Modeling spatio-temporal variations of dissolved organic matter in the Gulf of Finland

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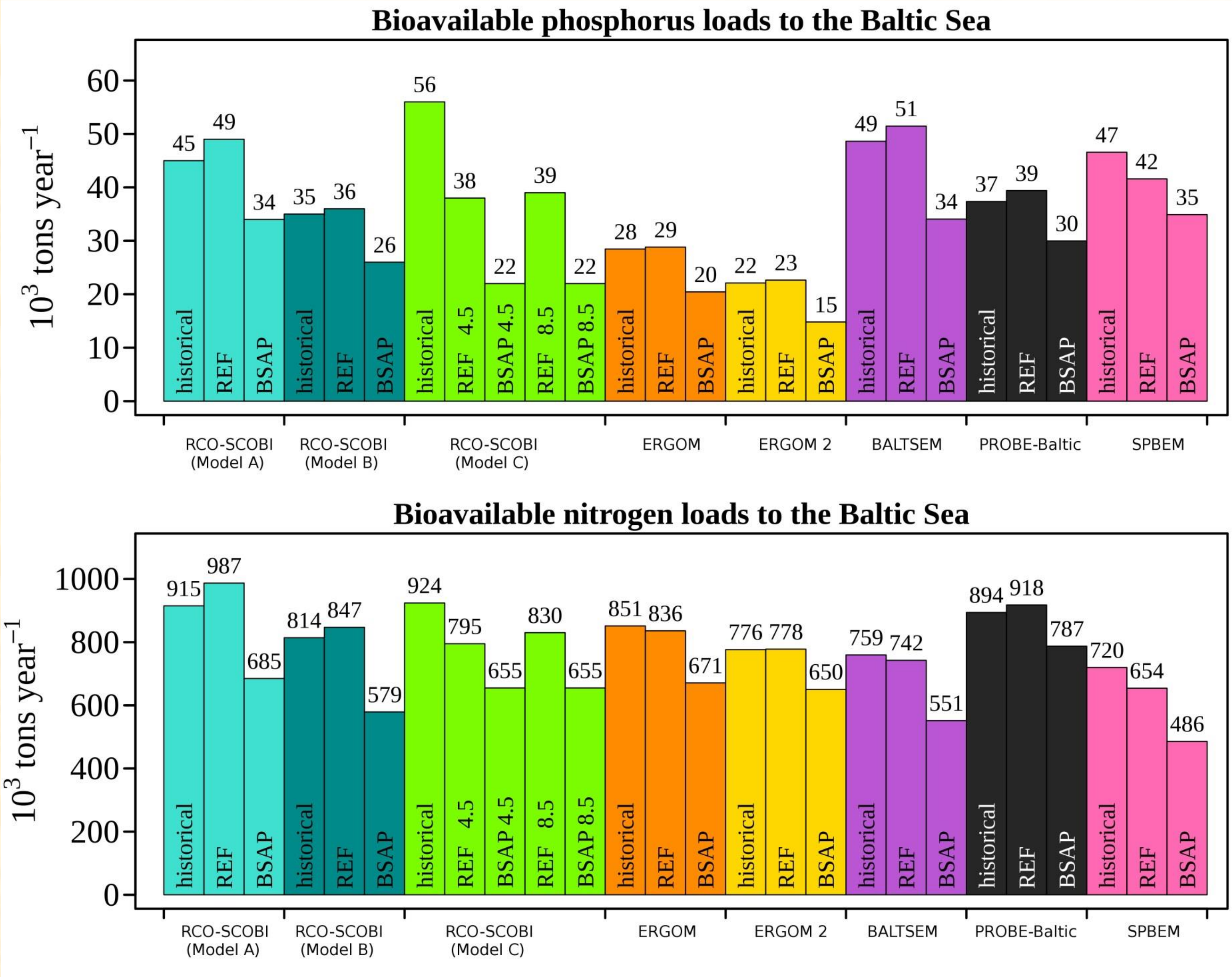


H. E. M. Meier et al (21 co-authors including Isaev, Ryabchenko & Savchuk). Assessment of eutrophication abatement scenarios for the Baltic Sea by multi-model ensemble simulations (in print)

The objective

Evaluation of the necessity of explicit description of dissolved organic nutrients in the Baltic Sea eutrophication models

The object

Spatial and temporal variations dissolved organic nutrients in the Gulf of Finland

The tool

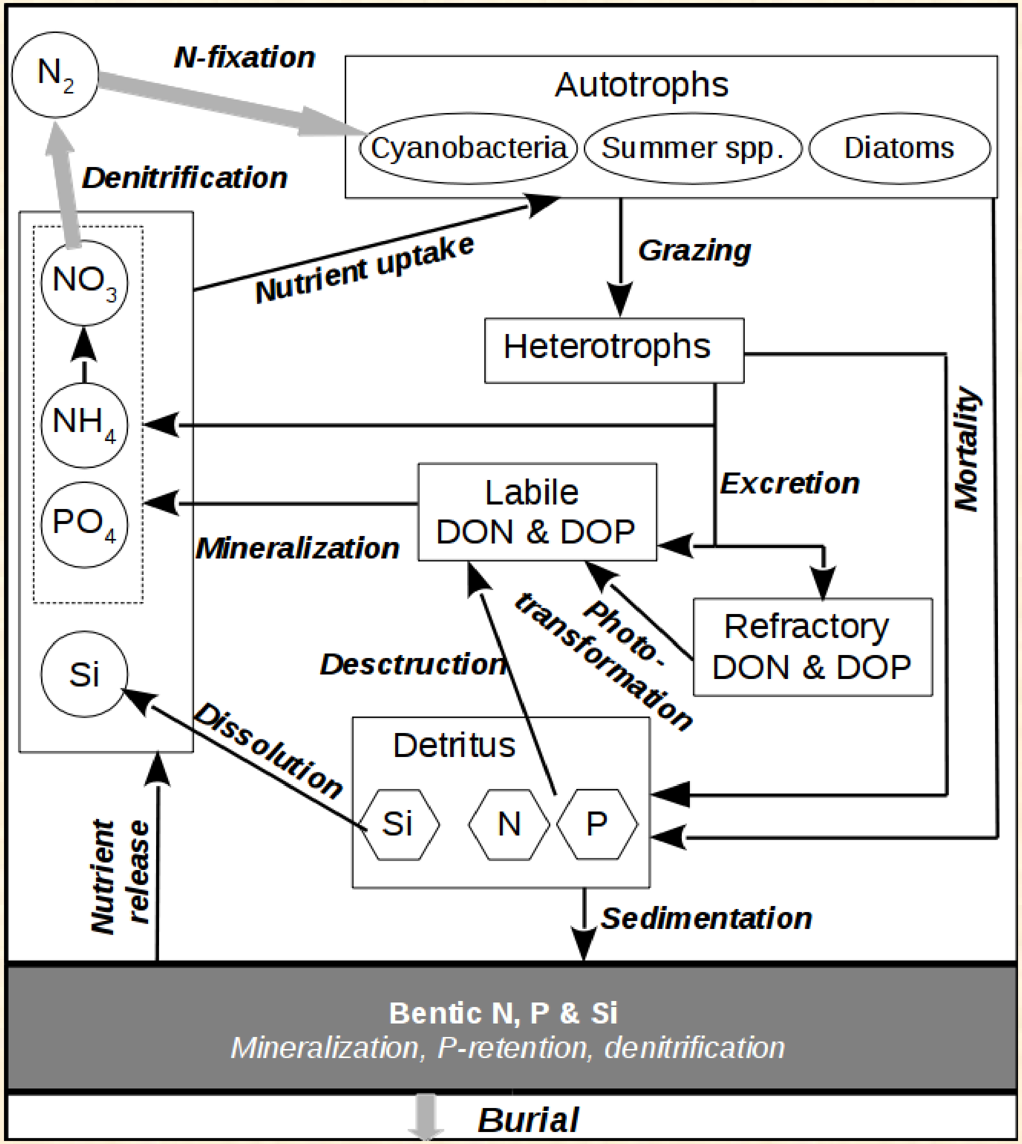
New 3D biogeochemical model SPBEM-2

Hydrodynamic module of St. Petersburg Baltic eutrophication model (SPBEM-2)

- The general circulation model of the Massachusetts Institute of Technology (MITgcm) in the hydrostatic approximation [open source]
- The vertical turbulent exchange is parameterized by the TKE closure scheme *[Gaspar, P., Gregoris, Y., Lefevre, J.-M. (1990). A simple eddy kinetic energy model for simulations of the oceanic vertical mixing: Tests at station Papa and long-term upper ocean study site // Journal of Geophysical Research, 95-C9. P. 179-193]*
- The sea ice dynamics in MITgcm is based on a model with viscous-plastic rheology *[Modeling a Variable Thickness Sea-Ice Cover, Hibler, Monthly Weather Review, 1980]*, *[Zhang J., and Hibler W.D., III. On an efficient numerical method for modeling sea ice dynamics // J. Geophys. Res. 1997.102(C4) P. 8691–8702.]*
- z-coordinate in vertical dimension

