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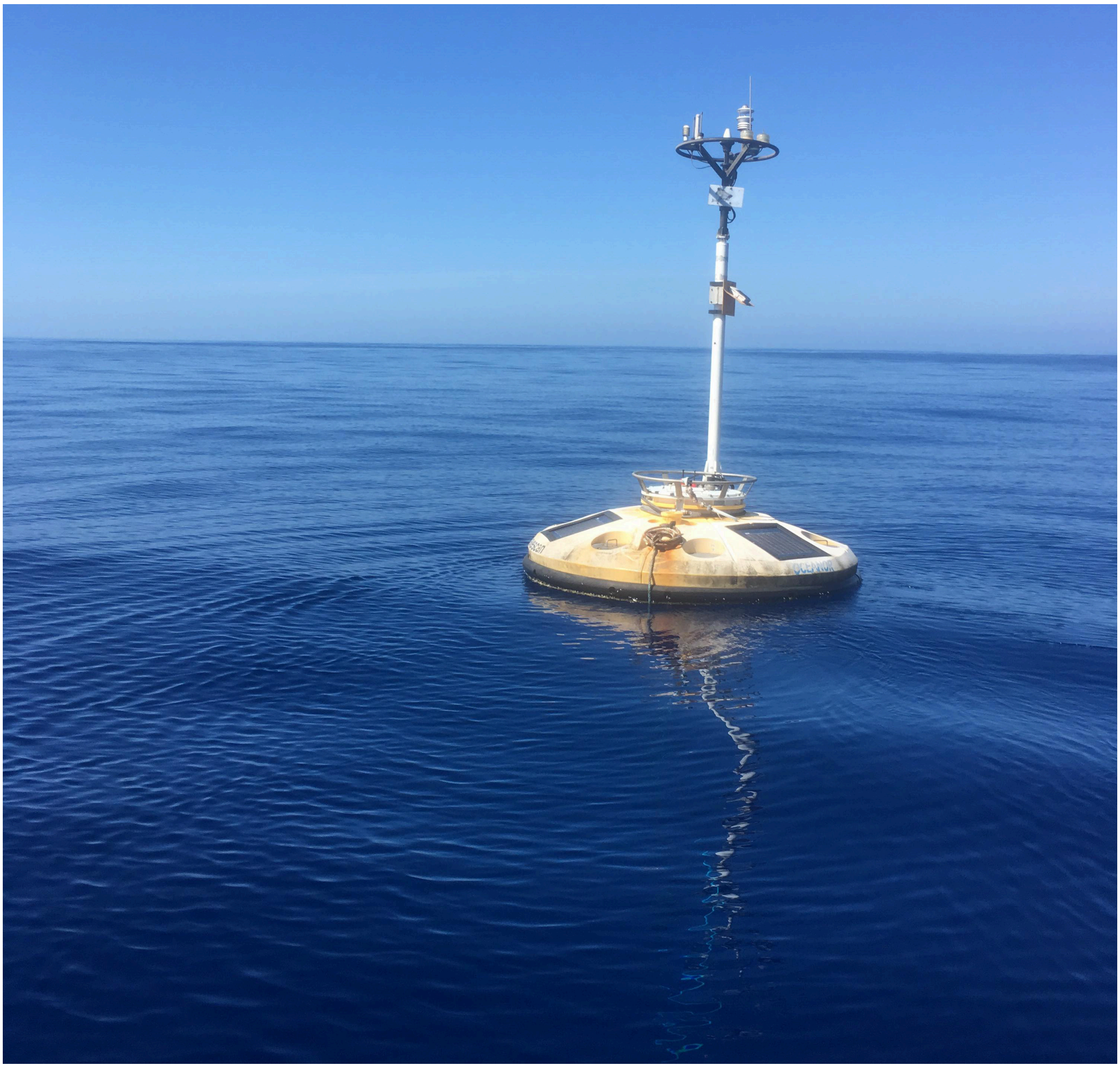
Copernicus Climatological Characterisation of Ocean Sites for OC-SVC



Hellenic Centre for Marine Research (HCMR)

Characterisation of the Greek Sites MSEA-N, MSEA-S, & Antikythera

Deliverable 3: Task 1 Report

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DELIVERABLE 3
TASK 1 REPORT: CLIMATOLOGICAL AND OBSERVATIONAL DATASETS

Prepared by

HCMR: Andrew C. Banks (PI), Dimitris Androulakis, Stella Psarra, Aris Karageorgis, George Petihakis and Nektarios Spyridakis

University of Crete: Nikos Kalivitis and Maria Kanakidou

Approved by	Contractor	Customer
Name:	Andrew Banks	Francois Montagner
Organisation:	Hellenic Centre for Marine Research (HCMR)	EUMETSAT
Position:	Project Coordinator	Project Officer
Date:	17/02/2021	
Signature:	Andrew Banks	

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TASK 1 REPORT: CLIMATOLOGICAL AND OBSERVATIONAL DATASETS

Applicable Documents
[AD-1] RSP Science Studies Web Template (EUM/RSP/DOC/18/1000216)
[AD-2] Mazeran et al., Requirements for Copernicus Ocean Colour Vicarious Calibration Infrastructure", EUMETSAT study report, https://www.eumetsat.int/website/wcm/idc/idcplg?IdcService=GET_FILE&dDocName=PDF_SS_OCEAN_COLOUR_CALIB_REQ&RevisionSelectionMethod=LatestReleased&Rendition=Web
[SOW] EUMETSAT Statement of Work for Climatological Characterisation of Ocean Sites for OC-SVC (SOW; EUM/RSP/SOW/20/1170709).

Reference Documents
[RD-1] Zibordi, G. and Mélin, F. (2017). An evaluation of marine regions relevant for ocean color system vicarious calibration. Remote Sensing of Environment, 190:122–136.
[RD-2] Antoine, D., Vellucci, V., Banks, A.C., Bardey, P., Bretagnon, M., Bruniquel, V., Deru, A., Fanton d'Andon, O.H., Lerebourg, C., Mangin, A., Crozel, D., Victori, S., Kalampokis, A., Karageorgis, A.P., Petihakis, G., Psarra, S., Golbol, M., Leymarie, E., Bialek, A., Fox, N., Hunt, S., Kuusk, J., Laizans, K., and Kanakidou, M. (2020). ROSACE: A proposed European Design for the Copernicus Ocean Colour System Vicarious Calibration Infrastructure. Remote Sensing 12, 1535. https://doi.org/10.3390/rs12101535.
[RD-3] ROSACE Preliminary Design of the Copernicus Ocean Colour Vicarious Calibration Project: Infrastructure, Project Planning and Costing Preliminary Design Document, EUMETSAT study report, https://www.eumetsat.int/website/home/Data/ScienceActivities/ScienceStudies/CopernicusOceanColourVicariousCalibrationInfrastructure/PreliminaryDesignProjectPlanandCostingforCopernicusOceanColourVicariousCalibrationInfrastructure/index.html
[RD-4] FRM4SOC D-240, Proceedings of WKP-1 (PROC-1). Report of the International Workshop. 2017. https://frm4soc.org/wp-content/uploads/filebase/FRM4SOC-WKP1-D240-Workshop_Report_PROC-1_v1.1_signedESA.pdf
[RD-5] Zibordi, G., Mélin, F. and Talone, M. (2017). System Vicarious Calibration for Copernicus Ocean Colour Missions: Requirements and Recommendations for a European Site; Publications Office of the European Union: Brussels, Belgium.
https://publications.jrc.ec.europa.eu/repository/bitstream/JRC105497/kj-na-28433-en-n%20pdf.pdf

Acronyms
List of the acronyms used in this document:

ACTRIS: Aerosols, Clouds and Trace gases Research InfraStructure network
ADCP: Acoustic Doppler Current Profiler
AERONET: AErosol RObotic NETwork
AOD: Aerosol Optical Depth
AOT: Aerosol Optical Thickness
AOP: Apparent Optical Property
BOUSSOLE : BOUée pour l'acquiSition d'une Série Optique à Long termE
BRDF: Bidirectional Reflectance Distribution Function
CAMS: Copernicus Atmosphere Monitoring Service
CDOM: Colored Dissolved Organic Matter
CEOS: Committee on Earth Observation Satellites
Chl-a: Chlorophyll-a
CMEMS: Copernicus Marine Environment Monitoring Service
CNR: Italian National Research Council
CTD: Conductivity, Temperature, Depth
DU: Dobson Units
E1-M3A (buoy)
EEZ: Exclusive Economic Zone

