Helmholtz-Zentrum
Geesthacht
Centre for Materials and Coastal Research

Statistical Assessment of the Black Sea Observing Systems: ARGO Floats and Altimetry During 2005-2012

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Motivation

- Estimating the possible outcome of using profiling float data as an enhancement to the data used at present in the operational modeling of the Black Sea

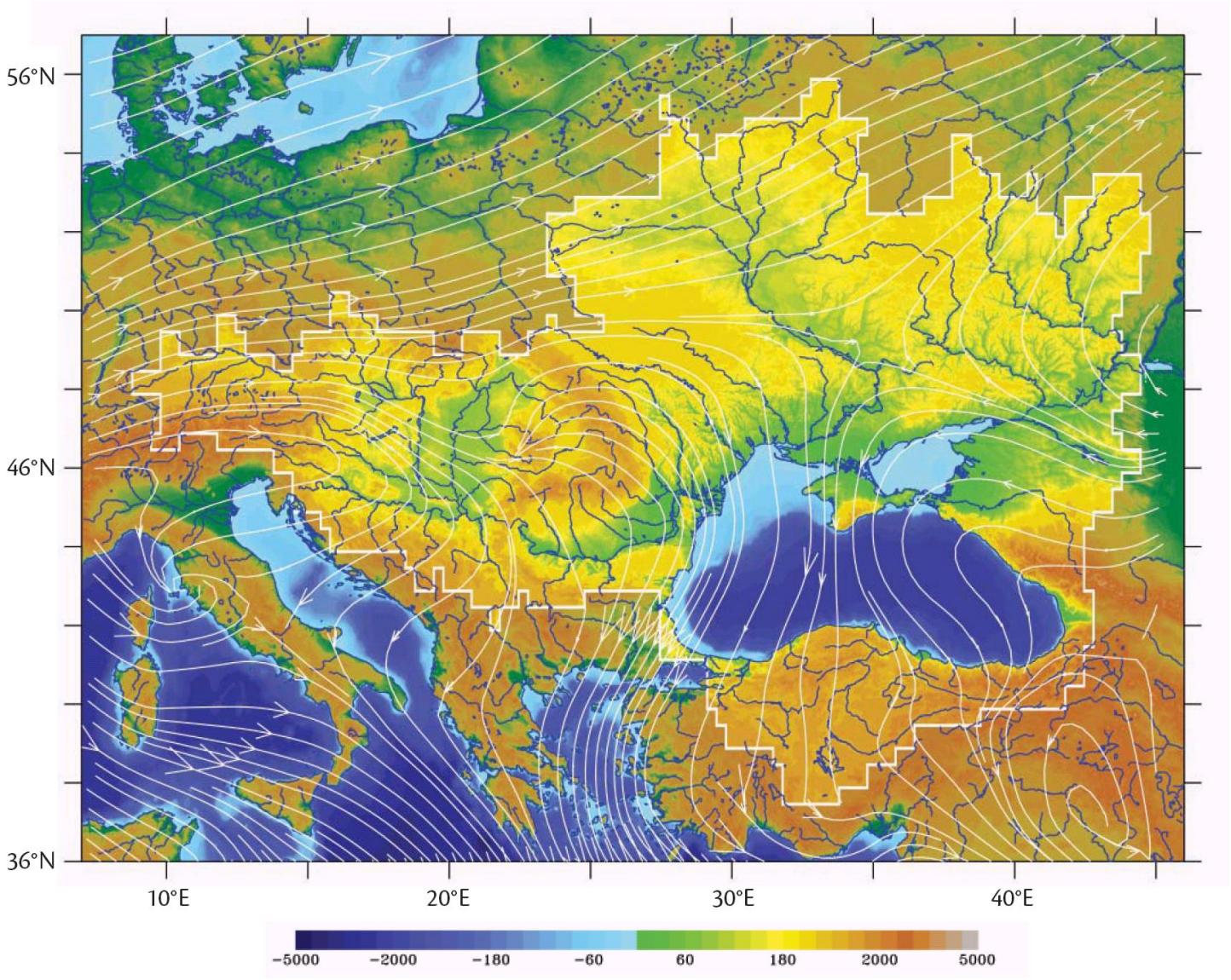
Basic questions:

- Does using Argo data improve (and how much) the quality of state estimates based on Altimetry and SST?
- How much Argo data is justifying their use in operational practice? This question is similar to the one addressed for the altimetry: How much in the forecast skill degrades when the number of altimeters is varied.

Outline

- Black Sea circulation
- Profiling float observations in the Black Sea
- Black Sea thermohaline state as seen in Argo observations
- Numerical modelling and data assimilation
- Experiments and results

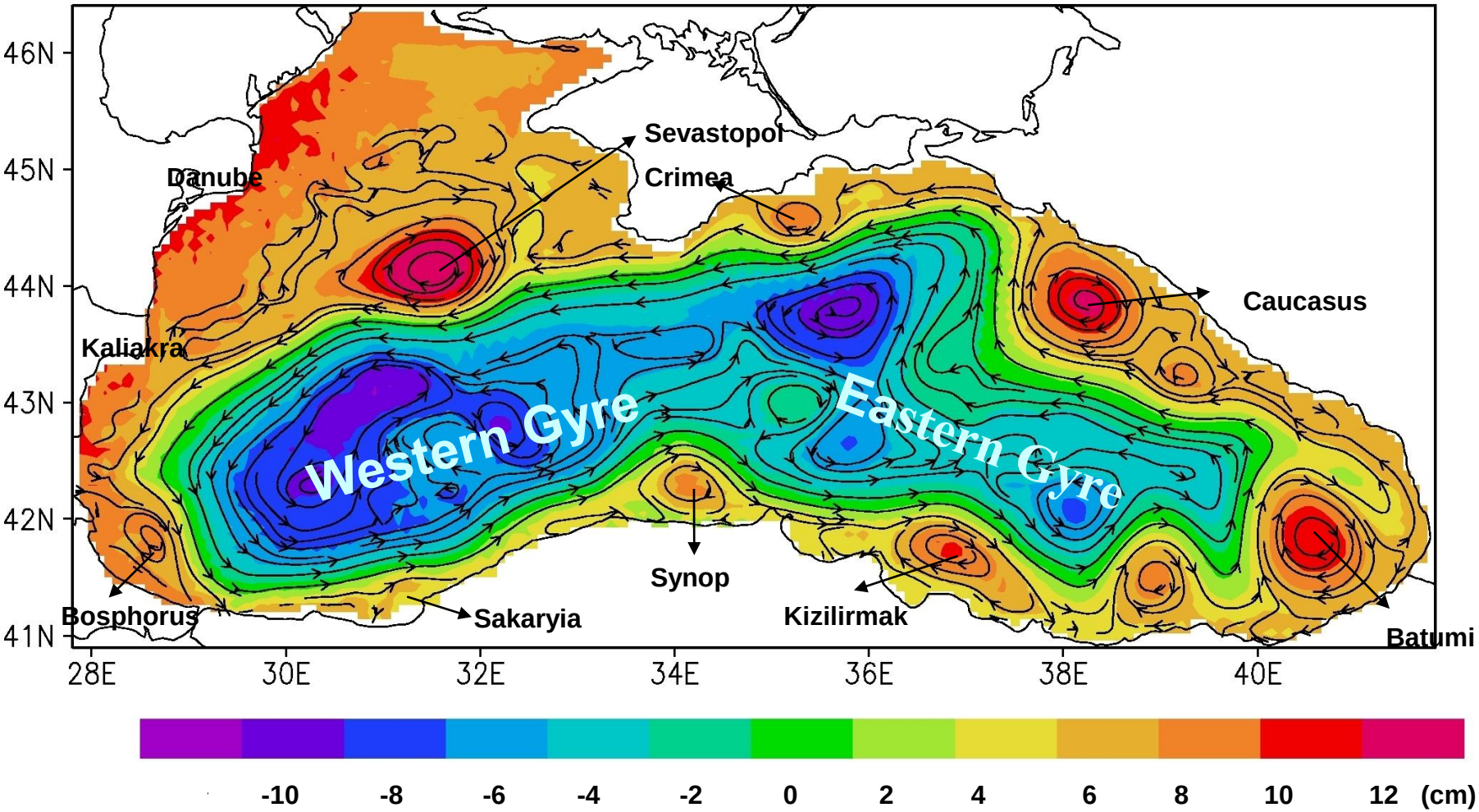
About the Black Sea: a deep estuarine basin



