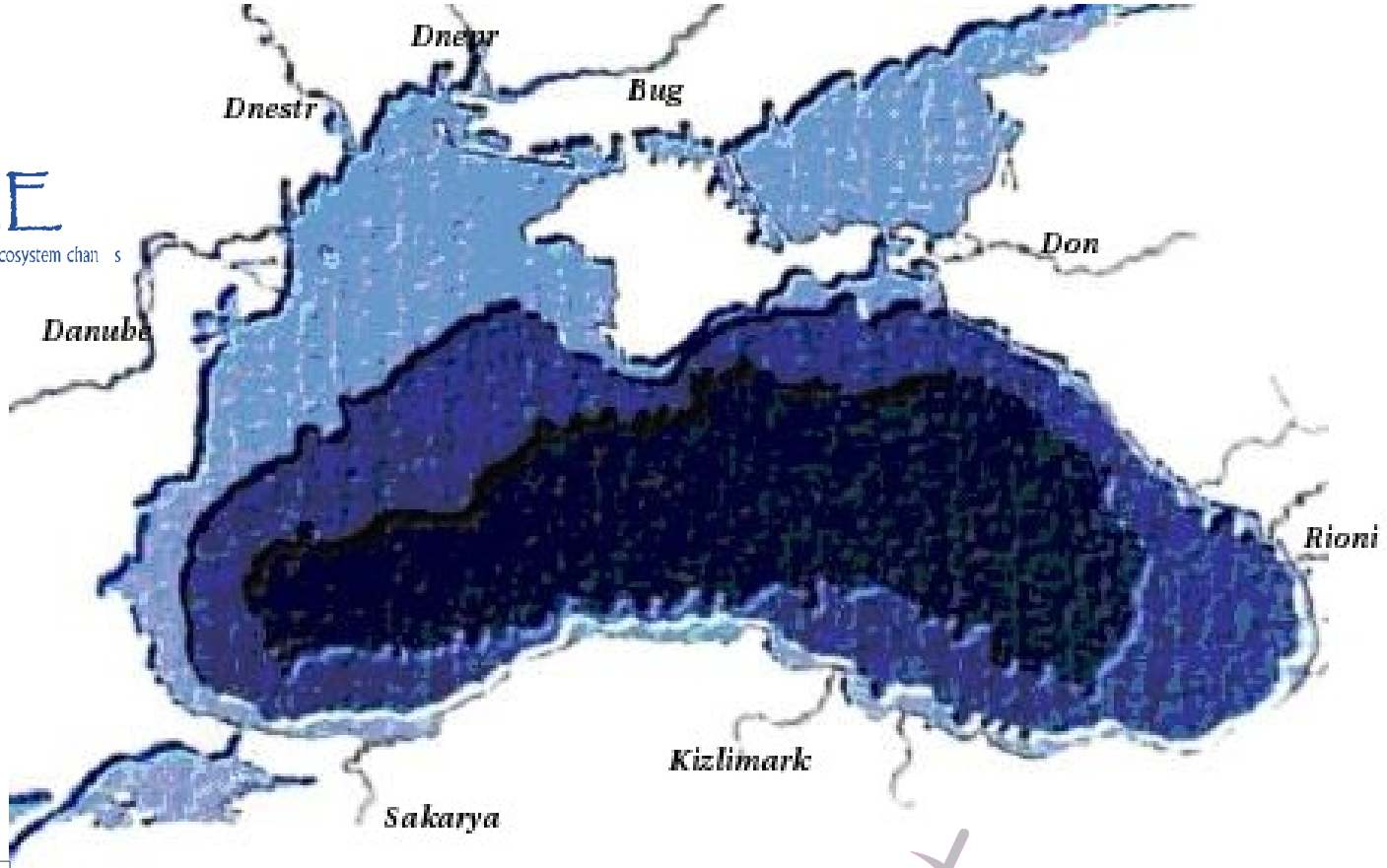
3D MODELLING OF THE BLACK SEA NORTH WESTERN SHELF ECOSYSTEM

SESAME
Southern European Seas: Assessing and Modelling Ecosystem chan s

WP 4 - 6



Université de Liège

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INTERFACULTARY CENTER FOR MARINE RESEARCH - LIEGE UNIVERSITY

GHER
GeoHydrodynamics and Environment Research

FNRS

Capet Arthur, Grégoire M, Beckers, JM.,Joassin P., Naithani J., Borges A.V., Soetaert K., Vandenbulcke L

Layout

* Interrannual physical run : Validate general structure and exploring hydrodynamic interannual variability.

* Biological model : Assess the capacity of the model.
Sediment dynamics.

* Sensibility of the ecosystem to variation in hydrodynamic structure.

Validation Process

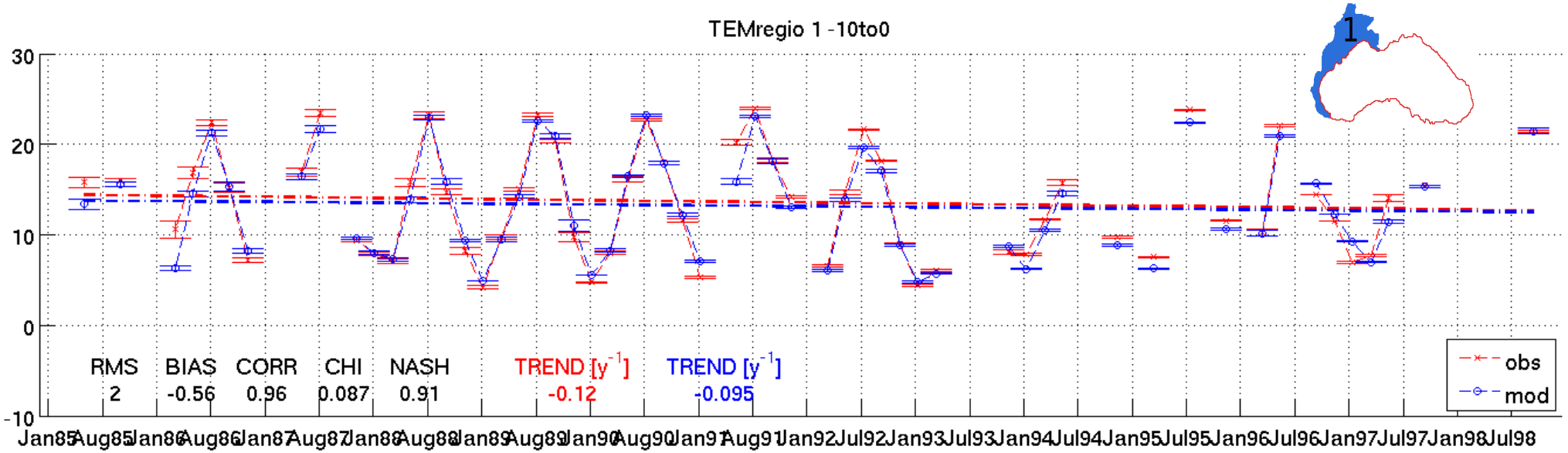
In-situ data are compared with their model equivalent in space and time.

Those couples are gathered by regions, depth levels, or timeslices in the validation exercice.

→ Representativity of spatial average or time evolution can be shifted by data location but the shift is the same in model and observations.
→ This direct comparison give a double error in statistics when some process/structure is shifted in space or time

In the following model results is in blue and observations in red

SST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1
30
20
10
0
-10
RMS
2
BIAS
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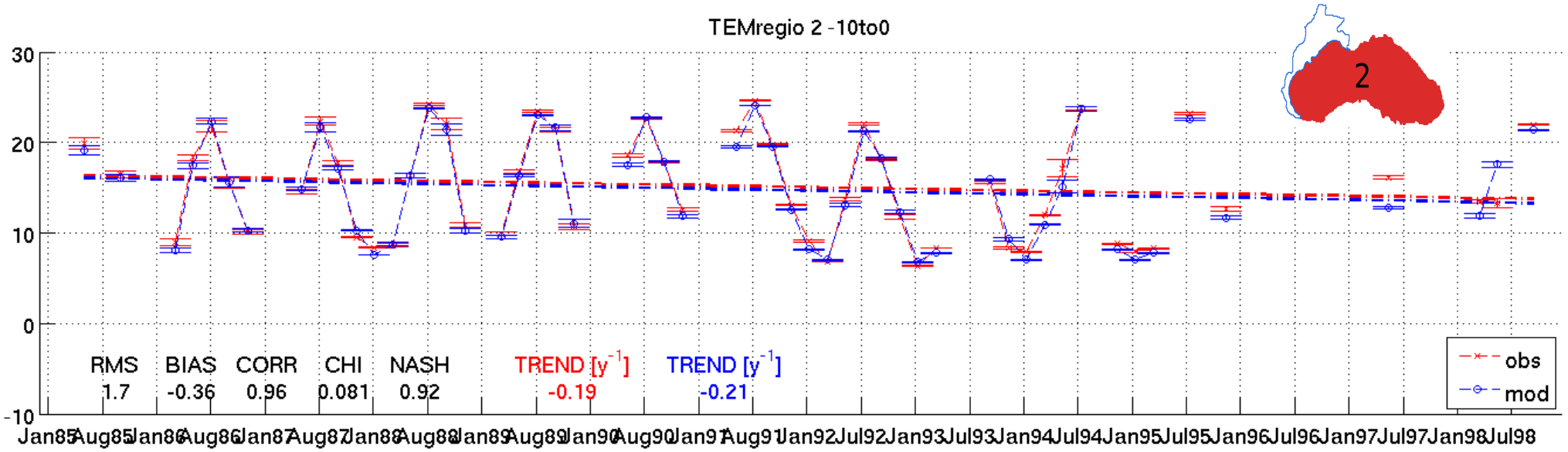
CORR
0.96
CHI
0.087
NASH
0.91
TREND [y-1]
-0.12
TREND [y-1]
-0.095
obs
mod
Jan85 Aug85 Jan86 Aug86 Jan87 Aug87 Jan88 Aug88 Jan89 Aug89 Jan90 Aug90 Jan91 Aug91 Jan92 Jul92 Jan93 Jul93 Jan94 Jul94 Jan95 Jul95 Jan96 Jul96 Jan97 Jul97 Jan98 Jul98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30
20
10
0
-10
RMS
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BIAS
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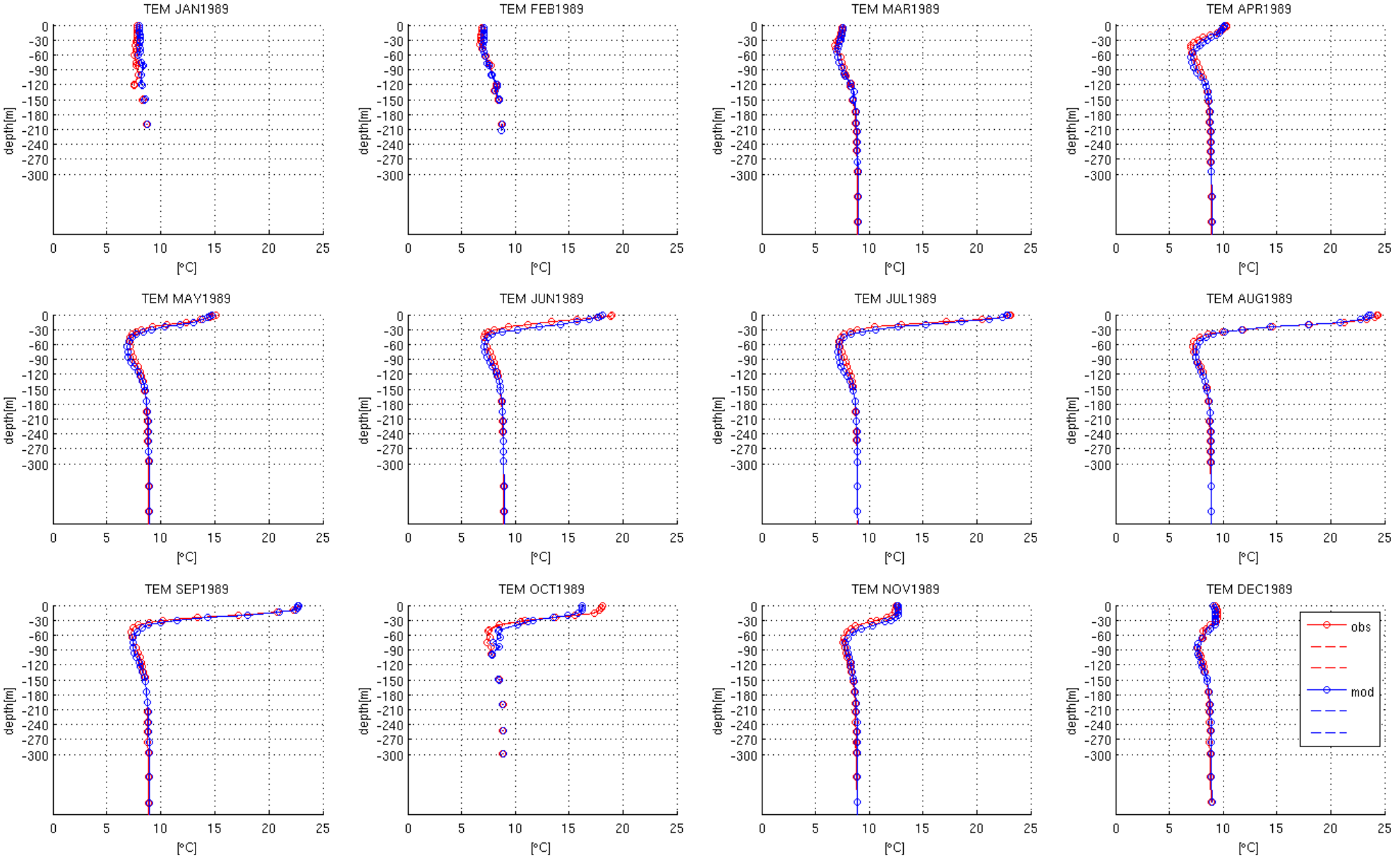
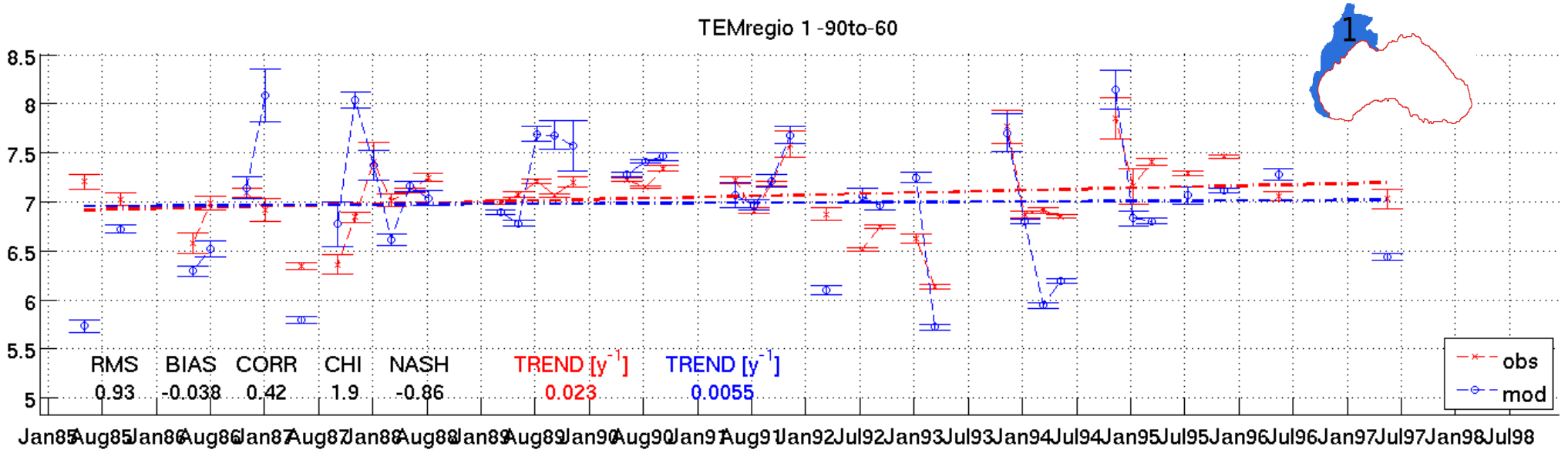
CORR
0.96
CHI
0.081
NASH
0.92
TREND [y-1]
-0.19
TREND [y-1]
-0.21
obs
mod
Jan85 Aug85 Jan86 Aug86 Jan87 Aug87 Jan88 Aug88 Jan89 Aug89 Jan90 Aug90 Jan91 Aug91 Jan92 Jul92 Jan93 Jul93 Jan94 Jul94 Jan95 Jul95 Jan96 Jul96 Jan97 Jul97 Jan98 Jul98

Monthly vertical profiles TEM



CIL T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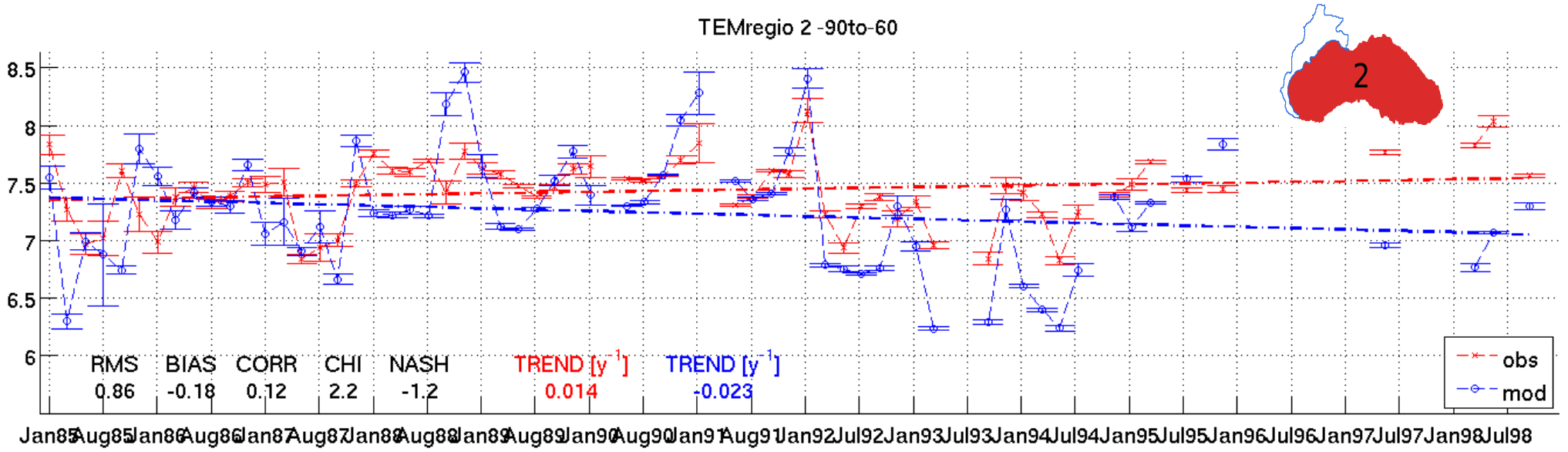
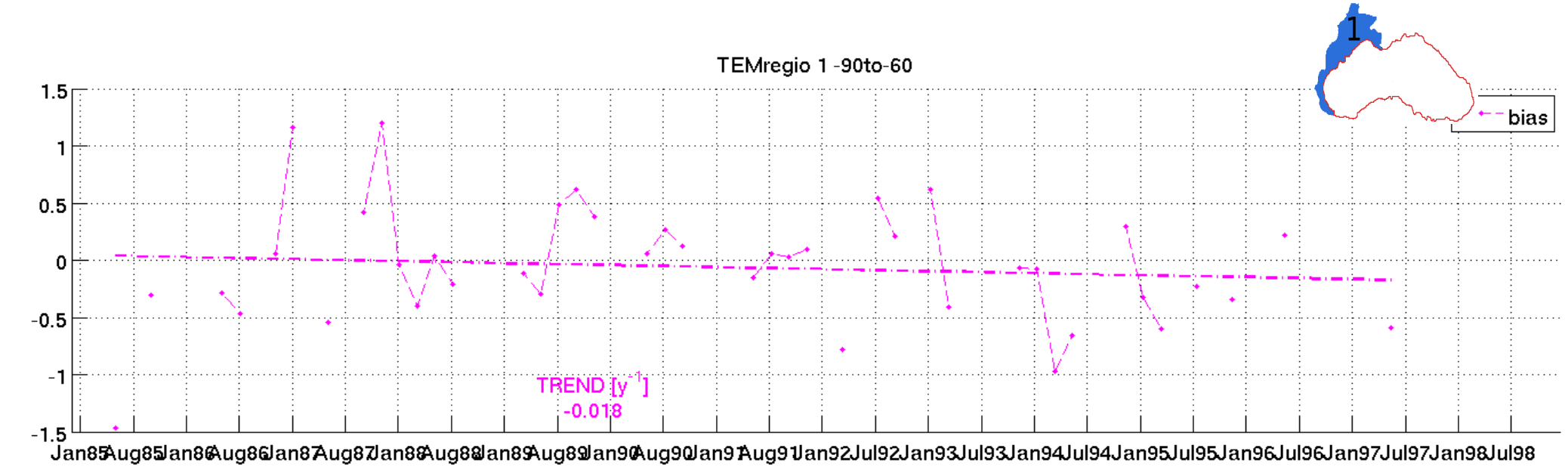
1
8.5
8
7.5
7
6.5
6
5.5
5
RMS
0.93
BIAS
-0.038
CORR
0.42
CHI
1.9
NASH
-0.86
TREND [y-1]
0.023
TREND [y-1]
0.0055
obs
mod
Jan85 Aug85 Jan86 Aug86 Jan87 Aug87 Jan88 Aug88 Jan89 Aug89 Jan90 Aug90 Jan91 Aug91 Jan92 Jul92 Jan93 Jul93 Jan94 Jul94 Jan95 Jul95 Jan96 Jul96 Jan97 Jul97 Jan98 Jul98


TEMregio 2 -90to-60
2
8.5
8
7.5
7
6.5
6
RMS
0.86
BIAS
-0.18
CORR
0.12
CHI
2.2
NASH
-1.2
TREND [y-1]
0.014
TREND [y-1]
-0.023
obs
mod
Jan85 Aug85 Jan86 Aug86 Jan87 Aug87 Jan88 Aug88 Jan89 Aug89 Jan90 Aug90 Jan91 Aug91 Jan92 Jul92 Jan93 Jul93 Jan94 Jul94 Jan95 Jul95 Jan96 Jul96 Jan97 Jul97 Jan98 Jul98

