

Seasonal Variability of the Black Sea Chlorophyll-*a* Concentration

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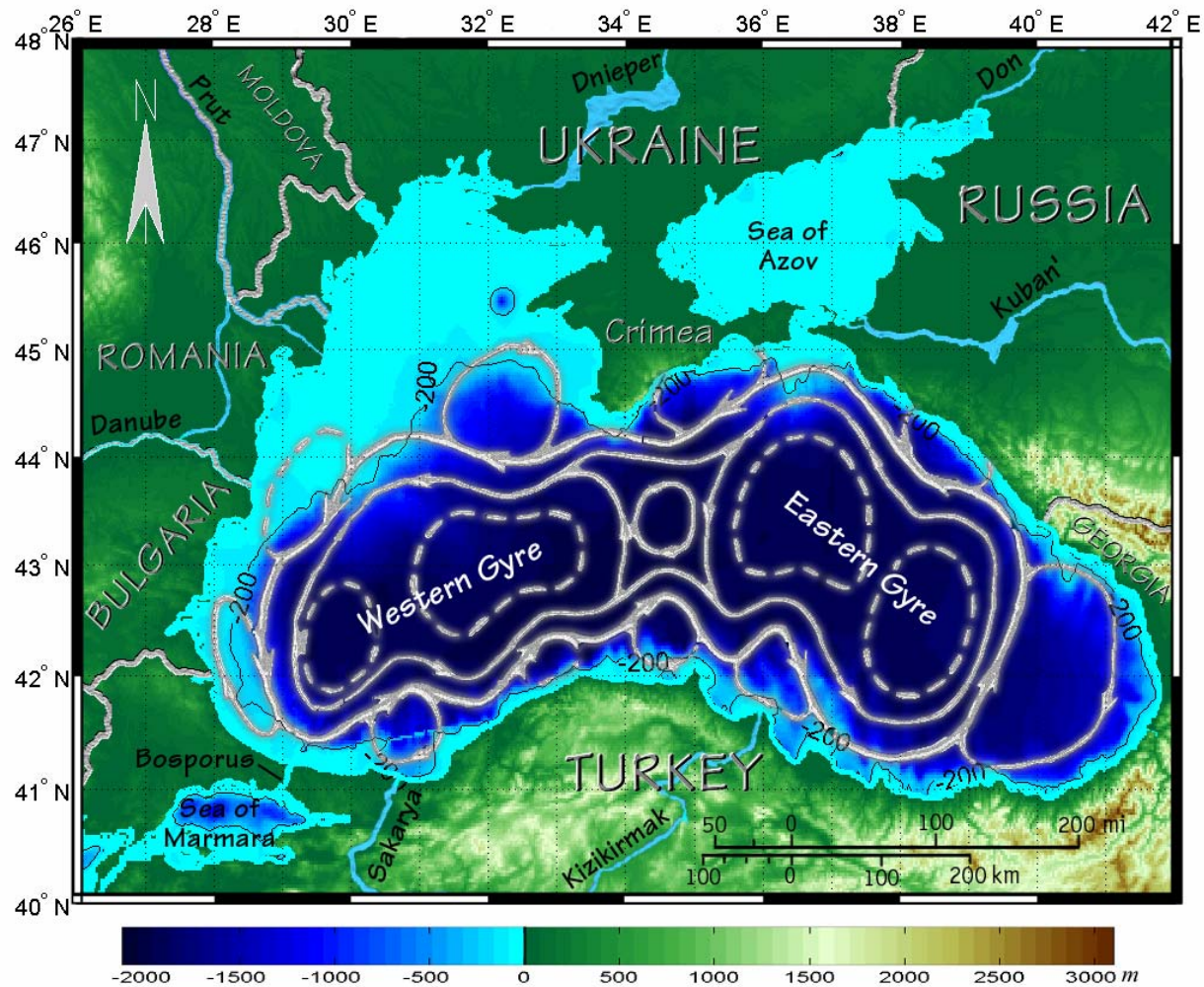
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