# Methane in the Changjiang (Yangtze River) Estuary and its Adjacent Marine Area: Riverine Input, Sediment Release and Atmospheric Fluxes

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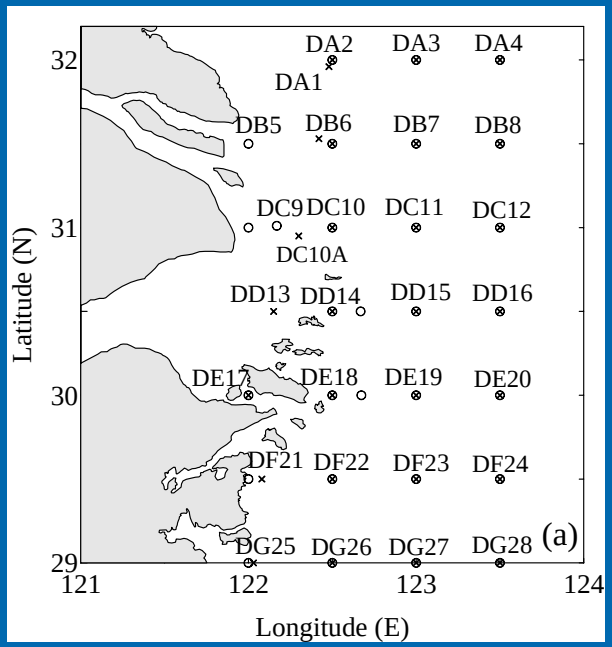
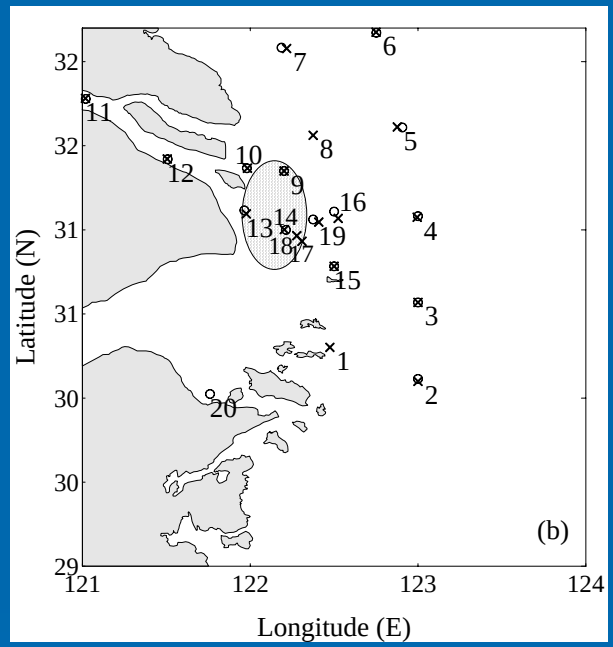
# Introduction

- $CH_4$ is an important atmospheric trace gas, which plays significant roles in the global warming and atmospheric chemistry (IPCC, 2001).
- $CH_4$ is a gaseous constituent of C cycle in marine environment
- Global oceans are net natural source of atmospheric $CH_4$
  - Oceanic emissions of $CH_4$ is 11-18 Tg $Yr^{-1}$, which is about 2-4% of atmospheric $CH_4$ (Bange *et al.*, 1994)
- Estuaries have been estimated to contribute to 7.4% of the total oceanic $CH_4$ emissions (Bange *et al.*, 1994).
- The oceanic source for $CH_4$ may be further enhanced by the increase in emission rates induced by eutrophication and other human-induced changes in highly perturbed coastal regions

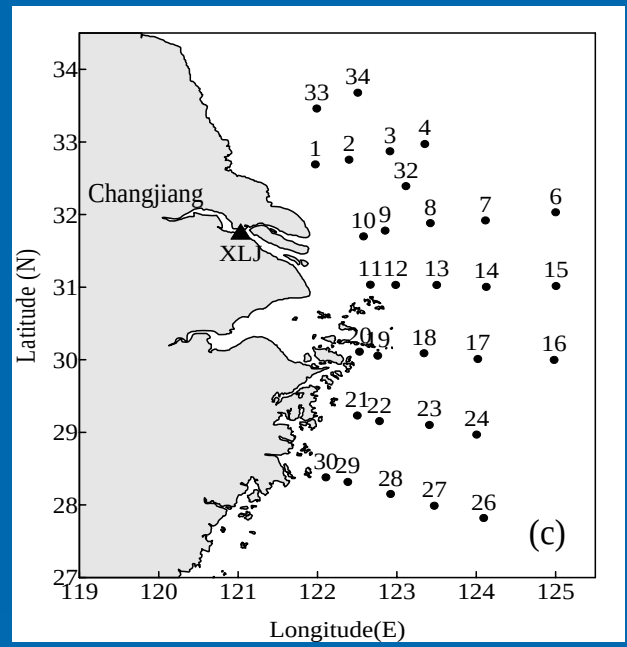
# Study Area




(a) April (×) and November (o) of 2002




(b) August of 2005 (circled area indicating the turbidity maximum)




(c) June, Aug., Oct. of 2006 (●) and Xuliujing (XLJ, solid triangle)

# $CH_4$ in the Changjiang estuary and its adjacent marine water

**Table 1.** Observed $CH_4$ concentrations in the surface and bottom waters of the Changjiang Estuary and its adjacent area (Numbers in the parentheses are the saturations of methane in %)

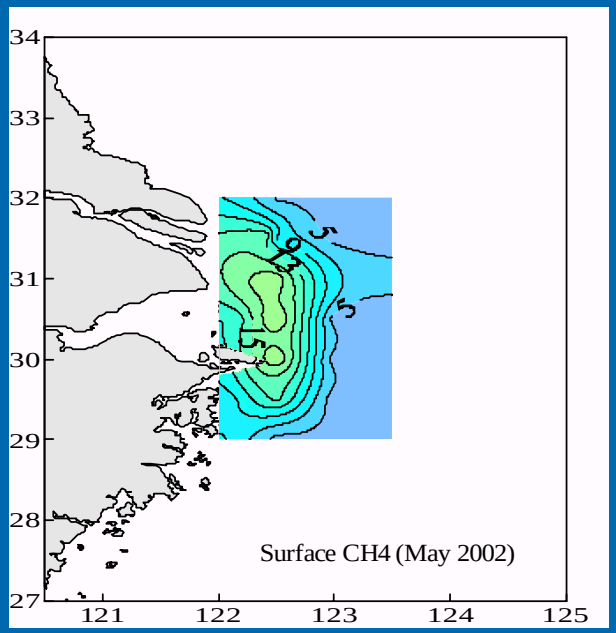
| | | Surface $CH_4$（nM） | | Bottom $CH_4$（nM） | |
|---|---|---|---|---|---|
| Date | n | Range | Average | Range | Average |
| Apr. 25-May 3, 2002 | 28 | 3.54-19.1 (154-782) | 7.95±5.24 (326±205) | 3.93-29.7 | 9.74±6.26 |
| Nov. 4-11, 2002 | 30 | 2.71-16.1 (123-595) | 5.84±3.64 (244±132) | 2.86-11.8 | 5.97±2.55 |
| Aug.21-30, 2005 | 40 | 3.46-88.7 （177-3841） | 18.0±15.8 （810±667） | 5.39-89.2 | 20.6±15.6 |
| June 2-11, 2006 | 21 | 3.66-35.07 (149-1533) | 9.46±8.33 (423±368) | 4.21-42.30 | 14.72±9.67 |
| Oct.3-13, 2006 | 27 | 3.71-54.50 (189-2601) | 9.28±10.01 (454±478) | 4.33-50.50 | 11.35±8.89 |