CILT drift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bias
1.5
1
0.5
0
-0.5
-1
-1.5
TREND [y^{-1}]
-0.018
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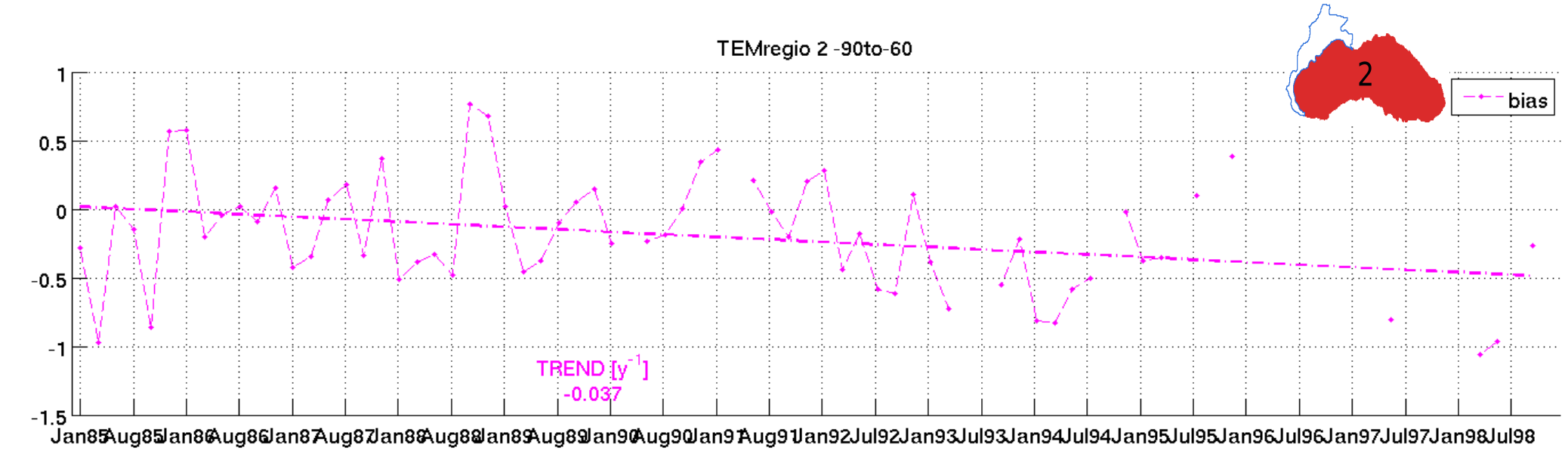
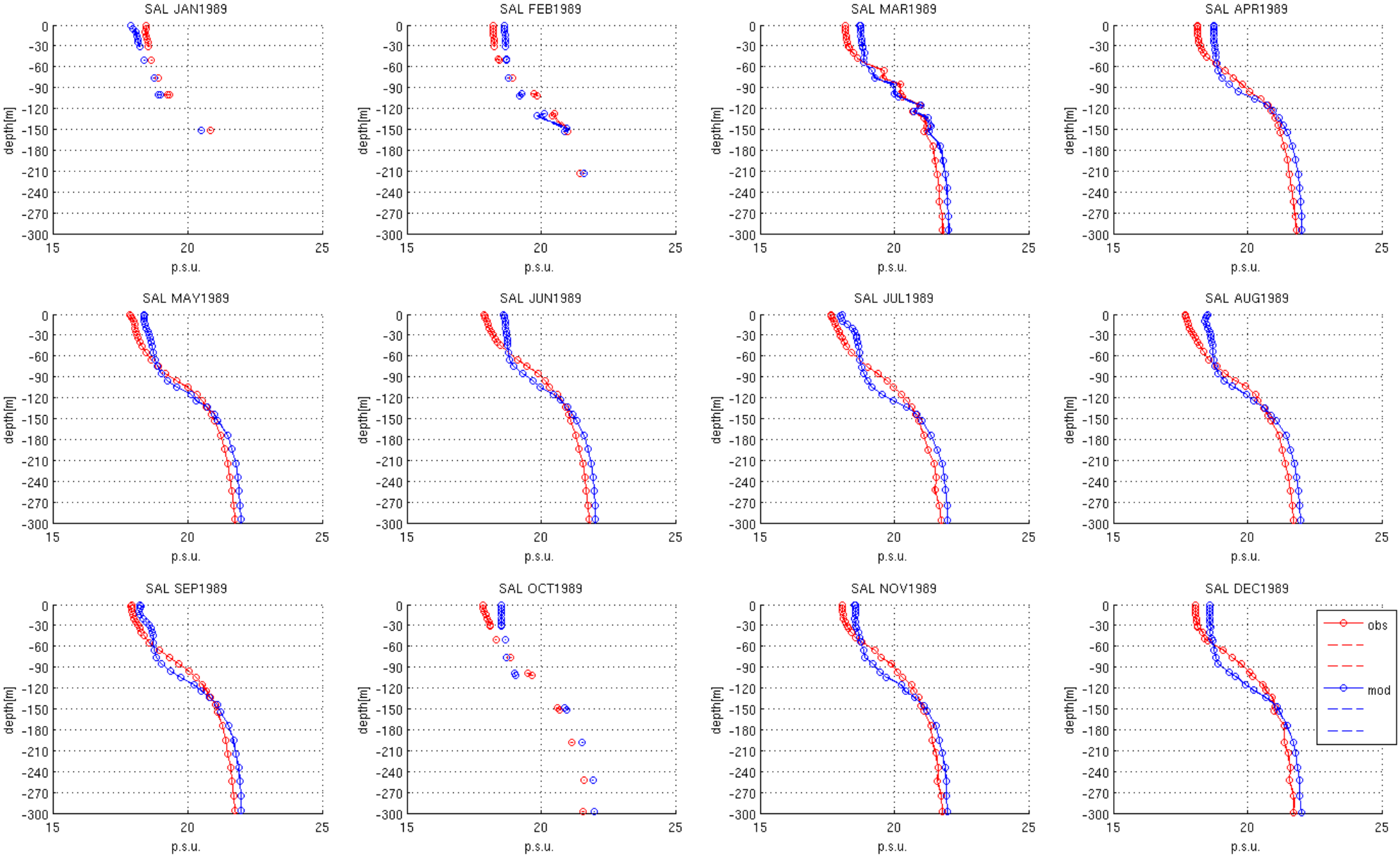
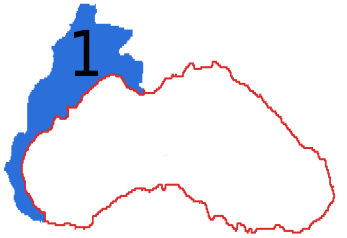
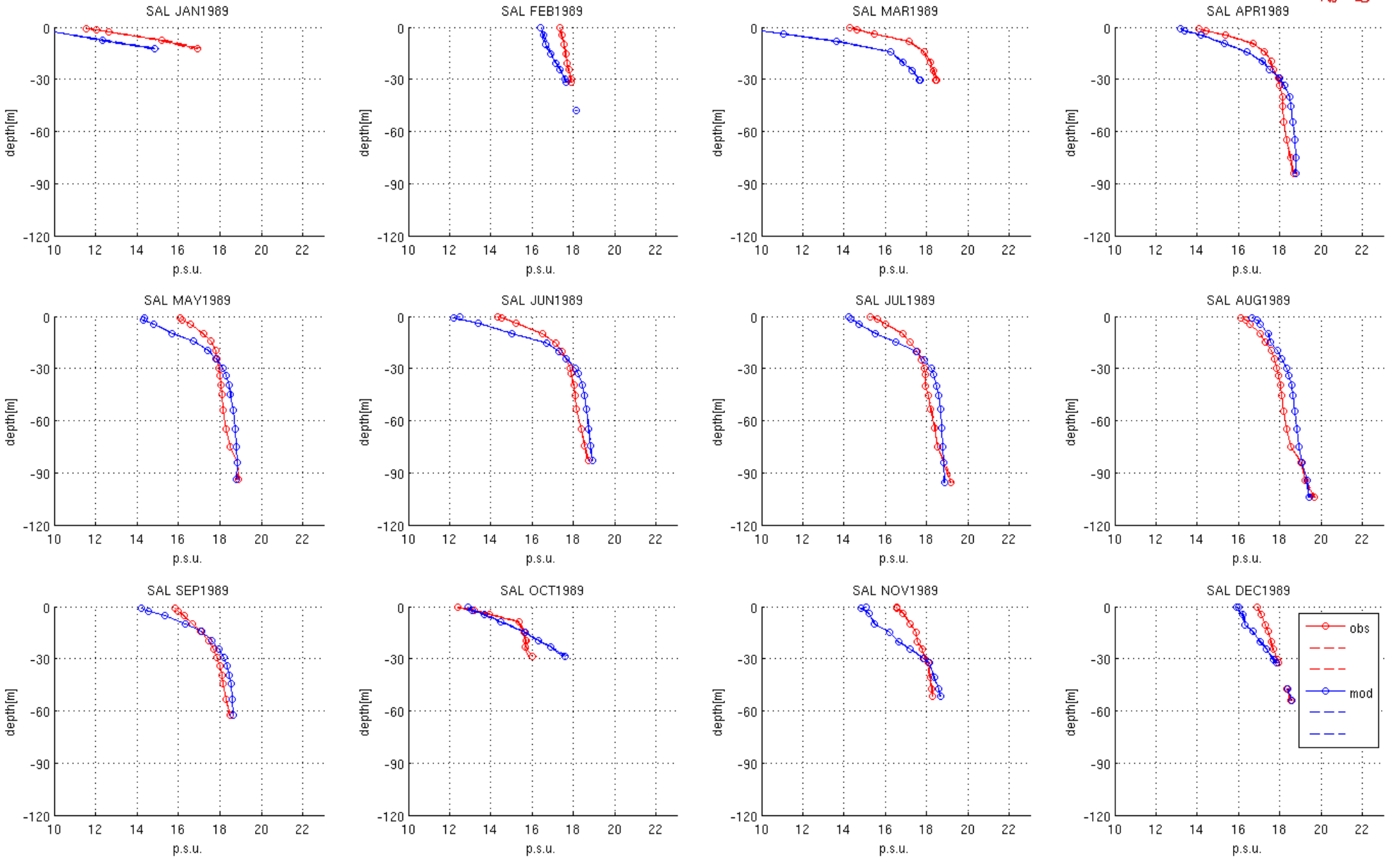

TEMregio 2 -90to-60
2
bias
1
0.5
0
-0.5
-1
-1.5
TREND [y^{-1}]
-0.037
Jan85 Aug85 Jan86 Aug86 Jan87 Aug87 Jan88 Aug88 Jan89 Aug89 Jan90 Aug90 Jan91 Aug91 Jan92 Jul92 Jan93 Jul93 Jan94 Jul94 Jan95 Jul95 Jan96 Jul96 Jan97 Jul97 Jan98 Jul98

SAL PROFILE BASIN

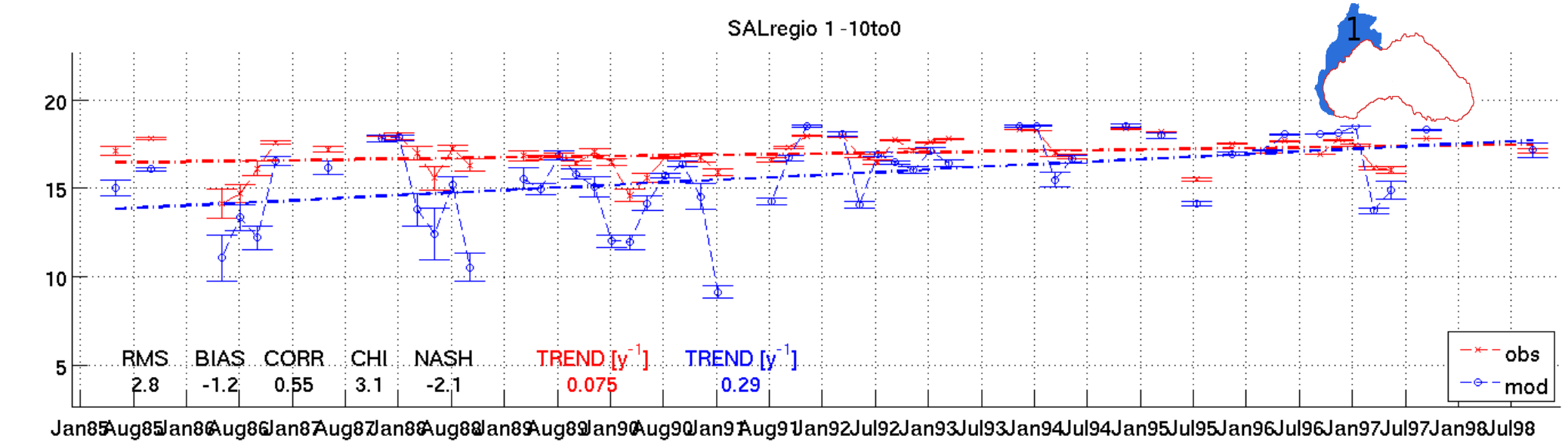


SAL PROFILE SHELF





SSS


SALregio 1 -10to0
1
20
15
10
5
RMS 2.8
BIAS -1.2
CORR 0.55
CHI 3.1
NASH -2.1
TREND [y-1] 0.075
TREND [y-1] 0.29
obs
mod
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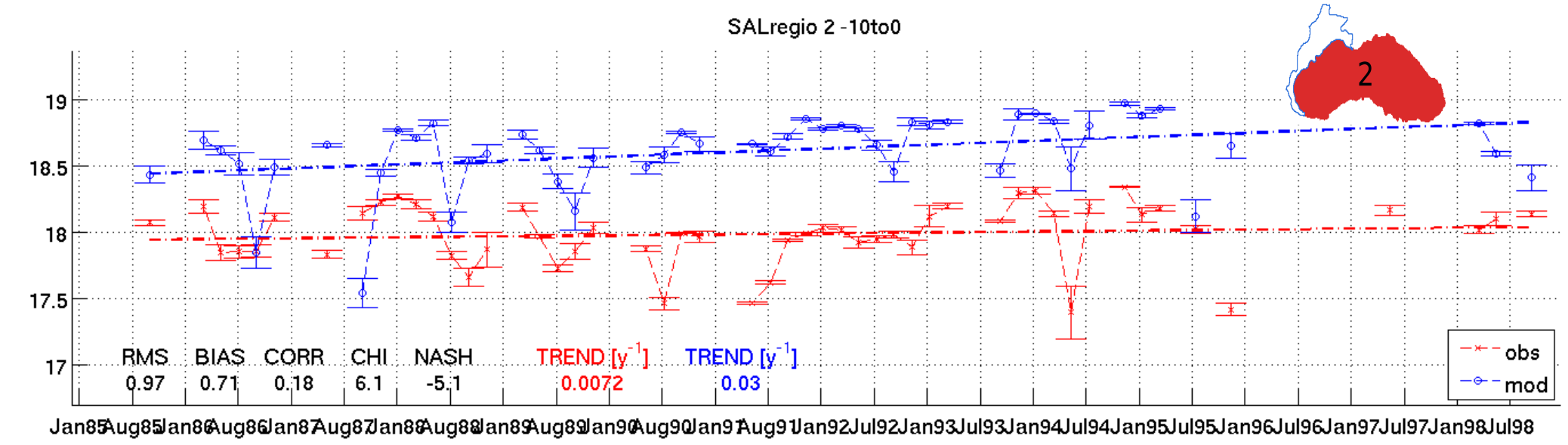
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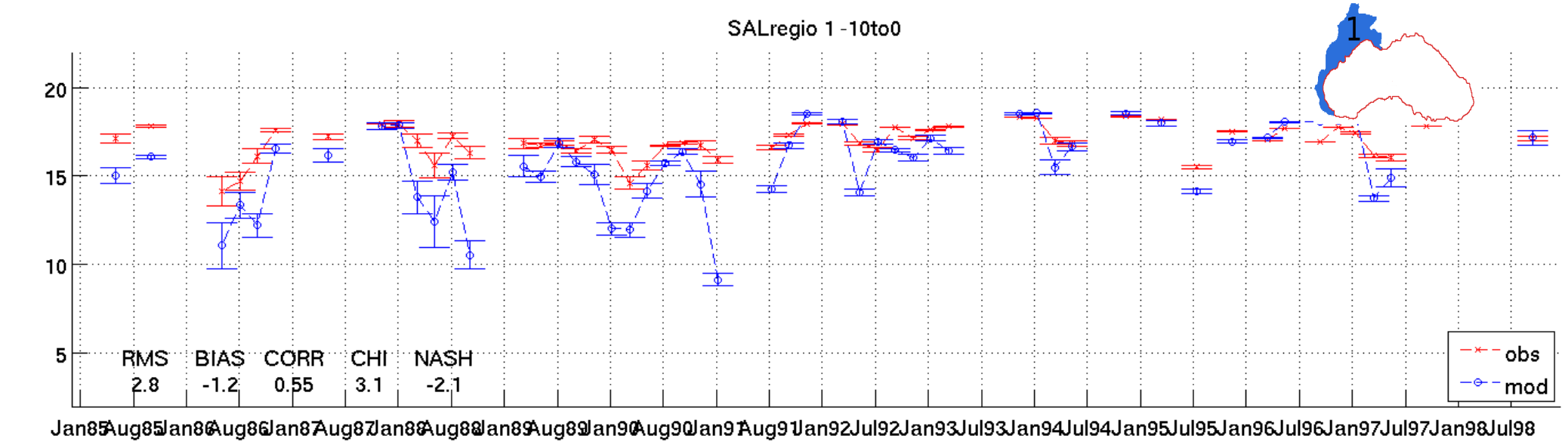
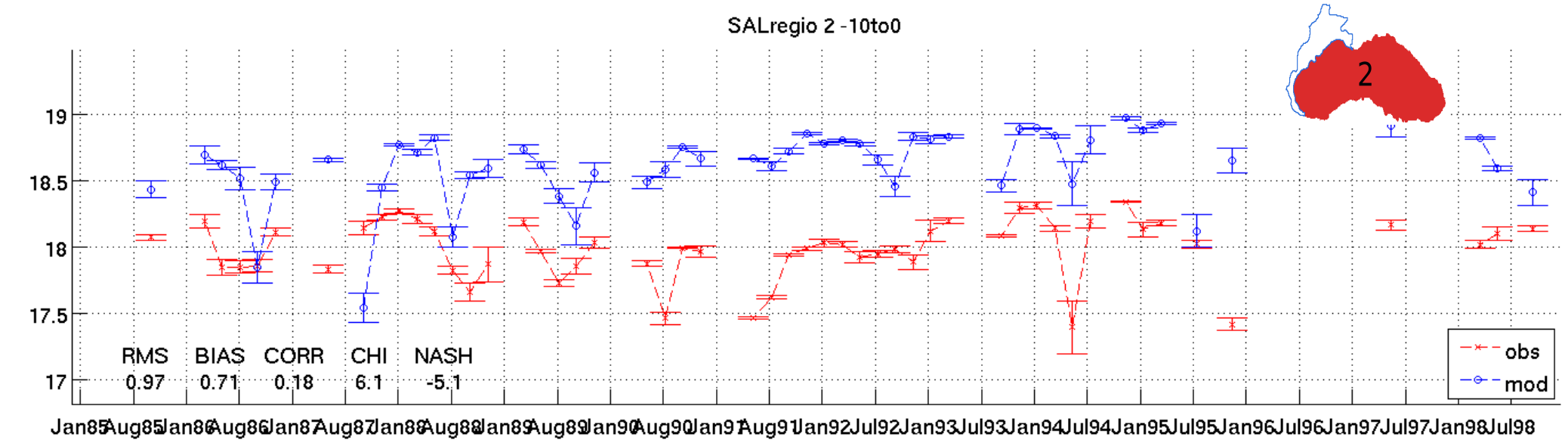
2
19
18.5
18
17.5
17
RMS 0.97
BIAS 0.71
CORR 0.18
CHI 6.1
NASH -5.1
TREND [y-1] 0.0072
TREND [y-1] 0.03
obs
mod
Jan85 Aug85 Jan86 Aug86 Jan87 Aug87 Jan88 Aug88 Jan89 Aug89 Jan90 Aug90 Jan91 Aug91 Jan92 Jul92 Jan93 Jul93 Jan94 Jul94 Jan95 Jul95 Jan96 Jul96 Jan97 Jul97 Jan98 Jul98

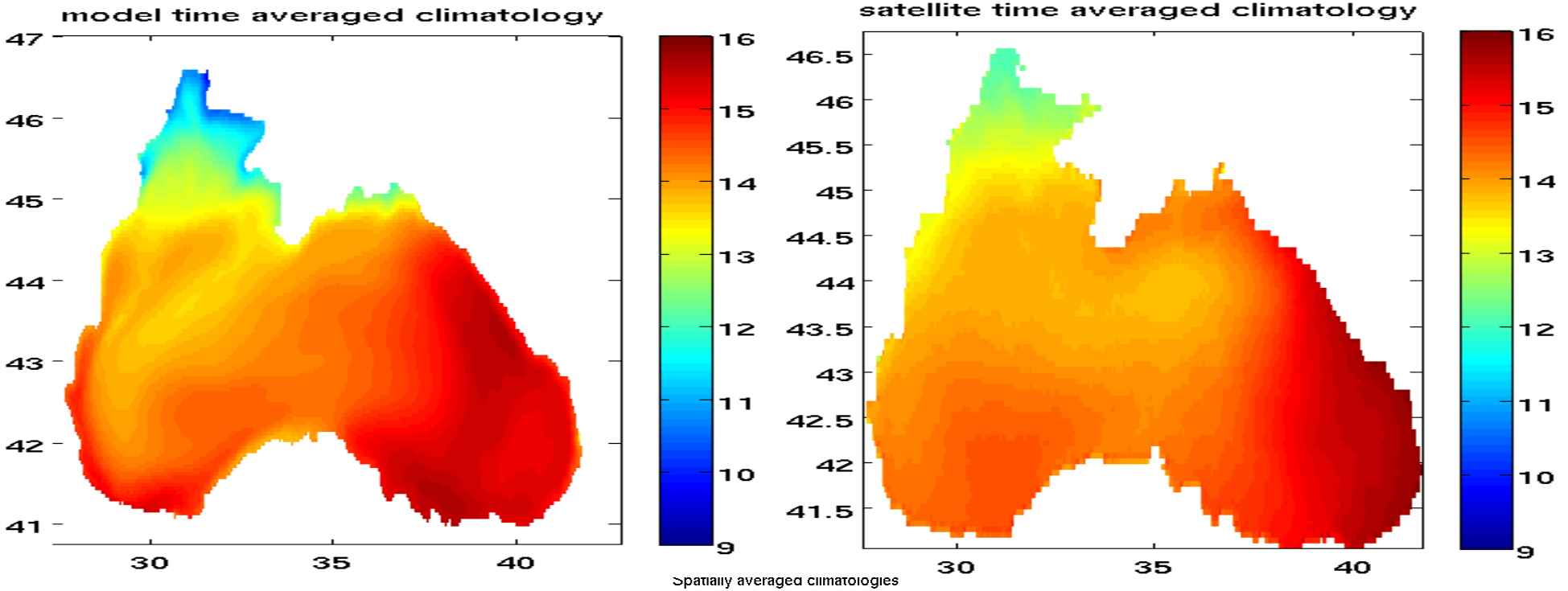
SSS


SALregio 1 -10to0
1
20
15
10
5
RMS 2.8
BIAS -1.2
CORR 0.55
CHI 3.1
NASH -2.1
obs
mod
Jan85 Aug85 Jan86 Aug86 Jan87 Aug87 Jan88 Aug88 Jan89 Aug89 Jan90 Aug90 Jan91 Aug91 Jan92 Jul92 Jan93 Jul93 Jan94 Jul94 Jan95 Jul95 Jan96 Jul96 Jan97 Jul97 Jan98 Jul98

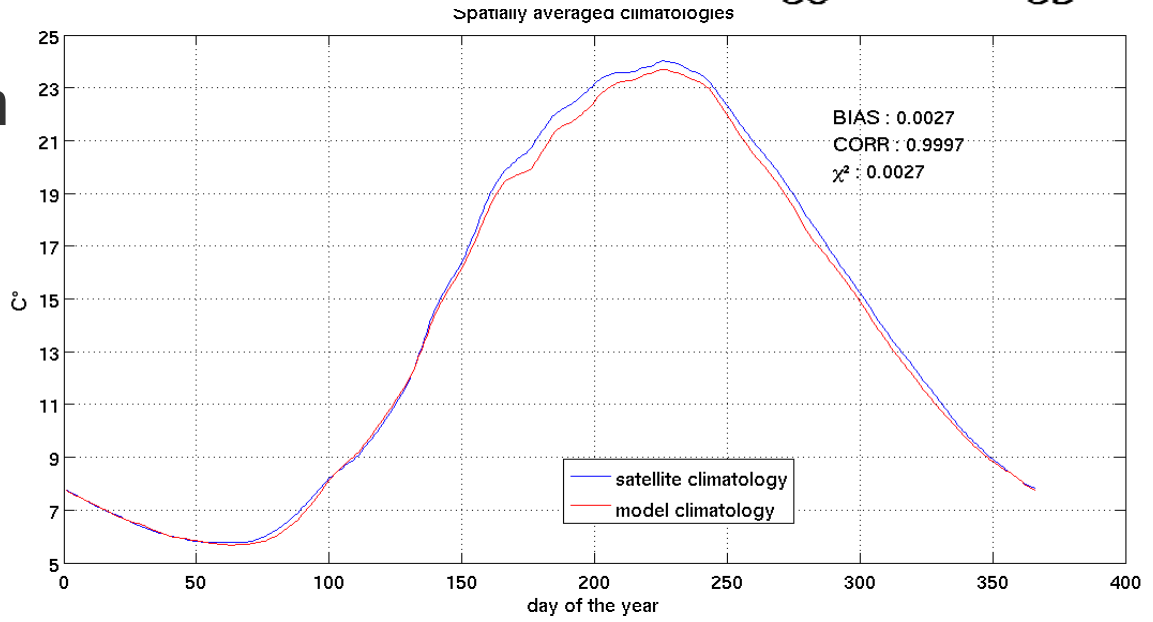

SALregio 2 -10to0
2
19
18.5
18
17.5
17
RMS 0.97
BIAS 0.71
CORR 0.18
CHI 6.1
NASH -5.1
obs
mod
Jan85 Aug85 Jan86 Aug86 Jan87 Aug87 Jan88 Aug88 Jan89 Aug89 Jan90 Aug90 Jan91 Aug91 Jan92 Jul92 Jan93 Jul93 Jan94 Jul94 Jan95 Jul95 Jan96 Jul96 Jan97 Jul97 Jan98 Jul98

