	1.59	1.64	1.34	0.93	1.14	1.41	1.46
18 (7)	0.97	1.23	1.86	2.20	2.09	2.06	1.89	1.37	1.89	2.80
19 (10)	0.77	0.55	0.89	1.73	1.71	1.24	1.26	1.11	0.22	1.89
20 (10)	0.41	0.06	0.78	0.96	0.99	0.77	0.75	0.95	0.60	1.77
21 (10)	0.18	0.20	0.18	1.17	1.20	1.60	1.57	0.63	0.20	1.60
22 (11)	0.16	0.06	0.33	0.71	1.52	1.49	1.96	1.61	1.34	0.72
23 (11)	0.12	-0.72	-0.22	0.95	1.95	0.95	0.95	1.45	0.28	0.62
24 (12)	-0.33	0.12	0.16	-0.19	0.49	1.40	1.88	1.54	0.67	0.93
25 (10)	0.06	-0.22	0.40	0.14	0.74	1.48	1.70	1.30	0.90	0.80
26 (12)	0.38	1.89	1.51	1.51	1.89	3.40	4.15	2.23	1.17	2.30
27 (4)	-0.53	-1.94	-0.49	-1.02	-0.77	-0.23	0.76	0.77	0.94	0.02
28 (89)	-1.56	-1.93	-0.40	1.14	1.50	0.79	-0.43	-0.74	0.33	-0.07
29 (89)										
30 (89)	0.08	-1.65	-0.50	-0.39	0.52	0.18	0.72	-0.03	0.73	0.58
31 (89)	0.04	-0.95	-0.27	0.60	0.44	0.27	1.01		0.94	1.20
32 (9b)	-1.12	-1.98	-1.48	-1.79	-1.40	-0.98	-1.70	-0.94	-1.07	-0.81

ΔT

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1 (12)	0.06	0.60	-1.52	0.32	1.22	0.04	0.04	3.50	-0.75	
2 (1)	1.02	0.93	-0.80	2.27	1.26	0.99	0.56	0.76	-0.55	0.91
3 (2b)	-0.23	0.09	0.06	1.86	0.49	0.96	0.88	0.50	1.19	-0.16
4 (2)	0.94	[illegible]	[illegible]	0.97	2.41	1.62	2.68	0.01	0.62	0.29
5 (2c)	1.59	1.20	0.54	-0.13	-0.56	-0.83				
6 (2c)	1.79	[illegible]	2.72	1.21	0.86	0.45	1.17	1.48	0.89	0.11
7 (2)	[illegible]	[illegible]	0.09	0.07	0.35	0.10	0.33	-1.55	-0.73	-1.06
8 (2)	3.55	-0.31	0.14	-1.77	-1.01	-0.02	0.88	-0.62	-0.31	0.38
9 (3)	1.02	0.07	-1.19	2.11	0.94	0.44	0.05	0.61	-0.02	-0.02
10 (3)	-0.44	-0.49	-1.04	1.54	0.39	-0.16	0.14	-0.44	0.38	0.27
11 (3)	0.52	0.73	0.47	2.22	2.15	3.34	1.95	1.89	1.19	2.07
12 (4b)	1.38	0.50	1.38	1.82	2.69	2.48	2.26	3.13		
[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14 (5b)	0.26	1.24	1.04	1.11	2.72	1.58	1.22	2.01	0.33	-0.07
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16 (6)	0.49	0.45	0.74	2.37	1.96	1.50	1.59	1.92	1.71	2.00
17 (7)	0.73	0.40	3.47	4.33	2.80	2.80	3.60	4.40	3.40	2.20
18 (7)	1.20	1.64	2.84	3.24	2.84	2.36	2.64	2.92	3.00	3.52
19 (10)	2.88	0.80	1.94	2.27	2.20	0.85	2.14	1.90	0.49	2.57
20 (10)	0.88	0.67	2.08	1.70	0.78	0.55	1.49	2.11	0.39	1.93
21 (10)	0.54	1.02	0.46	1.49	1.35	1.46	2.01	0.64	0.32	2.05
22 (11)	0.59	0.27	0.77	0.58	1.21	1.10	1.99	1.79	0.96	1.55
23 (11)	1.47	1.16	1.04	0.48	1.80	1.86	2.39	2.10	1.49	1.59
24 (12)	0.12	0.13	-0.08	-0.68	0.50	1.10	2.13	1.14	1.08	0.67
25 (10)	0.14	-0.20	0.35	-0.07	0.58	1.32	1.50	0.78	0.35	0.62
26 (12)	0.34	1.45	0.95	1.03	2.29	2.33	3.71	2.74	0.24	1.18
27 (4)	-0.47	-0.48	-0.37	0.21	-0.31	-2.10	-0.61	1.50	0.76	-1.57
28 (89)	1.53	1.53	2.65	3.79	3.00	1.85	2.71	2.29	1.38	2.00
29 (89)	0.60	0.49	0.69	0.84	0.68	0.17				
30 (89)	0.99	0.82	1.25	0.43	0.64	0.18	0.29	1.04	0.48	0.62
31 (89)	0.97	0.95	1.66	1.17	0.95	1.15	1.43		1.21	0.82
32 (9b)		1.20	2.84	0.29	0.98	1.76	2.23	2.23	2.06	1.64

Primary reason for warming of deep waters

- Lack in deep reaching overturn/deep convection:

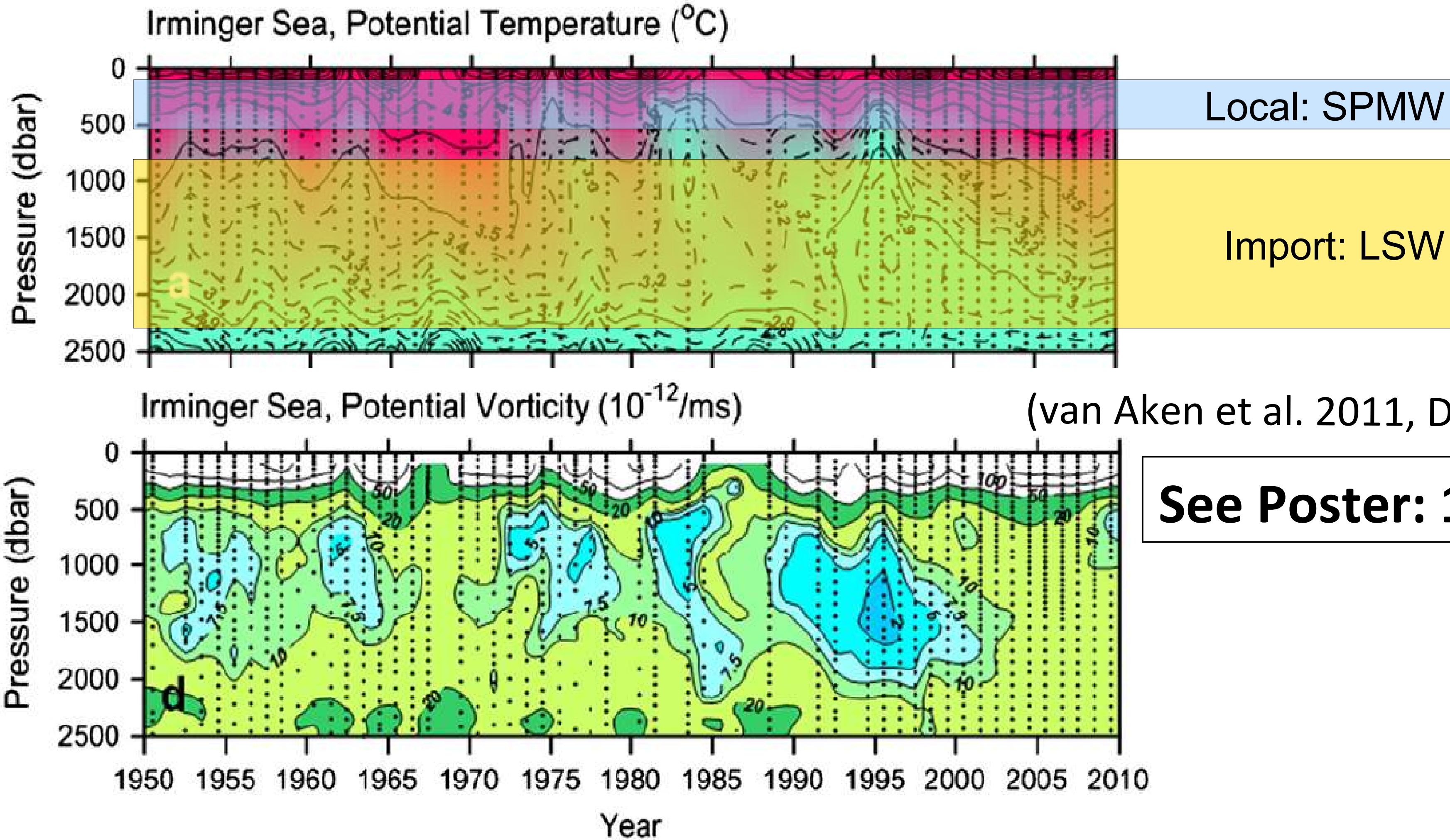


(van Aken et al. 2011, DSR1)

See Poster: 118

Primary reason for warming of deep waters

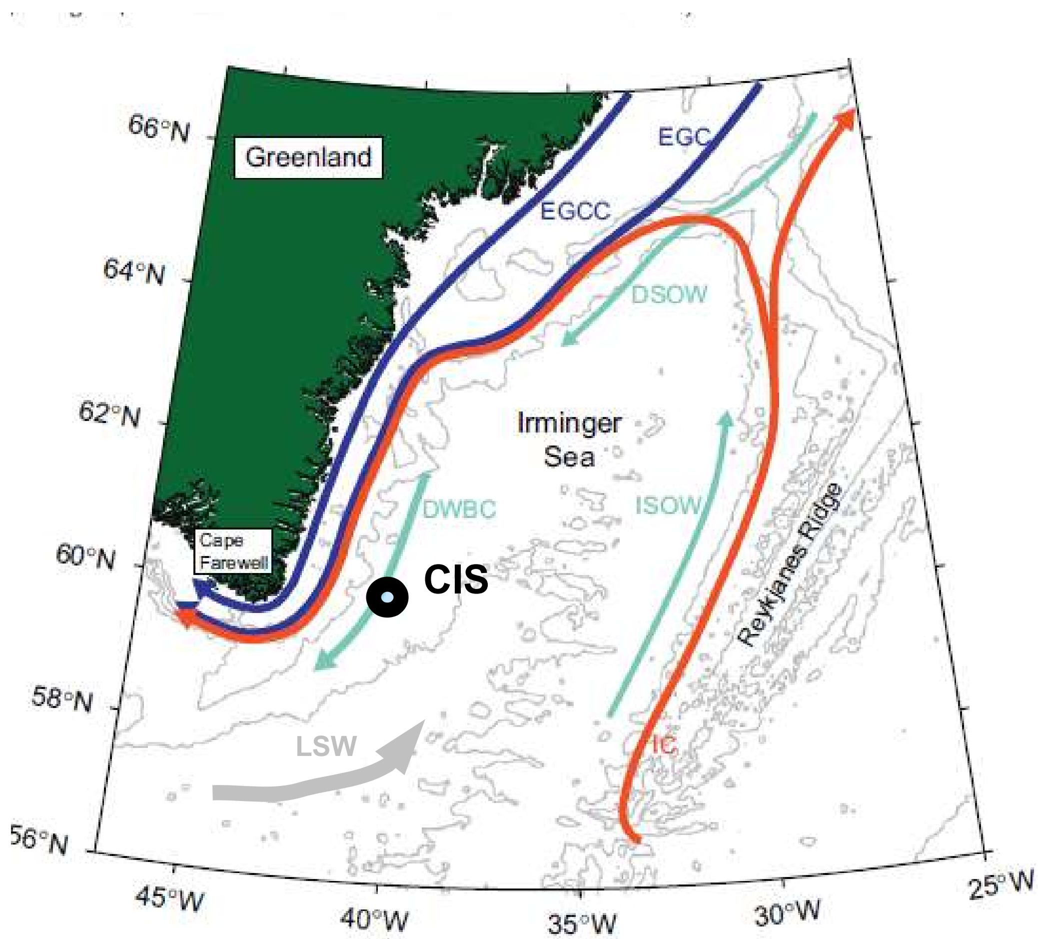
- Lack in deep reaching overturn/deep convection:



(van Aken et al. 2011, DSR1)

See Poster: 118

The Irminger gyre



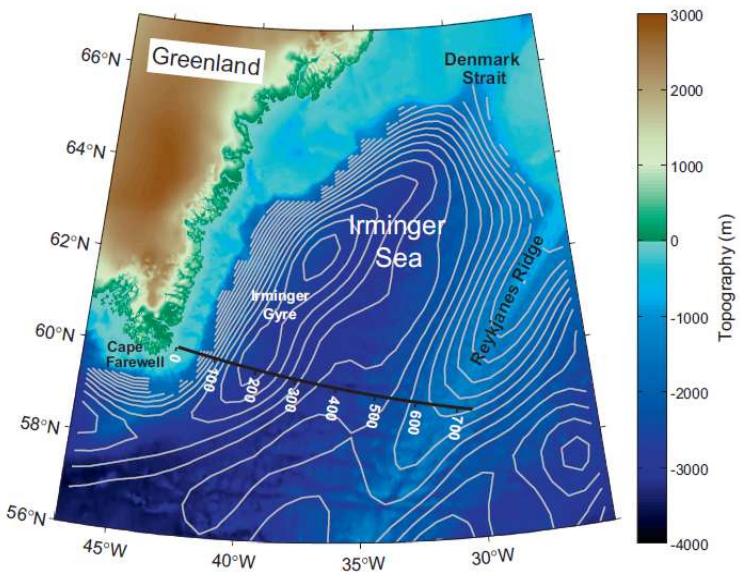
(based on K. Våge et al. 2011, DSR1)

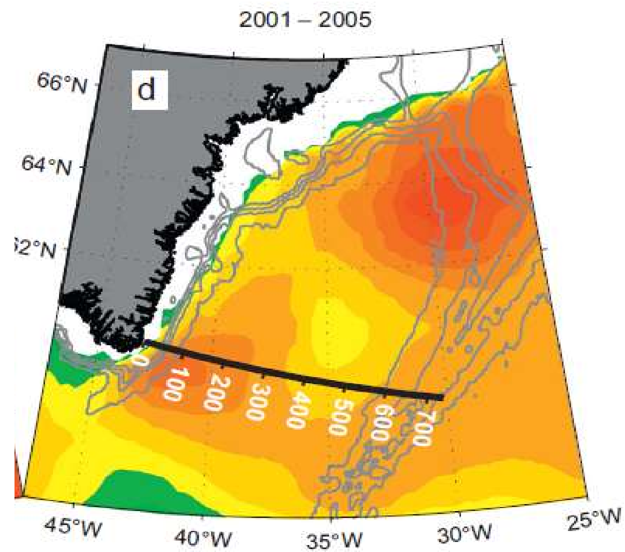
The Irminger gyre

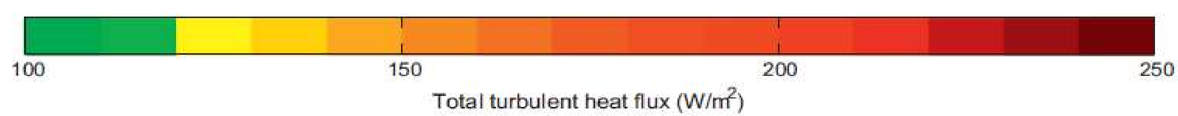
Geotrophic pressure

Heat flux

K. Våge et al. / Deep-Sea Research I 58 (2011) 590–614

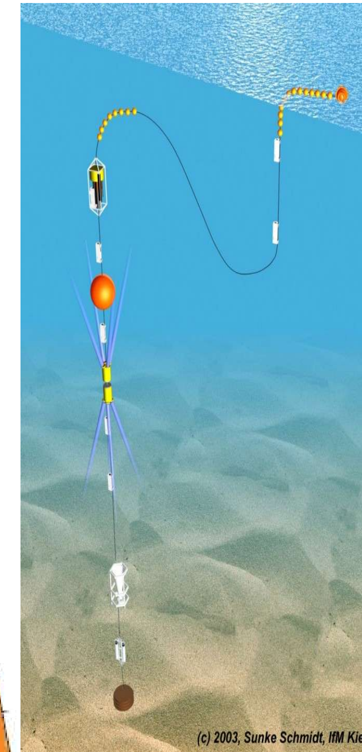




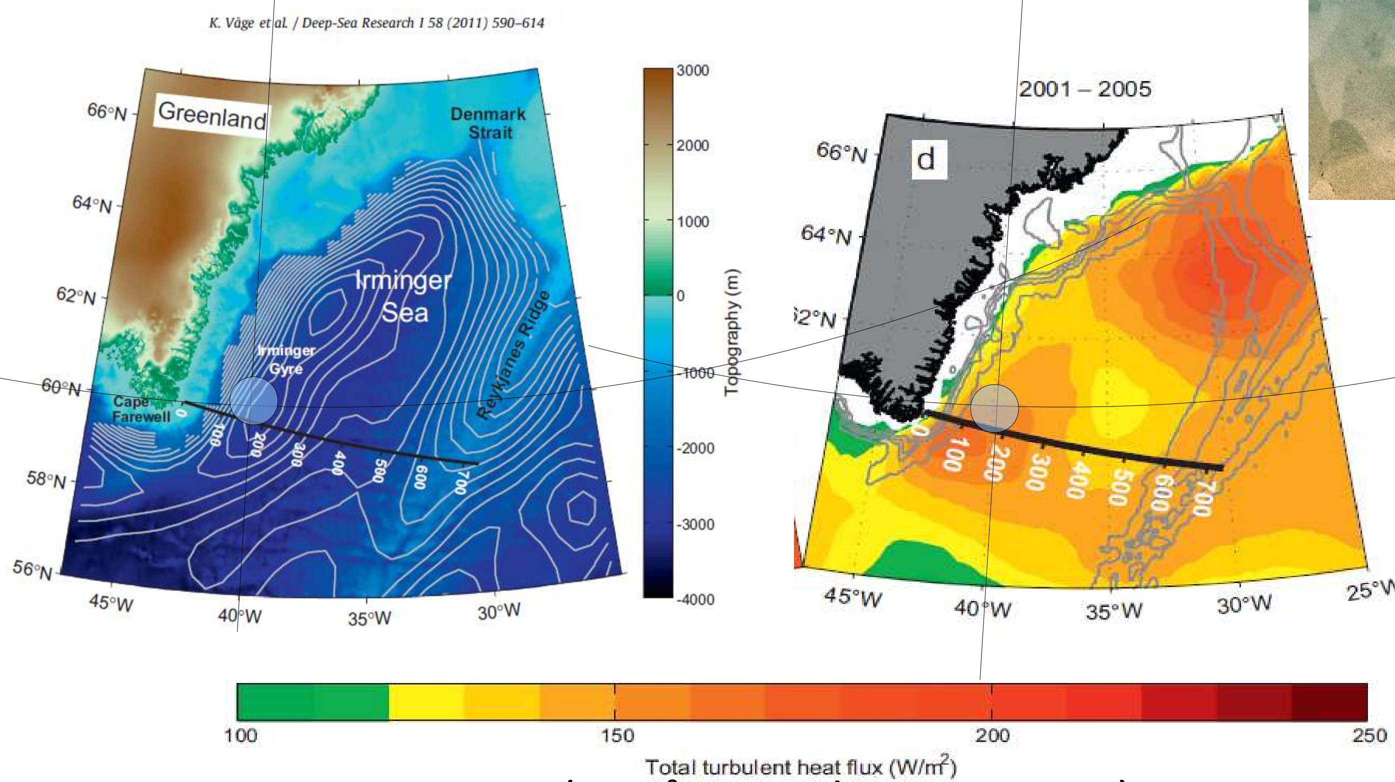


(K. Våge et al. 2011, DSR1)

The CIS mooring

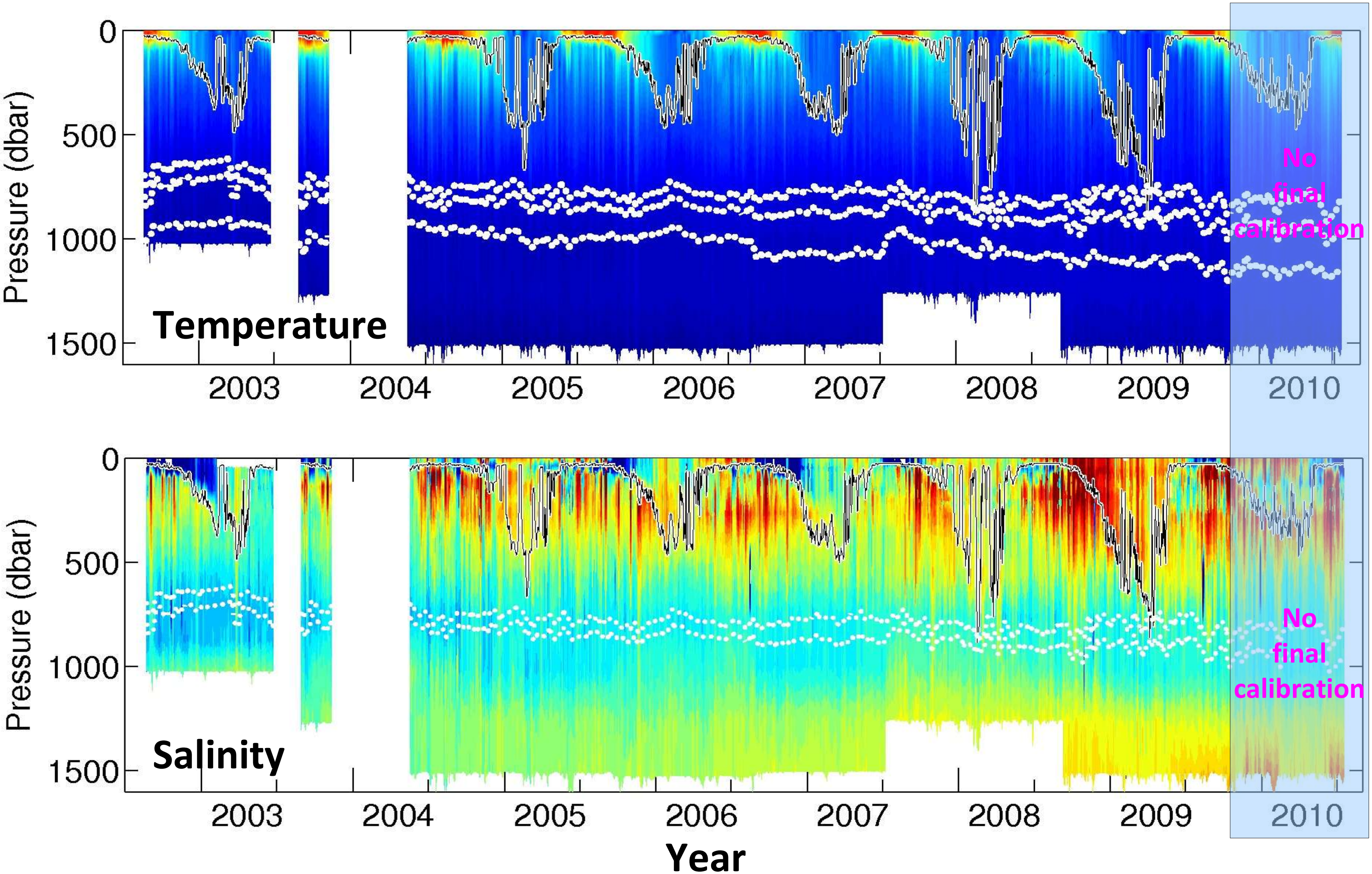


- Location: Compromise between
  Irminger Gyre centre
  & maximum heat loss (Greenland Tip Jet)

