

Copernicus Satellite Ocean Colour System Vicarious Calibration in Crete



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Prof. Nikos Mihalopoulos (National Observatory of Athens, UoC & coordinator of PANACEA)

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PANhellenic infrastructure for
Atmospheric Composition and
climatE chAnge



European Marine Board Meeting, Rhodes Aquarium, Rhodes, 02 October 2024

Source: NOAA (MOBY,
Clark and Brown, 2004)



Copernicus OC-SVC in Crete

PRESENTATION SUMMARY

A. What is OC-SVC and why in Crete?

B. Existing OC-SVC expertise and facilities at the Crete site

- i. Atmospheric monitoring (UoC & PANACEA)
- ii. HCMR large oceanographic infrastructure expertise
- iii. HCMR Research vessels
- iv. HCMR-Crete research buildings
- v. HCMR ocean colour and marine optics expertise
- vi. NASA HyperNAV OC-SVC ongoing deployments

D. Crete site development plans

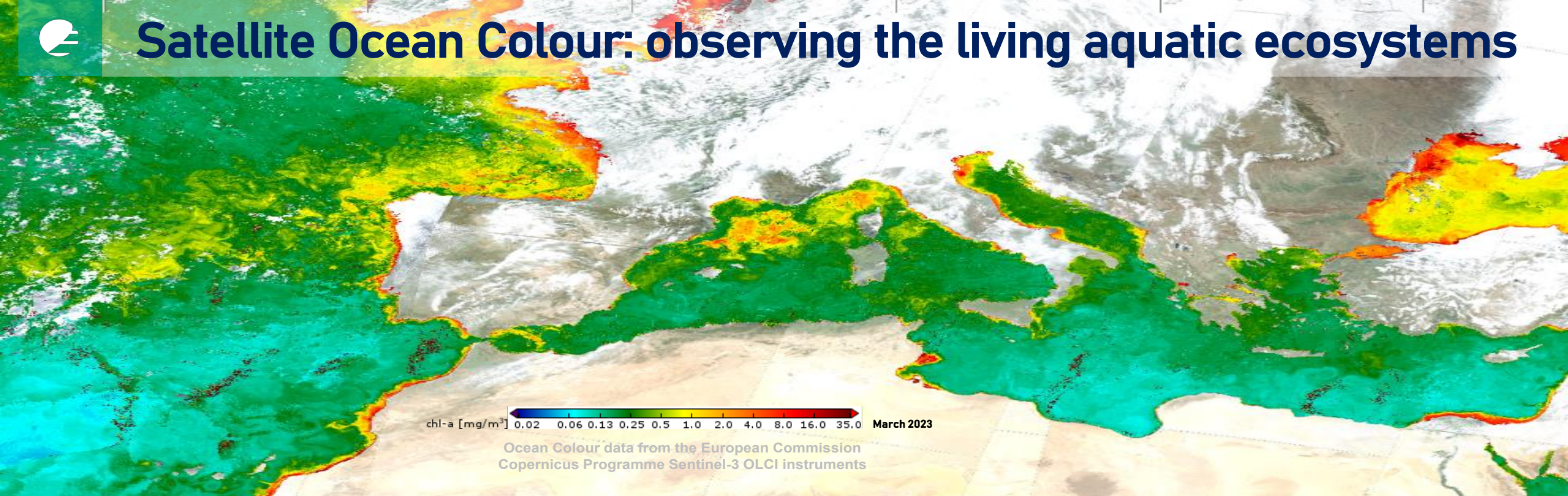
- i. New HCMR-Crete new buildings for OC-SVC
- ii. Buoy and radiometry
- iii. Calibration system (collaboration with NMI)
- iv. Operations and site safety & data transfer
- v. HCMR South Crete field station
- vi. Atmospheric monitoring developments
- vii. From design to operations – the bigger picture

ROADMAP

Phase	Status
<u>Requirements</u>	Completed
<u>Preliminary Design, Project Plan and Costing</u>	Completed
<u>Infrastructure Location</u>	Completed
Engineering Design, Technical Definition, Specifications	Proposed
Development, Testing and Demonstration in the Field	Proposed
Operations	Proposed



Satellite Ocean Colour: observing the living aquatic ecosystems



Water Quality

Drinking and bathing water quality
 Harmful Algal Blooms
 Tourism and coastal communities
 Eutrophication
 Ecosystem status and services
 Legislation, e.g. EU Water Framework Directive²³

Marine resources

Fisheries
 Aquaculture
 Biodiversity, ecosystem modelling
 Coastal management / ports
 Coastal sedimentation / erosion
 Legislation, e.g. EU Marine Strategy Framework Directive

Carbon/Climate

Aquatic phytoplankton are the Biological Carbon Pump
 Important Carbon sink
 Absorption of 20 – 30% of anthropogenic CO₂ emissions
 About 50% of Earth's primary production

EUM/RSP/REP/23



European Marine Board Meeting, Rhodes Aquarium | 02.10.2024

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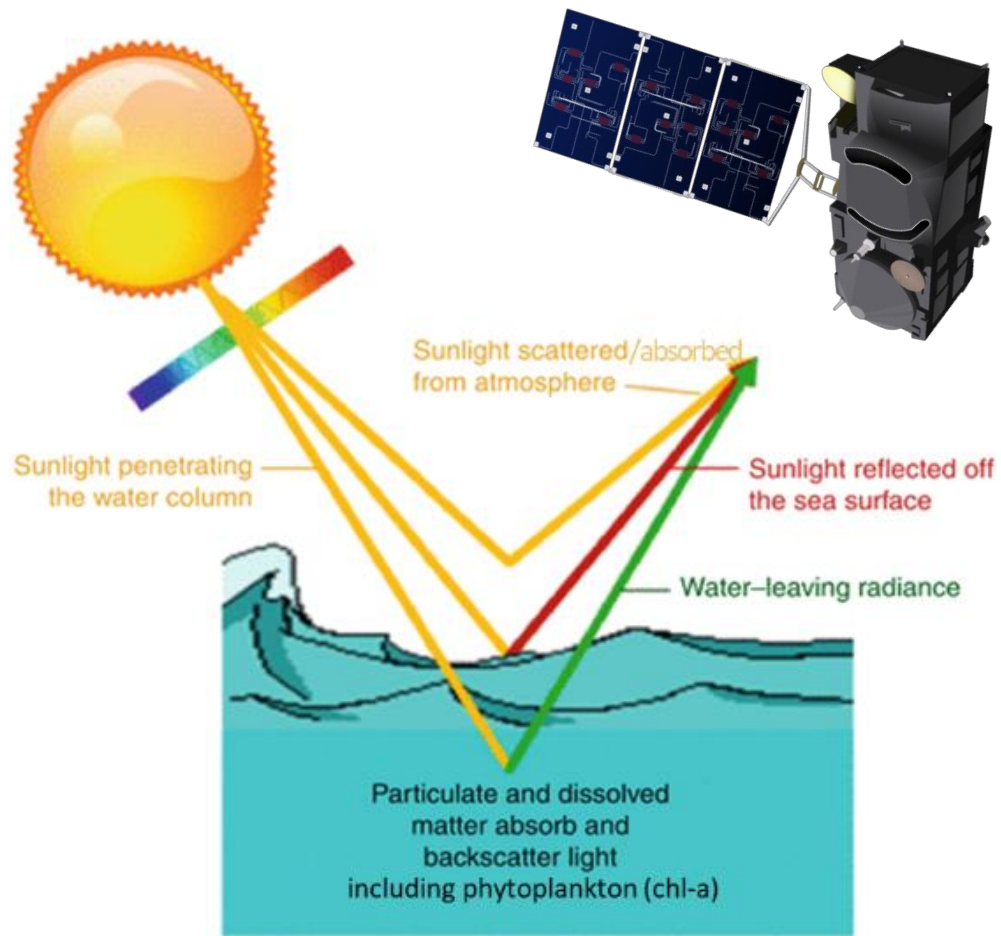




Ocean Colour measurement process

Multi (or hyper)-spectral satellite measurement in the Visible range of the electromagnetic spectrum

Water appears dark from space

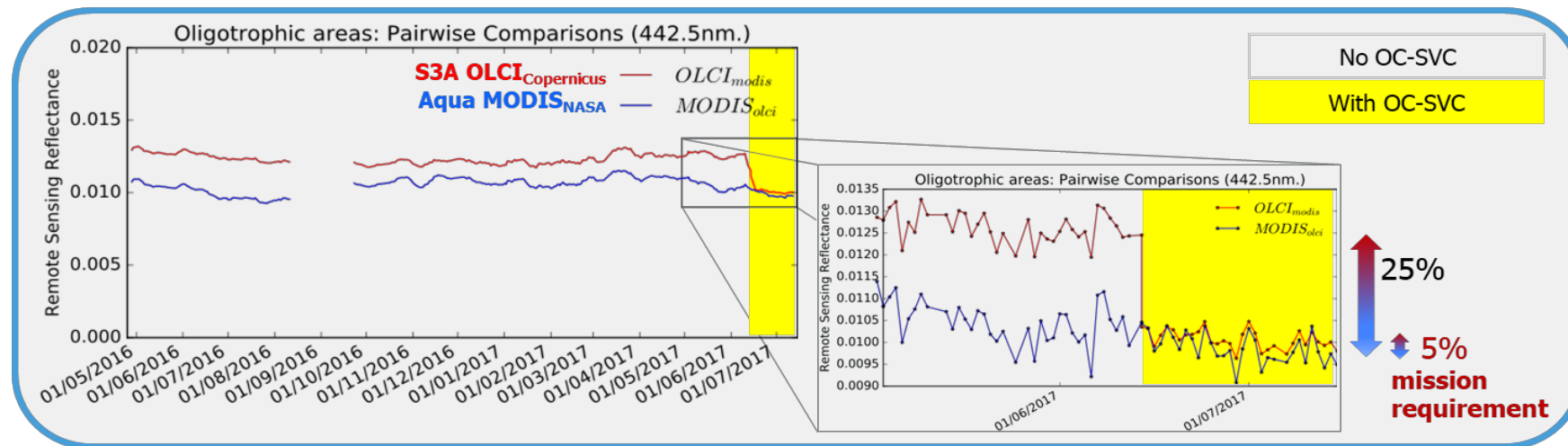


- **Water-leaving radiance** is a small fraction of the total radiance measured by the satellite
- Satellite instrument calibration uncertainties are magnified **~10-fold** for **water-leaving radiances**

