



Climatological Characterisation of Candidate Ocean Sites for Copernicus OC-SVC Infrastructure Placement

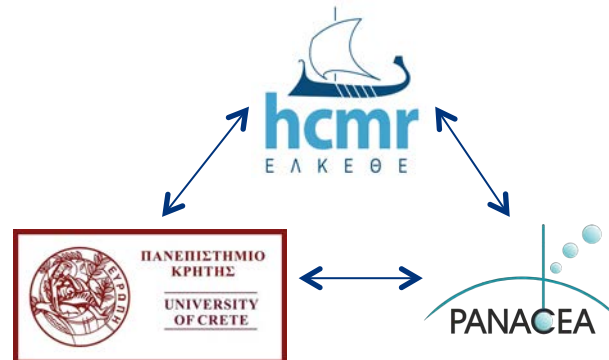
Site: CRETE (GR)
MSEA-N, MSEA-S, Antikythera

A.C. Banks (PI), D. Androulakis, S. Psarra, A. Karageorgis, G. Petihakis, A. Kalampokis,
E. Livanou, N. Spyridakis

(Institute of Oceanography, Hellenic Centre for Marine Research)

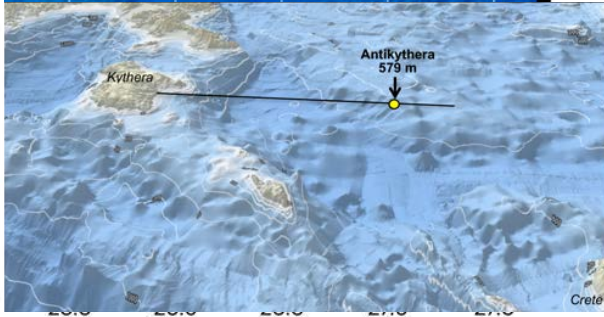
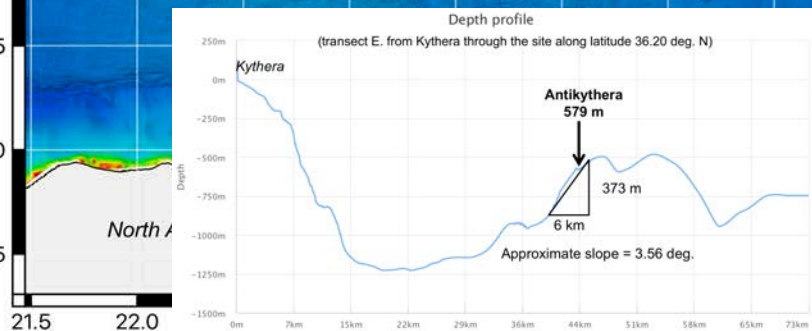
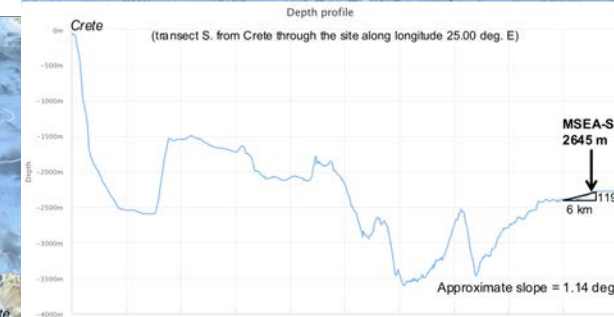
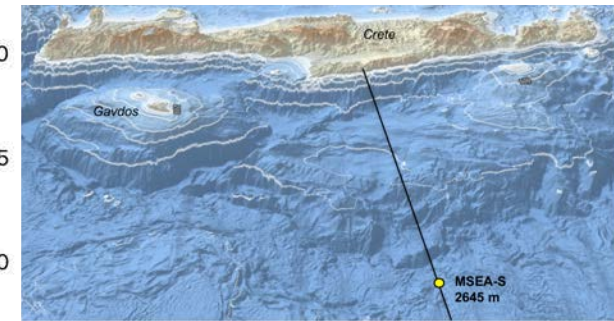
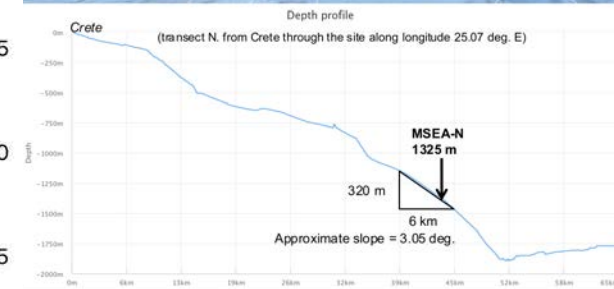
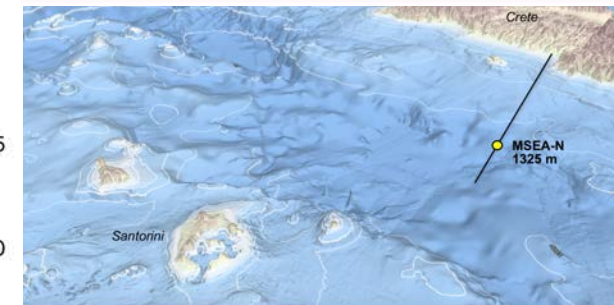
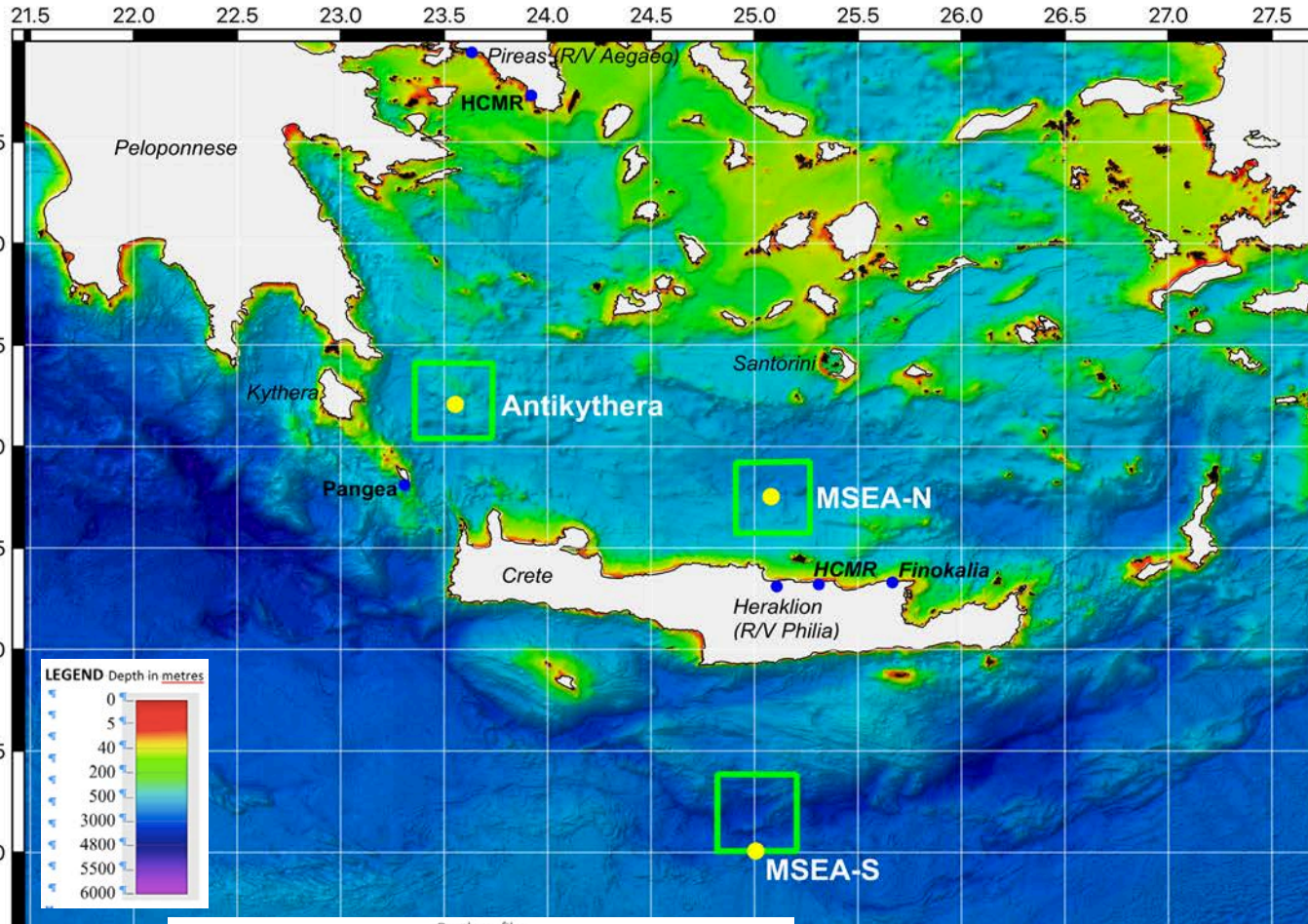
&

M. Kanakidou, N. Kalivitis, M. Chatziparaschos, N. Daskalakis, N. Gialesakis,
N. Mihalopoulos (PANACEA), V. Amiridis (National Observatory of Athens)
(University of Crete)



Site/s geography

MSEA-N	MSEA-S	Antikythera
Fully compliant	Partly compliant	Not compliant
OC-SVC requirement OC-VCAL-RD-38,49 (AD-2)		



Relevant local measurements and infrastructures

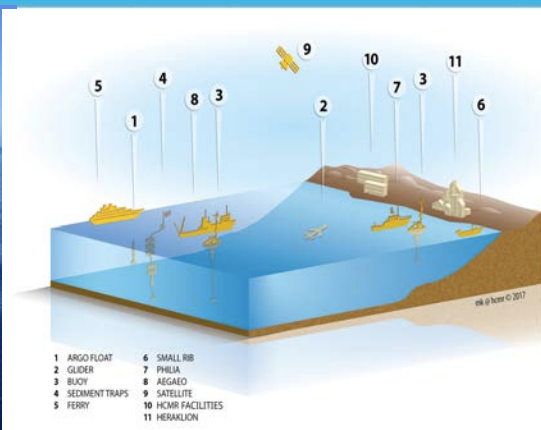
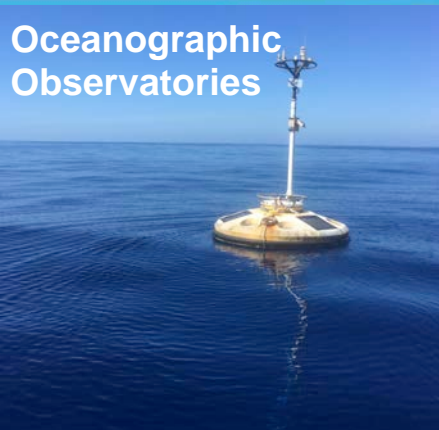
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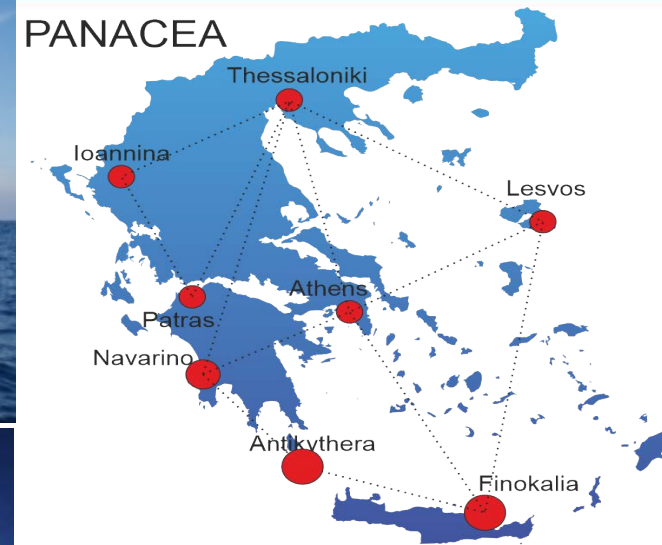
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OC-SVC requirement OC-VCAL-RD-12,34,40,50 (AD-2)

Oceanographic Observatories



PANACEA



HCMR POSEIDON / GOOS E1-M3A operational in situ oceanographic & biogeochemical measurements from same location as MSEA-N for > 20 years.

Integrated observatory (inc. HCB, ferryBox, glider, Argos, regular R/V sampling, data released through Copernicus).

Buoy mounted sensors: Temperature (air and water), Salinity, Fluorescence (Chl-a), Dissolved Oxygen, pH, pCO₂, Currents (ADCP), Wind (speed & direction), Atmospheric Pressure.

Sampled at buoy locations (monthly): Turbidity, PAR/Irradiance, NO₃ + NO₂ / Si(OH)₄, PO₄, Total Chl-a, Other Phytopigments, Viruses and Bacteria, Pico-, Nano-, Micro-phytoplankton, Ciliates, Zooplankton, A_T, DIC, TEP, POC / PN, DOC or TOC, TDN, DOP, Primary production, Bacterial production.

Atmospheric Observatories



The Finokalia station is facing the sea in the 270° to 90° wind sector.



FINOKALIA, PANGEA & PANACEA

At **Finokalia**, in situ aerosol chemical composition (major ions, metals, organics), meteorological parameters, O₃, reactive gases (CO, NO_x), PM₁₀, greenhouse gases (CO₂, CH₄), radon and thoron. Continuous aerosol light extinction (absorption, scattering), aerosol optical depth, aerosol size distribution, sunphotometer (Aeronet). Ions, metals, water soluble organics and nutrients in rainwater & dry deposition.

Observations further complemented by targeted state-of-the art measurements during intensive field campaigns

At **PANGEA**, Raman lidar & sunphotometer (Aeronet) operate and **full aerosol, cloud and trace gases remote sensing national facilities** (Doppler wind and cloud radars, ceilometer, microwave radiometer, X-band weather radar FTIR, PANDORA), will be operational in 2022



Prevailing meteorological circulation patterns

MSEA-N

MSEA-S

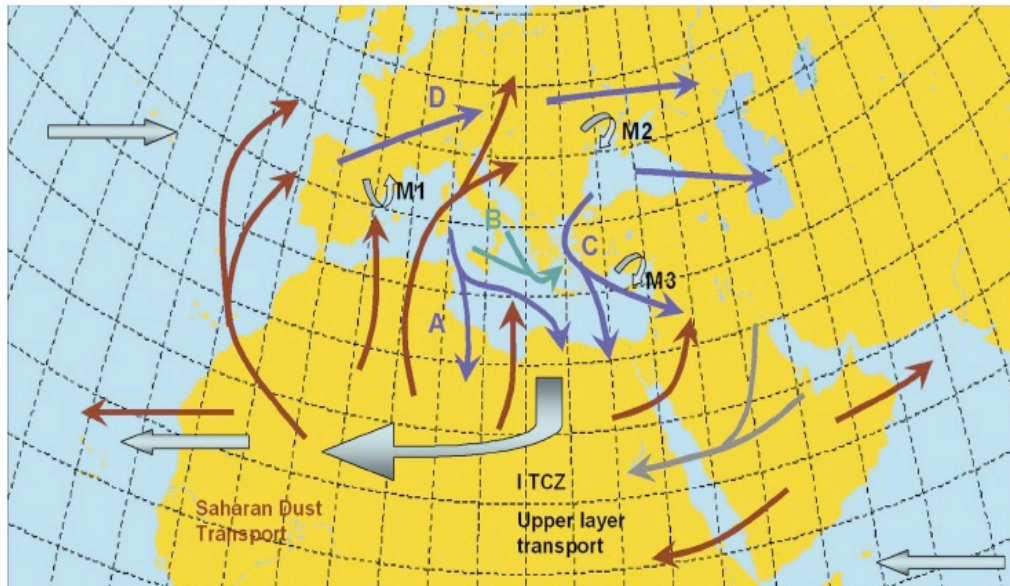
Antikythera

Fully compliant

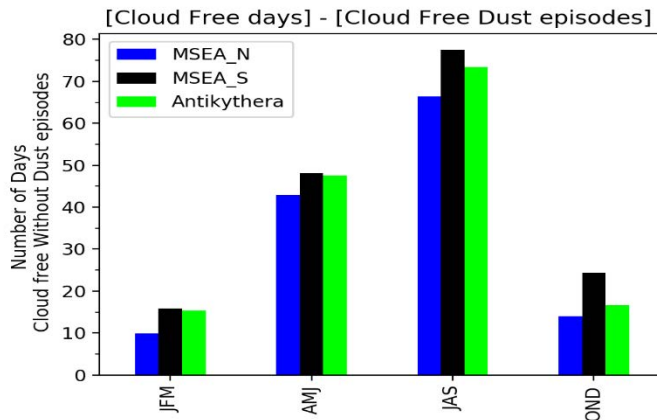
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OC-SVC requirement OC-VCAL-RD-7,12,33,34,36,37 (AD-2)



Blue and green transport from polluted regions
 C Etesians in the East Med. During summer
 Brown main paths of dust (different seasonality West and East Med)
 Gray upper layer transport paths
 M1,M2,M3 thermal recirculation
 Kallos et al., JAMC, 2007



Cloud free days (cloud fraction <math><0.1</math>) without dust episodes (dust episodes detected based on

Mostly driven by the Siberian anticyclone - expanded over the northern Balkans during the cold period, the subtropical Azores anticyclone expanded over North Africa during summer and the Asian monsoon Low expanded over the eastern Mediterranean during summer.