Validation : Physics

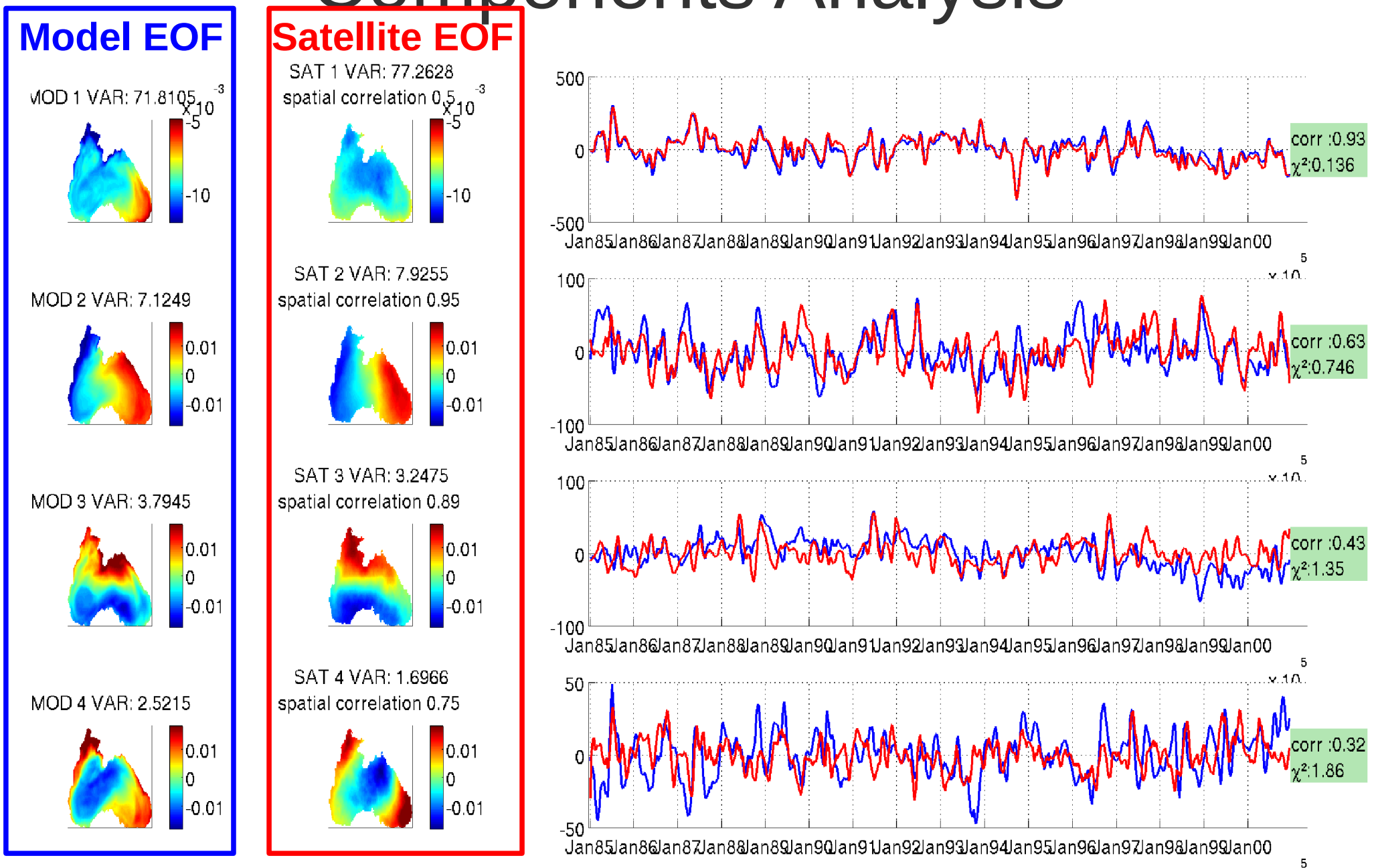
Comparison of SST climatologies from model and satellite



interranual run
85 to 90



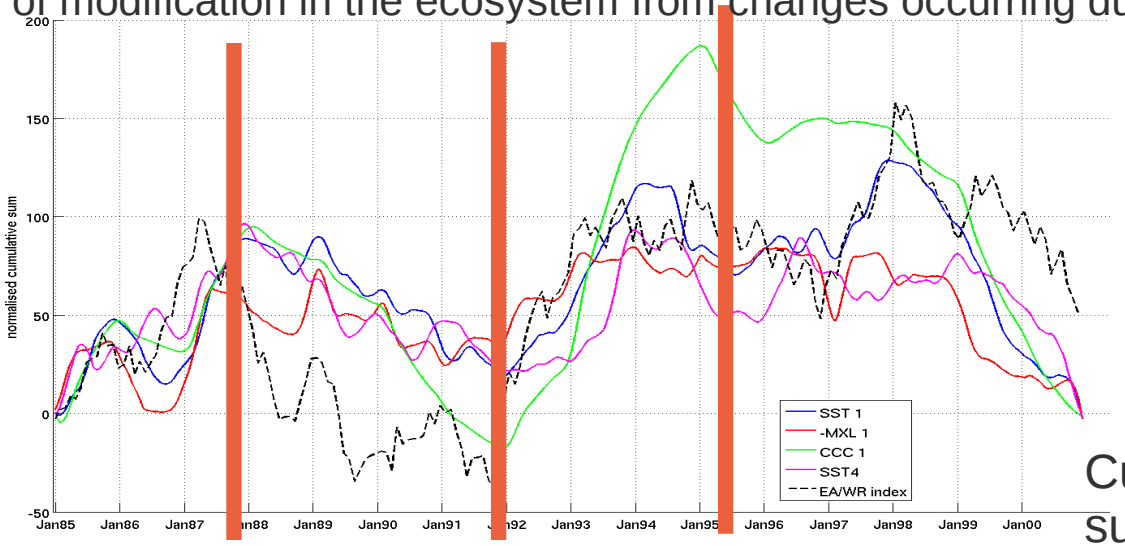
Interannual variability : Principal Components Analysis



Hydrodynamic regimes

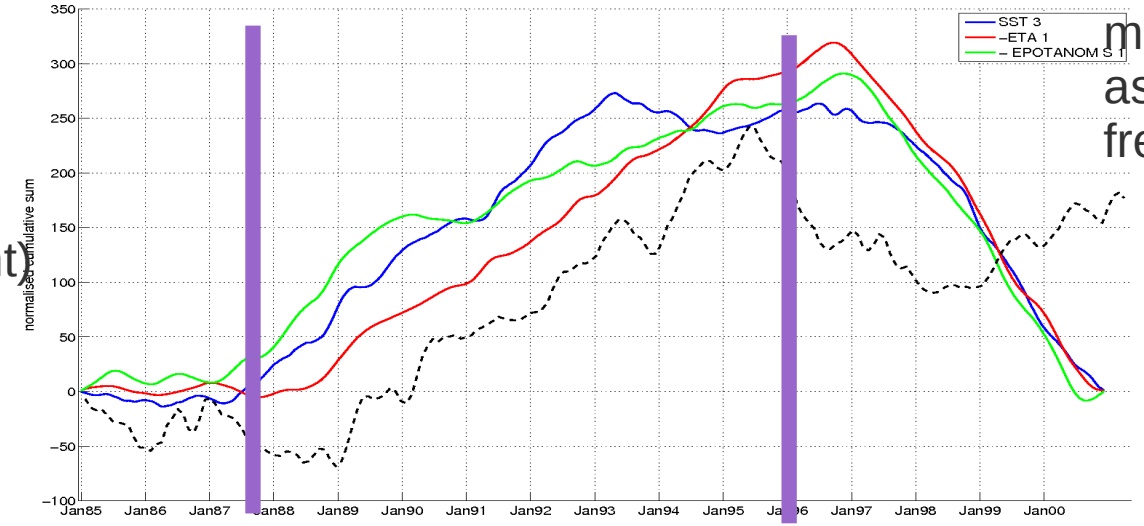
* The detailed study of interannual variability of hydrodynamics, lead to the identification of multivariate variability modes, linked to atmospheric patterns variation.
* This identifies shifts and coherent time-slices between the shifts.
* The identification of those modes and the corresponding impact on biological variables allows to distinguish the “atmospheric causes” of modification in the ecosystem from changes occurring due to “anthropogenic causes”.

Global mixing :
linked variables :
* First mode of SST
* Mixed Layer Depth
* Cold Layer Cold Content
* EA/WR

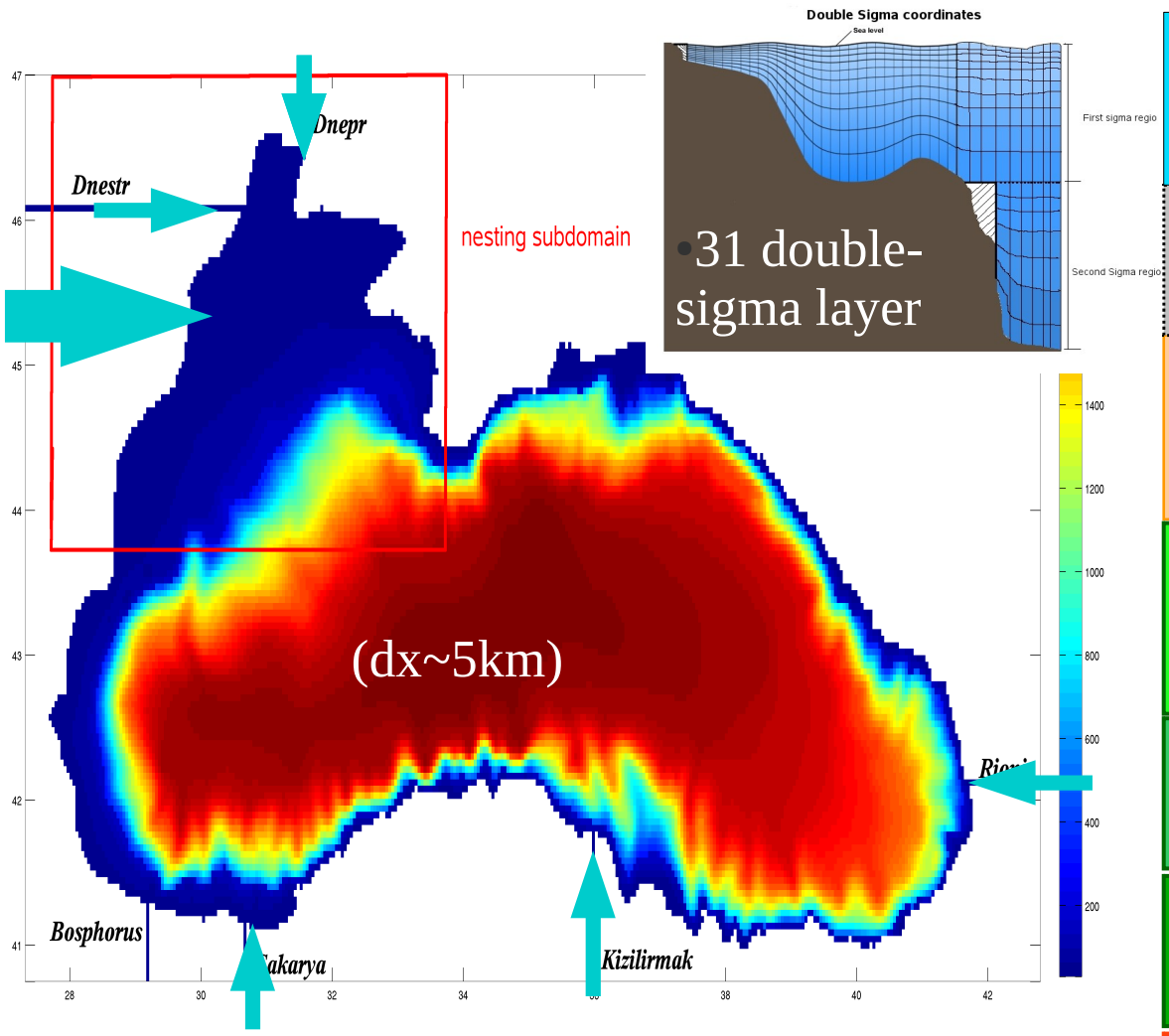


Cumulative sums of modes associated frequences

Rim Current intensity :
linked variables :
* Third mode of SST (N/S gradient)
* Sea Surface Curvature
* Haline Stratification



The Model



Monthly RIVERS fluxes and nutrients flows (from SESAME & A. Cociasu)

6h-atmospheric forcings from ECMWF (1.125°). (from ERA40)

36 States variables

Physics (5)
Currents, T°, Salinity,
Surface elevation, Turbulence

Oxygen and Dissolved Inorganic Carbon (2)

Inorganic nutrients (5)
SiO,NO3,NH4,PO4,"Reducers"

3 Phytoplankton (6) (free C/N)
Diatoms,Flagellates, Small Flagellates

Zooplancton (2)
Micro, Meso.

Gelatinous zooplankton(2)
Omnivorous , Carnivorous

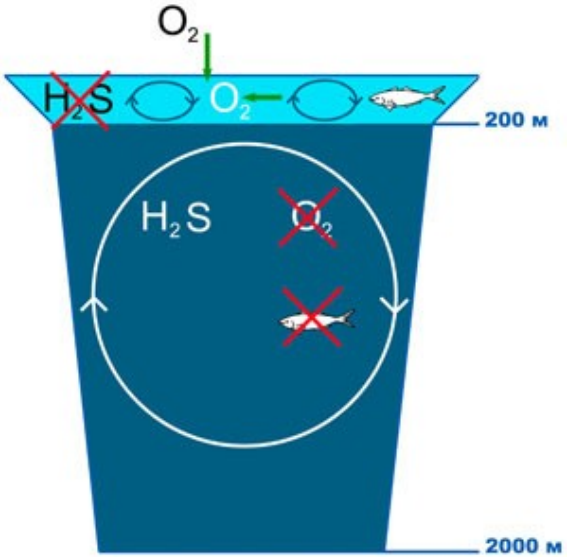
Detrital matter (8)
Particulate, Semi-labile and Labile forms
Silicious Detritus, Aggregates

Bacteria(1)

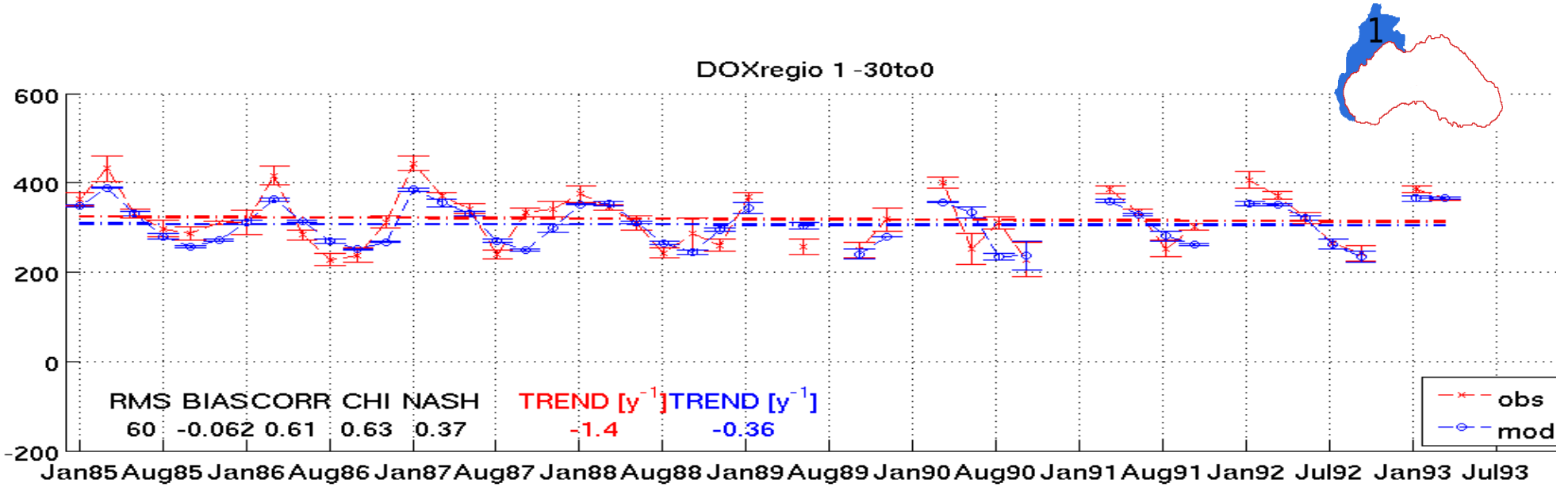
Model's Specificity

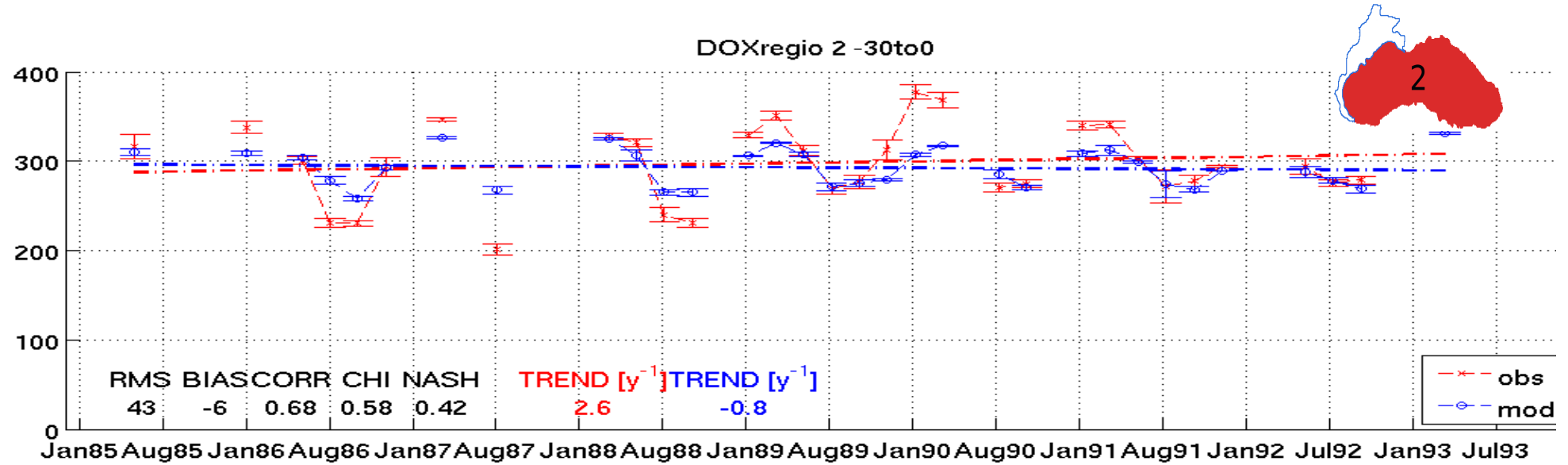
- No data assimilation : Necessity to construct specific Bosphorus representation to ensure conservation of volume and total salt content.

- Anoxic waters : The biological model explicitely includes anoxic chemistry trough the use of a variable 'Oxygen demanding Units', as a proxy for reducers acting in the anoxic zone.