EMODnet: The European Marine Observation and Data Network
EO: Earth Observation
ESA: European Space Agency
EUMETSAT: European Organization for the Exploitation of Meteorological Satellites
FRM4SOC: Fiducial Reference Measurements For Satellite Ocean Colour
GHRSST: Group for High resolution Sea Surface Temperature
GIS: Geographic Information System
GOOS: Global Ocean Observing System
HCMR: Hellenic Centre for Marine Research
HNHS: Hellenic Navy Hydrographic Service
HNMS: Hellenic National Meteorological Service
HPLC: High Precision Liquid Chromatography
HYPERNAV: Hyperspectral radiometric device for accurate measurements of water leaving radiance from autonomous platforms for satellite vicarious calibrations
IOP: Inherent Optical Property
IOCCG: International Ocean Colour Coordinating Group
JRC: Joint Research Centre
Lidar: Light detection and ranging
LST: Local Solar Time
E1-M3A (buoy)
MERIS: MEdium Resolution Imaging Spectrometer
MERMAID: MEris MAtchup In-situ Database
MOBY: Marine Optical BuoY
MODIS: MODerate-Resolution Imaging Spectroradiometer
MSEA: Crete OC-SVC buoy site
MSI: Multi-Spectral Instrument
NOAA: National Oceanic and Atmospheric Administration
NASA: National Aeronautics and Space Administration
NetCDF: Network Common Data Form
NIR: Near Infra-Red
NOx: Nitrogen Oxides
OBPG: Ocean Biology Processing Group
OC: Ocean Colour
OCR: Ocean Colour Radiometry
OLCI: Ocean and Land Colour Instrument
PANACEA: PANhellenic infrastructure for Atmospheric Composition and climatE chAnge
PANGEA: PANhellenic GEophysical observatory of Antikythera
PERSEUS: Policy-oriented marine Environmental Research for the Southern EUropean Seas
PI: Principal Investigator
ProVal: Profiling float for Validation of ocean color satellite products
PSU: Practical Salinity Unit
QAA: Quasi-Analytical Algorithm
QI: Quality Index
RIB: Rigid Inflatable Boat
ROSACE: Radiometry for Ocean Colour SAtellites Calibration & Community Engagement
Rrs: Remote Sensing Reflectance
RSP: Remote Sensing and Product division
R/V: Research Vessel
S2: Sentinel-2
S3A: Sentinel-3A
S3B: Sentinel-3B
S3VT: Sentinel-3 Validation Team
SeaWiFS: Sea-viewing Wide Field of View Sensor
SOW: Statement of Work
SST: Sea Surface Temperature

SVC: System Vicarious Calibration
SZA: Solar Zenith Angle
TChl-a: Total Chlorophyll-a
TOA: Top Of Atmosphere
TOMS: Total Ozone Mapping Spectrometer
TROPOMI: TROPOspheric Monitoring Instrument
UoC: University of Crete
UV: Ultra-Violet
VIIRS: Visible Infrared Imaging Radiometer Suite
VIS Visible (domain)
VNIR: Visible and Near-InfraRed
WAM: Wave Modeling

Greek OC-SVC sites to be characterised

The two EUMETSAT proposed sites listed in Table 2 of the Statement of Work (SOW) that are within the EEZ of Greece, and thus under the responsibility of HCMR for this study, are MSEA (35.74 °N, 25.07° E) and Antikythera (36.2° N, 23.55° E). Previously, as part of the ROSACE Copernicus OC-SVC Infrastructure Phase 2 study (RD-2 & RD-3), HCMR examined in detail potential sites around Crete because this area had been identified by RD-1, RD-4 & RD-5 as the best location for OC-SVC in European waters. The present MSEA site location was therefore fixed upon because it offered the necessary favourable environmental conditions to minimize the overall uncertainty budget and maximize good satellite matchup prospects, identified by the previous studies, as well as meeting the logistical requirements specified in AD-2 (RD-1, RD-2, RD-3, RD-4). MSEA and Antikythera were therefore originally agreed upon for this contract and study.

However, during the Webex kick-off meeting on 21/01/2021 (AD-4) the original location of MSEA in RD-1 (South of Crete at 34.00 °N, 25.00° E and henceforth to be called MSEA-S) was discussed and it was requested by EUMETSAT that the region around this location also be characterized in the same way as the other two Greek sites. This is in order to compare conditions with the location of MSEA used in ROSACE to the north of Crete (henceforth to be called MSEA-N). Because MSEA-S is so far from the coast of Crete it was also agreed that the coordinates for this site be the middle of the southern most edge of its 20 x 20 nautical mile bounding box bringing the characterized area closer to the Cretan coast and a more operationally feasible location with the ability to make maintenance visits with a RIB if needed.

Characterisation requirements

For the ROSACE Copernicus OC-SVC Infrastructure Phase 2 study (RD-3), HCMR and the University of Crete (UoC) produced a comprehensive characterization of MSEA-N using in-situ meteorological and oceanographic data from the HCMR-POSEIDON system / GOOS operational E1-M3A buoy, from the long-established Finokalia atmospheric monitoring station (a core part of the PANACEA network) which is close enough to be representative of the atmosphere above the open ocean MSEA-N location, and from other in-situ data such as those from research cruises as well as satellite data based climatologies where in-situ data were absent. Therefore, Requirements 3-8 (R-3 to R-8) from the SOW for MSEA-N will be fully addressed through a reprocessing by HCMR and UoC of these datasets to match the formats of the climatologies specified by this study's requirements. The sources for additional data, particularly to meet the "Other" data type requirements of SOW: R-7, have also already been identified for MSEA-N (SOW: R-9 to R-14) from local civil authorities and European monitoring networks. Thus for MSEA-N most of the characterization requirements can be addressed using the highest priority data type (SOW: R-4) and decadal time series giving more confidence in the accuracy of the characterization climatologies. For most of the atmospheric characterization parameters the same highest priority data type can also be used for Antikythera because of the presence of the PANGEA station. However, because of the relatively new status of this atmospheric monitoring station, decadal in-situ time series are not available yet and there is no in-situ oceanographic data for the Antikythera site location. There is also no in-situ atmospheric or oceanographic data for the MSEA-S site location. This will necessitate the use of lower priority and less accurate data sources for a lot of the characterization climatologies of Antikythera and MSEA-S (see sections below). Furthermore, for a harmonized comparable characterization for all parameters the same satellite and model output / reanalysis datasets will also be used for all three sites.

Climatological and observational datasets

The datasets to be used for MSEA-N had therefore, for the most part, already been identified for this site for RD-2 & RD-3. However, for Antikythera and MSEA-S as new sites the data acquisition necessarily starts from a lower level, particularly from the oceanographic side. This is somewhat ameliorated for the Antikythera site by the recent, mostly atmospheric, characterization work carried out by the PANACEA team for the PANGEA atmospheric monitoring site location on Antikythera, all of which is freely available to this study through the sub-contracting of the PANACEA coordinators, the UoC, and will help to meet R-3 to R-14 of the SOW for this additional site. For oceanographic characteristics of Antikythera and for both atmospheric and oceanographic characteristics of MSEA-S, as there is only very sparse existing in-situ data from cruises, HCMR will use a combination of data from its POSEIDON marine modeling and forecasting system (http://www.poseidon.hcmr.gr), its integration in CMEMS and satellite data sets where applicable to produce the required climatologies (SOW: R-7). HCMR and UoC conducted an extensive online survey to determine the best sources for each parameter required for this survey. The following table summarizes the data sources that will be used for each of the required characterization parameters and for each of the 3 sites. A section where each of the datasets and their sources are described in more detail follows this table.

Table 1: Required data for the study and their main sources for MSEA-N, MSEA-S and Antikythera

Characterisation parameter	MSEA-N	Antikythera	MSEA-S
1) Geography			
a) Site location shown on nautical charts, showing bathymetry and neighbouring land within 120 nautical miles	GIS, nautical charts, EMODnet bathymetry	GIS, nautical charts, EMODnet bathymetry	GIS, nautical charts, EMODnet bathymetry
b) Sea bottom depth (m) and slope at site	EMODnet bathymetry	EMODnet bathymetry	EMODnet bathymetry
c) Plot of cosine of Sun zenith angle at 08:30 UTC per day of year	NOAA solar model	NOAA solar model	NOAA solar model
2) Atmosphere characterisation and mapping a) Fractional cloud cover distribution statistics			
i) Fractional cloud cover histogram for a year and per season	HNMS weather station @ Heraklion, satellite data and modelling	HNMS weather station @ Kythera, satellite data and modelling	Satellite data & modelling
ii) Number of days in a year where fractional cloud cover at time 08:30 UTC is > 0.1	HNMS weather station @ Heraklion, satellite data and modelling	HNMS weather station @ Kythera, satellite data and modelling	Satellite data & modelling
iii) Plot of fractional cloud cover mean and standard deviation per month, at 08:30 UTC	HNMS weather station @ Heraklion, satellite data and modelling	HNMS weather station @ Kythera, satellite data and modelling	Satellite data & modelling
b) Wind velocity($m.s^{-1}$) and direction (deg) distribution statistics			
i) Wind velocity histogram for a year	E1-M3A+HNMS weather station @ Heraklion, satellite data & modelling	HNMS weather station @ Kythera, satellite data & modelling	Satellite data & modelling
ii) Wind velocity and direction distribution diagrams (rose diagrams) for each season	E1-M3A+HNMS weather station @ Heraklion, satellite data and modelling	HNMS weather station @ Kythera, satellite data and modelling	Satellite data & modelling

