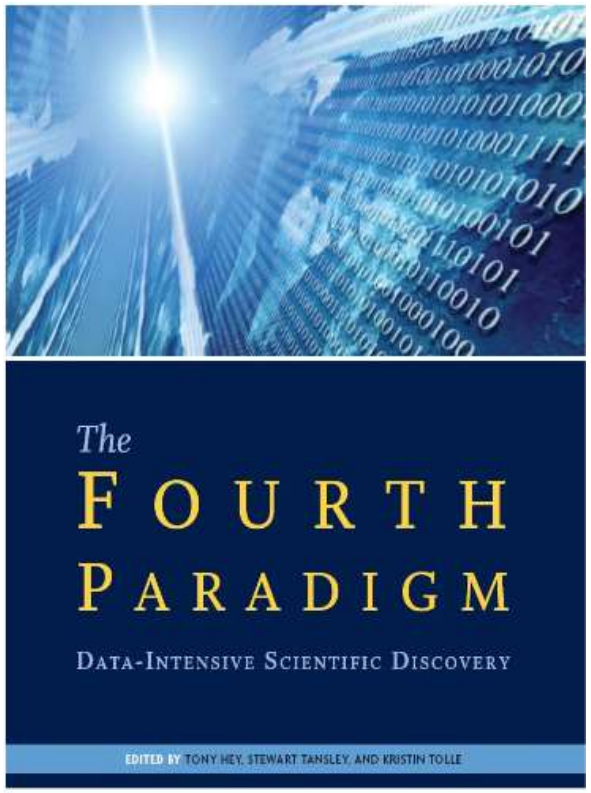
Science revolutions in oceanography and their Black Sea appearances

Emil V. Stanev



Data Deluge

Increasingly, scientific breakthroughs will be powered by advanced computing capabilities that help researchers manipulate and explore massive datasets.

Data Exploration

Science Paradigms

1. Thousand years ago – **Experimental Science**
   - Description of natural phenomena
2. Last few hundred years – **Theoretical Scienc**
   - Newton's Laws, Maxwell's Equations…
3. Last few decades – **Computational Science**
   - Simulation of complex phenomena
4. Today – **Data-Intensive Science**
   - Scientists overwhelmed with data sets from many different sources
     - Data captured by instruments
     - Data generated by simulations
     - Data generated by sensor networks
   - ➢ eScience is the set of tools and technologies to support data federation and collaboration
     - For analysis and data mining
     - For data visualization and exploration
     - For scholarly communication and dissemination

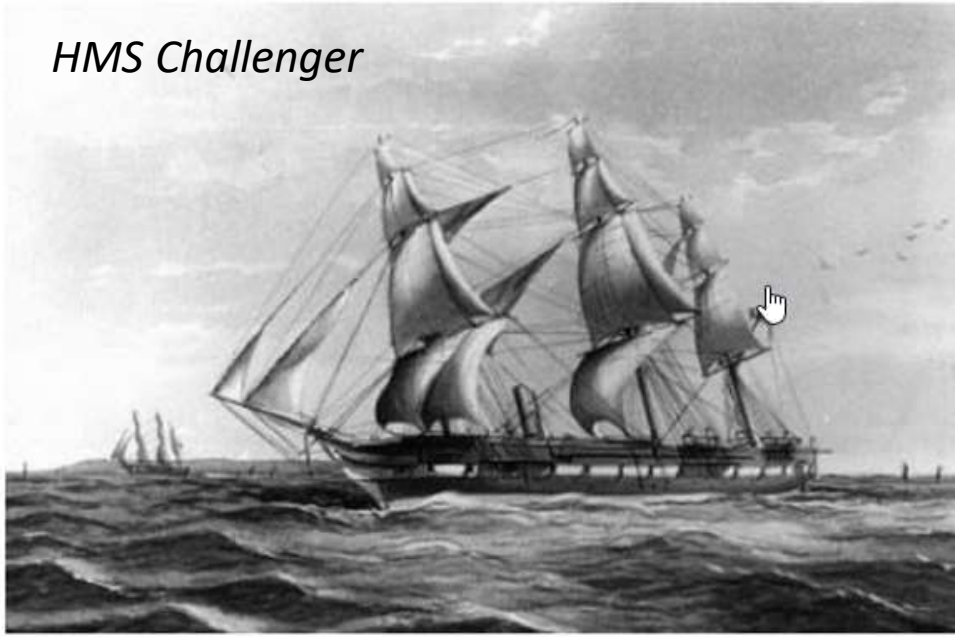
Smythe-Wright, D., Gould, W. J., McDougall, T. J., Sparnocchia, S., and Woodworth, P. L.: IAPSO: tales from the ocean frontier, Hist. Geo Space. Sci., 10, 137–150, https://doi.org/10.5194/hgss-10-137-2019, 2019.

- In the mid- to late 1700s Benjamin Franklin gave us knowledge of the Gulf Stream and currents

- One hundred years later Matthew Fontaine Maury published *The Physical Geography of the Sea*

- *HMS Challenger* which set out to specifically make systematic measurements of ocean parameters between 1872 and 1876.

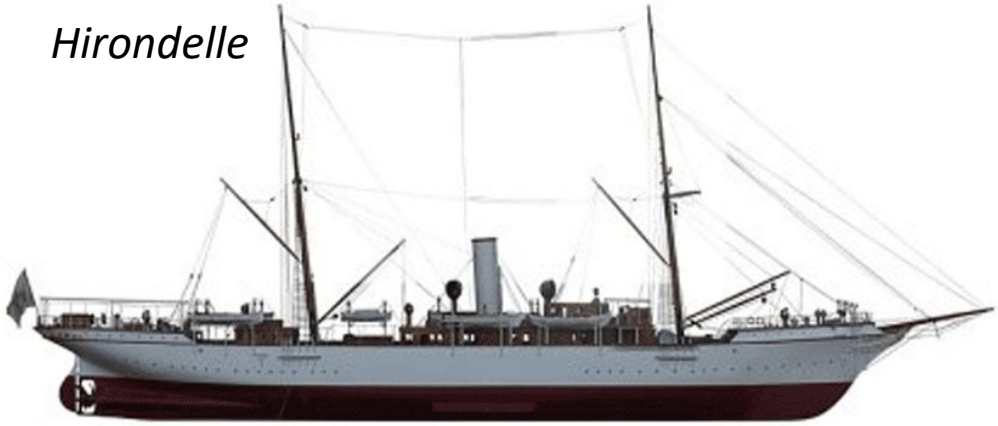
HMS Challenger

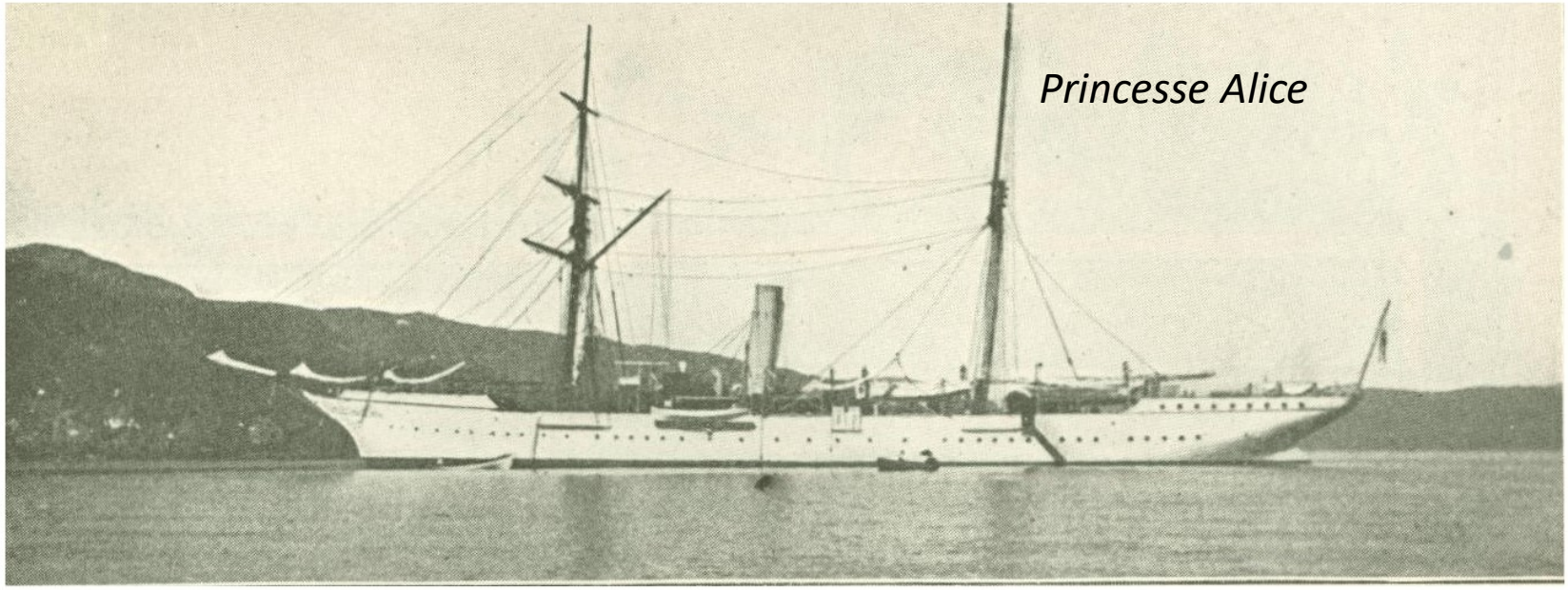


French naval vessels the *Travailleur* and the *Talisman* and the German *Gazelle* were making biodiversity and hydrographic measurements.

Prince Albert I of Monaco made a decision in 1884 to devote his time and resources to oceanography

Hirondelle





Princesse Alice

In July 1919 during the Constitutive Assembly of the newly formed International Research Council decided to form the International Union of Geodesy and Geophysics (IUGG) as a union of six sections. One of the sections was assigned to physical oceanography, dealing with tides, currents, temperature, salinity, and other physical phenomena of the oceans, and HMSH Prince Albert I took on the role of its first president.