- *In winter*: the atmospheric circulation is controlled by the westerlies; rather variable temperature and wind direction, rare but intense dust storms, cyclogenesis more frequent in the West than the East part of the Mediterranean basin
- *In Spring*: dust outbreak events of 2-3 days duration at most.
- *In summer*: the subtropical anticyclone is driving atmospheric circulation. The Aegean and Cretan Sea are subject to the Etesians: predictable, moderate speed winds blowing from the north (- *In fall*: progressive return to winter situation.
- *Potential distant sources*: agglomerations, shipping, air traffic, African desert, sea-water, vegetation, open fires
- **From May to September has little to no clouds, no major dust outbreaks, and almost constant meteorology in particular during July and August when it is subject to the constant wind flow of north Etesian winds**
- **There are, on average, about (109-126) days of cloud free conditions without dust episodes over the period from April to September during the last 20 years**

Cloudiness and solar illumination

MSEA-N

MSEA-S

Antikythera

Fully compliant

Fully compliant

Fully compliant

OC-SVC requirement OC-VCAL-RD-7,33,37,39,42 (AD-2)

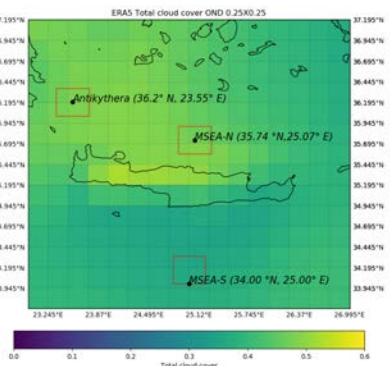
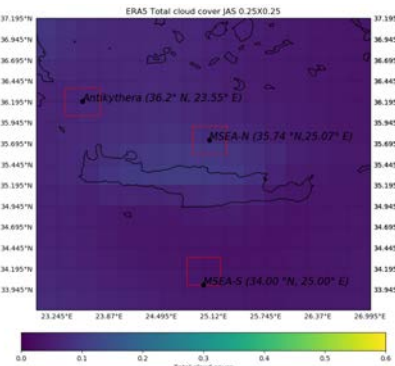
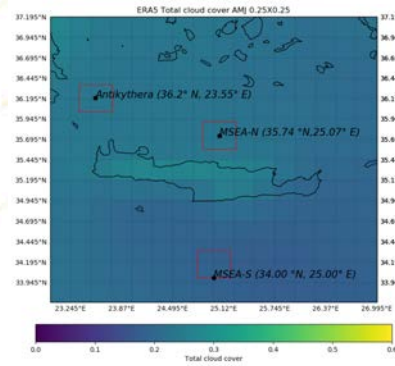
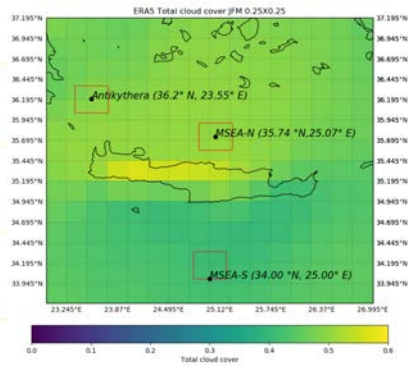
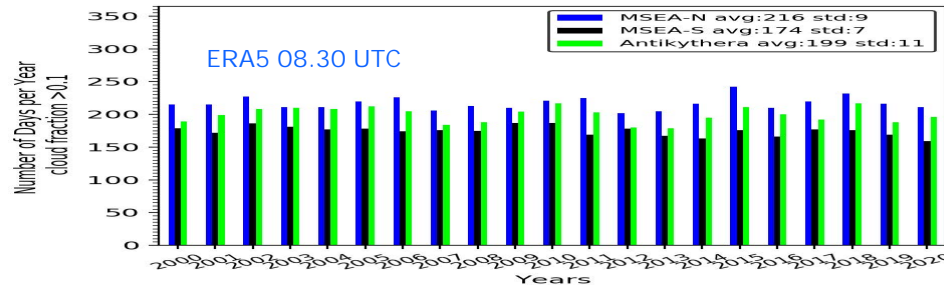
- Number of days in a year where fractional cloud cover is > 0.1

MSEA-N (216 \pm 9 days)

MSEA-S (174 \pm 7 days)

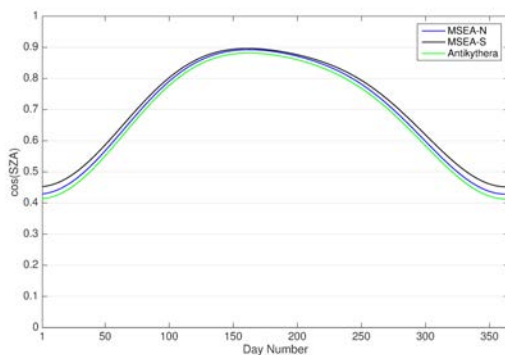
Antikythera (199 \pm 11 days)

- Seasonal maps of cloudiness



ERA5 2000-2019 at 08.30 UTC

- cosine of Sun zenith angle at 08.30 AM UTC



**HNMS
in situ data**
Heraklion airport (2000-2020)
Tympaki airport (2000-2020)
Kythera airport (2000-2004, 2009 & 2010)

Fractional cloud cover mean

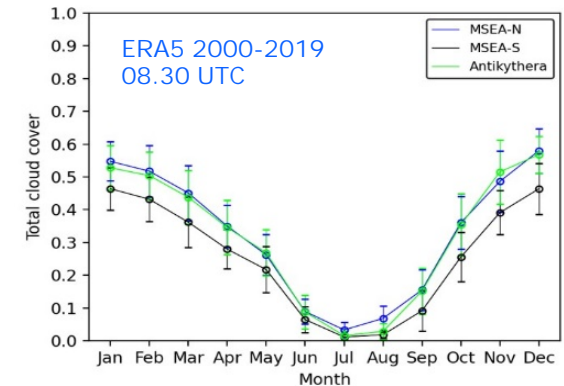
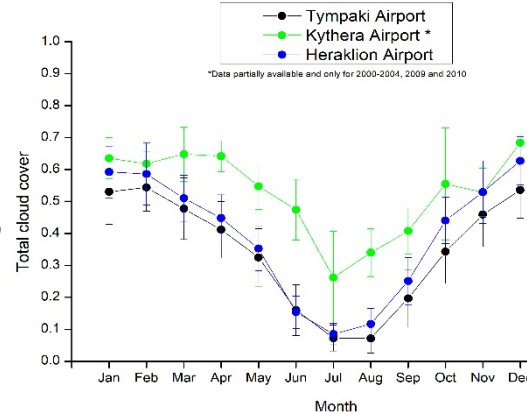


Figure G6. Cosine of the solar zenith angle (SZA) using the NOAA solar position model (based on equations from Astronomical Algorithms, by Jean Meeus) for MSEA-N, MSEA-S, and Antikythera for each day of an example year (2019) at the Sentinel 3 OLCI overpass time (08:30 UTC).

Winds

MSEA-N

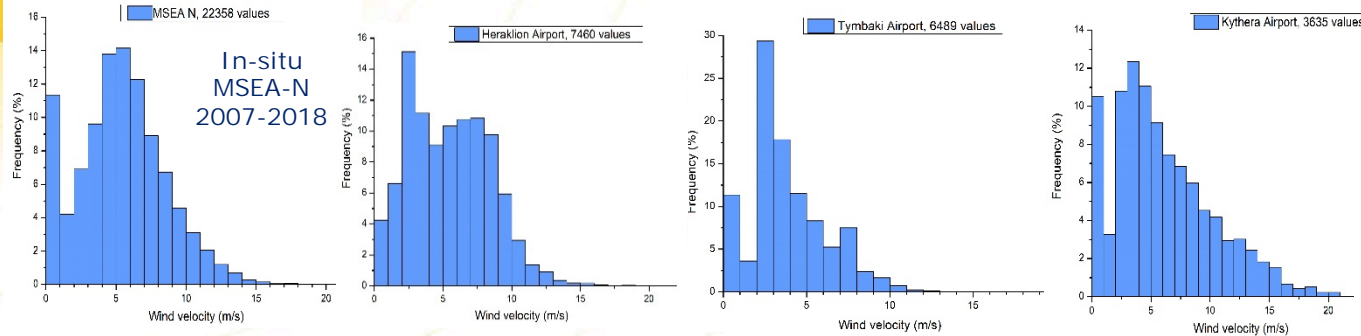
MSEA-S

Antikythera

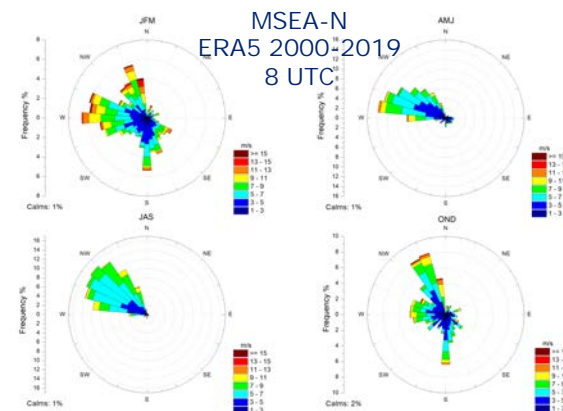
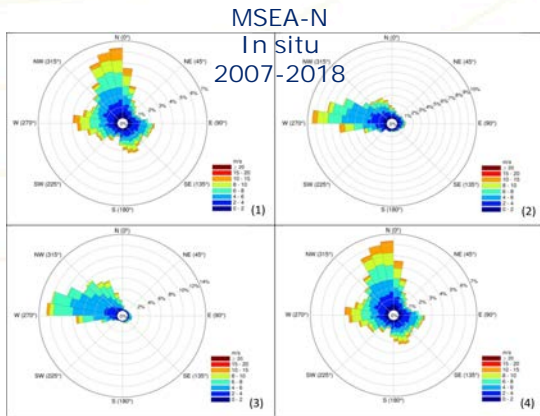
Fully compliant Fully compliant Fully compliant

OC-SVC requirement OC-VCAL-RD-36,37,45 (AD-2)

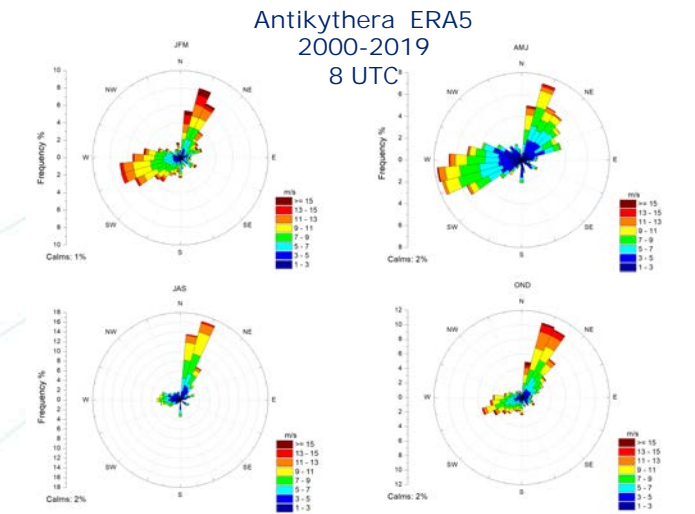
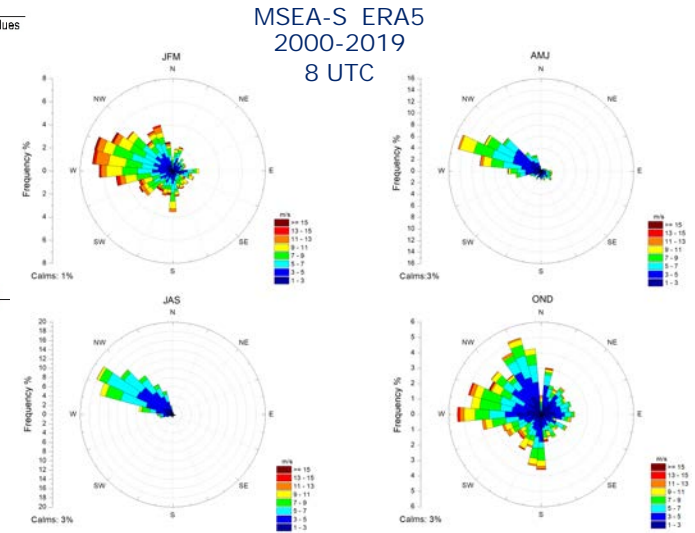
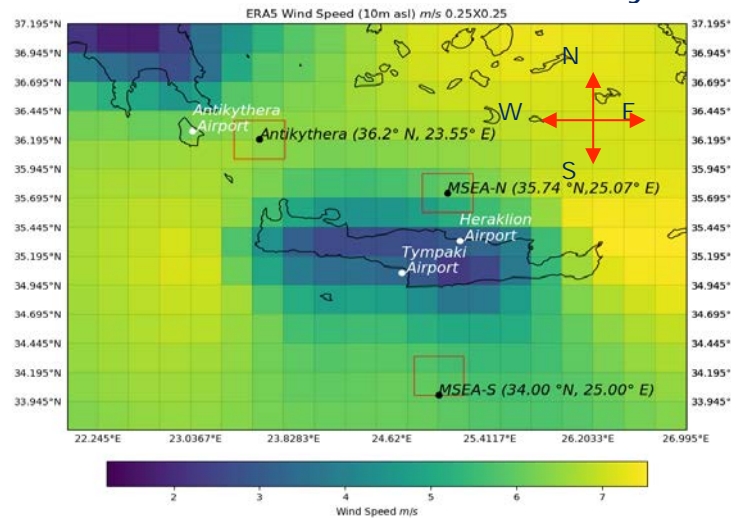
In-situ from weather service (HNMS) at 9 UTC (closest operation time)