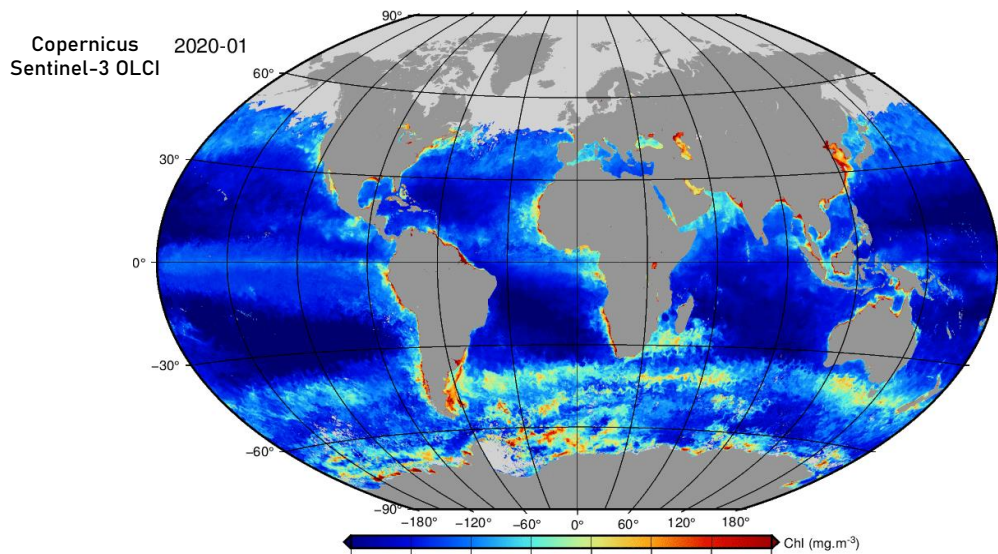
Additional calibration is required



System Vicarious Calibration is a requirement for all Ocean Colour missions



One year of monthly Chlorophyll-a Concentrations



- OC-SVC is the only way to meet the Ocean Colour uncertainty requirements
- Currently relying on NOAA's Marine Optical Buoy (MOBY) for OC-SVC of Copernicus Sentinel-3A and Sentinel-3B OLCI. Thank you NOAA!

The quality of Copernicus Ocean Colour Space Observations cannot be ensured without an OC-SVC infrastructure

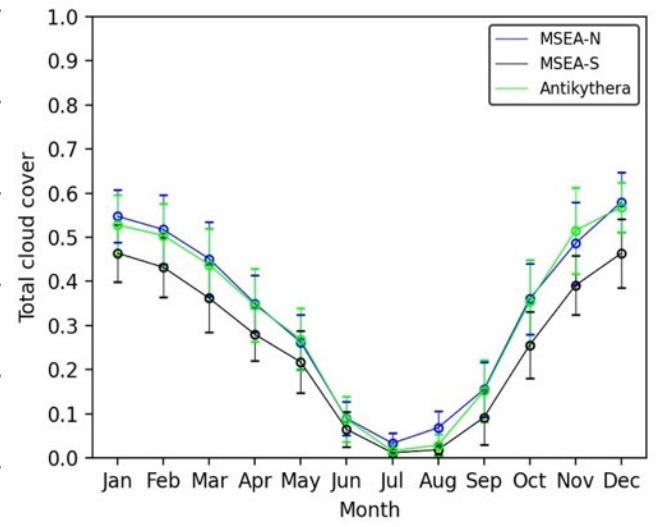
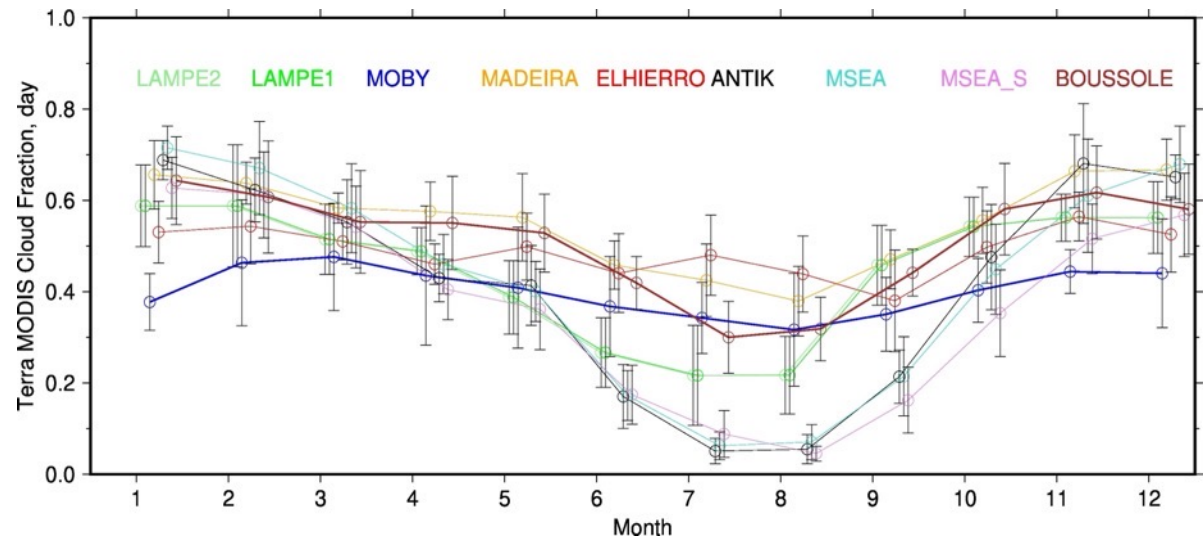
Why Copernicus OC-SVC in Crete?

- ✦ Identified from global survey for OC-SVC (Zibordi et al., Remote Sensing of Environment, 2017) as one of the 3 best potential sites worldwide with MOBY & EIO.
- ✦ Most important consideration for an OC-SVC site is to maximize the no. of high quality / low uncertainty matchups with the satellite sensor

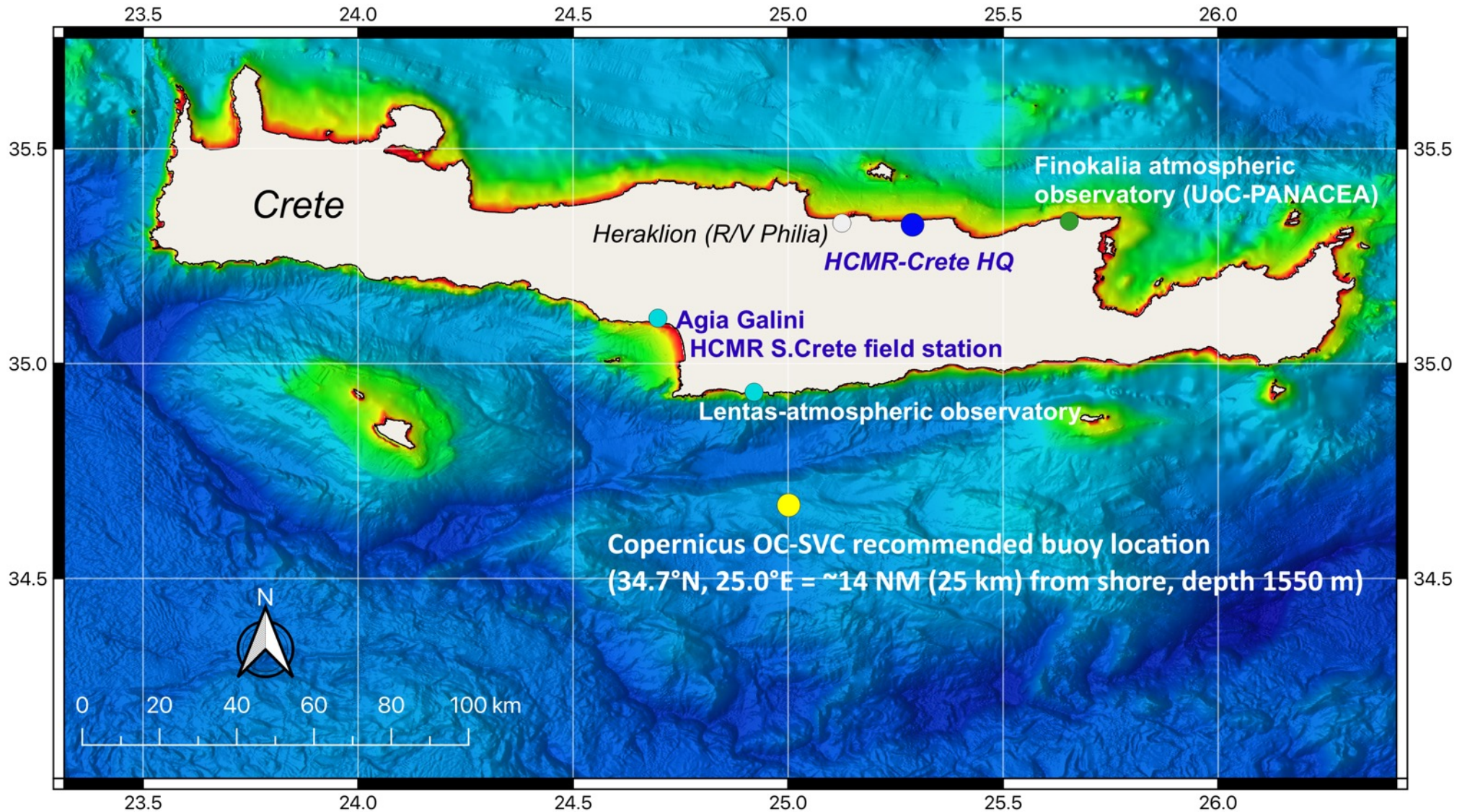
		N Overpass	SZA	Glint	Cloud	AOT	Chla		All Criteria	
							GLO	Med	GLO	Med
BOUSSOLE	N matchup	149	134	123	80	59	45	74	12	20
	% reduction		10.1%	17.4%	46.3%	60.4%	69.8%	50.3%	91.9%	86.6%
MSEA	N matchup	144	144	103	95	57	88	95	32	32
	% reduction		0.0%	28.5%	34.0%	60.4%	38.9%	34.0%	77.7%	77.7%
MOBY	N matchup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

