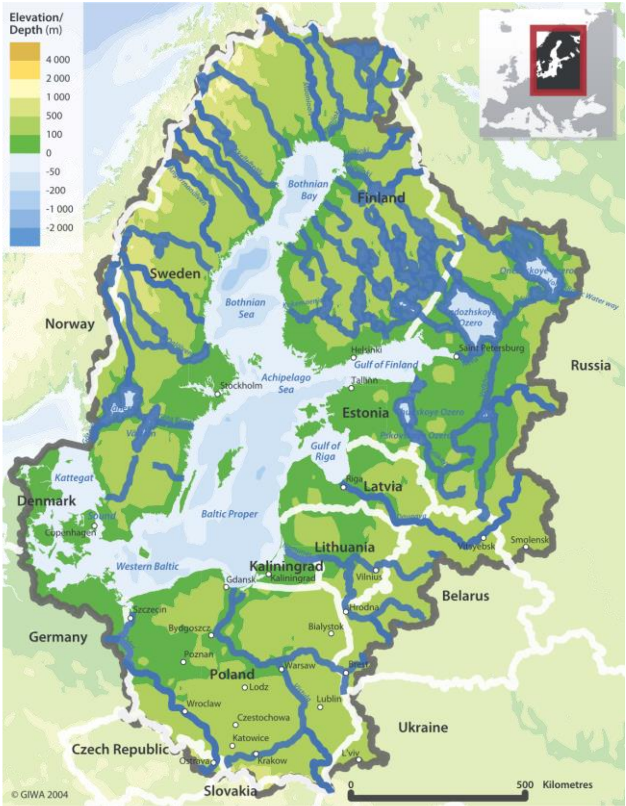
Sea-level, temperature and salinity change in the Black Sea simulated for 2000-2100