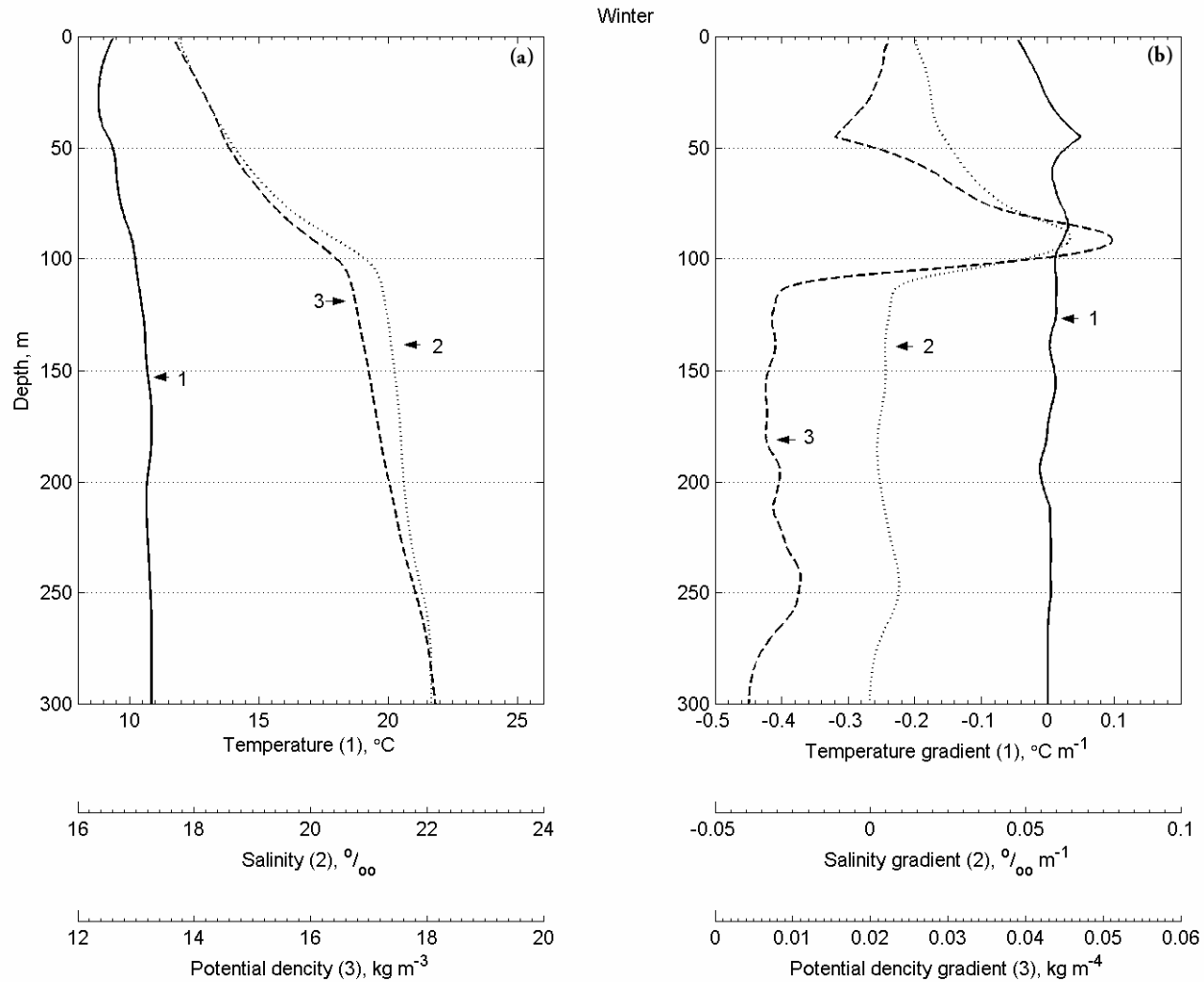
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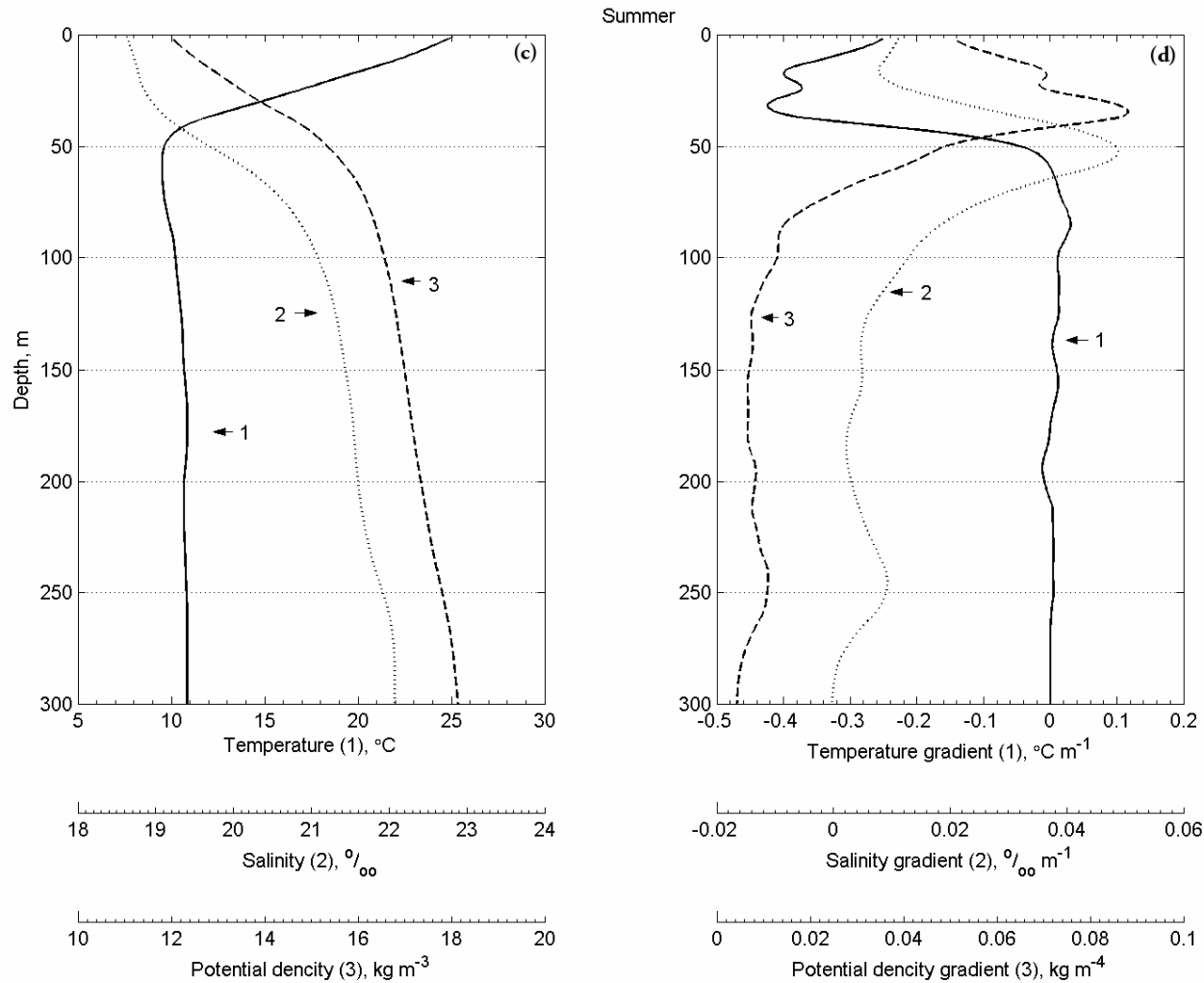
Black Sea Geography and Topography



