surface ocean **solas** lower atmosphere study

Report for the year 2021 and future activities

SOLAS '*GREECE*'
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This report has two parts:

***- Part 1:** reporting of activities in the period of January 2021 - Jan/Feb 2022*
***- Part 2:** reporting on planned activities for 2022 and 2023.*

The information provided will be used for reporting, fundraising, networking, strategic development and updating of the live web-based implementation plan. As much as possible, please indicate the specific SOLAS 2015-2025 Science Plan Themes addressed by each activity **or specify an overlap between Themes or Cross-Cutting Themes.**

1 Greenhouse gases and the oceans;
2 Air-sea interfaces and fluxes of mass and energy;
3 Atmospheric deposition and ocean biogeochemistry;
4 Interconnections between aerosols, clouds, and marine ecosystems;
5 Ocean biogeochemical control on atmospheric chemistry;
Integrated studies of high sensitivity systems;
Environmental impacts of geoengineering;
Science and society**.**

***IMPORTANT**: This report should reflect the efforts of the SOLAS community in the **entire country** you are representing (all universities, institutes, lab, units, groups, cities).*

First things first…Please tell us what the IPO may do to help you in your current and future SOLAS activities. ?

The Mediterranean region is often characterized as a climate change hotspot. According to this, it has been the object of the AR6-WG2 cross chapter paper 4 and is a well defined world region frequently mentioned also in other parts of the recent IPCC AR6 (in AR6-WG1, WG2-Chapter 13 Europe and WG2-Chapter 9 Africa). As Greece is entering now the SOLAS program, there is a great opportunity to be aided to support a community building on the SOLAS themes from national to the global level.

PART 1 - Activities from January 2021 to Jan/Feb 2022

1. Scientific highlight

*Describe one scientific highlight with a title, text (**max. 300 words**), a figure with legend and full references. Please focus on a result that would not have happened without SOLAS, and we are most interested in results of international collaborations. (If you wish to include more than one highlight, feel free to do so).*

2. Activities/main accomplishments in 2021 (e.g., projects; field campaigns; workshops and conferences; model and data intercomparisons; capacity building; international collaborations; contributions to int. assessments such as IPCC; collaborations with social sciences, humanities, medicine, economics and/or arts; interactions with policy makers, companies, and/or journalists and media).

Chemical characterization of the SML

We investigated the annual variations of natural organic compounds in surface waters (1 m) and the SML, i.e. TEPs and dissolved carbohydrates (CHOs) as well as CDOM/FDOM at a coastal site in the Eastern Mediterranean Sea (Fig.1). In parallel, taking into account their role in metal binding, we examine any interrelations with Cu and Cu complexing agents (L_T) as determined by anodic stripping voltammetry. We further explored the role of microplastics in Cu binding in the SML as part of a mesocosm experiment (https://www.poseidomm.eu/) considering microplastics as potential Cu binding agents.

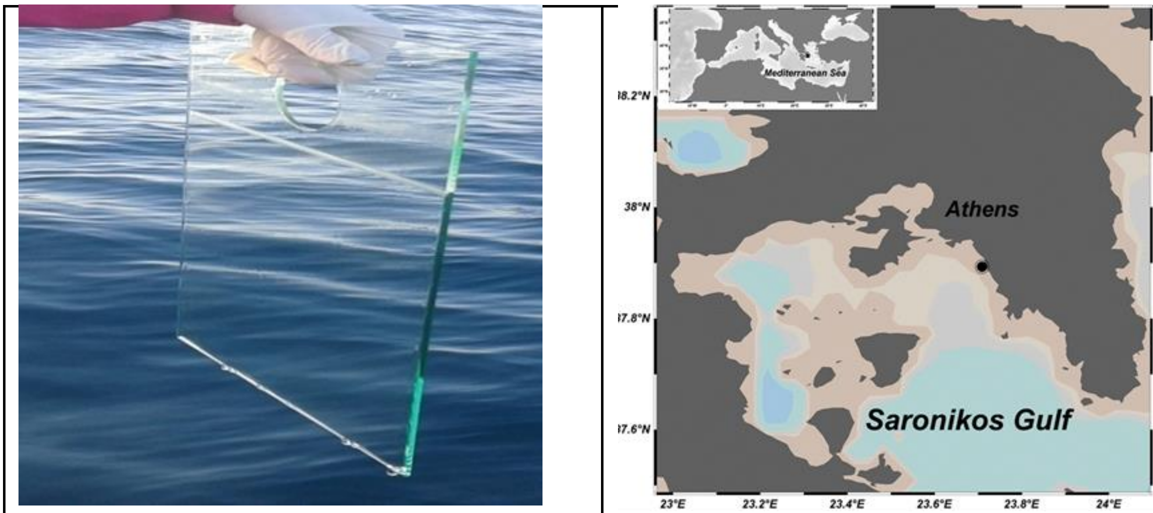


Fig. 1 (a) glass plate sampling of the SML; (b) the study site

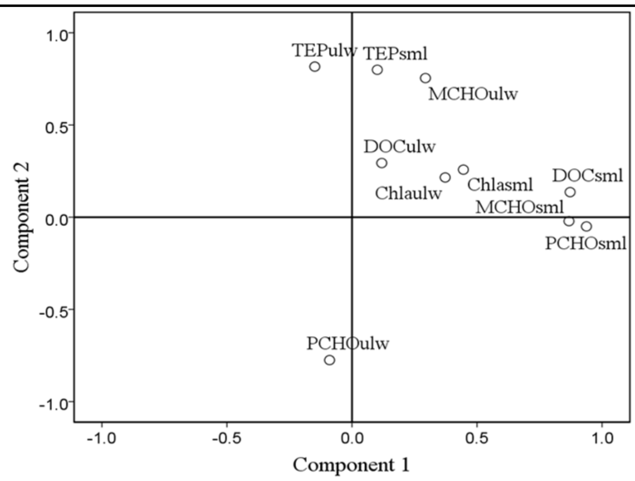


Fig 2. Principal component analysis of Chl-a, TEPs, DOC, MCHOs and PCHOs in the SML and the ULW in the field study.

The overall variability of the data as shown in Fig.2, showed that DOC and sugars follow the variations of chl-a in the SML. In contrast, the TEPs formation in both layers showed a time lag following the phytoplanktonic blooms, which were dominated by diatoms. The opposite relation of MCHOs with PCHOs in the ULW indicate the active polymerization of MCHOs to PCHOs in this layer. Similarly, the contrasting relation of PCHOs to TEPs in the ULW shows further aggregation of PCHOs to TEPs. The strong correlation TEPs in the two layers shows active aggregation processes in both layers. The formation of the SML at the study site, appears to be controlled mostly by upward transport processes of organic material as inferred by the strong positive relationships of Chl-a, TEPs and DOC between the SML and the ULW. Within the pool of DOM, mono- and poly- carbohydrates behave differently in the two layers having an active role in the polymerization and aggregation processes.