Biogeochemical module

based on BALTSEM (Savchuk, 2002; Savchuk et al., 2012; Gustafsson et al., 2013, 2017)

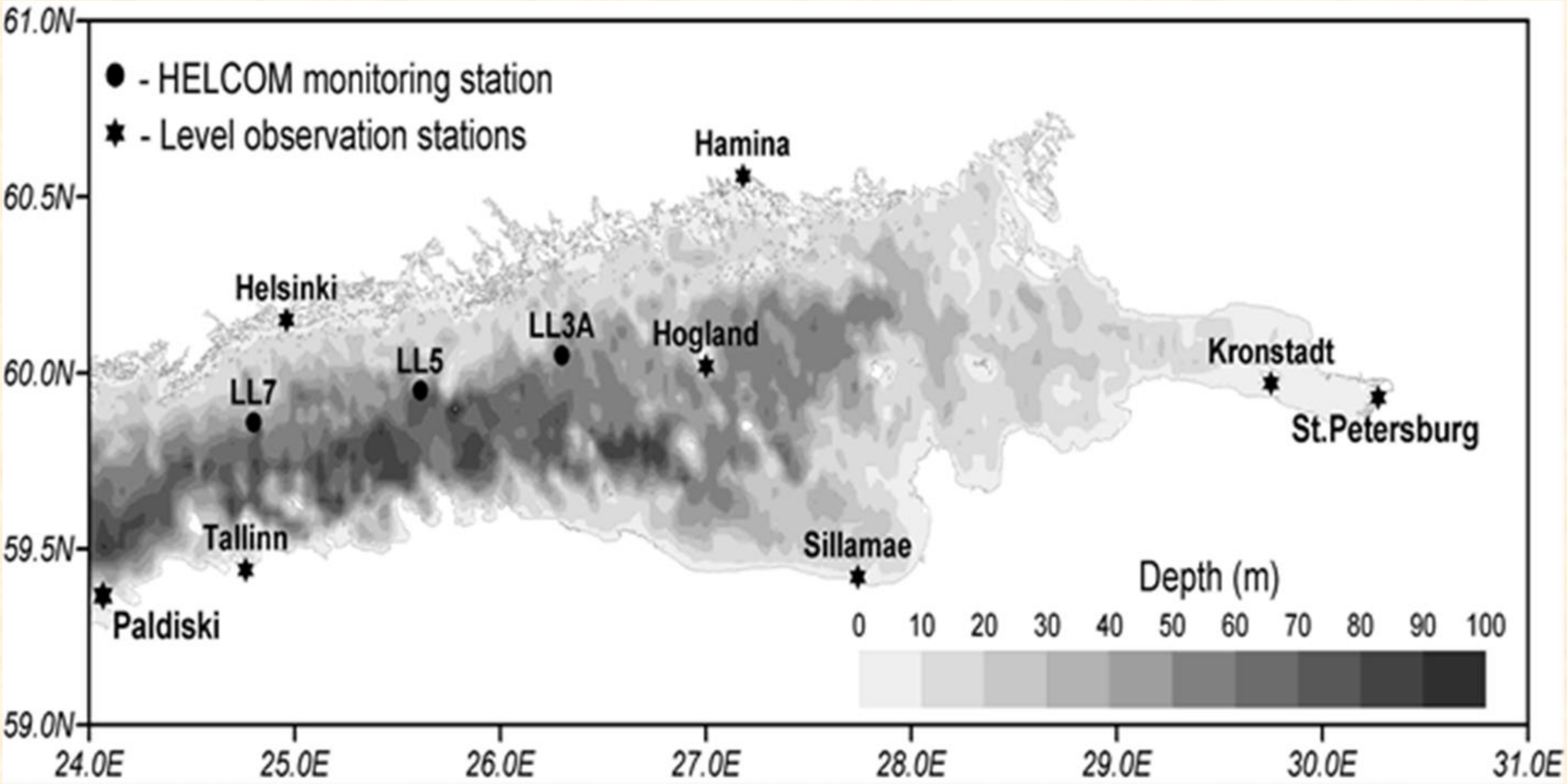


The module describes nutrient cycling in the coupled pelagic and sediment sub-systems.

State variables: 16 pelagic (zooplankton, diatoms, cyanobacteria, flagellates, nitrogen, phosphorus and silica detritus, ammonium, nitrite + nitrate, phosphate, labile dissolved organic phosphorus and nitrogen, refractory dissolved organic phosphorus and nitrogen, silicate and dissolved oxygen) and 3 sediment (benthic nitrogen, phosphorus and silicon).

Main processes are shown as generalized biogeochemical fluxes driving nutrient cycles in the model.

Simulation domain



- horizontal resolution of the spherical grid is about 2 NM along both meridian and parallel
- vertical resolution is 3 m from surface to bottom

Data sources

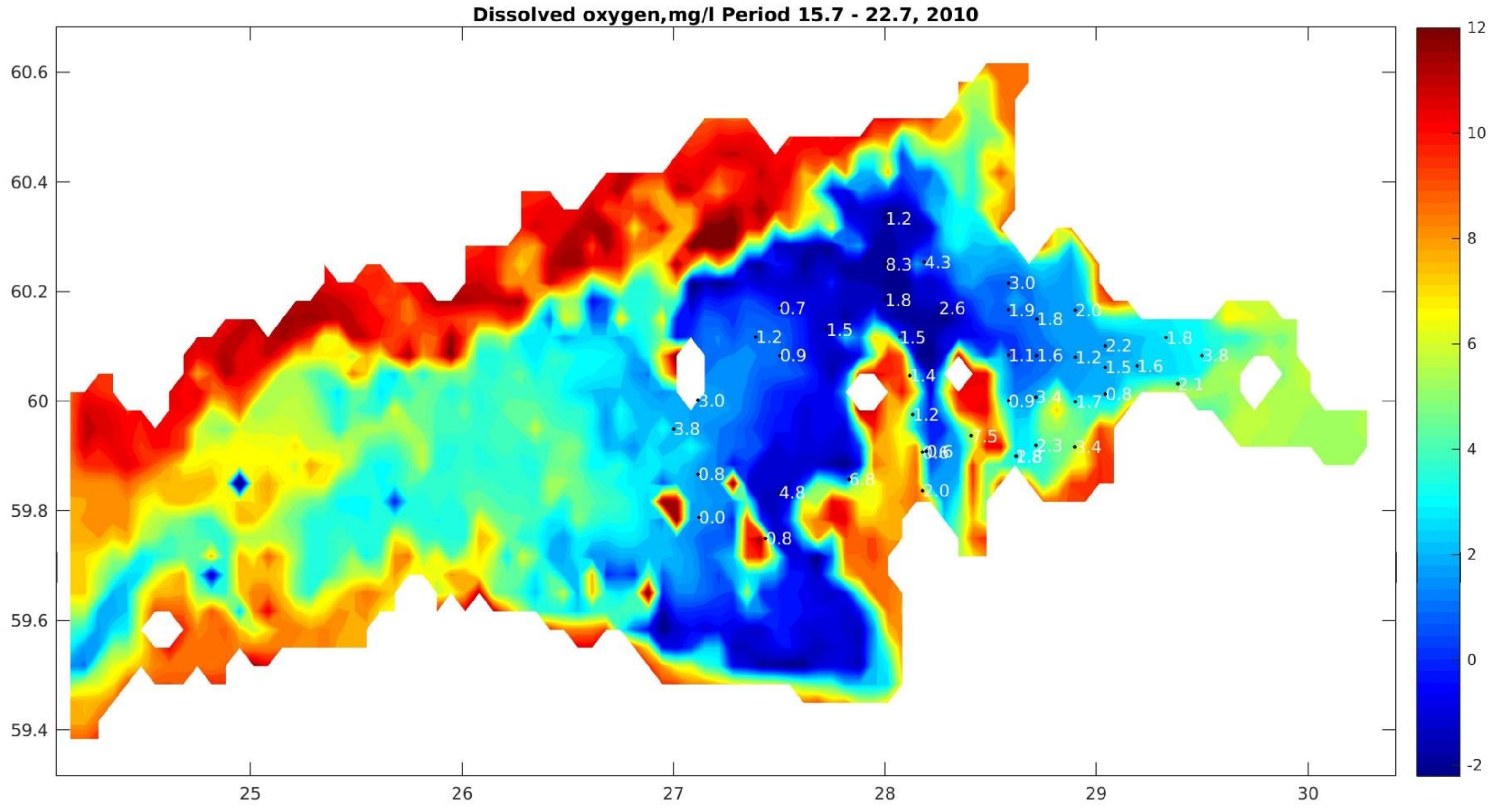
- Sea surface level (http://marine.copernicus.eu);
- Atmosphere forcing (ERA-Interim reanalysis fields https://www.ecmwf.int);
- Marine observations (Baltic Environmental Database http://nest.su.se/bed; (The Year of the Gulf of Finland 2014 database);
- Nutrient inputs (Updated Fifth Baltic Sea Pollution Load Compilation. BSEP 145, 2015)

