Towards Fiducial Reference Measurements in the Eastern Mediterranean for the Validation and Calibration of Satellite Ocean Colour

FRM4SOC Phase 2 FICE, CNR-ISMAR, Venice, 15/05/2024

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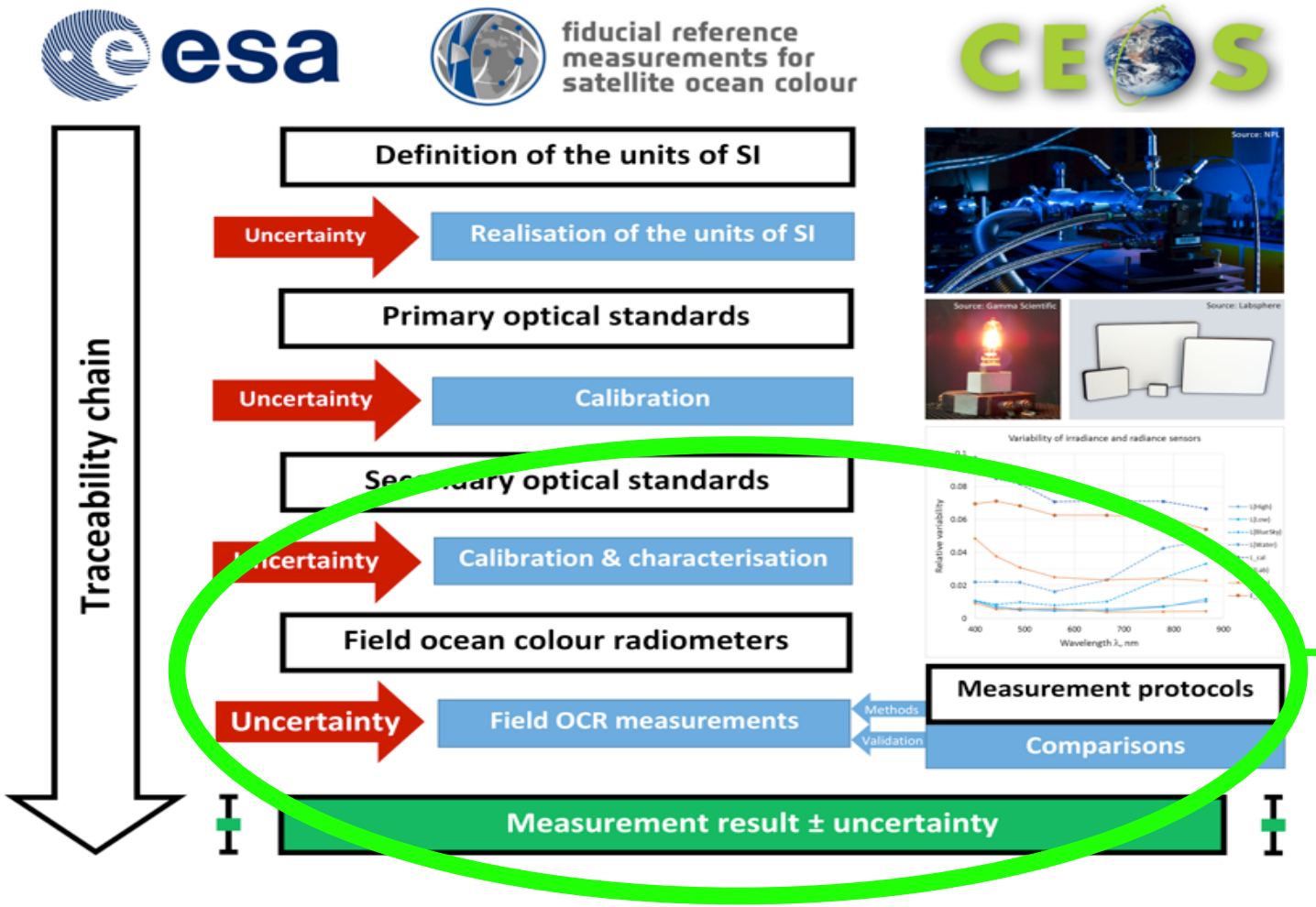
Institute of Oceanography, Hellenic Centre for Marine Research (HCMR), Crete, Greece

with great help from G. Zibordi (JRC / NASA), NPL & Tartu Observatory

Towards FRM in the Eastern Mediterranean
Key objectives & milestones



For HCMR OCR:

- SI traceable radiometric calibration and characterisation
- Follow FRM measurement & processing protocols
- Uncertainty budget from calibration to processed field measurement
- International radiometry comparisons
- OC-SVC and validation

