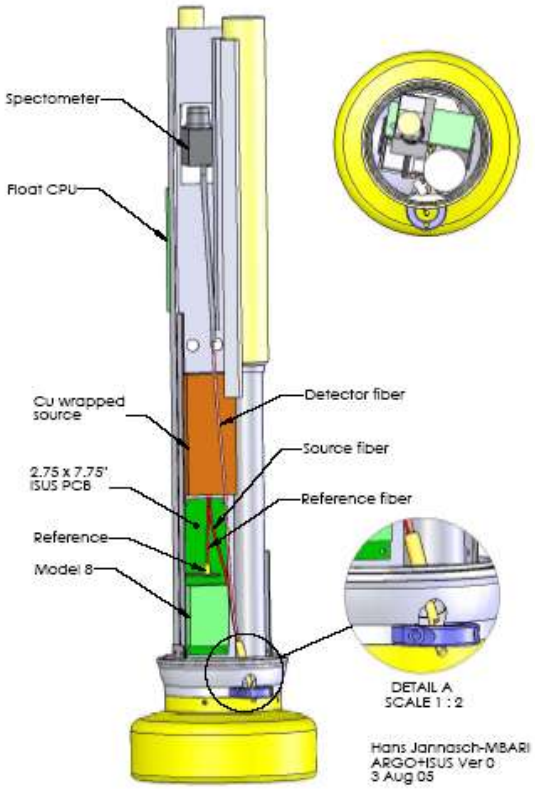
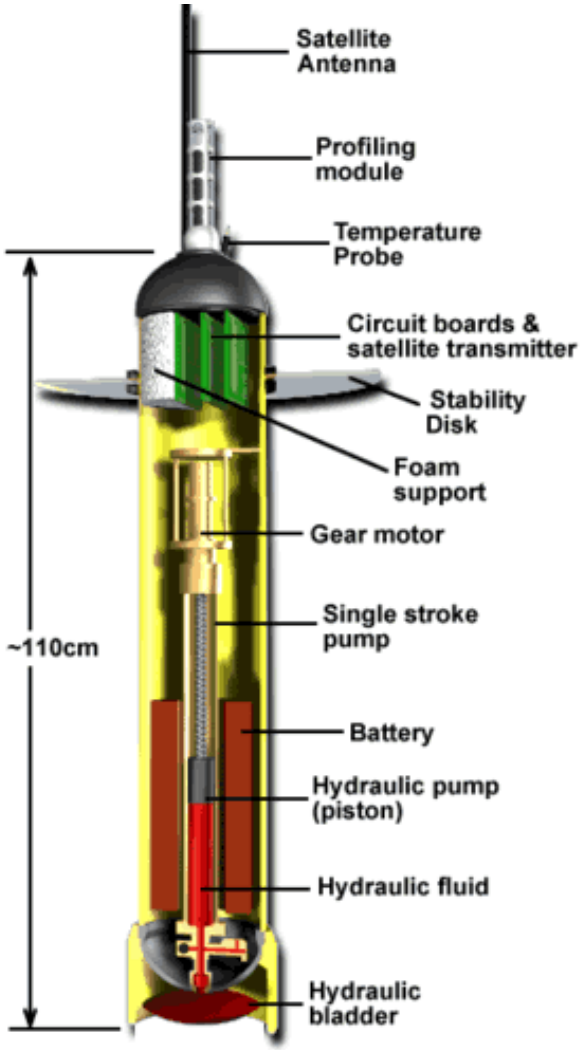
A Global Observing System for Biogeochemical Cycling of Carbon Based on Autonomous Profiling Floats

Ken Johnson
with contributions from:
Steve Riser
Arne Koertzinger
Emmanuel Boss
Jim Bishop

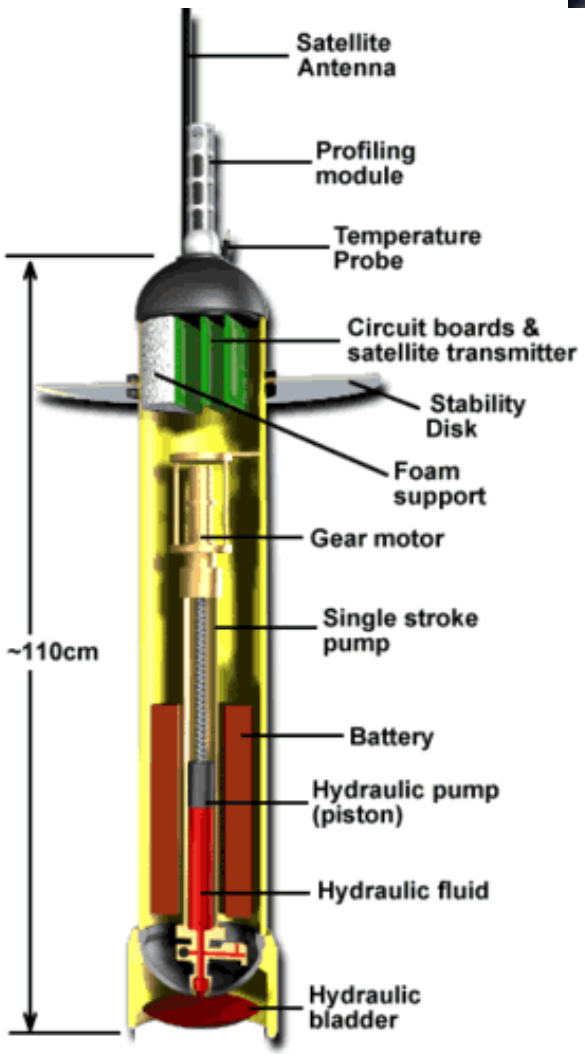


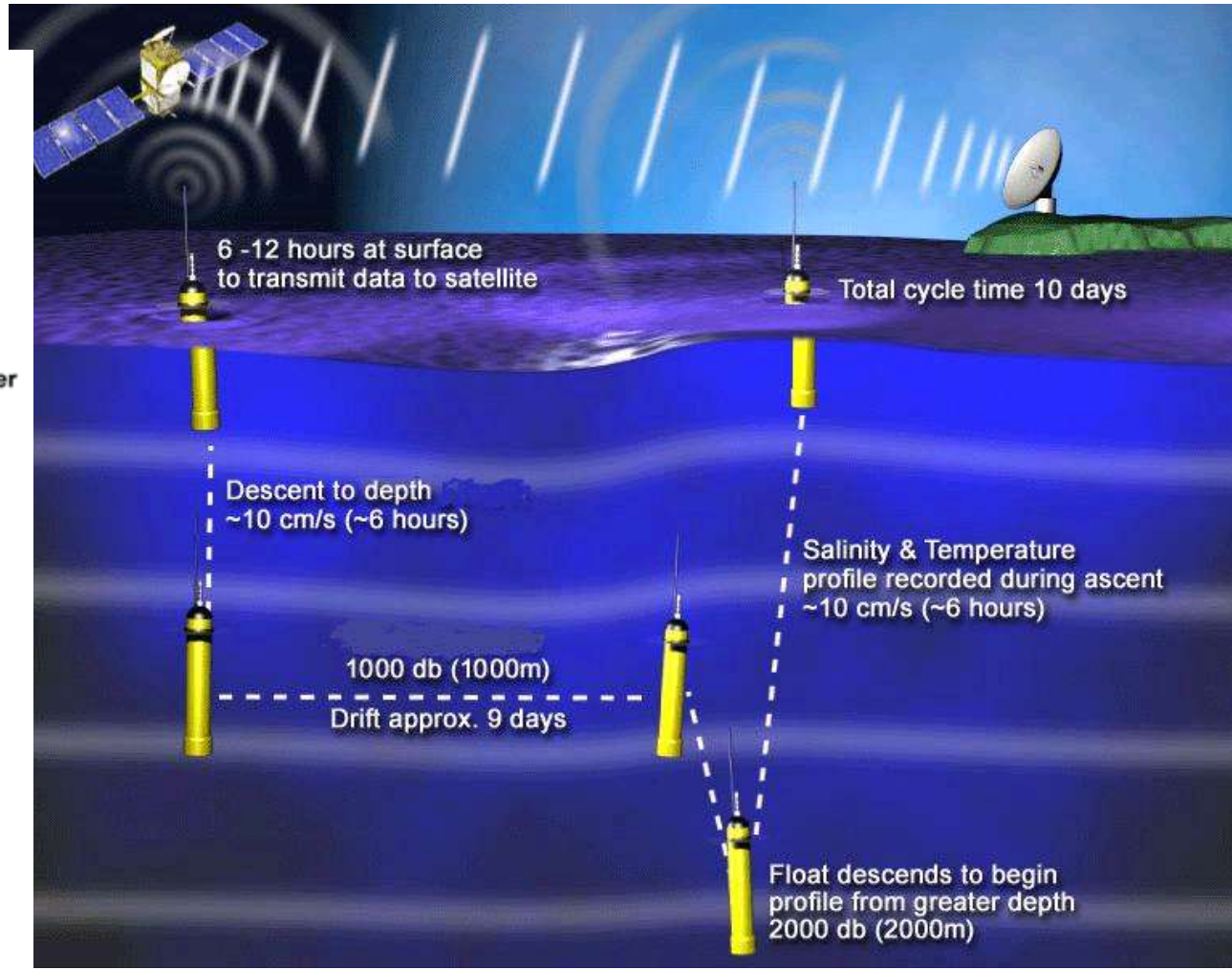


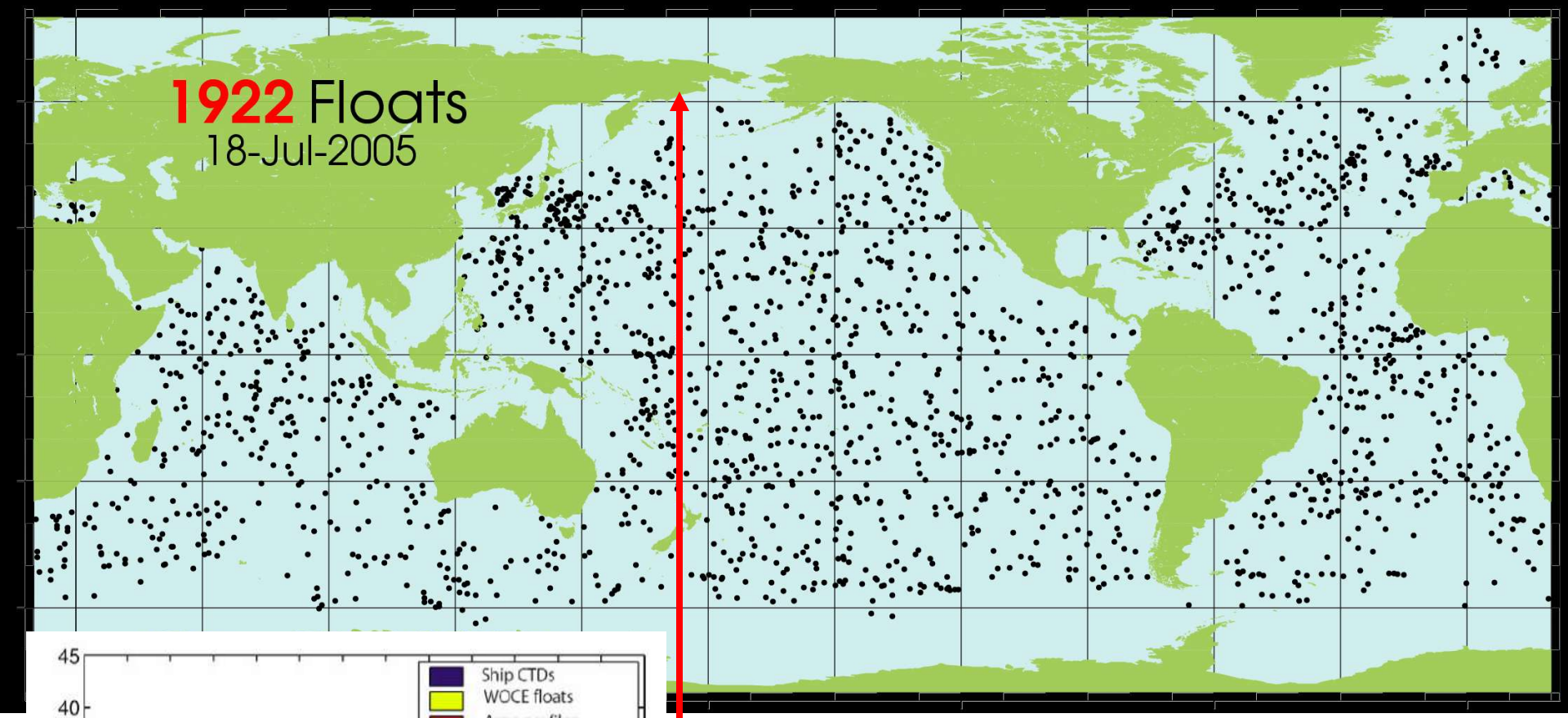
General Outline

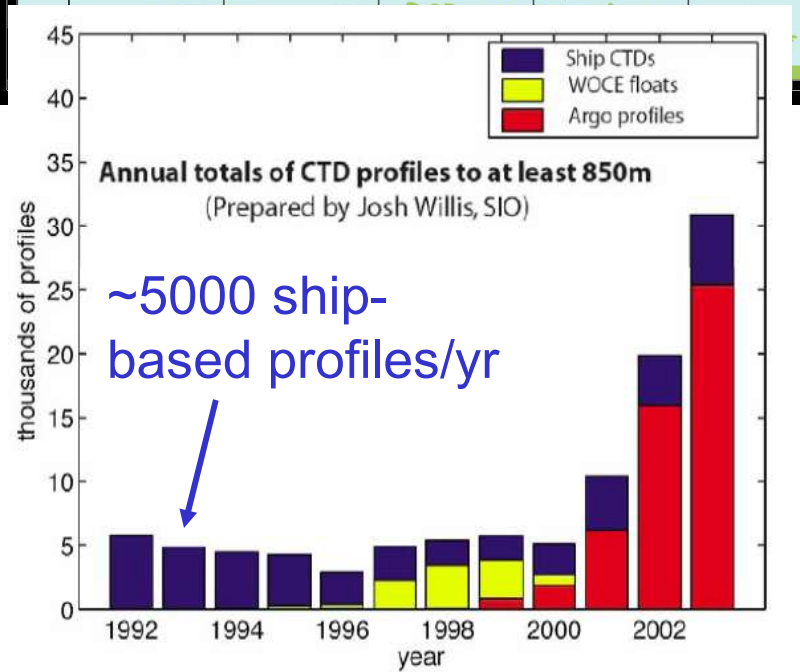
- What's a profiling float?
- Why do we want them? To measure basin to global scale primary production.
- What can we measure with them?
- The concept – a basin to global scale observing system for carbon cycling in the ocean. *It does not replace shipboard observations.* A real-time, product of merged observations from floats, gliders, satellites and models provides a long-term, basin-scale background for biogeochemical rates.
- Conclusion – it appears feasible to develop an autonomous biogeochemical observing system based on floats and gliders that would provide significant constraints on carbon cycling at basin or global scales.

Profiling floats are not tethered. Drift at depth, ascend to the surface making measurements, telemeter data and return to depth – typically 1000 m where sensors don't foul, but depth is programmable. Typically a 4 year life cycle.









100,000 float profiles projected in 2006

Profiling floats are capable of deployment in large numbers – this is the current Argo array and its moving to 3000 active floats in 2006.

What is being measured now?

Oxygen and bio-optics (phytoplankton biomass, chlorophyll fluorescence, etc.)

What could be done with current technology?

PIC – polarized light spectroscopy

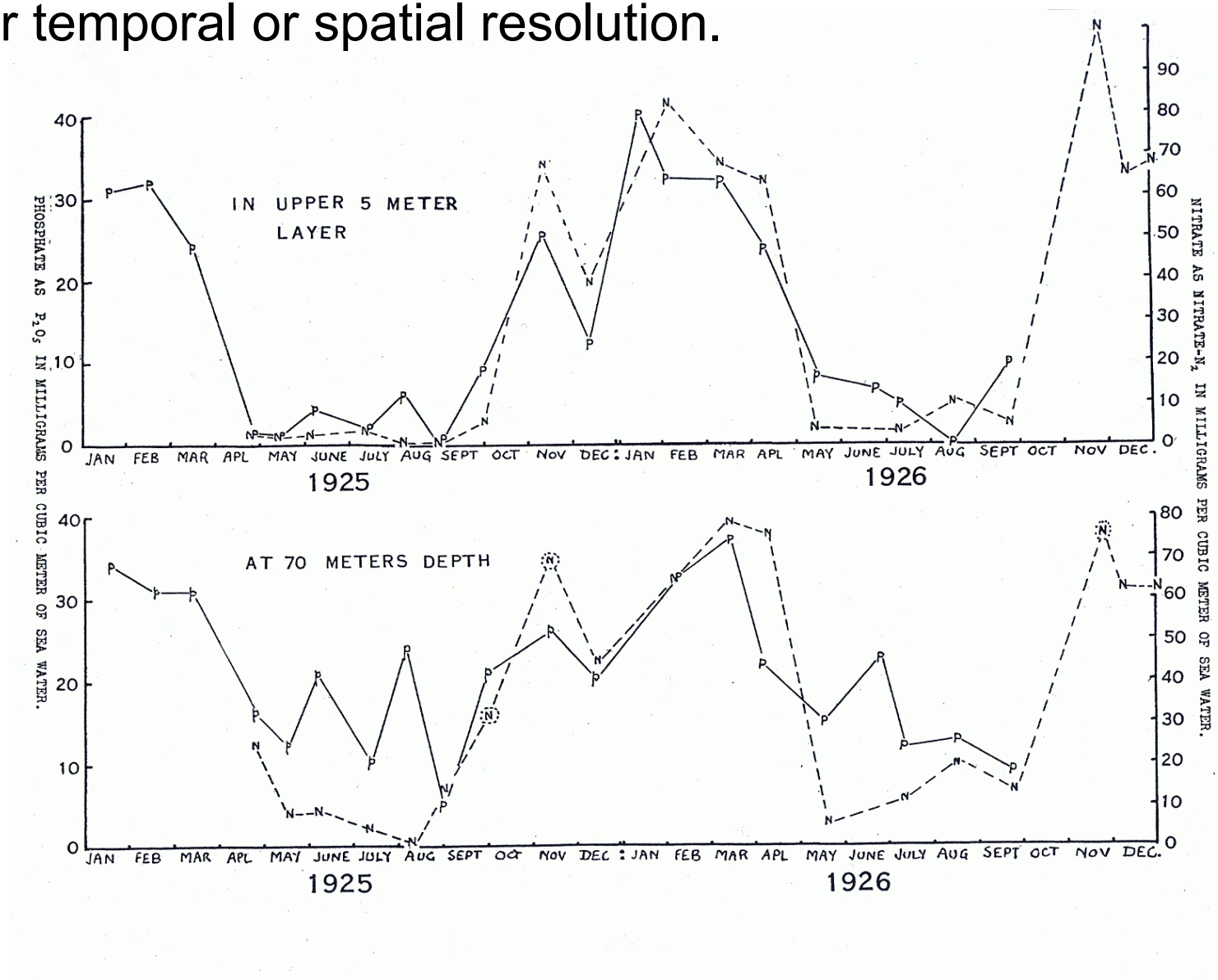
NO_3^-, CO_3^{2-} - UV spectroscopy

It's feasible to conceive of global or basin scale measurements of carbon cycling:

- nutrient availability, primary production, organic and inorganic carbon export

The state of the art in chemical observing for nearly 80 years.
Harvey (1928) – Annual cycle of nutrients in the English Channel.
Modern measurements are more sophisticated, but not often of higher temporal or spatial resolution.

Phosphate as P_2O_5 (µg/L)

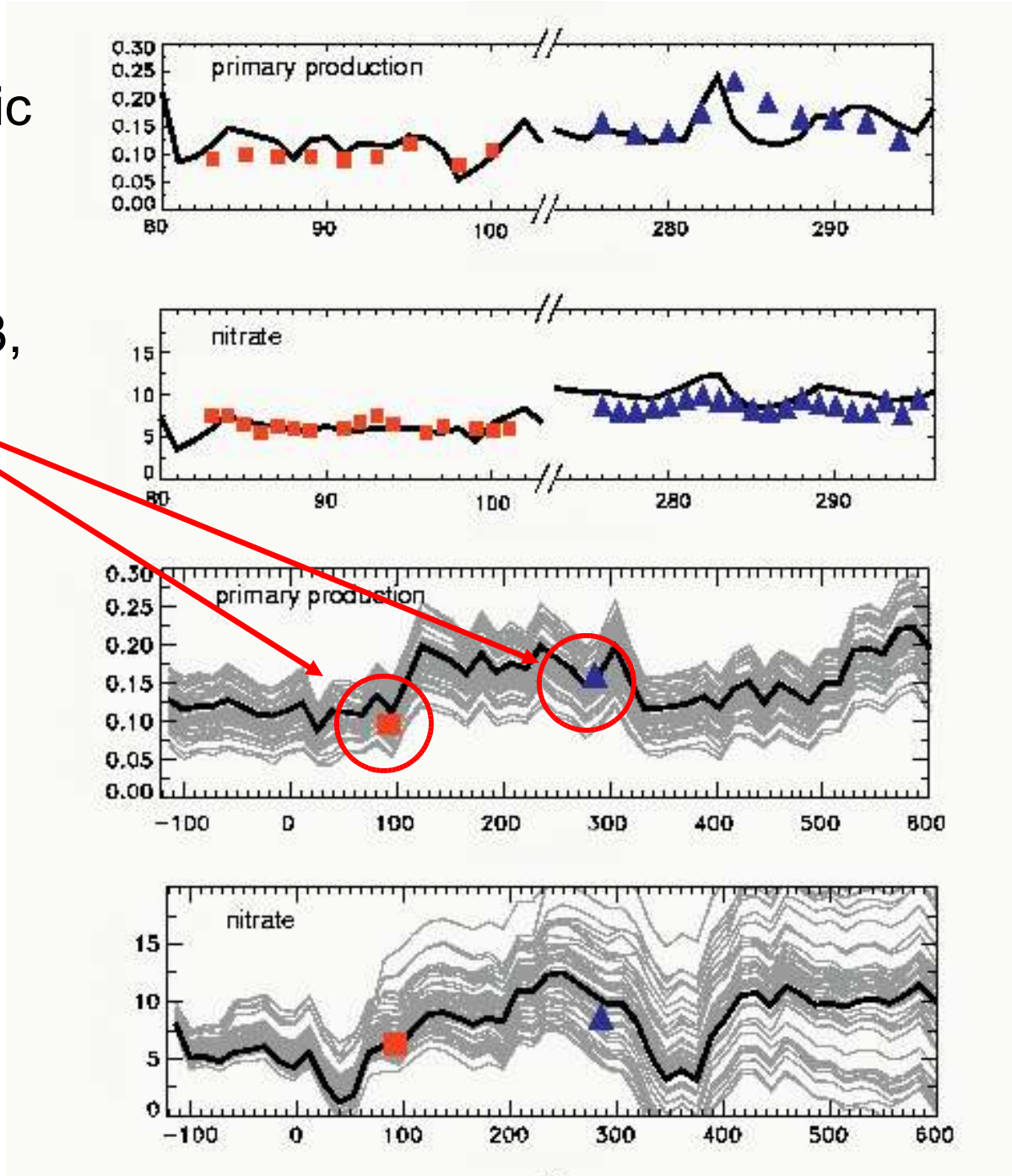


Nitrate as N_2 (µg/L)

The JGOFS Eq Pacific time series.

(from Doney et al. Oceanography 14, 93, 2001)

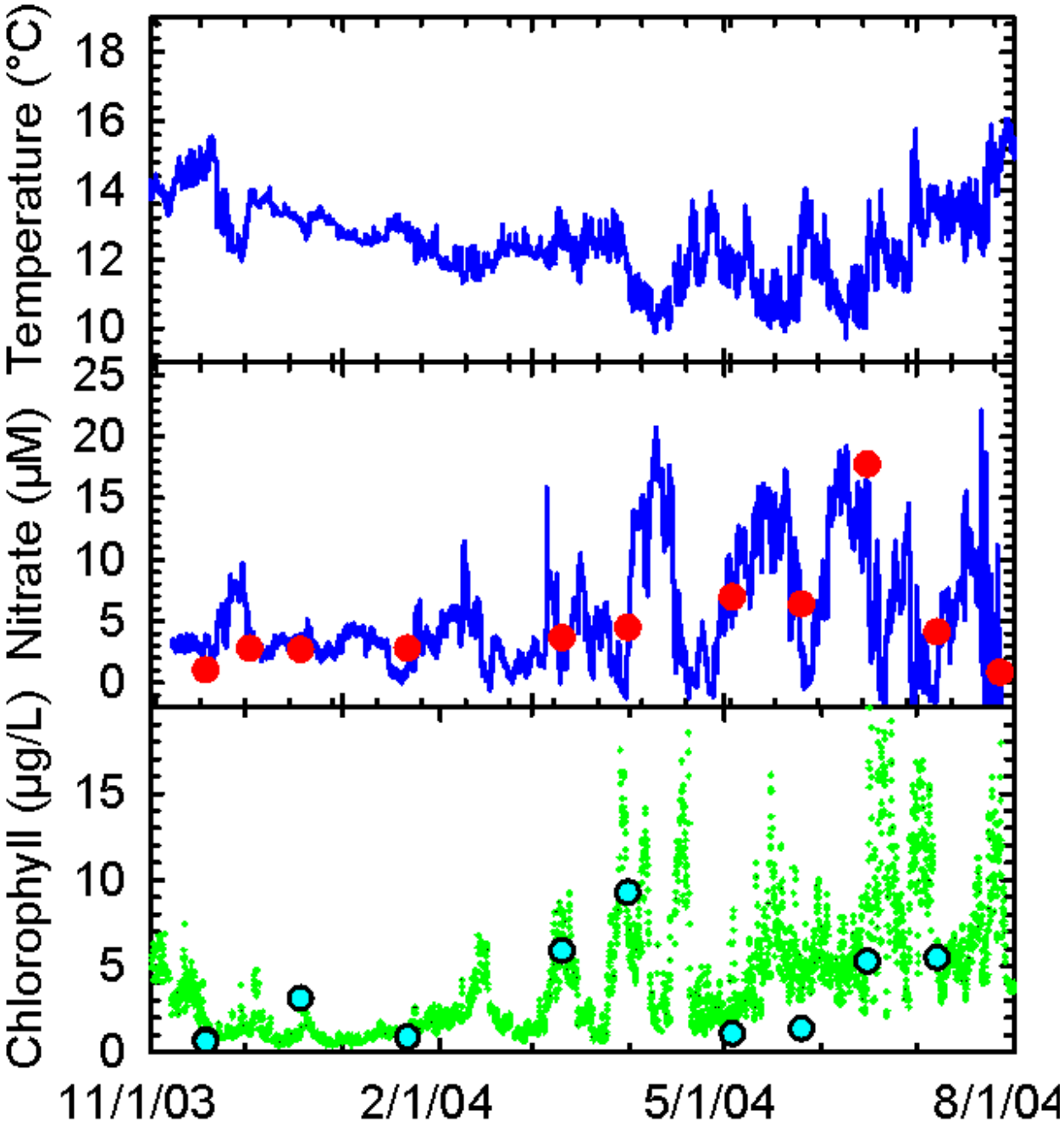
Is this scale of temporal or spatial resolution good enough?



Nine months of optical nitrate measurements on the M1 mooring in Monterey Bay.

Shipboard observations result in significant under-sampling of this system.

True everywhere?



Observed Pri. Prod = 408 mg C/m3/d (24 hr incubation)

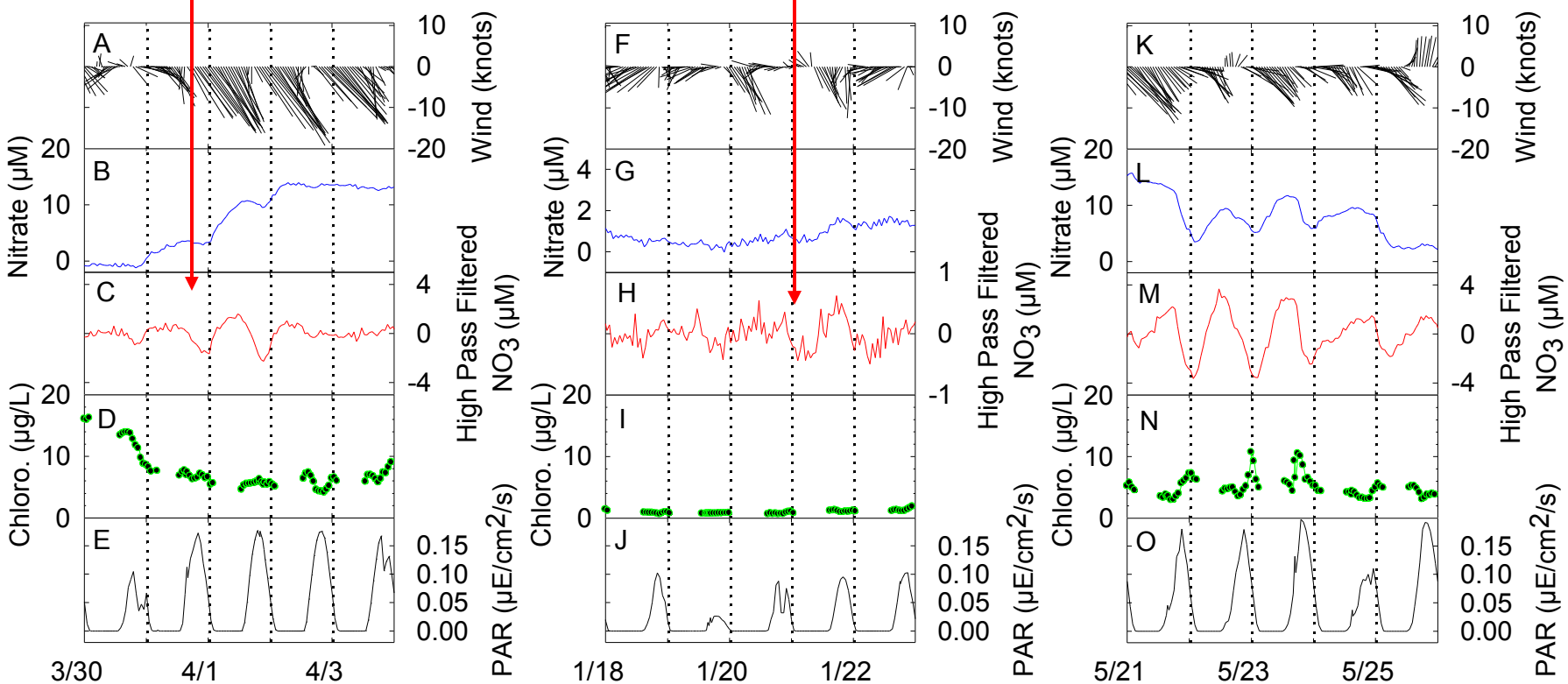
408/12/6.6 = 5.1 µM NO3 required

ΔNO3 = 2.1µM (4.6 next day)

Observed Pri. Prod = 43 mg C/m3/d

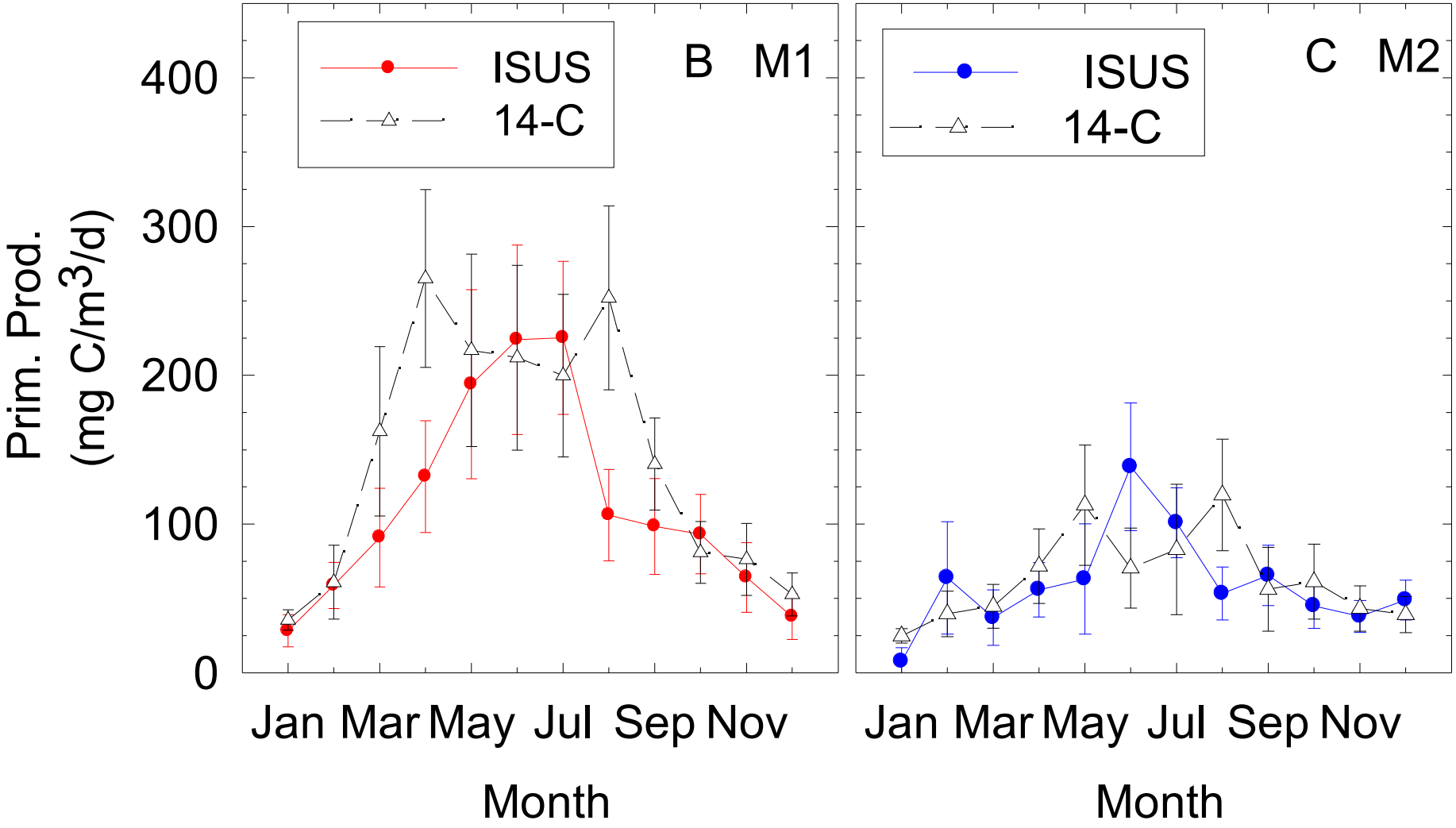
43/12/6.6 = 0.5 µM NO3 required

ΔNO3 = 0.6 µM observed

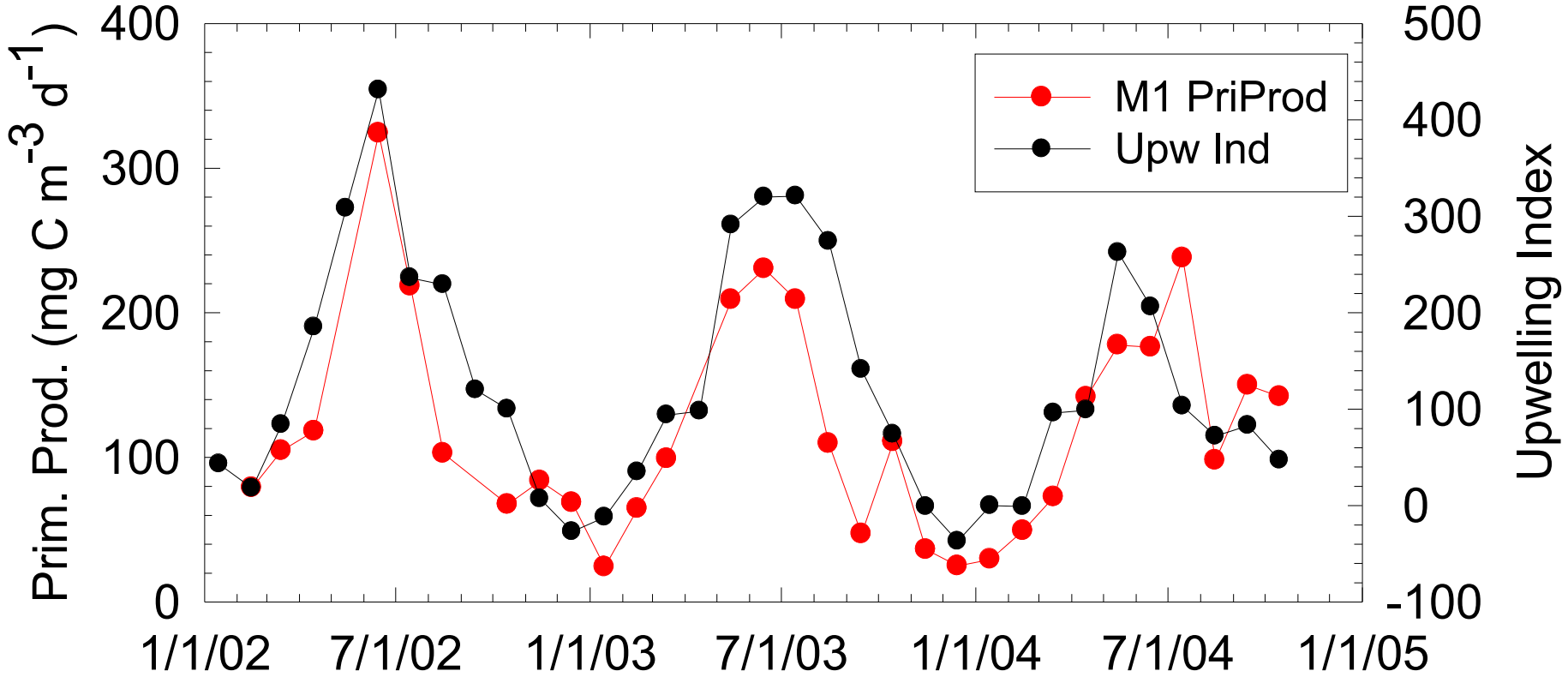


ISUS – monthly average 1/2002 to 10/2004

^{14}C – monthly average 1989 to 2004 – 24 hr incubation

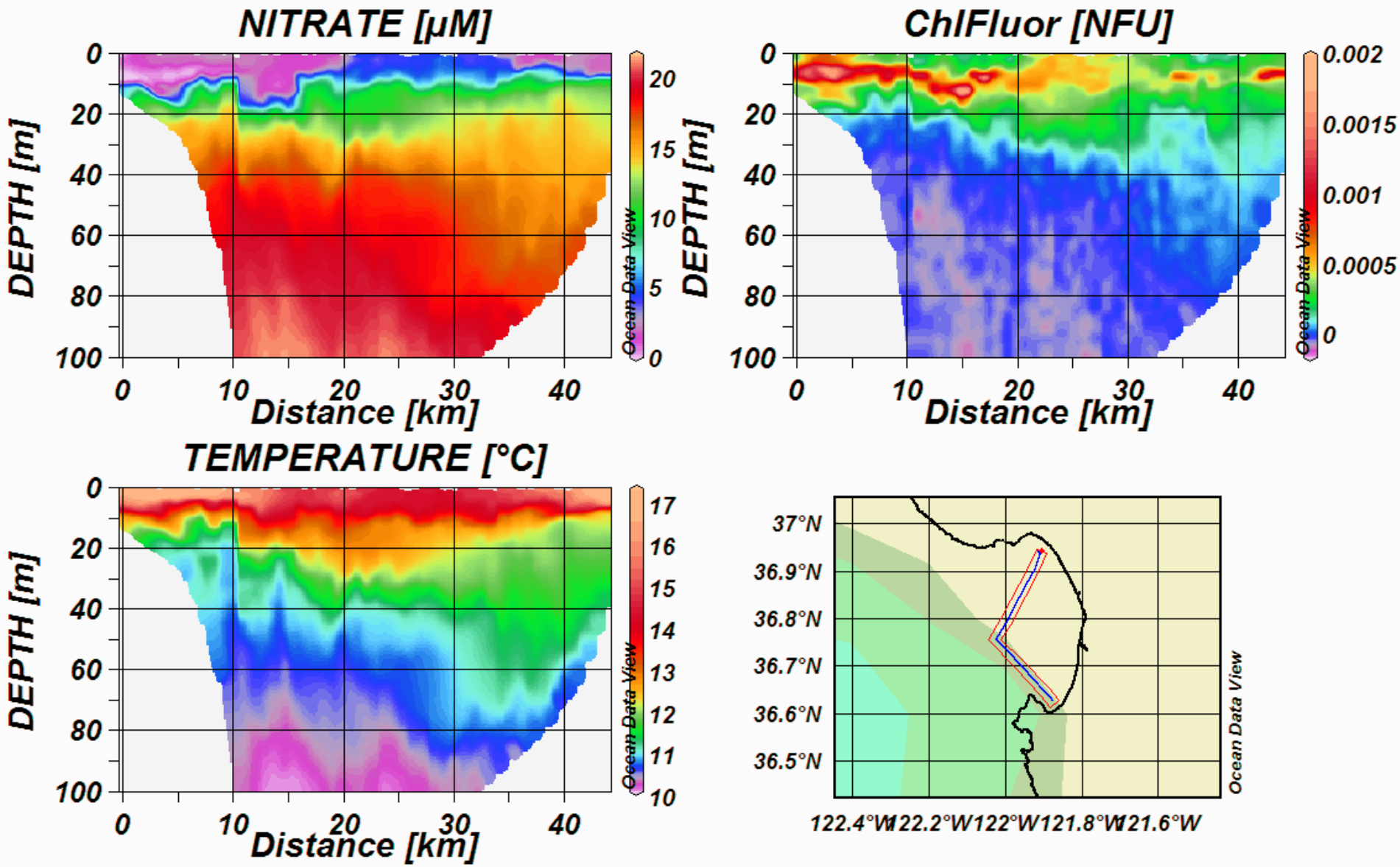


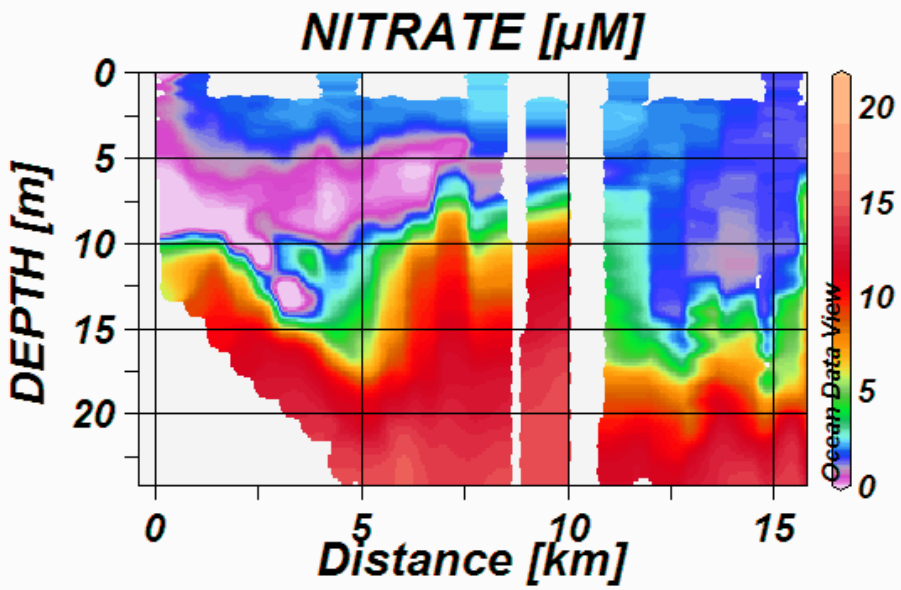
Primary production highly correlated with Bakun upwelling index ($m^3/s/100$ m coastline – www.pfel.noaa.gov)



Johnson et al., in review.

AUV Transect in Monterey Bay, YD 254 2004
16893 data points in each panel




NITRATE [µM]
DEPTH [m]
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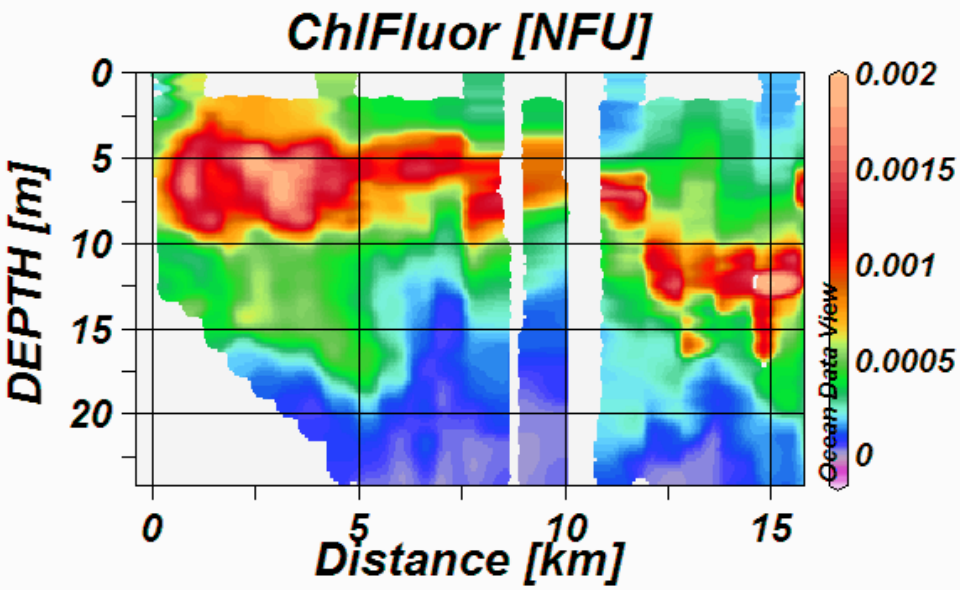
5
10
15
20
Distance [km]
0
5
10
15
Ocean Data View
20
15
10
5
0


ChlFluor [NFU]
DEPTH [m]
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Distance [km]
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Ocean Data View
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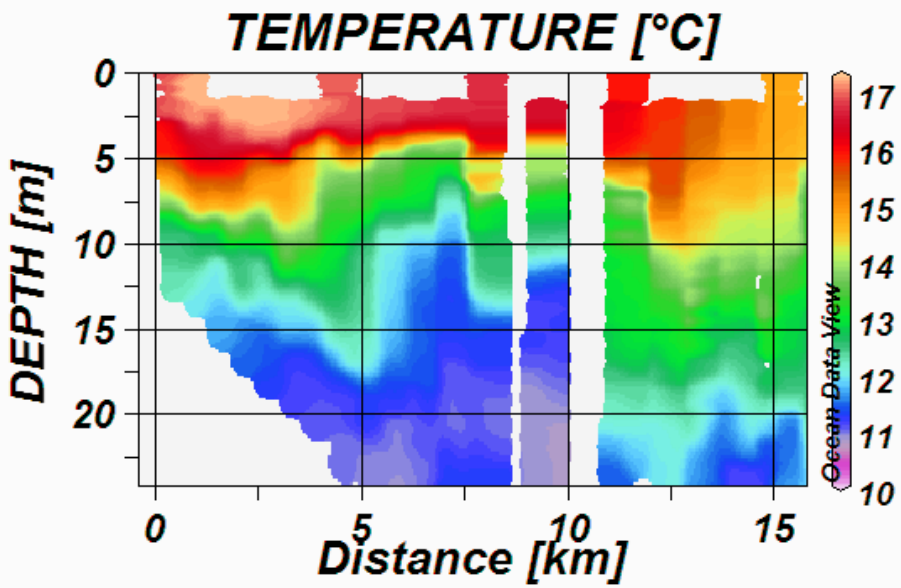
0.001
0.0005
0


TEMPERATURE [°C]
DEPTH [m]
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Distance [km]
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Ocean Data View
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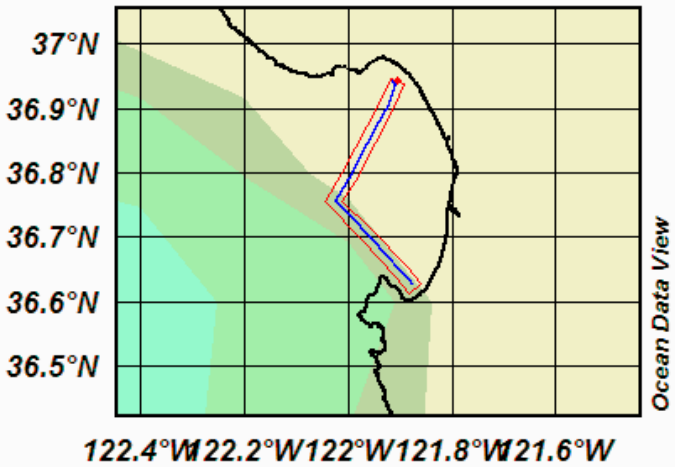
13
12
11
10


37°N
36.9°N
36.8°N
36.7°N
36.6°N
36.5°N
122.4°W
122.2°W
122°W
121.8°W
121.6°W
Ocean Data View

What can be measured from floats?

- O_2 with examples from Koertzinger and from Riser

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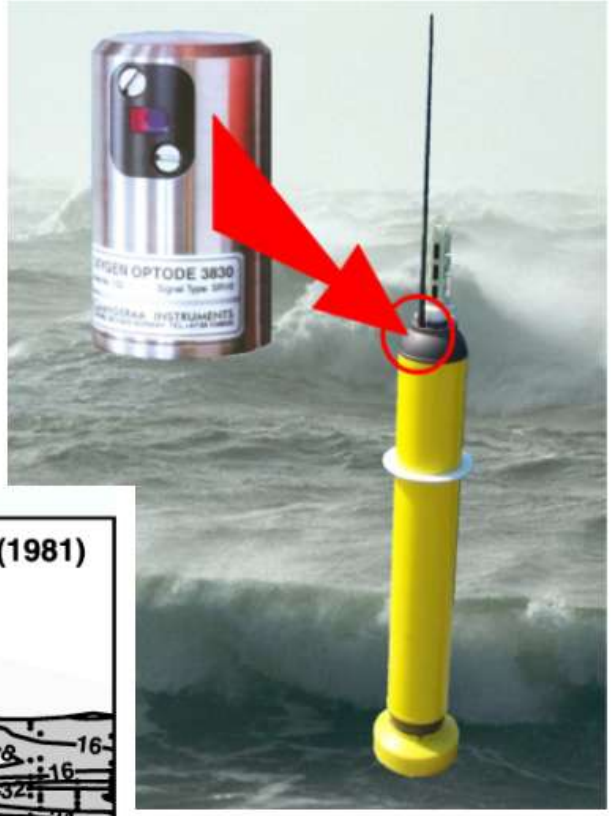
Trends in Marine Dissolved Oxygen: Implications for Ocean Circulation Changes and the Carbon Budget



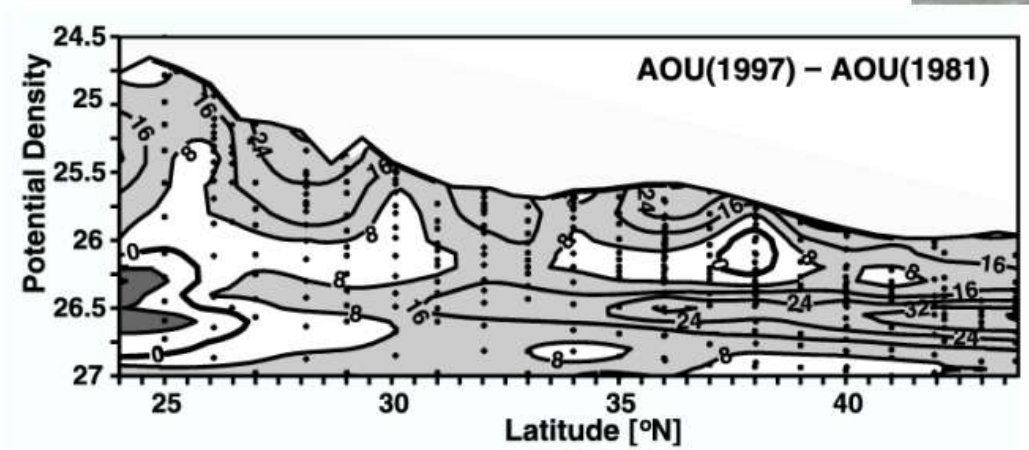


Fig. 1. Observed decrease in dissolved oxygen concentration in the thermocline of the North Pacific [Emerson et al., *2001*]. *Plotted are differences in apparent oxygen utilization (AOU) as measured on two cruises on the same transect between 24°N and 44°N in 1981 and 1997. The contour interval is 4 μmol kg⁻¹. AOU is the difference between the O_2 equilibrium concentration, calculated from the observed in-situ temperature and salinity and atmospheric O_2 pressure at sea level, and the measured in-situ concentration of O_2. An increase in AOU corresponds to a decrease in dissolved oxygen. (Figure courtesy of Steve Emerson).*

Joos et al., 2003

Oxygen float project: Körtzinger, IFM-GEOMAR, Kiel/Germany

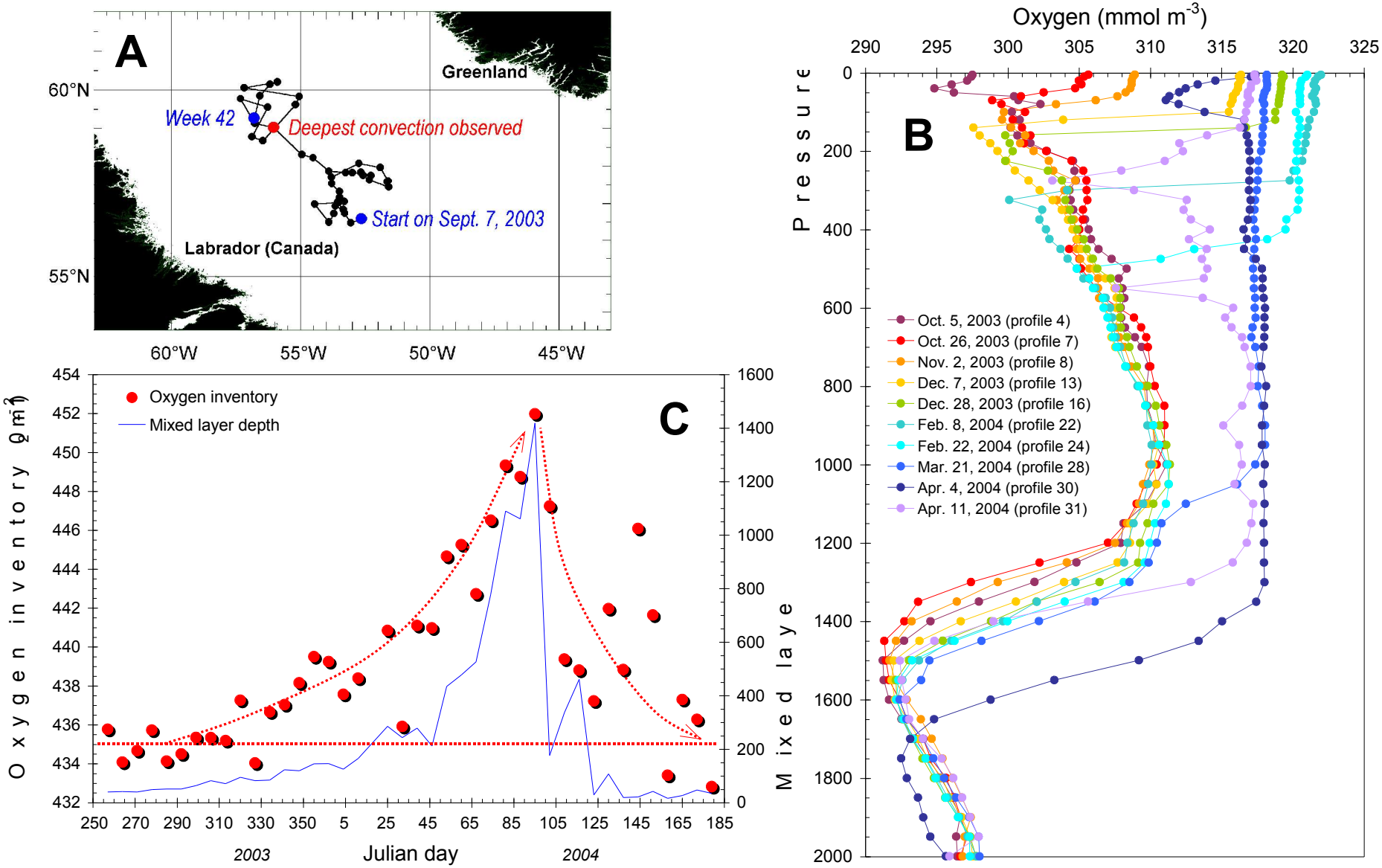
Aanderaa Instruments
Bergen, Norway

Webb Research Corporation
E. Falmouth, Massachusetts, U.S.A.

Martec
Serpe-Iesm
France

Ifremer

Oxygen float project: Körtzinger, IFM-GEOMAR, Kiel/Germany



Körtzinger et al. (2004). The ocean takes a deep breath. *Science* **306**, 1337.

Shulenberger, E., Reid, J.L., 1981. The Pacific shallow oxygen maximum, deep chlorophyll maximum, and primary productivity, reconsidered. Deep-Sea Research 28, 901-919.

SOM records primary production.

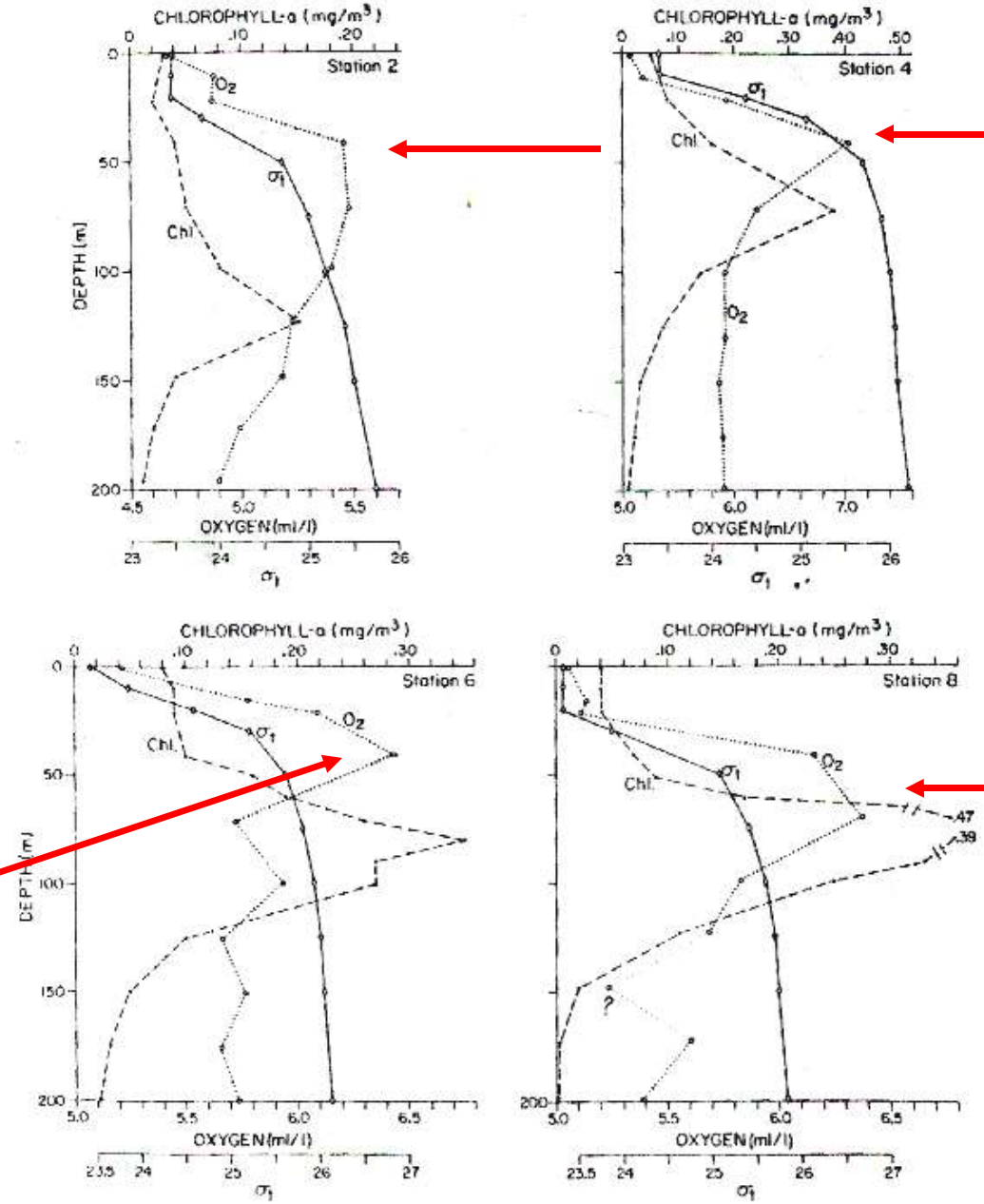
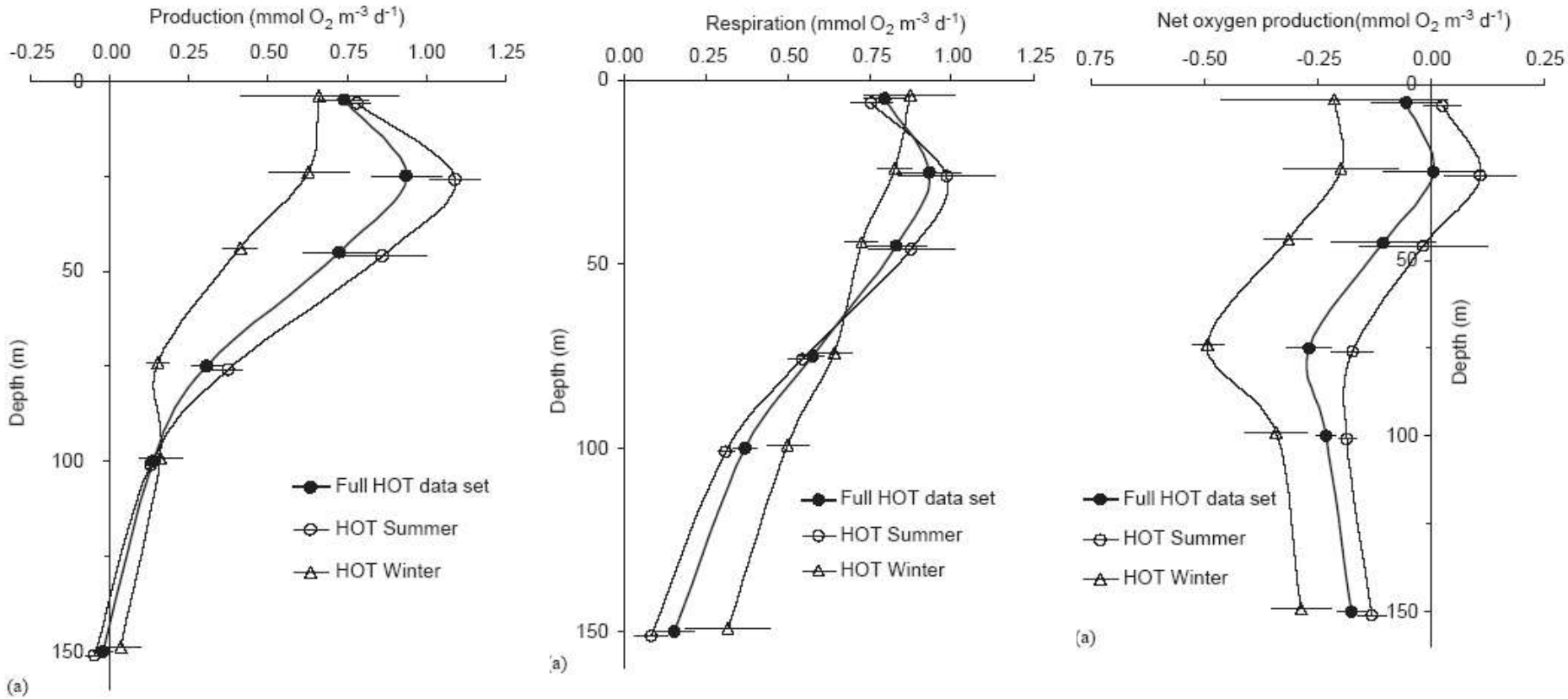


Fig. 10. Oxygen, chlorophyll, and σ_t from four stations in the North Pacific in July, INDOPAC-16 expedition. Sta. 2, 30°46'N, 163°30'W. Sta. 4, 35°N, 162°W. Sta. 6, 35°N, 160°W. Sta. 8, 35°N, 158°W. (Data from S.I.O., 1978; contoured sections in VENRICK, 1979.) ? = uncertain value.

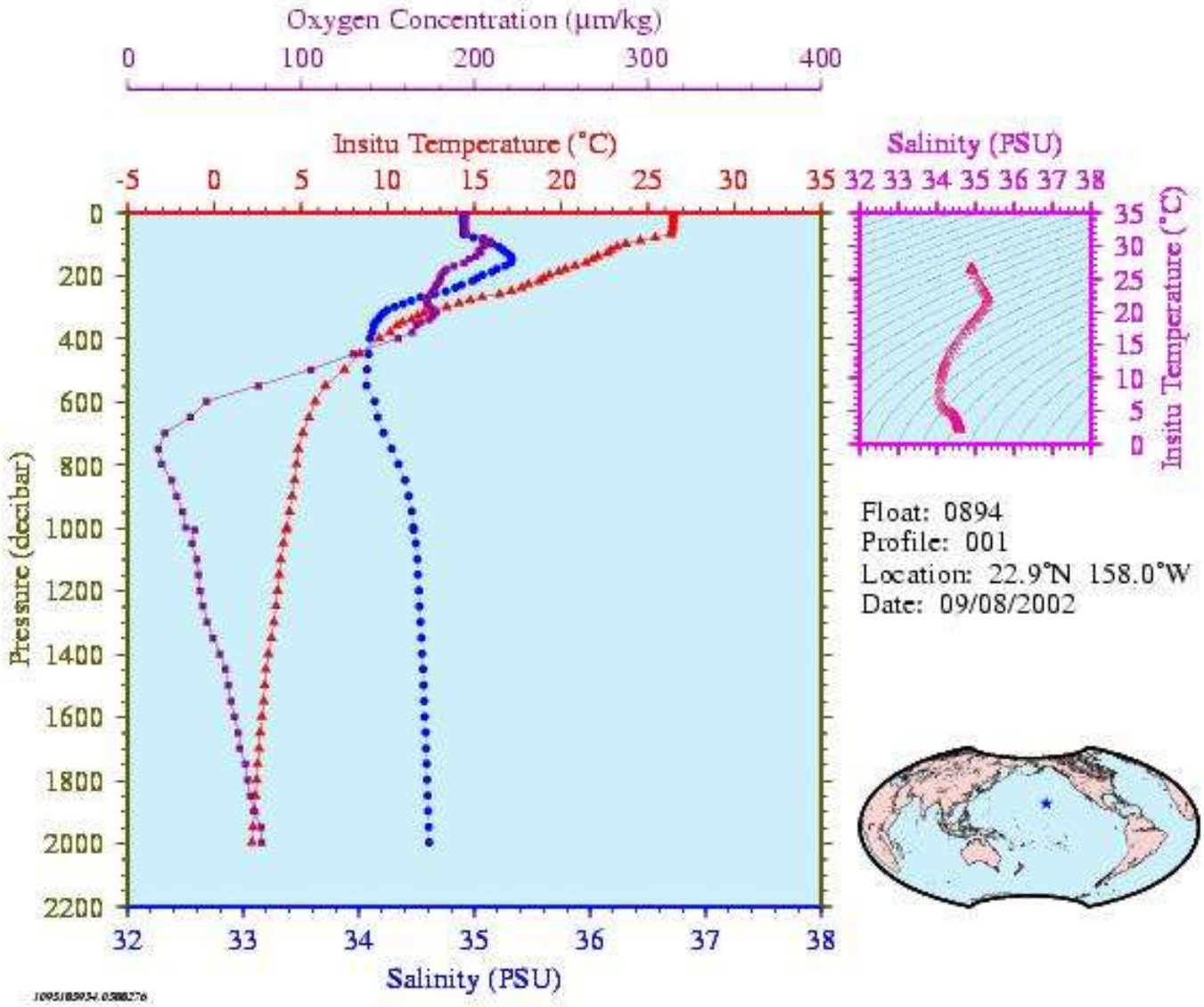
Williams, Morris & Karl, 2004. One year of light/dark bottle measurements of pri. prod./resp. at HOT.

O_2 Production O_2 Resp. O_2 Net

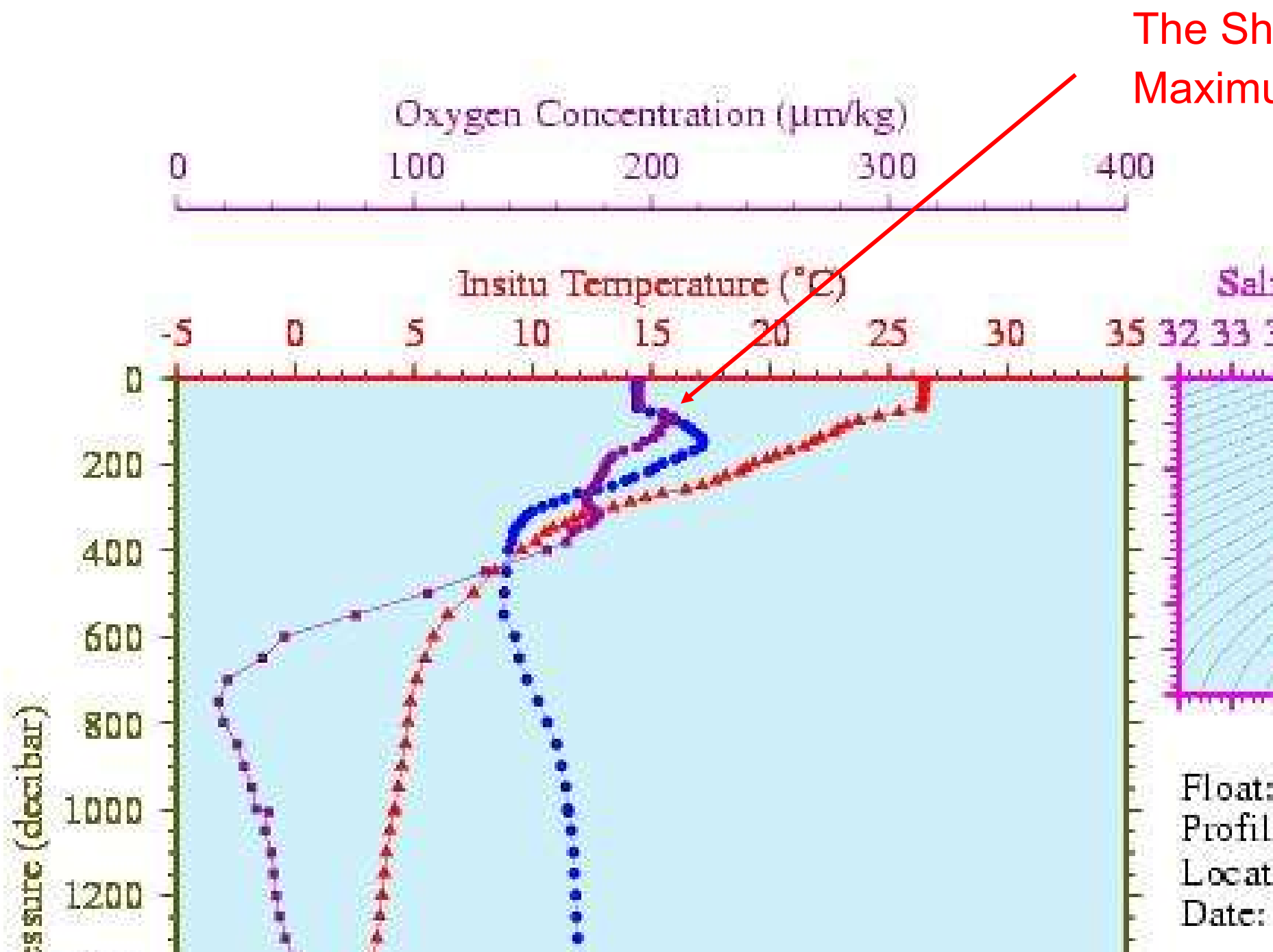


Perhaps pri. prod. is so episodic that it can't be sampled by monthly cruises.

