Black Sea Dynamics

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OUTLINE

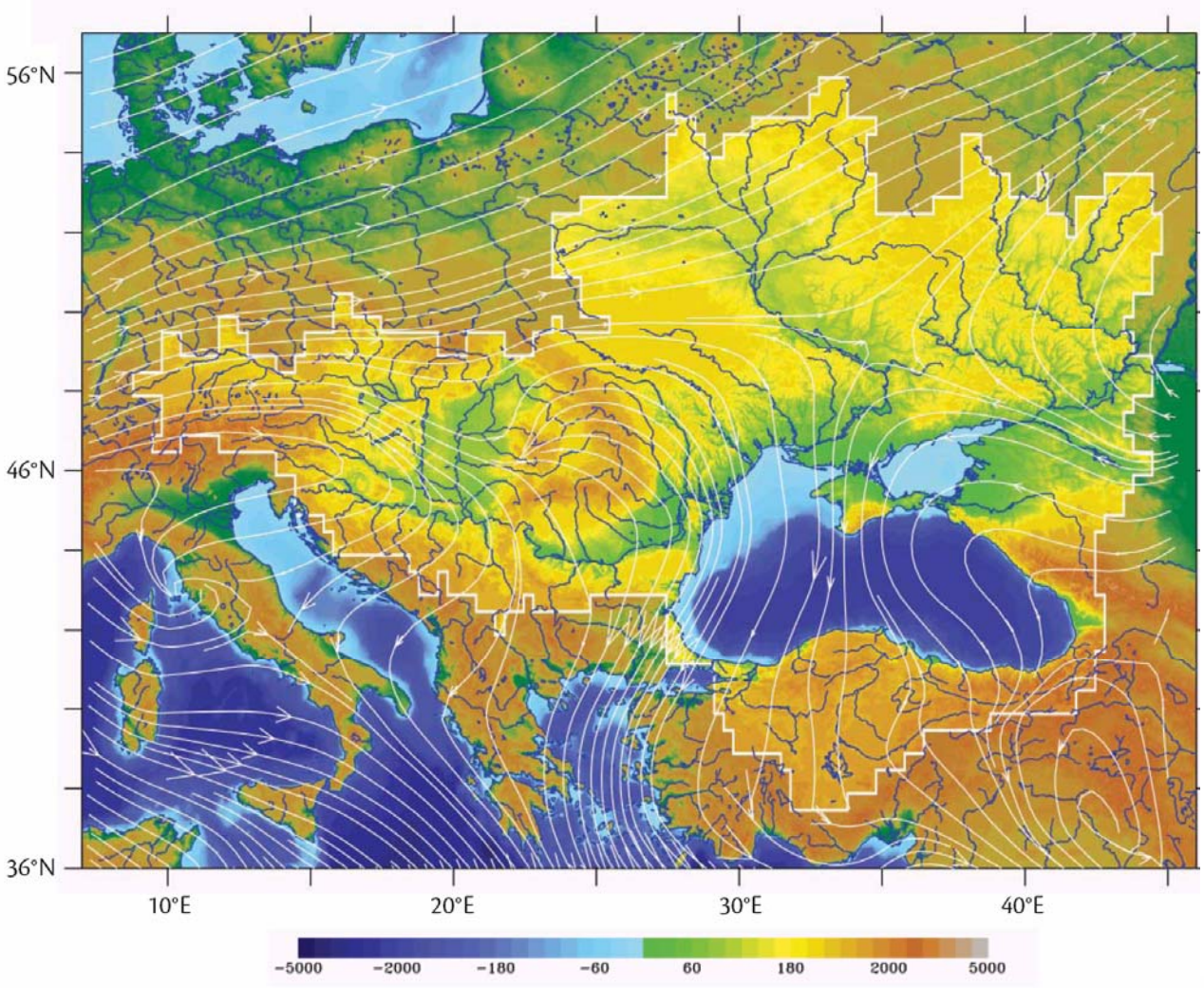
- Introduction
  - The Black Sea
  - Models used
- Results
  - Simulation of processes
  - Circulation
  - Water mass formation

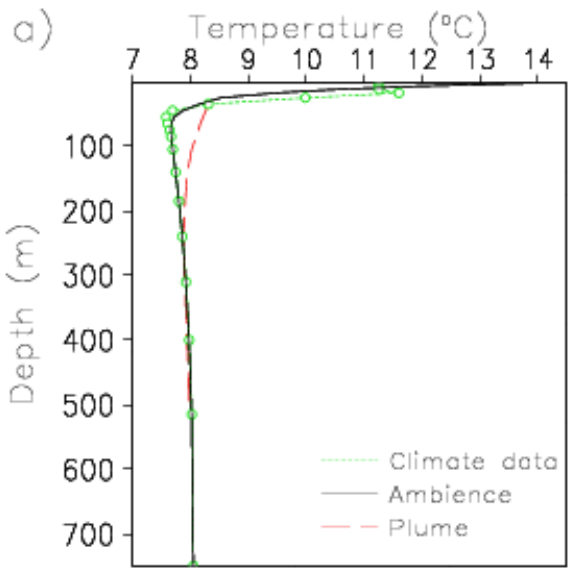
- Coupled physical-biogeochemical modelling

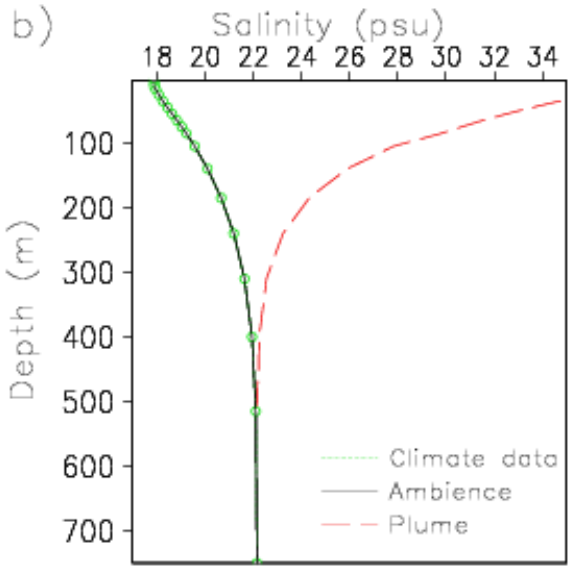
- Conclusions

The Black Sea is an estuarine basin

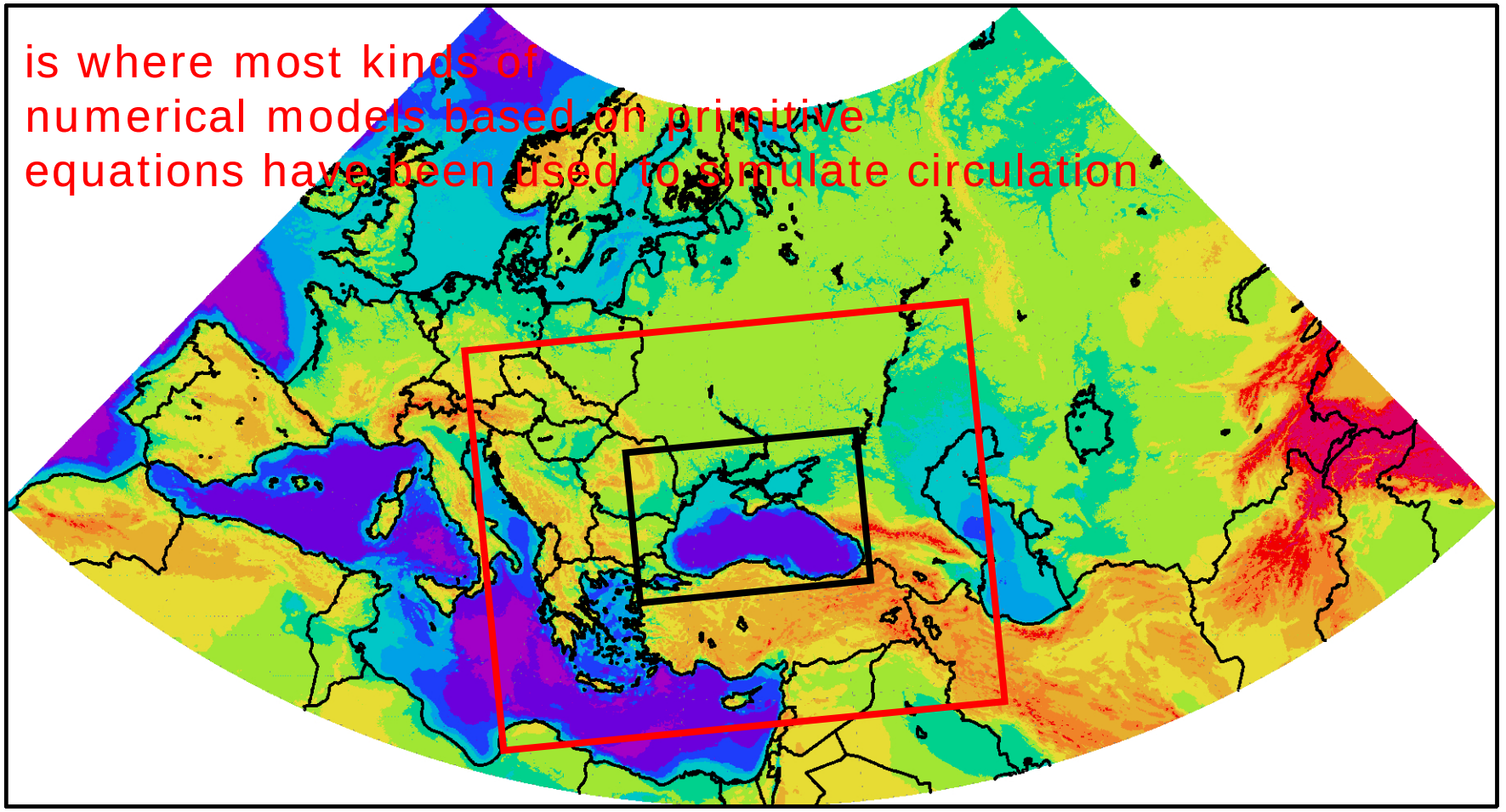
The total freshwater supply of 3 x 10^2 km^3/year is large compared to the basin volume (~ 5.4 x 10^5 km^3)
Unique water properties are due to small exchange in the straits.





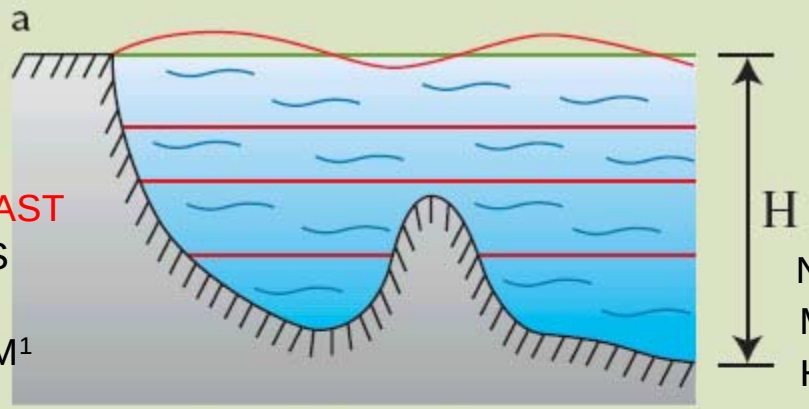


The Black Sea

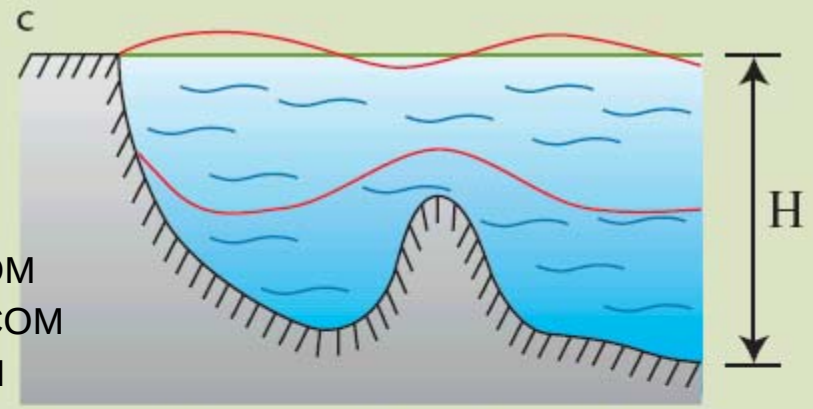


Ocean models

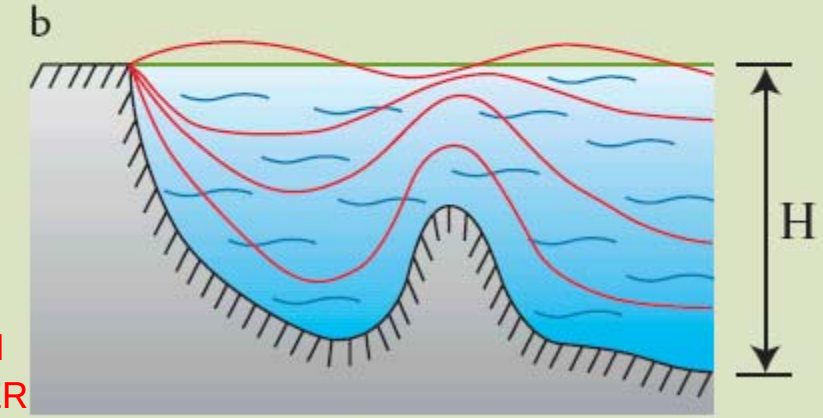
Ocean regimes and vertical coordinates



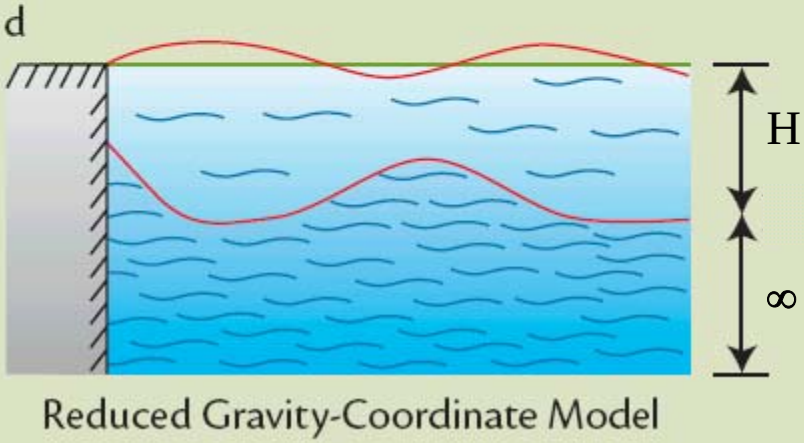
MOM
DieCAST
HOPS
POP
NCOM[1]