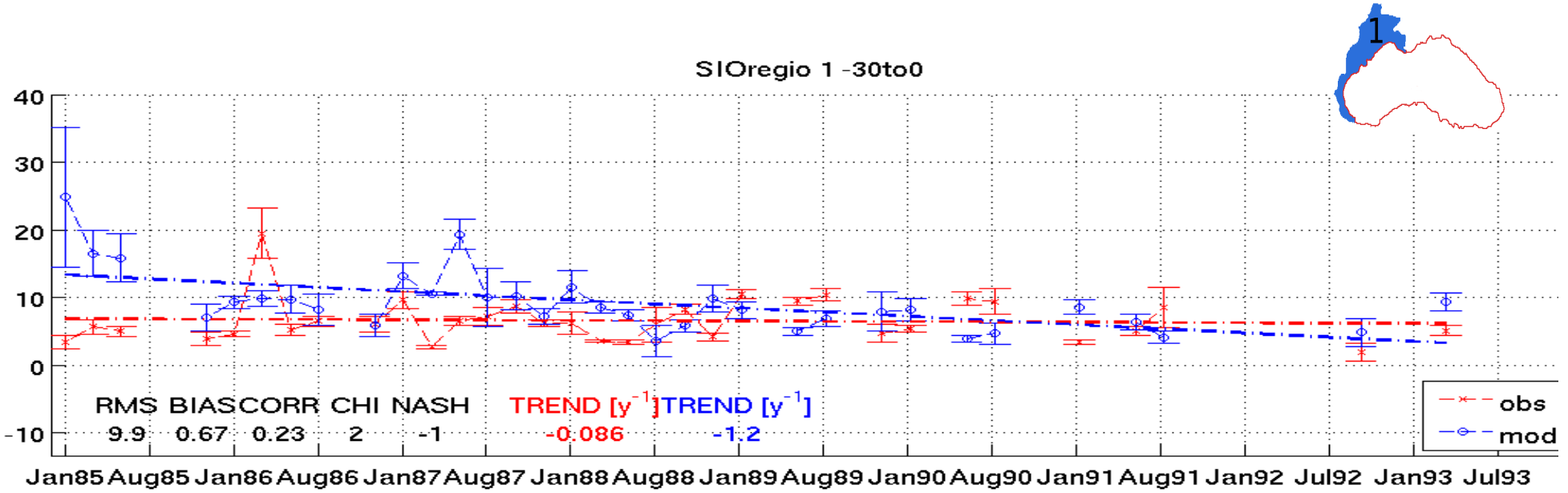


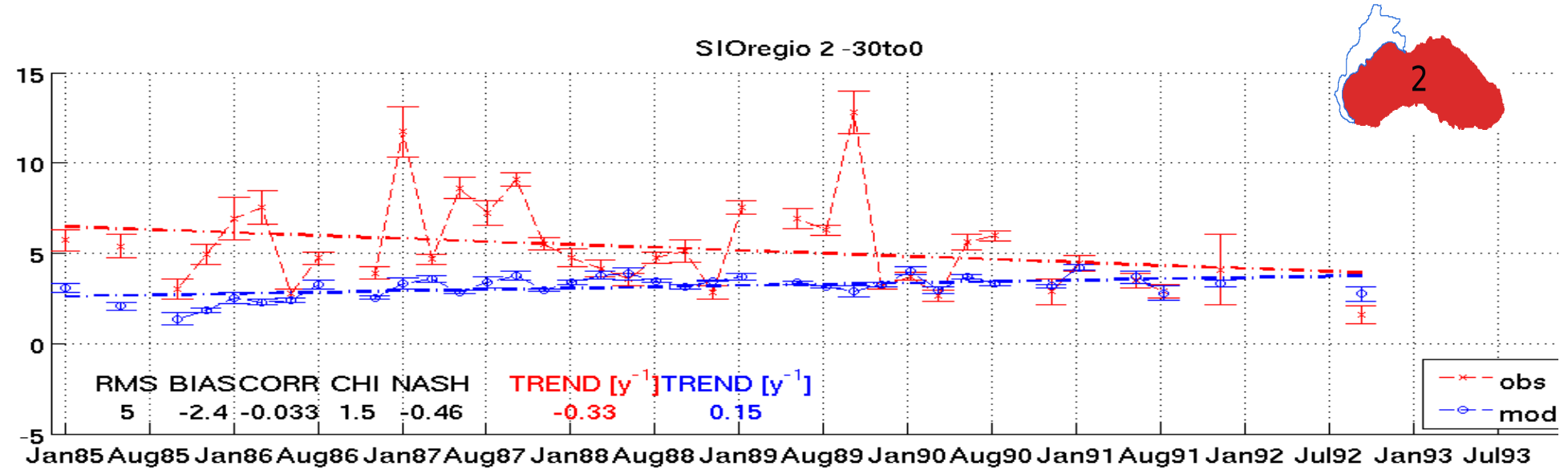
Interannual biological run



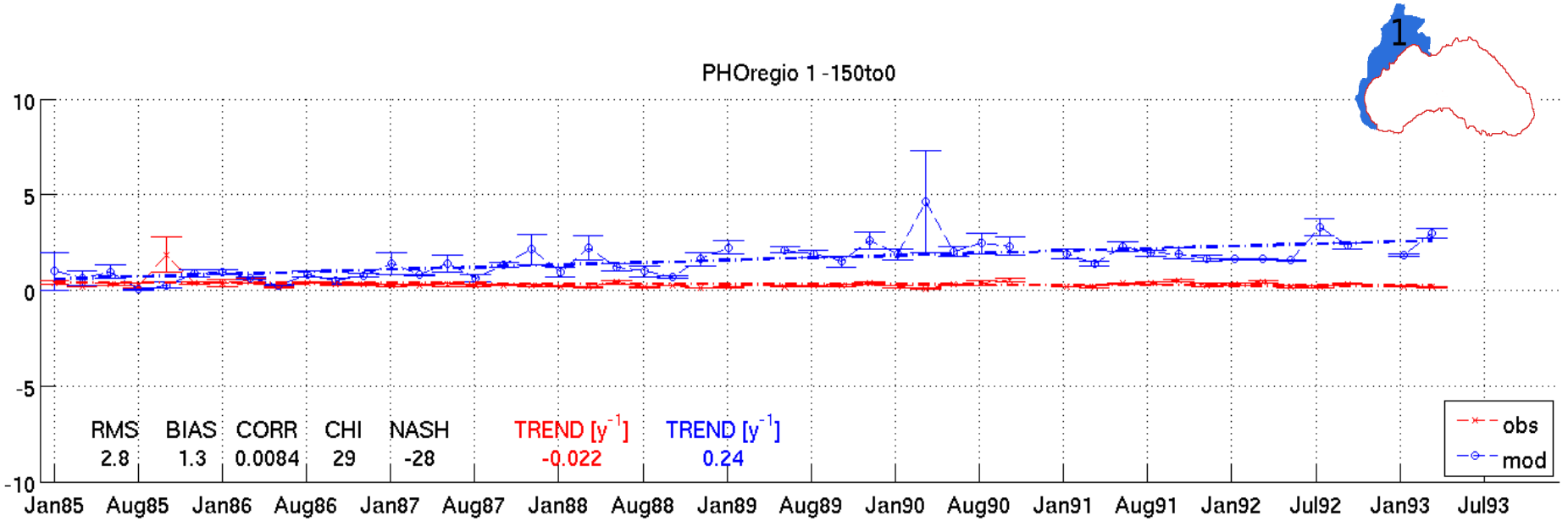


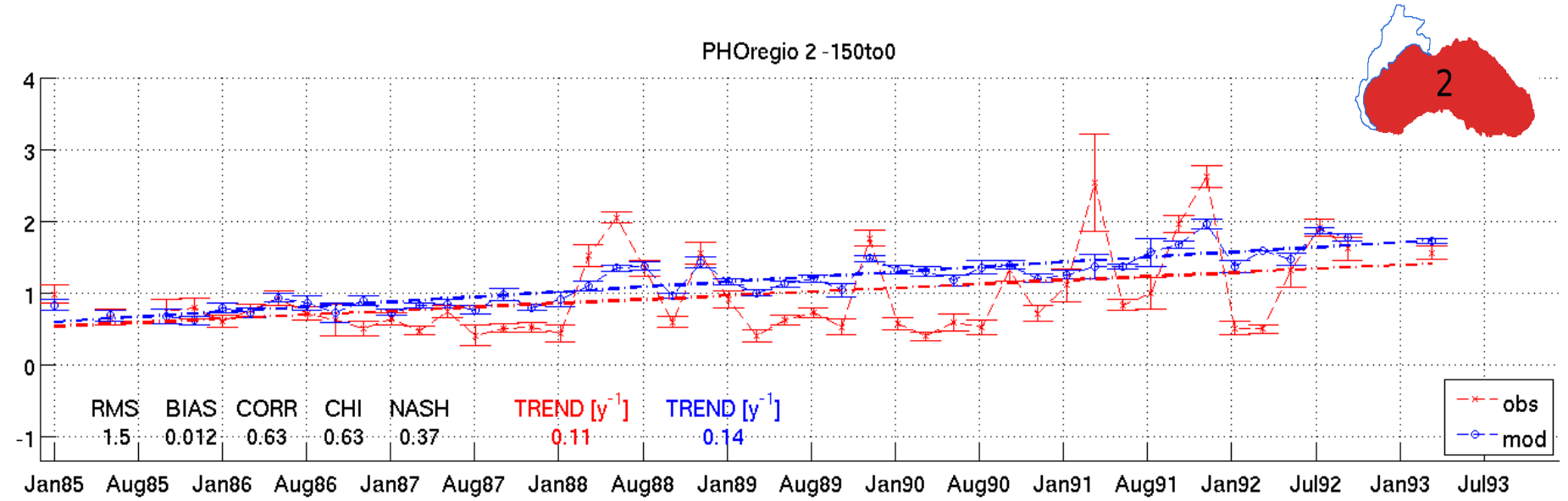
Interannual biological run



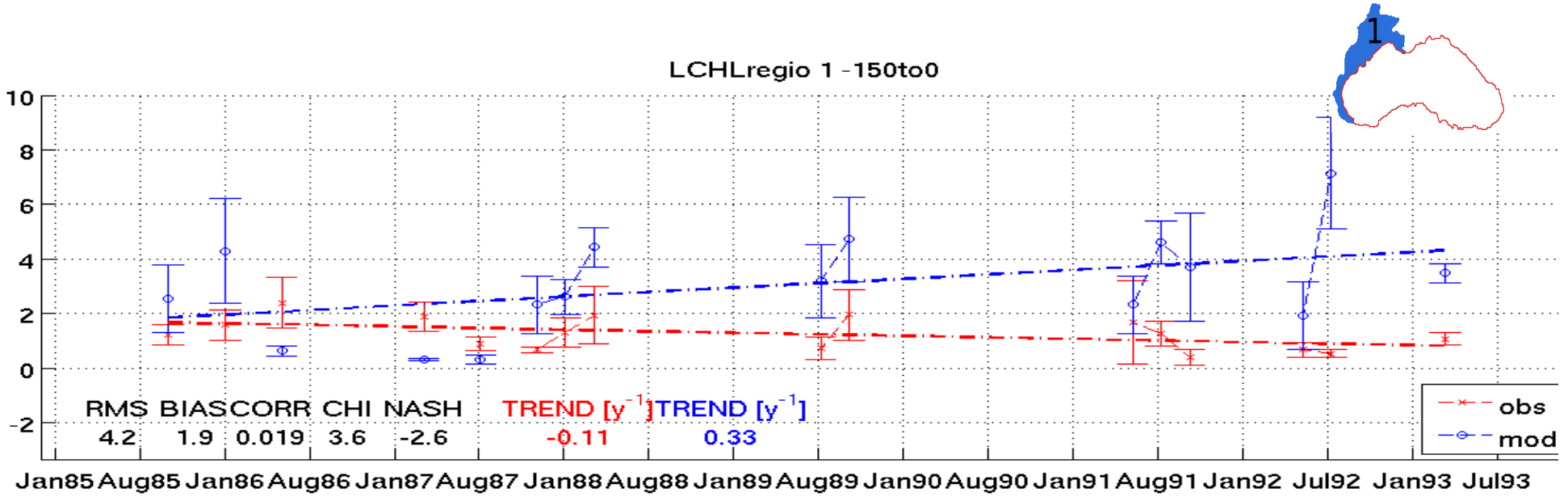


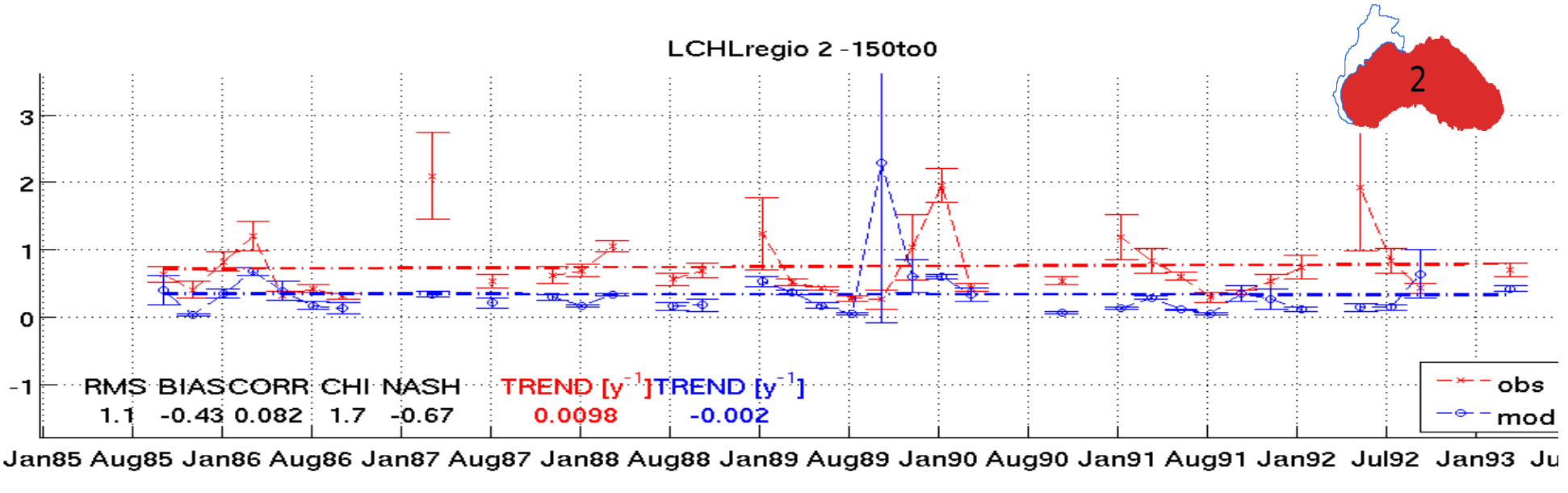
Interannual biological run



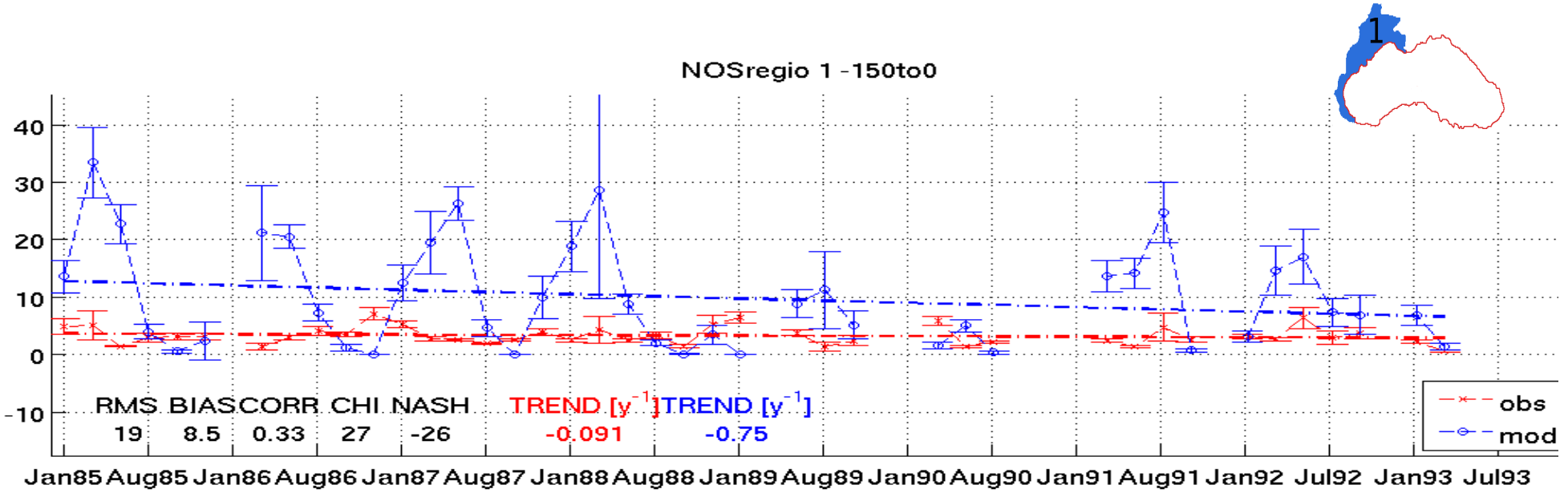


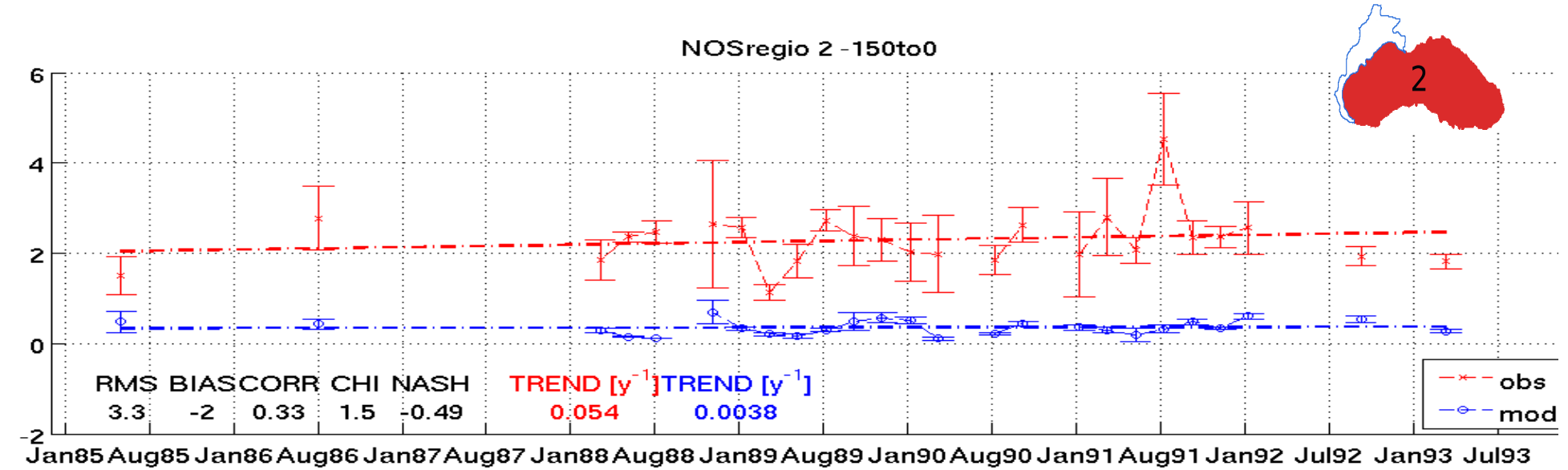
Interannual biological run





Interannual biological run

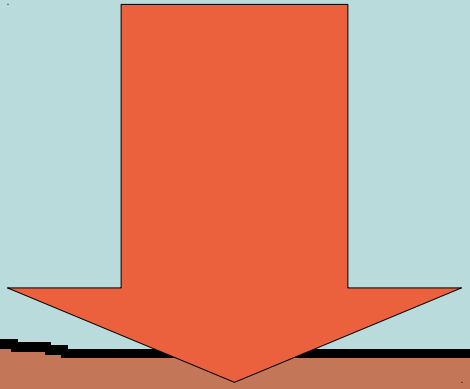




Sediment Model

The sediment pseudo-model compute the **exchanges between sediments and water column** based on stocked quantity, bottom water temperature, oxygen and nitrate concentration.
It is parametrized based on the results of a 1D multilayer sediment model.
(Soetart et al., 2000, *On the coupling of benthic and pelagic biogeochemicals models*, Earth-Science reviews, **51**)

3D model **sedimenting** variables
Diatoms
Silicious detritus
Particulate Organic Carbon
Particulate Organic Nitrogen



Outfluxes of **remineralised** Disssolved nutrients
Nitrate, Silicate, Phosphate, Ammonium, ODU

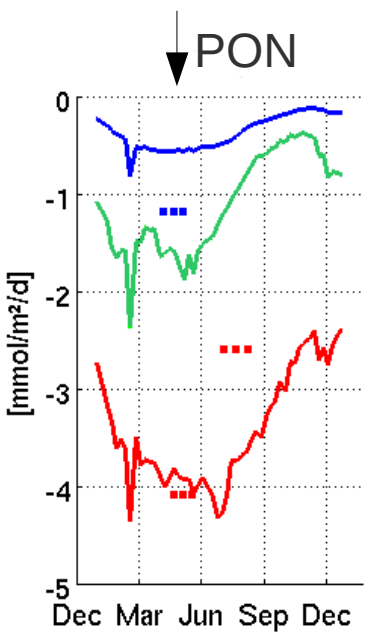
Consumption for sediment remineralisation
Oxygen, Nitrate

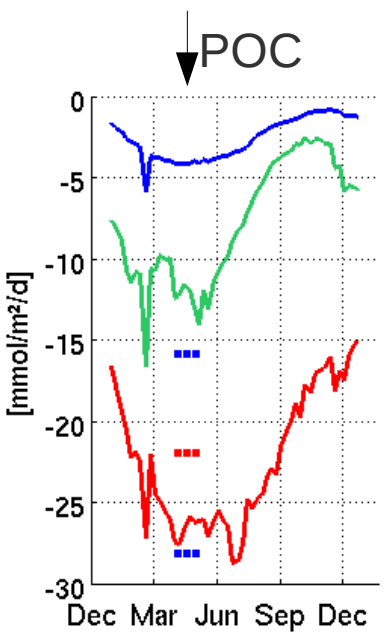
2D Sediment Variables

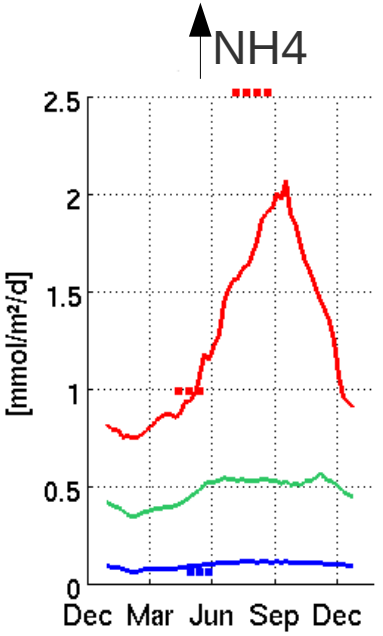
C stock
Fast remin. rate | Slow remin. rate
N/C ratio

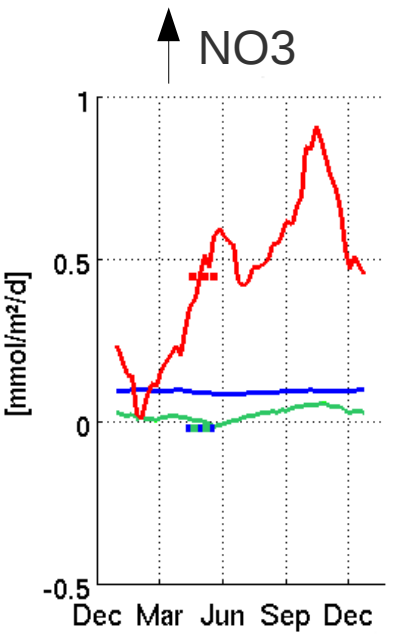
S Stock
Slow remin. rate | Fast remin. rate

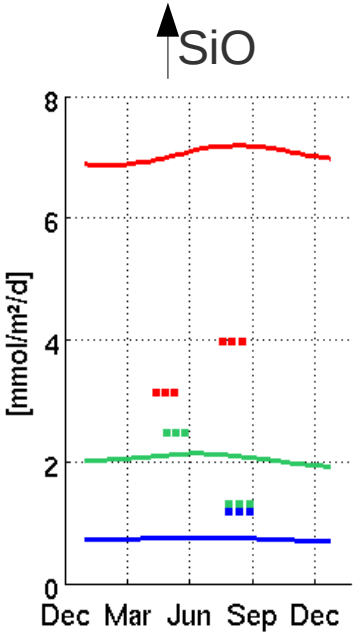
Fluxes values

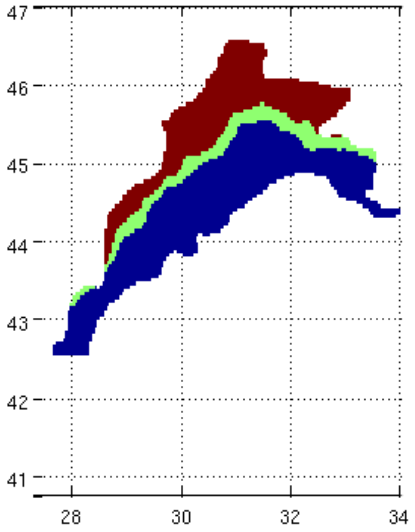








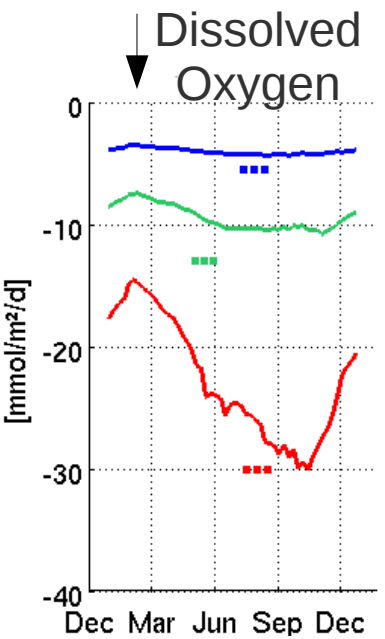


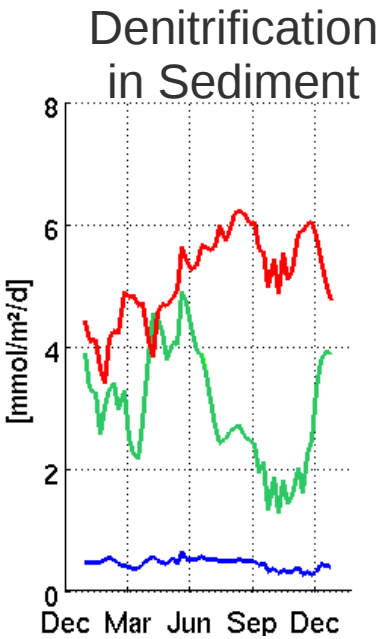


Spatially averaged fluxes for 3 areas of the shelf.

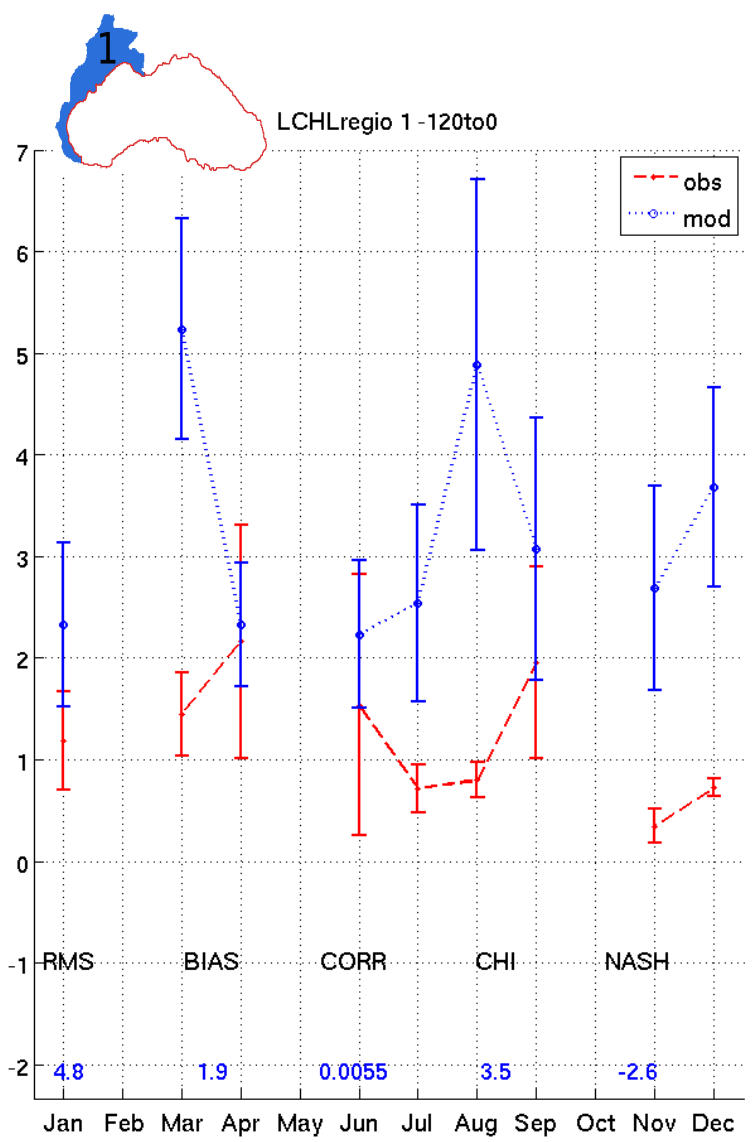
The dotted bars indicates value from EROS21 [Gregoire & Friedrich, 2004, Mar Ecol Prog Ser, **270**].