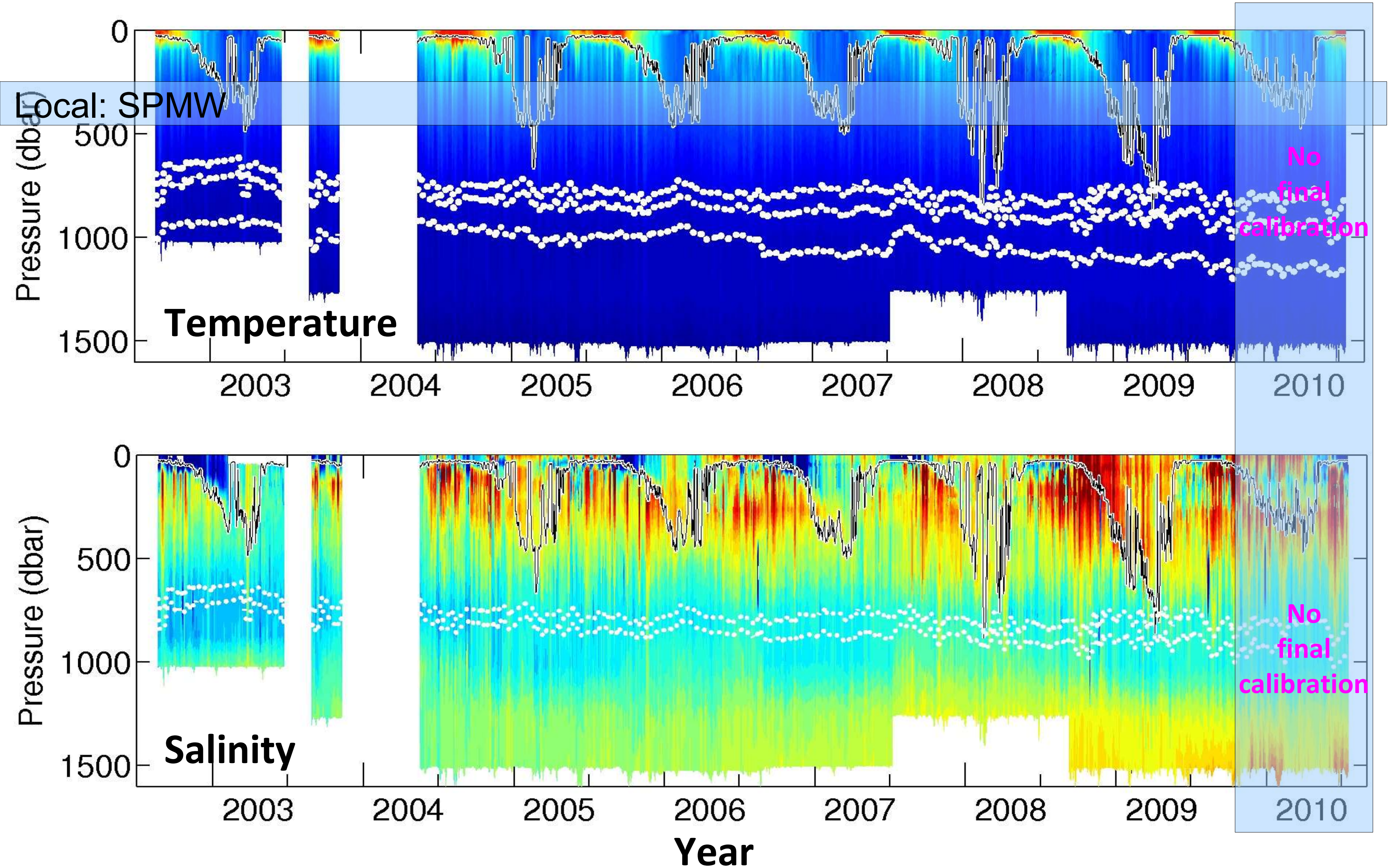


(K. Våge et al. 2011, DSR1)

Time series (upper 1500m) from 2002 to 2010

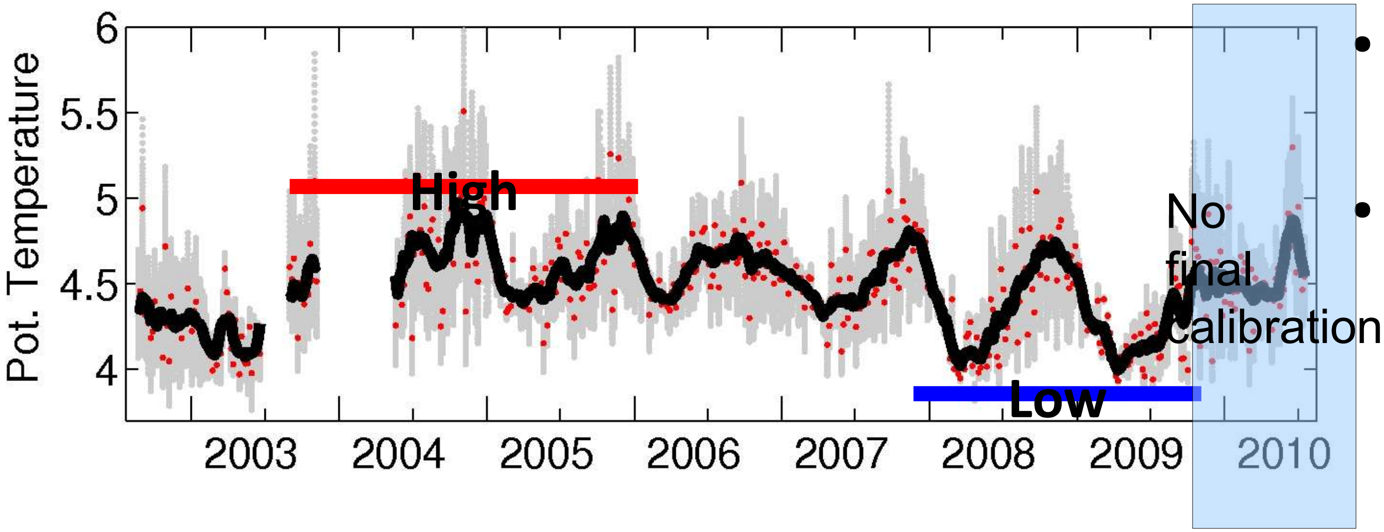


Time series (upper 1500m) from 2002 to 2010



Subpolar Mode water variability (2002-2010) at mooring site

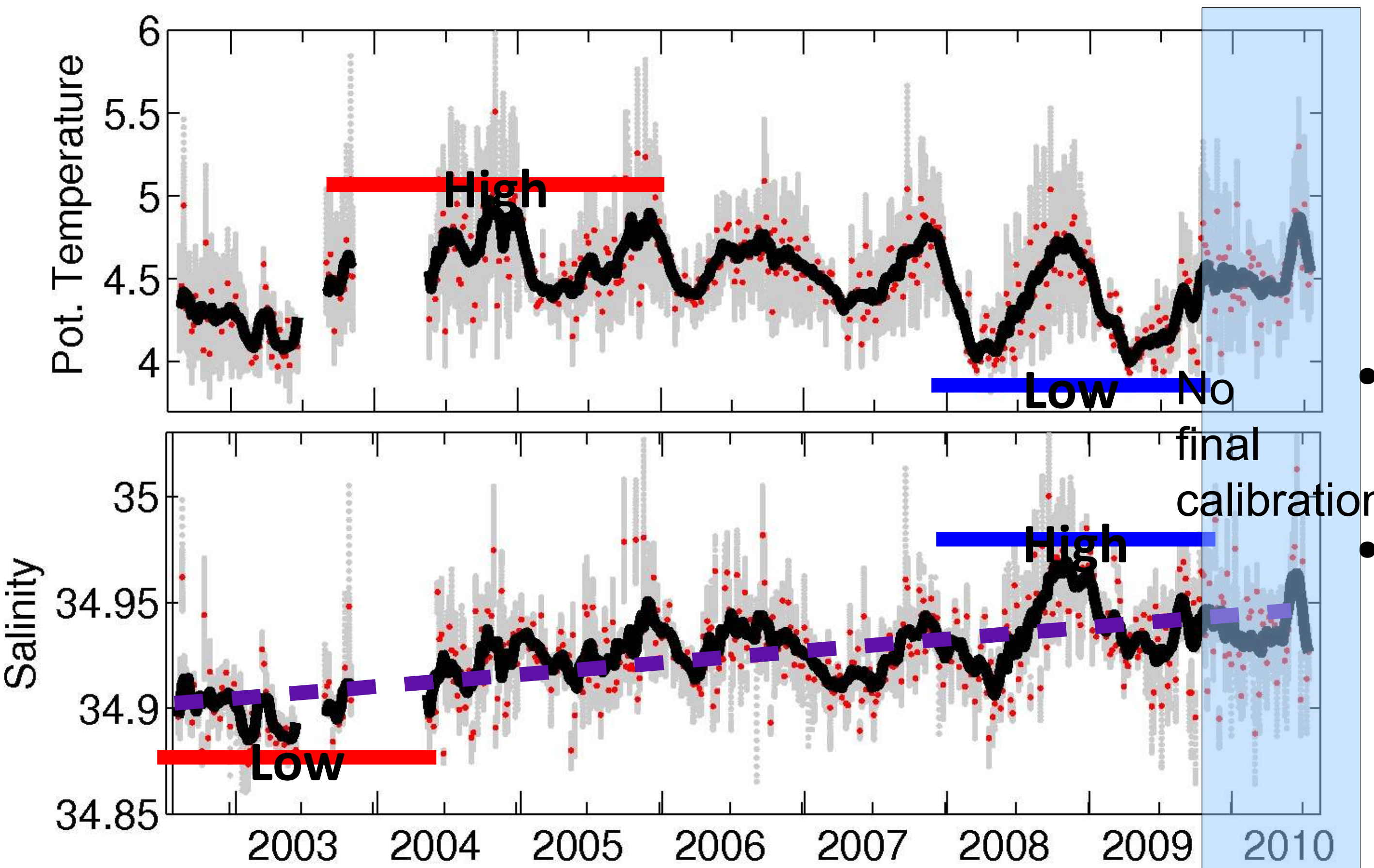
200-400m depth range; 7-day running mean:



- Seasonal variability
- Warmest T in 2004/2005, coldest 2008/2009 (deepest convection)