In the simulated conditions of high microplastics (MP) concentrations in the mesocosms, and the positive correlation of L_T with TEPs in the MP treatments in the SML ($r= 0.821$, $p= 0.023$, $n=7$) imply that in the presence of MPs physicochemical binding of Cu to either the TEPs or the MPs is facilitated. Furthermore, the general decrease in dissolved Cu concentrations ($\mu g L^{-1}$) towards the end of the experiment from both layers and the negative correlation of dissolved Cu with TEPs in controls $r= -0.786$, $p=0.036$, $n=7$) and in the MP treatments ($r= -0.679$, $p=0.094$, $n=7$) in the ULW corroborates the argument on the adhesion of Cu-D forms onto the particulate phase.

The work on CDOM/FDOM data evaluation is underway.

Reference: Tzempelikou E., Galgani L., Zeri C., Karavoltos S., Pitta E., Adamopoulou A., Assimakopoulou G., Iliakis S., Kalantzi I., Sakellari Aik., Tsapakis M., 2022, Annual variations of transparent extracellular particles, carbohydrates, and Cu-binding agents in the sea surface microlayer of a coastal Mediterranean site. Implications for the role of microplastics. Submitted to Frontiers in Marine Science

How atmospheric and oceanographic forcing impact the carbon sequestration in an ultra-oligotrophic marine system (as reported in the OCB Science highlights: https://www.us-ocb.org/forcing-impact-sequestration-oligotrophic/)

Sinking particles are a critical conduit for the export of material from the surface to the deep ocean. Despite their importance in oceanic carbon cycling, little is known about the composition and seasonal variability of sinking particles which reach abyssal depths. Oligotrophic waters cover ~75% of the ocean surface and contribute over 30% of the global marine carbon fixation. Understanding the processes that control carbon export to the deep oligotrophic areas is crucial to better characterize the strength and efficiency of the biological pump as well as to project the response of these systems to climate fluctuations and anthropogenic perturbations.

In a recent study published in Frontiers in Earth Science, authors synthesized data from atmospheric and oceanographic parameters, together with main mass components, and stable isotope and source-specific lipid biomarker composition of sinking particles collected in the deep Eastern Mediterranean Sea (4285m, Ierapetra Basin) for a three-year period (June 2010-June 2013). In addition, this study compared the sinking particulate flux data with previously reported deep-sea surface sediments from the study area to shed light on the benthic–pelagic coupling.

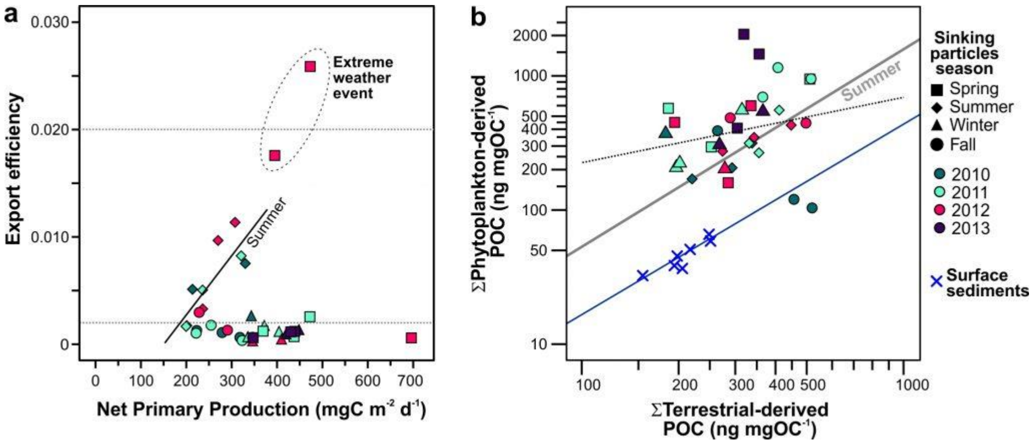


Figure Caption: a) Biplot of net primary productivity vs export efficiency (top and bottom horizontal dashed lines indicate threshold for high and low export efficiency regimes). b) Biplot of POC-normalized concentrations of terrestrial vs. phytoplankton-derived lipid biomarkers of the sinking particles collected in the deep Eastern Mediterranean Sea (Ierapetra Basin, NW Levantine Basin) from June 2010–June 2013, and surface sediments collected from January 2007 to June 2012 in the study area.

Both seasonal and episodic pulses are crucial for POC export to the deep Eastern Mediterranean Sea. POC fluxes peaked in spring April–May 2012 (12.2 mg m−2 d−1) related with extreme atmospheric forcing. Overall, summer particle export fuels more efficient carbon sequestration than the other seasons. The results of this study highlight that the combination of extreme weather events and aerosol deposition can trigger an influx of both marine labile carbon and anthropogenic compounds to the deep. Finally, the comparison of the sinking particles flux data with surface sediments revealed an isotopic discrimination, as well as a preferential degradation of labile organic matter during deposition and burial, along with higher preservation of land-derived POC in the underlying sediments. This study provides key knowledge to better understand the export, fate and preservation vs. degradation of organic carbon, and for modeling the organic carbon burial rates in the Mediterranean Sea.

Reference: Pedrosa-Pamies R, Parinos C, Sanchez-Vidal A, Calafat A, Canals M, Velaoras D, Mihalopoulos N, Kanakidou M, Lampadariou N and Gogou A (2021) Atmospheric and Oceanographic Forcing Impact Particle Flux Composition and Carbon Sequestration in the Eastern Mediterranean Sea: A Three-Year Time-Series Study in the Deep Ierapetra Basin. Front. Earth Sci. 9:591948. doi: 10.3389/feart.2021.591948

Optical properties and biochemical indices of marine particles in the open Mediterranean Sea: the R/V Maria S. Merian cruise.

The vertical distribution, horizontal distribution, and export at depth of particulate matter (PM) in the world ocean have been the subject of numerous studies over the past decades. Optical methods have been used for decades to describe PM behavior in the marine environment, as particle quality, distribution, abundance and size, directly affect light scattering in the ocean, and subsequently regulate the oceans' optical properties and the water-leaving radiance measured remotely from satellites.

The survey was carried out on board the German R/V Maria S. Merian from March 2nd to April 3rd 2018. The cruise started at Heraklion, Crete, Greece and ended in Cadiz, Spain. In total, 136 CTD casts were conducted during the cruise materializing a complete east-to-west Mediterranean transect plus another one in the Ionian Sea. At 62 stations (with depth < 3000 m) the LISST-Deep was deployed along with the rosette system to obtain optical parameters. At 15 stations, seawater samples were also collected for the elemental and stable isotopic analysis of carbon and nitrogen of PM.