Steve Riser/UW – > 3 year record for O_2 on Float 894 deployed near HOT



flux.ocean.washington.edu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ssure (decibar)
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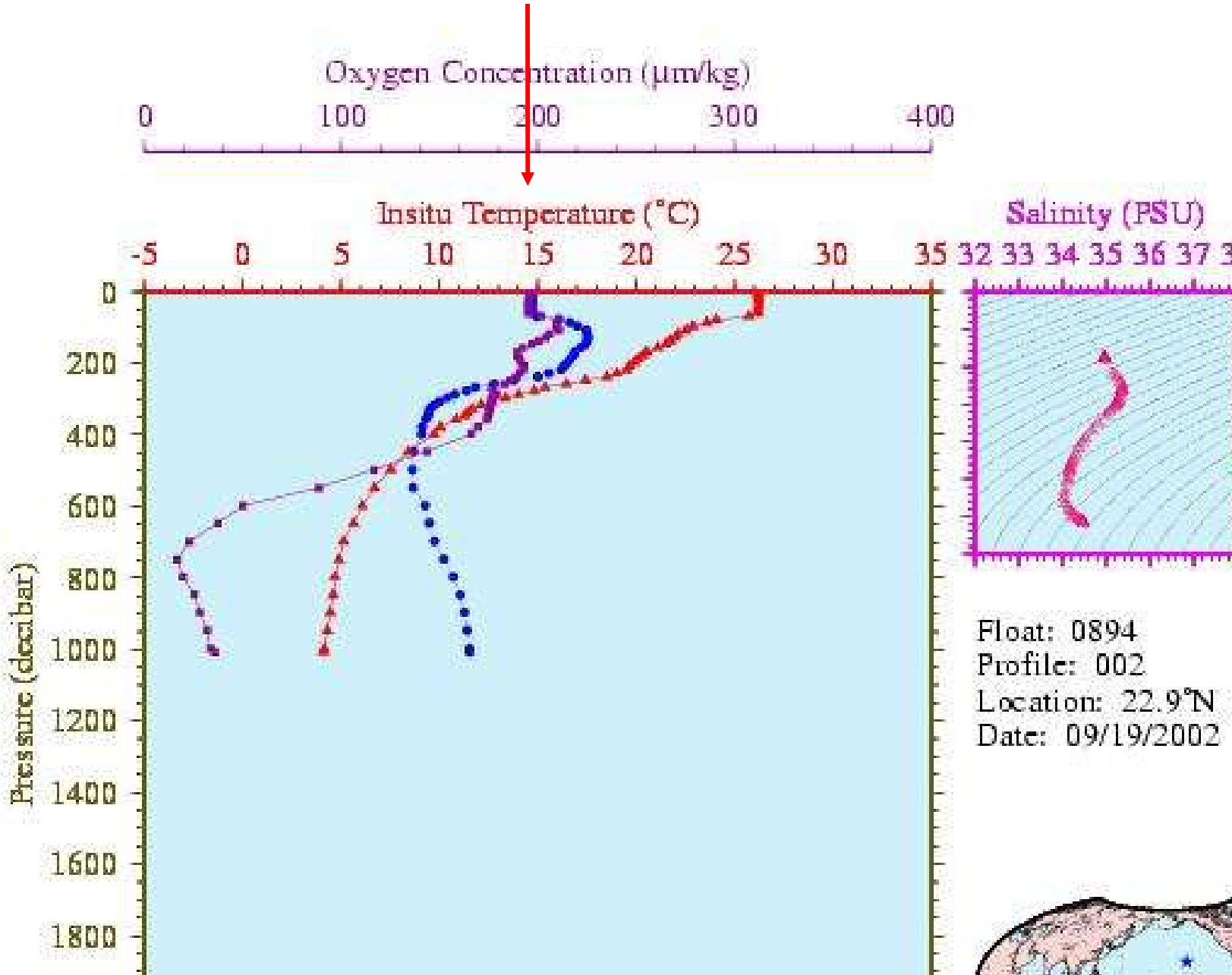
Oxygen Concentration (µm/kg)
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Insitu Temperature (°C)
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Salinity (PSU)
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Pressure (decibar)
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Profile: 002
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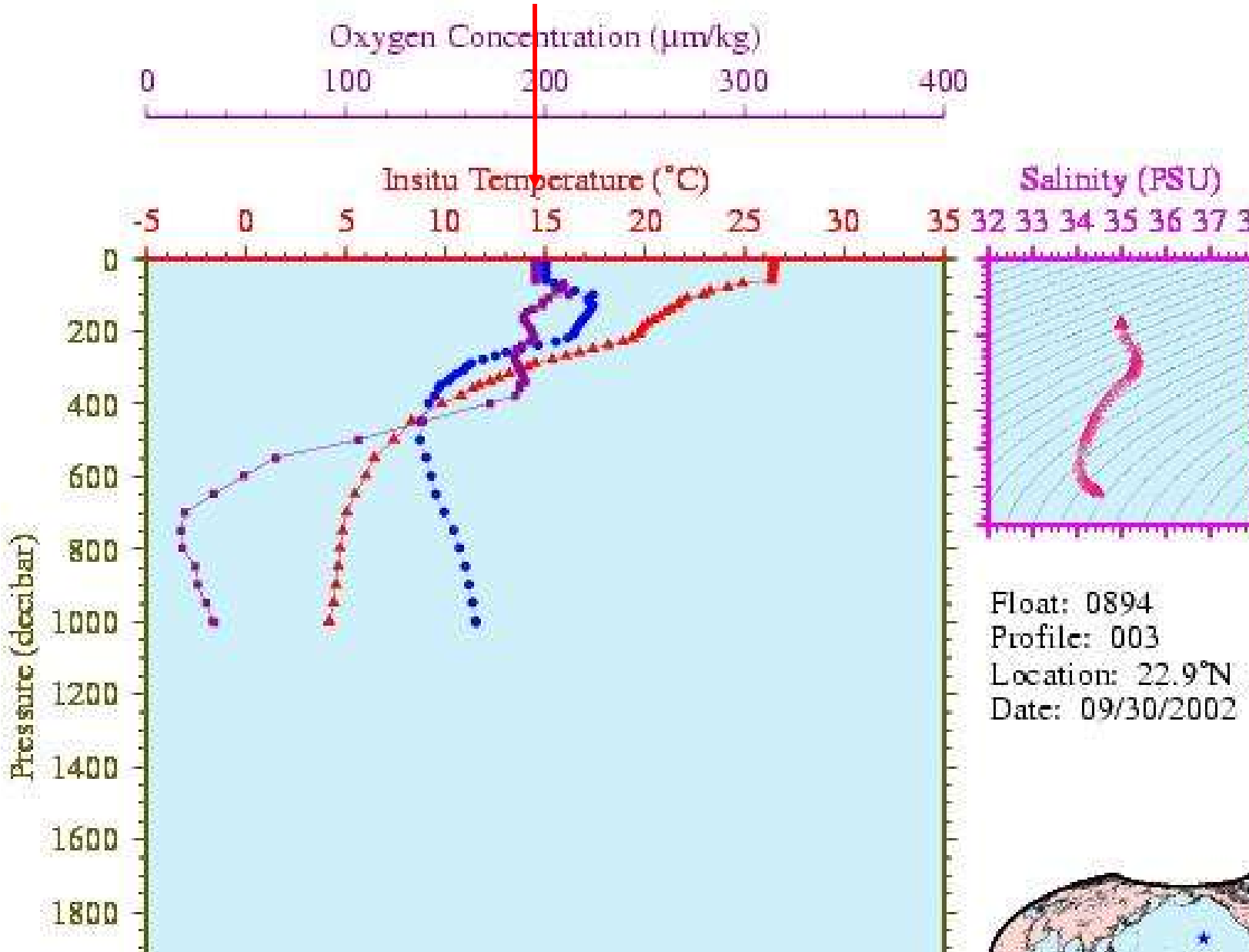
Date: 09/19/2002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Salinity (PSU)
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Pressure (decibar)
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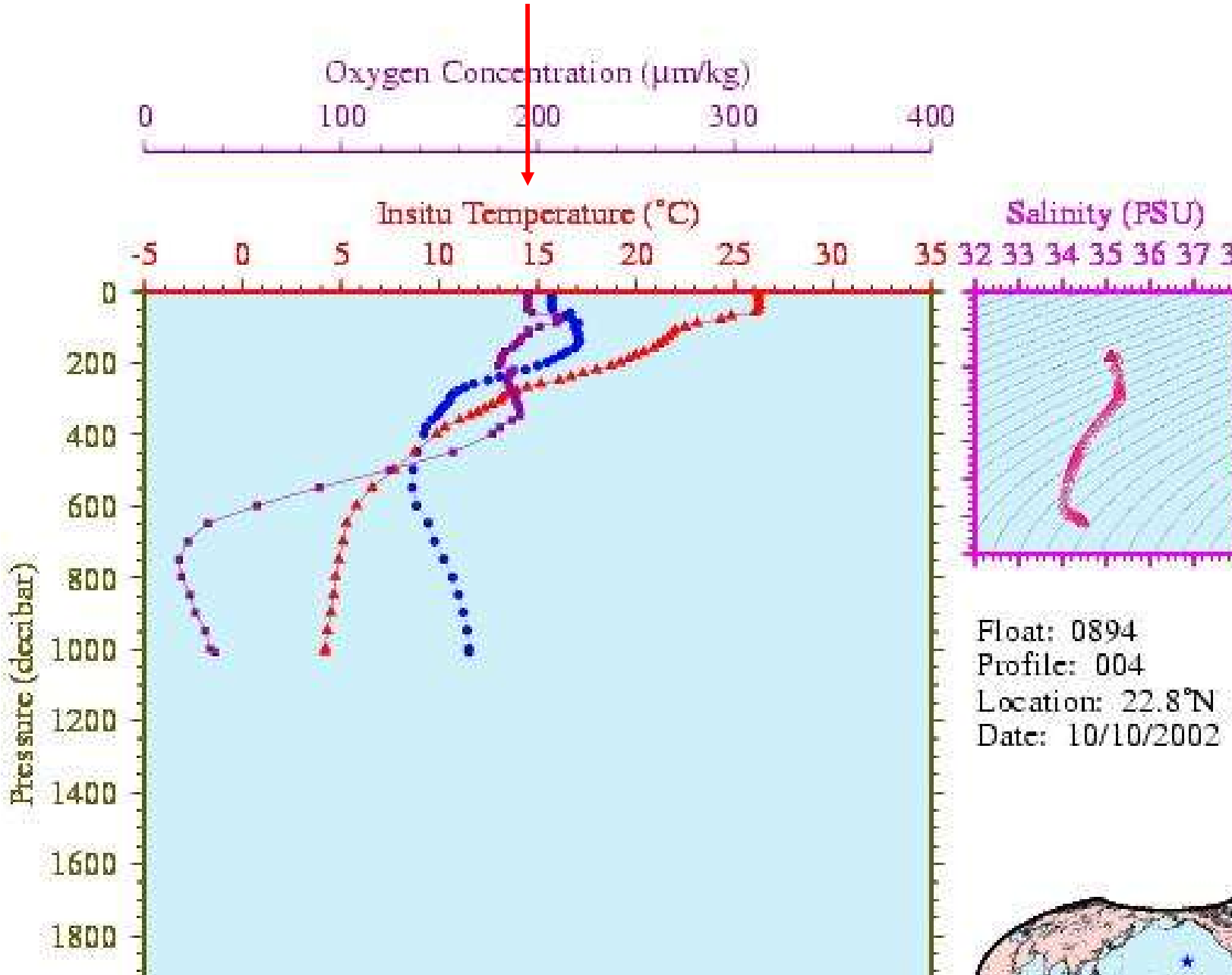
Date: 09/30/2002


Oxygen Concentration (µm/kg)
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Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
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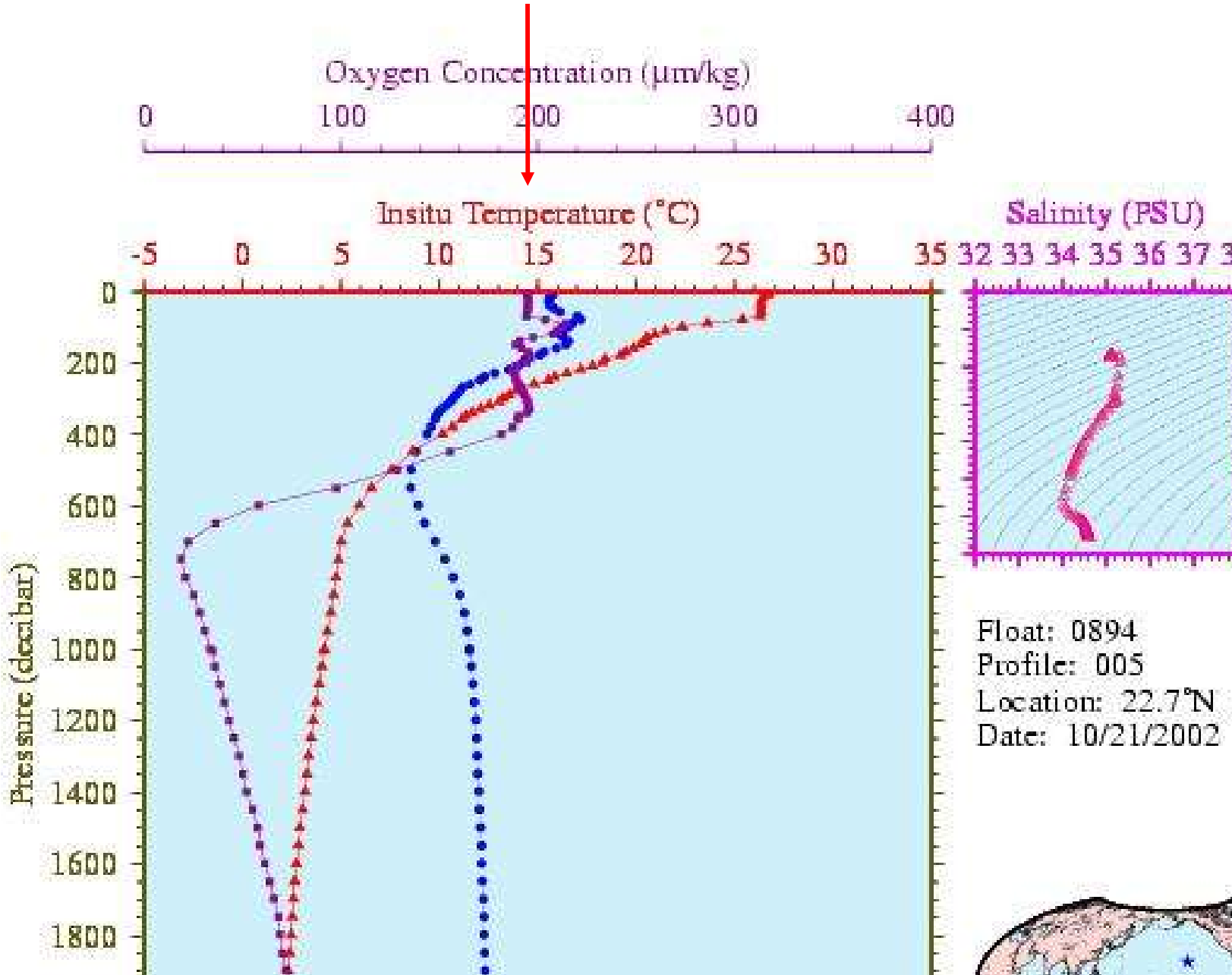
Date: 10/10/2002


Oxygen Concentration (µm/kg)
0
100
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Insitu Temperature (°C)
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25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
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200
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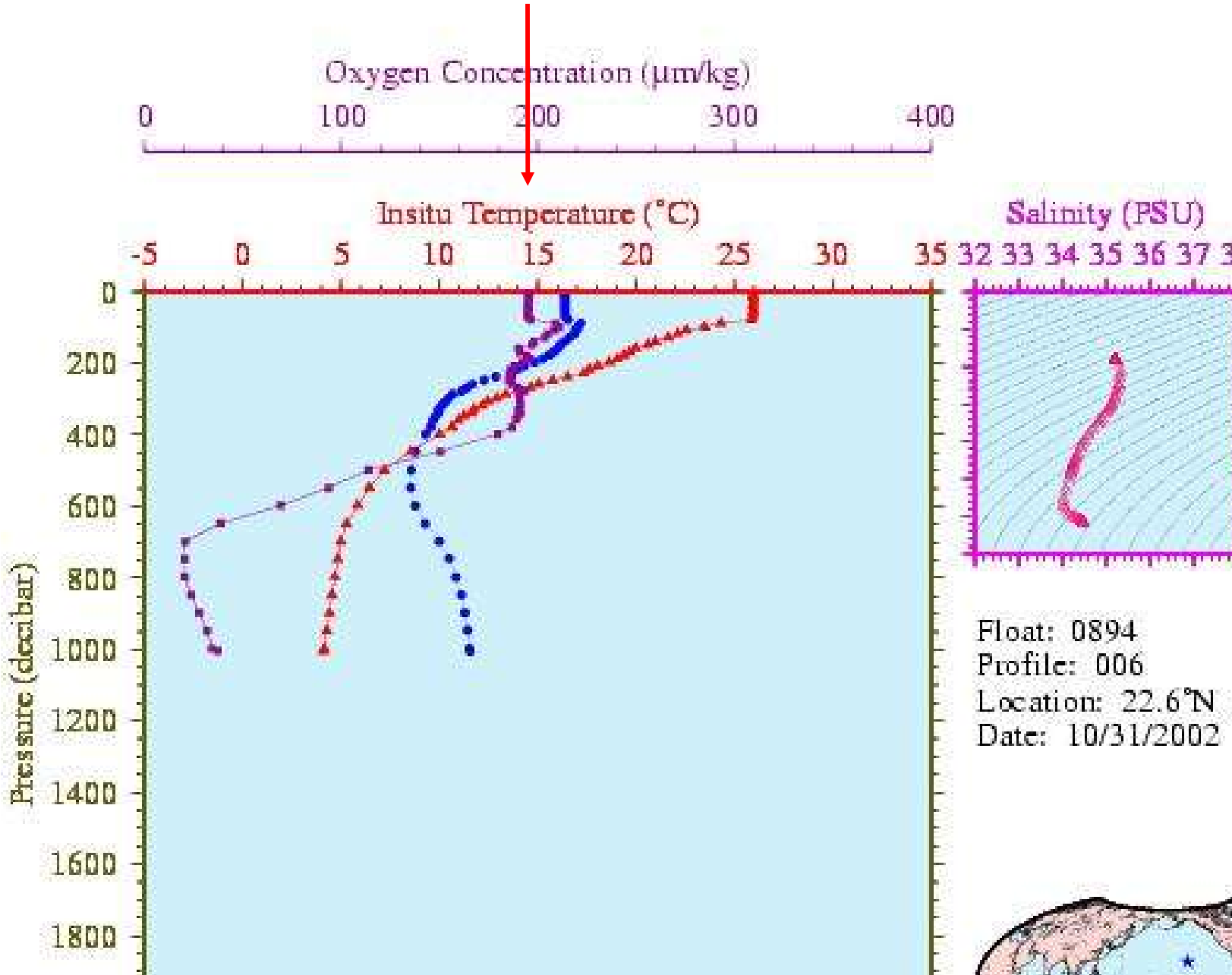
Oxygen Concentration (µm/kg)
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100
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Insitu Temperature (°C)
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10
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20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
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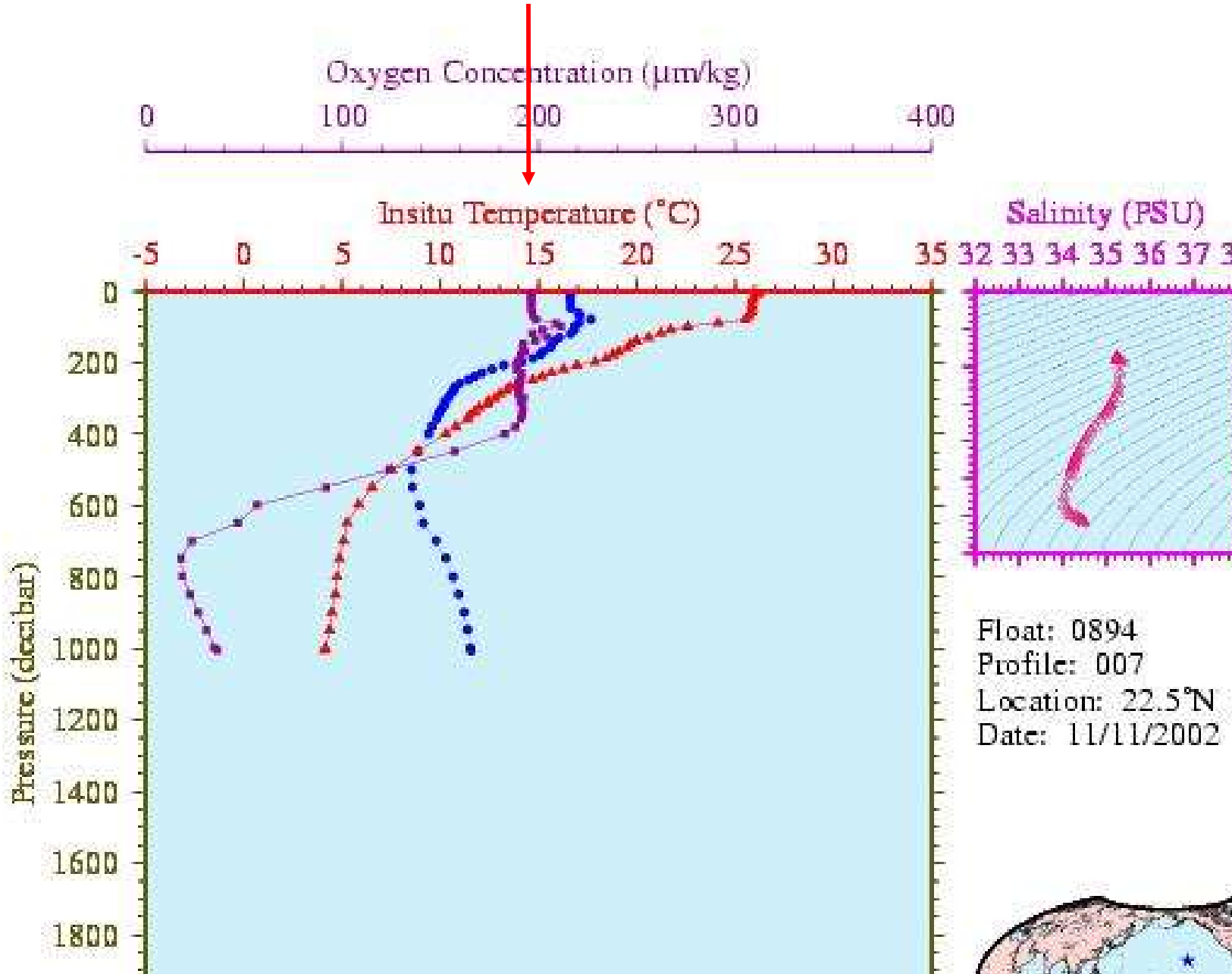
Oxygen Concentration (µm/kg)
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Insitu Temperature (°C)
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10
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30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
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Profile: 007
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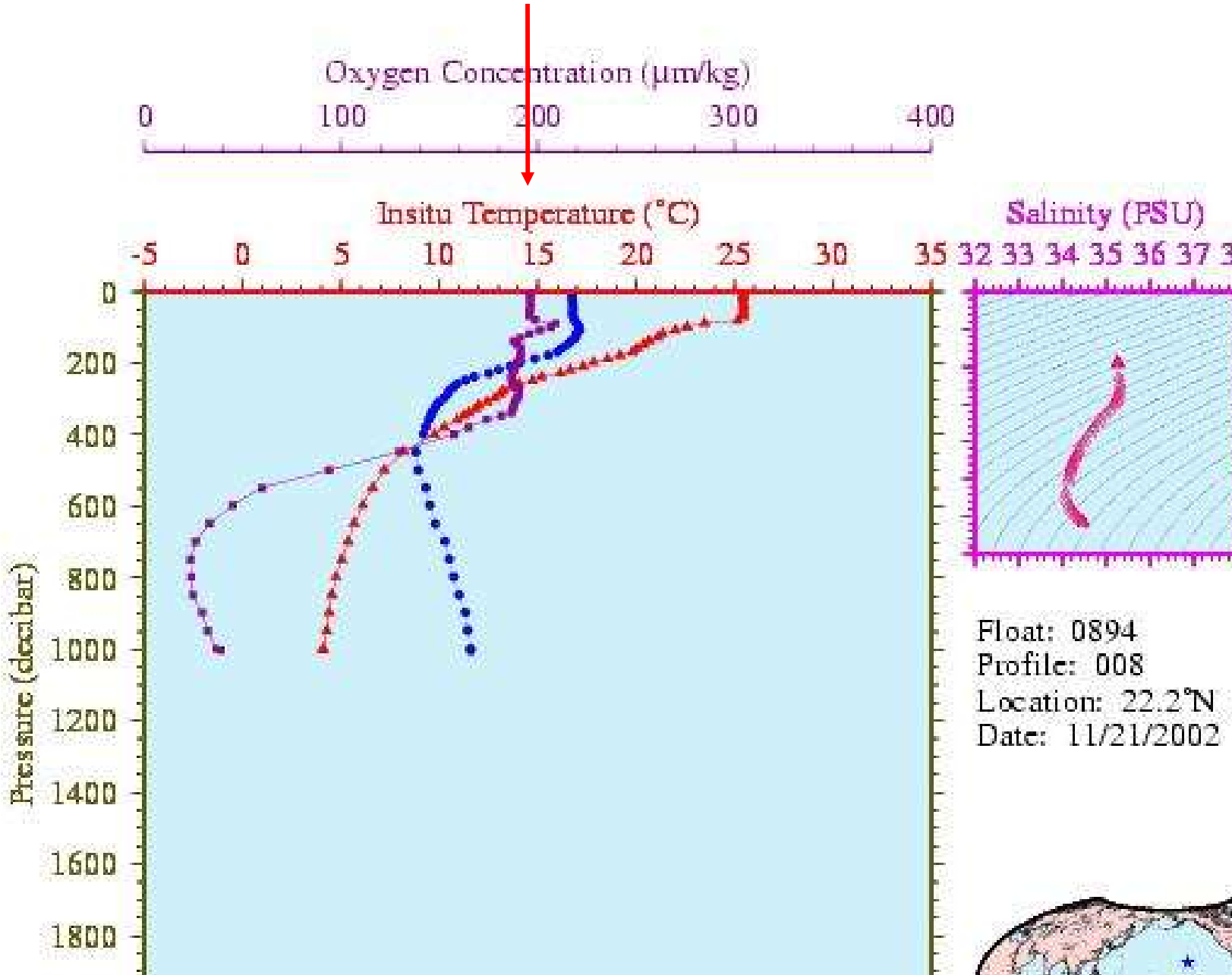
Oxygen Concentration (µm/kg)
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400
Insitu Temperature (°C)
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5
10
15
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25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
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1200
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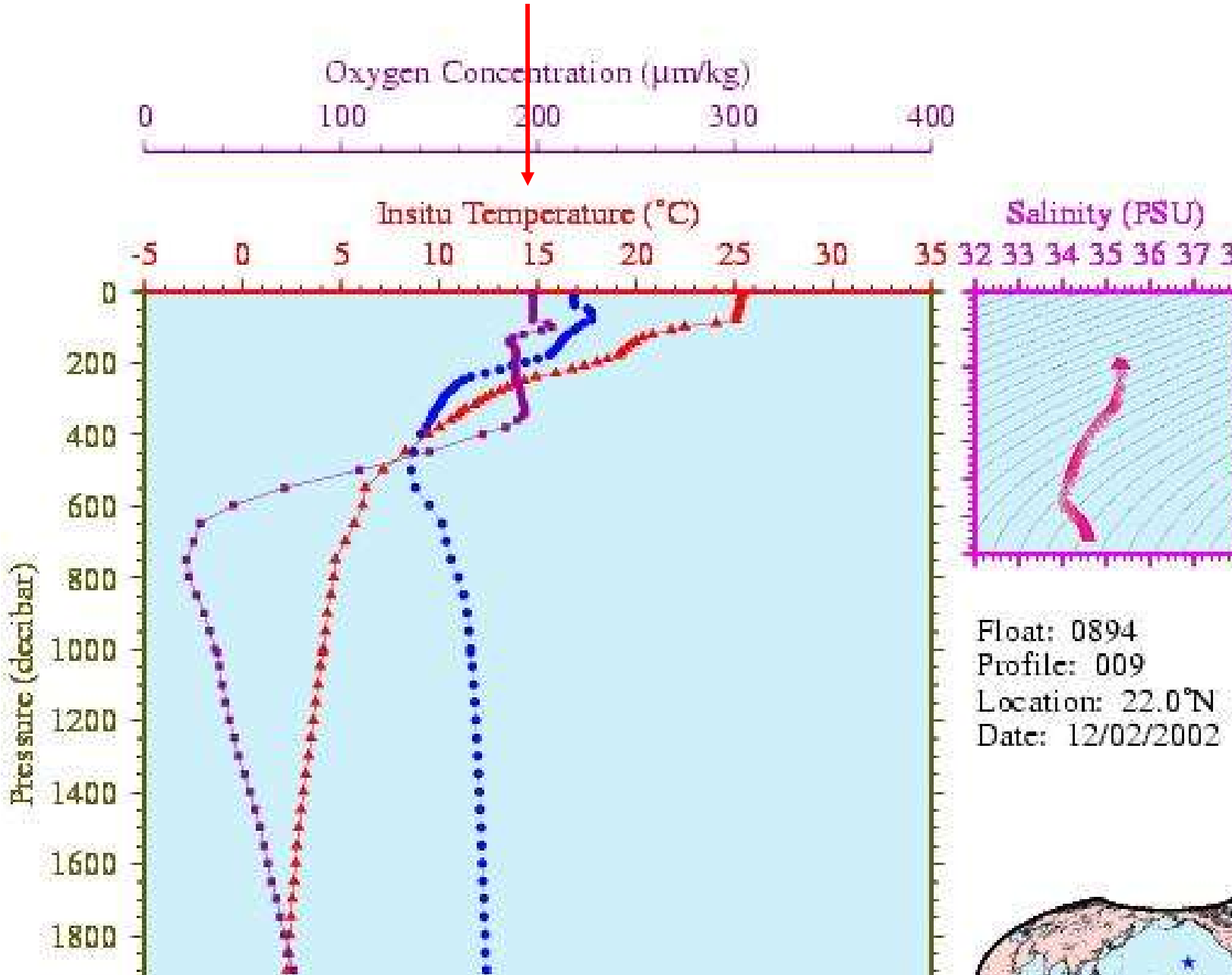
1600
1800
Float: 0894
Profile: 008
Location: 22.2°N
Date: 11/21/2002


Oxygen Concentration (µm/kg)
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Insitu Temperature (°C)
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Salinity (PSU)
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Pressure (decibar)
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Float: 0894
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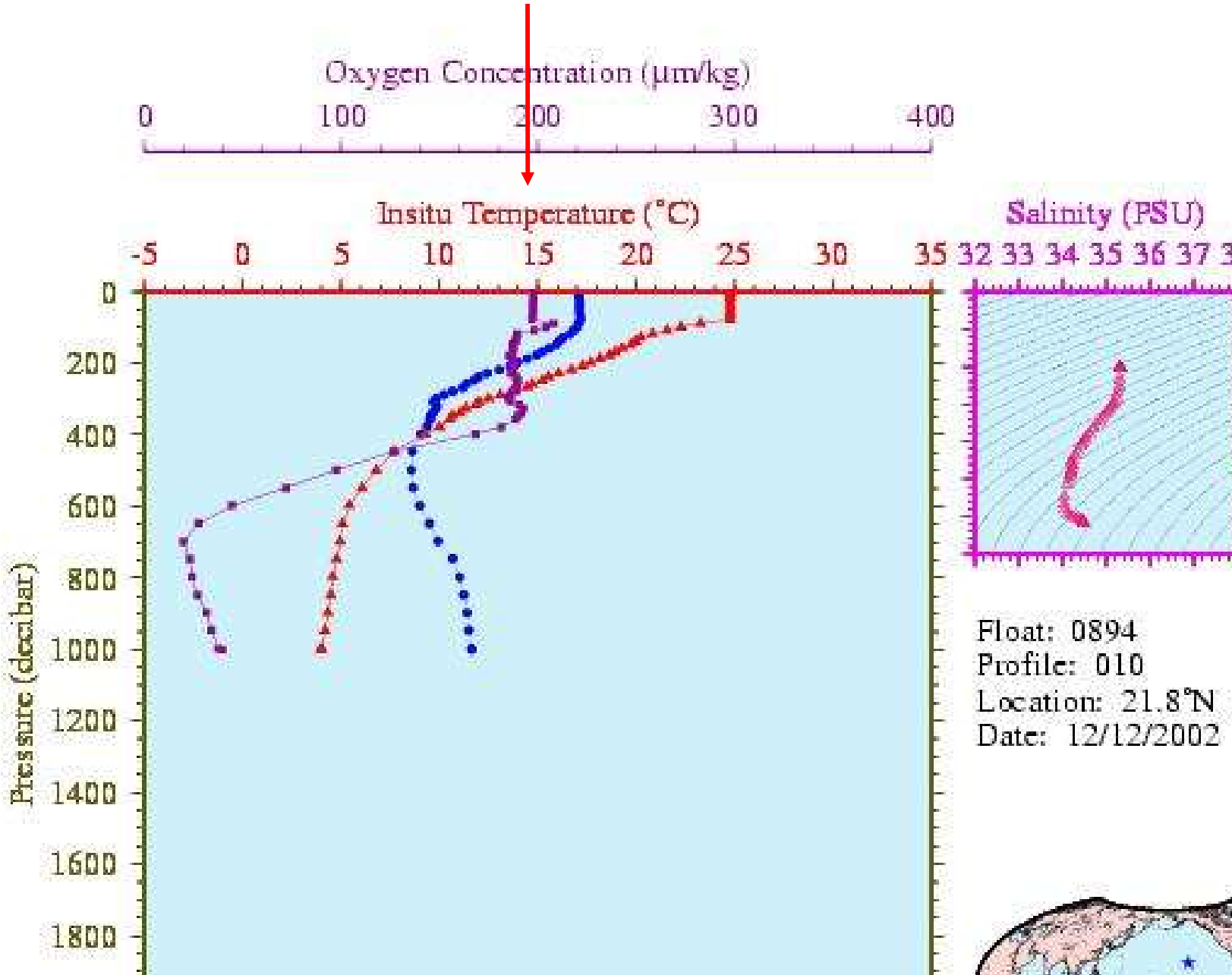
Date: 12/02/2002


Oxygen Concentration (µm/kg)
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Insitu Temperature (°C)
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Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
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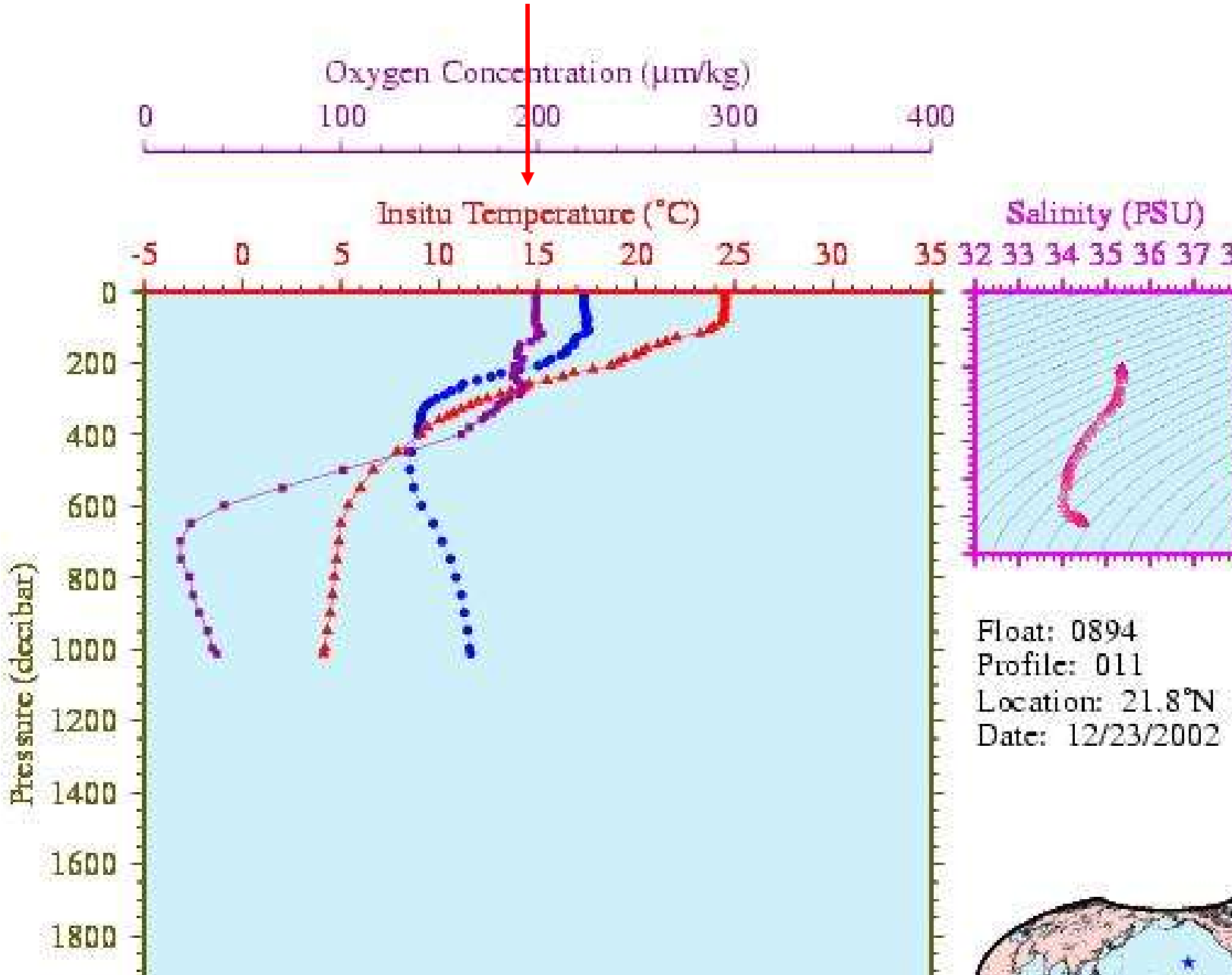
Date: 12/12/2002


Oxygen Concentration (µm/kg)
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Insitu Temperature (°C)
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25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
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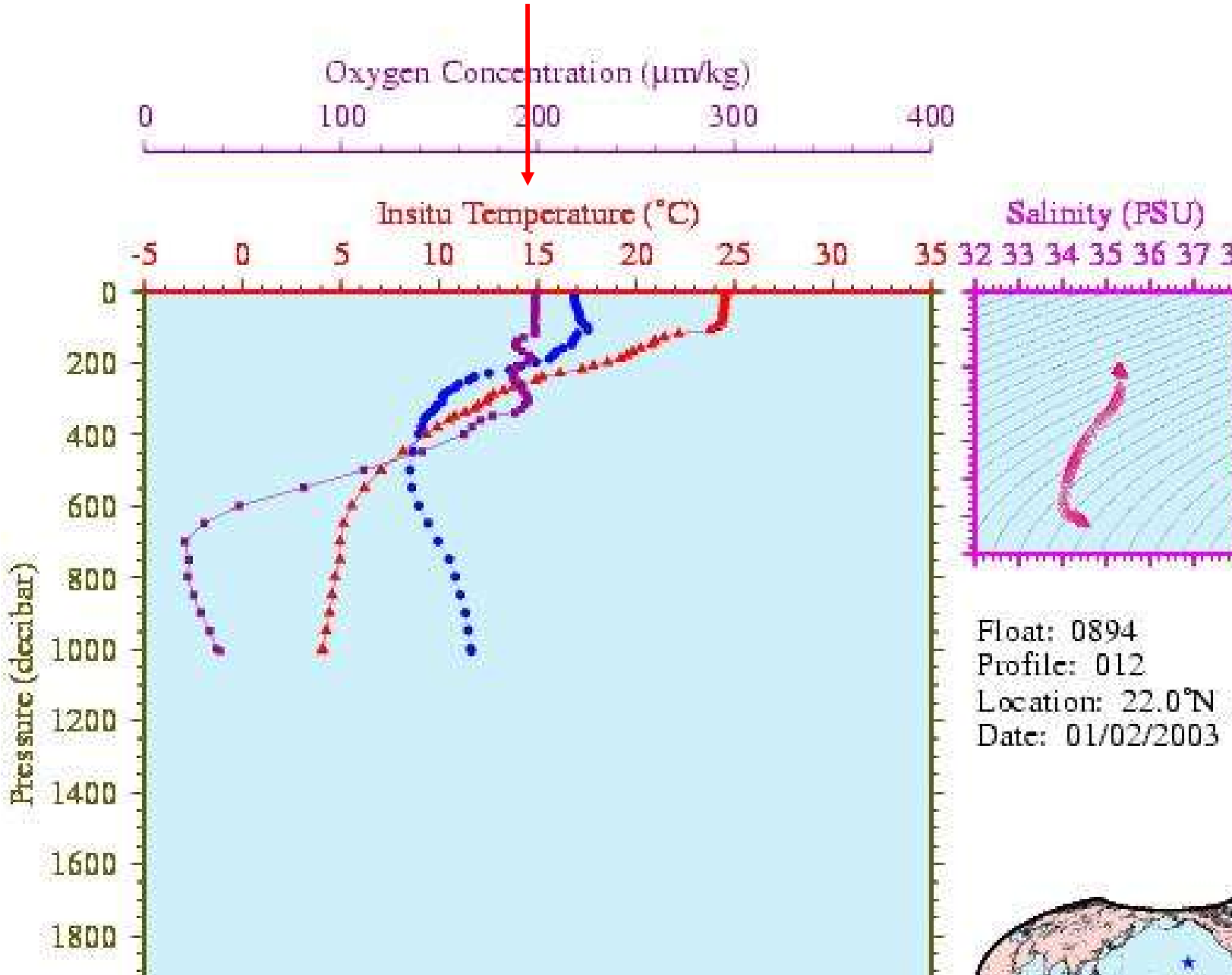
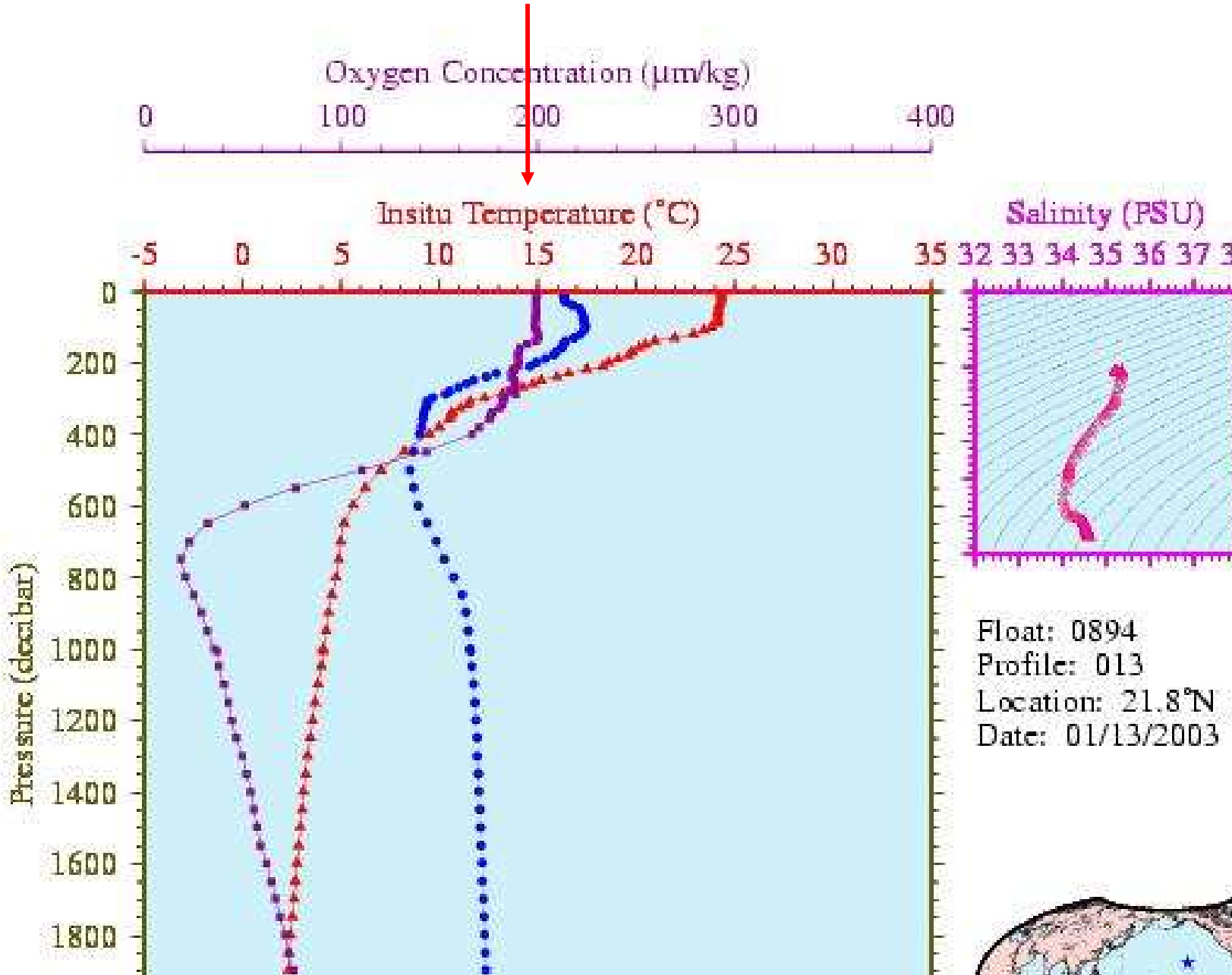
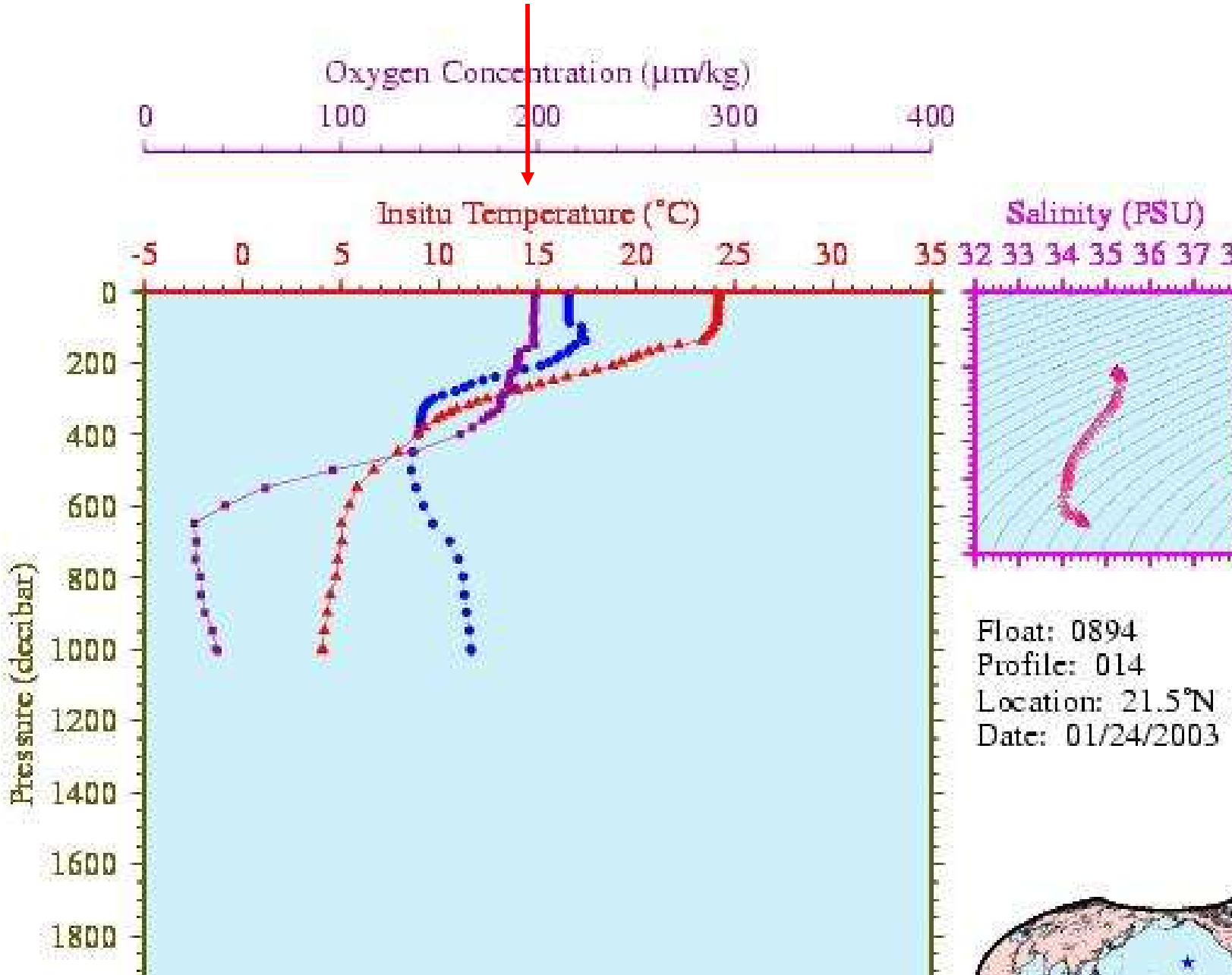
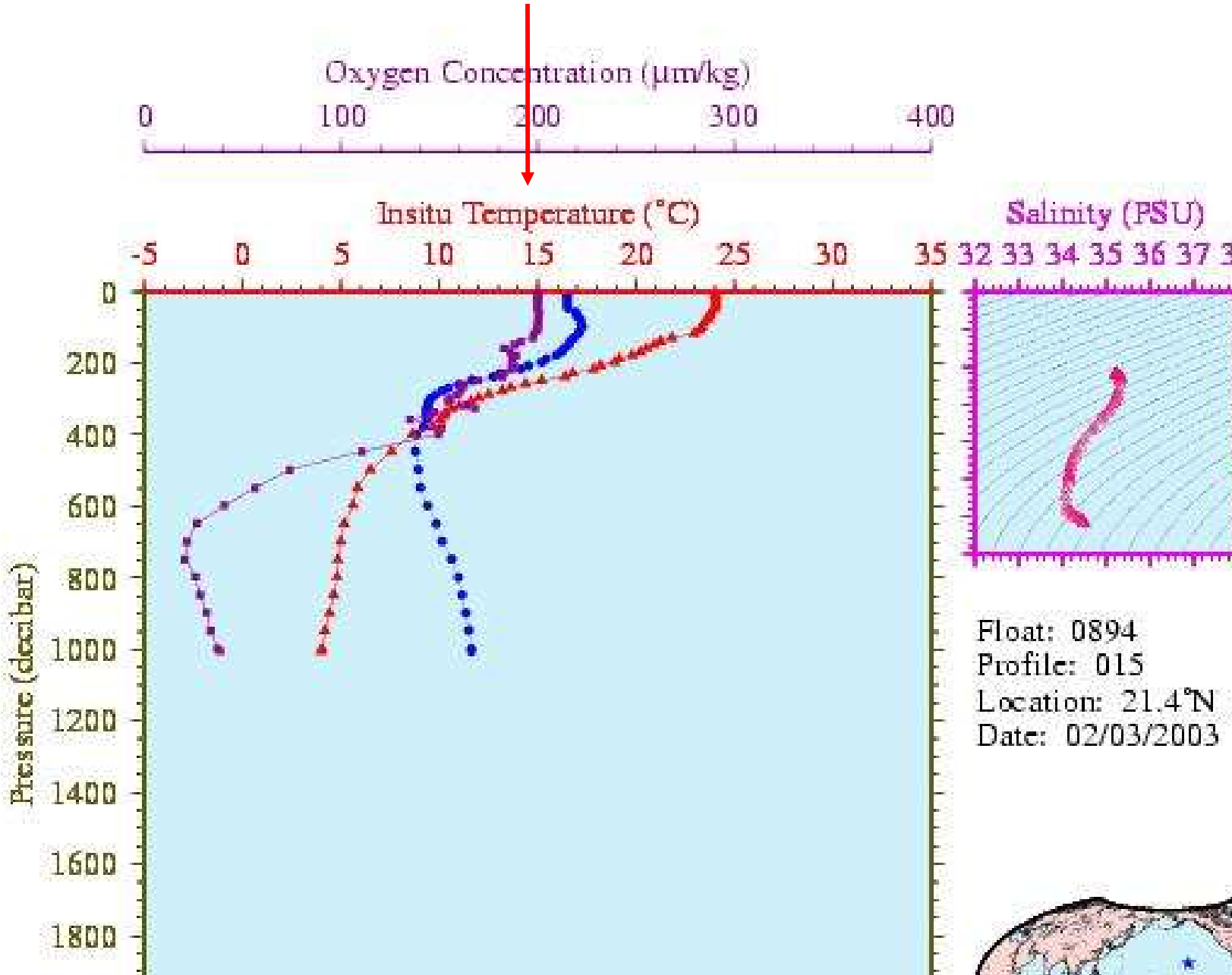
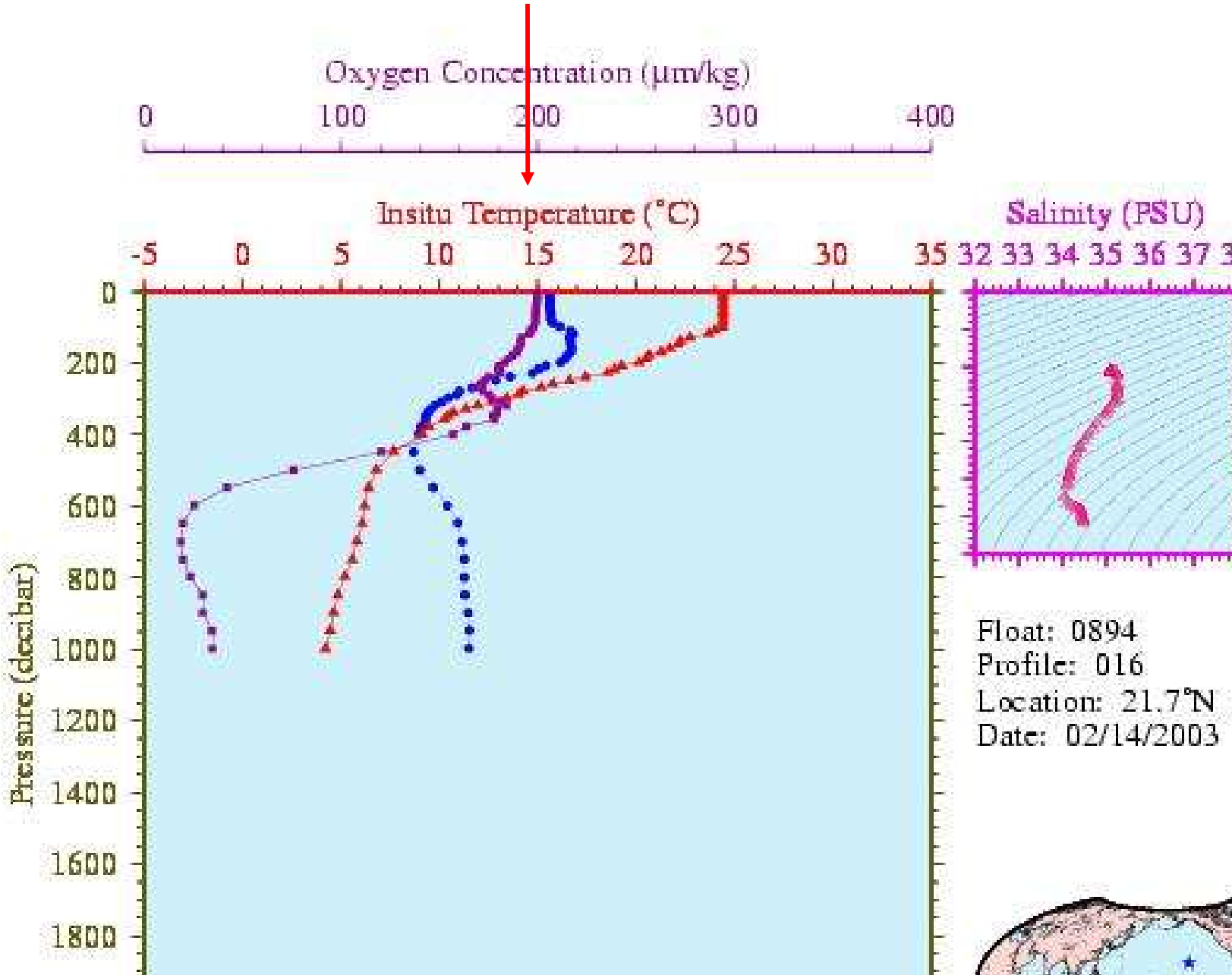
1400
1600
1800
Float: 0894
Profile: 011
Location: 21.8°N
Date: 12/23/2002

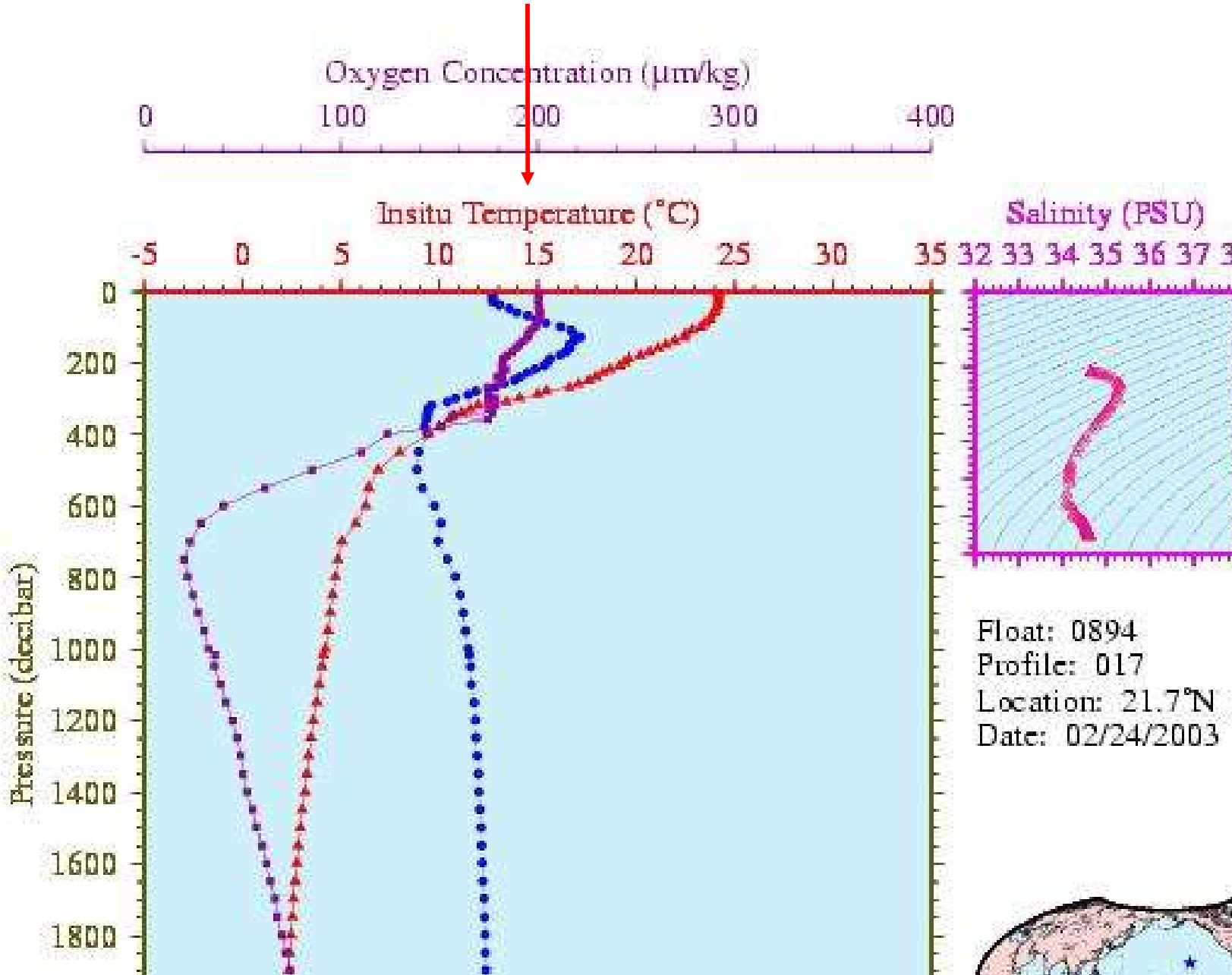

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 012
Location: 22.0°N
Date: 01/02/2003

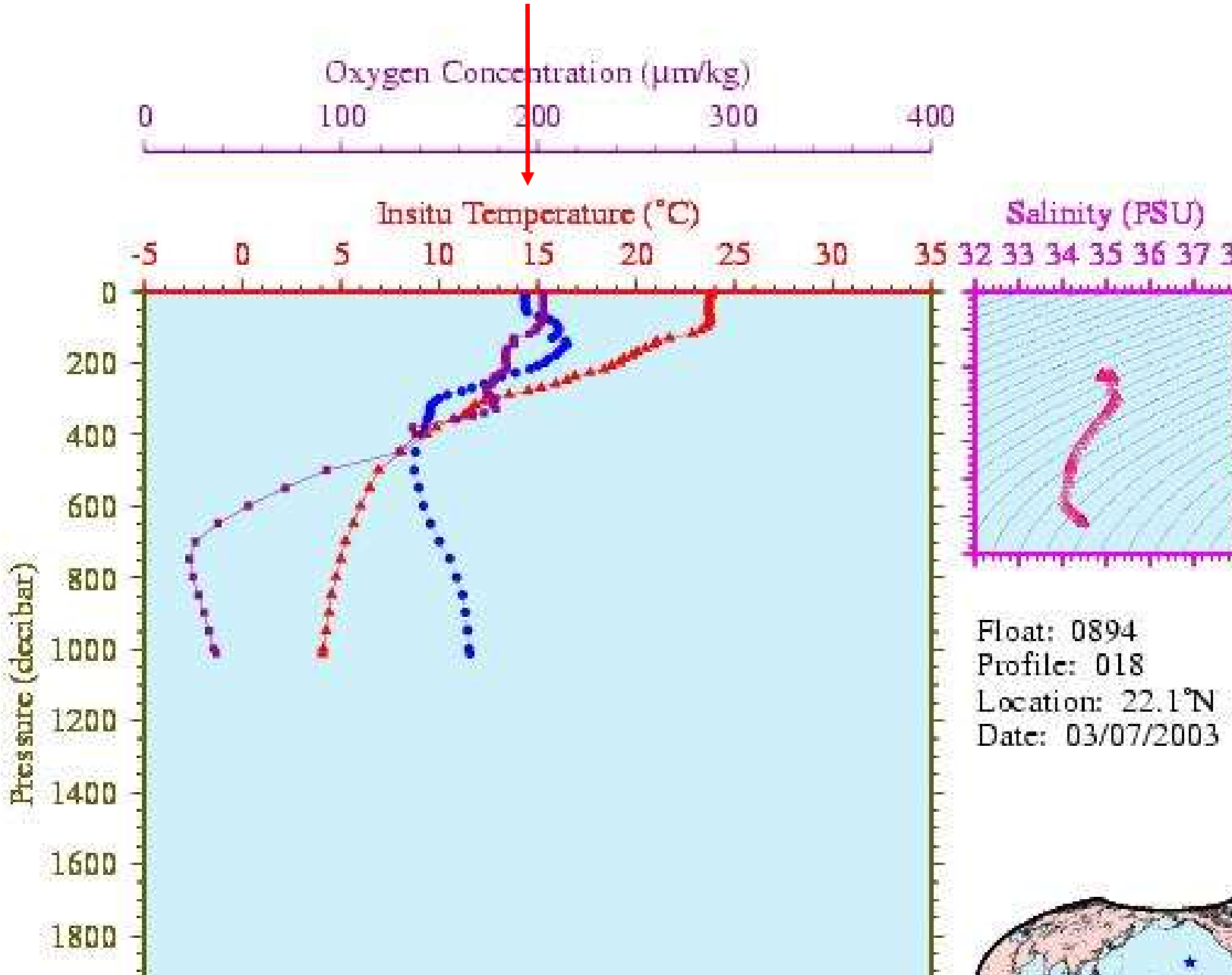

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 013
Location: 21.8°N
Date: 01/13/2003

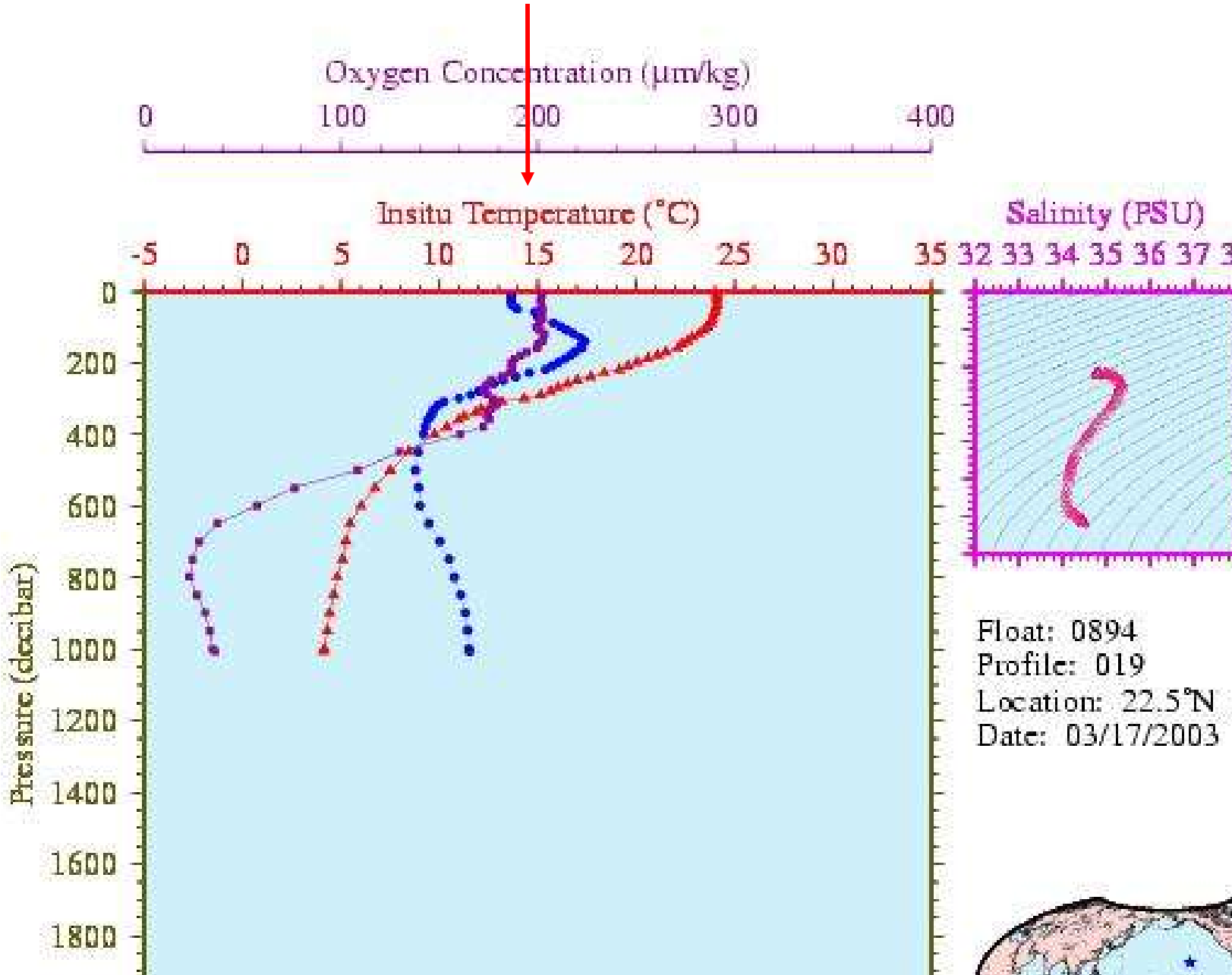

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 014
Location: 21.5°N
Date: 01/24/2003