Subpolar Mode water variability (2002-2010) at mooring site

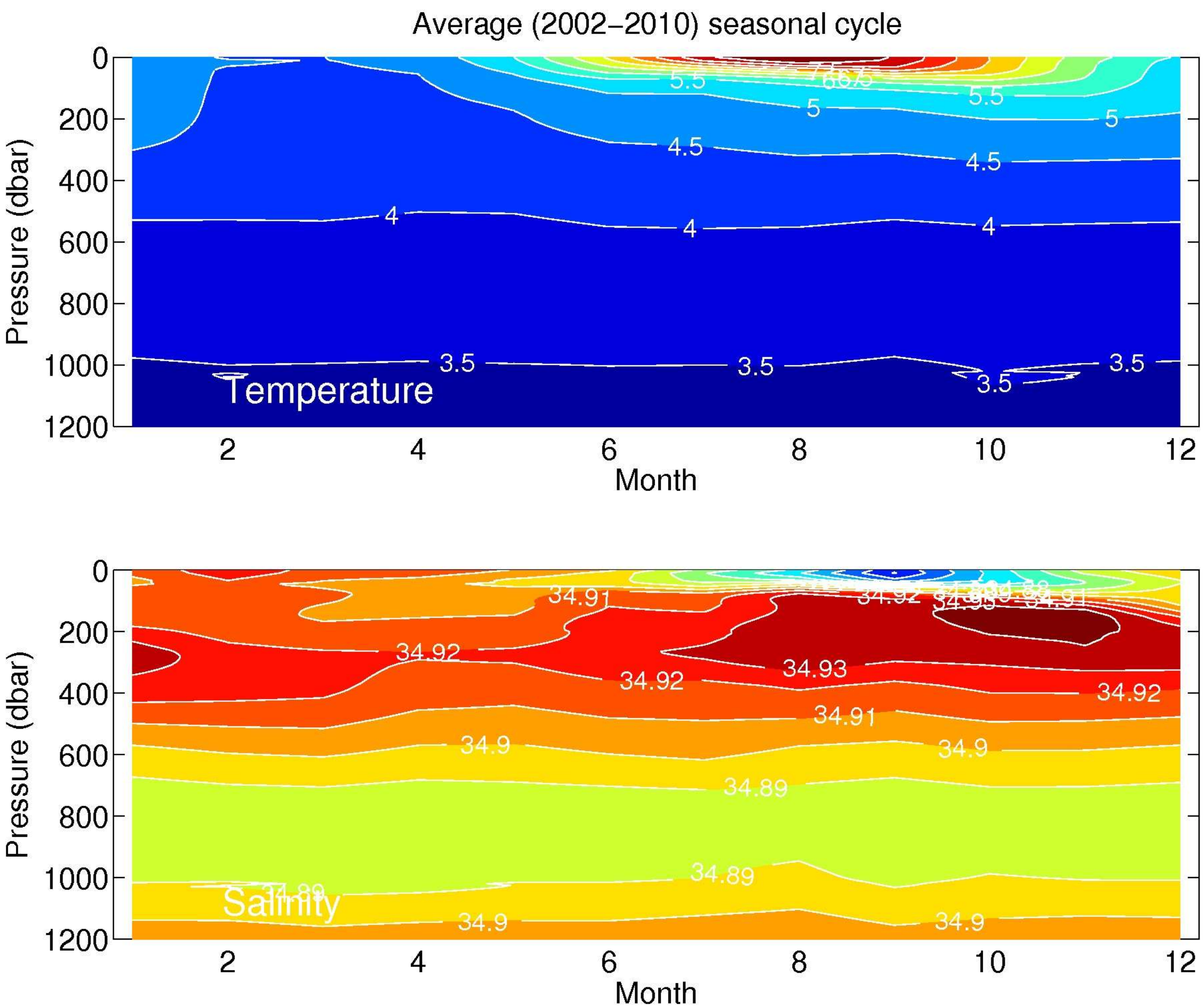
200-400m depth range; 7-day running mean:



- Seasonal variability
- Lowest S in 2003, most saline end of 2008
- Trend in S

Upper layer water mass transformation
- **average seasonal cycle** -

- Seasonality to ~500m



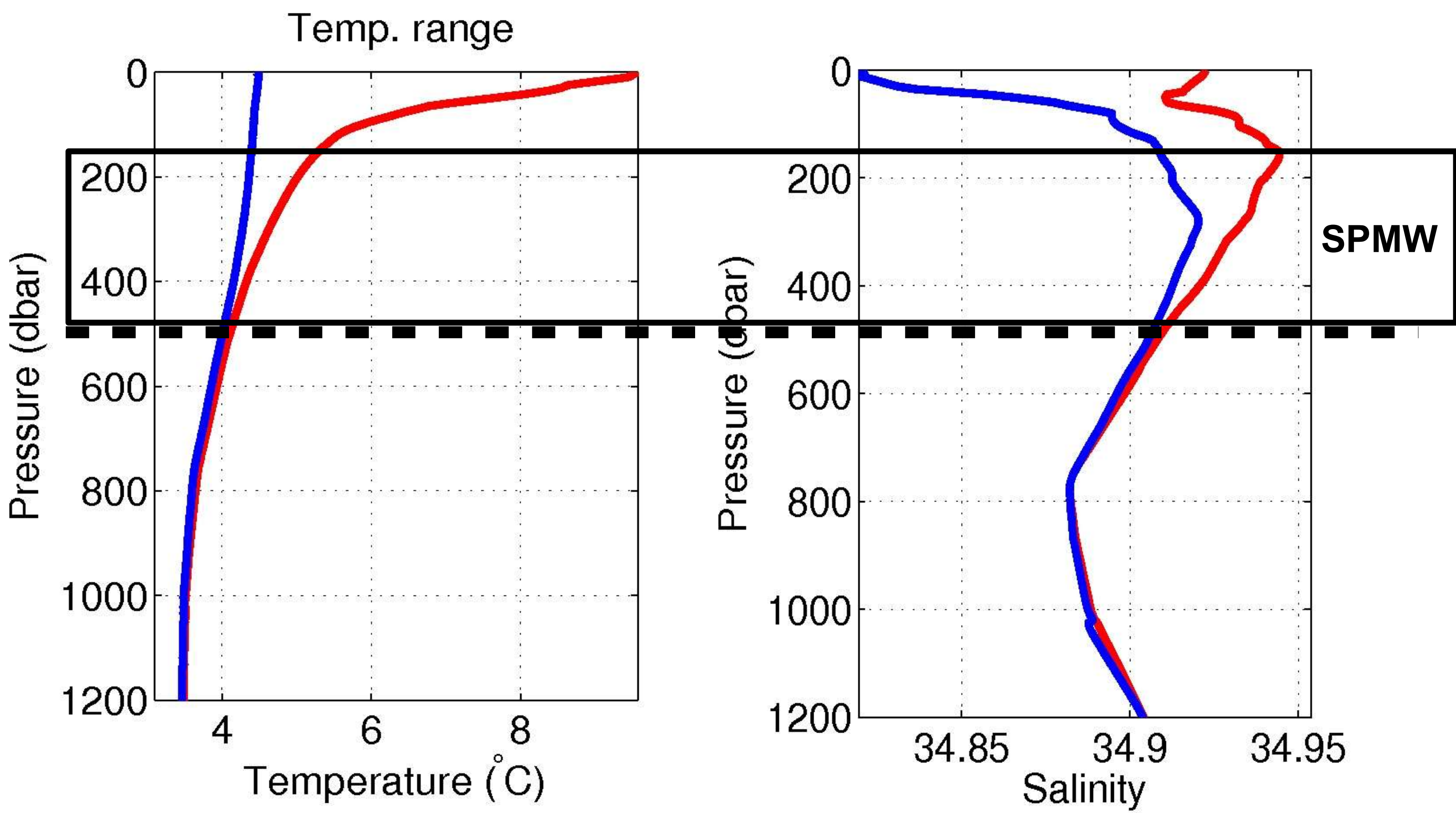
Is salinity important in the density (buoyancy) variability ?

- Separating **temperature** and **salinity** effects on density change:

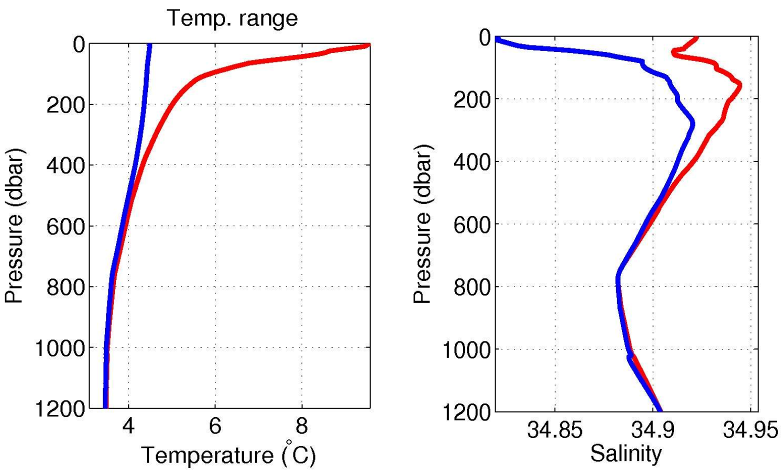
$$\rho = \rho_0[1 - \alpha(T - T_0) + \beta(S - S_0)]$$

  - ρ / ρ_0 : Density / reference density
  - α: thermal expansion
  - β: haline contraction

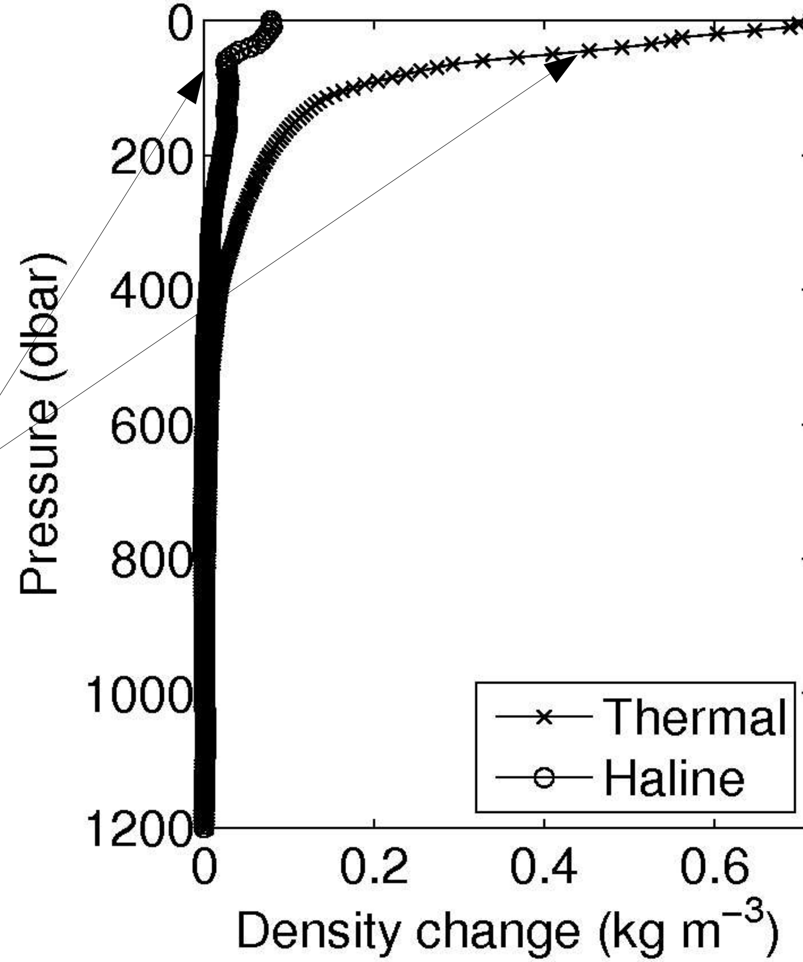
Upper layer water mass transformation
- average seasonal cycle -