Towards FRM in the Eastern Mediterranean
History of OCR at HCMR

2005

2010

2015

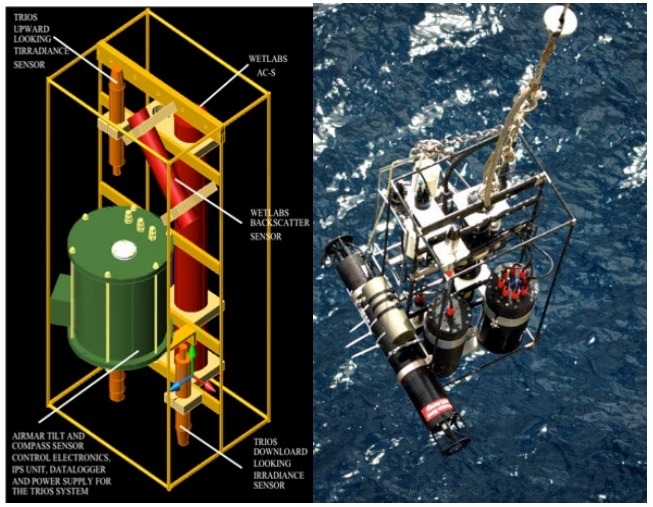
2020

TODAY

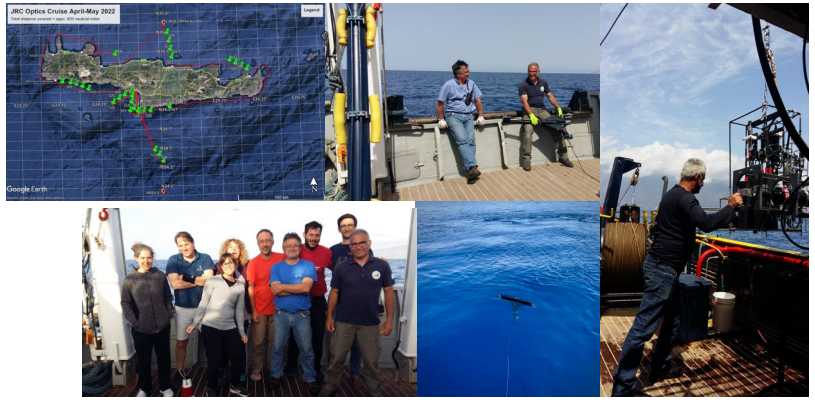
2007-2010:
- Dr. Banks purchases HCMR's first radiometers (TriOS RAMSES), first deployments above water.

2011-12:
- Design and construction of HCMR profiling optics suite – in water radiometry.
- Dr. Banks moves to JRC & NPL.

2013-2017:
- HCMR optics suite deployments in E. Med & Black Sea.



2018-2021:
- Dr. Banks moves back to HCMR.
- Start to follow FRM principles at HCMR.
- Proposed Crete Copernicus OC-SVC site.
- ProVal in Crete.
- Continued deployments of HCMR optics suite.



2022-2024:
- JRC-HCMR optics cruises around Crete.
- HyperNAV in Crete.
- Crete Copernicus OC-SVC site -> Design phase.
- Separation of OCR from IOPs – back above water
- NABUCCO & development of OCR calibration lab.

TOWARDS FRM IN THE EASTERN MEDITERRANEAN
HCMR marine optics and satellite oceanography team

Team members: Dr. Andrew Banks, Dr. Aris Karageorgis, Dr. Stella Psarra, Dr. Spyros Chaikalis, Dr. Alexandra Pelteki, Dr. Eleni Livanou, Dr. Elli Pitta, Dr. Christina Zeri, Mr. Nektarios Spyridakis, Prof. Panos Drakopoulos(UNIWA)

Institute of Oceanography,

Hellenic Centre for Marine Research (HCMR)

Contact: andyb@hcmr.gr

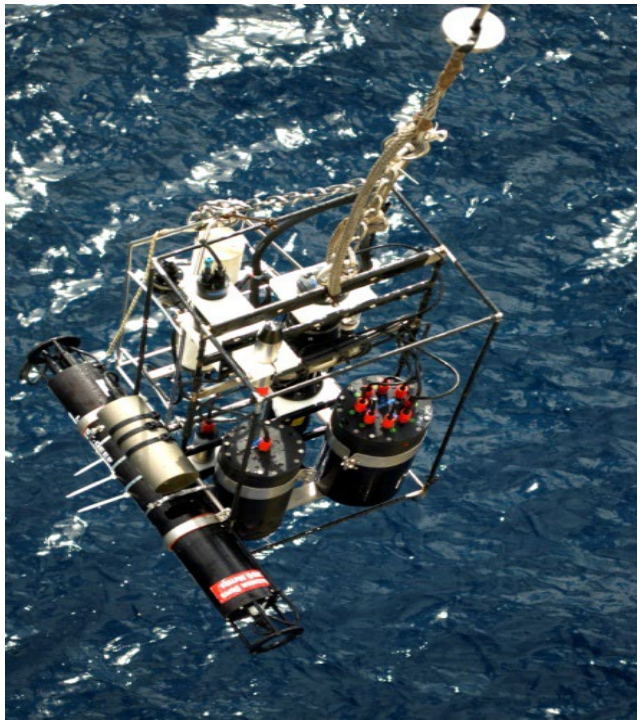
- 9 post doctoral researchers
- 1 dedicated engineer
- 15 years marine optics experience in the Eastern Mediterranean

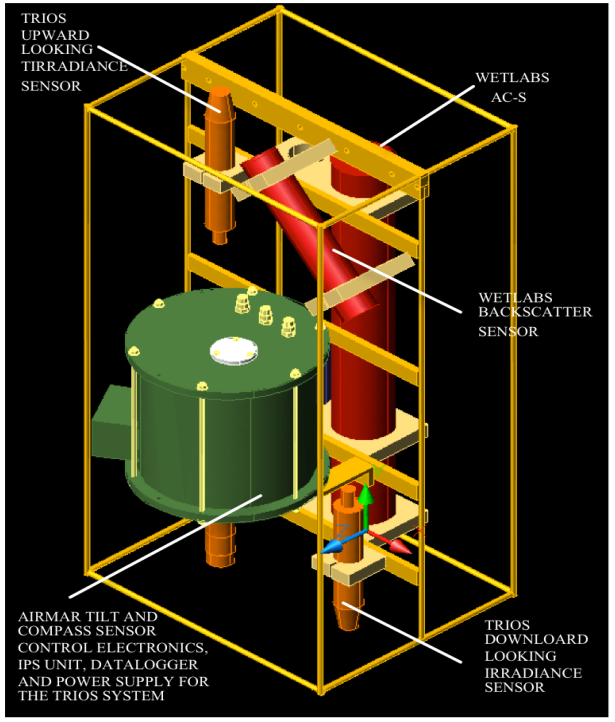
Towards FRM in the Eastern Mediterranean
Supporting infrastructure for OCR & FRM

HCMR-Crete is a modern 6000 m^2 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.

