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Objective Determination of Global Ocean Thermocline Strength from Profile Data

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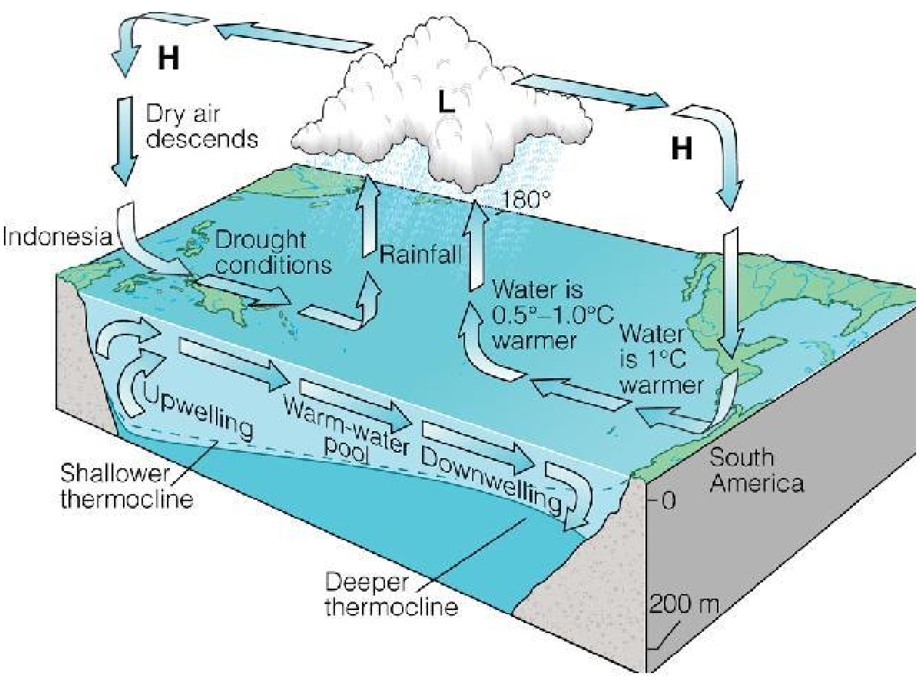
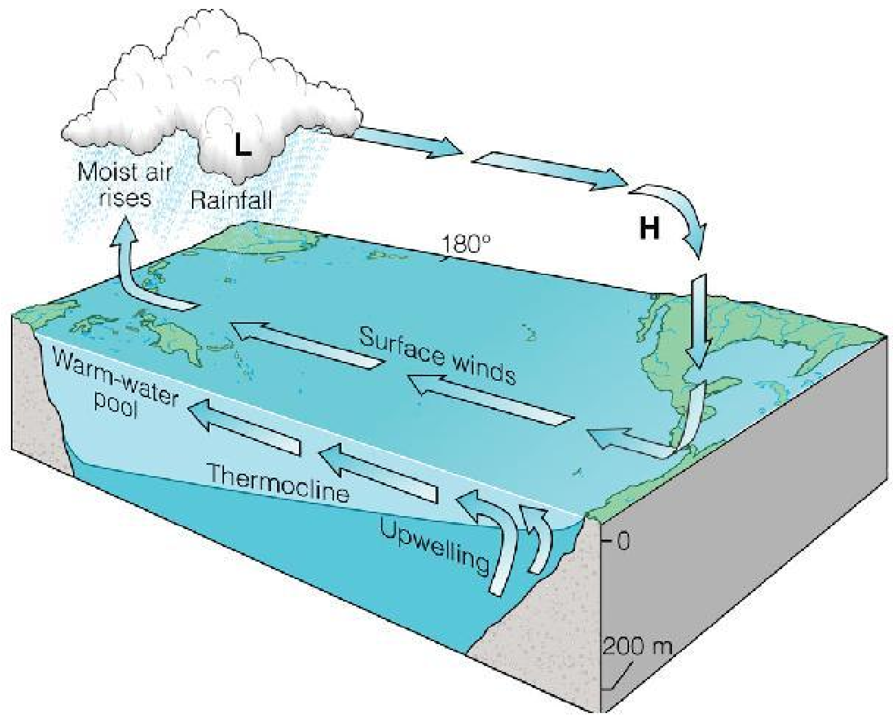
Outline

- (1) Thermocline and Climate
- (2) Gradient Ratio Method
- (3) Global Mixed Layer/Thermocline Data Set
- (4) Characteristics of Global Thermocline