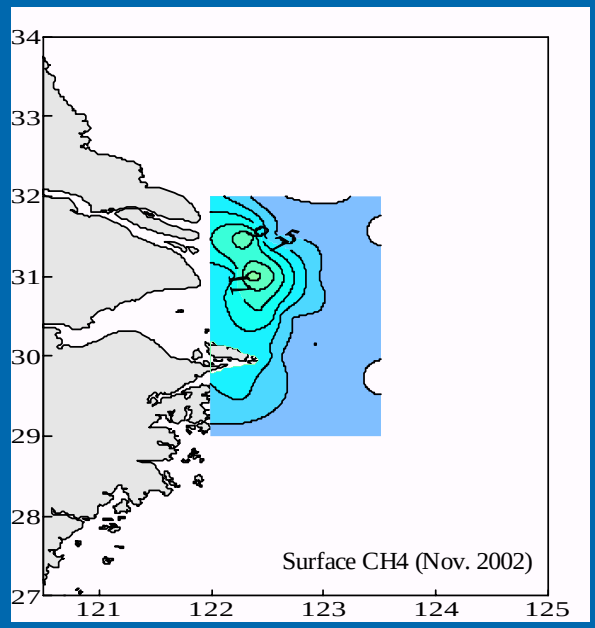
# $CH_4$ in various estuaries in the literatures

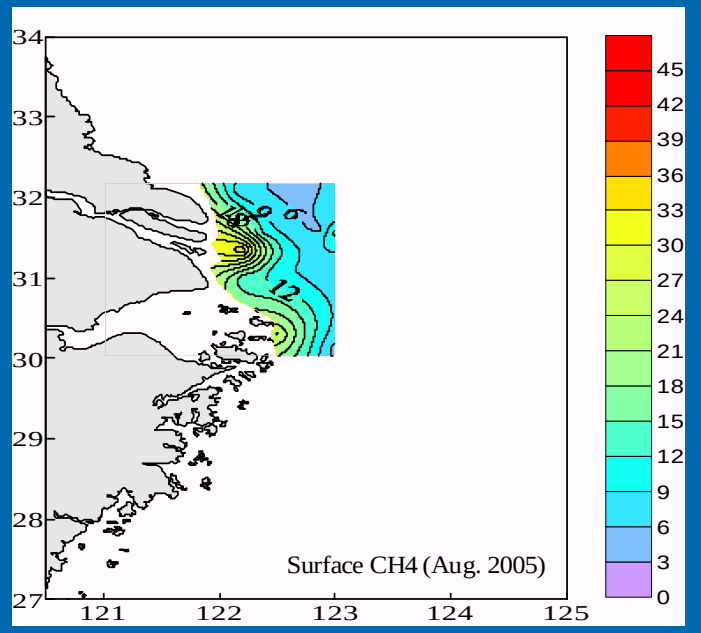
| Study Area | Date | Sur. $CH_4$ (nM) | Sur. R (%) | S | Flux ( μ mol·m$^{-2}$·d$^{-1}$) | References |
|---|---|---|---|---|---|---|
| Tomales Bay | 1990-19 91 | 8-100 | | | 6.75-10.1 | Sansone et al., 1998 |
| Columbia R. estuary | Aug. 1995 | 12-120 | | 7-23 | | Sansone *et al.*, 1999 |
| Parker River estuary | 1996/1997 | 28-930 | | 0-28 | | |
| Oregon estuaries Alsea estuary | 1979-1982 | 5.7-695 | 300-29000 | 2.0-33.7 | 2.5-1312.5 (181.3)[c] | De Angelis and Lilley, 1987 |
| Yaquina estuary | 1979-1982 | 8.1-323 | 125-42000 | 14.3-33.7 | | |
| Salmon estuary | 1979-1982 | 123-323 | 52000-124000 | 20.1-32.1 | | |
| Hudson River estuaty | | | | | 350 | De Angelis and Scranton, 1993 |
| Tyne Estuary | Jan. 1996 | 13.5-654 (164) | 450-20,000 (5843) | | | Upstill-Goddard *et al.*, 2000 |
| Elbe R. estuary | May 1994 | 20-63 | | 6-26 | | Rehder *et al.*, 1998 |
| Rhone R. plume | June 1998 | 397-1363 | | | | Marty *et al.*, 2001 |
| European estuaries | | | | | (130)[c] | Middleburg et al., 2002 |
| Elbe | Apr. 1997 | 4.2-111 | 130-2980 (580) | 0.4-29.3 | | |
| Rhine | Oct.96-Nov.98 | 4.1-1026 | 140-49700 (8400) | 0-33.8 | | |
| Scheldt | Jun. 96-Oct. 98 | 20-485 | 380-20400 (3210) | 0.4-33.3 | | |
| Gironde | Oct. 96-Feb. 98 | 3.7-559 | 70-13400 (580) | 0-35.1 | | |
| Danube Estuaries | July-Aug, 95 | (131±42) | (5340) | | (260)[a]; (470)[b] | Amouroux *et al.*, 2002 |
| Pulicat Lake | Dec. 2000 | 94-501 (242) | | | (54)[a]; (280)[b] | Shalini et al., 2006 |
| Changjiang estuary | 2002-2006 | 2.7-88.7 (10.1) | 123-3841 (451) | | | This study |