HCMR marine optics sensors

- 4 TriOS radiometers
- AC-S & ECOBB3
- Chelsea transmissometer
- LISST-Deep
- LISST-Holo 2





TOWARDS FRM IN THE EASTERN MEDITERRANEAN
Supporting infrastructure for OCR & FRM

HCMR research vessels

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

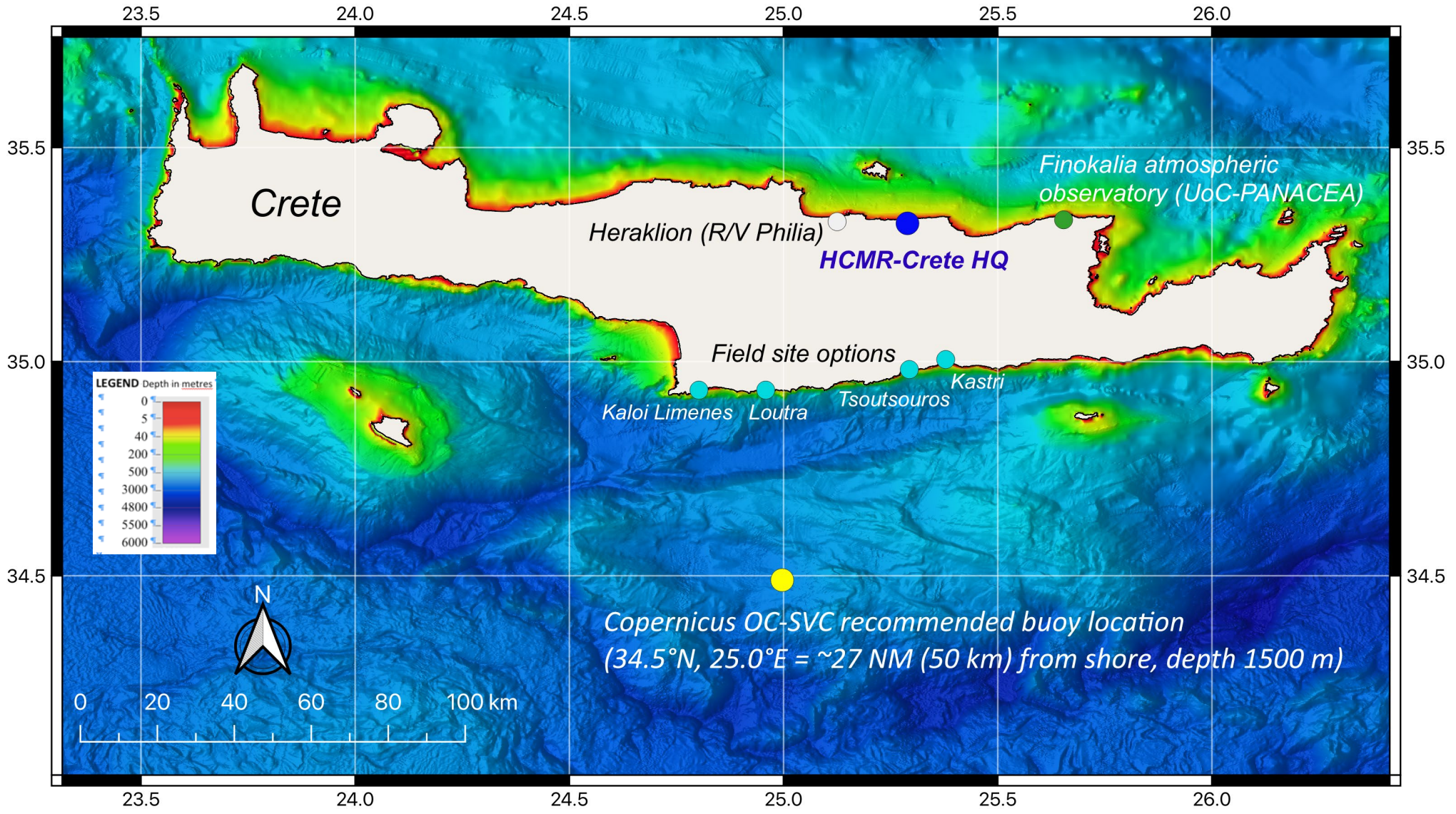
TO BE BUILT 2024-2026

ALKYON

Built in 2009; Length : 13.4 m

On-board Staff
Crew : 2 persons
Scientific personnel : 8 persons