Black Sea Winter (1) T, (2) S, and (3) ρ and Vertical Gradients

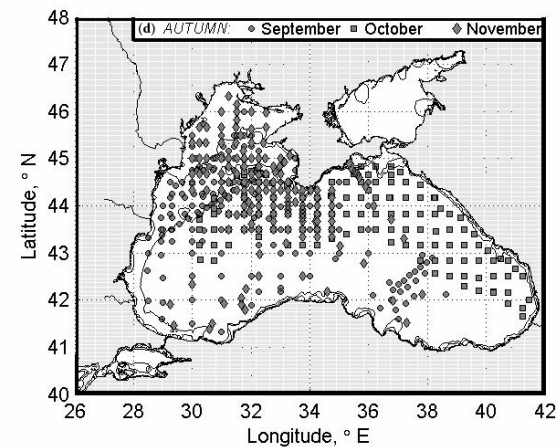
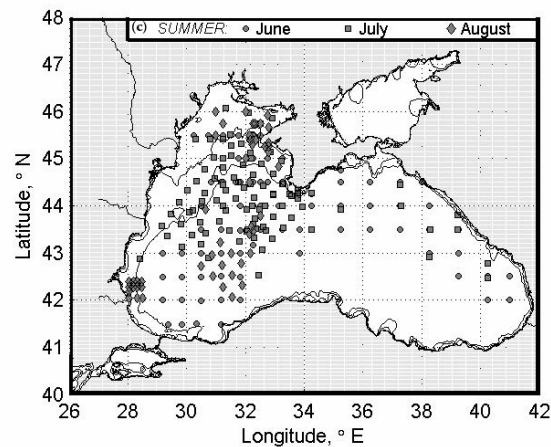
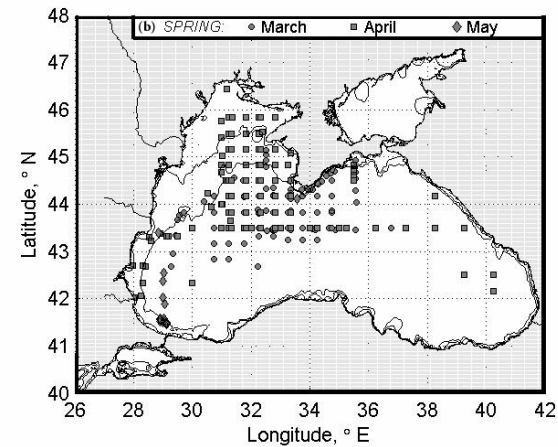
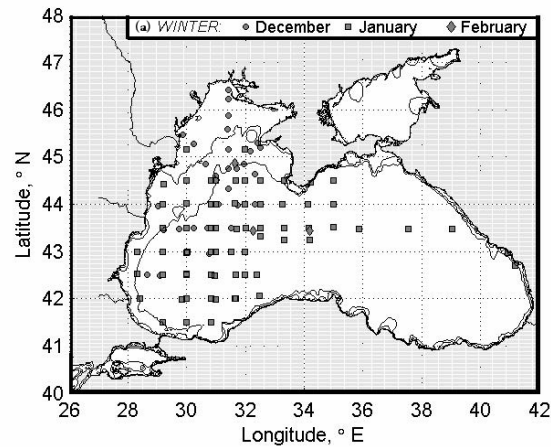