Fractional cloud cover:



Crete site location



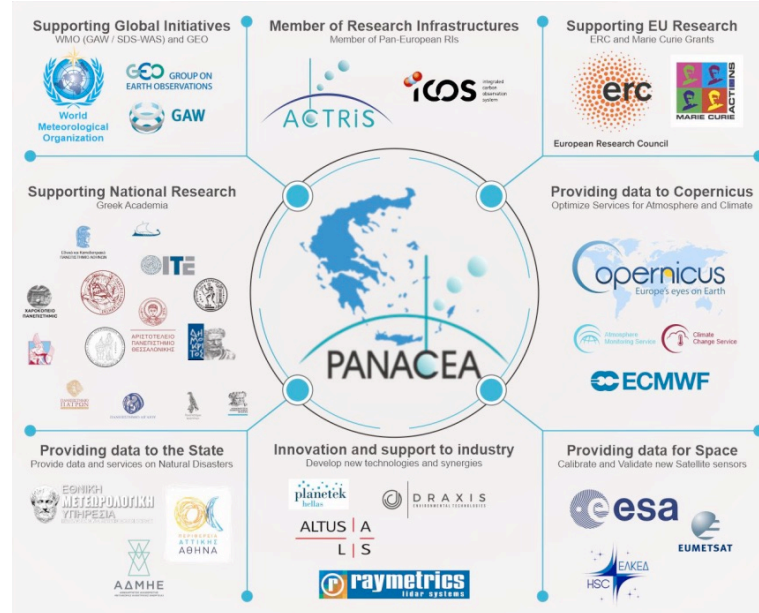
ROADMAP	
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Atmospheric monitoring sites

PANhellenic Infrastructure for the study of Atmospheric composition and climate Change (<https://panacea-ri.gr>)

Distributed Research Infrastructure (unique in SE Europe)

- In-situ observations (Finokalia, Athens, Helmos, PANGEA)
- Remote sensing - Lidar, DOAS (Thessaloniki, Athens, PANGEA, mobile)
- Reaction chamber (Patras)
- Mobile laboratories (Athens, Patras)
- Numerical modelling



FINOKALIA

Meteorological parameters

Gas species: O₃, CO, NOx, VOCs, GHGs,

Aerosols: Continuous aerosol light extinction (absorption, scattering), aerosol size distribution, PM₁₀, PM_{2.5}. Ions, metals, water soluble organics and nutrients in rainwater & dry deposition.

Remote sensing: sunphotometer (AERONET site)

PANGEA

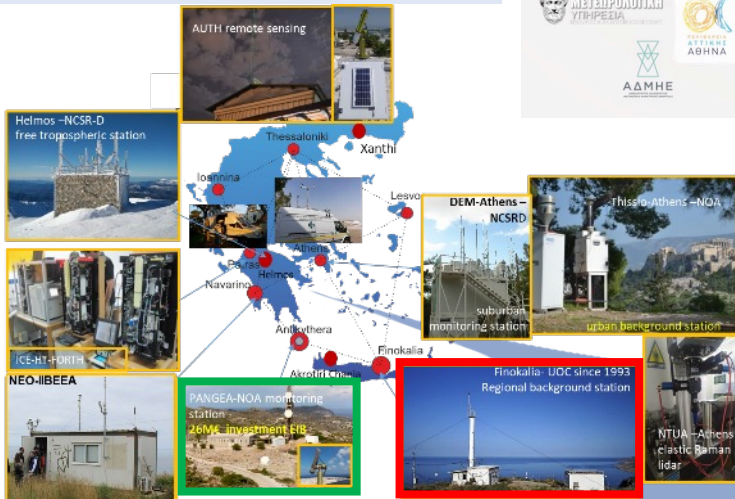
Remote sensing: Raman lidar, sunphotometer (AERONET site), polarimeter, atmospheric electricity

PANACEA

Remote sensing: Raman lidar (mobile), Pandora Spectrometer, Ceilometer, sunphotometer

PANACEA ecosystem

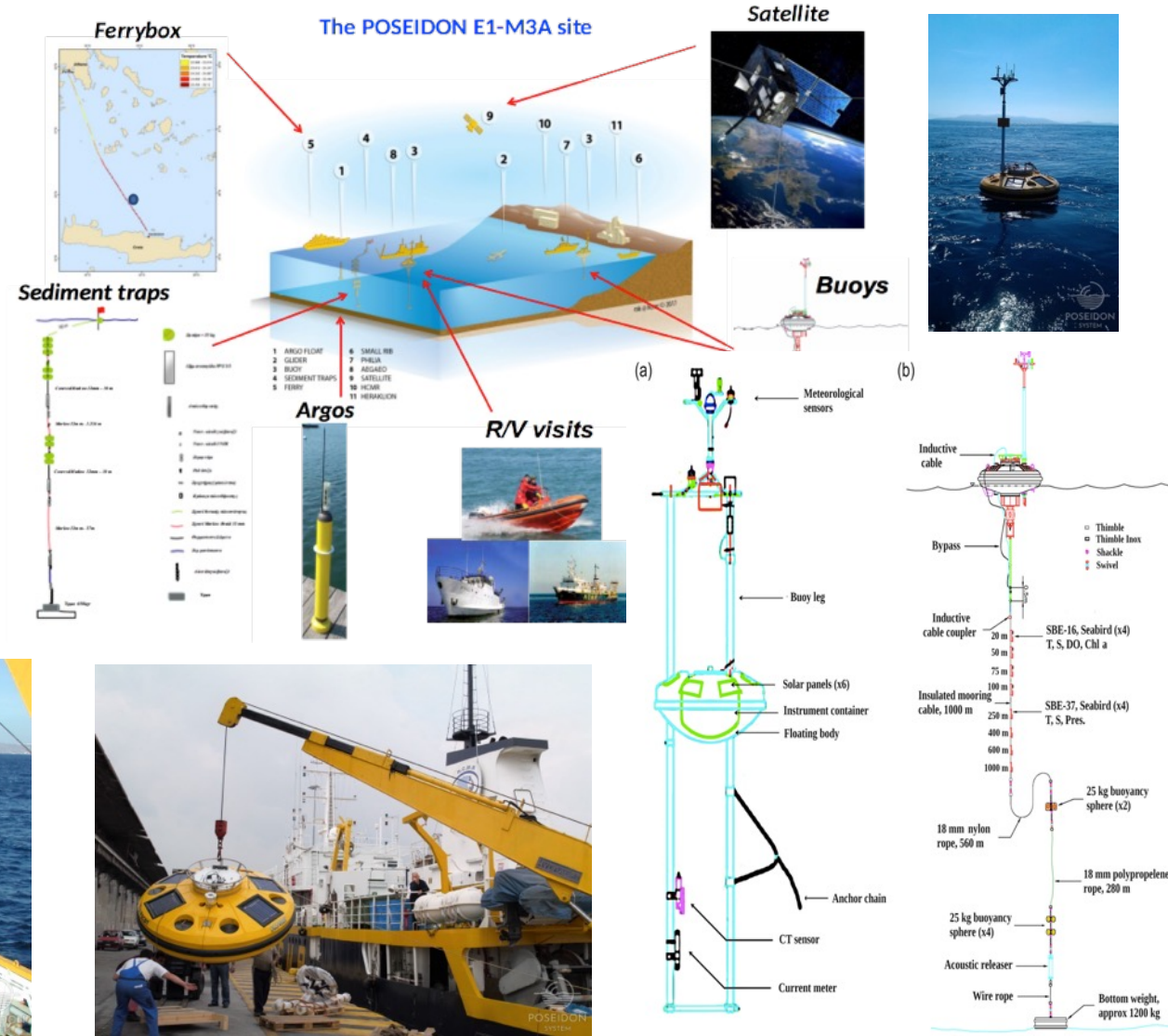
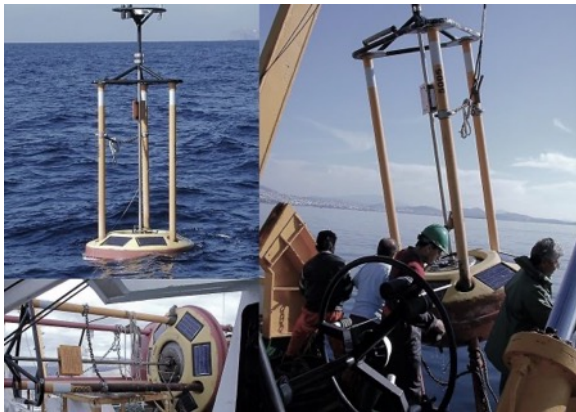
- 14 partners
- Supporting global initiatives
- Member of RIs
- EU and national research support
- Providing data to Copernicus
- Cal/Val activities
- Support entrepreneurship
- Providing data to the state