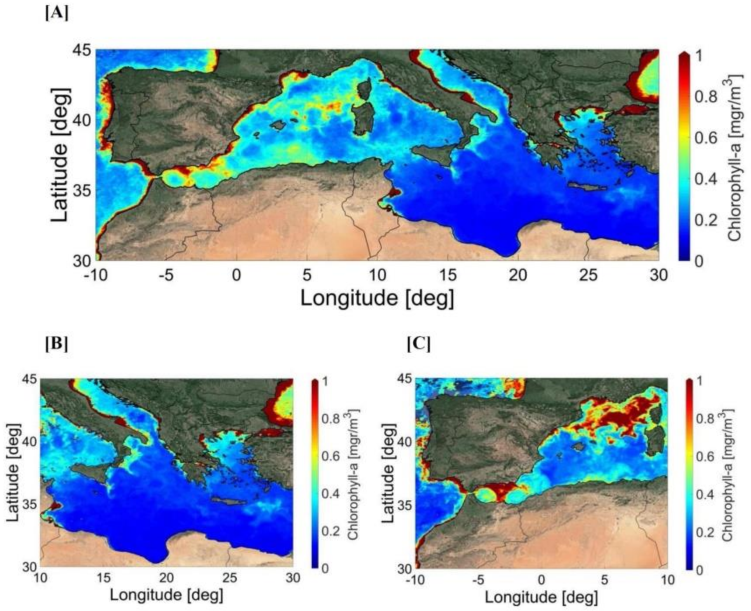


Fig. 1: Figure 1a shows the monthly mean average sea surface chlorophyll-a concentration in the Mediterranean Sea for March 2018, while Figures 1b & 1c shows the 8-day average sea surface chlorophyll-a concentrations in the Mediterranean Sea for the first (06-13/03/2018) and second (30/03/2018-06/04/2018) legs of the MSM72 cruise, which corresponds to the sampling periods in the EMed and WMed Mediterranean sub-basins, respectively. According to this, during the MSM72 cruise, a west-to-east, as well as a north-to-south gradient in oligotrophy, was observed in the two sub-basins (Figures 1a-c).

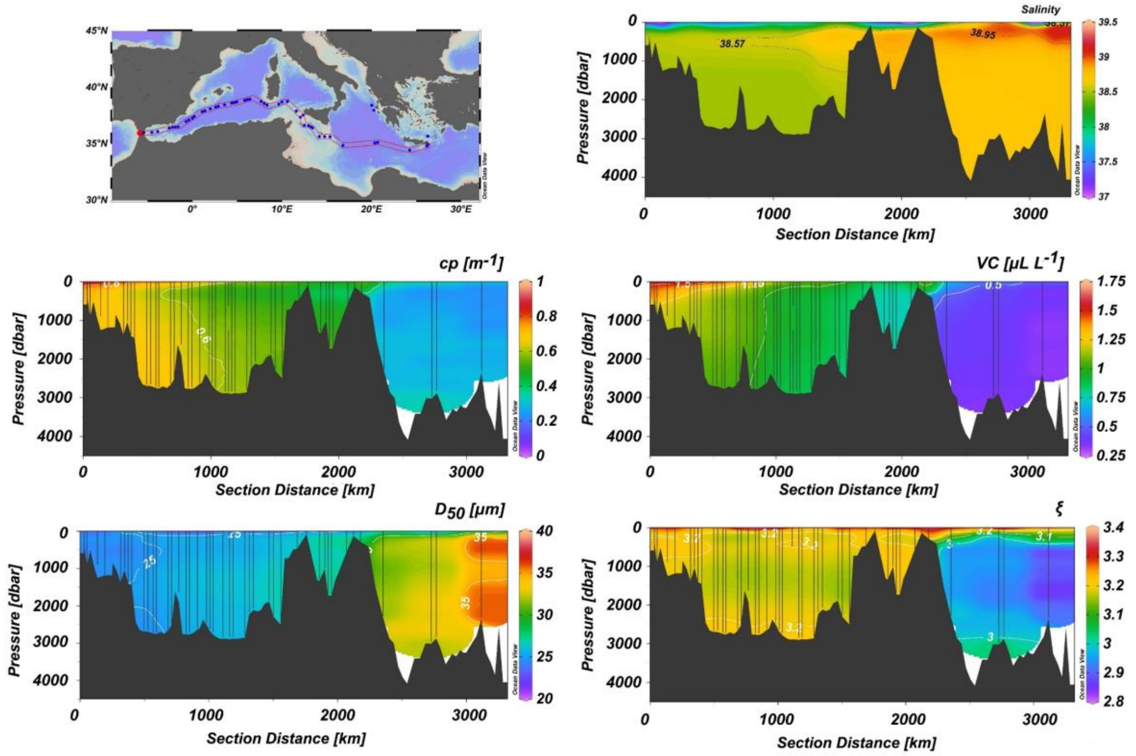


Fig. 2: A west-east section of Beam Attenuation (cp), Volume Concentration (VC), Median Diameter (D50), and PSD slope (ξ) distribution in the study area

The beam attenuation coefficient, cp, clearly exhibits higher values throughout the water column in the WMed, especially in the upper ~100 m and progressively the cp signal decreases towards the east. The particle volume concentration, VC, along the section shows similar characteristics to cp, with higher values in the WMed and progressively lower values towards the central Mediterranean and the EMed. Furthermore, the particle median diameter D50, in the Mediterranean shows an average of 27±3 µm. Its evolution from the west to the east is reversed with respect to the previously discussed parameters. Finally, the PSD slope ξ, along the section shows similar characteristics to cp and VC with high values in WMed and lower values in EMed.

Surface Atlantic waters were identified as the most turbid waters in the Mediterranean Sea, whilst Transitional Mediterranean Water represents the most transparent water mass. A direct relationship between hydrological parameters, water masses and LISST-derived particle optical properties was observed throughout the Mediterranean Sea. POC concentrations increase inversely with D50 and proportionally with ξ, indicating higher organic carbon contents within smaller particle populations.

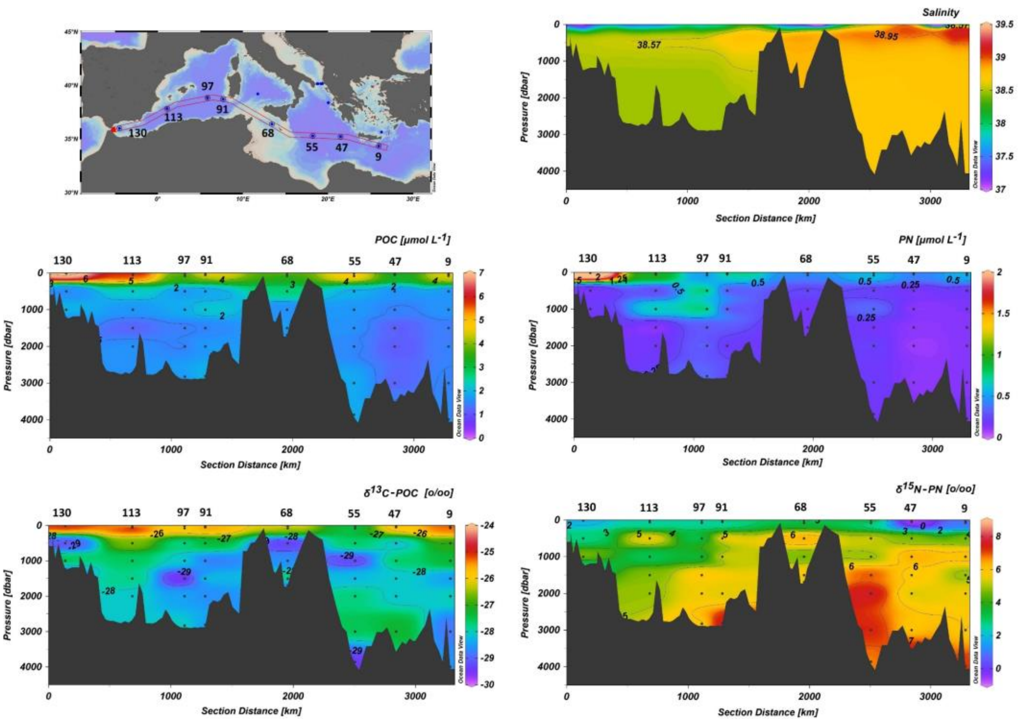


Figure 3: A west-east section of POC and PN contents and their isotopic composition in the study area.

