PEEX INAR+IMMSP online workshop

3D modeling of heat transfer and water quality in shallow waters

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Circulation model THREETOX

Governing equations

- System of Reynolds-averaged equations of continuity and horizontal momentum in Boussinesq and hydrostatic approximations
- Temperature and salinity transport equations
- Equation of state
- k-ε turbulence model equations

Maderich et al. (2008) Development and application of 3D numerical model THREETOX to the prediction of cooling water transport and mixing in the inland and coastal waters, *Hydrological Processes*, 22, pp. 1000-1013.

Circulation model THREETOX

Numerical setup

- The "staggered" Arakawa C-grid with horizontal curvilinear orthogonal coordinate system and vertical σ-system following the bottom topography
- Splitting on the 2D mode with small time step for fast barotropic long waves and 3D model with much larger time step for other processes
- Explicit numerical schemes are used in horizontal directions and implicit scheme – in vertical direction
- The advection of scalars is approximated by the high order total variation diminishing (TVD) scheme

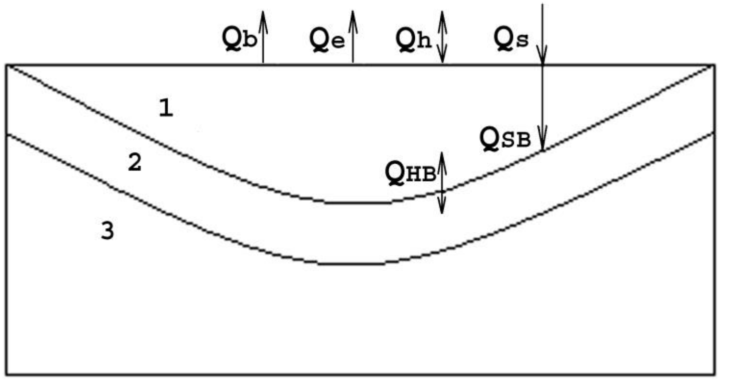
Heat fluxes

Q_S – Sun radiation flux (½ is absorbed in the surface layer, and ½ exponentially attenuate in the water layer)

Q_{SB} – Sun radiation flux at the bottom

Q_b – Long-wave thermal radiation flux (similar to black-body radiation)

Q_{HB} – Convection heat flux at the bottom that includes free convection and forced by near-bottom velocities convection



1 - water layer

2 – active bottom layer

3 – deep bottom layer

Formula describing these fluxes are standard (universal) for all applications

Heat exchange with bottom could be important for shallow water bodies

Evaporation and convection heat fluxes

Natural water bodies

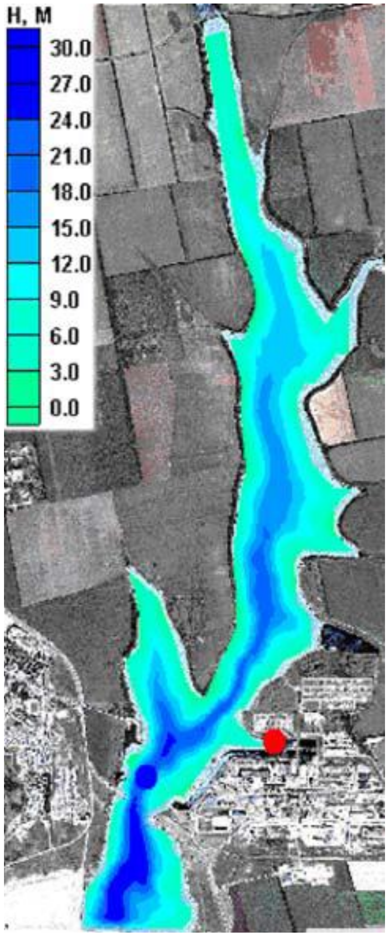
Blackadar (1979) parameterization

Cooling ponds

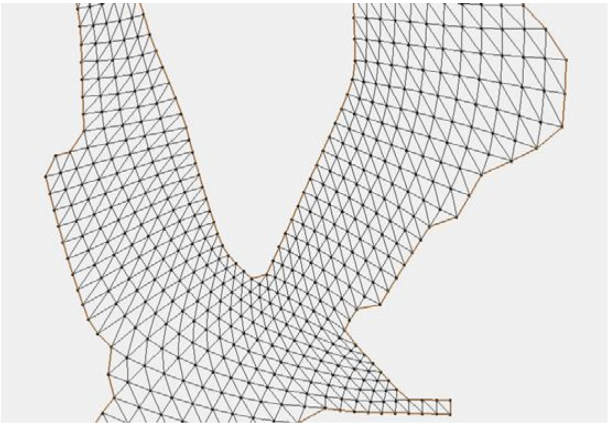
Rosati and Miyakoda (1988) formula

Intensive evaporation from the cooling pond forms special microclimate decreasing the heat losses (similar to Greenhouse effect)

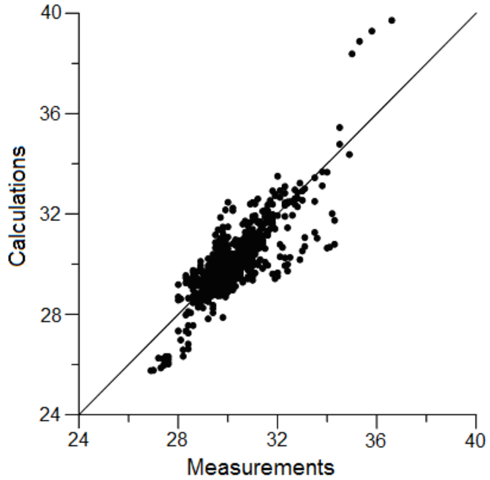
Increasing of cooling capacity of the Tashlyk cooling pond of the South-Ukrainian NPP