Initial and boundary conditions

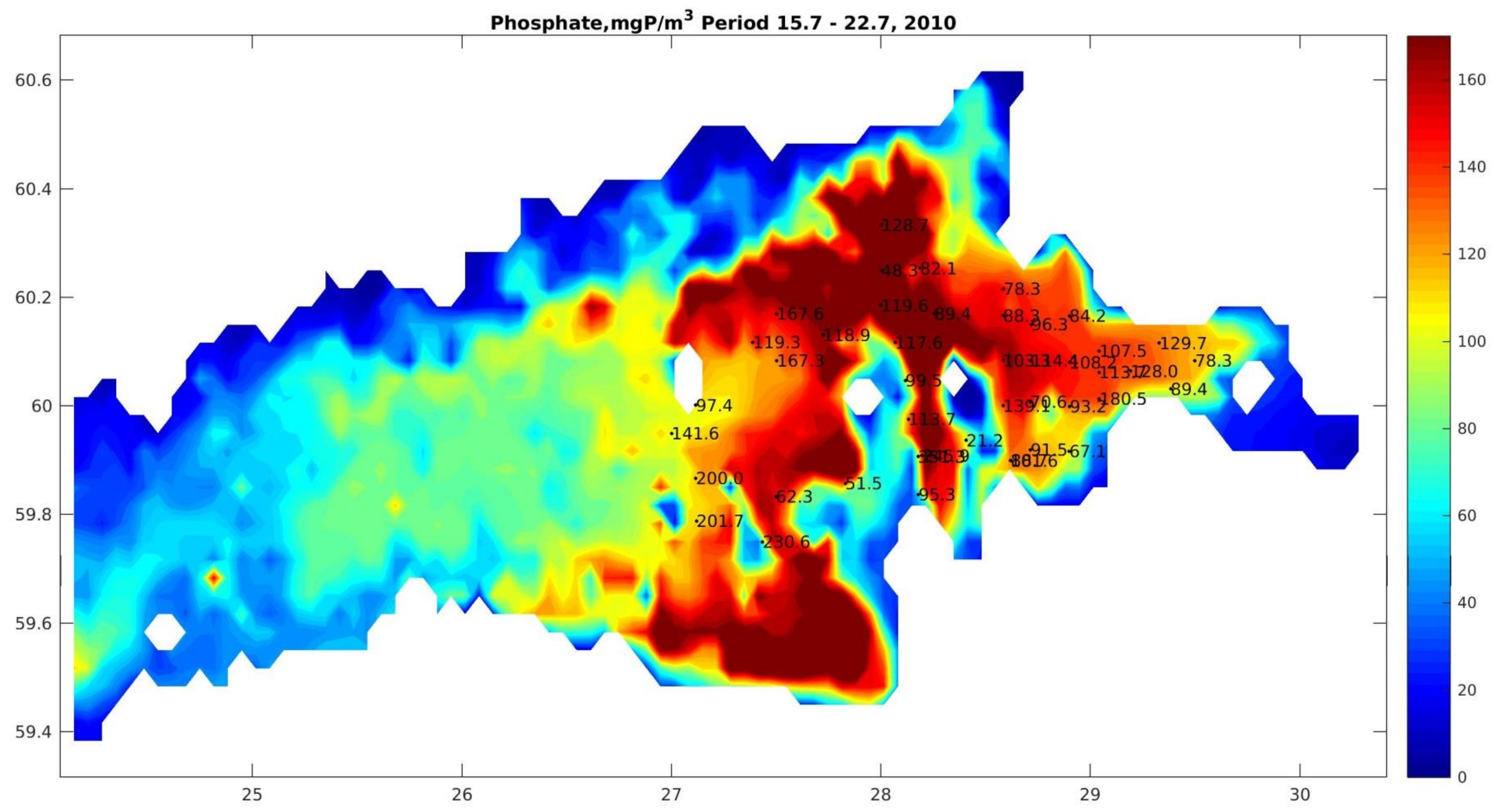
- The sea level height and currents velocity were set equal to zero;
- The initial distributions of pelagic variables were constructed by interpolation of averaged field observations from winter months of 2002 – 2012 into grid cells;
- Plankton and detritus concentrations were set very small;
- Distributions of benthic variables were picked up from the BALTSEM simulations model;
- Dissolved organic nitrogen and phosphorus were calculated as a difference between total amounts and their inorganic components;
- At the liquid boundary time-series of variables for 2009-2014 were reconstructed from observations in the adjacent strip; the hourly sea level values were taken from observations at Paldiski station

Period of simulations – 2009 – 2014.

Spatial distribution of bottom dissolved oxygen (15-22 July, 2010 year)



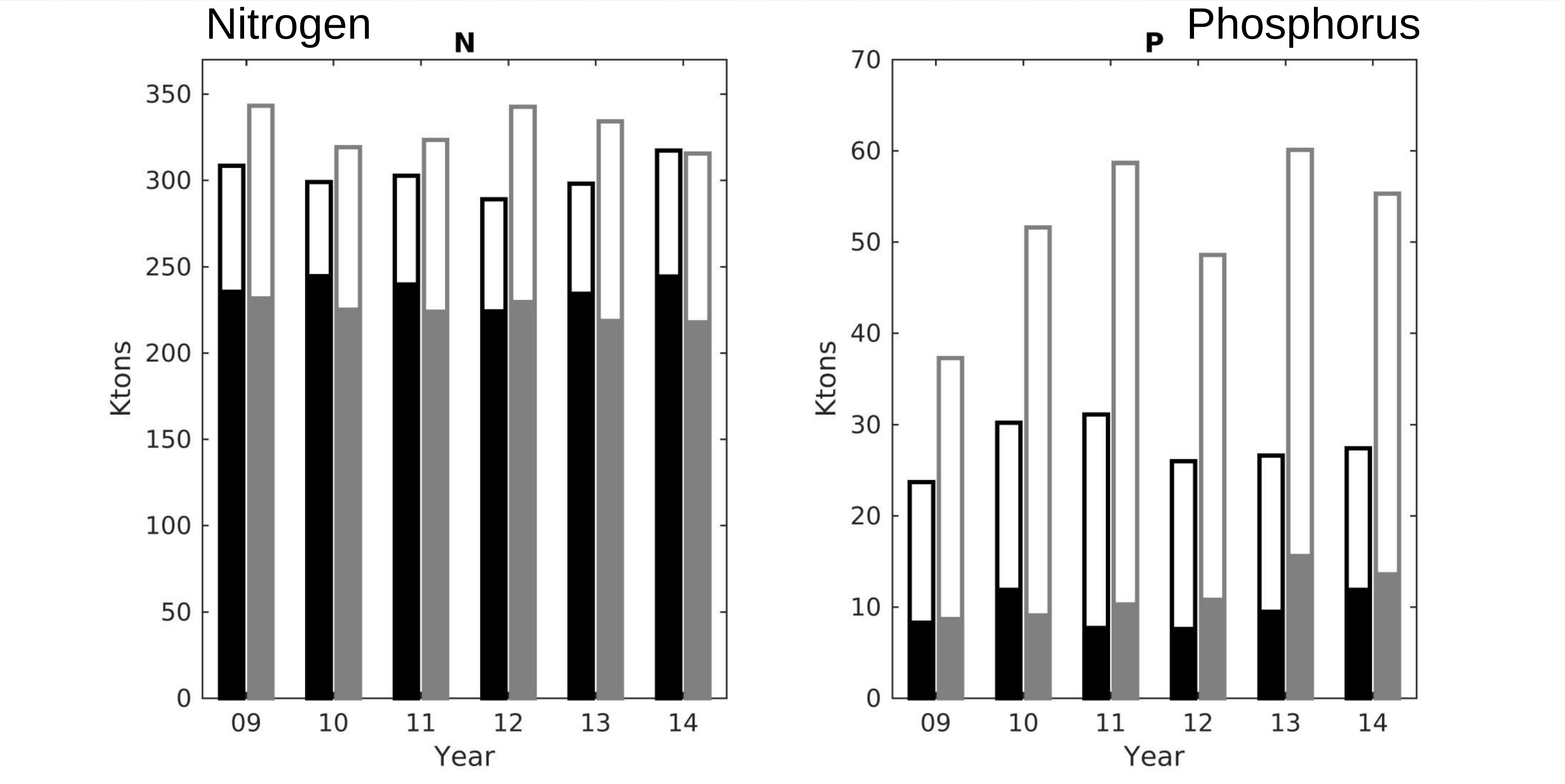
Spatial distribution of bottom phosphates (15-22 July, 2010 year)



Model-data comparison for the entire surface layer during the whole simulated period (2009-2014)

	Mean		Std		CF	R	Number of pairs
	Model	Observed	Model	Observed	Dimensionless		
Temperature, °C	9.27	11.09	6.07	6.84	**0.27**	**0.97**	2656
Salinity, g kg^{-1}	4.26	4.75	1.57	1.79	**0.26**	**0.92**	2656
NO_{2+3}, mg N m^{-3}	32	30	57	60	**0.02**	**0.66**	2656
Total N, mg N m^{-3}	359	381	77	127	**0.17**	**0.35**	1571
Phosphate, mg P m^{-3}	9.0	7.8	11.7	8.2	**0.14**	**0.70**	2656
Total P, mg P m^{-3}	31	27	15	12	**0.34**	**0.41**	1509
Oxygen, mg O_2 m^{-3}	10.2	9.7	3.8	3.5	**0.14**	**0.92**	2656

Inter-annual variations of annually averaged integral pools of simulated and observed organic and inorganic fractions of nitrogen and phosphorus.