Upper layer water mass transformation
- average seasonal cycle -

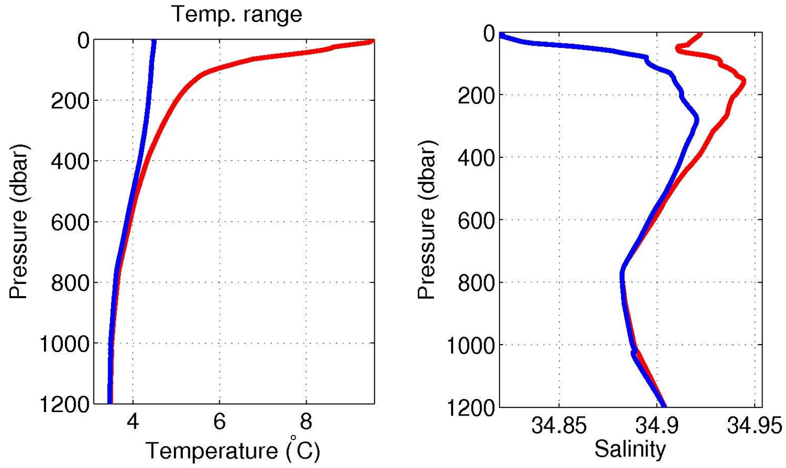


Density change:

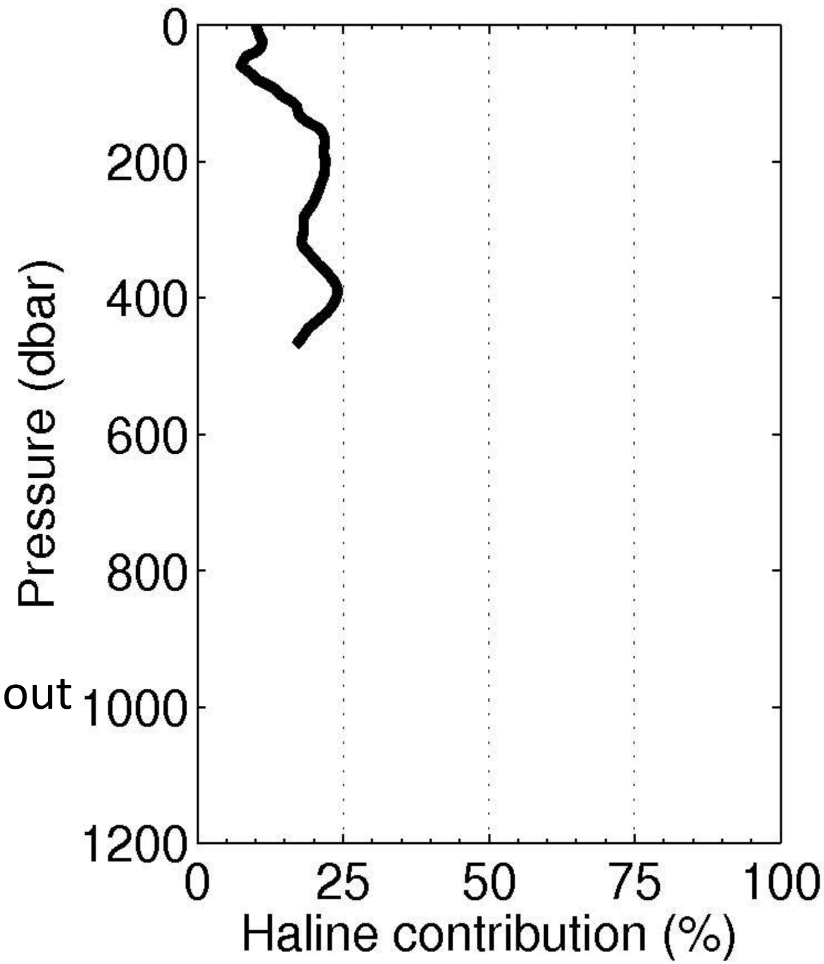


$$\rho = \rho_0[1 - \alpha(T - T_0) + \beta(S - S_0)]$$

Upper layer water mass transformation
- average seasonal cycle -



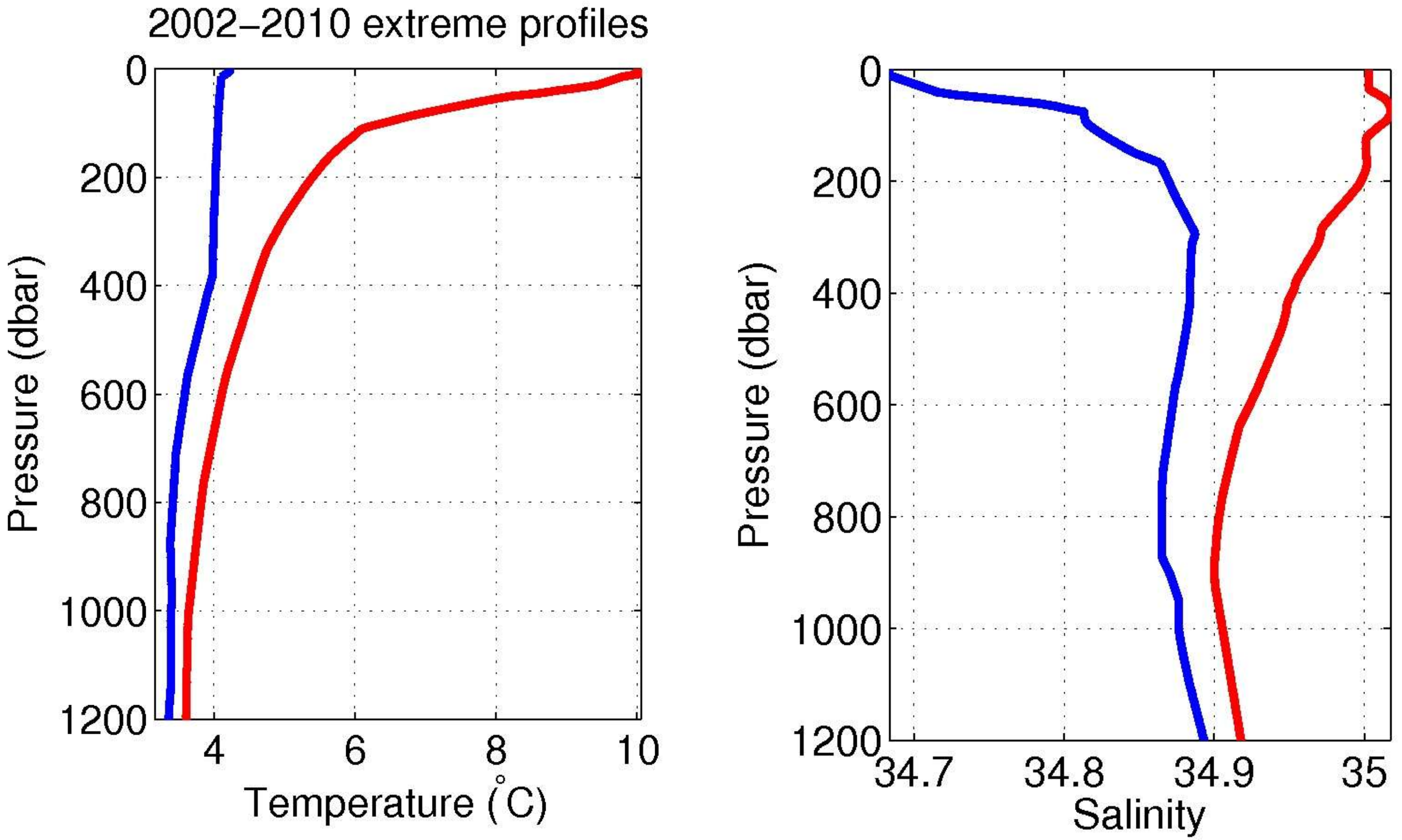
% on total density change:



- Upper 50m (summer mixed layer)
  thermal/ air-sea heat flux driven
- Below 50m:
  Haline buoyancy flux contributes about 20% to total buoyancy change.

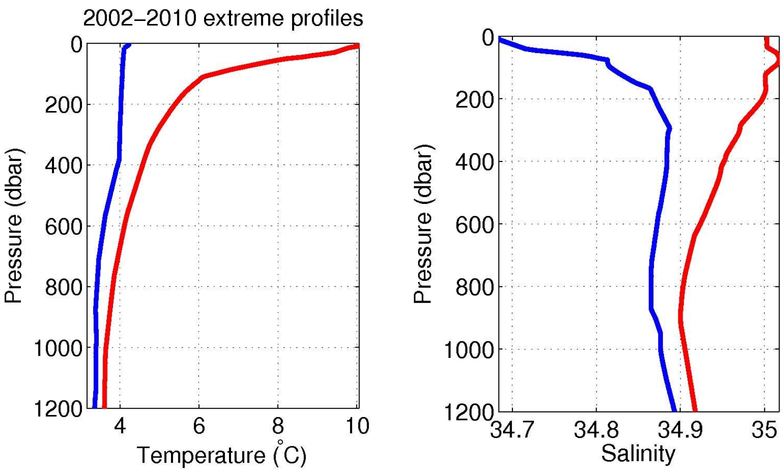
“Extreme” seasonal cycle

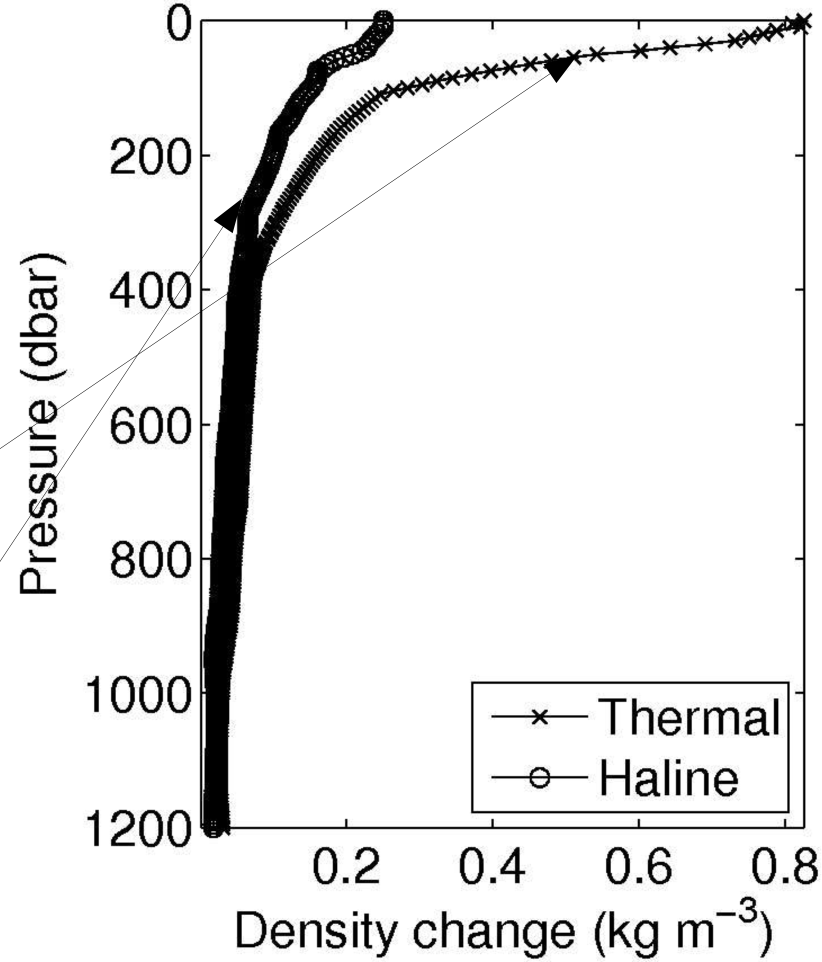
- Select the maximum/minimum T/S values for the whole time series 2002 to 2010 (monthly averages)