The total freshwater supply of 300km^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.

Two-gyre circulation plus anticyclonic coastal circulation



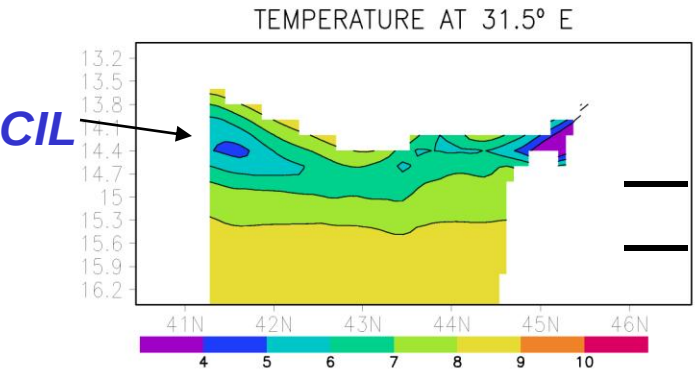
Seasonal amplitude of sea level: ~10 cm,

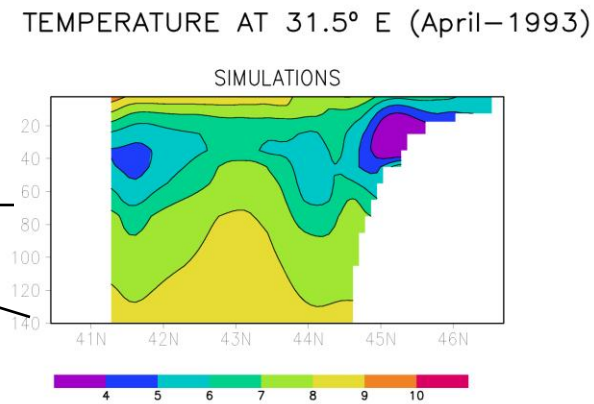
winter intensification of circulation

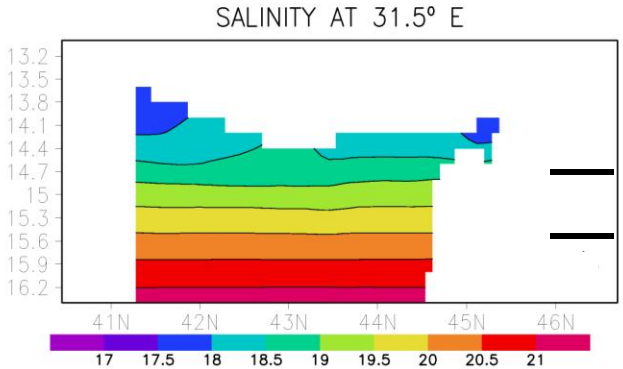
Strong vertical stratification (two layers), use of density coordinates

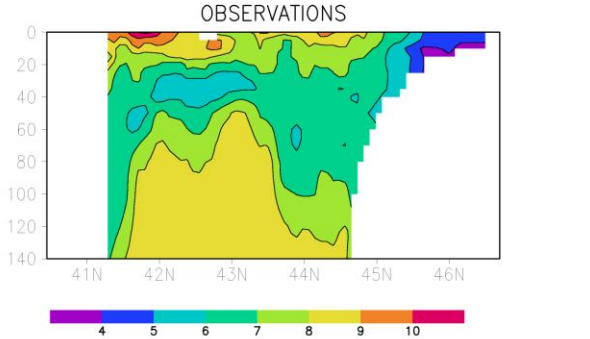
Below σ_t = 15.5 stratification is entirely dependent on salinity.