Grey – simulated data
Black – observed data

Filled – organic fraction
Open – inorganic fraction

Annual flows and fluxes of phosphorus, tons year^{-1}

Year	Nutrient uptake P (Vp)	Excretion of DIP	Excretion of LDOP	Mineralization	Out from sediments	Sedimentation	Inner processes DOP (Qi)	Loads + open boundary DOP (Qo)	Qo/Qi %	Qo/Vp %
2009	63451	28375	6656	20344	27582	25109	9800	7946	81	13
2010	68839	37417	8777	17914	31919	19951	11663	6453	55	9
2011	100674	61425	14408	25274	25638	22891	18079	7792	43	8
2012	71617	38516	9035	20695	18207	21802	12106	13482	111	19
2013	65931	34133	8006	26220	19771	20194	10968	12233	112	19
2014	73111	39159	9185	21435	17554	21008	12152	6322	52	9

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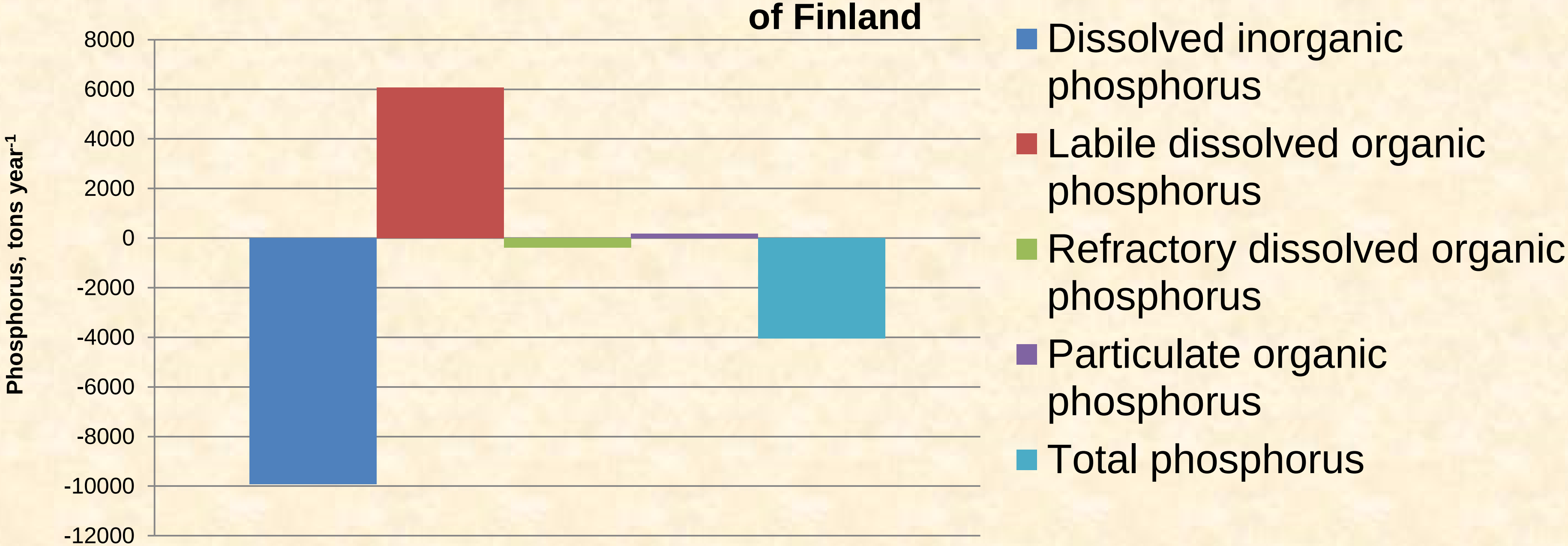
Average annual components of phosphorus pelagic budget in the Gulf of Finland

Flows of organic and inorganic phosphorus at the liquid boundary in Gulf of Finland



Conclusions

- Phosphorus is exported from the Gulf of Finland as phosphate, while it is imported as dissolved organic phosphorus;
- Amount of dissolved organic phosphorus entering the water area of the Gulf of Finland due to the inflow with river flow and exchange through the open border are comparable with the amount formed inside the water body;
- The contribution of dissolved organic phosphorus to the formation of primary production varies from 10 to 20%;
- It seems that accounting for dissolved organic matter in the modelling of the Baltic Sea eutrophication is really necessary for both:
  - reliable prescription of the external inputs and their possible changes