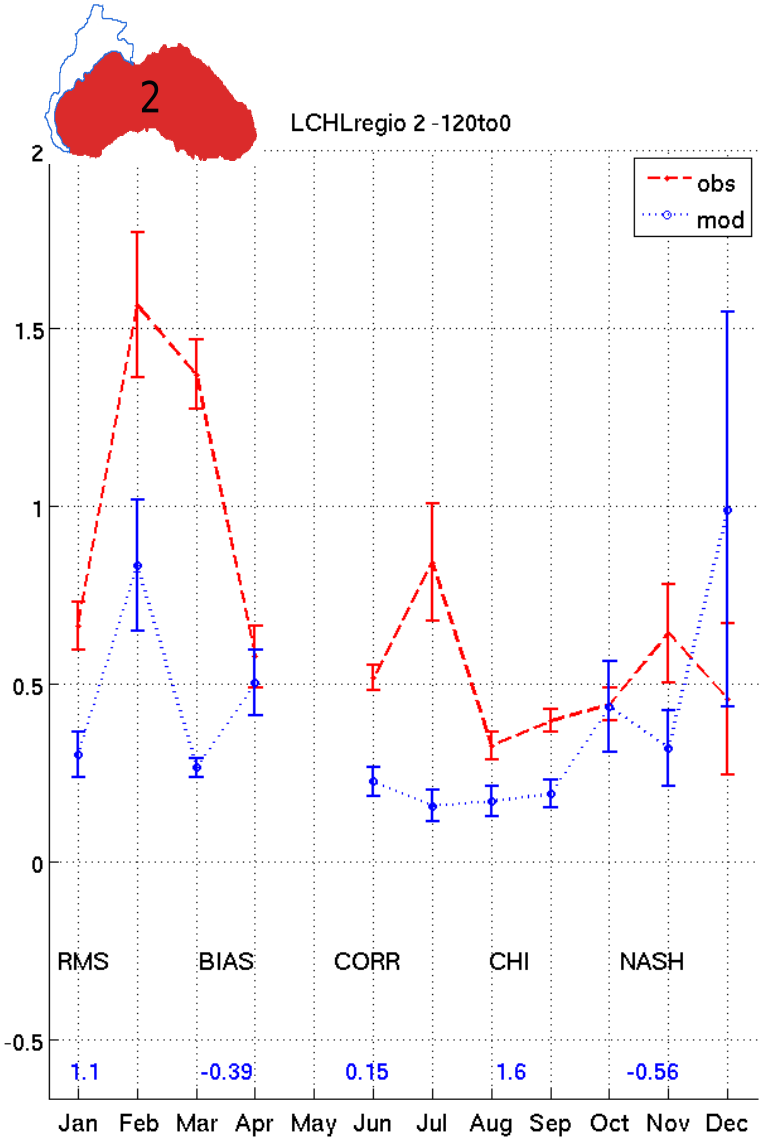
* Outfluxes shows good ranges.
* There seems to have an underestimation of sedimenting POC and PON on the outer part of the shelf → resuspension.
* Overestimation of Silicate outfluxes





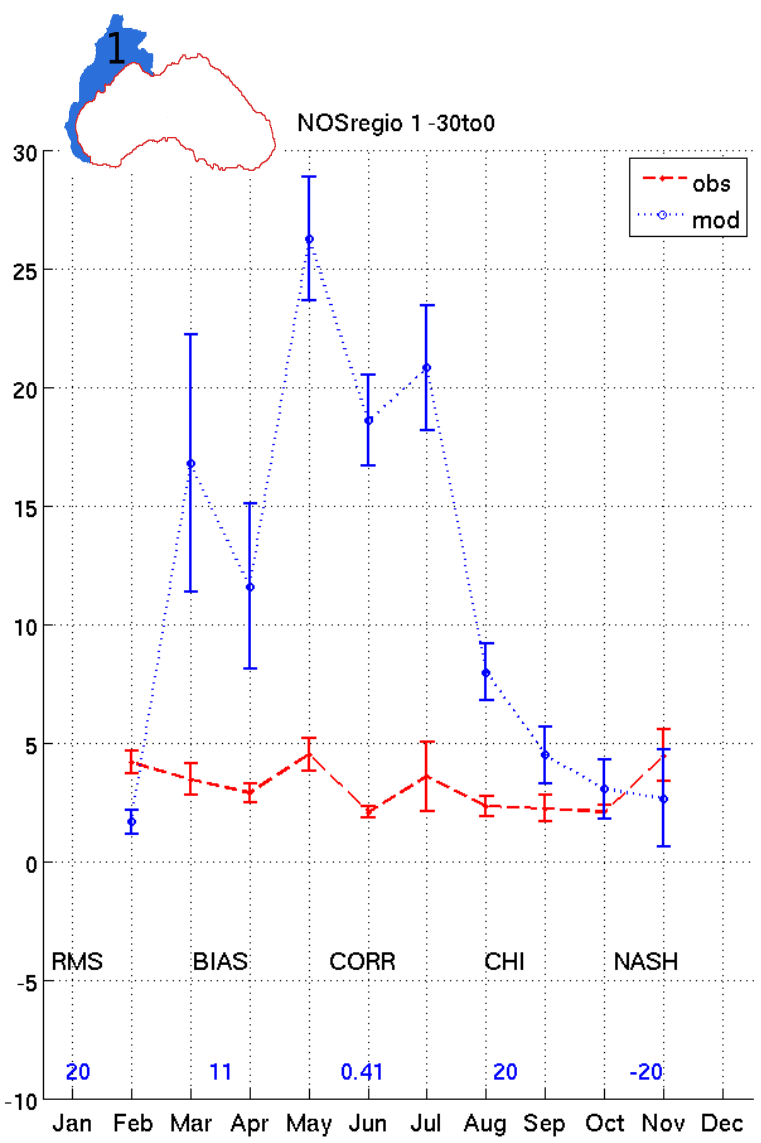
Climatologic biological run (87-92)

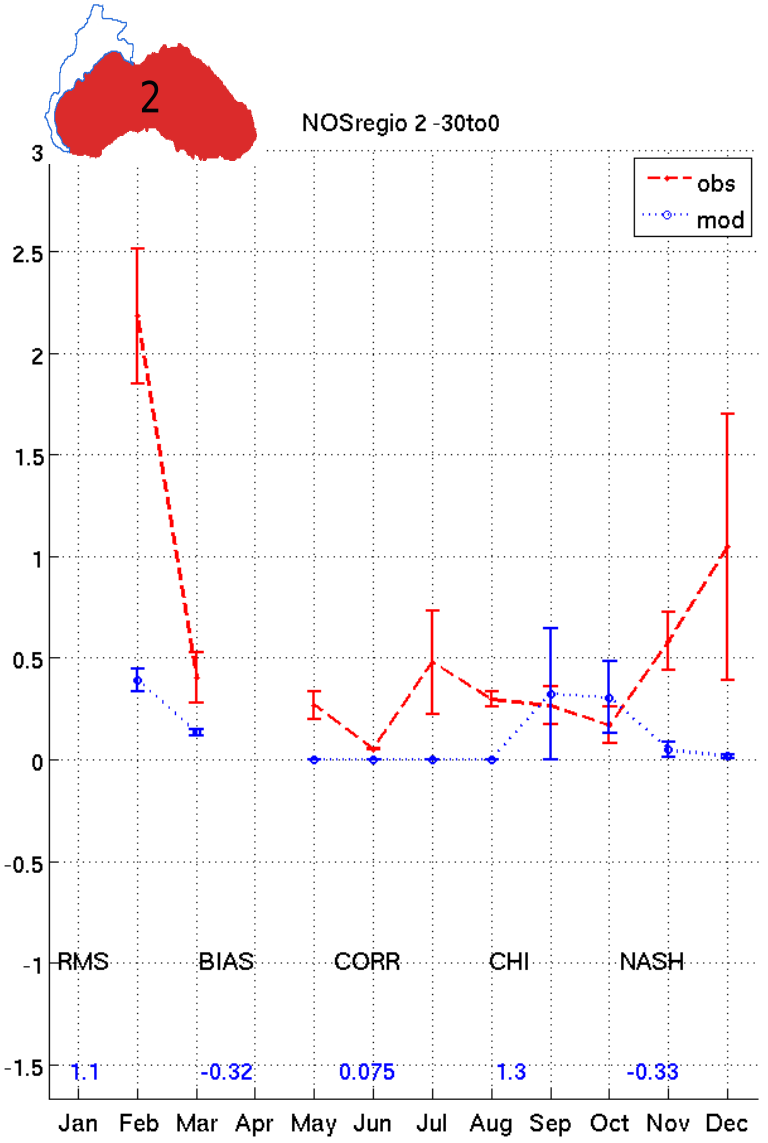




Climatologic biological run (87-92)

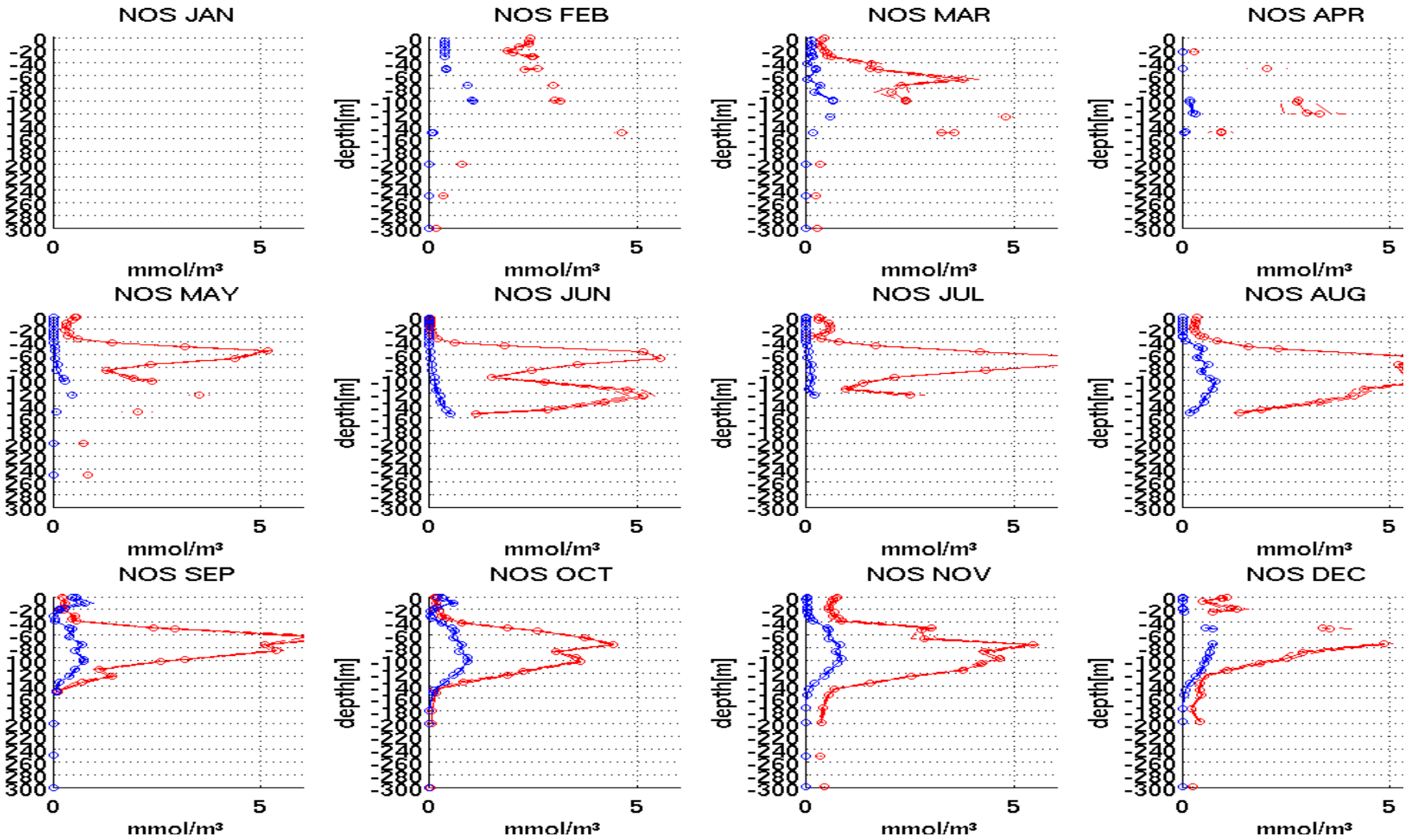
Nitrate seasonnal cycle





Climatologic biological run (87-92)

Monthly nitrate profile



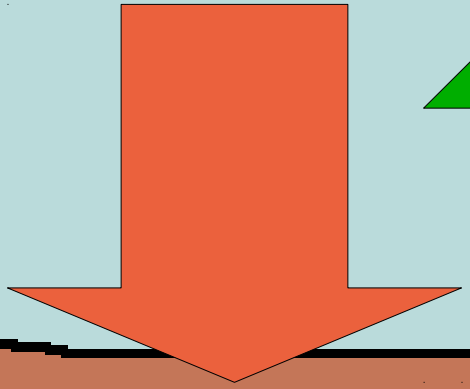
Resuspension

The **resuspension** rate depend on the **bottom stress** resulting from currents and wind waves.

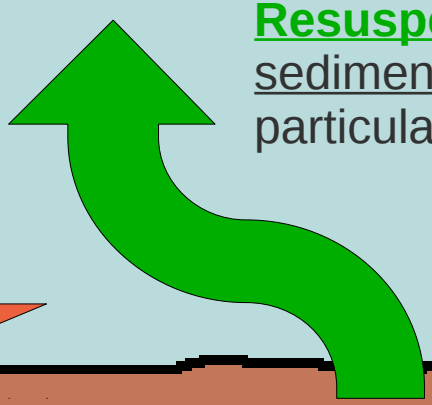
(SESAME deliverable D4.5.7, Emil Stanev and Rostislav Kandilarov)

Unfortunately it introduce a great sensibility in the model to remineralisation and resuspension rates, and initial conditions for Sediments Variables

3D model **sedimenting** variables
Diatoms
Silicious detritus
Particulate Organic Carbon
Particulate Organic Nitrogen



Resuspension of sediment in particulate form



Outfluxes of **remineralised** Disssolved nutrients
Nitrate, Silicate, Phosphate, Ammonium, ODU

Consumption for sediment remineralisation
Oxygen, Nitrate

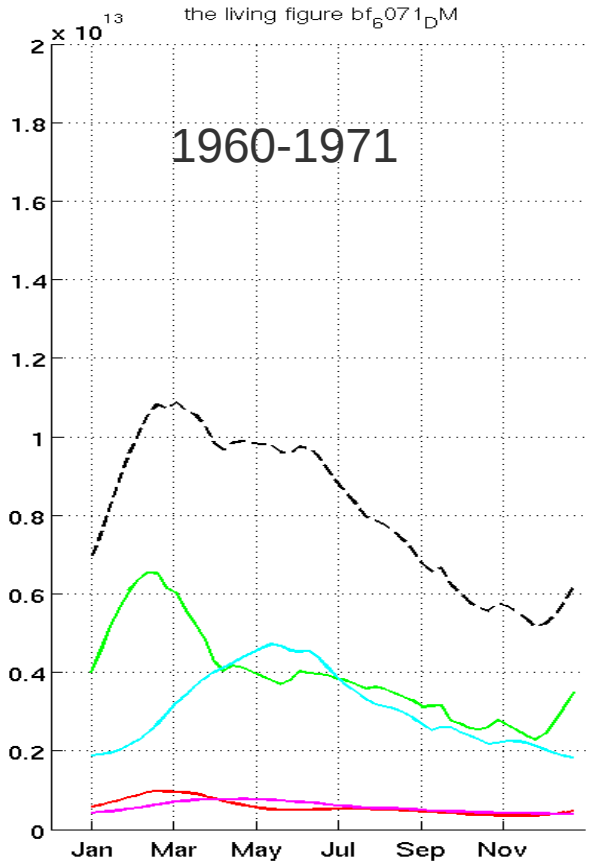
2D Sediment Variables

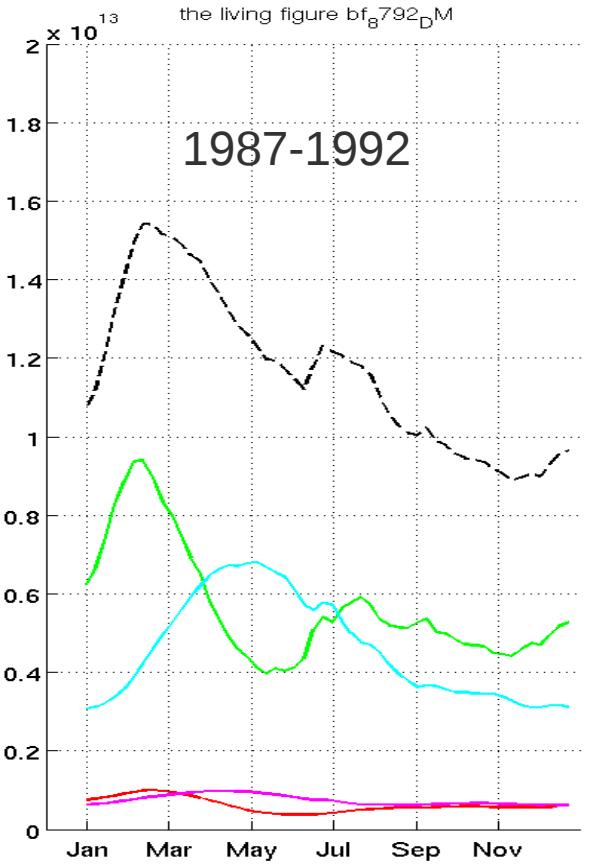
C stock
Fast remin. | Slow remin.
N/C ratio

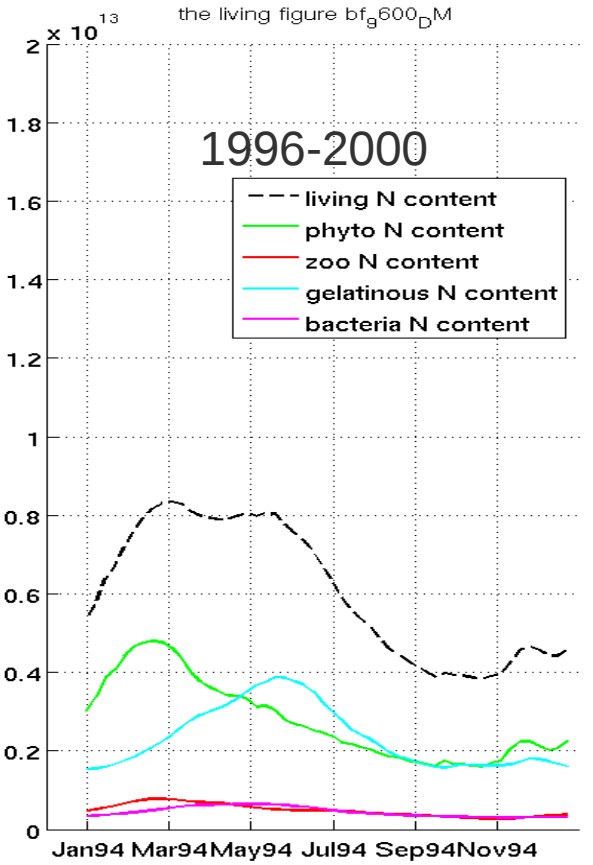
S Stock
Slow remin. | Fast remin.

Sensibility to different climatological forcings

Nitrate in living stocks for different climatological runs

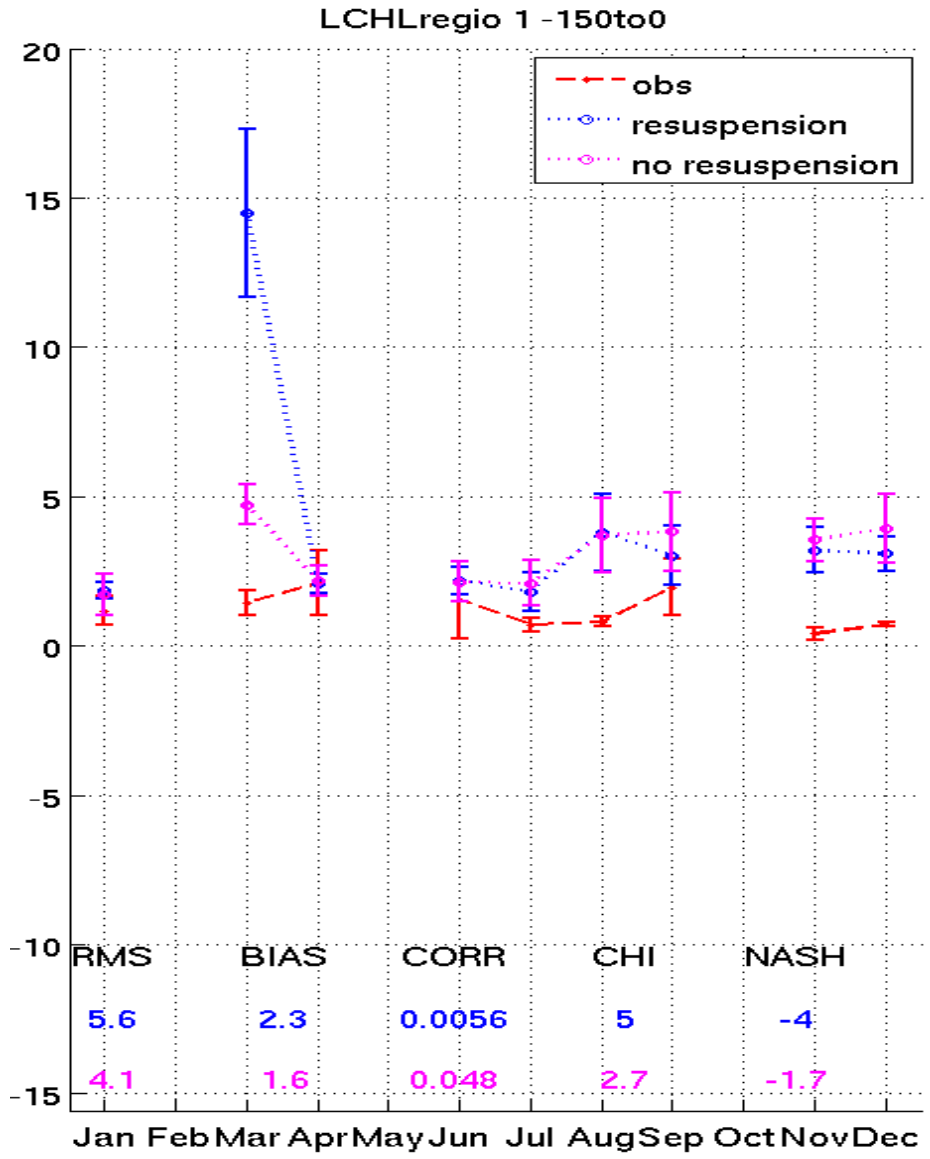


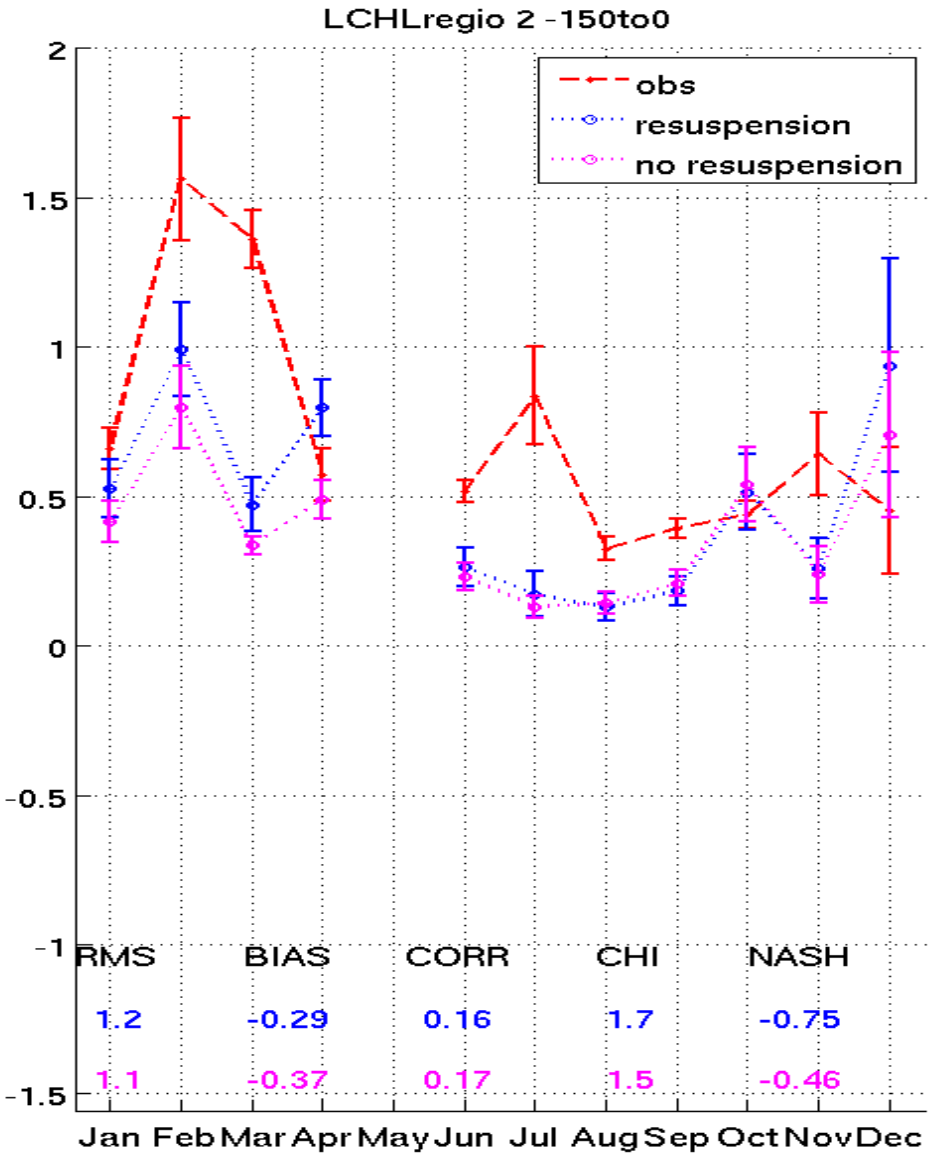


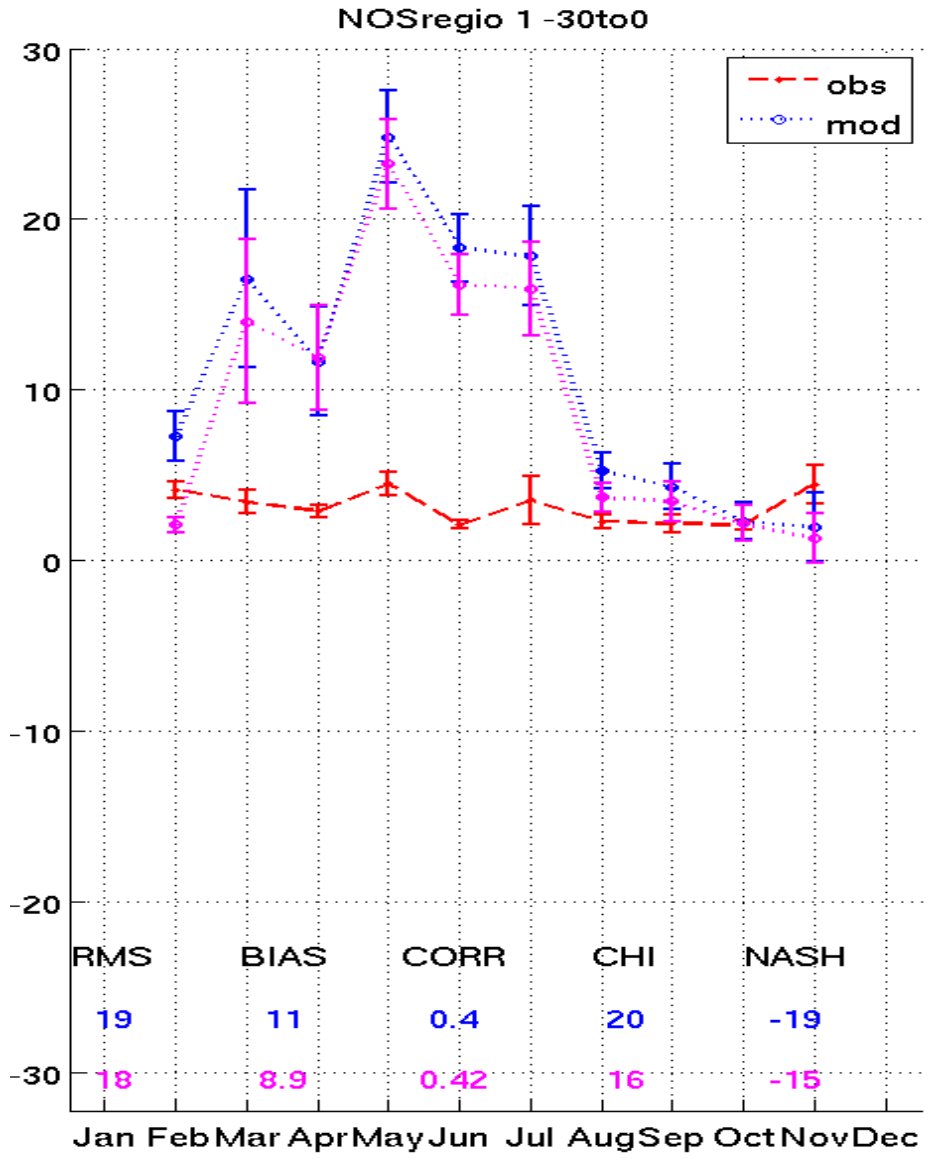


Sensibility of biological model to different set of climatological forcings is still hidden by :