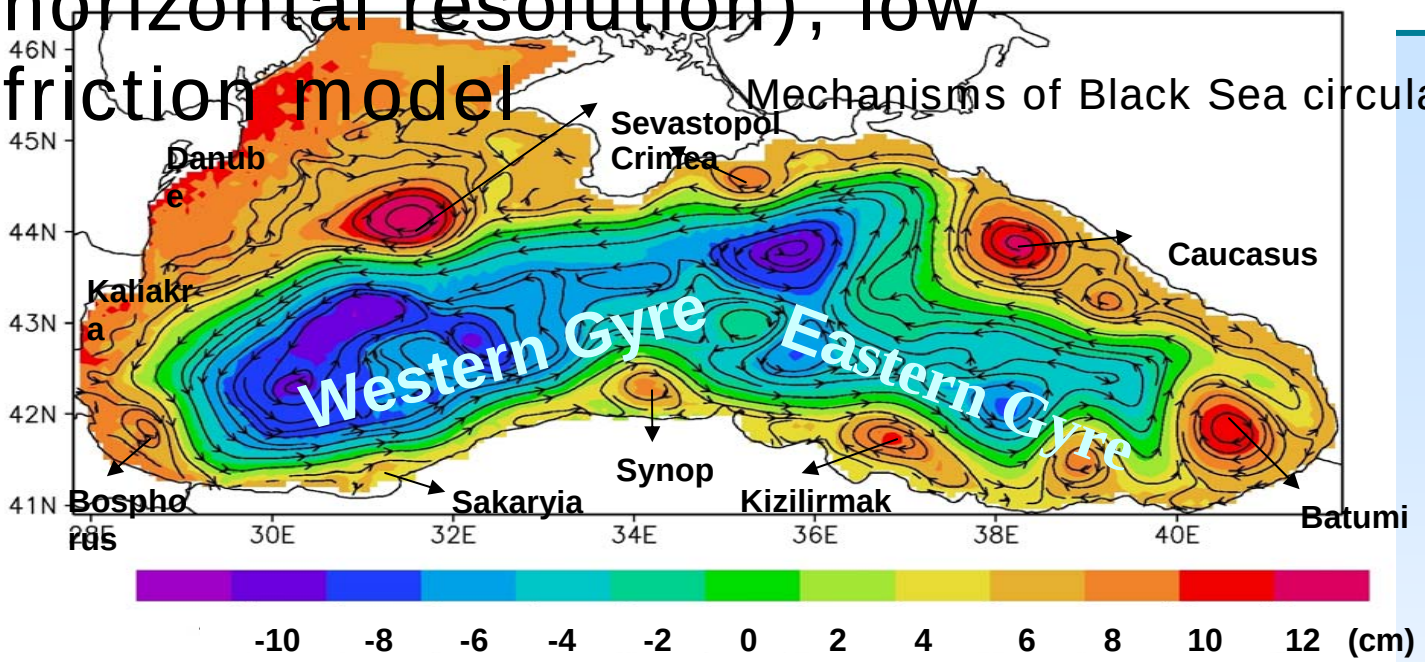
NLOM
MICOM
HIM
OPYC
HYCOM (z+σ+ρ)
Layered/Isopycnal-Coordinate Model



POM
GHER
POLCOMS
GETM, ROMS, TOMS, NCOM[2], OPA, z+σ

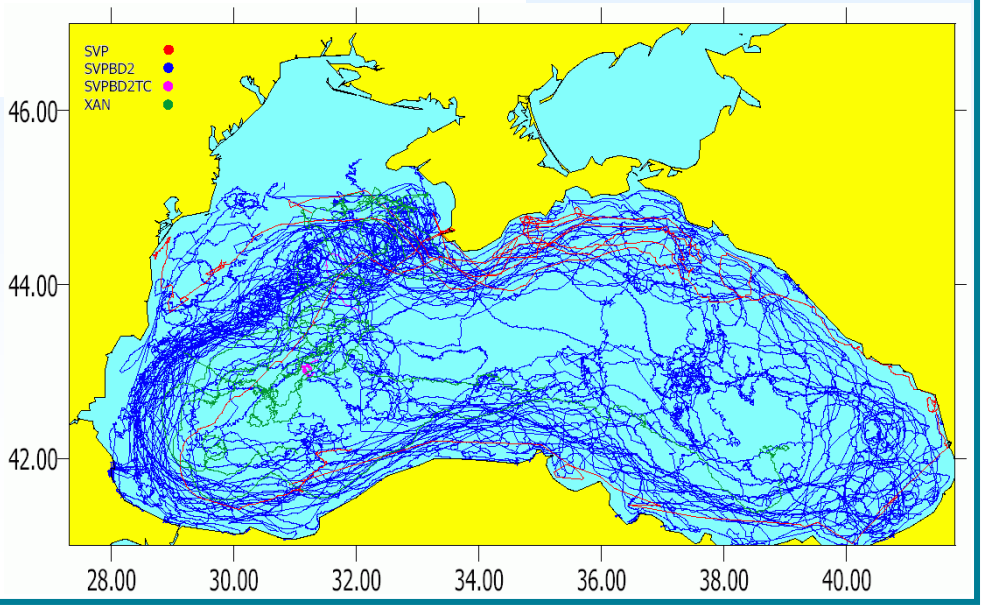


Black Sea DieCAST (5 nm horizontal resolution), low friction model



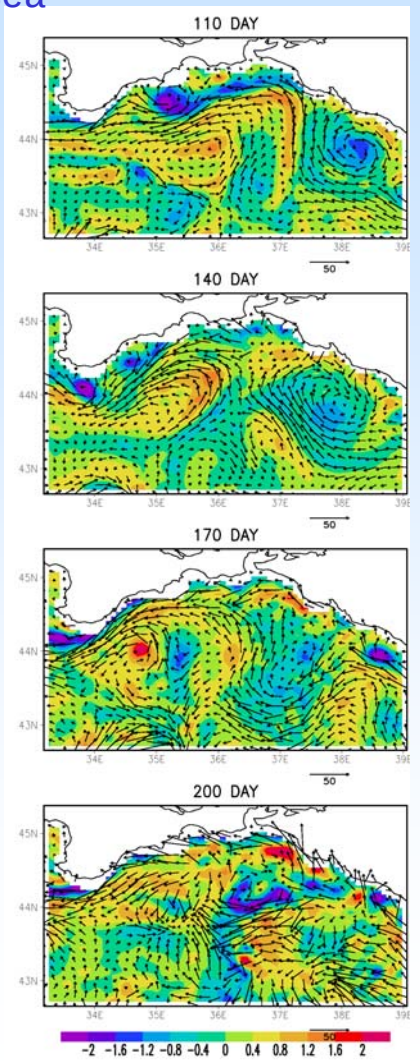
Seasonal amplitudes: ~10 cm

Amplitudes of interannual variations: ~5 cm.



Specific questions answered by numerical models

Deflection of Rim Current and entrainment of coastal water into the open sea



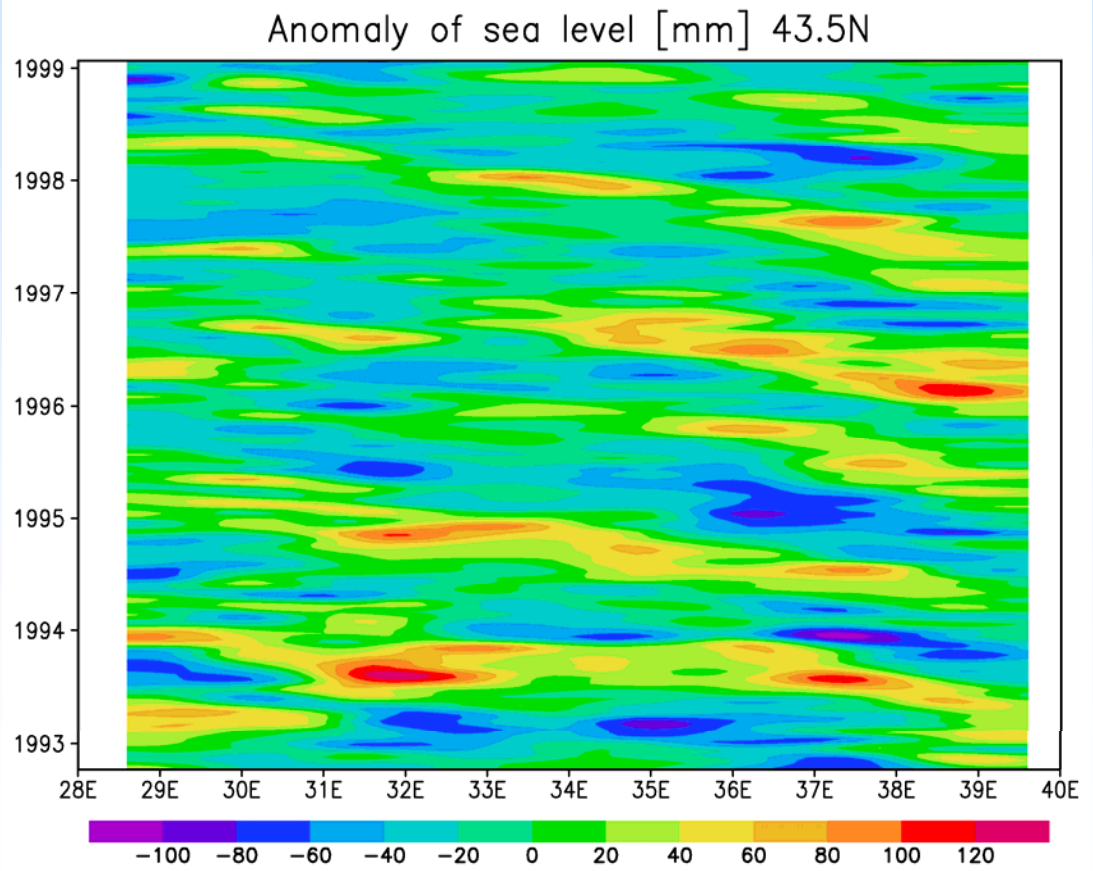
Staneva et al. (2001, JMS)

The transition between summer and winter circulation is controlled by baroclinic eddies.

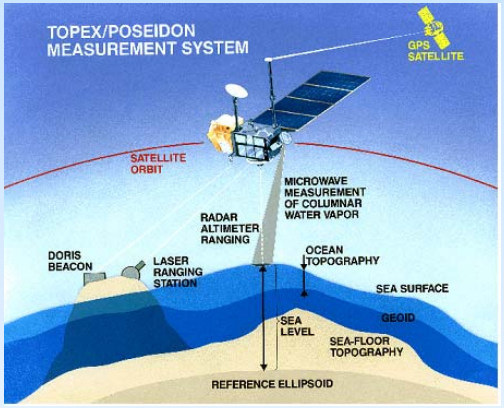
The large seasonal stratification cycle above a relatively shallow and strong pycnocline shapes the seasonal cycle of potential vorticity.