Bathymetry, inlet (blue) and outlet (red) positions

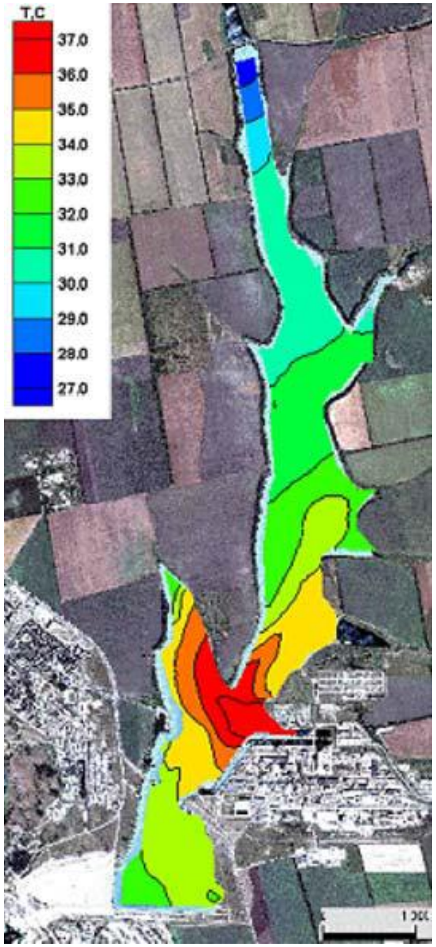


Part of the computational grid

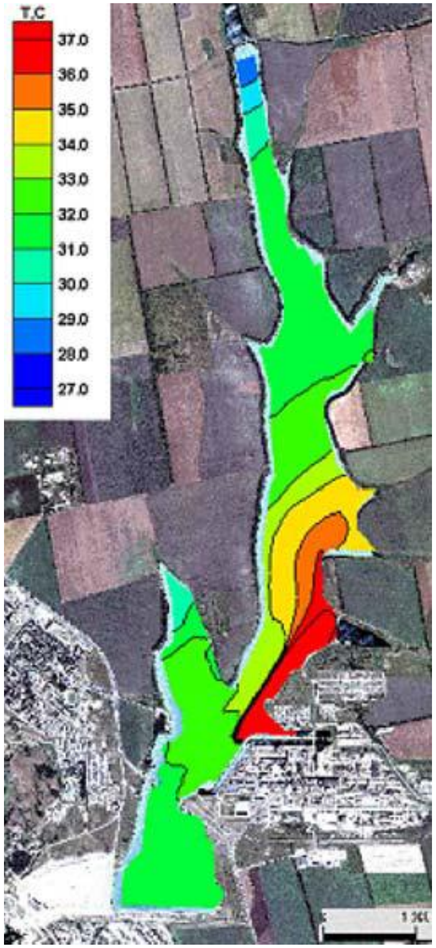


Validation for September 2007

Flow-directing dike



Surface temperature without dike



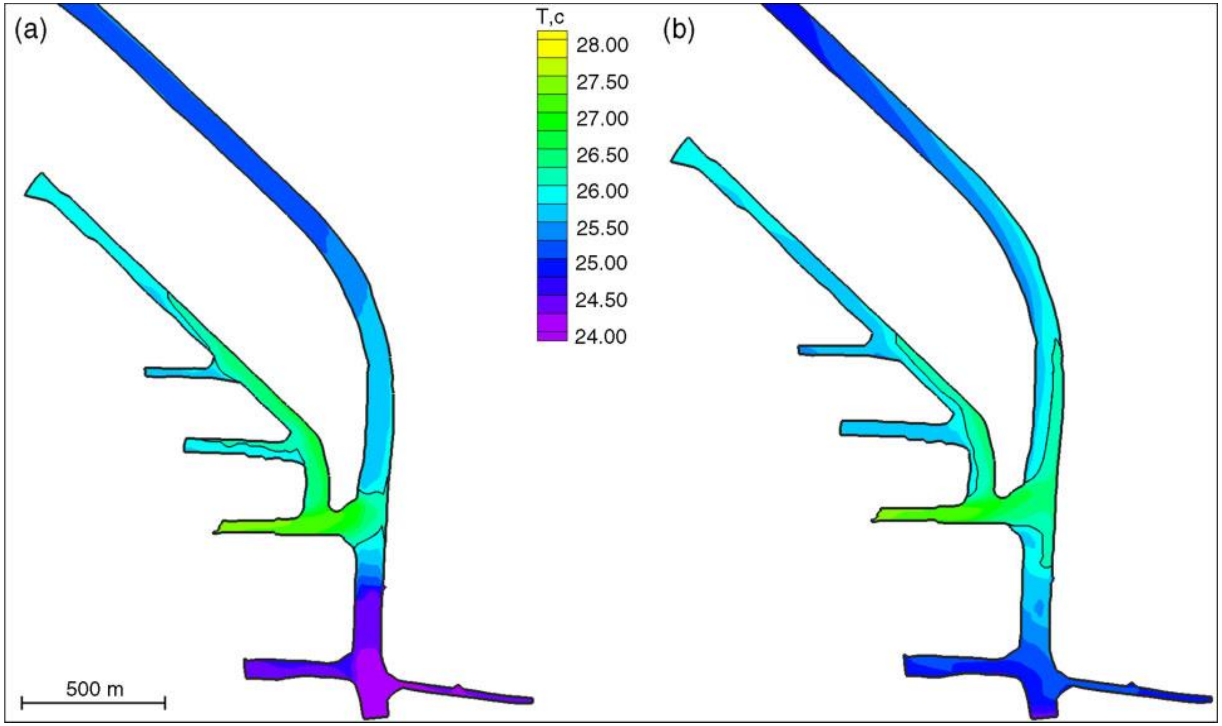
Surface temperature with dike

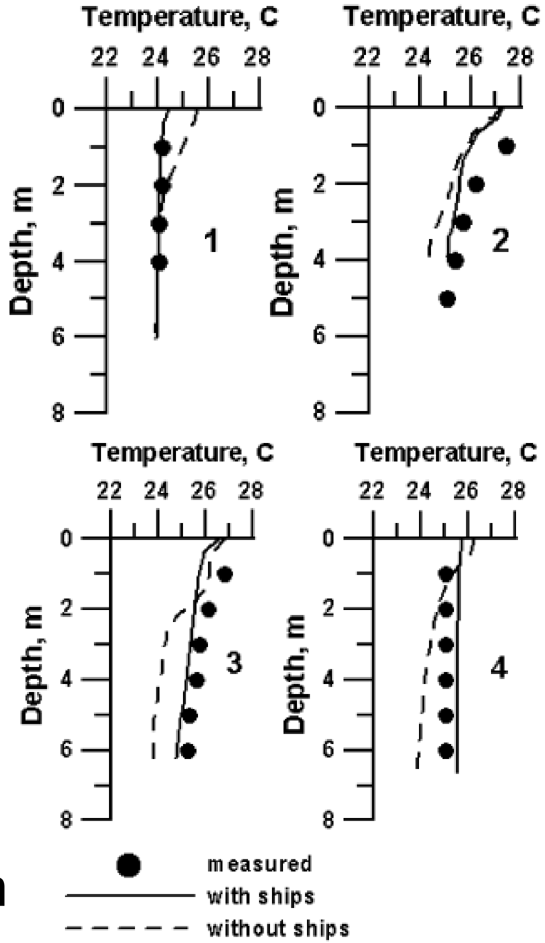
Construction of dike decreases T_{in} by 2°C similarly to construction of spray ponds