* Systematic error
* Great sensibility to sediment/resuspension model parameter and Initial conditions


LCHLregio 1 -150to0
obs
resuspension
no resuspension
20
15
10
5
0
-5
-10
-15
RMS
BIAS
CORR
CHI
NASH
5.6
2.3
0.0056
5
-4
4.1
1.6
0.048
2.7
-1.7
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


LCHLregio 2 -150to0
obs
resuspension
no resuspension
2
1.5
1
0.5
0
-0.5
-1
-1.5
RMS
BIAS
CORR
CHI
NASH
1.2
-0.29
0.16
1.7
-0.75
1.1
-0.37
0.17
1.5
-0.46
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec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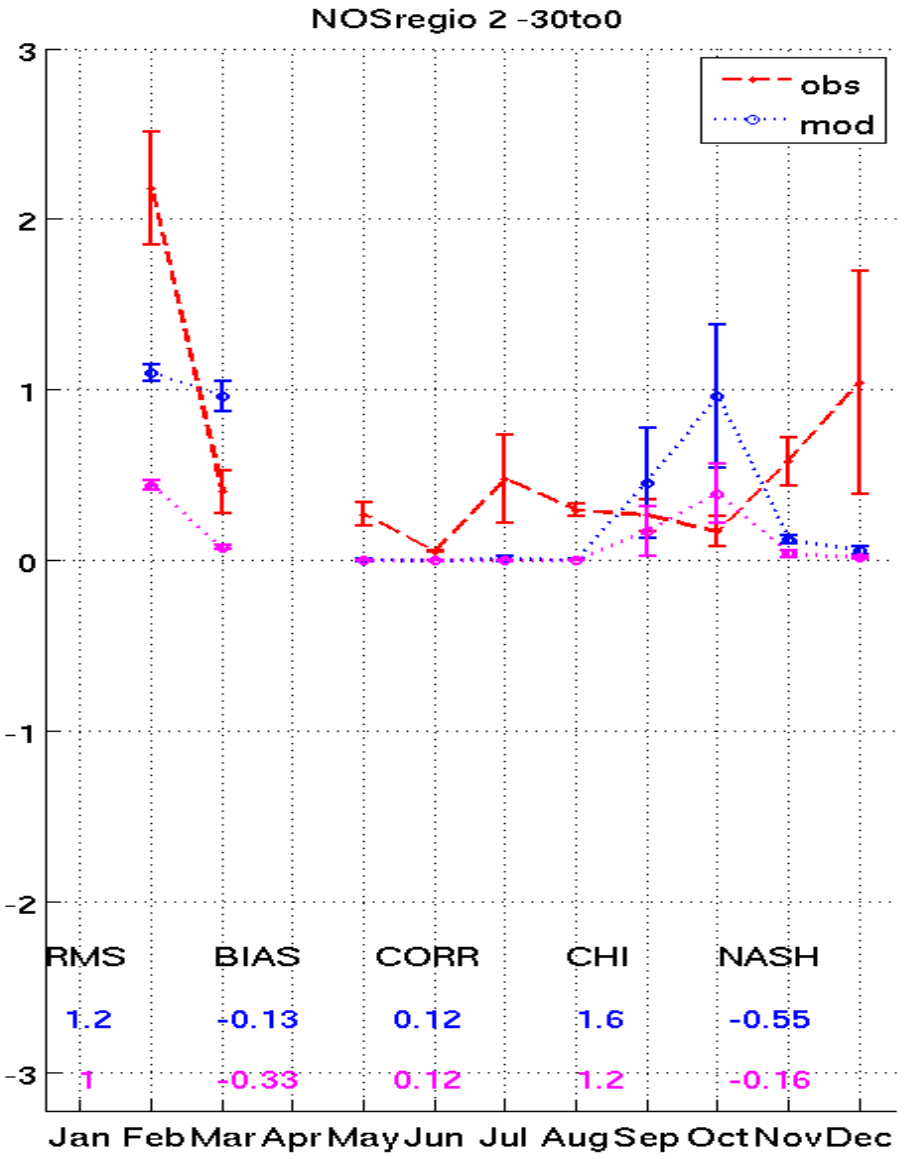
obs
mod
30
20
10
0
-10
-20
-30
RMS
BIAS
CORR
CHI
NASH
19
11
0.4
20
-19
18
8.9
0.42
16
-15
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec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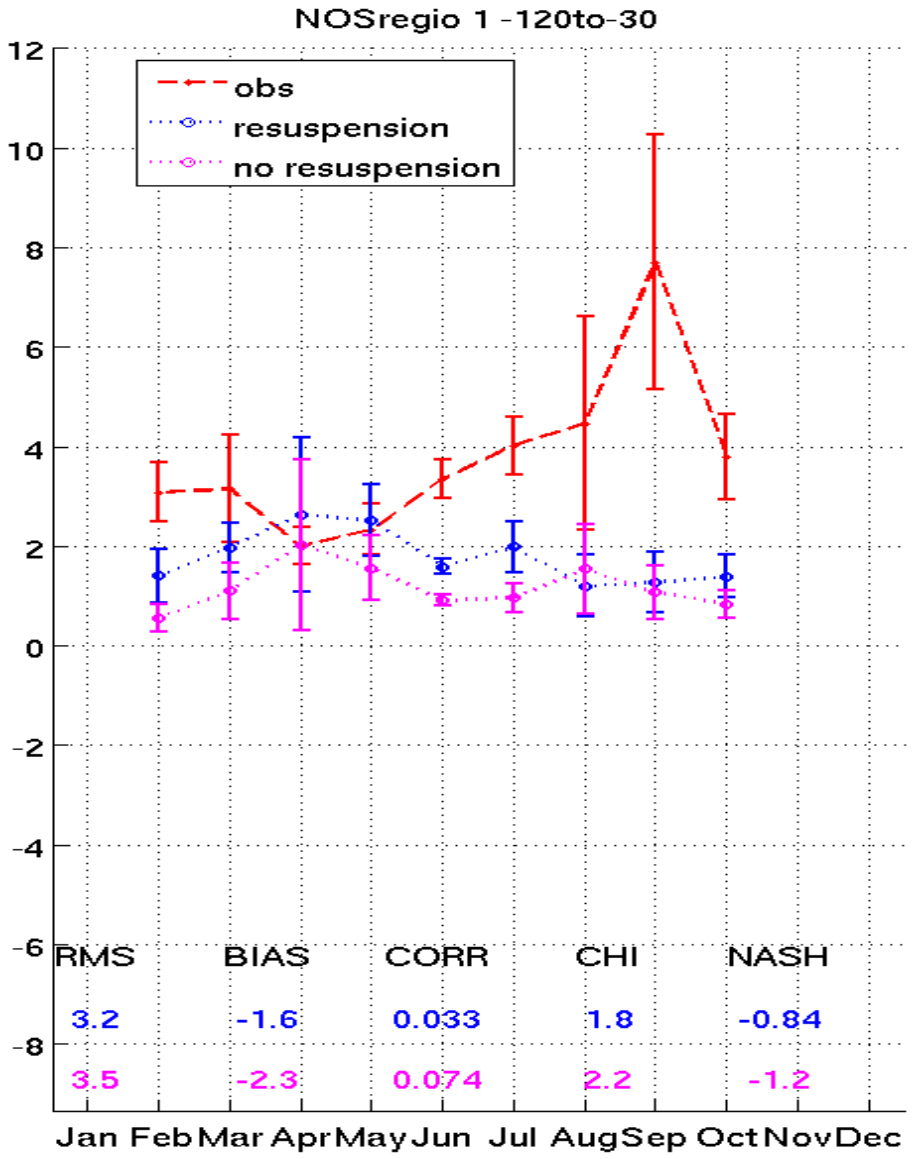
obs
mod
3
2
1
0
-1
-2
-3
RMS
BIAS
CORR
CHI
NASH
1.2
-0.13
0.12
1.6
-0.55
1
-0.33
0.12
1.2
-0.16
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec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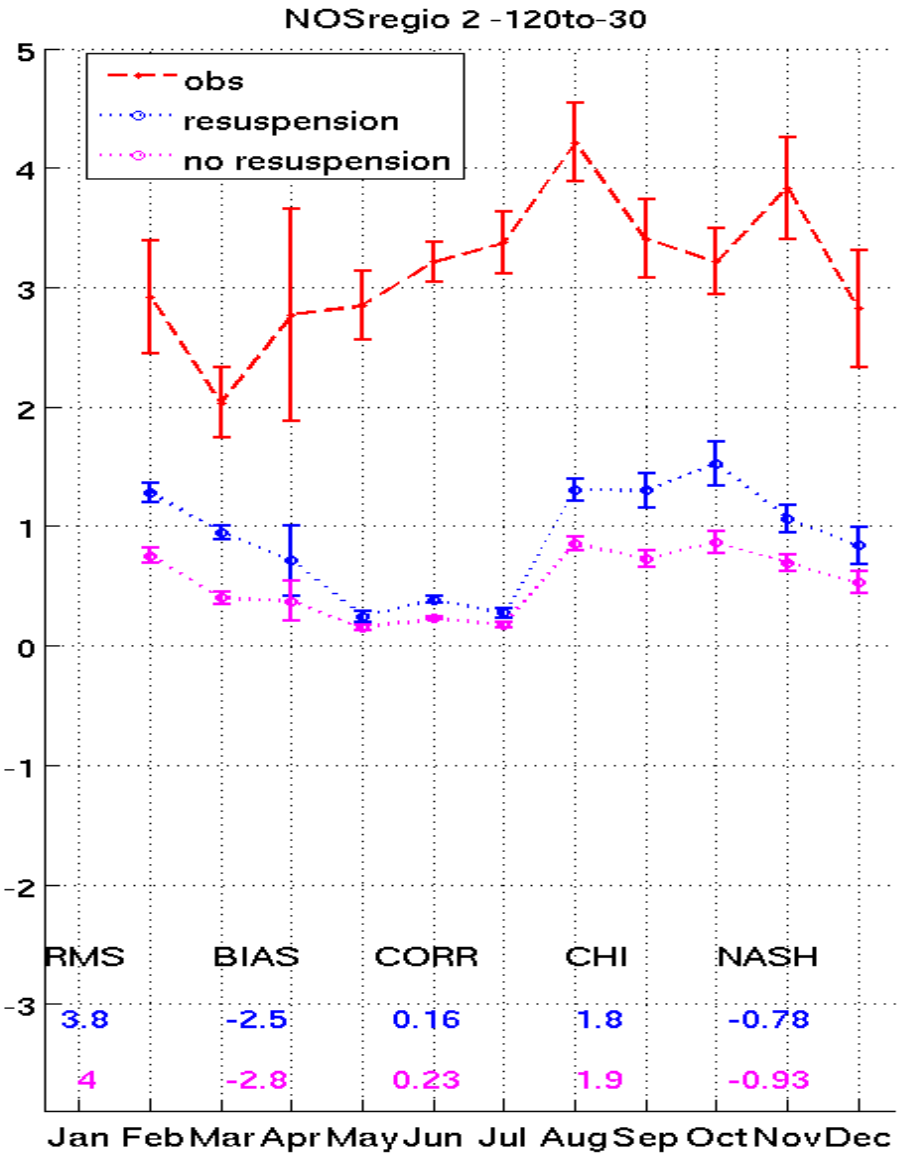
obs
resuspension
no resuspension
12
10
8
6
4
2
0
-2
-4
-6
-8
RMS
BIAS
CORR
CHI
NASH
3.2
-1.6
0.033
1.8
-0.84
3.5
-2.3
0.074
2.2
-1.2
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec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obs
resuspension
no resuspension
5
4
3
2
1
0
-1
-2
-3
RMS
BIAS
CORR
CHI
NASH
3.8
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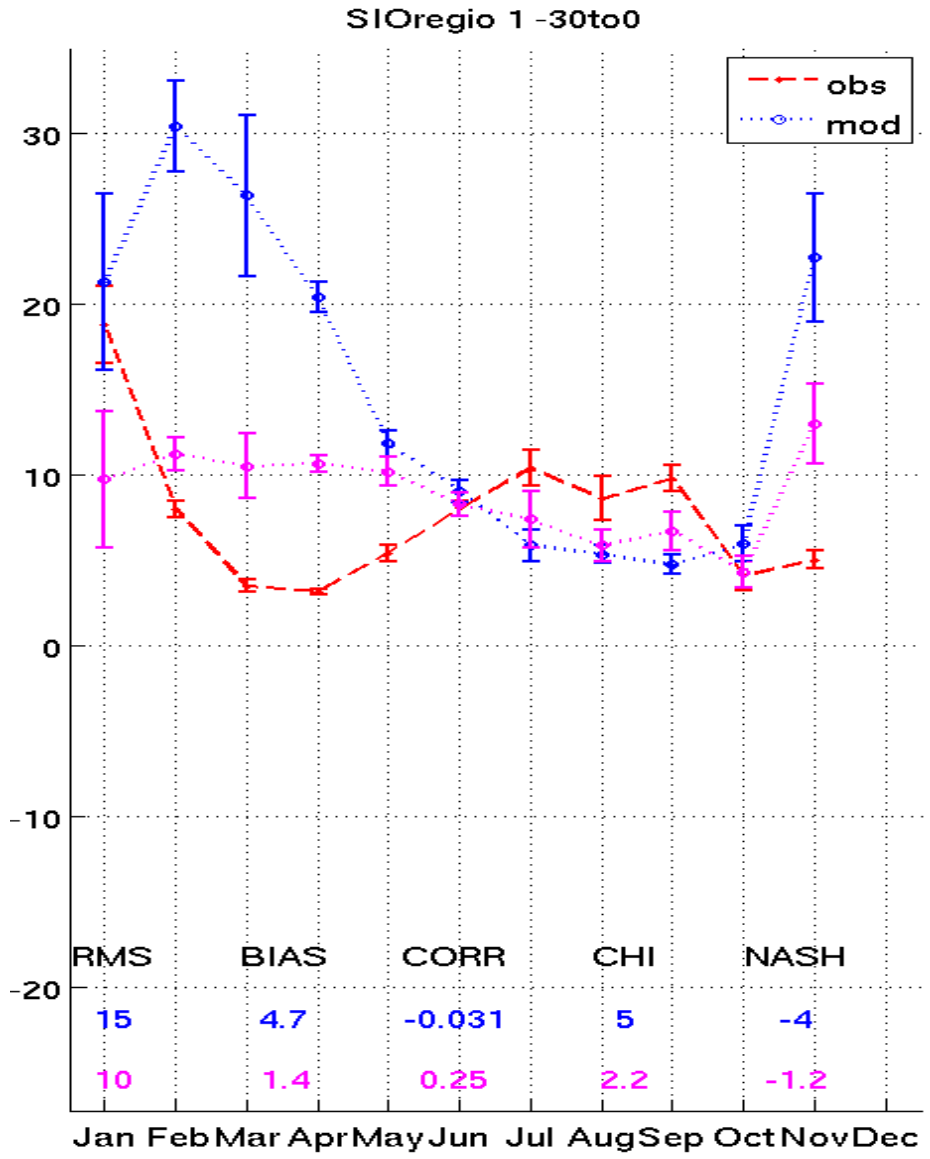
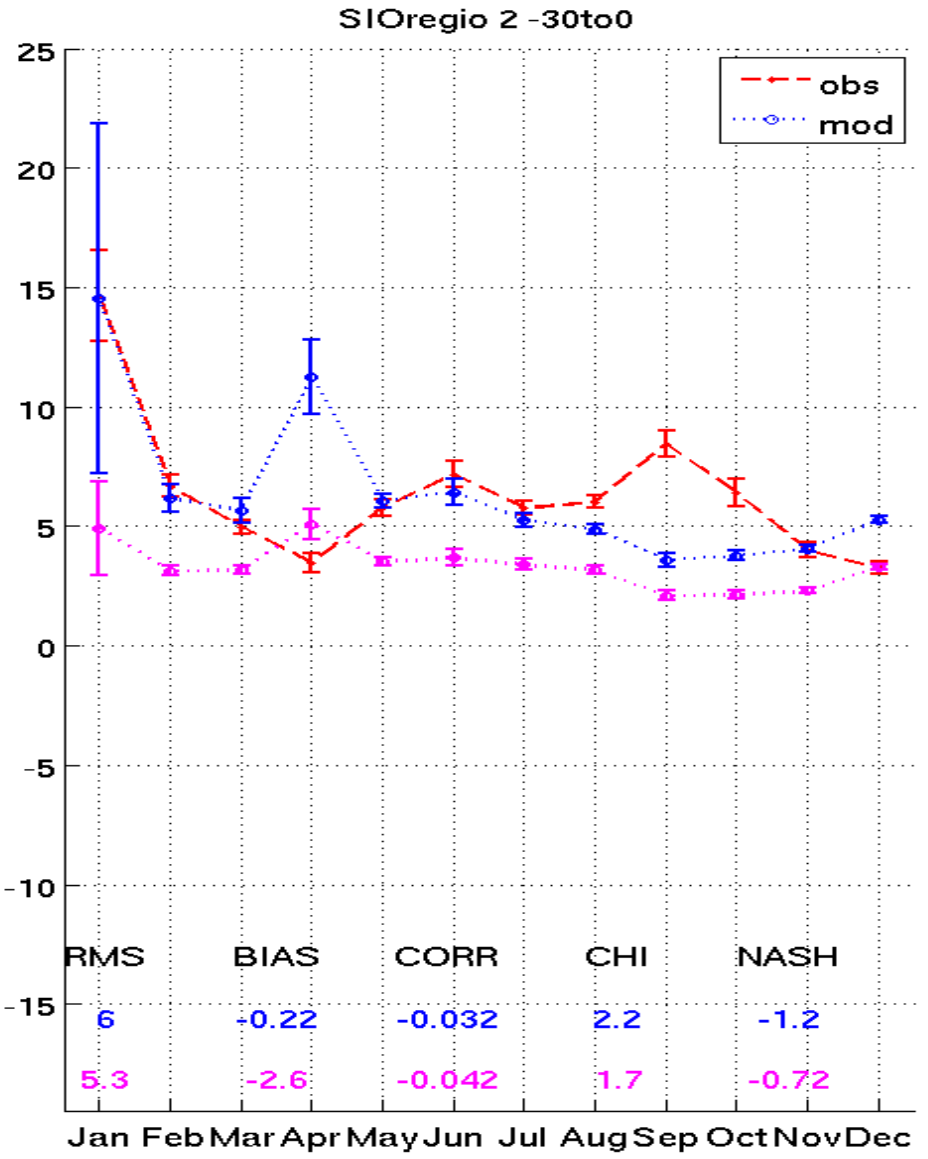
1.8
-0.78
4
-2.8
0.23
1.9
-0.93
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