DieCAST Results

Sea level Anomaly



T/P data: basin Rossby waves



Staneva et al. (2001, JMS)

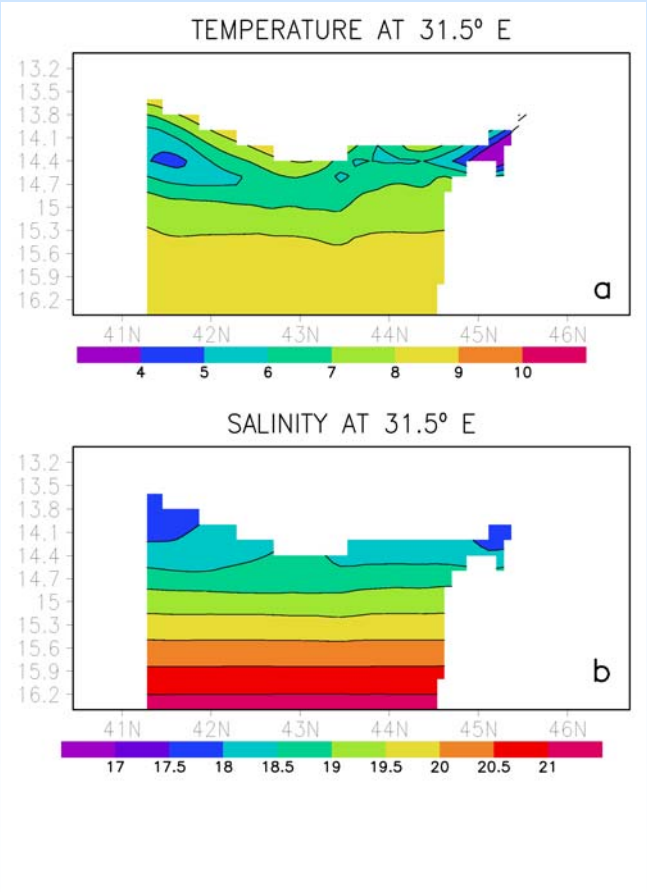
CIW formation in the Black Sea

- General characteristics
- Mixing basin
- Fresh water flux~300km^{3}yr^{-1}
- Two-layer exchange in straits
- Limited vertical exchange-the necessary condition of CIW mass formation

- Open questions
- Regions of formation
- Rates of formation
- Temporal and spatial patterns
- Transport of CIW
- No winter data

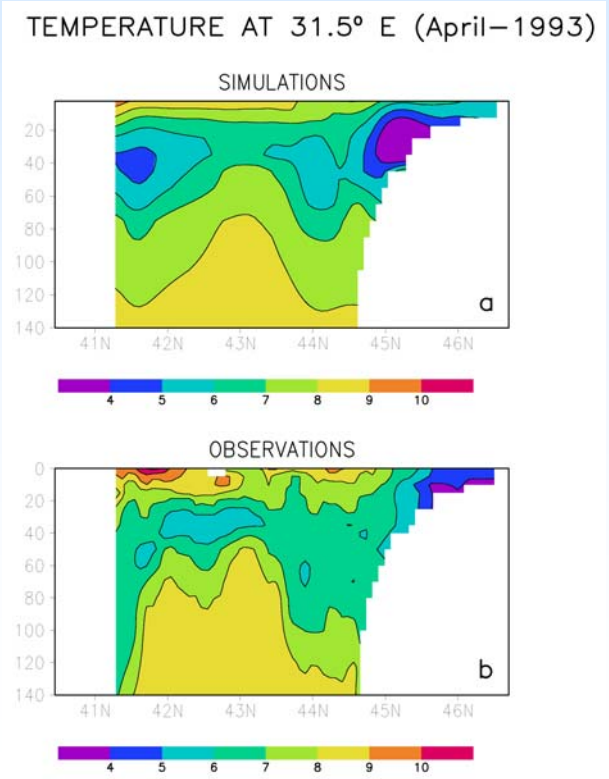
Black Sea MOM (5 nm resolution)

Below σ_t = 15.5 stratification is entirely dependent on salinity



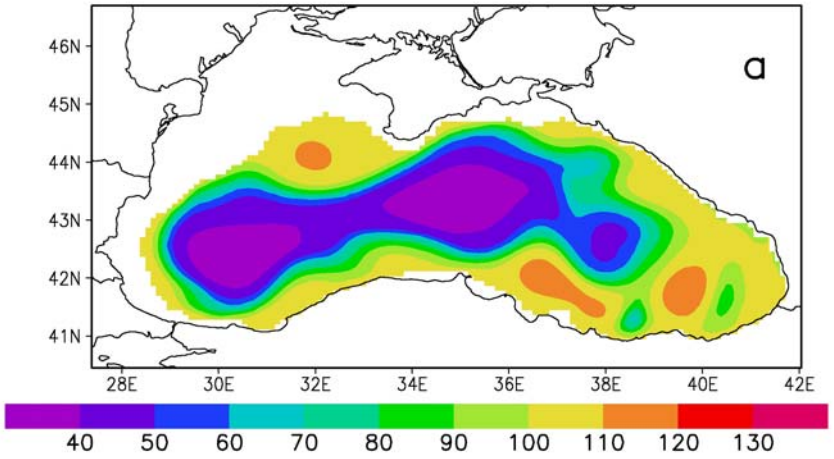
Stanev et al. (2003, JMR)

The vertical circulation (~$10^5 m^3/s$) is much weaker than horizontal circulation (~5 x $10^6 m^3/s$) and comparable with the amount of water entrained by the Mediterranean plume

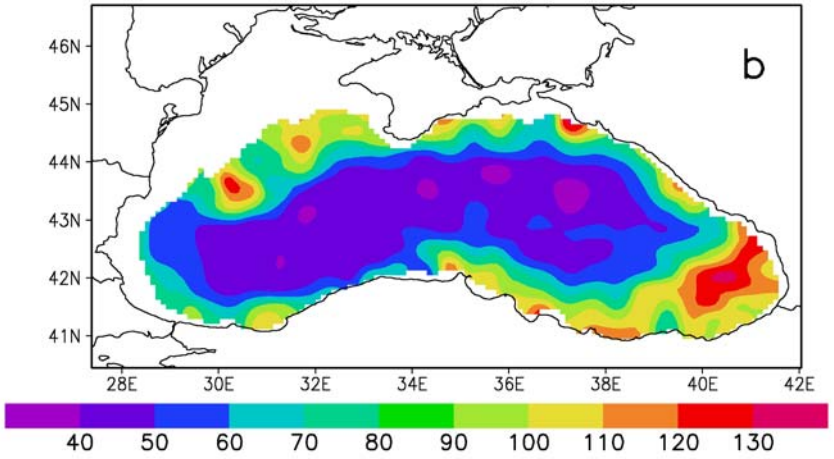


DEPTH OF SIGMA LEVEL 14.9 (July–1992)

SIMULATIONS

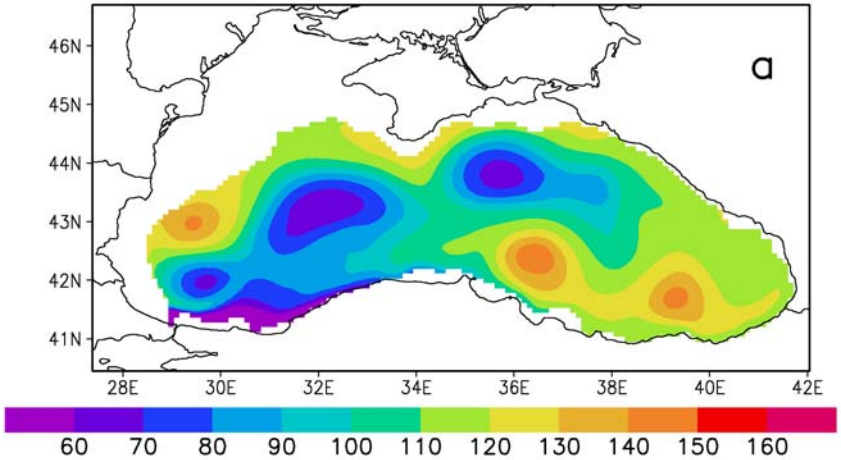


OBSERVATIONS

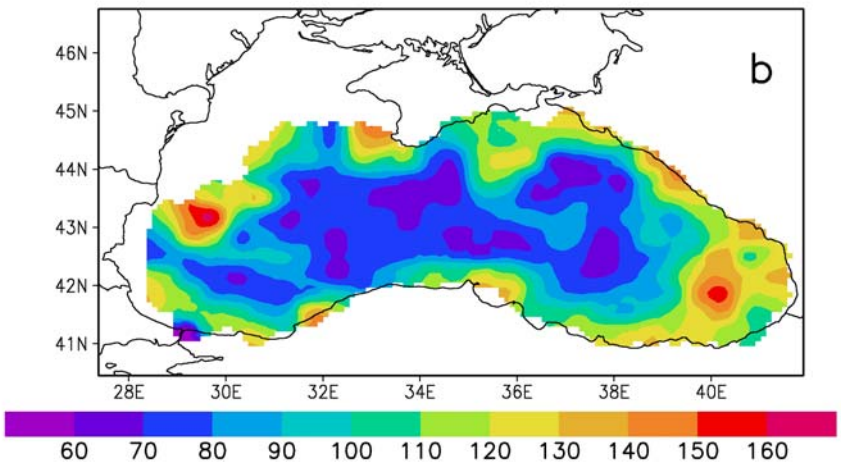


September – 1991

SIMULATIONS

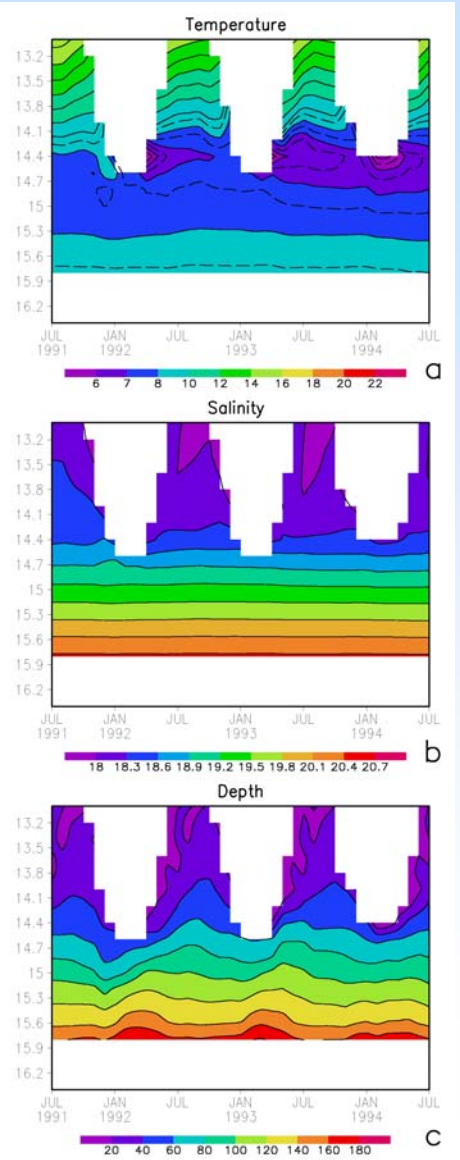


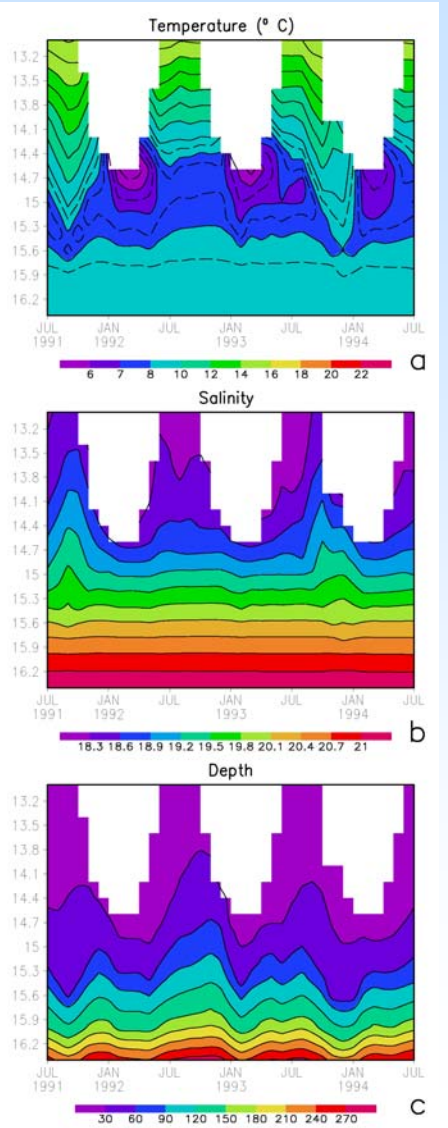
SURVEYS



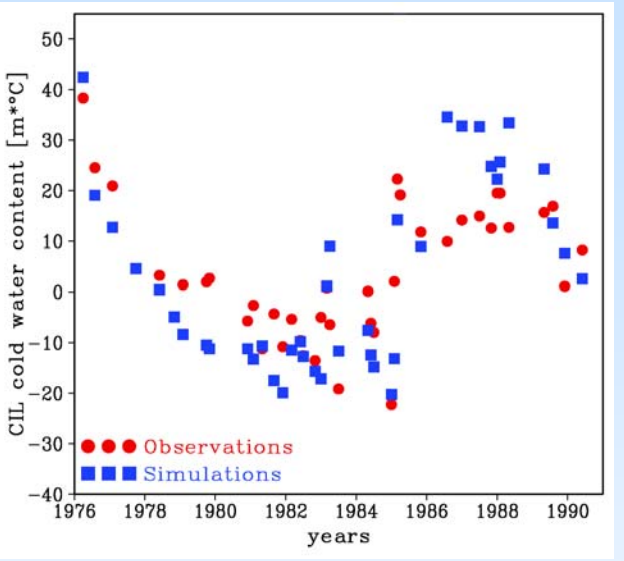
44.5N, 31E

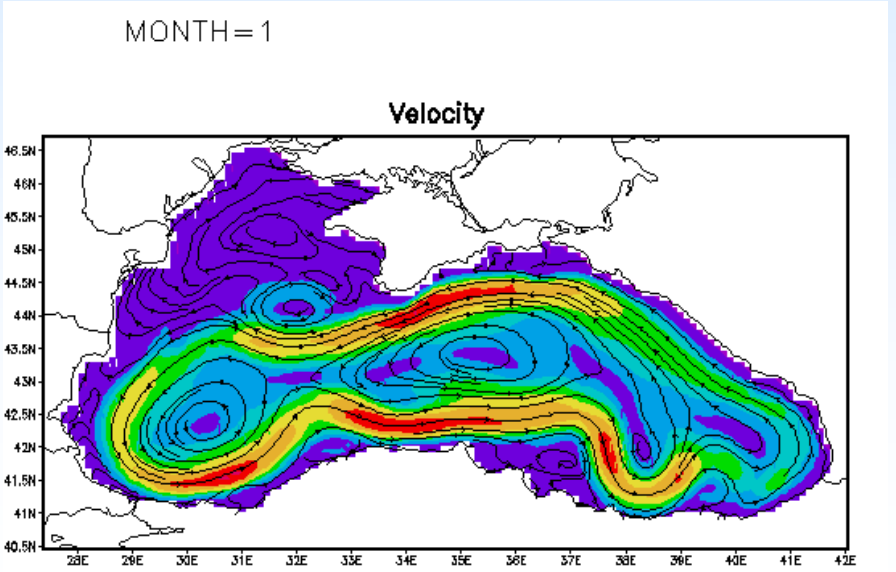
42.5N, 32E





Decadal changes (Black Sea MOM, 5 nm resolution)