Horizontal wind at 10 m seasonal rose diagrams



Plot of the mean wind velocity



Aerosols and AOT

MSEA-N

MSEA-S

Antikythera

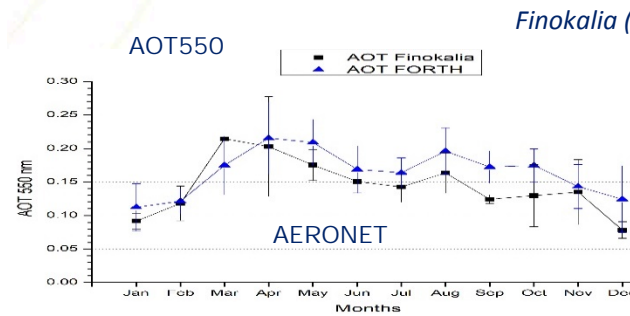
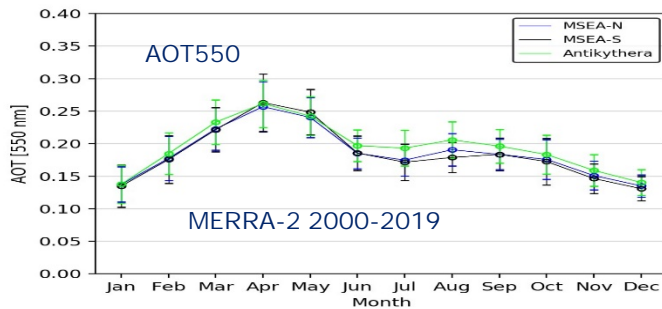
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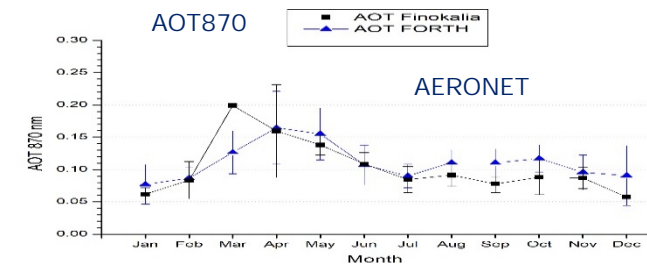
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OC-SVC requirement OC-VCAL-RD-7,12,34,36,37,45 (AD-2)

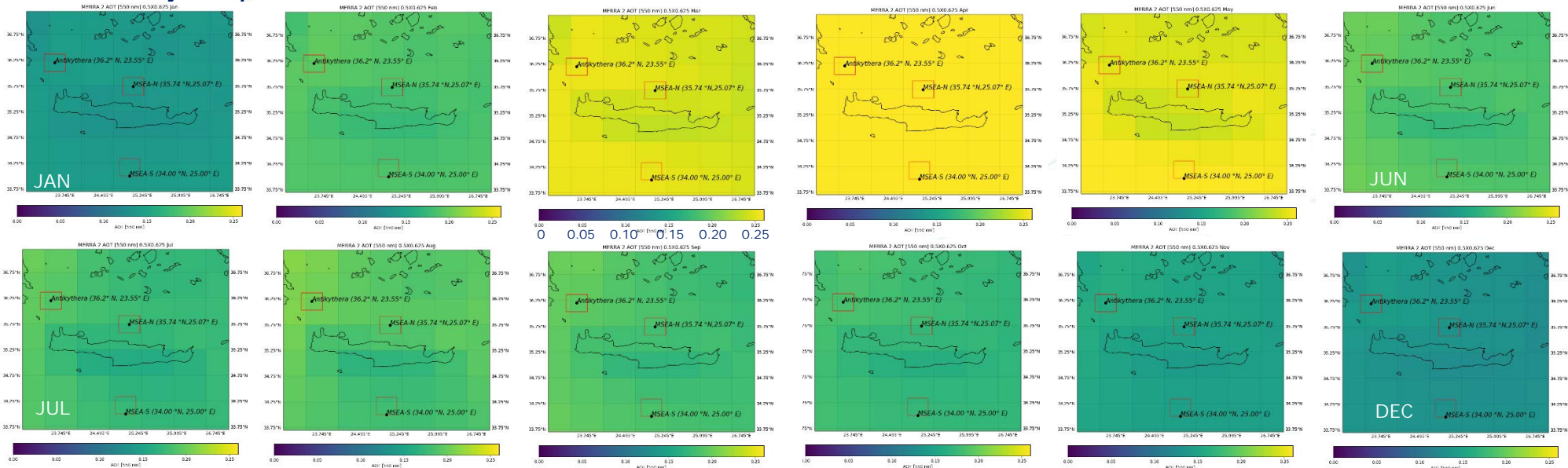
- Three main types: sea salt aerosol; dust aerosol; anthropogenic aerosol
- Aerosol stability and spatial uniformity, prevailing maritime aerosols
- AOT(550 nm) < 0.15 : AERONET-based : FORTH 52% , Finokalia 67%
- MERRA-2-based (20 yrs) : MSEA-N 44% , MSEA-S 48%, Antikythera 40%
- Annual time series of AOT 550nm mean and standard deviation per month



Finokalia (2014, 2017-2020) and FORTH (2003-2013, 2015-2017)



Monthly maps of mean AOT 550 nm –MERRA-2



Aerosols and Angstrom

MSEA-N

MSEA-S

Antikythera

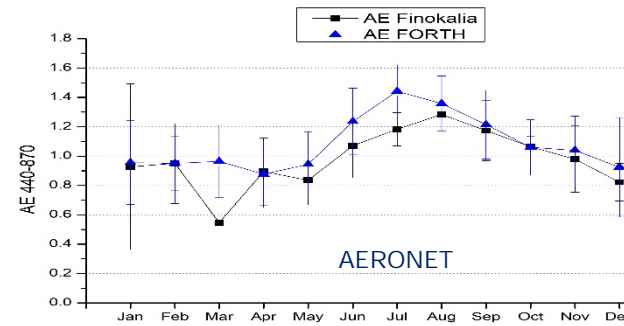
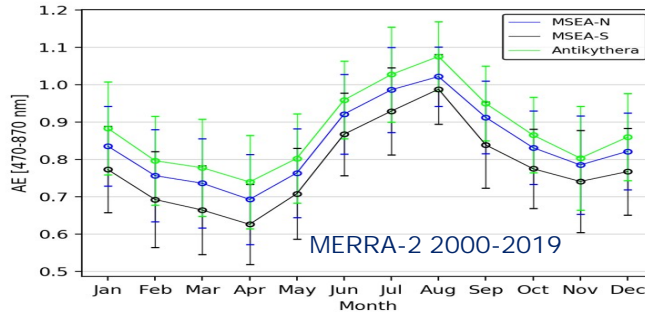
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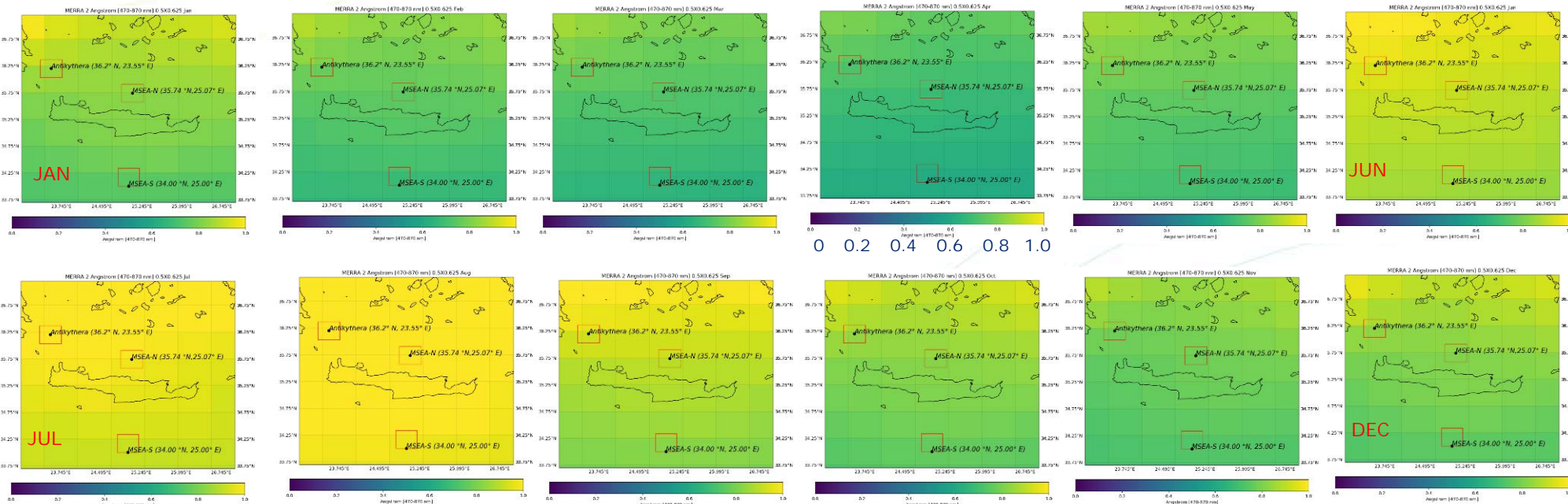
OC-SVC requirement OC-VCAL-RD-7,12,34,36,37 (AD-2)

Plot of annual time series of Angstrom (440 : 870 nm) mean and standard deviation per month



Finokalia (2014, 2017-2020)
FORTH (2003-2013,
2015-2017)

Monthly maps of mean Angstrom (440 : 870 nm) – MERRA-2



Anomalous aerosol conditions

MSEA-N

MSEA-S

Antikythera

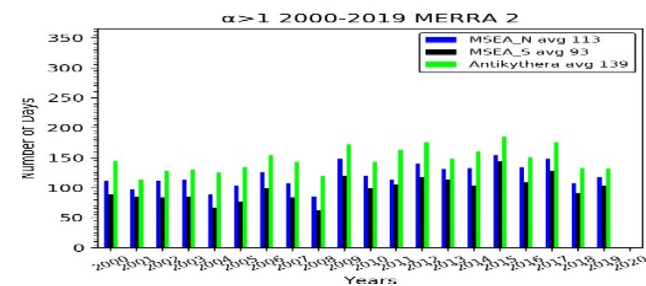
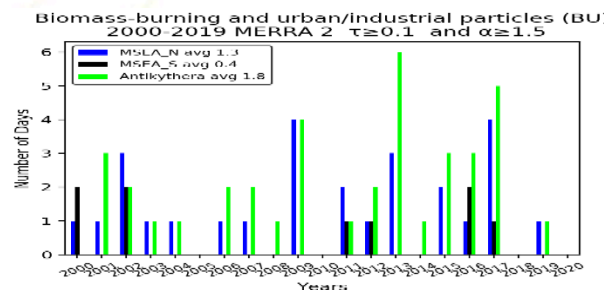
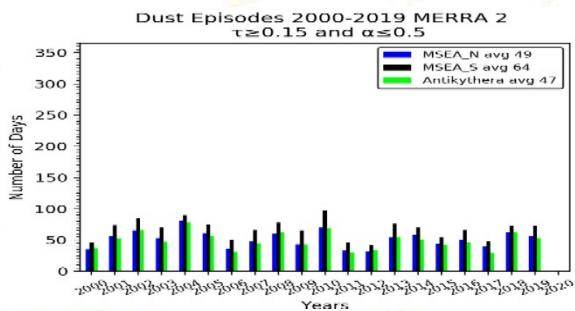
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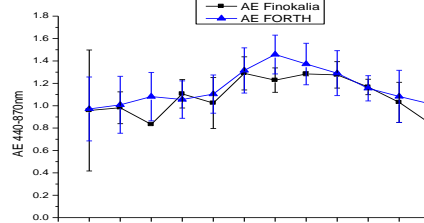
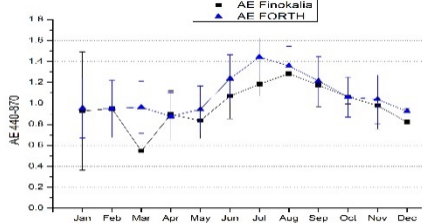
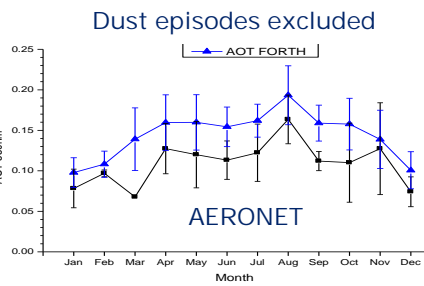
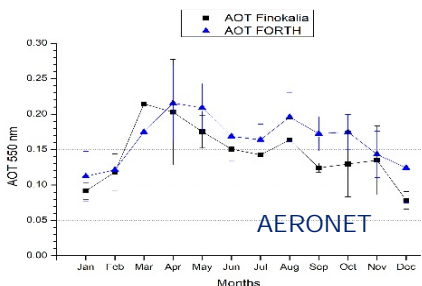
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OC-SVC requirement OC-VCAL-RD-7,12,34,36,37,45 (AD-2)

- Frequency of anomalous aerosol episodes (dust, biomass burning, pollution)
- Number of days/year of dust episodes: MSEA-N 49; MSEA-S 64 ; Antikythera 47
- Typical duration of dust episodes → 1 to 2 days (rarely 3 days)
- Number of days per year where $\alpha > 1$ based on 20 year MERRA-2 climatology:
MSEA-N 30% ; MSEA-S 25% ; Antikythera 38%

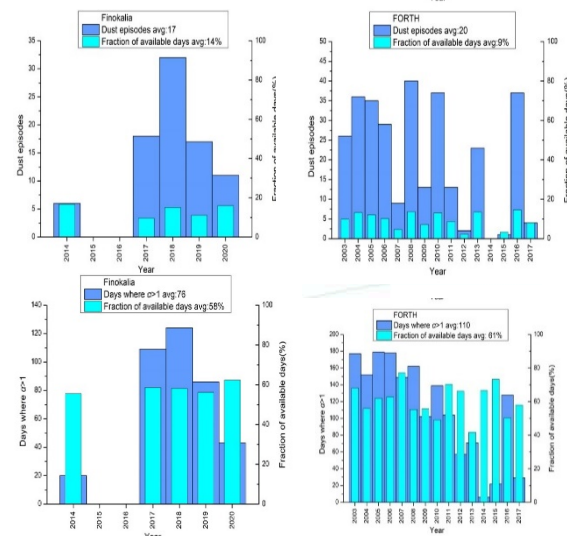


AOT (550 nm) & Angstrom (440 : 870 nm) monthly mean



Dust episodes based on AERONET

Days where $\alpha > 1$ based on AERONET



Absorbing gases

MSEA-N

MSEA-S

Antikythera

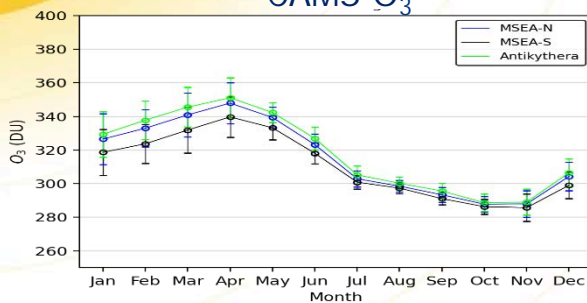
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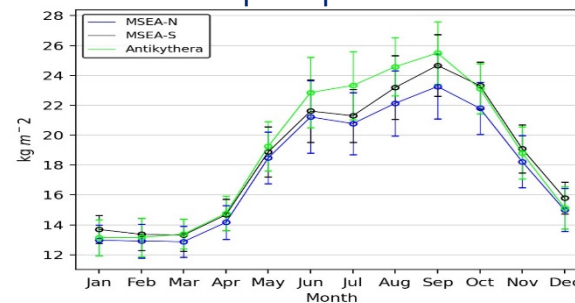
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OC-SVC requirement OC-VCAL-RD-7,12,34,36,37 (AD-2)