Effect of Thermocline on Climate





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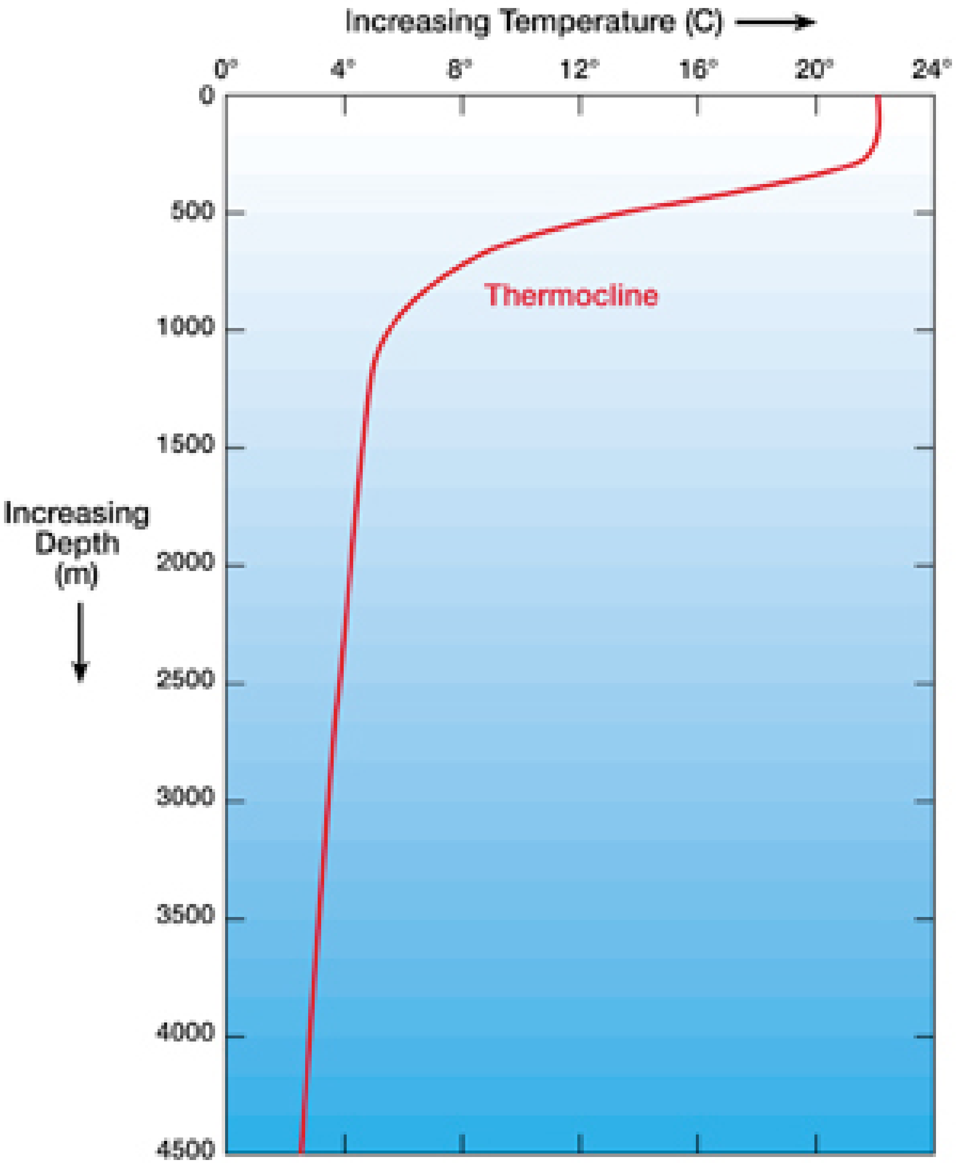
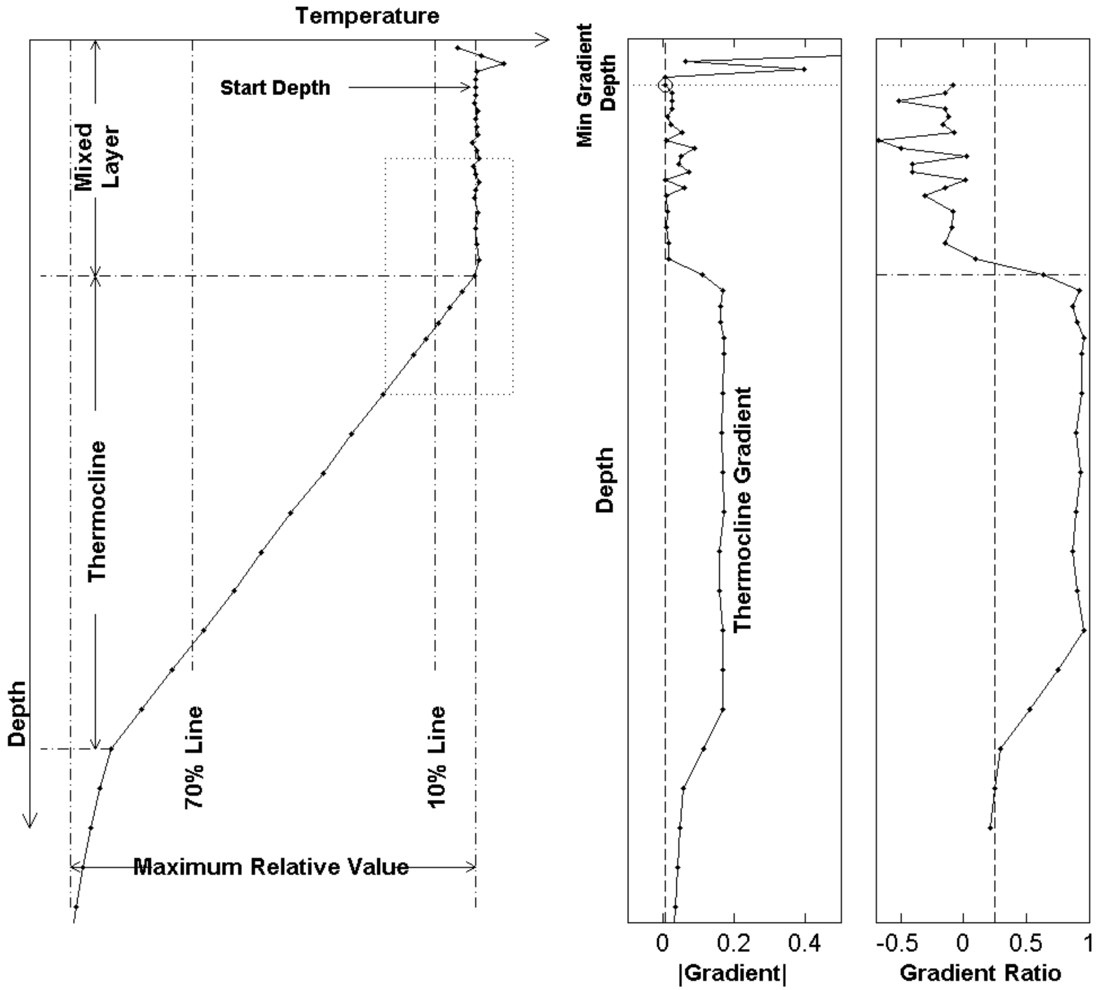
Ocean Thermal Structure



Observational Temperature Profile



Two Distinct Types of Gradients:

(1) Near 0 in Mixed Layer

(2) Finite in Thermocline

$$G_1 = \frac{T_2 - T_1}{z_2 - z_1}, \quad G_k = \frac{T_{k+1} - T_{k-1}}{z_{k+1} - z_{k-1}}, \quad G_K = \frac{T_K - T_{K-1}}{z_K - z_{K-1}}, \quad k = 2, \ldots, K\text{-}1$$