c) Aerosol type and optical thickness distribution statistics			
i) Textual description of dominant and occasional aerosol types. The typology shall include coarse, fine, weakly or strongly UV-Vis absorbing. In case of close urban areas or human activities, details on possible secondary organic particles presence are required.	Finokalia station data (inc. AERONET + PollyXT Lidar aerosol typology), satellite data and modelling	PANGEA station data (inc. AERONET + PollyXT Lidar aerosol typology), satellite data and modelling	Satellite data & modelling
ii) Aerosol optical thickness at 550nm (m^{-1}) histogram for a year	Finokalia station data (inc. AERONET), satellite data and modelling	PANGEA station data (inc. AERONET), satellite data and modelling	Satellite data & modelling
iii) Plot of aerosol optical thickness at 550nm mean and standard deviation per month	Finokalia station data (inc. AERONET), satellite data and modelling	PANGEA station data (inc. AERONET), satellite data and modelling	Satellite data & modelling
iv) Angström exponent (α) histogram for a year	Finokalia station data (inc. AERONET), satellite data and modelling	PANGEA station data (inc. AERONET), satellite data and modelling	Satellite data & modelling
v) Plot of α mean and standard deviation per month	Finokalia station data (inc. AERONET), satellite data and modelling	PANGEA station data (inc. AERONET), satellite data and modelling	Satellite data & modelling)
vi) Number of days per year of dust episodes	Finokalia station data (inc. AERONET), satellite data and modelling	PANGEA station data (inc. AERONET), satellite data and modelling	Satellite data & modelling
vii) Number of days per year where $\alpha > 1$	Finokalia station data (inc. AERONET), satellite data and modelling	PANGEA station data (inc. AERONET), satellite data and modelling	Satellite data & modelling
d) Absorbing gases distribution statistics			
i) Plot of atmosphere pressure (hPa) mean and standard deviation per month	E1-M3A+HNMS weather station @ Heraklion, satellite data and modelling	HNMS weather station @ Kythera, satellite data and modelling	Satellite data & modelling
ii) Plot of Total column ozone (DU) mean and standard deviation per month	Satellite data	Satellite data	Satellite data
iii) Plot of total precipitable water ($kg.m^{-2}$) mean and standard deviation per month	HNMS weather station @ Heraklion, satellite data and modelling	HNMS weather station @ Kythera, satellite data and modelling	Satellite data & modeling
iv) Plot of NO_2 surface concentrations (ppb), tropospheric and stratospheric columns ($kg.m^{-2}$) mean and standard deviation per month	Finokalia station data, satellite data	Satellite data	Satellite data
3) Ocean characterisation and mapping a) Chlorophyll distribution statistics			
i) Chlorophyll-a (Chl-a) concentration ($mg.m^{-3}$) histogram for a year	E1M3A bottle sample data, satellite data	Satellite data	Satellite data
ii) Plot of Chl-a concentration mean and standard deviation per month	E1M3A bottle sample data, satellite data	Satellite data	Satellite data
b) AOP distribution statistics			
i) Remote sensing reflectance (Rrs) (sr^{-1}) at 412, 442, 490, 510, 560nm histograms for a year	Satellite OC data (inc. Sentinel-3 OLCI)	Satellite OC data (inc. Sentinel-3 OLCI)	Satellite OC data (inc. Sentinel-3 OLCI)
ii) Plot of Rrs mean and standard deviation per month at all wavelengths above	Satellite OC data (inc. Sentinel-3 OLCI)	Satellite OC data (inc. Sentinel-3 OLCI)	Satellite OC data (inc. Sentinel-3 OLCI)
iii) Map of Rrs mean around the sites for each season at 442 and 560nm	Satellite OC data (inc. Sentinel-3 OLCI)	Satellite OC data (inc. Sentinel-3 OLCI)	Satellite OC data (inc. Sentinel-3 OLCI)

c) IOP distribution statistics			
i) Coloured Dissolved Organic Matter (CDOM) absorption at 440nm aCDOM (m^{-1}) histogram for a year	Satellite OC data (inc. Sentinel-3 OLCI)	Satellite OC data (inc. Sentinel-3 OLCI)	Satellite OC data (inc. Sentinel-3 OLCI)
ii) Plot of a_{CDOM} mean and standard deviation per month	Satellite OC data (inc. Sentinel-3 OLCI)	Satellite OC data (inc. Sentinel-3 OLCI)	Satellite OC data (inc. Sentinel-3 OLCI)
iii) Particulate backscatter at 560nm b_{bp} (m^{-1}) histogram for a year	Satellite OC data (inc. Sentinel-3 OLCI)	Satellite OC data (inc. Sentinel-3 OLCI)	Satellite OC data (inc. Sentinel-3 OLCI)
iv) Plot of b_{bp} mean and standard deviation per month	Satellite OC data (inc. Sentinel-3 OLCI)	Satellite OC data (inc. Sentinel-3 OLCI)	Satellite OC data (inc. Sentinel-3 OLCI)
d) Currents distribution statistics			
i) Current intensity ($cm.s^{-1}$) histogram for a year	E1-M3A ADCP data, POSEIDON hydrodynamic modeling system output -> CMEMS, satellite data	POSEIDON hydrodynamic modeling system output -> CMEMS, satellite data	POSEIDON hydrodynamic modeling system output -> CMEMS, satellite data
ii) Current intensity and direction distribution rose diagrams for each season	E1-M3A ADCP data, POSEIDON hydrodynamic modeling system output -> CMEMS, satellite data	POSEIDON hydrodynamic modeling system output -> CMEMS, satellite data	POSEIDON hydrodynamic modeling system output -> CMEMS, satellite data
e) Wave distribution statistics			
i) Wave height (m) histogram for a year	E1-M3A data, POSEIDON wave modeling system output -> CMEMS, satellite data	POSEIDON wave modeling system output -> CMEMS, satellite data	POSEIDON wave modeling system output -> CMEMS, satellite data
ii) Wave height and direction distribution rose diagrams for each season	E1-M3A data, POSEIDON wave modeling system output -> CMEMS, satellite data	POSEIDON wave modeling system output -> CMEMS, satellite data	POSEIDON wave modeling system output -> CMEMS, satellite data
In addition to wave height, wave period is also required for sites in the Atlantic Ocean because of swell :	N/A	N/A	N/A
iii) Wave period (s) histogram for a year	N/A	N/A	N/A
iv) Wave period and direction distribution rose diagrams for each season	N/A	N/A	N/A
f) SST distribution statistics			
i) SST (°C) histogram for a year	E1-M3A in-situ surface temperature data, satellite SST products (ESA CCI, CMEMS etc.)	Satellite SST products (ESA CCI, CMEMS etc.)	Satellite SST products (ESA CCI, CMEMS, etc.)
ii) Plot of SST mean and standard deviation per month	E1-M3A in-situ surface temperature data, satellite SST products (ESA CCI, CMEMS etc.)	Satellite SST products (ESA CCI, CMEMS etc.)	Satellite SST products (ESA CCI, CMEMS, etc.)
g) Salinity monthly maps and distribution statistics			
i) Salinity (PSU) histogram for a year	E1-M3A in-situ surface salinity data, CMEMS salinity reanalysis product	CMEMS salinity reanalysis product	CMEMS salinity reanalysis product
ii) Plot of salinity mean and standard deviation per month	E1-M3A in-situ surface salinity data, CMEMS salinity reanalysis product	CMEMS salinity reanalysis product	CMEMS salinity reanalysis product
4) Other			
a) Map of nearby shipping routes and monthly traffic statistics. An associated map of NO_2 concentration is desirable.	Hellenic coast guard / port authorities, EMODnet marine traffic, satellite data	Hellenic coast guard / port authorities, EMODnet marine traffic, satellite data	Hellenic coast guard / port authorities, EMODnet marine traffic, satellite data
b) Map of nearby airline routes and	Heraklion airport /	Kythera airport / Greek	Heraklion airport /

monthly traffic statistics	Greek civil aviation authority	civil aviation authority	Greek civil aviation authority
c) Fire occurrences in the surrounding areas (within 50 km): high, low, minimal.	Greek civil protection authorities, satellite maps from ESA/NASA/Copernicus	Greek civil protection authorities, satellite maps from ESA/NASA/Copernicus	Greek civil protection authorities, satellite maps from ESA/NASA/Copernicus
5) Compliance matrix of the site with the environmental requirements in [AD-2].	All above data	All above data	All above data

N.B. Satellite data and modelling listings may include reanalysis datasets.

Detailed Description of climatological and observational datasets to be used

1) Geography

1a) Site location shown on nautical charts, showing bathymetry and neighbouring land within 120 nautical miles

For all three sites these maps will be prepared using a combination of GIS, Hellenic Navy Hydrographic Survey (HNHS) digital nautical charts as well as EMODnet (https://portal.emodnet-bathymetry.eu) and NOAA (https://maps.ngdc.noaa.gov/viewers/bathymetry/) bathymetry mapping visualisations. HCMR will use webGIS available from the Hellenic Navy Hydrographic Service, EMODnet and NOAA and if they did not prove sufficient use will be made of offline software such as ArcGIS or similar to map the sites including the EMODnet bathymetry data. HCMR will provide a general map produced by GIS showing the neighbouring land within 120 nautical miles for all 3 sites together on one map including the bathymetry, and individual detailed zoomed site maps on HNHS nautical charts and maps showing more detailed bathymetry.