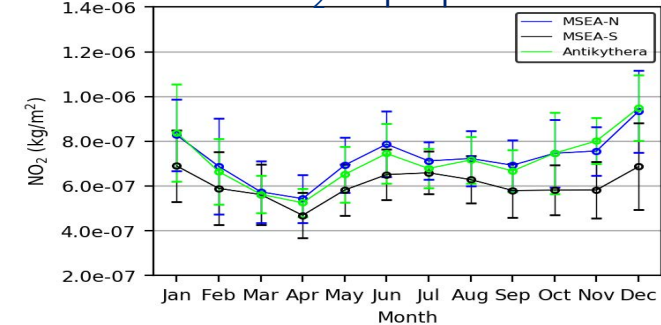
CAMS O₃



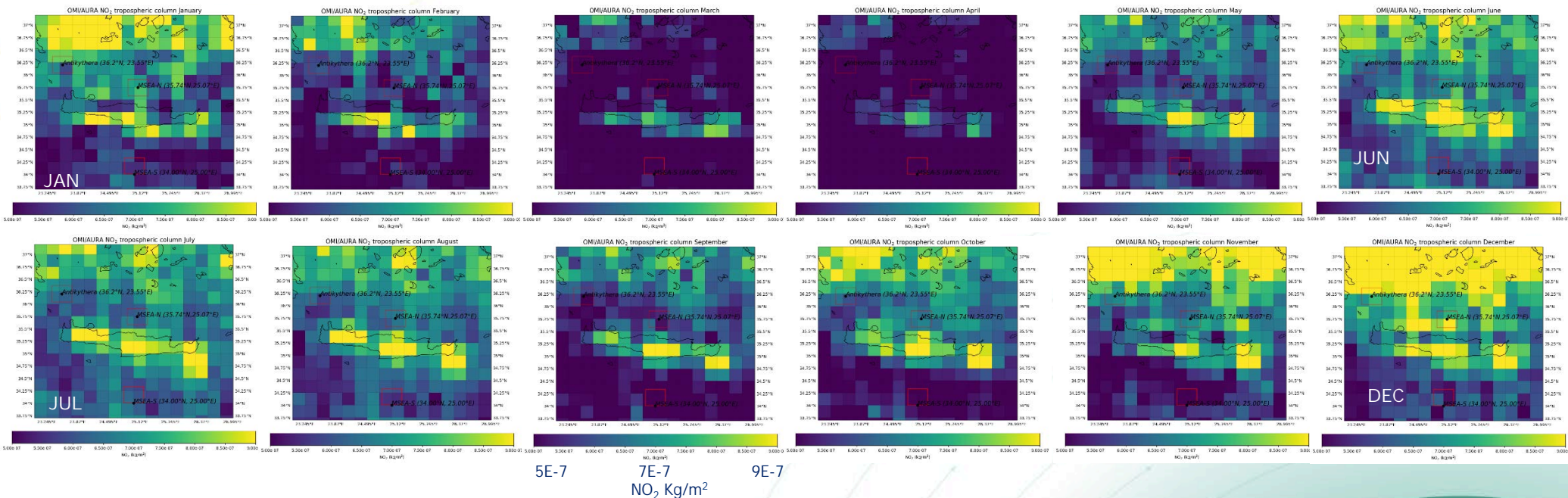
CAMS precipitable water



OMI/AURA NO₂ tropospheric column



Maps of mean tropospheric column of NO₂ per month



Prevailing oceanographic conditions

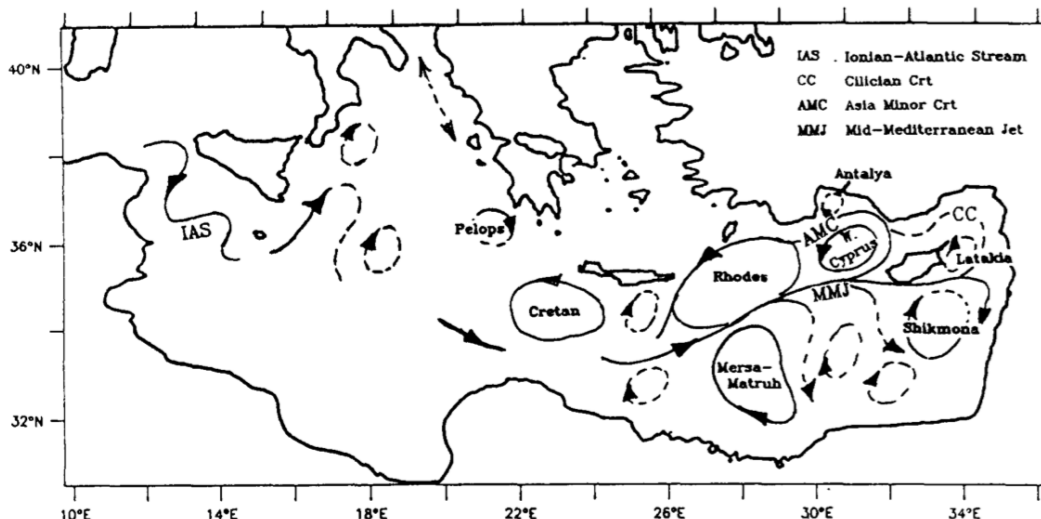
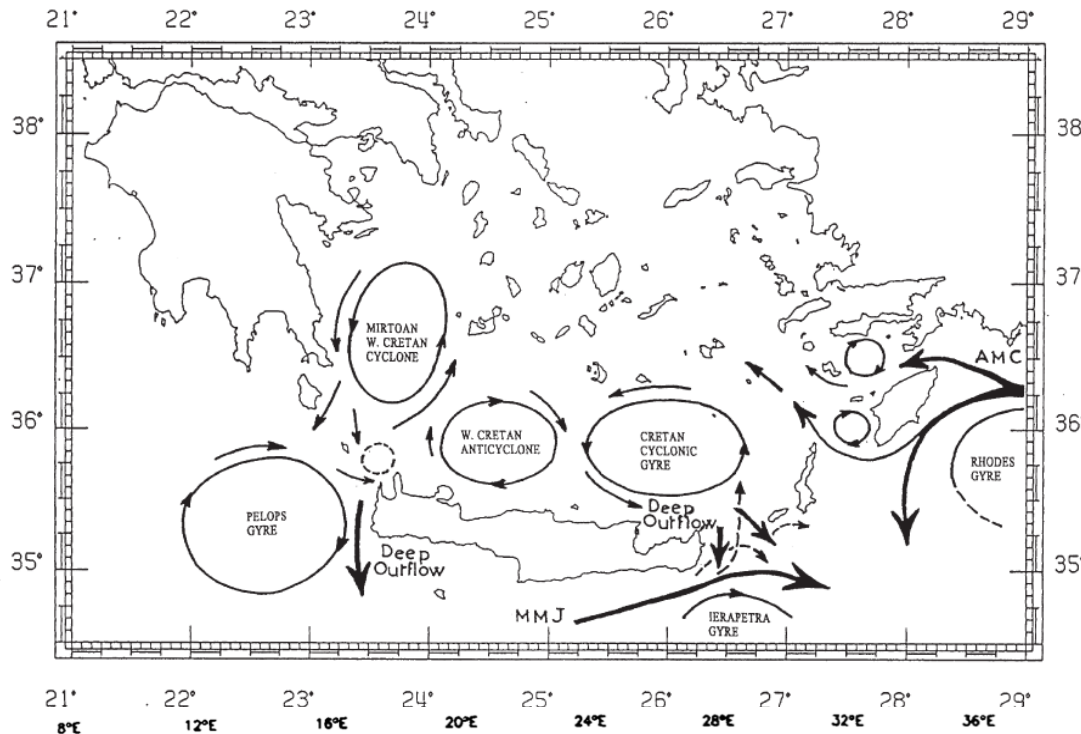
MSEA-N

MSEA-S

Antikythera

Fully compliant Fully compliant Fully compliant

OC-SVC requirement OC-VCAL-RD-35,36 (AD-2)



- The Sea of Crete has a slow moving circulation environment dominated by low intensity mesoscale features. Slightly higher current velocities south of Crete due to influence of MMJ. Low wave environment north and south (mean & median < 1m).
- Temperature-salinity mixed layer depth well below depth of buoy instrumentation all year with no surface intrusions at the sites. Seasonal changes to surface mixed layer dominated by levels of solar insolation.
- Ecosystem characterized by very low suspended particle concentrations. The Eastern Mediterranean, including the Cretan Sea to the north of Crete, generally characterized by oligotrophy throughout the year with a very limited phytoplankton late winter - early spring "bloom".
- **Minimal impact on Copernicus OC-SVC operations expected due to Crete oceanographic conditions.**



Chlorophyll-a

MSEA-N

MSEA-S

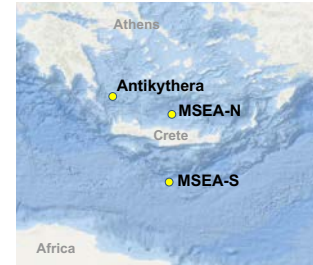
Antikythera

Fully compliant

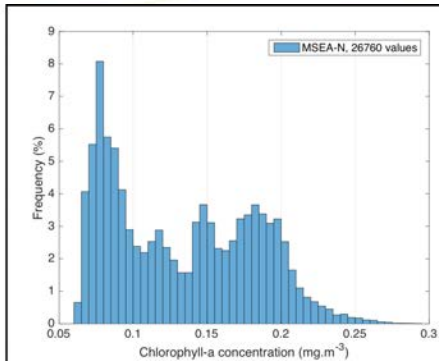
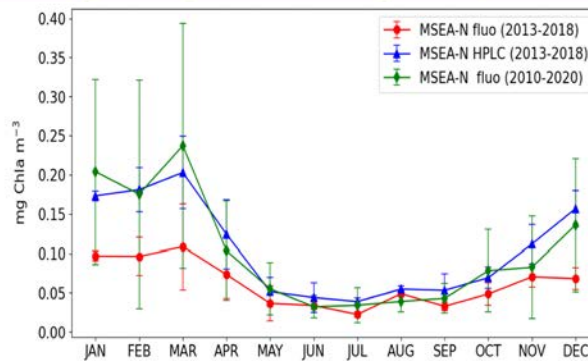
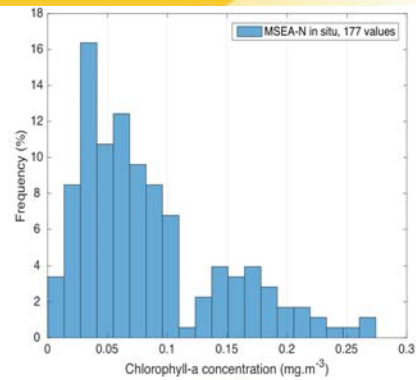
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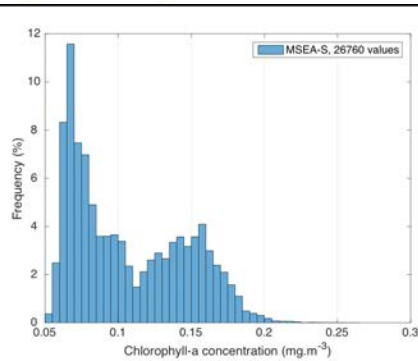
OC-SVC requirement OC-VCAL-RD-31,36,45 (AD-2)



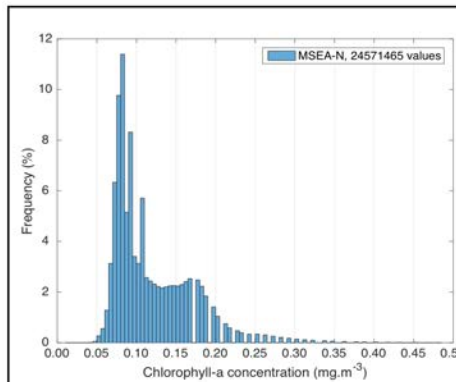
- We are confident that our in situ HPLC measurements are best representing chlorophyll-a values at the MSEA-N site. This is confirmed by the good agreement with fluorometry at lower levels and in full range when a longer time series of fluorometry data is considered.
- MODIS-Aqua, SeaWiFS, OC-CCI, CMEMS & S-3 OLCI all show same low levels and trends in Chl-a climatologies with limited late winter – early spring “productive” period.
- Sentinel 3 OLCI Collection 3 OC4ME showing good “first-look: agreement with in situ Chl-a. More complete validation underway for S3VT



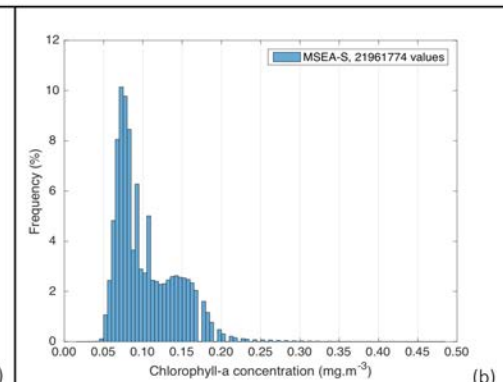
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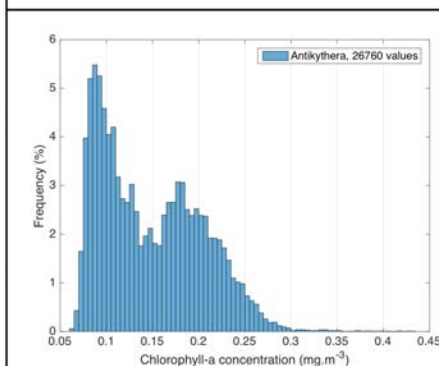
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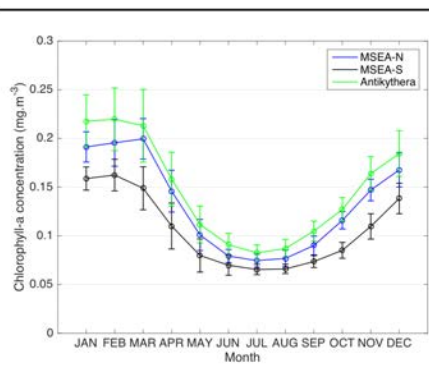
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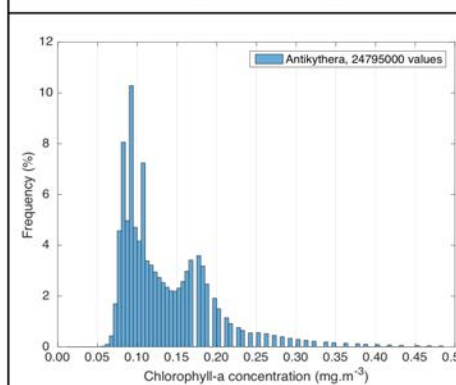
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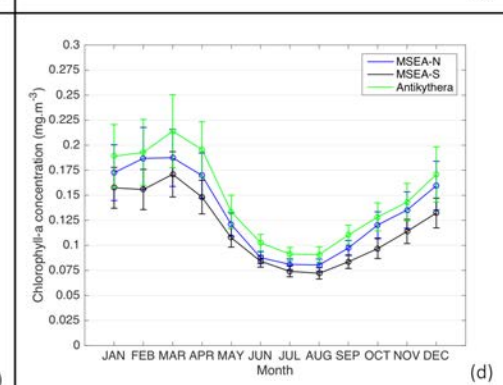
(c)



(d)



(c)



(d)

MODIS-Aqua chlorophyll-a (mg.m^{-3}) climatologies for the 20 x 20 nautical mile area of all 3 sites based on all complete years of climatology (2003-2020)

Sentinel-3 Collection 3 OC4ME chlorophyll-a (mg.m^{-3}) climatologies for the 20 x 20 nautical mile area of all 3 sites based on all years of climatology (2016-2021)

Chlorophyll-a cont.