POC and PN concentrations in the study area, considering the entire water column, ranged from 1.06 to 7.12 µmol L-1, 2.71±1.40 µmol L-1 on average, and from 0.09 to 1.99 µmol L-1, 0.40±0.32 µmol L-1 on average, respectively. POC/PN molar ratio ranged from 1.9 to 13.7, with an average of 8.5±2.6. Higher POC and PN concentrations were consistently recorded within surface waters or the maximum of chlorophyll fluorescence of all stations with the highest values being detected in the Alboran Sea and Algerian Basin while lower concentrations were observed in the eastern Ionian Sea and South Cretan margin. δ13C-POC ranged between -28.73 and -25.02‰. Close and Henderson (2020) [11] reported δ^{13}C-POC values in open oceanic waters that span over a broad range, varying from −35‰ at high latitudes to −16‰ at low-mid latitudes. δ^{15}N-PN values in our data set spans a range from -1.31 to 8.10‰. Depleted values are recorded within surface ranging from –1.31 to 3.35‰ (average 1.88‰)

Our data showed substantial differences between the western-central and the eastern sector of the basin, highlighting the transition from mesotrophic to oligotrophic conditions. The presence of relatively depleted δ^{15}N-PN values in the surface and the Transitional Mediterranean Water mass highlights the role of atmospheric deposition of anthropogenic N (Mara et al., 2009, Glob. Biogeochem. Cycles 23, GB4002. doi:10.1029/2008gb003395) has on marine biogeochemical parameters along with the observed changes in circulation patterns, driving the redistribution of particulate matter as a source of nutrients.

References:

Chaikalis S, Parinos C, Möbius J,, Gogou A, Velaoras D, Hainbucher D, Sofianos S, Tanhua T, Cardin V, Proestakis E, Amiridis V, Androni A and Karageorgis A (2021) Optical Properties and Biochemical Indices of Marine Particles in the Open Mediterranean Sea: The R/V Maria S.Merian Cruise, March 2018. Front. Earth Sci. 9:614703.doi: 10.3389/feart.2021.61470

Atmospheric Deposition of nutrients globally and onto the Mediterranean Sea

A number of pioneering global modelling studies have been performed by Greek SOLAS scientists focusing on nutrient atmospheric cycles and their atmospheric deposition using off-line chemistry climate models. They concern the first organic nitrogen and organic phosphorus global deposition studies (Kanakidou et al., GBC 2012), the global nitrogen cycle -accounting for its organic components and how this evolves under changing human-driven emissions (Kanakidou et al., JAS, 2016), the global iron cycle (Myriokefalitakis et al., BG, 2015) and global phosphorus cycle (Myriokefalitakis et al., BG 2016) accounting for iron and phosphorus solubilisation by chemical reactions in the atmosphere as well as for the contribution of bioaerosols to organic phosphorus atmospheric load.

As a follow-up of these studies focus was put in 2020 in the input of thee nutrients into the Mediterranean Sea (Kanakidou et al., Deep-Sea Research Part II 171 (2020) 104606). That study accounting for both inorganic and organic nutrients, estimated that atmospheric deposition fluxes of soluble nutrients to the Mediterranean Sea amount to 1281 Gg-N y^{-1}, 4.31 Gg-P y^{-1} and 6.32 Gg-Fe y^{-1} for the present day, and are within the range of the few estimates available in literature. An almost 6-fold increase in the atmospheric deposition of soluble N is also calculated to be the result of the increase in anthropogenic and biomass burning emissions since 1850, while soluble P and Fe deposition fluxes have increased by 59% and 114%, respectively. For future (2100) emissions, however, N deposition is projected to increase only slightly (4%) while soluble P and Fe fluxes will decrease by 34% and 32% compared to current estimates. The soluble organic N and P annual deposition fluxes are calculated to be 12% and 28–83% of total soluble N and P present-day annual deposition fluxes into the Mediterranean Sea respectively. To reconcile with the observed fluxes in the west and the east Mediterranean, ∼14 times higher flux of soluble P, in particular organic P, and at least 2.5 times higher flux of soluble Fe need to be considered in the model. Such high fluxes can be due to higher combustion emissions of soluble Fe and P, to higher dust emissions or solubilisation of Fe and P contained in dust aerosols, and also higher organic P flux associated with bioaerosols than currently used in the global models. These hypotheses are now under investigation.

The global N/P/Fe atmospheric deposition modeling has been also used to evaluate the impact of atmospheric acidity on these nutrients deposition and thereby on ecosystems. This study was performed in the frame of a GESAMP WG 38 workshop and published as part of the Baker et al., 2021 review paper in Sciences Advances:

Anthropogenic emissions to the atmosphere have increased the flux of nutrients, especially nitrogen, to the ocean, but they have also altered the acidity of aerosol, cloud water, and precipitation over much of the marine atmosphere. For nitrogen, acidity-driven changes in chemical speciation result in altered partitioning between the gas and particulate phases that subsequently affect long-range transport. Other important nutrients, notably iron and phosphorus, are affected, because their soluble fractions increase upon exposure to acidic environments during atmospheric transport. These changes affect the magnitude, distribution, and deposition mode of individual nutrients supplied to the ocean, the extent to which nutrient deposition interacts with the sea surface microlayer during its passage into bulk seawater, and the relative abundances of soluble nutrients in atmospheric deposition (Figure below). Atmospheric acidity change therefore affects ecosystem composition, in addition to overall marine productivity, and these effects will continue to evolve with changing anthropogenic emissions in the future.