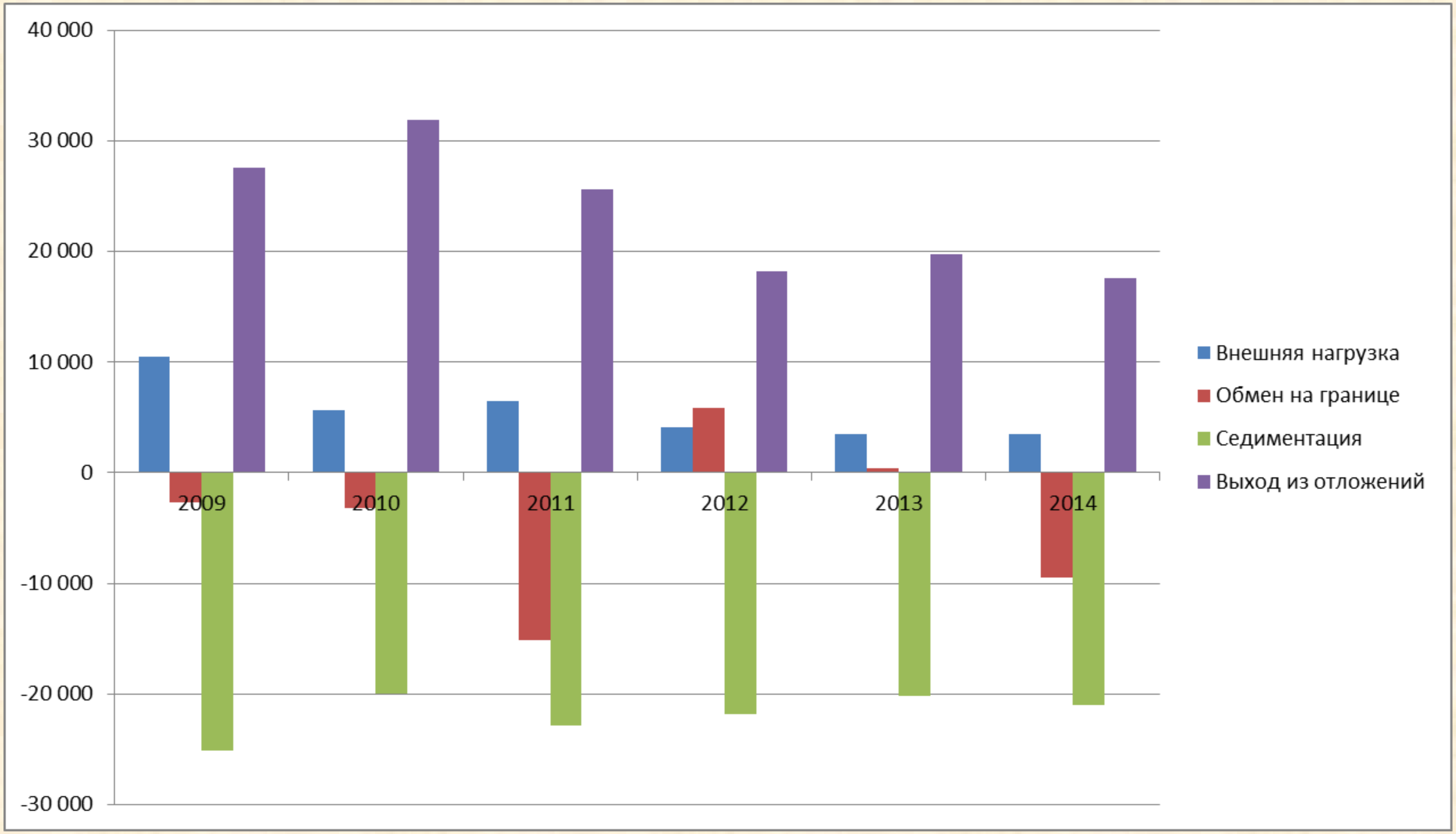
  and

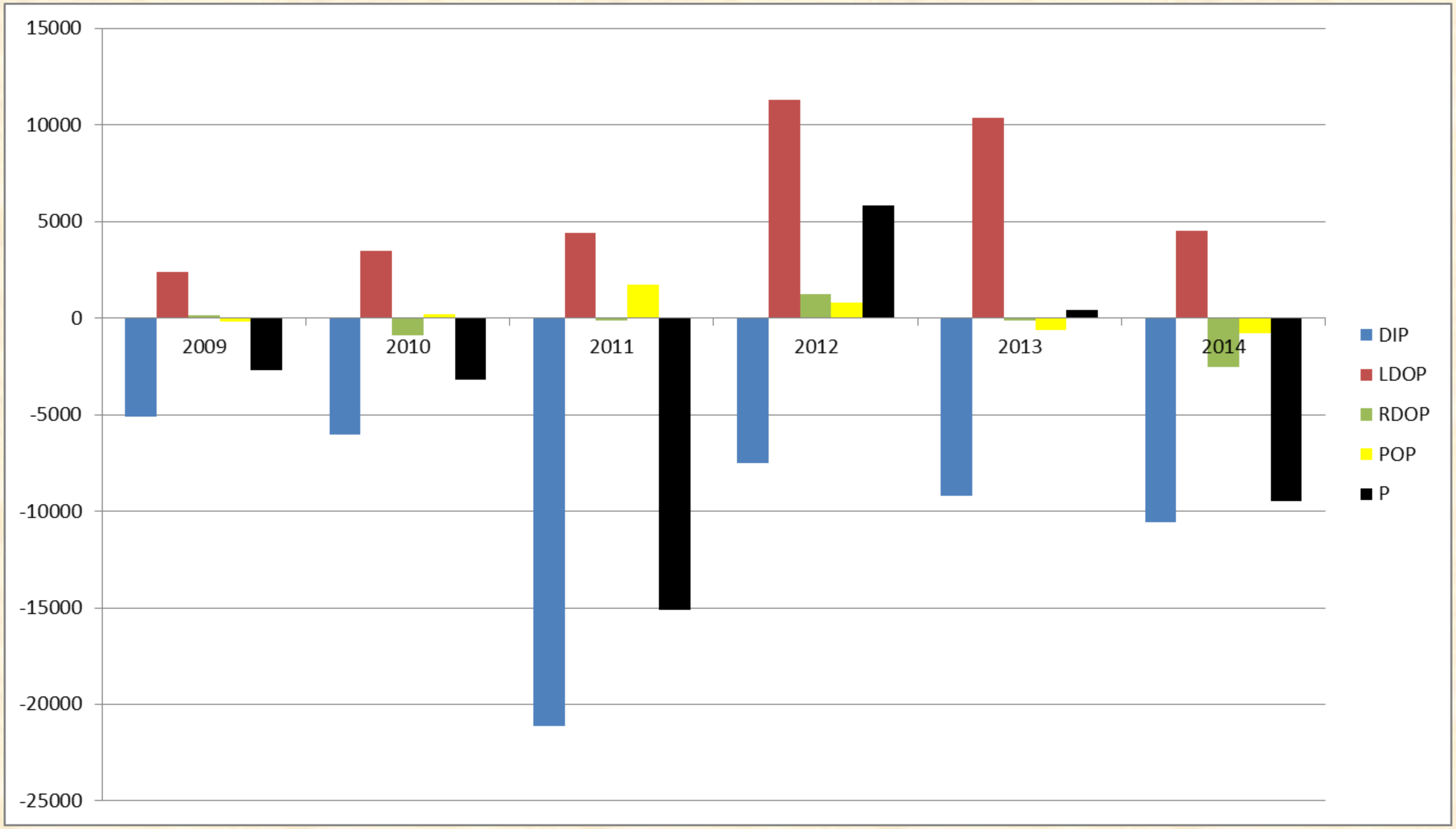
  - realistic simulation of nutrient transports and transformations

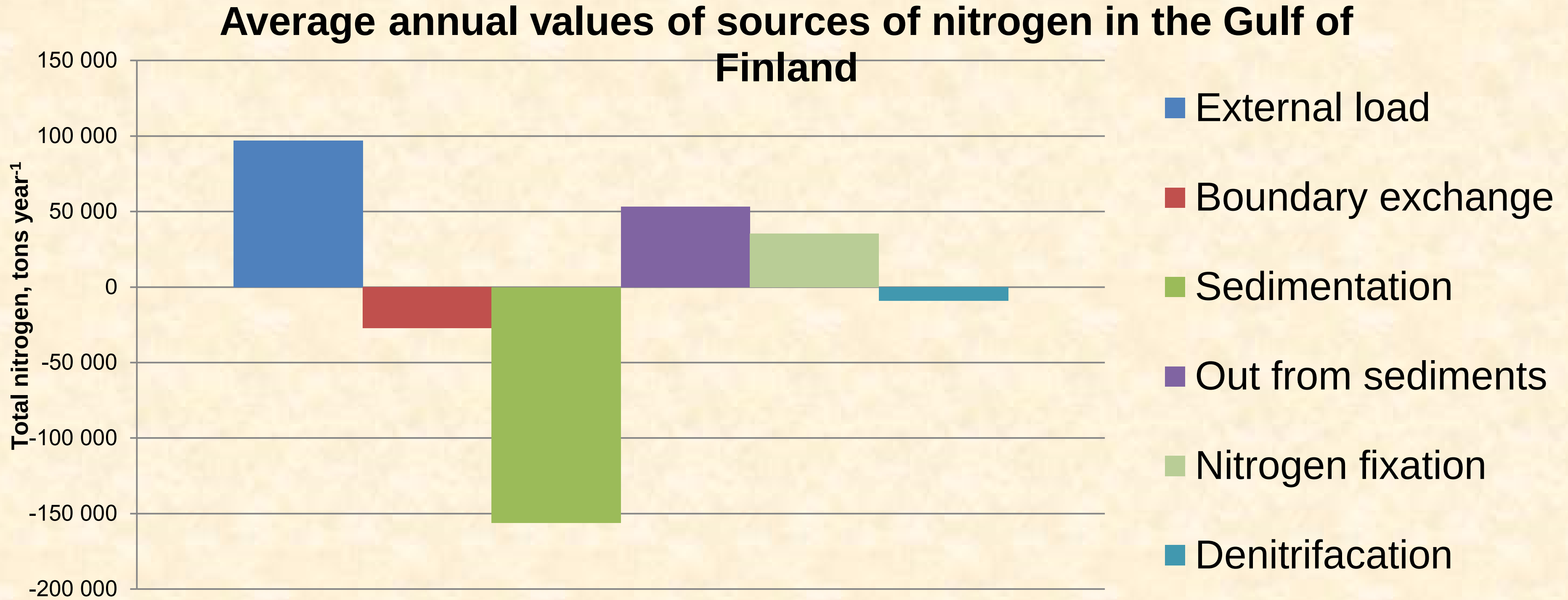
THANK YOU FOR YOUR ATTENTION

Statistics of simulated and observed sea level variations (cm) in the Gulf of Finland

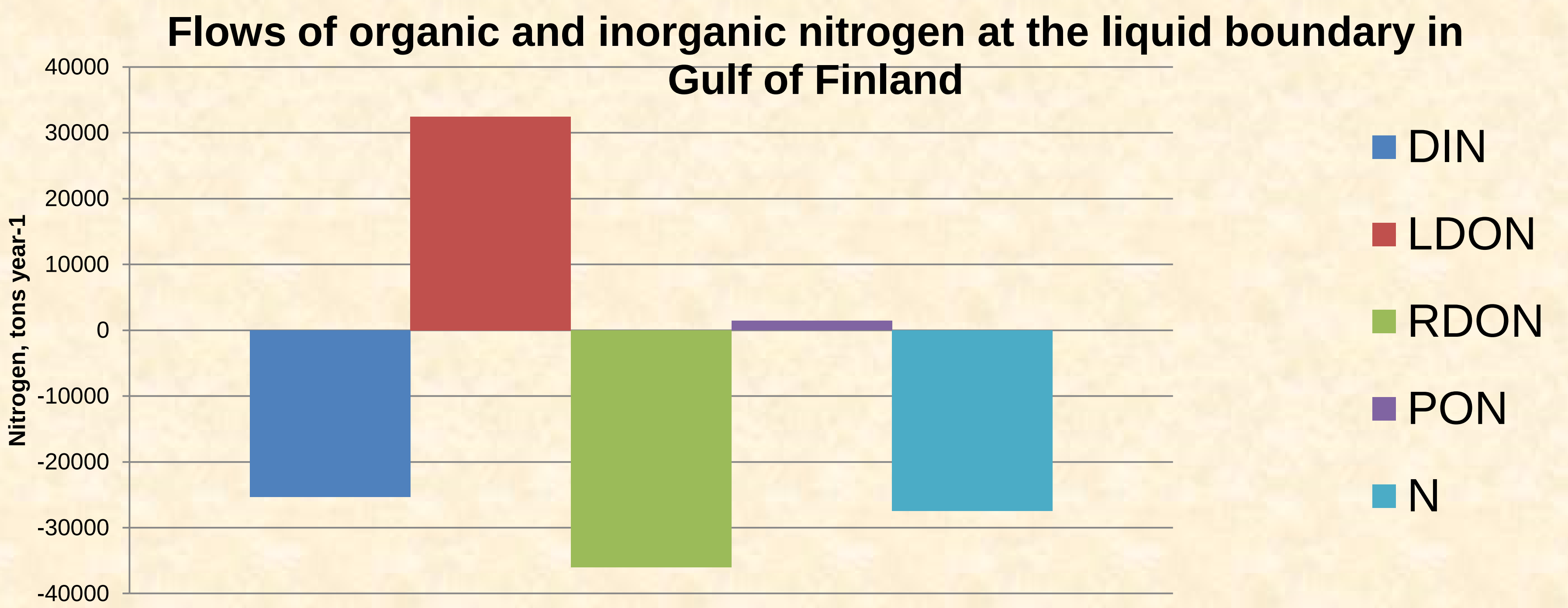
Station	Correlation coefficient	Standard deviation		Mean absolute error	Root mean square error
		Model	Data		
Hamina	0.97	0.23	0.24	0.041	0.054
Helsinki	0.98	0.22	0.22	0.037	0.047
Hogland	0.95	0.24	0.24	0.058	0.078
Kronstadt	0.97	0.25	0.26	0.049	0.068
Sillamae	0.94	0.24	0.23	0.070	0.084
St. Petersburg	0.95	0.26	0.25	0.059	0.082
Tallinn	0.97	0.22	0.22	0.040	0.056