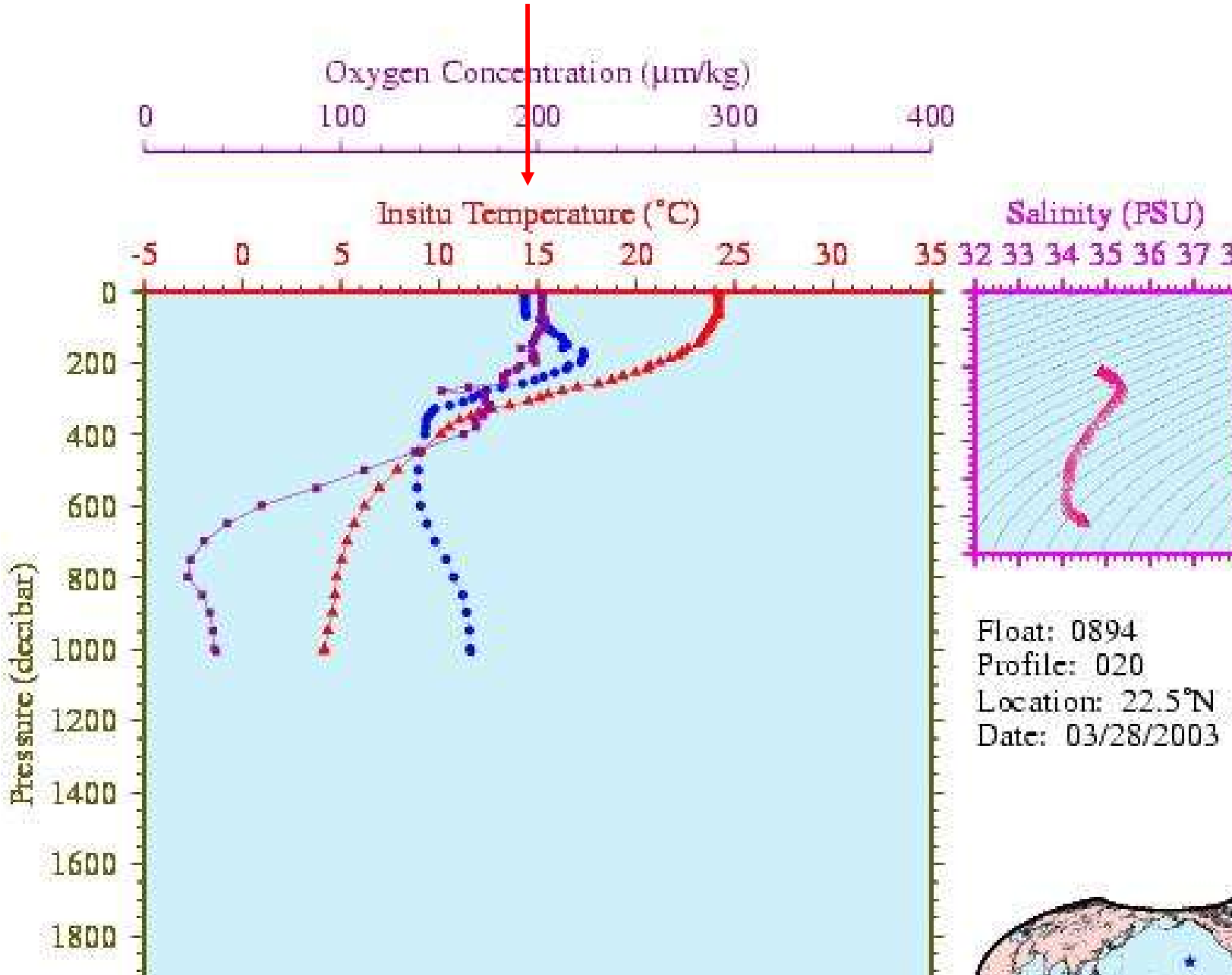

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 015
Location: 21.4°N
Date: 02/03/2003

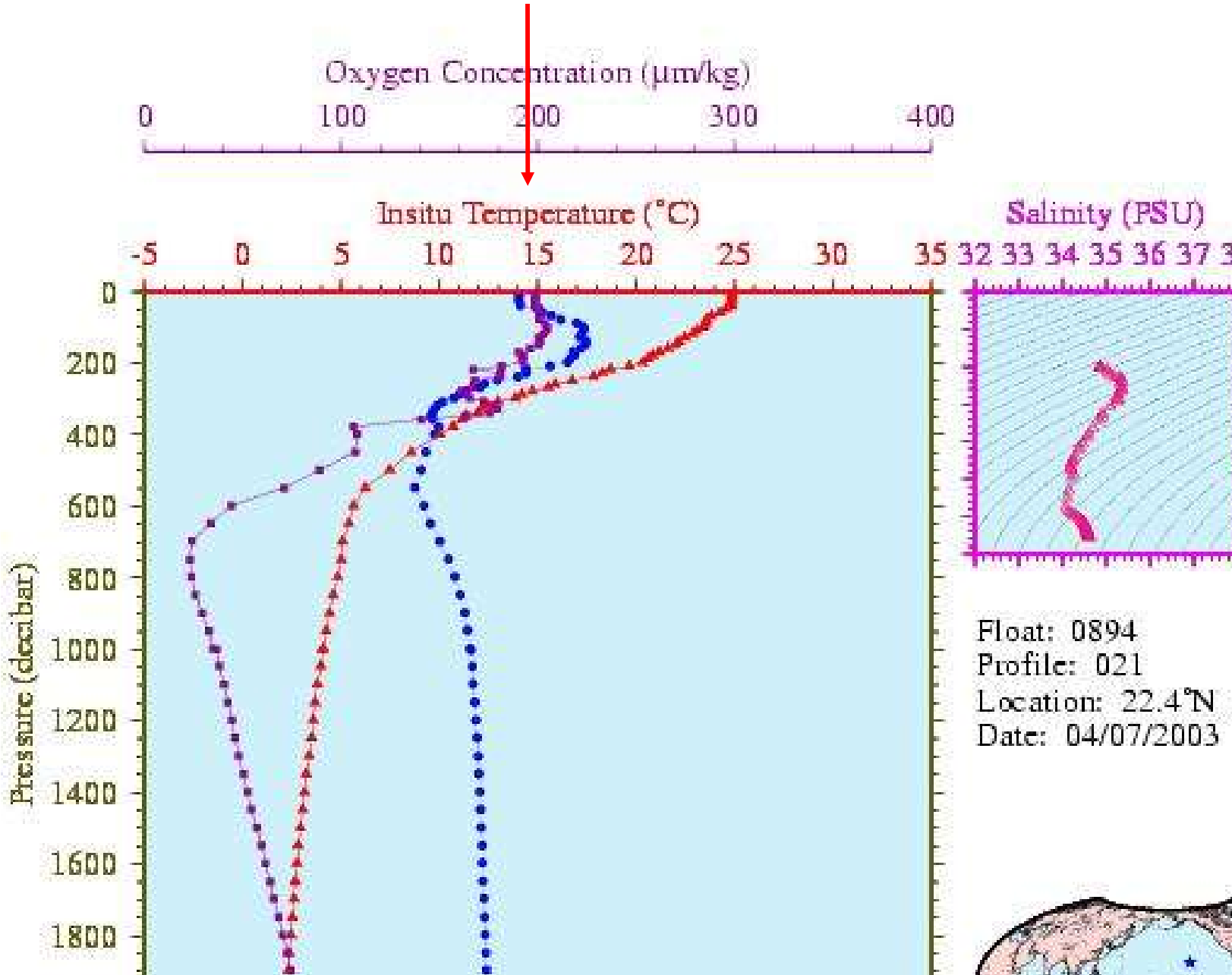

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 016
Location: 21.7°N
Date: 02/14/2003

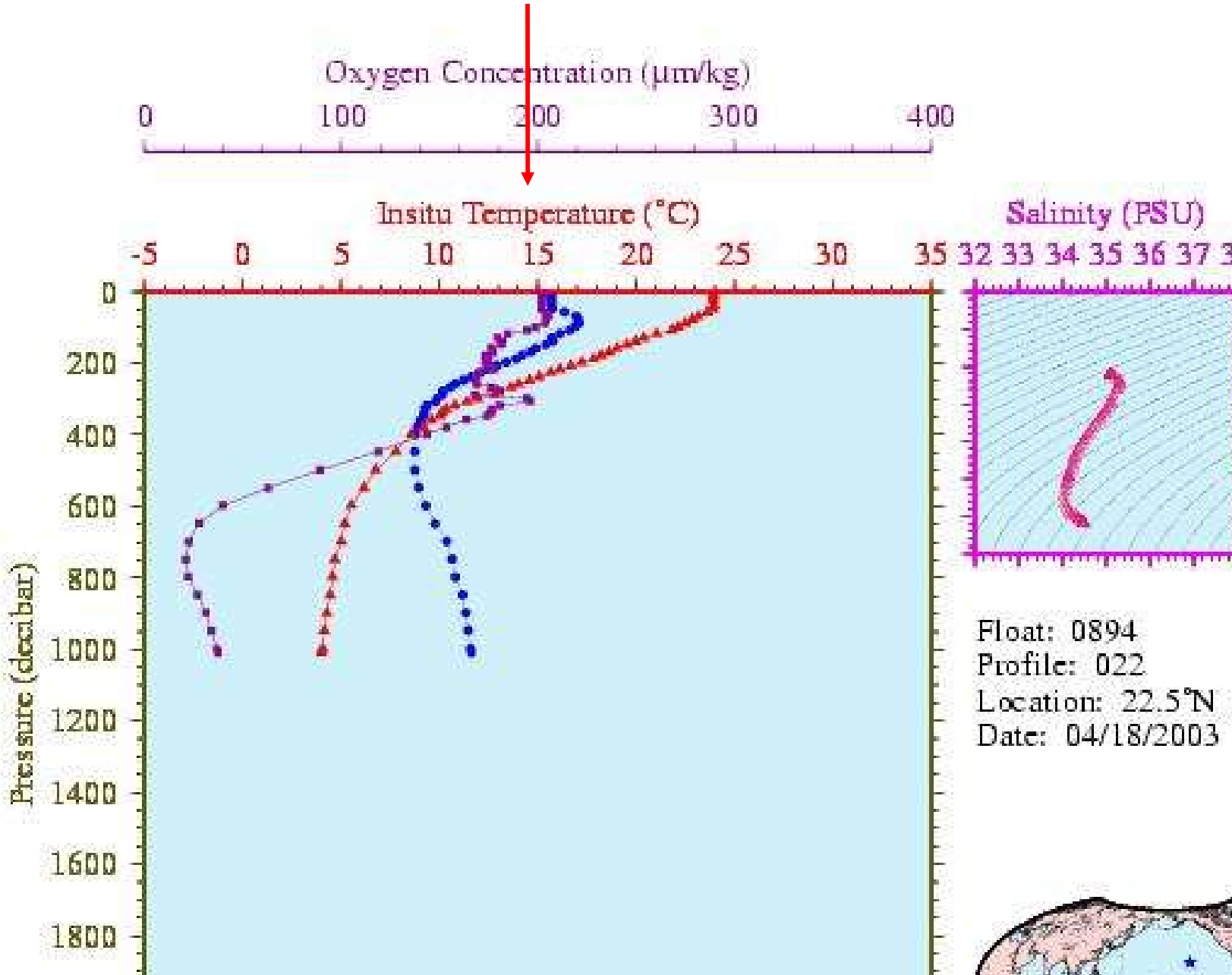

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 017
Location: 21.7°N
Date: 02/24/2003

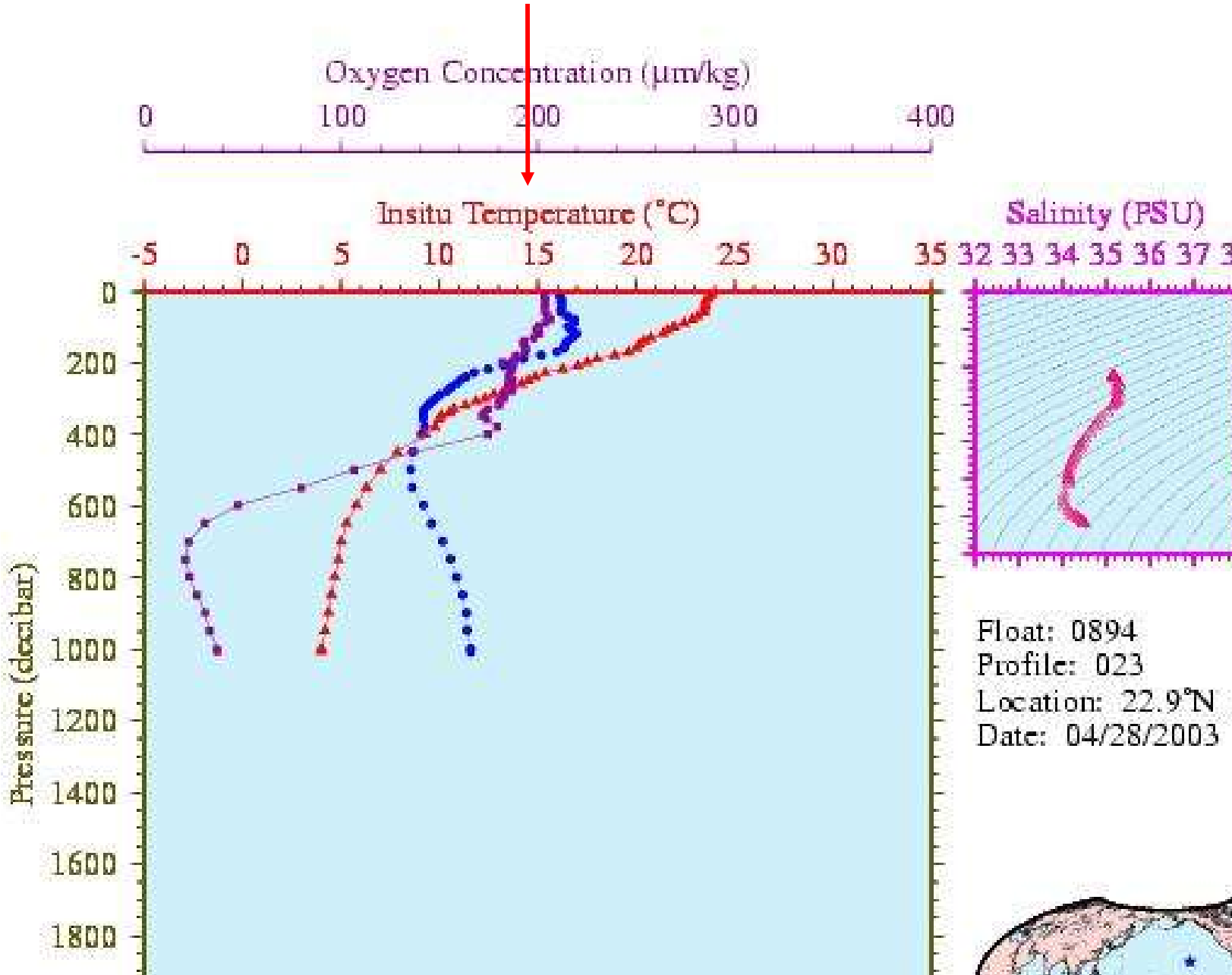

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 018
Location: 22.1°N
Date: 03/07/2003

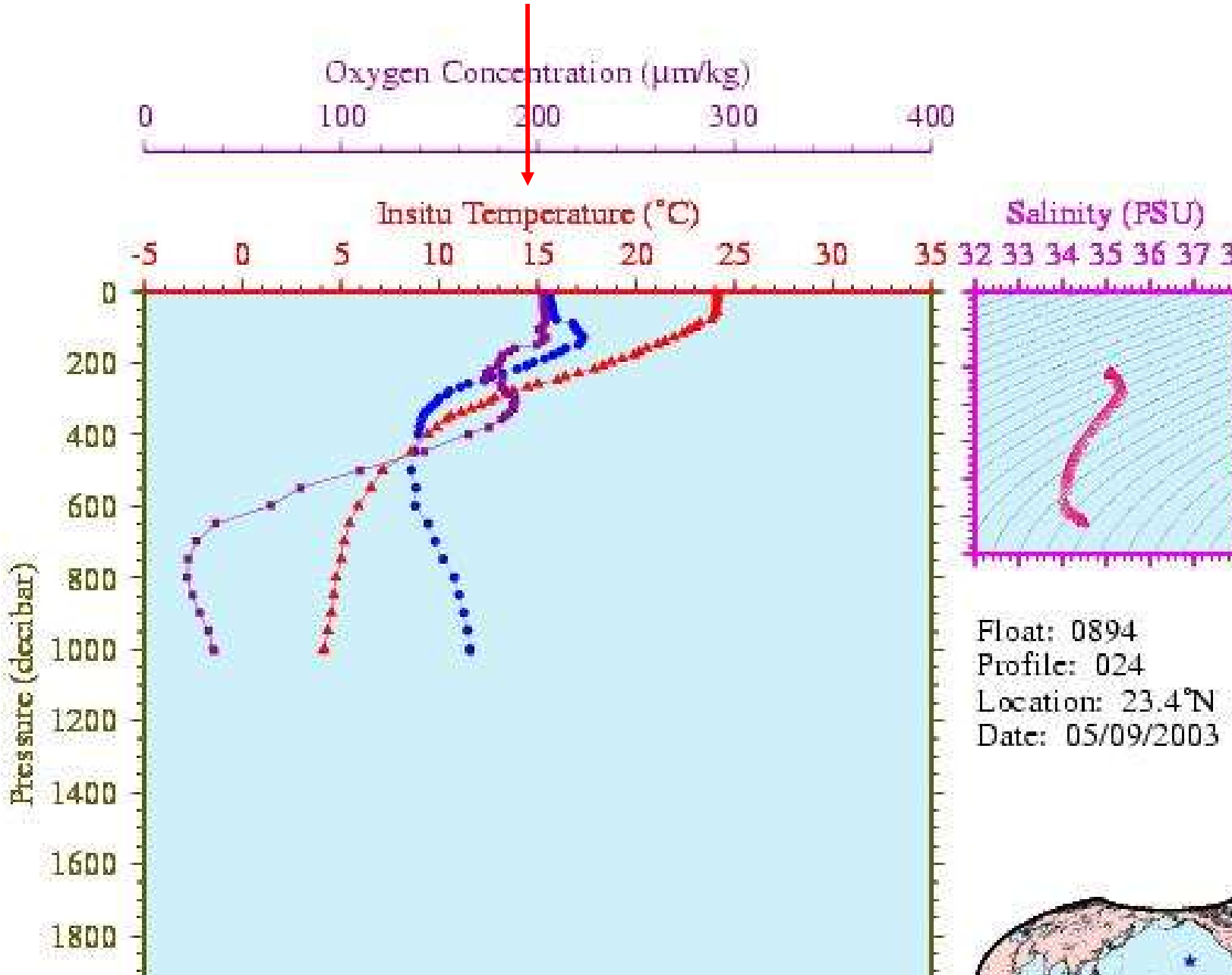

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 019
Location: 22.5°N
Date: 03/17/2003

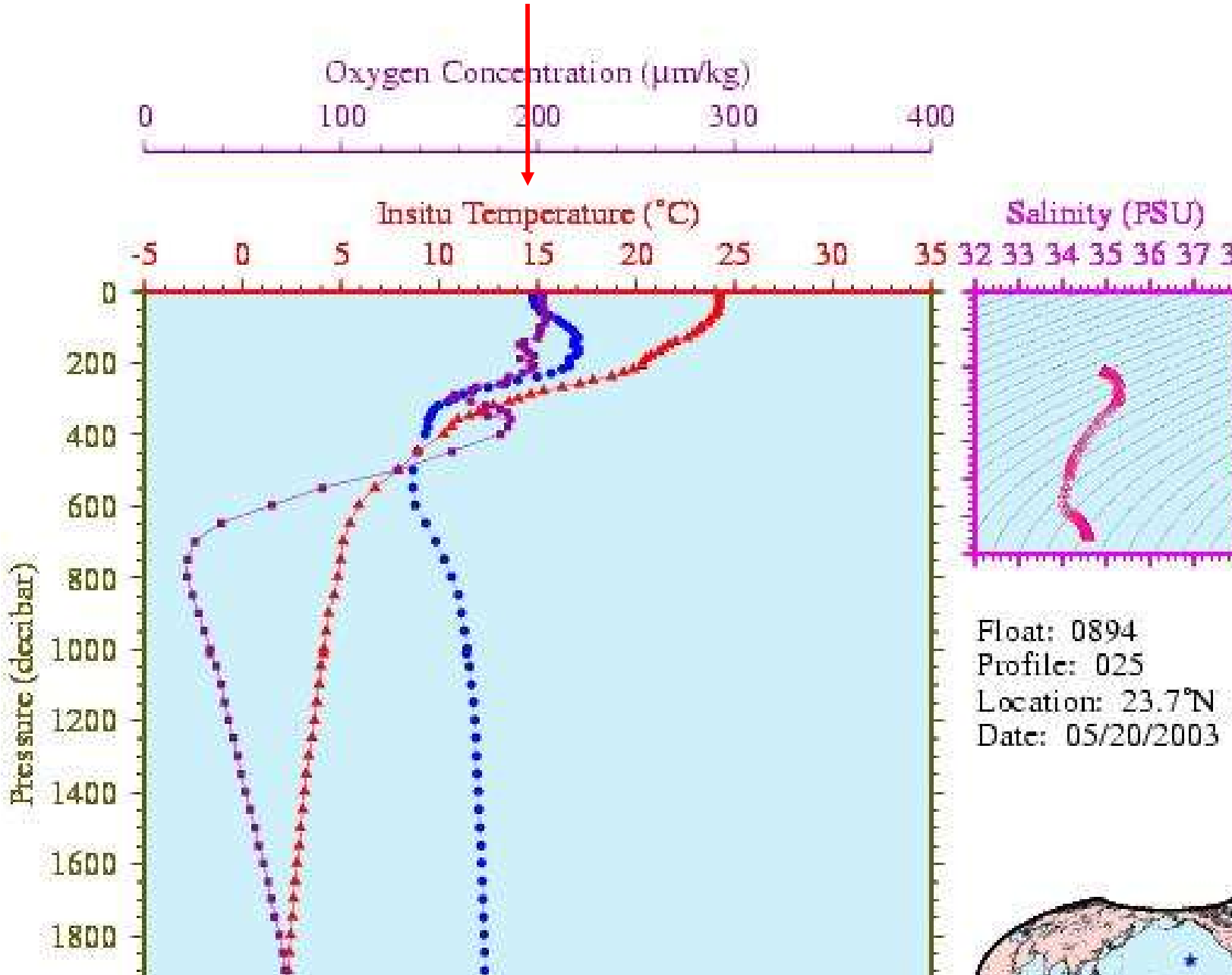

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 020
Location: 22.5°N
Date: 03/28/2003

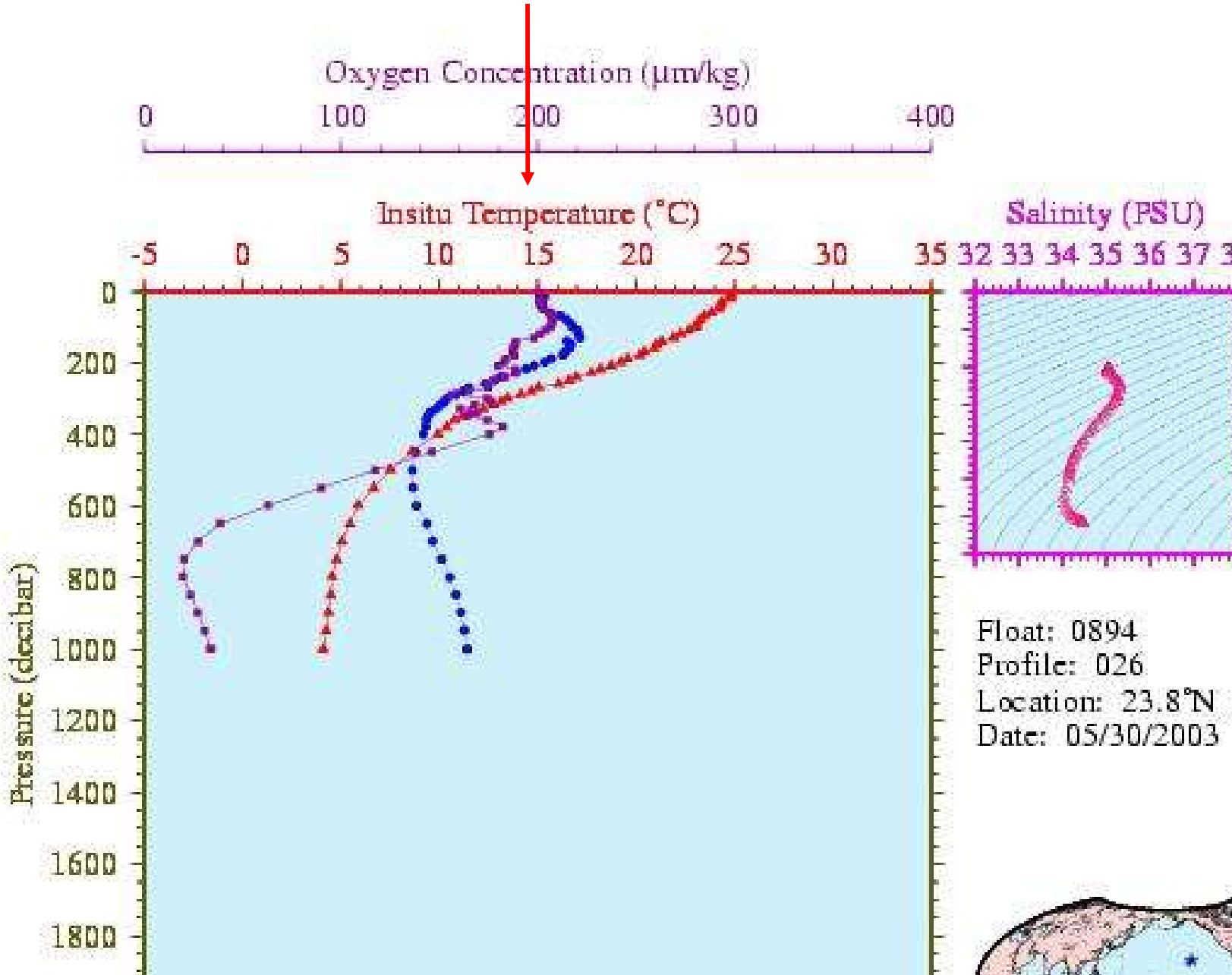

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 021
Location: 22.4°N
Date: 04/07/2003

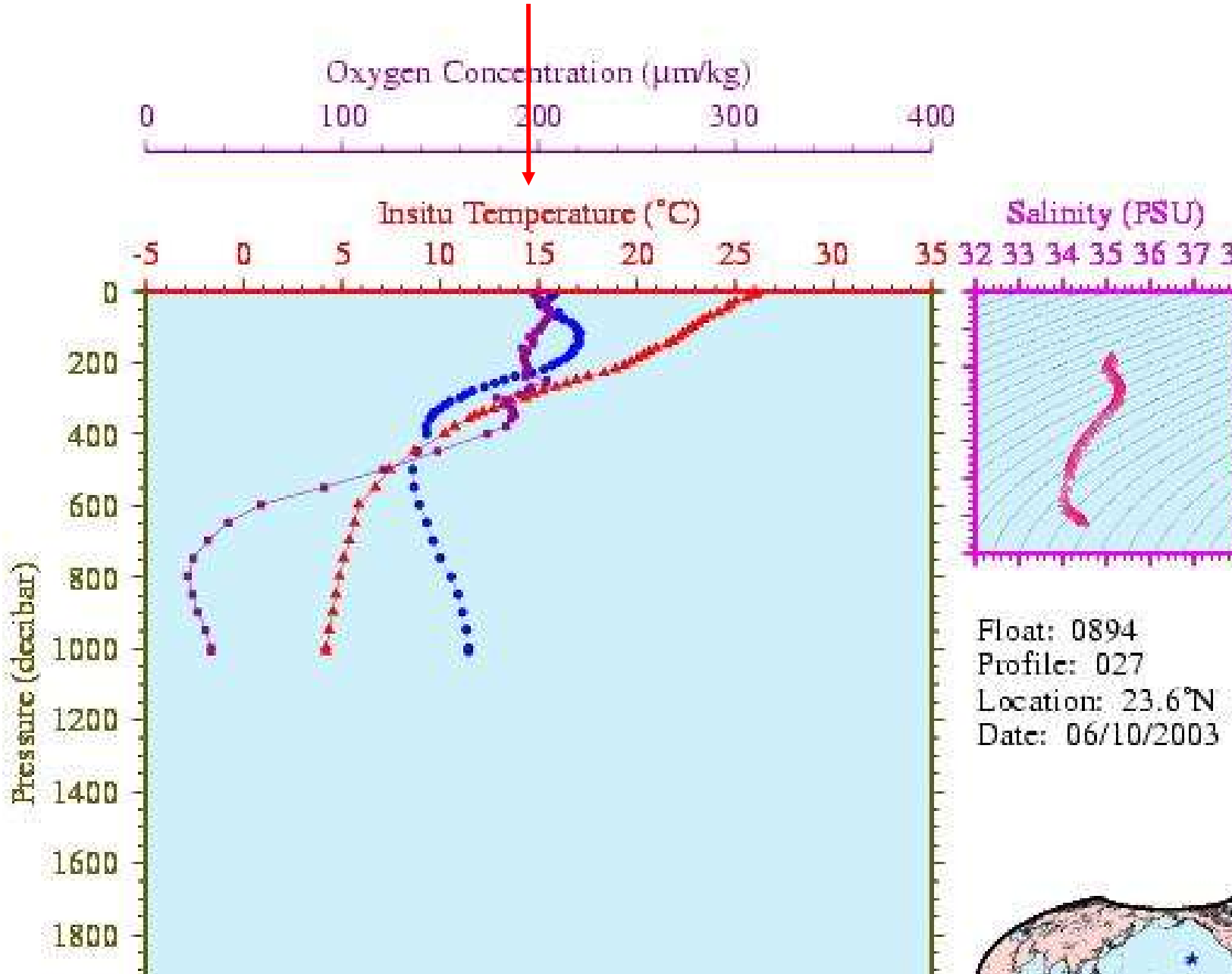

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 022
Location: 22.5°N
Date: 04/18/2003

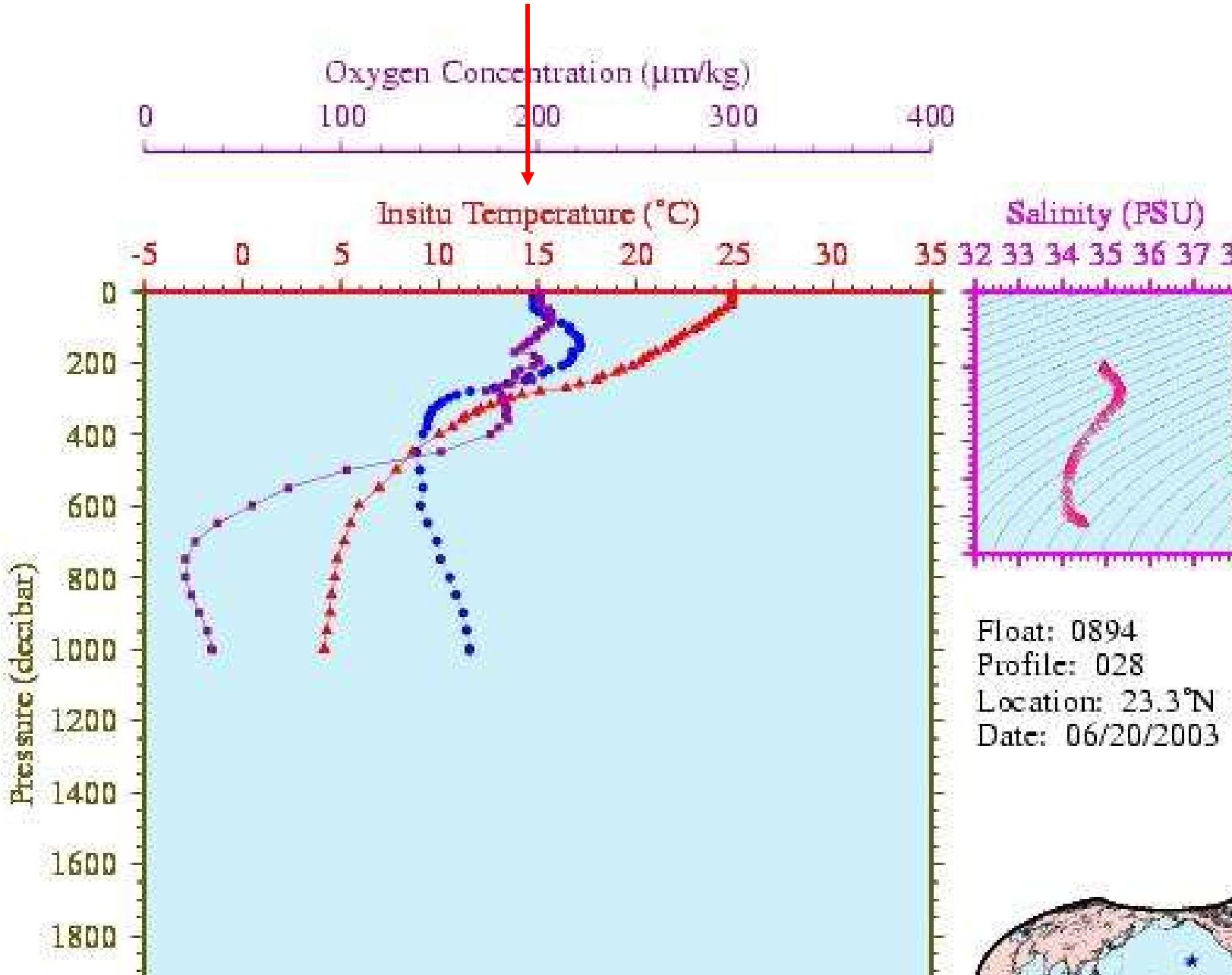

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 023
Location: 22.9°N
Date: 04/28/2003

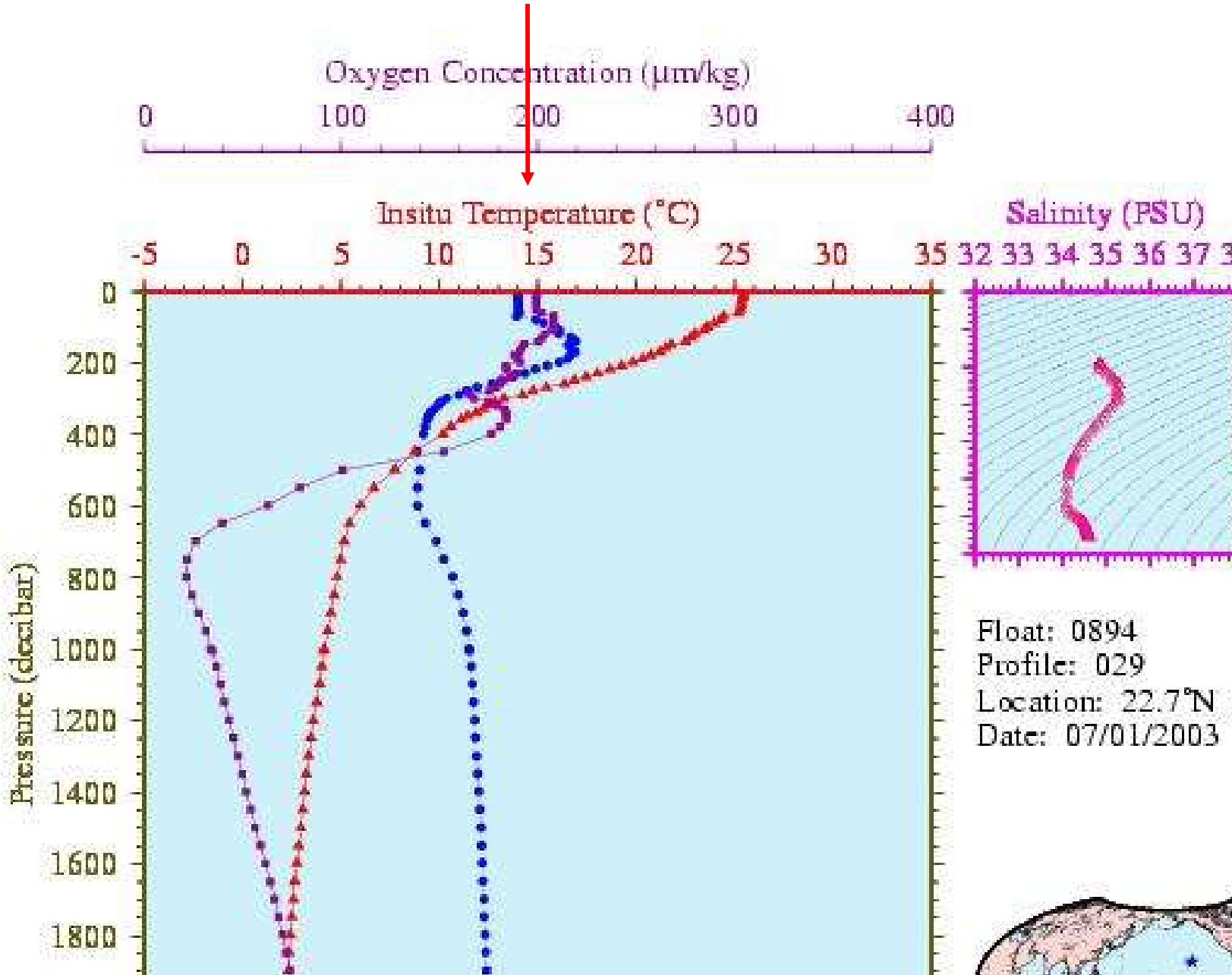

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 024
Location: 23.4°N
Date: 05/09/2003

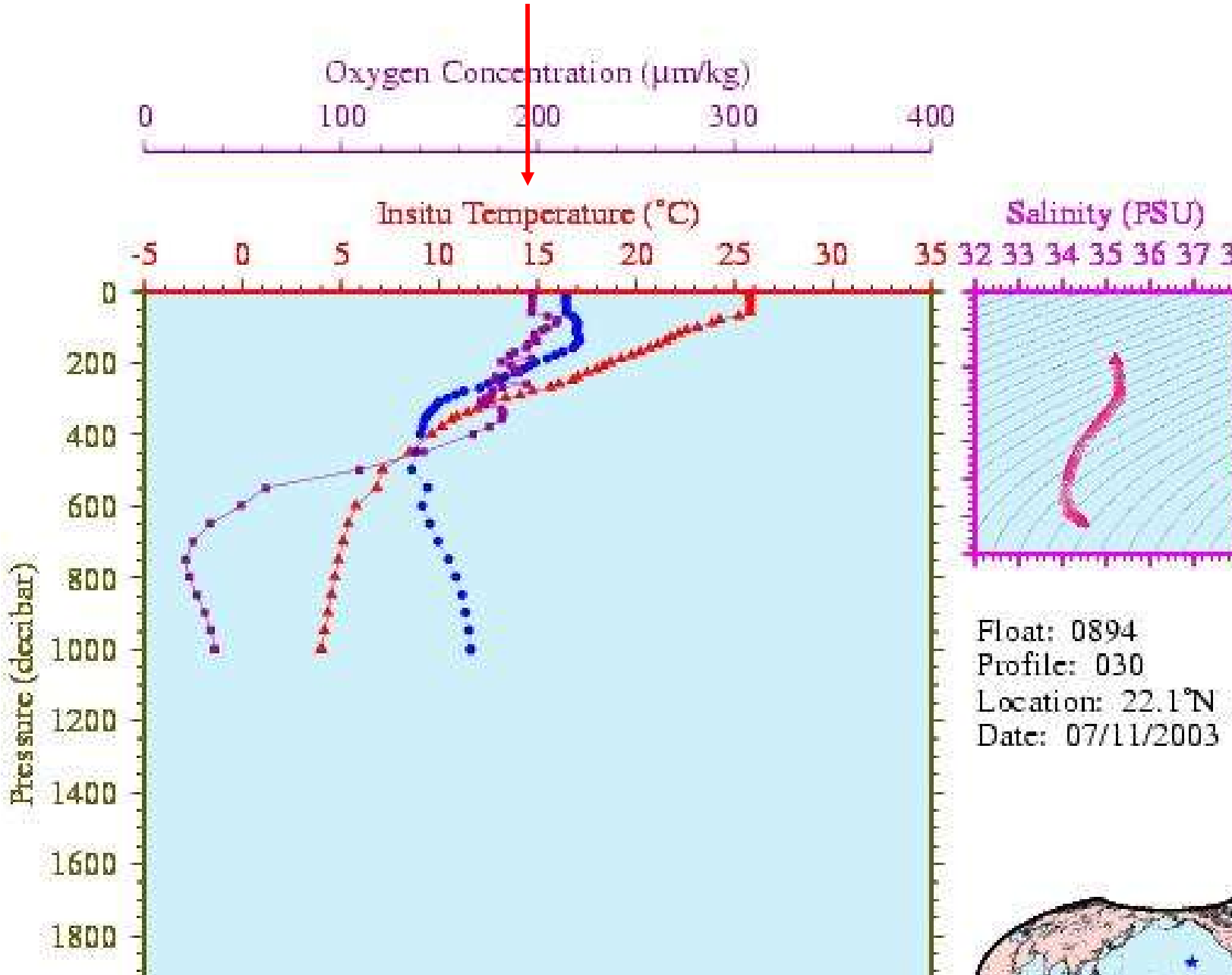

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 025
Location: 23.7°N
Date: 05/20/2003

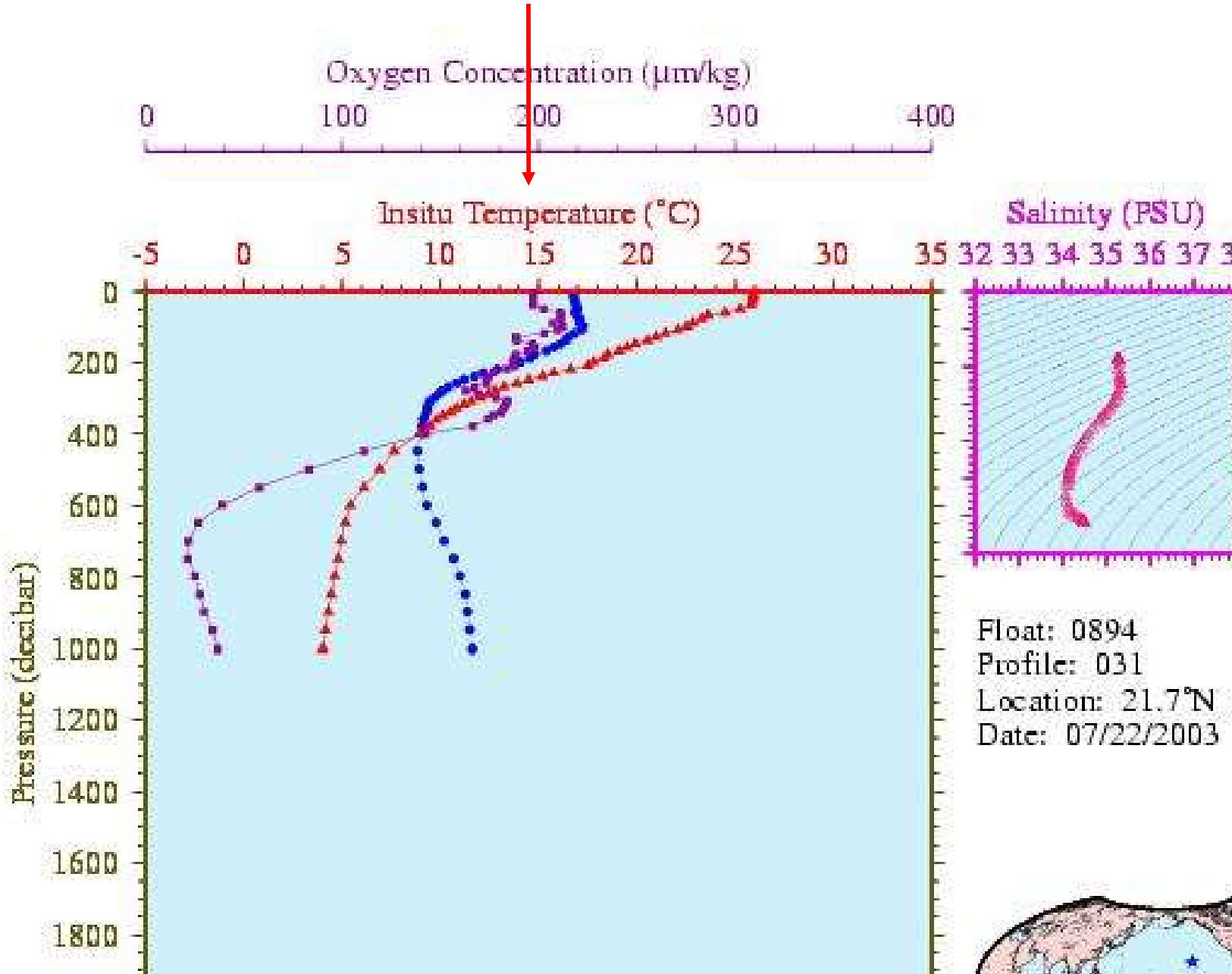

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 026
Location: 23.8°N
Date: 05/30/2003

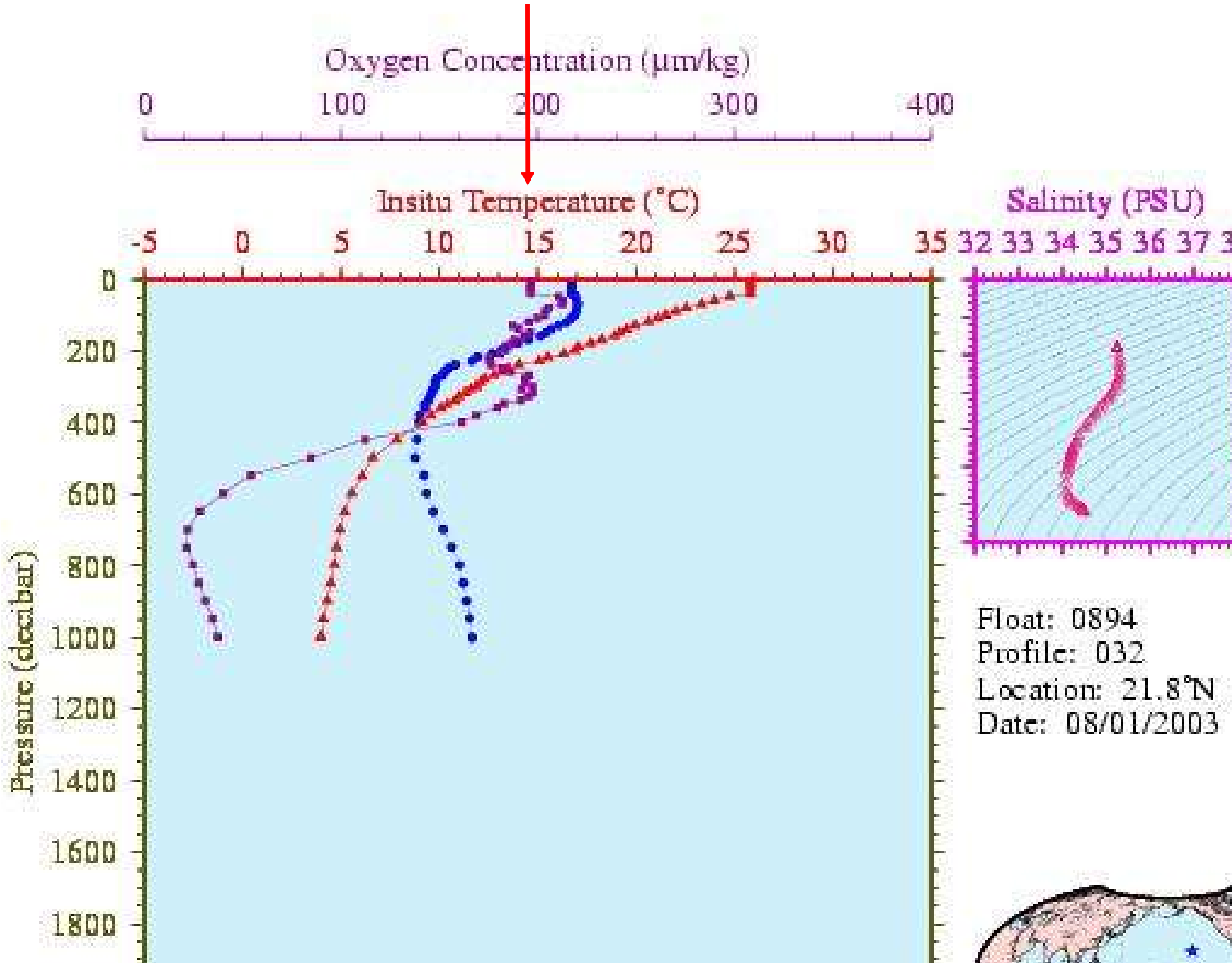

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 027
Location: 23.6°N
Date: 06/10/2003

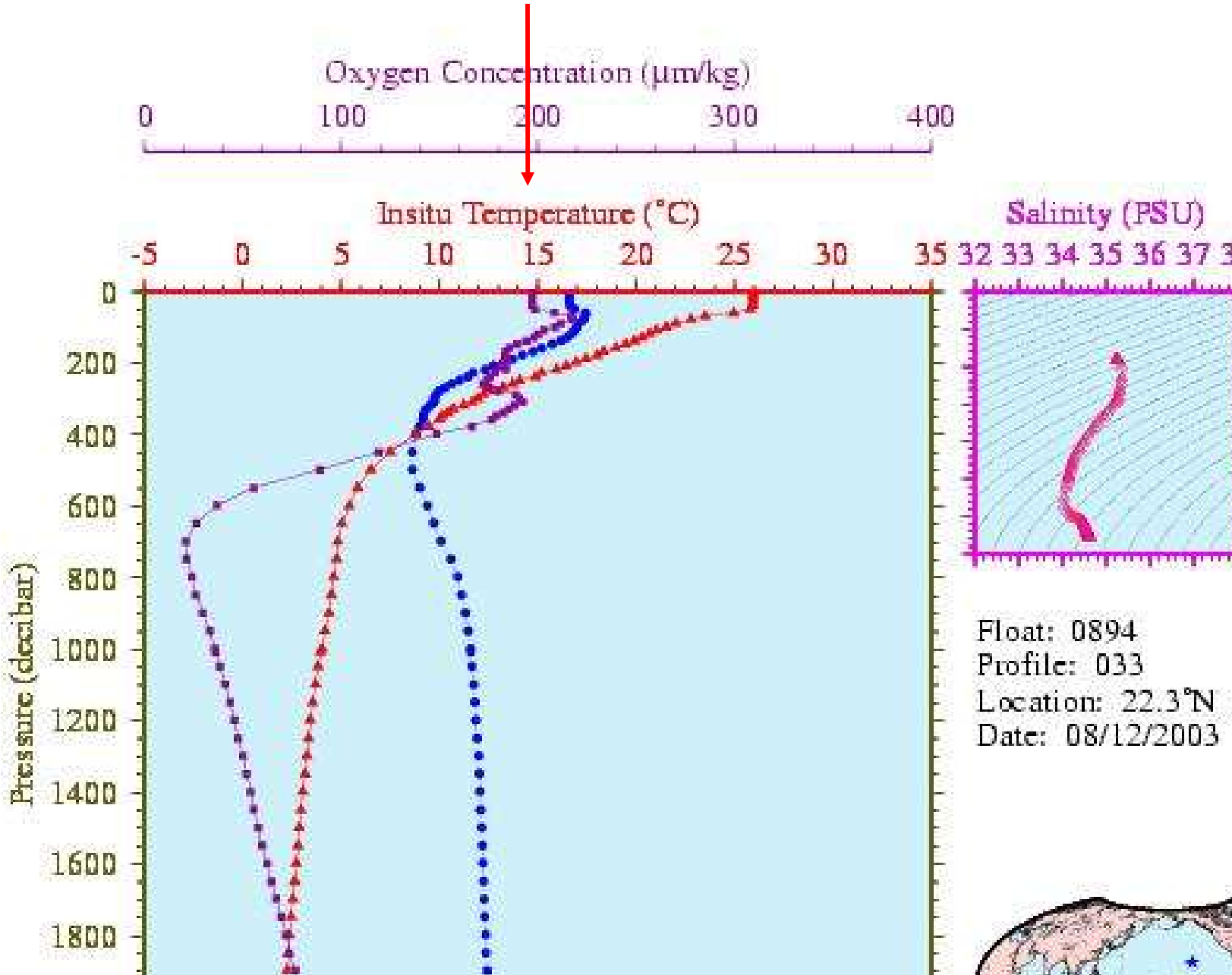

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 028
Location: 23.3°N
Date: 06/20/2003

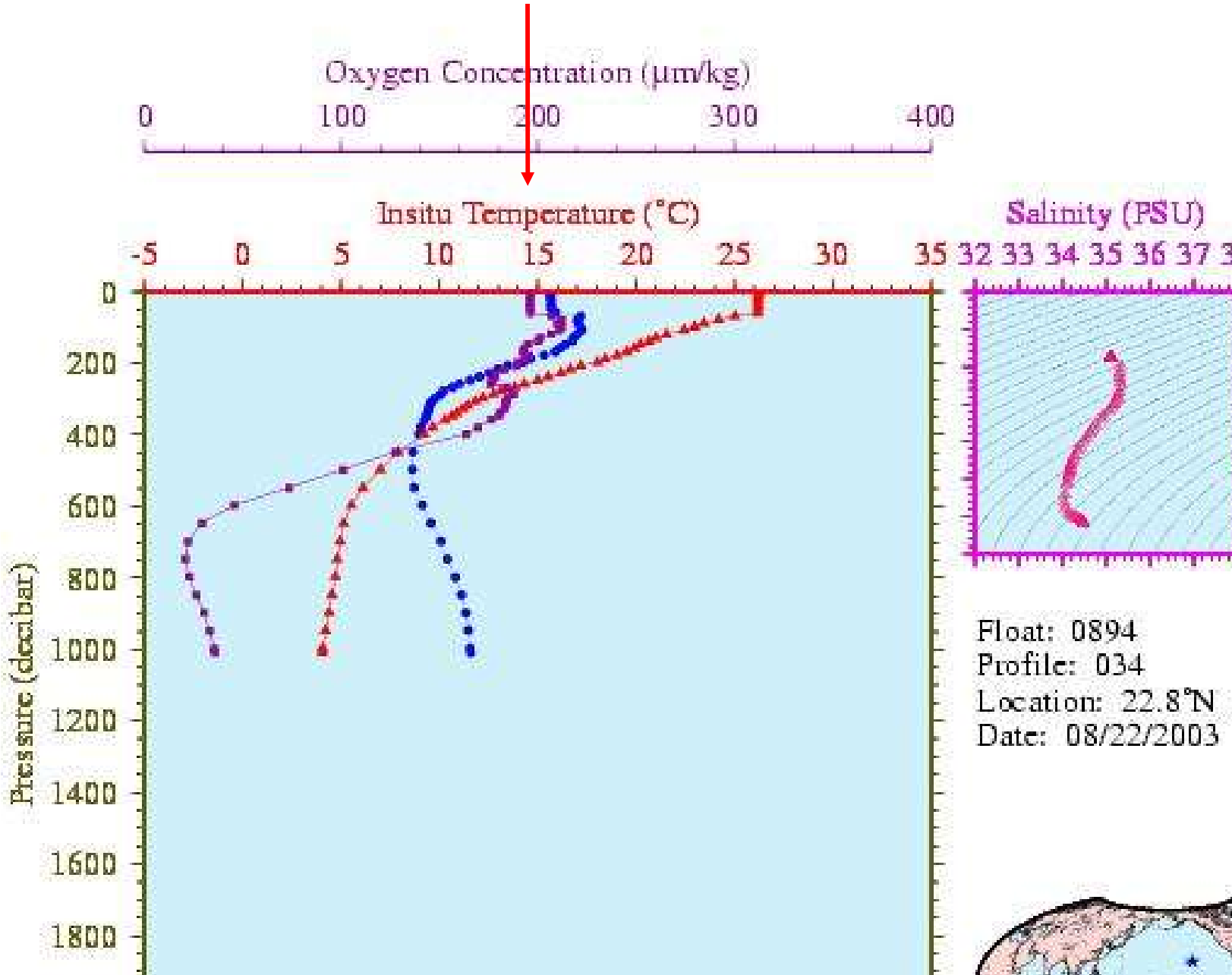

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 029
Location: 22.7°N
Date: 07/01/2003

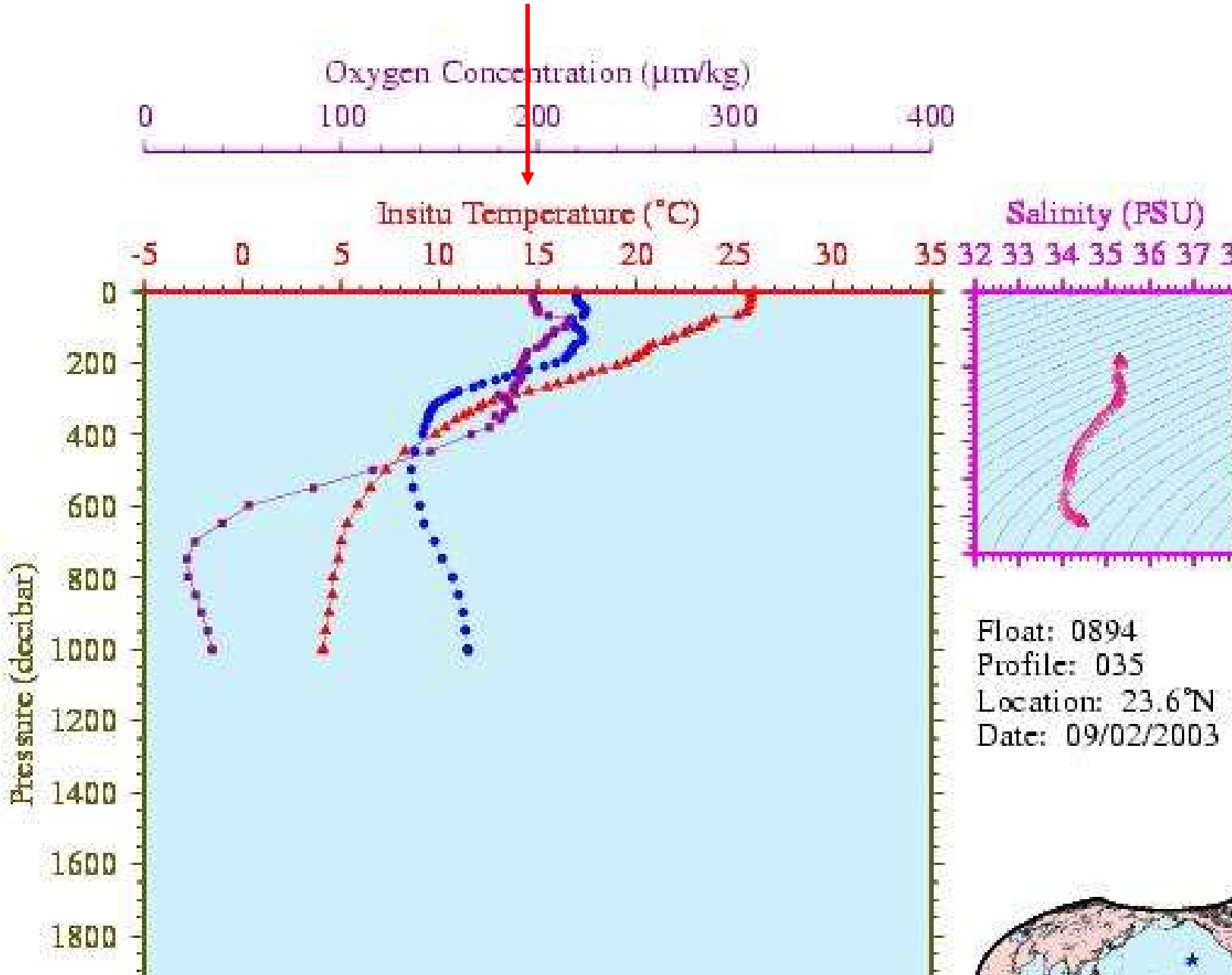

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 030
Location: 22.1°N
Date: 07/11/2003

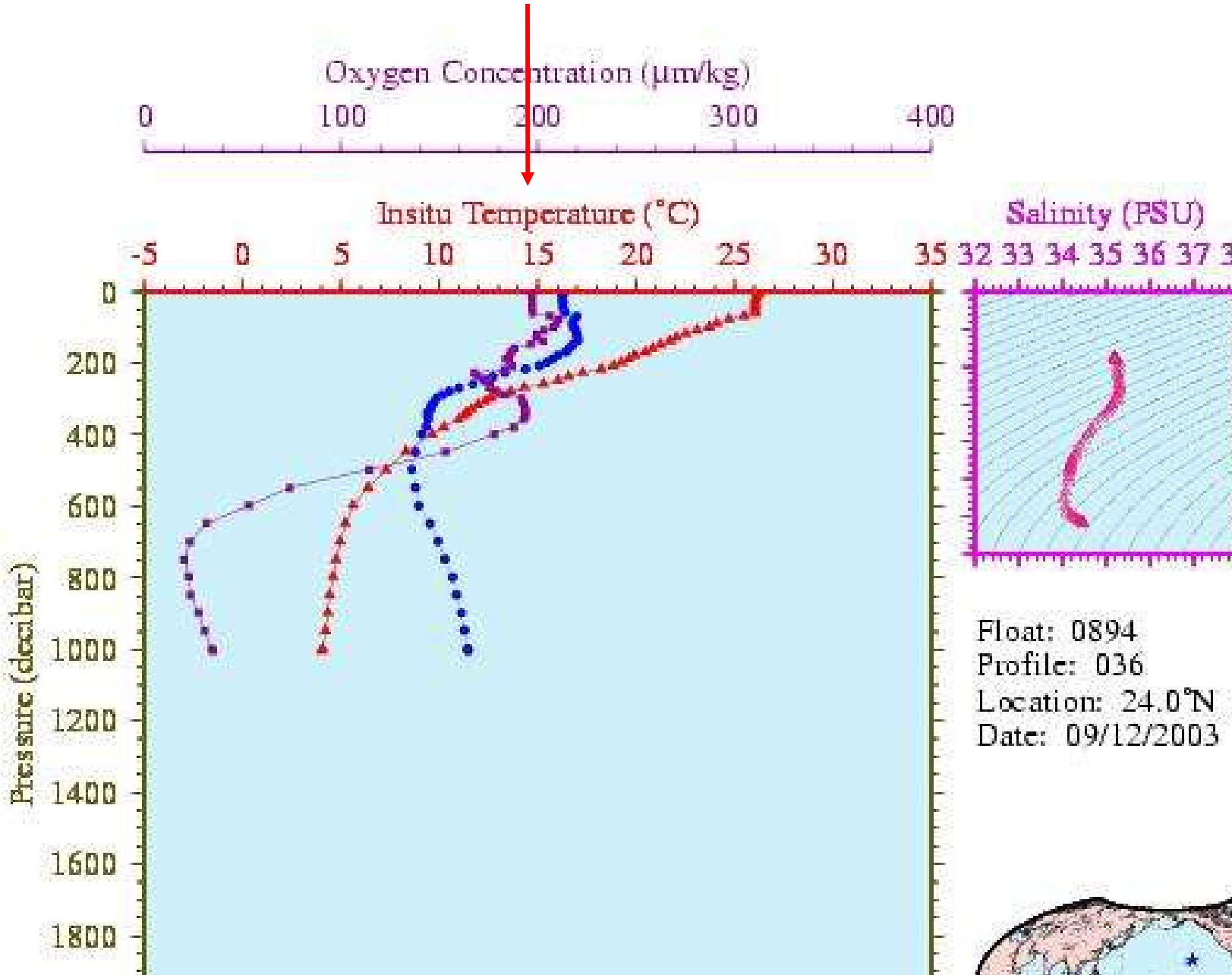

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 031
Location: 21.7°N
Date: 07/22/2003

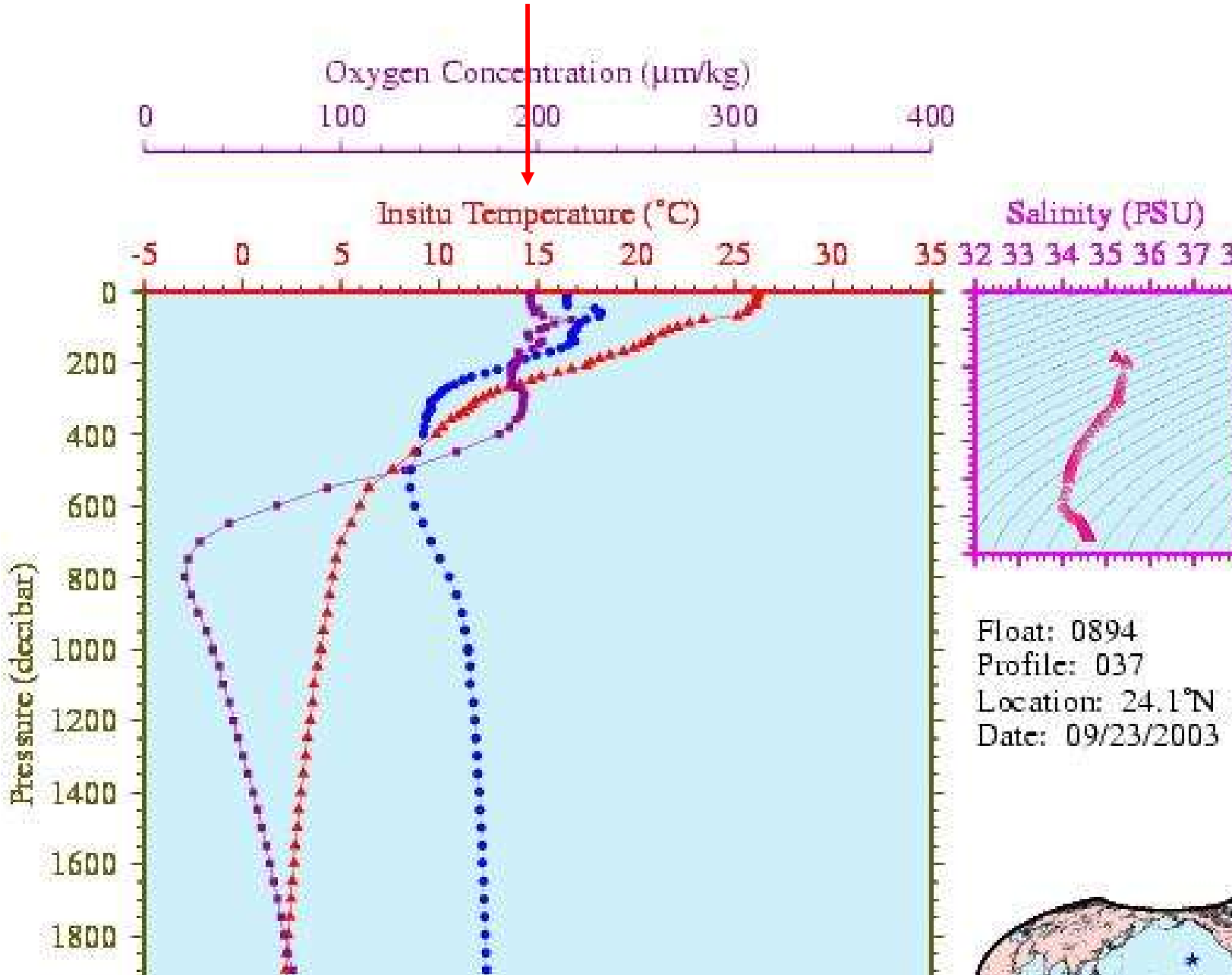

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 032
Location: 21.8°N
Date: 08/01/2003

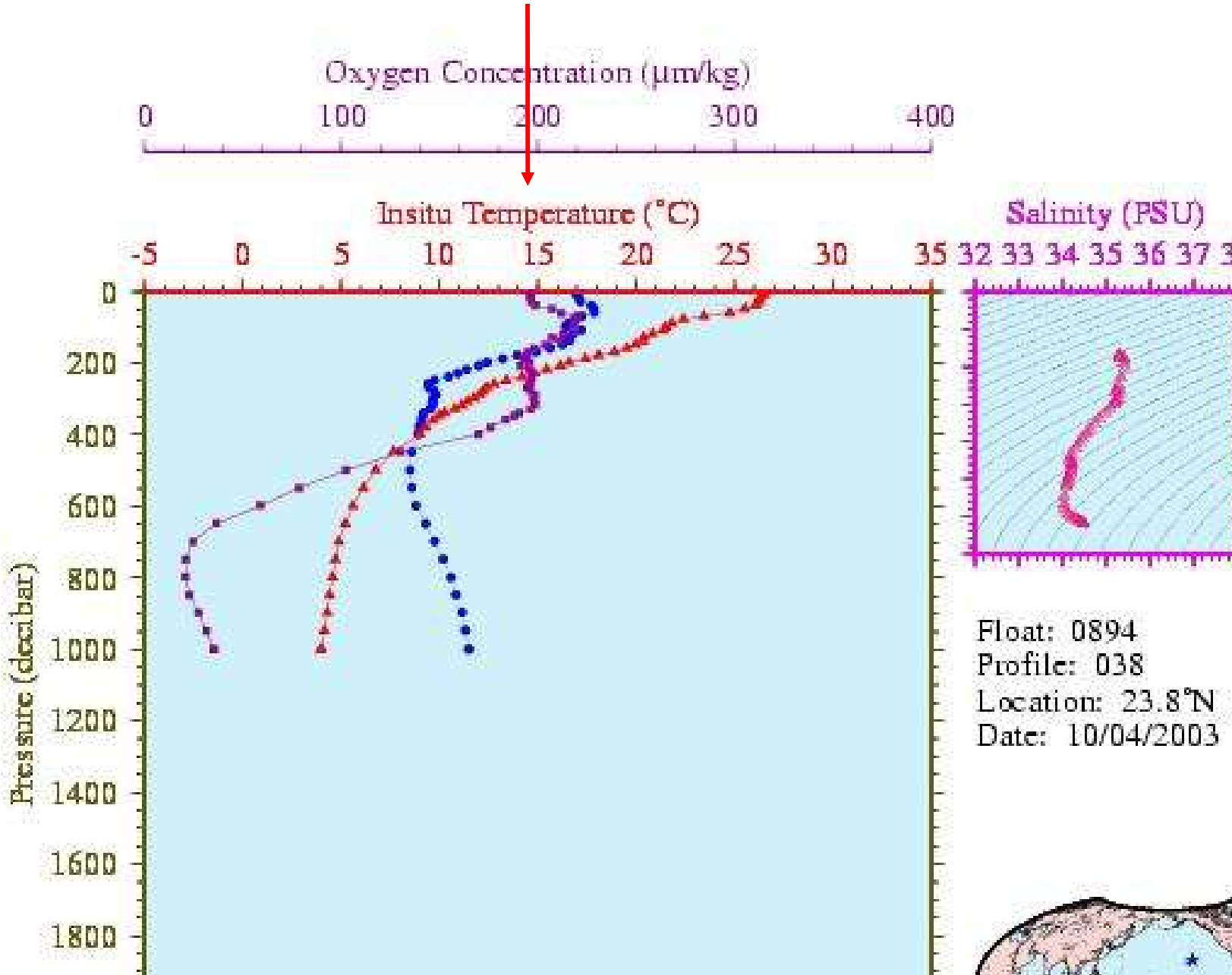

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 033
Location: 22.3°N
Date: 08/12/2003