Model versus hydrographic survey data (no assimilation)

Stanev et al. (2003, JMR)

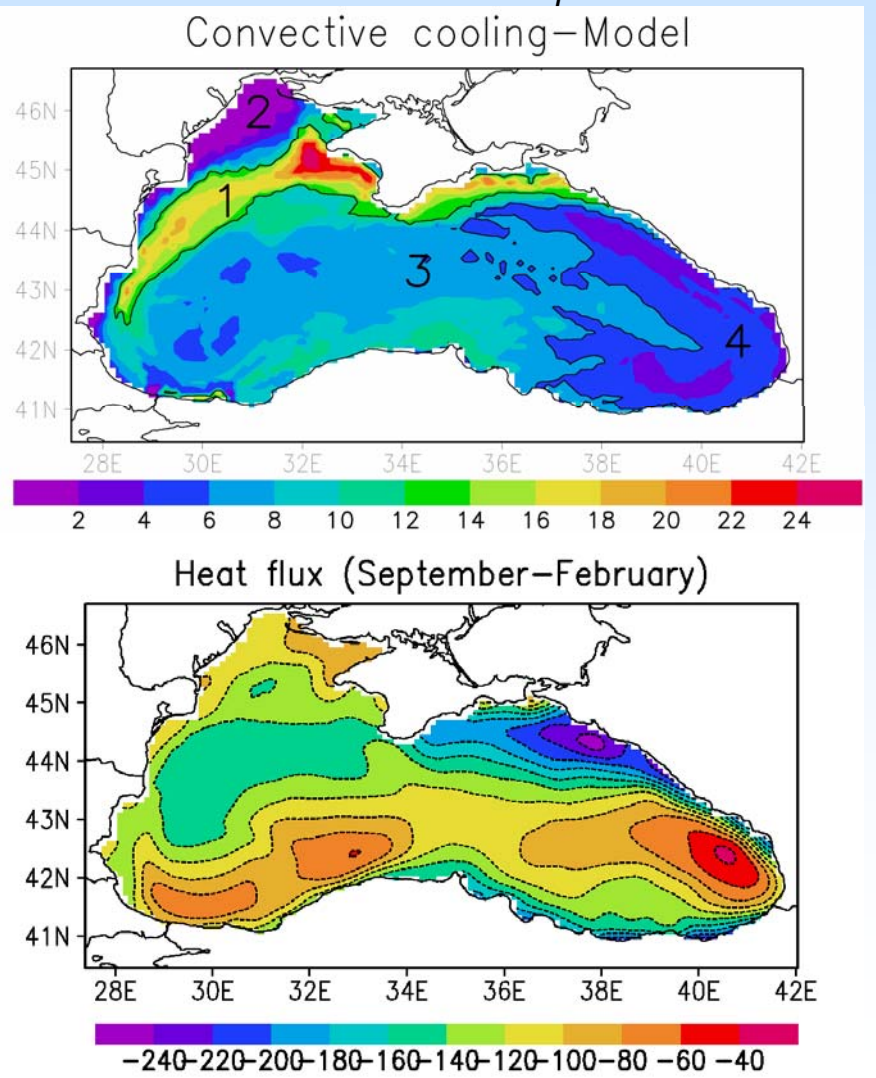
Coastal-Open ocean exchange: Black Sea MOM (5 nm resolution)

Water mass formation controlled by dynamics (topography)

Replenishment time of CIL ~5 years Lee et al. (2002)

Convective heat flux: $Q^{CF} = r_o C_p (T_a - T_b)/\Delta t$

$w^{conv} = Q^{CF} / (r_o C_p T)$

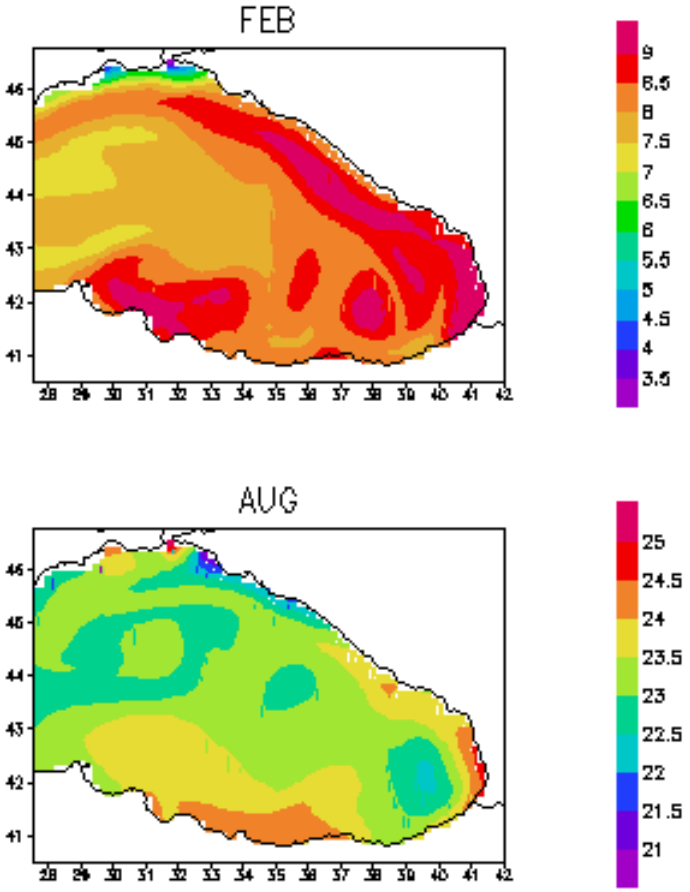


)

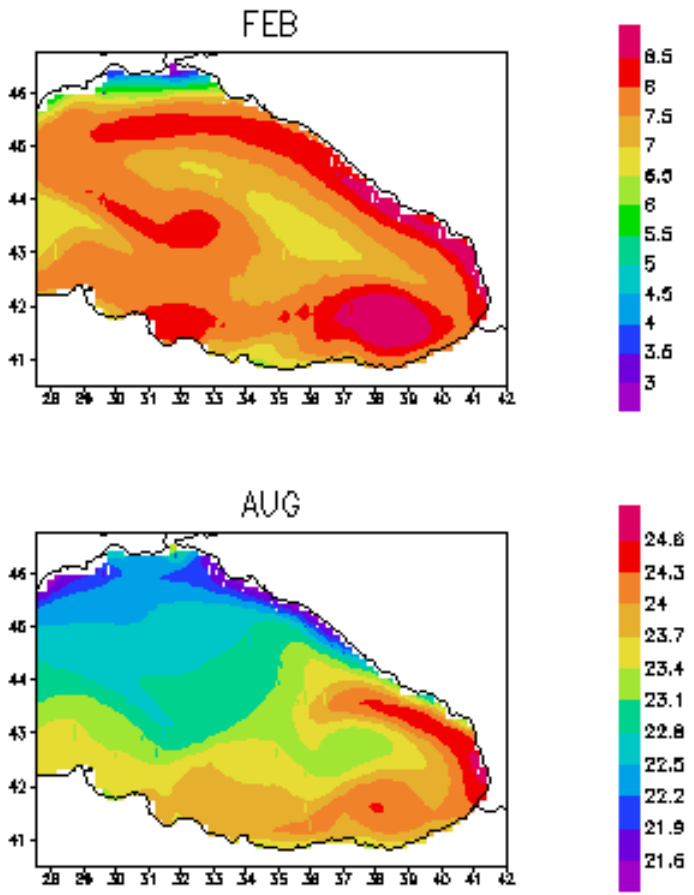
EBS-MOM-3 km

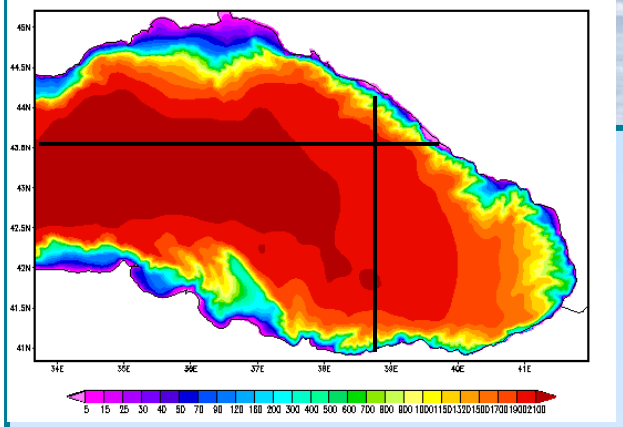
Sea Surface Temperature

1991



1993



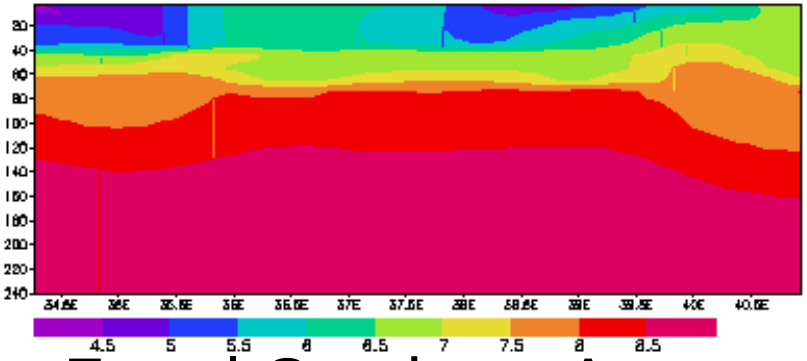


EBS-MOM-3 km

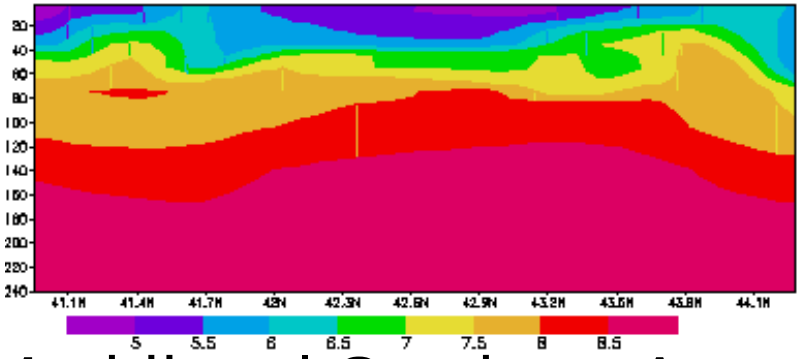
GKSS FORSCHUNGSZENTRUM in der HELMHOLTZ-GEMEINSCHAFT

Temperature Vertical Sections (1991)