MSEA-N

MSEA-S

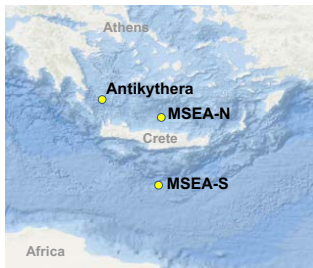
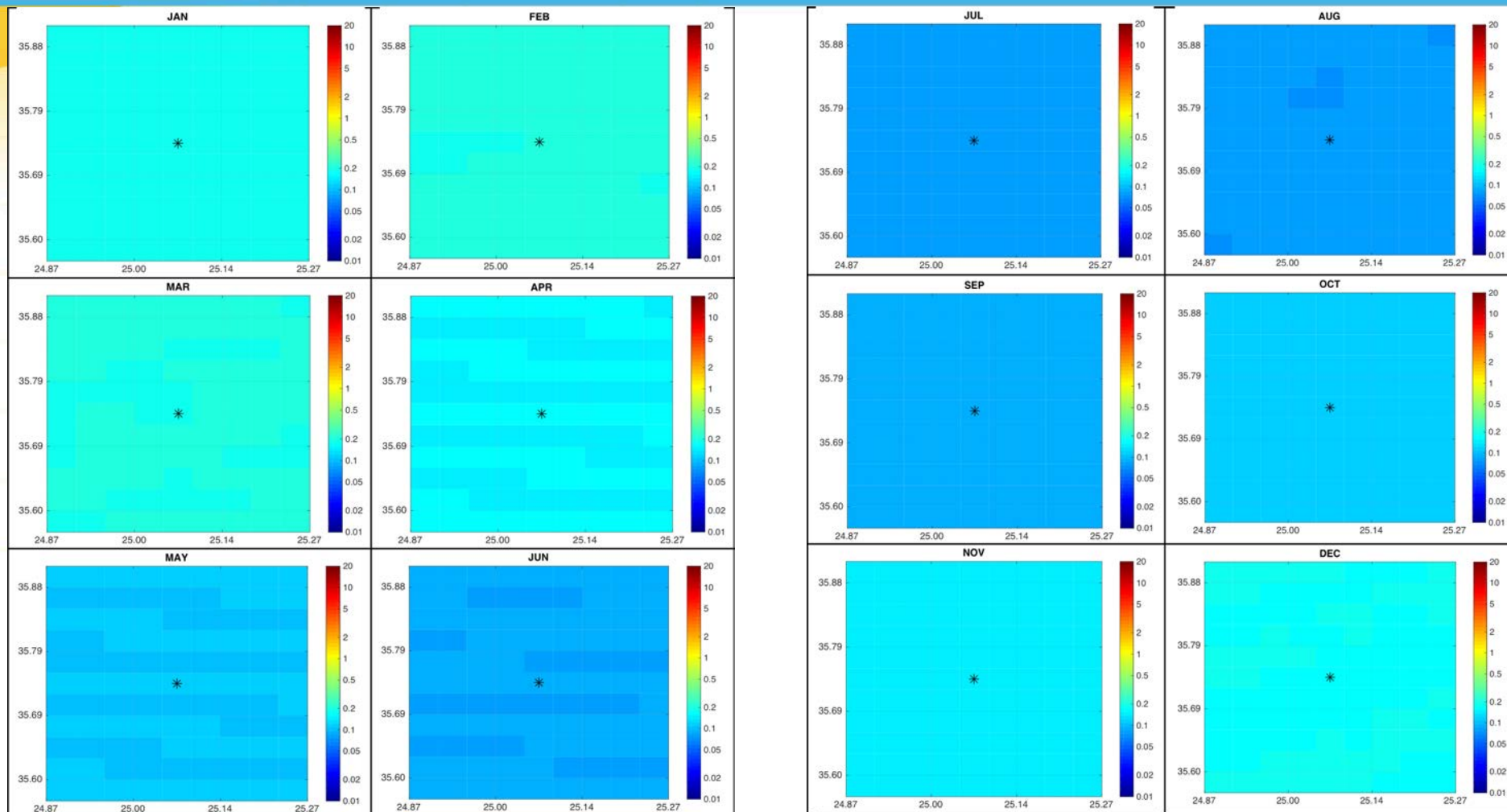
Antikythera

Fully compliant

Fully compliant

Partly compliant

OC-SVC requirement OC-VCAL-RD-31,35,45 (AD-2)



MODIS-Aqua chlorophyll-a ($\text{mg}\cdot\text{m}^{-3}$) monthly average images for the 20 x 20 nautical mile area of the MSEA-N site (marked as *) based on all years of the climatology (2002-2021); Colour scale is the standard log₁₀ chlorophyll-a scale and axes are longitude (E) and latitude (N) in decimal degrees. Shows spatial variation across area surrounding sites minimal.

Remote sensing reflectances

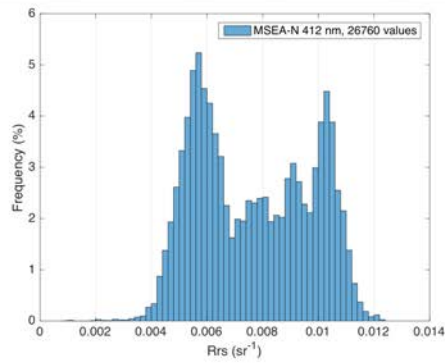
MSEA-N

MSEA-S

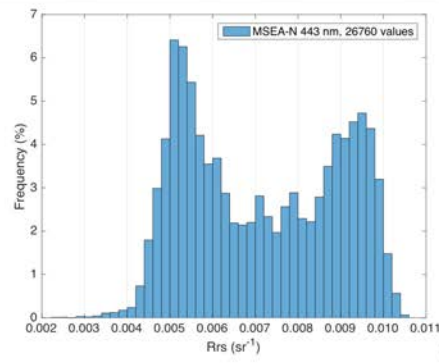
Antikythera

Fully compliant Fully compliant Fully compliant

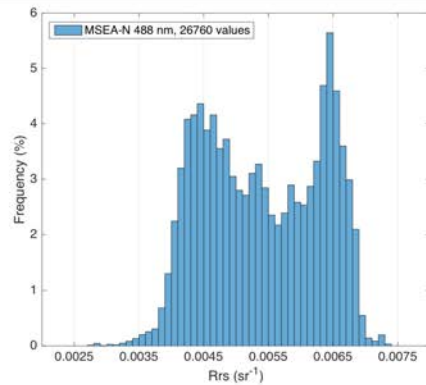
OC-SVC requirement OC-VCAL-RD-10,36 (AD-2)



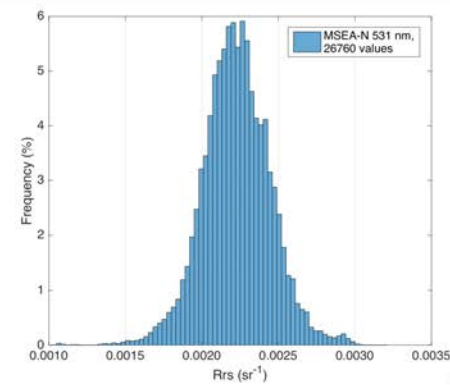
(a)



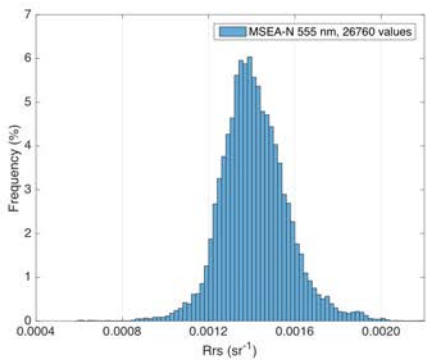
(b)



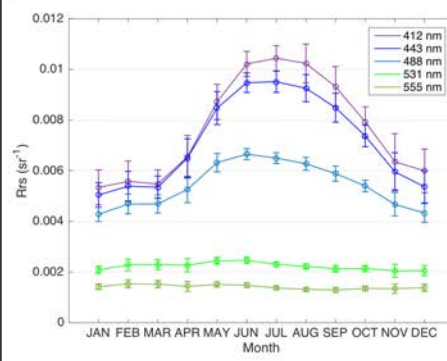
(c)



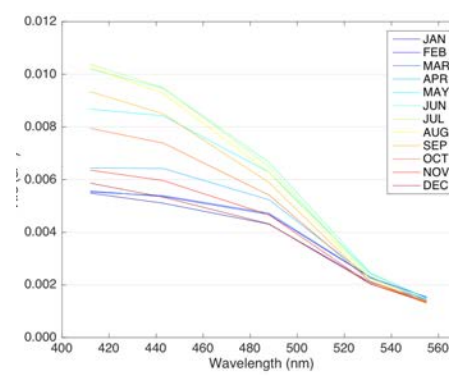
(d)



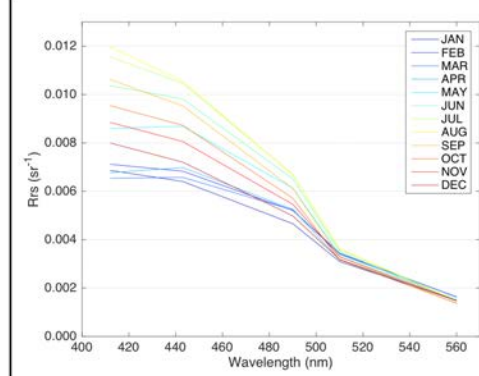
(e)



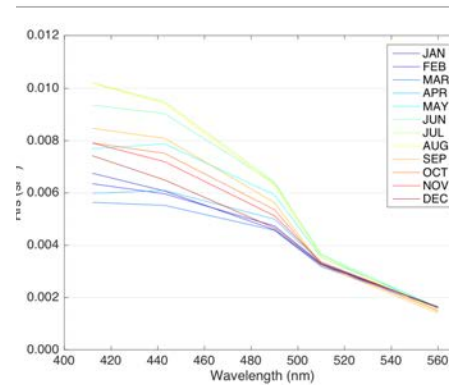
(f)



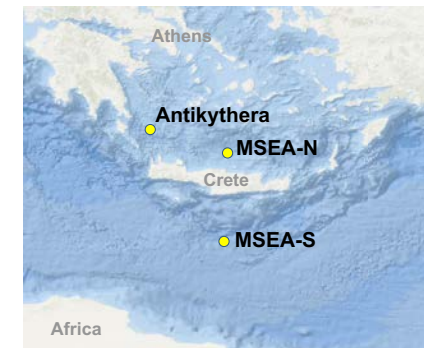
(a)



(b)



(c)



Sentinel-3 OLCI Collection 3 Rrs (sr⁻¹) climatology (2016-2021) spectra for the 20 x 20 nautical mile area of (a) MSEA-N, (b) MSEA-S, (c) Antikythera

- Very stable through time showing same climatologies from multiple sources.
- Distinctive steep spectra, typical of oligotrophic areas - very pronounced in summer months.

MODIS-Aqua Rrs (sr⁻¹) climatologies for the 20 x 20 nautical mile area of MSEA-N based on all complete years of climatology (2003-2020)

Remote sensing reflectances cont.

MSEA-N

MSEA-S

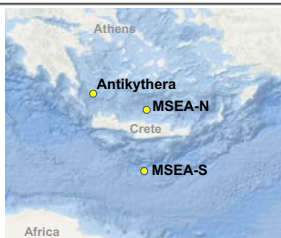
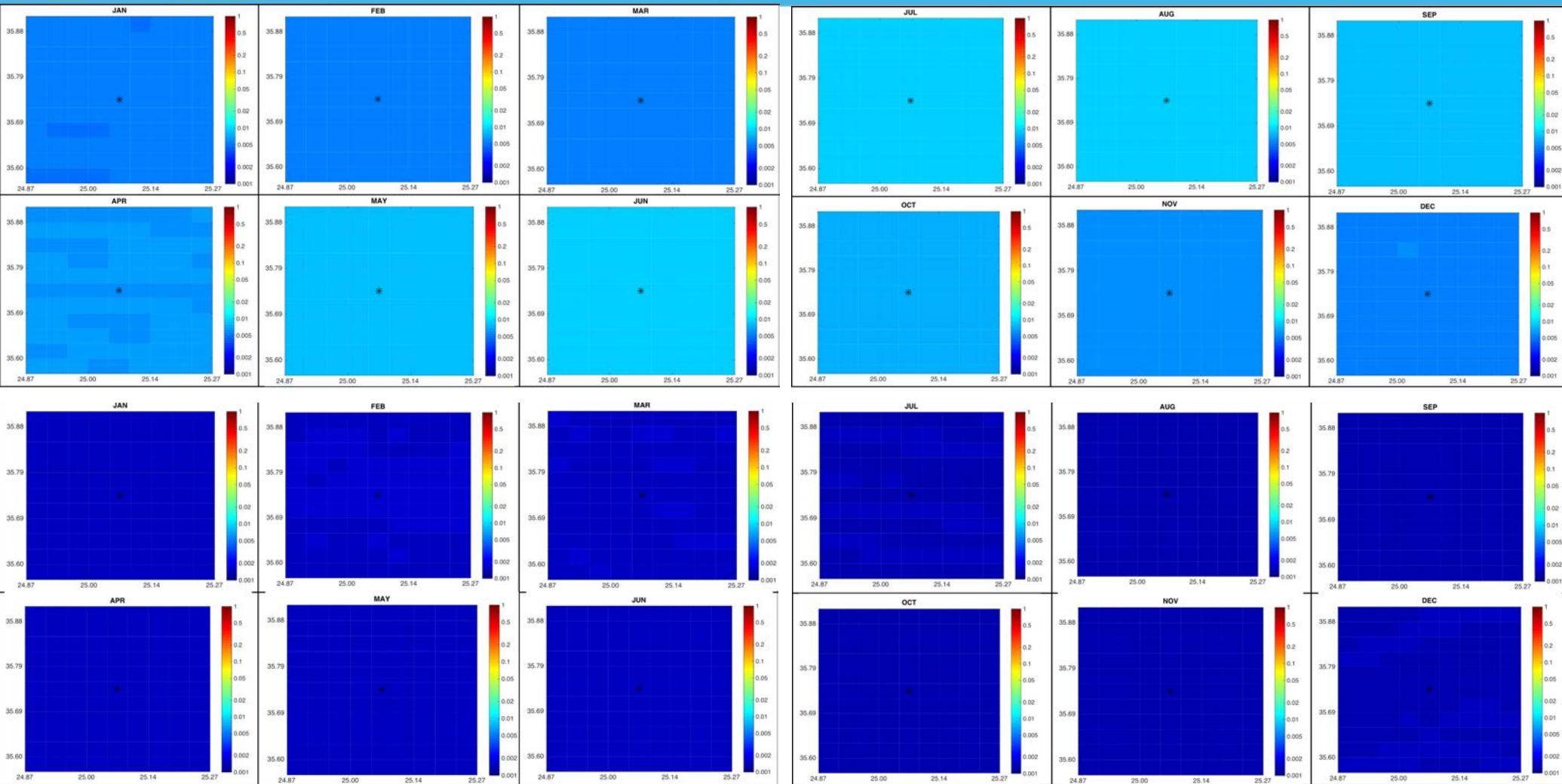
Antikythera

Fully compliant

Fully compliant

Fully compliant

OC-SVC requirement OC-VCAL-RD-10,35 (AD-2)