Here, k = 1 at the surface

Gradient Ratio Method

- (1) Downward from surface,

$$z_{\min} \rightarrow G_{\min} = \min_{K \geq k \geq 1}(|G_k|)$$

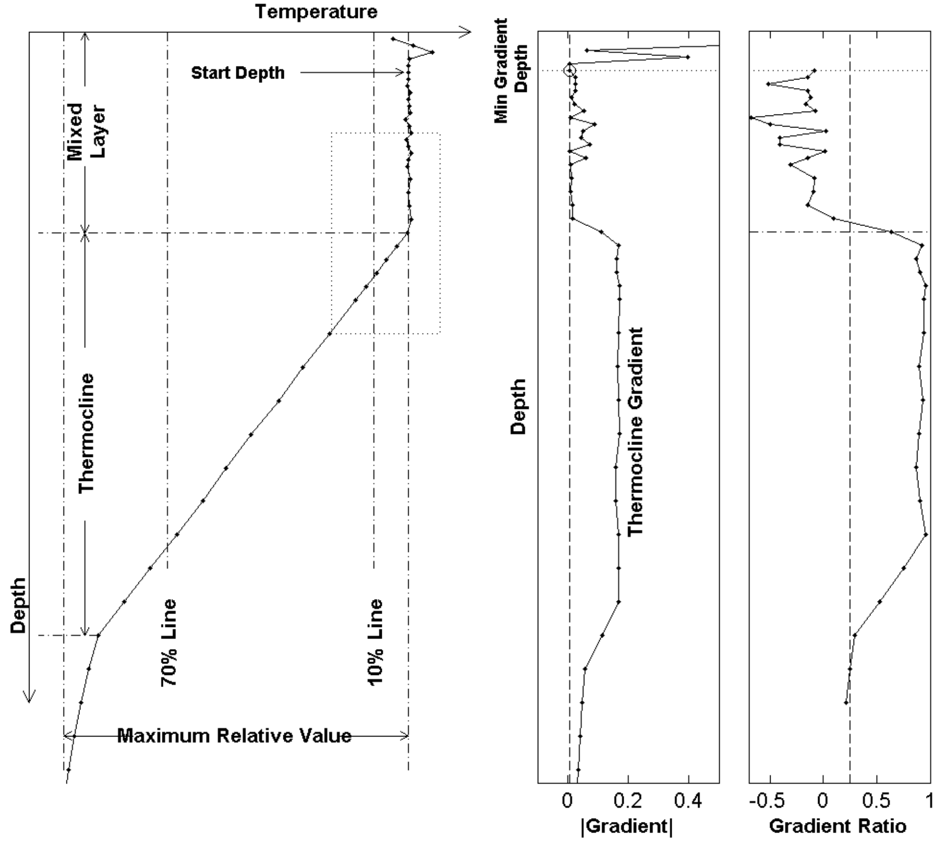
- (2) $\Delta T = T_{zmin} - T_K$

- (3) Main Part of thermocline

$z_{(0.1)}$ to $z_{(0.7)}$

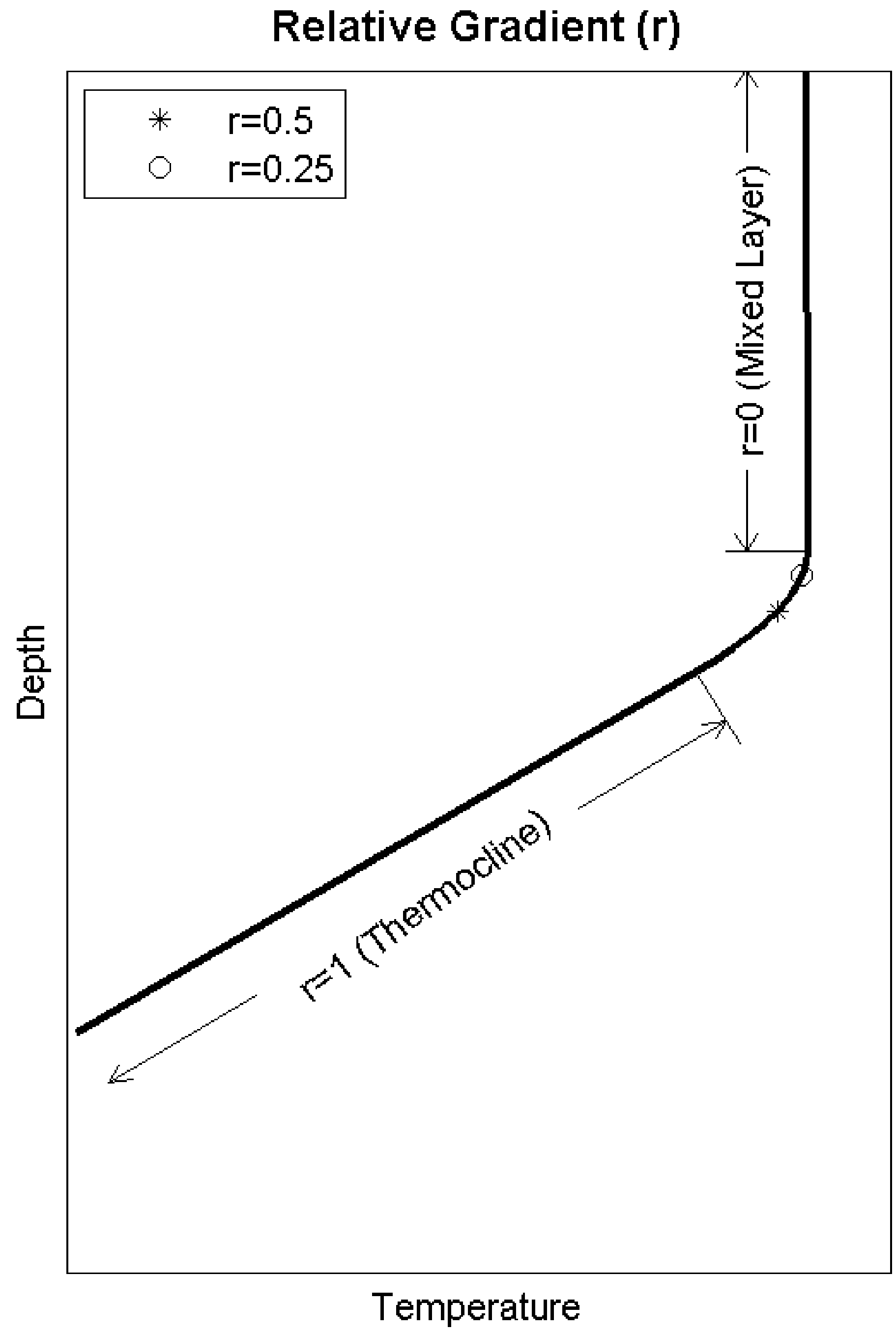
- (4) Maximum Gradient

$$G_{\max} = \max_{z_{(0.1)} > z_k > z_{(0.7)}} (G_k)$$



$$r_k = G_k / G_{\max}$$

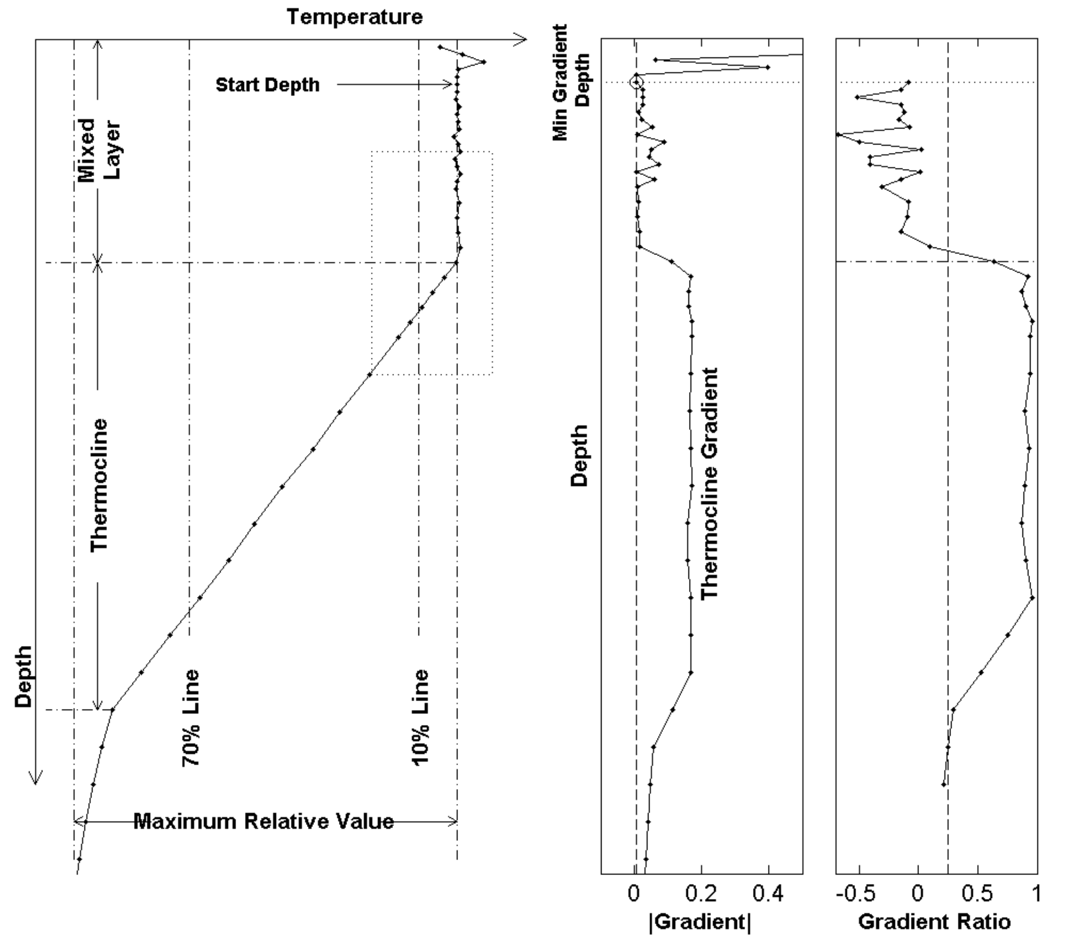
Gradient Ratio $r_k = G_k/G_{th}$ *to identify Mixed Layer Depth and Thermocline Characteristics*