Existing infrastructure and expertise for OC-SVC operations on Crete

HCMR large oceanographic infrastructure expertise POSEIDON (<https://poseidon.hcmr.gr>)

- Installing and maintaining operational very large in situ oceanographic / biogeochemical infrastructure in the Greek Seas for > 20 years (large team of 25 people)
- Integrated observatories (inc. moored buoys, ferryBox, gliders, Argos, regular R/V sampling, calibration lab)
- Data released through and part of Copernicus (CMEMS) in situ and modelling component (inc. single provider of wave forecasting for the Mediterranean)



Existing infrastructure and expertise for OC-SVC operations on Crete

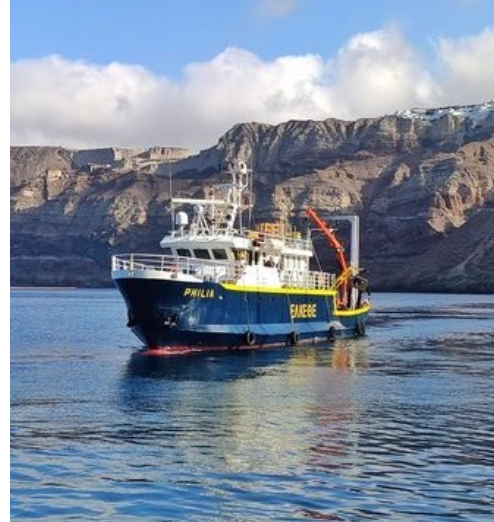
HCMR research vessels - for installation/periodic swap-outs/maintenance trips



AEGAEO

HOME PORT: PIRAEUS (ATHENS)
BUILT IN 1985, REBUILT IN 1997
LENGTH : 61.51 M
MAX. SPEED : 12.5 KNOTS
MAXIMUM CRUISING RANGE : 20 DAYS

ON-BOARD STAFF
CREW: 21 PERSONS
SCIENTIFIC PERSONNEL: 21 PERSONS



PHILIA

HOME PORT: HERAKLION
BUILT IN 1986
REBUILT IN 2021-2022
LENGTH: 31 M

ON-BOARD STAFF
CREW: 7 PERSONS
SCIENTIFIC PERSONNEL: 10 PERSONS



NEW RESEARCH VESSEL

EUROPEAN INVESTMENT BANK 55 M €

STATE-OF-THE-ART 70 M R/V
TO BE BUILT 2024-2026

POSEIDON OFFSHORE RIB

BUILT IN 2022; LENGTH : 10 M



ALKYON

BUILT IN 2009; LENGTH : 13.4 M

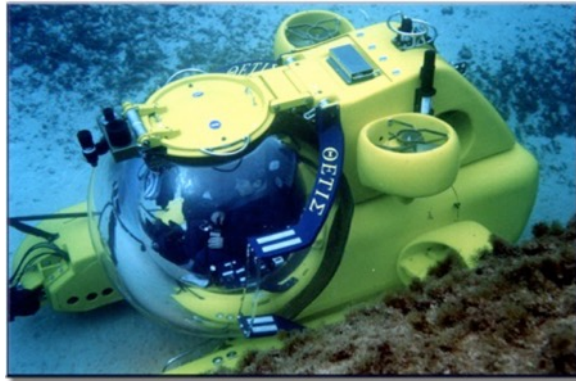
ON-BOARD STAFF
CREW : 2 PERSONS
SCIENTIFIC PERSONNEL : 8 PERSONS



Existing infrastructure and expertise for OC-SVC operations on Crete

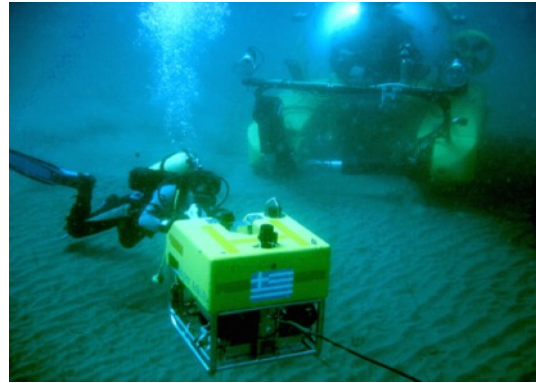
HCMR large oceanographic infrastructure expertise

SUBMERSIBLE VEHICLES



TWIN SEATER SUBMERSIBLE "THETIS"

OPERATING DEPTH : 610M



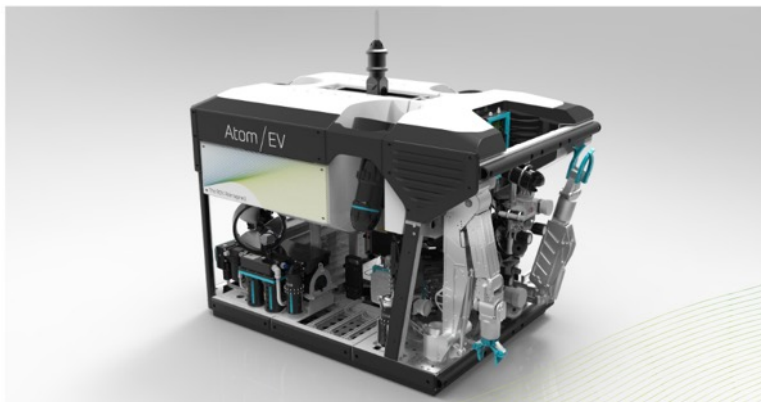
ROV SUPER ACHILLES

MAXIMUM OPERATING (DIVE)
DEPTH: 1.000 M



ROV MAX ROVER

MODEL: MAX ROVER MARK II
MAXIMUM OPERATING (DIVE)
DEPTH: 2000 M



New ROV

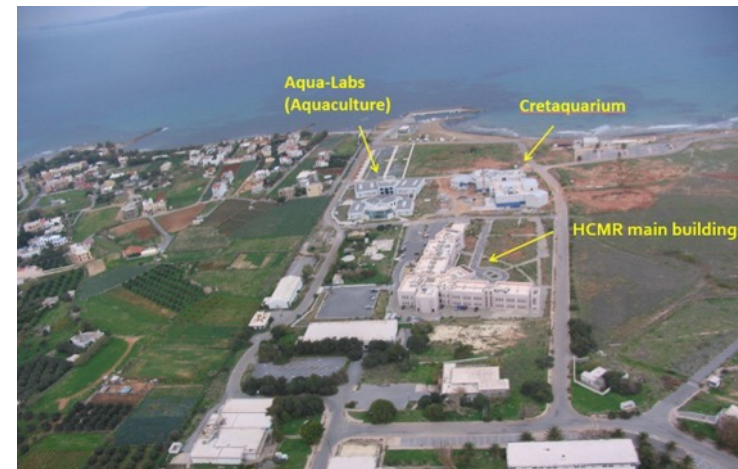
Recovery and Resilience Fund (RRF)
Operational depth: 4000 m

Existing infrastructure and expertise for OC-SVC operations on Crete

HCMR-Crete – headquarters for operations



HCMR-Crete is a modern 6000 m² marine research complex on the north coast of Crete with high speed internet, calibration, radiometric, and HPLC labs + many other marine labs and facilities already in place. Houses optics calibration lab & local QC data lab. Also home of R/V Philia, the HCMR optics suite, a 10m offshore RIB, in-house professional diving team, and the largest aquarium in Greece & the Eastern Mediterranean.