Construction of dike and spray ponds decreases T_{in} by 6°C due to flow of hot water directly to inlet of spray ponds

Heat transfer in the Amsterdam-Rhine Canal with intensive movement of ships

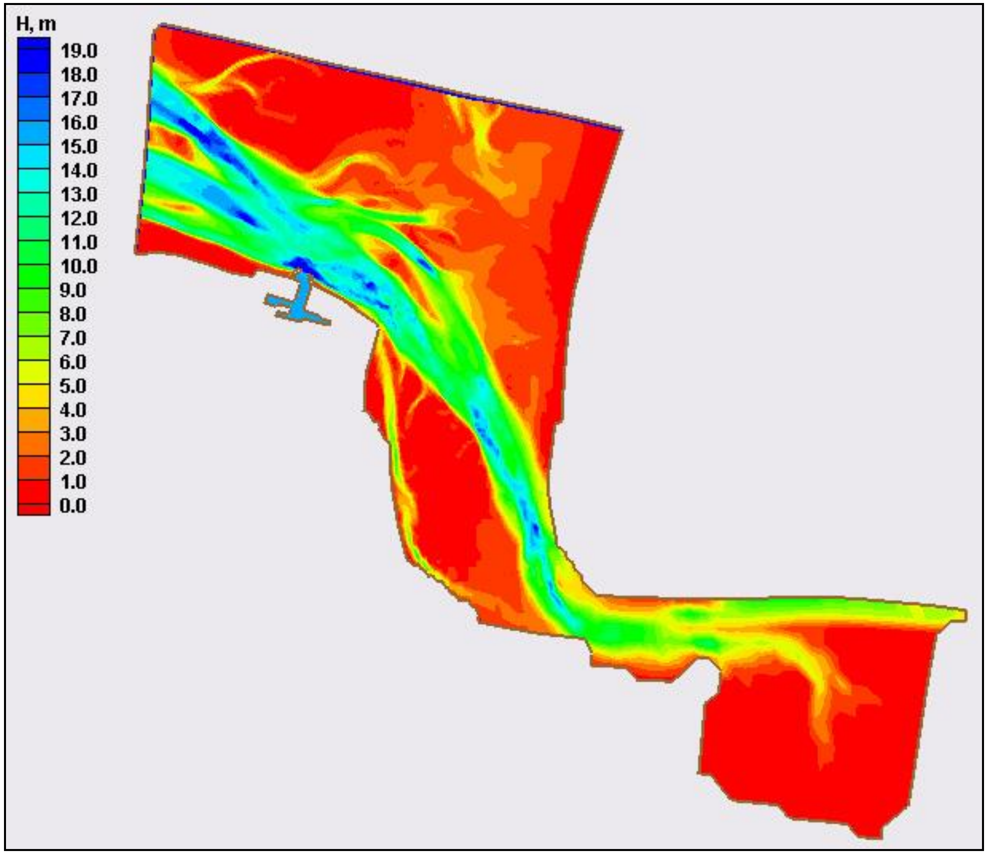
Movement of ships was parameterized by increasing of the vertical turbulent diffusion coefficient





With (left) and without (right) shipping parameterization

Ems-Dollard Estuary (Netherlands/Germany)