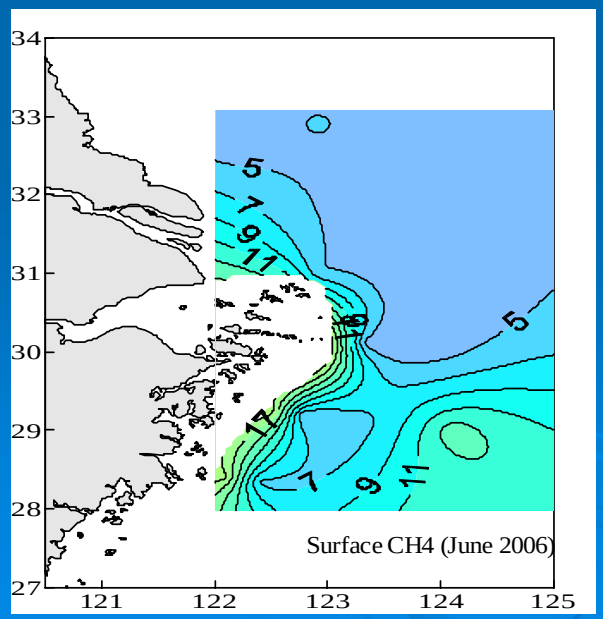
a. $K_w$ was estimated by the LM86 equation; b. $K_w$ was estimated by the W92 equation; c. Averaged value for all of the studied estuaries; Numbers in the parentheses are the average value

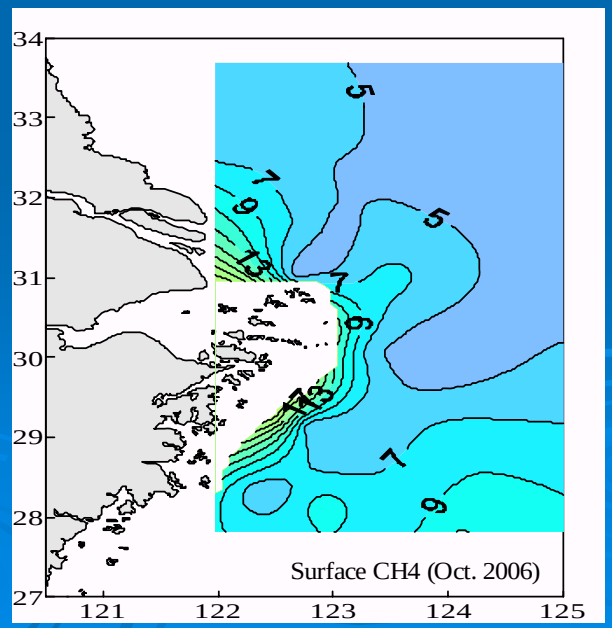
# Horizontal distributions of $CH_4$ in the Changjiang Estuary