Towards FRM in the Eastern Mediterranean
Area of Interest

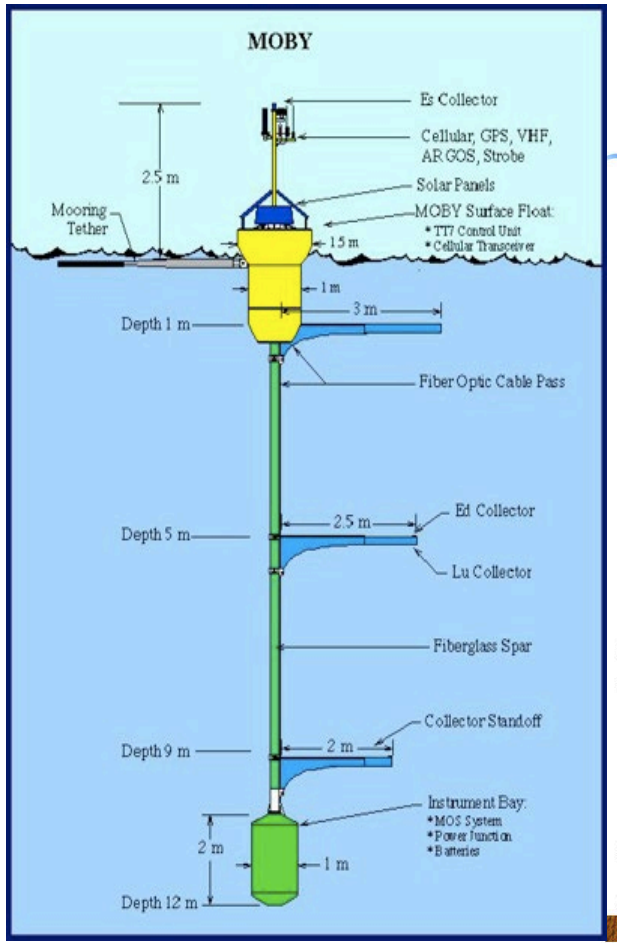


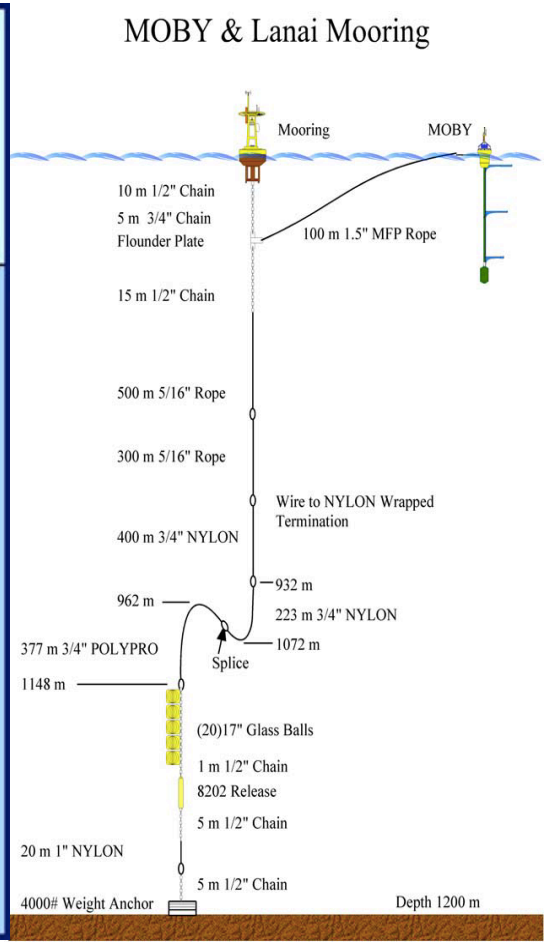
TOWARDS FRM IN THE EASTERN MEDITERRANEAN
Copernicus Ocean Colour System Vicarious Calibration (OC-SVC) Development

ROADMAP

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

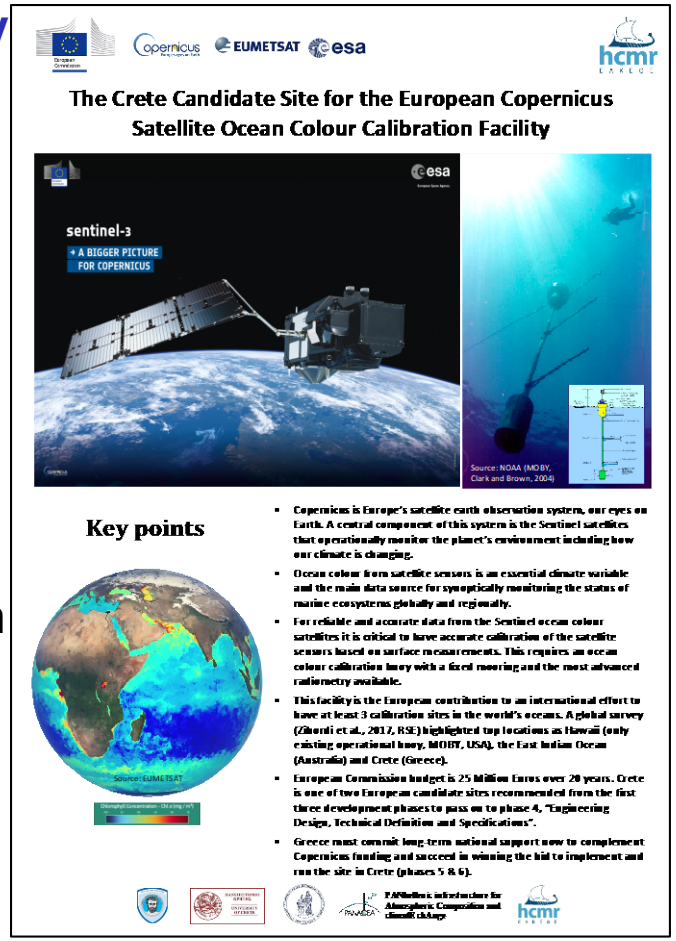
TOWARDS FRM IN THE EASTERN MEDITERRANEAN
OC-SVC in situ radiometric measurements – a special kind of FRM