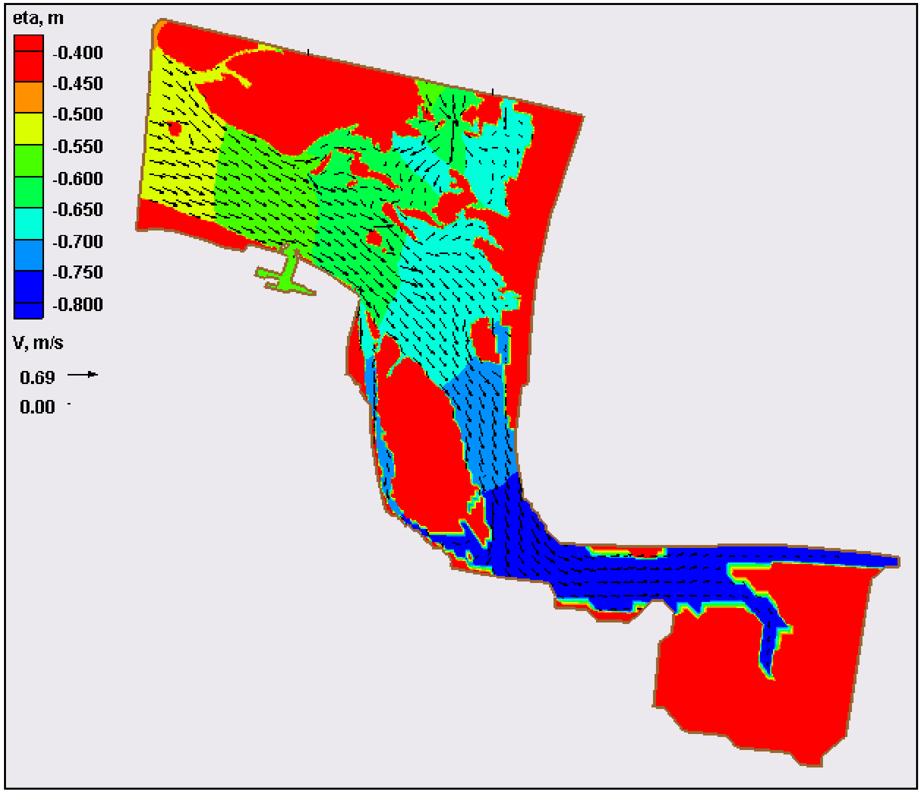


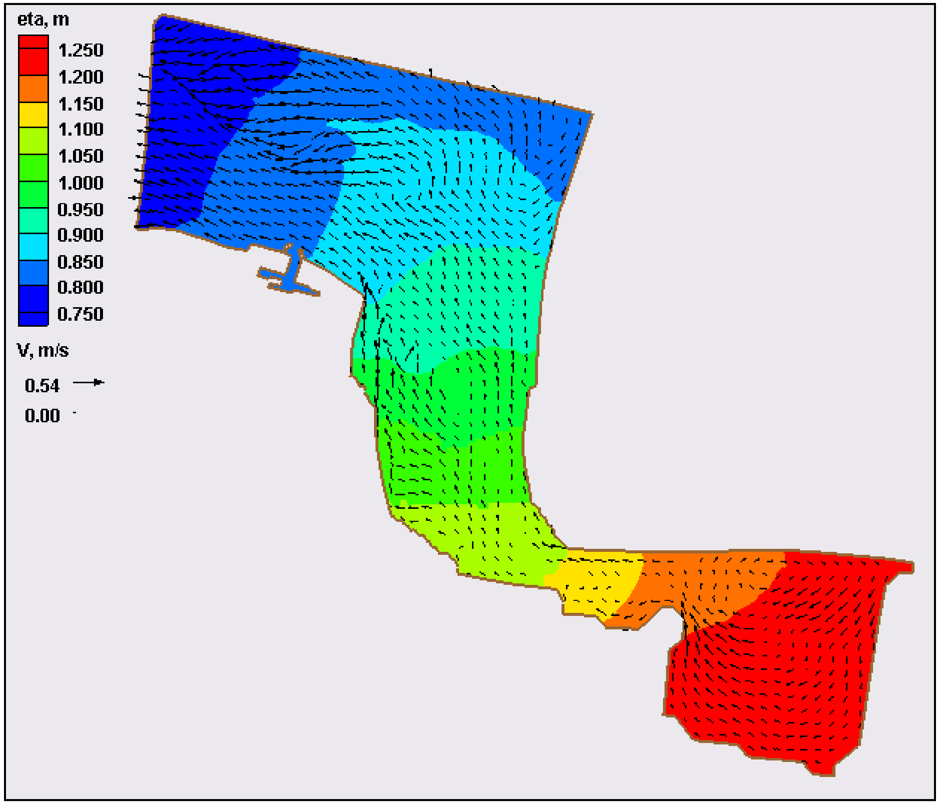
Bathymetry

Drying and wetting

Due to high tides in the North Sea, the large shallow areas in the Ems-Dollard Estuary are drying at low water level and wetting at high water level