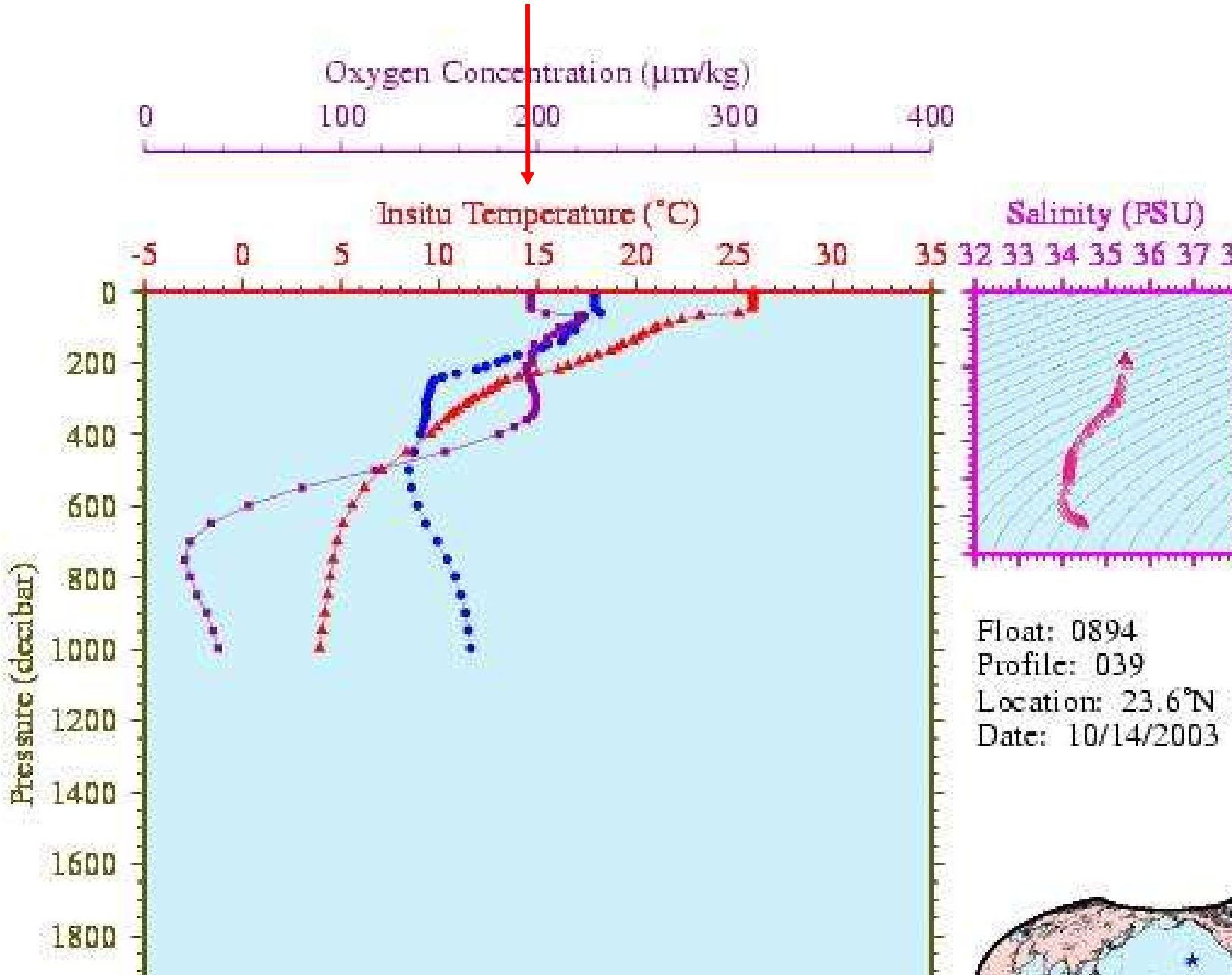

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 034
Location: 22.8°N
Date: 08/22/2003

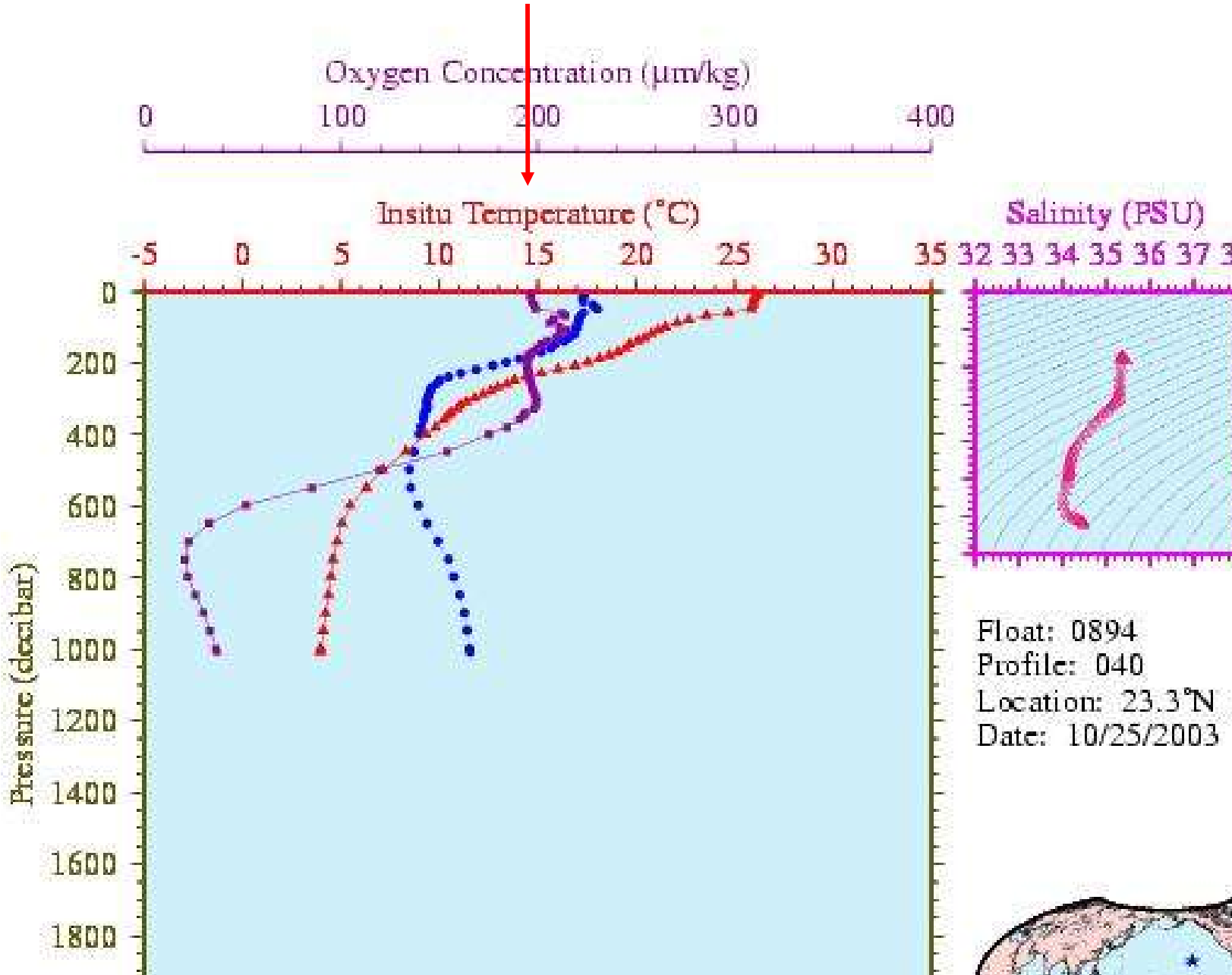

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 035
Location: 23.6°N
Date: 09/02/2003

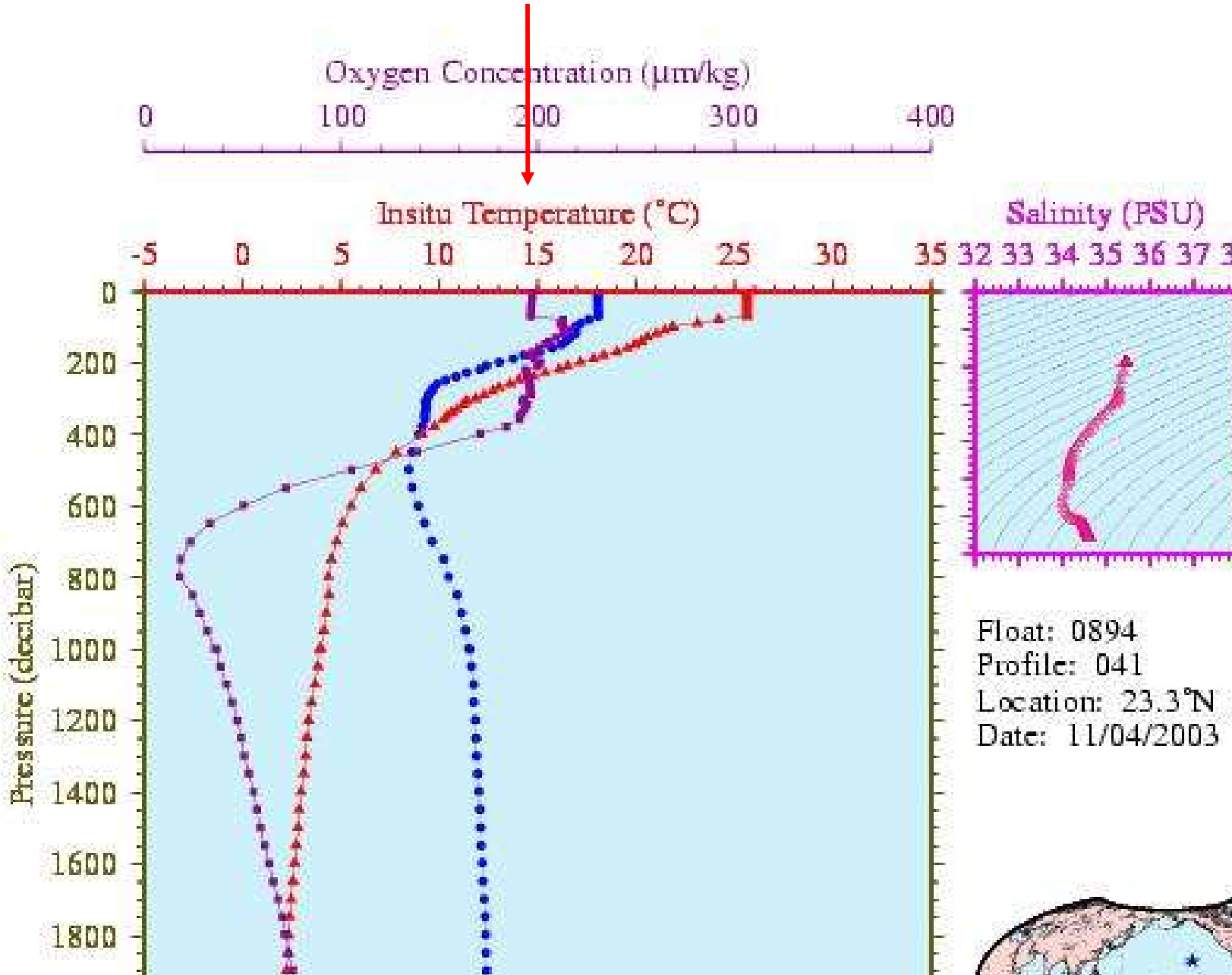

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 036
Location: 24.0°N
Date: 09/12/2003

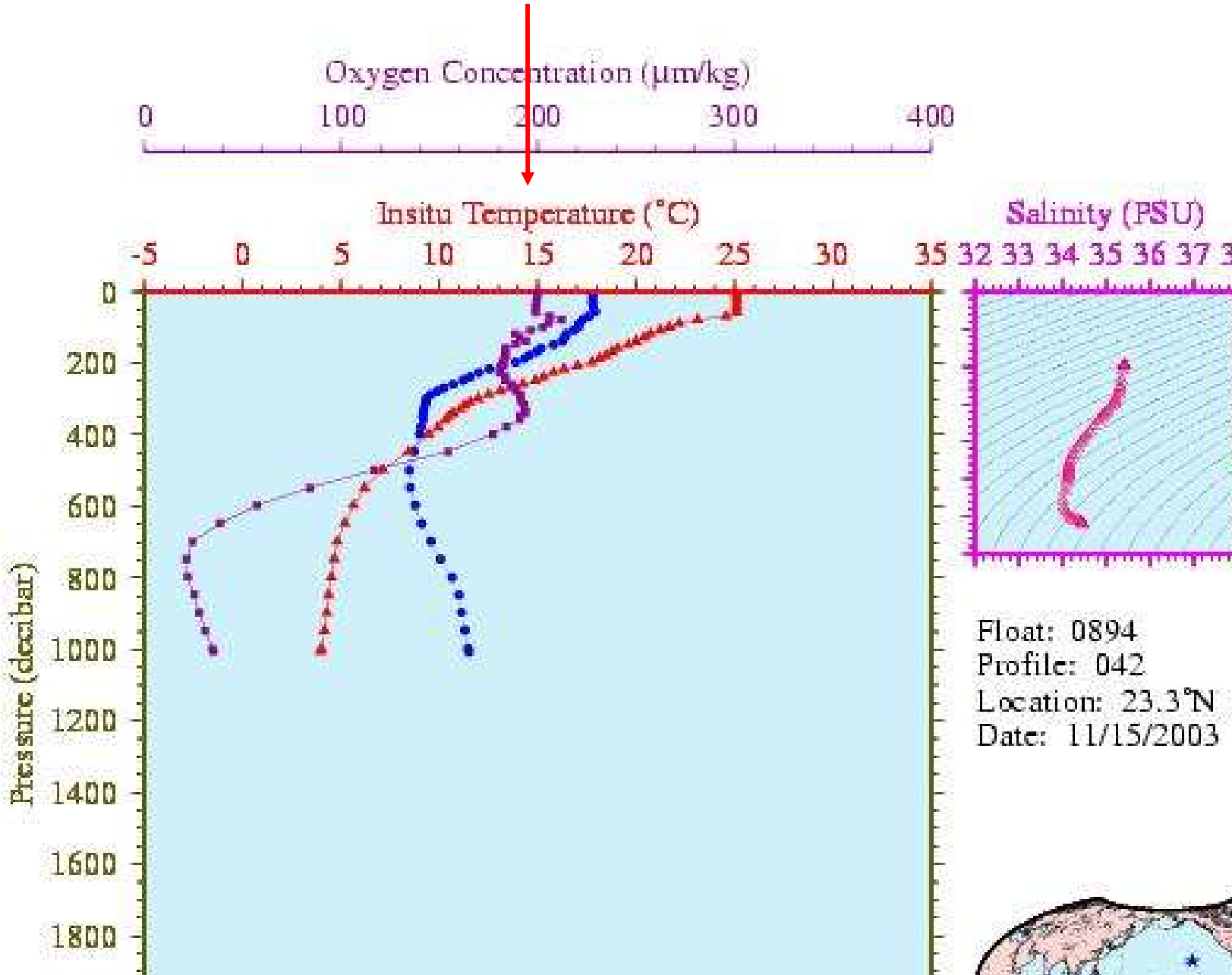

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 037
Location: 24.1°N
Date: 09/23/2003

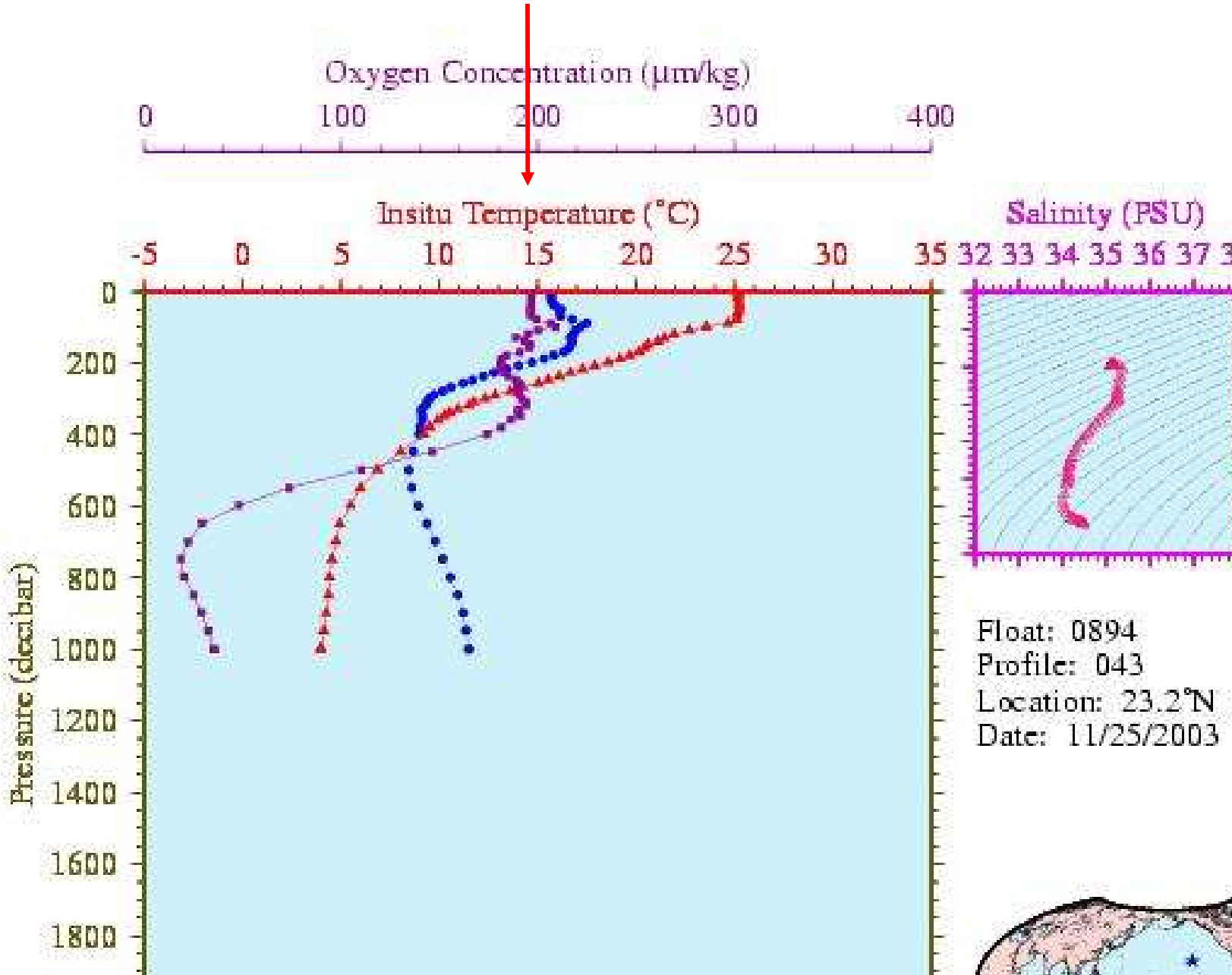

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 038
Location: 23.8°N
Date: 10/04/2003

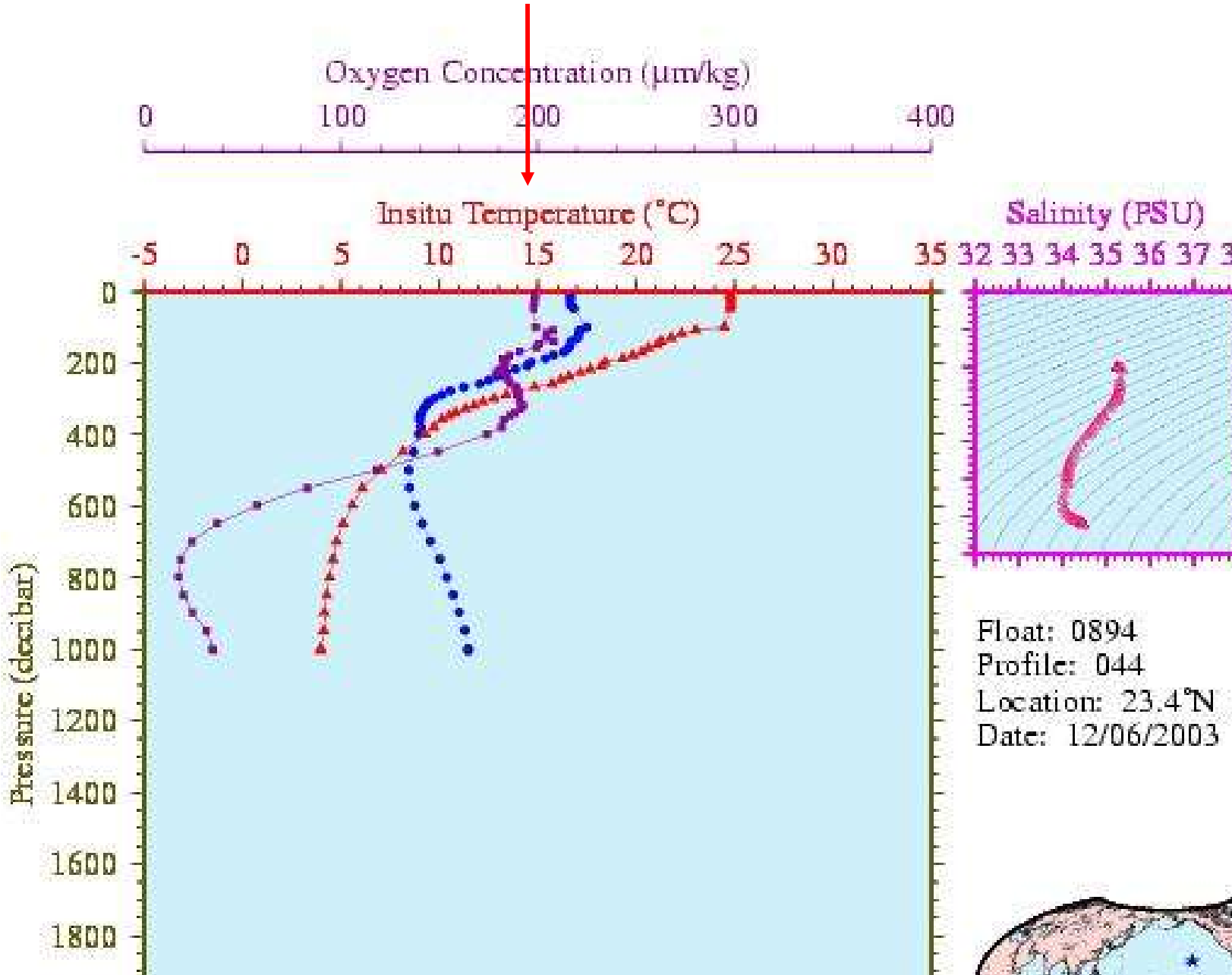

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 039
Location: 23.6°N
Date: 10/14/2003

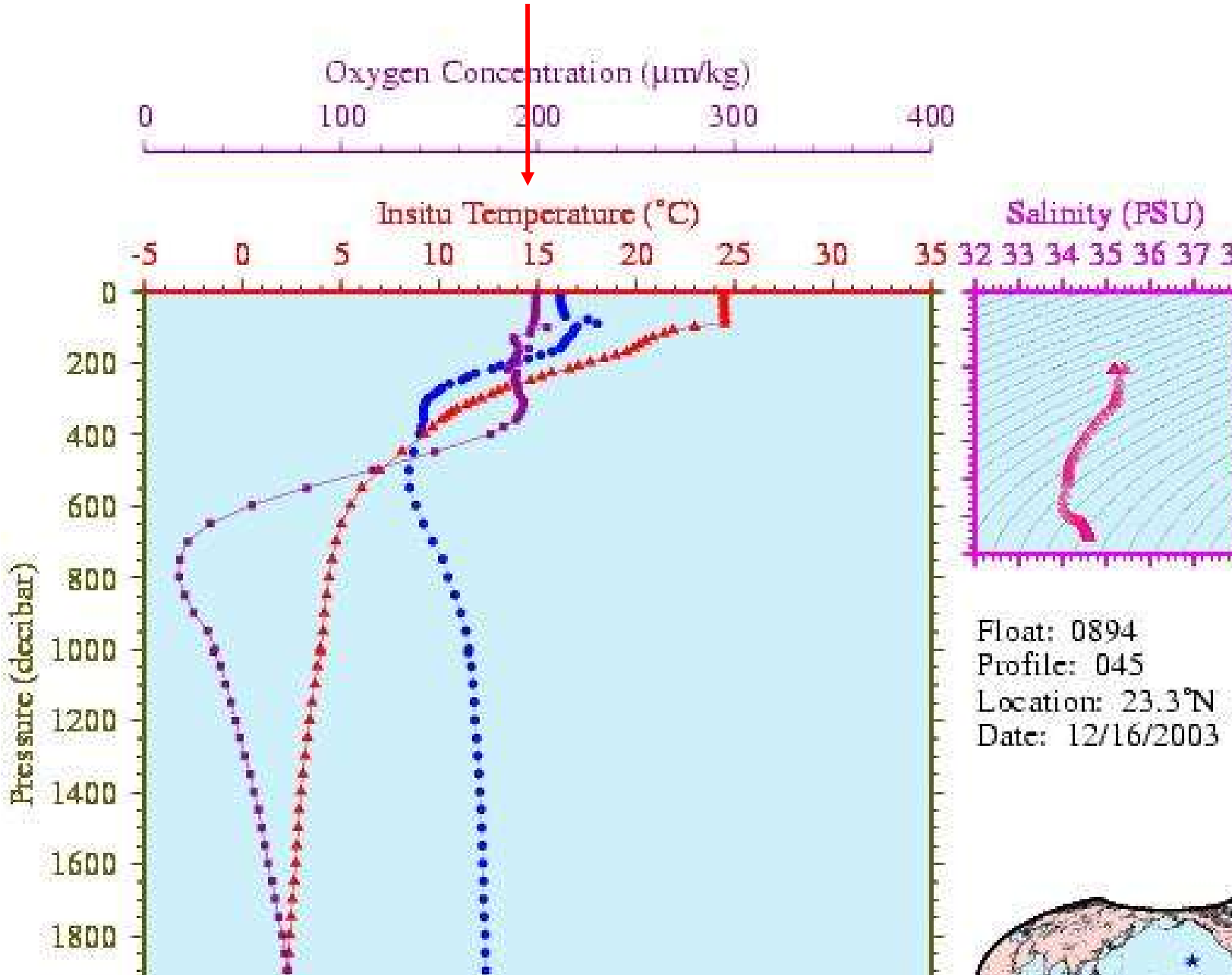

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 040
Location: 23.3°N
Date: 10/25/2003

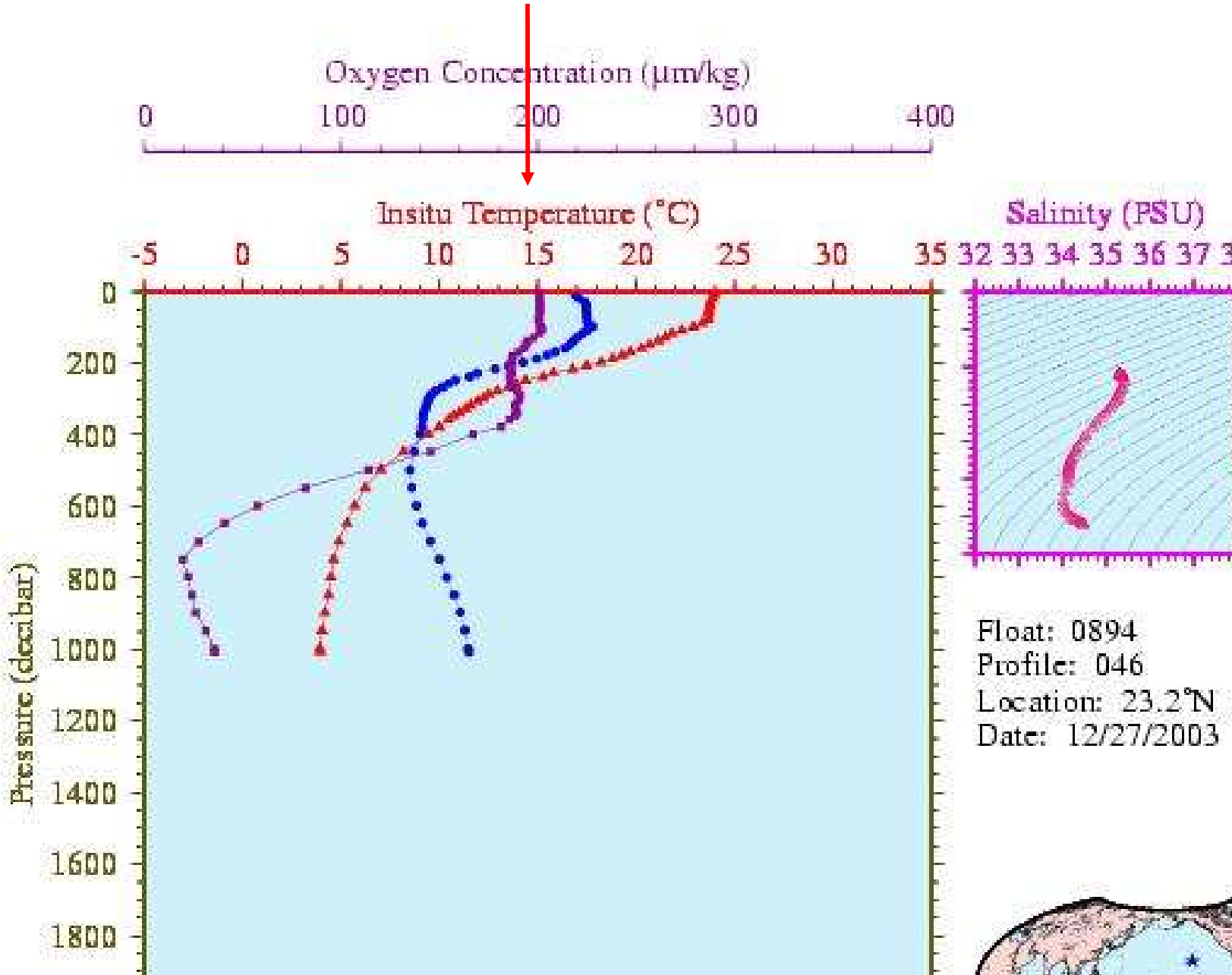

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 041
Location: 23.3°N
Date: 11/04/2003

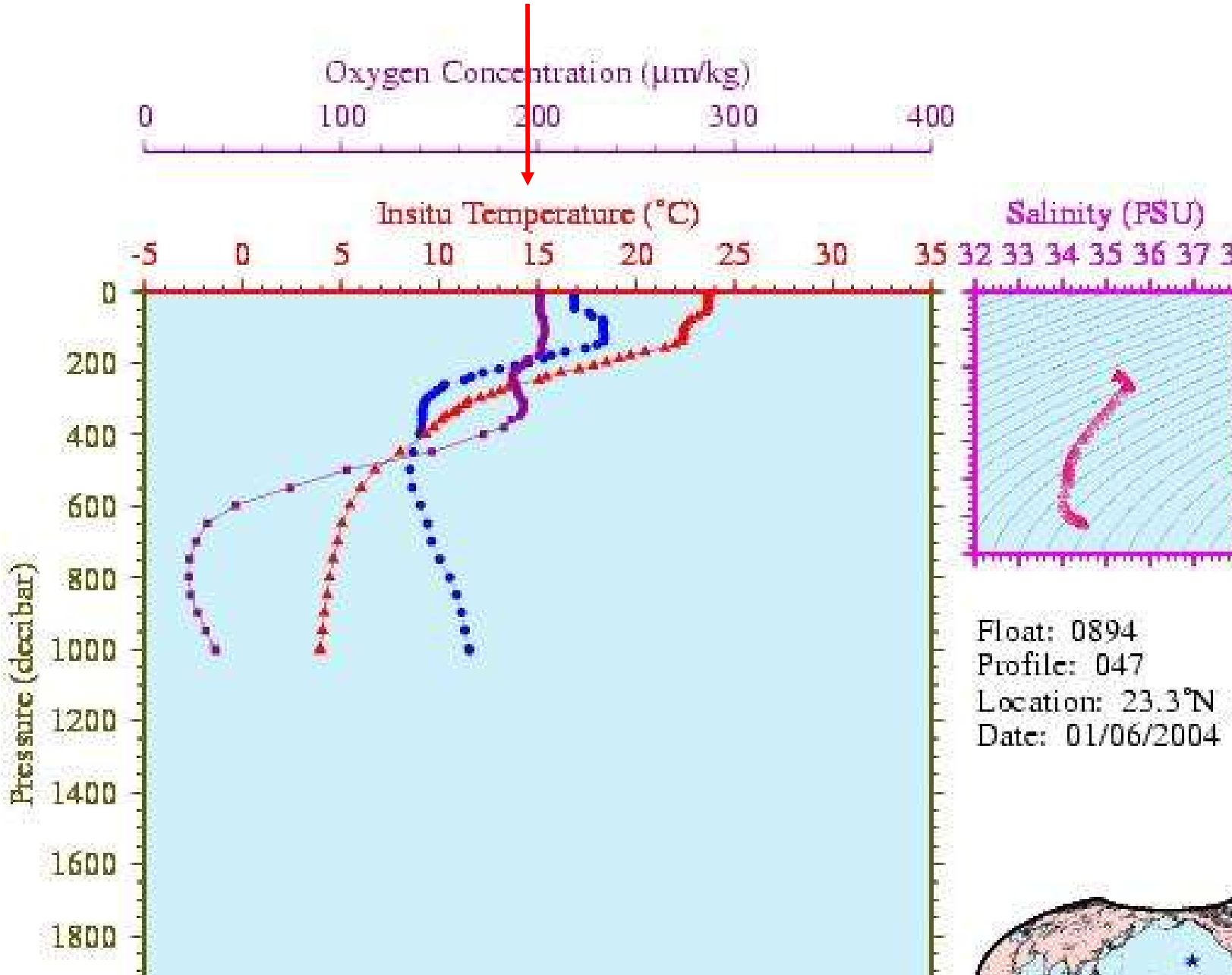

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 042
Location: 23.3°N
Date: 11/15/2003

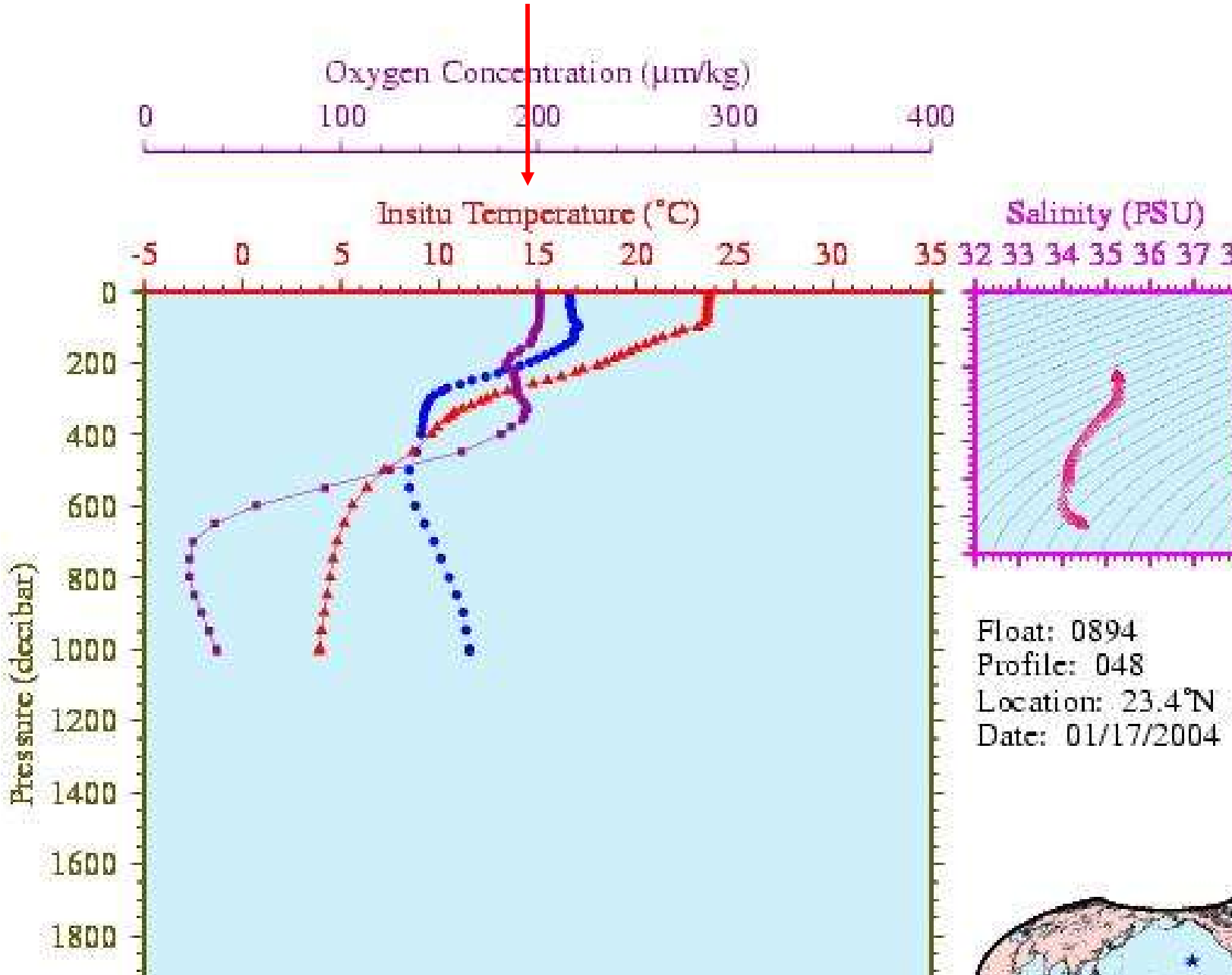

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 043
Location: 23.2°N
Date: 11/25/2003

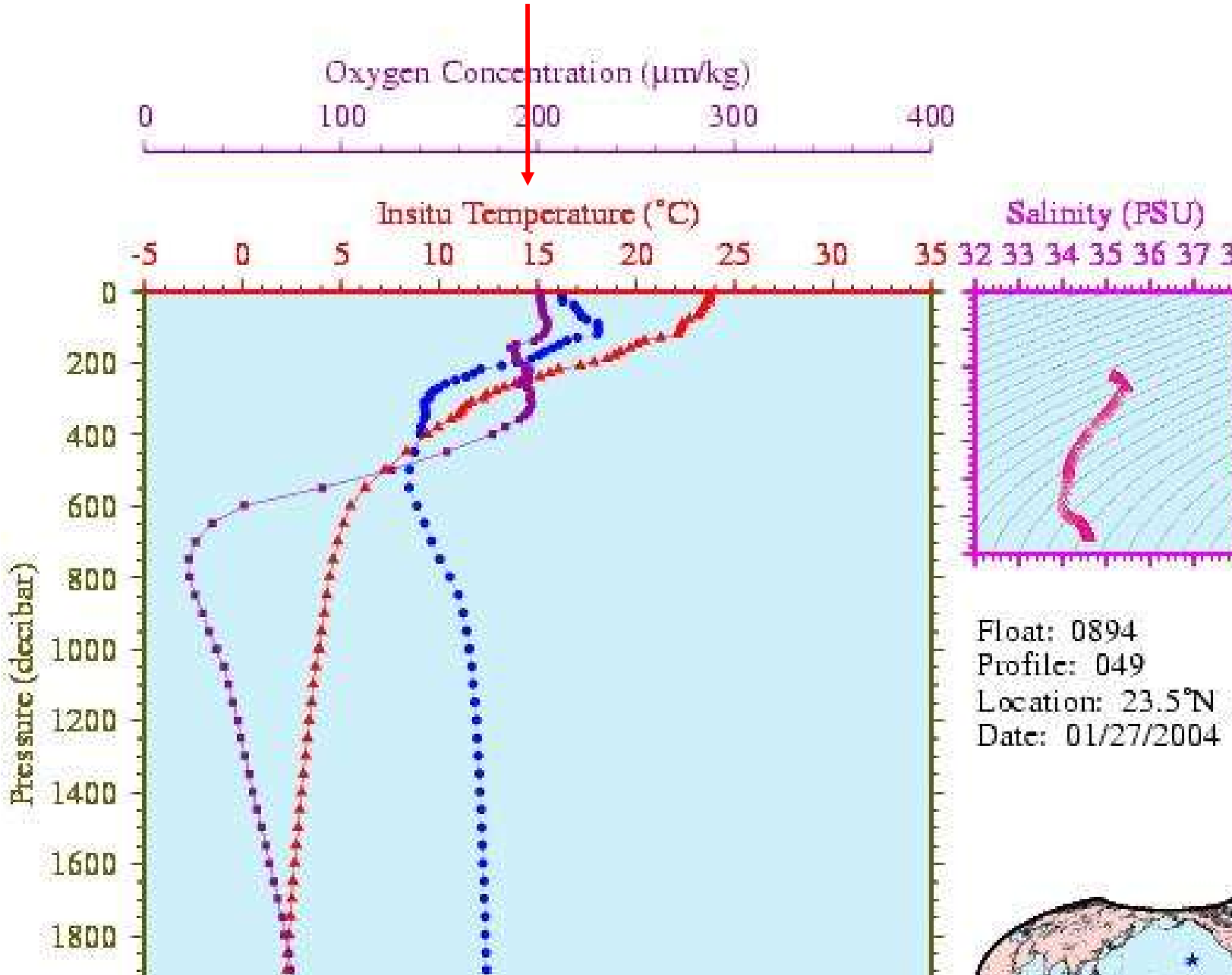

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 044
Location: 23.4°N
Date: 12/06/2003

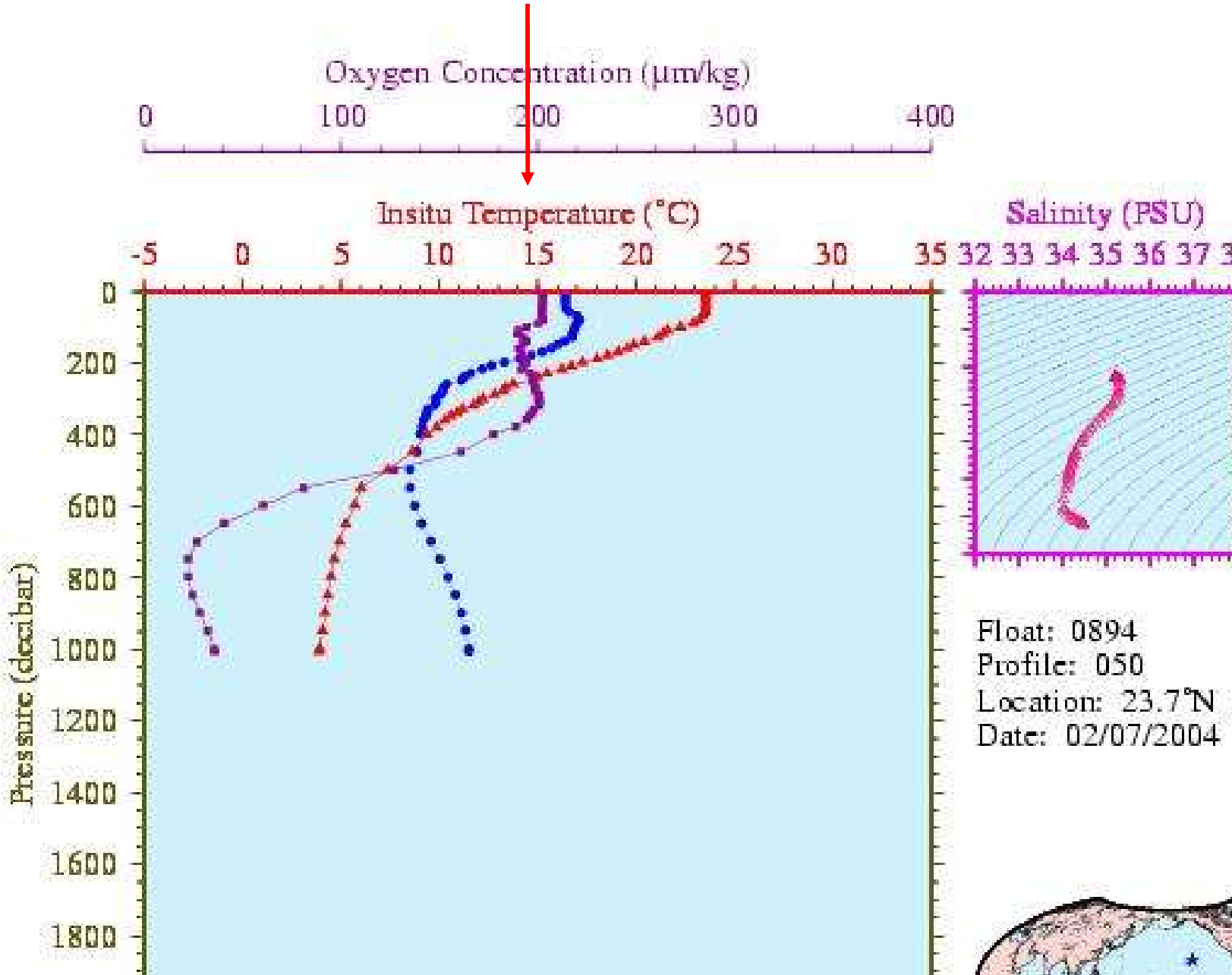

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 045
Location: 23.3°N
Date: 12/16/2003

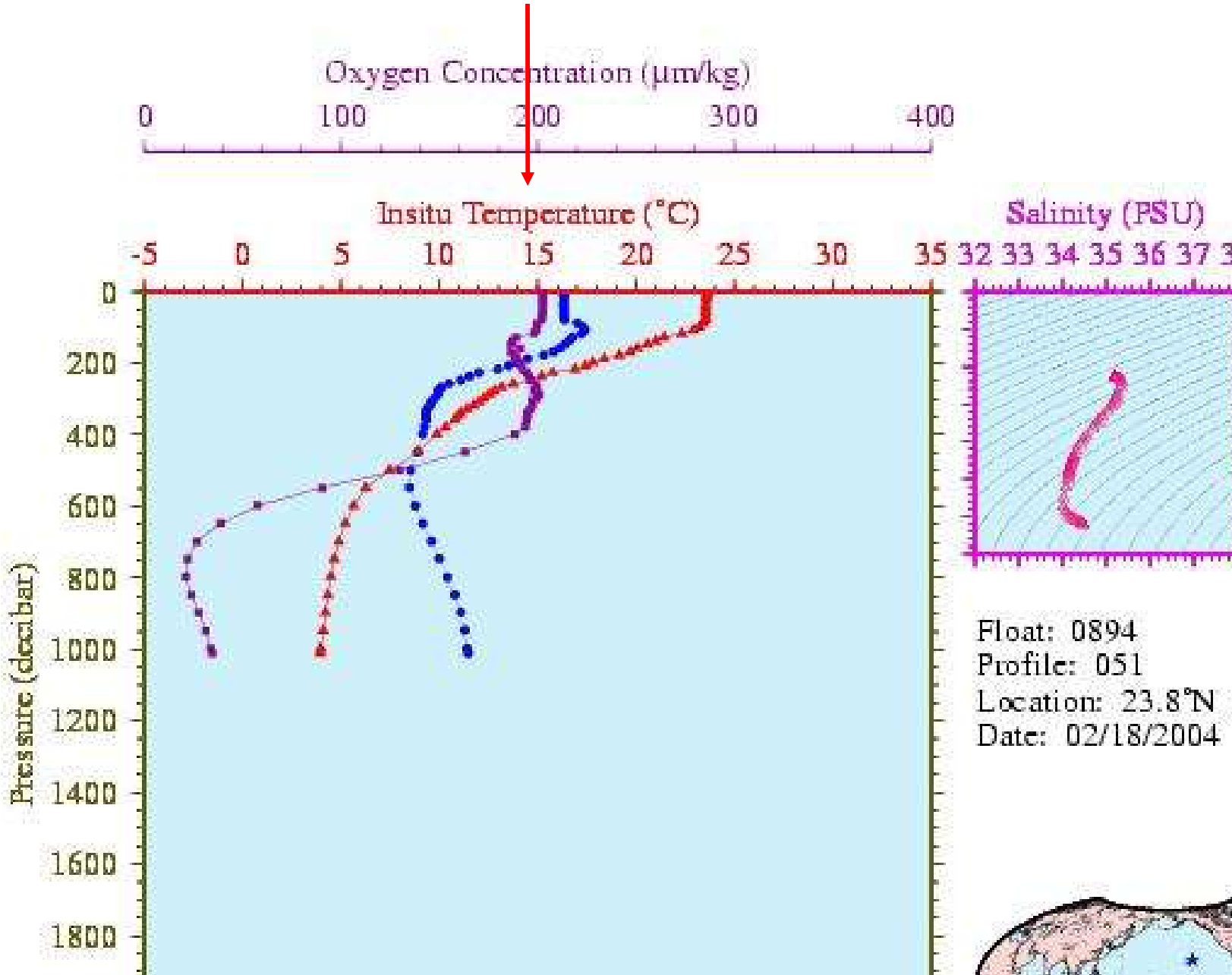

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 046
Location: 23.2°N
Date: 12/27/2003

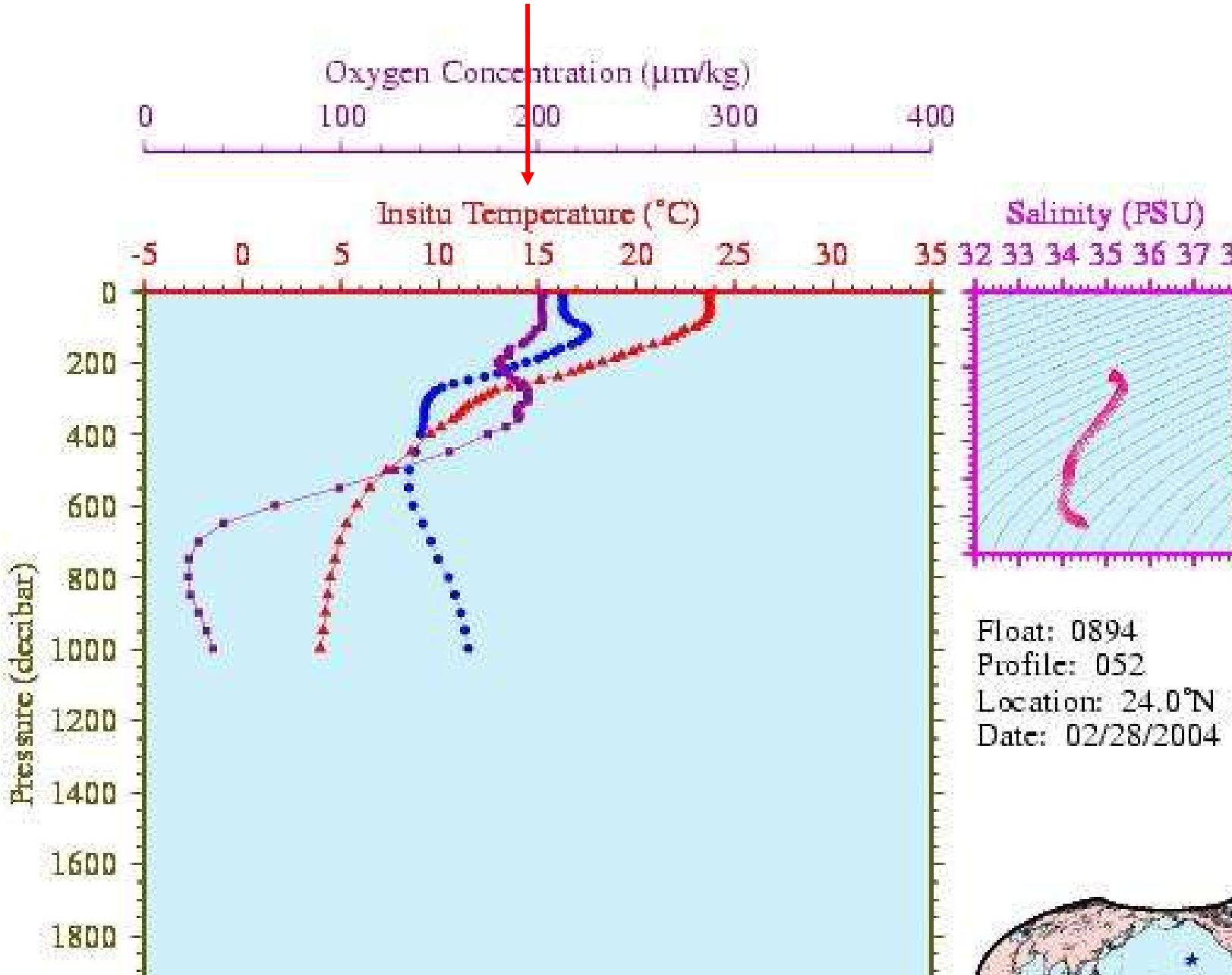

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 047
Location: 23.3°N
Date: 01/06/2004

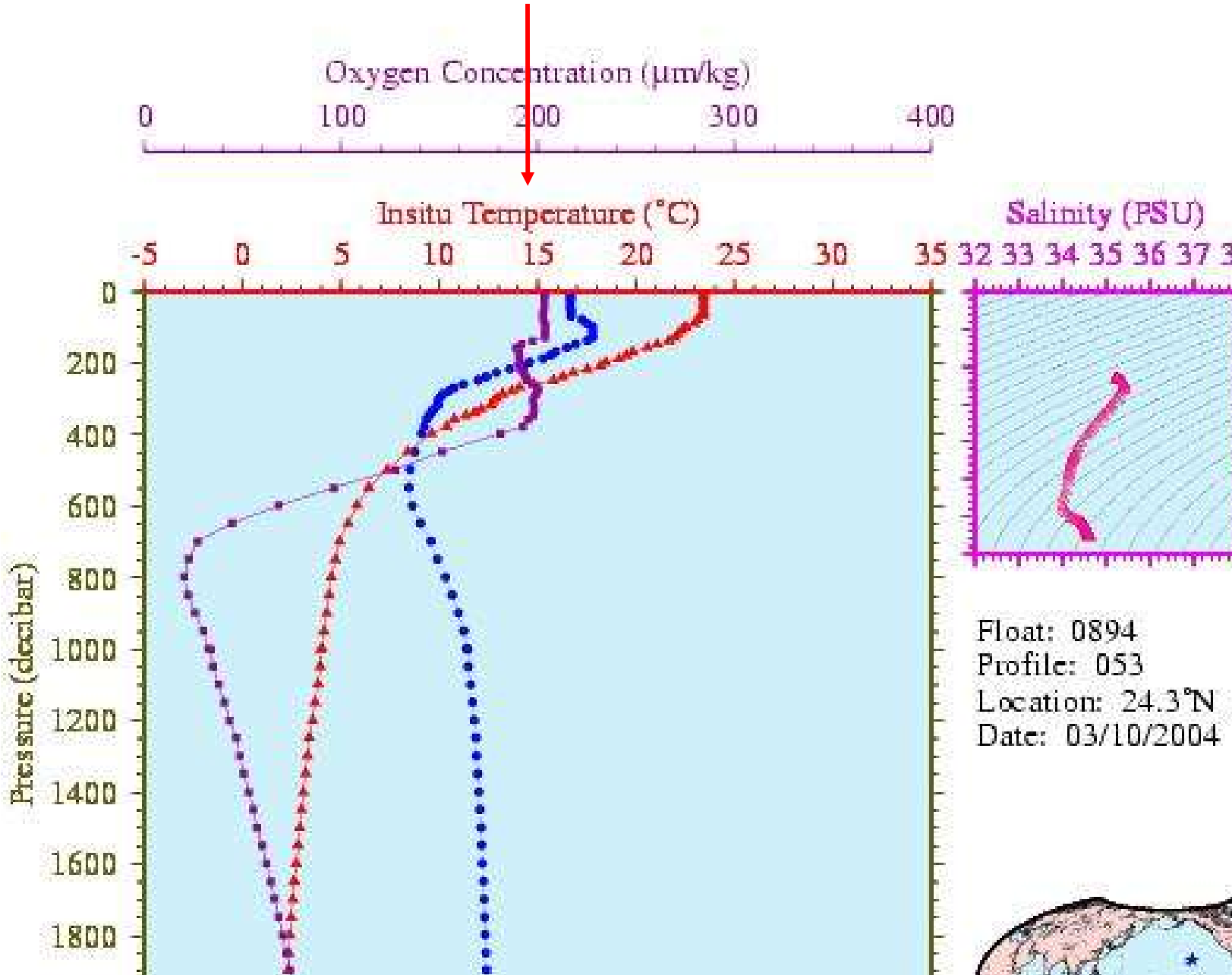

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 048
Location: 23.4°N
Date: 01/17/2004

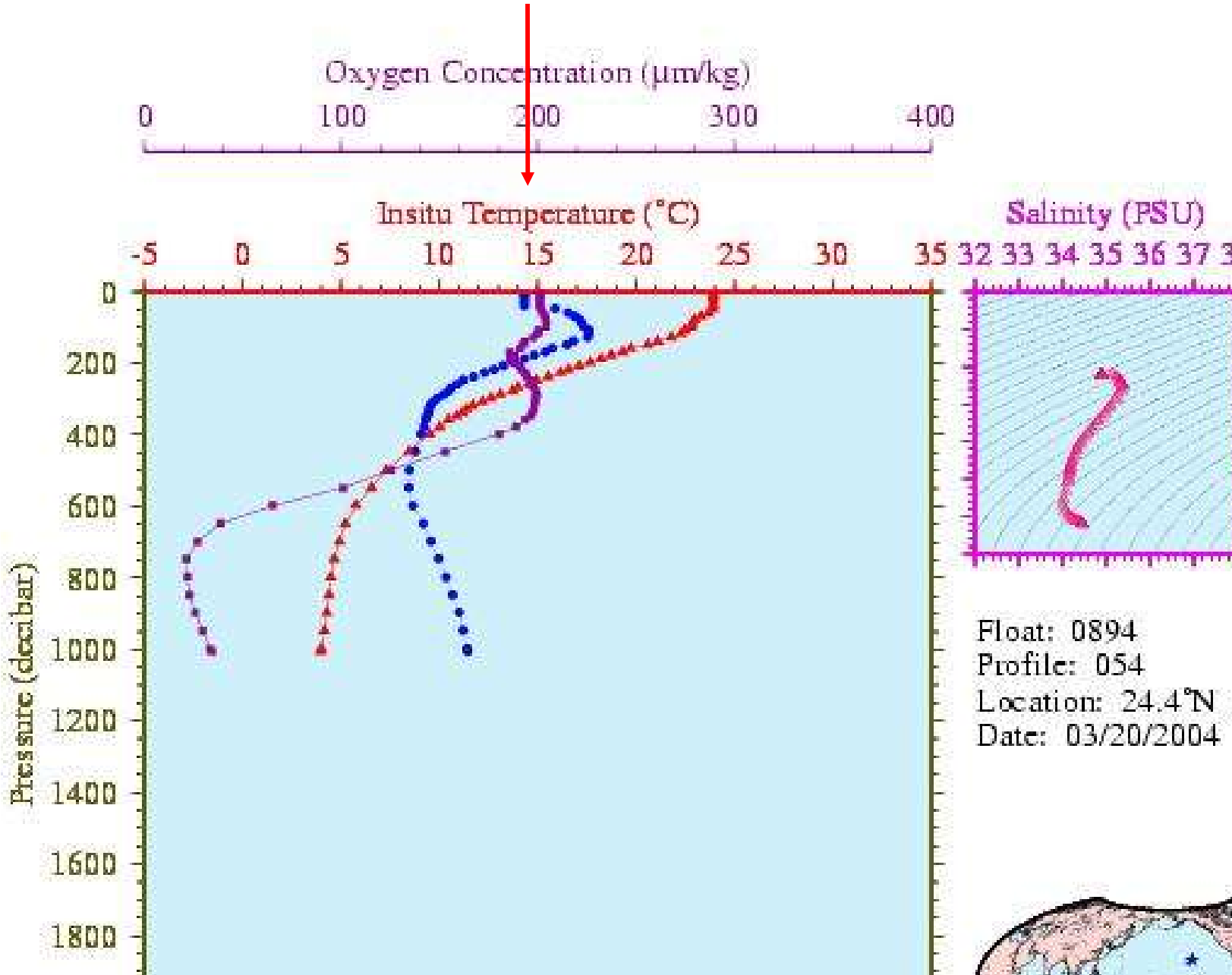

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 049
Location: 23.5°N
Date: 01/27/2004

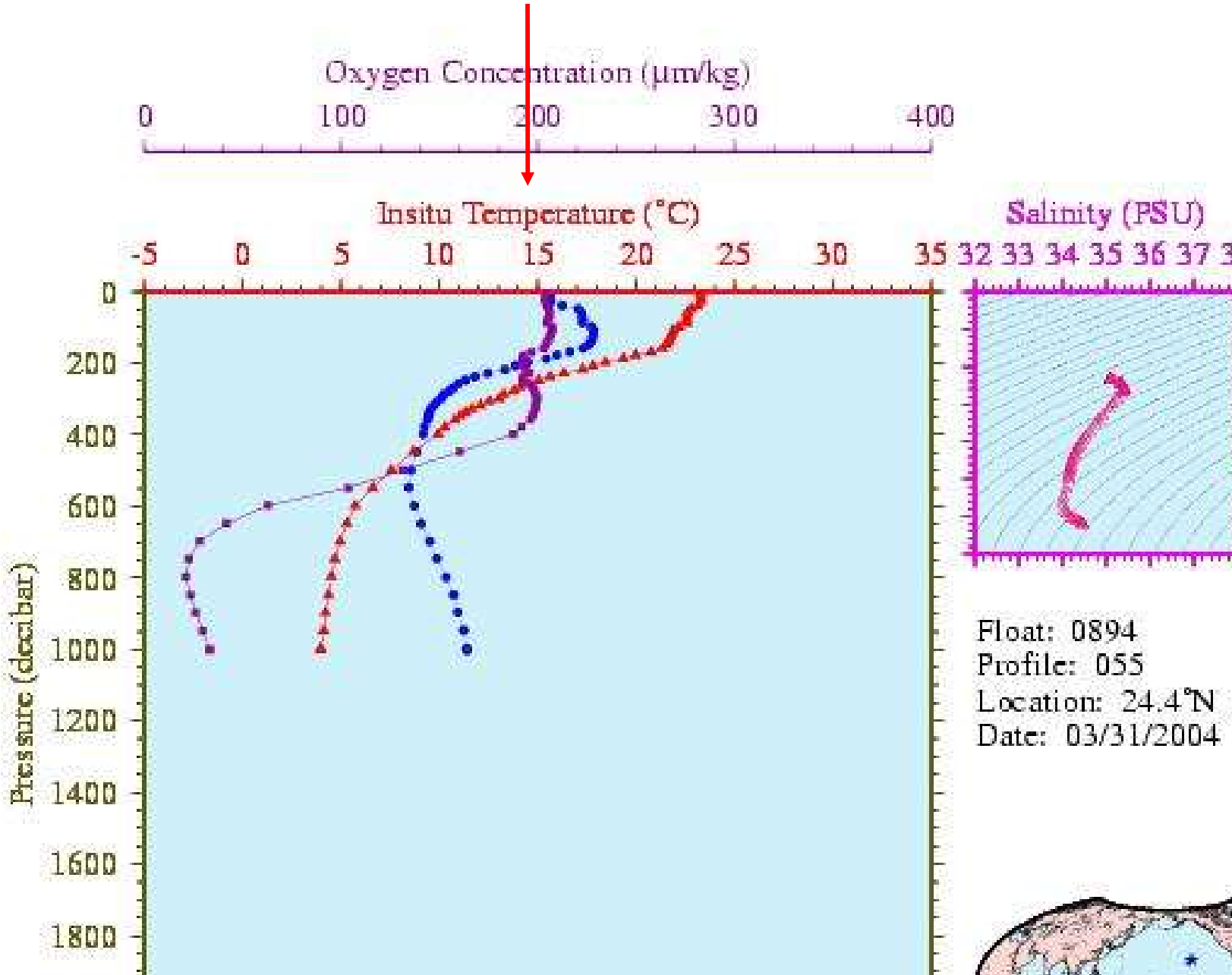

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 050
Location: 23.7°N
Date: 02/07/2004

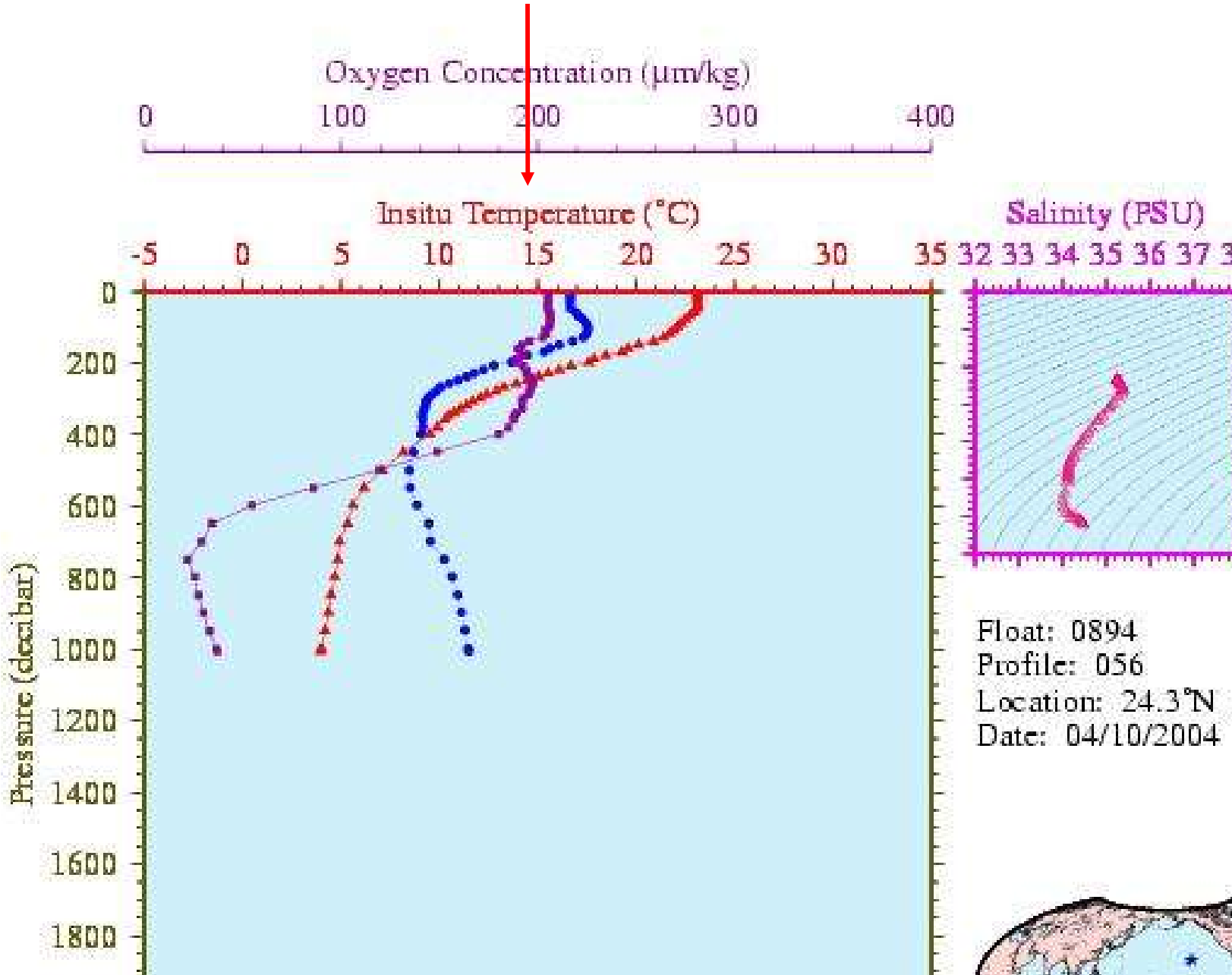

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 051
Location: 23.8°N
Date: 02/18/2004

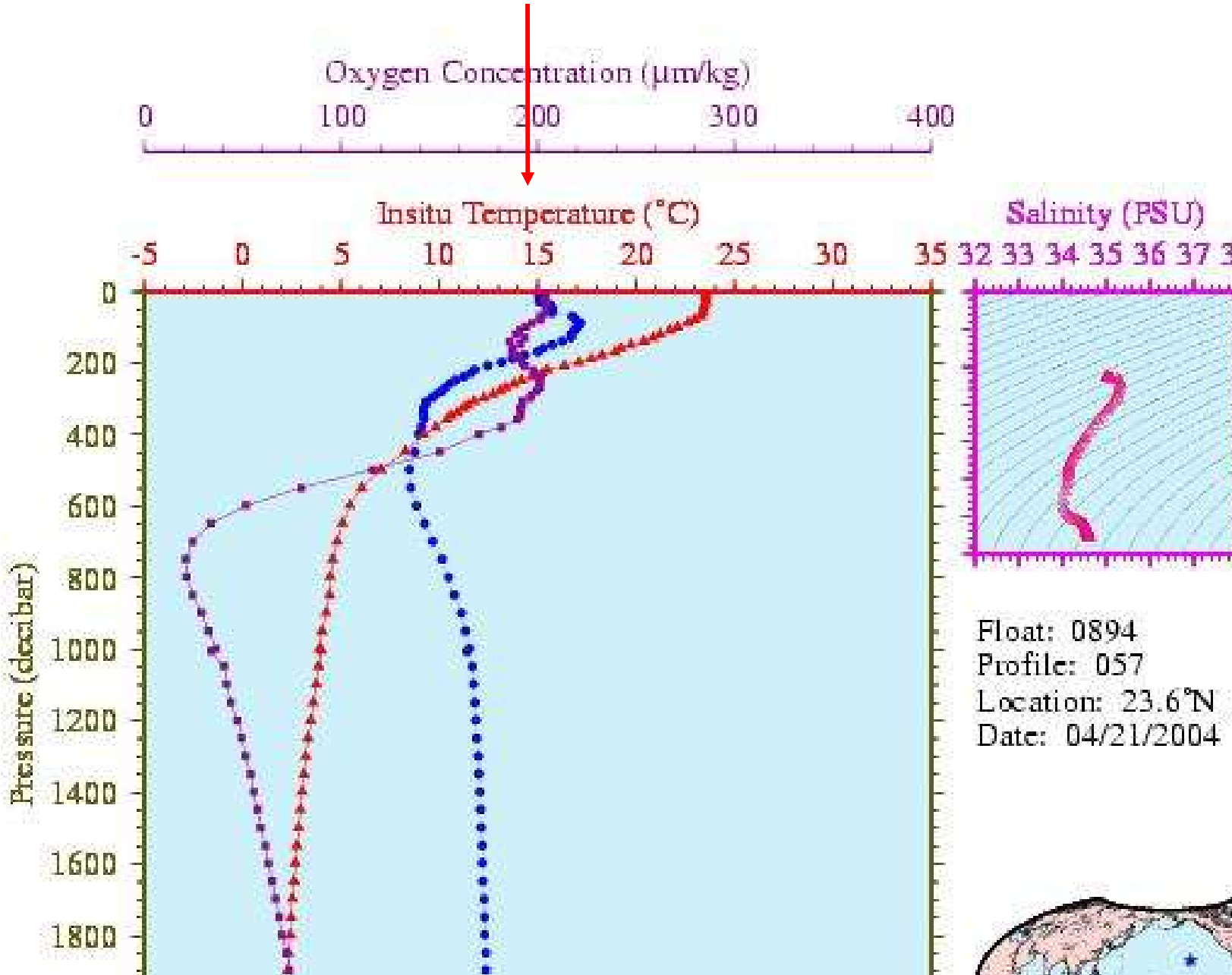

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 052
Location: 24.0°N
Date: 02/28/2004