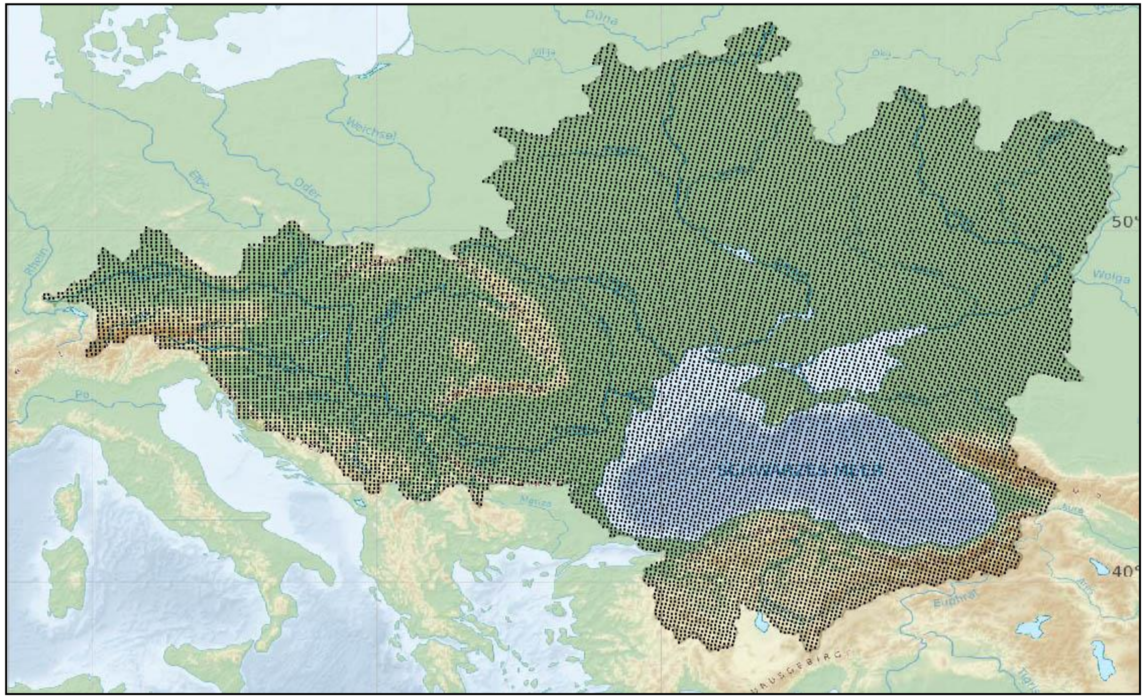
V. Maderych, I. Kovalets, I. Brovchenko

Institute of Mathematical Machine and System Problems, Kyiv, Ukraine

Black Sea vs Baltic Sea



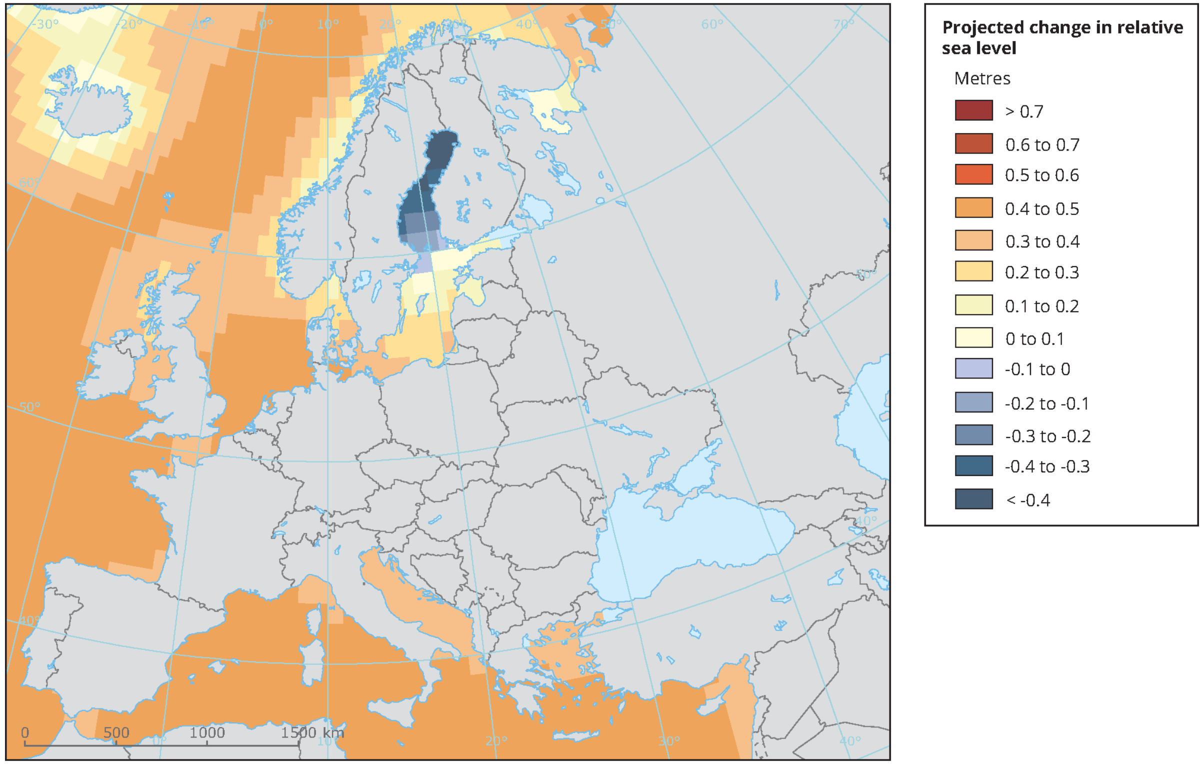
Baltic Sea with watershed



Black Sea with watershed

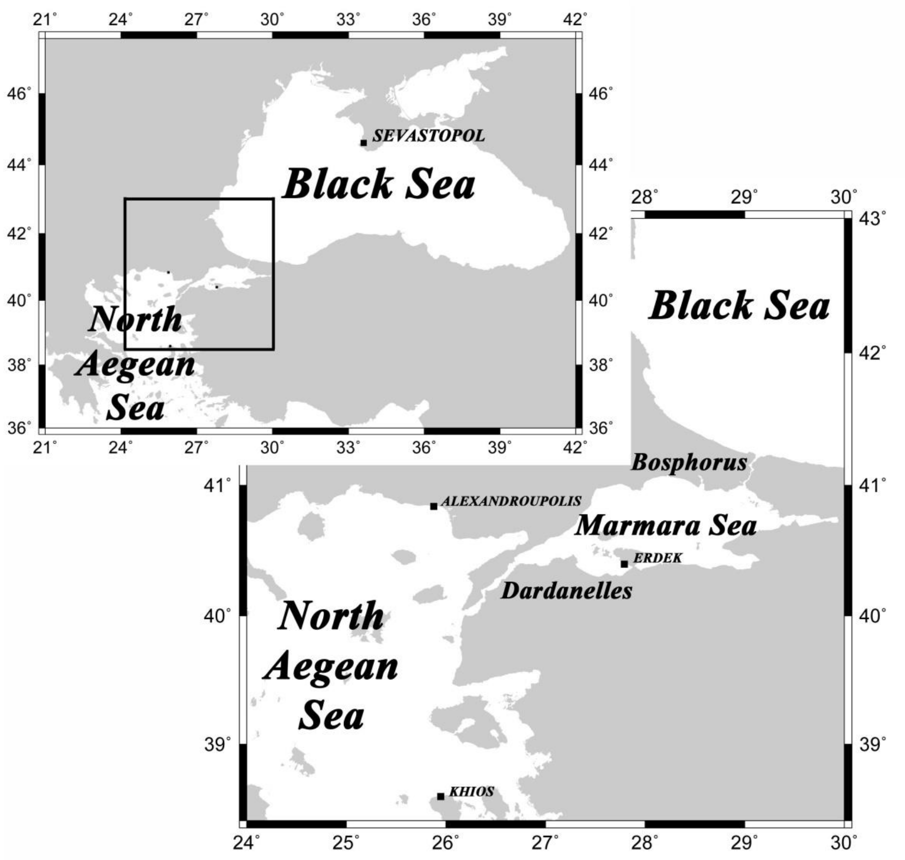
Research questions

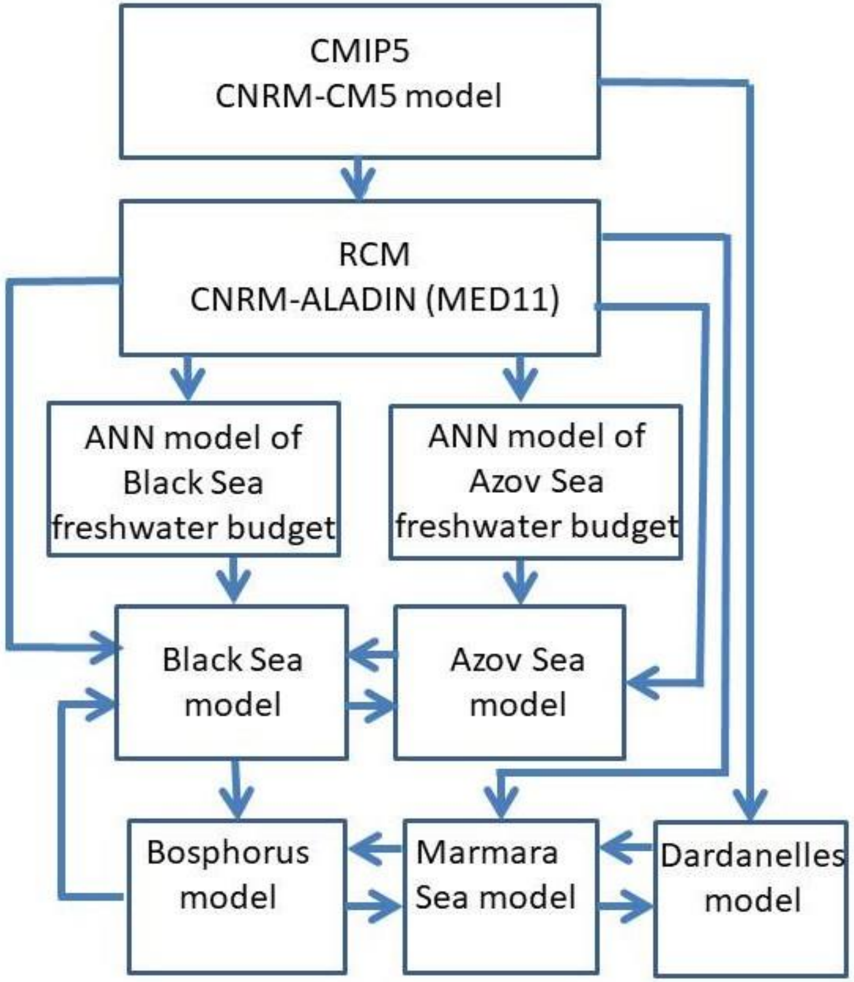
1. How climate change of fresh water budget will affect sea level and stratification in the semi-closed Black Sea?
2. How will climate change affect two-way exchange through the Turkish Strait System?
3. Do climate changes in the Black Sea's level, temperature and salinity differ from other seas?
4. Could an increase in evaporation and a decrease in river flow lead to the appearance of hydrogen sulfide in the surface layer of the Black Sea?



Projected change in relative sea level

Data flow in the model chain





Equations of a one-and-a-half-dimensional multi-layer Lagrangian model of the sea

$$V_u \frac{dT_u}{dt} = \sigma_u (T_n - T_u)(w_e + w_*) - q_T \sigma_u + (T_1^B(M) - T_u) Q_1^B(M),$$

$$V_u \frac{dS_u}{dt} = \sigma_u (S_n - S_u)(w_e + w_*) - S_u Q_f^M + (S_1^B(M) - S_u) Q_1^B(M),$$

The equations for temperature and salinity in surface mixed layer

$$V_i \frac{dT_i}{dt} = \sigma_{i+1}(T_{i+1} - T_i) w_* - \sigma_i (T_i - T_{i-1}) w_*,$$

$$V_i \frac{dS_i}{dt} = \sigma_{i+1}(S_{i+1} - S_i) w_* - \sigma_i (S_i - S_{i-1}) w_*,$$