Calculated flows at different tide

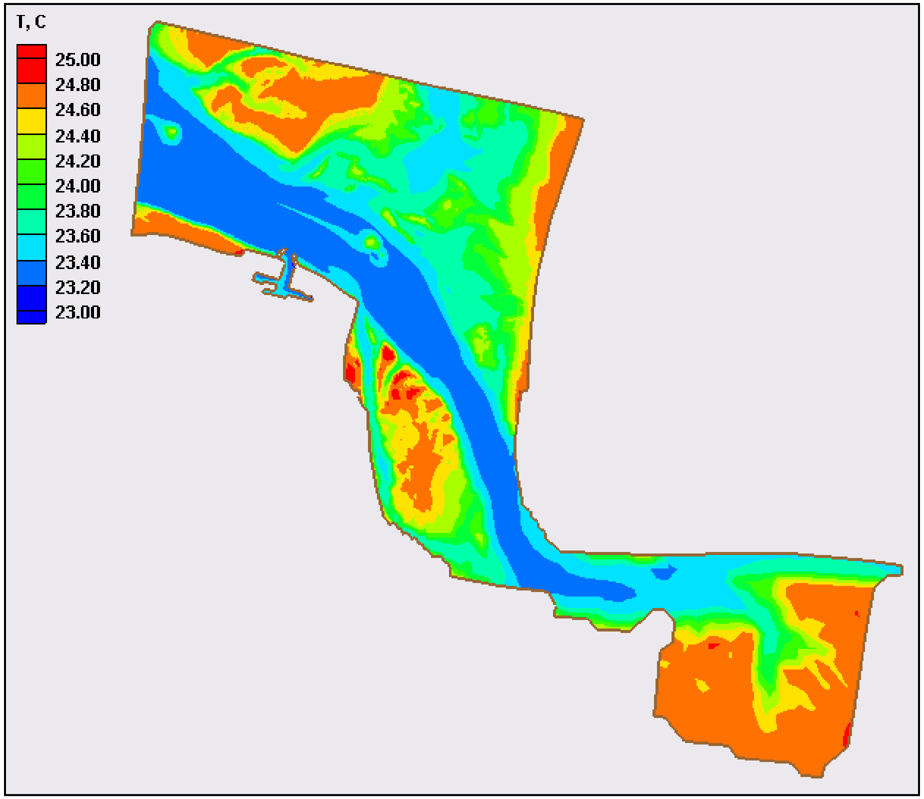




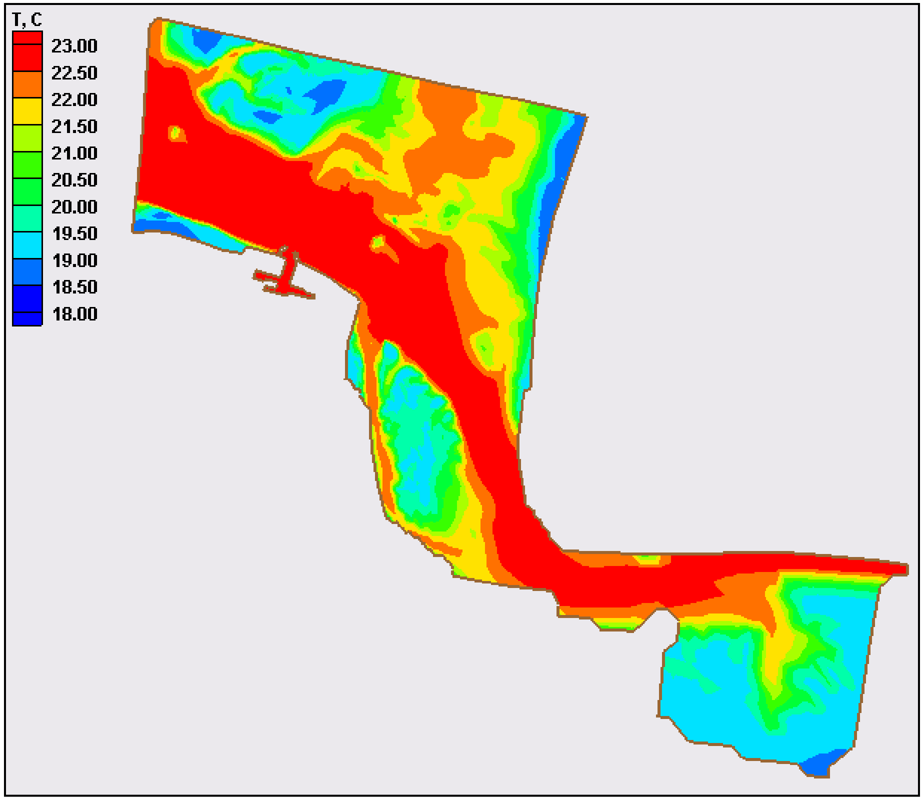
Velocities at low tide

Velocities at high tide

Calculated surface temperature at low tide

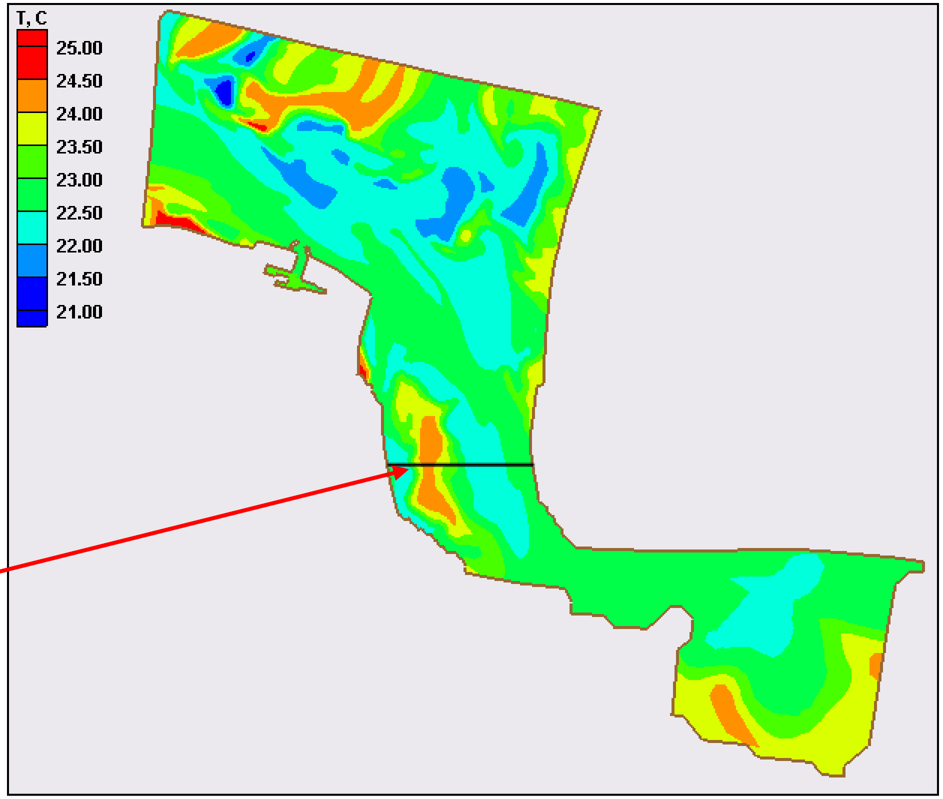