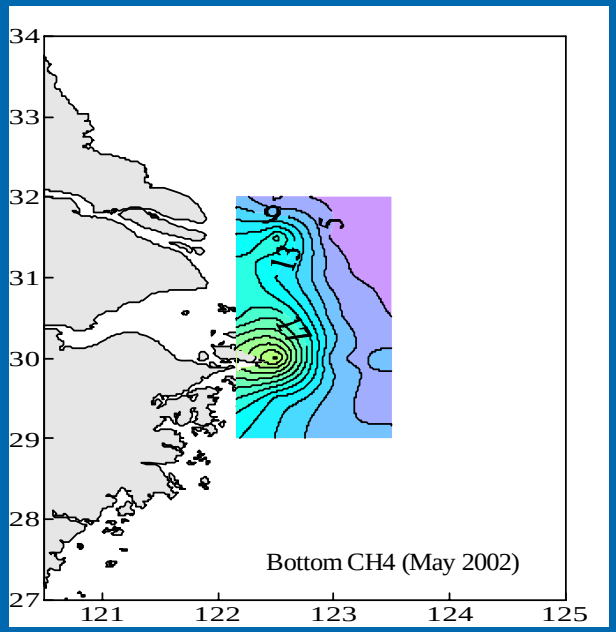



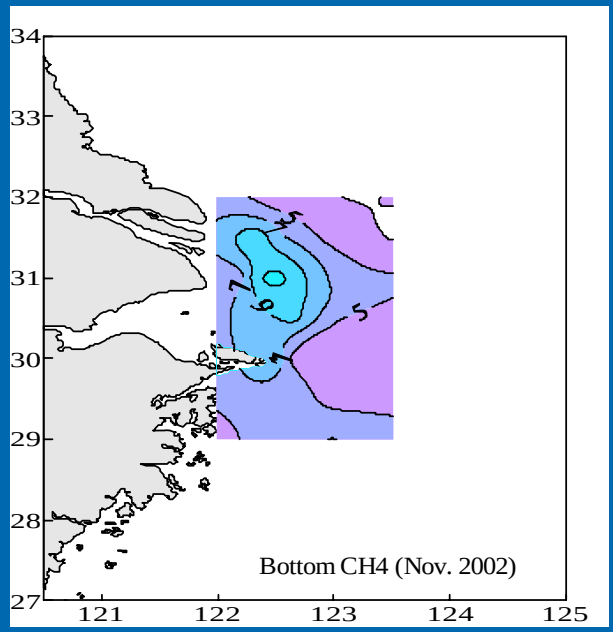



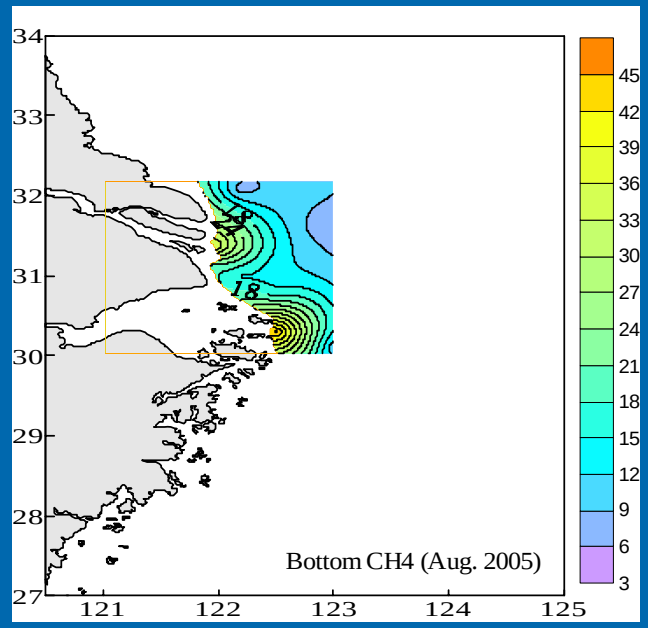



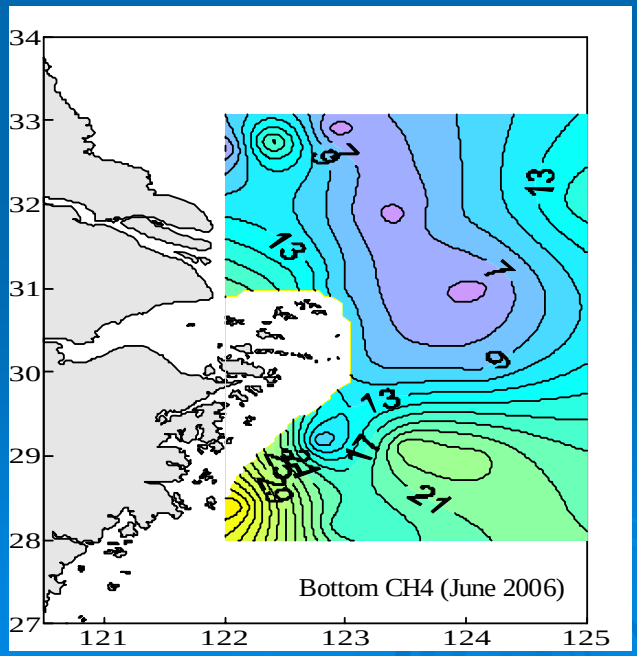



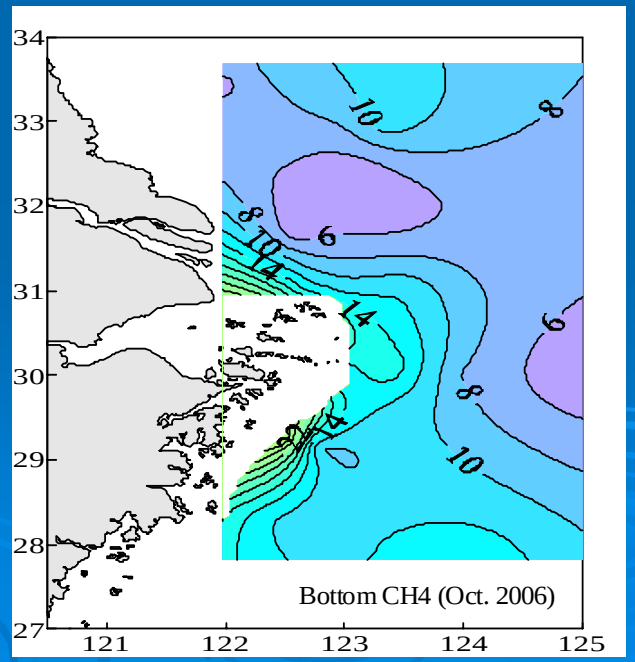

Surface


Bottom CH4 (May 2002)


Bottom CH4 (Nov. 2002)

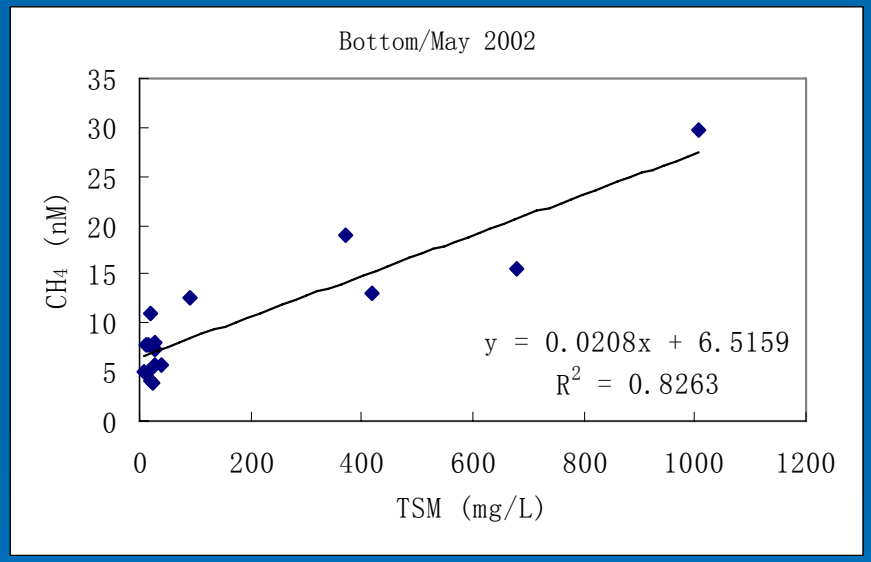

Bottom CH4 (Aug. 2005)

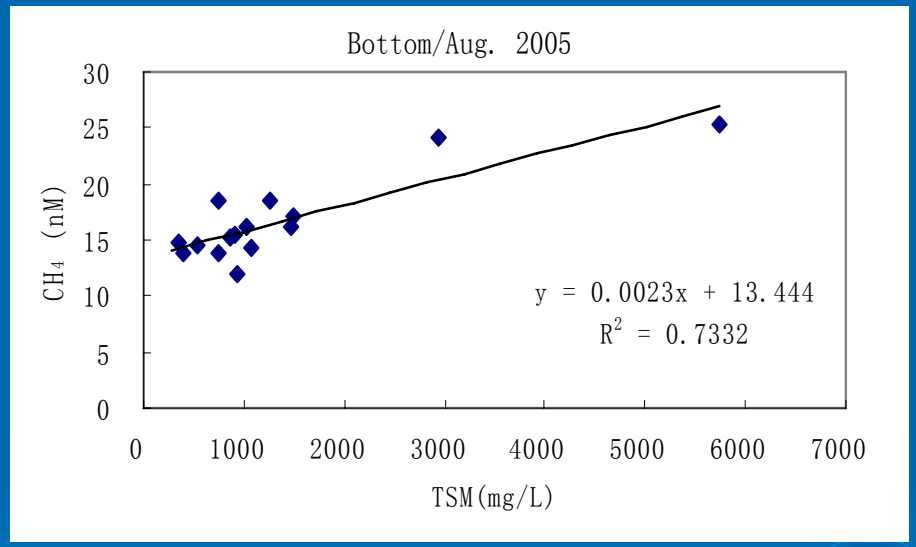

Bottom CH4 (June 2006)


Bottom CH4 (Oct. 2006)