Numerical modelling
Atmosphere
1950- Jule Charney, Agnar Fjörtoff & John von Neumann Report the First Weather Forecast by Electronic Computer

ENIAC (Electronic Numerical Integrator and Computer),

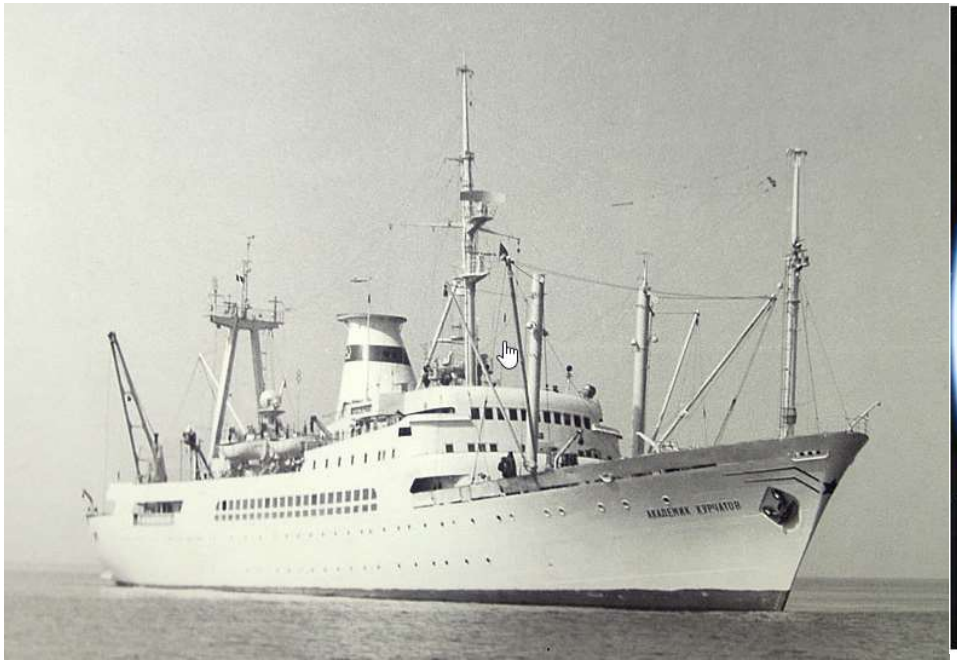
Numerical modelling
Ocean
1970-s
A.S. Sarkysian
K. Bryan

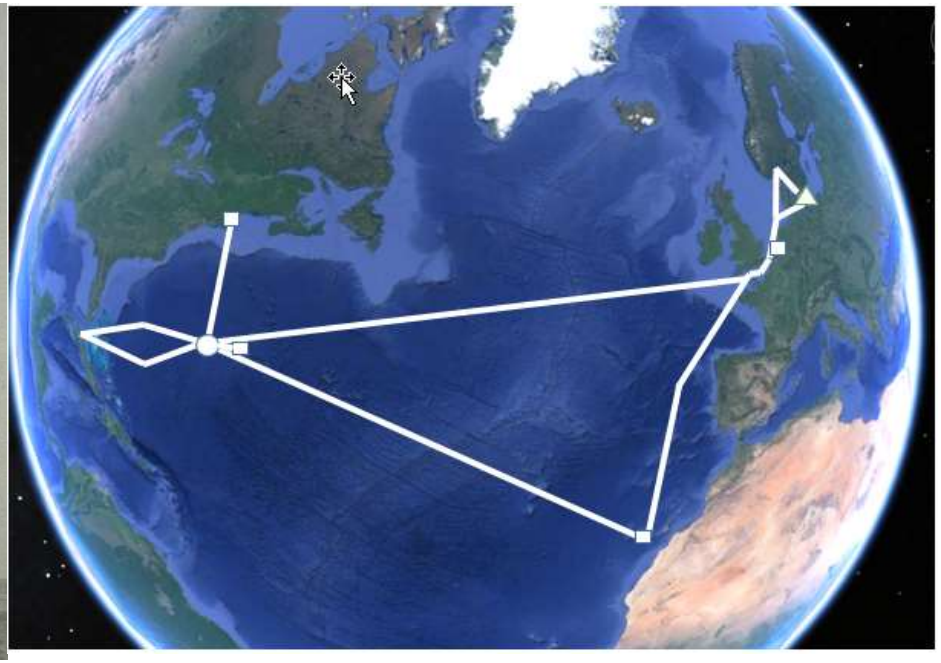
"Numerical Integration of the Barotropic Vorticity Equation." *Tellus* 2 (1950) 237-254.

Ocean eddies were discovered first in 1970 during the Polygon-70 experiment. The observational array included 17 buoys placed on a cross of 120 miles (193 km) in zonal and meridional direction with a center at 16.5° north and 33.5° west.

Polygon-70 was followed from March through mid-July 1973 by the Mid-Ocean Dynamics Experiment (MODE-1), which was designed to investigate mesoscale eddies in an area southwest of Bermuda.

In 1977–1978, US and Soviet Union joined forces in the experiment called POLYMODE (the name was a combination of Polygon and MODE) with the aim of advancing the science on eddy motion in the ocean.



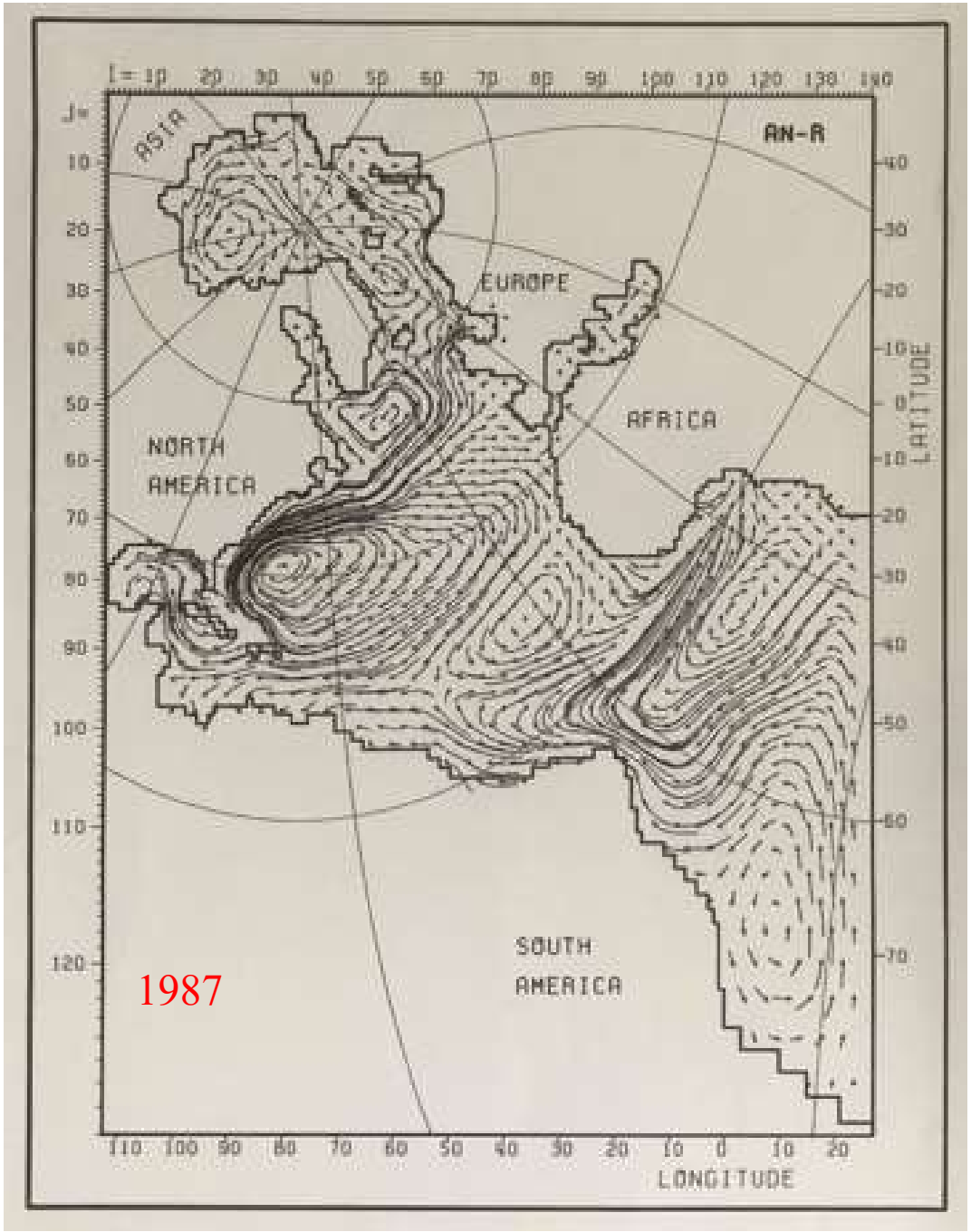


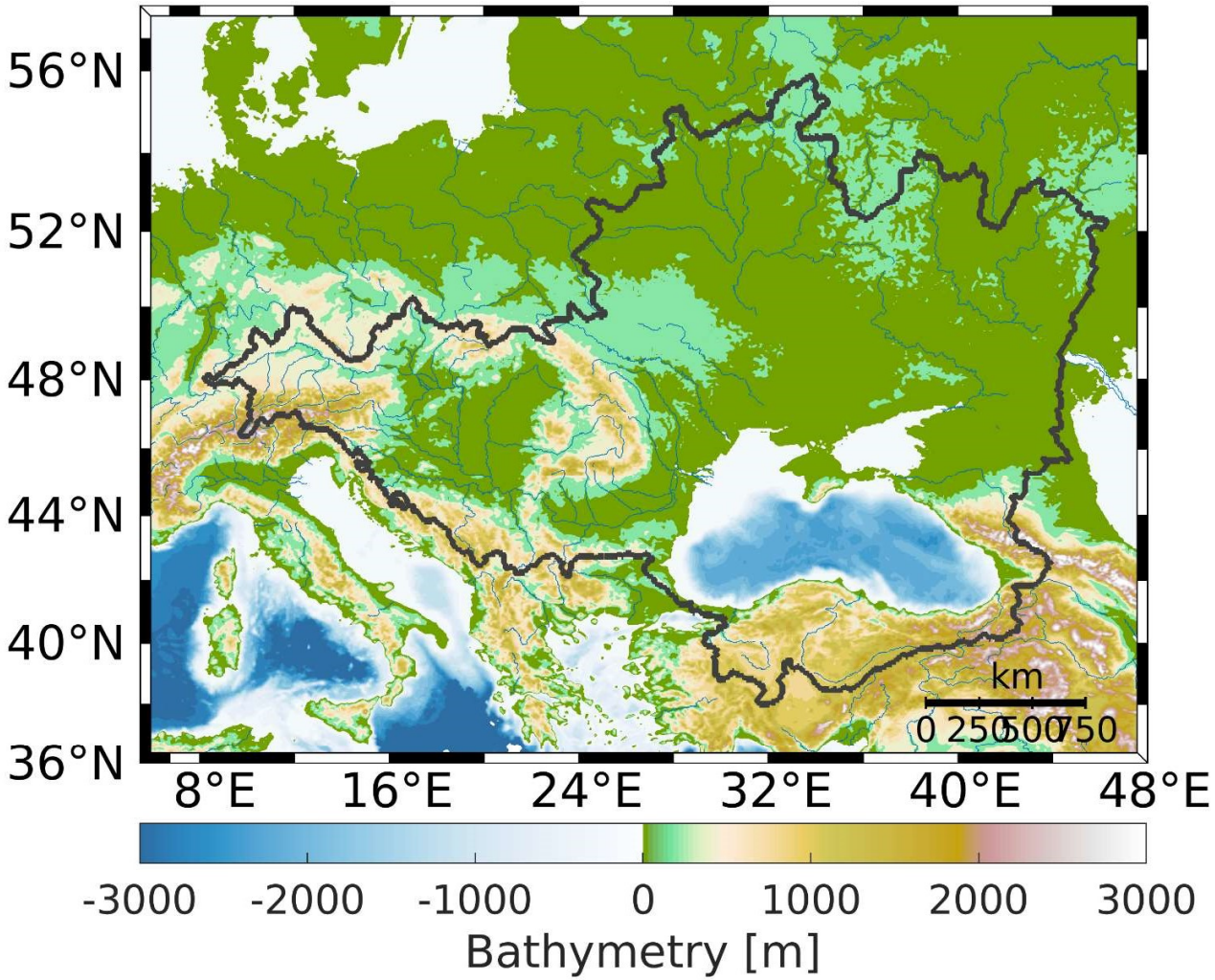
Limited computational resources and experience with numerical ocean modelling at that time were obstacles to the simulation of the dynamics at eddy scales.