Day time



Night time

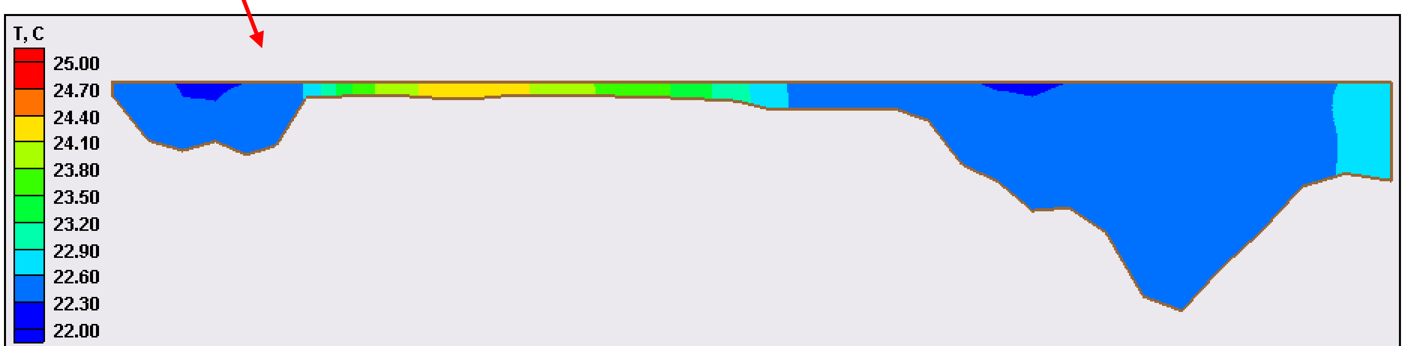
Surface temperature after flooding in daytime



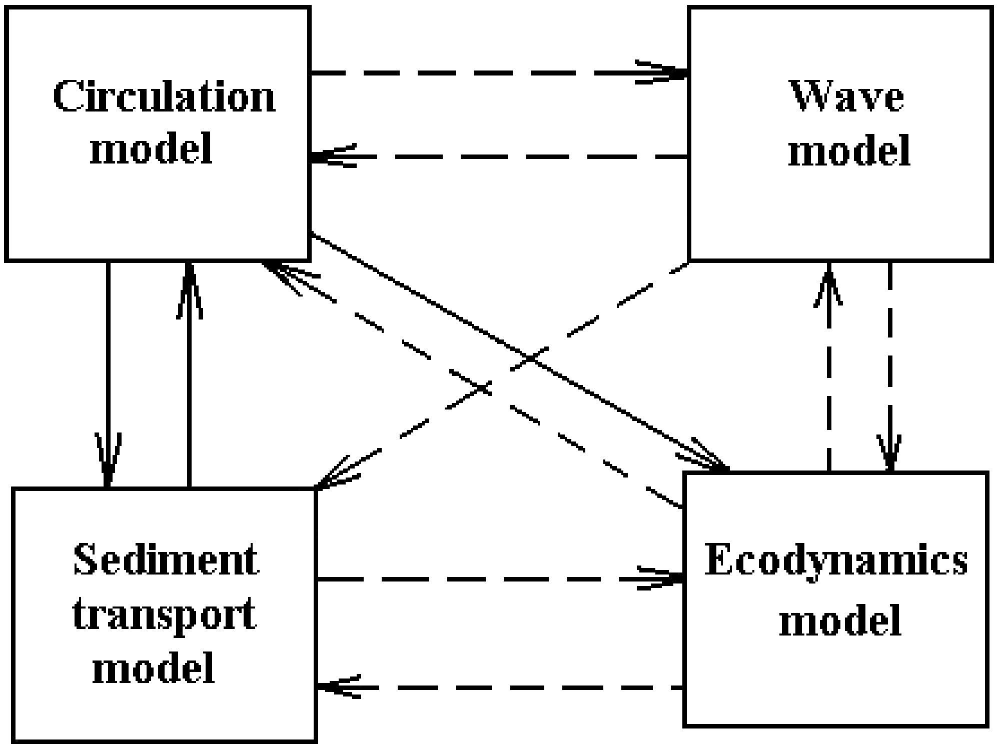
Heat exchange with bottom is important for heat budget of tidal flats