40 000
30 000
20 000
10 000
0
-10 000
-20 000
-30 000
2009
2010
2011
2012
2013
2014
Внешняя нагрузка
Обмен на границе
Седиментация
Выход из отложений


15000
10000
5000
0
-5000
-10000
-15000
-20000
-25000
2009
2010
2011
2012
2013
2014
DIP
LDOP
RDOP
POP
P



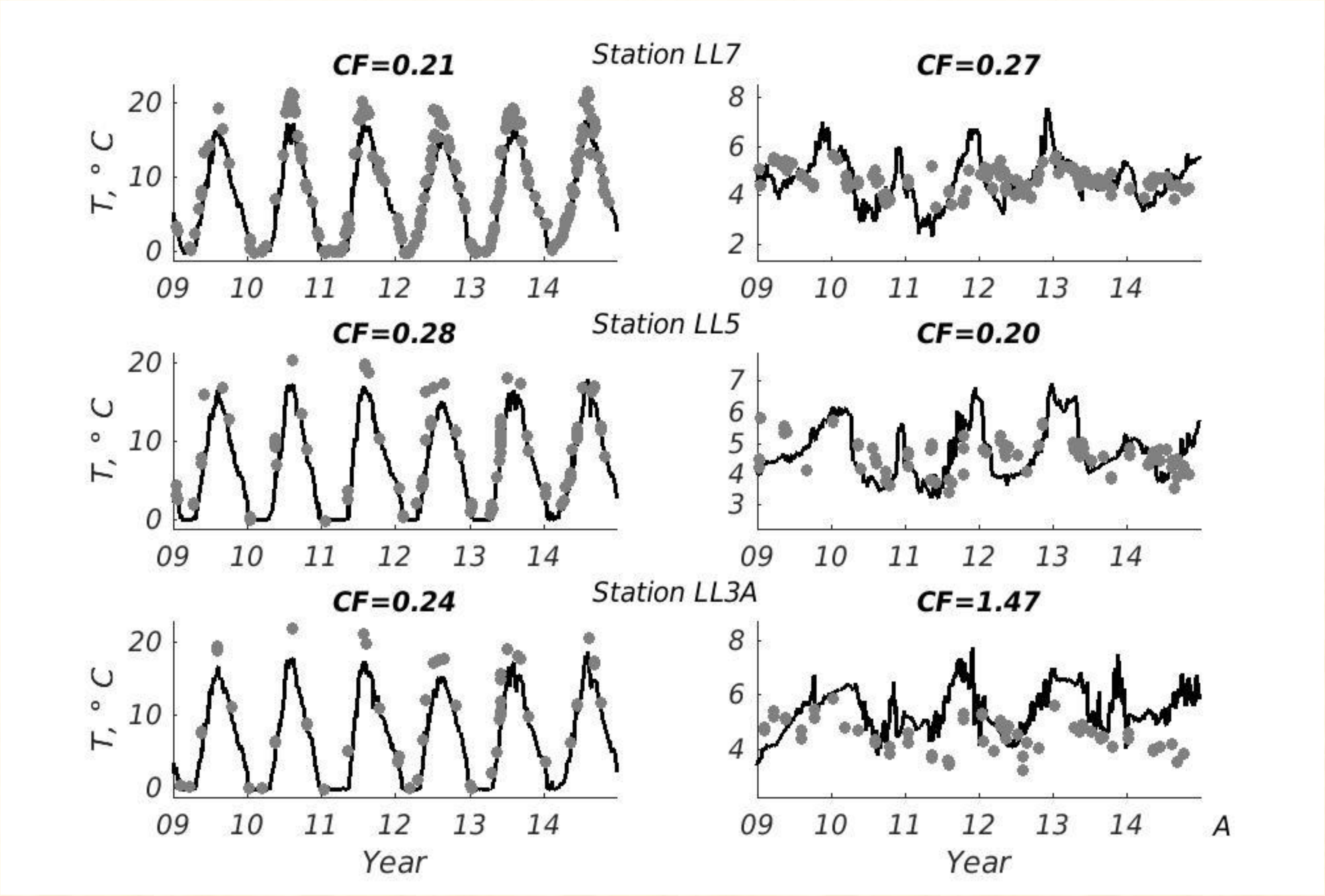
Average annual values of sources of nitrogen in the Gulf of Finland
150 000
100 000
50 000
0
-50 000
-100 000
-150 000
-200 000
Total nitrogen, tons year-1
External load
Boundary exchange
Sedimentation
Out from sediments
Nitrogen fixation
Denitrifacation



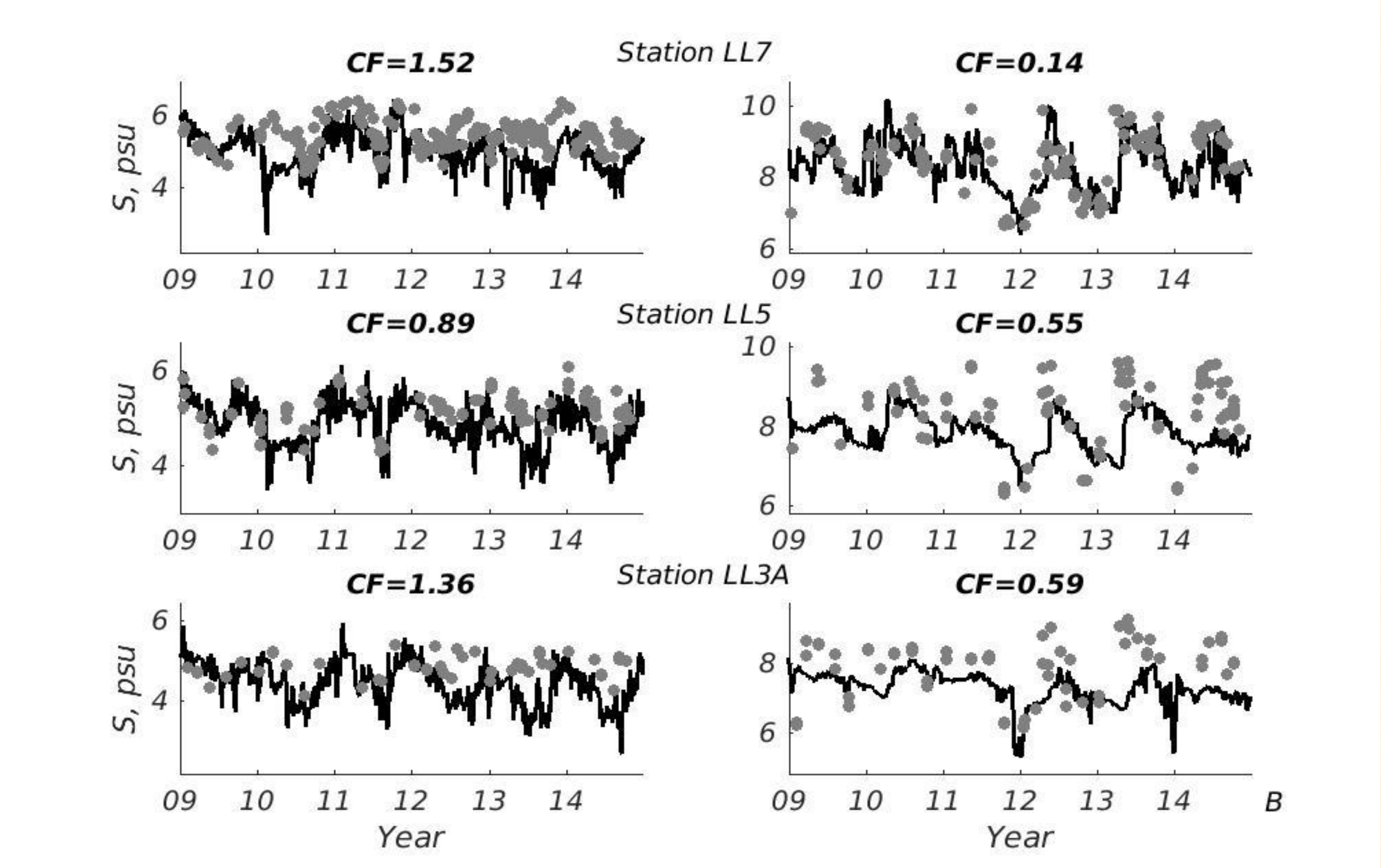
Flows of organic and inorganic nitrogen at the liquid boundary in Gulf of Finland
40000
30000
20000
10000
0
-10000
-20000
-30000
-40000
Nitrogen, tons year-1
DIN
LDON
RDON
PON
N