*The equations for temperature and salinity in the internal layer (**i=2,n**)*

$$V_1 \frac{dT_1}{dt} = \sigma_2 (T_2 - T_1) w_* + (T_1 - T_2^D(M)) Q_2^D(M),$$

$$V_1 \frac{dS_1}{dt} = \sigma_2 (S_2 - S_1) w_* + (S_1 - S_2^D(M)) Q_2^D(M)$$

The equations for temperature and salinity in near bottom layer

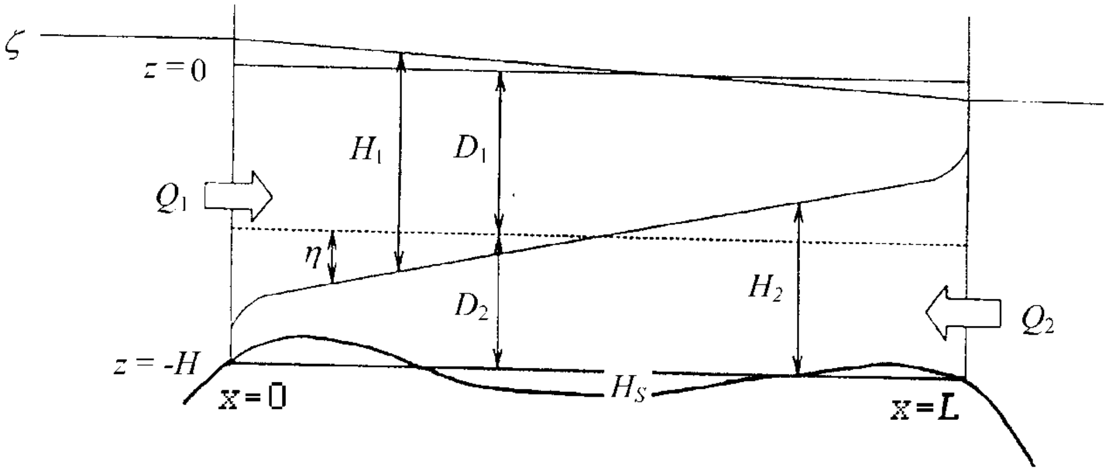
$$\sigma_u \frac{dh_u}{dt} = \sigma_u w_e - Q_2^D(M),$$

The equation for thickness surface mixed layer

$$\sigma_i \frac{dh_i}{dt} = -Q_2^D(M)$$

The equation for the position of internal layers

Two-layer hydraulic model of the long strait



Hydraulic control

$$G^2 = F_1^2 + F_2^2 = 1,$$

$$F_1^2 = \frac{Q_1^2}{g' H_1^3 A^2}, \quad F_2^2 = \frac{Q_2^2}{g' H_2^3 A^2}.$$

$$(1-G^2)\frac{d}{dx}(H_2 + H_s) = -\frac{1}{A_0 - A_s}((D - H_2 - H_s)F_1^2 - H_2 F_2^2)\frac{dA_s}{dx} - F_2^2 \frac{dH_s}{dx}$$

$$+c_i\left[\left(\frac{D-H_s}{H_2}\right)^{1/2} F_1 - \left(\frac{D-H_s}{D-H_s-H_2}\right)^{1/2} F_2\right]^2 + c_b F_2^2.$$

$$\frac{1}{2}\left(\frac{Q_1^2}{A^2(L)\;H_1^2(L)} - \frac{Q_2^2}{A^2(L)\;H_2^2(L)}\right) + g' H_2(L) = g\Delta\varsigma - c_i \int_0^L \frac{|u_1 - u_2|(u_1 - u_2)}{H_1} dx.$$

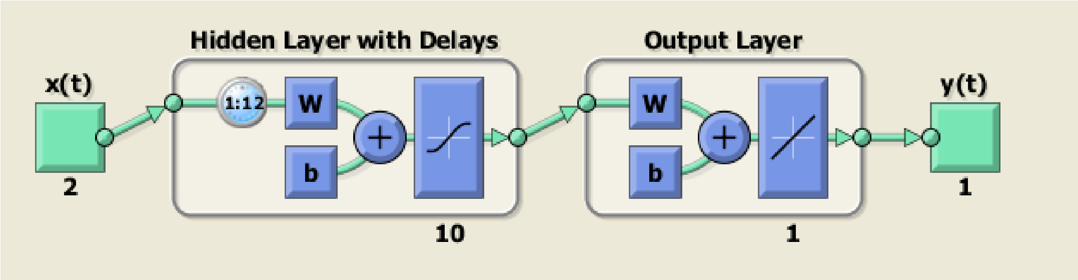
Maderich V., Ilyin Yu., Lemeshko E. (2015). *Mediterranean Marine Science,* 16 (2)

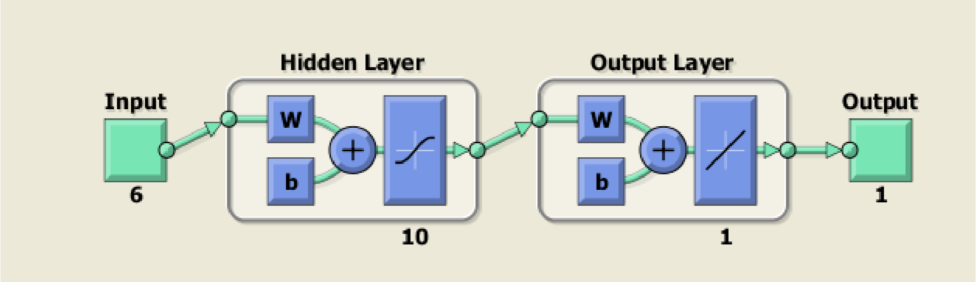
The Black Sea river runoff and evaporation-precipitation difference were simulated using an artificial neural network

The river runoff and evaporation-precipitation difference over the Black Sea were simulated using an artificial neural network (ANN) to the projections by RCM CNRM-ALADIN (MED-11) for 2010-2100.