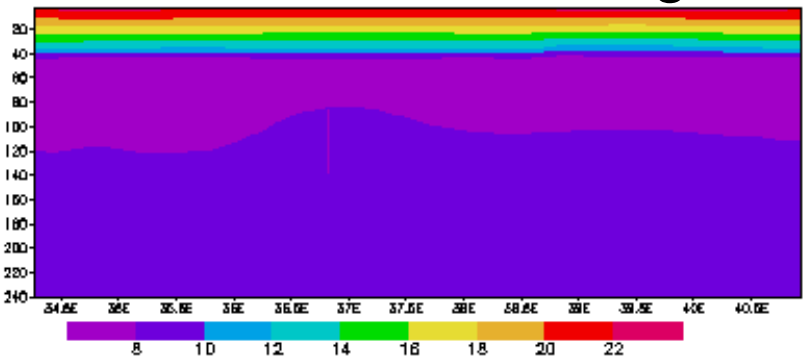
Zonal Section –February



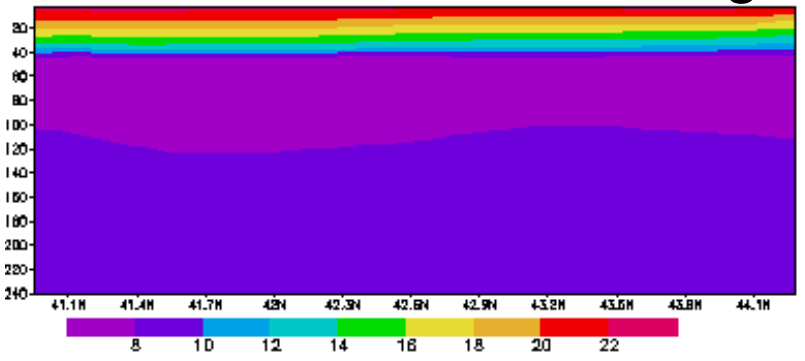
Meridional Section –February



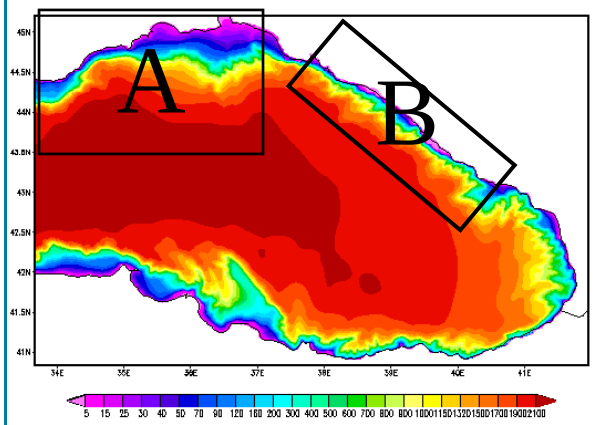
Zonal Section –August



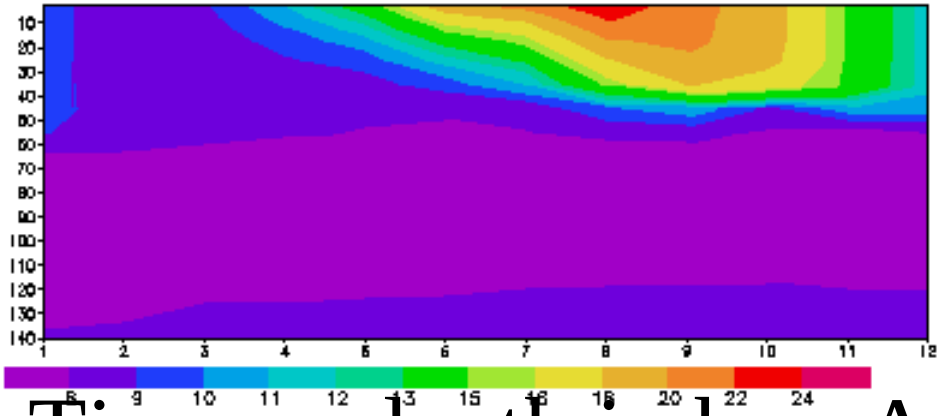
Meridional Section –August



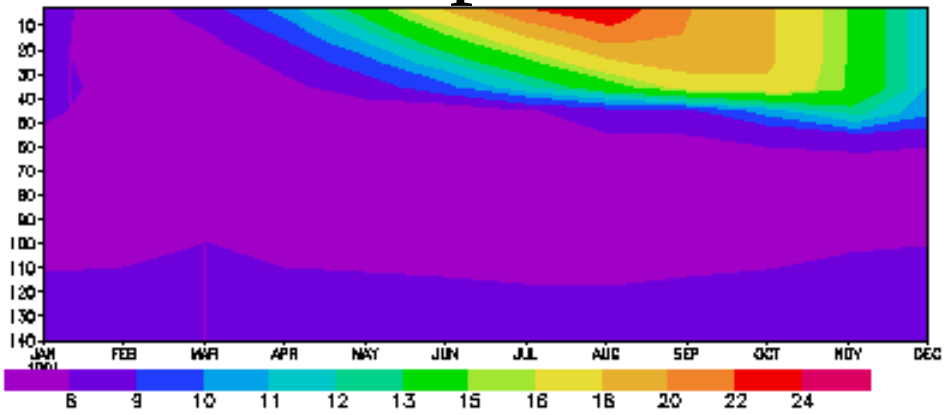
Temperature (EBS-MOM-3 km)



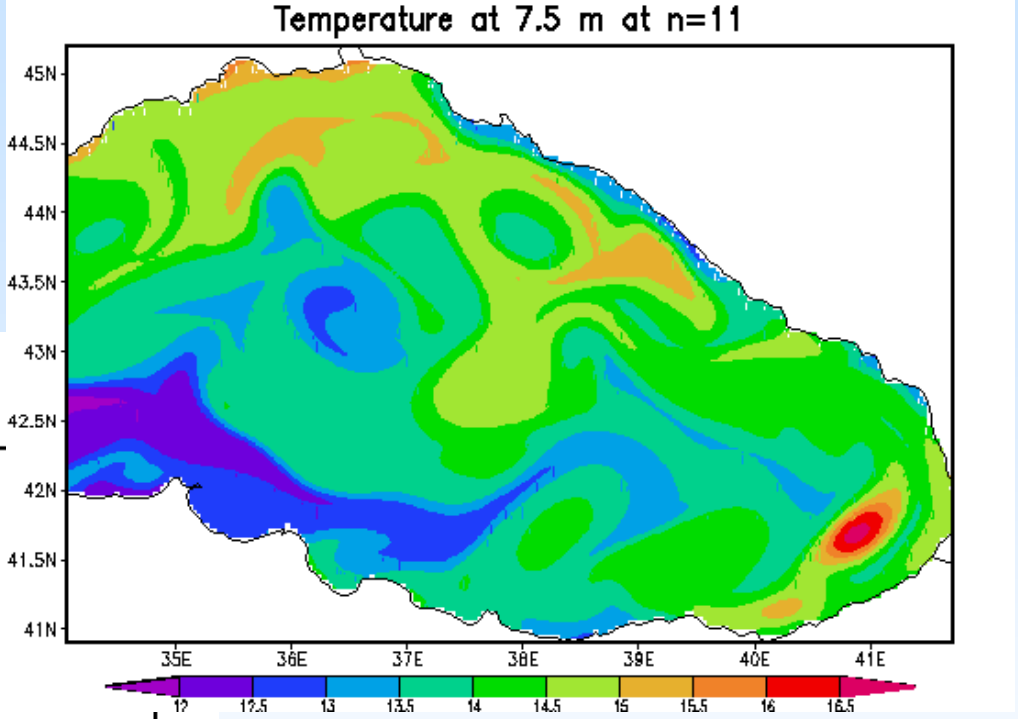
Time *vs* depth in box B

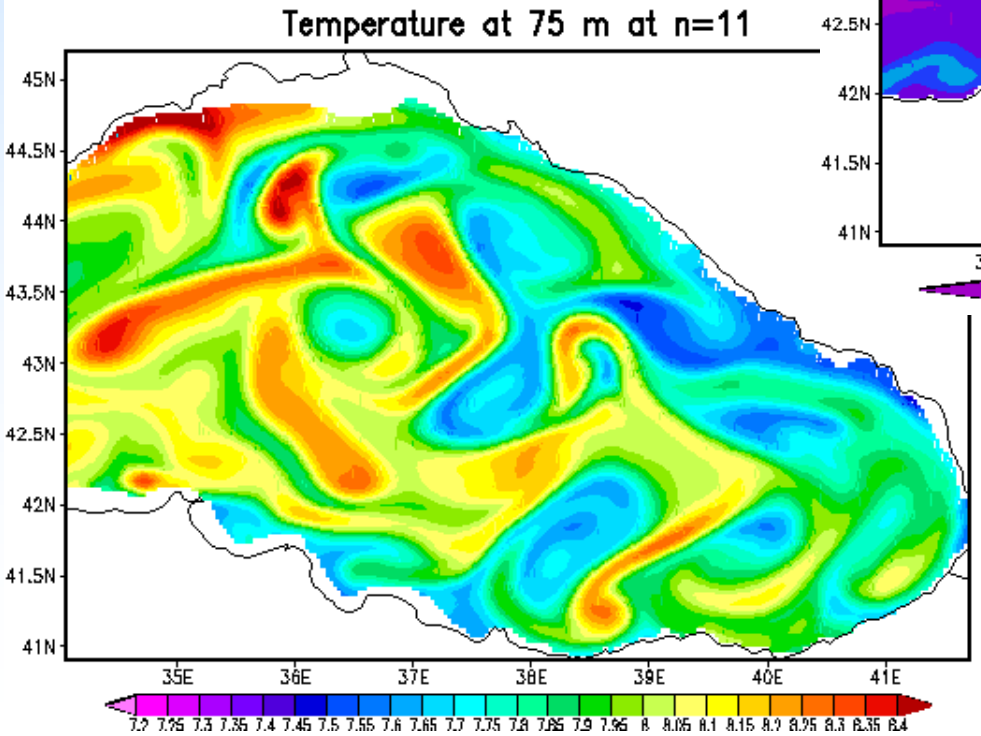


Time *vs* depth in box A



Temperature (EBS-MOM-3 km)





To conclude this part

The Black Sea provides optimal possibilities, using easily manageable models and observational data to address a wide spectrum of processes observed in the ocean.

It is a useful test region for developing models, which can then be applied to larger scales.

Biogeochemical modelling

... to address the functioning of the ecosystem and its response to climate variabiliy and human forcing

- **Models: ERSEM, NPZD, BIOGEN**
- ***with different levels of complexity and different resolution***

Determine: process and mechanisms of mass tranfer from land to ocean

Validation: model simulations *versus* survey and satellite data

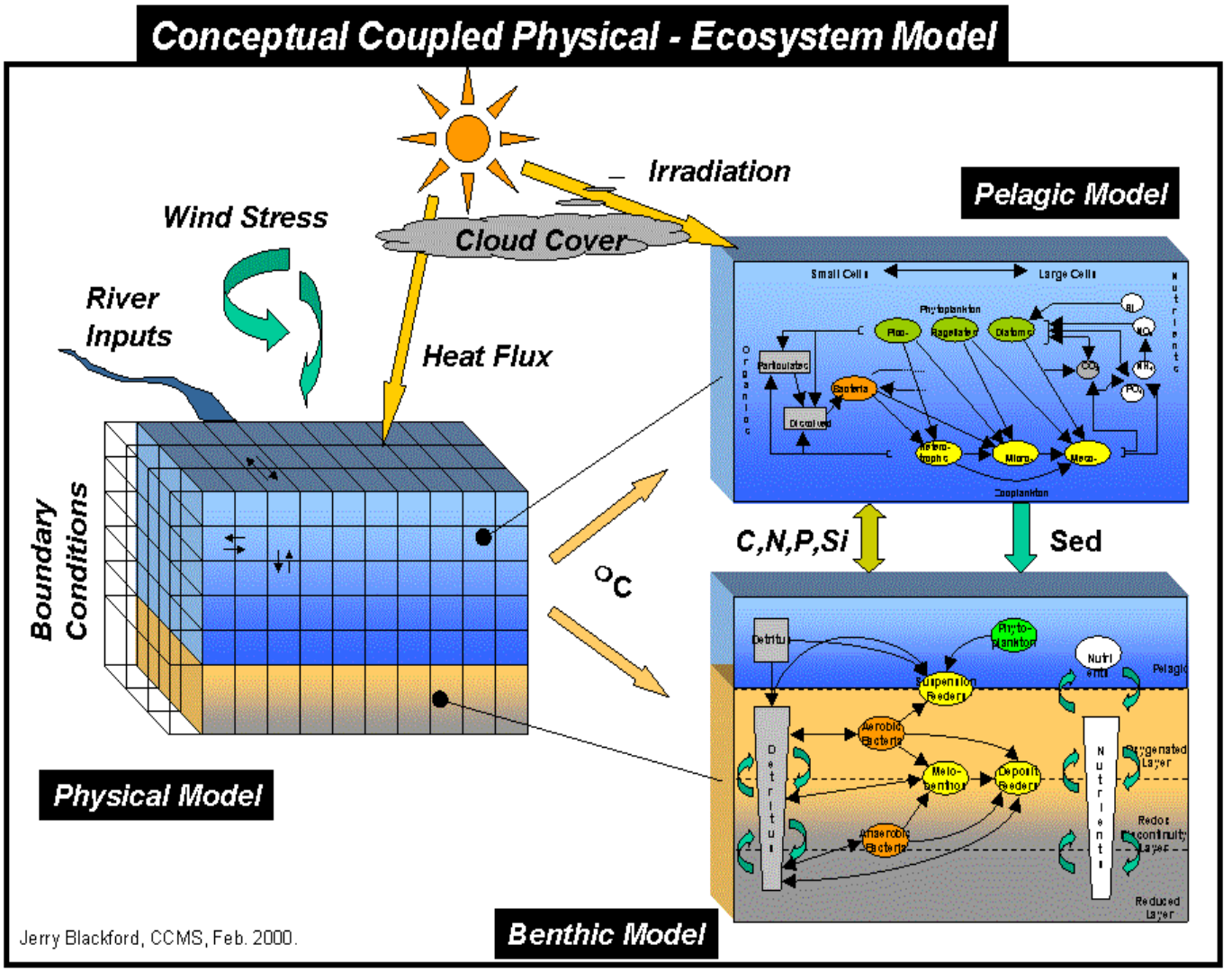
WHY A MODEL CAN DO BETTER THAN CORRELATIONS BETWEEN EVENTS?