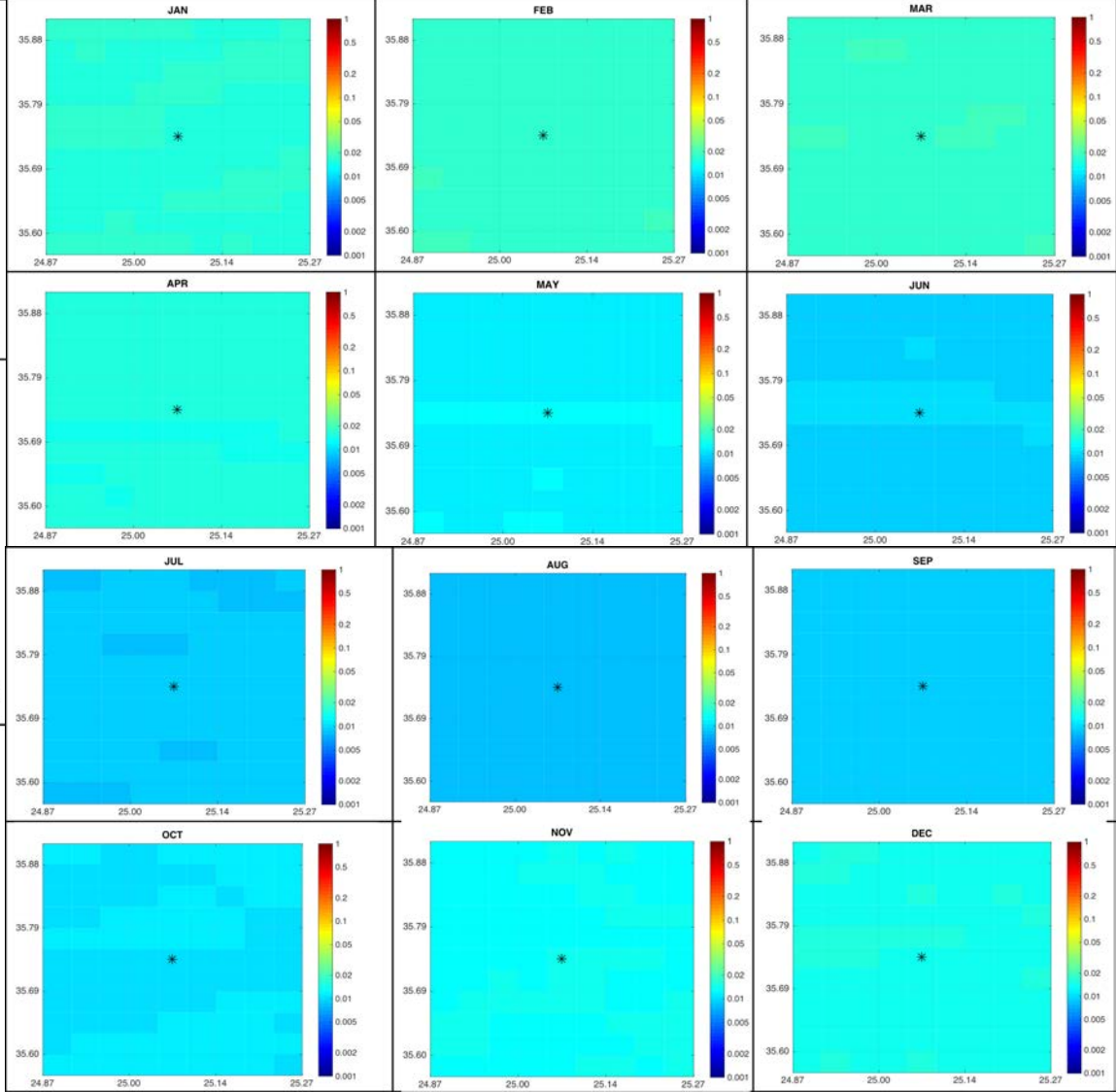
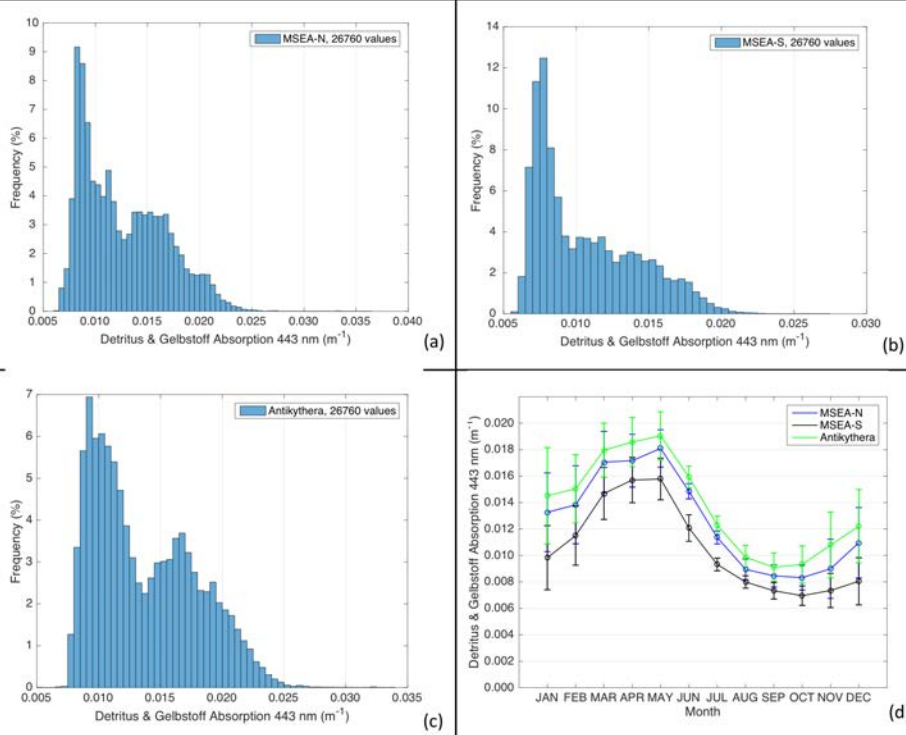


MODIS-Aqua Rrs at 443 & 555 nm (sr⁻¹) monthly average images for the 20 x 20 nautical mile area of the MSEA-N site (marked as *) based on all years of the climatology (2002-2021); Colour scale is the standard log₁₀ Rrs scale and axes are longitude (E) and latitude (N) in decimal degrees. Shows spatial variation across area surrounding sites minimal.



IOPs – coloured dissolved organic matter

MSEA-N	MSEA-S	Antikythera
Fully compliant	Fully compliant	Fully compliant
OC-SVC requirement OC-VCAL-RD-31,32,35,36 (AD-2)		



MODIS-Aqua adg443 (m^{-1}) climatologies for the 20 x 20 nautical mile area of all 3 sites based on all complete years of climatology (2003-2020)

- Low values throughout year associated with oligotrophic environment, “Case-1” water characteristics
- Peak associated with more productive period of year (late winter – early spring)



- Sampled CDOM concentrations from waters around Crete also found to be insignificant, values around 3-5 ppb.
- Spatial variation across area surrounding sites minimal.

MODIS-Aqua adg at 443 nm (m^{-1}) monthly average images for the 20 x 20 nautical mile area of the MSEA-N site (marked as *) based on all years of the climatology (2002-2021); Colour scale is the standard log₁₀ adg scale and axes are longitude (E) and latitude (N) in decimal degrees.

IOPs – particulate backscatter

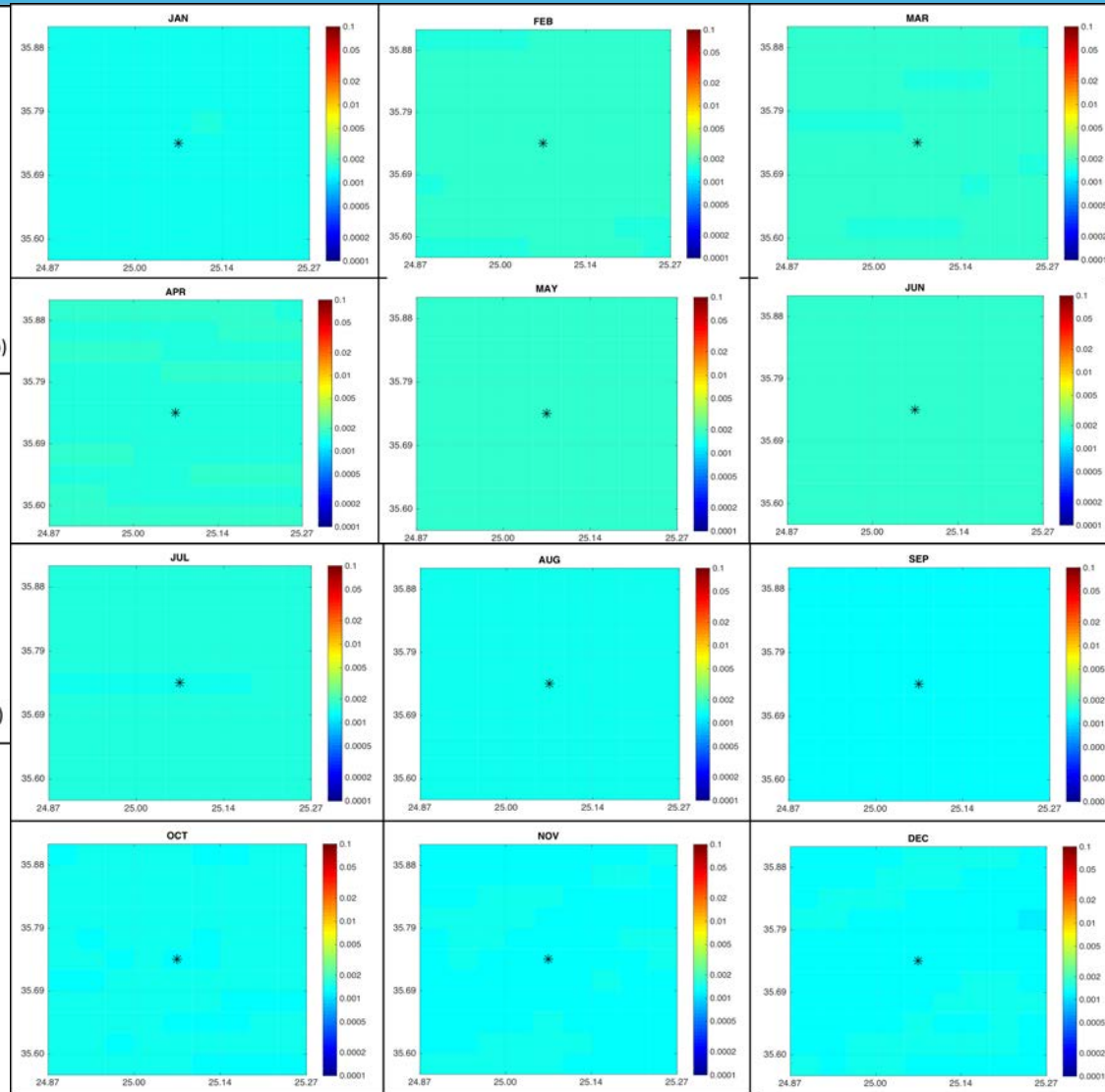
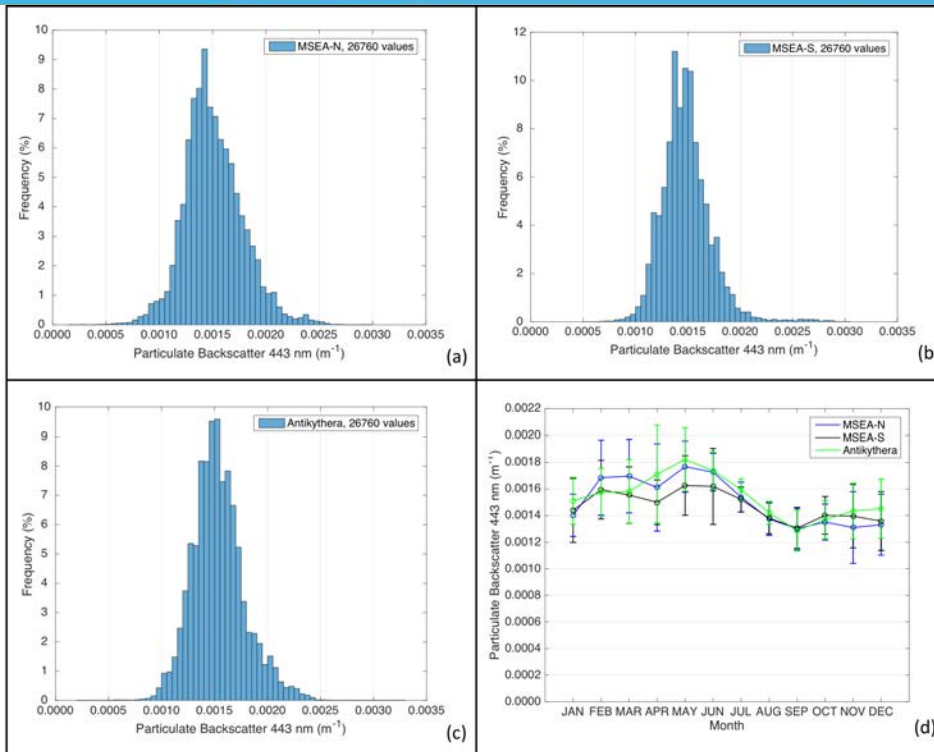
MSEA-N

MSEA-S

Antikythera

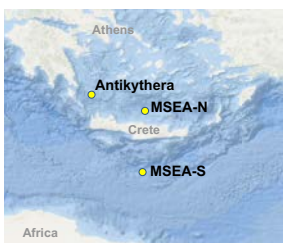
Fully compliant Fully compliant Fully compliant

OC-SVC requirement OC-VCAL-RD-32,35,36 (AD-2)



MODIS-Aqua bbp443 (m^{-1}) climatologies for the 20 x 20 nautical mile area of all 3 sites based on all complete years of climatology (2003-2020)

- Low values throughout year associated with Case-1 waters and open ocean oligotrophic environment
- Very similar across sites, constant across seasons, minimal input from coastal sediments
- Spatial variation across area surrounding sites minimal.



MODIS-Aqua bbp at 443 nm (m^{-1}) monthly average images for the 20 x 20 nautical mile area of the MSEA-N site (marked as *) based on all years of the climatology (2002-2021); Colour scale is the standard log10 particulate backscatter scale and axes are longitude (E) and latitude (N) in decimal degrees.