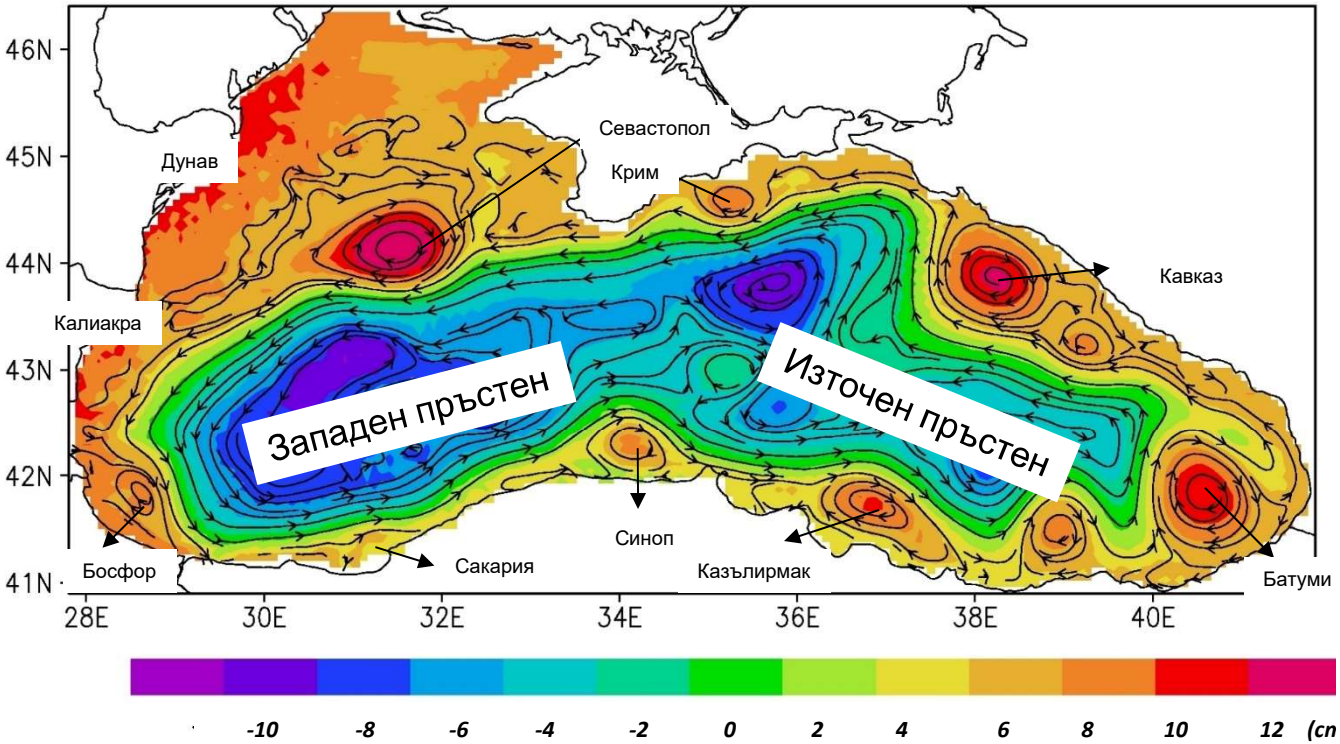
Only in 1992 Semtner and Cherwin described a concerted effort to simulate the global ocean circulation with resolved eddies. However, their model with a resolution of 0.5° (which is about 50 km) could hardly resolve mesoscale eddies, many of which have the size of their grid.

Ten years after this pioneering work, global models reached a resolution of 1/10° demonstrating a major step forward in high resolution ocean modeling, with applications to prediction and climate.

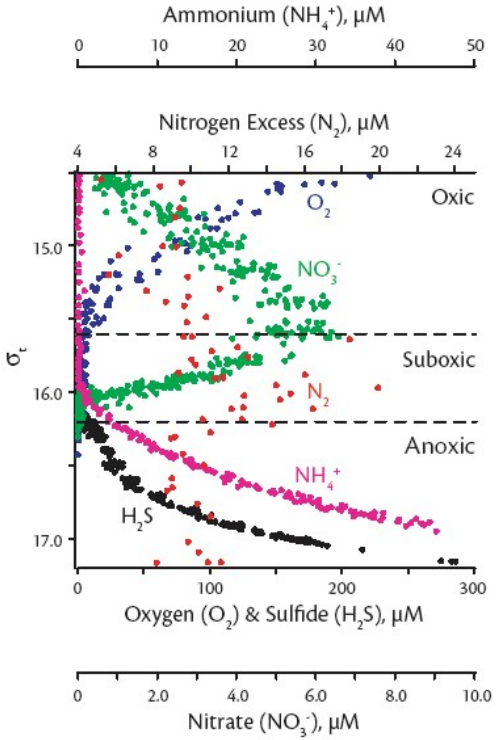
Now, the resolution in current global °models 1/16 is even superior to that of the first limited area eddy resolving models (~ 20 km) from the time of POLYMODE.




56°N
52°N
48°N
44°N
40°N
36°N
8°E
16°E
24°E
32°E
40°E
48°E
km
0 250 500 750
-3000
-2000
-1000
0
1000
2000
3000
Bathymetry [m]



Stanev, E. V. (2005) Understanding Black Sea Dynamics: Overview of recent numerical modelling, *Oceanography*, Vol.18, No.2, 52-71



Konovalov, S. K., Murray, J. W., & Luther, G. W., III (2005). Basic processes of the Black Sea biogeochemistry. Oceanography, 18(2), 28–35.

Quantified

- the role of wind vorticity as the main driving force in creating the cyclonic (counterclockwise) general circulation of the Black Sea.

- the "competition" and complementarity between effects related to the Earth's rotation, topography, coastal and bottom friction, and vertical stratification.

- the amount of water transported vertically (upwelling) in the Black Sea is ~ 105 m3/s and this flow is mainly concentrated in the upper 200-300 m layer. In the horizontal direction the currents transport ~ 5 x 106 m3/s, i.e. about fifty times more water. The vertical circulation cell includes downward movements in the coastal zones and compensatory upward transport in the interior of the basin. The downward motions are structured in separate anticyclones between the main Black Sea current and the

Stanev, E. V. (1990) On the mechanisms of the Black Sea circulation. *Earth-Science Rev.*, 28, 285-319.

Cooperative Marine Science Program for the Black Sea *(CoMSBlack)*

The International Seminar on the Black Sea was held in Varna from 30 September to 4 October 1991.

- to assess natural and anthropogenically induced changes in the marine environment using historical data;
- to determine fluxes of water, sediment, carbon, nutrients, heavy metals, hydrocarbons and other selected materials from rivers, the atmosphere, the Strait, and bottom sediments, both past and present.
- Determine the fluxes of carbon, nutrients, organisms, and selected contaminants in coastal and shelf areas, as well as continental slope and inland basin areas;
- Elucidate the underlying physical and biogeochemical processes governing the transport and transformation of carbon, nutrients, and suspended sediments;
- Provide a quantitative understanding of the physical and biogeochemical processes, as well as nutrient fluxes, affecting primary productivity;
- to assess human and natural influences on ecosystem structure and functioning in the water column (phytoplankton and zooplankton) and in the benthos;
- develop different interactive models of general and mesoscale circulation, ecosystem, and regional processes applicable to relevant studies in marine ecology and biogeochemistry;
- To assess the spatial and temporal scales of the general and mesoscale circulation, their energetics and the processes leading to the formation, propagation and transformation of the cold intermediate layer.

1991

The first observational campaign, called HYDROBLACK '91, it took place from 2 to 29 September 1991 with the participation of five research vessels from three different Black Sea coastal countries.

Measurements were made at nearly 300 stations.

This was the first quasi-synoptic picture of the Black Sea.

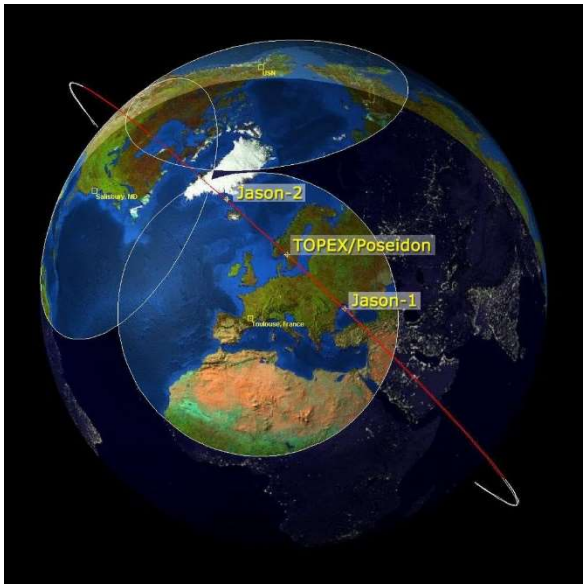
1992

CoMSBlack '92a observing campaign, which also involved five ships.