Black Sea Summer (1) T, (2) S, and (3) ρ and Vertical Gradients



Horizontal distribution of chlorophyll-*a* concentration observational stations (1980-95):

(a) winter, (b) spring, (c) summer, and (d) autumn



Arithmetic mean of the data only shows one bloom (winter/spring bloom) [*Vedernikov and Demidov, 1997*]

Spectral Decomposition (Chu et al. 2003a,b, JTECH)

$$c(\mathbf{x}, z_k, t) = A_0(z_k, t) + \sum_{m=1}^M A_m(z_k, t) \Psi_m(\mathbf{x}, z_k)$$

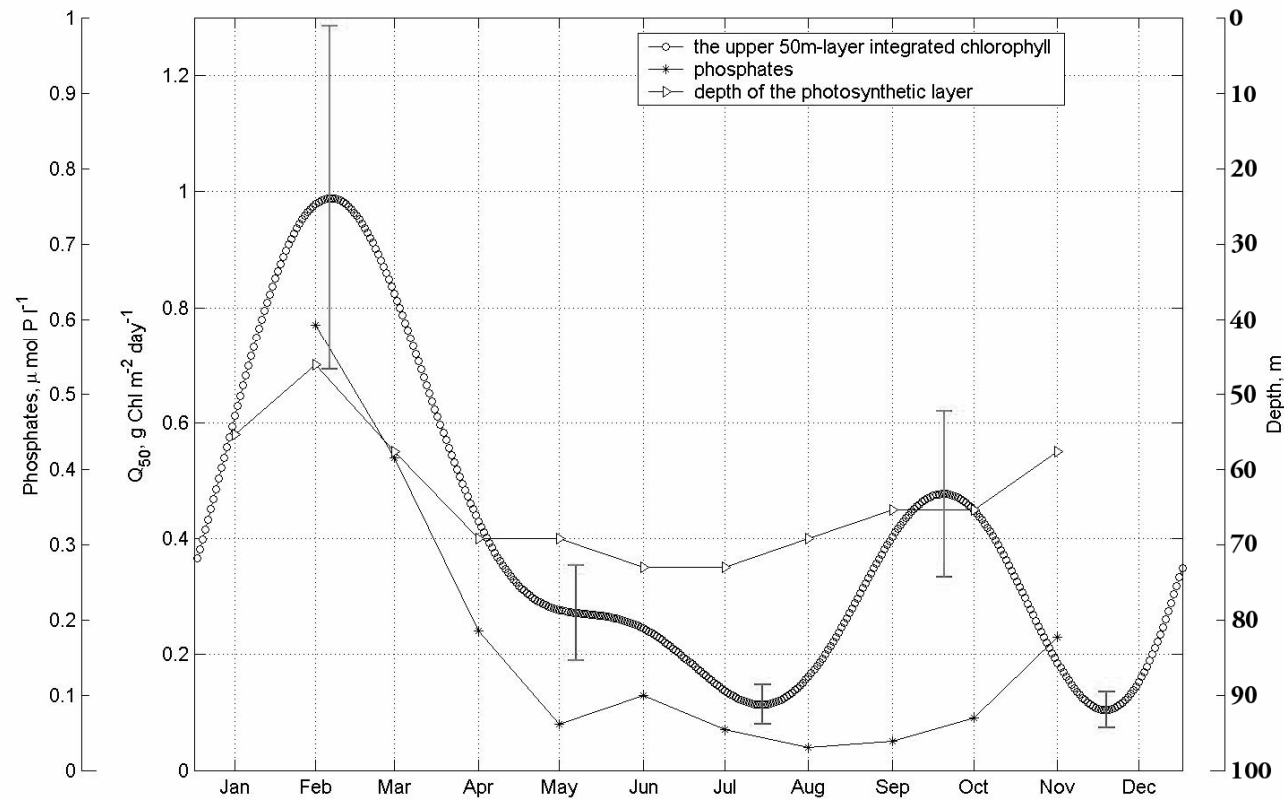
$$\mathbf{x} \in R_k$$

$$\iint_{R_k} \Psi_m(x, z_k) d\mathbf{x} = 0 \quad \text{for } m = 1, \dots, M.$$