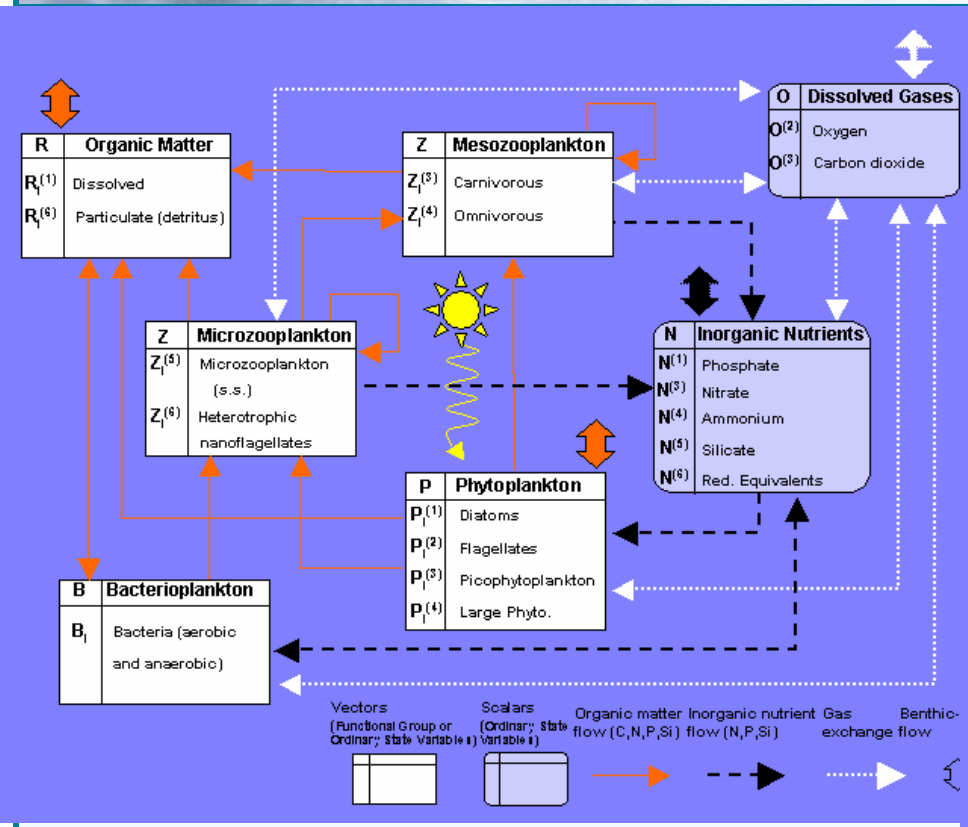
- **The synergy between the different human forcing cannot be assessed from simple correlations between ecological observations and historical correlations.**

- **Mechanistic models, which describe the kinetics between biological and chemical compartments as a function of meteorological and human forcings provide a powerful tool which encompasses this complexity.**

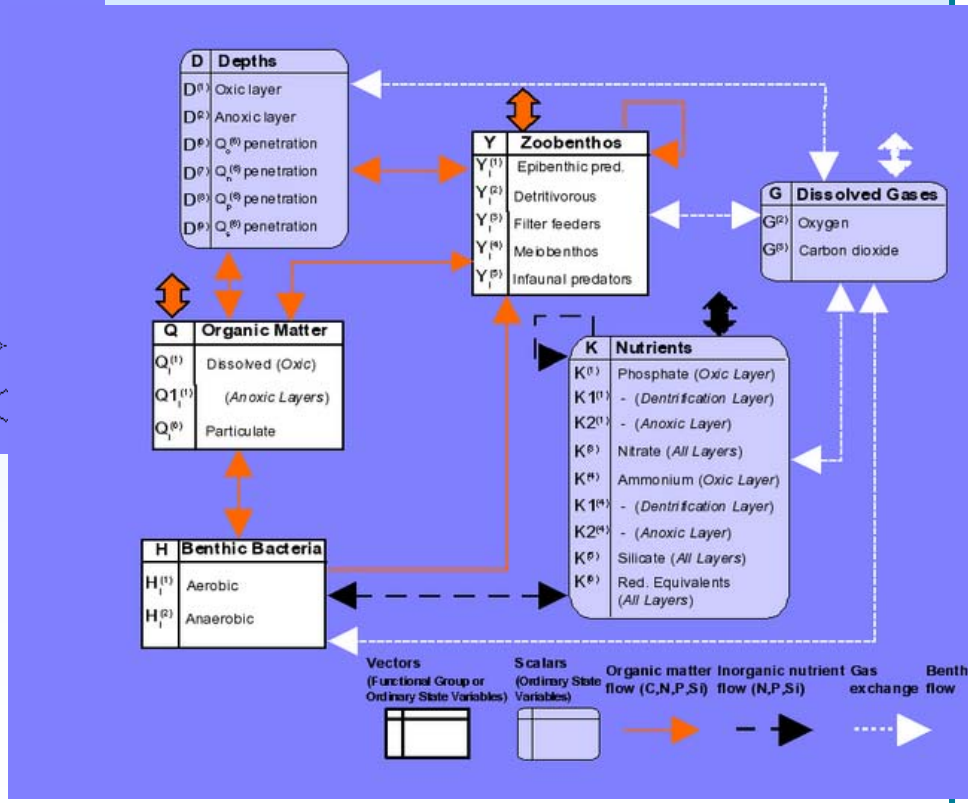
- **The ecological model ERSEM is established in order to assess the response of the north-western Black Sea ecosystem to human-induced changes and predict its future evolution.**

ERSEM


Conceptual Coupled Physical - Ecosystem Model
Irradiation
Wind Stress
Cloud Cover
River Inputs
Heat Flux
Pelagic Model
Boundary Conditions
°C
C,N,P,Si
Sed
Physical Model
Benthic Model
Jerry Blackford, CCMS, Feb. 2000.



Benthos model



Pelagic model

OFF-LINE COUPLING BETWEEN MOM AND ERSEM

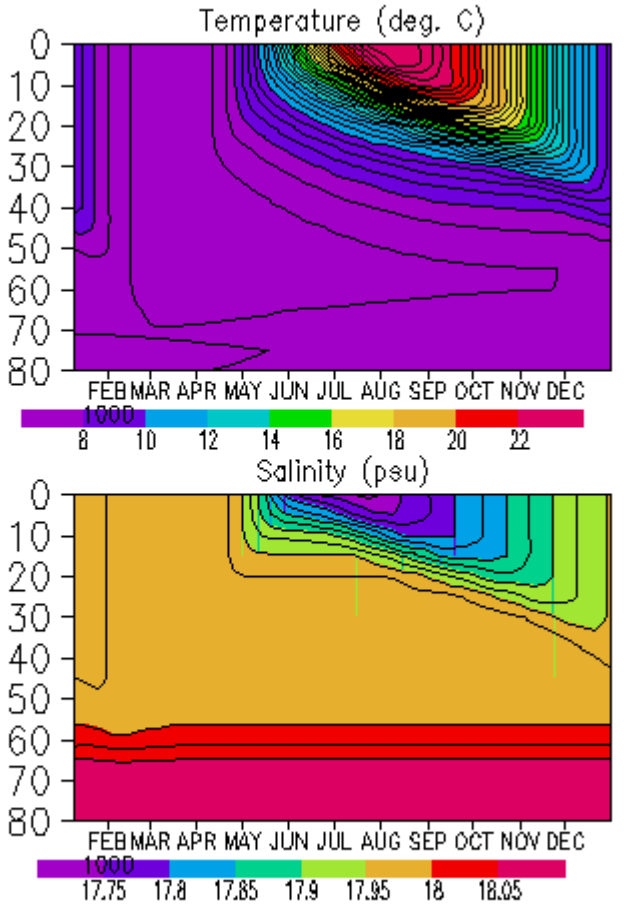
- Atmospheric forcing – high frequency atmospheric analyses data from ECMWF
- River discharge – daily data taken from A. Cociasu
- Open BC – Black Sea MOM

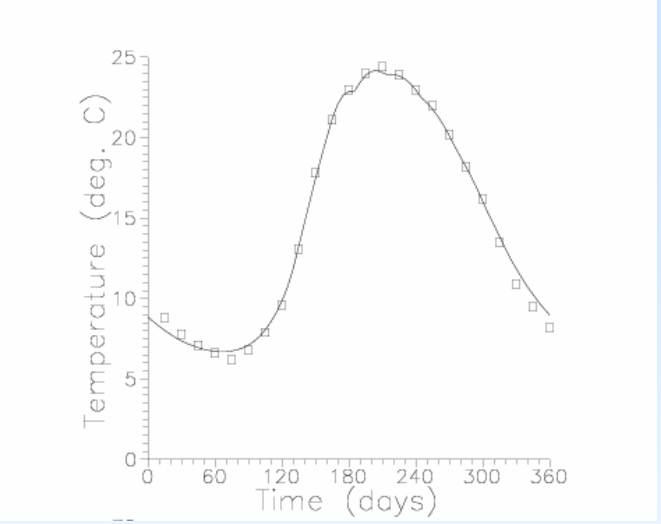
- Initialization:

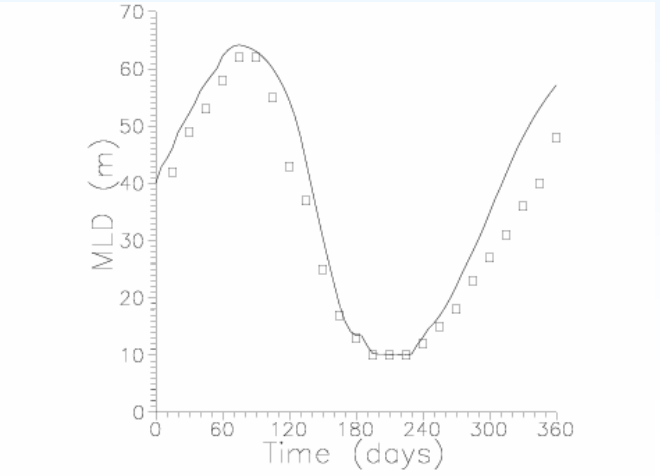
Physical sub-model – MOM output

Biogeochemical sub-model – ERSEM, observational data

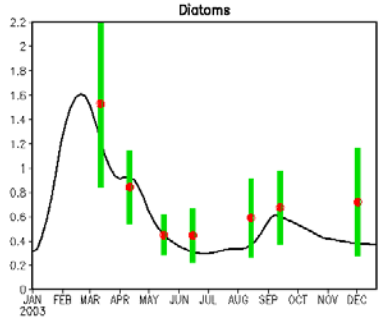
Seasonal evolution of the vertical profiles of T and S