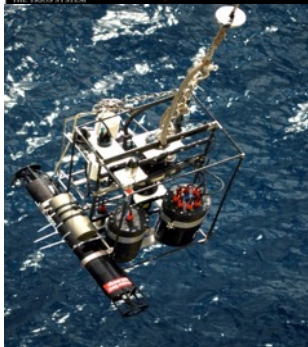
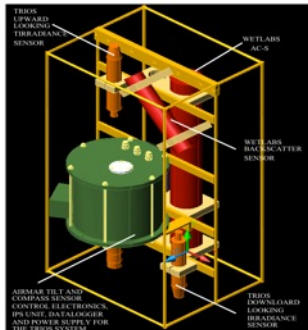
Existing infrastructure and expertise for OC-SVC operations on Crete

HCMR ocean colour & marine optics team

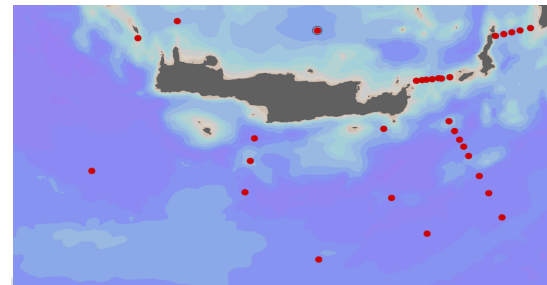
- 7 post doctoral researchers
- 2 PhDs
- 1 dedicated engineer
- 15 years experience in E.Med

HCMR marine optics equipment

- 4 Trios radiometers
- AC-S & ECOBB3
- Chelsea transmissometers
- LISST-Deep
- LISST-Holo 2



1. Pelagic Ecosystem Response to dense water formation in the Levant Experiment (**PERLE 2**) cruise 27 February-15 March 2019



Recent OCR validation cruises

2. MARine monitoring system of the Hellenic Seas using REmote sensing satellite data and in-situ measurements (**MARRE**) cruise 25 – 28 September 2020



3. JRC-HCMR Bio-optics cruise 29 April - 09 May 2022



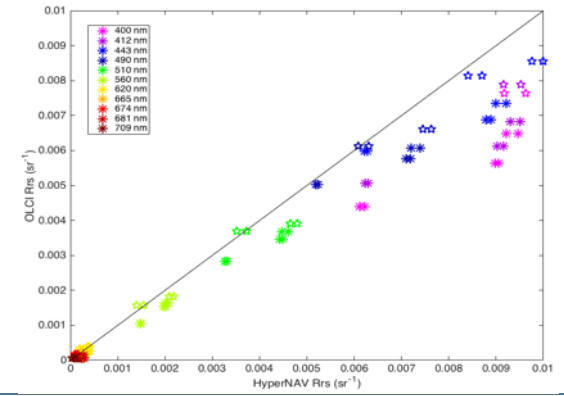
Existing infrastructure and expertise for OC-SVC operations on Crete



NASA HyperNAV



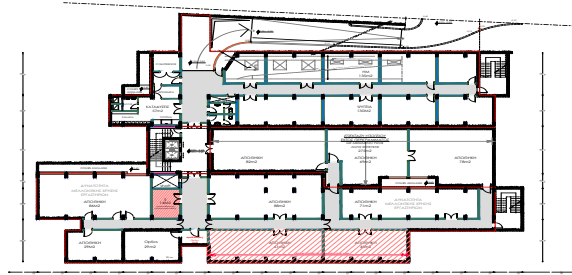
Deployed by HCMR offshore Crete for 3 months May-August 2022, 2 months Mar-May 2023, 5 months Feb-July 2024, more planned for 2024-2025. Used for OC-SVC of the NASA PACE OC satellite.



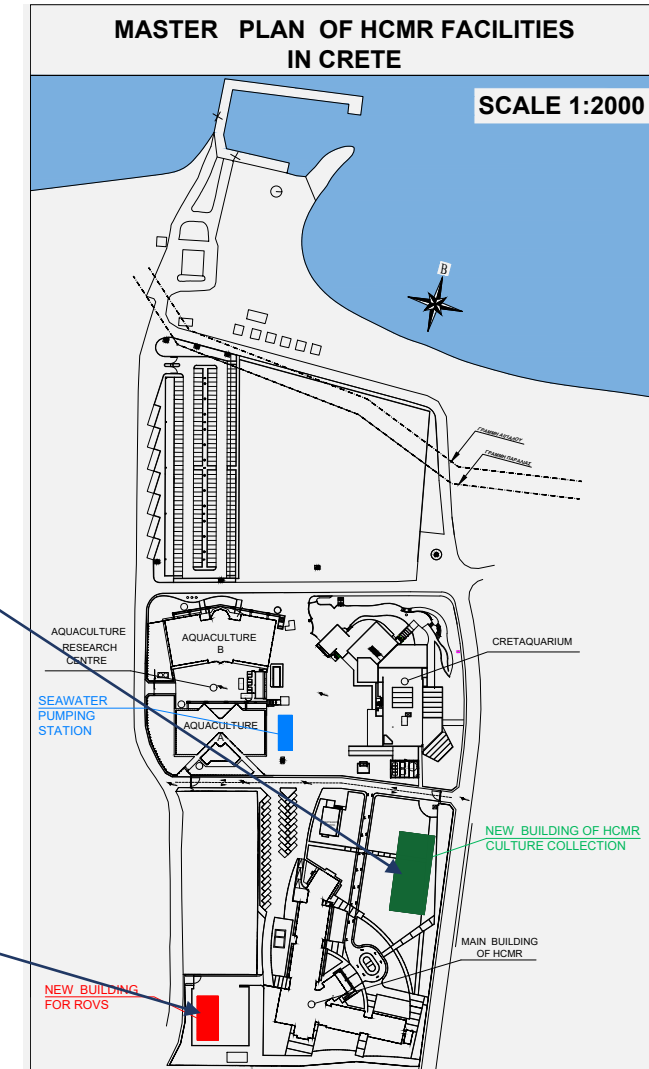
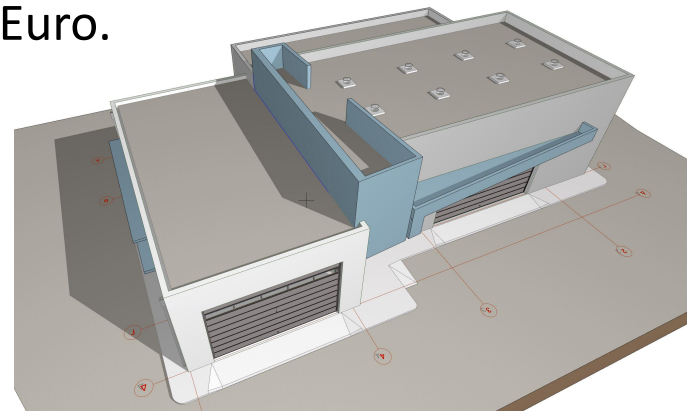
Crete site development plans for OC-SVC

HCMR-CRETE NEW BUILDINGS - FACILITIES

- 5 M Euro new HCMR-Crete research labs extension to existing 6000m² with custom optics calibration lab

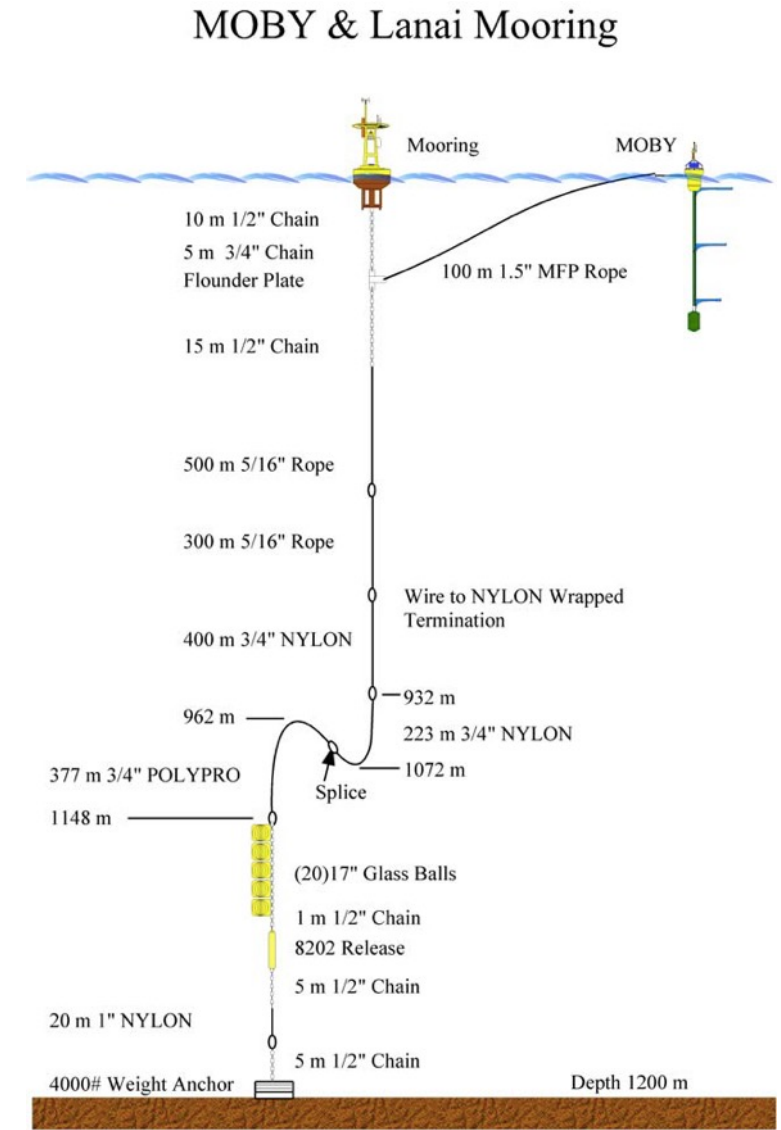
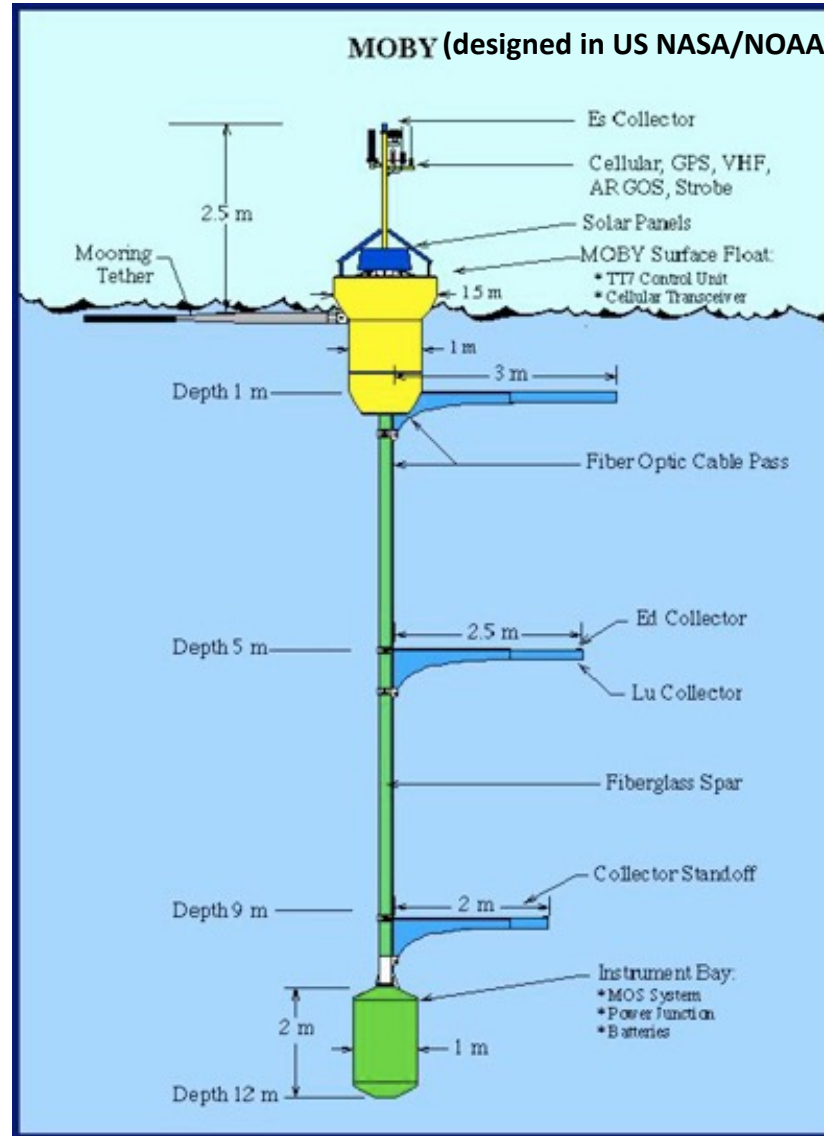