Maximum and Mean Gradients in Thermocline

G_{max} or $\bar{G}_{th}$ → Thermocline Strength

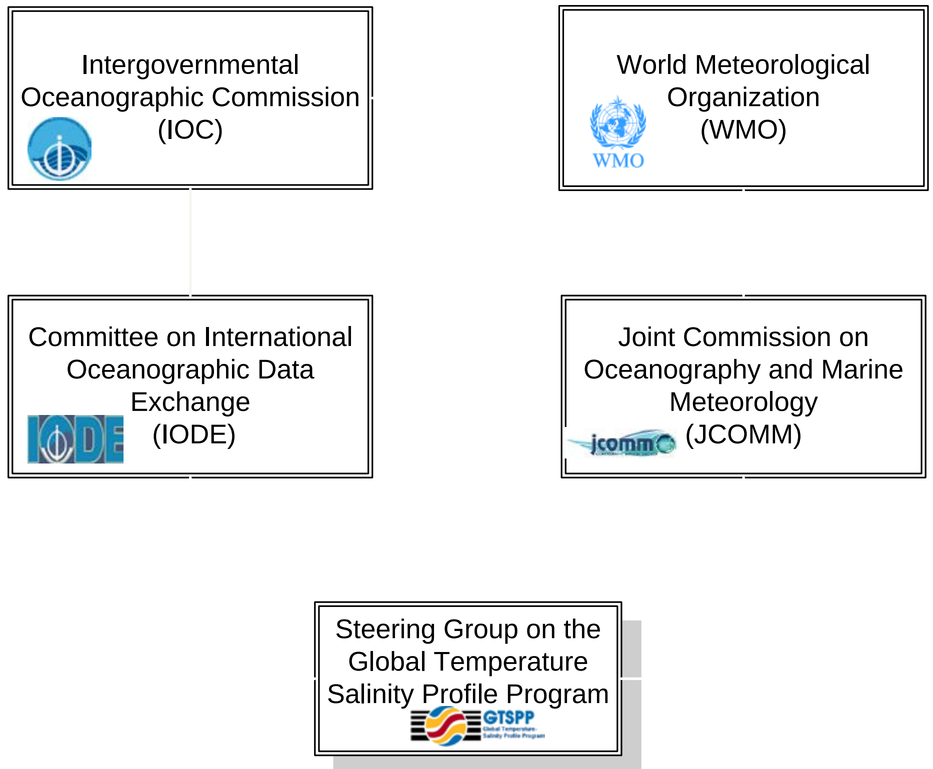
$$\bar{G}_{th} = \underset{r_k > 0.5}{mean}(G_k)$$