1994

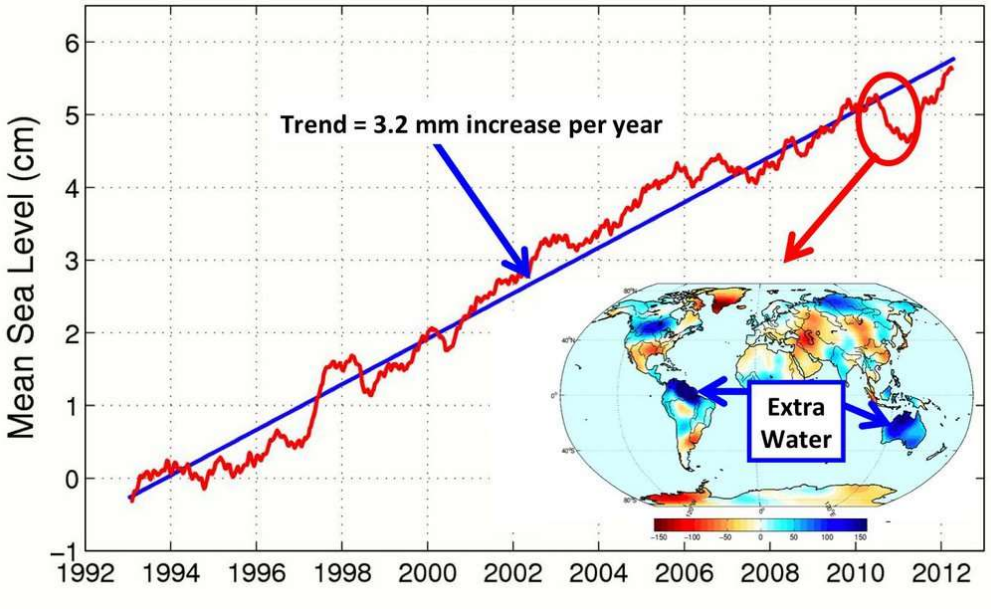
Black Sea Ecosystem Modelling Workshop.
The meeting took place from 23 to 25 March 1994. It was one of the main events of the NATO TU-BLACK SEA project. The meeting was at a high expert level therefore only 31 selected scientists participated.

Altimeters

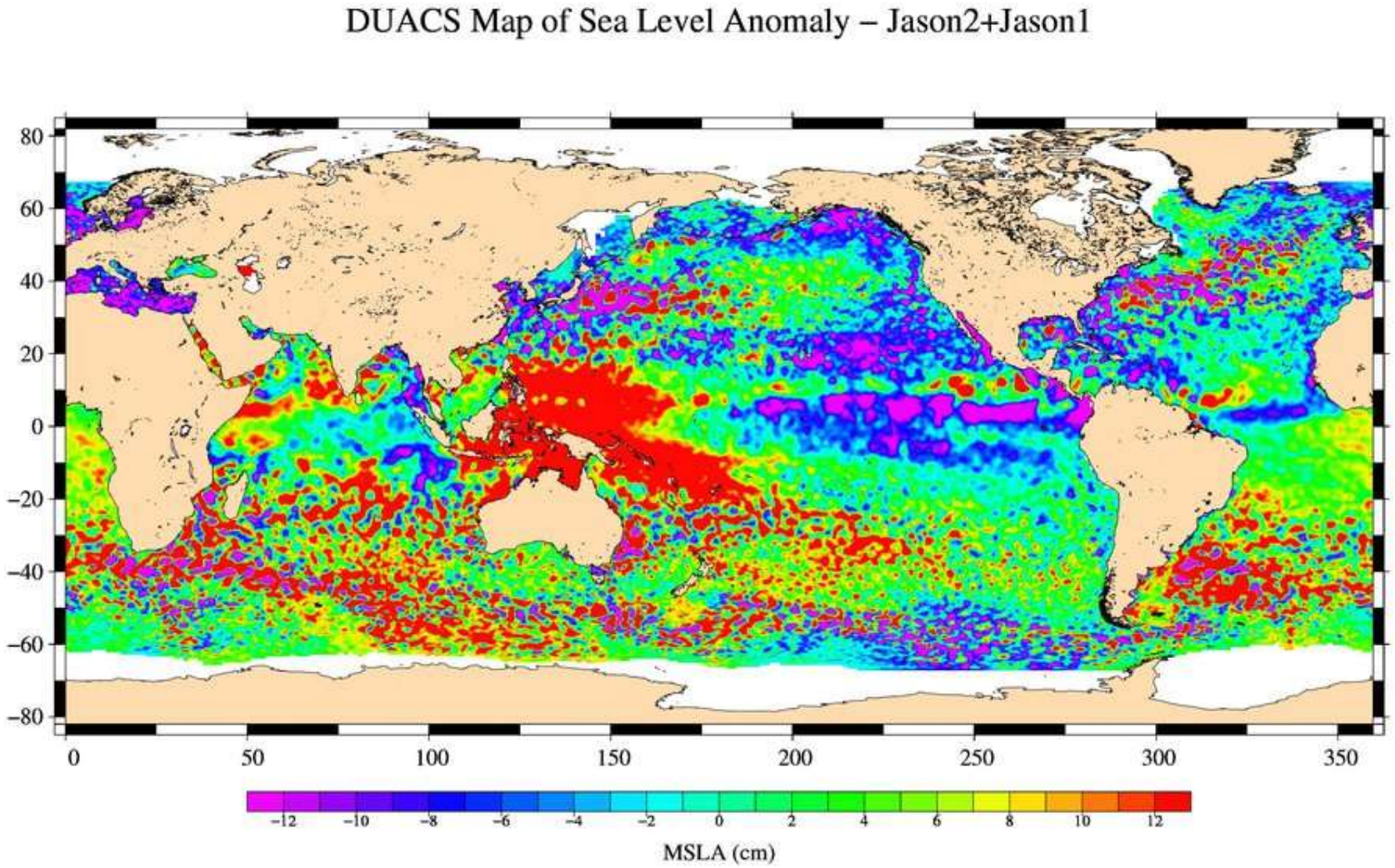


Launched in 1992, Topex/Poseidon was a joint venture between CNES, the French space agency, and NASA to map ocean surface topography. Among its many achievements, Topex/Poseidon measured sea levels with unprecedented accuracy to better than 5 centimeters, mapped year-to-year changes in heat stored in the upper ocean, and produced the most accurate global maps of tides ever.

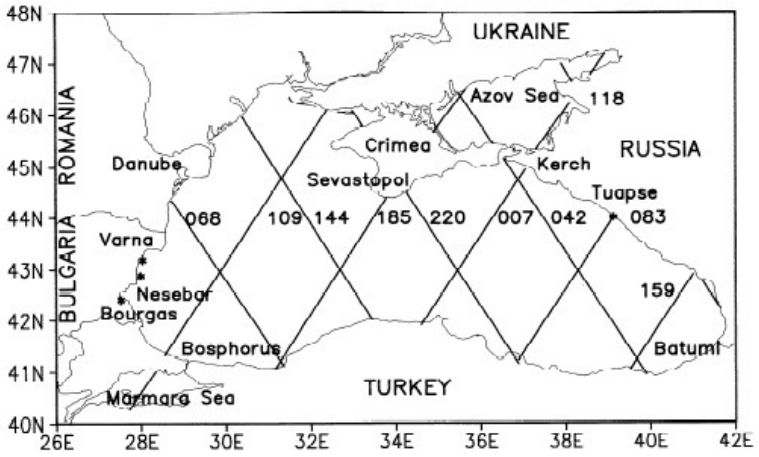
Karl Wunsch, one of the organisers of satellite altimetry: "When I had to defend the project, the main argument against us was how it was possible to expect such great results as we promised from such a cheap project. They compared it to other projects, many of them for military purposes."



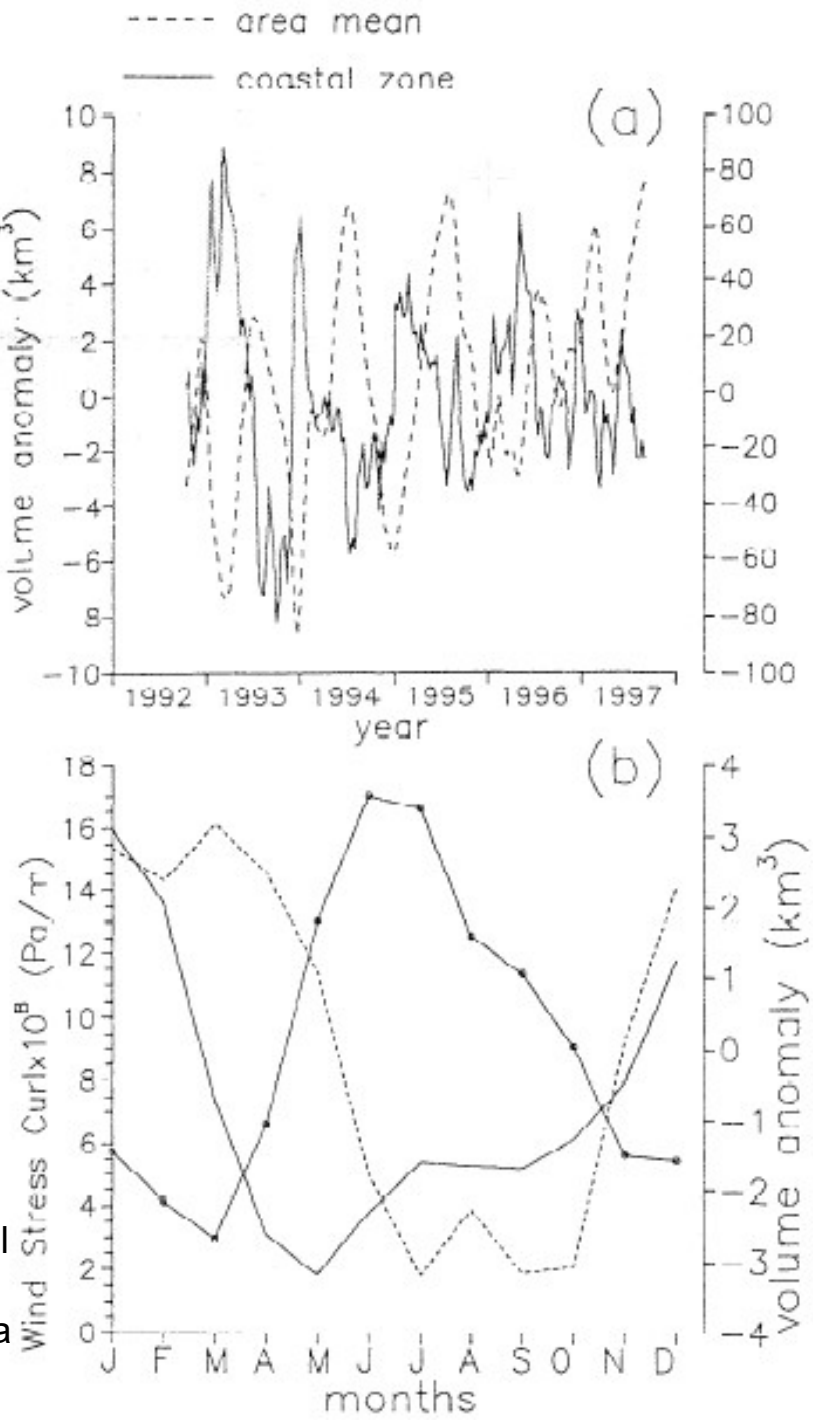
The inset shows changes in Earth's water mass from the beginning of 2010 to mid 2011. Blue colors indicate an increase in water mass over the continents. A new NASA study shows that most of the sea level drop in 2010-11 [red circle] was related to the mass transport of water from the ocean to the continents (primarily Australia, northern South America and Southeast Asia [blue arrows]). While the ocean "lost" water, the continents experienced a gain because of increased rainfalls brought on by the 2010/11 La Nina.