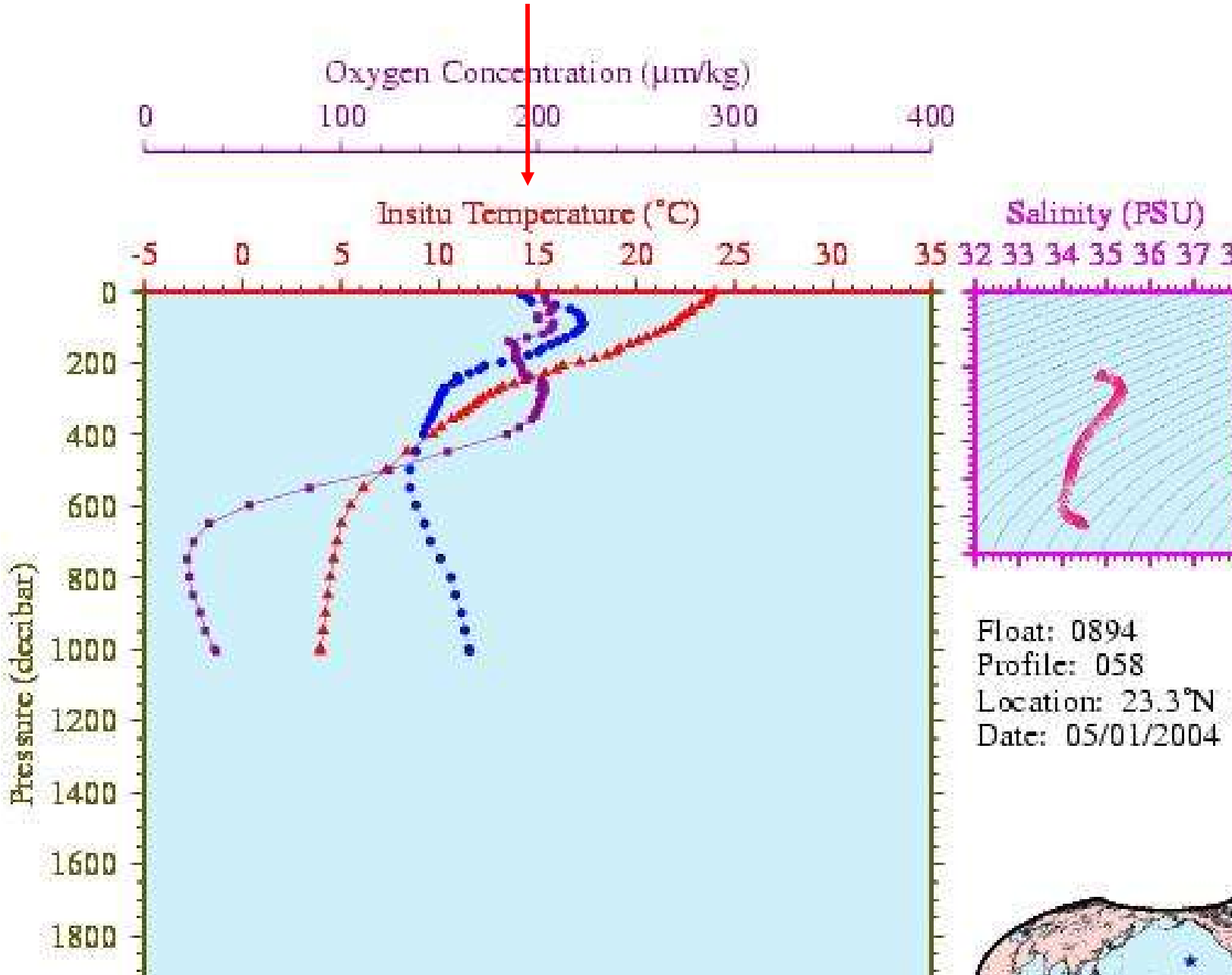

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 053
Location: 24.3°N
Date: 03/10/2004

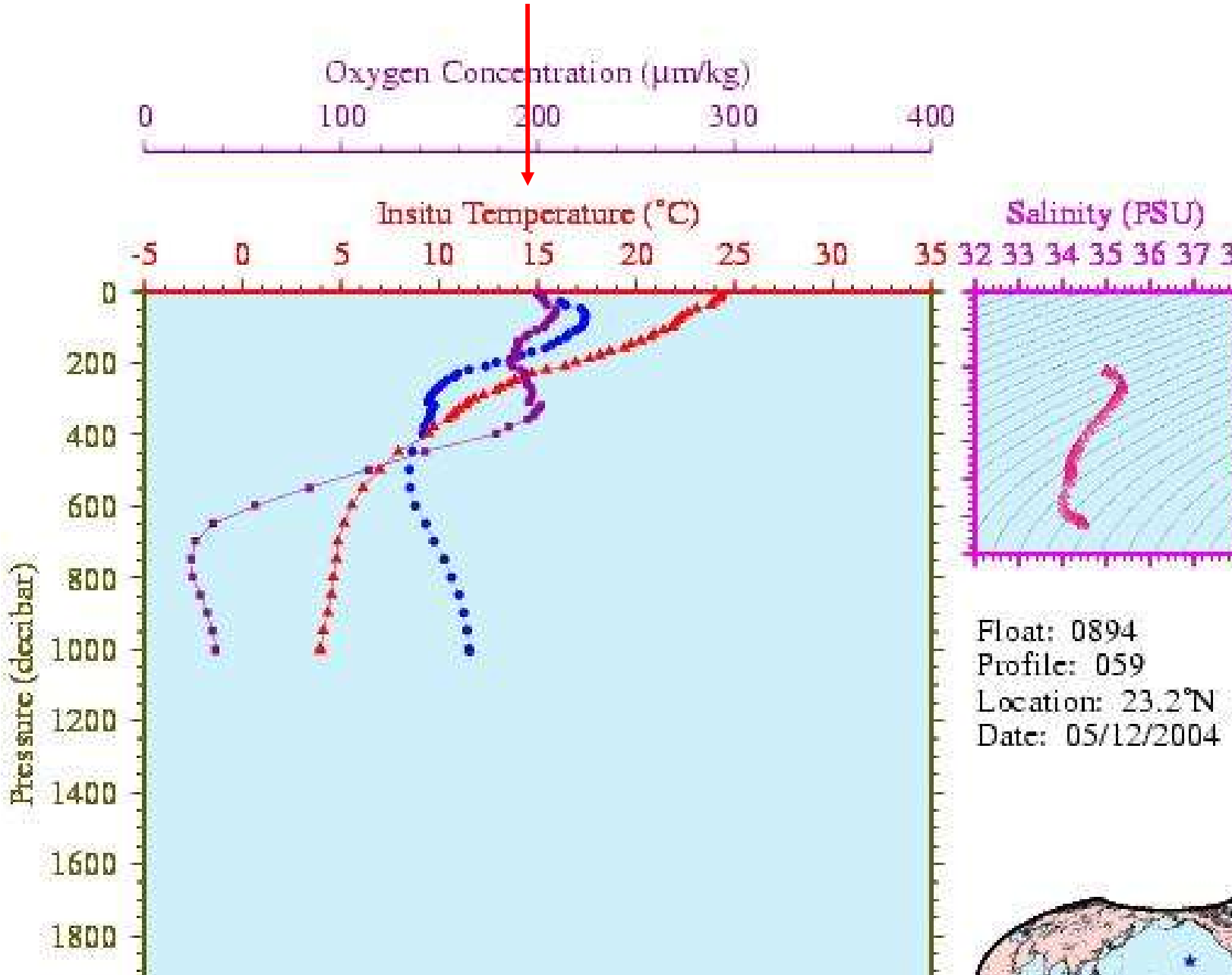

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 054
Location: 24.4°N
Date: 03/20/2004

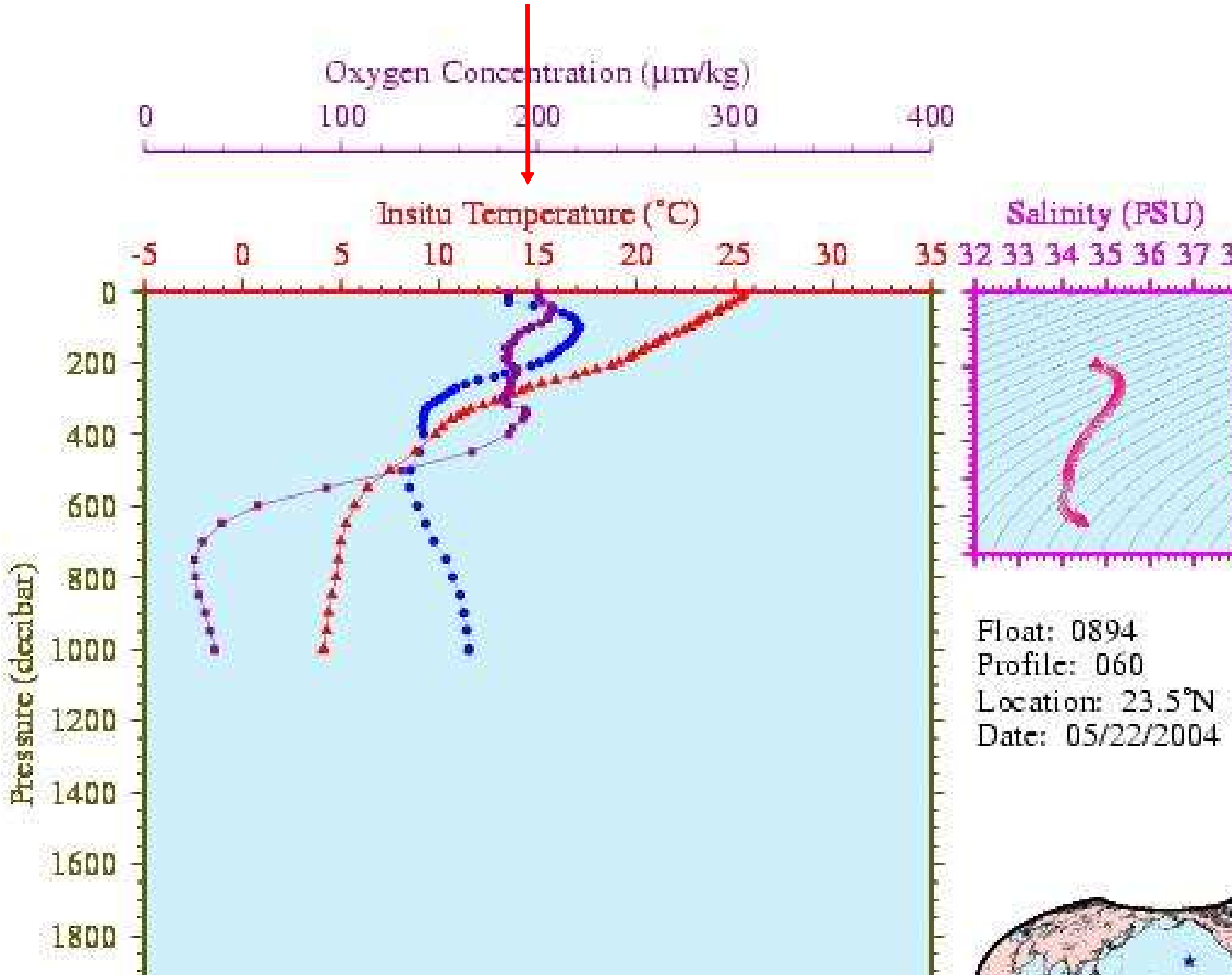

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 055
Location: 24.4°N
Date: 03/31/2004

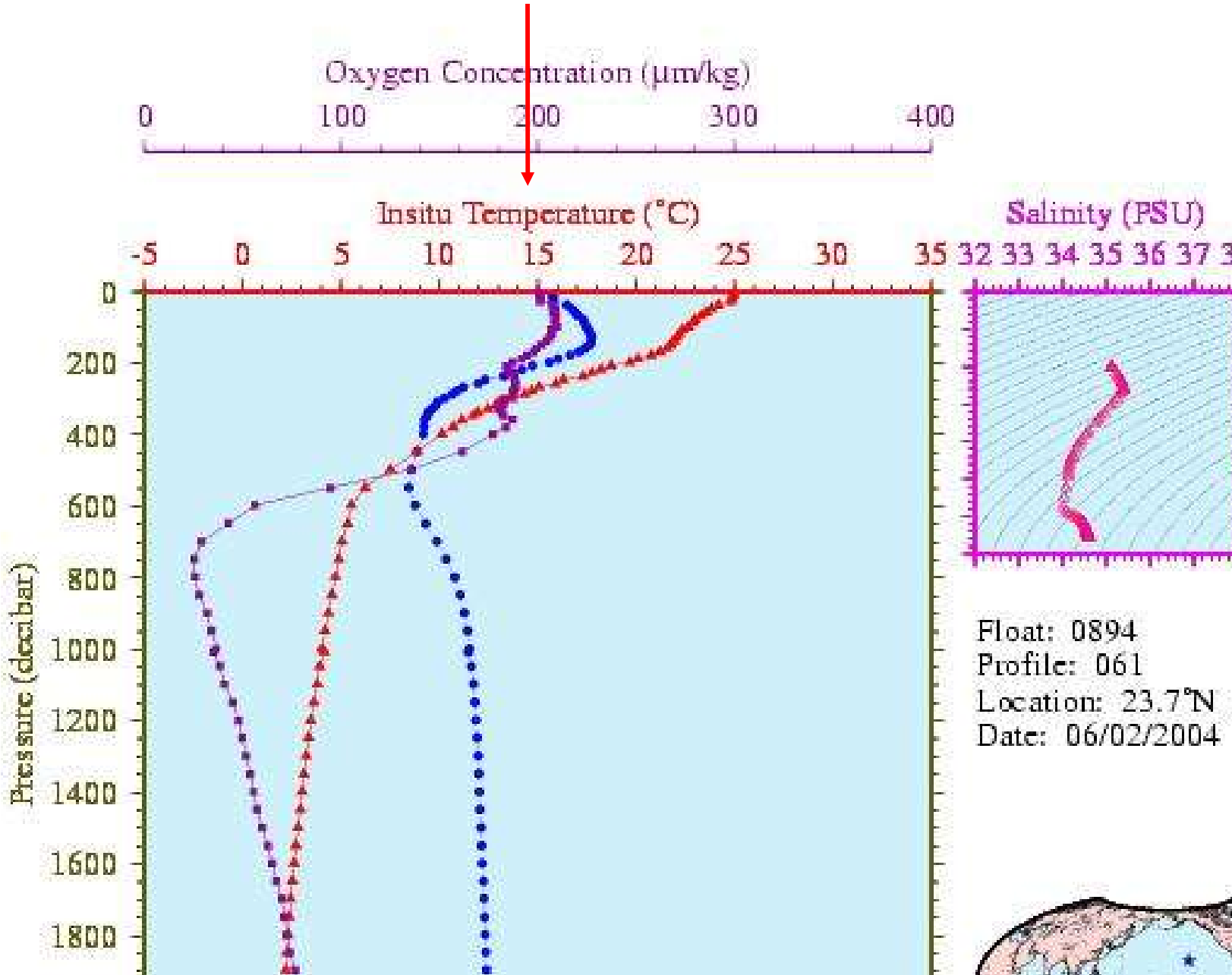

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 056
Location: 24.3°N
Date: 04/10/2004

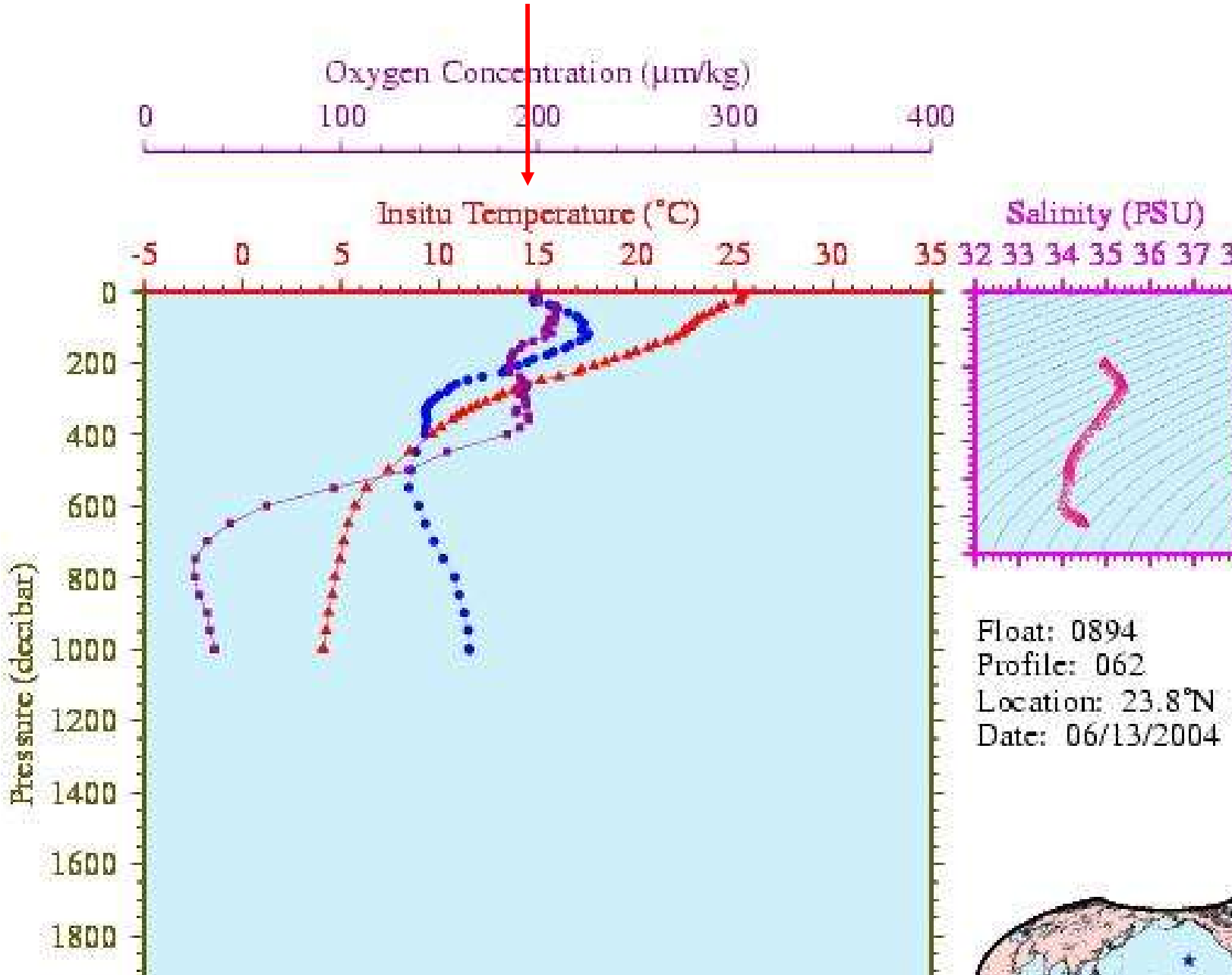

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 057
Location: 23.6°N
Date: 04/21/2004

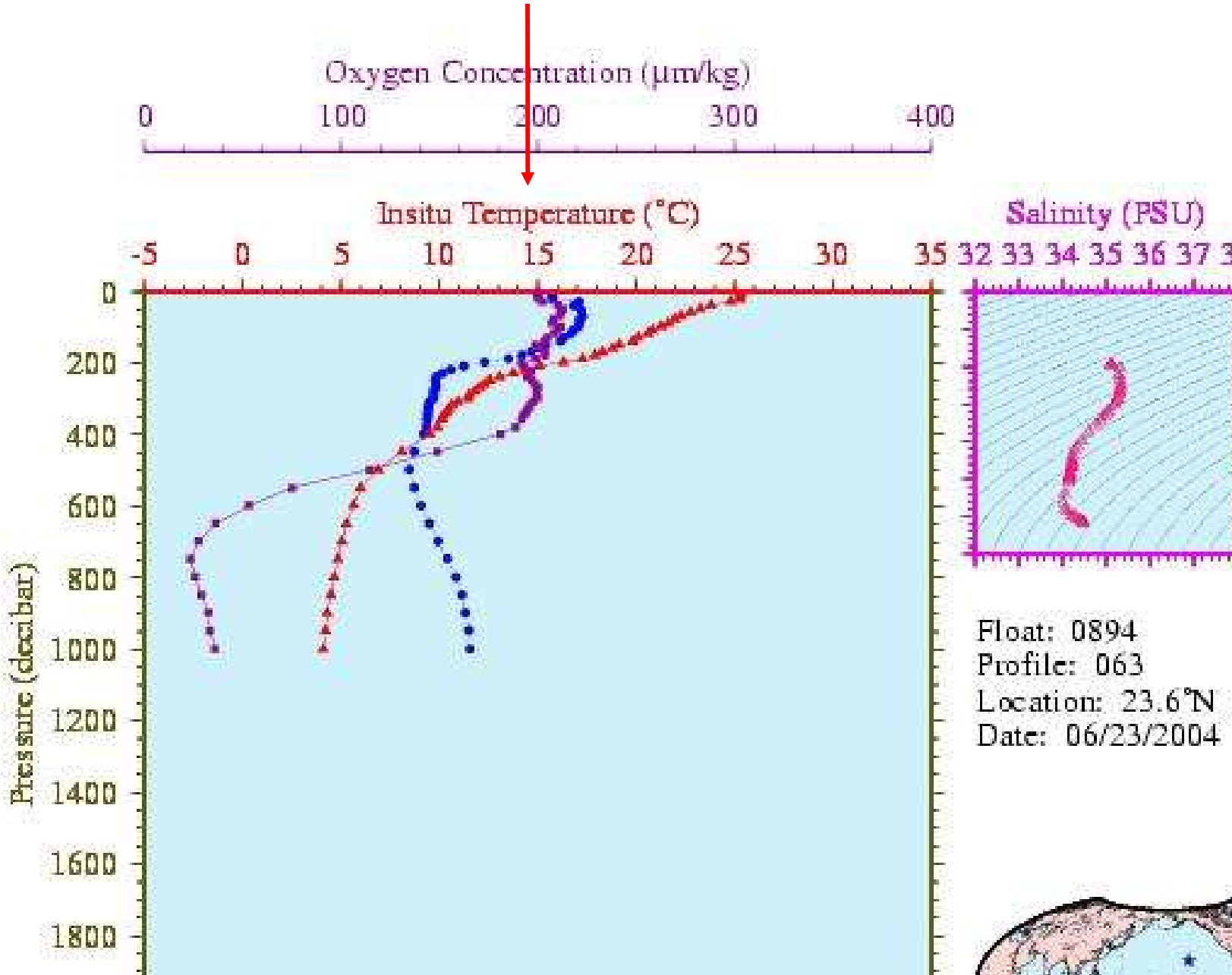

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 058
Location: 23.3°N
Date: 05/01/2004

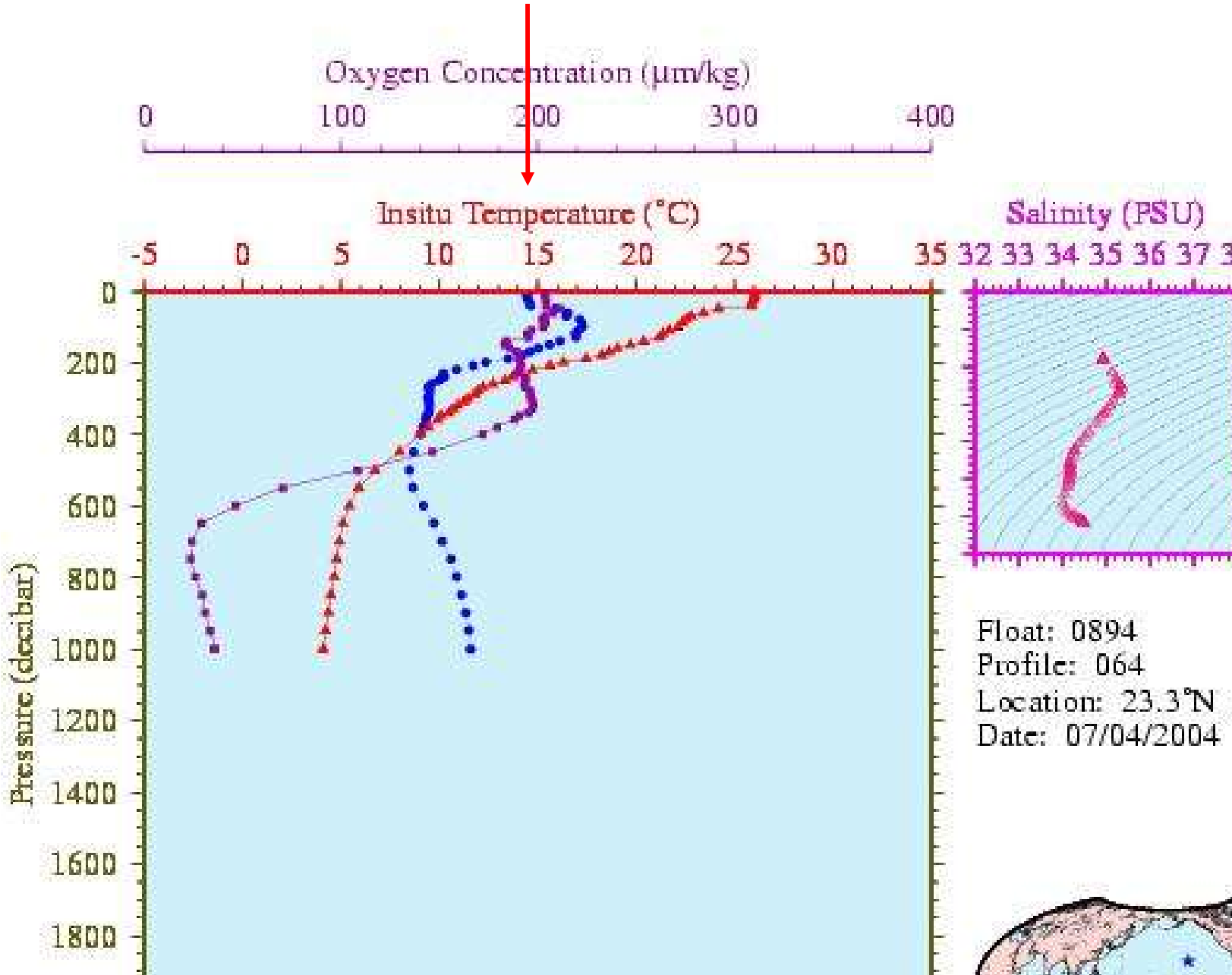

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 059
Location: 23.2°N
Date: 05/12/2004

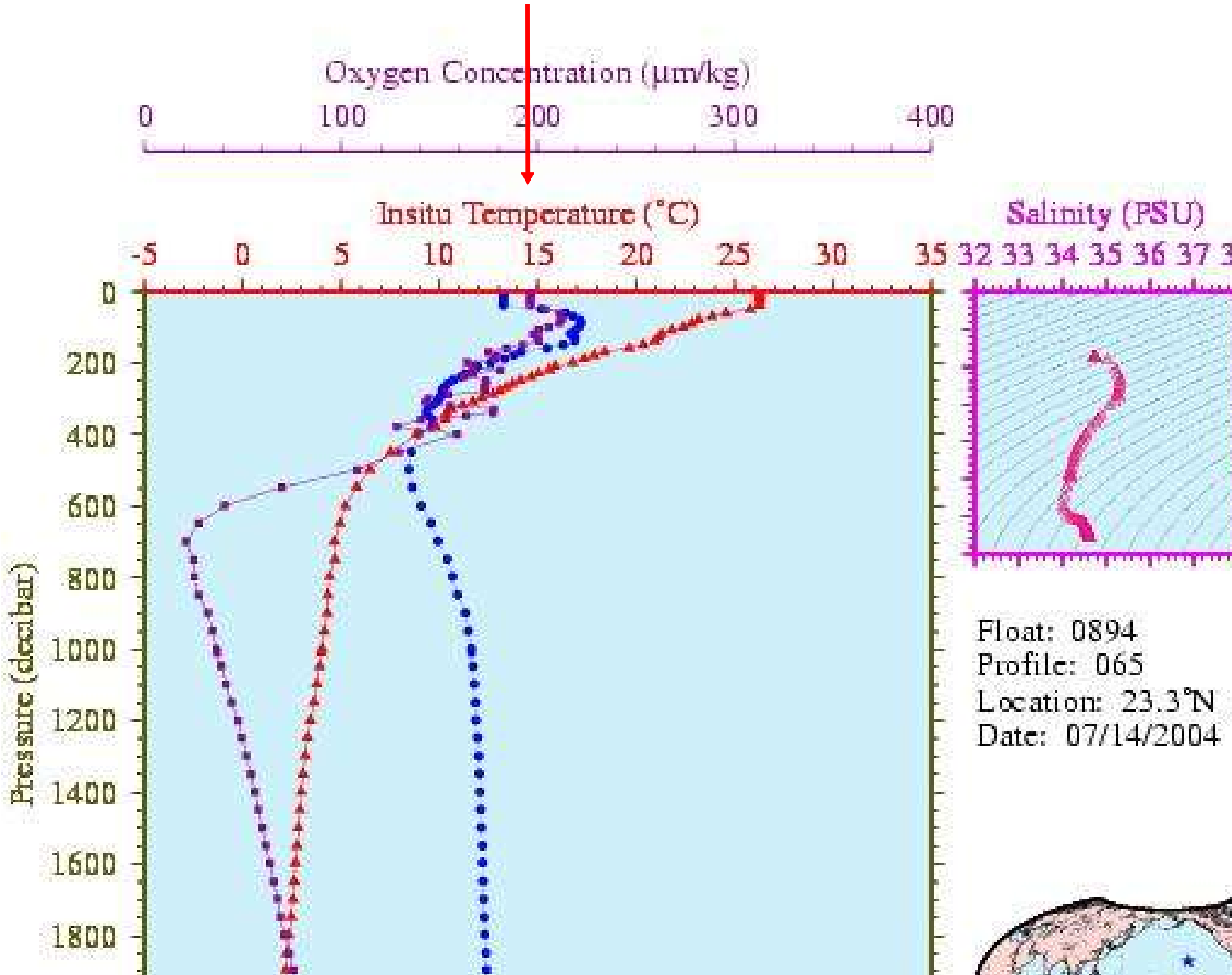

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 060
Location: 23.5°N
Date: 05/22/2004

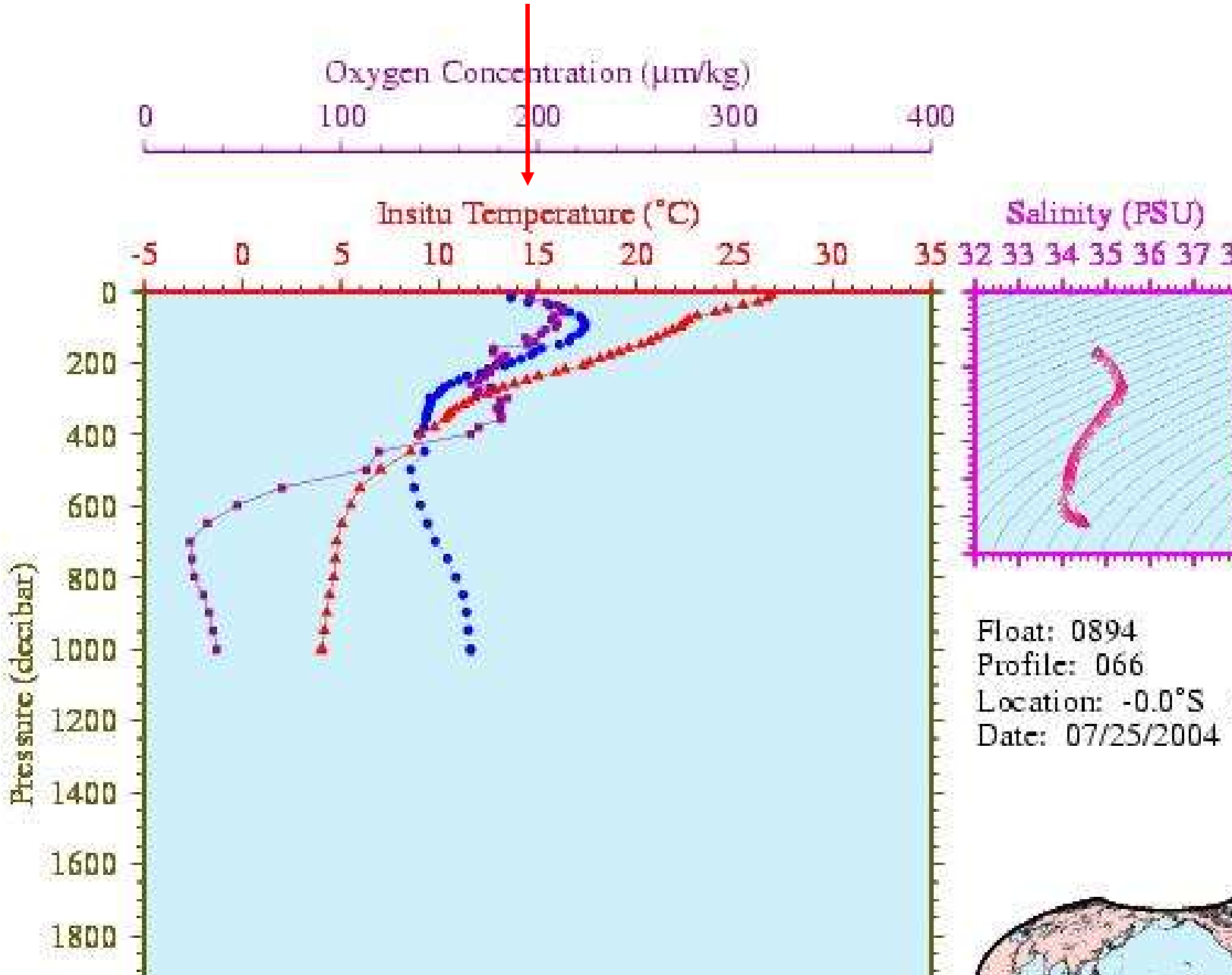

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 061
Location: 23.7°N
Date: 06/02/2004

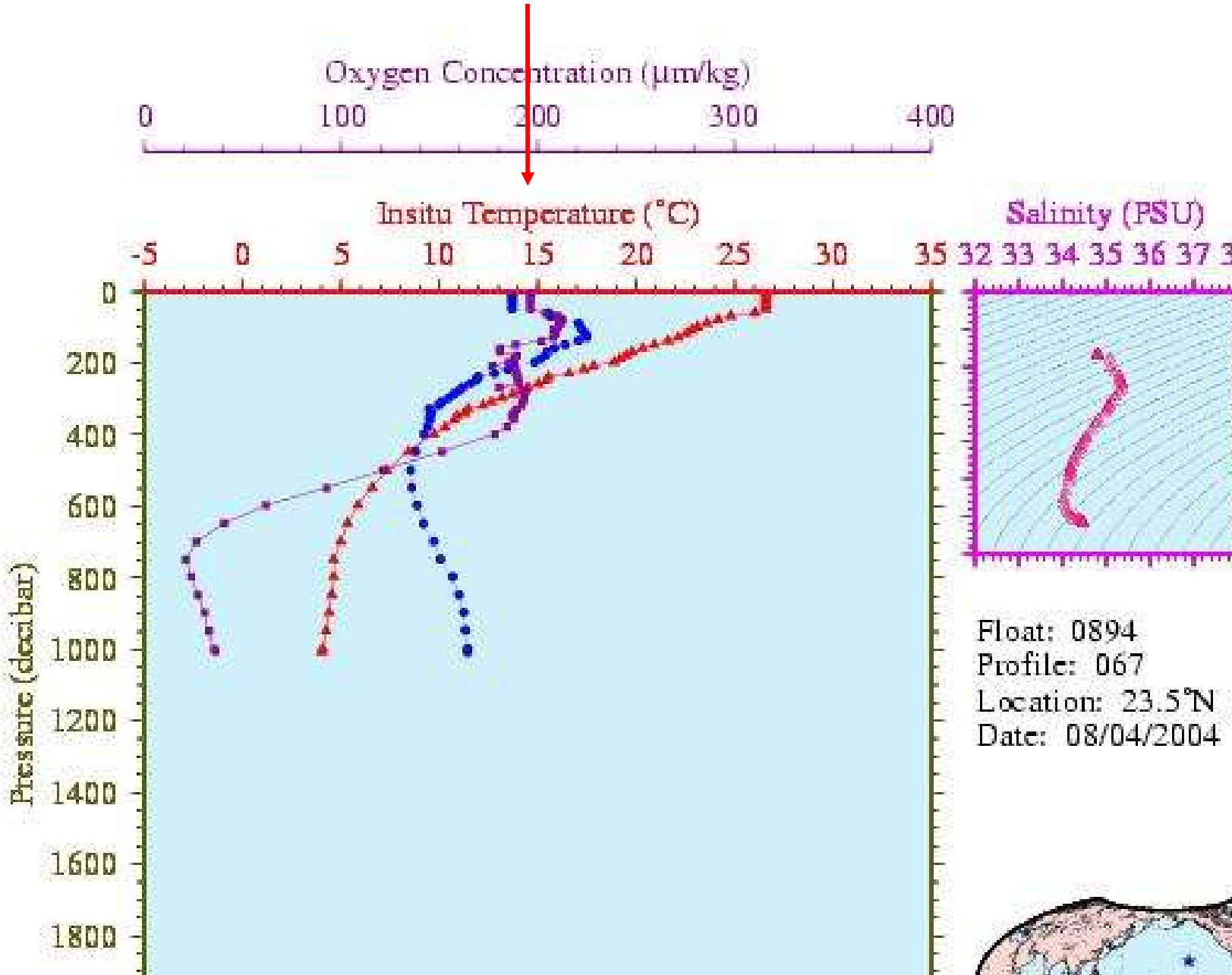

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 062
Location: 23.8°N
Date: 06/13/2004

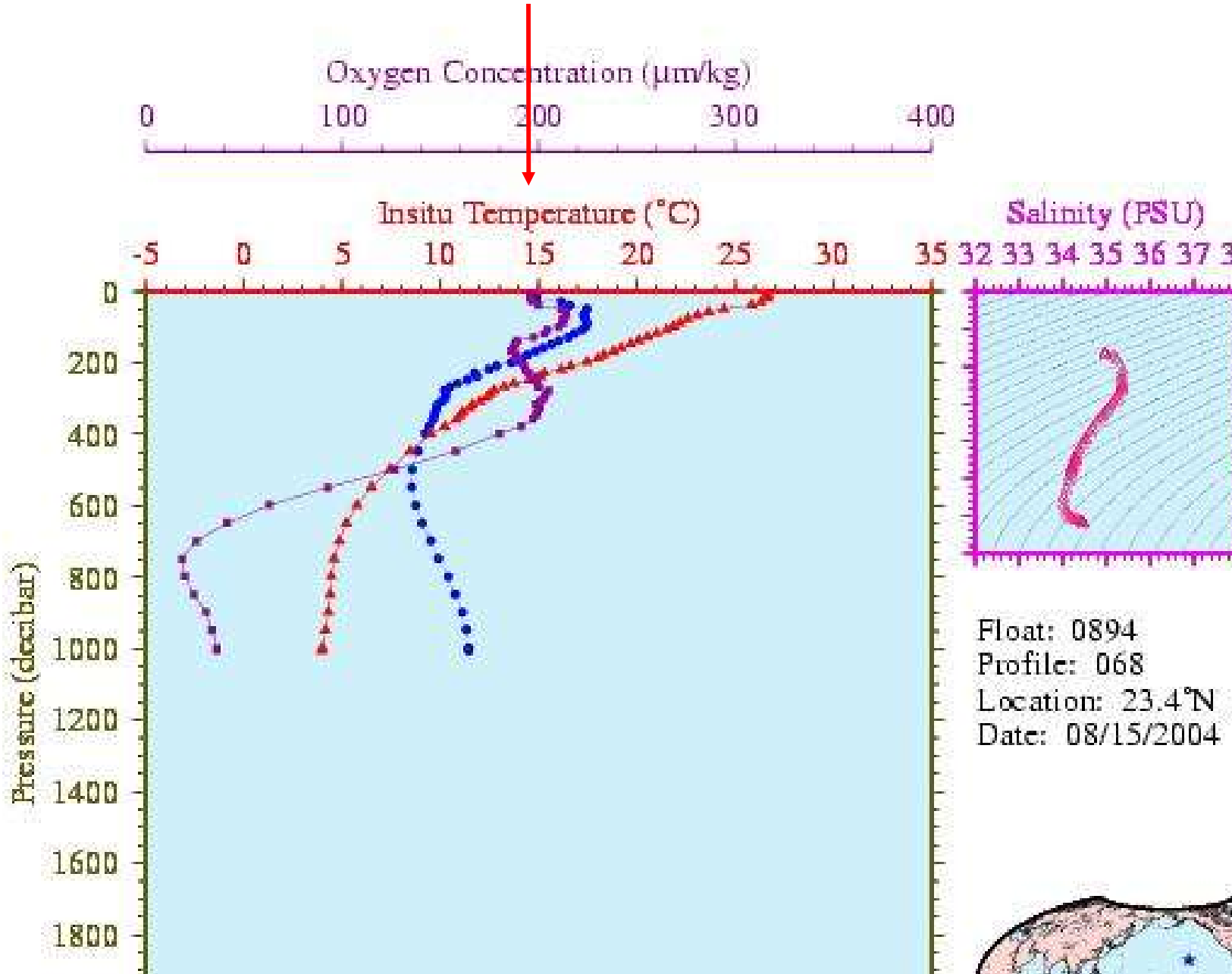

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 063
Location: 23.6°N
Date: 06/23/2004

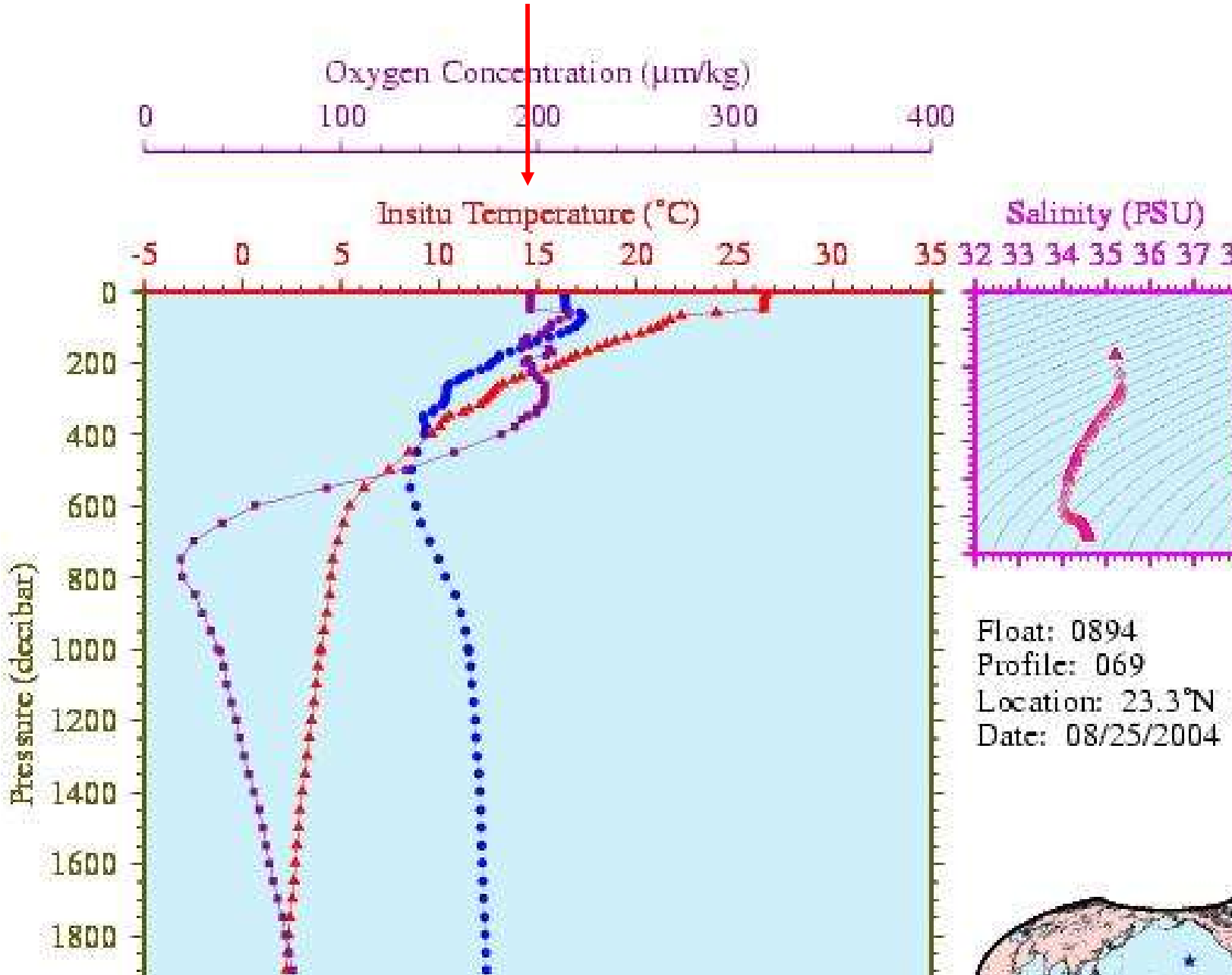

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 064
Location: 23.3°N
Date: 07/04/2004

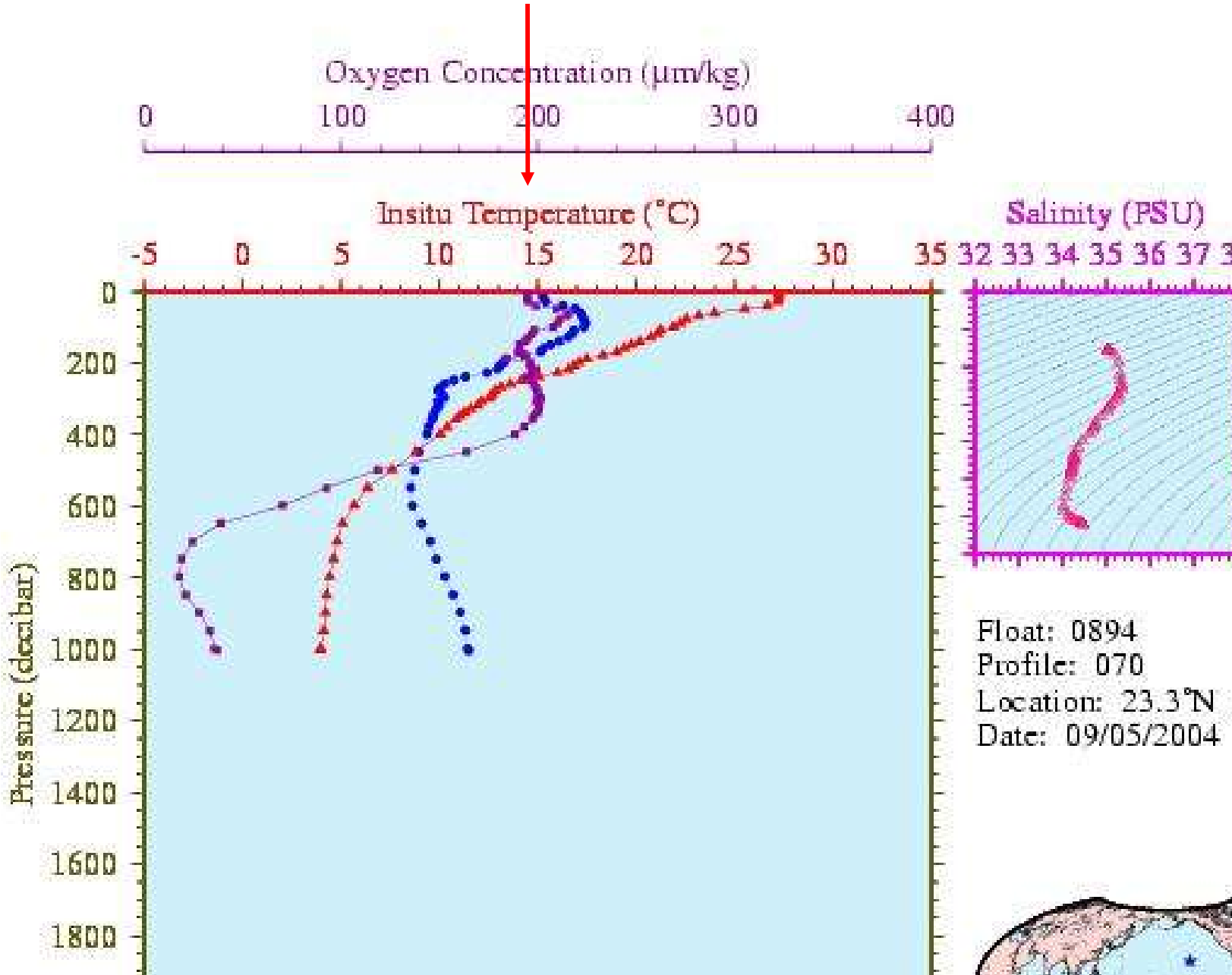

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 065
Location: 23.3°N
Date: 07/14/2004

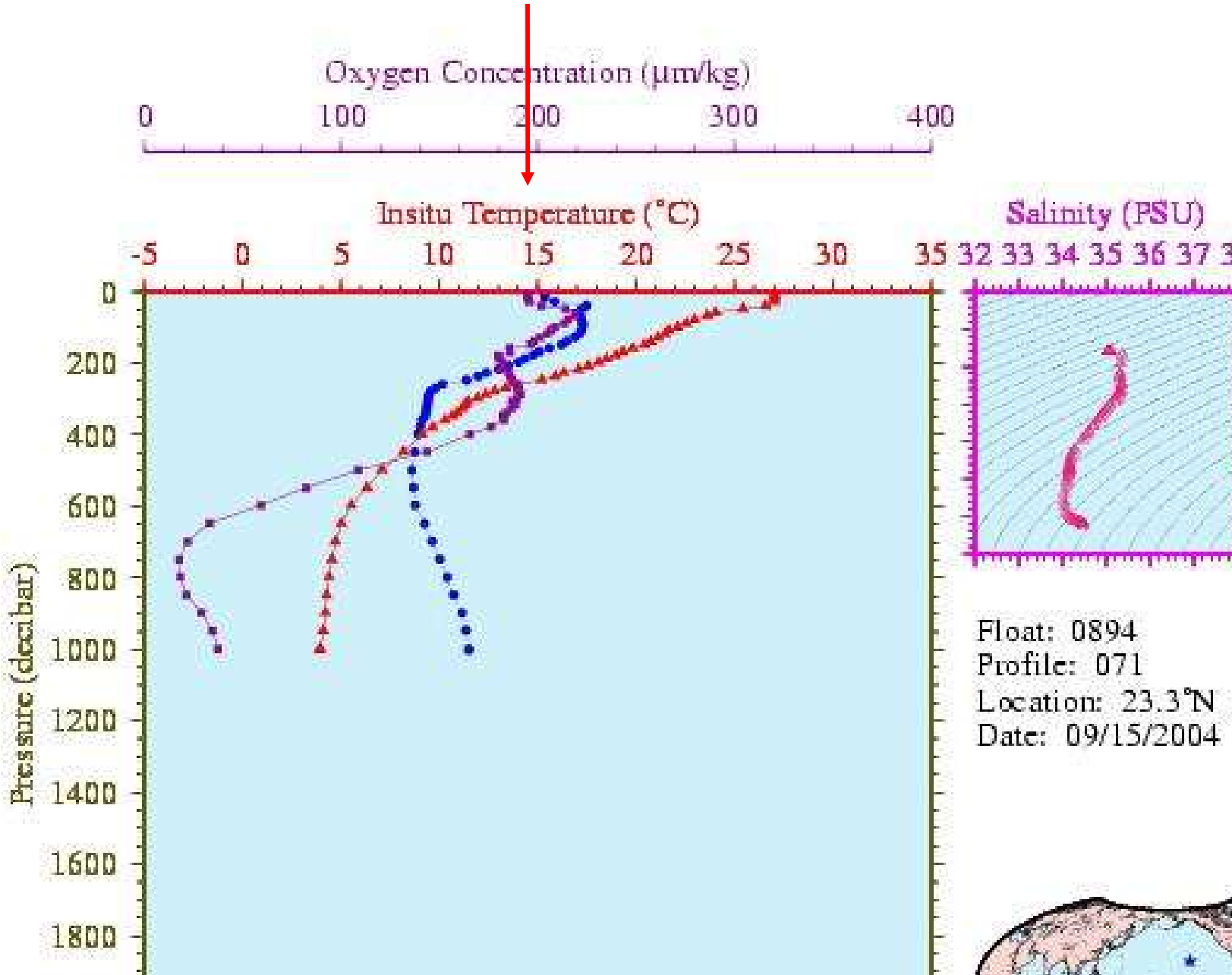

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 066
Location: -0.0°S
Date: 07/25/2004

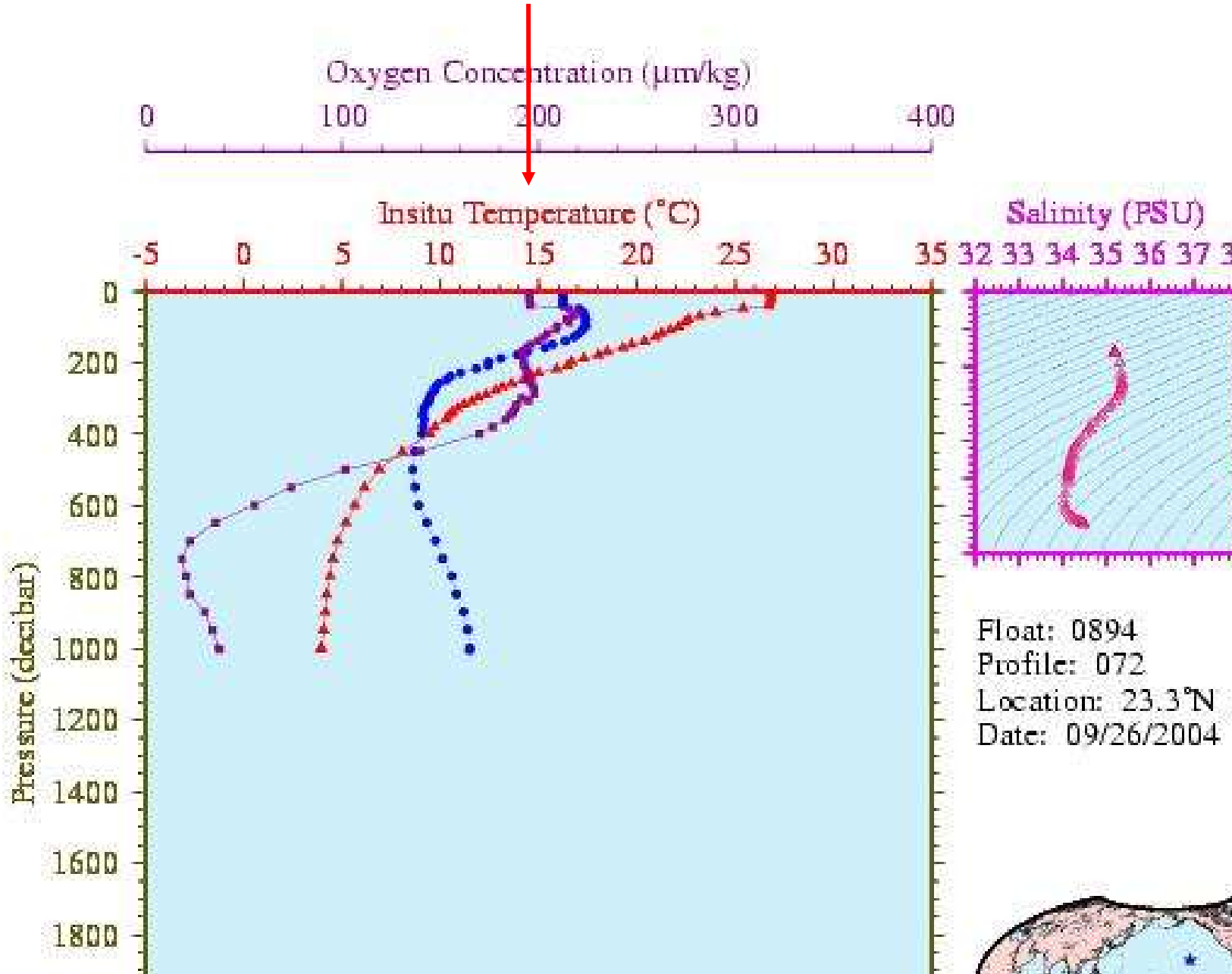

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 067
Location: 23.5°N
Date: 08/04/2004

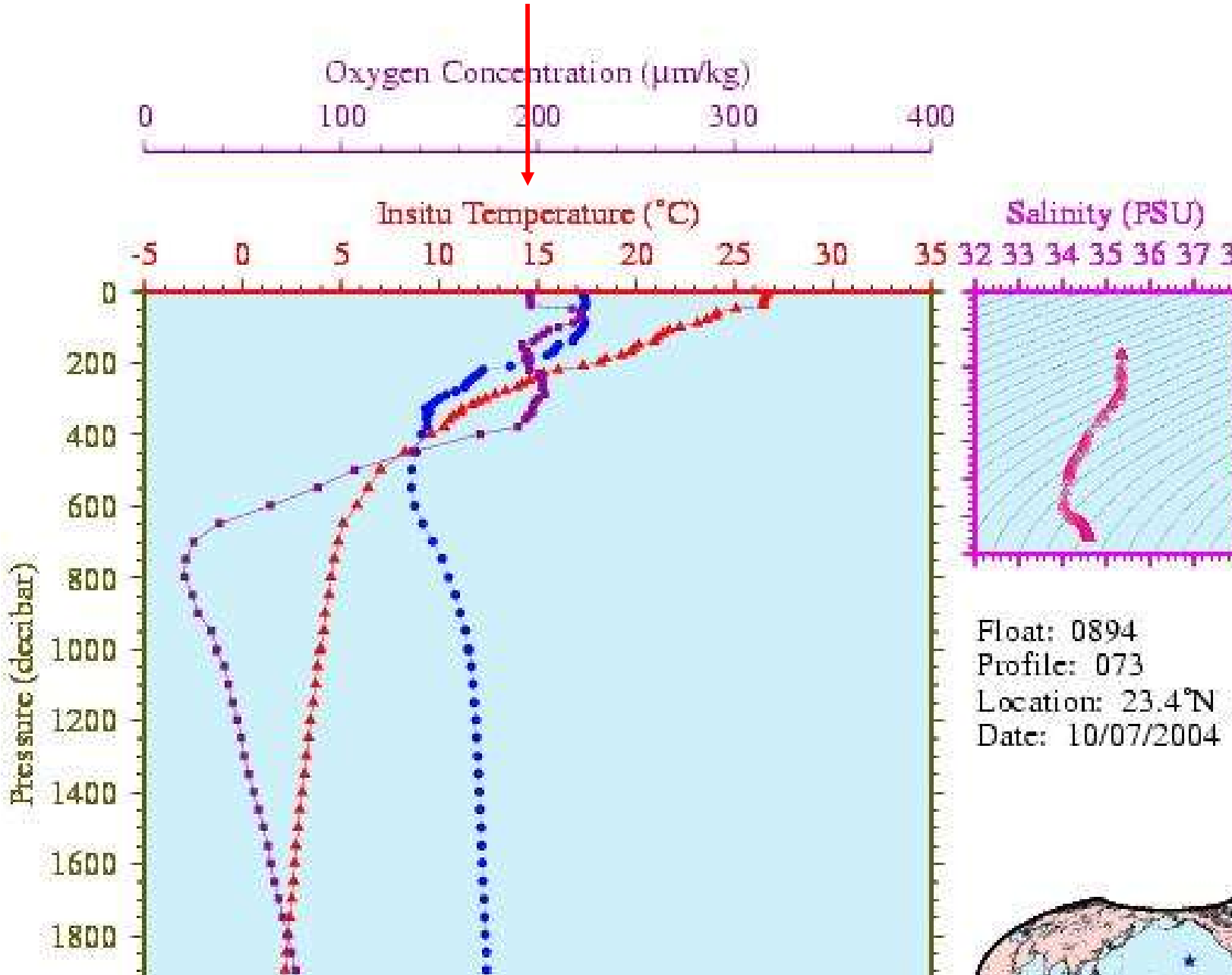

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 068
Location: 23.4°N
Date: 08/15/2004

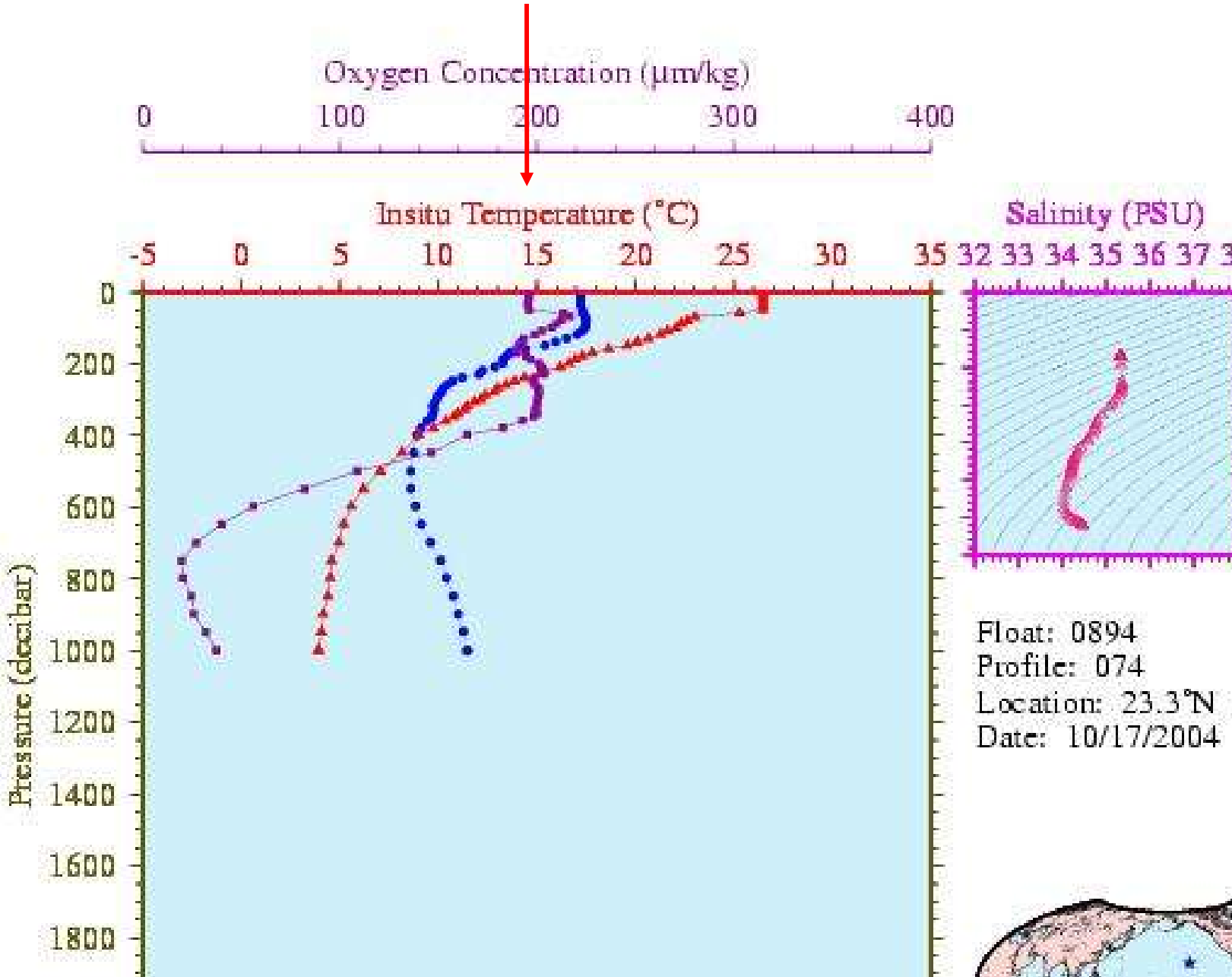

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 069
Location: 23.3°N
Date: 08/25/2004

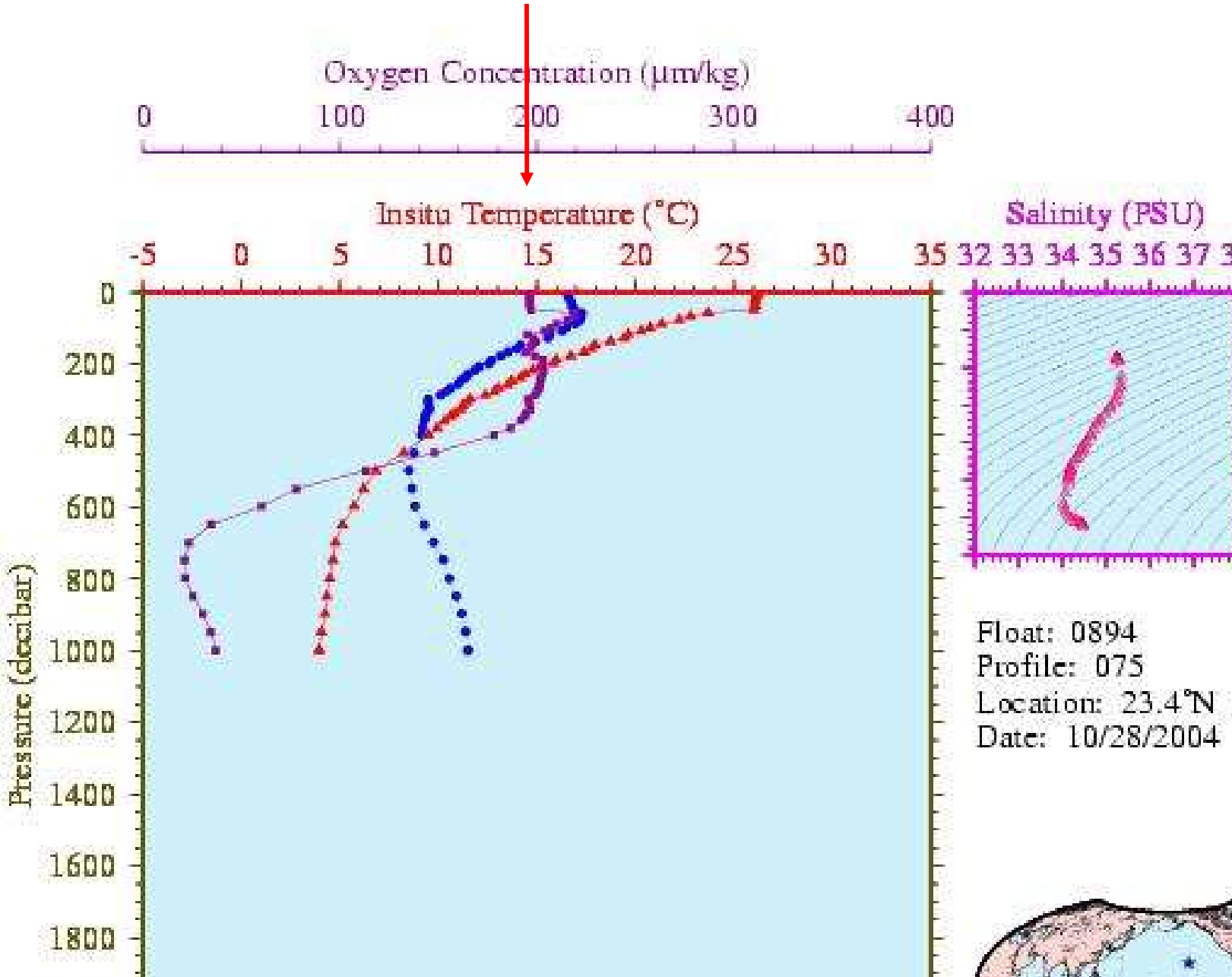

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 070
Location: 23.3°N
Date: 09/05/2004

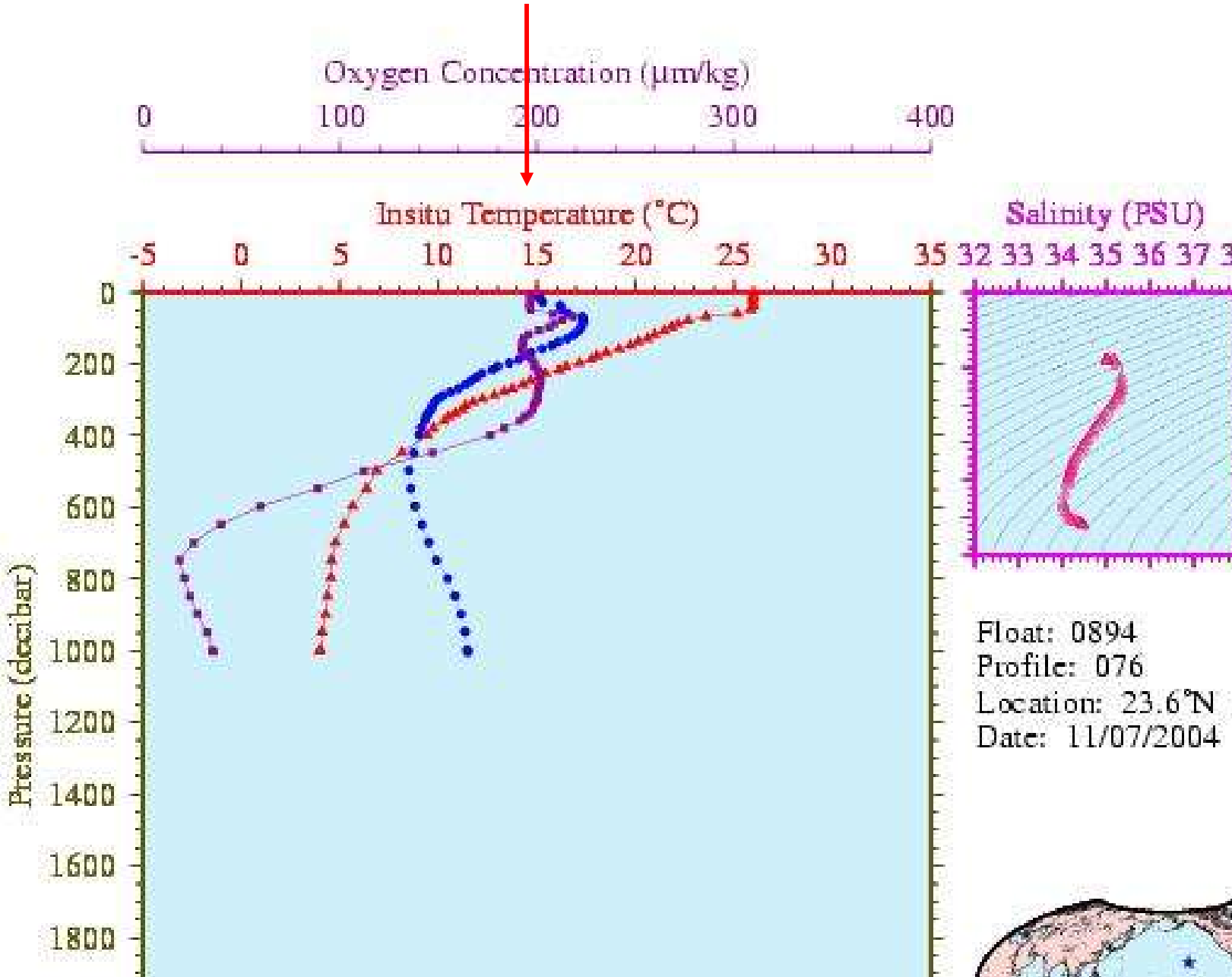

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 071
Location: 23.3°N
Date: 09/15/2004