- New large marine engineering building at HCMR-Crete with area for handling OC-SVC buoy components – 1.2 M Euro.



Crete site development plans for OC-SVC - buoy design

- At present only one operational OC-SVC site in the world in Hawaii (MOBY).
- To follow MOBY / MARONET design for buoy and radiometry to ensure consistency in global satellite OC-SVC.
- MARONET is based on MOBY and a buoy is being installed in the East Indian Ocean off the coast of Australia.
- Copernicus site to become the third OC-SVC site in the world.

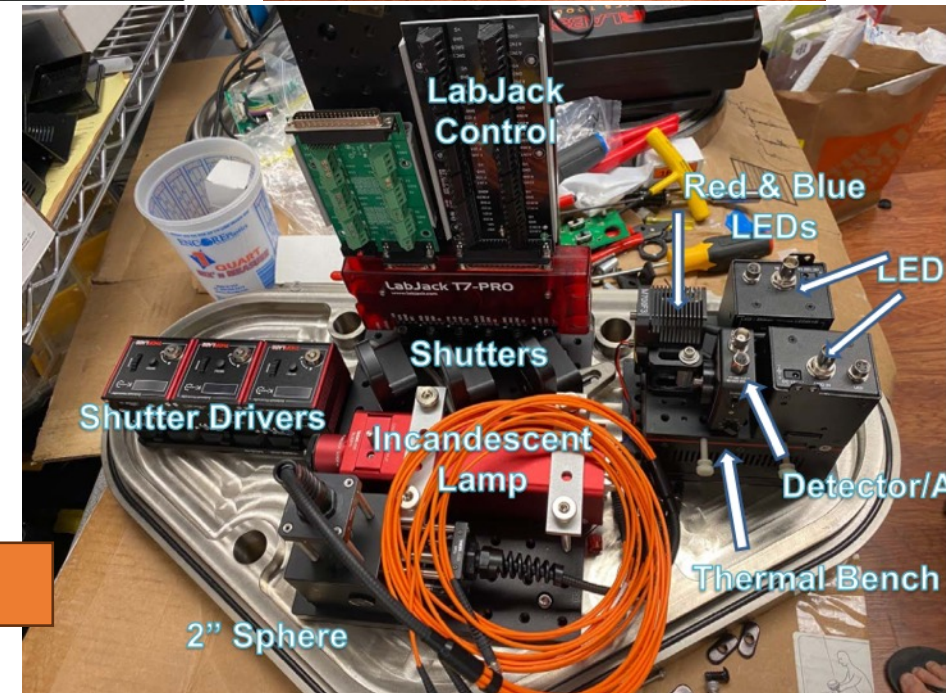
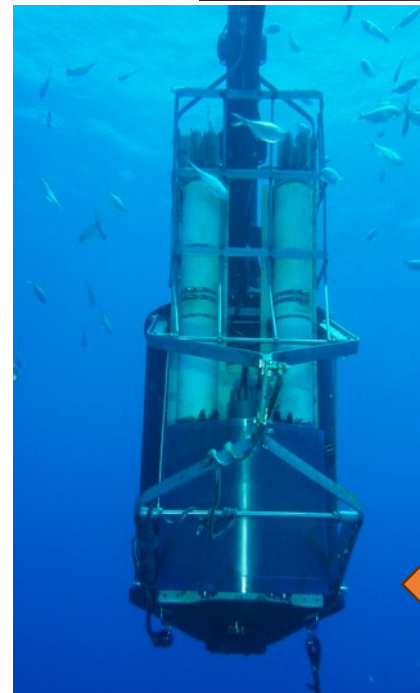
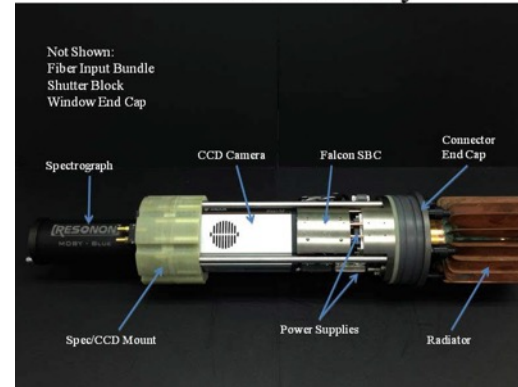


Crete site development plans for OC-SVC – radiometry

MOBY / MARONET radiometry

- Follows MOBY design from US
- Identical instrumentation with MOBY
- Base spectrometer from Resonon (camera from Apogee)
- Complex custom assembly
- Separate blue and red wavelength range spectrometers
- Consistent calibration system with MOBY and EIO site

BS1-#1 Assembly



Crete site development plans for OC-SVC - calibration system and lab.

NPL National Physical Laboratory
STAR-CC-OGSE
 Spectroscopically Tuneable Absolute Radiometric – Calibration and Characterisation – On Ground Support Equipment

Large spectrum source
 Filter wheel: attenuators + shutter
 Movable rotating linear polariser
 Integrating sphere
 Monitoring photodiodes
 Laser source input port
 Rotation plate

Hyperspectral ocean colour radiometer

M-squared SolsTIS tuneable Ti:Sapphire laser

STAR-CC-OGSE used for ROSACE as:

- SI-traceable reference low uncertainty absolute radiometric calibration of OCR
- Full instrument characterisations, inc. stray light, detector spectral accuracy, polarisation, linearity, temperature dependence, and noise characterisation

Stability issue detected from 6 monthly cals



Calibration and/or characterisations reset (initially and as needed)

NPL National Physical Laboratory
SMART-CC
 Stability Monitoring and Absolute Radiometric Calibration and Characterisation facility

Large spectrum source
 Integrating sphere
 Small set of diode lasers

Hyperspectral ocean colour radiometer

Combined FEL-laser photodiode-integrating sphere fixed facility (includes lab-based hyperspectral transfer radiometer exact same as those deployed)

SMART-CC dedicated ROSACE facility for:

- Calibration and characterisation stability checks
- Regular absolute radiometric low uncertainty calibration of OCR, SI-traceable and referenced back to STAR-CC-OGSE

Monthly (before and after maintenance)

IN-SITU-SC

UNIVERSITY OF TARTU Tartu Observatory

Portable marine deployable device for in-situ instrument responsivity stability checking