This image shows sea-level anomaly data from the first 14 days of the interleaved orbit of Jason-1 and OSTM/Jason-2, the period beginning on Feb. 20, 2009.

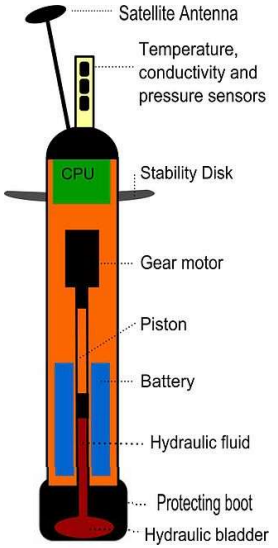


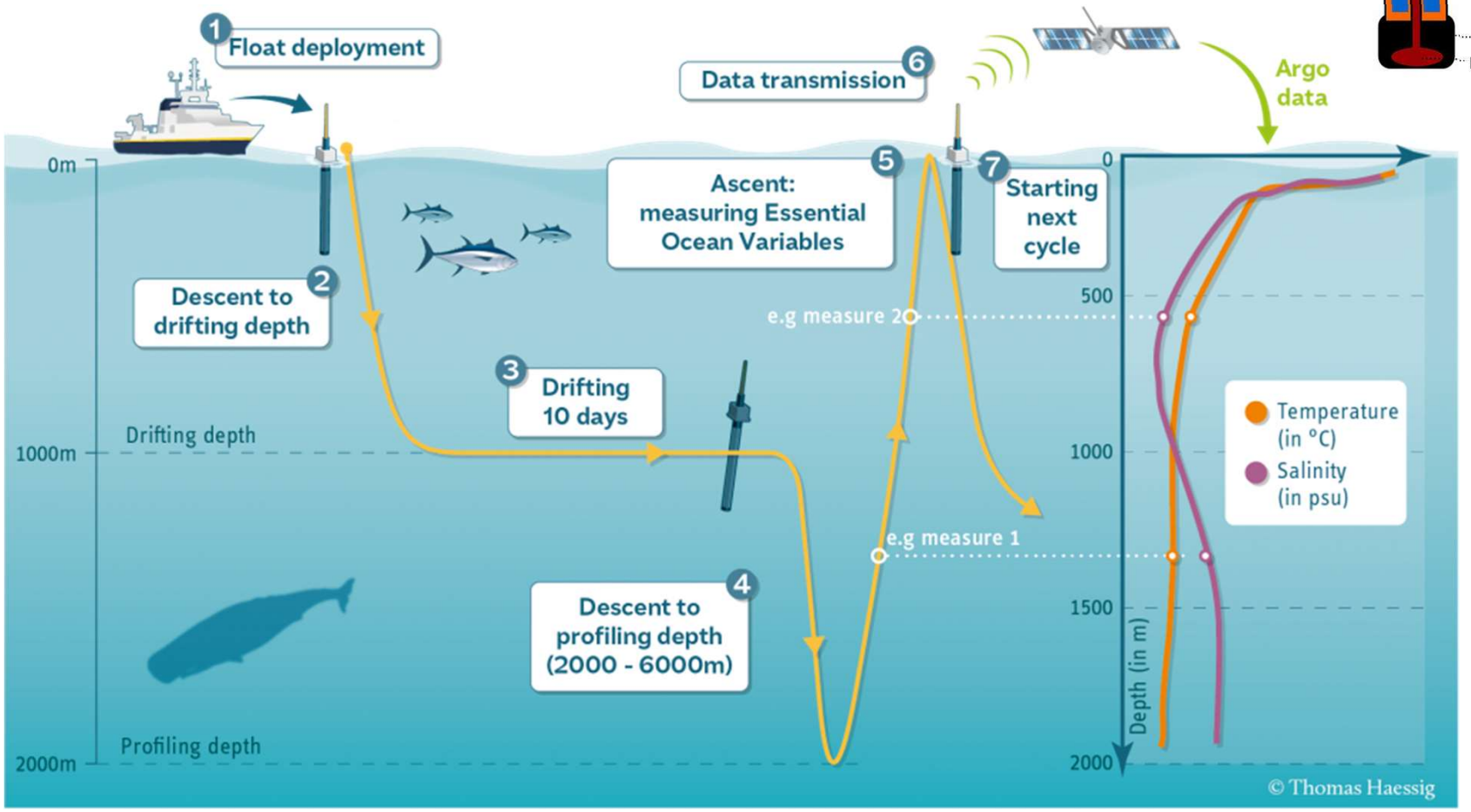
Stanev, E. V., P. Y. Le Traon, and E. L. Peneva (2000) Sea level variations and their dependency on meteorological and hydrological forcing: Analysis of altimeter and surface data for the Black Sea. *J. Geoph. Res.*, 105, C7, 17203-17216.

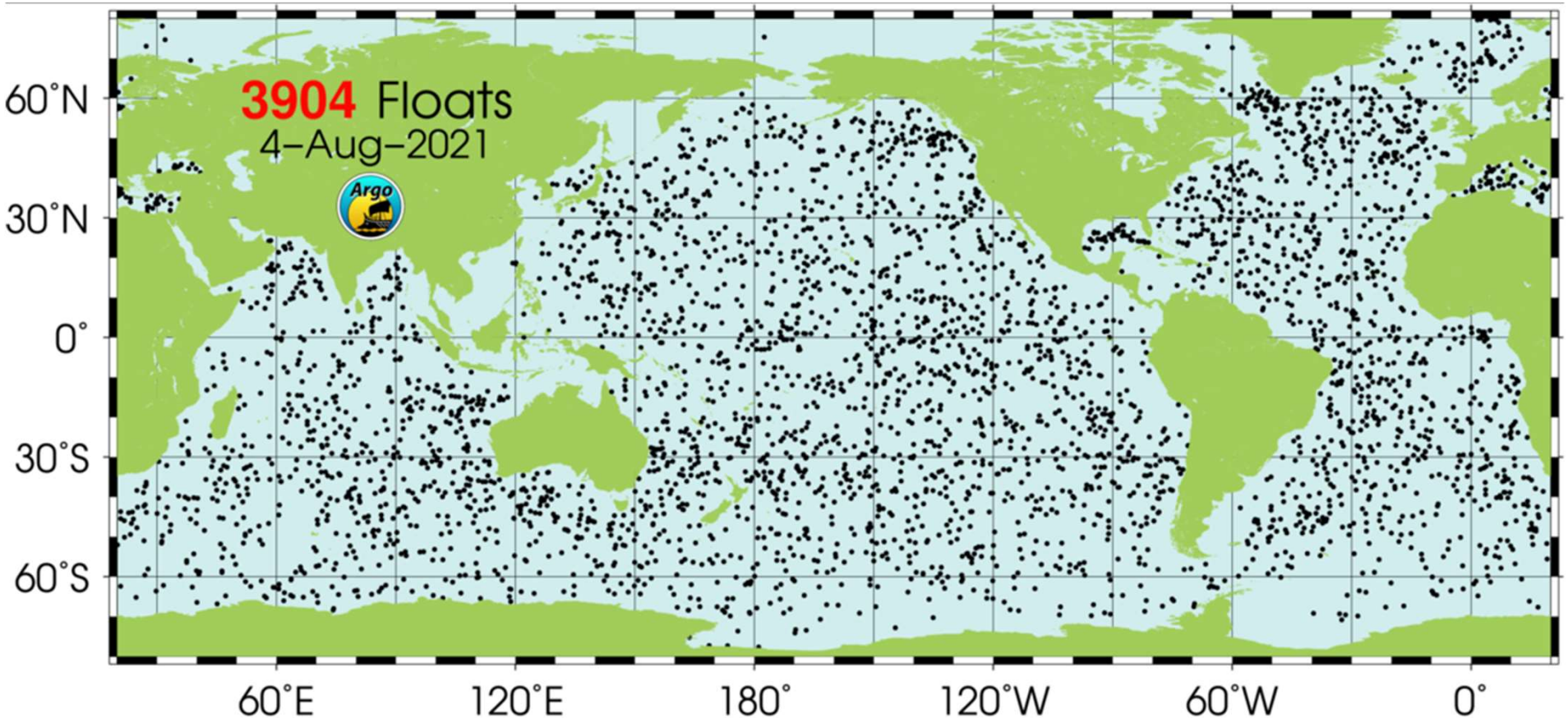


(a) variability of the SLA in the coastal zone minus basin mean SLA (left Y axis) (solid line) and variability of the basin mean SLA (right Y axis) (dashed line) and (b) seasonal variability of the wind stress curl estimated from climatic data [Staneva and Stanev, 1998] (solid line), and SLA in the coastal zone minus basin mean SLA times the area of coastal zone (dashed line). The curve with circles is the mean for the 4 year period SLA, corresponding to the solid line in Figure 2a scaled by 10 -• to be comparable with the dashed line curve.