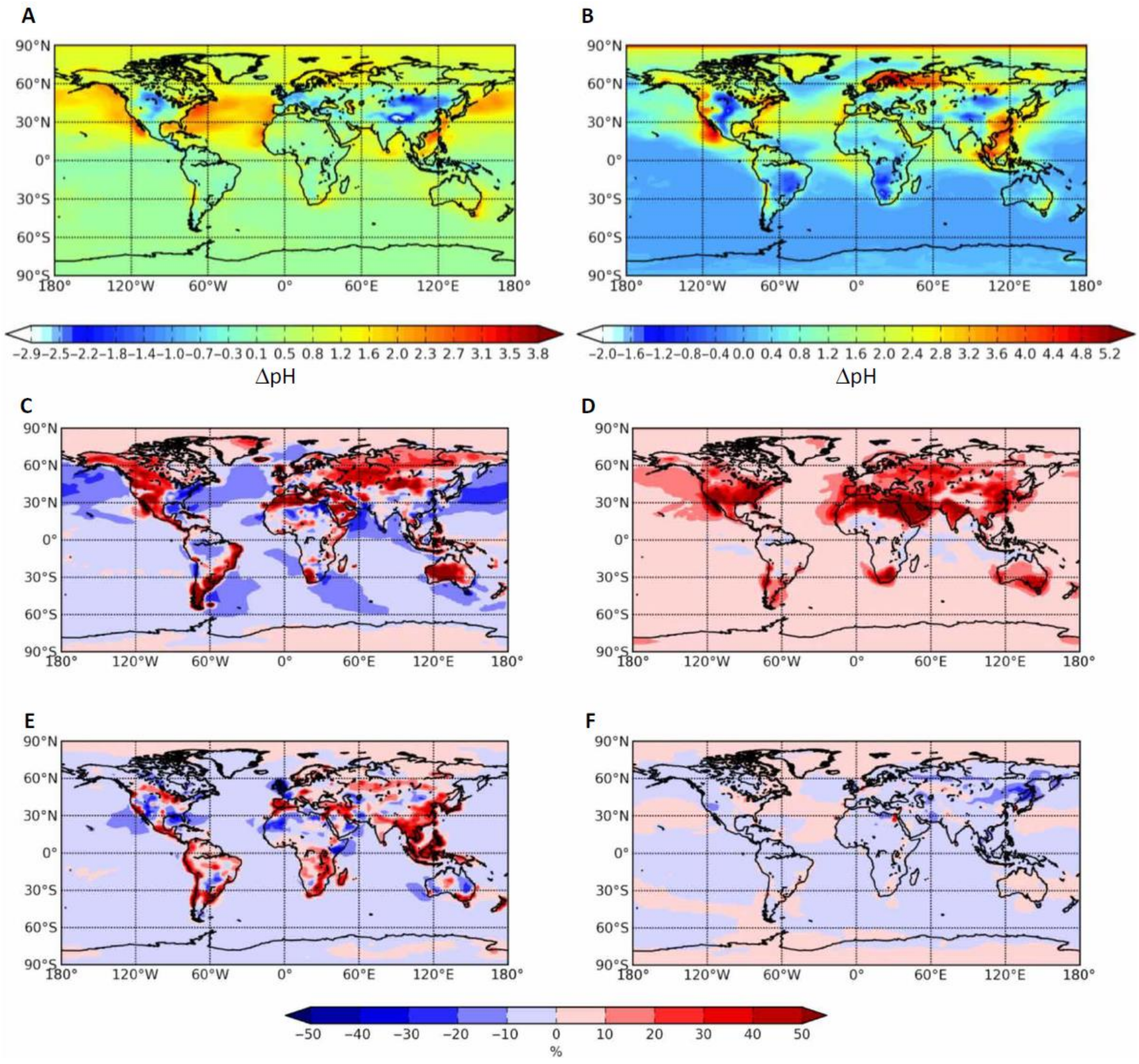


Fig. Impact of anthropogenic and biomass burning emissions changes (1850 to 2010) on aerosol pH and nutrient wet deposition fractions. Change in the annual mean near-surface (**A**) fine aerosol pH and (**B**) coarse aerosol pH and the change in the fractions of (**C**) wet NH_4^+ to the total NHx, (**D**) wet NO_3^- to the total NO3, (**E**) wet L-Fe to the total L-Fe, and (**F**) wet L-P to the total L-P between 1850 and 2010. (C to F) The difference between 1850 and 2010, expressed as a percentage of the 2010 condition. Negative values denote higher values in 2010 than in 1850.

To evaluate the impact of the atmospheric deposition to the marine environment, coupling of the amtosphere to the ocean is needed. Therefore, the parameterizations from the off-line model have been recently implemented in TM5 model that is part of the EC-Earth Earth System model and enabled the study on '*Global simulations of multiphase processes with the climate- chemistry model EC-Earth: the importance on atmospheric oxalate, sulfate, and iron cycles*'

Understanding how multiphase processes affect the iron-containing aerosol cycle is key to predict ocean biogeochemistry changes and hence the feedback effects on climate. For this work, the EC-Earth Earth system model in its climate-chemistry configuration is used to simulate the global atmospheric oxalate (OXL), sulfate (SO_4^{2-}), and iron (Fe) cycles, after incorporating a comprehensive representation of the multiphase chemistry in cloud droplets and aerosol water. The model considers a detailed gas-phase chemistry scheme, all major aerosol components, and the partitioning of gases in aerosol and atmospheric water phases. The dissolution of Fe-containing aerosols accounts kinetically for the solution's acidity, oxalic acid, and irradiation. Aerosol acidity is explicitly calculated in the model, both for accumulation and coarse modes, accounting for thermodynamic processes involving inorganic and crustal species from sea-salt and dust.

Simulations for present-day conditions (2000-2014) have been carried out with both EC-Earth and the atmospheric composition component of the model in standalone mode driven by meteorological fields from ECMWF's ERA-Interim reanalysis. The calculated global budgets are presented and the links between the 1) aqueous-phase processes, 2) aerosol dissolution, and 3) atmospheric composition, are demonstrated and quantified. The model results are supported by comparison to available observations. We obtain an average global OXL net chemical production of 12.61 ± 0.06 Tg yr^{-1} in EC-Earth, with glyoxal being by far the most important precursor of oxalic acid. In comparison to the ERA-Interim simulation, differences in atmospheric dynamics as well as the simulated weaker oxidizing capacity in EC-Earth result overall in a ~30 % lower OXL source. On the other hand, the more explicit representation of the aqueous-phase chemistry in EC-Earth compared to the previous versions of the model leads to an overall ~20% higher sulfate production, but still well correlated with atmospheric observations.

The total Fe dissolution rate in EC-Earth is calculated at 0.806 ± 0.014 Tg Fe yr_{-1} and is added to the primary dissolved Fe (DFe) sources from dust and combustion aerosols in the model (0.072 ± 0.001 Tg Fe yr^{-1}). The simulated DFe concentrations show a satisfactory comparison with available observations, indicating an atmospheric burden of ~0.007 Tg Fe, and overall resulting in an atmospheric deposition flux into the global ocean of 0.376 ± 0.005 Tg Fe yr^{-1}, well within the range reported in the literature. All in all, this work is a first step towards the development of EC-Earth into an Earth System Model with fully interactive bioavailable atmospheric Fe inputs to the marine biogeochemistry component of the model.