Currents

MSEA-N

MSEA-S

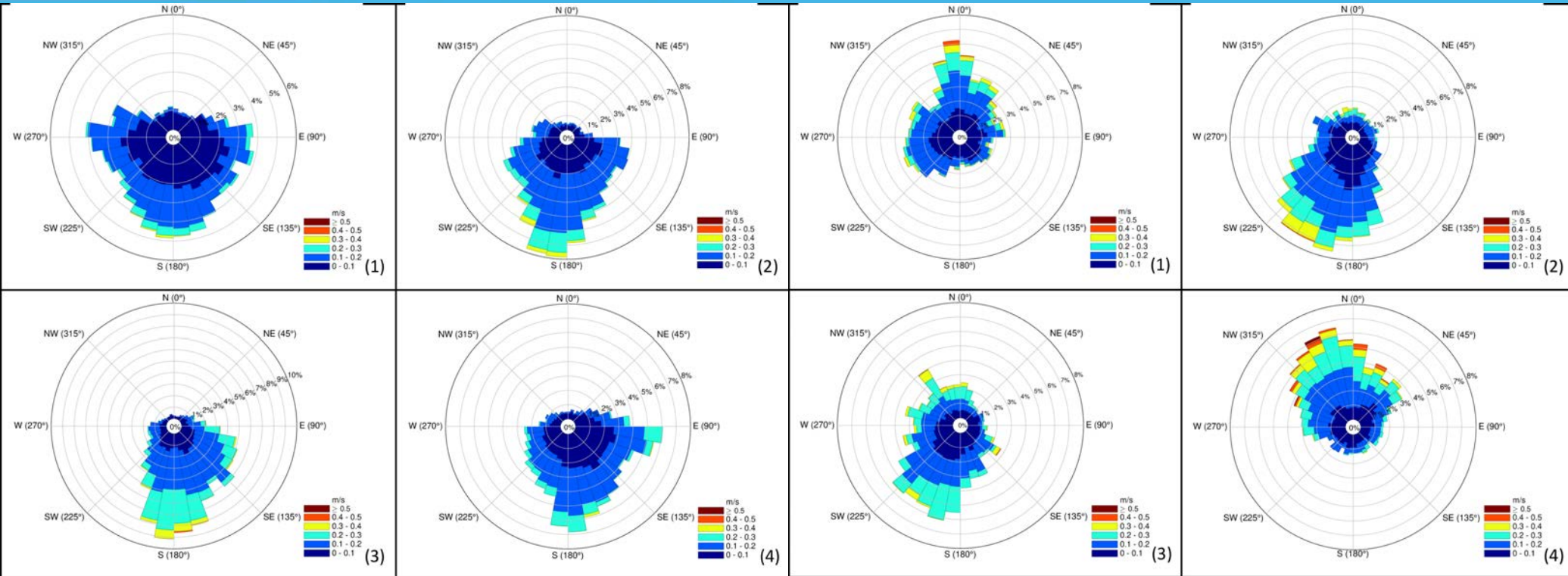
Antikythera

Fully compliant

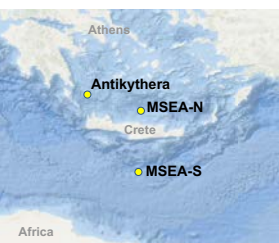
Compliant

Fully compliant

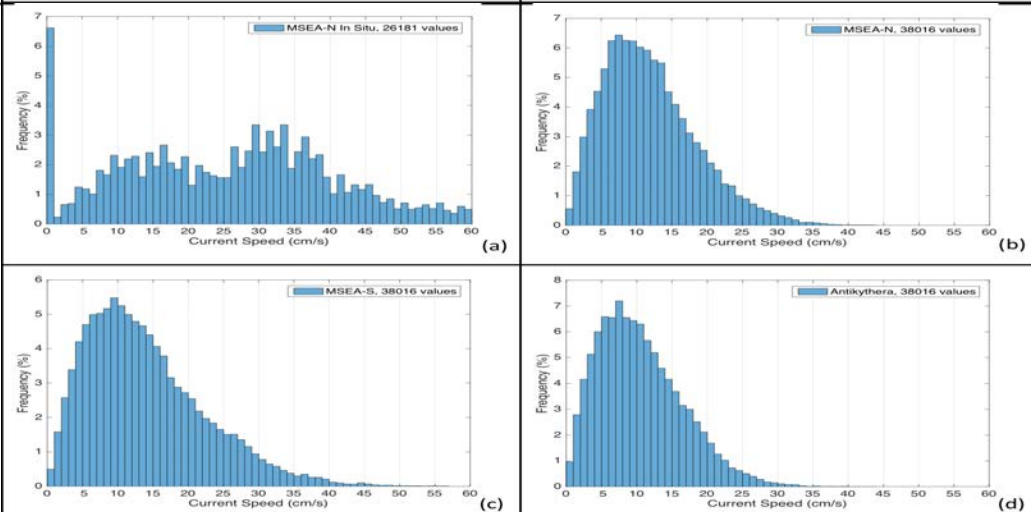
OC-SVC requirement OC-VCAL-RD-27,35,36,37 (AD-2)



CMEMS 1m depth current speed (m/s) and direction (to, degrees) seasonal climatologies for the MSEA-N (left) & MSEA-S (right) sites from 1987-2019: Season (1) is JFD; Season (2) is AMJ; Season (3) is JAS; Season (4) is OND. Histograms from same data (b) MSEA-N, (c) MSEA-S, (d) Antikythera, except (a) MSEA-N in situ ADCP



- Low current speeds at all sites (minimal impact on buoy tilt)
- Similar across sites, with MSEA-S slightly higher (0.4 m/s vs 0.3 m/s)



Waves

MSEA-N

MSEA-S

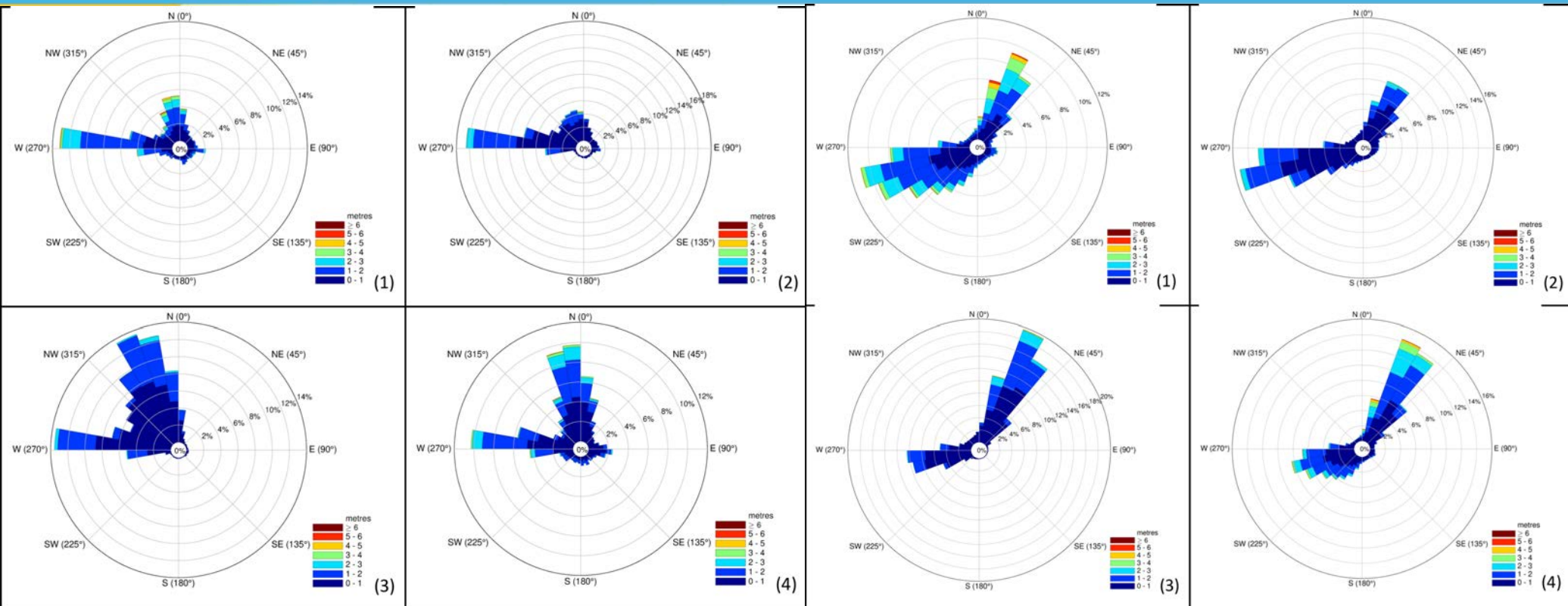
Antikythera

Fully compliant

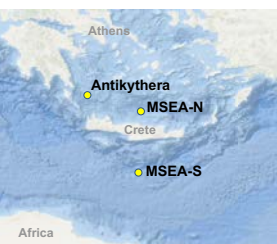
Fully compliant

Compliant

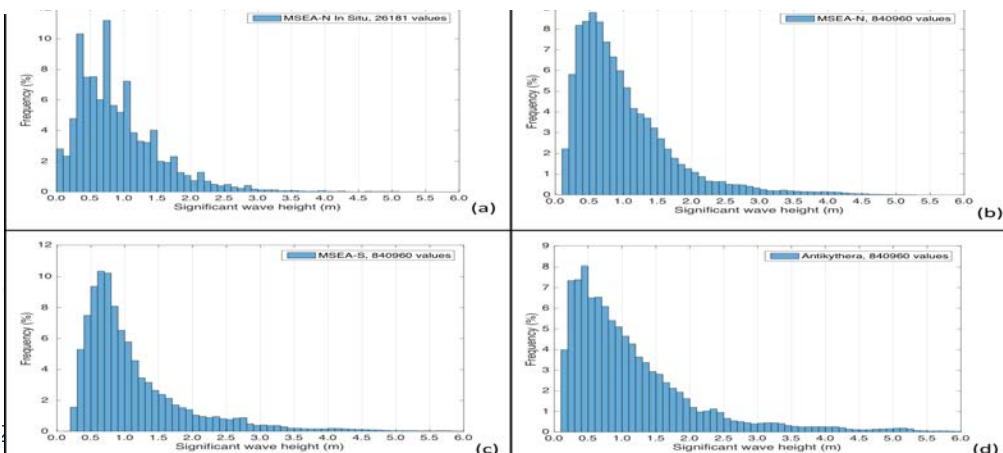
OC-SVC requirement OC-VCAL-RD-27,35,36,40 (AD-2)



CMEMS significant wave height (m) and direction (from, degrees) seasonal climatologies for the MSEA-N (left) & Antikythera (right) sites from 2006-2019: Season (1) is JFD; Season (2) is AMJ; Season (3) is JAS; Season (4) is OND. Histograms from same data (b) MSEA-N, (c) MSEA-S, (d) Antikythera, except (a) MSEA-N in situ.



- Low wave height environment at all sites (median and mean ≤ 1 m)
- Very few large waves > 3 m associated with winter storms
- Similar across sites with Antikythera slightly higher due to fetch from N. longer for wind-driven waves.



SST and SSS

MSEA-N

MSEA-S

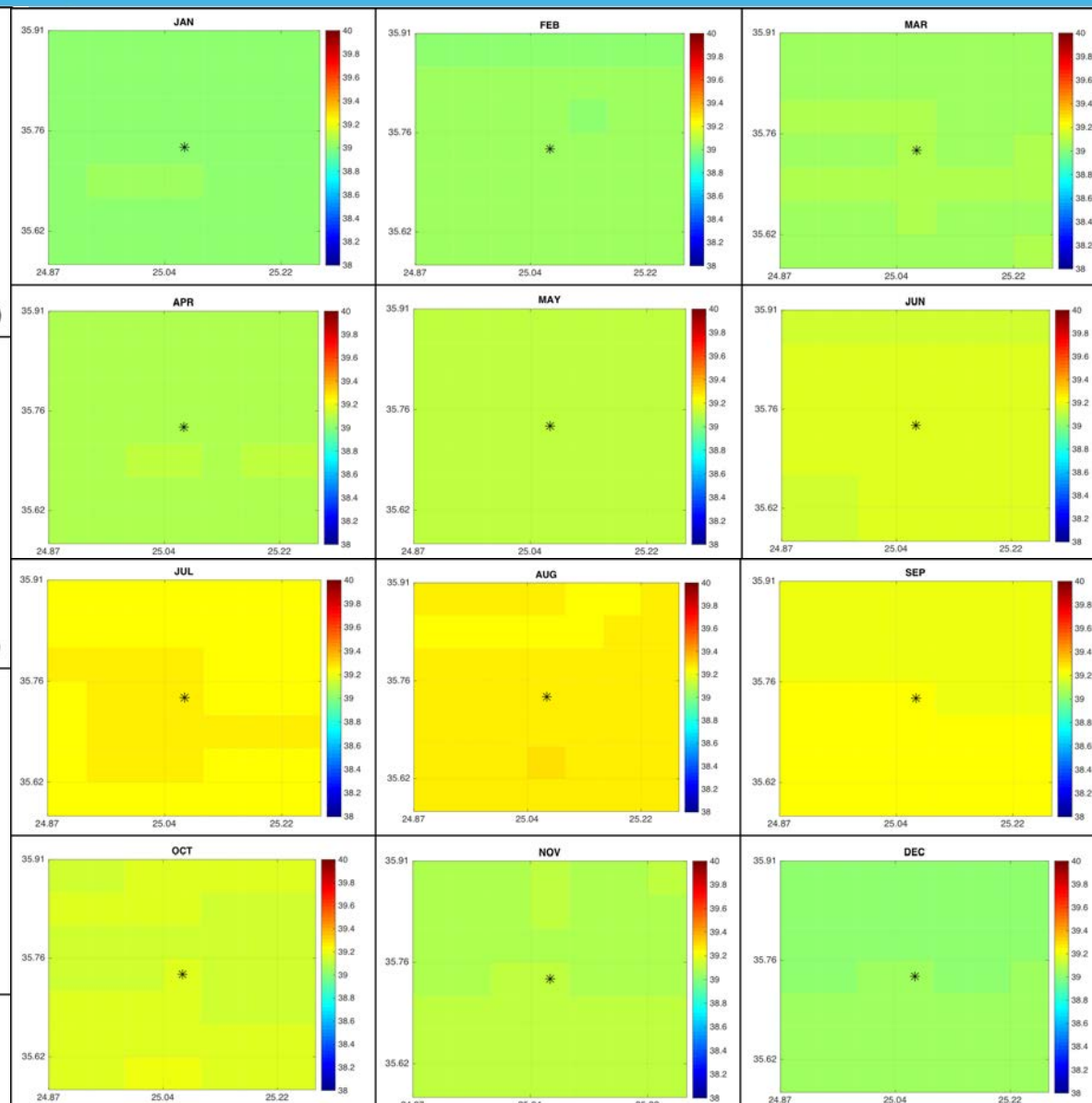
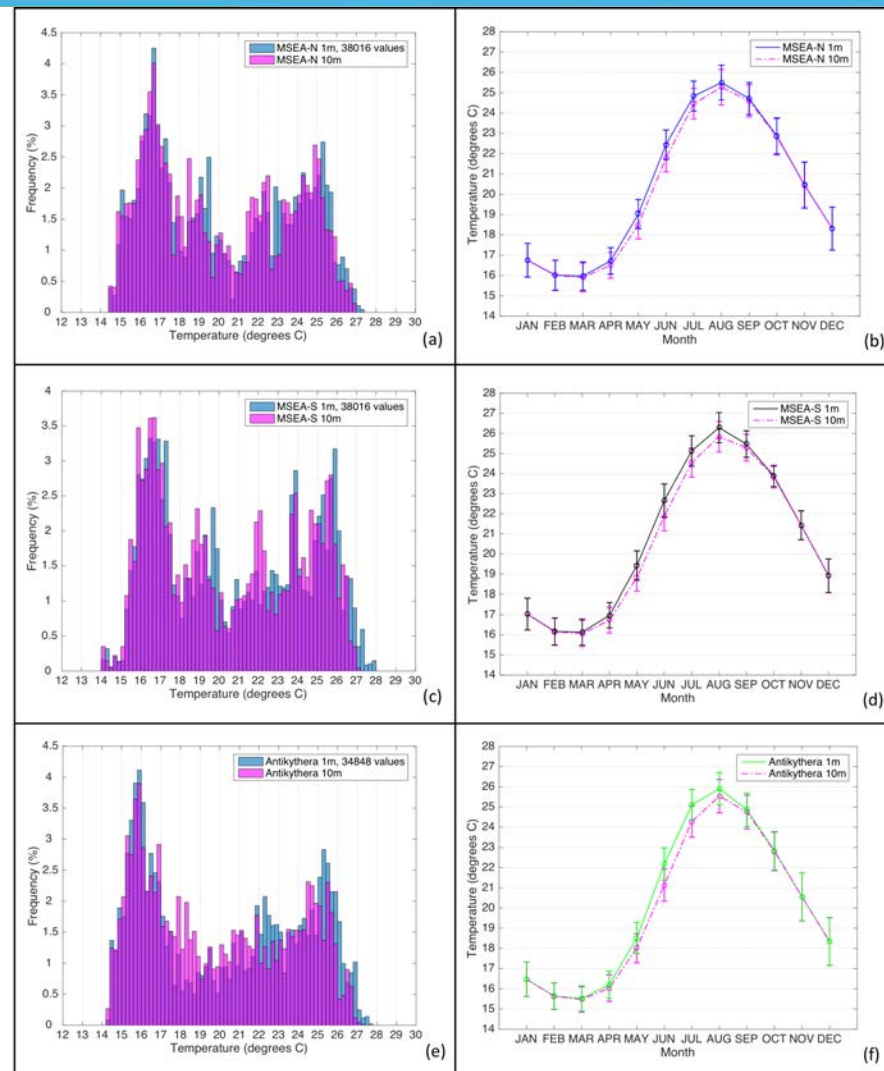
Antikythera

Fully compliant

Fully compliant

Fully compliant

OC-SVC requirement OC-VCAL-RD-20,28,29,35,36 (AD-2)



CMEMS temperature (1m and 10m depth) climatologies for the 20 x 20 nautical mile area of all the Greek sites for all complete years of climatology (1987-2019).