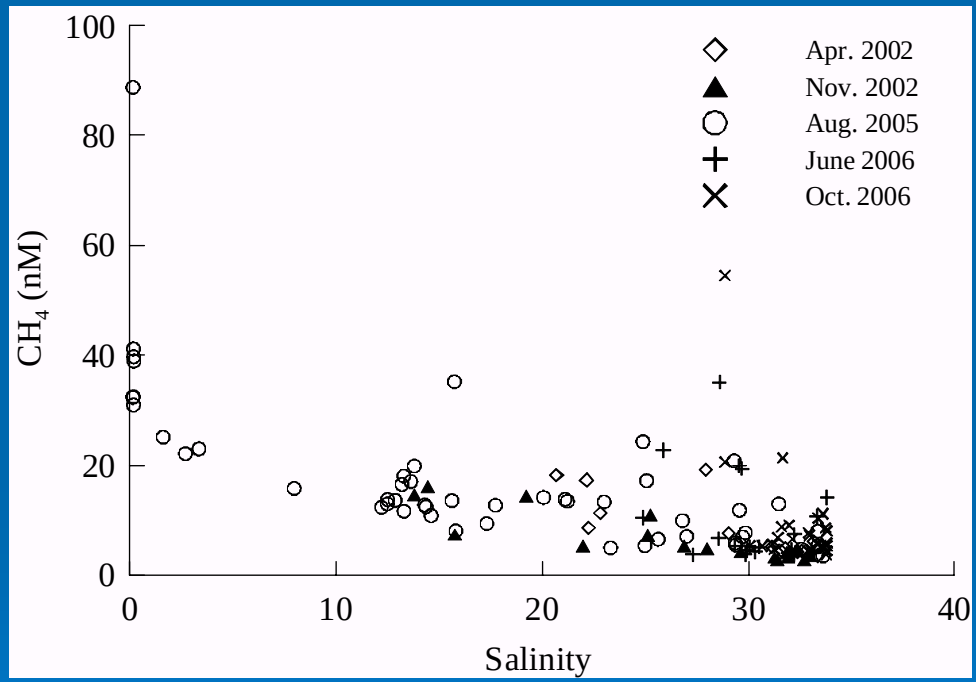
Bottom

# $CH_4$ and Turbidity

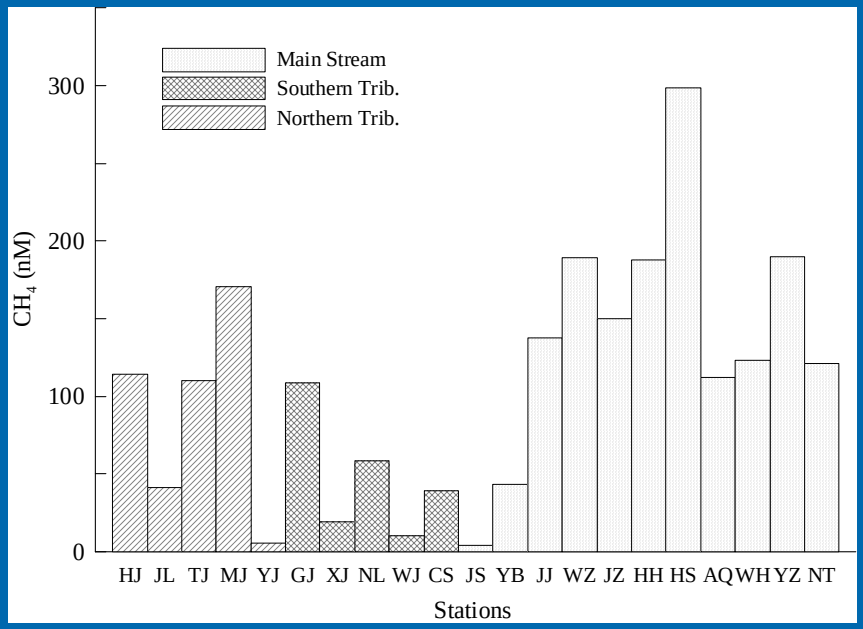


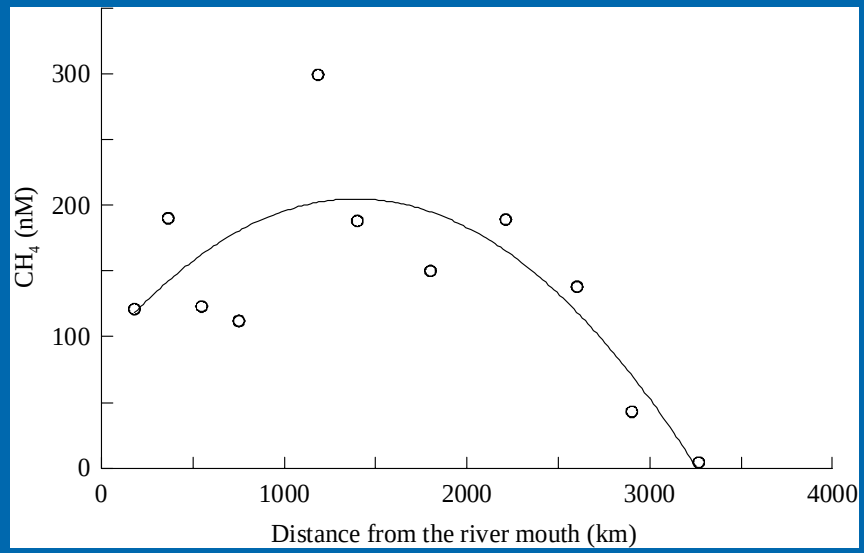



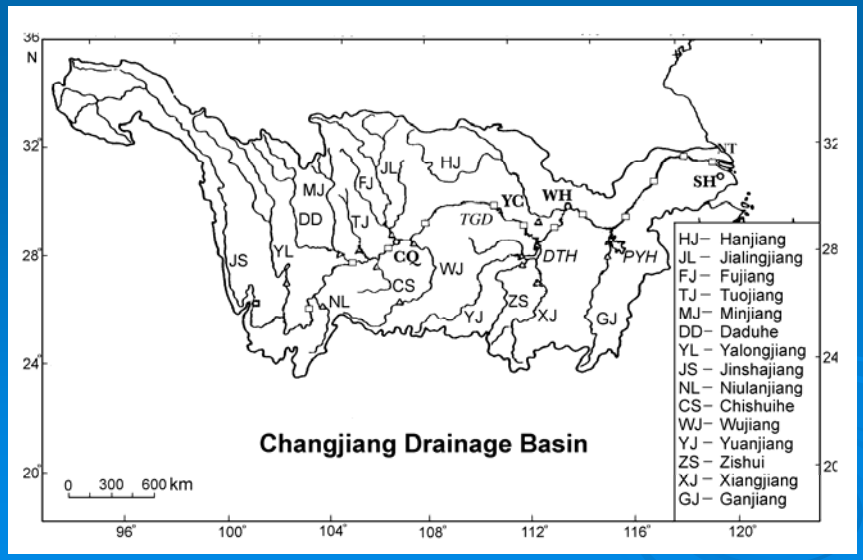
# $CH_4$ vs. salinity in surface waters of the Changjiang Estuary