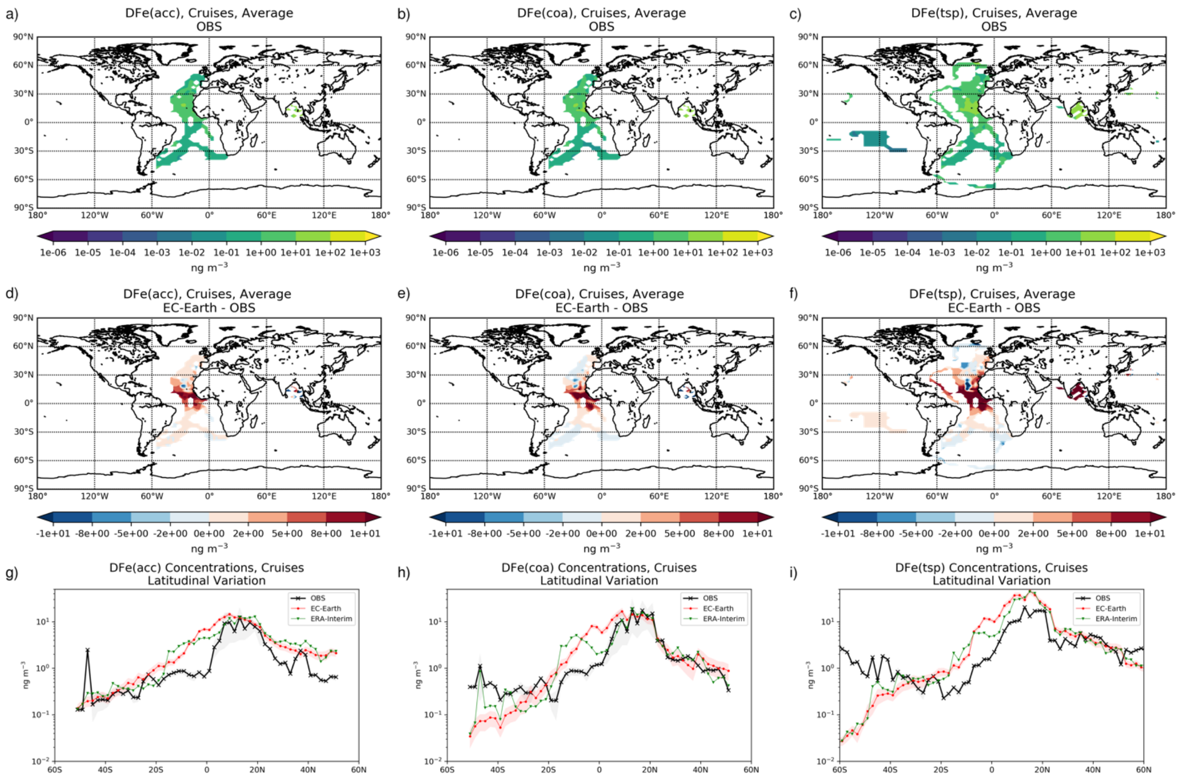


Figure : Observed dissolved iron (DFe) concentrations (ng m^{-3}) of a) accumulation aerosols, b) coarse aerosols, and c) total suspended particles (tsp), the respective absolute differences to the ERA-Interim simulation (d, e, f), and the comparison to observations (black x-line) in latitudinal order (g,e,f) with the EC-Earth (red circle-line) and ERA-Interim(green triangle-line) simulations; the grey shaded areas correspond to the standard deviation of the observations and the red shaded areas correspond to the standard error of the multi-annual mean for the individual observational period for the EC-Earth simulations.

Microplastics and nanoplastics in the marine-atmosphere environment

We have also contributed to a review article by Allen et al 2021 in Nature Reviews – Earth & Environment that summarizes current knowledge on the occurrence of atmospheric micro(nano)plastic, their transport in the amtosphere and the ocean–atmosphere exchanges. This overview shows how complex is the marine plastic cycle, how limited are the observations and points to the negative implications for the ecosystems and for human health. It quantifies the processes and fluxes of the marine-atmospheric micro(nano)plastic

cycle and identifies the remaining unknowns in atmospheric micro(nano)plastic transport. The uncertainty of the amounts of micro(nano)plastics transported annually within the marine atmosphere and deposited in the oceans is large, with estimated fluxes spanning 4 orders of magnitude ranging between 0.013 and 25 million metric tons per year.
This high uncertainty is related to the lack of sufficient data and of study intercomparability. To address the uncertainties and remaining knowledge gaps in the marine-atmospheric micro(nano)plastic cycle, this review article proposes a future global marine-atmospheric micro(nano)plastic observation strategy, incorporating novel sampling methods and the creation of a comparable, harmonized and global data set. Together with long-term observations and intensive investigations, this strategy will help to define the trends in marine-atmospheric pollution and any responses to future policy and management actions.

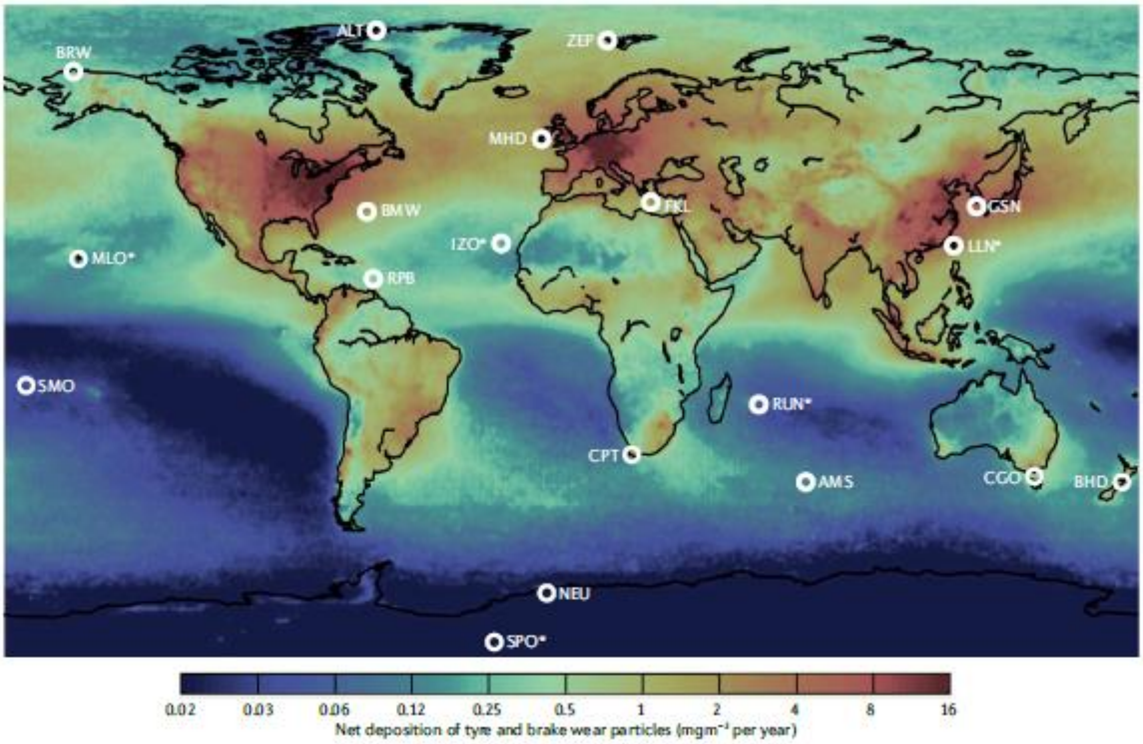


Figure from Allen et al., Nature Reviews, 2022: The proposed global observation network

<u>Investigation of the response of the Aegean Sea to the Etesian wind forcing</u>

Coastal upwelling regions are of economic and scientific interest as they are among the most productive areas of the global ocean. The fertilization of surface layers by upwelled nutrients supports several coastal marine ecosystems and fisheries around the globe. Several regions exhibiting seasonal coastal upwelling have been identified in the Mediterranean Sea. The complicated coastlines and vicinity of large land masses impose strong regional winds of seasonal character (such as the Bora, Mistral and Etesian winds), and it might be expected that the Mediterranean would be fertilized by seasonal injections of nutrients in its euphotic zone through coastal upwelling. However, most evidence suggests that this is not the case.