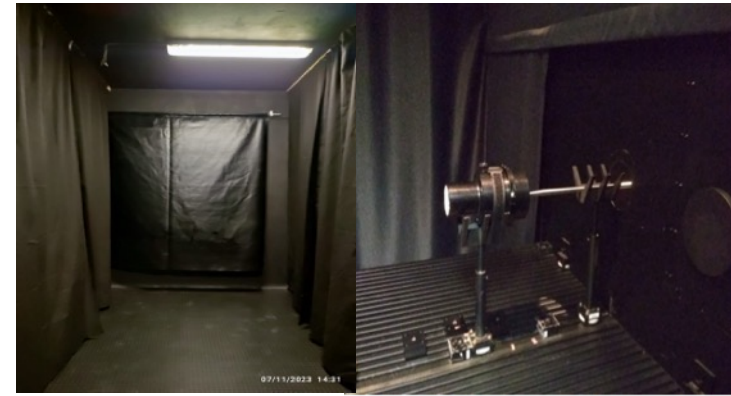
HCMR-Crete – OPTICS CALIBRATION LABORATORY



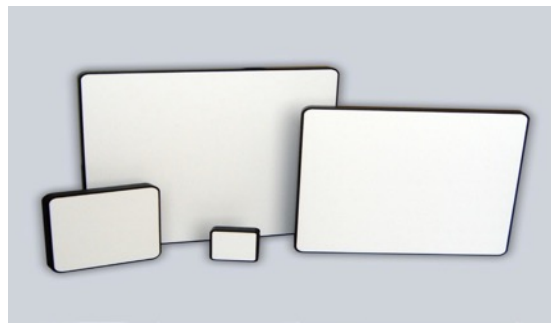
THORLABS 2.5 x 1.5 m optical table with stabilizing legs & instrument fittings



Gigahertz-Optik BN-9101 FEL 1000 W calibration lamps



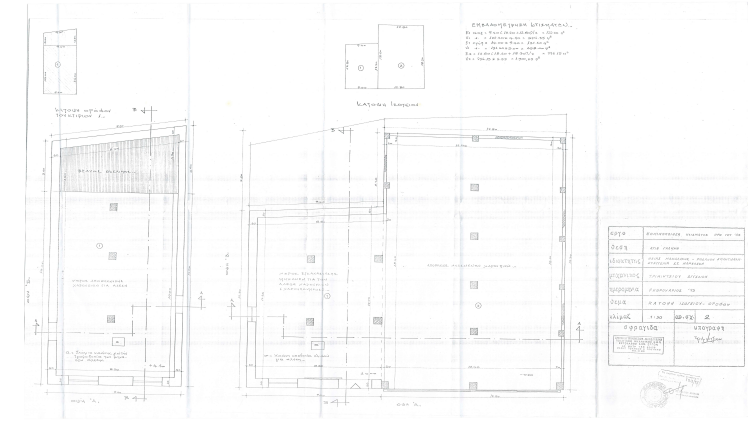
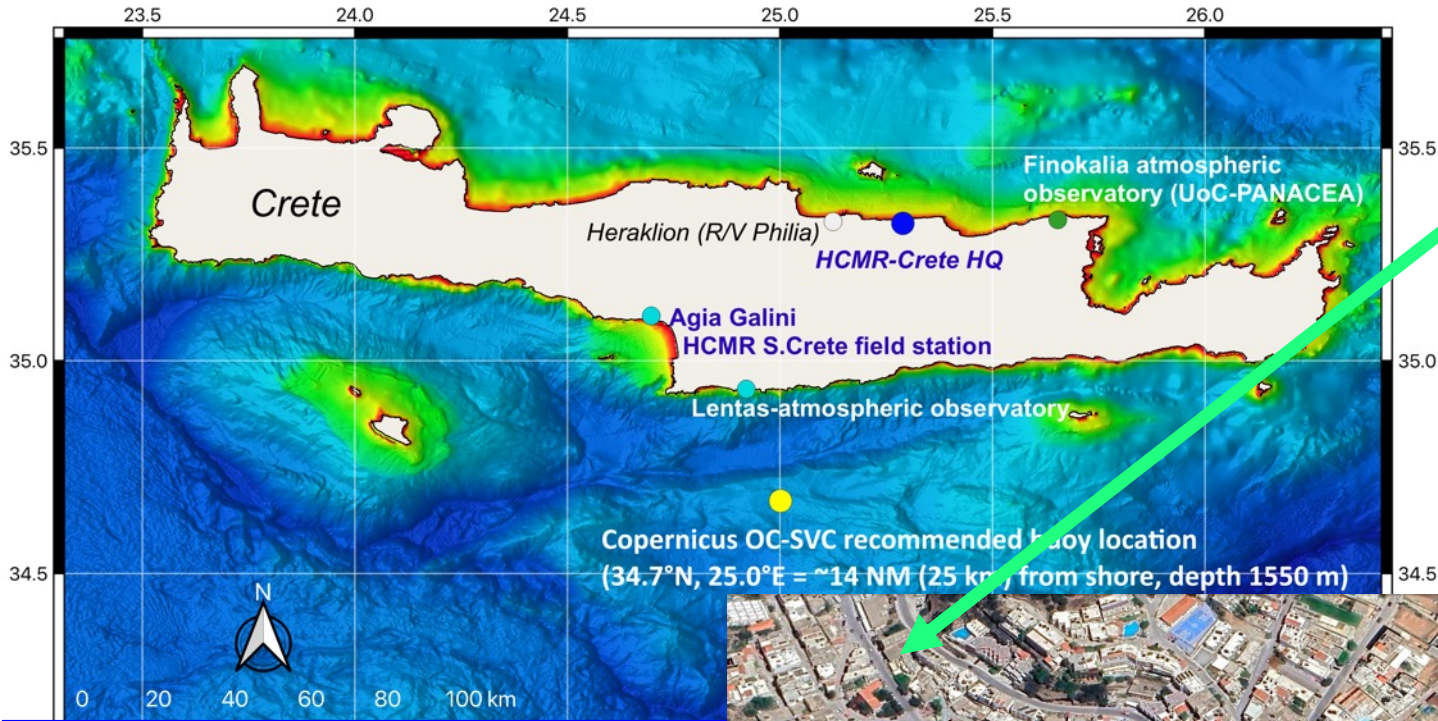
Black out wooden baffling, curtains, flooring and paint



Spectralon 99% reflectance panel from LabSphere

Crete site development plans for OC-SVC - field station

Field Station in Agia Galini, Crete



LENTAS AND PORT OF AGIOS FAULOS, LOUTRA

- 15 nautical miles from OC-SVC buoy
- 86 km (1 hr 35 min) drive to HCMR-Crete
- Remote, no village
- Large refuge port

A small inset map shows the location of the port of Agios Faulos, Loutra, relative to the coast of Crete. The map includes a scale bar and a north arrow.



Crete site development plans for OC-SVC

Atmospheric monitoring sites

Developments in PANACEA RI relevant to Copernicus OC-SVC



FINOKALIA

- New COPERNICUS ready building by 2026
- New Guesthouse and Conference hall planned with capacity 30 guests and 100 attendees
- Instrumentation update already underway

PANGEA

- New infrastructure planned and approved for funding
- Full aerosol, cloud and trace gases remote sensing national facilities
- Doppler wind and cloud radars, ceilometer, microwave radiometer, X-band weather radar FTIR, PANDORA



New infrastructure for Copernicus OC-SVC



Sunphotometer

PANDORA

Ceilometer

Raman Lidar (campaign based)

Meteorological parameters

In-situ Gas species: O₃, NO_x

In-situ Aerosols: Continuous aerosol light extinction (absorption, scattering). Chemical speciation: Ions, metals, water soluble organics and nutrients in rainwater & dry deposition.

Crete site development plans for OC-SVC - site safety

Operations and site safety

Shipping

- Minimal risk from fishing and tourism at site (detailed maps provided previous phase).
- Minimal risk from commercial shipping (maps provided in previous phase).

Proposal

- **Hellenic National Meteorological Service (HNMS) to play a key role in providing meteorological and sea state forecasts as well as weather warnings in support of field operations**
- Hellenic Navy Hydrographic Service (HNHS) to include buoy on digital charts.
- Hellenic Coastguard and HNHS to issue warning / notification to all shipping.
- No charge for the above (Greek public service collaboration with HCMR).
- Safety measures on-board buoy follow IALA-AISM regulations / recommendations (yellow colour & X, radar reflector, yellow beacon), e.g. CLS ARGOS MARGET tracker and a Sealite solar marine light with integrated GPS, GSM and satellite emergency communication, including the marine Automatic Identification System (AIS).



MARGET-II

DRIFTING TRACKER

Monitoring moored buoys or tracking pollution (oil, plastic or sargassum) is an easy job with the Argos-GPS MARGET-II tracker. Compact and flexible, the MARGET-II drifting buoy integrates a GPS data logger and will be able report up to 96 accurate positions a day thanks to the upcoming Kinéis constellation.