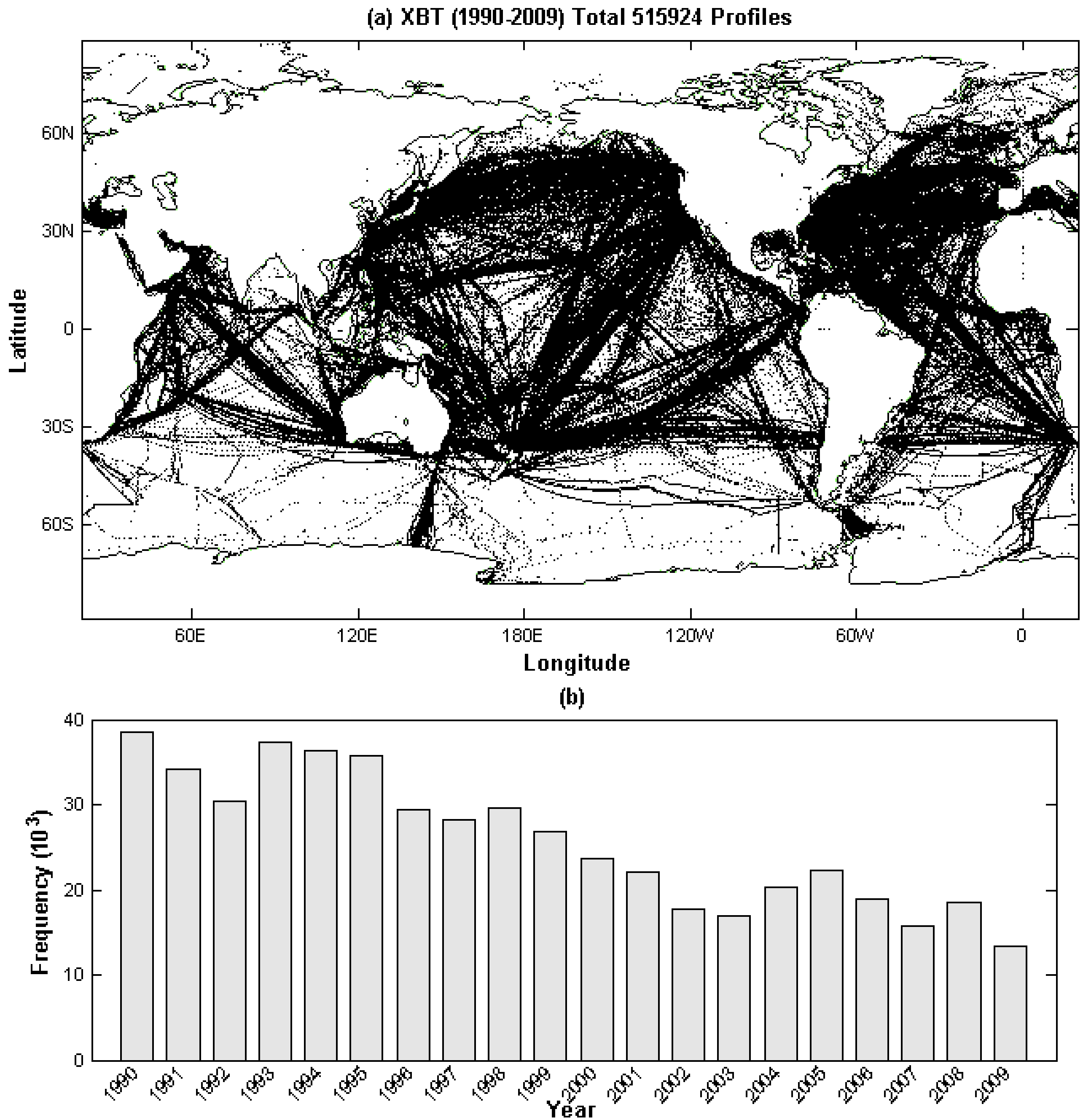


GTSPP

GTSPP = Global Temperature Salinity Profile Program

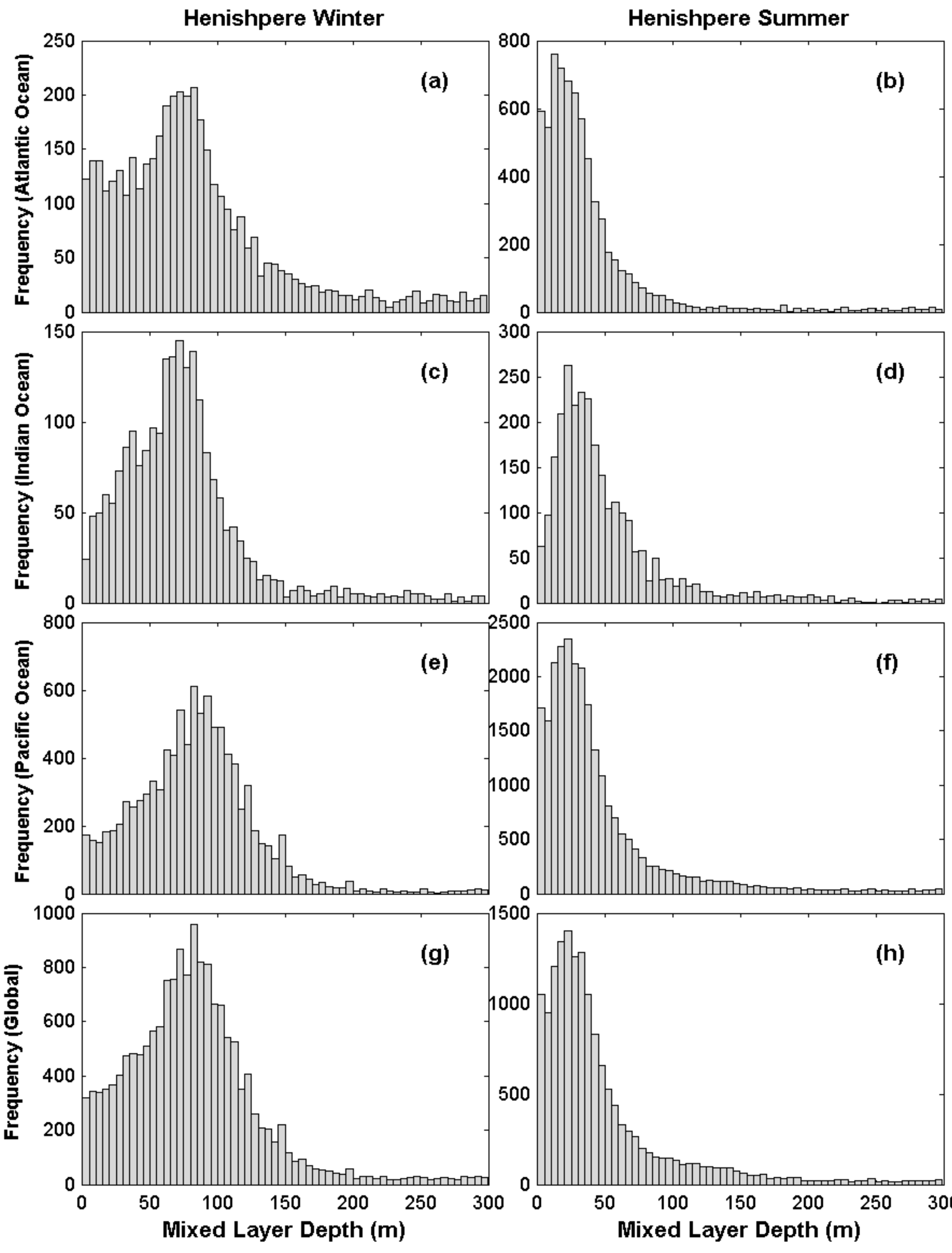
- GTSPP is a joint WMO-IOC program designed to provide improved access to the highest resolution, highest quality data as quickly as possible.
- GTSPP began as an official IODE pilot project in 1989.
- It went into operation in November 1990.





(a) XBT (1990-2009) Total 515924 Profiles
60N
30N
0
30S
60S
Latitude
60E
120E
180E
120W
60W
0
Longitude
(b)
40
30
20
10
0
Frequency (10 3)
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Year

Histograms of Mixed Layer Depth (MLD)