Upper layer water mass transformation

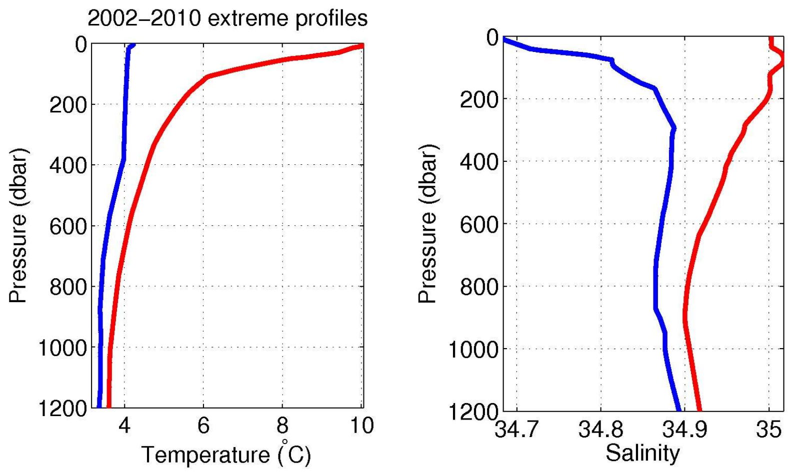
- extreme seasonal cycle -



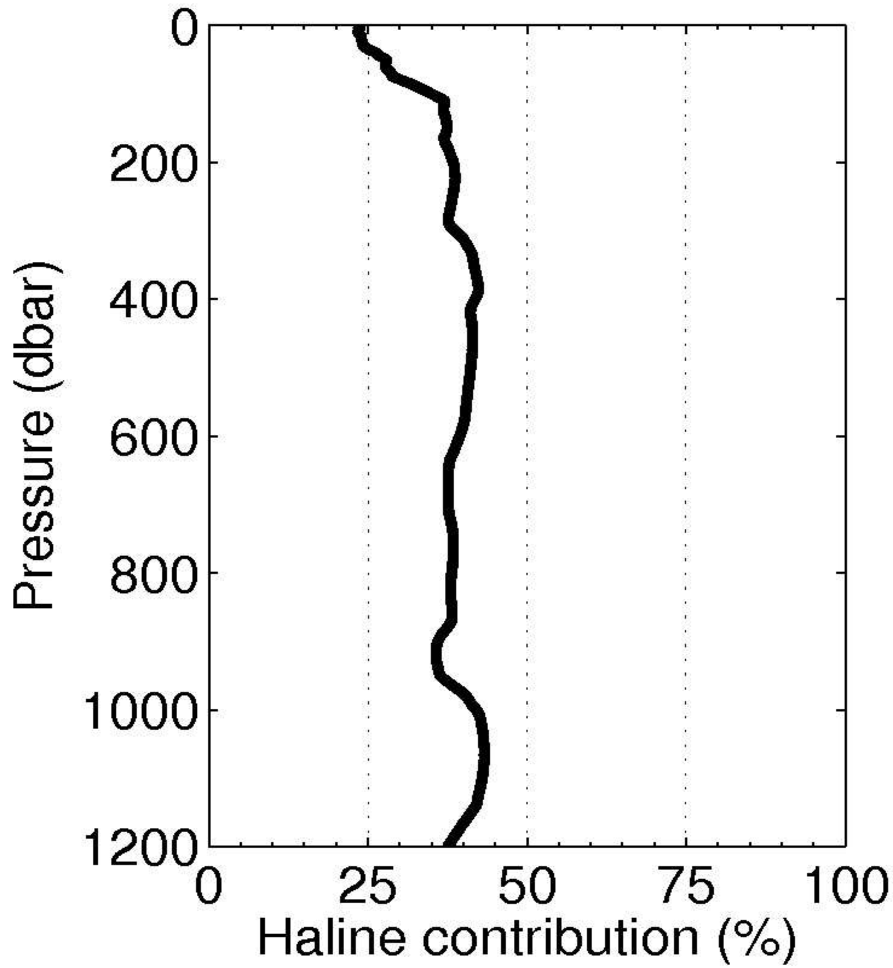


$$\rho = \rho_0[1 - \alpha(T - T_0) + \beta(S - S_0)]$$

Upper layer water mass transformation
- extreme seasonal cycle -

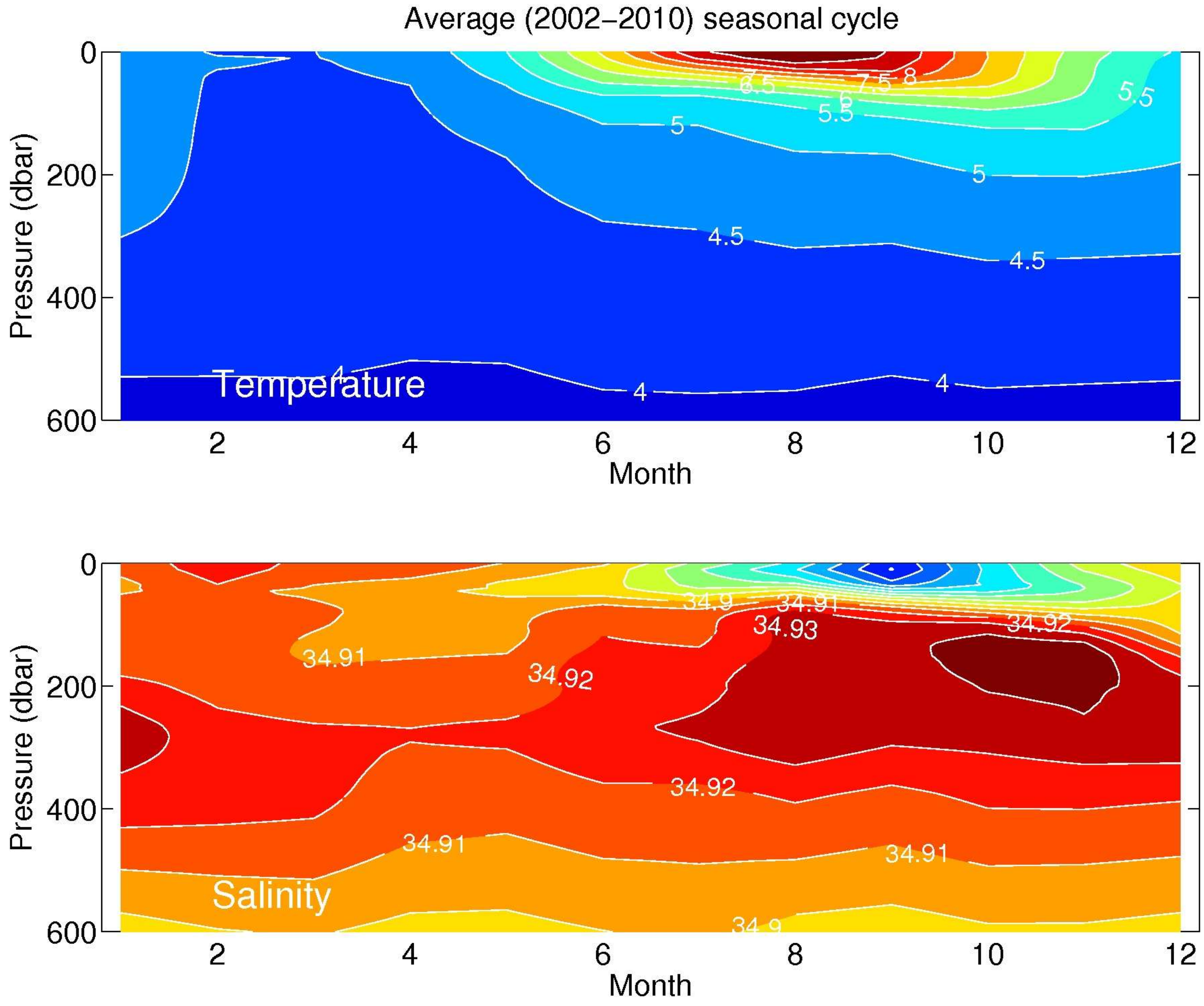


% on total density change:



- Haline buoyancy flux accounts for approx. 40% of tota below 100m
- Dominated by general warming & salinity increase of water column – "the trend!"

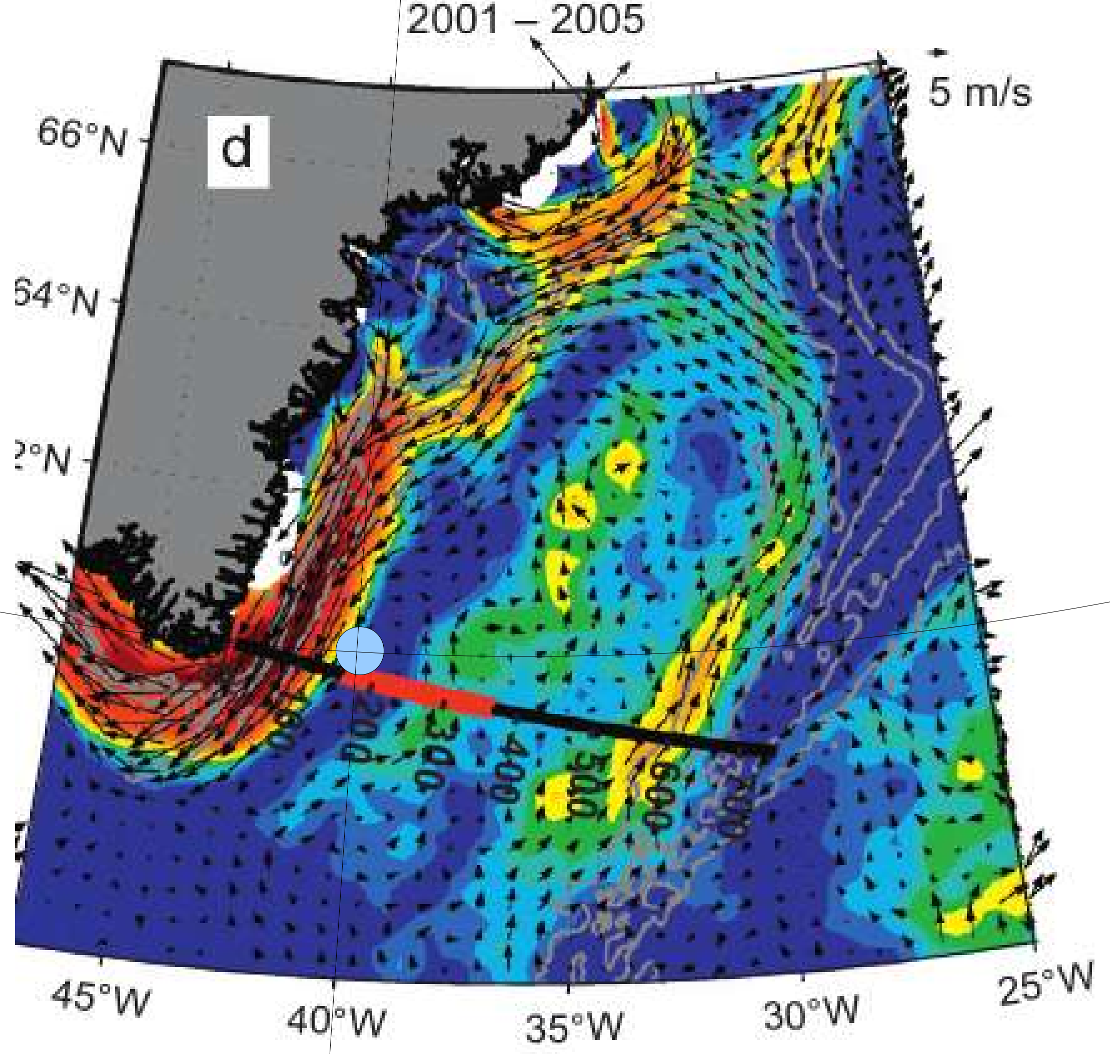
What drives the subsurface salinity variability?