# $CH_4$ in the Changjiang (April/May 2003)



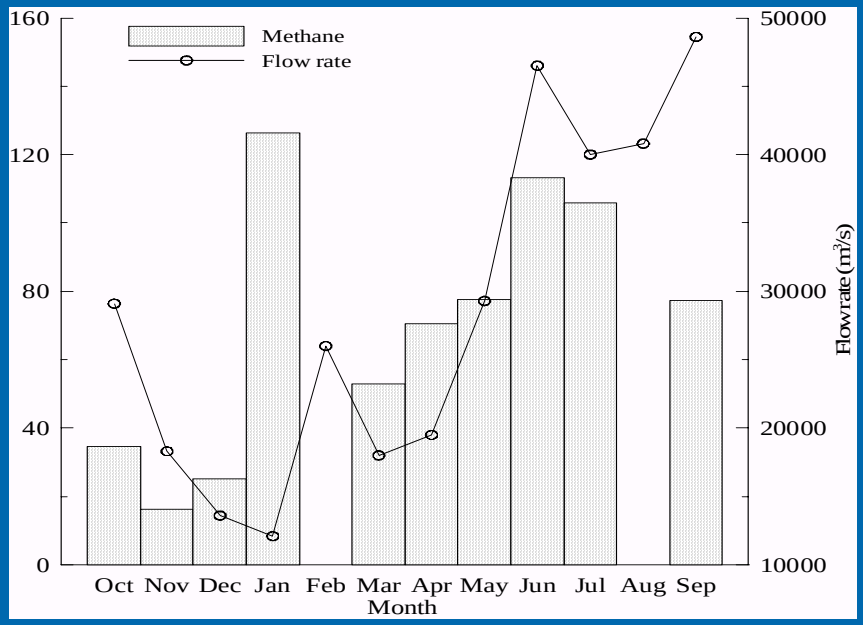

- $CH_4$: 4.50-299 nM

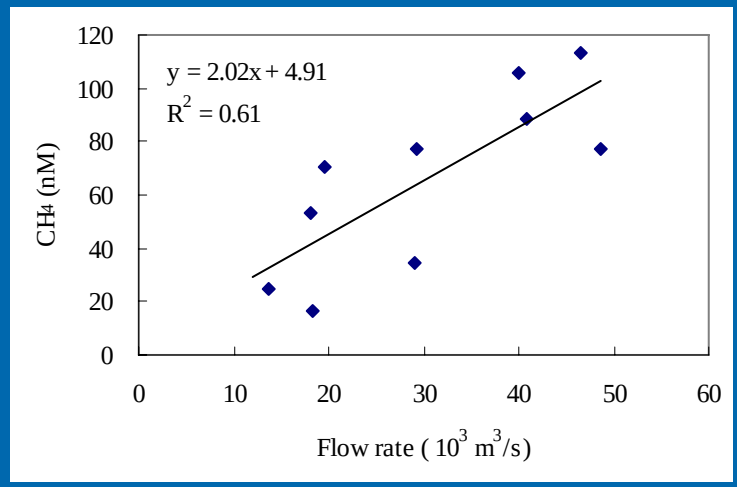
  106 ± 76.7 nM

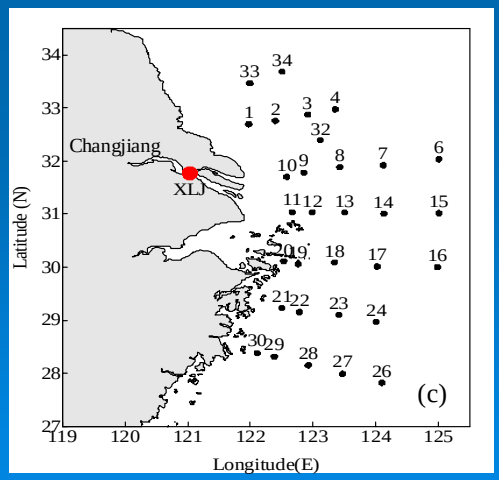
Compilation of dissolved methane in various rivers (Numbers in the parentheses are the average value)

| Rivers | Description | $CH_4$ (nM) | $CH_4$ (%) | References |
|---|---|---|---|---|
| Oregon rivers<br>McKenzie<br>Willamette<br>Alsea<br>Yaguina<br>Siletz | 1979-1982 | <br>5-79<br>155-298<br>22-729<br>276-1,730<br>500-1,100 | <br>200-2600<br>5200-11100<br>700-30,300<br>9,500-59,800<br>17,500-38,500 | De Angelis and Lilley, 1987 |
| Mississippi | | 107-366 | 3,600-15,200 | Swinnerton & Lamontagne, 1974 |
| Hudson | In summer<br>In spring | 98-940<br>101-303 | 4,400-42,400<br>2,700-8,100 | De Angelis and Scranton, 1993 |
| Walker creek | | 140-950 | 6,000-40,000 | Sansone *et al.*, 1998 |
| Amazon | Open water | 460-3,700 | 16,100-129,500 | Devol *et al.*, 1990 |
| | Main stem | (180±30) | (6,300±1,050) | Bartlett *et al.*, 1990 |
| Orinoco | Main stem, Sep.-March | (170) | | Smith et al., 2000 |
| Ouse | Dec. 1996 | (119±47) | (3,861±667) | Upstill-Goddard, 2000 |
| Tyne | Dec. 1996 | 2.6-146 | 75-4,129 | Upstill-Goddard, 2000 |
| Scheldt | Jun. 1996-Oct.1998 | 179-485 (282±138) | | Middelburg et al., 2002 |
| Elbe | | 60-120 | 1,750-3,500 | Wernecke *et al.*, 1994 |
| | April 1997 | 111 | | Middelburg et al., 2002 |
| Douro | Sep. 1998 | 63-128 | | Middelburg et al., 2002 |
| Rhine | Oct. 1996-Apri. 1998 | 37-1437 | | |
| Gironde | Oct. 1996-Feb. 1998 | 10–559 | | |
| Thames | April 1997 | 273 | | |
| Yangtze River | Oct. 2004-Sep. 2005<br>Apr/May 2003, main stem | 16.2-126.2 (71.6±36.3)<br>106±76.7 | | This study |