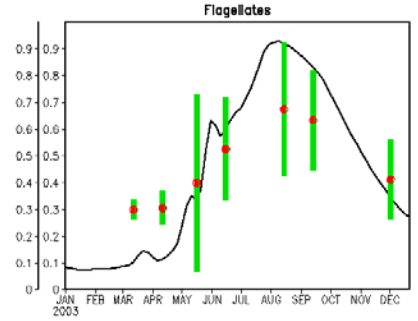


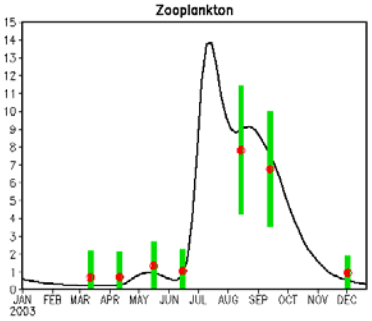


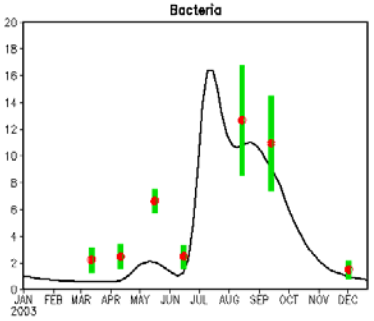


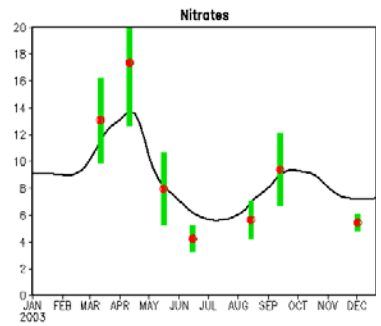
Model-data comparissons in 2003

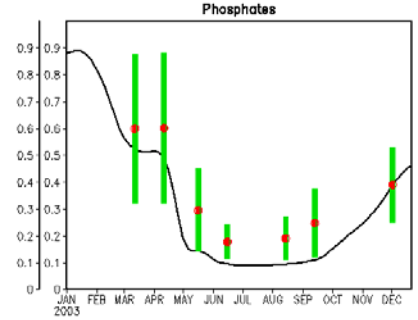


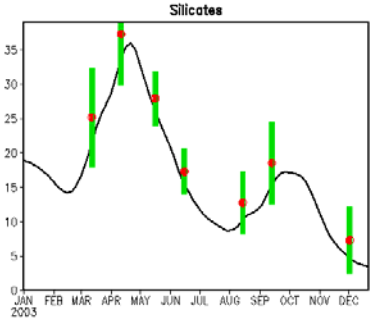


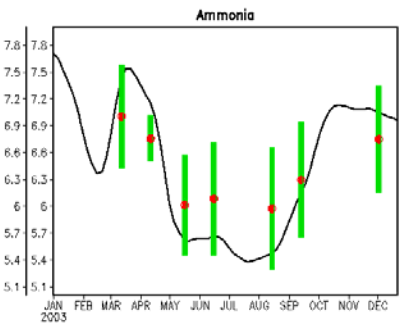


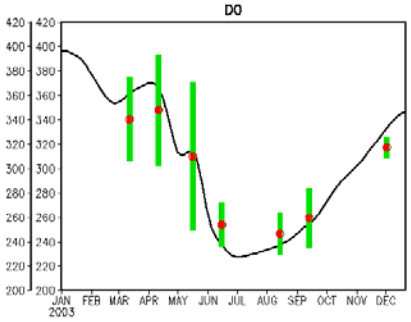


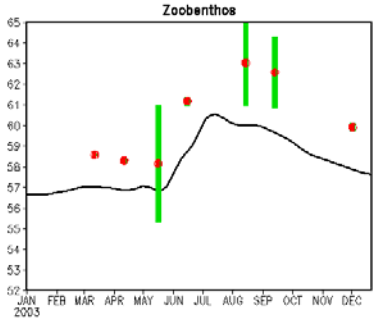




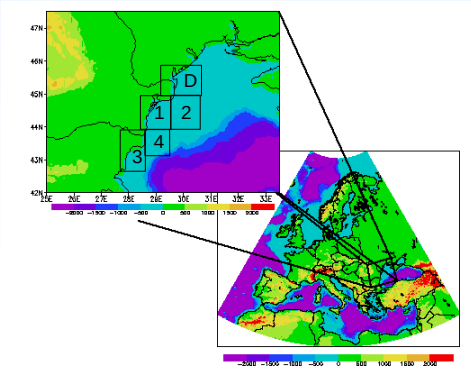




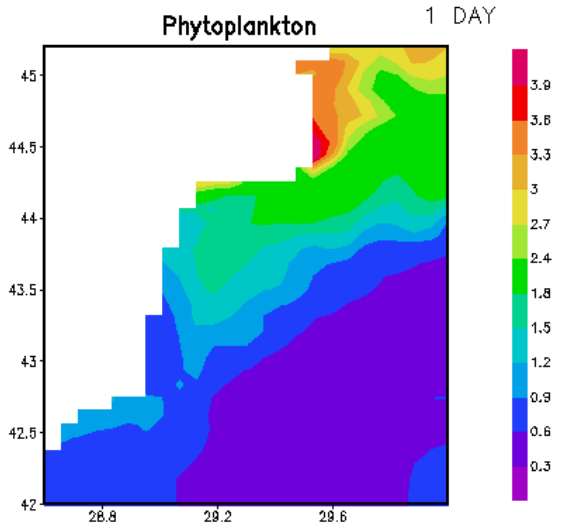


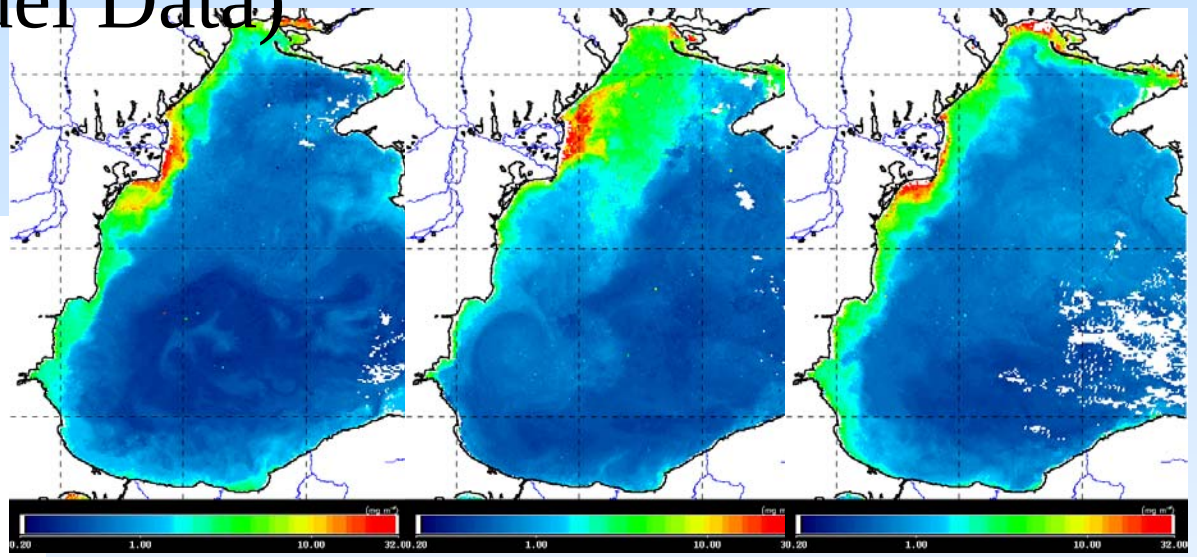


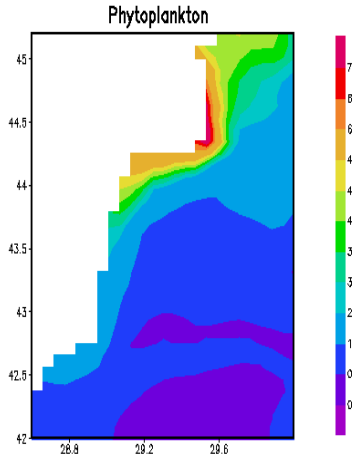
- **Reg. 4**

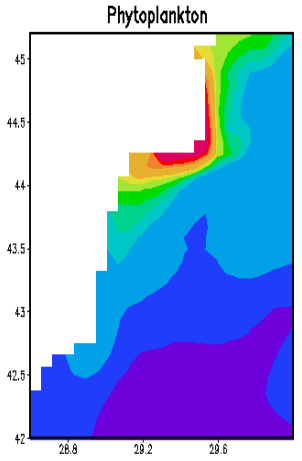


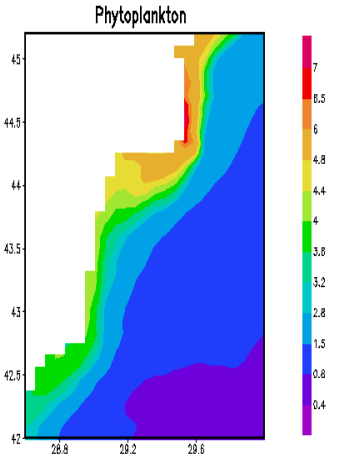
Biogeochemical modelling (Satellite v/s Model Data)



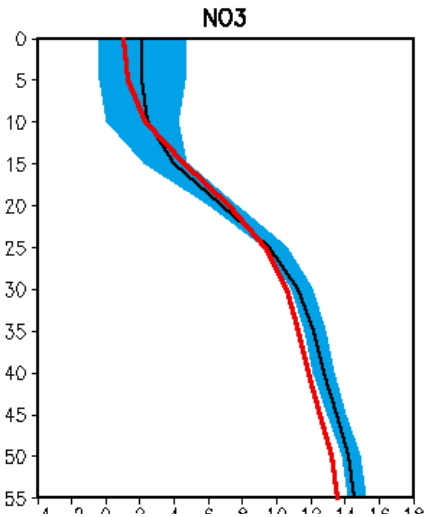


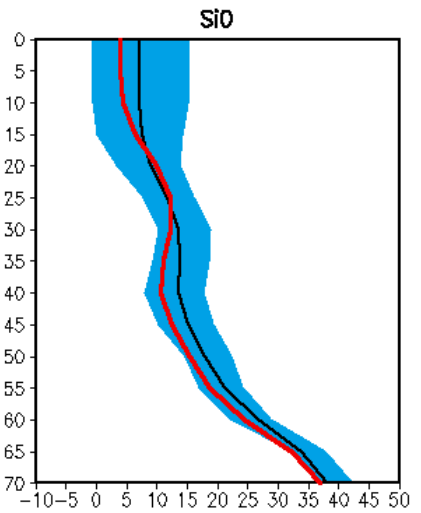


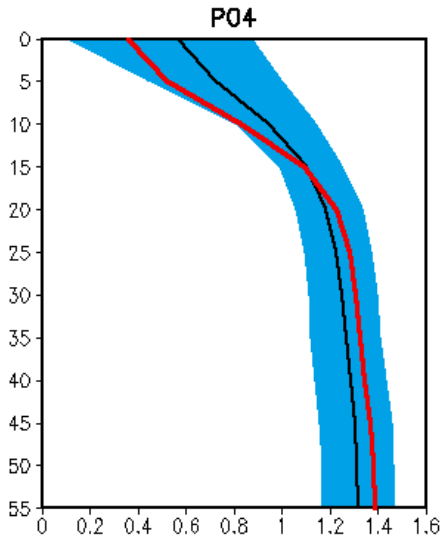




Vertical profiles - 2003



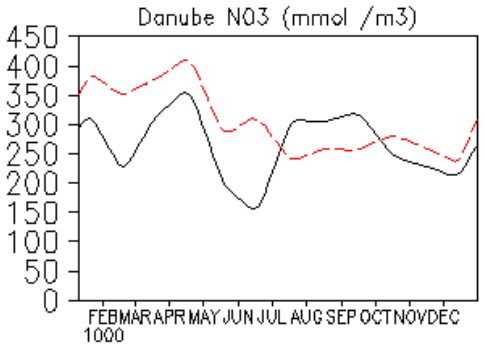


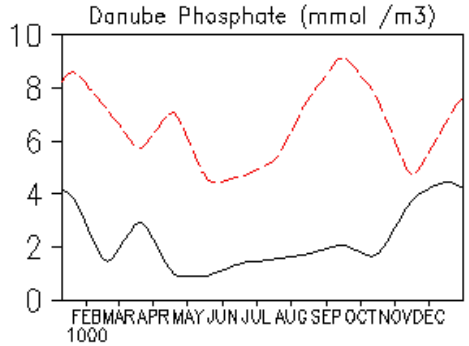


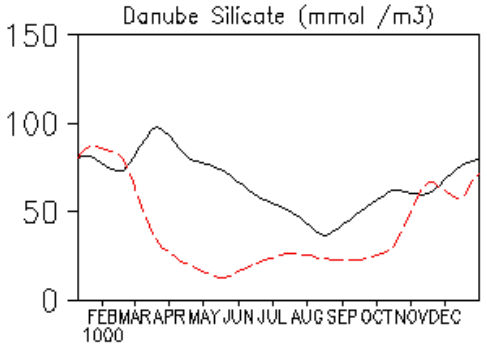
Spring

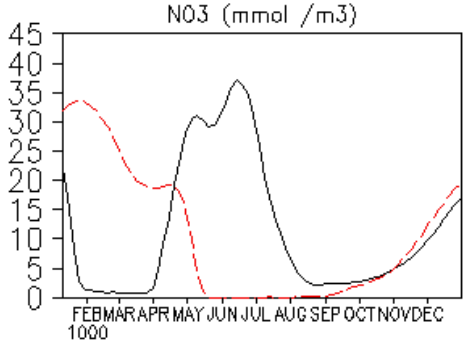
Scenario simulations

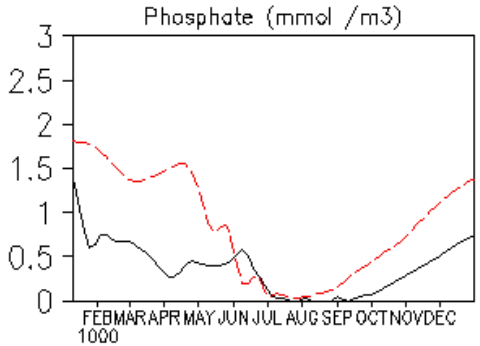
top-Danube discharge; bottom-model results. Black line 1984 (pre-eutrophication period); red line- 1993 (high eutrophication)

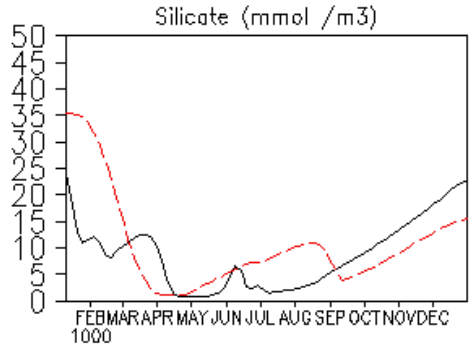






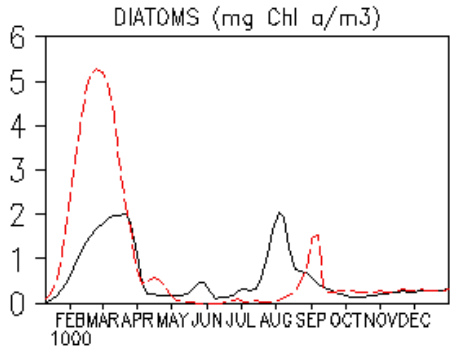


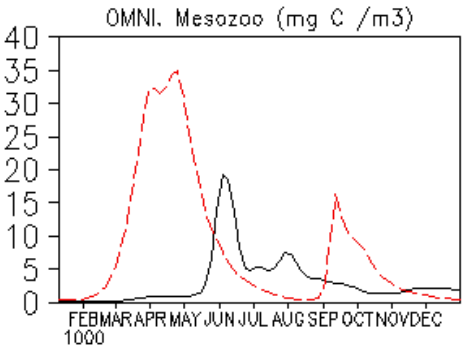


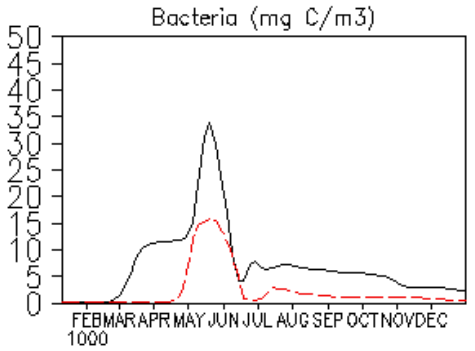


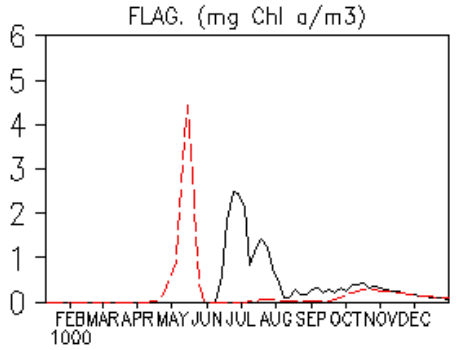
Time evolution of some of the ecosystem variables

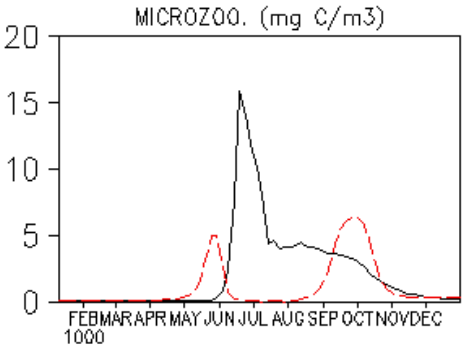
Black line 1984; red line 1993.