MOBY / MARONET radiometry

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



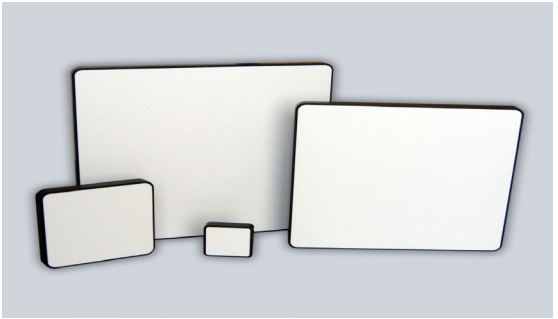
TOWARDS FRM IN THE EASTERN MEDITERRANEAN
Preparation activities for OC-SVC

HCMR-Crete – ABSOLUTE RADIOMETRIC 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

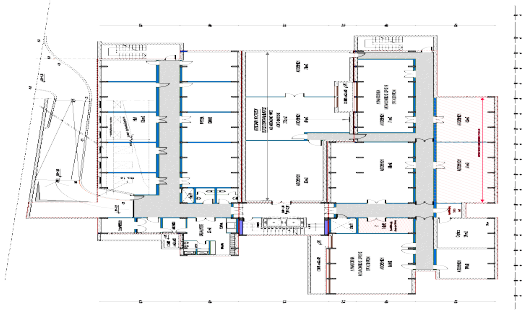
Black out wooden baffling, curtains, flooring and paint + optics table and stages, power, climate control and air filtering systems (not shown)



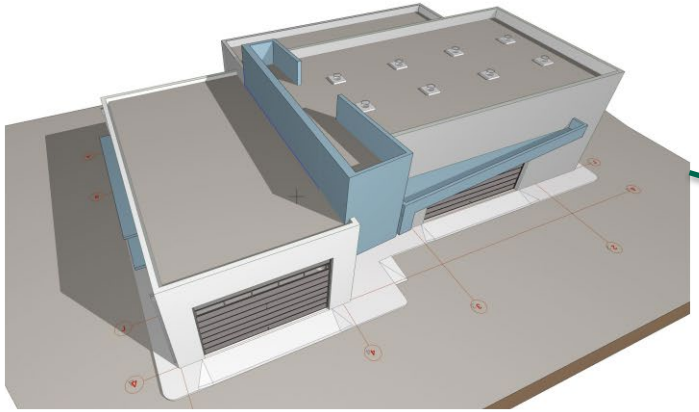
Spectralon 99% reflectance panel from LabSphere

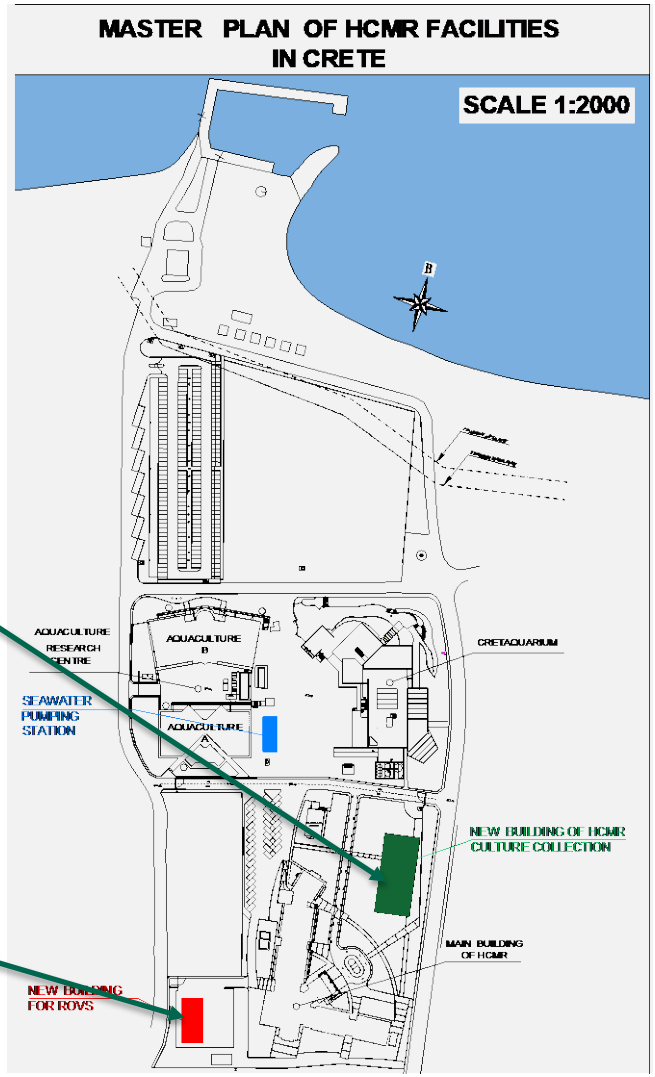
HCMR-CRETE NEW BUILDINGS - FACILITIES

- 5 M Euro new HCMR-Crete research labs extension to existing 6000m^2 with custom optics calibration lab