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

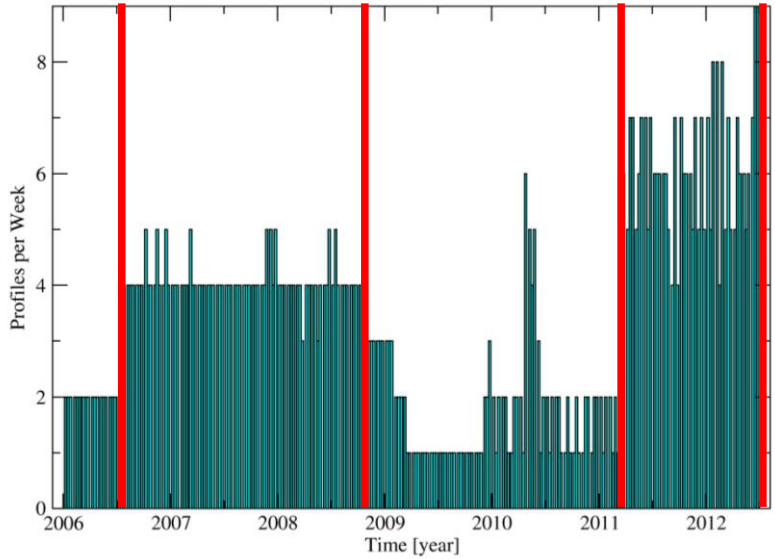


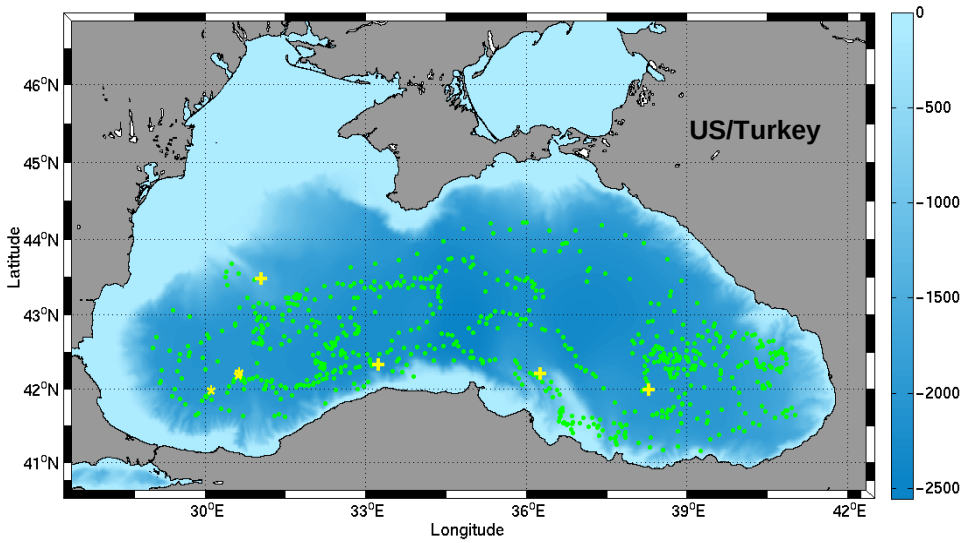


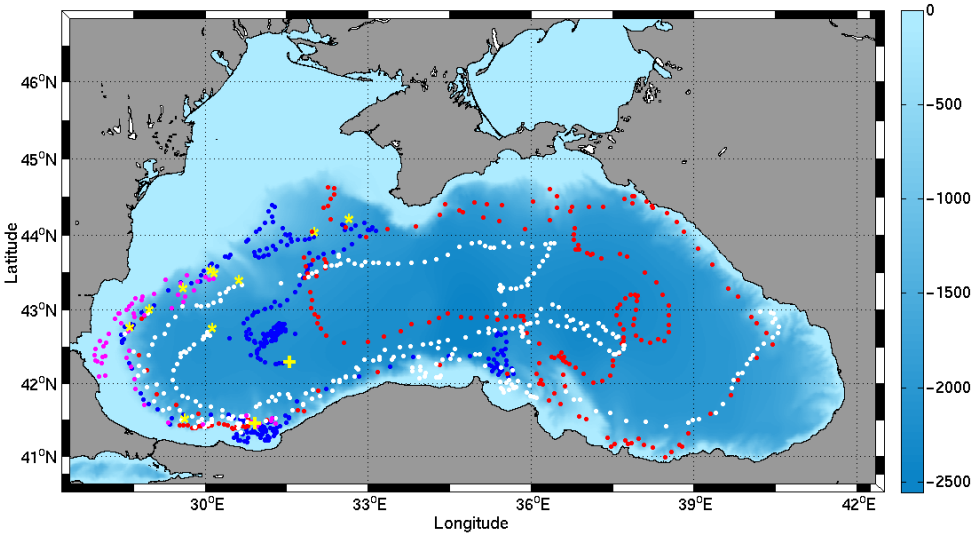




Temporal Coverage of ARGO Float Measurements

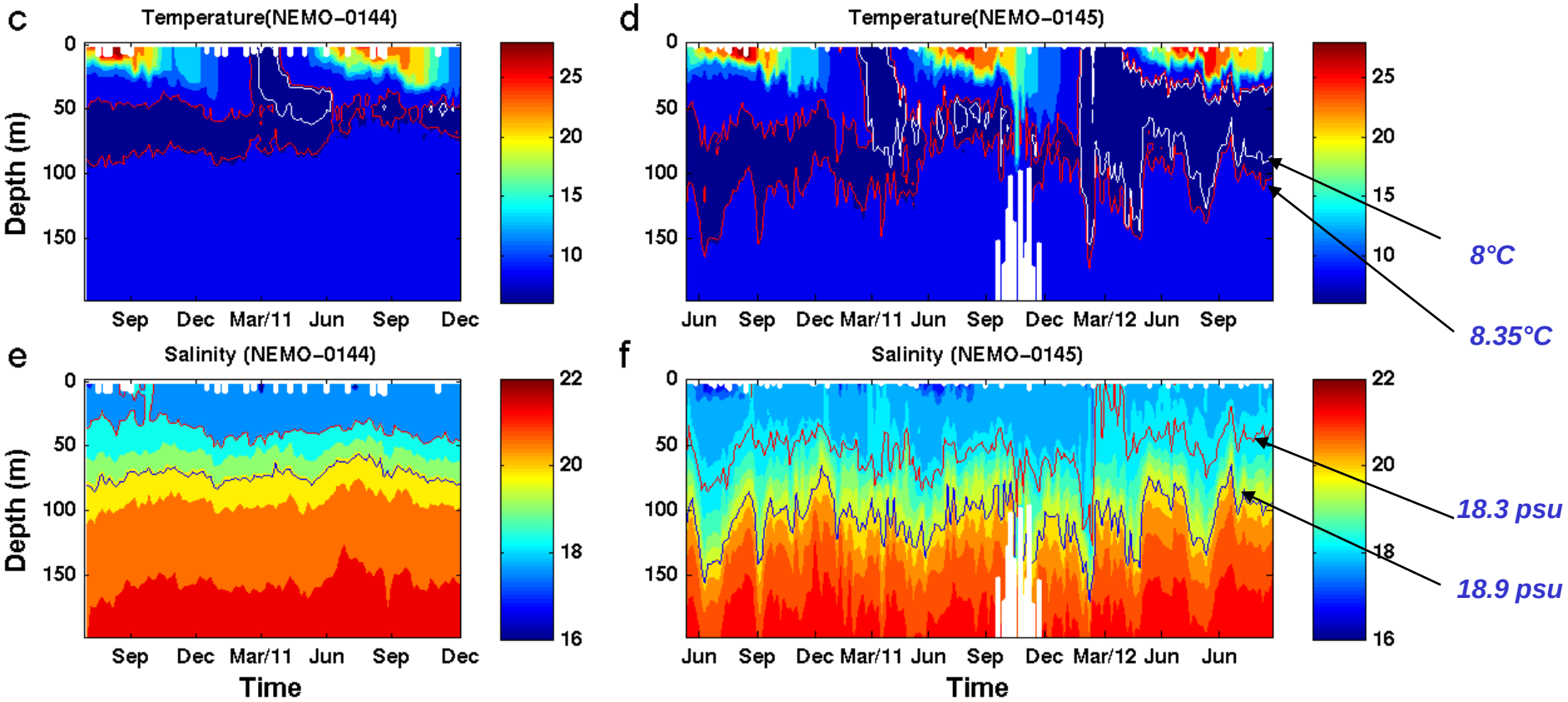






France	PROVOR	
• France	PROVOR	+
• Germany	NEMO	+
• Germany	NEMO	
Bulgaria	APEX	
• Bulgaria	APEX	
Bulgaria	APEX	
Italy	ARVOR	
Italy	ARVOR	
Italy	ARVOR	

Argo is the only observation platform that provides global-scale information for constraining salinity