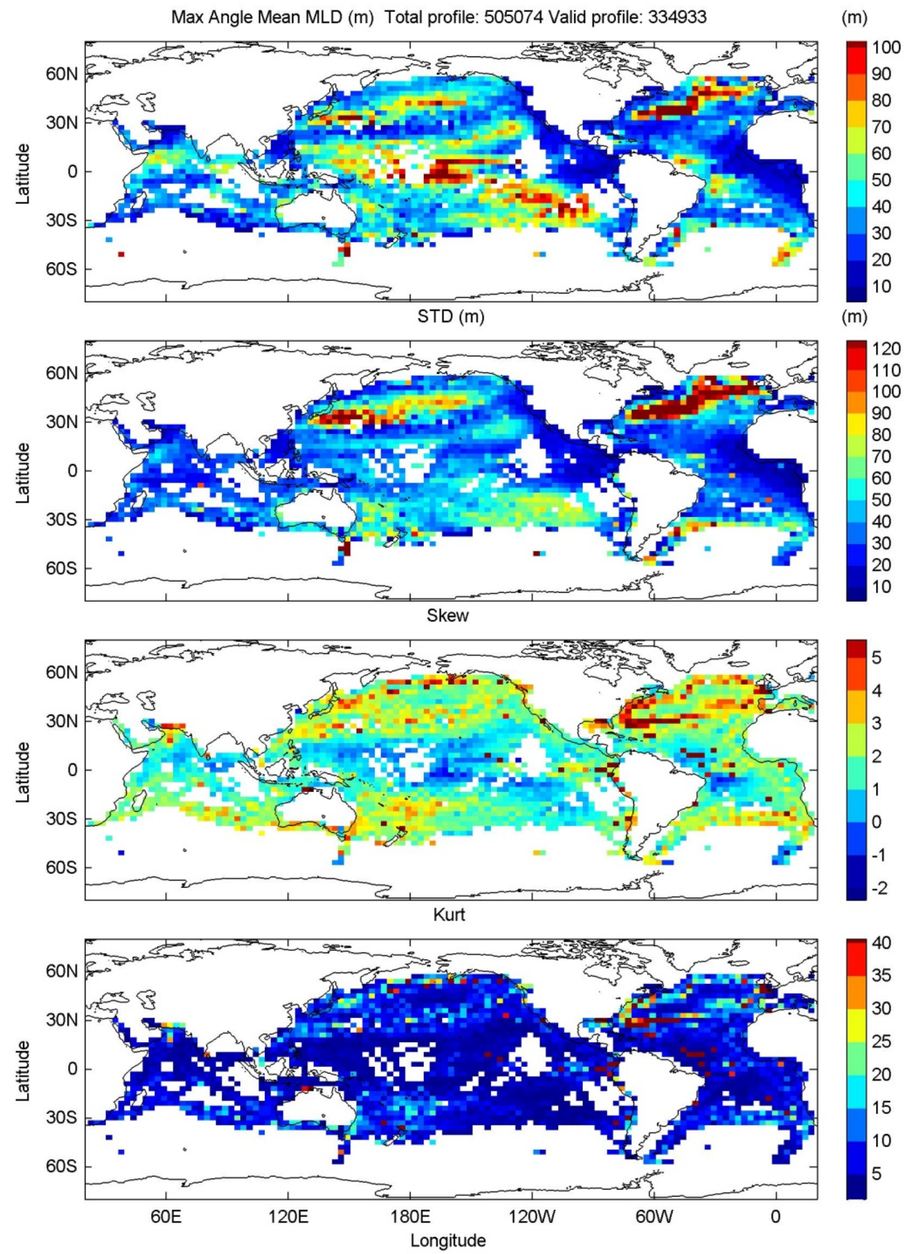
Statistical Characteristics of MLD

Mean (m)

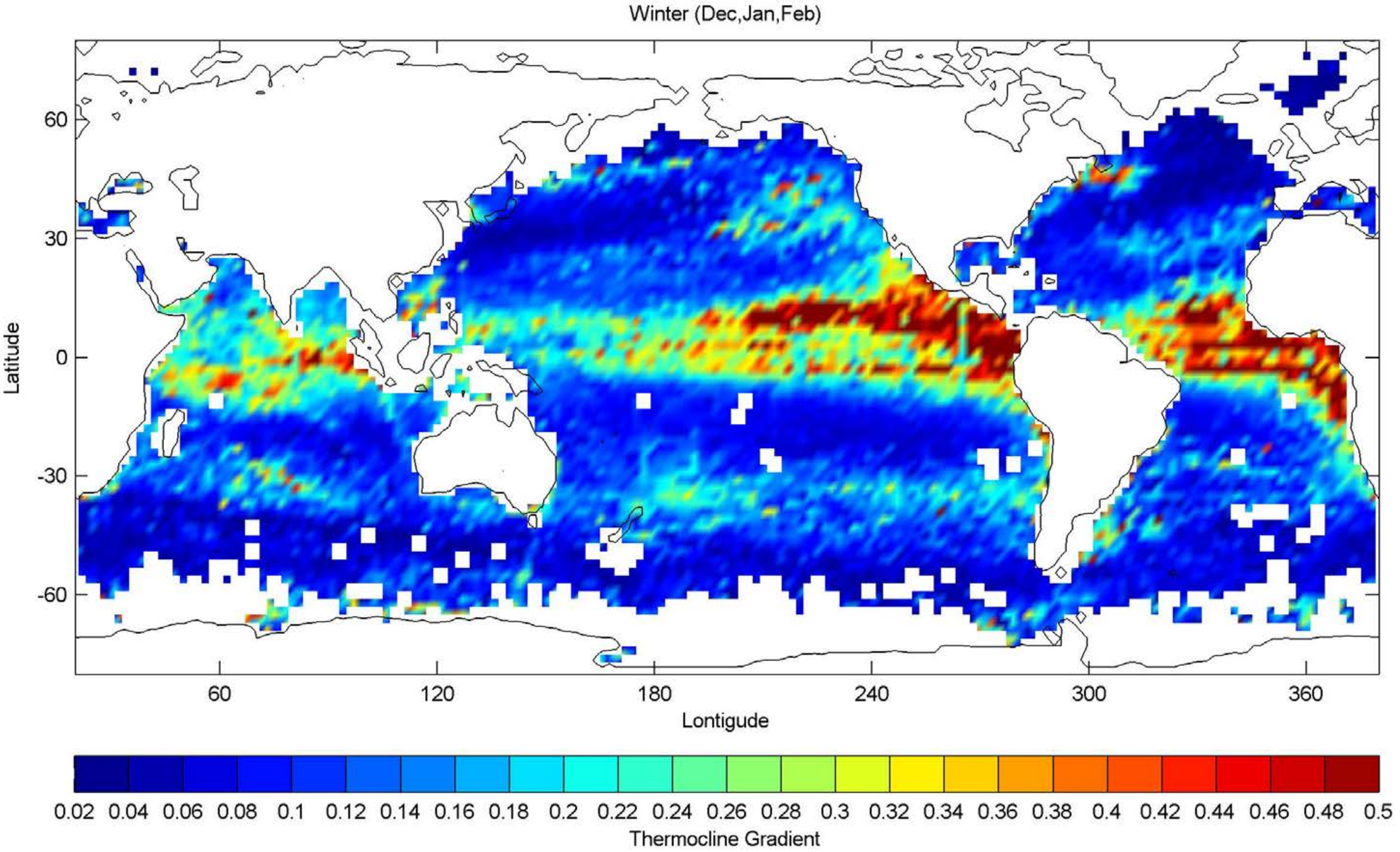
Std (m)