After flooding heated bottom layer returns heat to the water

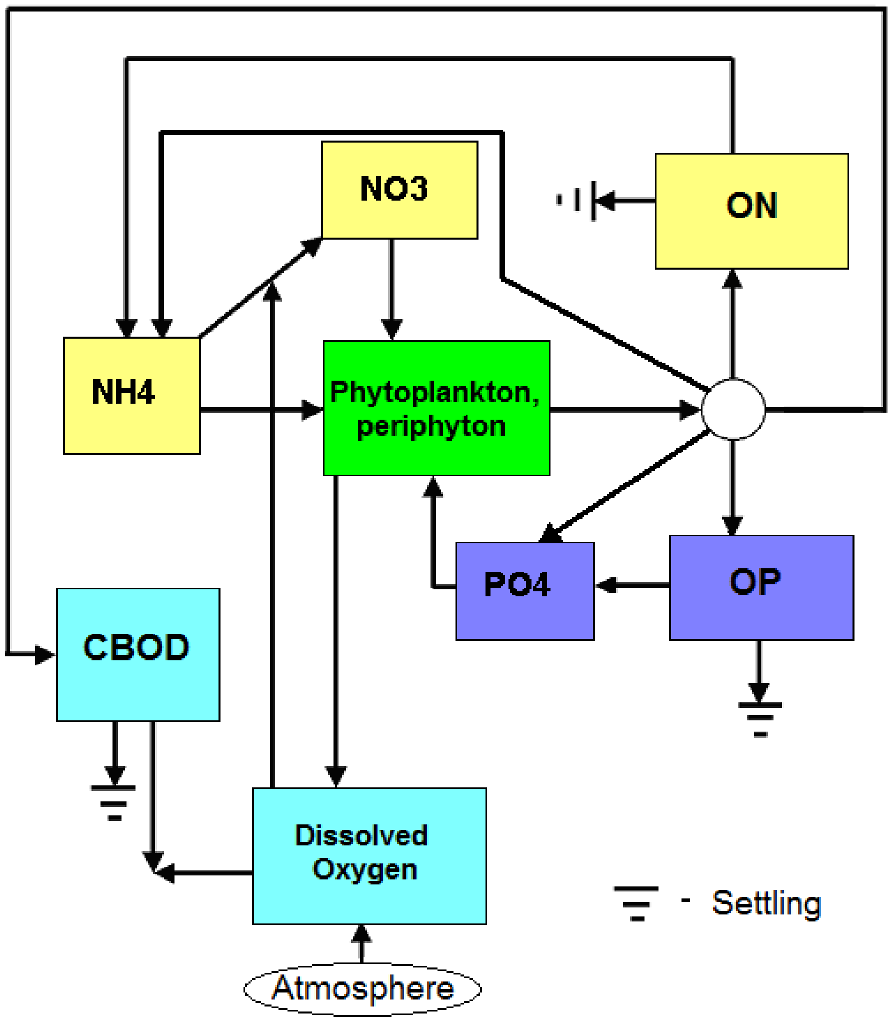
cross-section



Modeling system for shallow waters



The ecodynamics model



The transport of components of model is described by equations

$$\frac{\partial C_i}{\partial t} + U\frac{\partial C_i}{\partial x} + V\frac{\partial C_i}{\partial y} + \left(W - W_{gi}\right)\frac{\partial C_i}{\partial z} =$$

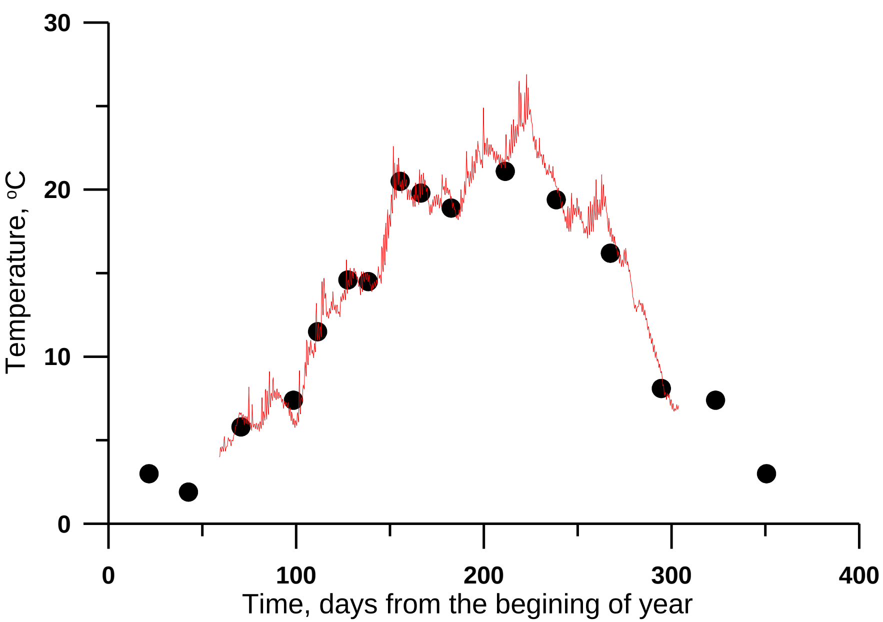
$$\frac{\partial}{\partial z}\left(v_t'\frac{\partial C_i}{\partial z}\right) + \frac{\partial}{\partial x}\left(A_h\frac{\partial C_i}{\partial x}\right) + \frac{\partial}{\partial y}\left(A_h\frac{\partial C_i}{\partial y}\right) + S_i$$