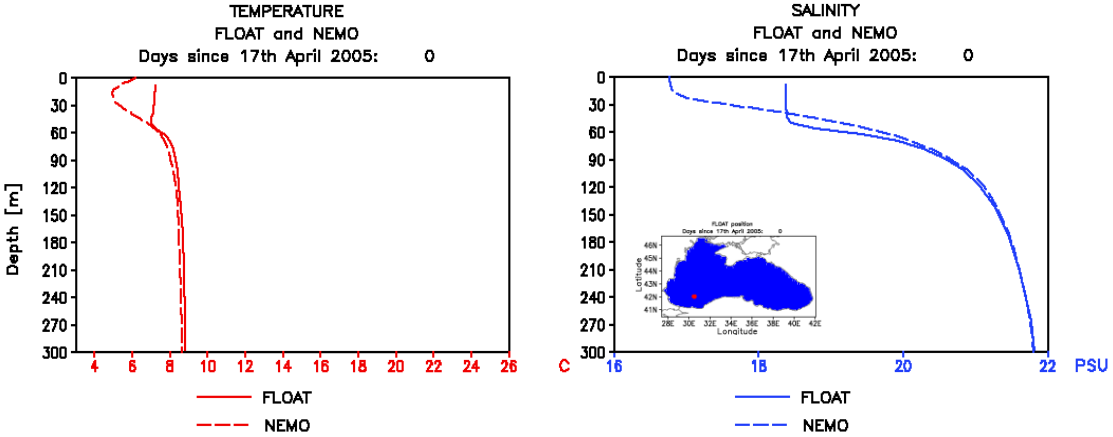


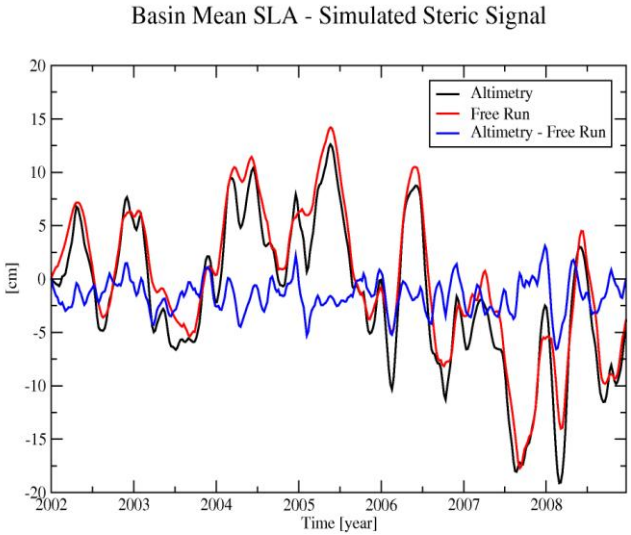
The model (NEMO)

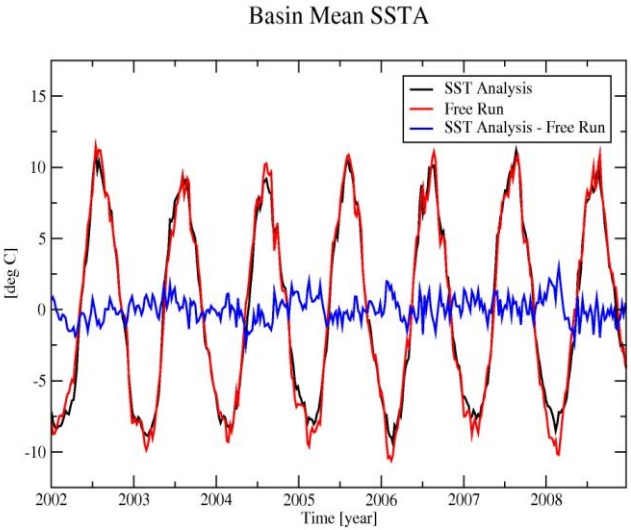
Resolution: *- horizontal ~1/12 deg*
- vertical 31 z-levels

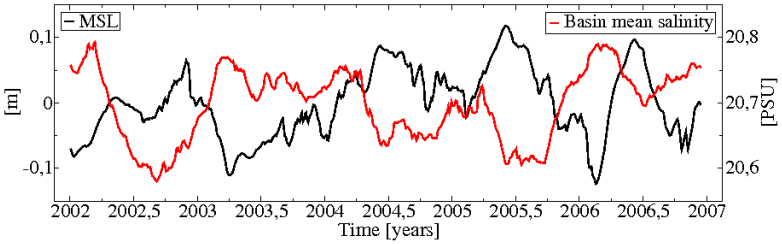
Forcing: *-ECMWF atmospheric data;*
- statistically reconstructed river runoff;
- Bosporus transport constrained by altimeter observation prescribed as inflow of salty water at 75m
- the Kerch straits is closed

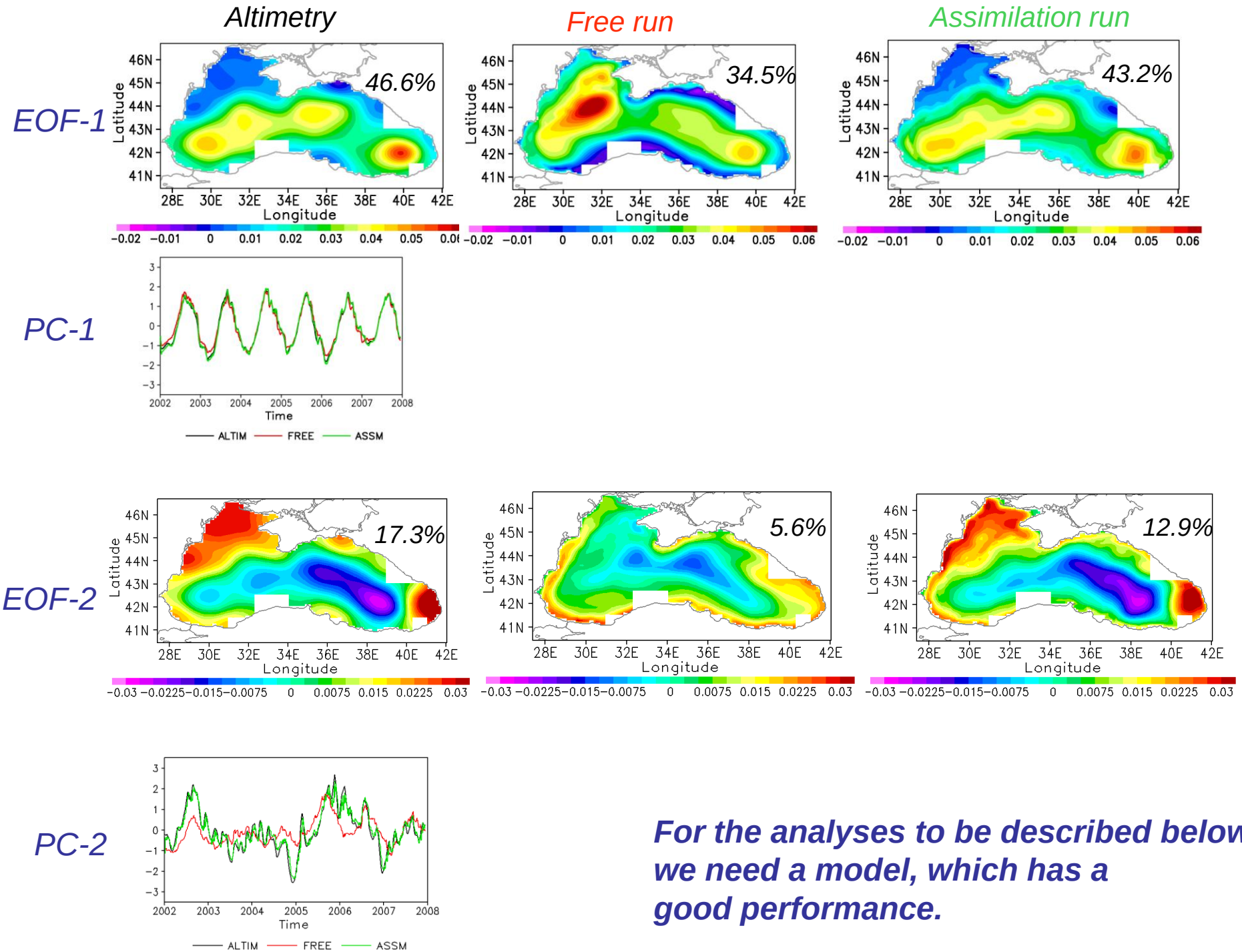
In Assimilation Mode:
- Aviso Altimetry (weakly)
- SST Analysis: Reynolds (daily)