Skewness

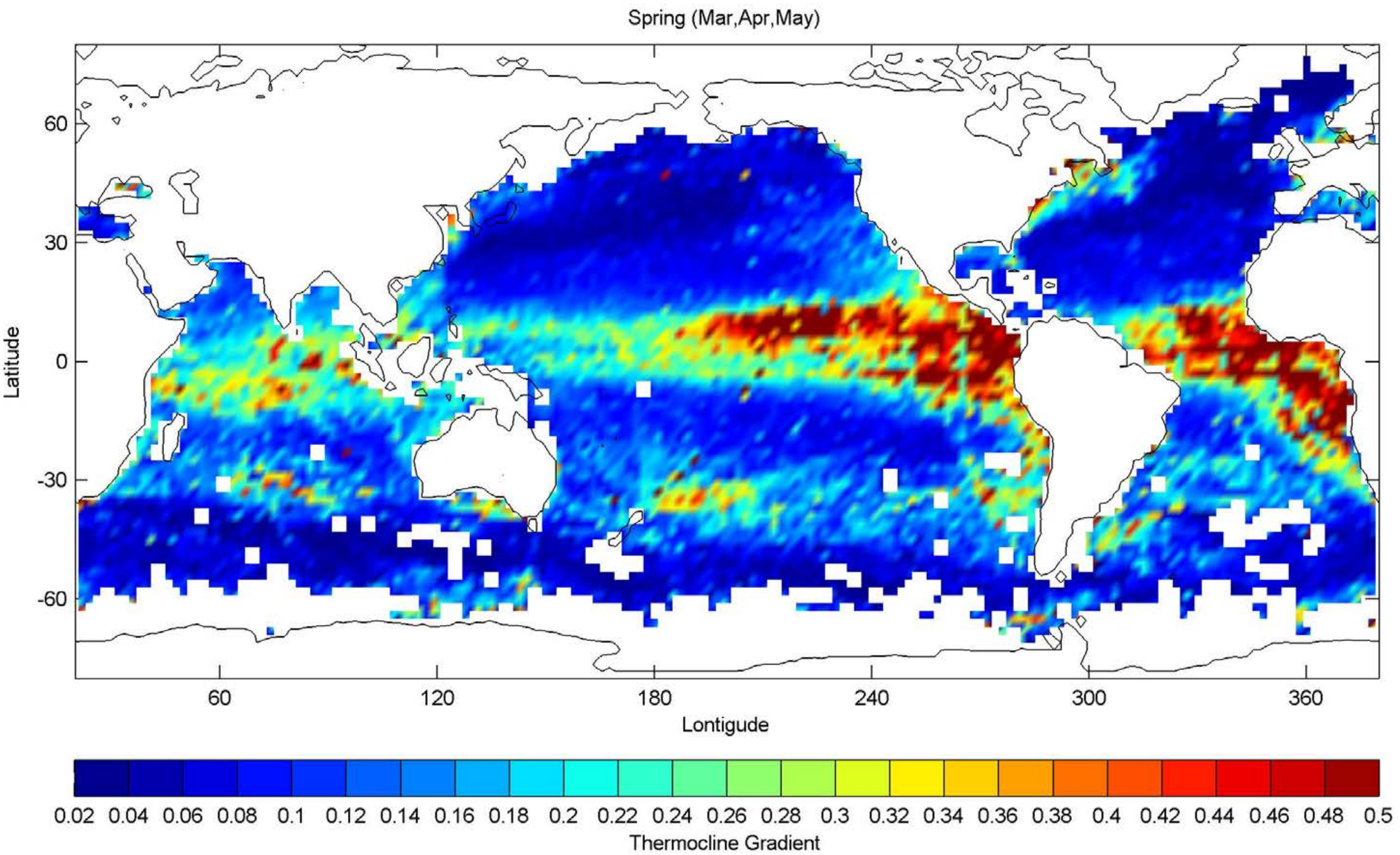
Kurtosis



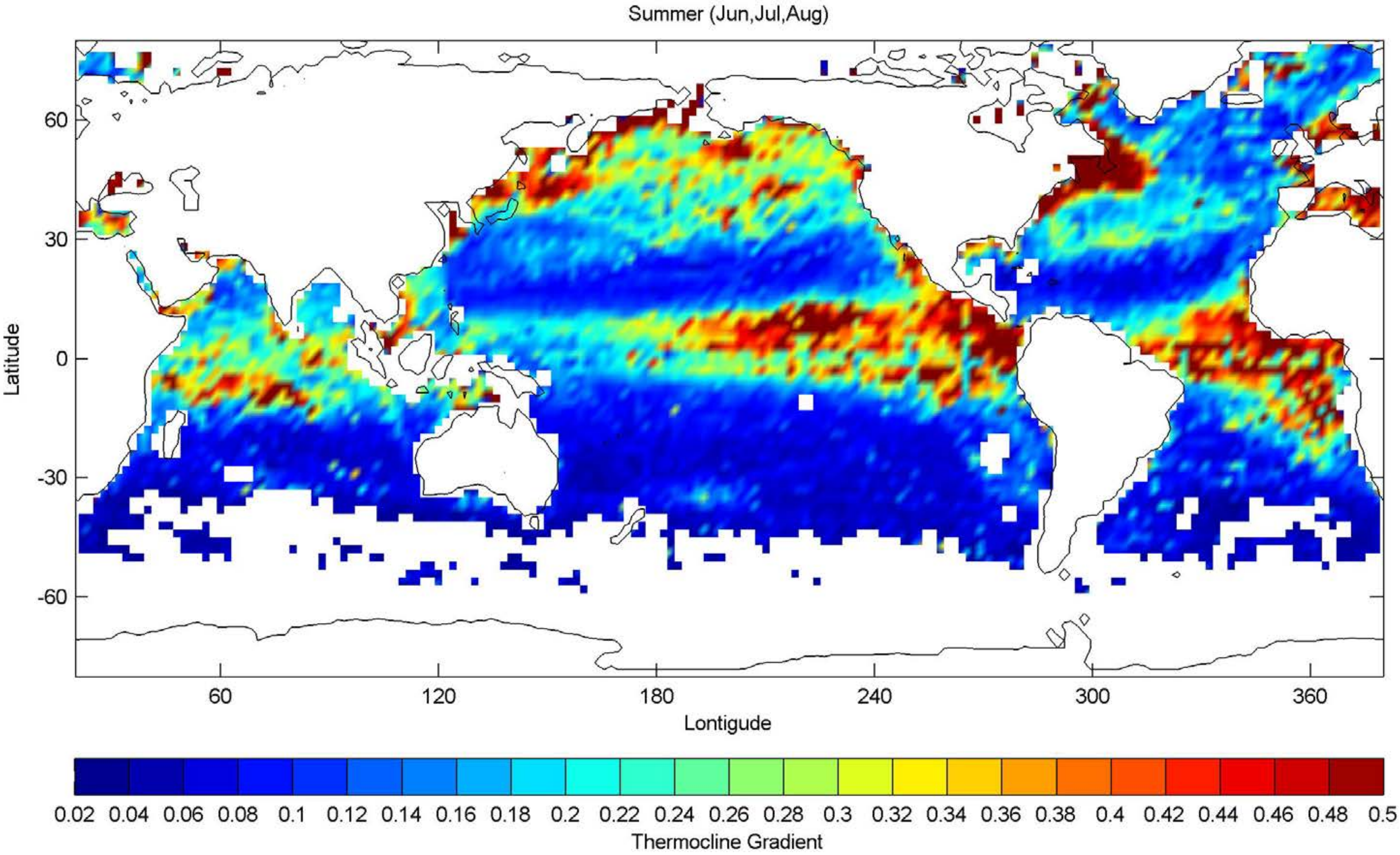
Thermocline G_{max} (Dec-Feb)