The runoff vector of predictors consisted of the values of the difference evaporation - precipitation, integrated over the catchment area and 1 month in time, as well as the average monthly air temperature averaged over the catchment area.

The evaporation-precipitation difference vector of predictors consisted of the values of the difference evaporation - precipitation, air temperature, sea surface temperature, wind velocity, specific humidity, integrated over the sea area

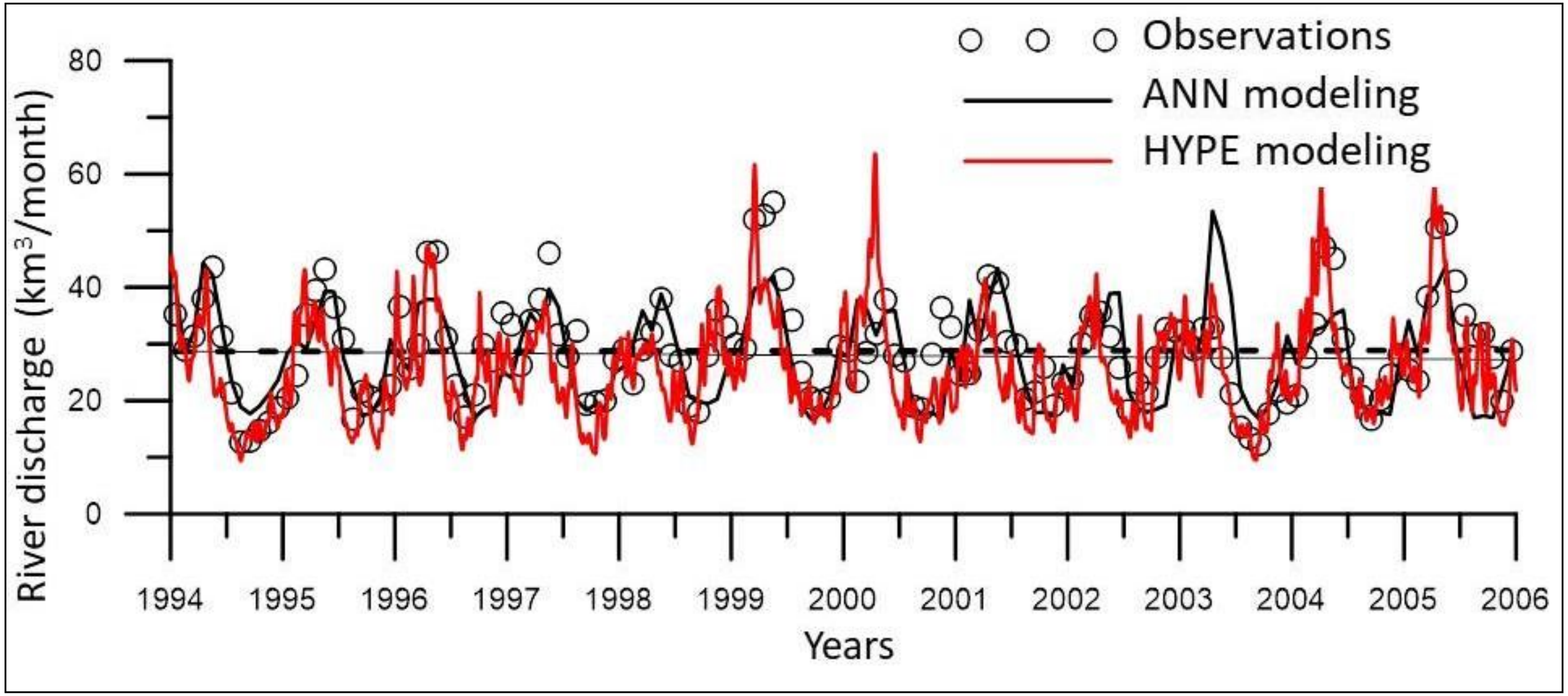




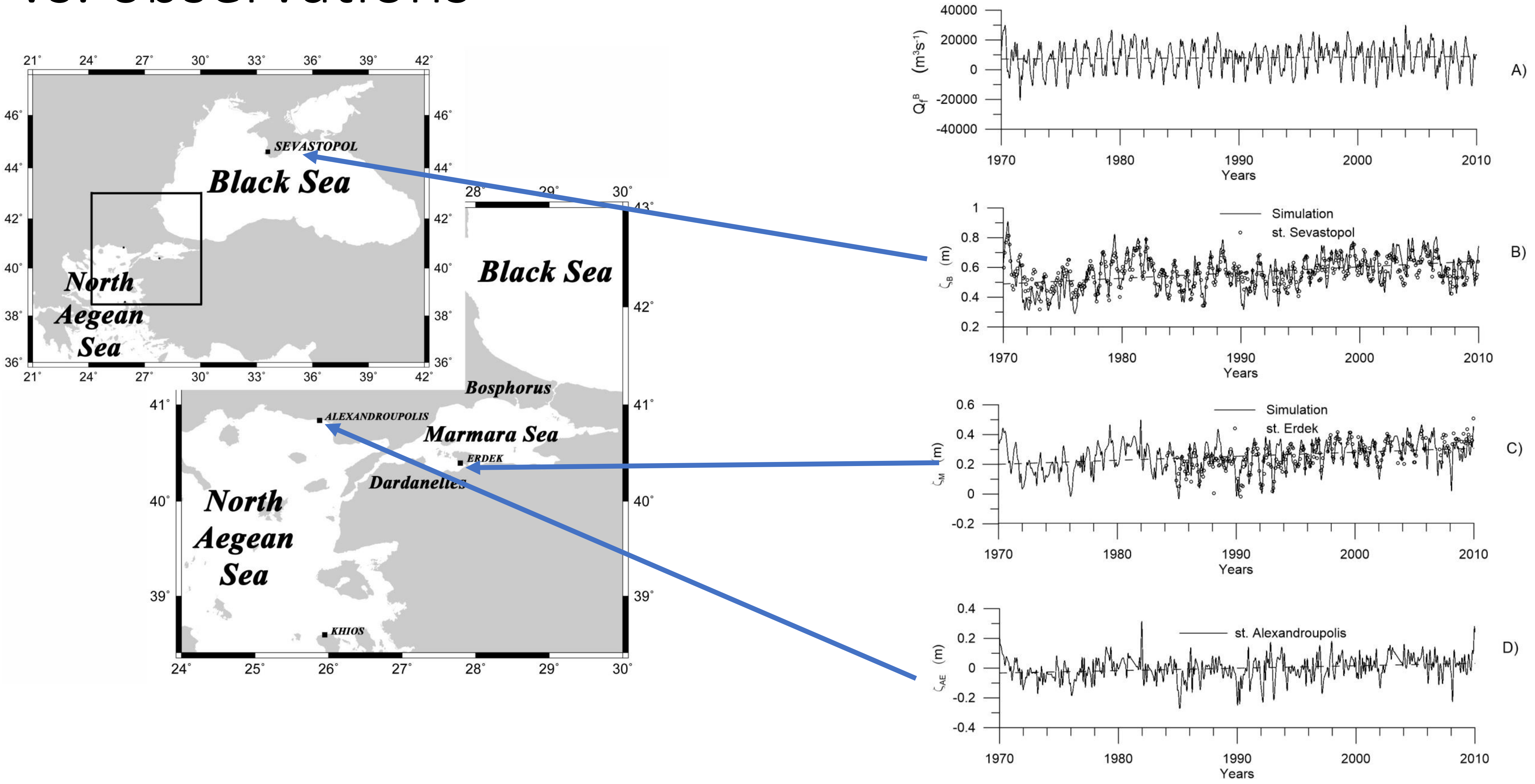
The Neural Network Toolbox neural network consisted of two layers of neurons

Modelling system validation using historical data

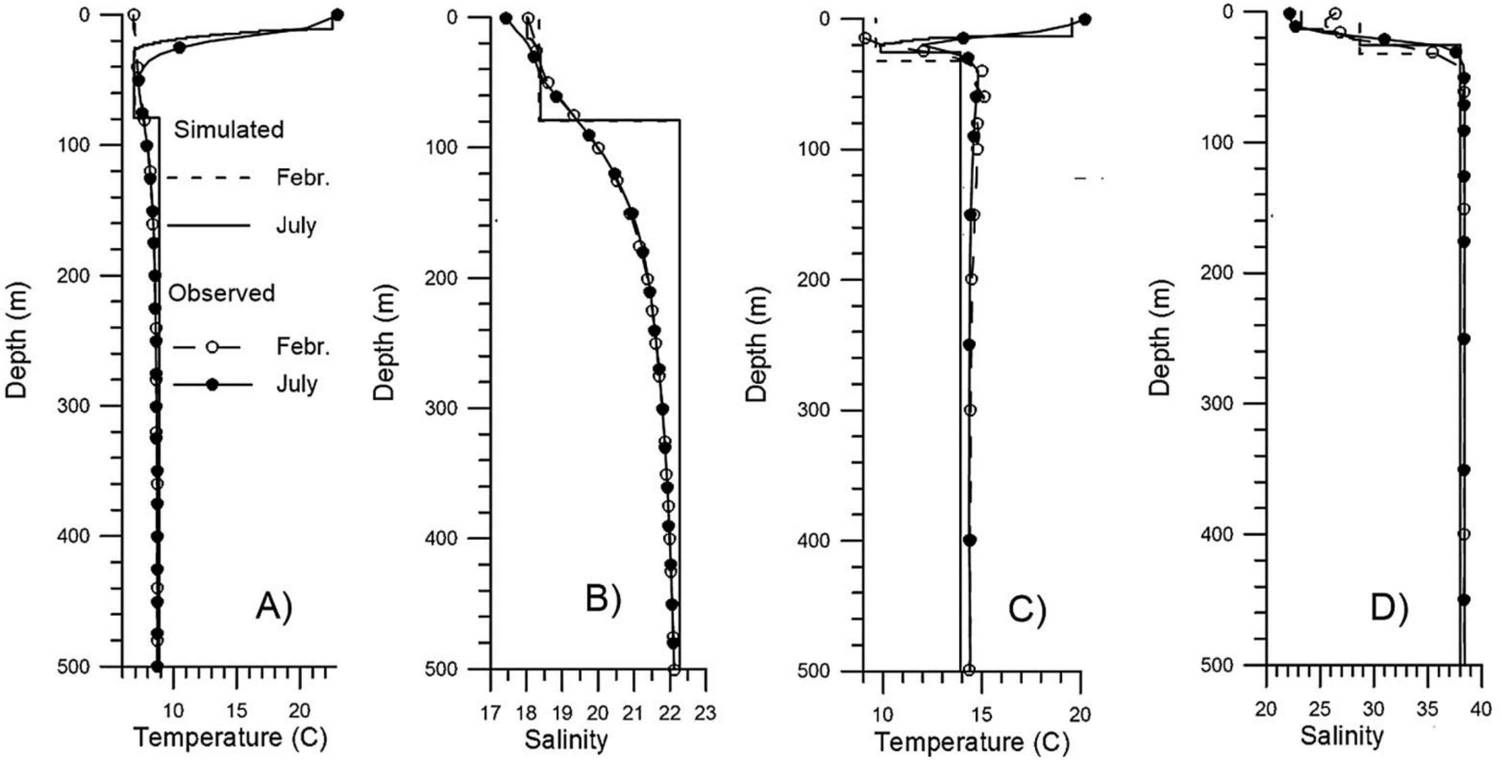
Comparison of ANN modelling with observations and hydrological model HYPE (SMHI)