For the analyses to be described below we need a model, which has a good performance.

The General Concept of Linear State Reconstruction of hydrophysical states

Le Hénaff et al. (2009): representer matrix spectra method identifies patterns in observation space, which can be well measured by the network.

Frolov et al. (2008): optimal linear estimation of the ocean state from given measurements.

We are following Frolov et al. (2008) and look for a optimal linear estimator.

Task: reconstruct ocean state from observations taking into account both the prior distribution of the state and measurement errors (the network is assessed in terms of its ability to capture the natural variability of the system).

Simple Theory of Linear State Reconstruction of hydrophysical states. Definitions:

x *(dim=N)* is the state vector (temporal mean removed),

H *(dim=MxN)* is the observation operator which maps x onto a measurement vector y *(dim=M)*

$$y = Hx + \epsilon$$

ε Gausian measurement noise.

P the prior covariance matrix of the state vector x

G error covariance matrix

Task: using a linear approach to estimate the state x from a given measurement y:

$$x = Ky$$

That is to find the reconstruction matrix K.

Simple Theory (continued)

Using the "*model world*" we interpret x and y as full (Global) and sub-sampled (Local) state.
Then we could interpret the above method as a reconstruction of the „Global" state from a sub-sampled state.

K minimises the absolute reconstruction error and can be found after minimizing the error of reconstruction

$$d = x - K\left(Hx + \epsilon\right) = min$$

K is the well known Kalman gain matrix

$$K = PH^T(HPH^T + G)^{-1}$$

Simple Theory (continued)

The optimal re-construction can be interpreted as an analysis with no information from the forecast,

i.e., the mean state is taken as the a priori state estimate.

Schulz-Stellenfleth and Stanev (2010):

1. The expression for the reconstruction error simplifies to the posterior error

2. Error estimates for the re-constructions can be calculated from the given covariance matrix and the measurement operator:

$$\Gamma_{t_i} = \sqrt{\frac{1}{m}\left(P(t_i) - P(t_i)H^T(HP(t_i)H^T + R)^{-1}HP(t_i)\right)}$$

Reduce the dimension of the problem: express the state in terms of EOFs:

$$P = VUV^T$$

To get a realistic Γ, we need to use a realistic P.

In the following demonstration P is derived from 8-years simulation.

Experiments and results

OSE:

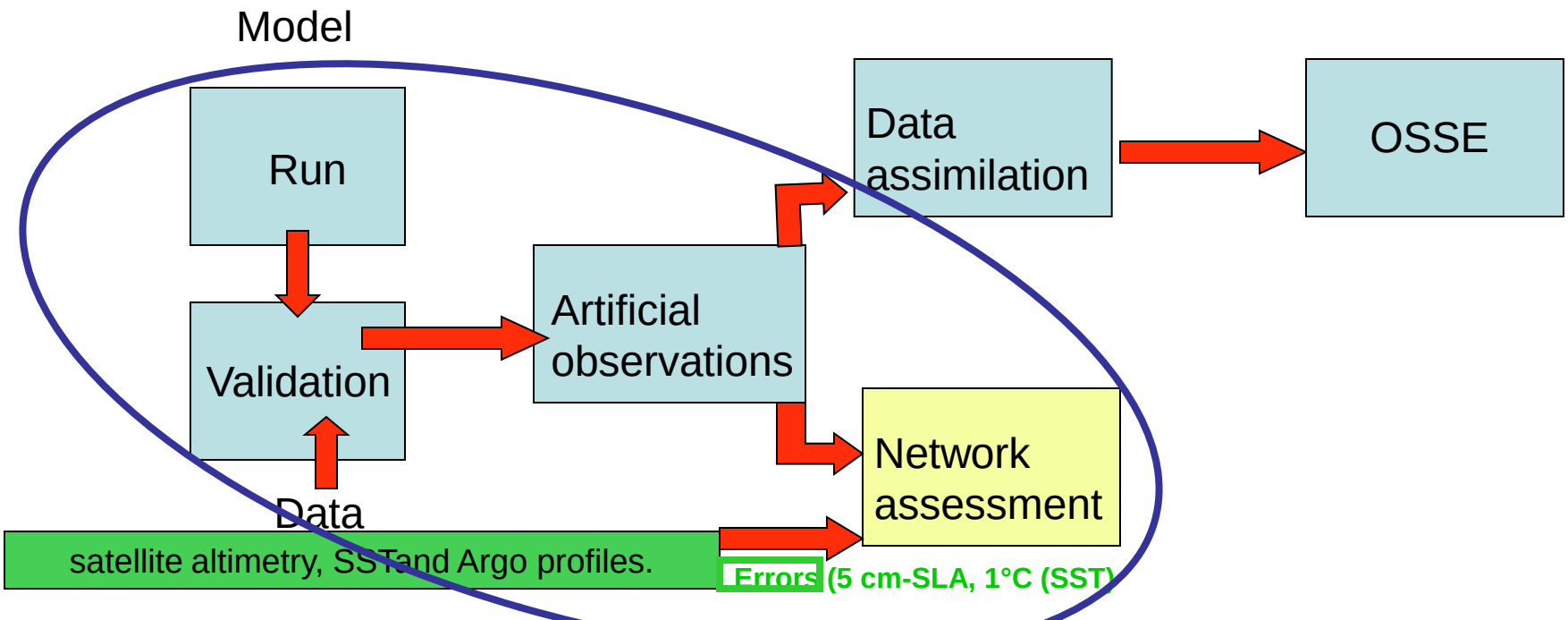
can assess the degradation in quality of a forecast or analysis when where different components of the observing system are used/not used (dependence of the skill of a model on each observation type).

ADJOINT- and ensemble-based approaches:

can be used to design and evaluate ocean observing systems.