	Mean		Std		CF	R	Number of pairs
	Model	Observed	Model	Observed	Dimensionless		
Temperature, °C							
GoF	9.27	11.09	6.07	6.84	0.27	0.97	2656
EGoF	9.84	11.96	6.38	7.01	0.33	0.97	817
WGoF	9.02	10.72	5.92	6.74	0.29	0.98	1839
Salinity, g kg^{-1}							
GoF	4.26	4.75	1.57	1.79	0.26	0.92	2656
EGoF	3.06	3.49	1.04	1.23	0.41	0.79	812
WGoF	4.79	5.32	1.48	1.71	0.36	0.92	1844
NO_{2+3}, mg N m^{-3}							
GoF	32	30	57	60	0.02	0.66	2656
EGoF	47.49	46.83	71.34	77.36	0.01	0.60	1101
WGoF	21.16	18.88	41.63	41.57	0.05	0.75	1555
Total N, mg N m^{-3}							
GoF	359	381	77	127	0.17	0.35	1571
EGoF	382	430	84	138	0.58	0.27	819
WGoF	334	328	60	88	0.10	0.27	752
Phosphate, mg P m^{-3}							
GoF	9.0	7.8	11.7	8.2	0.14	0.70	2656
EGoF	8.21	7.89	12.31	9.71	0.03	0.61	1019
WGoF	9.50	7.79	11.33	7.22	0.15	0.81	1637
Total P, mg P m^{-3}							
GoF	31	27	15	12	0.34	0.41	1509
EGoF	29	26	15	13	0.21	0.36	767
WGoF	33	27	15	12	0.37	0.48	742
Oxygen, mg O_2 m^{-3}							
GoF	10.2	9.7	3.8	3.5	0.14	0.92	2656
EGoF	10.5	9.8	3.8	3.5	0.17	0.90	954
WGoF	10.0	9.6	3.8	3.5	0.11	0.94	1702

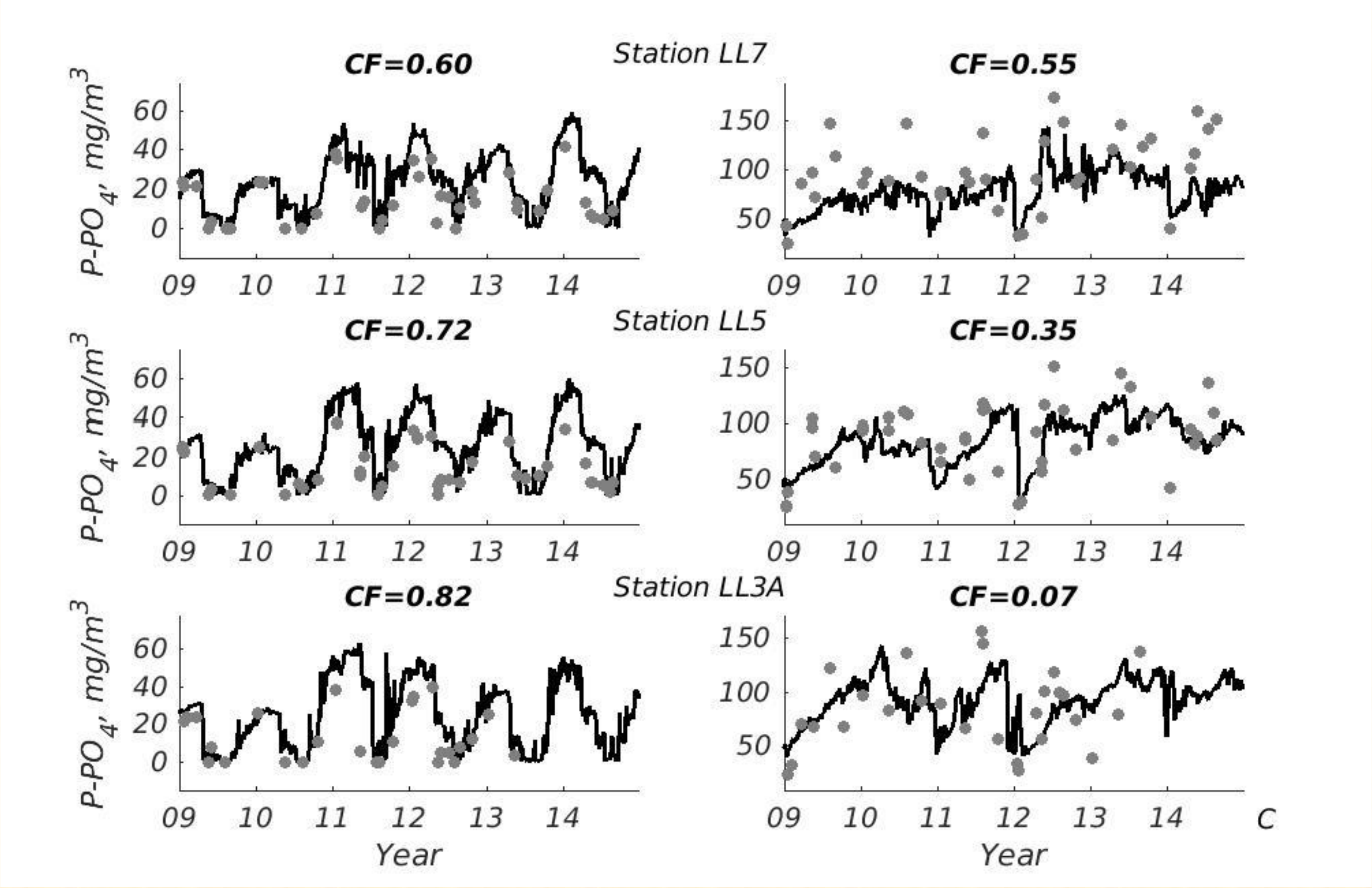
Verifications of the results.
Temperature on stations LL7, LL5, LL3A



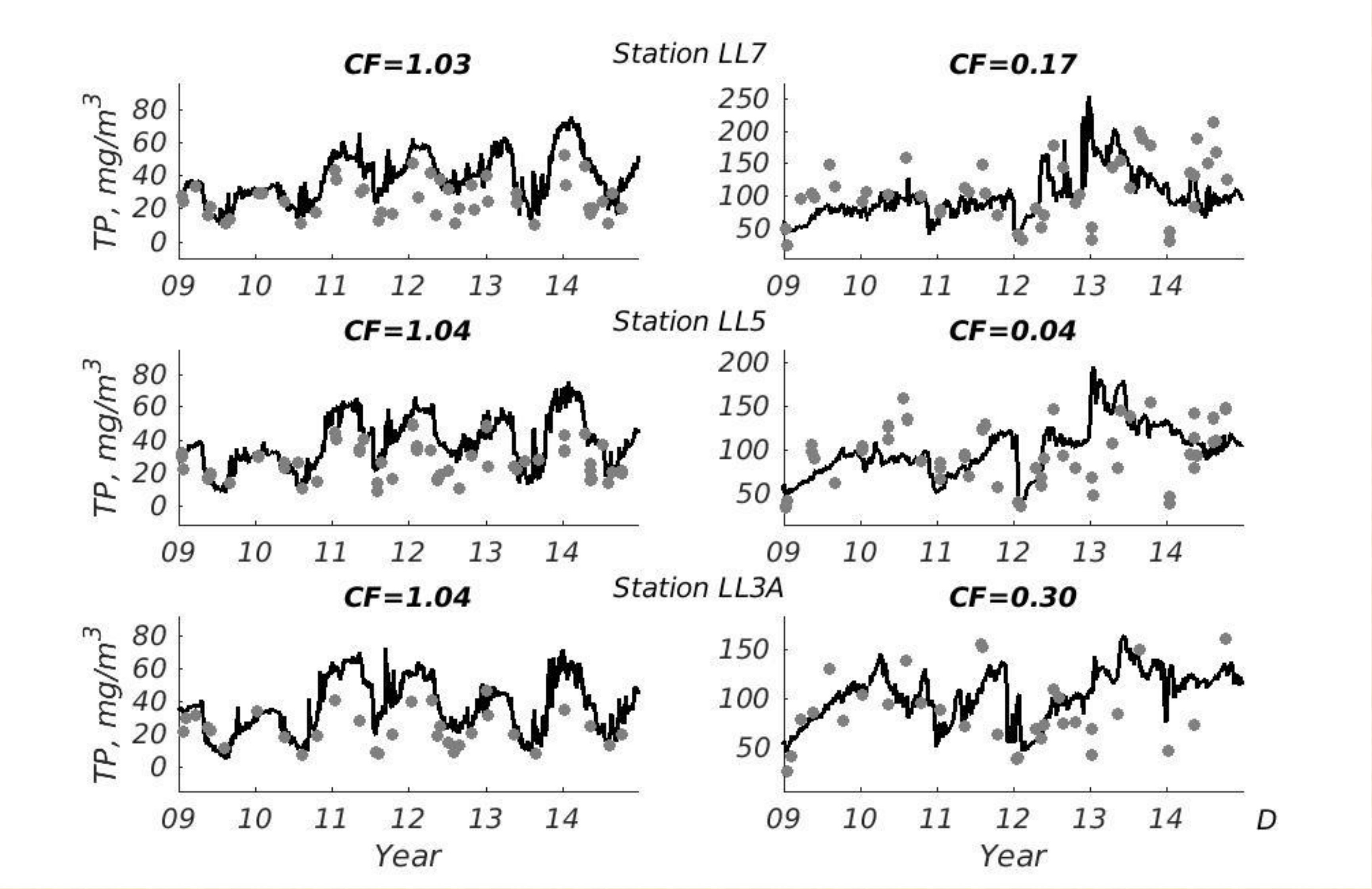
Verifications of the results
Salinity on stations LL7, LL5, LL3A