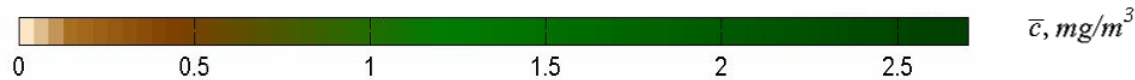
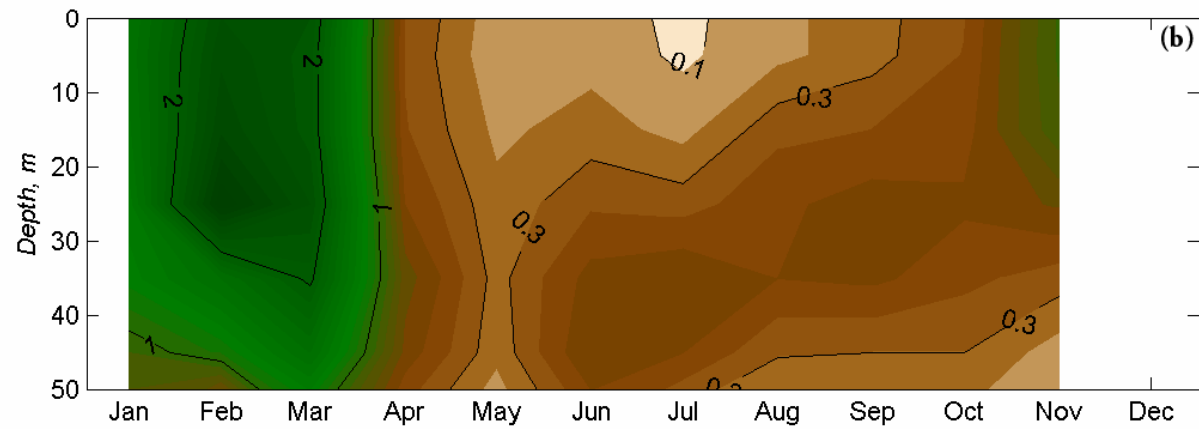
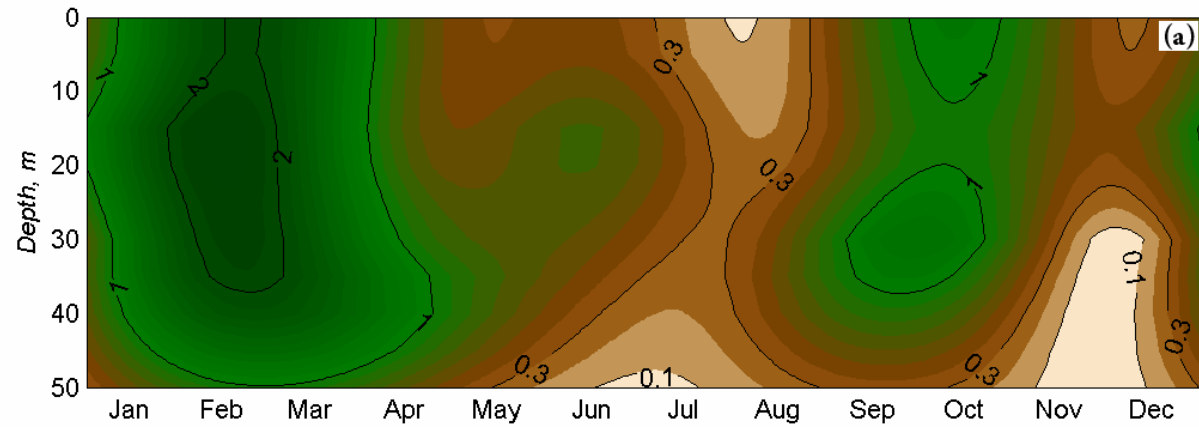
Optimal Truncation

$$J_{emp} = J(\tilde{A}_1, \dots, \tilde{A}_M, P, M) = \frac{1}{P} \sum_{j=1}^P \left(c^{(j)} - \sum_{m=1}^M \tilde{A}_m(z, t) \Psi_m^{(j)}(\mathbf{x}, z) \right)^2 \rightarrow \min$$