OSSEs

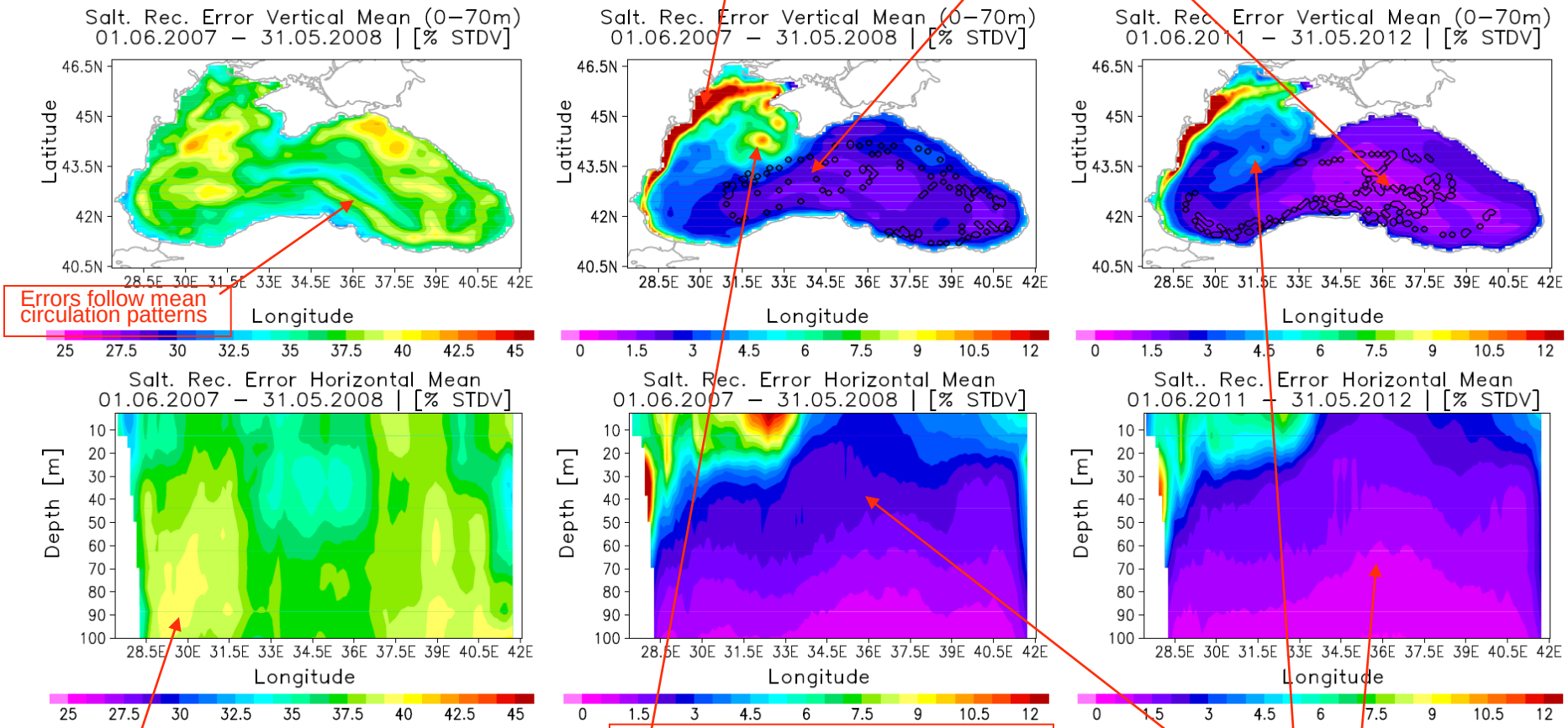
often involve so twin experiments, where a model is sampled in a way that resembles real observations, and those observations are assimilated into an alternative model.



Annual mean error (**salinity**)

Fresh water zone
Shows big errors

Errors are strongly dependent on the position of observations



Errors follow mean circulation patterns

Errors increase with depth

Sub-basin scale eddies (Sevastopol) show larger errors (diapycnic processes and watermass formation)

Errors propagate with The water masses

Profile data reduce substantially errors in deep ocean.

2011 is not shown because observational positions (SLA) are the same and P does not differ much.

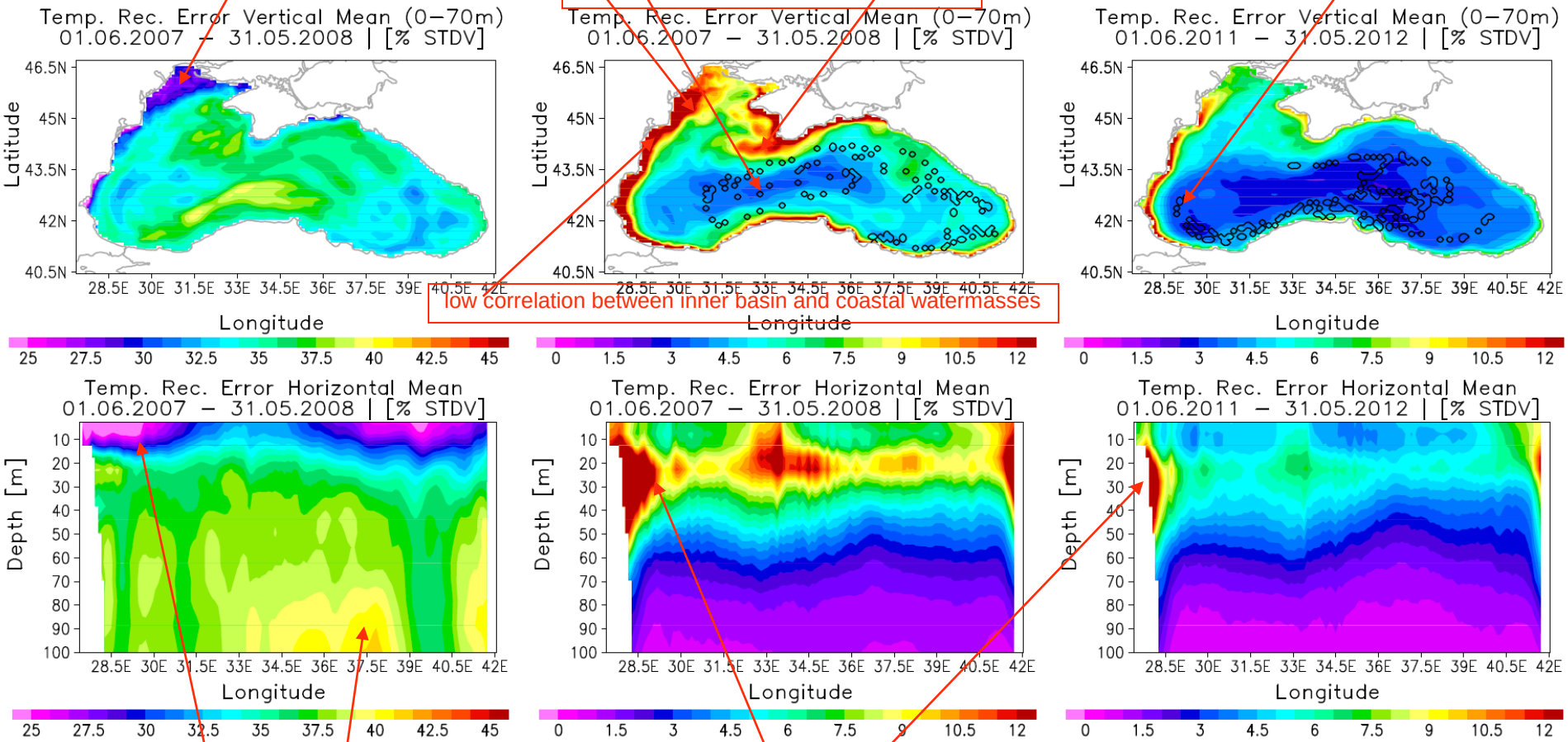
Relevance to rim current and mesoscale (eddy) variability, as well as to shelf sea salinity dynamics.