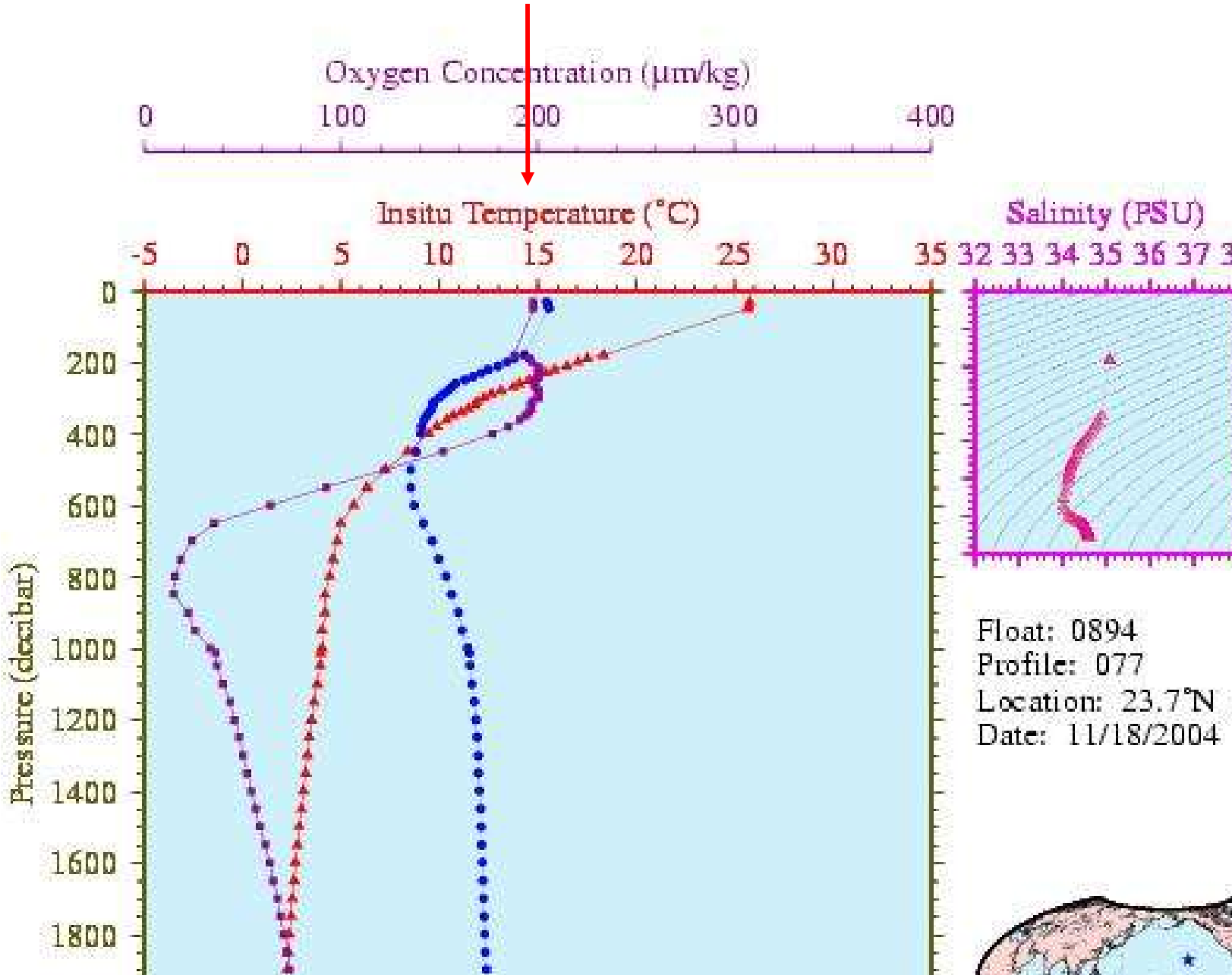

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 072
Location: 23.3°N
Date: 09/26/2004

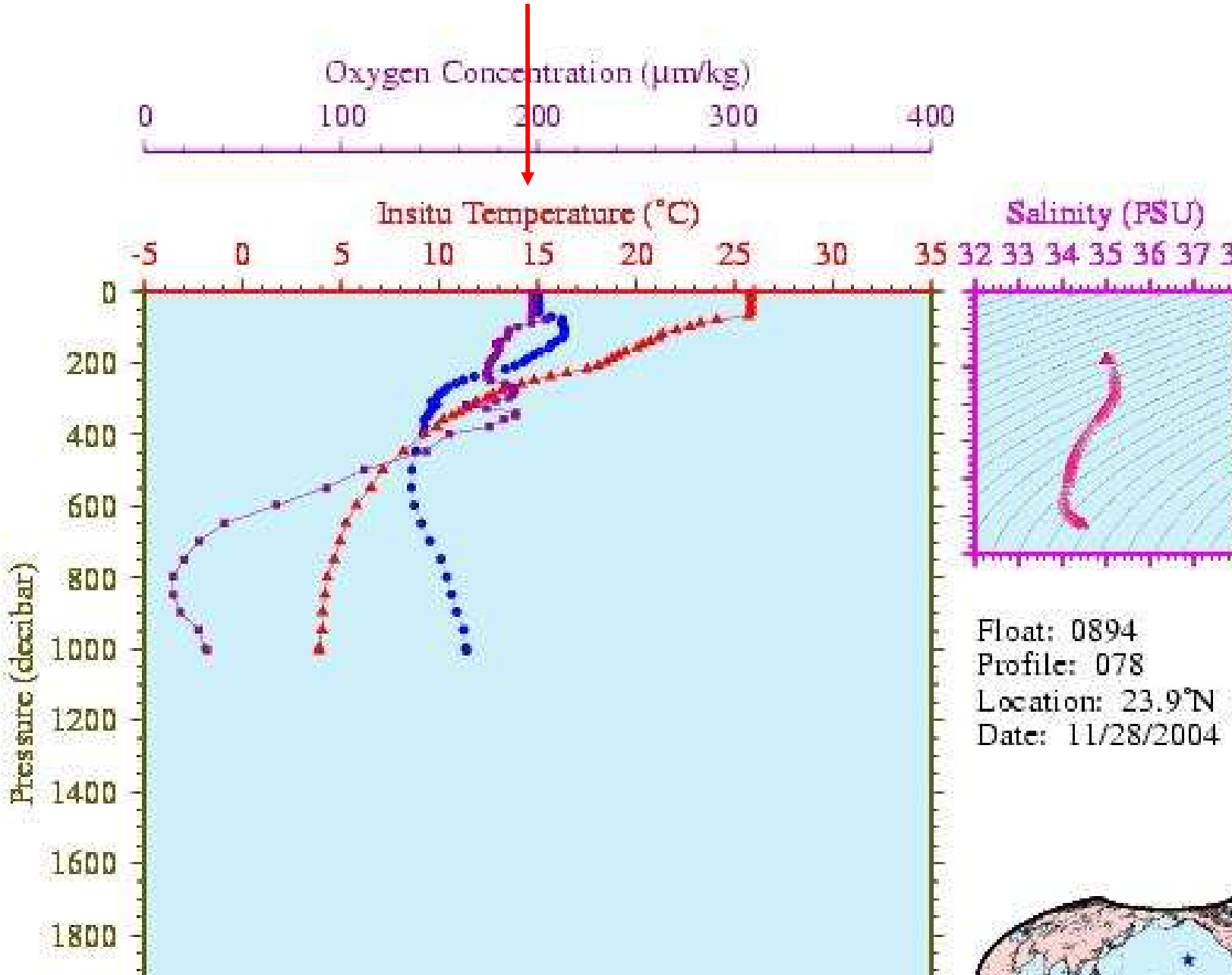

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 073
Location: 23.4°N
Date: 10/07/2004

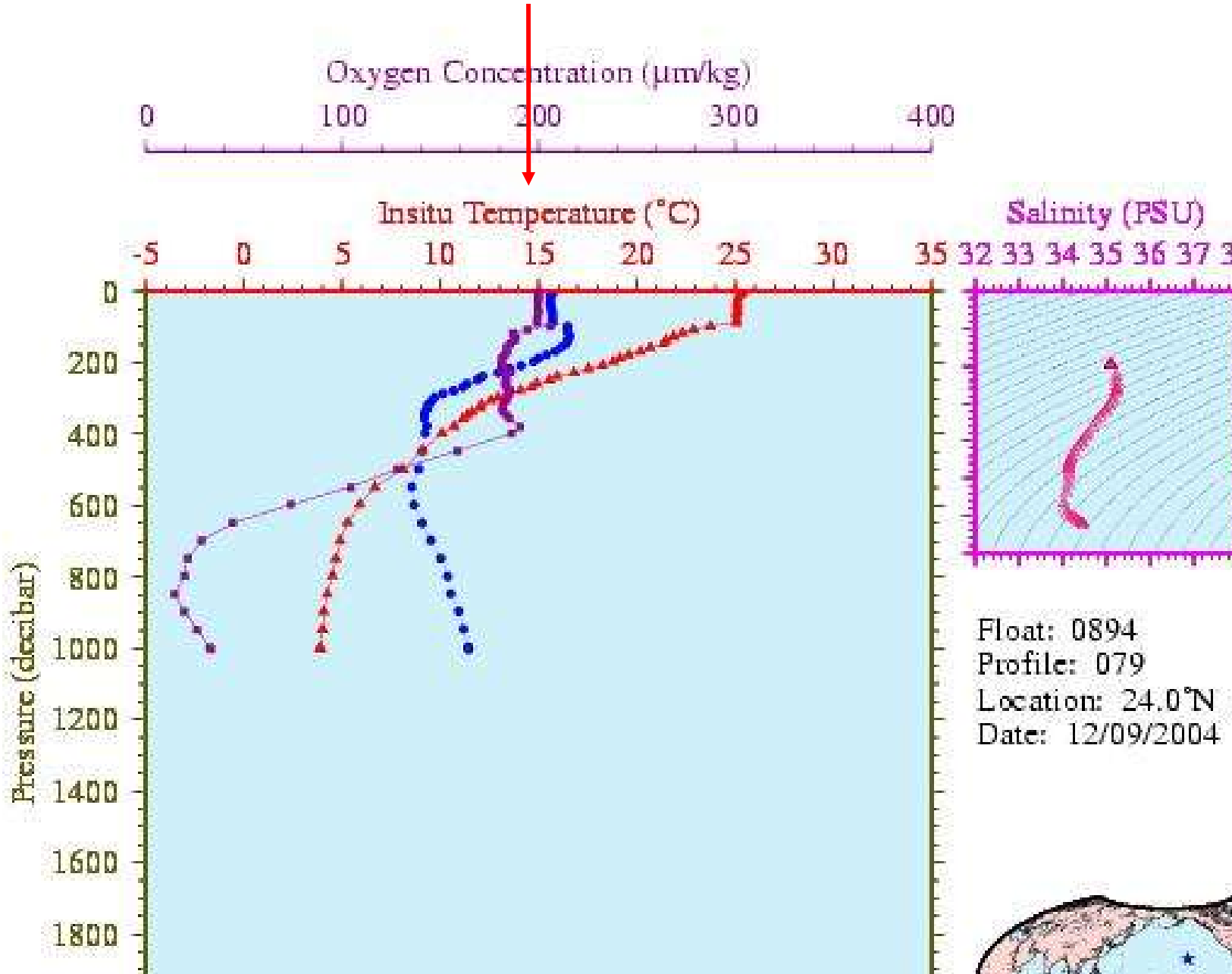

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 074
Location: 23.3°N
Date: 10/17/2004

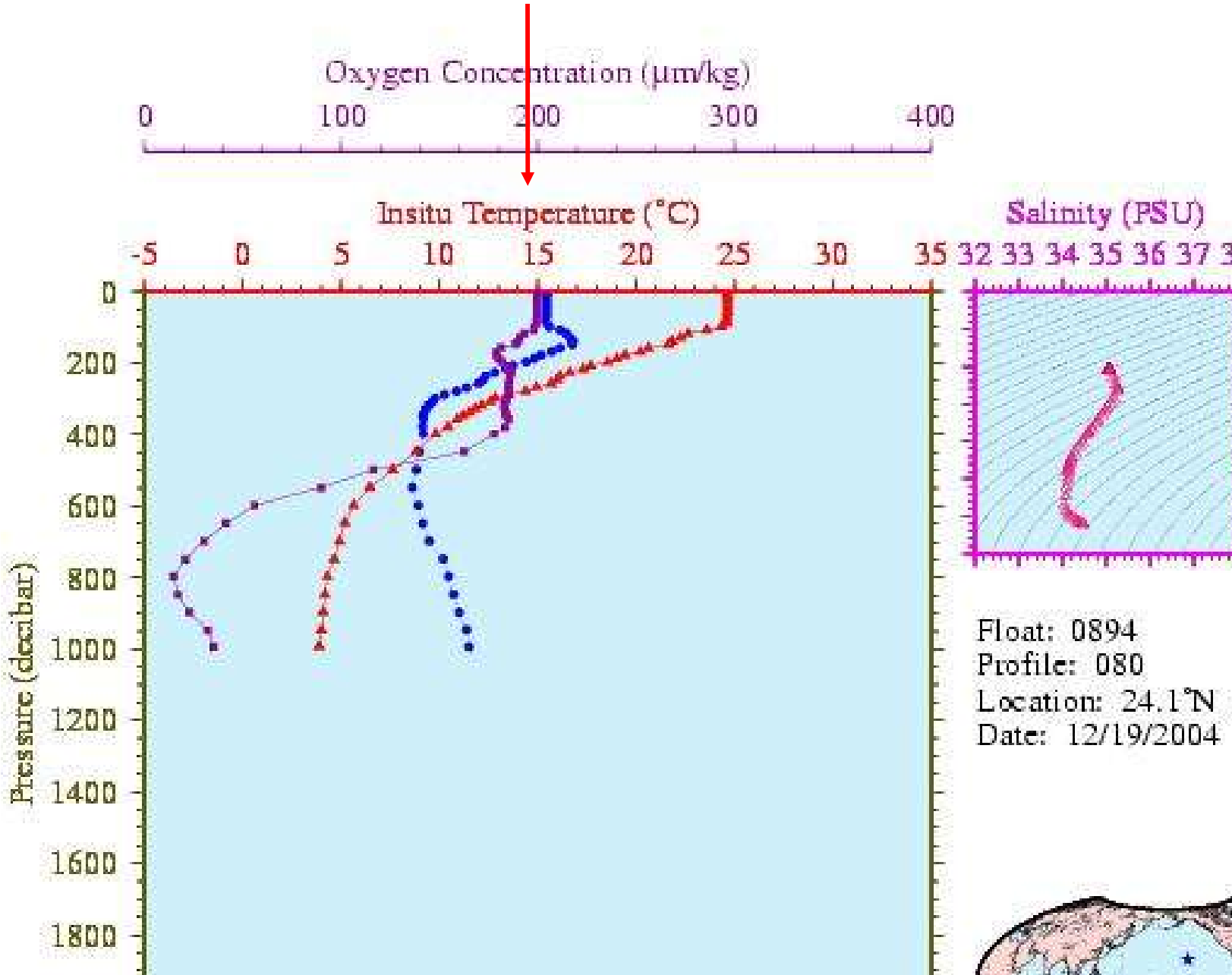

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 075
Location: 23.4°N
Date: 10/28/2004

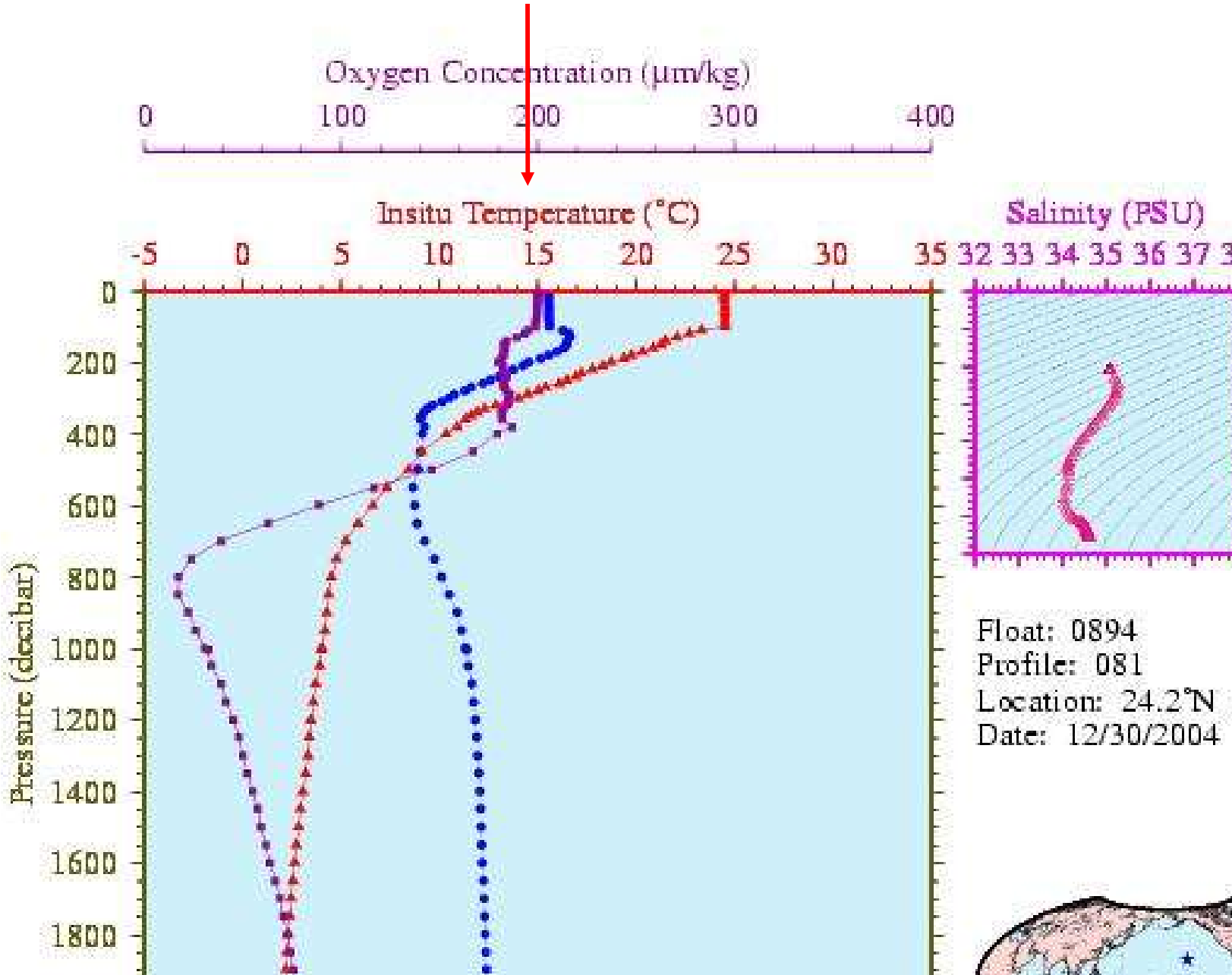

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 076
Location: 23.6°N
Date: 11/07/2004

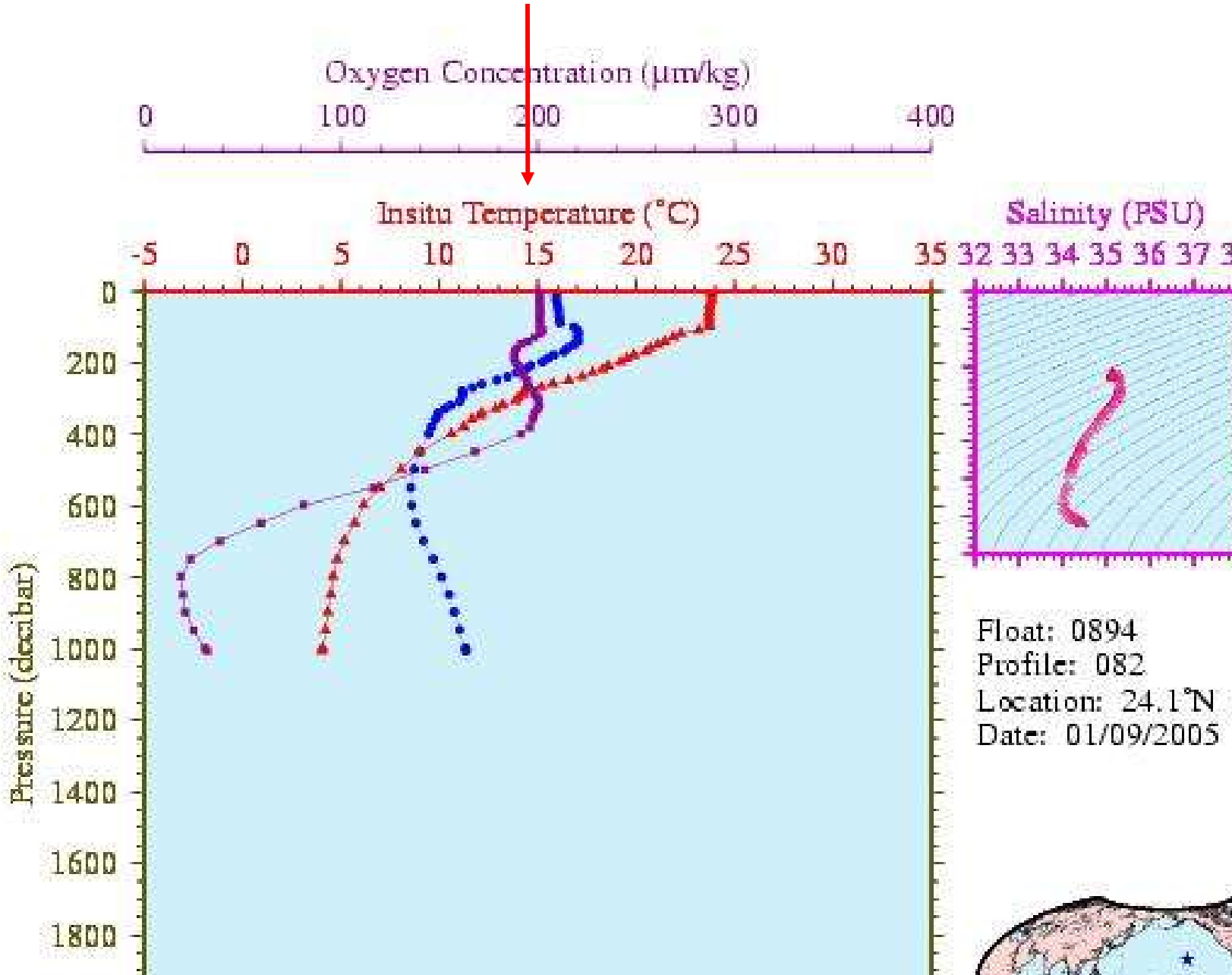

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 077
Location: 23.7°N
Date: 11/18/2004

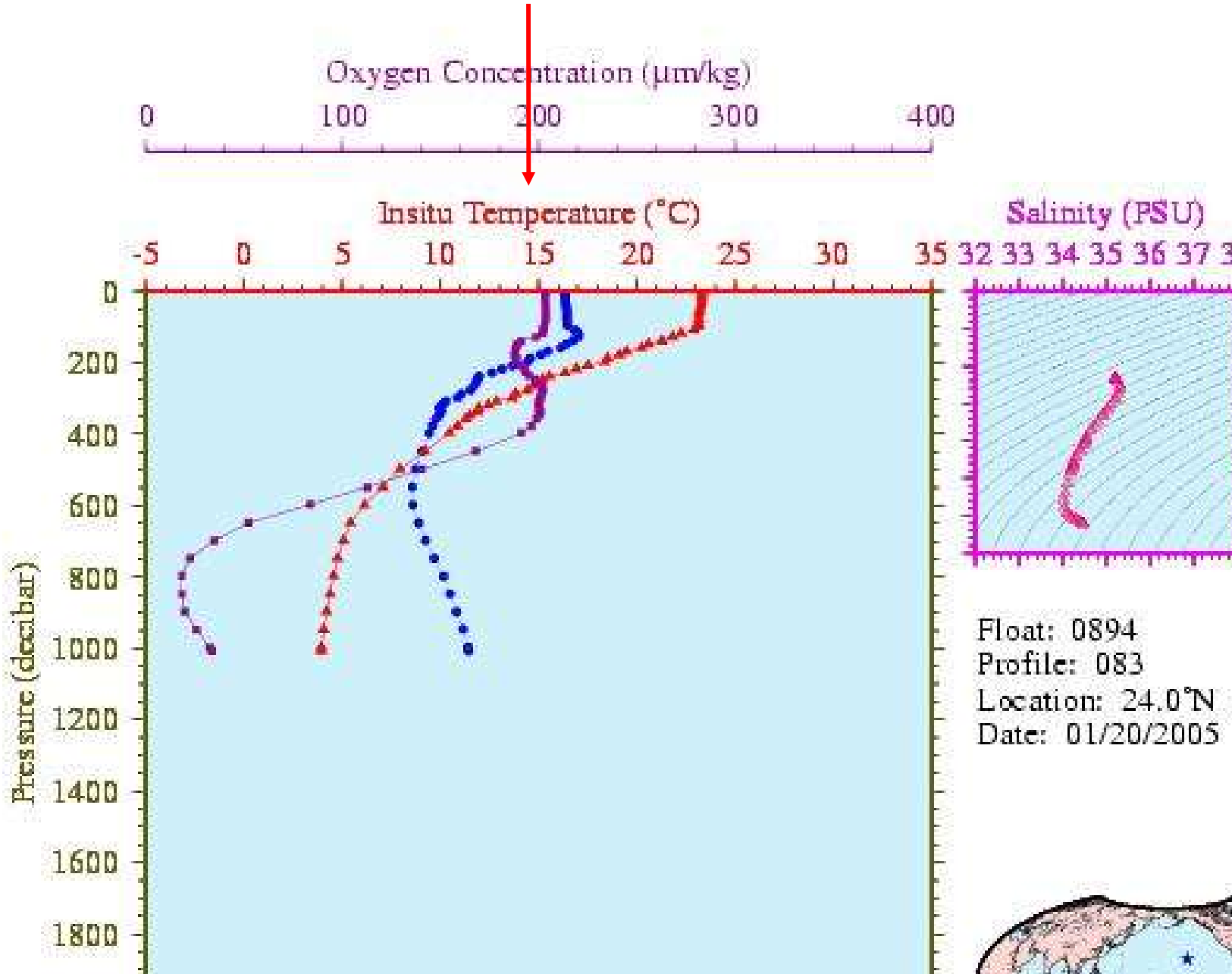

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 078
Location: 23.9°N
Date: 11/28/2004

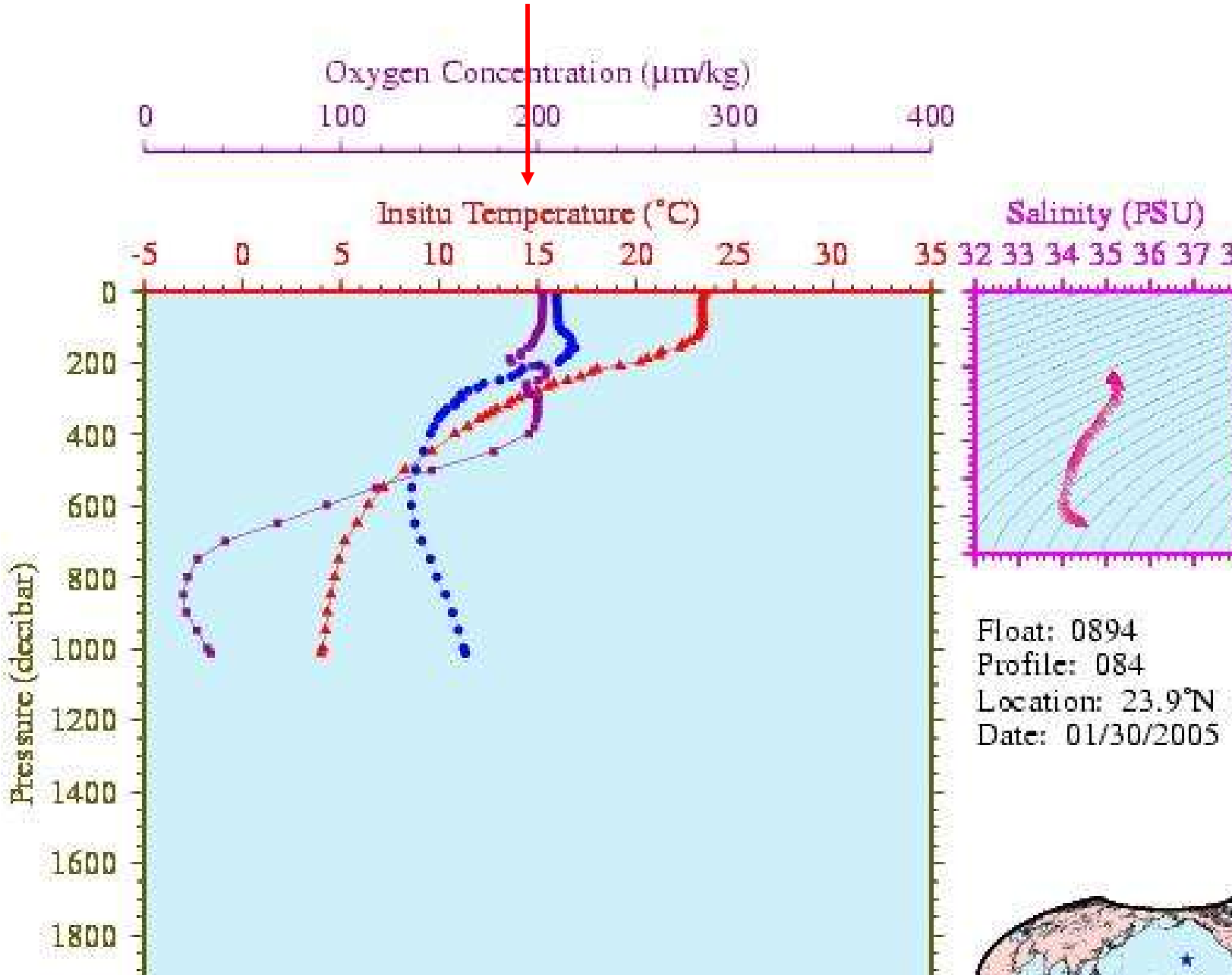

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 079
Location: 24.0°N
Date: 12/09/2004

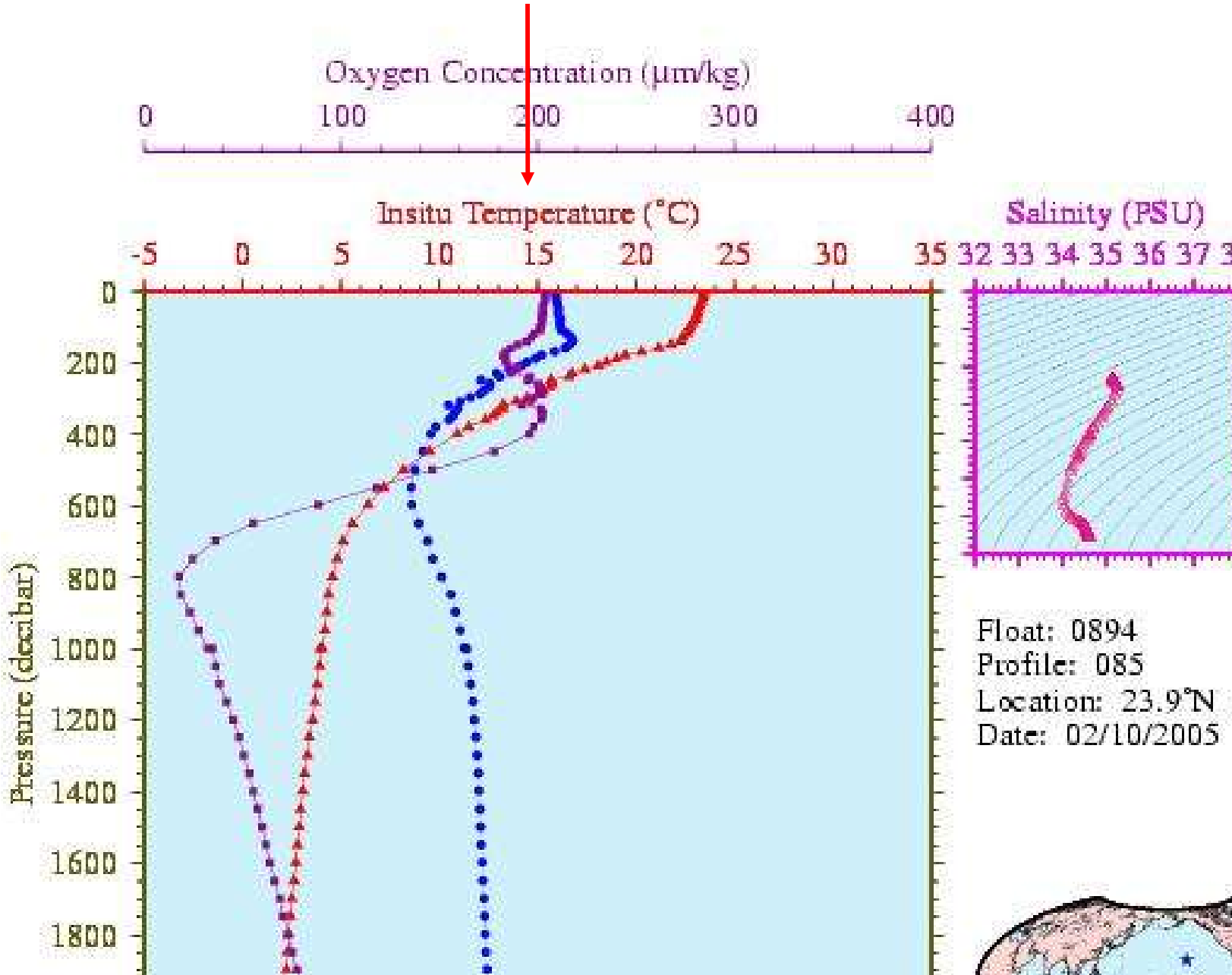

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 080
Location: 24.1°N
Date: 12/19/2004

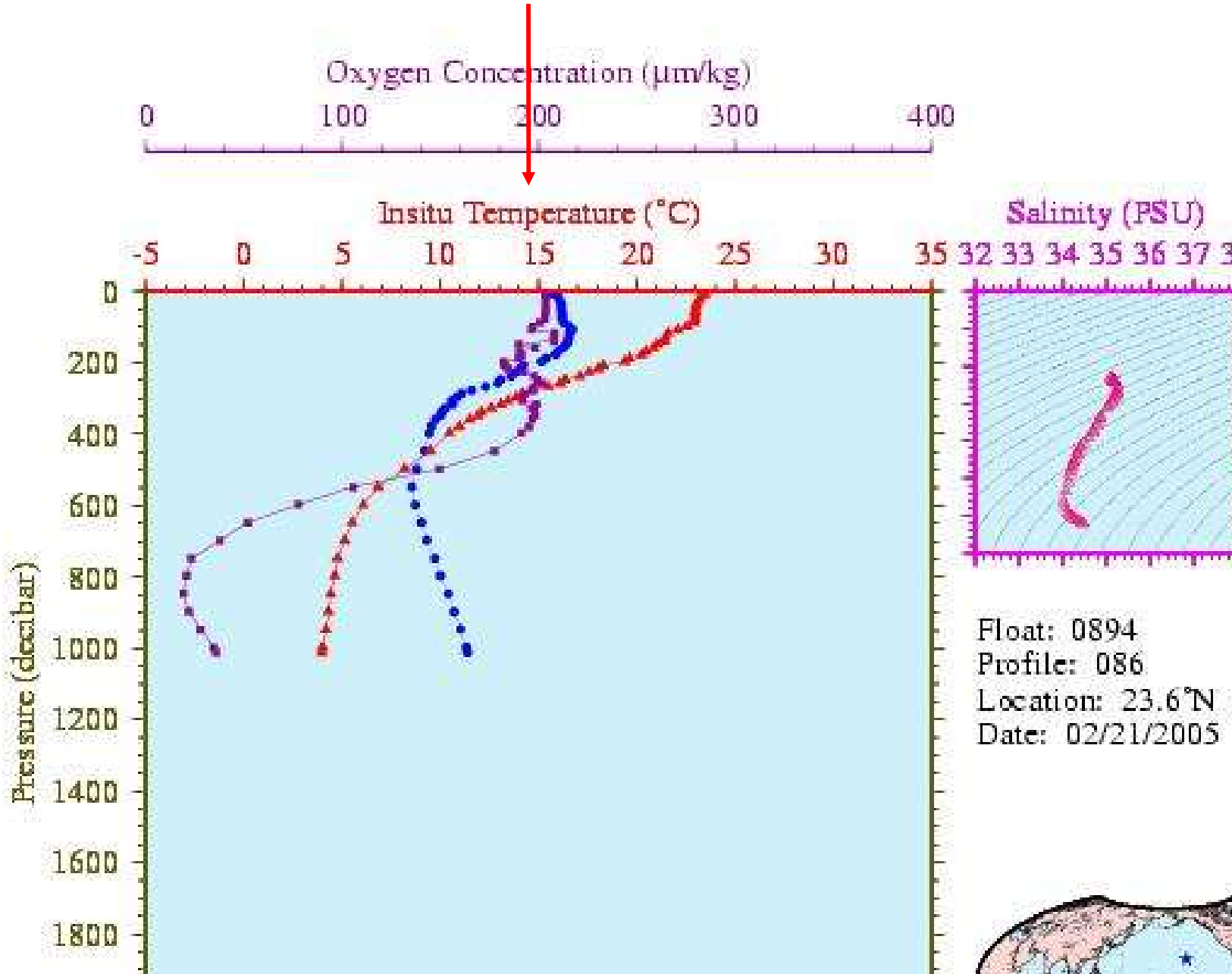

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 081
Location: 24.2°N
Date: 12/30/2004

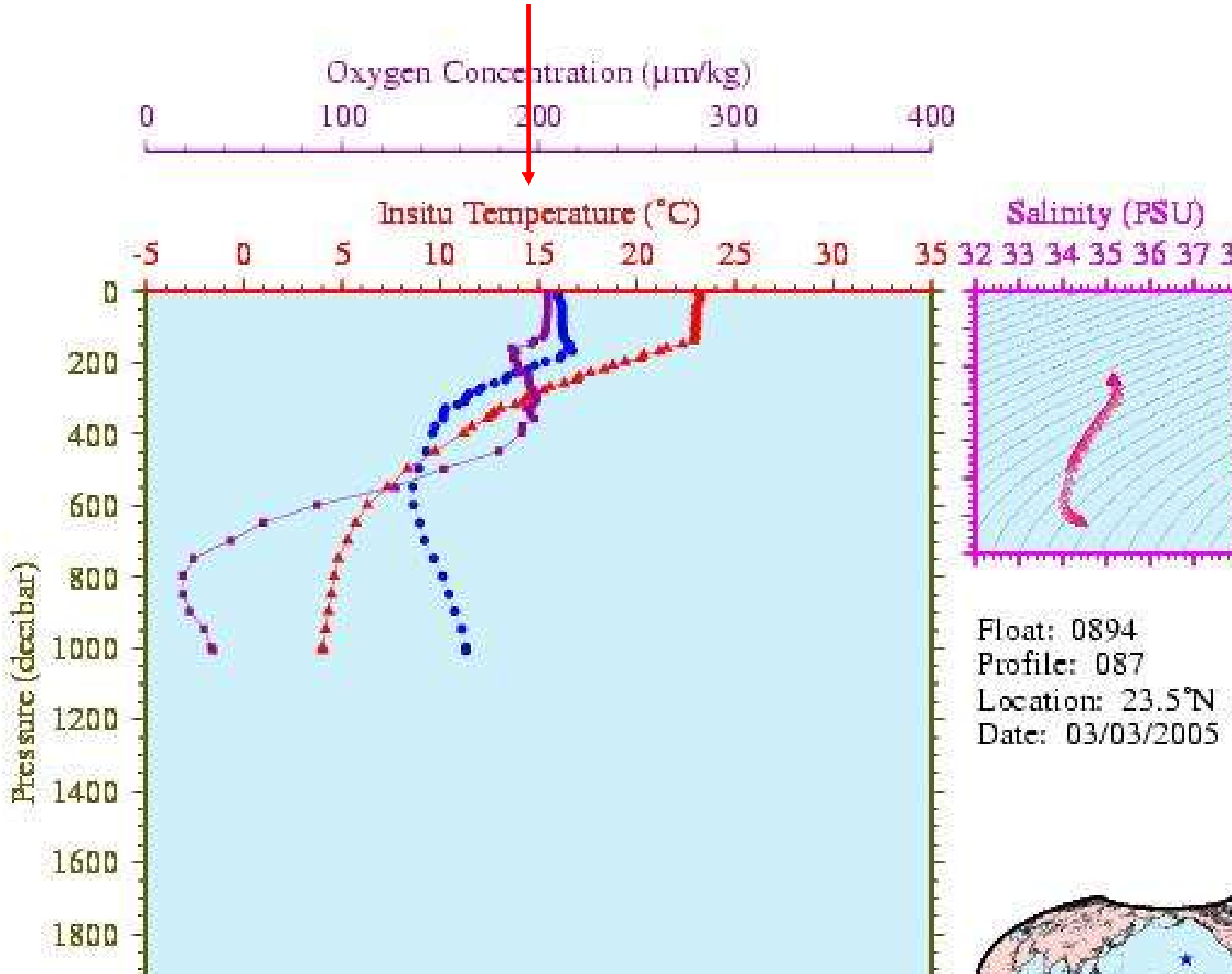

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 082
Location: 24.1°N
Date: 01/09/2005

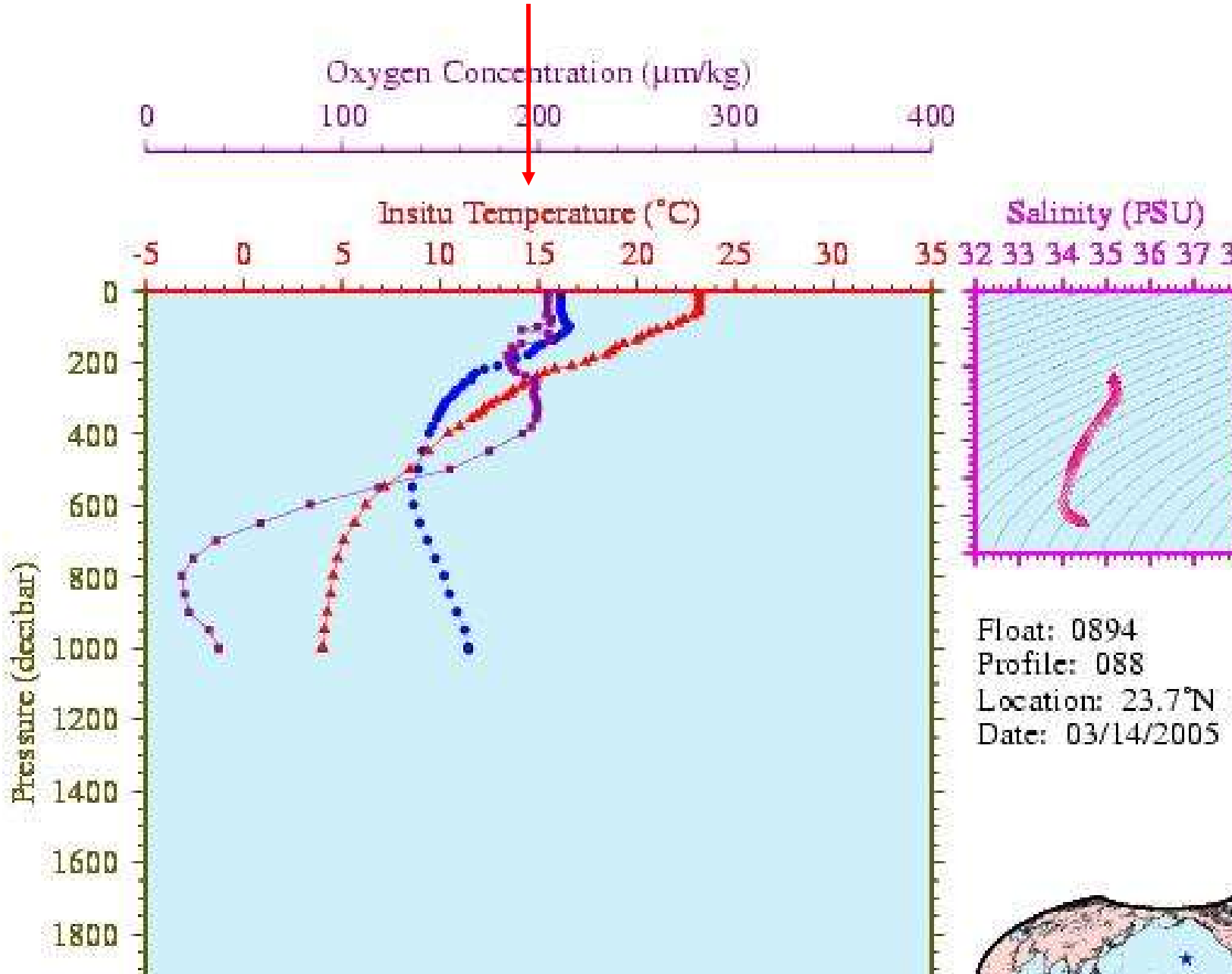

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 083
Location: 24.0°N
Date: 01/20/2005

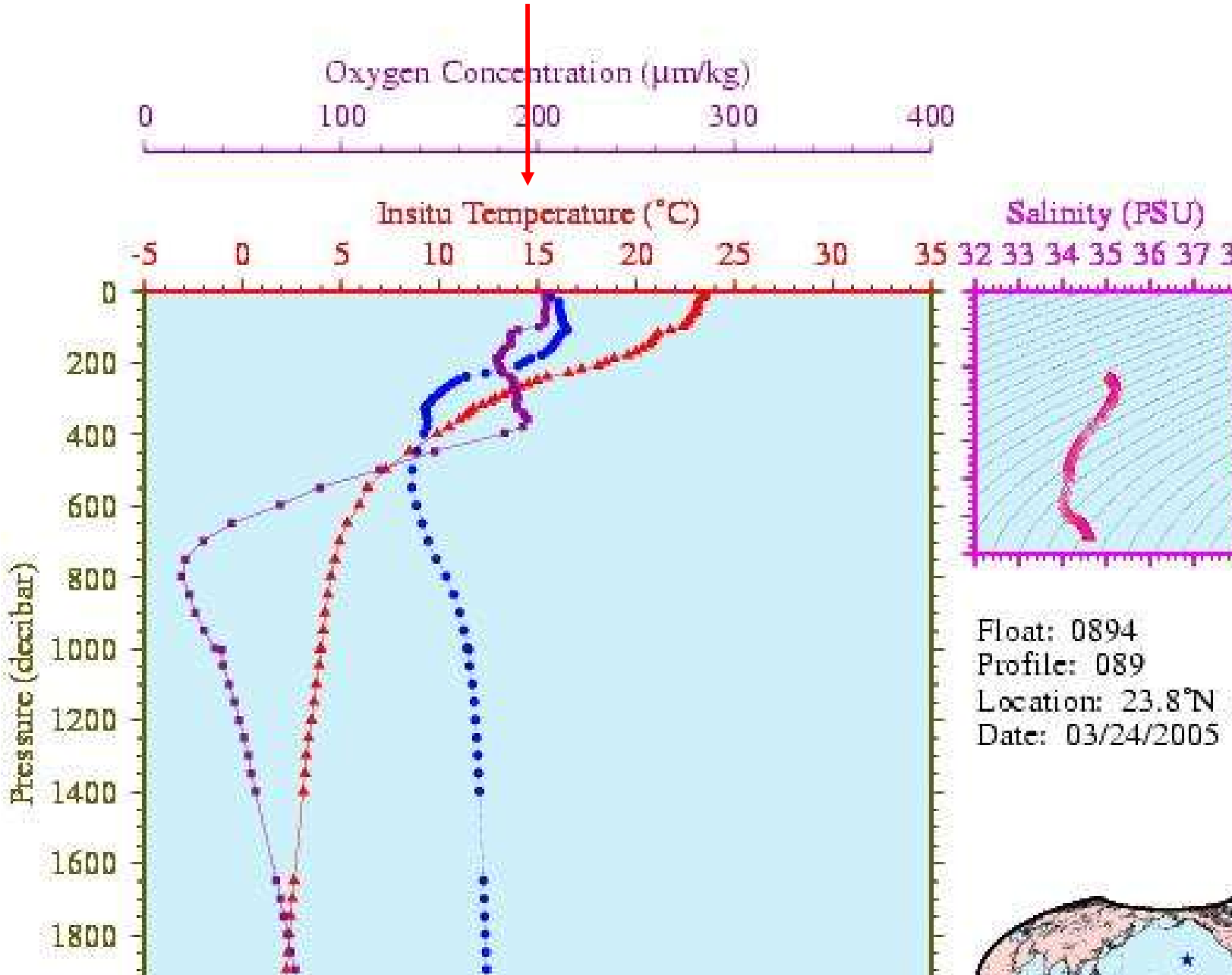

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 084
Location: 23.9°N
Date: 01/30/2005

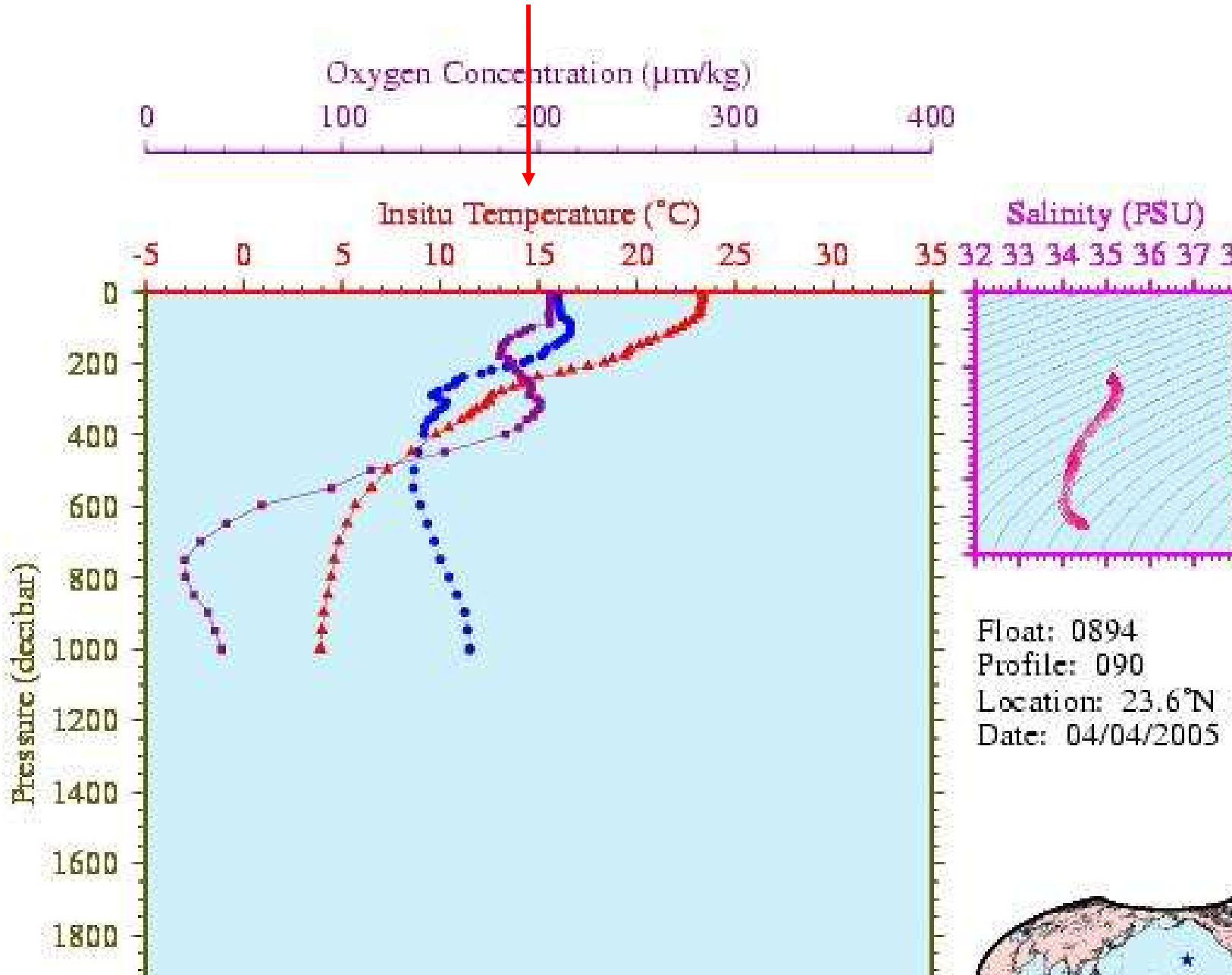

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 085
Location: 23.9°N
Date: 02/10/2005

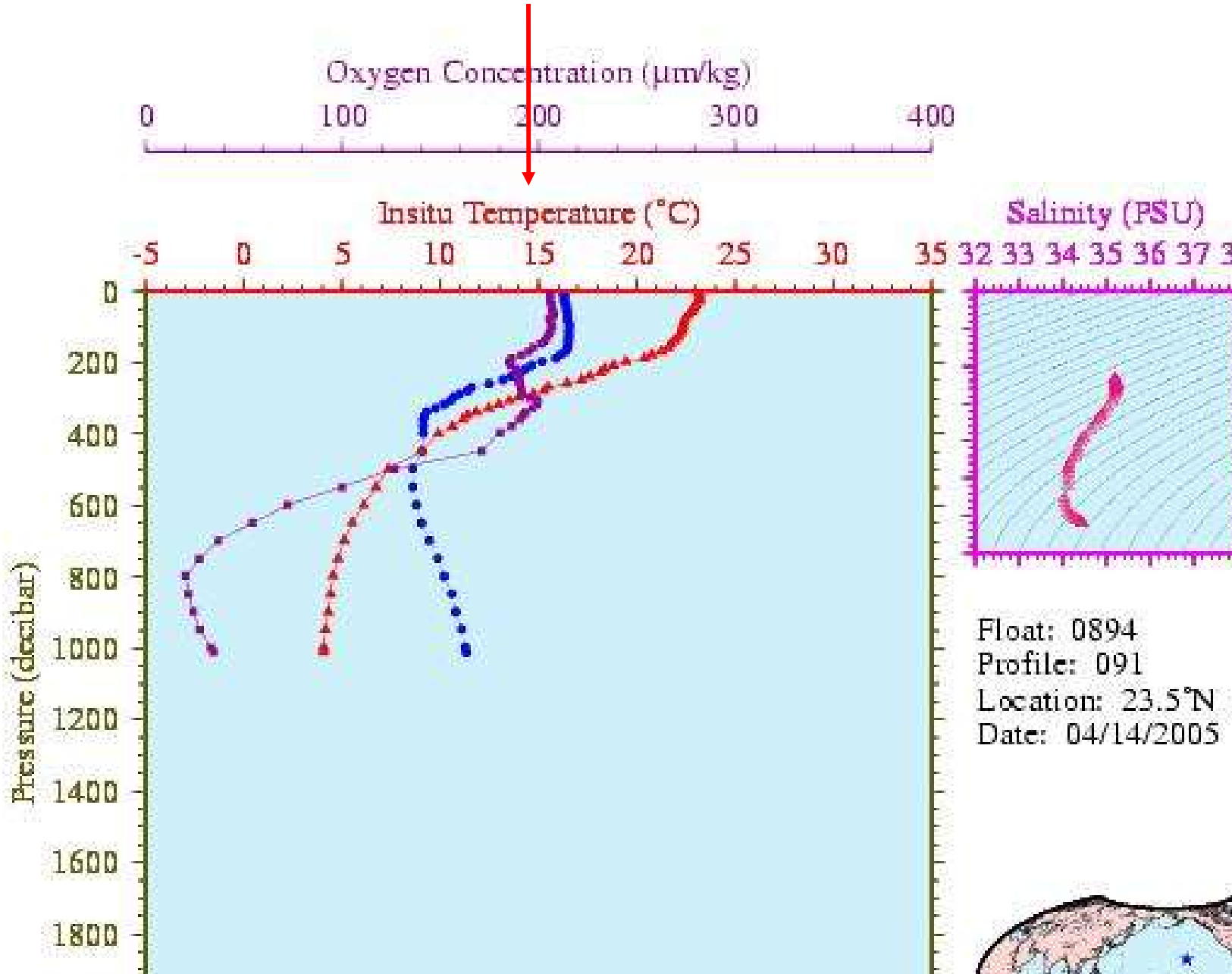

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 086
Location: 23.6°N
Date: 02/21/2005

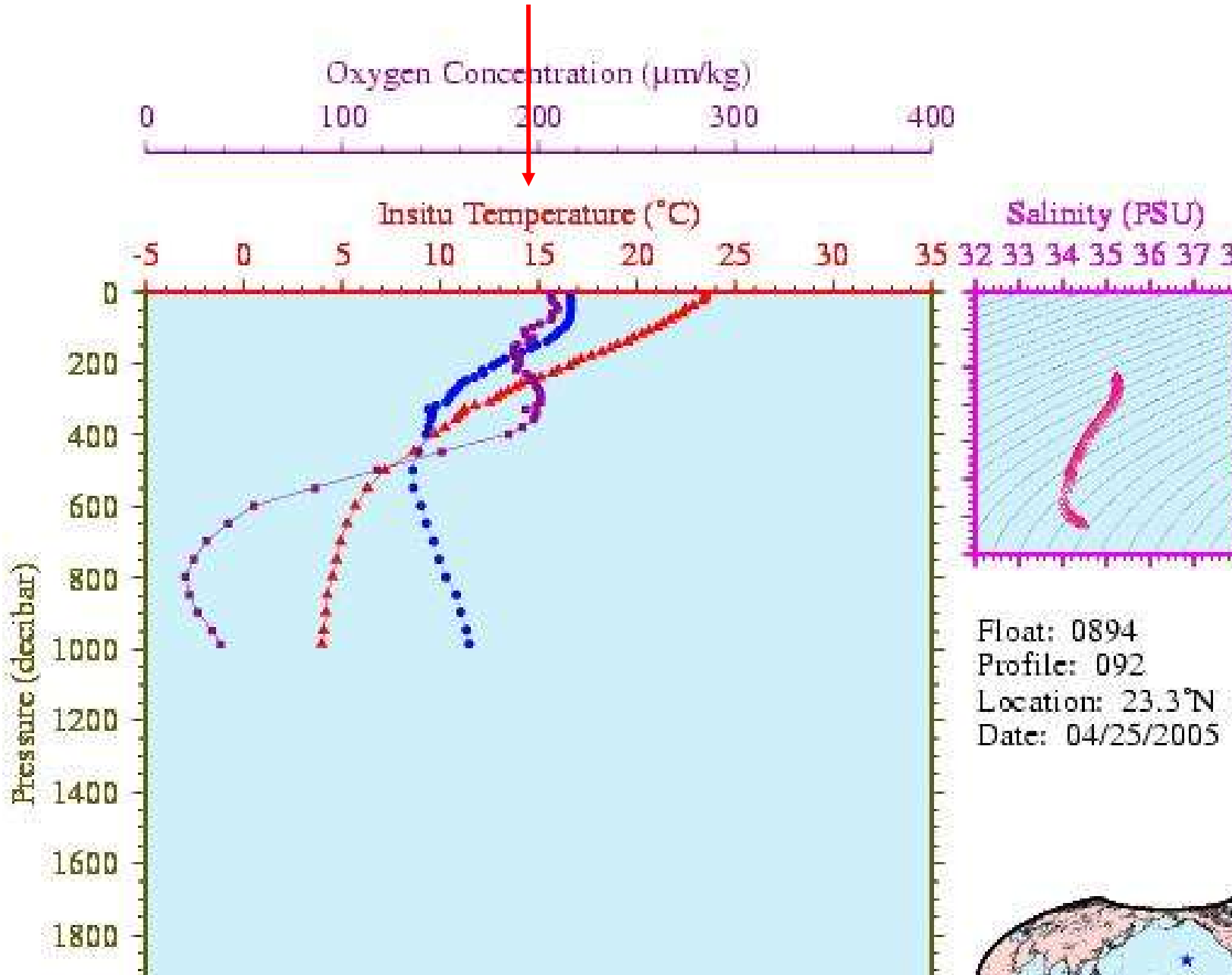

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 087
Location: 23.5°N
Date: 03/03/2005

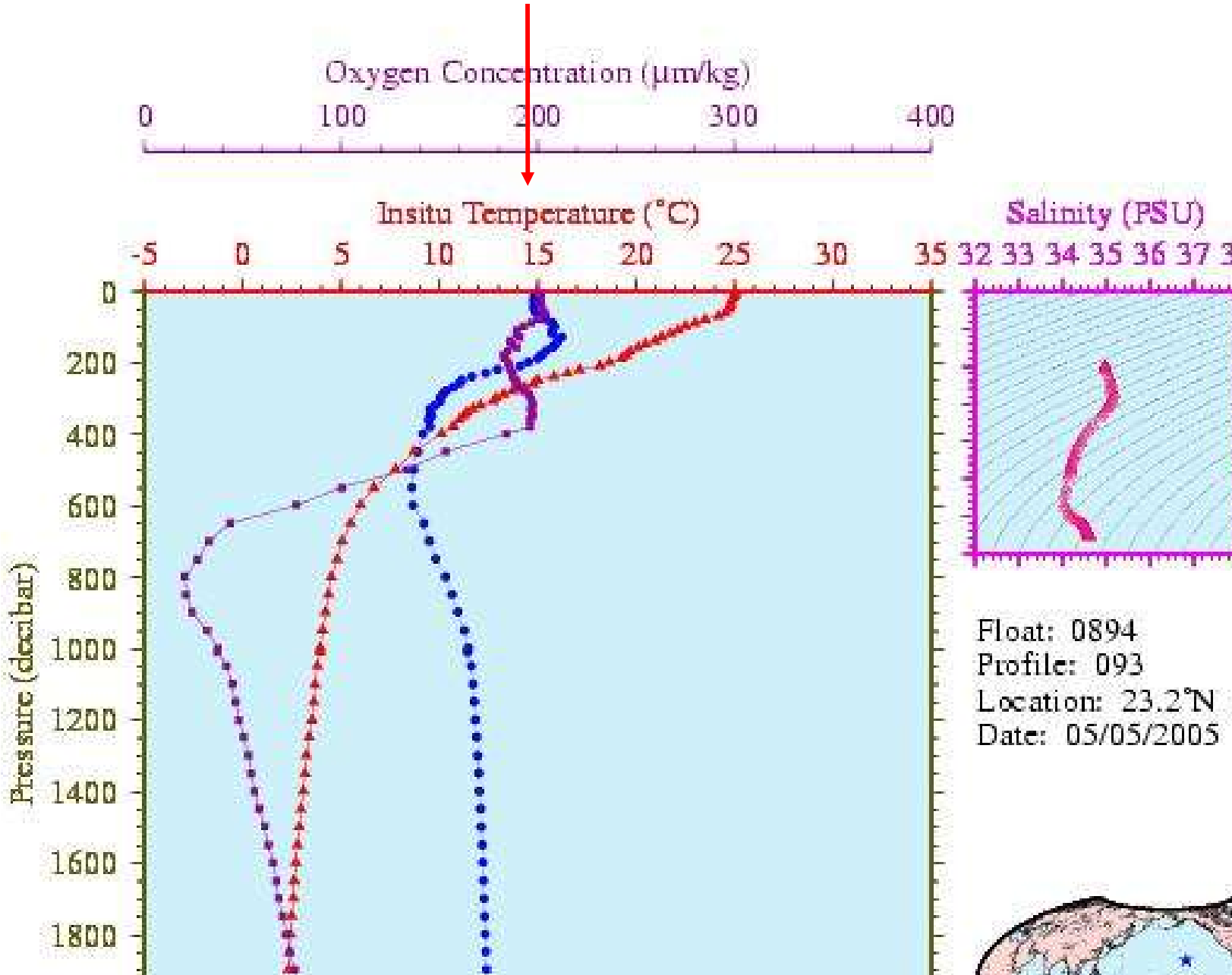

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 088
Location: 23.7°N
Date: 03/14/2005

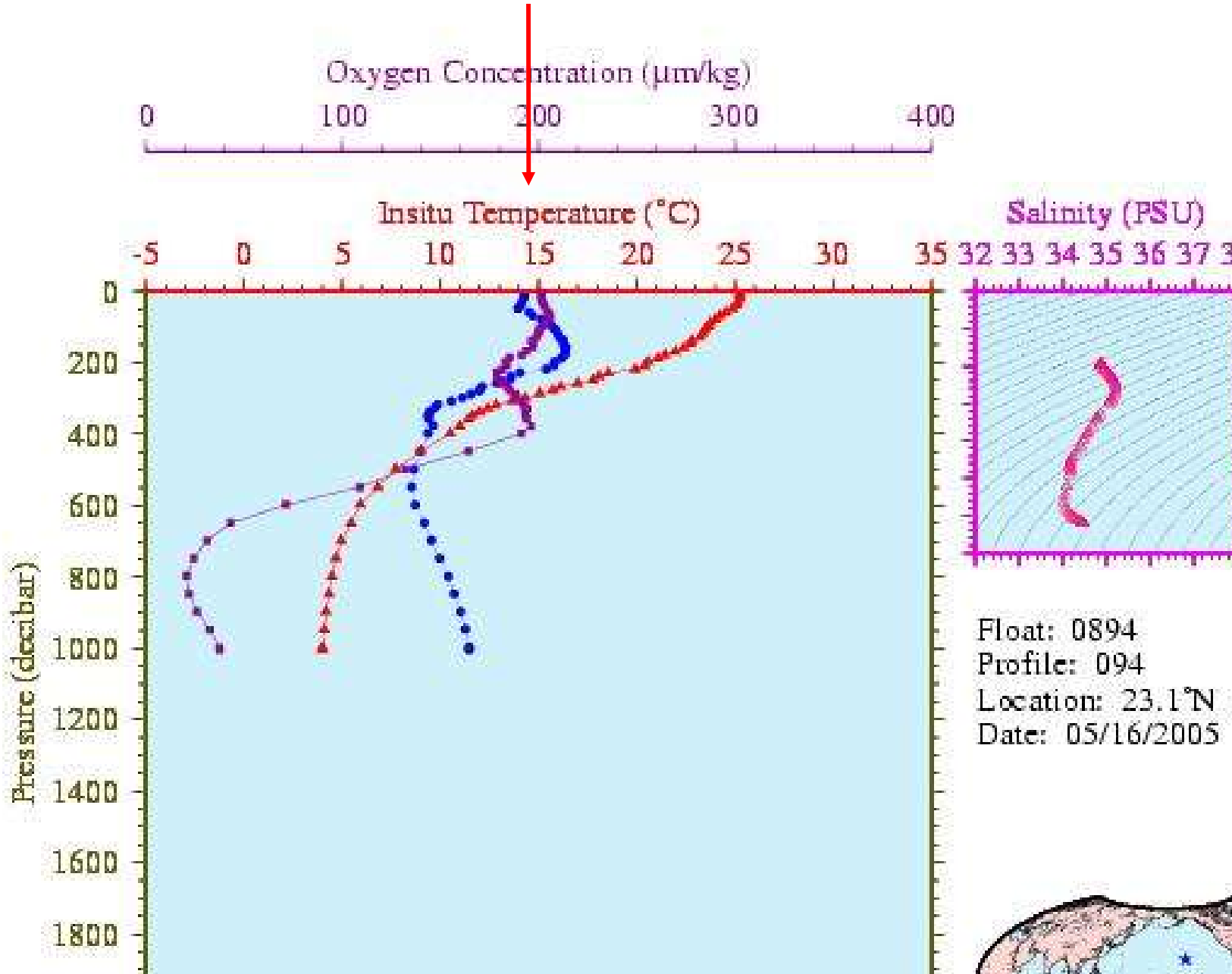

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 089
Location: 23.8°N
Date: 03/24/2005

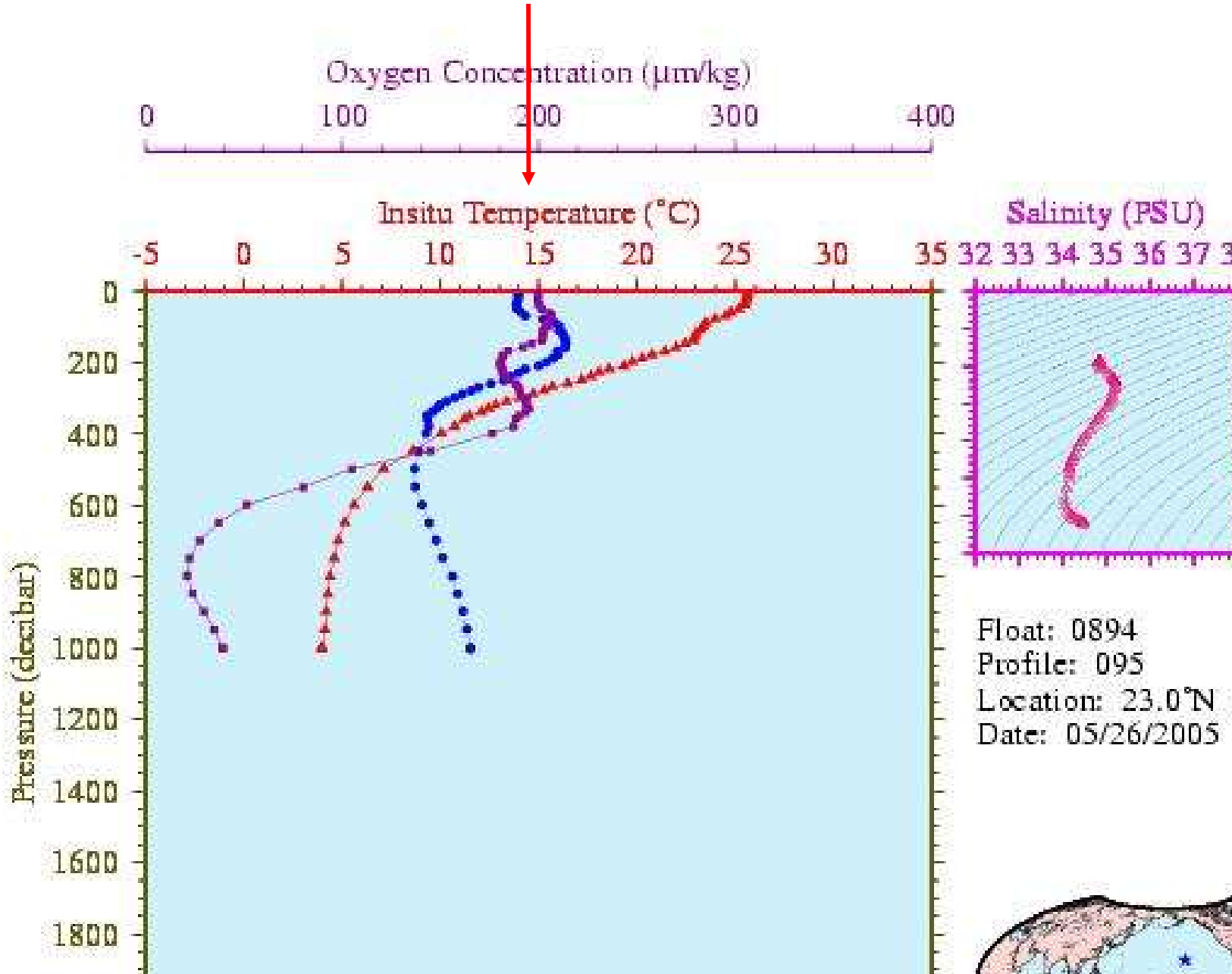

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 090
Location: 23.6°N
Date: 04/04/2005