1b) Sea bottom depth (m) and slope at site

For each site these data will be extracted and calculated from the downloaded EMODnet bathymetry grids (freely available from https://portal.emodnet-bathymetry.eu).

1c) Plot of cosine of Sun zenith angle at 08:30 UTC per day of year

These will be calculated for the exact location of each of the three sites using the NOAA solar position model from the NOAA Global Monitoring Laboratory (https://www.esrl.noaa.gov/gmd/grad/solcalc/). The focus time will be 08:30 UTC here and for all parameters where 10AM LST was previously listed as this is the actual mean overpass time of Sentinel-3 A/B satellite and thus OLCI sensor for the Greek site locations.

2) Atmosphere characterisation and mapping

2a) Fractional cloud cover distribution statistics

i) Fractional cloud cover histogram for a year and per season
ii) Number of days in a year where fractional cloud cover at time 08:30 UTC is > 0.1
iii) Plot of fractional cloud cover mean and standard deviation per month, at 08:30 UTC

For each of the suggested locations cloud cover data have been requested from the Hellenic National Meteorological Service (HNMS) from the nearest meteorological station providing cloud cover observations. For the MSEA-N site, Heraklion airport meteorological station (25 nautical miles to the south) has been chosen (WMO ID 754), for the MSEA-S, Tympaki airport meteorological station (WMO ID 759, 65 nautical miles north of the site) and for the Antikythera site, Kythera airport station has been chosen (WMO ID 743, 26 nautical miles west of the site). All are close to sea level. Total cloud cover data with an hourly time step have been requested from the HNMS (request approval still pending) for years 2000-2020. From *Total cloud cover* provided from HNMS in Okta units, obtained directly by a human observer, fractional cloud cover at 08:30 UTC will be calculated and subsequently (i), (ii) and (iii) as described above will be provided. Data will be available after personal communication with HNMS.

As the in-situ data refer to coastal or land locations that do not coincide with the suggested locations in the Greek waters, we will also provide cloud cover statistics based on ERA5 reanalysis data. ERA5 provides hourly estimates with a horizontal resolution of 0.25° x 0.25°. We will use the *Total cloud cover* variable, which is the proportion of a grid box covered by cloud. For each site the appropriate grid box will be selected and we will perform analysis for the years 2000-2020 to retrieve fractional cloud cover, also at 08:30 UTC. Data are publicly available at:
https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels?tab=form
The reanalysis data are provided with a spatial resolution of 0.25° x 0.25° while the in-situ observations refer to locations at significant distance from the proposed sites. Therefore the cloud cover analysis described earlier might not be fully representative for the sites and thus we will provide additional information about cloud cover using satellite data at a higher spatial resolution. For this purpose Moderate Resolution Imaging Spectroradiometer (MODIS) data including the MOD04_3K - MODIS/Terra Aerosol 5-Min L2 Swath 3km product will be analyzed, using the *Aerosol_Cloud_Fraction_Ocean* variable. The spatial analysis of this product is 3km and the temporal is 5 min, and therefore 08:30 UTC can be provided here as well. Data can be found at:
https://ladsweb.modaps.eosdis.nasa.gov/missions-and-measurements/products/MOD04_3K/.
These MODIS data will also be used to add to the comparative cloud fraction climatology published in RD-2 and RD-3 for MSEA-N, MOBY and BOUSSOLE.

2b) Wind velocity ($m.s^{-1}$) and direction (deg) distribution statistics

i) Wind velocity histogram for a year
ii) Wind velocity and direction distribution diagrams (rose diagrams) for each season

For MSEA-N HCMR has a long (>10 year) time series of in-situ wind velocity and direction from the GOOS/HCMR E1-M3A buoy in the same location. This infrastructure has been developed based on a Fugro/OCEANOR SEAWATCH Wavescan buoy, which has wind velocity and direction sensors fitted at ~3.5m above the sea surface (http://www.oceanor.info/datasheets/SW06_WavescanBuoy(LR).pdf); Petihakis et al., 2018). These data were already graphed, published, reported and provided to EUMETSAT through the Copernicus OC-SVC phase 2 project ROSACE (RD-2, RD-3). The data from E1-M3A are freely available through HCMR and Copernicus.
(https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=INSITU_MED_NRT_OBSERVATIONS_013_035).

Wind statistics will also be provided for the meteorological stations described in section 2a. *Wind*

velocity and direction data with a 3-hourly time step have been requested from the HNMS (request approval still pending) for years 2000-2020. HNMS data will be available after personal communication.
Furthermore we will provide wind statistics based on ERA5 reanalysis data for all three sites. ERA5 provides hourly estimates with a horizontal resolution of 0.25° x 0.25°. We will use *10m u-component of wind* and *10m v-component of wind* variables to calculate wind velocity and direction. For each site the appropriate grid box will be selected and we will perform analysis for the years 2000-2020 to calculate wind statistics and create the polar plot. ERA5 data are publically available at https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels?tab=form

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2c) Aerosol type and optical thickness distribution statistics

i) Textual description of dominant and occasional aerosol types.
ii) Aerosol optical thickness at 550nm (m^{-1}) histogram for a year
iii) Plot of aerosol optical thickness at 550nm mean and standard deviation per month
iv) Angström exponent (α) histogram for a year
v) Plot of α _mean and standard deviation per month
vi) Number of days per year of dust episodes
vii) Number of days per year where α _> 1

We will utilize various data sets to describe aerosol types in the atmosphere of the Greek seas where MSEA-N, MSEA-S and Antikythera sites are located. We will use atmospheric composition data from the environmental research station of Finokalia (University of Crete; https://finokalia.chemistry.uoc.gr), a well-established site considered representative for the background conditions of the eastern Mediterranean atmosphere (Lelieveld et al., 2002).
We will also use remote sensing data, such as AERONET data (see below) and satellite data (i.e. Aerosol Index from TOMS https://disc.gsfc.nasa.gov/datasets/TOMSEPL3daer_008/summary and from TROPOMI referred to as the Ultraviolet Aerosol Index (L2__AER_AI) https://sentinels.copernicus.eu/web/sentinel/data-products) to provide a thorough description of the various aerosol types encountered in the atmosphere of the area under investigation.

For aerosol particles' properties, data from the AERONET network will be used for the characterization of the MSEA-N and Antikythera sites. AERONET is an international federation of ground-based sun and sky scanning radiometers and, for the present work, data from two sites on Crete will be used, FORTH_CRETE (35.333N, 25.282E; Operative 2003-2017) and Finokalia-FKL (35.338N, 25.670E; Operative 2017-present) as well as a site on Antikthera island (Antikythera_NOA - 35.861N, 23.310E; Operative 2018-present). For all sites, Level 1.5 (cloud-screened and quality controlled) and Level 2.0 (quality-assured) daily averaged data from Version 3 database will be used. For the present study AOD_551nm and 440-870_Angstrom_Exponent will be used as provided directly from the Version 3 algorithm. For the identification of dust episodes we will use the criteria described in Kalivitis et al. (2007), α parameter lower than 0.5 and AOT higher than 0.25, given that air mass back trajectories at 1000 or 3000m indicate possible dust transport from N. Africa. AERONET data are publicly available at https://aeronet.gsfc.nasa.gov/. Air mass back trajectories will be calculated with the HYSPLIT model, available at https://www.ready.noaa.gov/HYSPLIT.php.

Since for the MSEA-S site there is no AERONET data, while for the Antikythera only two years of data are available, we will further use reanalysis data for all three sites under investigation in order to provide a direct comparison. Specifically, we will use the Modern-Era Retrospective analysis for Research and Applications version 2 (MERRA-2), which is a NASA atmospheric reanalysis using the Goddard Earth Observing System Model, Version 5 (GEOS-5) with its Atmospheric Data Assimilation System (ADAS), version 5.12.4. We will use data with a spatial resolution of 0.5 x 0.625 ° that are available for the period 2000- 2020. For optical thickness statistics we will use both Aerosol Optical Depth Analysis and Total Aerosol Extinction AOT 550 nm with monthly and hourly temporal resolution respectively. For α statistics we will use Total Aerosol Angstrom parameter (470-870 nm) with monthly and hourly temporal resolution. We will examine AOT and α to identify dust episodes, once again with the prerequisite that air masses back trajectories had potentially been affected by desert dust. Data are available at: DOI: 10.5067/XOGNBQEPLUC5, DOI: 10.5067/KLICLTZ8EM9D, DOI: 10.5067/FH9A0MLJPC7N, DOI: 10.5067/KLICLTZ8EM9D.

Since the reanalysis data are provided with a spatial resolution of 0.5 x 0.625 ° there is the possibility to provide further information about aerosol climatology using satellite data at a higher spatial resolution, in particular to examine if there is any fine scale variability using random checks at sub MERRA-2 grid scale using the higher resolution satellite data. For that purpose the MOD04_3K - MODIS/Terra Aerosol 5-Min L2 Swath 3km product will also be analyzed, using the Optical_Depth_Land_And_Ocean variable, along with the TOMS and TROPOMI data. The spatial analysis of this product is 3km and the temporal is 5 min. Data can be found at https://ladsweb.modaps.eosdis.nasa.gov/missions-and-measurements/products/MOD04_3K/.