In a recent study (published in Continental Shelf Research), the question of potential biochemical response of the North Aegean to coastal upwelling due to the Etesian winds is revisited, by examining correlations between wind velocity, sea surface temperature (SST), sea surface chlorophyll-a concentration (chl-a) and fishery landings, utilizing the latest available datasets, to improve our understanding of wind driven coastal upwelling processes in the Northern Aegean Sea. The research focuses on the summer months July and August when northerly Etesian winds prevail in the Aegean archipelago.

To that end, a site-specific response criterion for upwelling intensity has been developed, based on the zonal SST gradient between eastern and western Aegean. Combined use of the above criterion with cross-correlation between wind, zonal surface temperature gradient, surface chl-a concentration and local fish landings reveals a well-hidden (until now) signal of chl-a increase in response to intensification of wind forcing, as well as a relation between fish landings and upwelling events, challenging the conclusions of previous studies suggesting that the Aegean Sea is immune to summer coastal upwelling, due to the great depth of its nutricline.

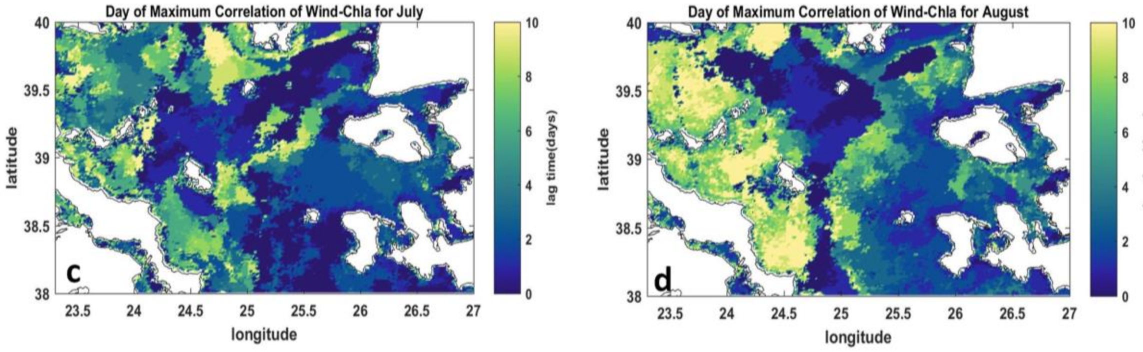


Figure. Wind and chl-a correlation in the Northern Aegean Sea, for the months of July (left) and August (right): (a) and (b) Maximum magnitude of the vector correlation coefficient (black dots indicate data points where the correlation coefficient is statistically significant (p-value<0.05)).

Reference: Chaniotaki, M., Kolovoyiannis, V., Tragou, E., Herold, L.A., Batjakas, I.E., Zervakis, V., 2021. Investigation of the response of the Aegean Sea to the Etesian wind forcing. *Continental Shelf Research*, 225, 104485. https://doi.org/10.1016/j.csr.2021.104485.

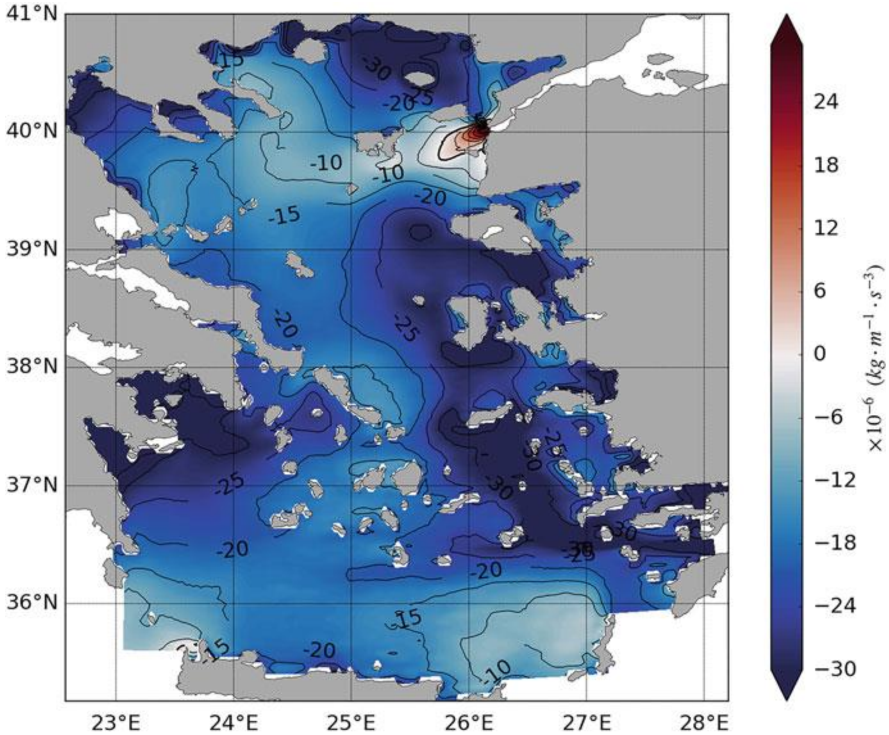
Air–Sea Interaction: Heat and Fresh-Water Fluxes in the Aegean Sea

The Aegean Sea is an intriguing sub-basin of the Mediterranean, due to (a) its capability to produce large amounts of very dense water, temporarily becoming the major producer of Eastern Mediterranean Bottom Water (recorded during the EMT period) and (b) due to its direct connection with the Black Sea that supplies the Aegean Sea with light, low-salinity waters which contribute buoyancy to the surface layers, and potentially control local convection processes. Thus, a similarity with the North Atlantic rises, in the sense of gradually increased stratification due to the addition of low-salinity surface waters, in an area capable to produce very dense waters, and thus possibly turning the North Aegean to a natural laboratory for studying such intriguing processes. The buoyancy exchanges with the atmosphere over the Aegean basin are partially controlled by the buoyancy gain and the subsequent formation of a shallow surface layer of the modified Black Sea waters. In this study, we examine the characteristics and variability of the heat and freshwater and the overall buoyancy fluxes with the exchanges with the atmosphere, focusing on the potential role of the interaction with the Black Sea for the period 1985–2015.

The wealth of information provided by a numerical model in combination with the ERA-Interim data has produced a much better understanding of the forcing of the basin.

For the first time, the diverse role of the BSW outflow as a moderator of the buoyancy loss of the basin has been revealed: Not only the thin surface layer of modified BSW absorbs the air–sea fluxes acting as an effective insulator regarding dense-water formation processes, but also (a) moderates the buoyancy fluxes over its path and (b) provides significant lateral buoyancy to the basin, thus making it very sensitive to meteorological forcing.

It should be noted that climatological mean buoyancy loss over the Aegean has been estimated through this study to be $-9.1 \times 10^{-6}\,\mathrm{kg\,m^{-1}\,s^{-3}}$. However, if the BSW inflow was absent, the buoyancy loss would correspond to the high values observed over the Eastern Aegean, an area not directly affected by the presence of the BSW, i.e. about $-30 \times 10^{-6}\,\mathrm{kg\,m^{-1}\,s^{-3}}$. This study reveals that the vertical heat loss over the Aegean is much higher than all neighbouring seas, including the Adriatic, the dominant dense-water formation site for the Eastern Mediterranean.
Through the realization of the various ways in which the Dardanelles outflow affects the Aegean Sea buoyancy budget, it becomes evident that improvement of the simulations of the basin's variability in terms of its role as a dense-water exporter for the Eastern Mediterranean requires improvement of the understanding and simulations of the exchange through the Turkish Strait System.
Furthermore, this study may shed some light to the role that the Aegean Sea had to the Mediterranean prior to the connection of the Mediterranean with the Black Sea or during the times when the Mediterranean and the Black Sea were separated.