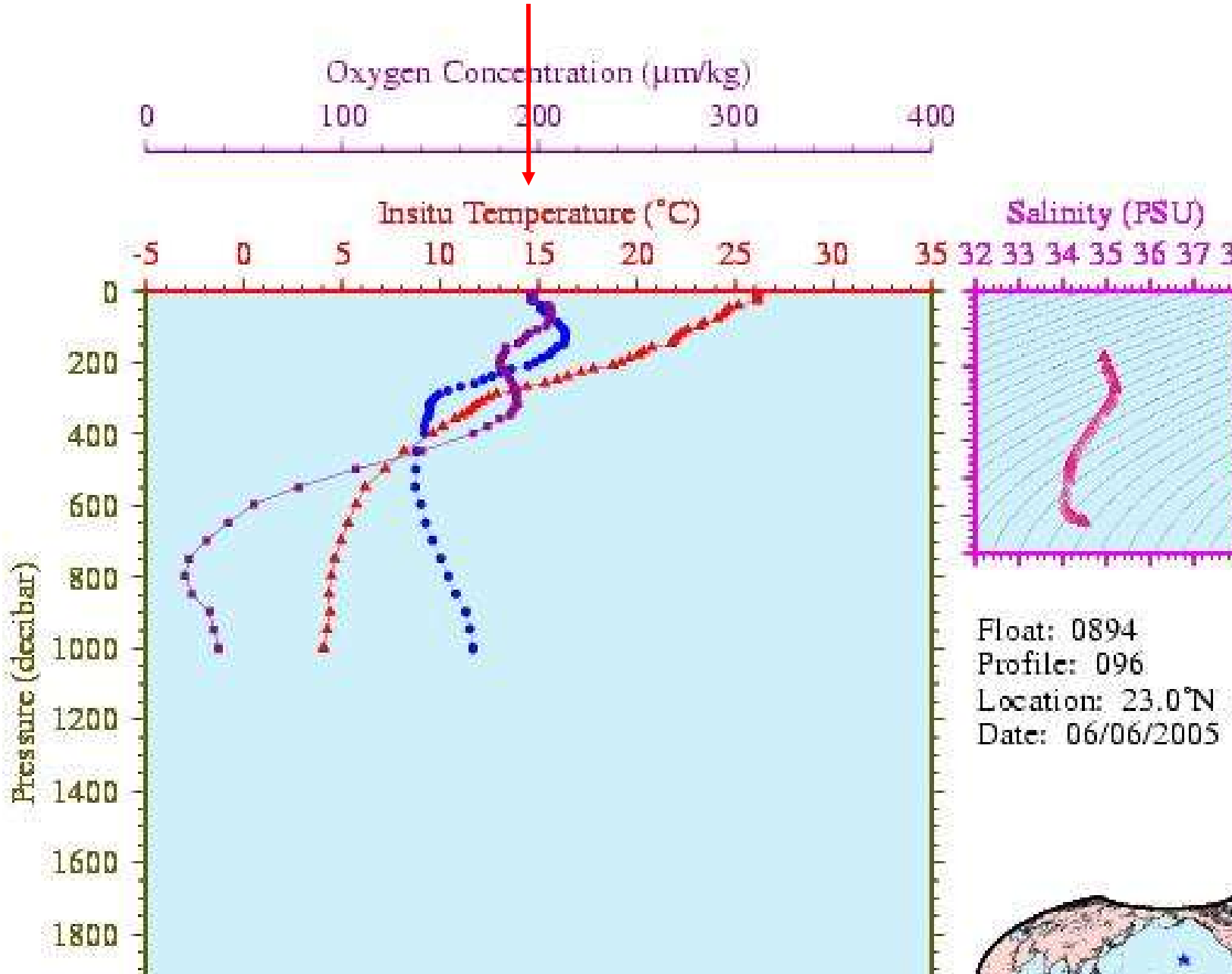

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 091
Location: 23.5°N
Date: 04/14/2005

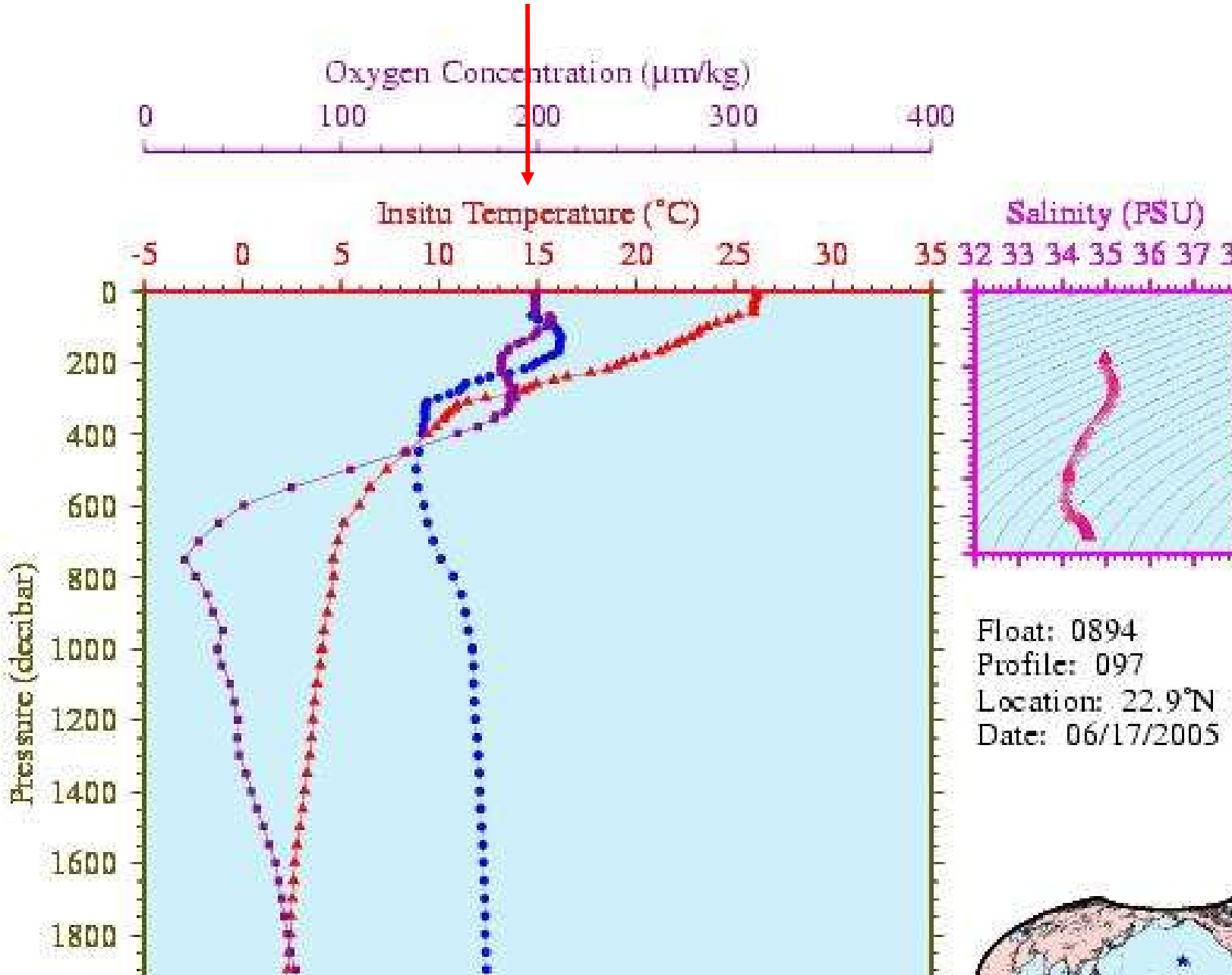

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 092
Location: 23.3°N
Date: 04/25/2005

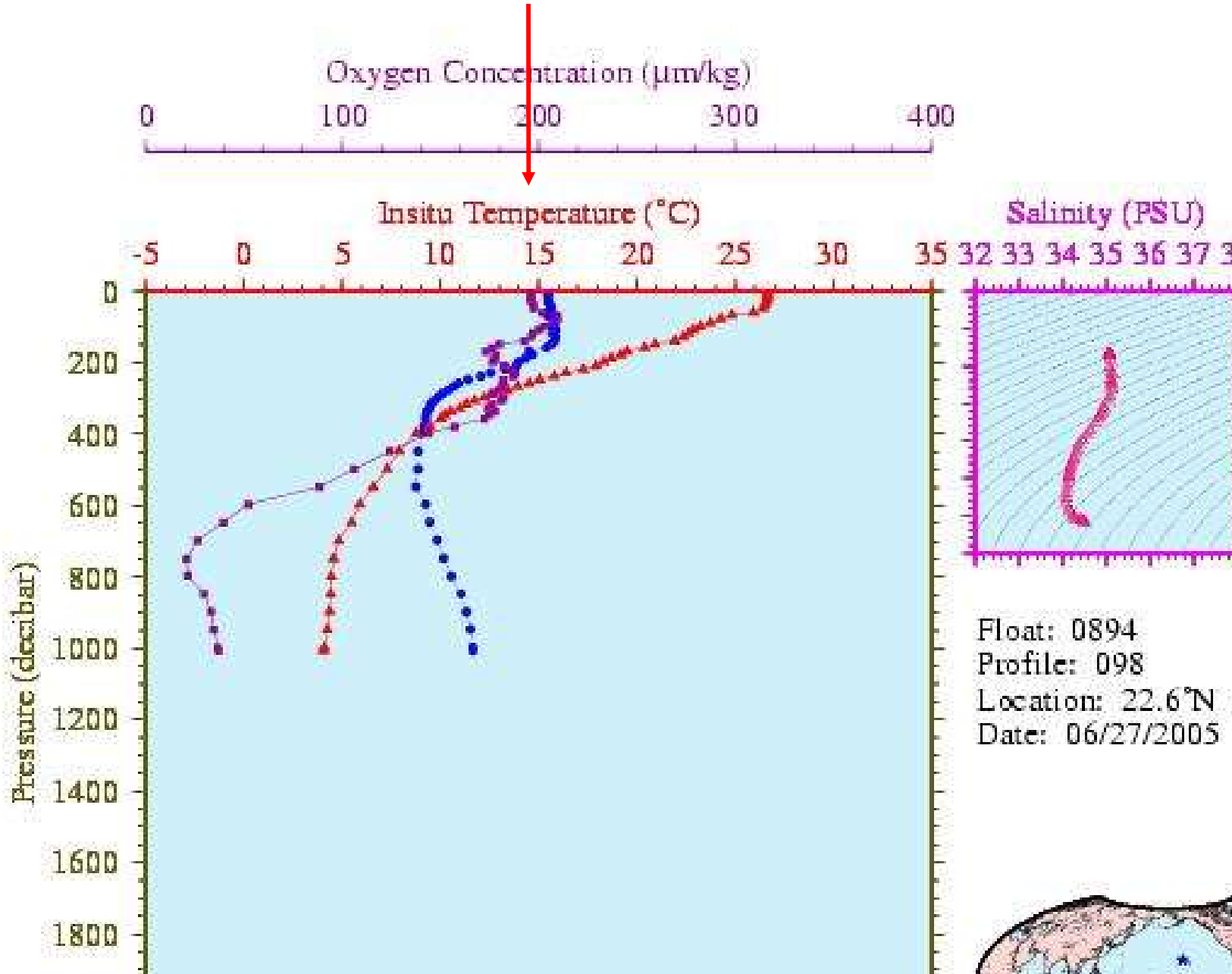

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 093
Location: 23.2°N
Date: 05/05/2005

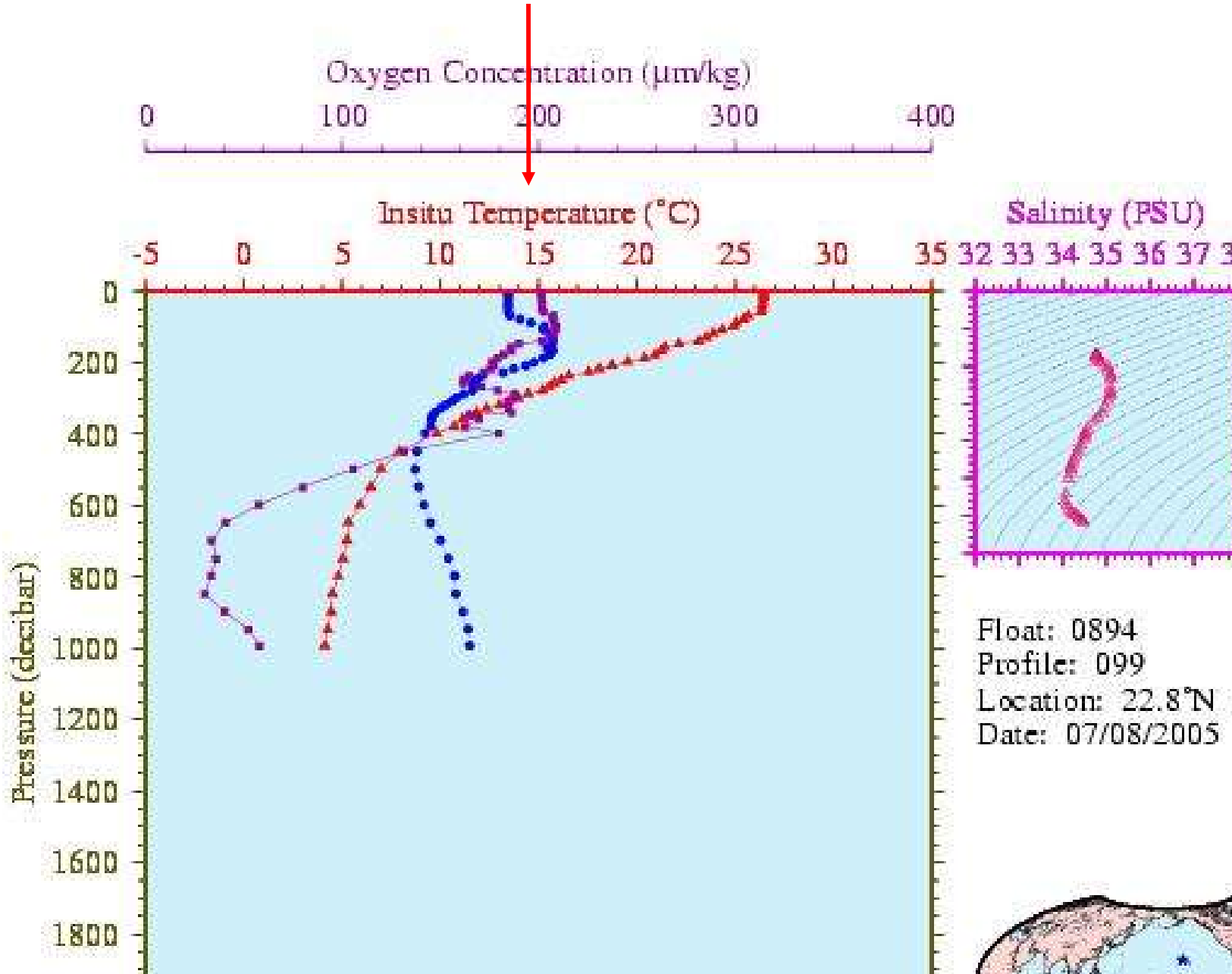

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 094
Location: 23.1°N
Date: 05/16/2005

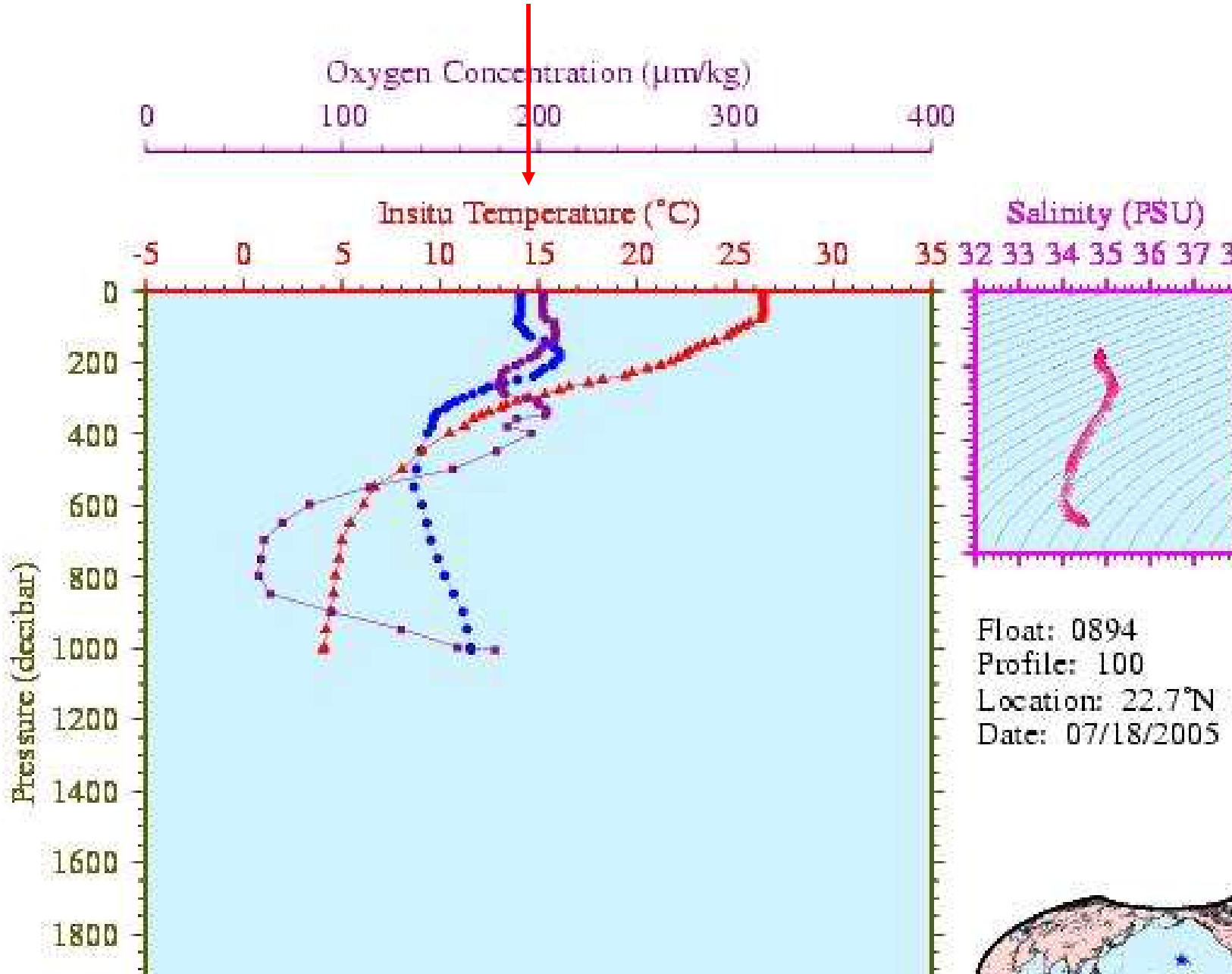

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 095
Location: 23.0°N
Date: 05/26/2005

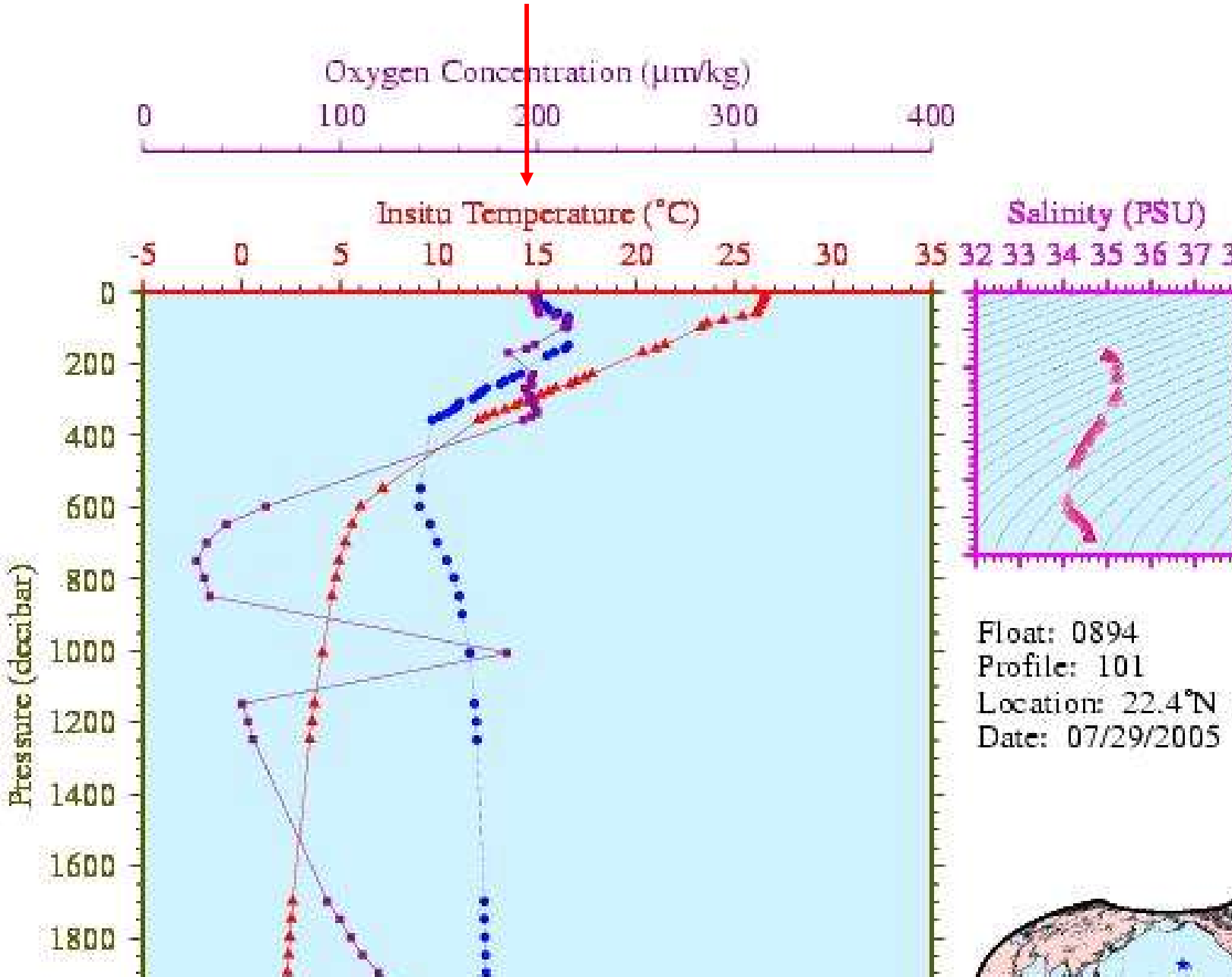

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 096
Location: 23.0°N
Date: 06/06/2005


Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 097
Location: 22.9°N
Date: 06/17/2005

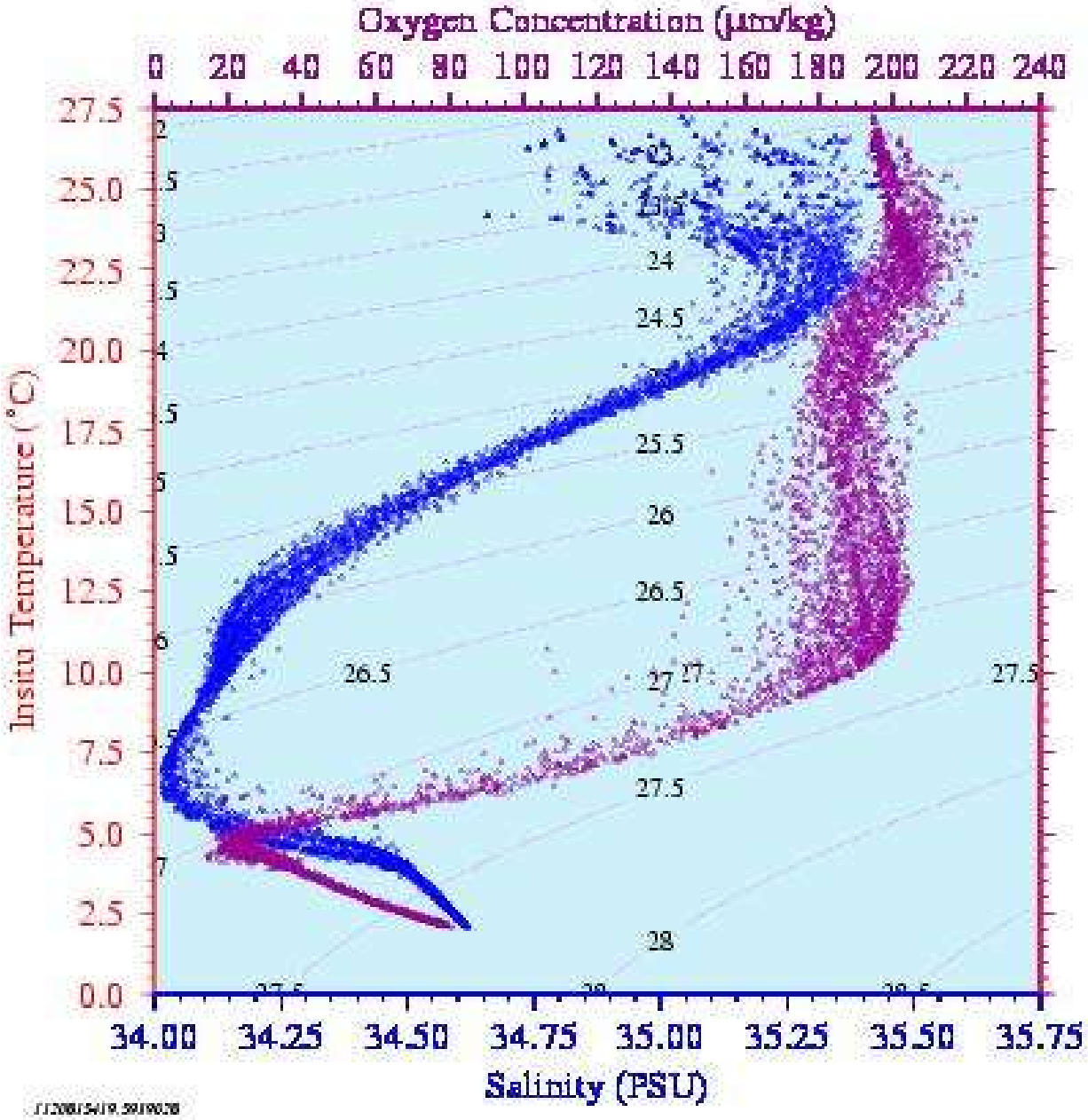

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 098
Location: 22.6°N
Date: 06/27/2005

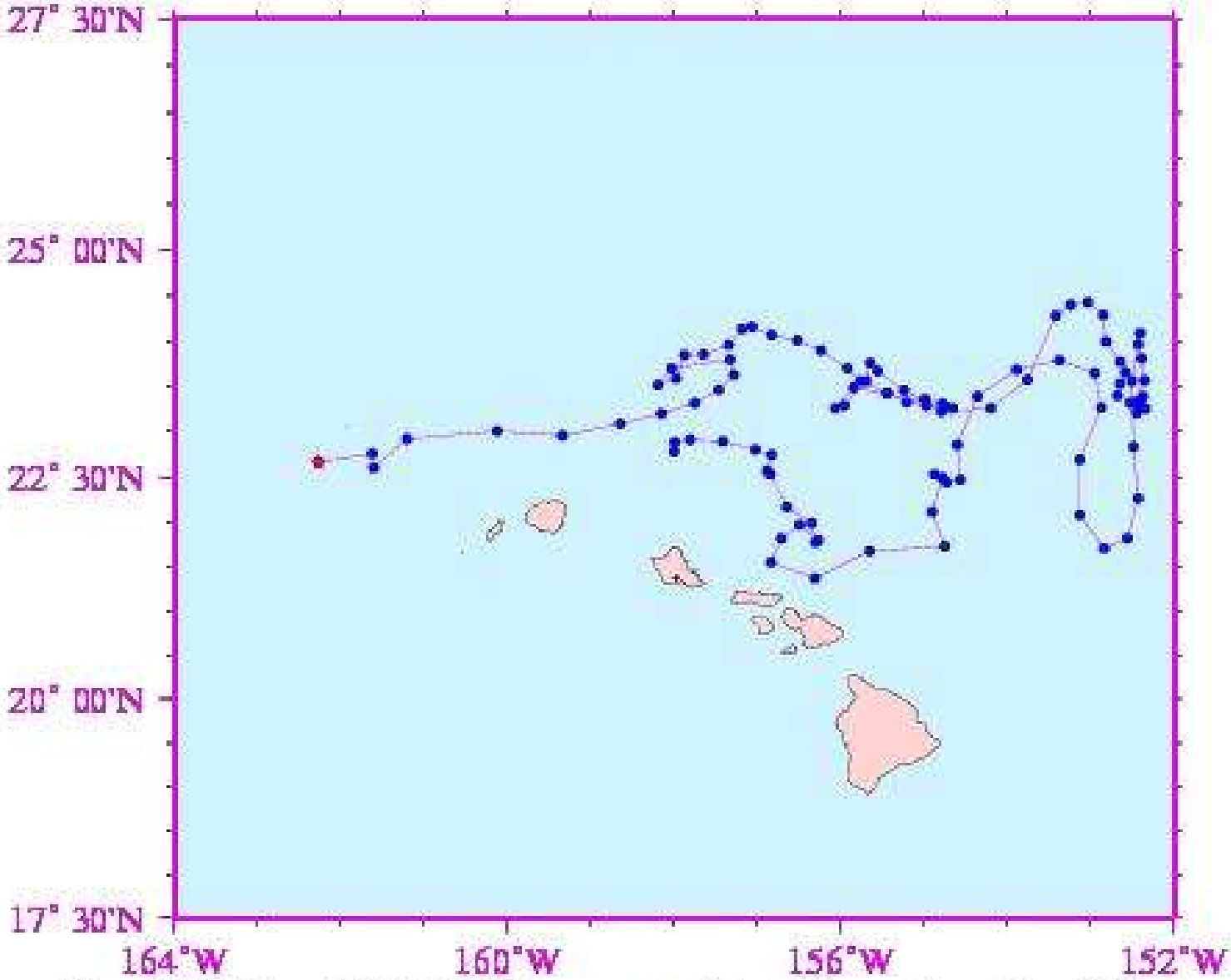

Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 099
Location: 22.8°N
Date: 07/08/2005


Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 100
Location: 22.7°N
Date: 07/18/2005


Oxygen Concentration (µm/kg)
0
100
200
300
400
Insitu Temperature (°C)
-5
0
5
10
15
20
25
30
35
Salinity (PSU)
32 33 34 35 36 37
Pressure (decibar)
0
200
400
600
800
1000
1200
1400
1600
1800
Float: 0894
Profile: 101
Location: 22.4°N
Date: 07/29/2005

Float 0894 (All profiles as of 08 Jul 2005)





Float 0894 (As of 19 Jul 2005)

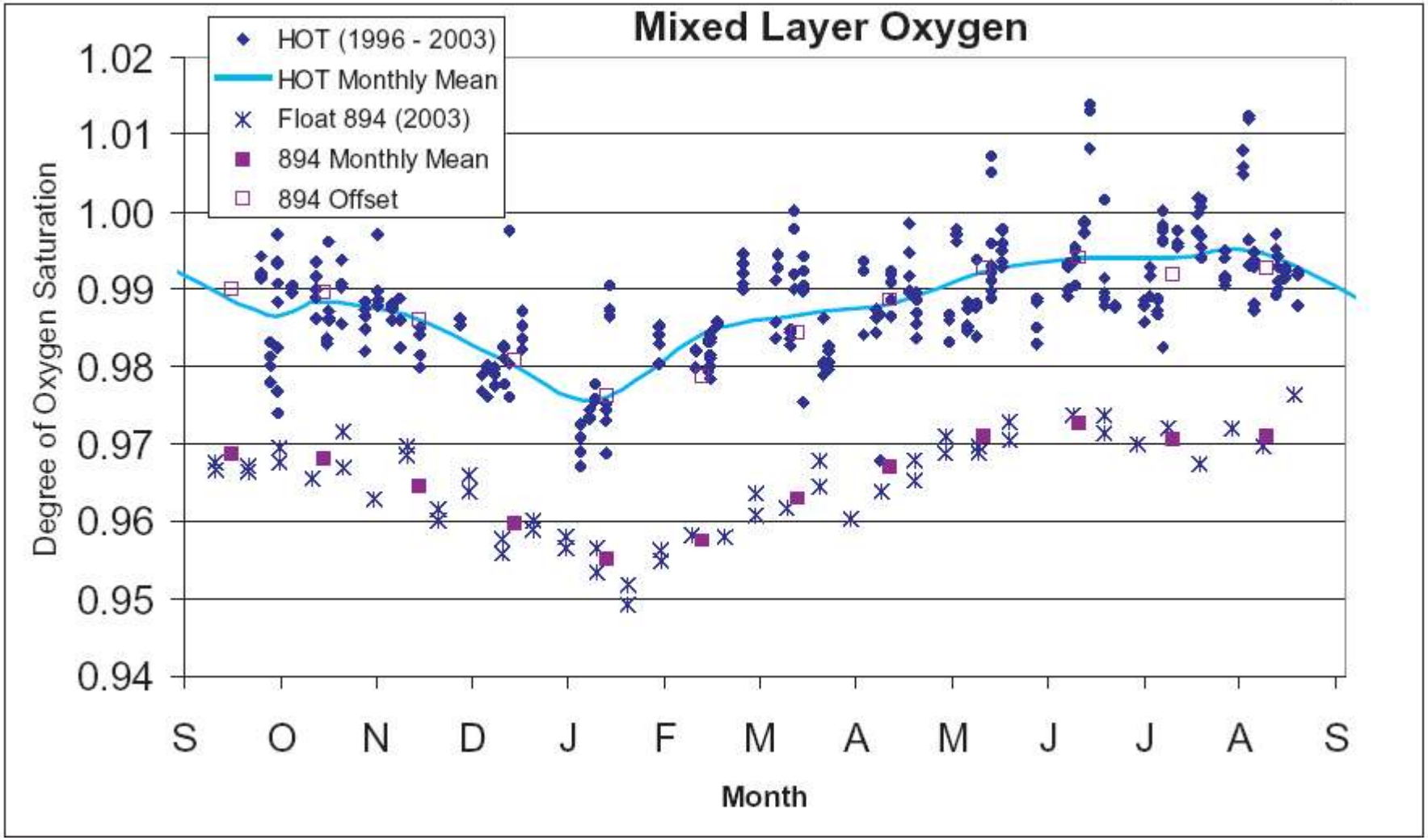
★ : Most Recent Location of Float.

1121785725.005-080

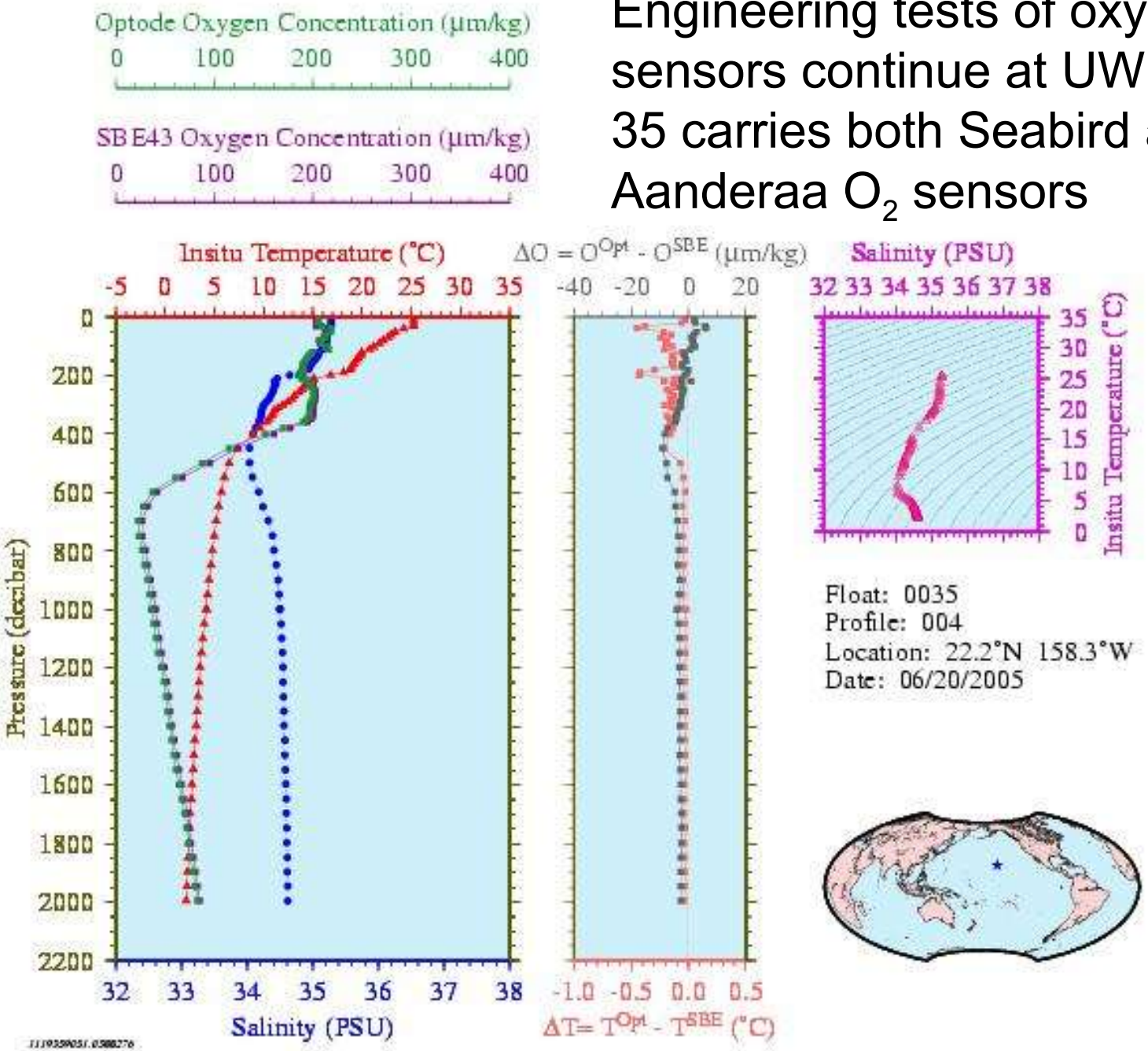
Larson et al. “A year of oxygen measurements...

www.seabird.com/technical_references

Figure 3



Engineering tests of oxygen sensors continue at UW – Float 35 carries both Seabird and Aanderaa O_2 sensors

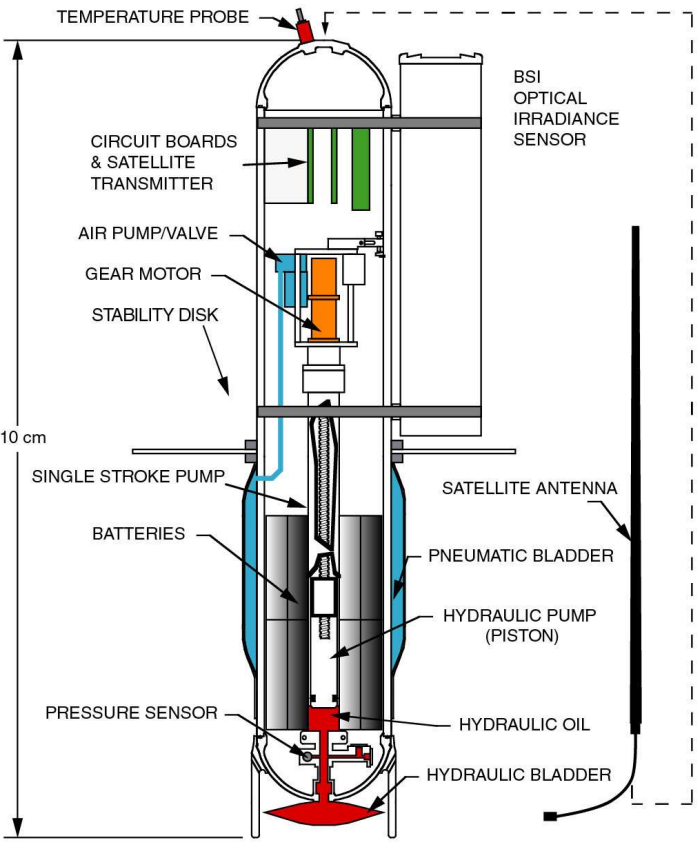


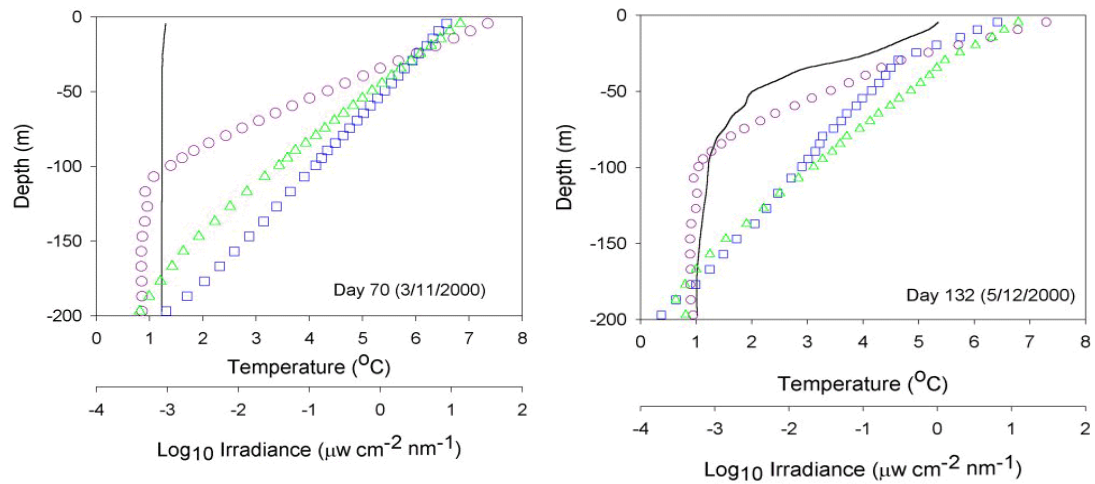
Example of some Ocean Color/Optics related studies: Prepared by Emmanuel Boss.

1. K-SOLO float (G. Mitchell, M. Kahru, J. Sherman, 2000)

3-wavelengh downwelling irradiance (Ed) sensor (380, 490 and 555 nm)

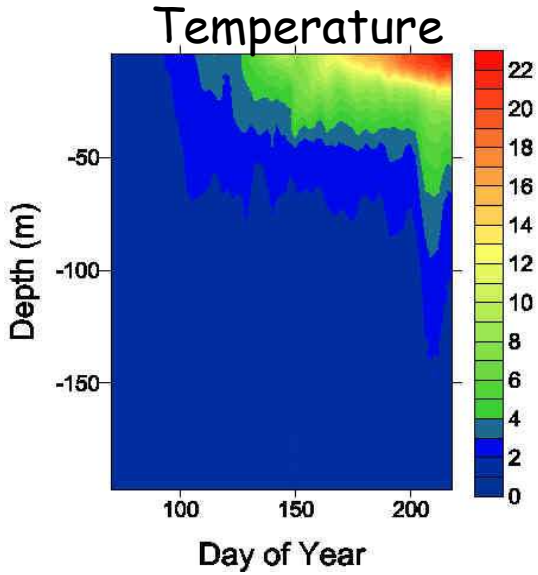
K = -1/Ed dEd/dz

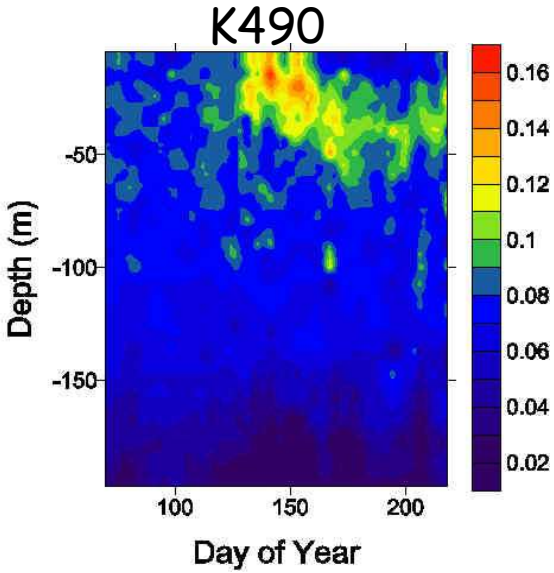




Vertical profiles of temperature (__) and irradiance at three wavelengths (380 m - ○; 490 nm - □; 555 nm - △) transmitted by KSOLO for A. March 11 and B. May 12, 2000.

Vernal bloom in the Sea of Japan:



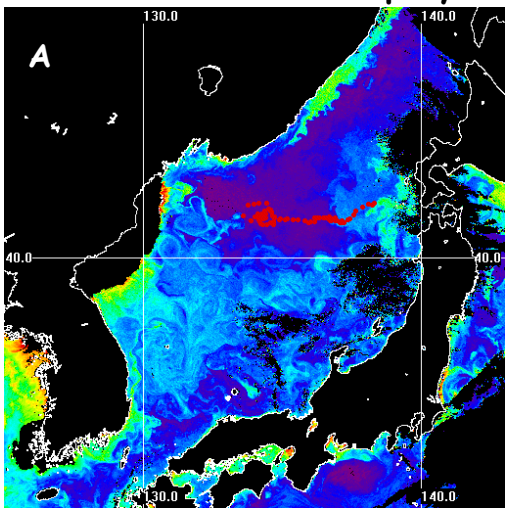


Supports use for:

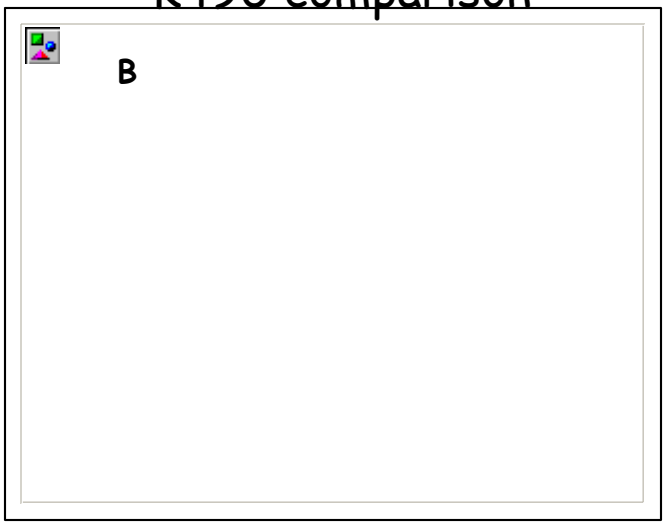
1. Providing sub-surface structure.

2. Remote sensing validation.

SeaWIFS chlorophyll



K490 comparison



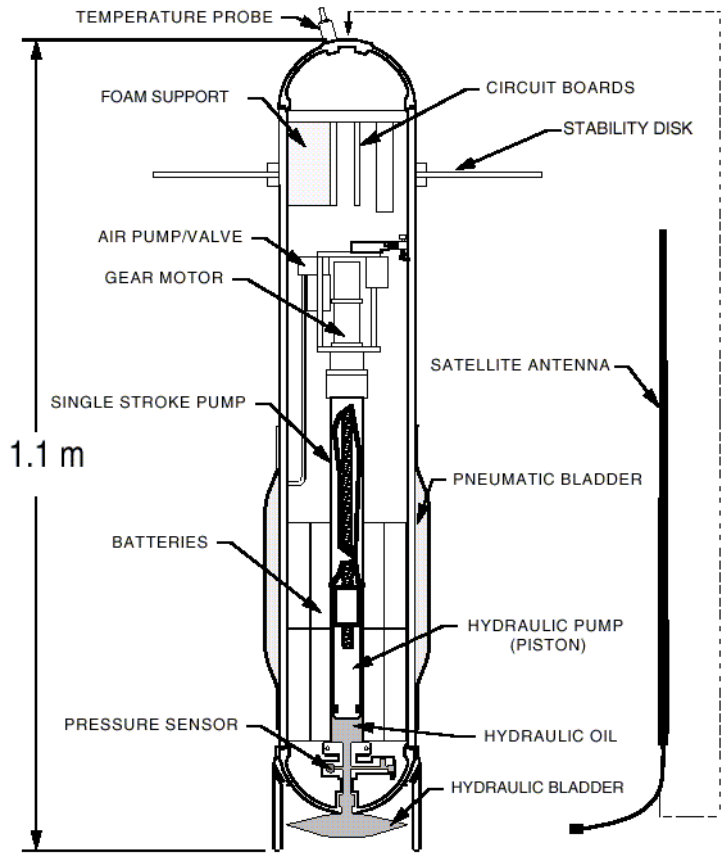
Example of some Ocean Color/Optics related studies:

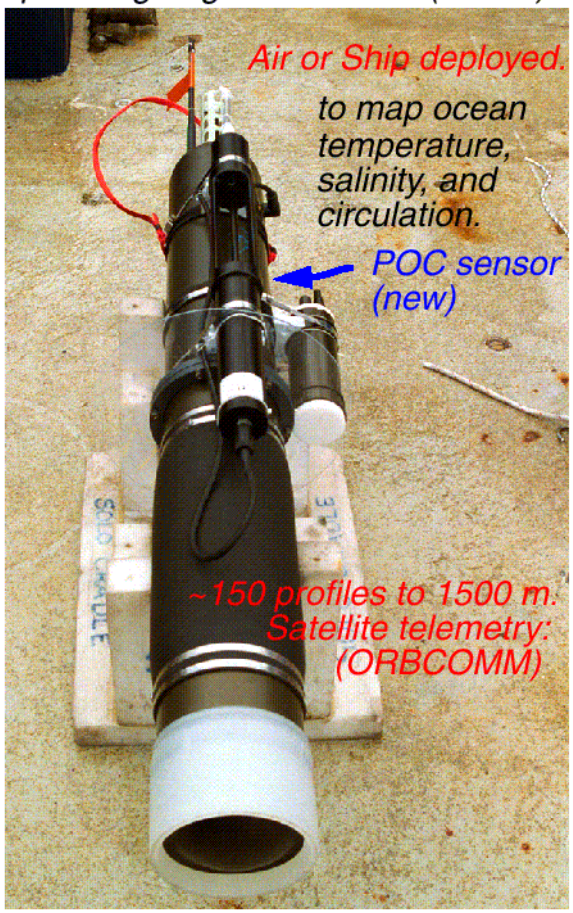
2. SOLO float (J. Bishop, R. Davis, J. Sherman) – Carbon explorers

Beam-c used as a proxy of POC.

Sensor developed through NOPP.

NEW OBSERVING SYSTEMS: Sounding Oceanographic Lagrangian Observer (SOLO)



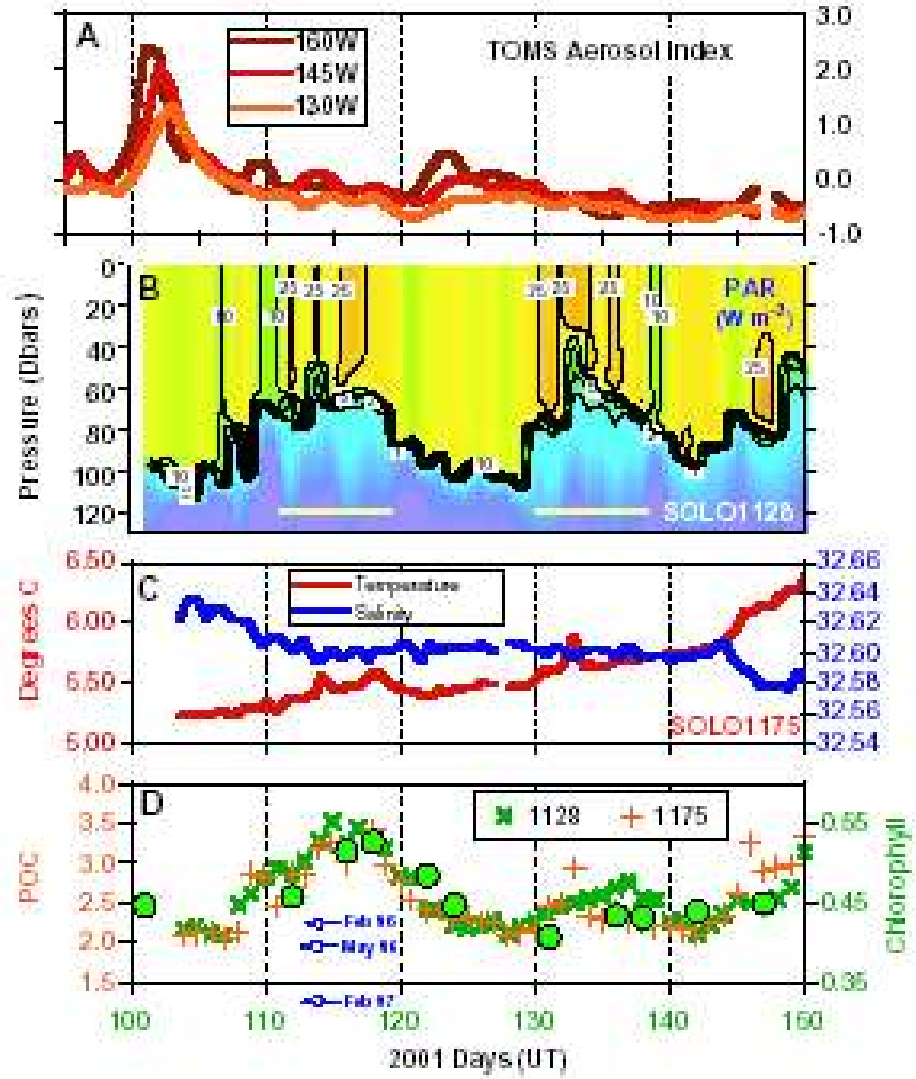


(Davis et al., 1999)

Blooms near station PAPA:

Two blooms of phytoplankton in North Pacific following dust deposition event.

SeaWIFS [chl] and c_p (POC) covary.



Bishop et al., Science, 2002

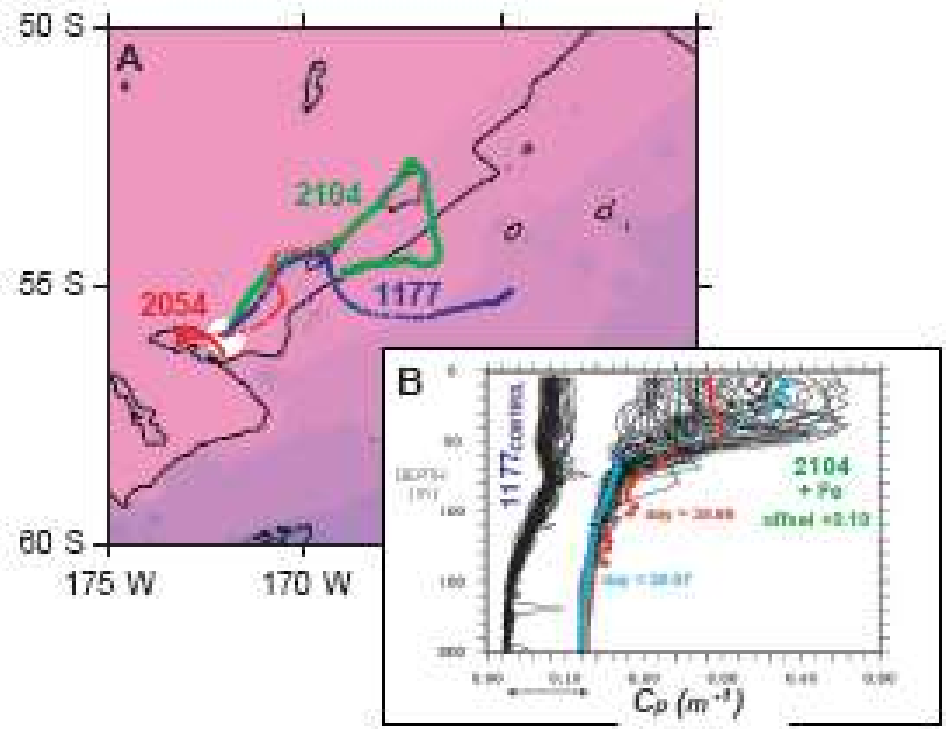
SOFEx iron fretilization
(Southern Ocean, 3 floats):

Increase in beam-c (pools) within and below the enriched patch.

Increase in flux down to depth (as measured by deposition on sensor's windows).

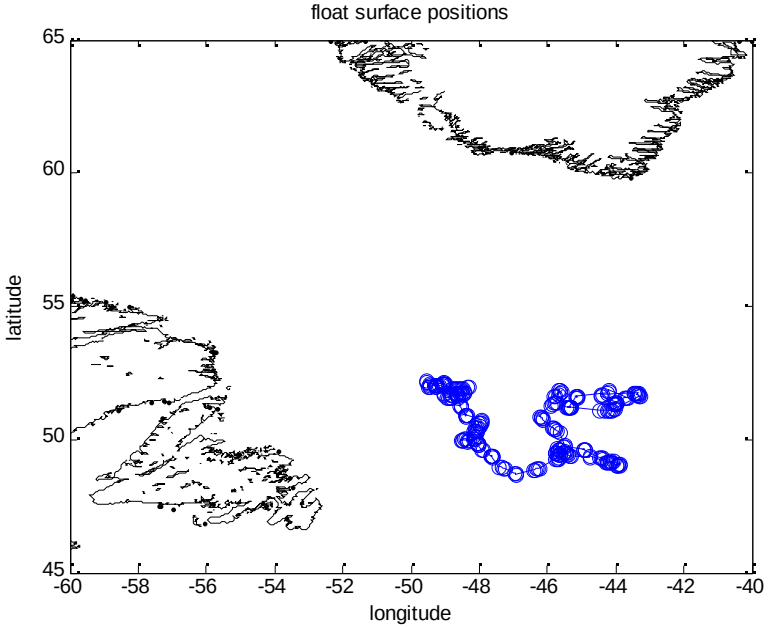
Supports use for:

Assessing magnitudes of carbon pools and possibly carbon flux.

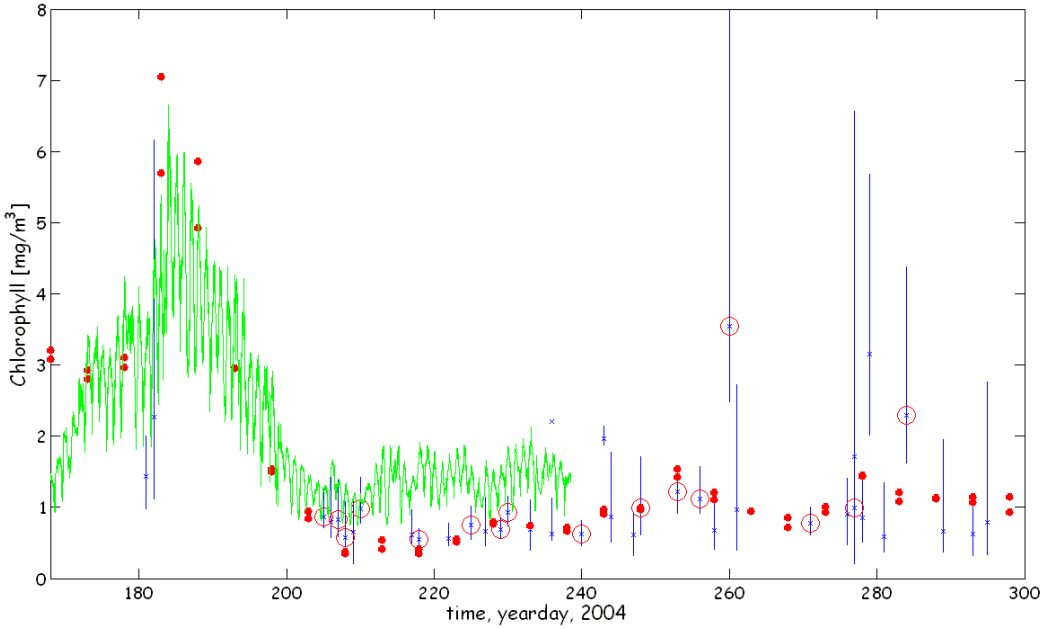


Float in the Labrador Sea:

- 300day (60 profiles to date).
- No noticeable drift in optical sensors.
- Bloom (mostly missed by SeaWIFS & MODIS).



Chlorophyll comparison with mooring + SeaWIFS

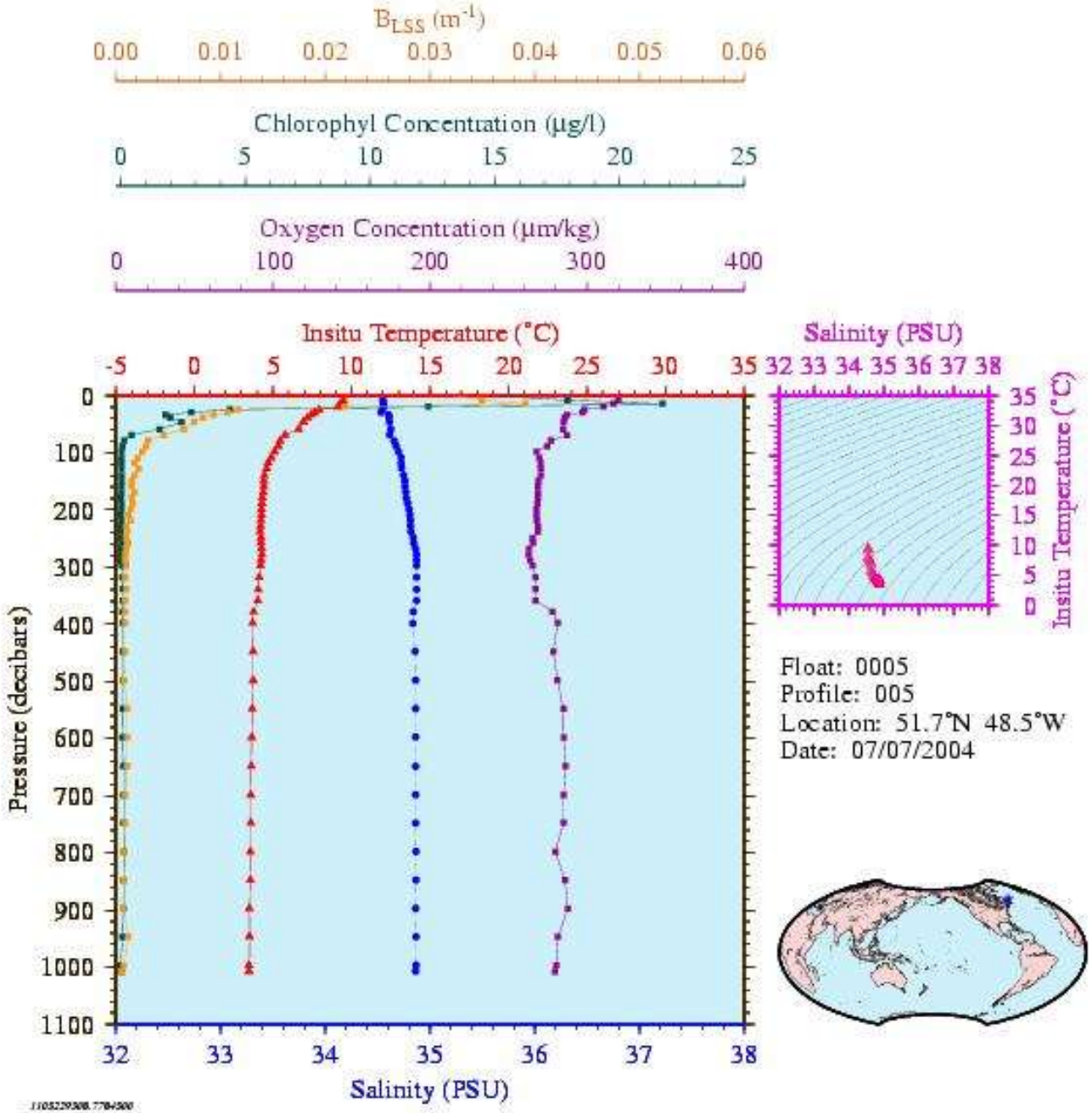


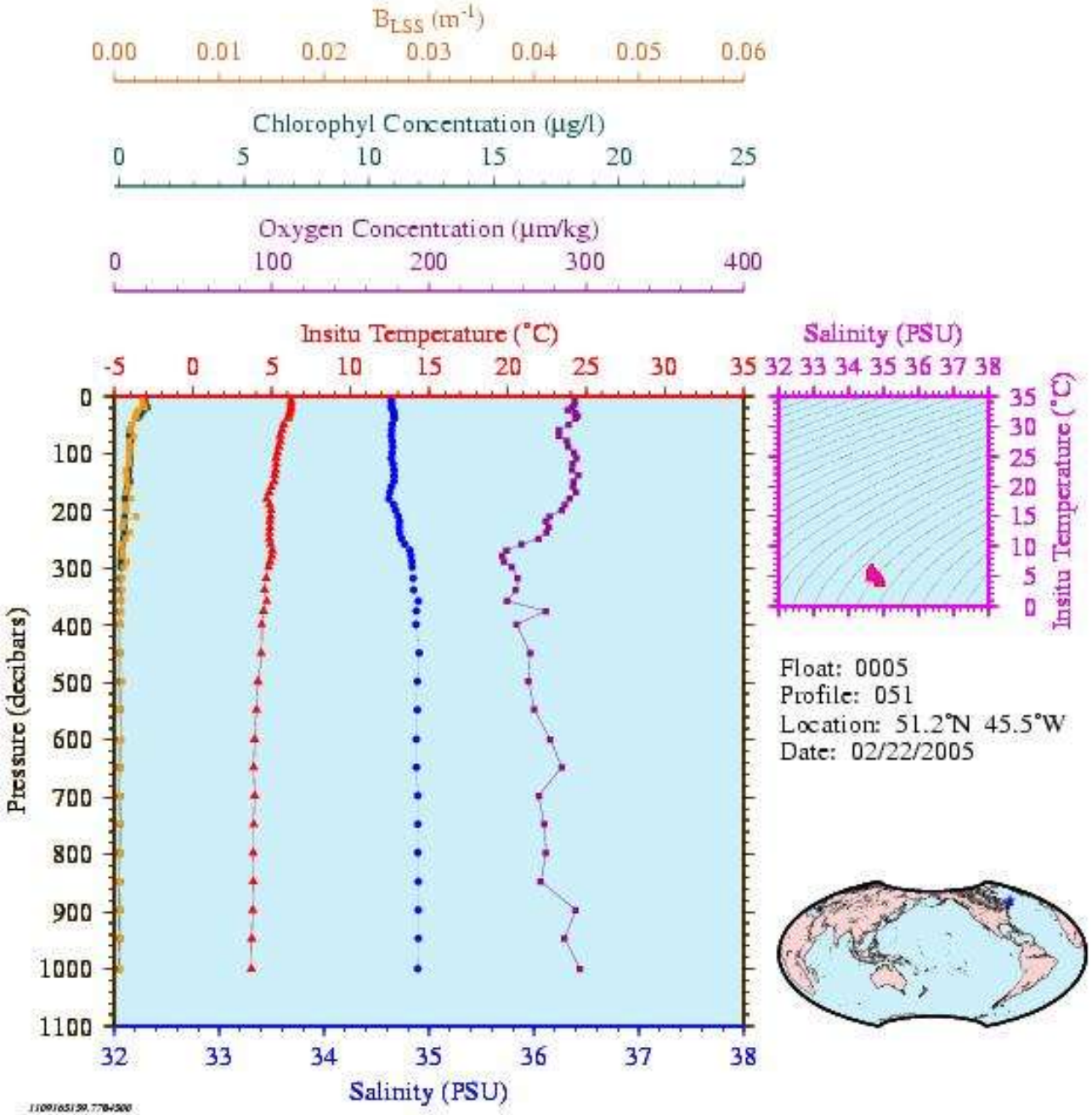
Supports use for:

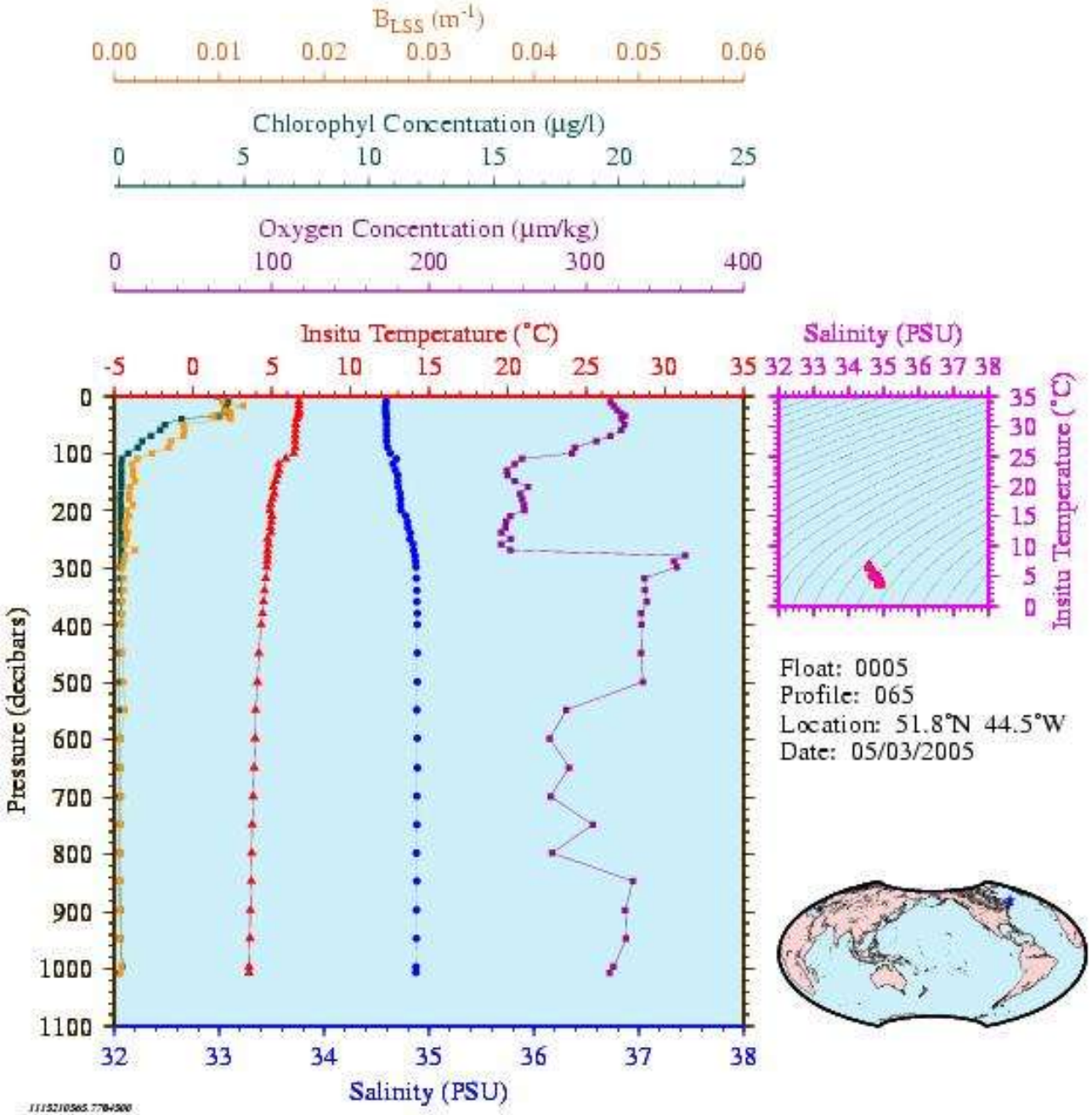
1. Providing sub-surface structure.