The CIS mooring

- Close to Irminger Gyre front to EGC

CIS mooring

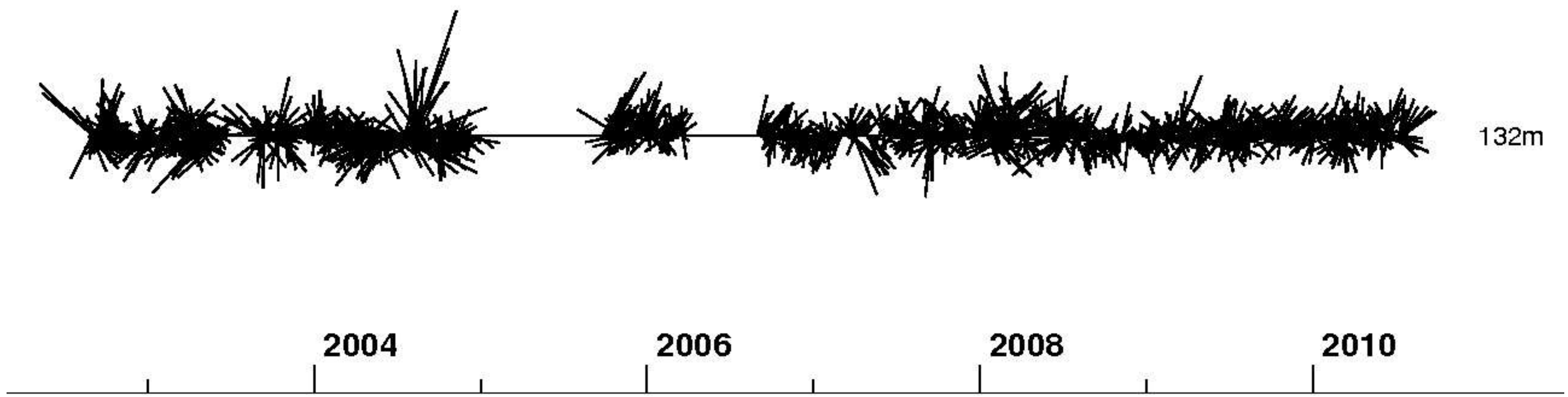


(K. Våge et al. 2011, DSR1)

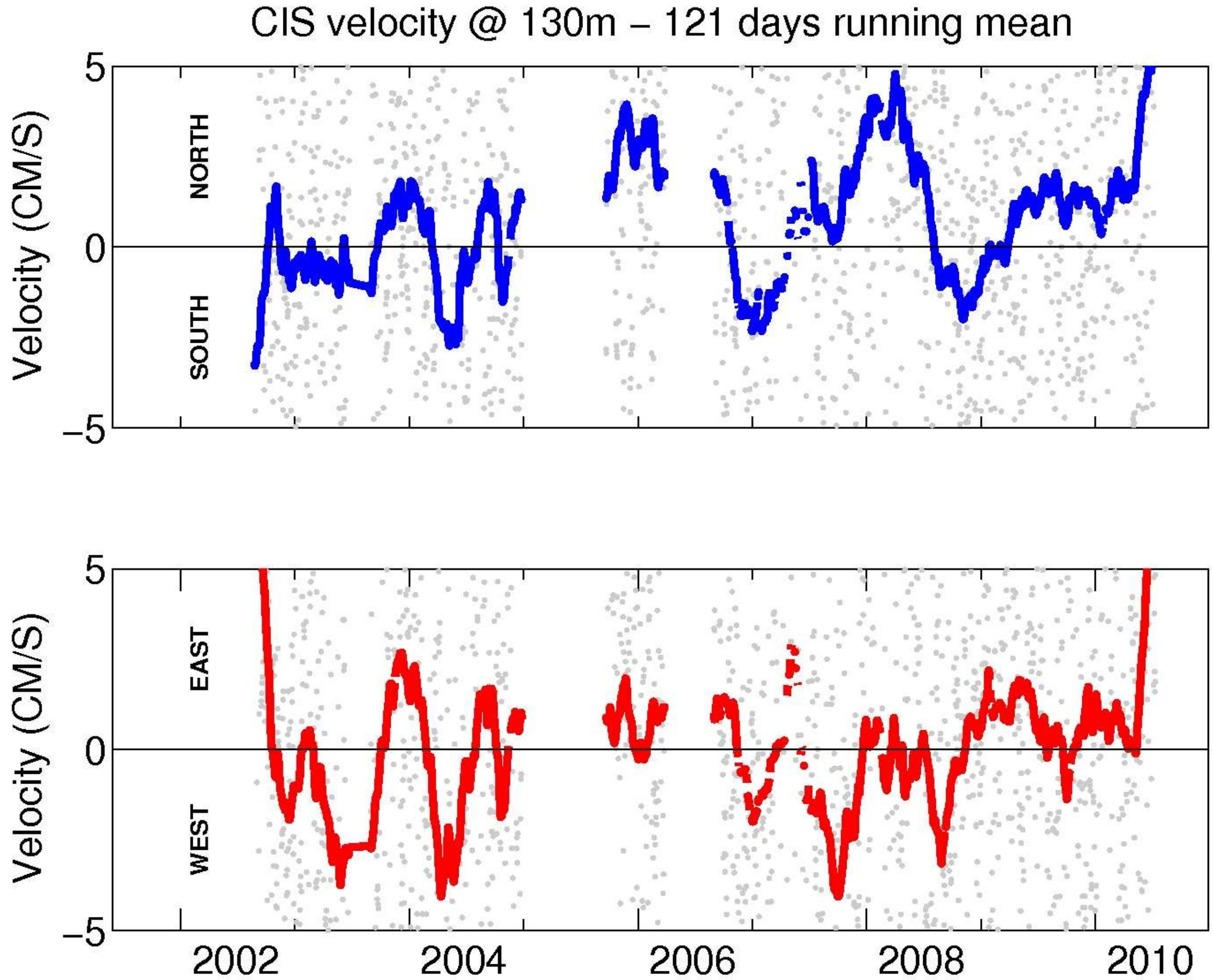
Currents at CIS site

- 1-day running mean:

  dominated by eddies!



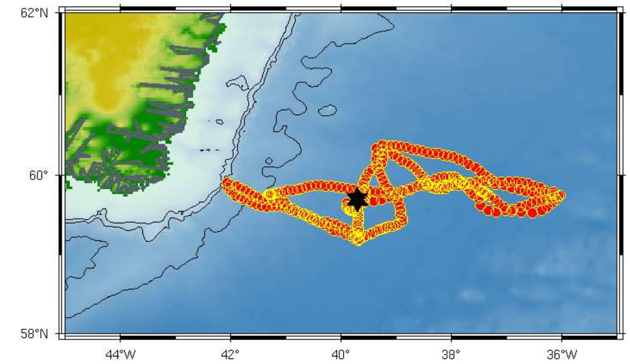
Currents at CIS site

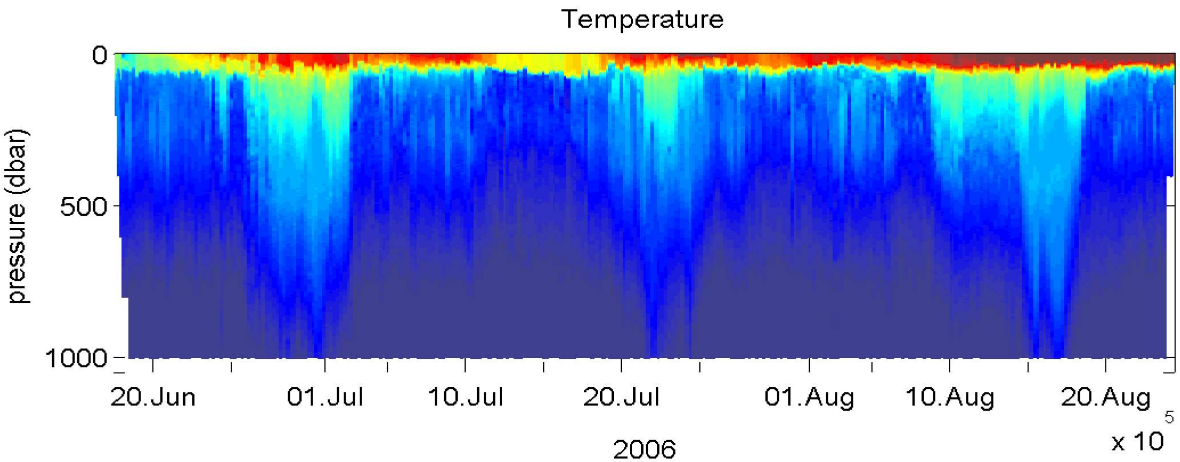


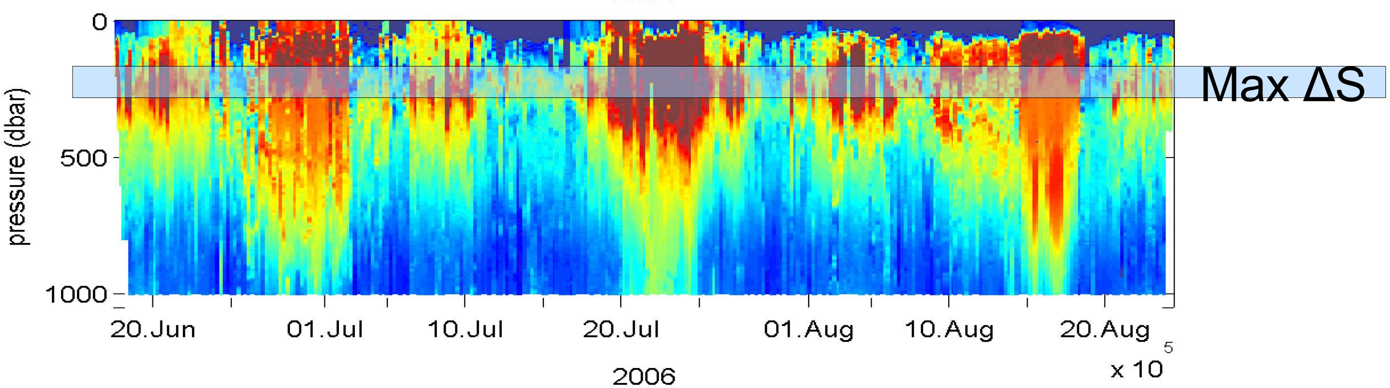
- Mooring NOT in southward branch of Irminger Gyre
- Does such a branch exists?
- Are there strong recirculation cells at the rim of the current?