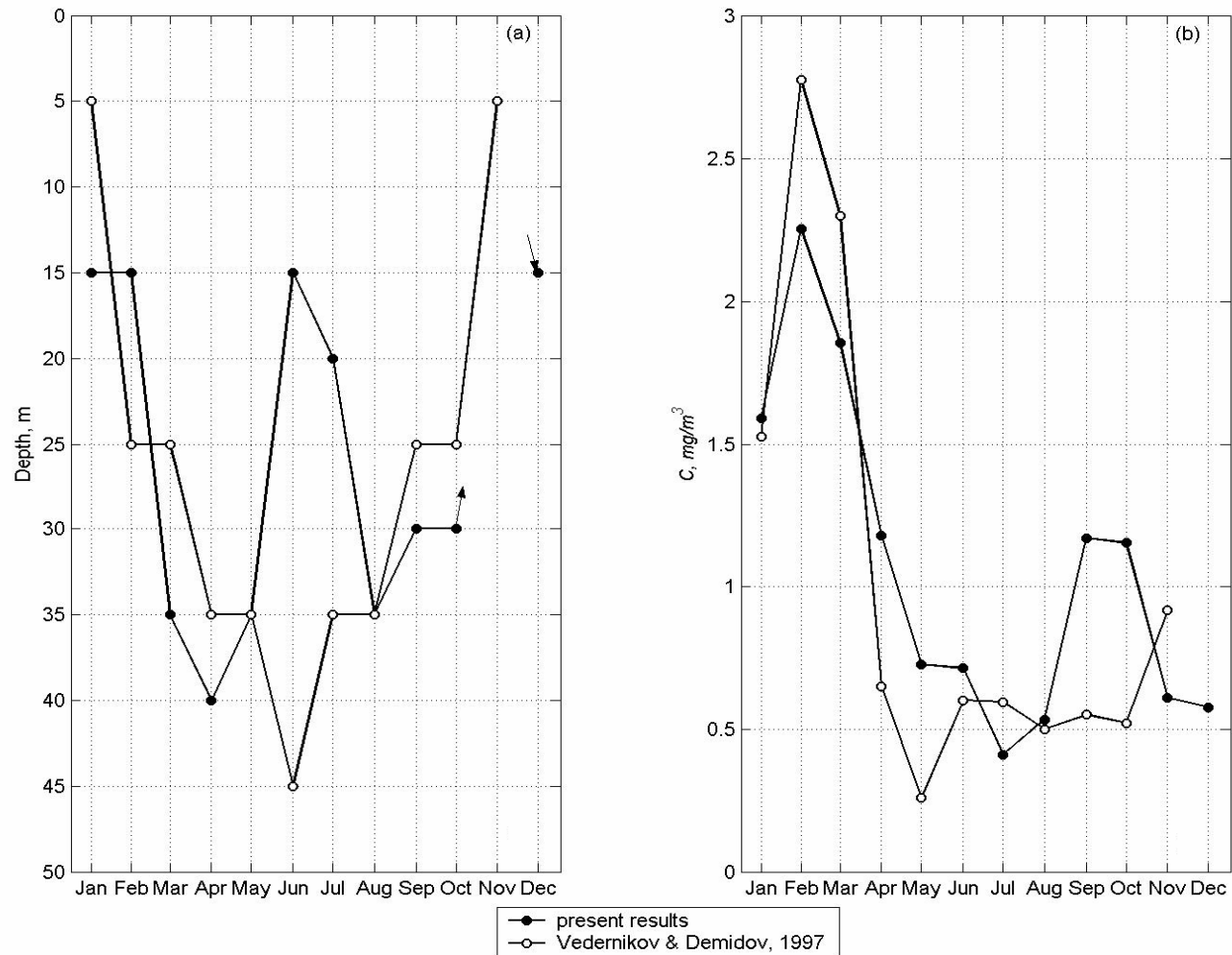
Reconstructed climatic seasonal attractor of Q_{50} with the accuracy indicated by the vertical error bars