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2d) Absorbing gases distribution statistics

i) Plot of atmosphere pressure (hPa) mean and standard deviation per month
ii) Plot of Total column ozone (DU) mean and standard deviation per month
iii) Plot of total precipitable water ($kg.m^{-2}$) mean and standard deviation per month
iv) Plot of NO_2 surface concentrations (ppb), tropospheric and stratospheric columns ($kg.m^{-2}$) mean and standard deviation per month

For MSEA-N HCMR has a long (>10 year) time series of in-situ atmospheric pressure from the GOOS/HCMR E1-M3A buoy in the same location. This infrastructure has been developed based on a Fugro/OCEANOR SEAWATCH Wavescan buoy, which has an air pressure sensor fitted at ~3.5m above the sea surface (http://www.oceanor.info/datasheets/SW06_WavescanBuoy(LR).pdf; Petihakis et al., 2018). These data were already graphed, published, reported and provided to EUMETSAT through the Copernicus OC-SVC phase 2 project ROSACE (RD-2, RD-3). The data from E1-M3A are freely available through HCMR and Copernicus.
(https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=INSITU_MED_NRT_OBSERVATIONS_013_035).

Additionally, atmospheric pressure will be provided for the meteorological stations described in section 2a. Three-hour average mean sea level pressure and 24-hr PAN pressure have been requested from the HNMS (request approval still pending) for years 2000-2020. HNMS data will be available after personal communication. Furthermore we will provide atmospheric pressure statistics based on ERA5 reanalysis data. ERA5 provides hourly estimates with a horizontal resolution of 0.25° x 0.25°. We will use the sea surface pressure variable. For each site the appropriate grid box will be selected and we will perform analysis for the years 2000-2020. Data are publicly available at https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels?tab=form.

As no in-situ data for ozone column are available we will rely on reanalysis data from CAMS global reanalysis (EAC4) dataset. We will use the total column ozone variable for the time period 2003-2020, with a horizontal resolution of 0.75° x 0.75°, available at a 3-hourly temporal interval. Data are publicly available at: https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-global-reanalysis-eac4?tab=form.

In order to perform statistics for the total column ozone we will use additional data from the Ozone Monitoring Instrument (OMI). OMI measures ozone profiles in the UV. Specifically, we will use Level-3 Aura/OMI Global OMDOAO3e data products (horizontal resolution of 0.25° x 0.25°). For the total column ozone variable, data are provided daily and are available since 01/10/2004. OMI data provide better spatial coverage of the suggested sites areas. Data are publicly available at https://disc.gsfc.nasa.gov/datasets/OMDOAO3e_003/summary.

We will also use reanalysis data from the CAMS global reanalysis (EAC4) dataset to calculate monthly means of precipitable water for the three sites. We will use specifically the total column water variable, for the time period 2003-2020, with a horizontal resolution of 0.75° x 0.75°, available at a 3-hourly temporal interval. Data are publicly available at https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-global-reanalysis-eac4?tab=form.

For the MSEA-N site we will use surface NO_2 measurements from the atmospheric research station at Finokalia, Crete (35.34N, 25.67E). Data are collected every five minutes with Thermo Fisher Scientific NO-NO_2-NO_x monitors (type 42c and 42i). Data are available after personal communication with ECPL, Department of Chemistry, University of Crete.

As no in-situ data are available for all the sites, we will use reanalysis data for surface NO_2. We will use the Nitrogen dioxide variable at 1000 hPa from CAMS global reanalysis (EAC4) dataset to calculate monthly means of surface NO_2 for the three sites. Data are available for the time period 2003-2020, with a horizontal resolution of 0.75° x 0.75°, available at a 3-hourly time step. Data are publicly available at: https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-global-reanalysis-eac4?tab=form.

For the calculation of tropospheric and stratospheric columns mean and standard deviation per month at all three sites we will use data from the OMI. We will use OMI Level-2 NO_2 product OMNO2 (horizontal resolution of 0.25° x 0.25°). Data are provided daily and are available since 01/10/2004. As OMNO2 provides information about total and tropospheric NO_2, stratospheric NO_2 will be calculated by subtracting tropospheric from total columnar NO_2. Data are publicly available at https://disc.gsfc.nasa.gov/datasets/OMNO2G_003/summary. The total and tropospheric columns of NO_2 will be also derived from the Sentinel 5p TROPOMI high spatial resolution (3.5x7km) product publicly available for the last 3 years at https://sentinels.copernicus.eu/web/sentinel/data-products/-/asset_publisher/fp37fc19FN8F/content/sentinel-5-precursor-level-2-nitrogen-dioxide.

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3) Ocean characterisation and mapping

3a) Chlorophyll distribution statistics

i) Chlorophyll-a (Chl-a) concentration (mg.m^{-3}) histogram for a year

ii) Plot of Chl-a concentration mean and standard deviation per month

In-situ chlorophyll data for the MSEA-N location from the GOOS/HCMR E1-M3A buoy (Petihakis et al., 2018) will be used for these statistics for MSEA-N and are available from: a) in-situ sensor array since 2000 and b) from regular in-situ sampling (bottle data) since 2010. The continuous recordings of the fluorescence sensor on the E1-M3A buoy (WET Labs FLNTU) are supplemented with the discrete CTD fluorescence profiles from in-situ sampling casts (WET Labs ECO-AFL/FL 9 or Chelsea Aqua 3, Petihakis et al., 2018). Fluorescence sensors are regularly calibrated at the POSEIDON calibration lab (housed in the HCMR premises at Heraklion) considering the local environmental conditions (e.g. for low chlorophyll concentration and native phytoplankton species). However, the bottle sample lab analysis data are considered by HCMR to be more accurate and reliable than the fluorescence sensor data and will be used as the primary source to form the climatologies of chlorophyll for MSEA-N.
The vast majority of casts (> 80% after 2010) during the R/V visits at the site to take the samples, are made between 09:00 and 14:00 local time, coinciding with Sentinel-3 and MODIS-Aqua satellite overpasses and allowing Chl-a matchup analysis (RD-2, RD-3). The sampling procedure and storing protocols follow the international recommendations described by Lorenzoni and Benway (2013) and have remained consistent since 2010, with recording of cruise metadata (cruise summary reports are available at http://www.seadatanet.org). From the bottle samples, analytical laboratory measurements of Chlorophyll-a initially involved fluorometric analysis by size fractions (0.2-2.0, 2.0-5.0 and > 5.0 um, corresponding to pico-, small nano- and microphytoplankton, respectively) according to Holm-Hansen, et al. (1965). Since 2013, these fluorometric measurements have been complemented with high performance liquid chromatography (HPLC) analysis of total Chl-a and phytoplankton accessory pigments following the method described by Van Heukelem and Thomas (2001) as modified by Lagaria et al (2017) and also expanding the information on autotrophic phylogenetic groups through the use of CHEMTAX software (Mackey et al., 1996).
A number of quality control procedures for the validity of the in-situ data and a series of metadata correctness tests are applied before the release of the relevant data files. The data quality control process includes different routines for NRT products (sensor data) and the delayed mode/reprocessed products (bottle data) (Petihakis et al., 2018). The more accurate sample based in-situ Chl-a data were already graphed, published, reported and provided to EUMETSAT through the Copernicus OC-SVC phase 2 project ROSACE (RD-2, RD-3). They are freely available to the public, the stakeholders and the scientific community, acknowledging the EC INSPIRE directive.

Individual chlorophyll-a climatologies for all three sites will also be made by HCMR from data from two of the main ocean colour satellite sensors of the last three decades, i.e. SeaWiFS (1997-2010) and MODIS-Aqua (2002-present day) as these have the appropriate coverage and run for more than 10 years each. A note of caution regarding these satellite datasets and the others mentioned below, is that for the oligotrophic waters of the Eastern Mediterranean the satellite data (even with Mediterranean tuned algorithms, e.g. MEDOC4) consistently overestimates Chl-a and this should be borne in mind when considering the satellite climatologies and any threshold for chlorophyll used as a cut-off for potentially good OC-SVC matchups. This was clearly shown in the ROSACE report (RD-3] when using the accurate in situ data increased the number of good matchups for S3-OLCI at MSEA-N from 31 to 52 per year. Additional to these a climatology based on less years will be made from Sentinel-3 OLCI (2016-present) as this is the main Copernicus ocean colour sensor and is the initial focus sensor for Copernicus OC-SVC. These satellite data are freely available from the NASA Ocean Biology Processing Group's web portal (https://oceancolor.gsfc.nasa.gov/data/overview/) and from EUMETSAT's Copernicus Online Data Access (CODA) portal (https://coda.eumetsat.int/) respectively.
As a supplement for Sentinel-3, through the EUMETSAT S3VT, a new processing (Collection 3) using a

neural network that is designed to handle oligotrophic/low chlorophyll waters will also be used to form an alternative potentially more accurate satellite based Chl-a climatology.