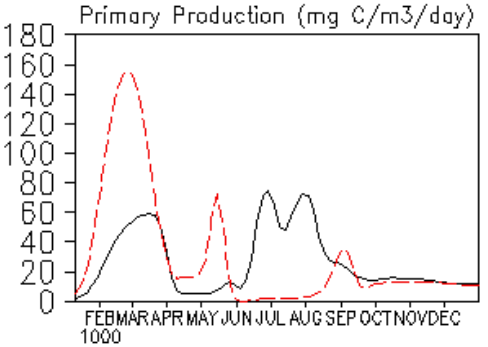








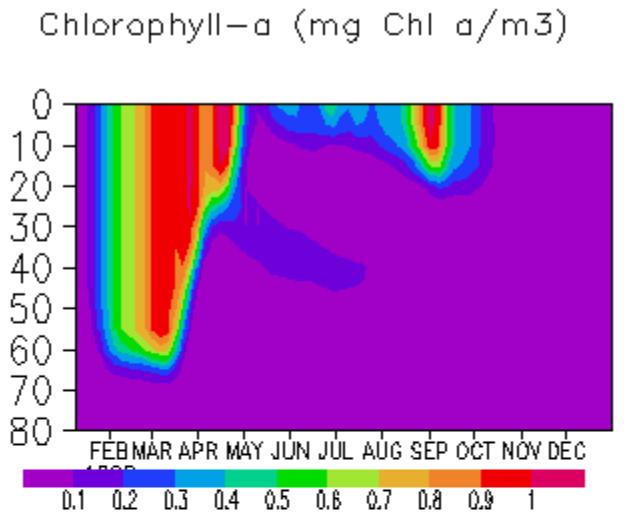


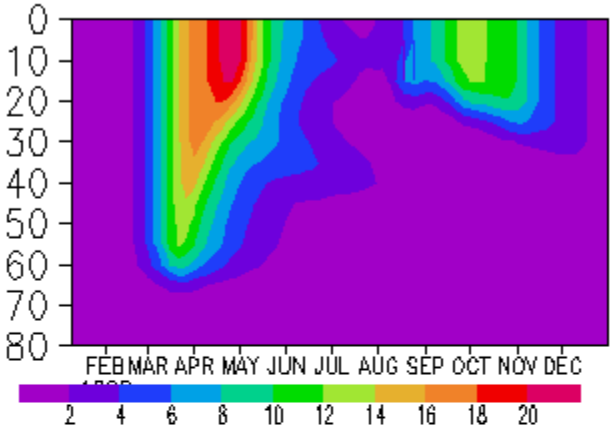


Scenaria: Evolution of the vertical profiles

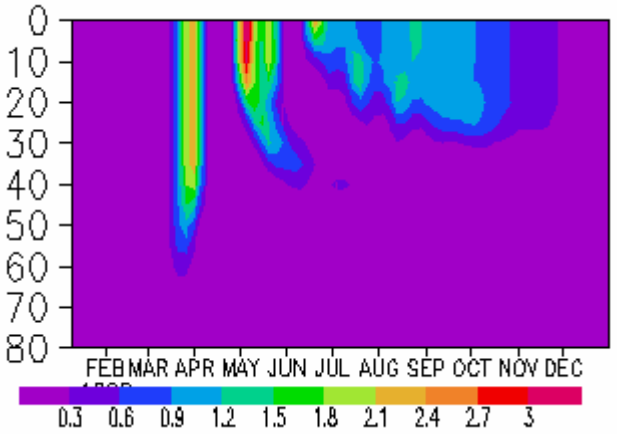
diatoms [mg.Chla. m $^{-3}$]

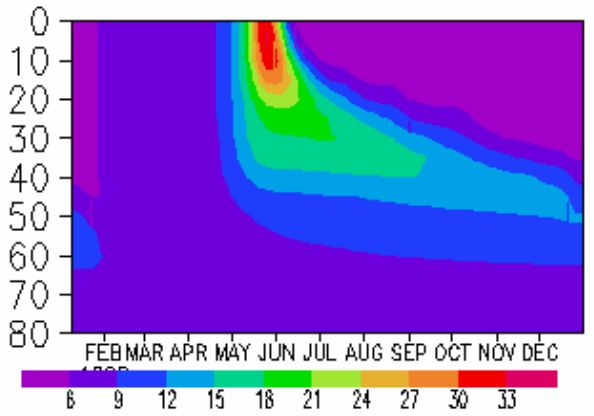
copepods [mg.C m $^{-3}$]





80s



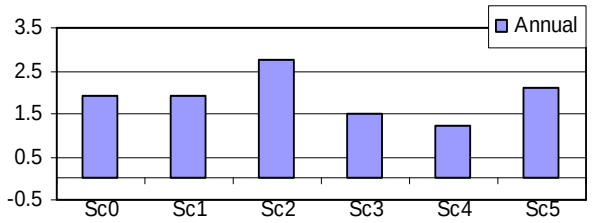


90s

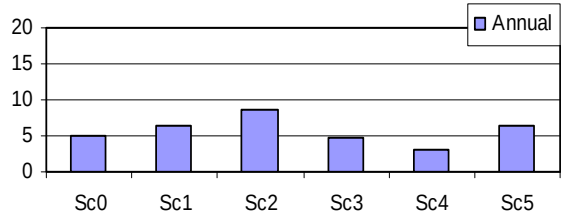
SCENARIO - SIMULATIONS

Sc1 “Business usual scenario”
Sc2 “High production scenario”
Sc3 “Best available technique scenario”
Sc4 “Green scenario”
Sc5 “Policy scenario”

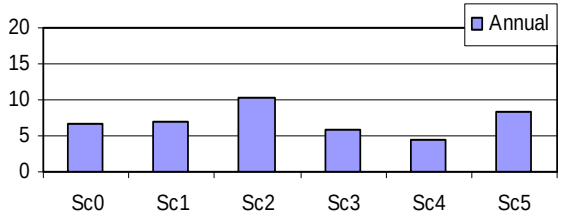
Diatoms (mg Cla /m^3)



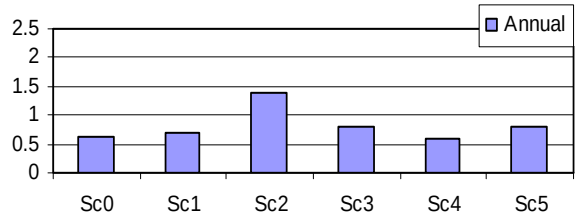
Copepods (mg C /m^3)



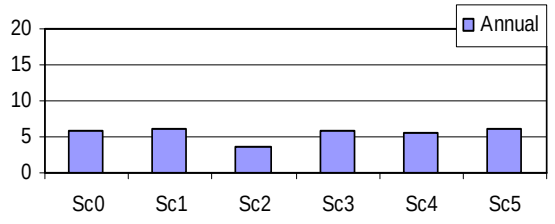
Bacteria (mg C /m^3)



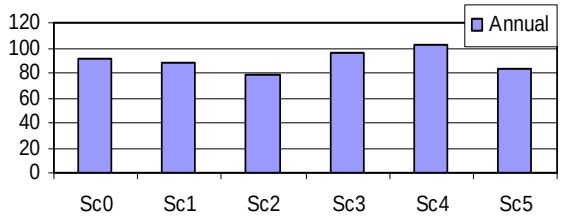
Flagellates (mg Cla /m^3)



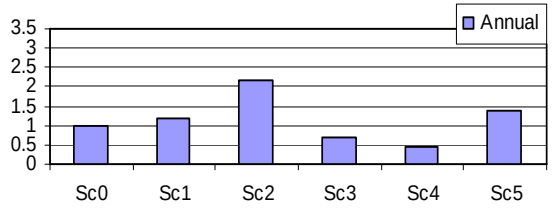
Microzooplankton (mg C /m^3)



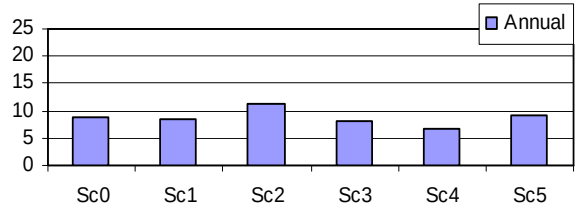
Oxygen saturation (%)



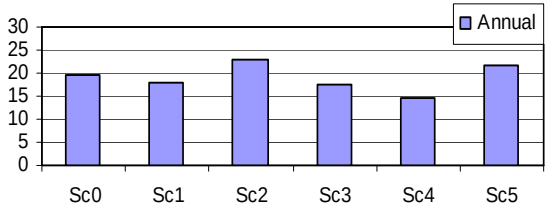
PO_4 (mmol /m^3)



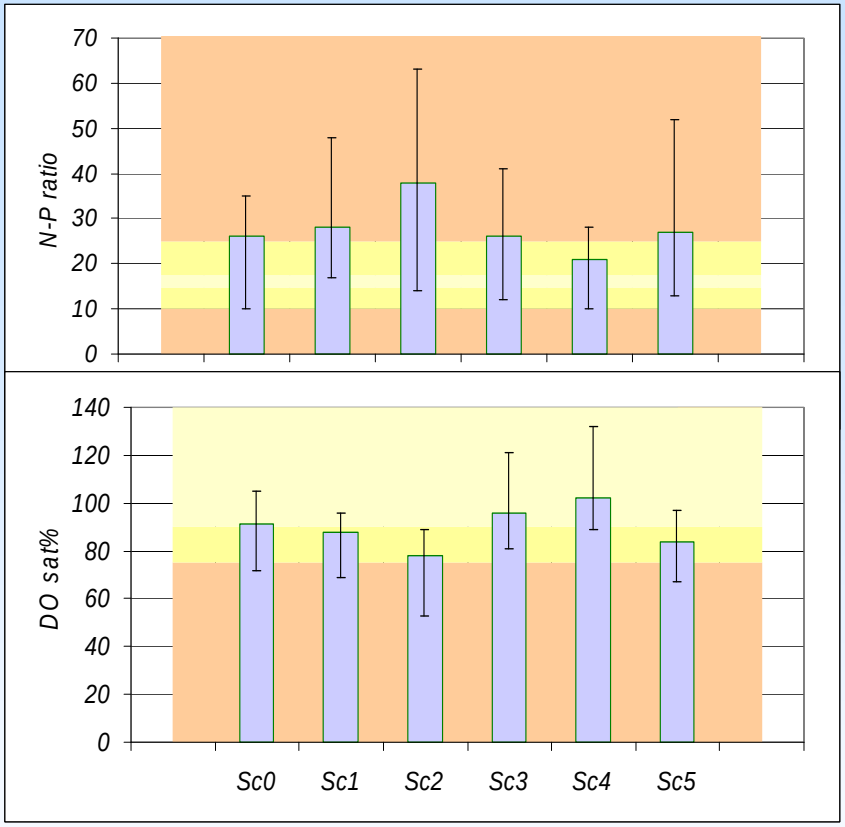
NO_3 (mmol /m^3)

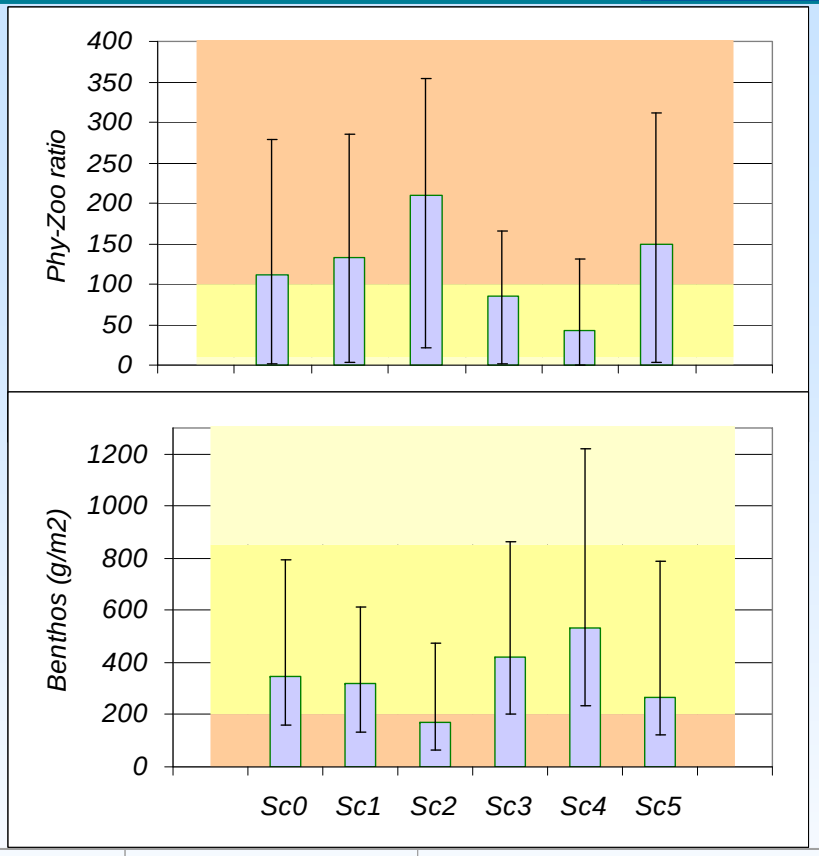


SiO (mmol/m^3)



SCENARIO - INDICATORS





Indicators ranges	N/P	P/Z	O2	Benthic biomass
Bad state	<10 and > 25	<100	50-75%	1.5-200 g.m-^{2}
Moderate state	10-14and18-25	10-100	75-90%	200-850 g.m-^{2}
Good state	15 – 17	>10	> 90%	850 - 6500g.m-^{2}

SUMMARY

- **The sequence of ecological events that took place in the north-western Black Sea can be reproduced by the coupled model.**

- **The model addresses the study of an ecosystem submitted to changes both of its structure and functioning.**

- **The model predictions show that the euthrophication-related problem is a question of changing of the nutrient balance, not only qualitatively, but also quantitatively.**

SUMMARY

- **The model is calibrated for the Black Sea conditions using hierarchy of observational data**
- **It allows testing of different scenarios, regarding the structure of the ecosystem as a function of meteorological and human forcing.**
- **Thus, the model predictions will be of interest for both scientists and policy makers and can be used for management purposes.**

Conclusions

1. **Motivating results**

2. **Further increase of multidisciplinary studies as well as synergy between observations and models is needed**

3. **Rapid development in the field of ecosystem modelling, climate variability, coastal operational oceanography is expected in the years to come (e.g. a number of international & national programmes, ECOOP, SESAME, EU-FP7)**

GKSS
FORSCHUNGSZENTRUM
in der HELMHOLTZ-GEMEINSCHAFT

Thanks for your attention!