Annual mean error (**temperature**)

Low errors in the shallow sea

Argo data decrease the errors in the open sea (relatively higher errors in the coastal zone and behind the headlands

Differently from salinity, errors in individual years can change a lot (Argo closer to the Western coast).



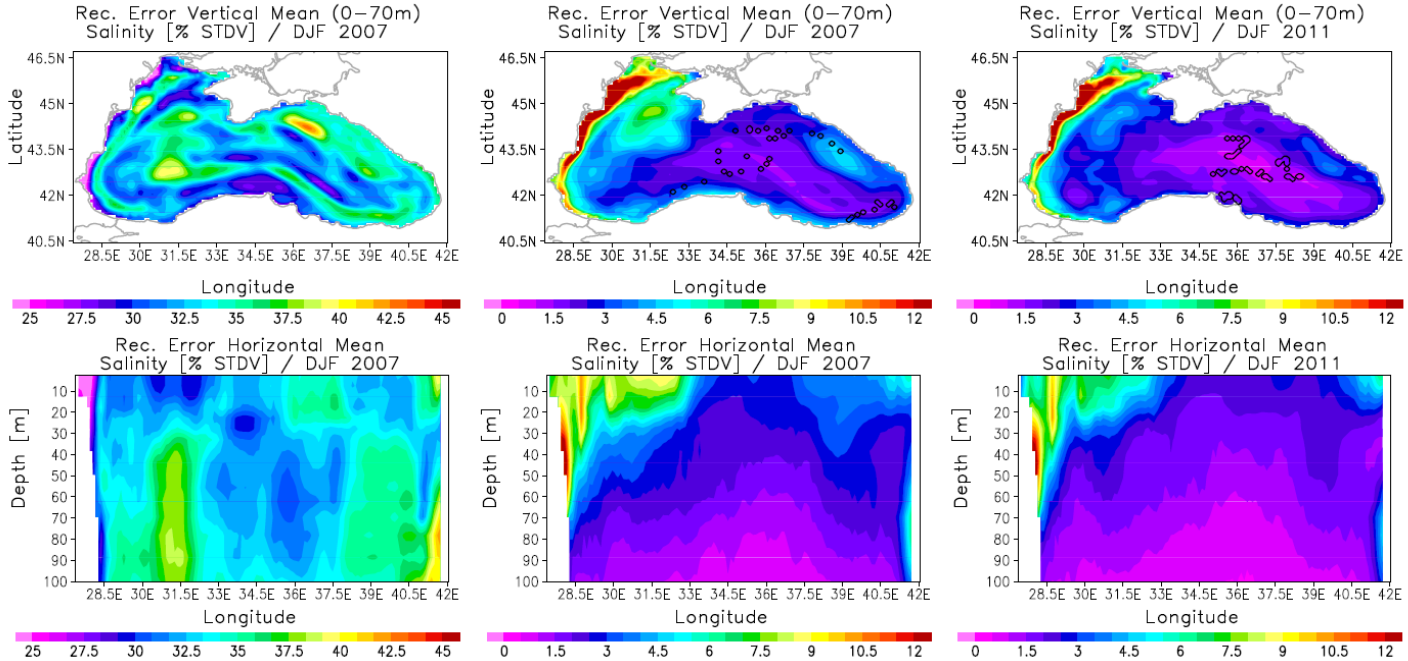
low correlation between inner basin and coastal watermasses

Low errors in surface ocean
(The impact of SST observatiions)

CIL development
No similar problem is seen in salinity.

In the deep ocean the situation
Is similar to the one of salinity
(but opposie patterns).

Relevance to mesoscale (eddy) variability, mixed layer dynamics, water mass formation (incl. upper-ocean properties).