SIOregio 1 -30to0
obs
mod
30
20
10
0
-10
-20
RMS
BIAS
CORR
CHI
NASH
15
4.7
-0.031
5
-4
10
1.4
0.25
2.2
-1.2
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec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mod
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-5
-10
-15
RMS
BIAS
CORR
CHI
NASH
6
-0.22
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-1.2
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1.7
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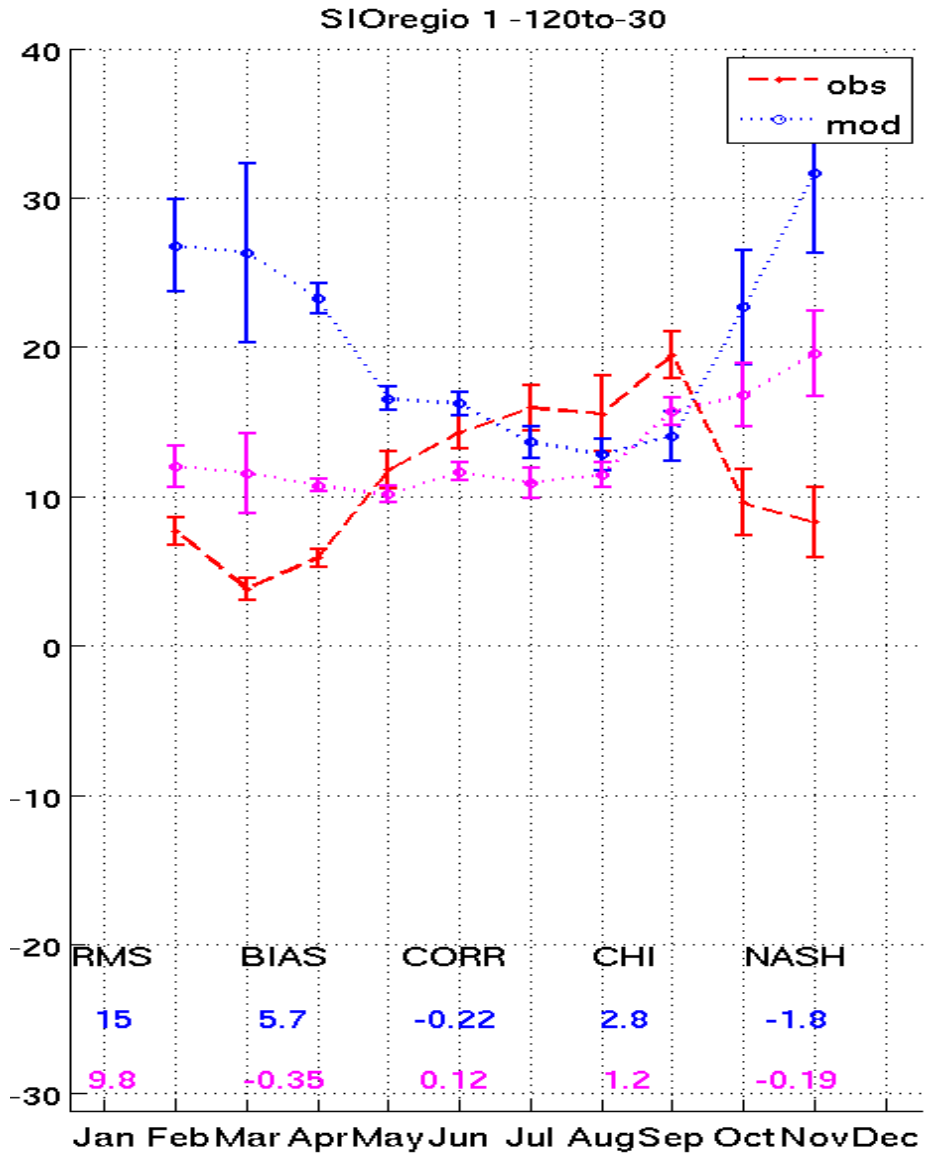
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec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obs
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20
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0
-10
-20
-30
RMS
BIAS
CORR
CHI
NASH
15
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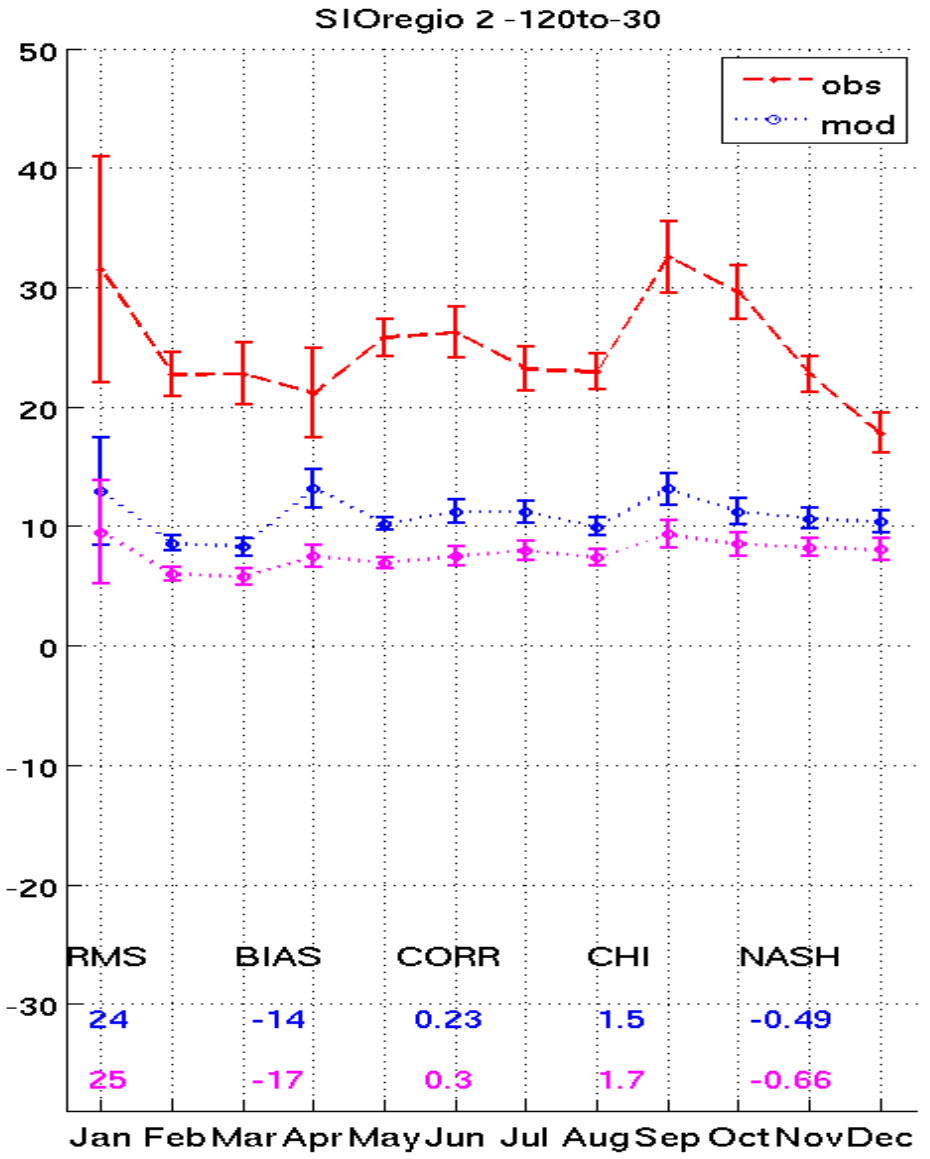
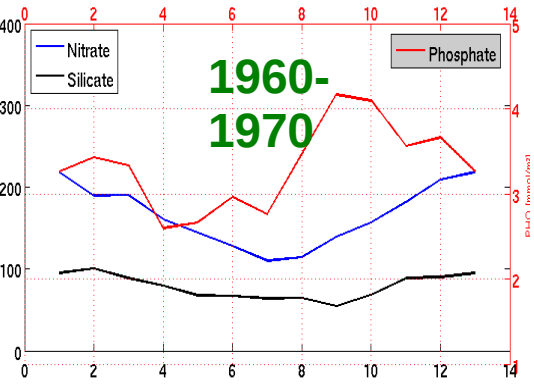
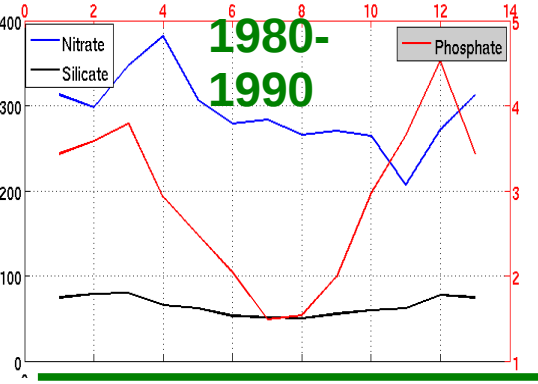
9.8
-0.35
0.12
1.2
-0.19
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

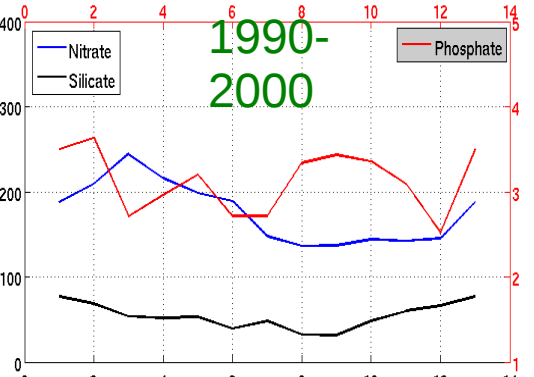

SIOregio 2 -120to-30
obs
mod
50
40
30
20
10
0
-10
-20
-30
RMS
BIAS
CORR
CHI
NASH
24
-14
0.23
1.5
-0.49
25
-17
0.3
1.7
-0.66
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

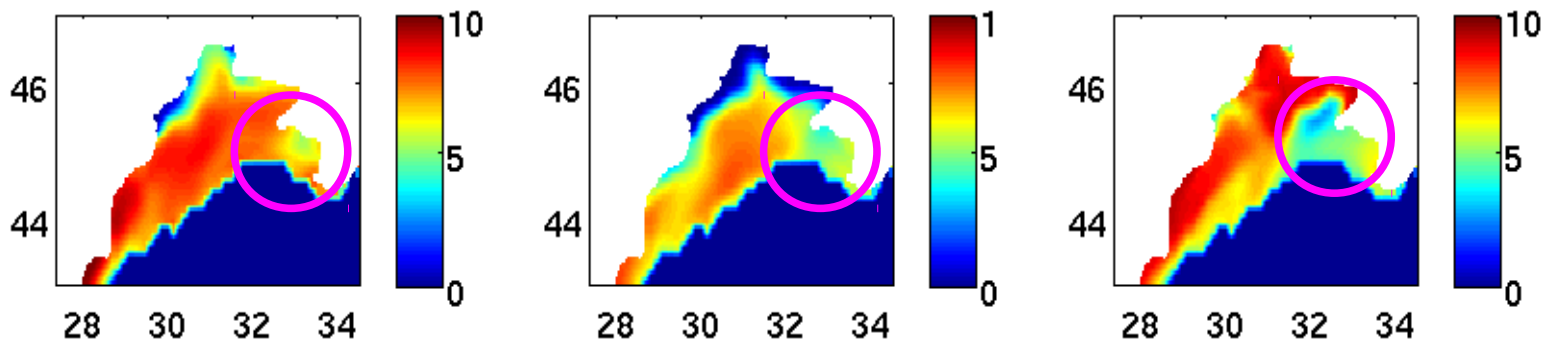
Hydrodynamical process impacting on ecosystem :
1. Sevastopol eddy Activity
Sensibility of the Area

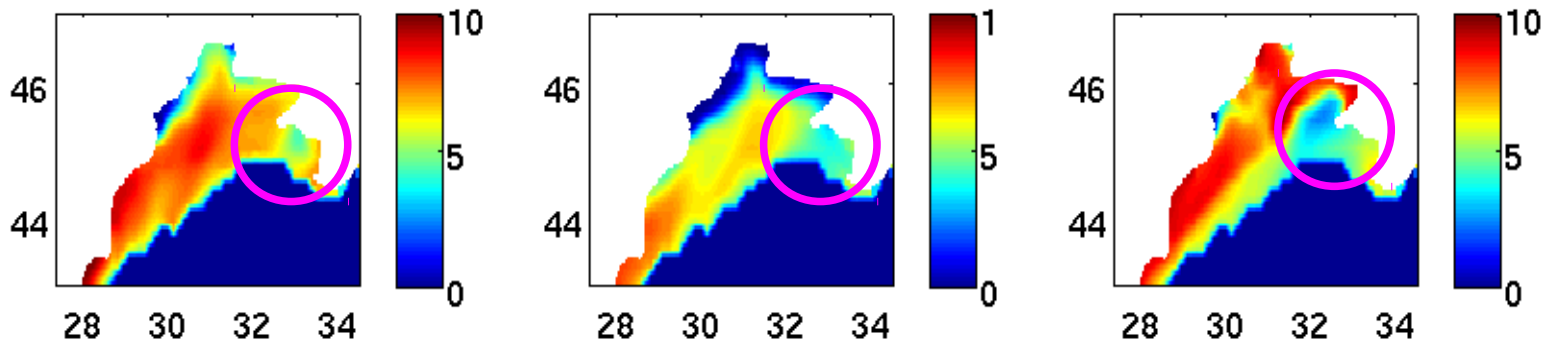
Bottom Dissolved Oxygen [mg/l]

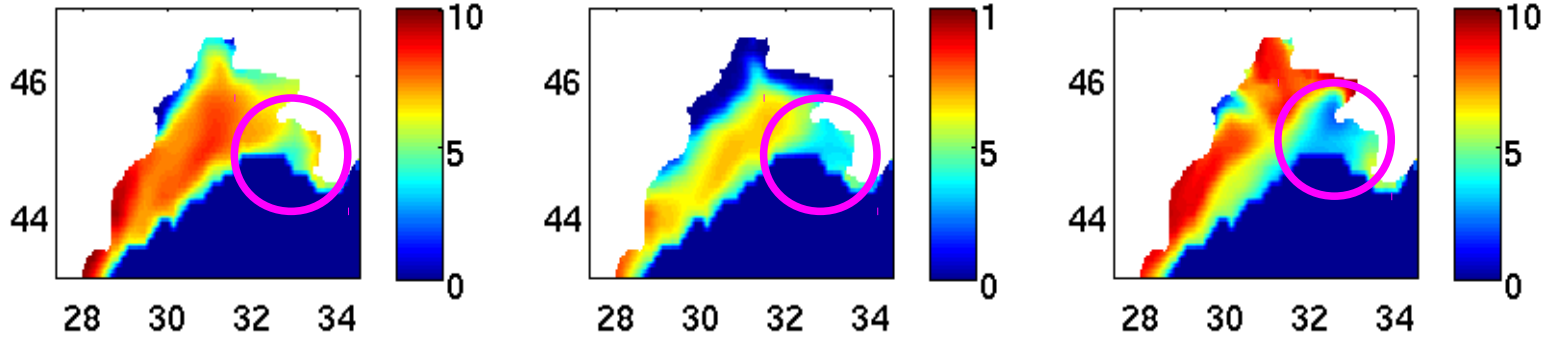








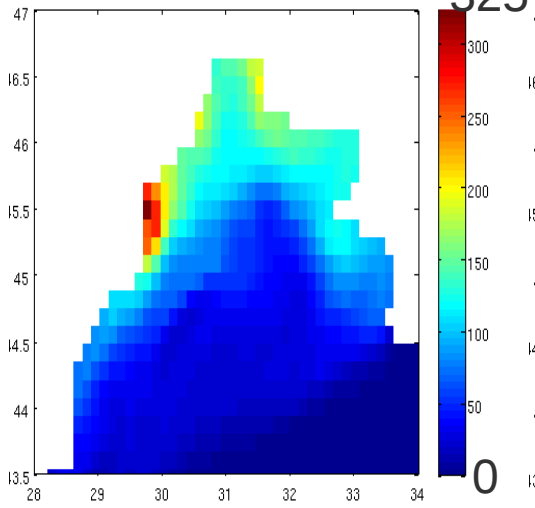




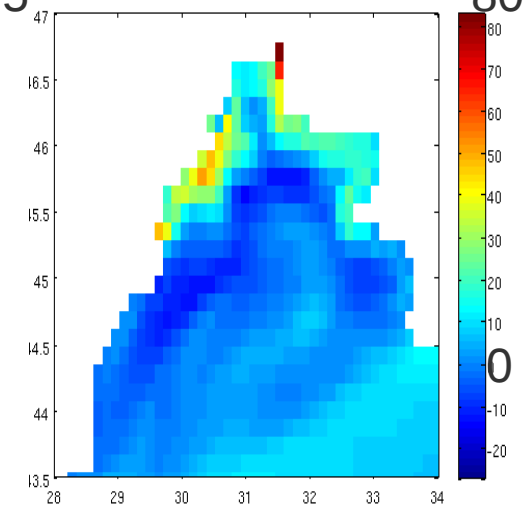
Hydrodynamical process impacting on ecosystem :
1. Sevastopol eddy Activity
Fluxes involved in Oxygen budget

SOURCE

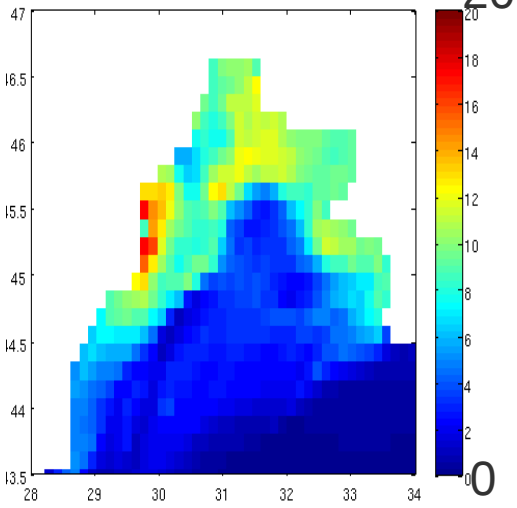
Primary Production



Surface Fluxes



Nitrate reduction

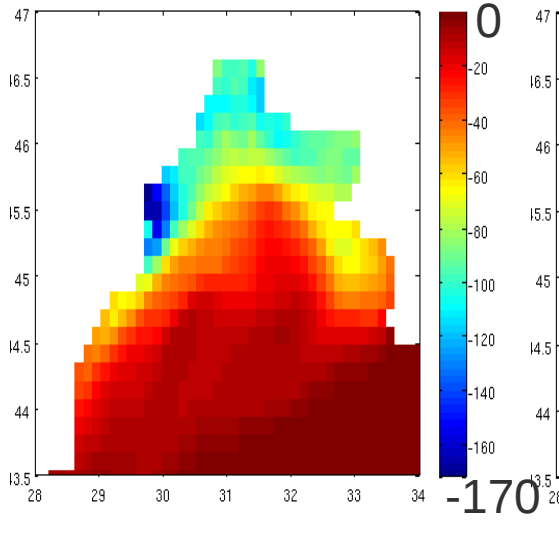


Annual mean.
Vertically integrated.

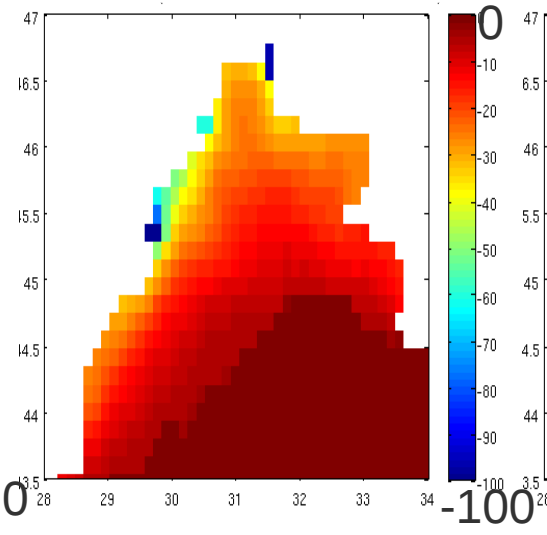
Units :
mmolO/m²/day

SINK

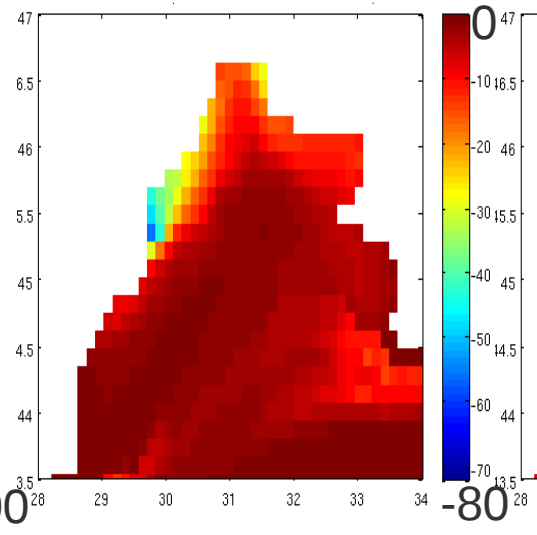
Respiration



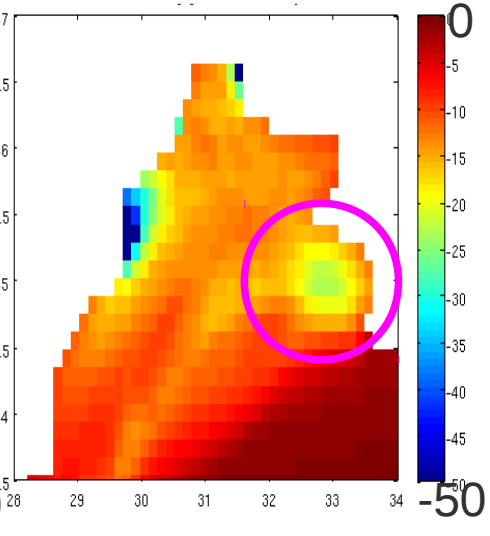
Bottom Fluxes



Nitrification



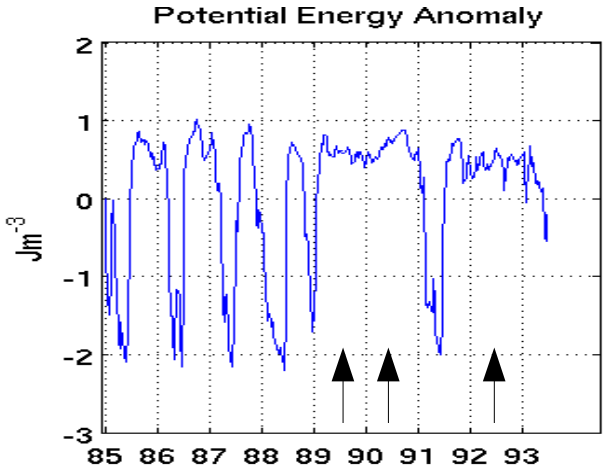
Bacterial Activity

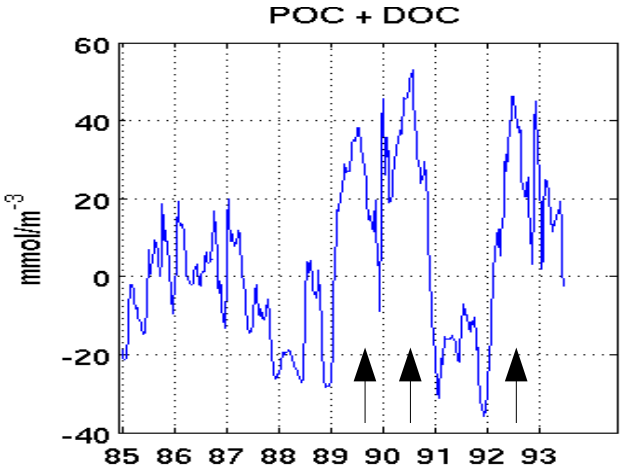


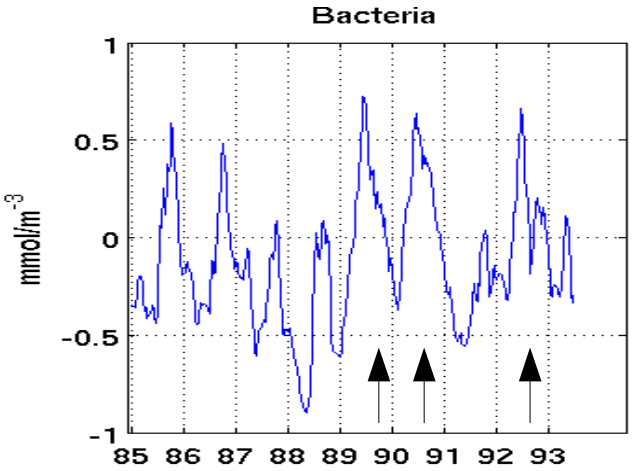
Hydrodynamical process leading to ecosystem sensibility : 1. Sevastopol eddy Activity

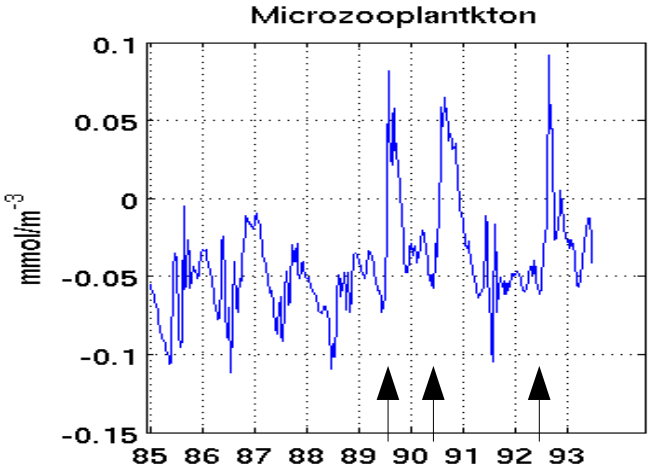
Interannual signature of Sevastopol activity

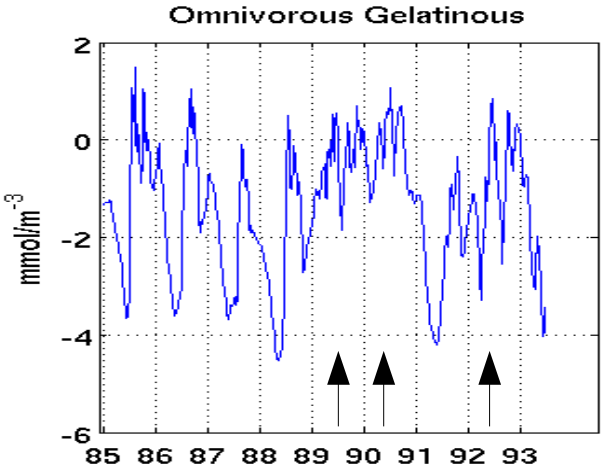
Anomalies between concentration at Sevastopol location and averaged concentration over the shelf. The impact of the Sevastopol Eddy on zooplankton community is underlined in D.1.2.4.