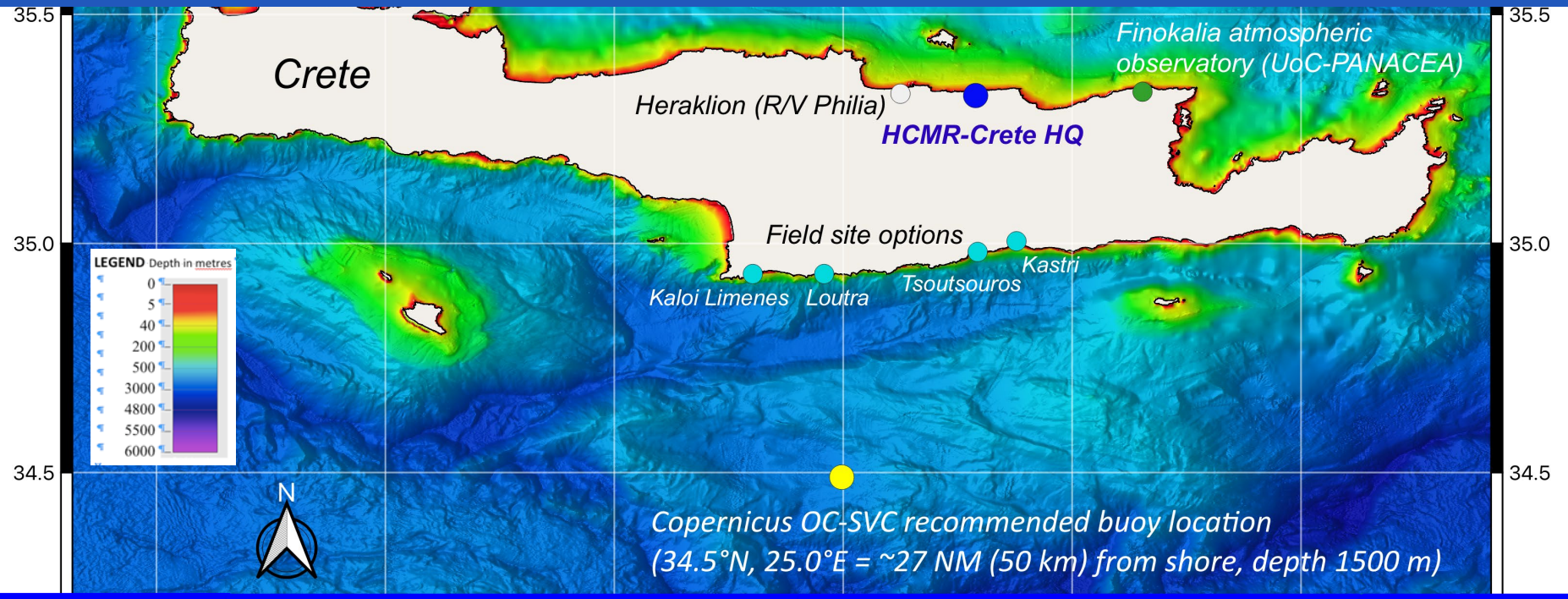
- New large marine engineering building at HCMR-Crete with area for handling OC-SVC buoy components – 1.2 M Euro.

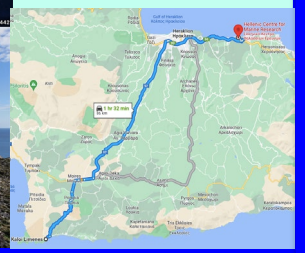




Towards FRM in the Eastern Mediterranean

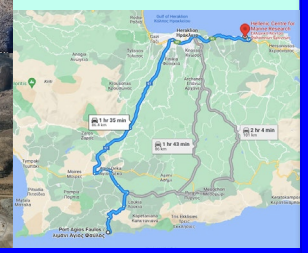
Preparation activities for OC-SVC – field site





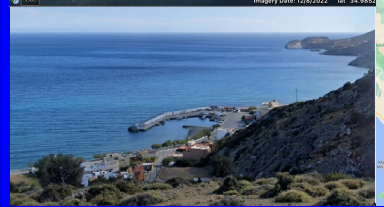
Port of Kaloi Limenes

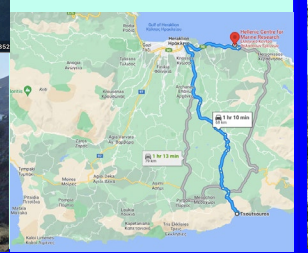
- 27.5 nautical miles from OC-SVC buoy
- 86 km (1 hr 32 min) drive to HCMR-Crete
- Developed village
- Small port & cargo ship fuel station



Port of Agios Faulos, Loutra

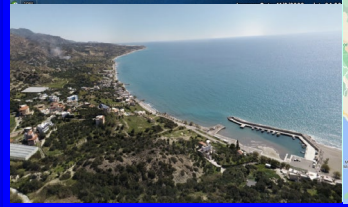
- 26 nautical miles from OC-SVC buoy
- 86 km (1 hr 35 min) drive to HCMR-Crete
- Remote, no village
- Large refuge port

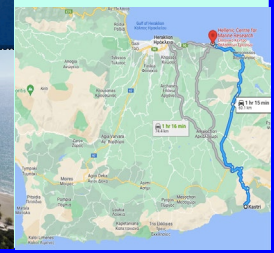




Port of Tsoutsouros

- 32 nautical miles from OC-SVC buoy
- 68 km (1 hr 10 min) drive to HCMR-Crete
- Developed village
- Small port