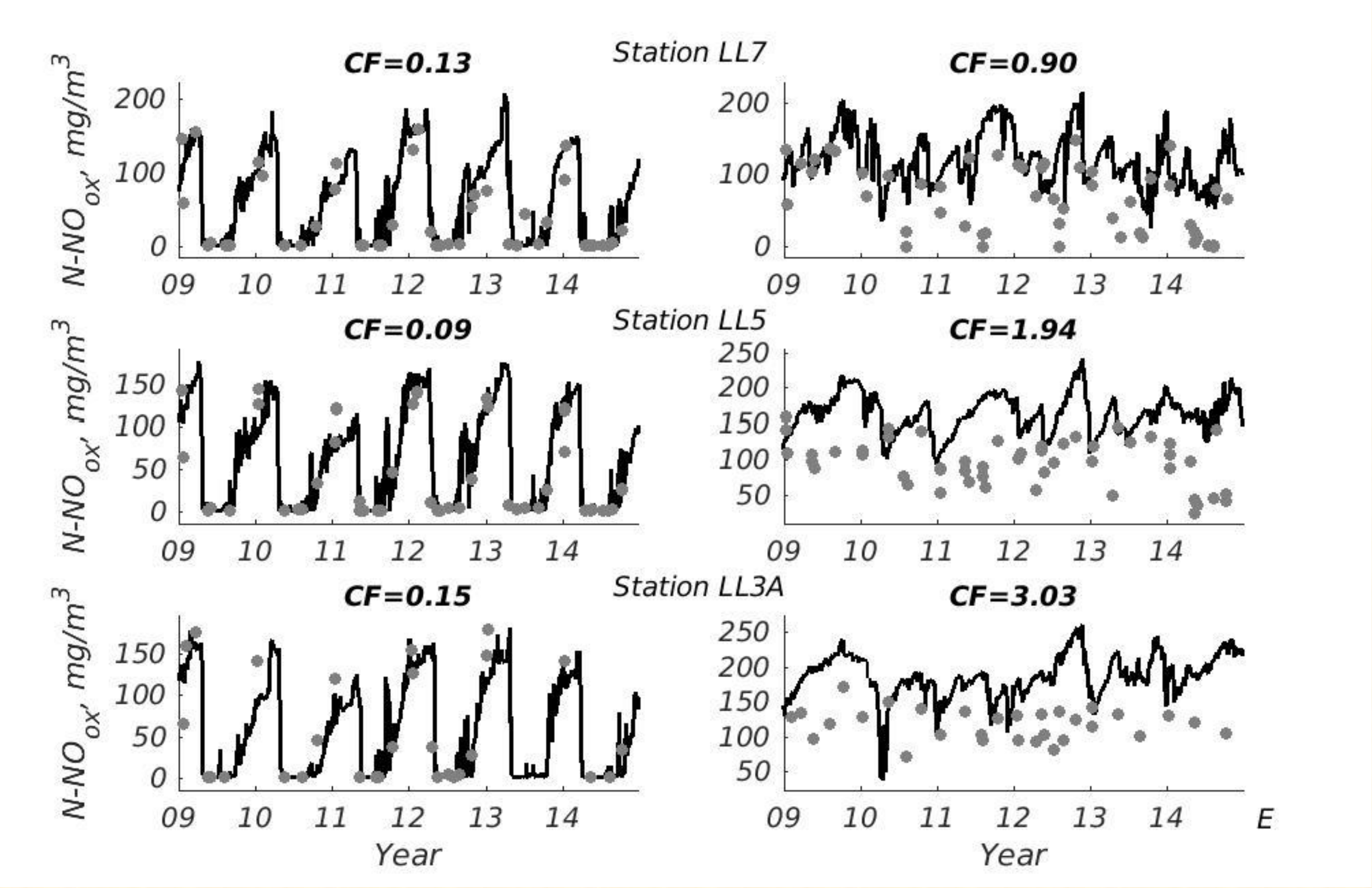
Verifications of the results.
PO_4 on stations LL7, LL5, LL3A



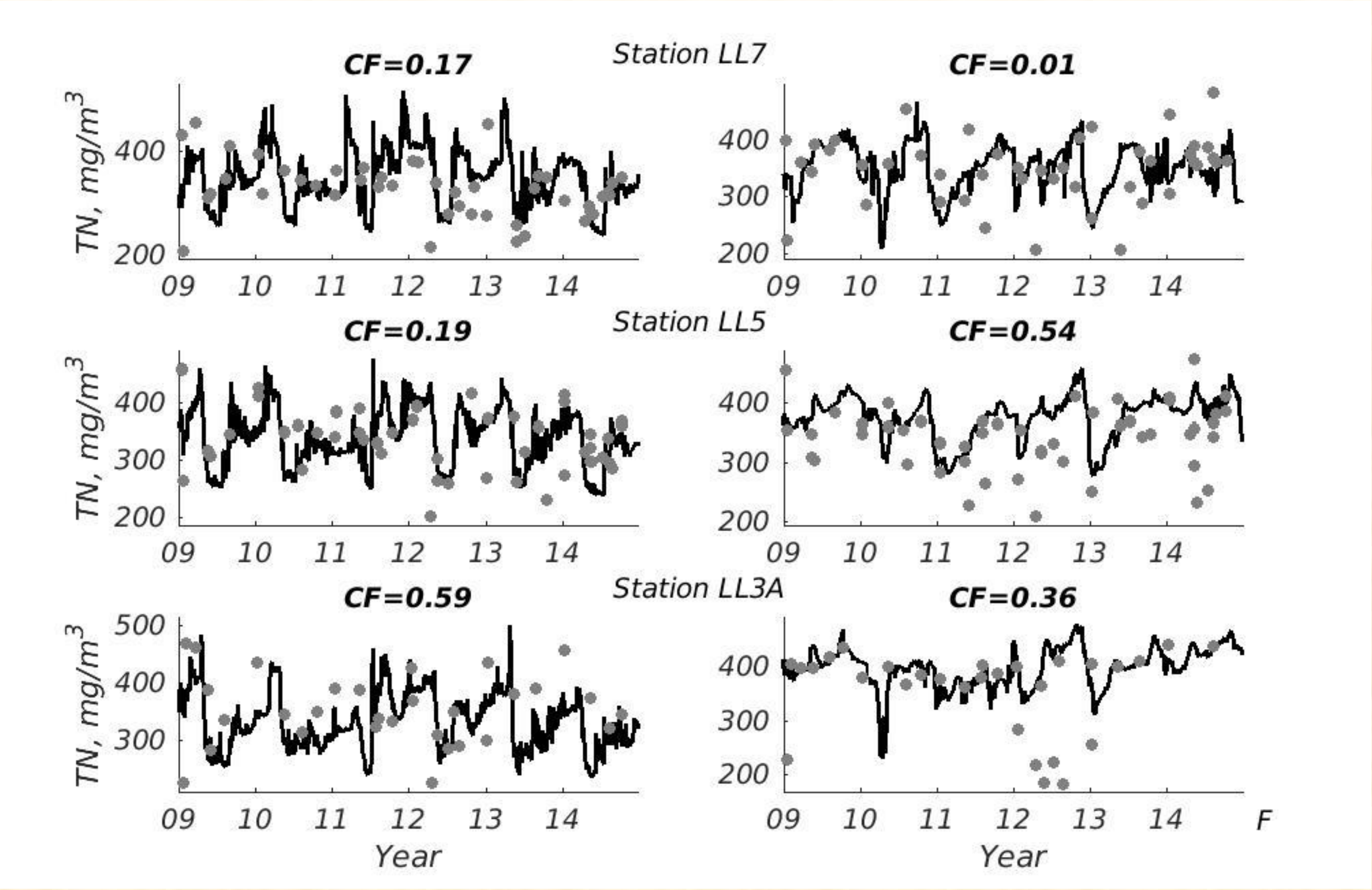
Verifications of the results.
Total phosphorus on stations LL7, LL5, LL3A



Verifications of the results.
NO_x on stations LL7, LL5, LL3A



Verifications of the results.
Total nitrogen on stations LL7, LL5, LL3A



Verifications of the results.
Oxygen on stations LL7, LL5, LL3A