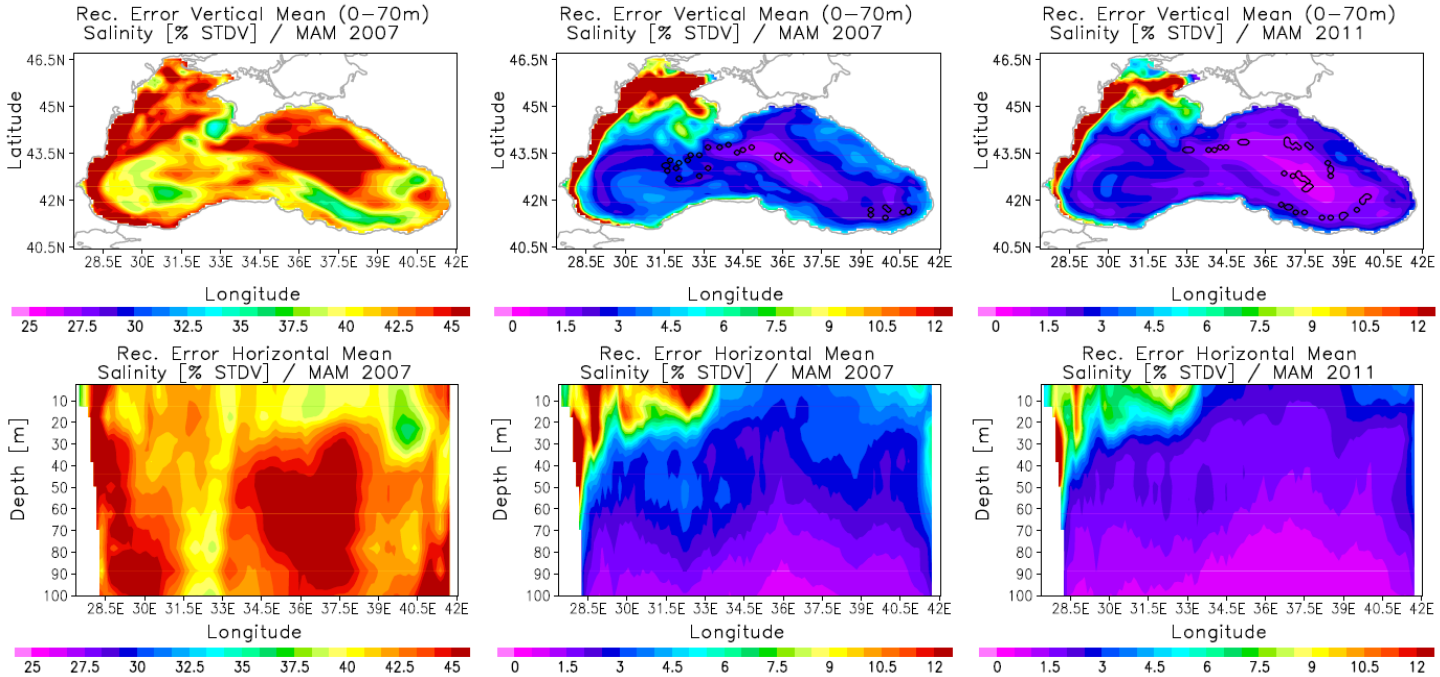


Winter

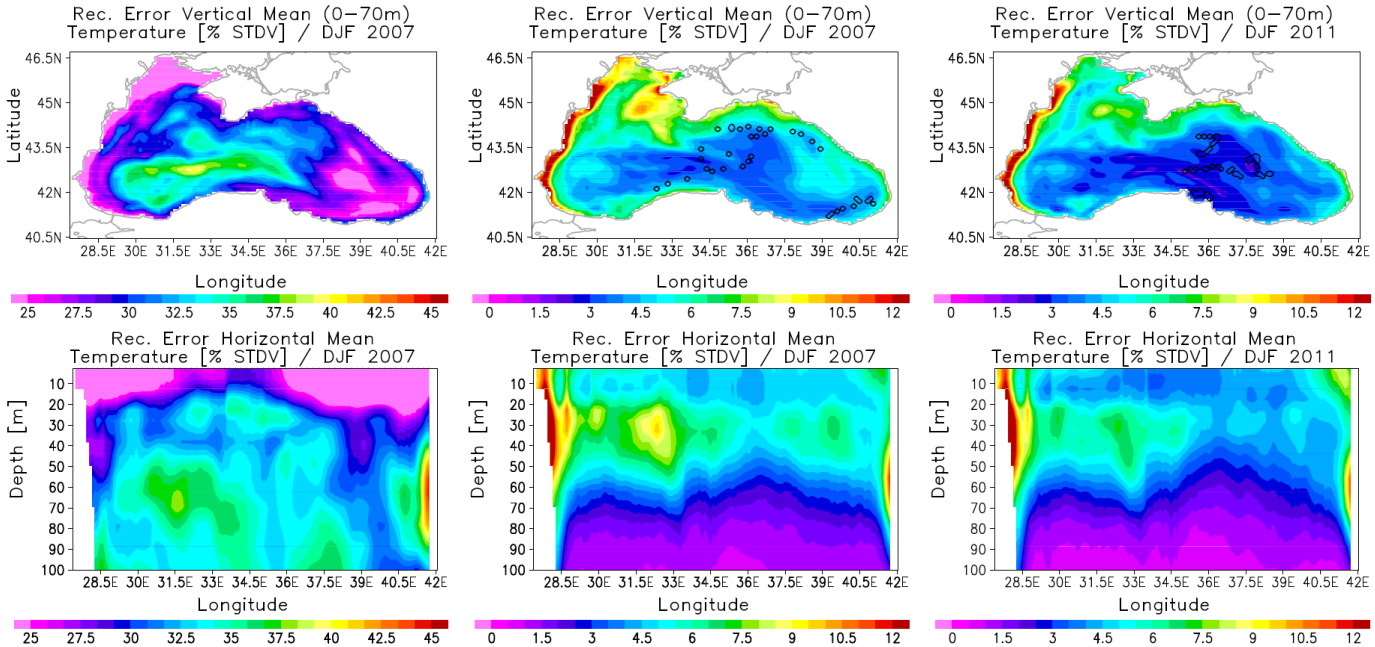
S

Something unexpected: the role of fresh water fluxes

Highest seasonal reconstruction error, due to the high spring freshwater input and restratification due to heating



Spring



Winter

Winter mixing enables the deeper penetration of surface signals (strongest vertical mixing in shelf/anticyclonically dominated parts of the basin

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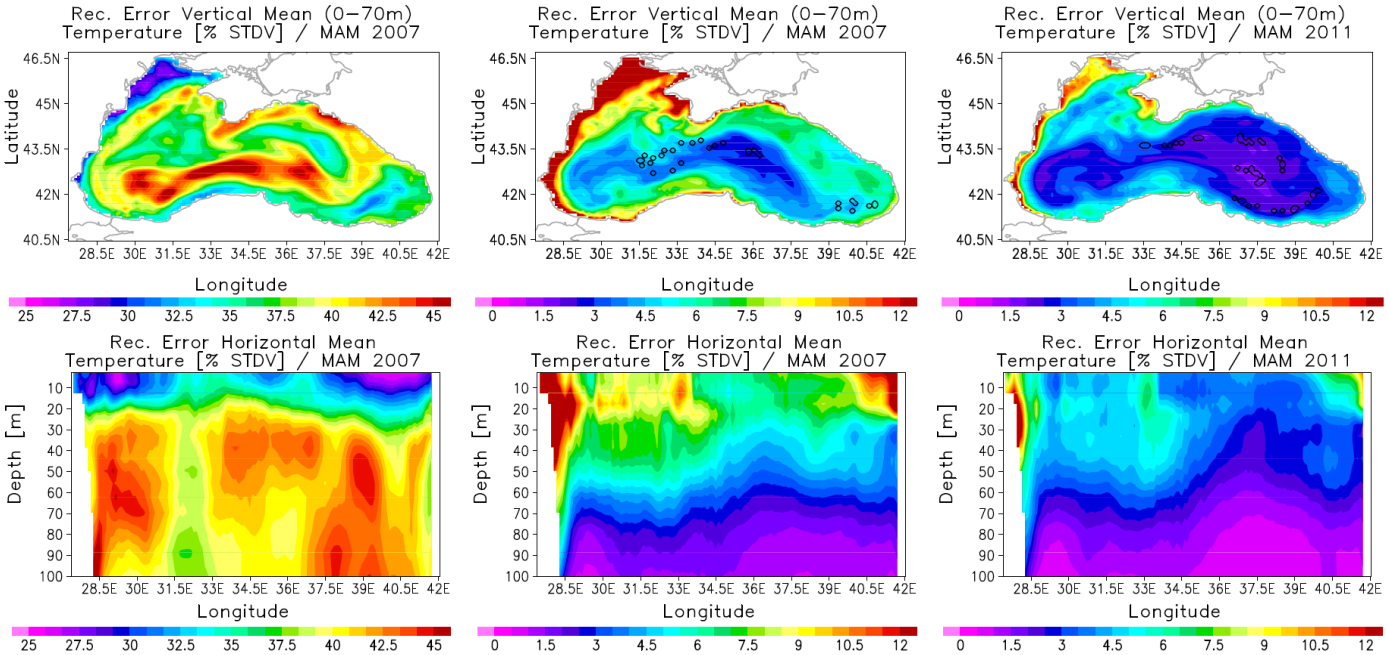
The role of stratification

Enhansed stratification reduces the depth of penetration of surface signals. Error field „sees“ the rim current when the stratification is strong.



Spring

Conclusions

We quantified the impact of different observations on an analysis, given the assumed errors.

In areas of intense meso-scale variability and diapycnic exchange the errors are high. Special care is needed.

Positive expectations for the transition of OSE/OSSE activities towards routine monitoring of the Black Sea observational network.