2. Sampling under clouds (11/26 co-located SeaWIFS pixels).

3. Algorithm validation.


B_{LSS} (m^{-1})
0.00 0.01 0.02 0.03 0.04 0.05 0.06
Chlorophyl Concentration (µg/l)
0 5 10 15 20 25
Oxygen Concentration (µm/kg)
0 100 200 300 400
Insitu Temperature (°C)
-5 0 5 10 15 20 25 30 35
Salinity (PSU)
32 33 34 35 36 37 38
Insitu Temperature (°C)
35 30 25 20 15 10 5 0
Pressure (decibars)
0 100 200 300 400 500 600 700 800 900 1000 1100
Salinity (PSU)
32 33 34 35 36 37 38
Float: 0005
Profile: 005
Location: 51.7°N 48.5°W
Date: 07/07/2004

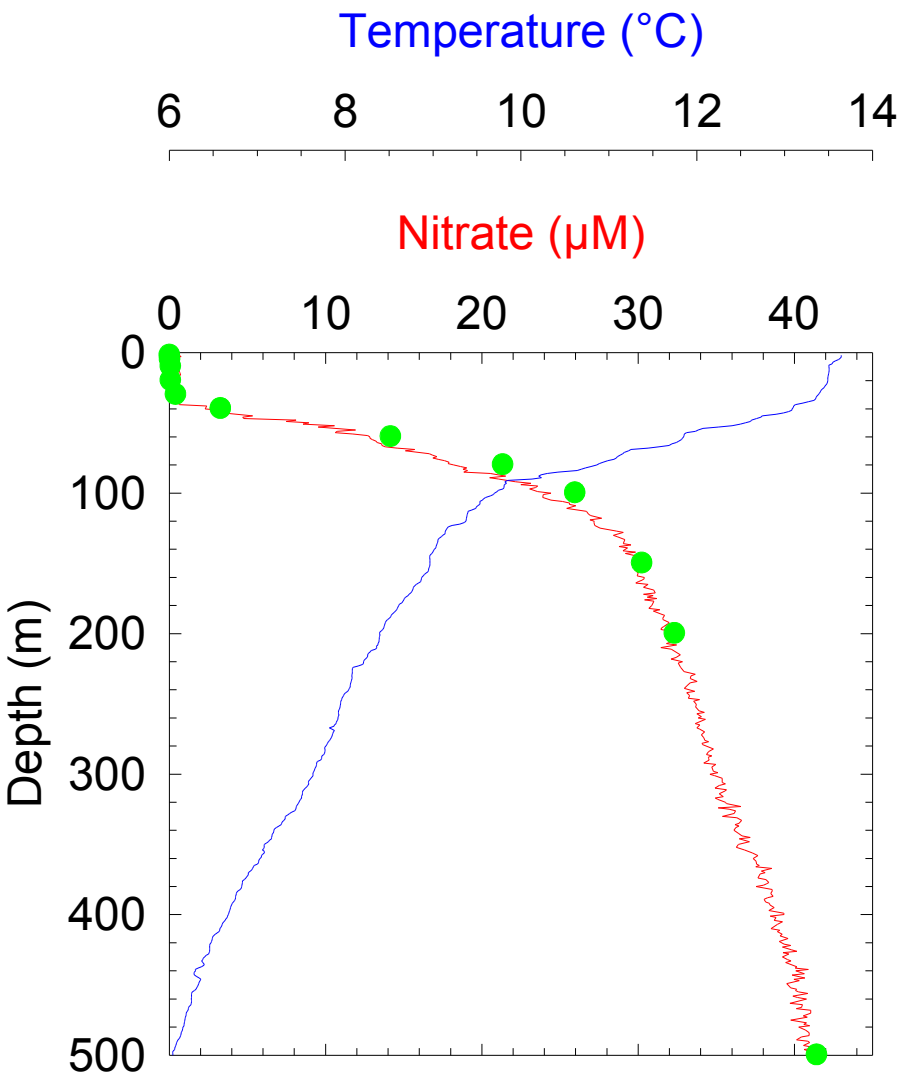

B_{LSS} (m^{-1})
0.00 0.01 0.02 0.03 0.04 0.05 0.06
Chlorophyl Concentration (µg/l)
0 5 10 15 20 25
Oxygen Concentration (µm/kg)
0 100 200 300 400
Insitu Temperature (°C)
-5 0 5 10 15 20 25 30 35
Salinity (PSU)
32 33 34 35 36 37 38
Pressure (decibars)
0 100 200 300 400 500 600 700 800 900 1000 1100
Insitu Temperature (°C)
35 30 25 20 15 10 5 0
Float: 0005
Profile: 051
Location: 51.2°N 45.5°W
Date: 02/22/2005

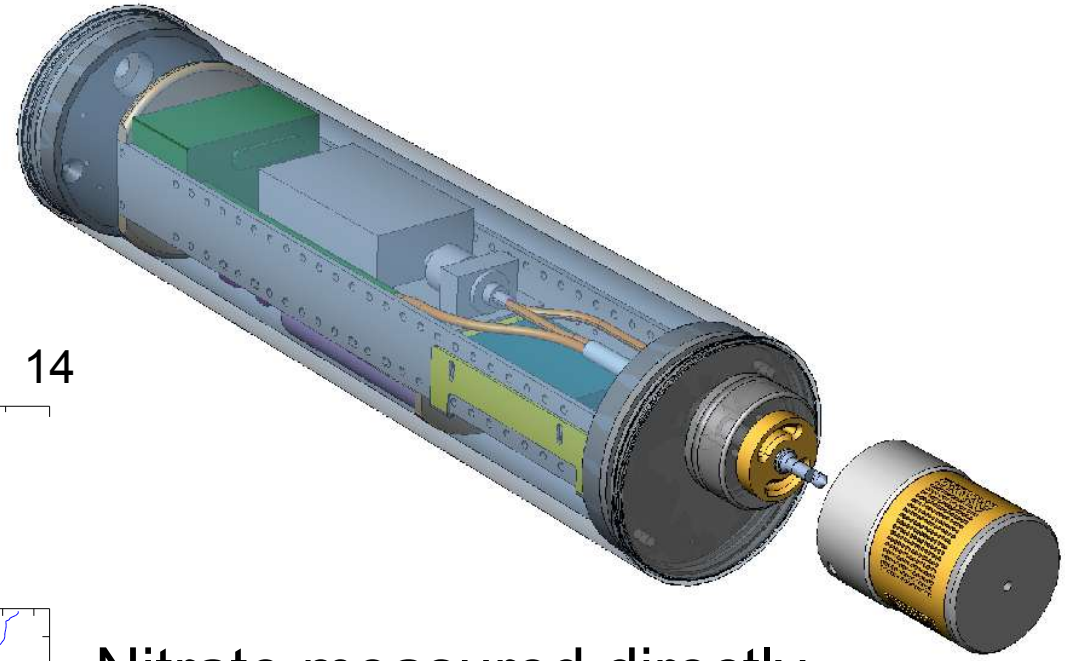

B_{LSS} (m^{-1})
0.00 0.01 0.02 0.03 0.04 0.05 0.06
Chlorophyl Concentration (µg/l)
0 5 10 15 20 25
Oxygen Concentration (µm/kg)
0 100 200 300 400
Insitu Temperature (°C)
-5 0 5 10 15 20 25 30 35
Salinity (PSU)
32 33 34 35 36 37 38
Pressure (decibars)
0 100 200 300 400 500 600 700 800 900 1000 1100
Salinity (PSU)
32 33 34 35 36 37 38
Insitu Temperature (°C)
35 30 25 20 15 10 5 0
Float: 0005
Profile: 065
Location: 51.8°N 44.5°W
Date: 05/03/2005

Other Potential Float Sensors:

- Particulate Inorganic Carbon – Jim Bishop
- Nitrate – MBARI ISUS
- PCO_2 – Arne Koertzinger

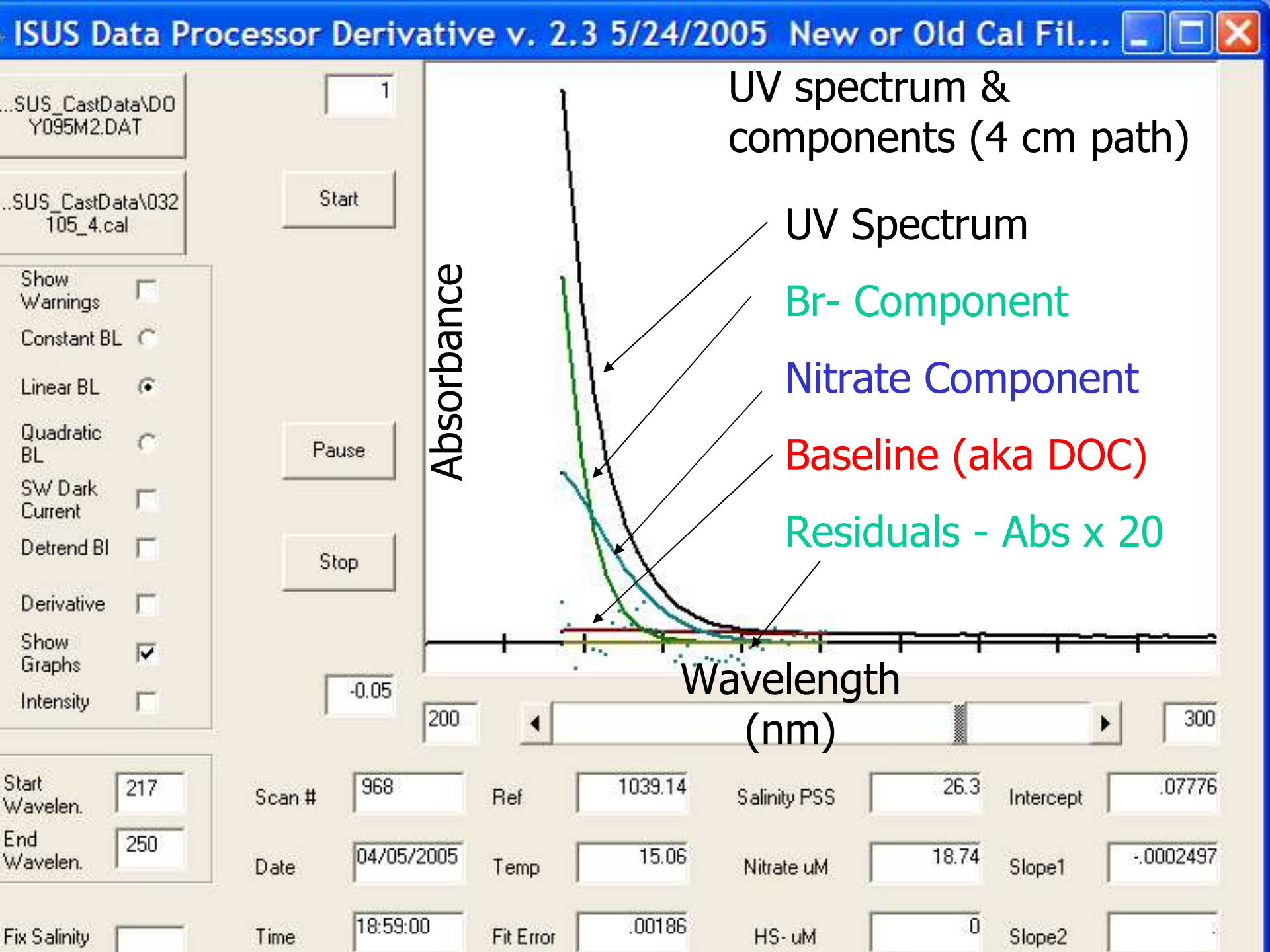
MBARI In Situ Ultraviolet Spectro-photometer (ISUS)



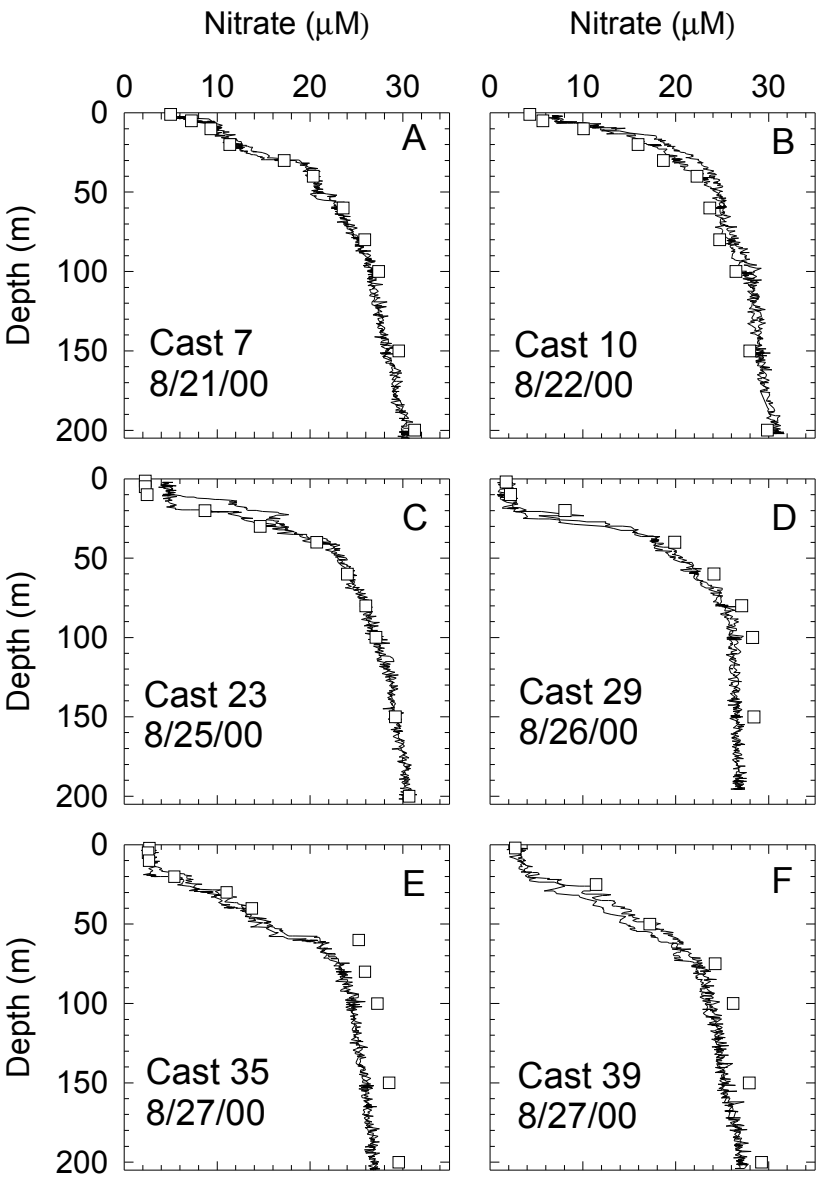


Nitrate measured directly using UV absorption spectrum from 217 to 250 nm. Would be about 20% of float power budget.

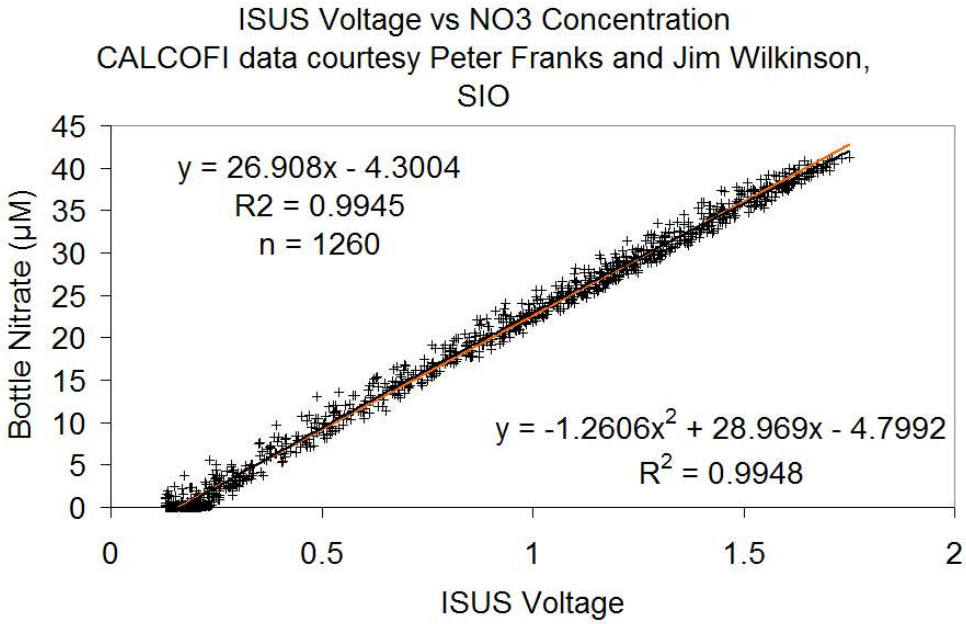
Johnson & Coletti, 2002, Deep-Sea Res. I, 49, 1291.

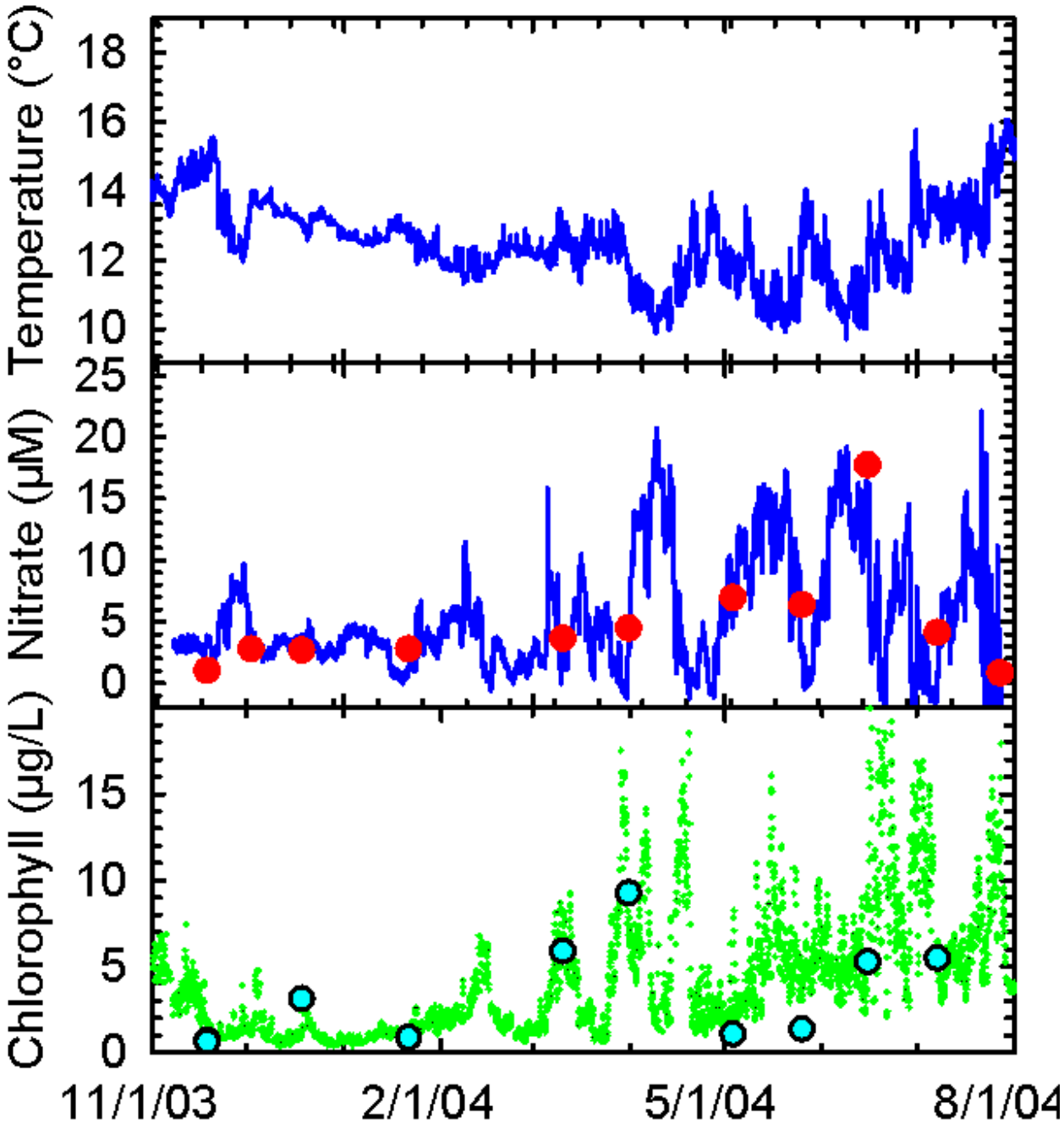

ISUS Data Processor Derivative v. 2.3 5/24/2005 New or Old Cal Fil...
...SUS_CastData\DO Y095M2.DAT
..SUS_CastData\032 105_4.cal
1
Start
Pause
Stop
Show Warnings
Constant BL
Linear BL
Quadratic BL
SW Dark Current
Detrend BI
Derivative
Show Graphs
Intensity
-0.05
UV spectrum & components (4 cm path)
UV Spectrum
Br- Component
Nitrate Component
Baseline (aka DOC)
Residuals - Abs x 20
Absorbance
Wavelength (nm)
200
300
Start Wavelen.
217
End Wavelen.
250
Scan #
968
Date
04/05/2005
Time
18:59:00
Ref
1039.14
Temp
15.06
Fit Error
.00186
Salinity PSS
26.3
Nitrate uM
18.74
HS- uM
0
Intercept
.07776
Slope1
-.0002497
Slope2
Fix Salinity

Vertical Profiles

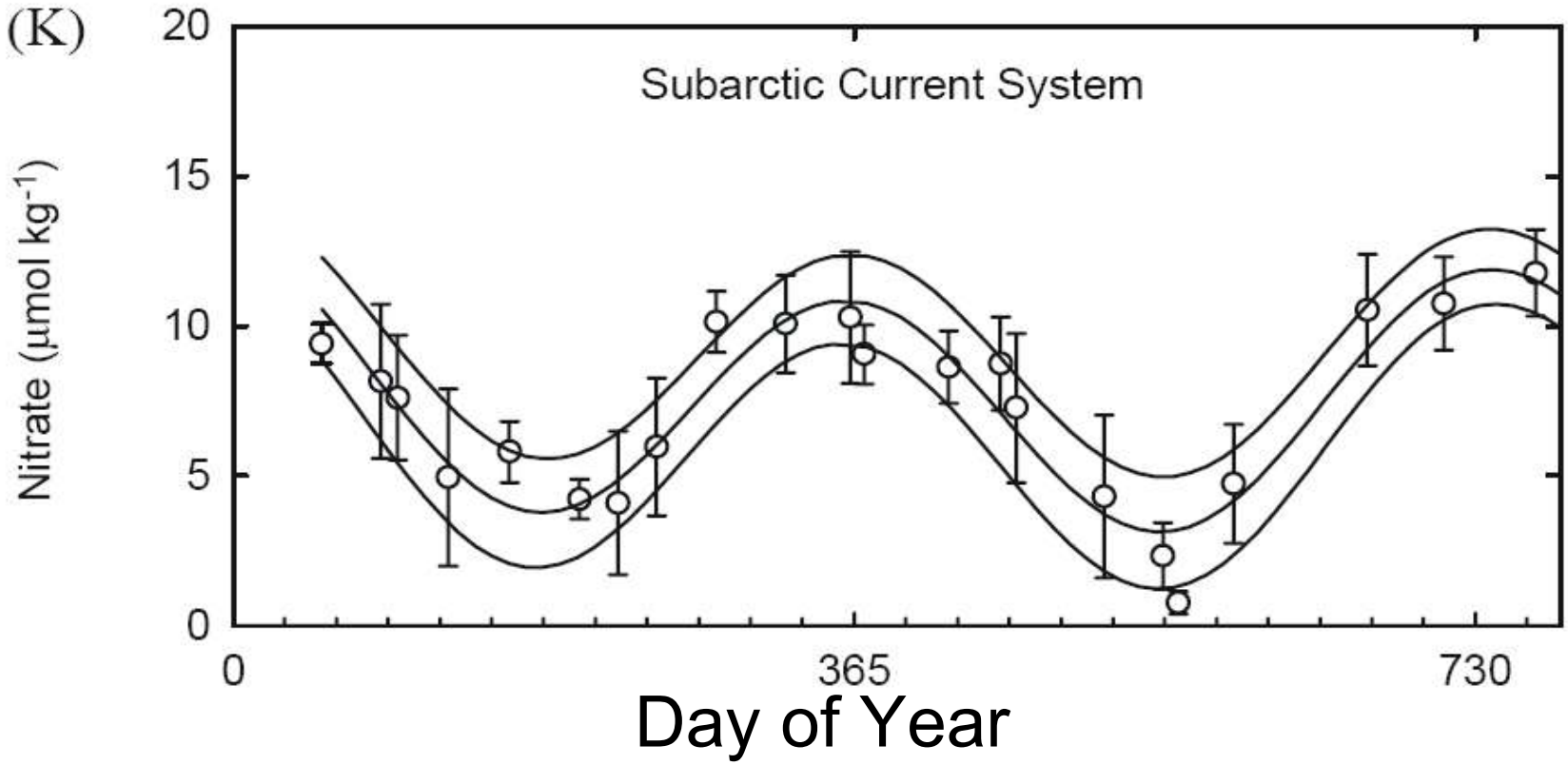


Validation from CALCOFI Cruise. Courtesy of Peter Franks and Jim Wilkinson, SIO. 70 stations (~20 bottles/station) over 18 days.



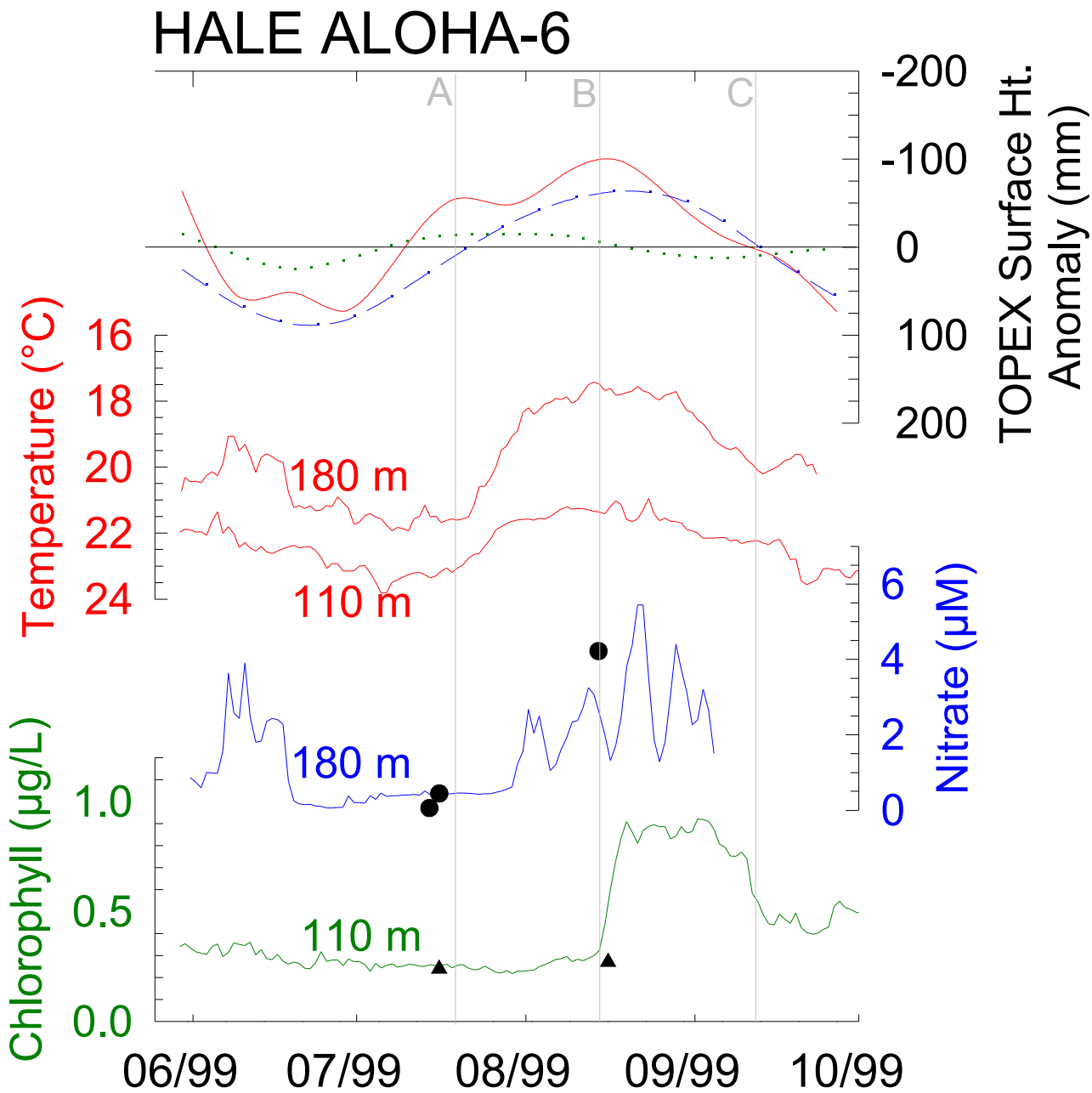

Temperature (°C)
18
16
14
12
10
Nitrate (µM)
25
20
15
10
5
0
Chlorophyll (µg/L)
15
10
5
0
11/1/03
2/1/04
5/1/04
8/1/04

At high latitudes, nitrate would provide direct estimates of new primary production. Potentially constrain Redfield stoichiometry with O_2 and NO_3.

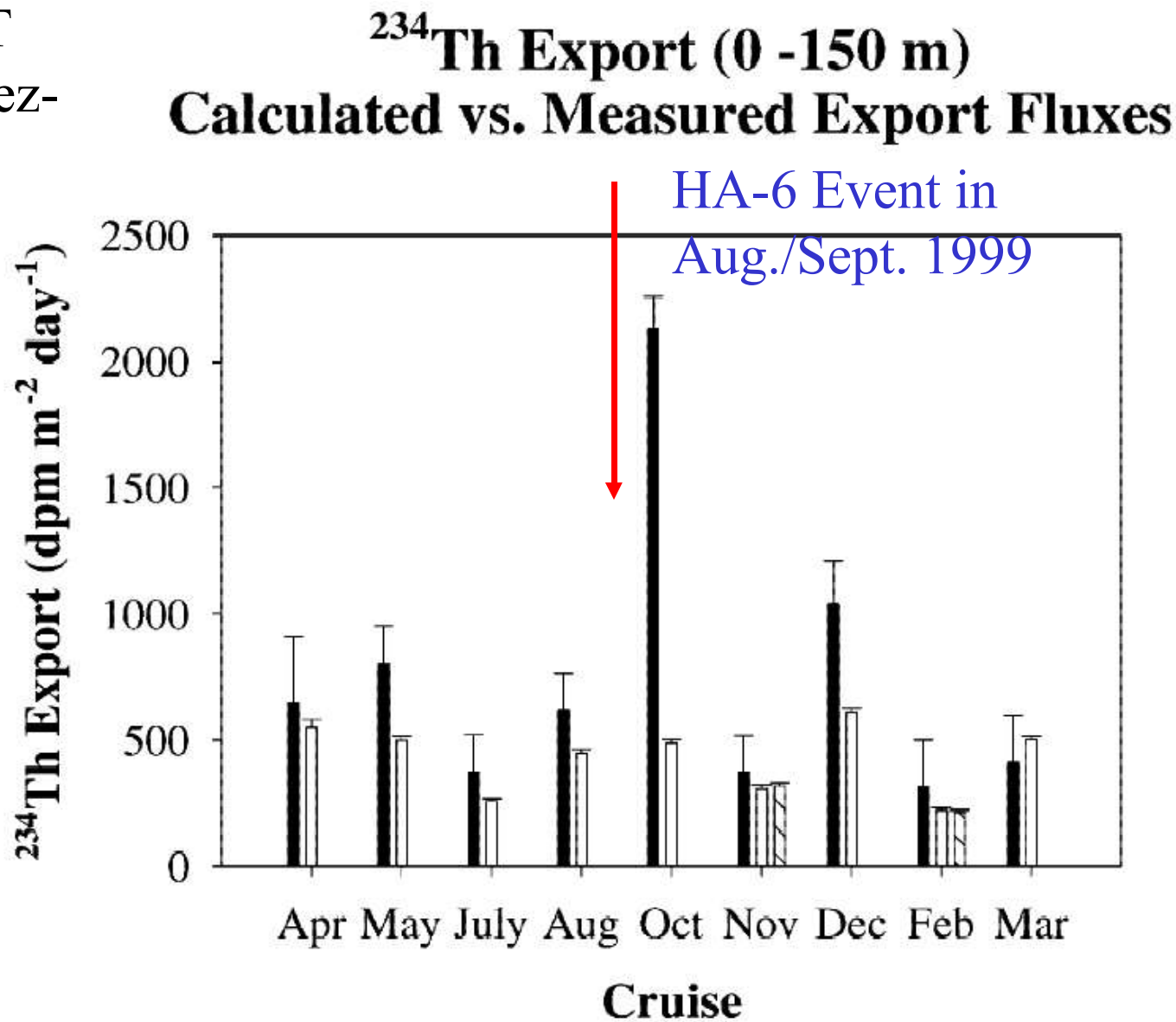


Nitrate concentrations plotted versus day of year in the Subarctic North Pacific. From Wong et al. (Deep-Sea Res. II, 49, 5317, 2002).

In oligotrophic waters, nitrate sensors would provide information on temporal variability driven by physical processes such as eddies and Rossby waves (from Sakamoto et al., JGR, 2004).

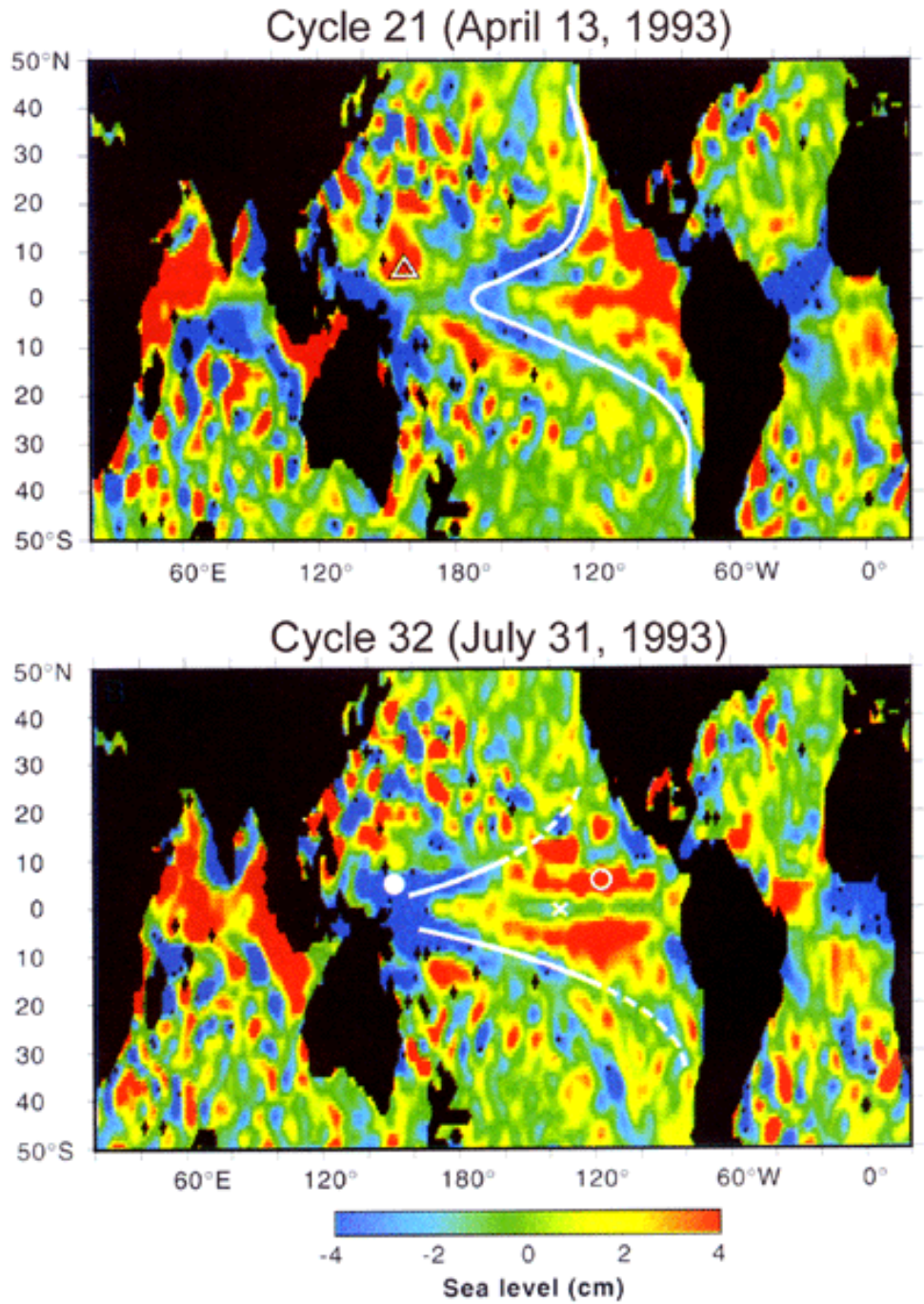


1999/2000 HOT Th data – Benitez-Nelson et al.

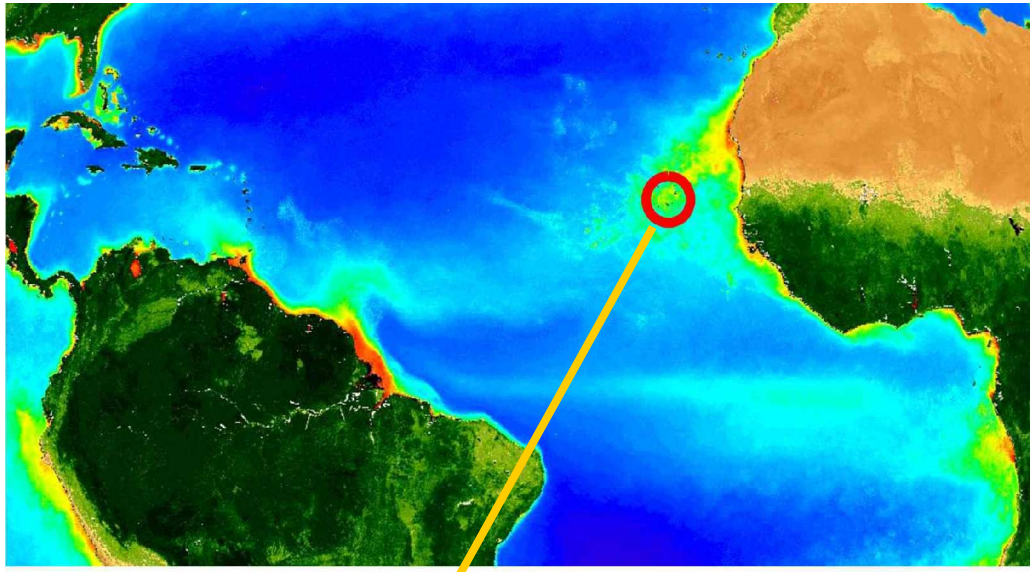


Rossby Waves in the ocean - westward propagating, basin scale anomalies detected by Sea Surface Height Altimetry. They can take months to cross the Pacific. Is there a corresponding C export signal?

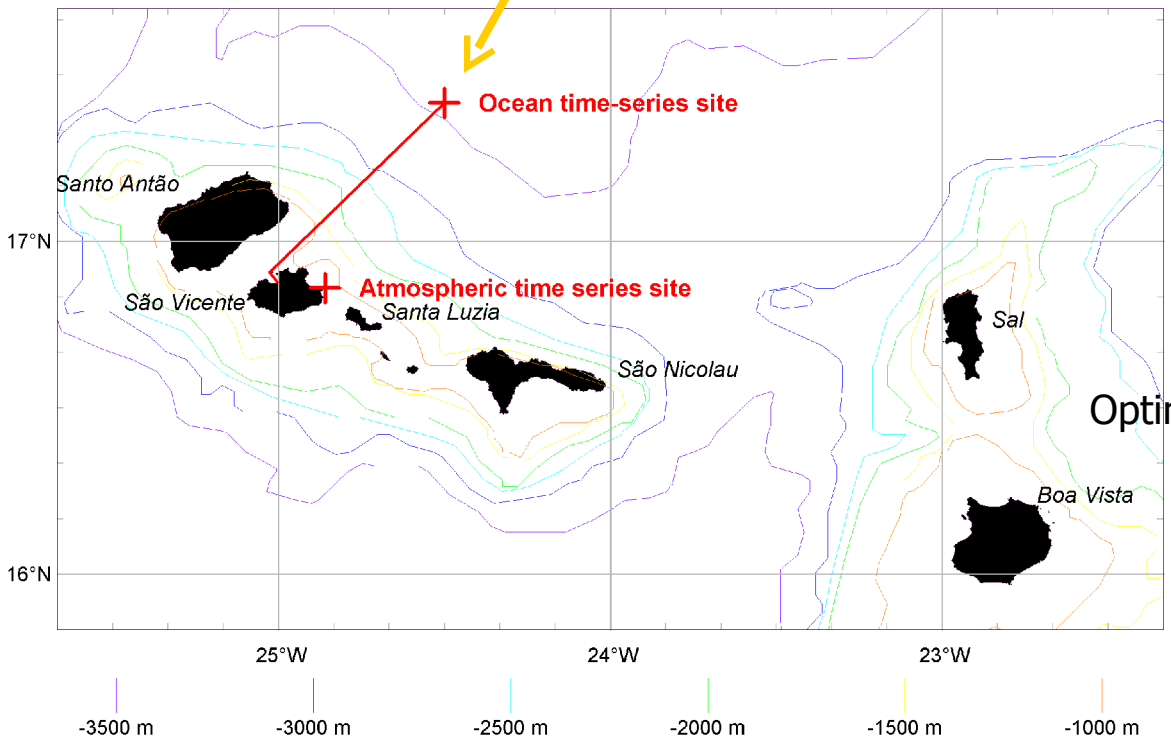
(Chelton, D. B., and M. G. Schlax, 1996: Global observations of oceanic Rossby waves. Science, vol. 272, pp. 234-238)

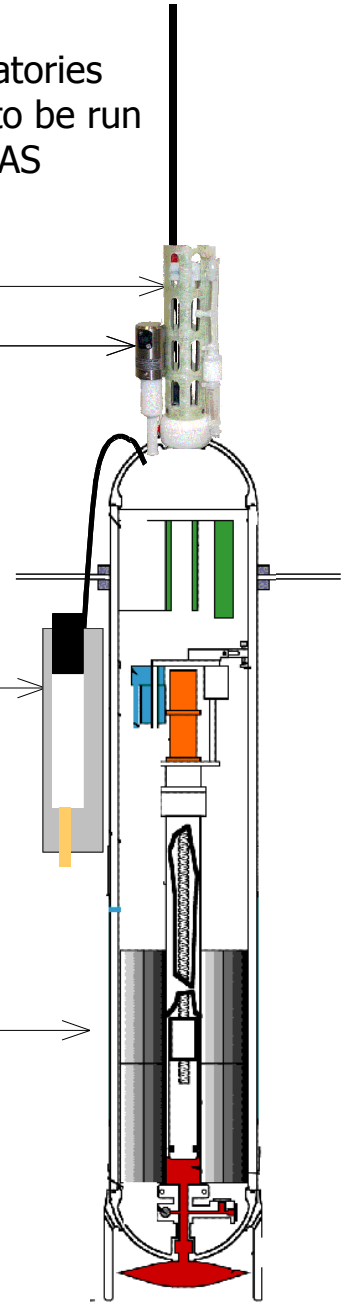


Cape Verdean Time-Series with profiling O_2/CO_2 floats: Körtzinger, IFM-GEOMAR, Kiel/Germany



Combined long-term observatories for atmosphere and ocean, to be run jointly by German & UK SOLAS





What would a system cost?

About $6,000,000/y to deploy 110 floats each year.

By way of comparison, US Argo cost is $10,000,000/y for 400 floats/y.

The NSF OOI is a $300,000,000 initiative.

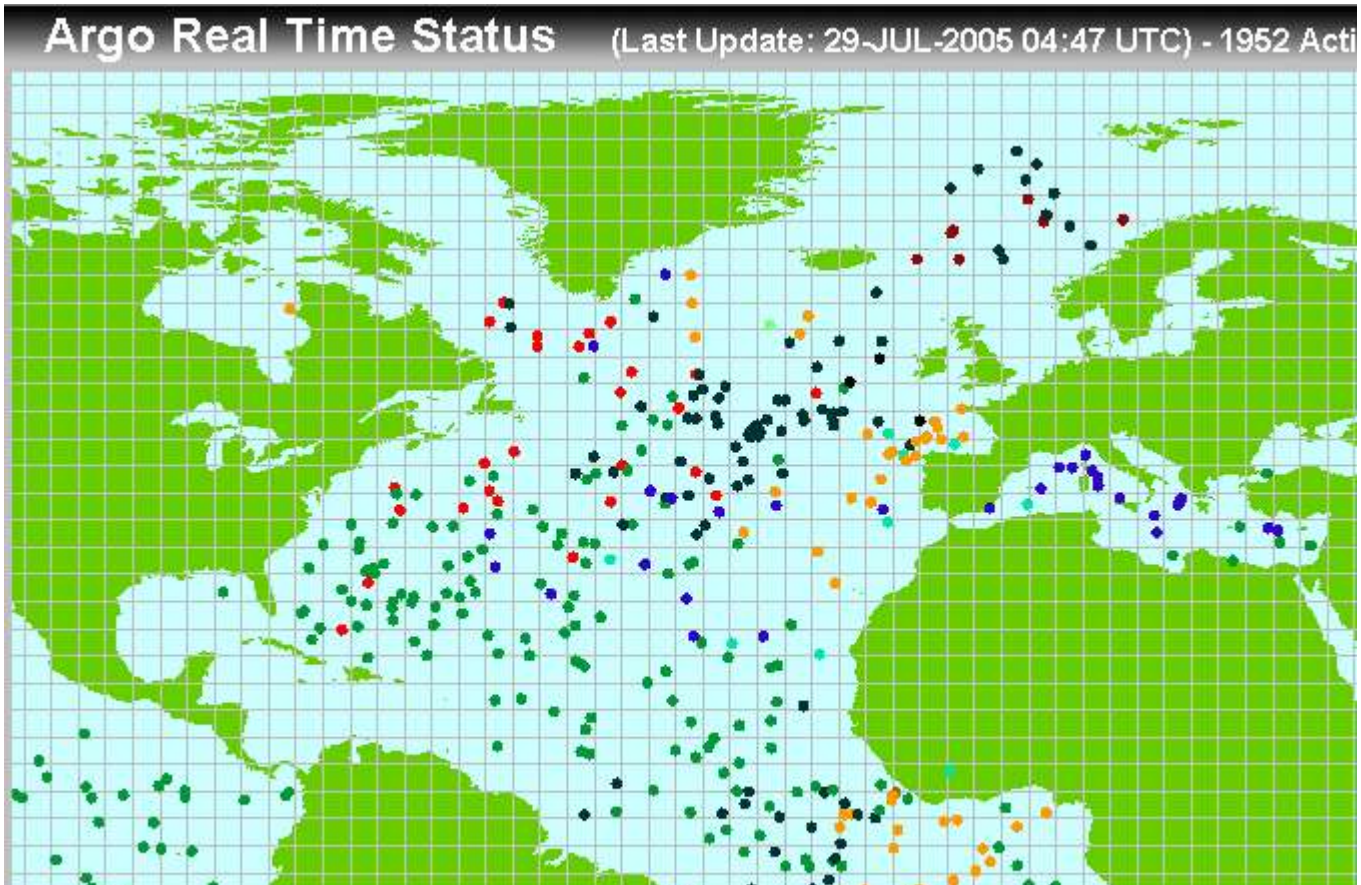
Basic Float T, S, Z	$12,500	110	$1,375,000
Oxygen	$3,000	110	$330,000
Bio-optics	$2,500	110	$275,000
Nitrate	$15,000	110	$1,650,000
Other Sensors	$3,000	110	$330,000
Float Total	$36,000	110	$3,960,000
Ship TIme	$680,000	1	$680,000
Iridium Telemetry	$500,000	1	$500,000
Float Prep, Calib, & Devel.	$500,000	1	$500,000
Data Office	$500,000	1	$500,000
Total Cost			$6,140,000
Cost/Float			$55,818
Number of profiles		200	
Observations/Profile		50	
Cost/Observation set (T, S, O2, Fluor, OBS, NO3)			$6

What does ~100 floats/year buy you? Coverage of the N. Atlantic in about 4 years. Currently ~295 floats and ~500 3° grid points in the N. Atlantic.

The float data merged with ocean color imagery and a data assimilating biogeochemical model could be used to assess temporal and spatial variability in primary production and carbon export.

(Southern Ocean may be a better target)

As with Argo, data would have to be immediately in the public domain.



Major questions:

- Will sensors stay in calibration for 4 years?
  - Experience so far with O_2 and optics is good, but more testing required. New sensors will require testing soon, if there is interest.
- Is 3°x3° resolution enough for biogeochemical processes?
  - Really need to do a careful simulation with eddy-resolving biogeochemical models.
- Who would pay annual operating costs?
  - NOAA?, NSF? Merging with an Argo type program makes costs much more affordable, if neither mission is compromised. Operation as an international program (US does ½?) also helps.

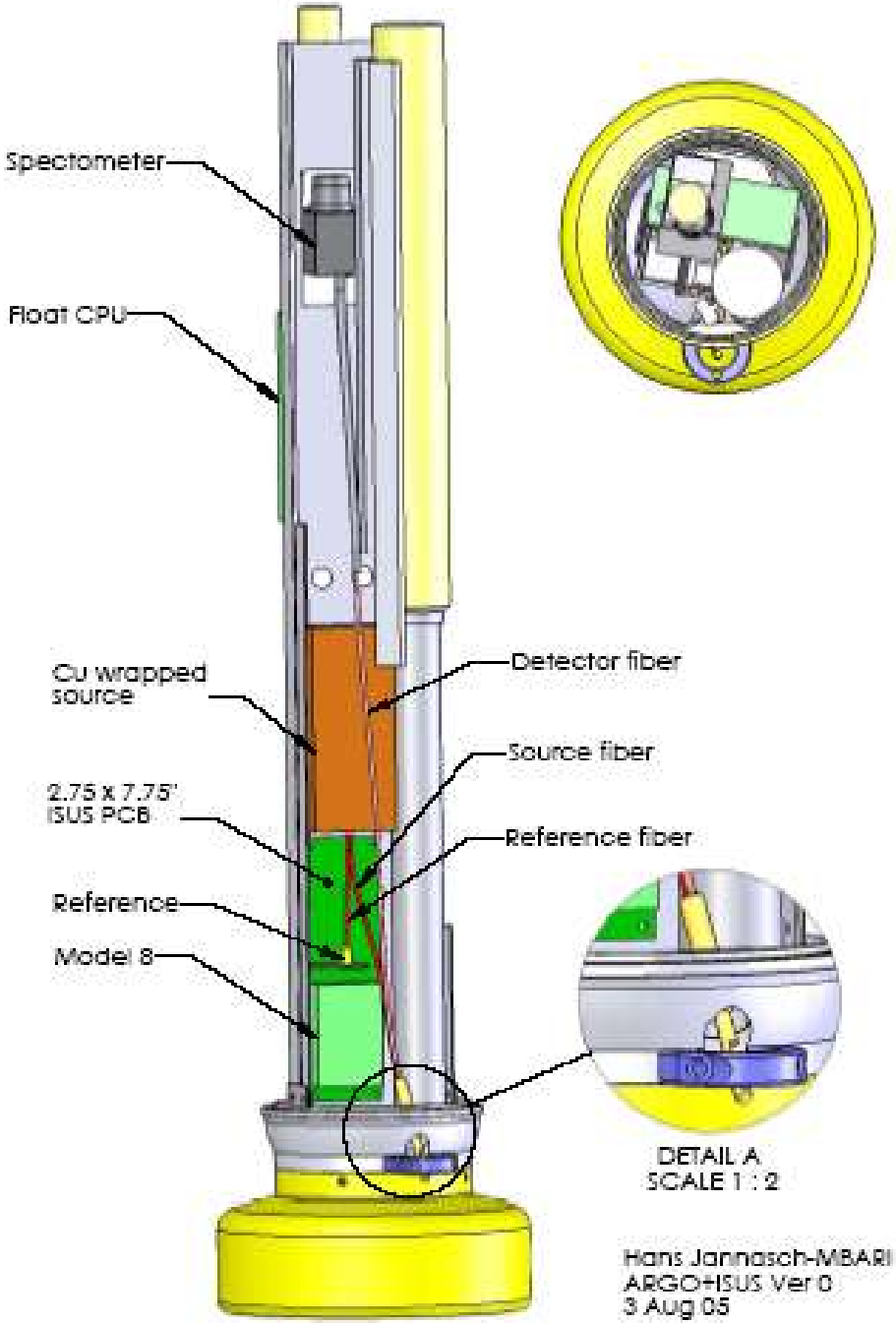
What are the next steps?

- Determine required performance – i.e., what precision is needed for basin-scale primary production estimates – ±10%?

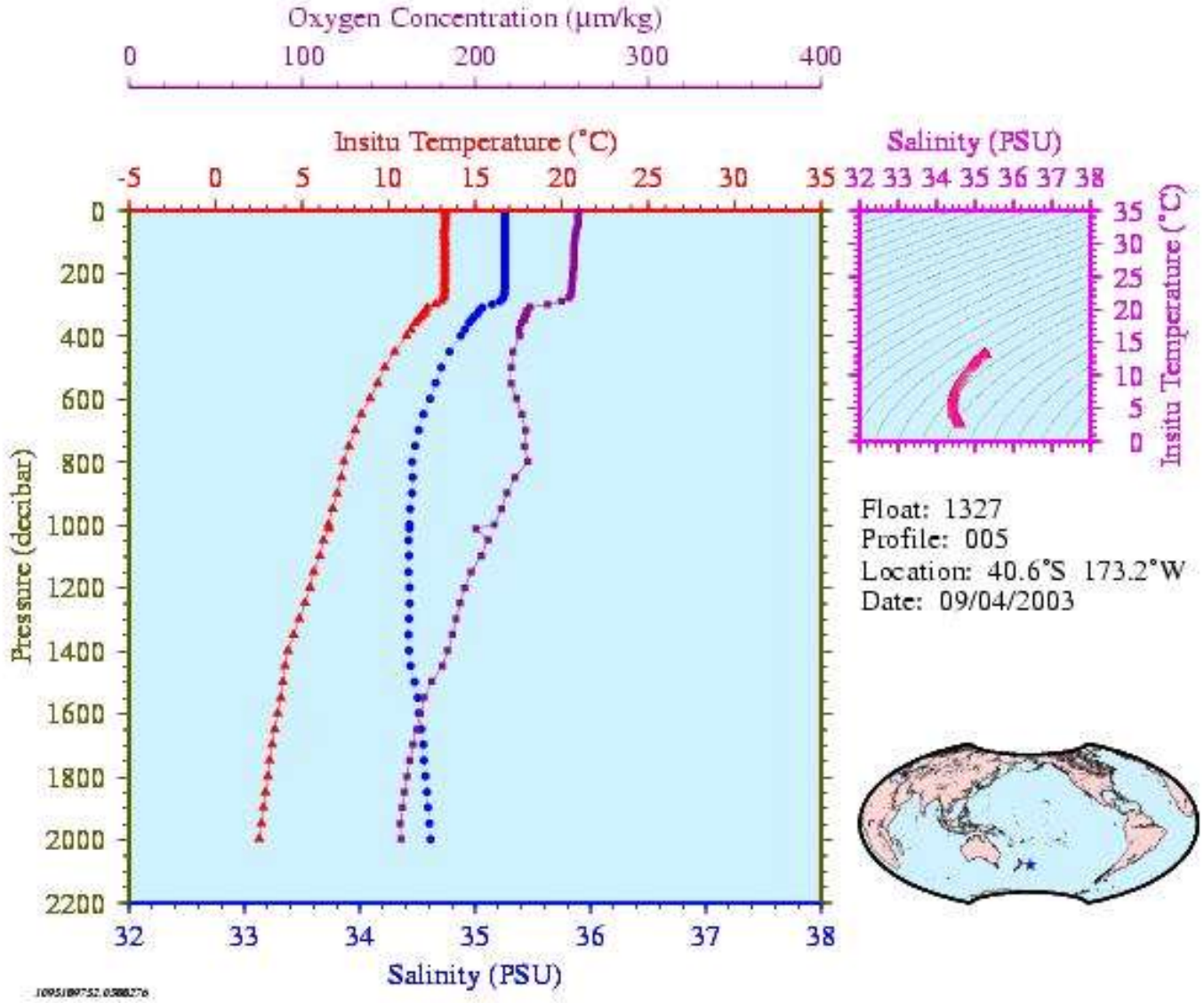
- Observing system simulation experiment to assess the performance that would be required from sensors and platforms. What are impacts of small amounts of sensor drift? What density of observing system is needed to get mesoscale processes with statistical significance?

- Careful assessment of sensor performance, reliability and engineering needs. Are new float platforms required, or do current platforms with incremental changes meet needs.

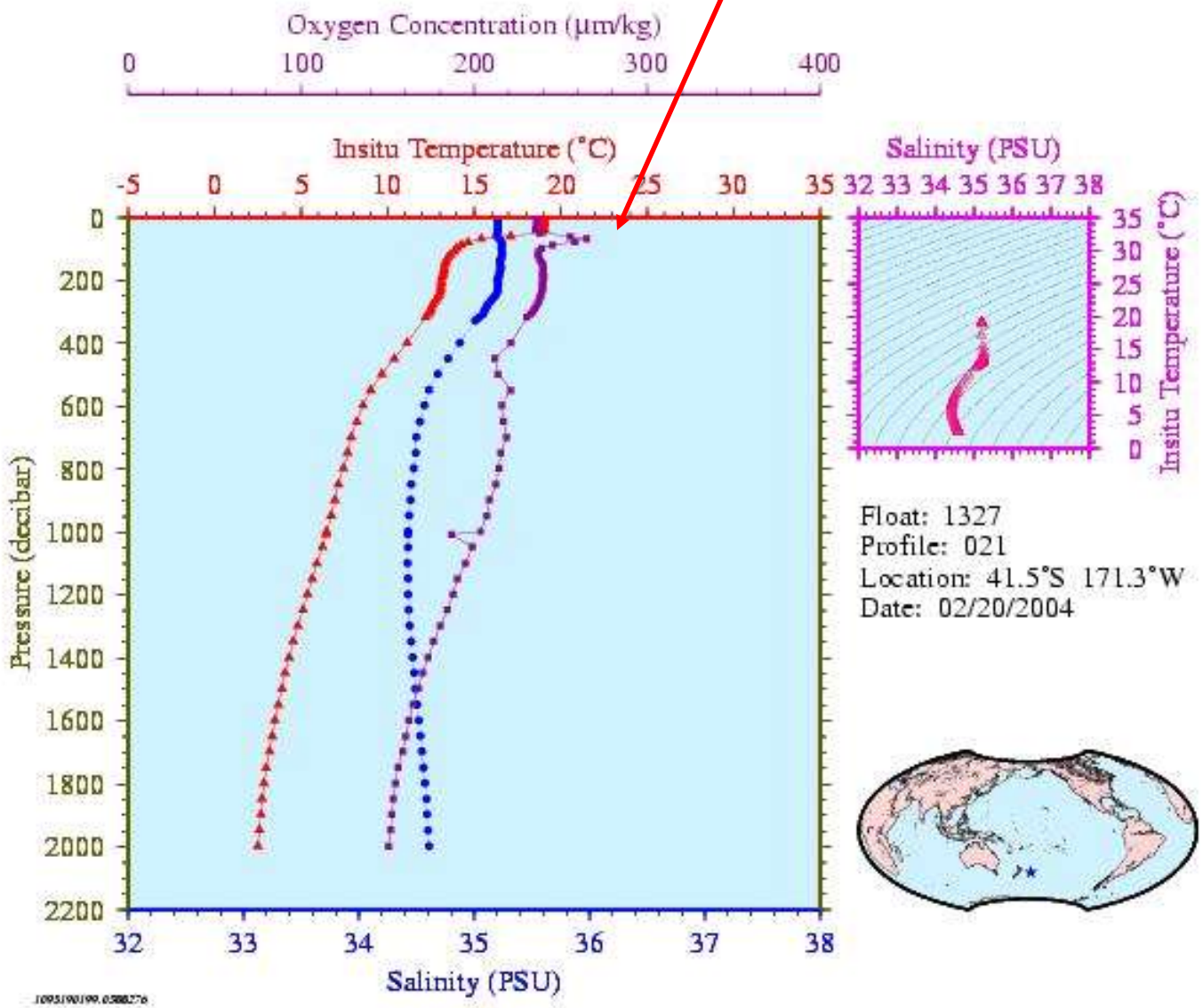
ISUS/APEX float mechanical design. Nitrate, oxygen and bio-optics. Power budget implies its good for ~200 profiles. It will have trouble surfacing in the equatorial warm pool due to limitations in the buoyancy change.



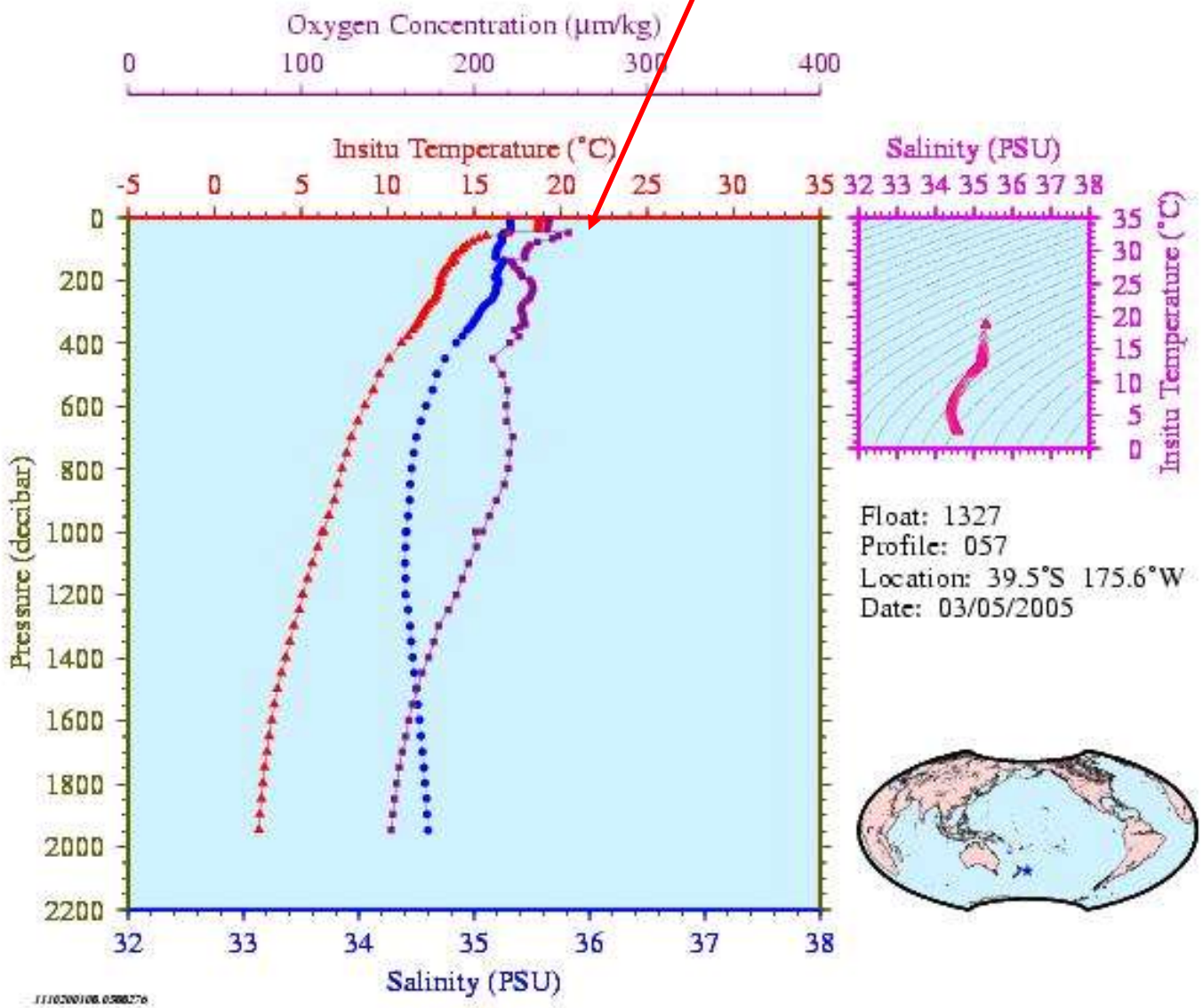
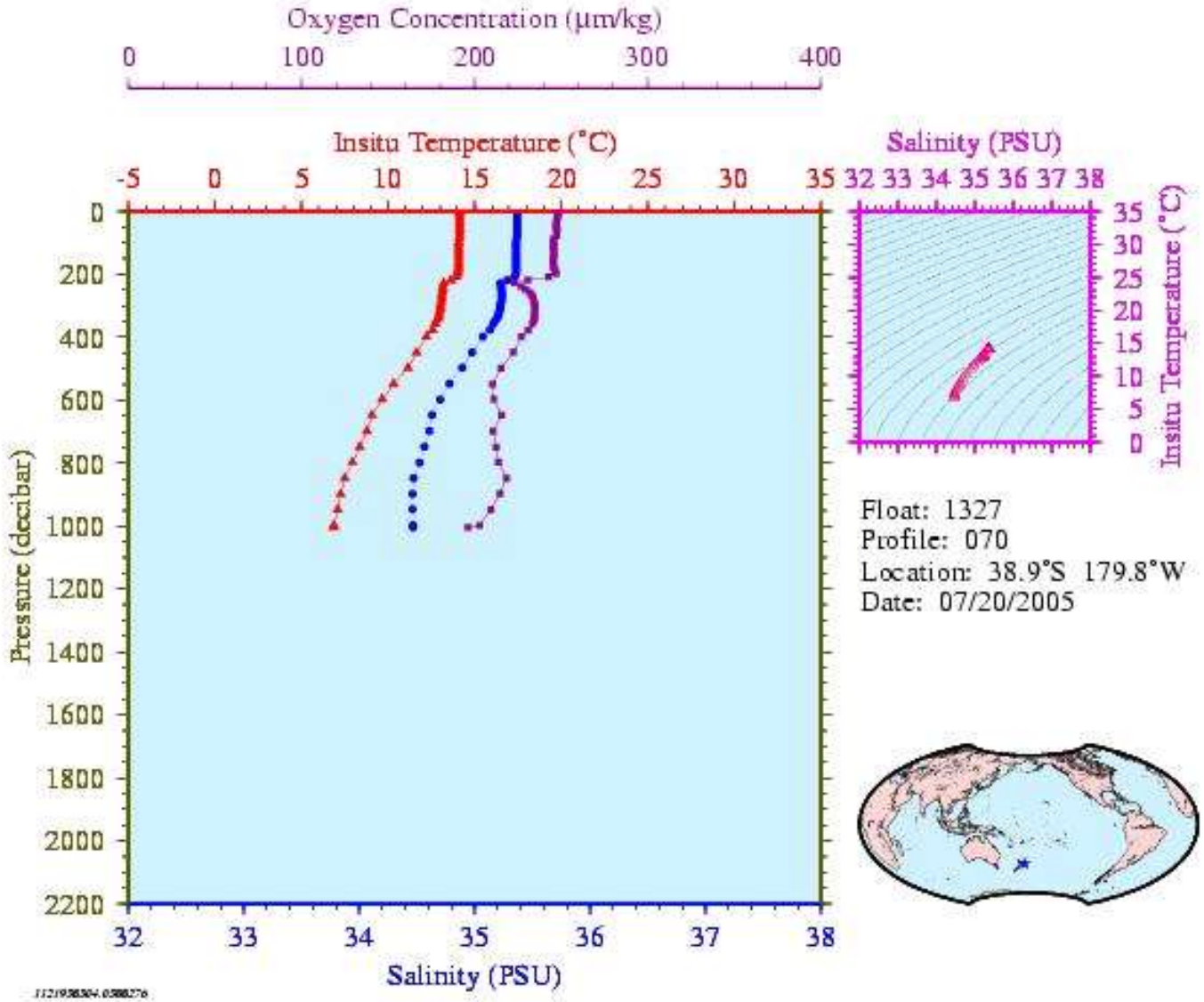
Floats can survive and collect good data in nasty environments. This float is at 40°S. Creates opportunity in the Southern Ocean



Shallow O_2 max. in austral summer 2004



Shallow O_2 max. in austral summer 2005



Back to deep winter mixed layer.