Also, the ESA Ocean Colour Climate Change Initiative (OC-CCI) multi-sensor merged chlorophyll product and monthly climatology ocean colour product (September 1997 to the end of 2019) will be used for all three sites. The ESA Ocean Colour CCI project (https://www.oceancolour.org) has produced global level 3, binned, multi-sensor time-series of satellite ocean-colour data with a particular focus for use in climate studies. This dataset contains their Version 4.2 Chlorophyll-a product (in mg/m^3) on a geographic projection at 4 km spatial resolution and at a number of time resolutions (daily, 5 day, 8 day and monthly composites). This data product is on a geographic grid projection, which is a direct conversion of latitude and longitude coordinates to a rectangular grid, typically a fixed multiplier of 360x180. The netCDF files follow the CF convention for this projection with a resolution of 8640x4320. The monthly climatology dataset of the generated ocean colour products includes chlorophyll-a concentration with Information on uncertainties also provided. These OC-CCI datasets are freely available from:
https://catalogue.ceda.ac.uk/uuid/aeae1a19608347f7b802691db6984343

Additionally, the CMEMS products, OCEANCOLOUR_MED_CHL_L4_REP_OBSERVATIONS_009_078 and OCEANCOLOUR_MED_CHL_L3_REP_OBSERVATIONS_009_073 will be used for all three sites to make Chlorophyll-a climatologies. These are produced by the Global Ocean Satellite monitoring and marine ecosystem study group (GOS) of the Italian National Research Council (CNR) in Rome. They are Level-3 & 4 products that include daily and monthly averaged datasets and climatological fields, all at 1 km spatial resolution. Daily and Monthly averaged datasets are derived from Rrs multi-sensor (MODIS-AQUA, NOAA20-VIIRS, NPP-VIIRS, Sentinel 3A-OLCI) spectra using state-of-the-art algorithms for multi-sensor merging. Single sensor Rrs fields are band-shifted, over the SeaWiFS native bands (using the QAAv6 model, Lee et al., 2002) and merged with a technique aimed at smoothing the differences among different sensors. Reprocessed (multi-year) products are consistent and homogeneous in terms of format, algorithms and processing software. The Chl-a dataset is obtained by means of the Mediterranean Ocean Colour regional algorithm: an updated version of the MedOC4 (Case 1 waters, Volpe et al., 2019, with new coefficients) and AD4 (Case 2 waters, Berthon and Zibordi, 2004). Discrimination between the two water types is performed by comparing the satellite spectrum at pixel-by-pixel level with the average water type spectral signature from in-situ measurements for both water types. Reference in-situ dataset is MedBiOp (Volpe et al., 2019) where pure Case II spectra are selected using a k-mean cluster analysis (Melin et al., 2015). Merging of Case 1 and Case 2 information is performed estimating the Mahalanobis distance between the observed and reference spectra and using it as weight for the final merged value. SeaWiFS daily climatology provides reference for the calculation of Quality Indices (QI) for the Chl-a observations. The time series runs from September 1997 to June 2020 and the data product is freely available from:
https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=OCEANCOLOUR_MED_CHL_L3_REP_OBSERVATIONS_009_073 and
https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=OCEANCOLOUR_MED_CHL_L4_REP_OBSERVATIONS_009_078.

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3b) AOP distribution statistics

i) Remote sensing reflectance (Rrs) (sr^{-1}) at 412, 442, 490, 510, 560nm histograms for a year
ii) Plot of Rrs mean and standard deviation per month at all wavelengths above
iii) Map of Rrs mean around the sites for each season at 442 and 560nm

Individual remote sensing reflectance climatologies for all three sites at the main ocean colour wavelengths of 412, 442, 490, 510, and 560nm will be made by HCMR from data from two of the main ocean colour satellite sensors of the last three decades, i.e. SeaWiFS (1997-2010) and MODIS-Aqua (2002-present day) as these have the appropriate coverage and run for more than 10 years each. Additional to these a climatology based on less years will be made from Sentinel-3 OLCI (2016-present) Rrs data as this is the main Copernicus ocean colour sensor and is the initial focus sensor for Copernicus OC-SVC. These data are freely available from the NASA Ocean Biology Processing Group's web portal (https://oceancolor.gsfc.nasa.gov/data/overview/) and from EUMETSAT's Copernicus Online Data Access (CODA) portal (https://coda.eumetsat.int/) respectively. As a supplement for Sentinel-3, through the EUMETSAT S3VT, a new processing (Collection 3) using a neural network that is designed to handle oligotrophic/low chlorophyll waters will also be used to form an alternative potentially more accurate satellite based Rrs climatology.

Also, the ESA Ocean Colour Climate Change Initiative (OC-CCI) multi-sensor merged Remote Sensing Reflectance (Rrs) product and monthly climatology ocean colour product (September 1997 to the end of 2019) will be used for all three sites. The ESA Ocean Colour CCI project (https://www.oceancolour.org) has produced global level 3 binned multi-sensor time-series of satellite ocean-colour data with a particular focus for use in climate studies. This dataset contains the Version 4.2 Rrs product on a geographic projection at approximately 4 km spatial resolution and at a number of time resolutions (daily, 5-day, 8-day and monthly composites). Values for Rrs at the sea surface are provided for the standard SeaWiFS wavelengths (412, 443, 490, 510, 555, 670nm) with pixel-by-pixel uncertainty estimates for each wavelength. These are merged products based on SeaWiFS, MERIS and Aqua-MODIS data. This data product is on a geographic grid projection, which is a direct conversion of latitude and longitude coordinates to a rectangular grid, typically a fixed multiplier of 360x180. The netCDF files follow the CF convention for this projection with a resolution of 8640x4320. The monthly climatology dataset of the generated ocean colour products includes Rrs with Information on uncertainties also provided. These OC-CCI datasets are freely available from:
https://catalogue.ceda.ac.uk/uuid/aeae1a19608347f7b802691db6984343.

Additionally, the CMEMS product OCEANCOLOUR_MED_OPTICS_L3_REP_OBSERVATIONS_009_095 will be used for all three sites to make Rrs climatologies. The Global Ocean Satellite monitoring and marine ecosystem study group (GOS) of the Italian National Research Council (CNR), in Rome operationally distributes Remote Sensing Reflectance (Rrs) and the diffuse attenuation coefficient of light at 490 nm (Kd490) data. These datasets are derived from Rrs multi-sensor (MODIS-AQUA, NOAA20-VIIRS, NPP-VIIRS, Sentinel 3A-OLCI) spectra using state-of-the-art algorithms for multi-sensor merging. Single sensor Rrs fields are band-shifted, over the SeaWiFS native bands (using the QAAv6 model, Lee et al., 2002) and merged with a technique aimed at smoothing the differences among different sensors. Reprocessed (multi-year) products are consistent and homogeneous in terms of format, algorithms and processing software. The Rrs product is defined as the ratio of upwelling radiance and downwelling irradiance at any wavelength (412, 443, 490, 555, and 670 nm). The daily temporal consistency is evaluated as a Quality Index (QI):QI=(CurrentDataPixel-ClimatologyDataPixel)/STDDataPixelwhere QI is the difference between the current daily data and the relevant climatological field as a signed multiple of climatological standard deviations (STDDataPixel).

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3c) IOP distribution statistics

i) Coloured Dissolved Organic Matter (CDOM) absorption at 440 nm aCDOM (m^{-1}) histogram for a year
ii) Plot of aCDOM mean and standard deviation per month
iii) Particulate backscatter at 440 nm and 560 nm (where available) bbp (m^{-1}) histogram for a year
iv) Plot of bbp mean and standard deviation per month

Individual aCDOM and bbp climatologies for all three sites will be made by HCMR from the data from two of the main ocean colour satellite sensors of the last three decades, i.e. SeaWiFS (1997-2010) and MODIS-Aqua (2002-present day) as these have the appropriate coverage and run for more than 10 years each. Additional to these a climatology based on less years will be made from Sentinel-3 OLCI (2016-present) aCDOM and bbp data as this is the main Copernicus ocean colour sensor and is the initial focus sensor for Copernicus OC-SVC. These data are freely available from the NASA Ocean Biology Processing Group's web portal (https://oceancolor.gsfc.nasa.gov/data/overview/) and from EUMETSAT's Copernicus Online Data Access (CODA) portal (https://coda.eumetsat.int/) respectively. As a supplement for Sentinel-3, through the EUMETSAT S3VT, a new processing (Collection 3) using a neural network that is designed to handle oligotrophic/low chlorophyll waters will also be used to form alternative potentially more accurate satellite based IOP climatologies.

Also, the ESA Ocean Colour Climate Change Initiative (OC-CCI) multi-sensor merged Inherent Optical Properties (IOP) product and monthly climatology ocean colour product (September 1997 to the end of 2019) will be used for all three sites. The ESA Ocean Colour CCI project (https://www.oceancolour.org) has produced global level 3 binned multi-sensor time-series of satellite ocean-colour data with a particular focus for use in climate studies. This dataset contains their Version 4.2 IOP product on a geographic projection at approximately 4 km spatial resolution and at a number of time resolutions (daily, 5-day, 8-day and monthly composites). The IOP dataset consists of the total absorption and particle backscattering coefficients, and, additionally, the fraction of detrital & dissolved organic matter absorption and phytoplankton absorption. The total absorption (units m-1), the total backscattering (m-1), the absorption by detrital and coloured dissolved organic matter, the backscattering by particulate matter, and the absorption by phytoplankton share the same spatial resolution of ~4 km. The values of IOP are reported for the standard SeaWiFS wavelengths (412, 443, 490, 510, 555, 670nm). This data product is on a geographic grid projection, which is a direct conversion of latitude and longitude coordinates to a rectangular grid, typically a fixed multiplier of 360x180. The netCDF files follow the CF convention for this projection with a resolution of 8640x4320. The monthly climatology dataset of the generated ocean colour products includes the IOP products. These OC-CCI datasets are freely available from: https://catalogue.ceda.ac.uk/uuid/aeae1a19608347f7b802691db6984343.