Calculated variations of the total freshwater flux and level in the Black Sea, Marmara Sea and North Aegean vs. observations



Simulated *vs*. observed vertical temperature and salinity profiles in the Black Sea and the Marmara Sea



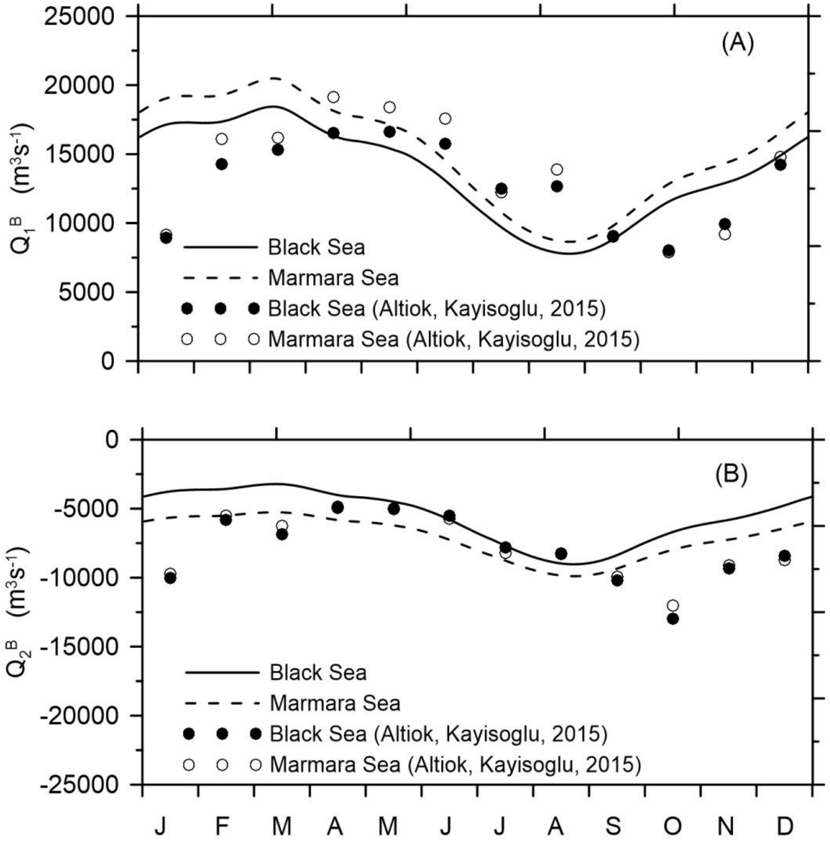
Black Sea

Marmara Sea

Turkish Straits model vs observations

Upper layer

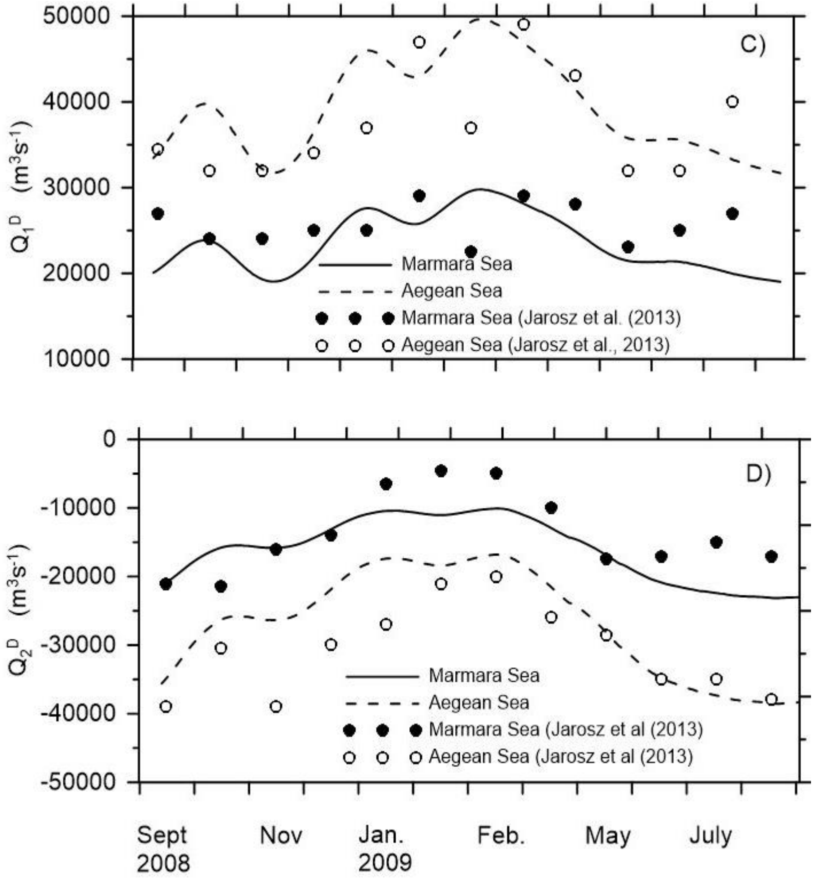
Bottom layer



Bosphorus

Upper layer

Bottom layer



Dardanelles

TRENDS OF THE BLACK SEA PROJECTIONS 2000-2100

Input parameter trends for Scenarios RCP4.5 та RCP8.5

Parameter	RCP4.5	RCP8.5	Unit
Air temperature over the Black Sea	+0.027	+0.042	°C/y
Air temperature over the Azov Sea	+0.030	+0.048	°C/y
Air temperature over the Marmara Sea	+0.026	+0.043	°C/y
Water temperature in the Aegean Sea	+0.0074	+0.013	°C/y
Salinity in the Aegean Sea	+0.00043	+0.00037	PSU/y
Fresh water budget in the Black Sea	-0.85	-0.99	$(km^3/y)/y$
Fresh water budget in the Azov Sea	0.25	-0.00018	$(km^3/y)/y$
Sea level in the Aegean Sea	+3.7	+0.49	mm/y

Black Sea elevation trends

Parameter	RCP 4.5	RCP8.5
Black Sea freshwater budget (км^3/y)/y	-0.85	-0.99
Black Sea elevation (mm/y)	+3.2	+4.2
Sea level difference Black - Aegean Seas (mm/y)	-0.6	-0.6
Thermohalosteric correction (mm/y)	+0.4	+0.4
Black Sea elevation with steric correction (mm/y)	+3.6	+4.6

Black and Azov Seas temperature and salinity trends

Parameter	RCP 4.5	RCP8.5
Air temperature over the Black Sea (°C/y)	+0.027	+0.042
Black Sea surface temperature (°C/y)	+0.027	+0.041
Black Sea surface salinity (PSU/y)	+0.017	+0.018
Azov Sea surface temperature (°C/y)	+0.030	+0.048