Dynamics of periphyton in bottom layer

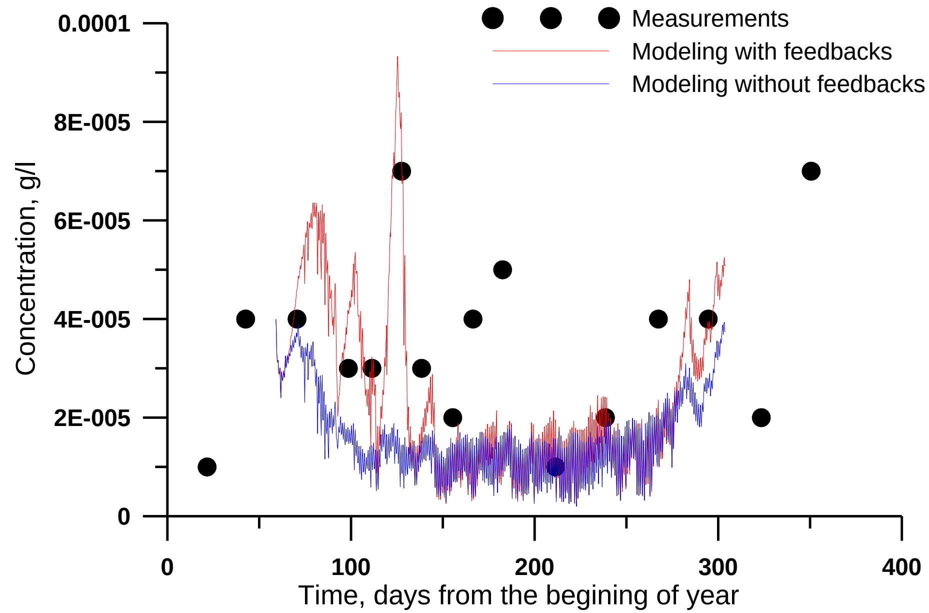
$$\frac{\partial C_P}{\partial t} = S_P$$

S_i – source terms responsible for transformation processes (based on WASP model)

Application to the Lake Markermeer (Netherlands)

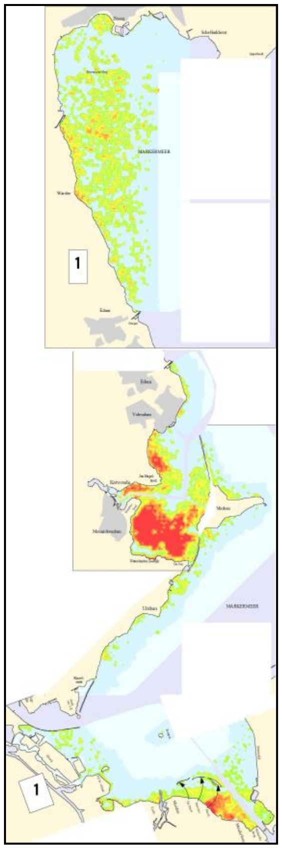


Surface temperature

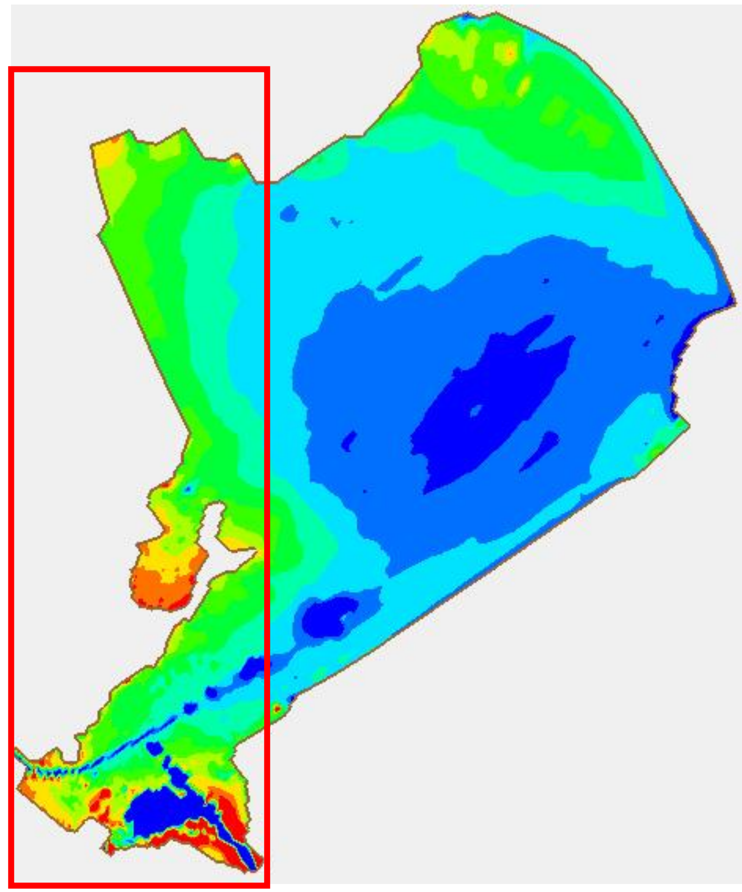


Concentration of ammonium nitrogen

Calculated and measured concentration of bottom vegetation



Measurements



Calculations

Conclusions

- Correct parameterization of heat fluxes in the system atmosphere – water – bottom is crucial for correct simulation of temperature changes in water bodies
- Temperature of water affect the ecodynamics parameters like eutrophication, level of dissolved oxygen and density of bottom vegetation
- The problem of overheating of natural waters or artificial cooling ponds could become relevant in the case of global warming