Argo, end of 1990s

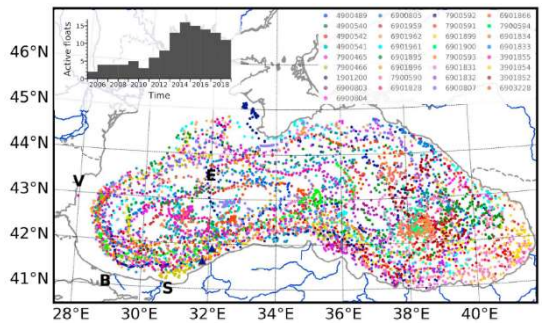




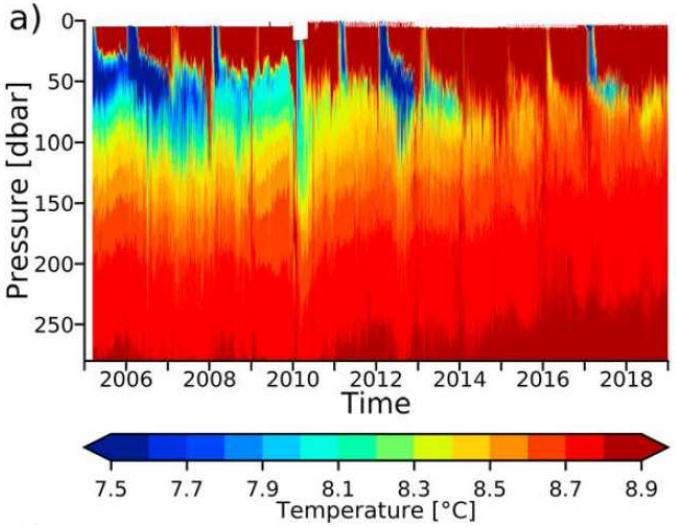

3904 Floats
4-Aug-2021
Argo
60°N
30°N
0°
30°S
60°S
60°E
120°E
180°
120°W
60°W
0°

Stanev, E. V., Peneva, E., & Chtirkova, B. (2019). Climate change and regional ocean water mass disappearance: Case of the Black Sea. *Journal of Geophysical Research: Oceans*, *124*. https://doi.org/10.1029/2019JC015076

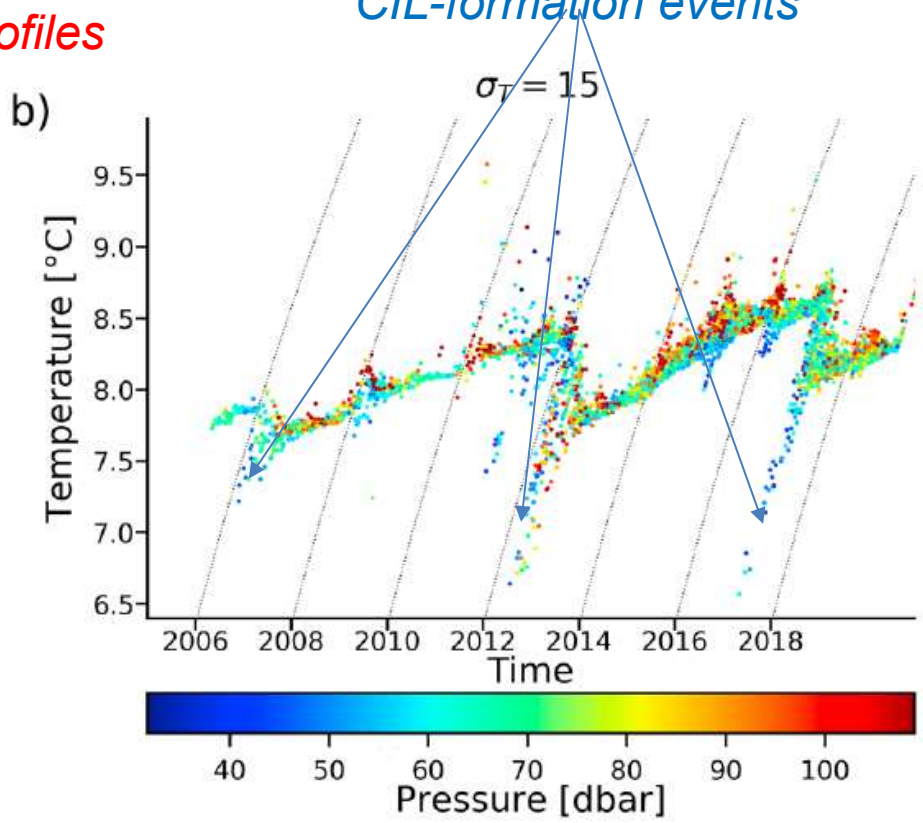
- *The warming trend in the cold intermediate layer (CIL) of ~0.05 °C/year was more than double the trend in previous decades. Its temperature approached that of the waters in the deeper layers (~9 °C), which signified its disappearance.*
- *In the absence of a pronounced CIL in recent years, the relative role of salinity variability in the thermohaline state of the upper layers increased.*



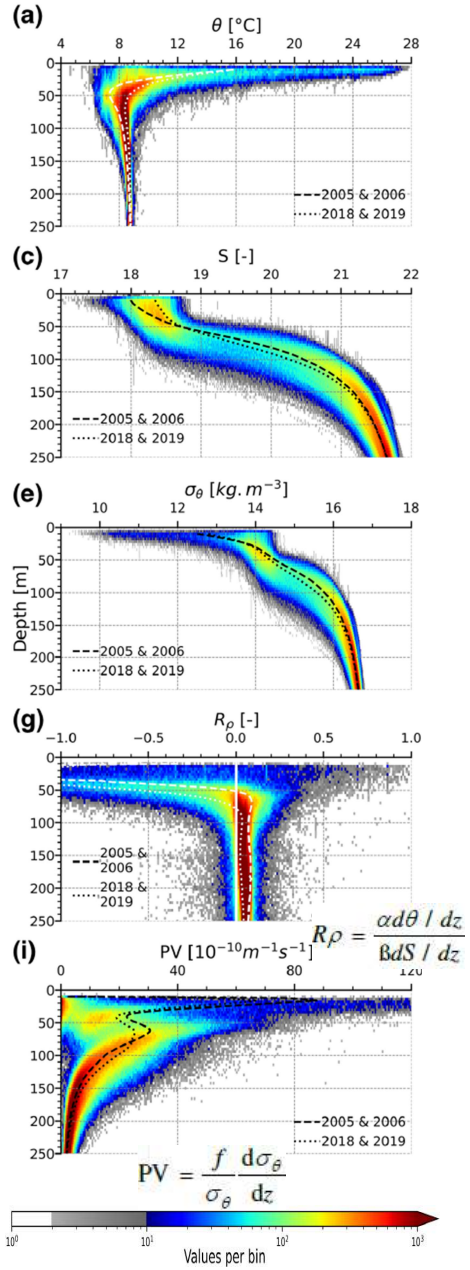
>6000 profiles



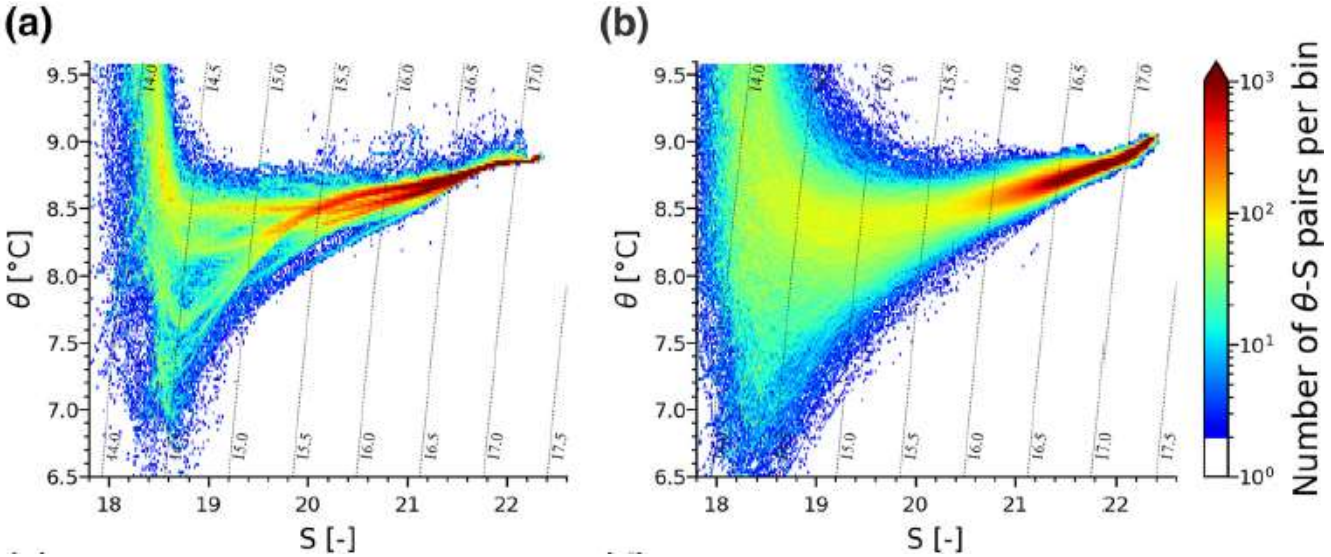
CIL-formation events



Stanev, E. V., & Chtirkova, B. (2021). Interannual change in mode waters: Case of the Black Sea. *Journal of Geophysical Research: Oceans*, *126*, e2020JC016429. https://doi.org/10.1029/2020JC016429



- Several mixing pathways, which are not known from previous studies, dominate the ocean states.
- Mixing parameterizations of models need further improvements.



Observations

Copernicus product (model)