Additionally, the CMEMS product OCEANCOLOUR_MED_OPTICS_L3_REP_OBSERVATIONS_009_095 will be used for all three sites to make aCDOM and bbp climatologies. The Global Ocean Satellite monitoring and marine ecosystem study group (GOS) of the Italian National Research Council (CNR), in Rome operationally distributes these optics products that are derived from Rrs multi-sensor (MODIS-AQUA, NOAA20-VIIRS, NPP-VIIRS, Sentinel3A-OLCI) spectra using state-of-the-art algorithms for multi-sensor merging. Single sensor Rrs fields are band-shifted, over the SeaWiFS native bands (using the QAAv6 model, Lee et al., 2002) and merged with a technique aimed at smoothing the differences among different sensors. Then geophysical fields including aCDOM and bbp are estimated via state-of-the-art algorithms for better product quality. The entire data set is consistent and processed in one-shot mode (with an unique software version and identical configurations). Reprocessed (multi-year) products are consistent and homogeneous in terms of format, algorithms and processing software. The daily temporal consistency is evaluated as a Quality Index (QI):QI=(CurrentDataPixel-ClimatologyDataPixel)/STDDataPixel where QI is the difference between the current daily data and the relevant climatological field as a signed multiple of climatological standard deviations (STDDataPixel).

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3d) Currents distribution statistics

i) Current intensity (cm.s-1) histogram for a year

ii) Current intensity and direction distribution rose diagrams for each season

For MSEA-N HCMR has a long (~10 year) time series of in-situ currents (intensity and direction) from the GOOS/HCMR E1-M3A buoy in the same location (Petihakis et al., 2018). This infrastructure has been developed based on a Fugro/OCEANOR SEAWATCH Wavescan buoy (http://www.oceanor.info/datasheets/SW06_WavescanBuoy(LR).pdf), on which we have installed a Teledyne RDI 75 kHz acoustic Doppler current profiler (ADCP) that provides data on surface currents and throughout the water column. These data were already graphed, published, reported and provided to EUMETSAT through the Copernicus OC-SVC phase 2 project ROSACE (RD-2, RD-3). The data from E1-M3A are freely available through HCMR and Copernicus.
(https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=INSITU_MED_NRT_OBSERVATIONS_013_035).

For all three sites similar surface current intensity and direction statistics will be derived from the CMEMS product MEDSEA_MULTIYEAR_PHY_006_004, which is the Med MFC physical reanalysis product generated by a numerical system composed of an hydrodynamic model, supplied by the Nucleous for European Modelling of the Ocean (NEMO) and a variational data assimilation scheme (OceanVAR) for temperature and salinity vertical profiles and satellite Sea Level Anomaly along track data. The model horizontal grid resolution is 1/24˚ (ca. 4-5 km) and the unevenly spaced vertical levels are 141. The time series runs from 1987 to the end of 2019 and the data product is freely available from: https://doi.org/10.25423/CMCC/MEDSEA_MULTIYEAR_PHY_006_004_E3R1

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3e) Wave distribution statistics
i) Wave height (m) histogram for a year
ii) Wave height and direction distribution rose diagrams for each season
iii) Wave period (s) histogram for a year
iv) Wave period and direction distribution rose diagrams for each season

For MSEA-N HCMR has a long (>10 year) time series of in-situ wave data (height, direction and period) from the GOOS/HCMR E1-M3A buoy in the same location (Petihakis et al., 2018). This infrastructure has been developed based on a Fugro/OCEANOR SEAWATCH Wavescan buoy (http://www.oceanor.info/datasheets/SW06_WavescanBuoy(LR).pdf), which has a directional wave sensor fitted as standard. These data were already graphed, published, reported and provided to EUMETSAT through the Copernicus OC-SVC phase 2 project ROSACE (RD-2, RD-3). The data from E1-M3A are freely available through HCMR and Copernicus.
(https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=INSITU_MED_NRT_OBSERVATIONS_013_035).

For all three sites similar wave statistics will be derived from the CMEMS product MEDSEA_HINDCAST_WAV_006_012, which is the multi-year product of the Mediterranean Sea Waves forecasting system. It is a multi-year wave hindcast from February 2006 until the end of 2019, composed by hourly wave parameters at 1/24° horizontal resolution, covering the Mediterranean Sea and extending up to -18.125W into the Atlantic Ocean. The Mediterranean Sea Waves forecasting system is a wave model based on WAM Cycle 4.5.4, which has been developed as a nested sequence of two computational grids (coarse and fine) to ensure that swell propagating from the North Atlantic (NA) towards the strait of Gibraltar is correctly entering the Mediterranean Sea (MED). The coarse grid covers the North Atlantic Ocean from 75° W to 10° E and from 70° N to 10° S in 1/6° resolution while the nested fine grid covers the Mediterranean Sea from 18.125° W to 36.2917° E and from 30.1875° N to 45.9792° N with a 1/24° (~4.6km) resolution. The Med-Waves modelling system resolves the prognostic part of the wave spectrum with 24 directional and 32 logarithmically distributed frequency bins. The product is freely available from https://doi.org/10.25423/CMCC/MEDSEA_HINDCAST_WAV_006_012.

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3f) SST distribution statistics

i) SST (°C) histogram for a year
ii) Plot of SST mean and standard deviation per month

For MSEA-N HCMR has a long (>10 year) time series of in-situ surface layer temperature from the GOOS/HCMR E1-M3A buoy in the same location. This infrastructure has been developed based on a Fugro/OCEANOR SEAWATCH Wavescan buoy, which has a Seabird SBE 16plus V2 SeaCAT high-accuracy conductivity and temperature recorder fitted just below the surface (~1m) (http://www.oceanor.info/datasheets/SW06_WavescanBuoy(LR).pdf; Petihakis et al., 2018). These data were already graphed, published, reported and provided to EUMETSAT through the Copernicus OC-SVC phase 2 project ROSACE (RD-2, RD-3). The data from E1-M3A are freely available through HCMR and Copernicus. (https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=INSITU_MED_NRT_OBSERVATIONS_013_035).

For all three sites Level-3 SST data at ~4km spatial resolution from MODIS will be used by HCMR to make SST climatologies. NASA standard processing and distribution of the Sea Surface Temperature (SST) products from the MODIS sensors is now performed using software developed by the Ocean Biology Processing Group (OBPG). The OBPG generates Level-2 SST products using the Multi-Sensor Level-1 to Level-2 software (l2gen), which is the same software used to generate MODIS ocean color products. The SST algorithm and quality assessment logic are the responsibility of the MODIS Science Team Leads for SST (currently P. Minnett and R. Evans of the Rosenstiel School of Marine and Atmospheric Science (RSMAS) at the University of Miami). The MODIS Level 3 quality checked data from 1999-present day are freely available from https://oceandata.sci.gsfc.nasa.gov/MODIS-Aqua/L3SMI/ and https://oceandata.sci.gsfc.nasa.gov/MODIS-Terra/L3SMI/.

Furthermore, the ESA Sea Surface Temperature (SST) Climate Change Initiative (SST-CCI) Level 4 analysis climate data record product will be used for climatologies of all three sites. This v2.1 SST-CCI Level 4 Analysis Climate Data Record (CDR) provides a globally-complete daily analysis of sea surface temperature (SST) on a 0.05 degree regular latitude - longitude grid. It combines data from both the Advanced Very High Resolution Radiometer (AVHRR) and Along Track Scanning Radiometer (ATSR) SST-CCI Climate Data Records, using a data assimilation method to provide SSTs where there were no measurements. These data cover the period between 09/1981 and 12/2016. The dataset has been produced as part of the European Space Agency (ESA) Climate Change Initiative Sea Surface Temperature project (ESA SST-CCI). The data products from SST-CCI accurately map the surface temperature of the global oceans over the period 1981 to 2016 using observations from many satellites. The data provide independently quantified SSTs to a quality suitable for climate research. Data are made freely and openly available under a Creative Commons License by Attribution (CC By 4.0 https://creativecommons.org/licenses/by/4.0/) and can be downloaded from: https://catalogue.ceda.ac.uk/uuid/62c0f97b1eac4e0197a674870afe1ee6.