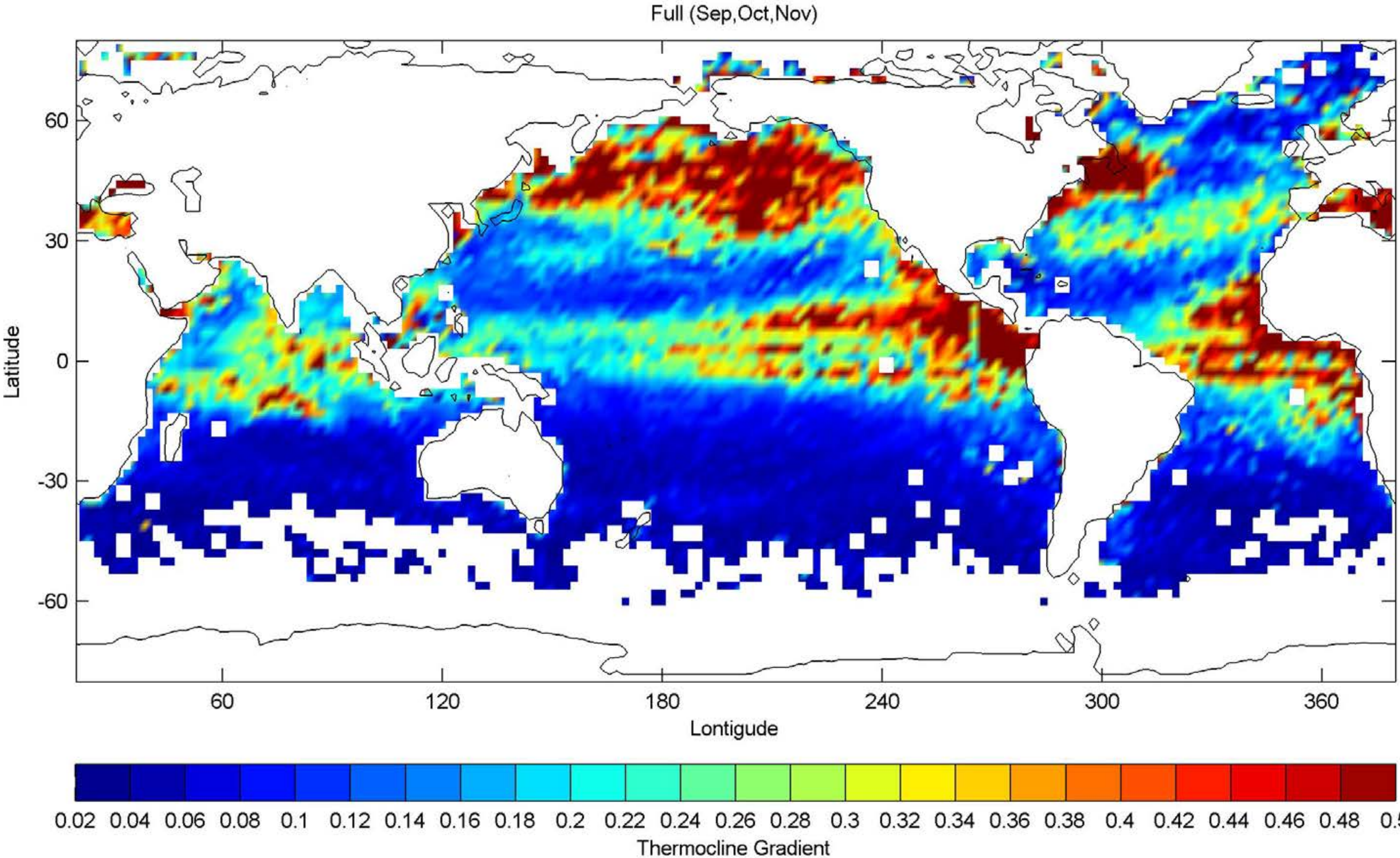
Thermocline Gmax (Mar-May)



Thermocline Gmax (Jun-Aug)

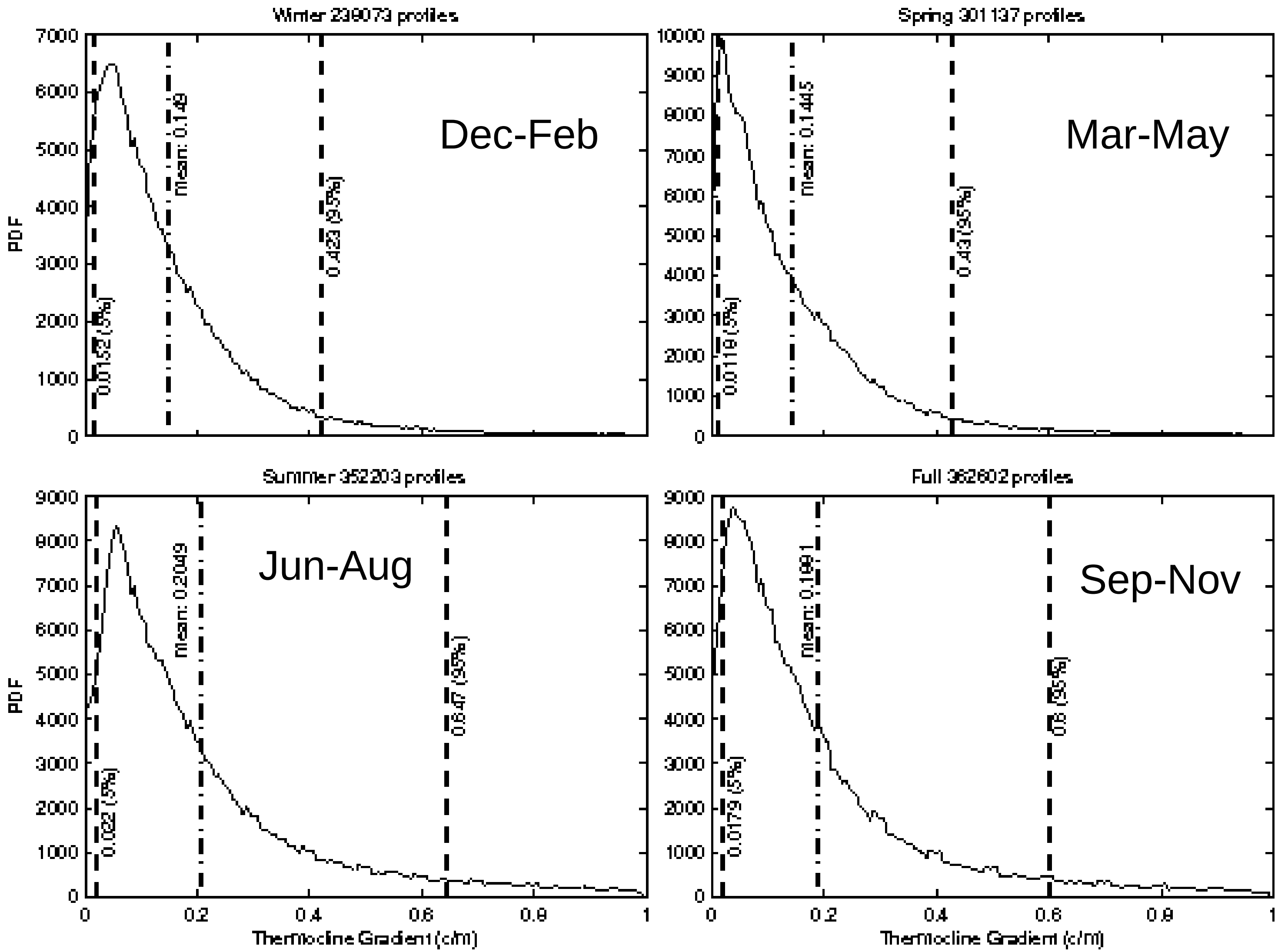


Thermocline Gmax (Sept – Nov)



PDF – Global Thermocline Gmax →

near Rayleigh Distribution



Conclusions

- (a) The gradient ratio method is an objective method to determine characteristics for mixed layer and thermocline.
- (b) Thermocline has strong gradient in the tropical oceans all year round.
- (c) Thermocline strength has larger seasonal variability in the Northern Hemisphere.
- (d) Thermocline strength is stronger in summer than in winter.
- (e) The mixed layer depth, and thermocline gradient data can be used for various studies.