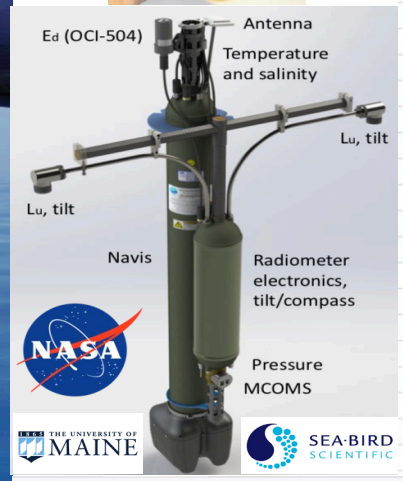




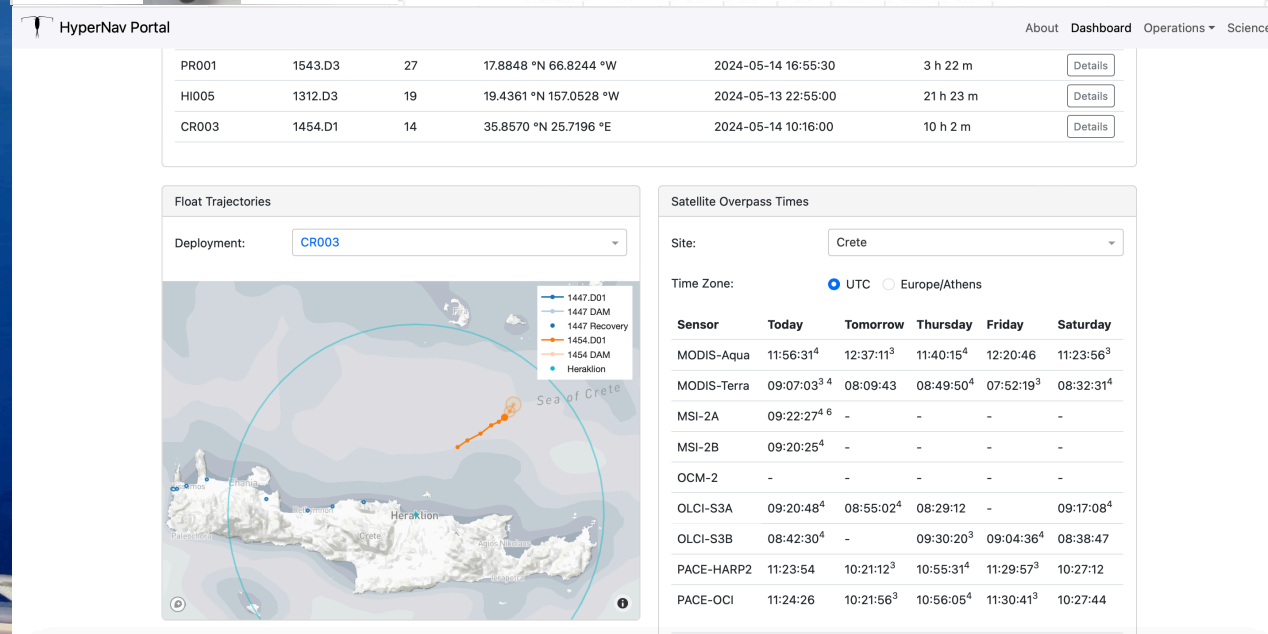
Port of Kastri

- 35 nautical miles from OC-SVC buoy
- 60 km (1 hr 15 min) drive to HCMR-Crete
- Developed village
- Large port

Towards FRM in the Eastern Mediterranean
NASA HyperNAV in Crete in support of PACE OC-SVC



Source	380nm	412nm	443nm	490nm	510nm	550nm	665nm	Method
Calibration	1.88	1.87	1.80	1.74	1.68	1.68	1.71	
Irradiance Standard	0.55	0.51	0.48	0.44	0.42	0.4	0.34	Manufacturer certificate
Reflectance Target	1.1	1.1	1	0.9	0.8	0.8	0.9	Manufacturer certificate
Geometric Effects	1.4	1.4	1.4	1.4	1.4	1.4	1.4	Modeling based on Hooker et al (2002)
Reproducibility	0.23	0.23	0.23	0.23	0.23	0.23	0.23	Previous studies (see Orrico et al 2018)
Instrument	1.43	0.71	0.64	0.45	0.66	0.46	1.17	
Polarization	0.9	0.5	0.4	0.1	0.06	0.07	0.5	Laboratory measurements
Thermal	0.08	0.08	0.08	0.08	0.08	0.08	0.08	Laboratory measurements
Immersion	0.43	0.45	0.45	0.36	0.4	0.39	0.3	Laboratory measurements & Feinholz et al. (2017)
Integration Time Linearity	0.05	0.05	0.05	0.05	0.05	0.05	0.05	Laboratory measurements
Counts Linearity	0	0	0	0	0.01	0.03	1	Characterized by NIST
Stray Light	0.12	0.1	0.09	0.08	0.05	0.04	0.09	Characterized by NIST
Wavelength @ Cal	0.19	0.15	0.13	0.09	0.08	0.06	0.03	Laboratory measurements
Wavelength @ Field	1	0.1	0.1	0.2	0.5	0.2	0.1	Field data
Field	2.58	2.55	2.54	2.54	2.62	2.78	5.42	
Self-shading	0.3	0.26	0.22	0.24	0.32	0.56	2.7	Modeling using SimulO software
Tilt Effects	2.2	2.2	2.2	2.2	2.2	2.2	2.2	Field data and Kwiatkowska et al. (2017)
Biofouling	1	1	1	1	1	1	1	Brown et al. (2007)
Wave Focusing	0.5	0.5	0.5	0.5	0.5	0.5	0.5	Estimated from literature
Depth Uncertainty	0.7	0.56	0.54	0.54	0.82	1.14	4	Extrapolated from Voss et al. 2017 and field data
Surface Transmittance	0.1	0.1	0.1	0.1	0.1	0.1	0.1	Modeling based on Quan & Fry (1995)
Total, k=1	3.5	3.2	3.2	3.1	3.2	3.3	5.8	



TOWARDS FRM IN THE EASTERN MEDITERRANEAN
NABUCCO project

New chlorophyll-a concentration retrieving Algorithm Based on fidUcial referenCe measurements of ocean COlour (NABUCCO).