Additionally, the CMEMS products SST_MED_SST_L3S_NRT_OBSERVATIONS_010_012 and SST_MED_SST_L4_REP_OBSERVATIONS_010_021 will be used for all three sites to make satellite SST climatologies. For the Mediterranean Sea (MED), the CNR MED Sea Surface Temperature (SST) processing chain provides supercollated (merged multisensor, L3S) SST data remapped over the Mediterranean Sea at high (1/16°) and Ultra High (0.01°) spatial resolution, representative of nighttime SST values (00:00 UTC). The L3S SST data are produced selecting only the highest quality input data from input L2P/L3P images within a strict temporal window (local nightime), to avoid diurnal cycle and cloud contamination. Consequently, the L3S processing is run daily, but L3S files are produced only if valid SST measurements are present on the area considered.
The CMEMS reprocessed Mediterranean SST dataset provides 37 years of daily (nighttime) optimally interpolated (L4) satellite-based estimates of the foundation SST in the Mediterranean Sea and adjacent North Atlantic box over a 0.05° resolution grid, covering the period 1982-2018. This product is built from a consistent reprocessing of the level-3 (merged multi-sensor, L3) climate data record provided by the ESA Climate Change Initiative (CCI) and Copernicus Climate Change Service (C3S) initiatives, but also include in input an adjusted version of the AVHRR Pathfinder dataset version 5.3 to increase the input observation coverage. These data are freely available from:
https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=SST_MED_SST_L4_REP_OBSERVATIONS_010_021

To provide information below the skin temperature given by satellite SST products, for all three sites similar surface layer (0-10m, i.e. where the OC-SVC buoy radiometers will be installed) temperature statistics will be derived from the CMEMS product MEDSEA_MULTIYEAR_PHY_006_004. This is the Med MFC physical reanalysis product generated by a numerical system composed of an hydrodynamic model, supplied by the Nucleous for European Modelling of the Ocean (NEMO) and a variational data assimilation scheme (OceanVAR) for temperature and salinity vertical profiles and satellite Sea Level Anomaly along track data. The model horizontal grid resolution is 1/24˚ (ca. 4-5 km) and the unevenly spaced vertical levels are 141. The time series runs from 1987 to the end of 2019 and the data product is freely available from:
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3g) Salinity monthly maps and distribution statistics

i) Salinity (PSU) histogram for a year
ii) Plot of salinity mean and standard deviation per month

For MSEA-N HCMR has a long (>10 year) time series of in-situ surface layer salinity from the GOOS/HCMR E1-M3A buoy in the same location. This infrastructure has been developed based on a Fugro/OCEANOR SEAWATCH Wavescan buoy, which has a Seabird SBE 16plus V2 SeaCAT high-accuracy conductivity and temperature recorder fitted just below the surface (~1m) (http://www.oceanor.info/datasheets/SW06_WavescanBuoy(LR).pdf; Petihakis et al., 2018). These data were already graphed, published, reported and provided to EUMETSAT through the Copernicus

OC-SVC phase 2 project ROSACE (RD-2, RD-3). The data from E1-M3A are freely available through HCMR and Copernicus. (https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=INSITU_MED_NRT_OBSERVATIONS_013_035).

For all three sites similar surface layer (0-10m) salinity statistics will be derived from the CMEMS product MEDSEA_MULTIYEAR_PHY_006_004, which is the Med MFC physical reanalysis product generated by a numerical system composed of an hydrodynamic model, supplied by the Nucleous for European Modelling of the Ocean (NEMO) and a variational data assimilation scheme (OceanVAR) for temperature and salinity vertical profiles and satellite Sea Level Anomaly along track data. The model horizontal grid resolution is 1/24˚ (ca. 4-5 km) and the unevenly spaced vertical levels are 141. The time series runs from 1987 to the end of 2019 and the data product is freely available from: https://doi.org/10.25423/CMCC/MEDSEA_MULTIYEAR_PHY_006_004_E3R1

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4) Other

4a) Map of nearby shipping routes and monthly traffic statistics with associated map of NO2 concentration.

The Hellenic Republic - Ministry of Maritime Affairs and Insular Policy - Hellenic Coast Guard have agreed to supply HCMR with the map of the nearby shipping routes to all three sites and are allowing us to access their vessel logs to derive some traffic statistics. As a fellow public institution we have permission to reproduce this data and to give to EUMETSAT for this study. However, any further publication will need the prior permission of the Ministry and HCMR.

The tropospheric column of NO_2 that will be derived from the Sentinel 5p TROPOMI high spatial resolution (3.5x7km) product provides clear information on regional high NO_2 tropospheric columns over the sea that correspond to the shipping tracks. Annual mean and seasonal maps focusing on the region covering the three investigated locations will be provided averaged for the 3 full years of the operation of TROPOMI. This dataset is publicly available for the last 3 years at https://sentinels.copernicus.eu/web/sentinel/data-products/-/asset_publisher/fp37fc19FN8F/content/sentinel-5-precursor-level-2-nitrogen-dioxide

Maps of shipping traffic and the associated data for all three sites will also be downloaded from EMODnet. EMODnet Vessel Density maps were created by Cogea in 2019 in the framework of EMODnet Human Activities, an initiative funded by the EU Commission. The maps are based on AIS data purchased by Collecte Localisation Satellites (CLS) and ORBCOMM. The maps show shipping density in 1km*1km cells of a grid covering all EU waters (and some neighbouring areas). Density is expressed as hours per square kilometre per month. The following ship types are available: Other; Fishing; Service; Dredging or underwater ops; Sailing; Pleasure Craft; High speed craft; Tug and towing; Passenger; Cargo; Tanker; Military and Law Enforcement; Unknown and All ship types. Data are available by month of year. Yearly averages are also available. This facility provides free access to GIS data on vessel density in European waters. It is possible to view the vessel density data on an interactive map of Europe by clicking on a cell to retrieve the value (hours per square km per month) by ship type or download raster GIS files (GeoTIFF). Datasets are also available via OGC compliant web map services (WMS) and web coverage service (WCS). The metadata can be downloaded as XML files. These data are freely available from the EMODnet human activities web portal (https://www.emodnet-humanactivities.eu/view-data.php and https://www.emodnet-humanactivities.eu/download-data.php).

4b) Map of nearby airline routes and monthly traffic statistics

The Hellenic Republic - Ministry of Infrastructure and Transport - Civil Aviation Authority will supply HCMR with the map of the airline routes for Greek air space as well as allowing us access to the traffic statistics for any routes or airports that are nearby each of the three sites. As a fellow public institution we have permission to reproduce this data and to give to EUMETSAT for this study. However, any further publication will need the prior permission of the Ministry and HCMR.

HCMR are also investigating the possibility of creating these maps and monthly statistics with additional data from open access and subscription based online sources (e.g. Eurostat and flightradar24.com) that may also contain information on over flights through Greek airspace, which is data unavailable from the Civil Aviation Authority.

4c) Fire occurrences in the surrounding areas (within 50 km): high, low, minimal

The Hellenic Republic - Ministry of Citizen Protection - Hellenic Fire Service are giving HCMR access to their logs of fire occurrences in the Crete Prefectures of Heraklion and Rethimnon as well as for the island of Kythera. As a fellow public institution we have permission to reproduce this data and to give to EUMETSAT for this study. However, any further publication will need the prior permission of the Ministry and HCMR.

Additionally, for Heraklion and Rethimnon prefectures and the island of Kythera we will make use of the ESA Fire Disturbance Climate Change Initiative (Fire-CCI) data, which has produced maps of global burned area derived from satellite observations. The MODIS Fire-CCI v5.1 pixel products are distributed as 6 continental tiles and are based upon data from the MODIS instrument onboard the TERRA satellite at 250m resolution for the period 2001-2019. The v5.1 dataset was initially published for 2001-2017, and was later extended to include 2018 and then 2019. Updated 2007 European data are also available. The Fire-CCI v5.1 Pixel product described here includes maps at 0.00224573-degrees (approx. 250m) resolution. Burned area (BA) information includes 3 individual files, packed in a compressed tar.gz file: date of BA detection (labelled JD), the confidence level (CL, a probability value estimating the confidence that a pixel is actually burned), and the land cover (LC) information as defined in the Land Cover CCI v2.0.7 product. Files are in GeoTIFF format using a geographic coordinate system based on the World Geodetic System (WGS84) reference ellipsoid and using Plate Carrée projection with geographical coordinates of equal pixel size. The data are freely available from: https://catalogue.ceda.ac.uk/uuid/58f00d8814064b79a0c49662ad3af537.

HCMR will also request historical statistics from the European Forest Fire Information Service (EFFIS) database of forest and wildfires (https://effis.jrc.ec.europa.eu/applications/data-and-services) and make use of other online resources such as the Diachronic Inventory of Forest Fires, which aims to depict the results of the diachronic mapping of burned areas over Greece for the last 35 years (1984 to 2019 - http://ocean.space.noa.gr/diachronic_bsm/).

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5) Compliance matrix of the site with the environmental requirements in [AD-2]

All the atmospheric and oceanographic data referred to above will be used to create a compliance matrix with the environmental requirements of AD-2 for each of the three sites (MSEA-N, MSEA-S and Antikythera). Although not one of the climatological or observational datasets it is worth mentioning that included on the location maps, in the final report and in the compliance matrix will be details of the supporting infrastructure available for OC-SVC for all three sites. This will be provided in terms of details of and distances to oceanographic and atmospheric measurement stations as well as OC-SVC operational support infrastructure including ships and calibration and other laboratories (AD-2, RD-2, RD-3, RD-4).