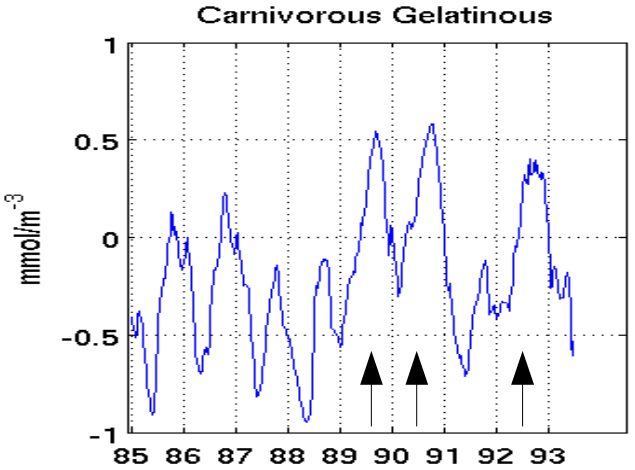






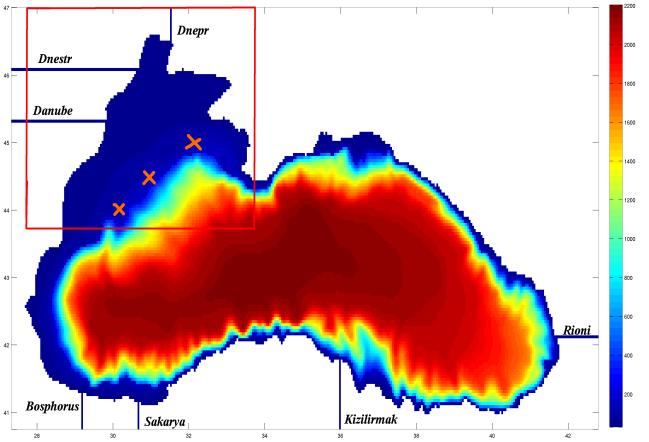




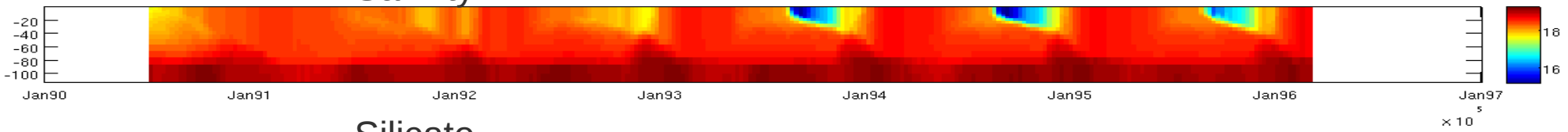


Hydrodynamical process leading to ecosystem sensibility :

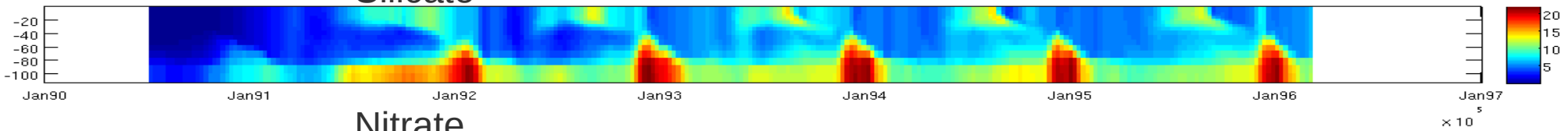
2. Basin Water Signature in profile



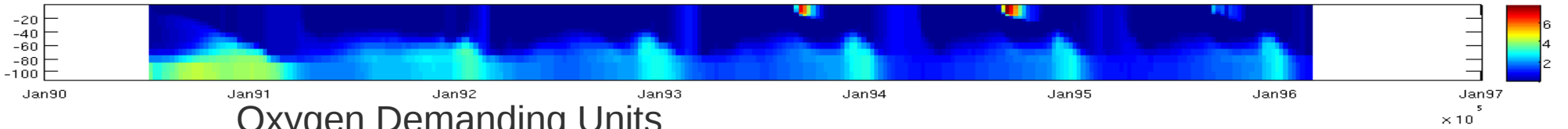
Salinity



Silicate

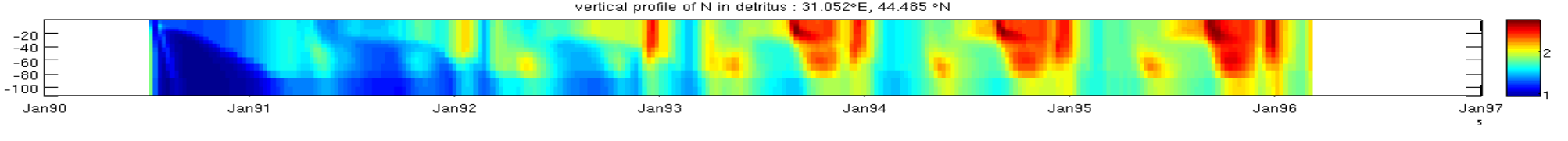


Nitrate



Oxygen Demanding Units

PON + DON



Hydrodynamical process leading to ecosystem sensibility : 2. Basin Water

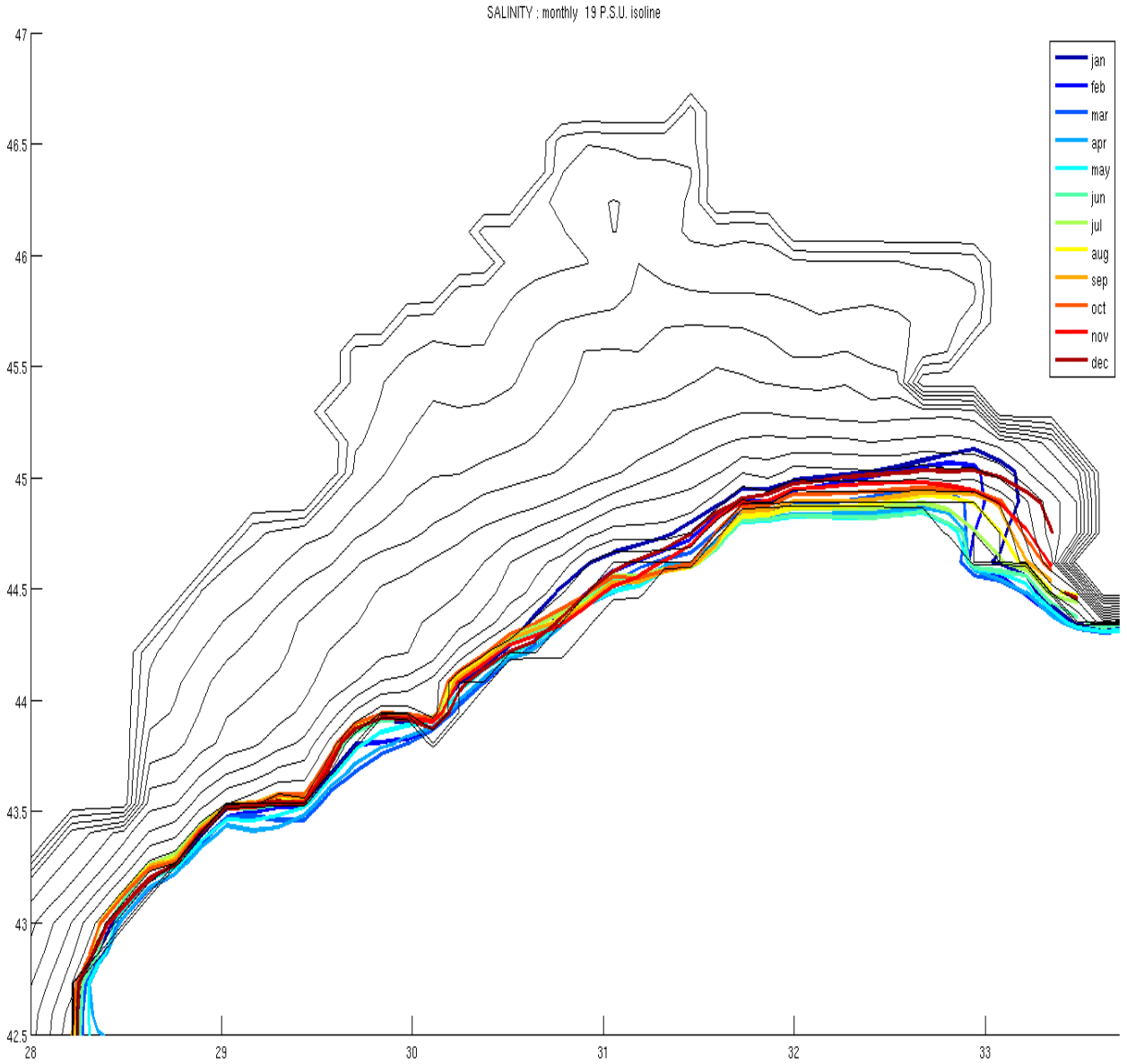
Seasonnal oscillation of 19 p.s.u. iso-haline

There is an seasonnal oscillation of the level where the pycnocline meet the shelf break.

It's influence were evidenced for in-situ temperature (G. Shapiro, *personnal communication*), by correlating bottom dense water temperature to basin water.

We suspect it's influence on nutrient exchanges through the shelf break, hence on nutrient concentration on the shelf.

Any evidence in in-situ data ?



Conclusion

* We detailed the variability of the hydrodynamic structure, and underlined shifts that have occurred in the past.

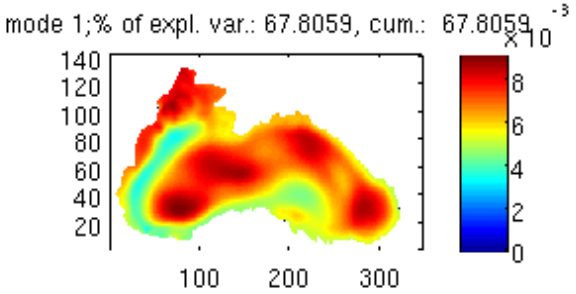
* We evidenced process through which those regimes driven by atmospheric forcings can impacts on the ecosystem.

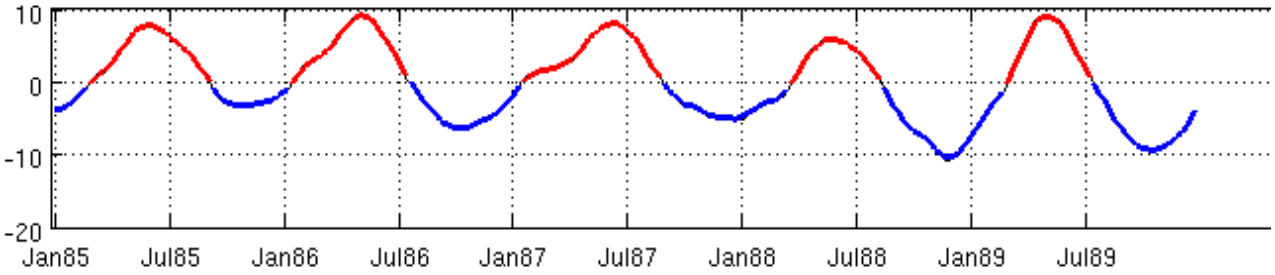
* In order to appreciate the impacts of changes in anthropogenic forcings, the budget of nutrients and in particular the dynamics of sediment has to be resolved.

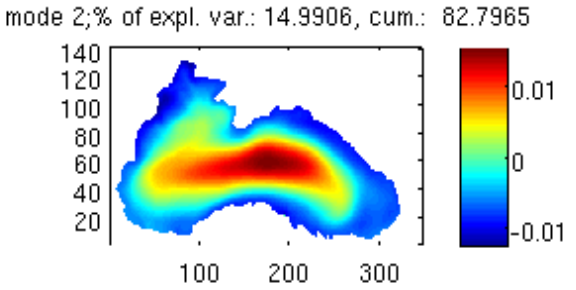
The Black Sea, P. Alechinsky

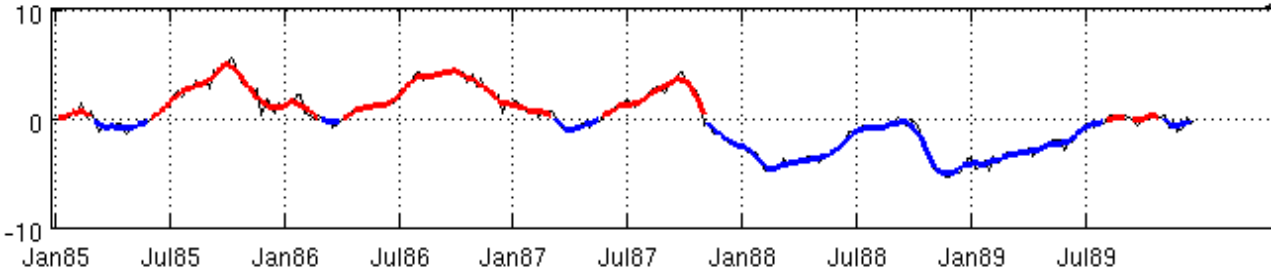
Thanks for patience, attention and for your questions

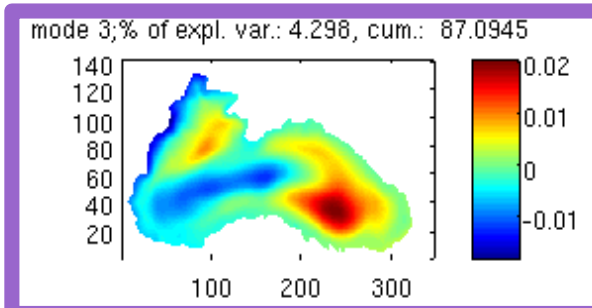
Surface Elevation principal modes

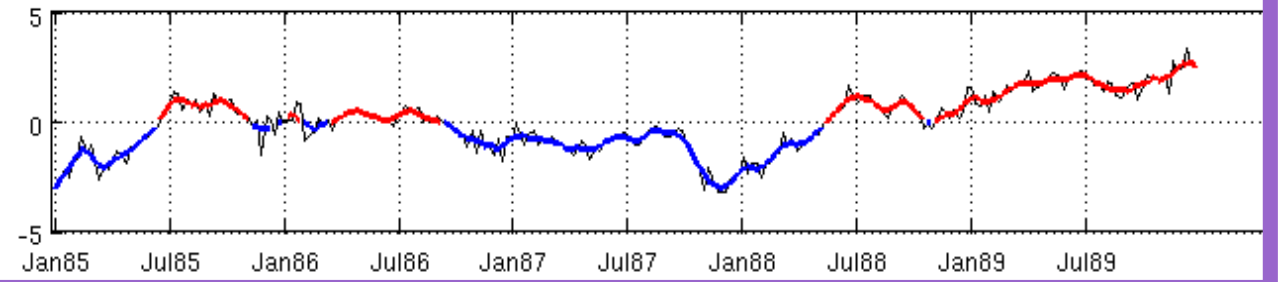


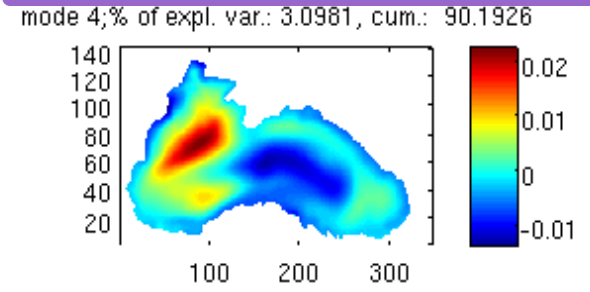


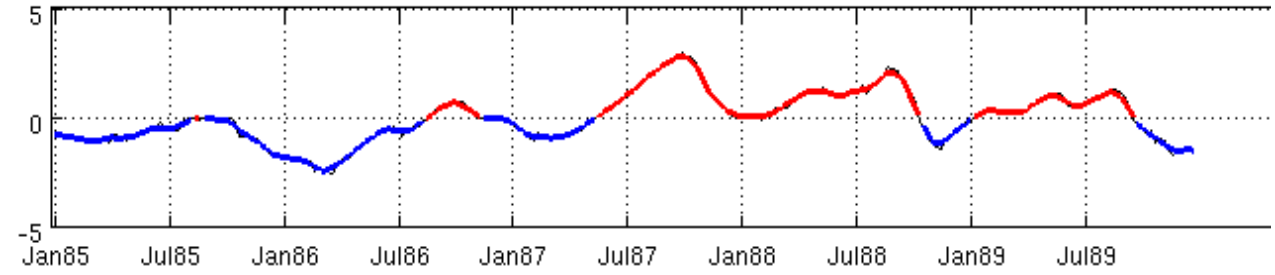






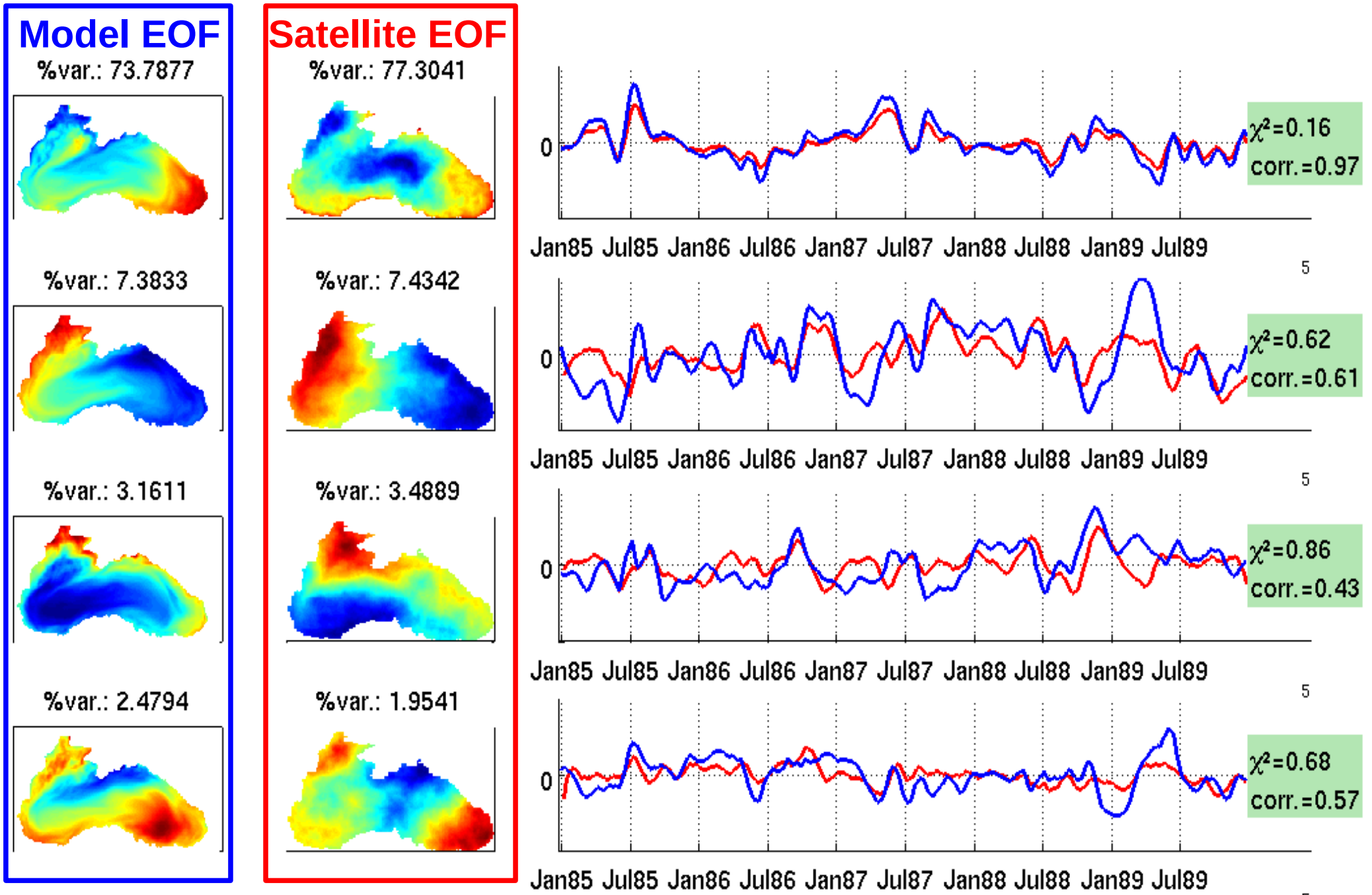


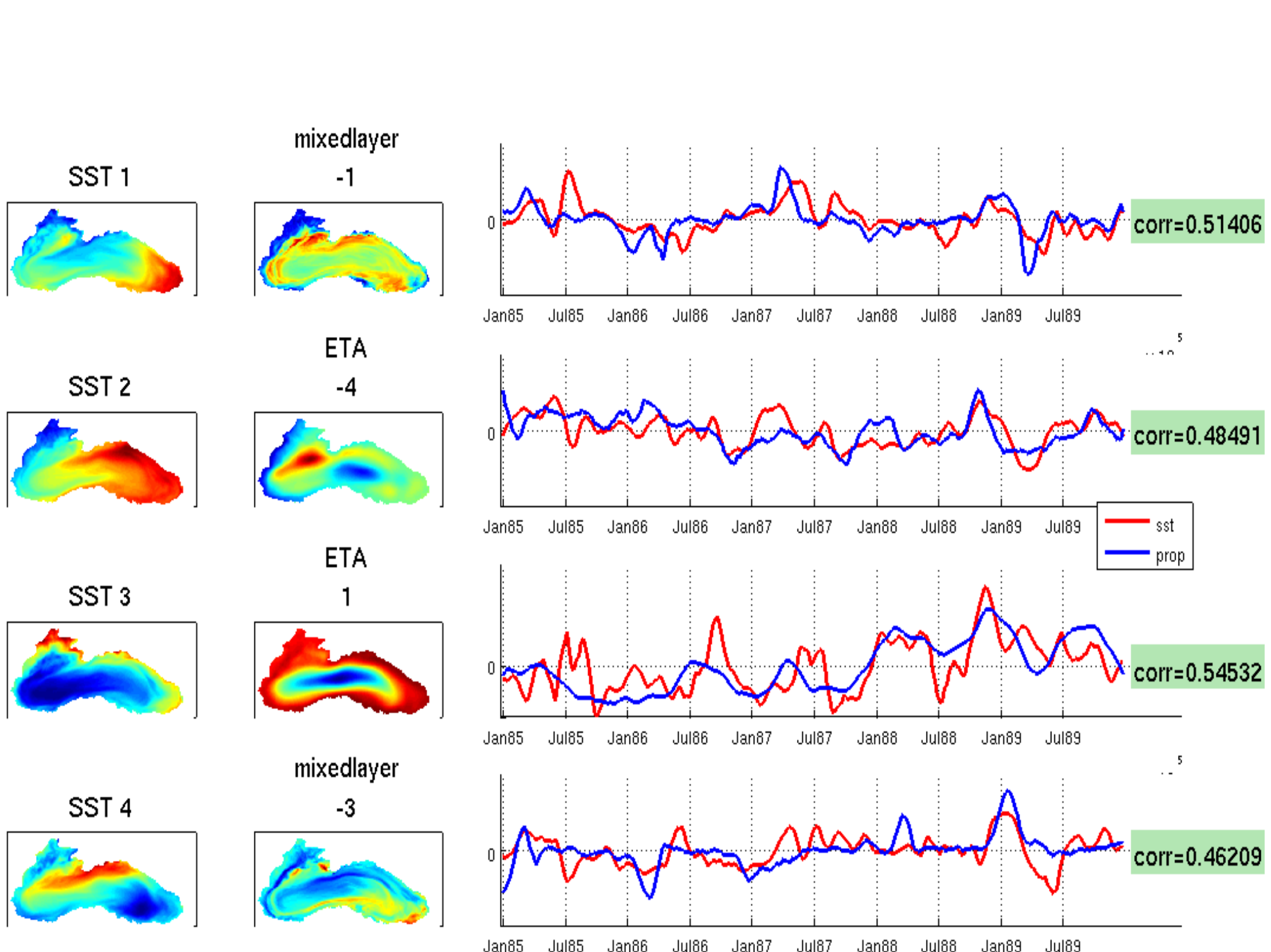




Validation : Physics (interranual run 85 to 90)

Comparison of SST modes of interannual variability with satelitte




SST 1
mixedlayer
-1
SST 2
ETA
-4
SST 3
ETA
1
SST 4
mixedlayer
-3
0
Jan85
Jul85
Jan86
Jul86
Jan87
Jul87
Jan88
Jul88
Jan89
Jul89
corr=0.51406
corr=0.48491
corr=0.54532
corr=0.46209
sst
prop

Reduction in anoxic water

$$(CH_2O)_x(NH_3)_y\ (H_3PO_4) + 2xMnO_2 + 4xH^+ \rightarrow 2xMn^{2+} + \underline{xCO_2} + yNH_3 + H_3PO_4 + 3xH_2O$$

$$2xH_2O + 2xMn^{2+} + \underline{xO_2} \rightarrow 2xMnO_2 + 4xH^+$$

$$(CH_2O)_x(NH_3)_y\ (H_3PO_4) + 2xFe_2O_3 + 8xH^+ \rightarrow 4xFe^{2+} + \underline{xCO_2} + yNH_3 + H_3PO_4 + 5xH_2O$$

$$4xH_2O + 4xFe^{2+} + \underline{xO_2} \rightarrow 2xFe_2O_3 + 8xH^+$$

$$(CH_2O)_x(NH_3)_y\ (H_3PO_4) + 0.5xSO_4^{2-} \rightarrow 0.5xS^{2-} + \underline{xCO_2} + yNH_3 + H_3PO_4 + xH_2O$$

$$0.5xS^{2-} + \underline{xO_2} \rightarrow 0.5xSO_4^{2-}$$

$$(CH_2O)_x(NH_3)_y\ (H_3PO_4) + An\ oxidant \rightarrow xODU + \underline{xCO_2} + yNH_3 + H_3PO_4 + xH_2O$$

$$ODU + \underline{xO_2} \rightarrow An\ oxidant$$

(OxygenDemanding Unit = 0.5H2S + 2Mn2+ + 4Fe2+).

Soetaert et al., 1996. A model of early diagenetic processes from the shelf to abyssal depths. Geochimica et Cosmochimica Acta.

Validation : Biology-climatic run

Spatio-temporal repartition of point-2-point statistics

Atmospheric and river forcings are averaged on decadal periods in order to construct a “climatological” seasonal cycles.

Those climatic runs are run under repetition of those seasonal forcings, in order to study equilibrium states in response to some typical environmental conditions.

This allow us to better analyse the interannual runs

Validation of those runs is done by gathering in-situ data from those decades, and comparing each data by its model spatio-temporal equivalent.