“Currents” at CIS site

- Eddy fluxes play a dominant role in transporting information from east







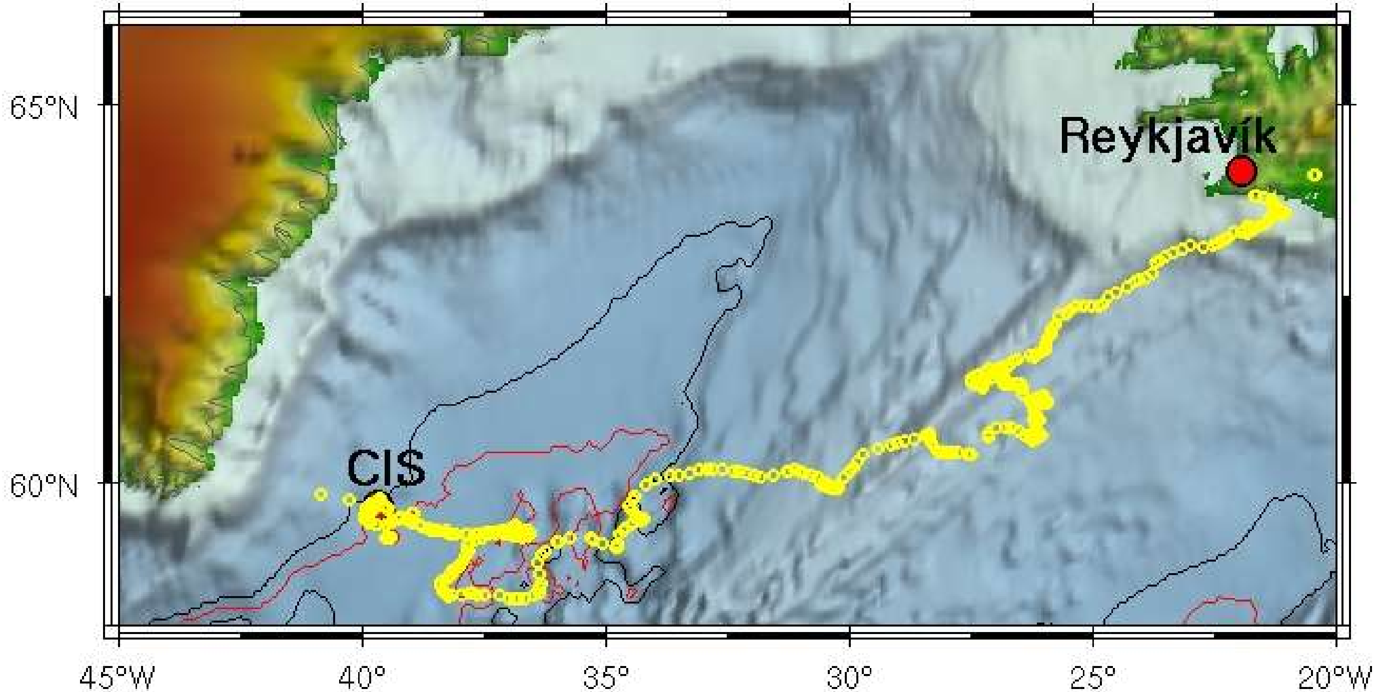
Glider in summer 2006 (X. Fan, SIO)

Conclusion

- Below shallowest mixed layer (~50m) salinity variability is largest at about 200m depth
- In the upper 50m, air/sea heat flux dominates the changes in density
- Average seasonal cycle indicates that haline driven water mass transformation accounts for 20% on density changes (below 50m)
- Including the long-trem trend (2002 to 2010) the haline contribution accounts for > 40% on density changes (below 100m)
- Interannual variability in subsurface salinity can not be related directly to observed mean current variability – need to check correlation with eddy variability.
- Modelling Irminger Sea overturn requires "accurate" subsurface salinity information

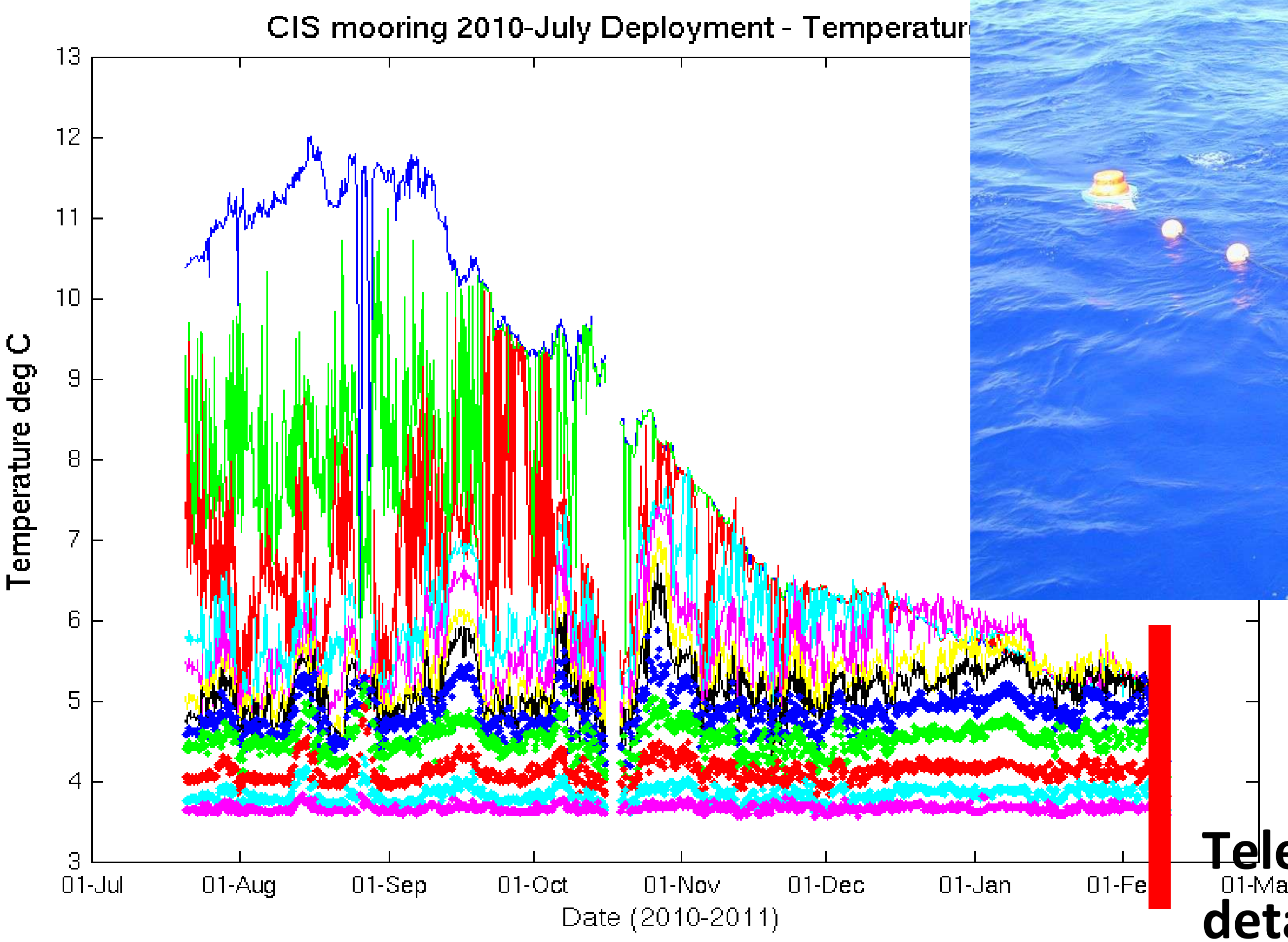
Flow field

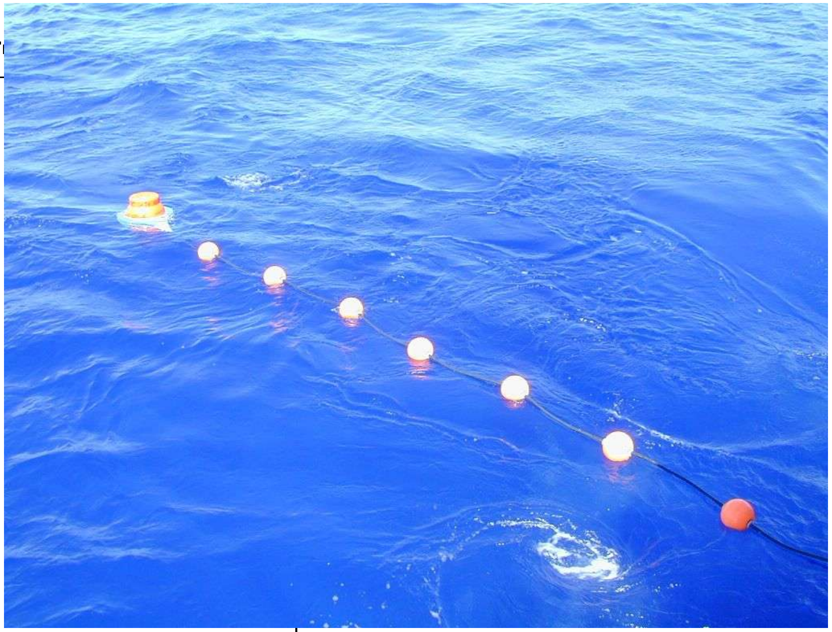
- Two month surface drift
  (mid Feb 2011- mid April 2011)



The 2010 to 2011 data

- Real-time (4h) data telemetry system



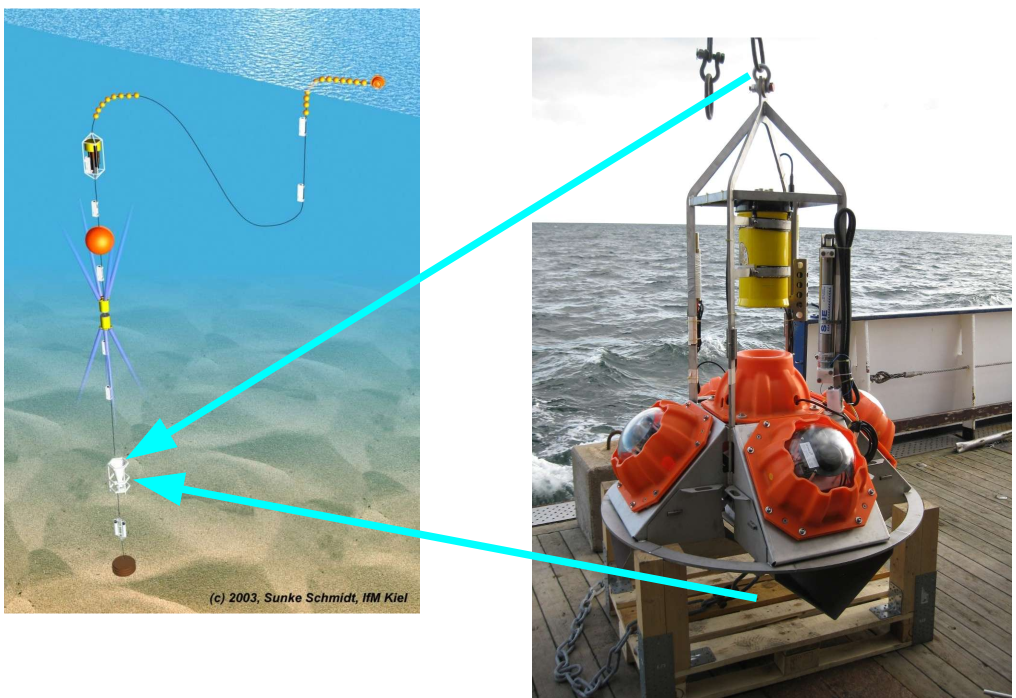


Telemetry buoy detached

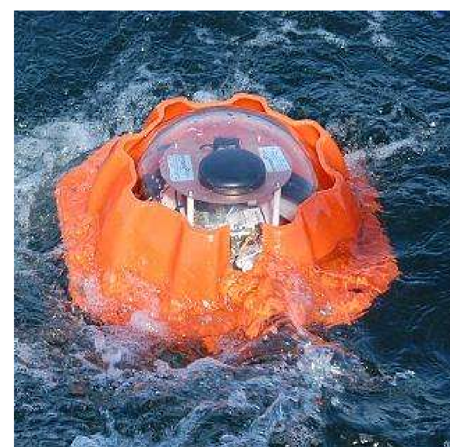
See Poster: 108

A subsurface Telemetry system

- In 2011 a new telemetry system based on pop-up buoy's will be tested at the site (collaboration with FP7 THOR)
- Pop-up "messenger" buoys come to surface autonomously and send data to shore via Iridium satellite communication
- Serial & Inductive connection of instruments



Buoy drifting at surface ...



Thank you!

ICES Report on Ocean Climate 2009

Central Irminger Sea: SPMW T / S Timseries (1991-2009)