# Riverine input of $CH_4$ via Changjiang (Oct. 04-Sep. 05)



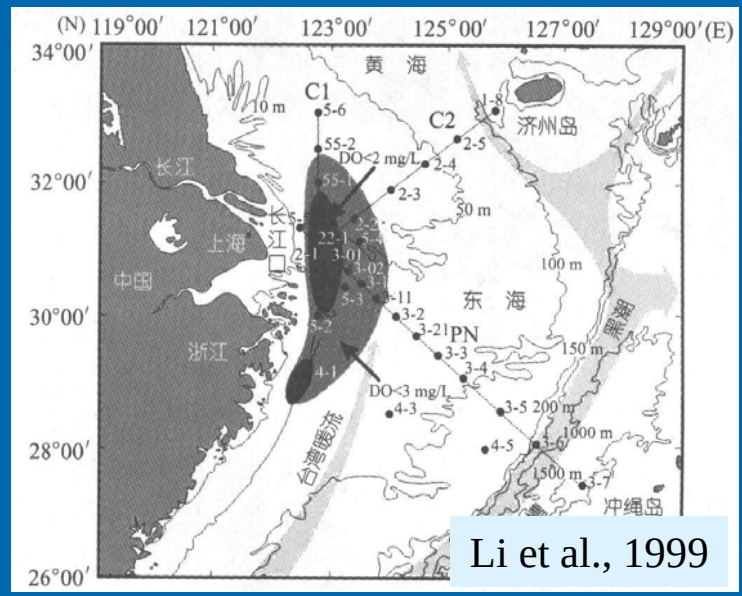




- $CH_4$ in Xuliujing (XLJ) ranged between 16.2 to 126.2 nM with an average of 71.6±36.3 nM
- $CH_4$ input via Changjiang is estimated to be $70.6 \times 10^6$ mol/yr

# Sediment release of $CH_4$ from Changjiang Estuary

| Station | Date | Description | $CH_4$ emission rate $\mu$ mol.m$^{-2}$.d$^{-1}$ |
|---|---|---|---|
| DB6 | Apr. 2002 | Silt, depth 23m | 2.42 |
| DC10 | Apr. 2002 | Clay, depth 10m | 1.91 |



Li et al., 1999

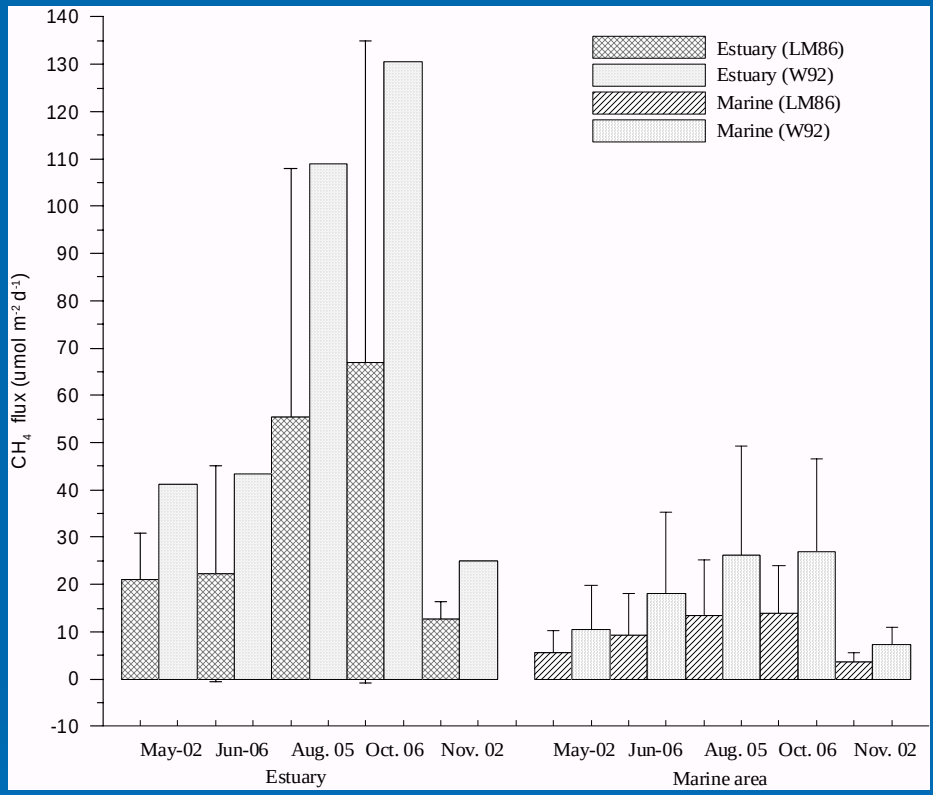
- Sediment release of $CH_4$ from the Changjiang Estuary was estimated to be $25 \times 10^6$ mol yr$^{-1}$, which is equal to about 40% of the riverine input of $CH_4$
- $CH_4$ production in the sediments may be much higher in summer than in spring
- More measurements on the $CH_4$ emission rates at different seasons in the Changjiang Estuary will be conducted to assess the source strength of sediment release accurately

# Air-sea fluxes of $CH_4$ from the Changjiang Estuary

Estuary:

LM86: 35.7±23.9

W92: 69.8±46.8




Marine area:

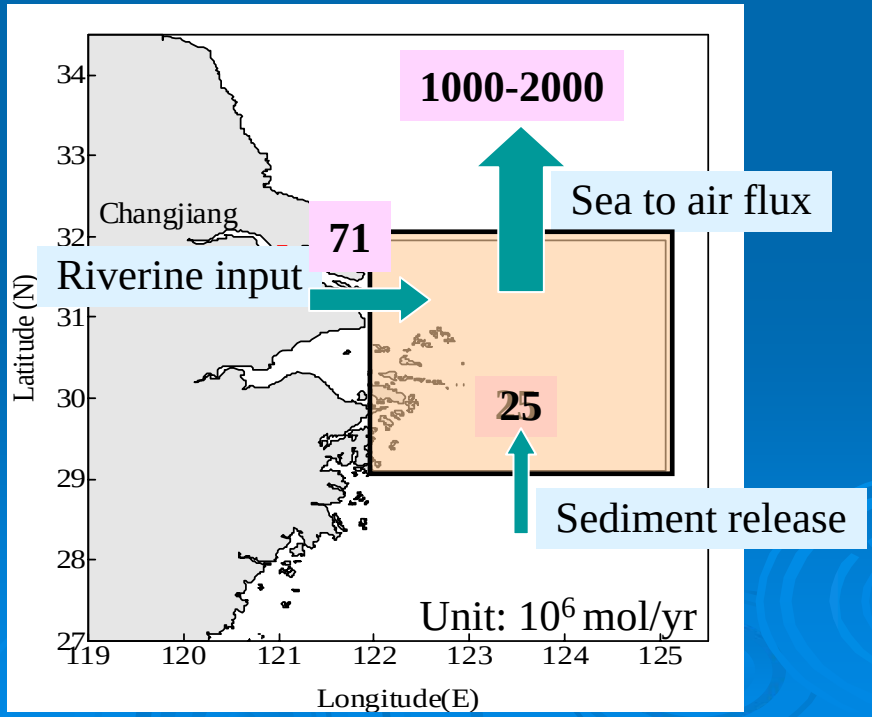
LM86: 9.1±4.6

W92: 17.8±8.9

- Sea to air $CH_4$ fluxes from the Changjiang Estuary is obviously higher than those from the adjacent marine area.
- Annual $CH_4$ emission from the studied region was $10.0\times10^8$ and $19.6\times10^8$ mol $yr^{-1}$ by LM86 and W92 equation.