- Minimal variation to 10 m (no shear because of year long MLD) and spatially for both temperature and salinity

CMEMS surface (1m) salinity monthly average images for the 20 x 20 nautical mile area of the MSEA-N site (marked with *) based on all years of the climatology (1987-2019); Colour scale is a linear salinity scale between 38 and 40 PSU and axes are longitude (E) and latitude (N) in decimal degrees.

Shipping, airline and fire

MSEA-N

MSEA-S

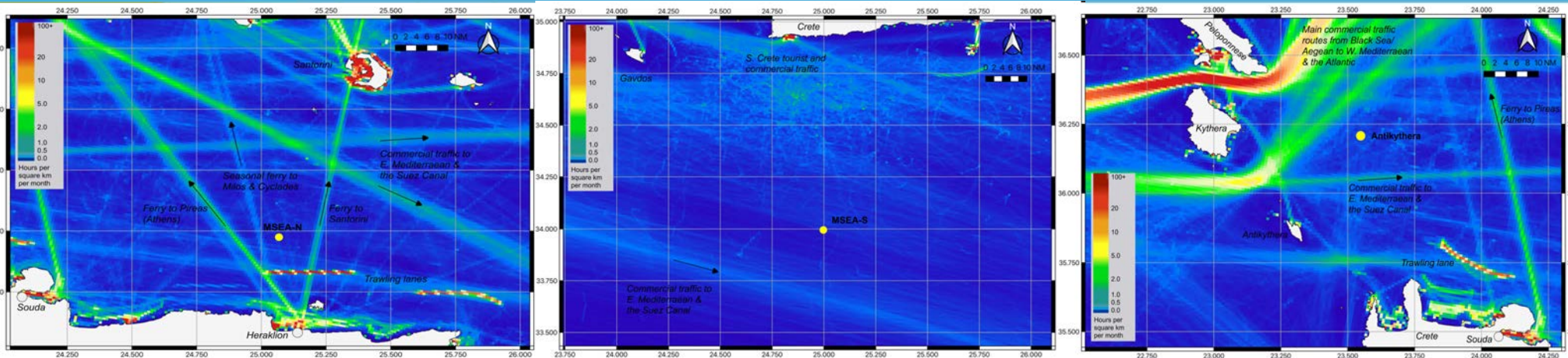
Antikythera

Compliant

Compliant

Partly compliant

OC-SVC requirement OC-VCAL-RD-12,36,37,49 (AD-2)



Map of nearby shipping routes to the MSEA-N, MSEA-S and Antikythera sites (left to right) shown as EMODnet monthly vessel density (hours per square km per month) using the example year of 2019

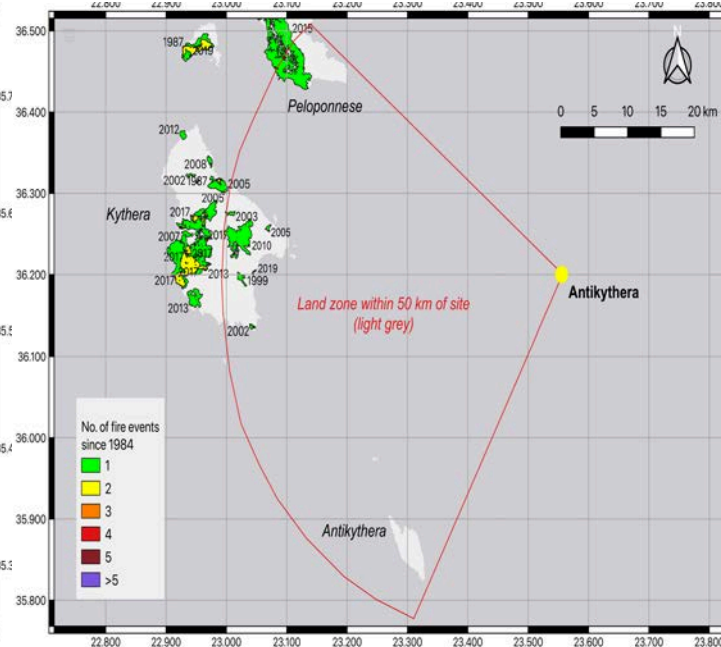
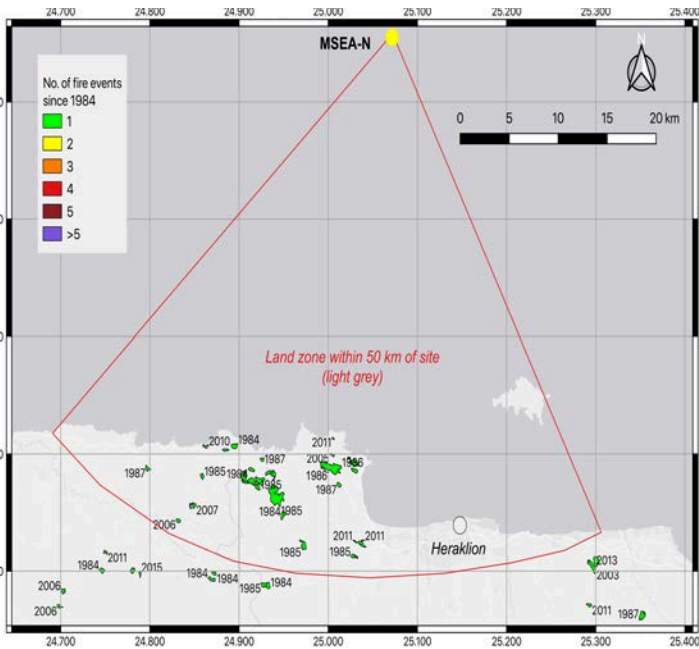


Table OT6. AIR TRAFFIC MONTHLY STATISTICS FOR 2019 (REFERENCE YEAR)

Airport	HERAKLION	CHANIA	KALAMATA	KYThERA
Month				
JAN	1475	464	42	32
FEB	1530	402	50	32
MAR	1864	462	74	38
APR	3989	1106	174	68
MAY	6717	1934	368	82
JUN	8534	2893	558	140
JUL	9516	3136	610	160
AUG	9869	3080	660	148
SEP	8581	2657	584	136
OCT	6774	1767	292	62
NOV	2426	528	74	32
DEC	1820	494	28	36
TOTAL	63095	18923	3514	966

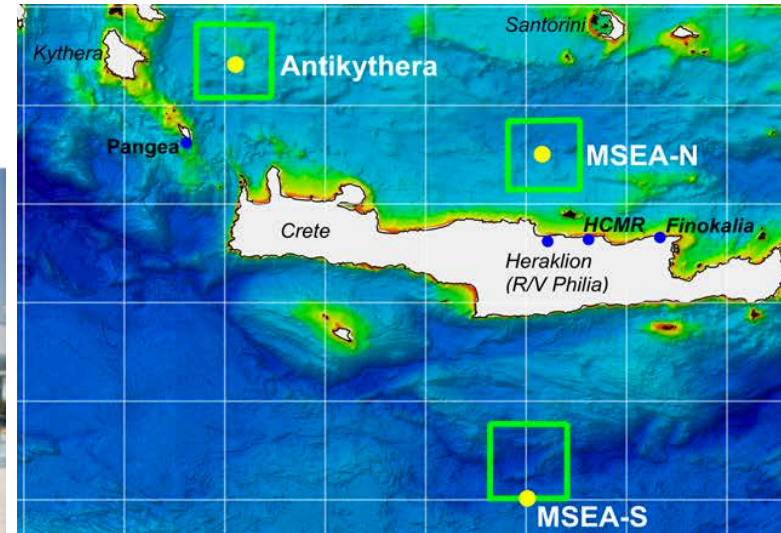
Number of fire events within 50 km of the MSEA-N and Antikythera sites since 1984 from Landsat burn scar mapping data from the National Observatory of Athens.

Site logistics

MSEA-N	MSEA-S	Antikythera
Fully compliant	Partly compliant	Partly compliant
OC-SVC requirement OC-VCAL-RD-25,38,49 (AD-2)		

A) Major marine research centre close to MSEA-N on the coast of Crete (HCMR-Crete)

Copernicus OC-SVC will be supported by the HCMR-Crete “Thalassokosmos” infrastructure, which is on the sea front 15 km east of Heraklion, approximately 27 nautical miles south of the MSEA-N location and has been operational since 2001.



- 25 NM / 2.5 hrs to MSEA-N
- 90 NM / 9-10 hrs to Antikythera
- 220 NM / 24 hrs to MSEA-S
- Heraklion fully equipped port handling small fishing boats to largest cruise and container ships.
- Heraklion home port of HCMR R/V Philia
- HCMR-Crete is a modern 6000 m² marine research complex with high speed internet, calibration, radiometric, & HPLC labs + many other marine labs and facilities already in place.
- In-house professional diving team.
- **Breaking News! Several million Euros of Greek national infrastructure funding acquired to further extend HCMR-Crete large scale marine engineering capabilities = perfect for handling Copernicus OC-SVC buoy!**



B) Research vessel support

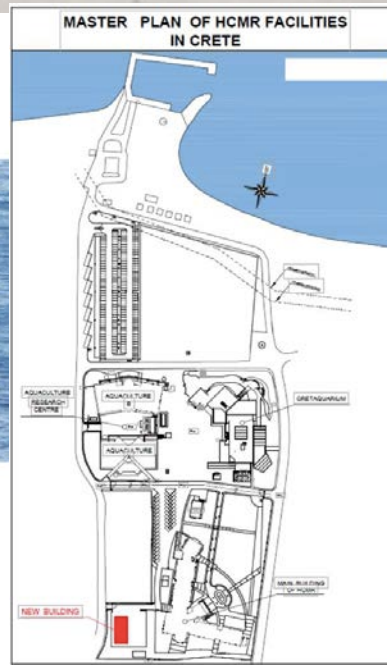
Ships of the national fleet:



AEGAEO (1985/1997)
 Length: 62 m
 Cruise speed: 12 knots
 Max cruise days: 20
 On-board staff: crew 22, scientists 21



PHILIA (1986/2021)
 Length: 31 m (extended from 26 m)
 Cruise speed: 10 knots
 Max cruise days: 21
 On-board staff: crew 7, scientists 10



Site highlights

MSEA-N	MSEA-S	Antikythera
Fully compliant	Fully compliant	Fully compliant
OC-SVC requirement OC-VCAL-RD-11,47 (AD-2)		

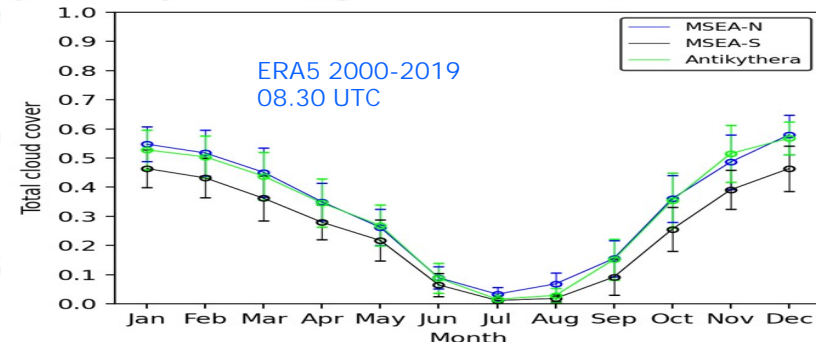
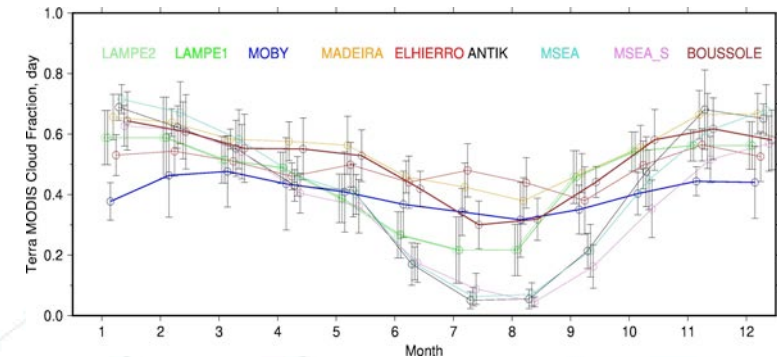
• For all 3 Crete sites:

✧ Most important consideration for an OC-SVC site is to maximize the no. of high quality / low uncertainty matchups with the satellite sensor

- ✧ **Clear sky conditions above the waters around Crete are the highest in Greece & among highest in frequency in Europe**
- ✧ Calm stable (temporally and spatially) oligotrophic oceanographic conditions also ideal for OC-SVC buoy deployment and operations
- ✧ GOOS biogeochemical oceanographic buoy / integrated observatory fully operational at MSEA-N for > 20 years
- ✧ Large marine research infrastructure with all necessary facilities and expertise to support the Copernicus OC-SVC buoy including large R/Vs available closeby for installation and maintenance + new large engineering infrastructure.
- ✧ Network of supporting atmospheric observatories (in situ and remote sensing)

		N Overpass	SZA	Glint	Cloud	AOT	Chla		All Criteria	
							GLO	Med	GLO	Med
BOUSSOLE	N matchup	149	134	123	80	59	45	74	12	20
	% reduction		10.1%	17.4%	46.3%	60.4%	69.8%	50.3%	91.9%	86.6%
MSEA	N matchup	144	144	103	95	57	88	95	32	32
	% reduction		0.0%	28.5%	34.0%	60.4%	38.9%	34.0%	77.7%	77.7%
MOBY	N matchup	111	111	81	66	58	74		31	
	% reduction		0.0%	27.0%	40.5%	47.7%	33.3%		72.1%	

Table 5-2 Impact of each selection criterion when taken individually, and when all combined together (last column) with the threshold values indicated in the text. The percent reductions are calculated from the number of matchups after excluding the glint risk (so N=135 for BOUSSOLE, 129 for MSEA and 99 for MOBY). Red highlighting indicates critical criteria for each site, and green highlighting indicates the less sensitive parameters. GLO corresponds to the OC4ME algorithm and Med to the MedOC4ME algorithm.





Thank you!