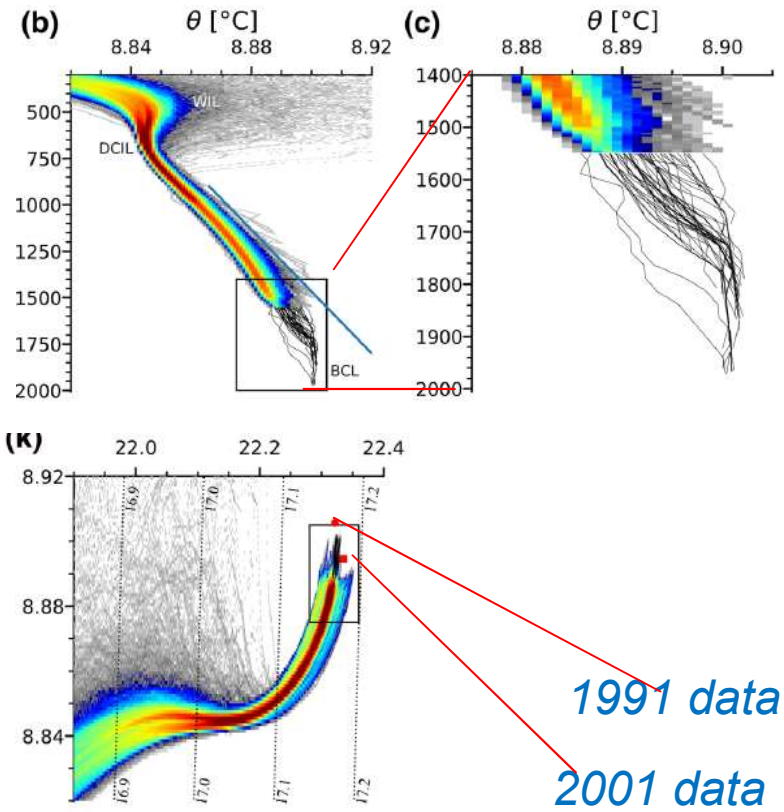
Data shown as probability distributions

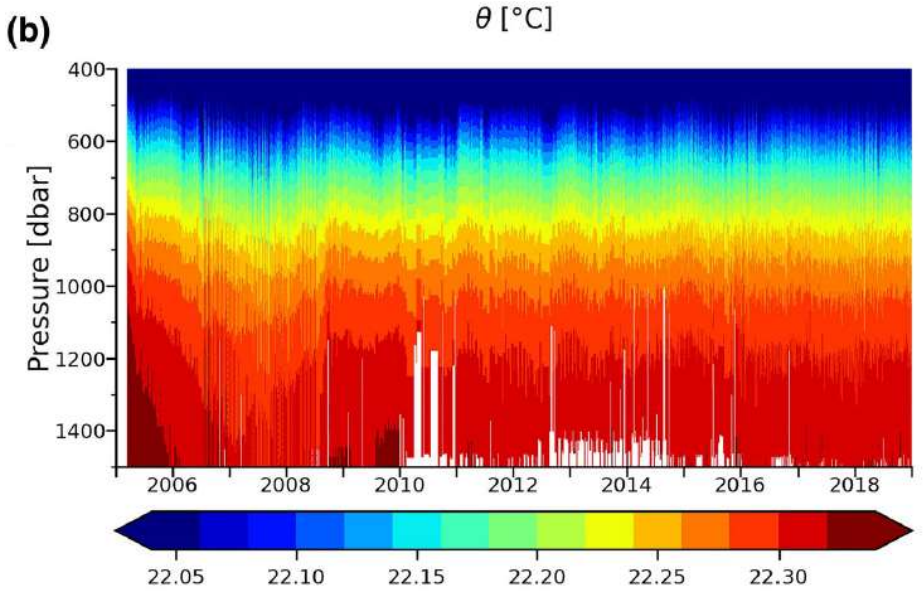
Stanev, E. V., Chtirkova, B., & Peneva, E. (2021). Geothermal convection and double diffusion based on profiling floats in the Black Sea. *Geophysical Research Letters*, *48*, e2020GL091788. https://doi.org/10.1029/2020GL091788

- Deep transition layer (DTL) between 700 and 1,700 m acts as an interface between the baroclinic layer and the largest bottom convective layer (BCL) of the world oceans.

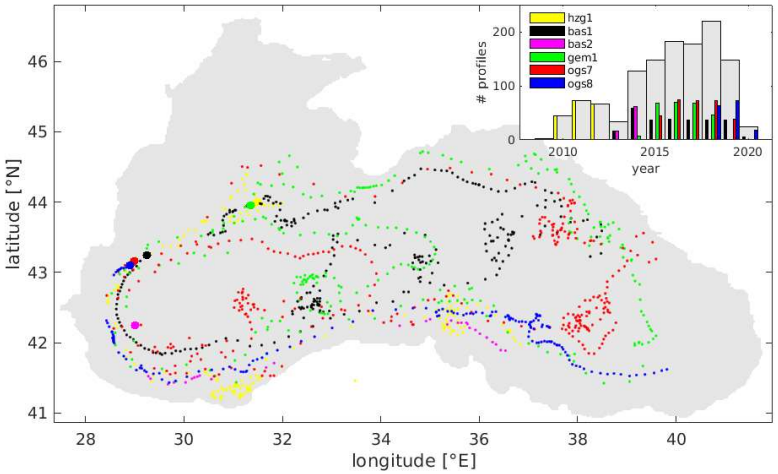
- On top of DTL are the warm intermediare layer (WIL) and deep cold intermediate layer (DCIL), which showed strong trends in the last 15 years

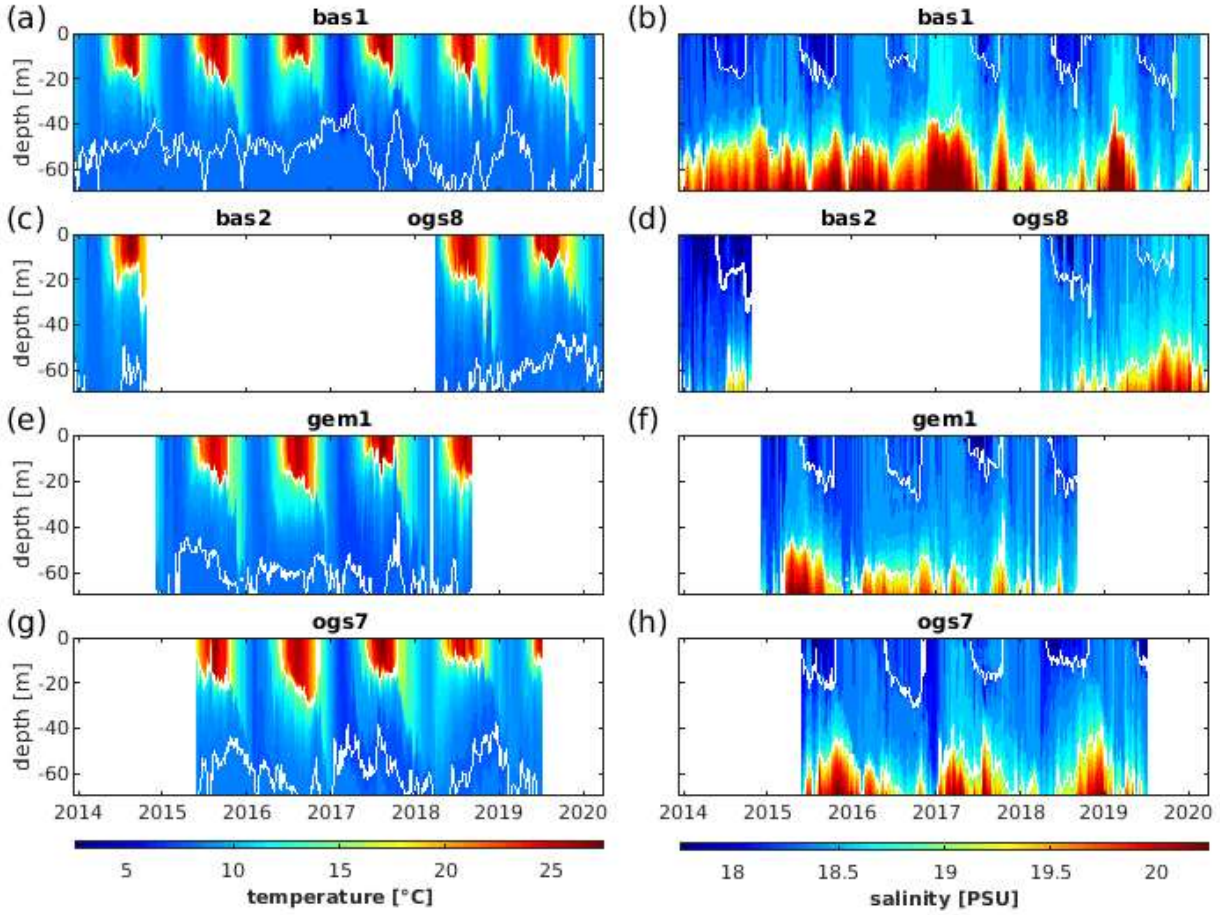
- A "salinity wave" in 2005–2009 below ~1,700 m evidenced for the first time the penetration of gravity flow from Bosporus down to the bottom.