# Conclusions

- Riverine input and sediment release are important sources of $CH_4$ in the Changjiang estuary and its adjacent area
- The Changjiang estuary and its adjacent area acts as a significant source of atmospheric $CH_4$




# *Thank you!*


# Computation of sea-to-air fluxes

Saturation: $R(\%) = C_{obs}/C_{eq}$

Sea-to-air flux: $F = k \times (C_{obs} - C_{eq})$

Where $C_{obs}$ is the observed concentration of dissolved gases; $C_{eq}$ is the air-equilibrated seawater gases concentration; k is gas transfer velocity

| References | relationships to estimating k | $U_{10}$（m/s） |
|---|---|---|
| Liss and Merlivat (1986, LM86) | $k=0.17U_{10}(Sc/600)^{-2/3}$<br>$k=(2.85 \times U_{10}-9.65)(Sc/600)^{-1/2}$<br>$k=(5.9 \times U_{10}-49.3)(Sc/600)^{-1/2}$ | $0< U_{10} \leqslant 3.6$<br>$3.6< U_{10} \leqslant 13$<br>$13 < U_{10}$ |
| Wanninkhof (1992, W92) | $k=0.31\ U_{10}^2(Sc/660)^{-1/2}$<br>$k=0.39\ U_{10}^2(Sc/660)^{-1/2}$ | In situ wind speed<br>Long term wind speed |
| Raymond and Cole (2001, RC01) | $k=1.91\exp(0.35U_{10})$ | |

$Sc=2039.2-120.31T+3.4209T^2-0.040437T^3$ $CH_4$ (Wanninkhof , W92)

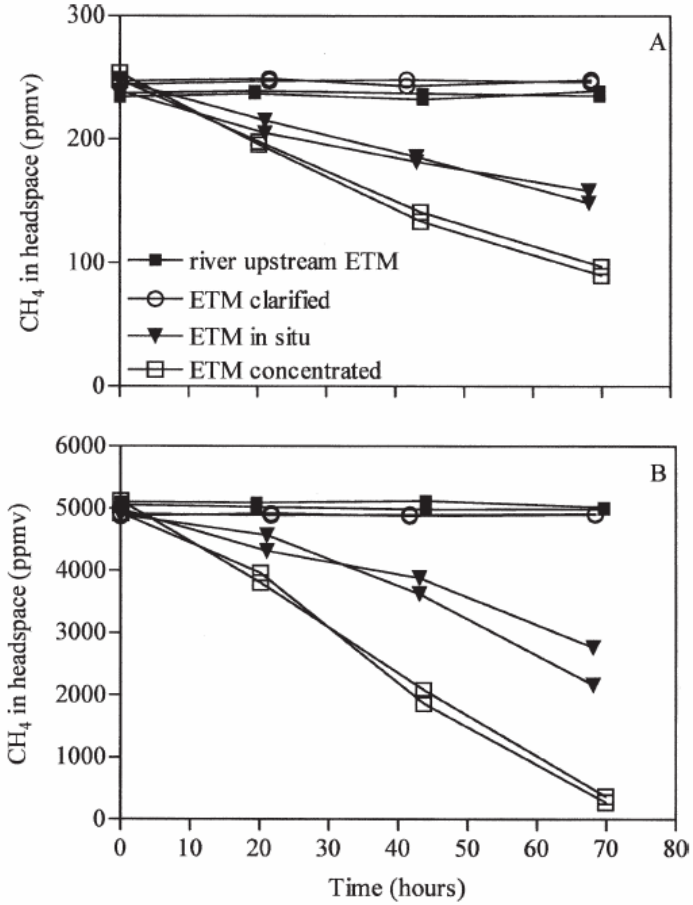



Fig. 3. Time-course of methane concentrations in headspaces of vials containing different water samples from the Garonne tidal river in April 2005. The "river upstream ETM" sample is from Sta. G30 and had a SPM concentration of 3.2 mg $L^{-1}$. The three ETM samples are from Sta. G70; the "ETM in situ" sample was incubated without any treatment and had a SPM concentration of 2,020 mg $L^{-1}$; in the "ETM clarified" sample, the particles were removed by settling during 54 h, and the SPM concentration was 16 mg $L^{-1}$; in the "ETM concentrated" sample, SPM was increased by settling and was 8,720 mg $L^{-1}$. Headspace and sample volumes were both ~80 mL. Incubations started at two different dissolved methane concentrations in the water: (A) 360 nmol $L^{-1}$ and (B) 7,200 nmol $L^{-1}$.

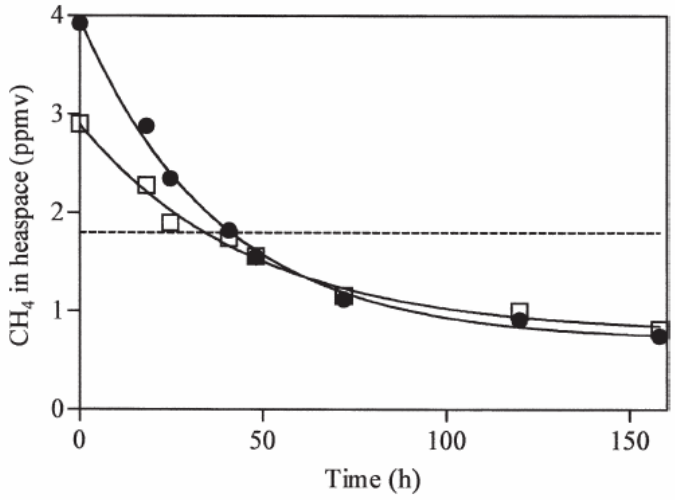



Fig. 4. Time-course of methane concentrations in headspaces of vials containing a water samples from the Garonne ETM in May 2005 (SPM concentration: 1,730 mg $L^{-1}$) performed at low methane concentrations. The dashed line shows the atmospheric methane concentration of 1.8 ppmv.

Source: Abril et al., 2007