Azov Sea surface salinity (PSU/y)	+0.012	+0.022

Turkish Straits flux trends

Parameter	RCP 4.5	RCP8.5
Bosphorus upper layer transport (кm^3/y)/y	**-0.65**	**-0.75**
Bosphorus lower layer transport (кm^3/y)/y	**-0.19**	**-0.27**
Dardanelles upper layer transport (кm^3/y)/y	**-0.74**	**-0.87**
Dardanelles lower layer transport (кm^3/y)/y	**-0.11**	**-0.14**

Conclusions

RCM projections predict a reduction in runoff and an increase in evaporation resulting in decreased sea level difference between Black and Aegean Seas and decreased transport through TSS.

The effect of reducing river runoff and increasing evaporation is offset by rising water temperature in the upper layer of the sea, which will not lead to deep convection in the Black Sea and the appearance of hydrogen sulfide in the upper layers of the Black Sea.

The calculated changes in the physical characteristics of the Black and Azov seas can have a significant impact on the state of the ecosystems of these basins, coasts and coastal infrastructure.

A sea level rise of 0.36 and 0.46 m according to the RCP4.5 and RCP8.5 scenarios will lead to flooding in the lowland coast (for example, the Arabat Spit in Crimea) and intensification of coastal erosion.

Increasing the air temperature (by 3 and 4.8 °C) and SST of the Black Sea (by 2.7 and 4.1 °C) will worsen the ecosystems of the sea, increase the likelihood of algae blooms and deteriorate water quality in the coastal zone.

Even higher sea temperature rise (by 3 and 4.8 ^{o}C) results in corresponding environmental change in the shallow Azov Sea.