Reference: Tragou E., Petalas S. Mamoutos I., 2022. Air-Sea Interaction: Heat and Fresh-Water Fluxes in the Aegean Sea. In: The Handbook of Environmental Chemistry. Springer, Berlin, Heidelberg. https://doi.org/10.1007/698_2021_841

3. List SOLAS-related publications published in 2021 (only PUBLISHED articles). If any, please also list weblinks to models, datasets, products, etc.

Pedrosa-Pamies R, Parinos C, Sanchez-Vidal A, Calafat A, Canals M, Velaoras D, Mihalopoulos N, Kanakidou M, Lampadariou N and Gogou A (2021) Atmospheric and Oceanographic Forcing Impact Particle Flux Composition and Carbon Sequestration in the Eastern Mediterranean Sea: A Three-Year Time-Series Study in the Deep Ierapetra Basin. Front. Earth Sci. 9:591948. doi: 10.3389/feart.2021.591948

Chaikalis S, Parinos C, Möbius J,, Gogou A, Velaoras D, Hainbucher D,Sofianos S, Tanhua T, Cardin V, Proestakis E, Amiridis V, Androni A and Karageorgis A (2021) OpticalProperties and Biochemical Indices of Marine Particles in the OpenMediterranean Sea: The R/V Maria S.Merian Cruise, March

2018. Front. Earth Sci. 9:614703.doi: 10.3389/feart.2021.61470 (PDF) Optical Properties and Biochemical Indices of Marine Particles in the Open Mediterranean Sea: The R/V Maria S. Merian Cruise, March 2018.

Myriokefalitakis, S., Bergas-Massó, E. Gonçalves-Ageitos, M., Pérez García-Pando, C., van Noije, T., Le Sager, P., Ito, A., Nenes, A., Kanakidou, M., Krol, M.C., Gerasopoulos, E.: *Global simulations of multiphase processes with the climate- chemistry model EC-Earth: the importance on atmospheric oxalate, sulfate, and iron cycles,* Geosci. Model Dev., 15, 3079–3120, 2022, https://doi.org/10.5194/gmd-15-3079-2022

Baker, A. R., Kanakidou, M., Nenes, A., Myriokefalitakis, S., Croot, P. L., Duce, R. A., Gao, Y., Guieu, C., Ito, A., Jickells, T. D., Mahowald, N. M., Middag, R., Perron, M. M. G., Sarin, M. M., Shelley, R. and Turner, D. R.: *Changing atmospheric acidity as a modulator of nutrient deposition and ocean biogeochemistry*, Sci. Adv., 7(28), eabd8800, doi:10.1126/sciadv.abd8800, 2021.

D. Allen, S. Allen, S. Abbassi, A.Baker, M. Bergmann, J. Brahney, T. Butler, R. A. Duce, S. Echhardt, N. Evangeliou, T. Jickells, M. Kanakidou, P. Kershaw, P. Laj, J. Levermore, D. Li, P. Liss, K. Liu, N. Mahowald, P. Masque, D. Materić, A. Mayes, P. McGinnity, I. Osvath, K. A. Prather, J. Prospero, L. Revell, S. Sander, W. J. Shim, J. Slade, A. Stein, O. Tarasova, S. Wright, The Atmospheric Cycle of Micro and Nano plastics in the Marine Environment, *Nat Rev Earth Environ 3,* 393–405 (2022). https://doi.org/10.1038/s43017-022-00292-x

Chaniotaki, M., Kolovoyiannis, V., Tragou, E., Herold, L.A., Batjakas, I.E., Zervakis, V., 2021. Investigation of the response of the Aegean Sea to the Etesian wind forcing. *Continental Shelf Research*, 225, 104485. https://doi.org/10.1016/j.csr.2021.104485.

Mamoutos, I., Potiris, E., Tragou, E., Zervakis, V., Petalas, S., 2021. A High-Resolution Numerical Model of the North Aegean Sea aimed at Climatological Studies. Journal of Marine Science and Engineering, 9(12), 1463; http://doi.org/10.3390/jmse9121463.

Tragou E., Petalas S. Mamoutos I., 2022. Air-Sea Interaction: Heat and Fresh-Water Fluxes in the Aegean Sea. In: The Handbook of Environmental Chemistry. Springer, Berlin, Heidelberg. https://doi.org/10.1007/698_2021_841

4. Did you engage any stakeholders/societal partners/external research users in order to co-produce knowledge in 2021? If yes, who? How did you engage?

We worked closely with GESAMP and contributed to the publications by Baker et al., 2021 on the importance of atmospheric acidity for atmospheric deposition to the ocean & by Allen et al., 2022 on the atmospheric cycle of microplastics.

PART 2 - Planned activities for 2022 and 2023

1. Planned major national and international field studies and collaborative laboratory and modelling studies (incl. all information possible, dates, locations, teams, work, etc.).

BIOCAN (a 3 years project that started May 2022 supported by the Hellenic Foundation for Research and Innovation- PI M. Kanakidou, University of Crete): It aims to provide observational and modelling survey of the East Mediterranean atmosphere in order to increase accuracy of bioaerosol distribution and deposition in the region and the nutrients they carry, in particular nitrogen and phosphorus, to the ocean and unravel the sources of atmospheric phosphorus in this oligotrophic region where the ocean is P limited.

2. Events like conferences, workshops, meetings, summer schools, capacity building etc. (incl. all information possible).

EGU -SOLAS session co-organised in 2021, 2022 and is proposed also for 2023

3. Funded national and international projects/activities underway.

PANhellenic infrastructure for Atmospheric Composition and climatE chAnge (PANACEA) is envisioned to become the high-class, integrated Research Infrastructure (RI) for atmospheric composition and climate change not only for Greece, but also for southern Europe and eastern Mediterranean, an area that is acknowledged as a hot spot for climate change. The RI is designed to be in full compliance with EU Regulation 651/26.6.2014 and act as the Greek component of ACTRIS/ESFRI (Aerosols, Clouds and Trace gases Research Infrastructure) and ICOS/ESFRI (Integrated CO2 Observation System).

https://panacea-ri.gr/?lang=en

4. Plans / ideas for future national or international projects, programmes, proposals, etc. (please indicate the funding agencies and potential submission dates).

CLIMPACT Greek National Project: https://climpact.gr/about/overview

The CLIMPACT network seeks cooperation with the National Commission for Climate Change, with the Climate Change Impact Study Committee of the Bank of Greece but also with other relevant initiatives and actions. CLIMPACT aims to be a pole of valid and multifaceted expertise and an advisory body of the State and Society.

5. Engagements with other international projects, organisations, programmes, etc.

We actively participate in IMBER and MedCLIVAR international programmes.

Comments