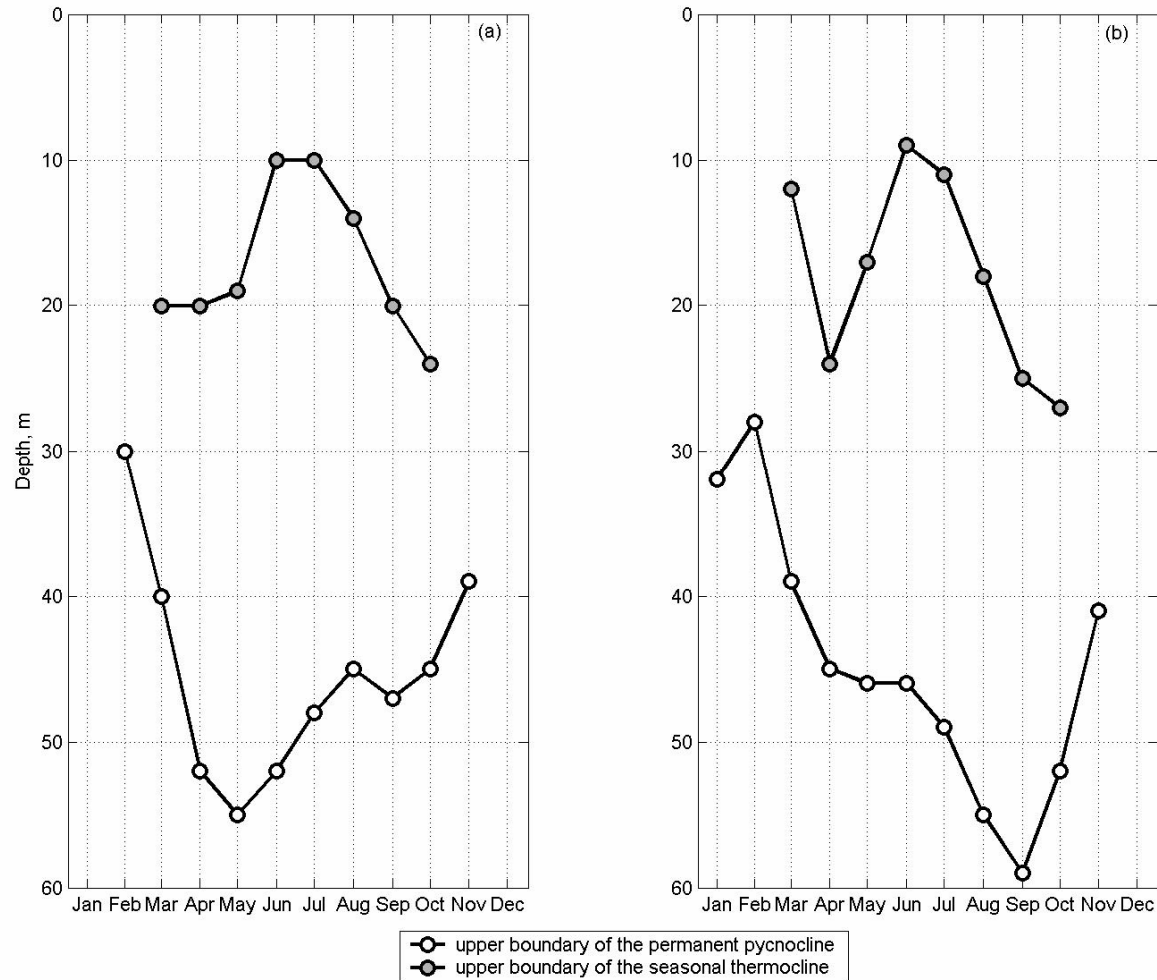
(a) Reconstructed field with two blooms, (b) *Vedernikov and Demidov's* [1997] with only one bloom (without reconstruction)



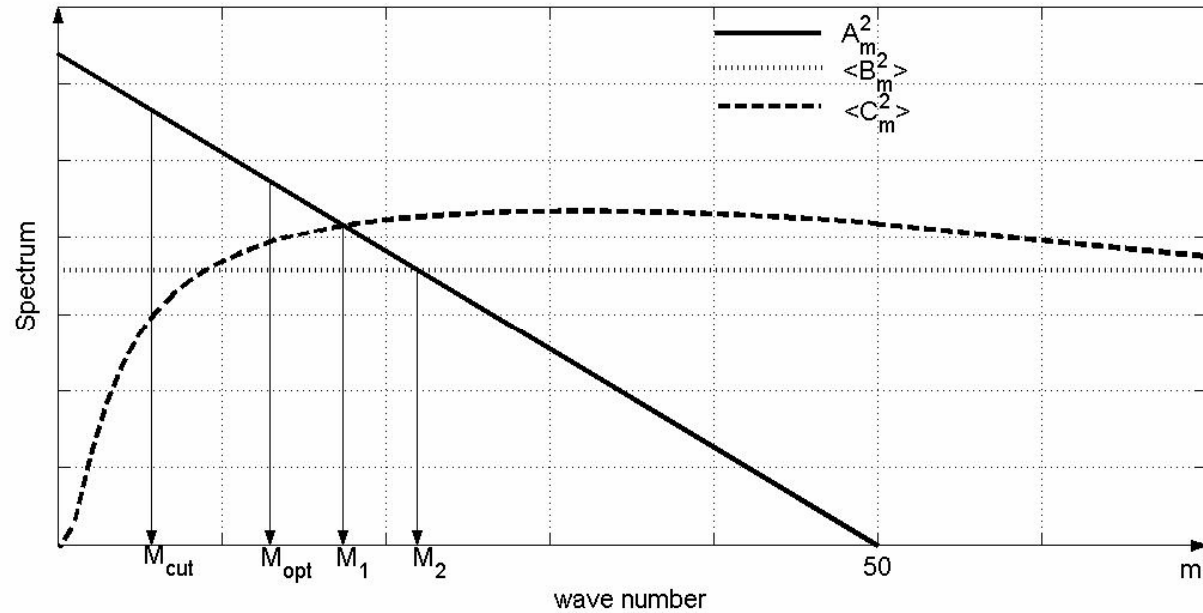
Monthly mean (a) subsurface chlorophyll-*a* maximum depth, and (b) Q_{50} with and without reconstruction