Robust and very easy to install, the MARGET-II is a long-lasting beacon that requires no maintenance and has been designed for a variety of applications:

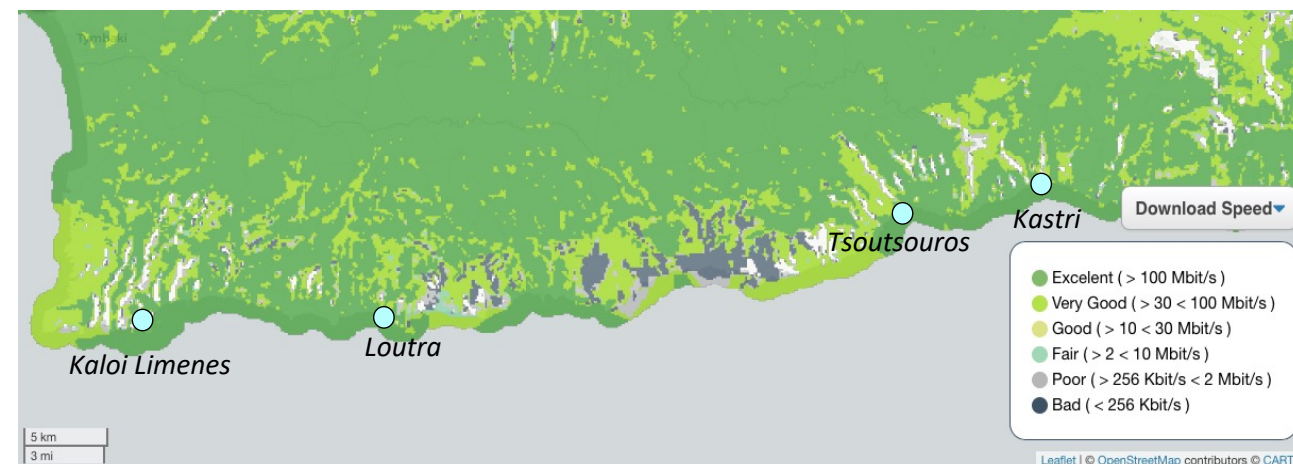
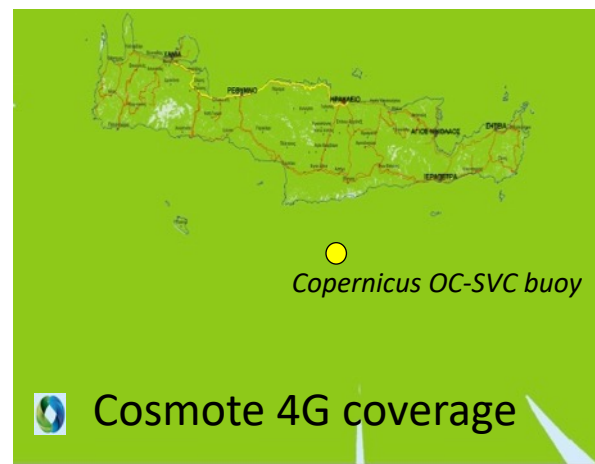
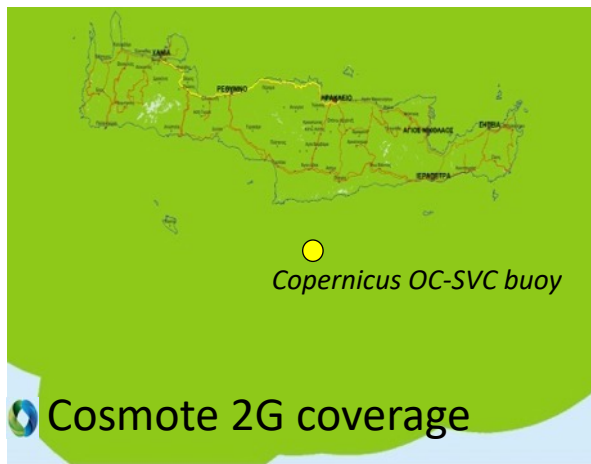


Crete site development plans for OC-SVC – data communication

High Volume Data Communication Links

Proposal

- MOBY data volume context, 650 MB / day
- Based on modernised version of existing POSEIDON buoy data communication, i.e. combination of GSM and Iridium satellite data communication, UHF/VHF/LF link for emergency back-up.
- Cellular network coverage in Greece extends south to provide good coverage for site.

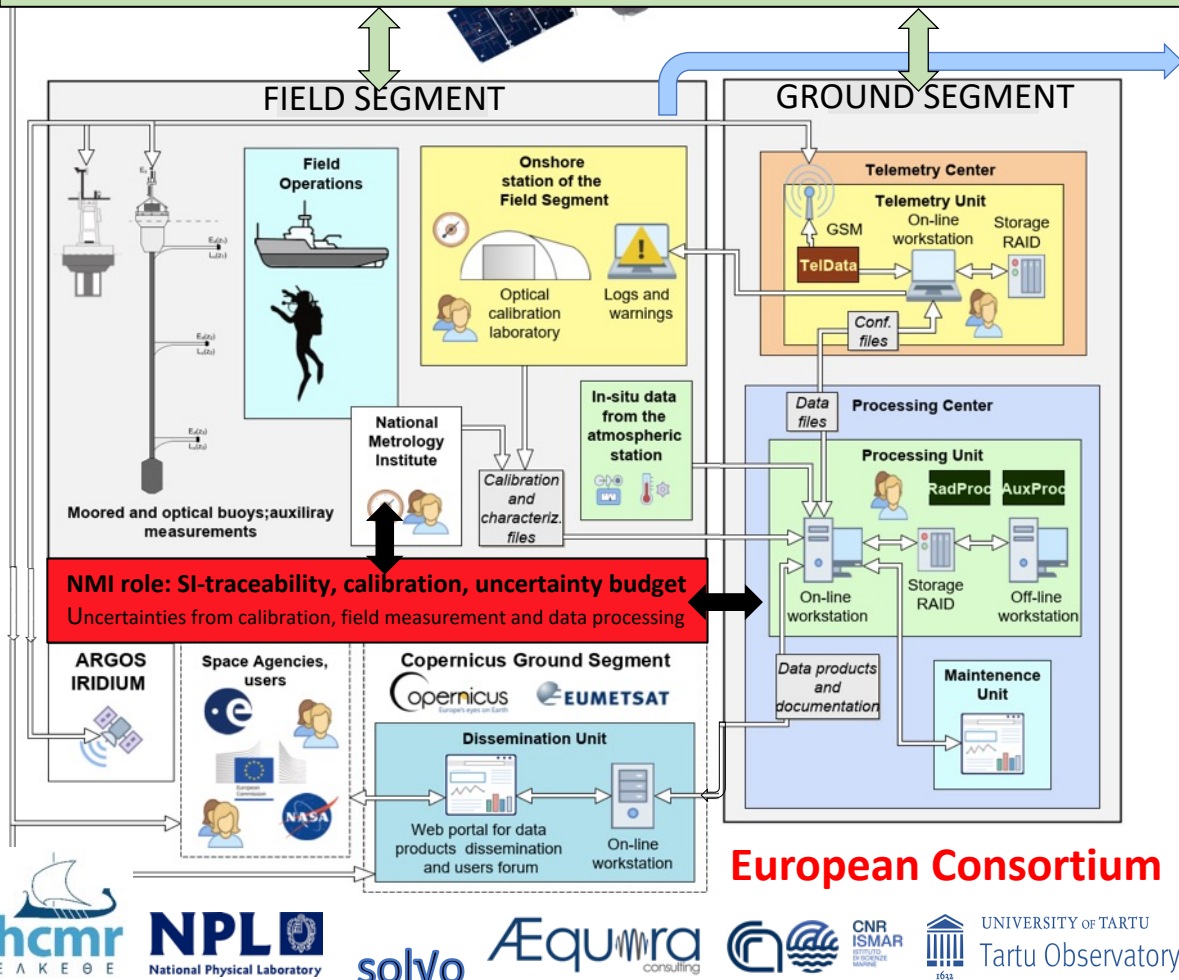


- Cosmote unlimited GSM data plan to be used whenever possible.
- Iridium satellite solution has been worked out with CLS as a backup and emergency system



Copernicus OC-SVC Crete site – design to operations

OVERALL GOVERNANCE – Copernicus & EUMETSAT supported by international organisations (IOCCG & CEOS OCR-VC) and an independent international expert advisory group (existing review panel with additional members)



Crete Field Segment – Greek consortium management structure

Field segment coordinators

Main responsibilities:

- Operational & financial management of field segment on Crete & the Greek national consortium (PI: Dr. A.C. Banks, HCMR)
- Field operations organisation & management, inc. buoy installation, swap-outs, & maintenance infrastructure & teams (e.g. buildings & facilities, R/Vs & RIB, scientists, engineers, & diving crew)
- On-site calibrations & optical calibration laboratory with NMI
- Data delivery. On-shore data transfer station and data telemetry centre (with first stage of quality flagging for Ground Segment)



Atmospheric monitoring

Run by UoC supported by PANACEA network & NOAA, reporting to HCMR

Main responsibilities:

- Atmospheric monitoring stations inc. new South Crete installation
- Delivery of data on atmospheric aerosols & absorbing gases above South Crete OC-SVC site

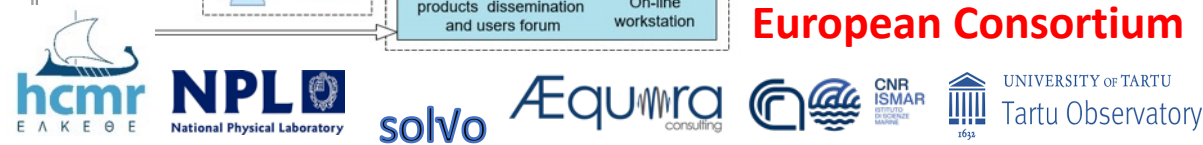


Operational meteorological support

Run by HNMS, reporting to HCMR

Main responsibilities:

- Meteorological & sea state forecasts for field operations
- Weather safety warnings for field operations





Thank you!



Contact: andyb@hcmr.gr