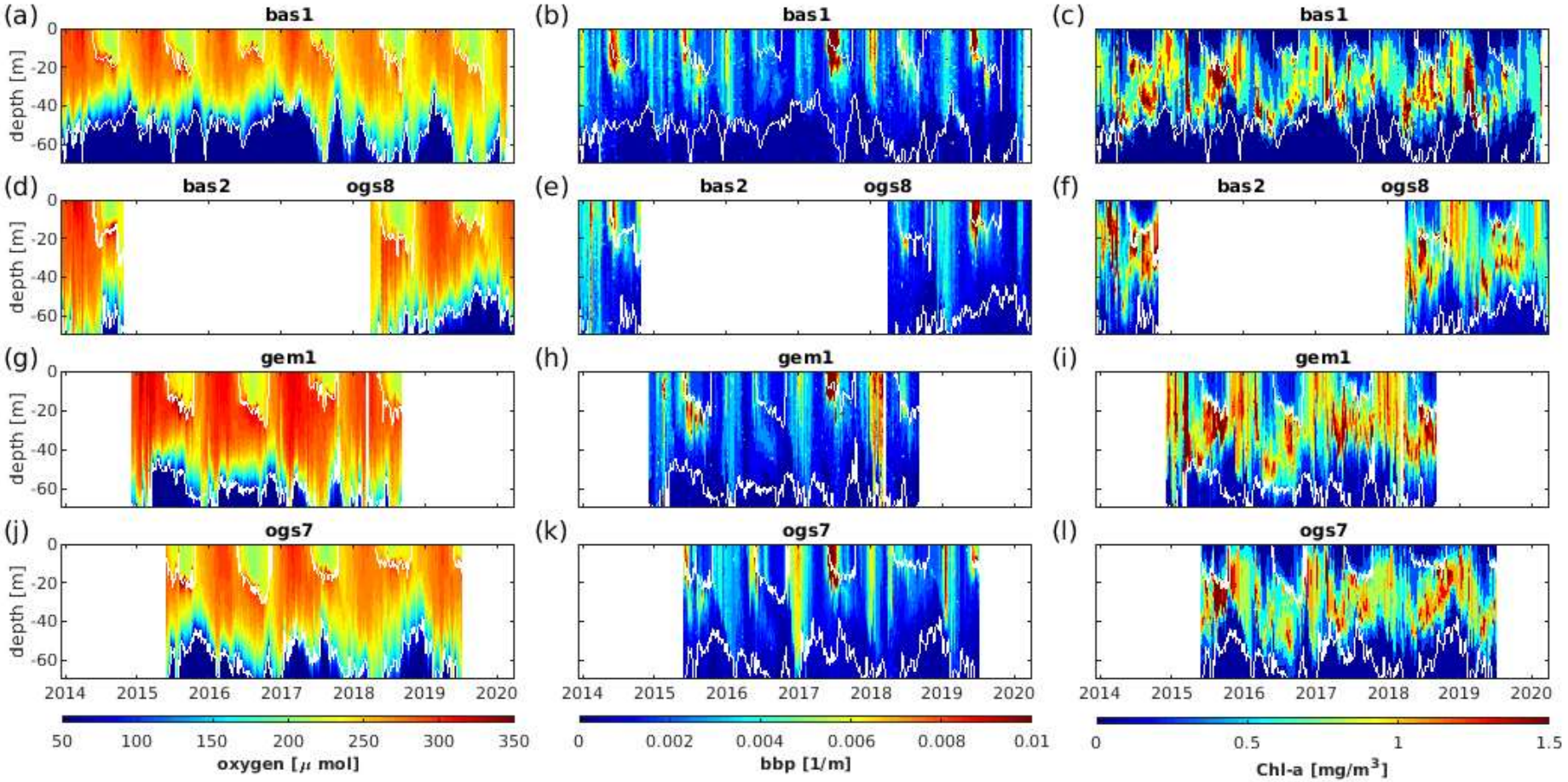


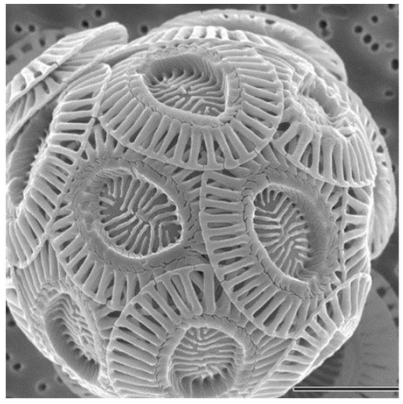
BGC Argo



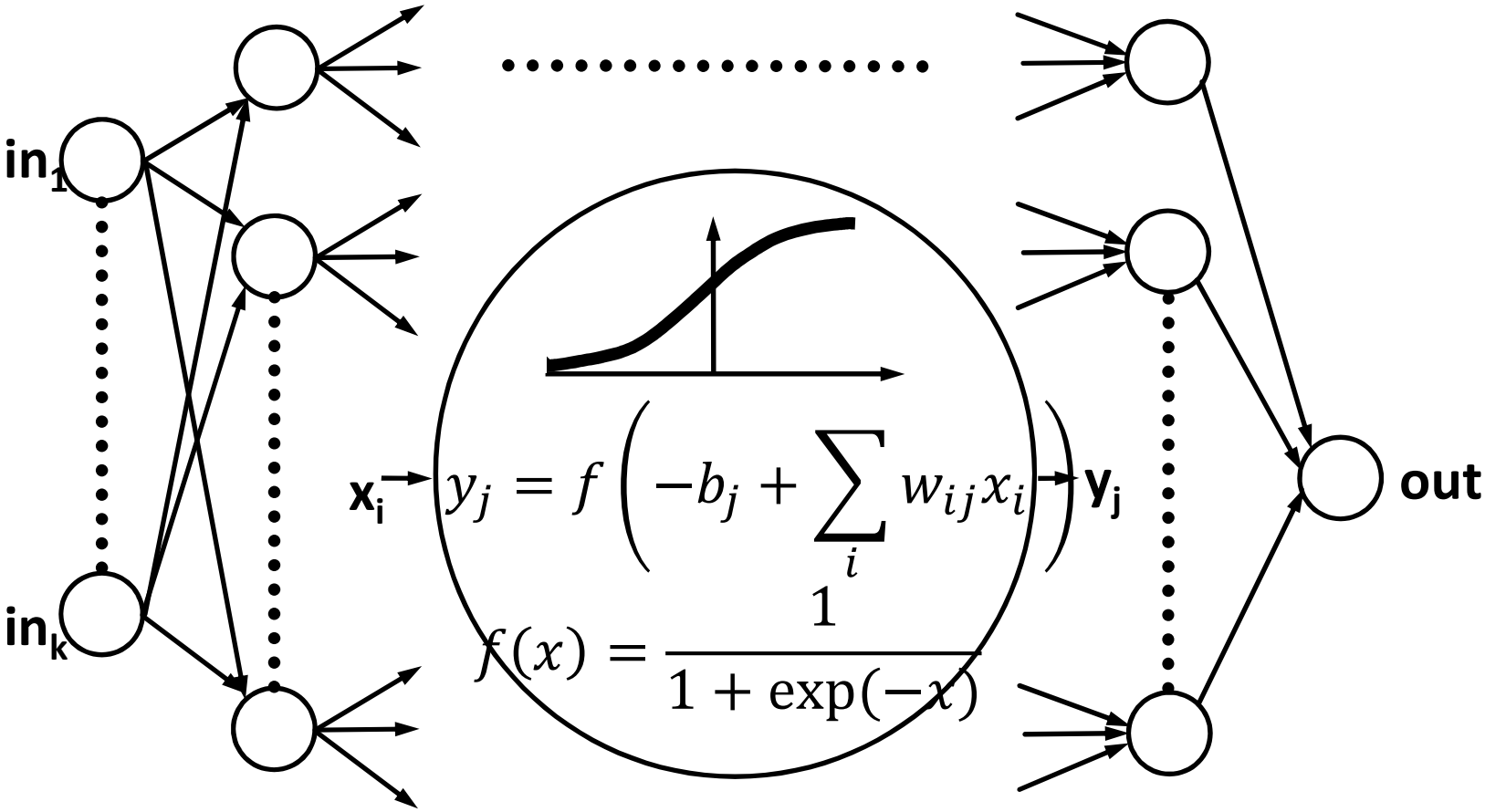


Stanev, et al., 2021, submitted to JGR

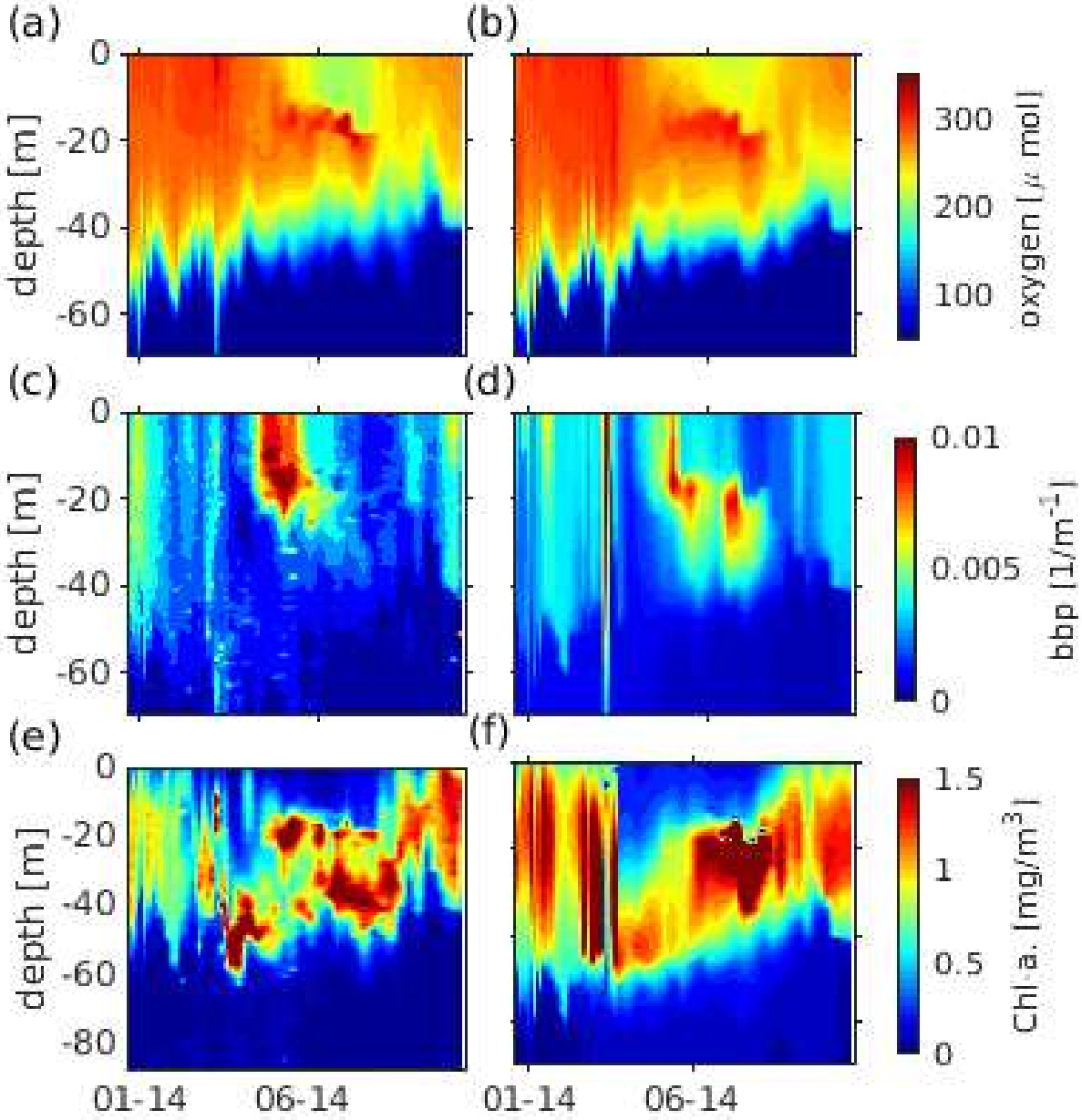




Emiliania huxleyi



NN is used to derive BGC variables from physical variables. This method can be understood as a kind of input-output mapping in which the neurons combine the input data in such a way that the output can be considered as a nonlinear combination of input data. This ensures that, unlike some statistical methods, e.g. EOF analysis, signal processing can “capture” the nonlinear interactions.


(a)
(b)
(c)
(d)
(e)
(f)
depth [m]
0
-20
-40
-60
-80
01-14
06-14
300
200
100
oxygen [μ mol]
0.01
0.005
0
bbp [1/m^{-1}]
1.5
1
0.5
0
Chl-a. [mg/m^3]

		NN(ARGO_o)	NN(ARGO_ss)	NN(CMEMS)	CMEMS (bio)
oxygen	bas1	0.92	0.92	0.64	0.42
	gem1	0.92	0.92	0.66	0.51
	ogs7	0.93	0.94	0.83	0.56
	ogs8	0.90	0.90	0.62	0.40
bbp	bas1	0.73	0.73	0.54	-
	gem1	0.92	0.92	0.81	-
	ogs7	0.84	0.89	0.54	-
	ogs8	0.77	0.77	0.51	-
Chl-a	bas1	0.76	0.76	0.48	0.29
	gem1	0.82	0.79	0.48	0.47
	ogs7	0.71	0.79	0.53	0.25
	ogs8	0.71	0.72	0.42	0.41

Conclusion:
Who wants to do the next step?

Thank you for your attention