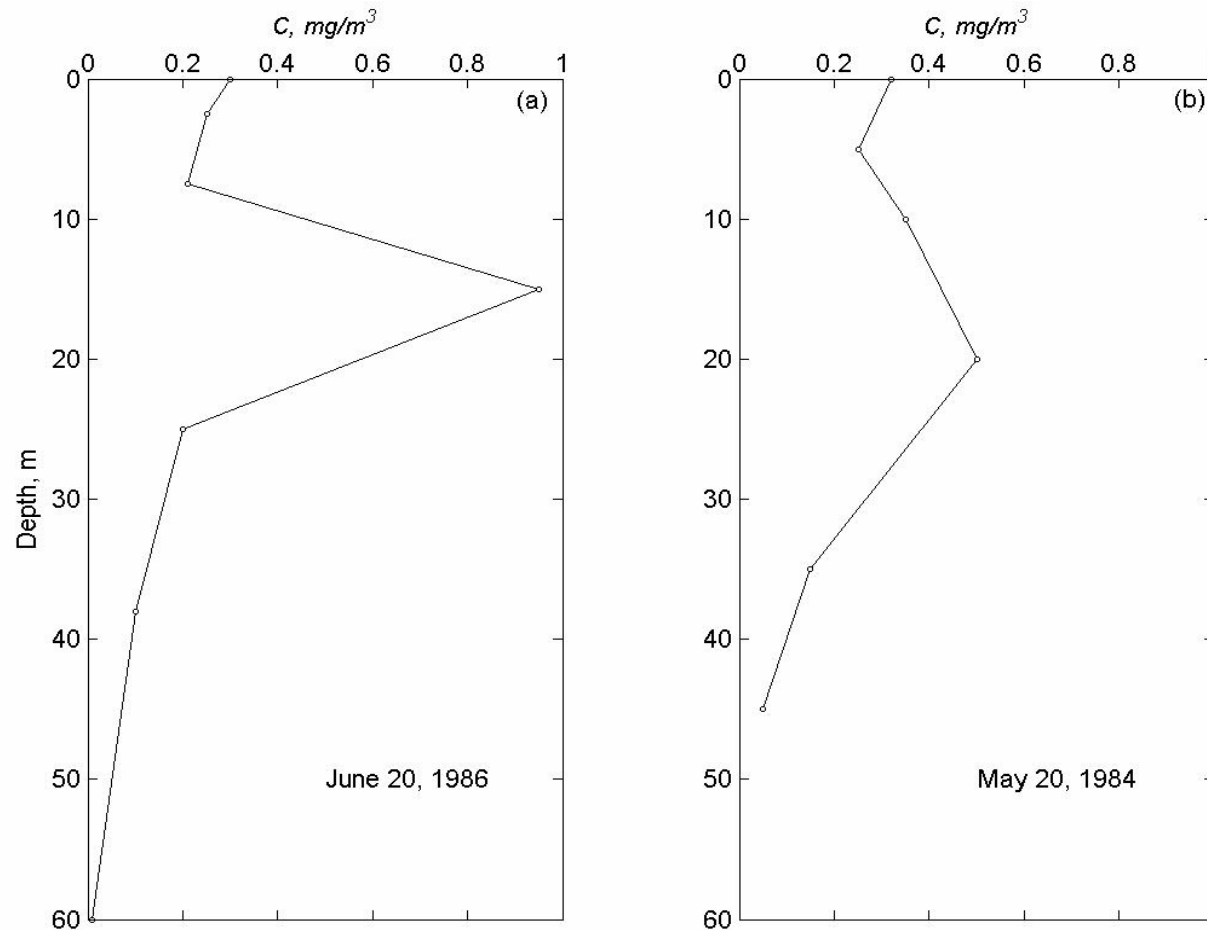
Permanent pycnocline and seasonal thermocline in the (a) western and (b) eastern cyclonic gyres



Spectral characteristics of the climatic signals, measurement errors, and unresolved-scale errors



Two observed summer vertical profiles of chlorophyll-*a* in the Black Sea: (a) June 20, 1986, and (b) May 20, 1984



Conclusions

- The reconstructed field possesses two statistically significant features: (a) seasonal variability represented by two blooms (winter/spring and fall) in the year, and (b) existence of a permanent subsurface chlorophyll-*a* maximum.