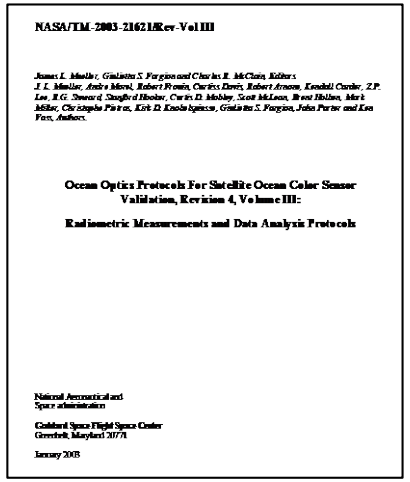
- Aims at measuring and studying the optical properties of seawater in the oligotrophic Cretan and NW Levantine Seas, improving their SI-traceability and uncertainty evaluation and thereby deriving an appropriately accurate regional Chl-a retrieval algorithm.

- WP1: Fiducial reference measurements, technological development and new field data.
    - New optics calibration lab.
    - New FRM field data collection.
- WP2: Data analysis and modelling
    - FRM database of existing and new optical data.
    - Radiative transfer modelling in optical closure experiments and remote sensing reflectance estimation from IOPs.
    - Processing AOPs with FRM4SOC & IOCCG protocols.
- WP3: Algorithm development and testing
    - Using the basis of FRM data - evaluate existing and develop new algorithms to estimate Chl-a concentration more accurately from satellite products of the oligotrophic E. Mediterranean.

Towards FRM in the Eastern Mediterranean
Field measurement protocols

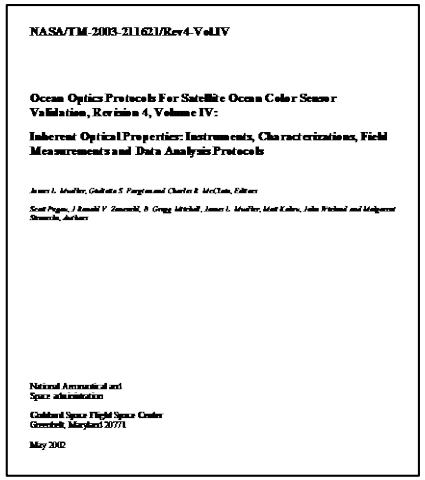
OCR in situ by HCMR above water 2007-2012, in water profiling 2012-2022

- We have been following NASA protocols (Mueller et al., 2003) since 2007
- Trying to follow FRM principles (Banks et al., 2020) and FRM4SOC protocols update (Ruddick et al., 2019a&b) since 2018-2019
- Following IOCCG protocols (Zibordi et al., 2019) since 2020.


NASA/TM-2003-21621/Rev-Vol III

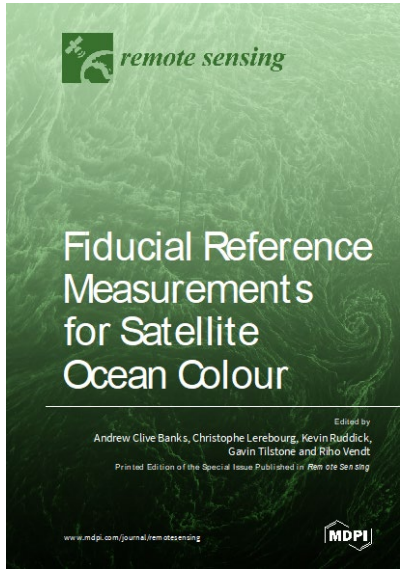
Ocean Optics Protocols For Satellite Ocean Color Sensor Validation, Revision 4, Volume III:

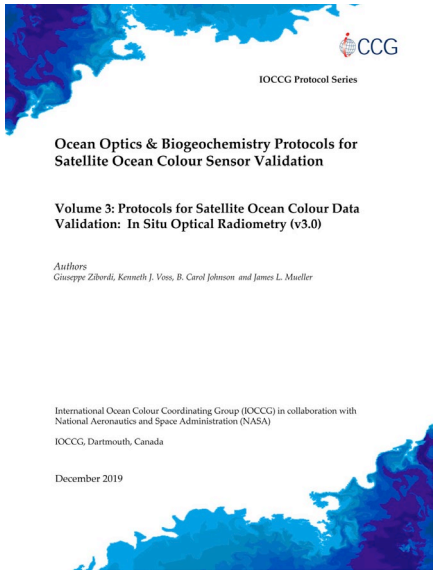
Radiometric Measurements and Data Analysis Protocols


NASA/TM-2003-211621/Rev4-Vol.IV

Ocean Optics Protocols For Satellite Ocean Color Sensor Validation, Revision 4, Volume IV:

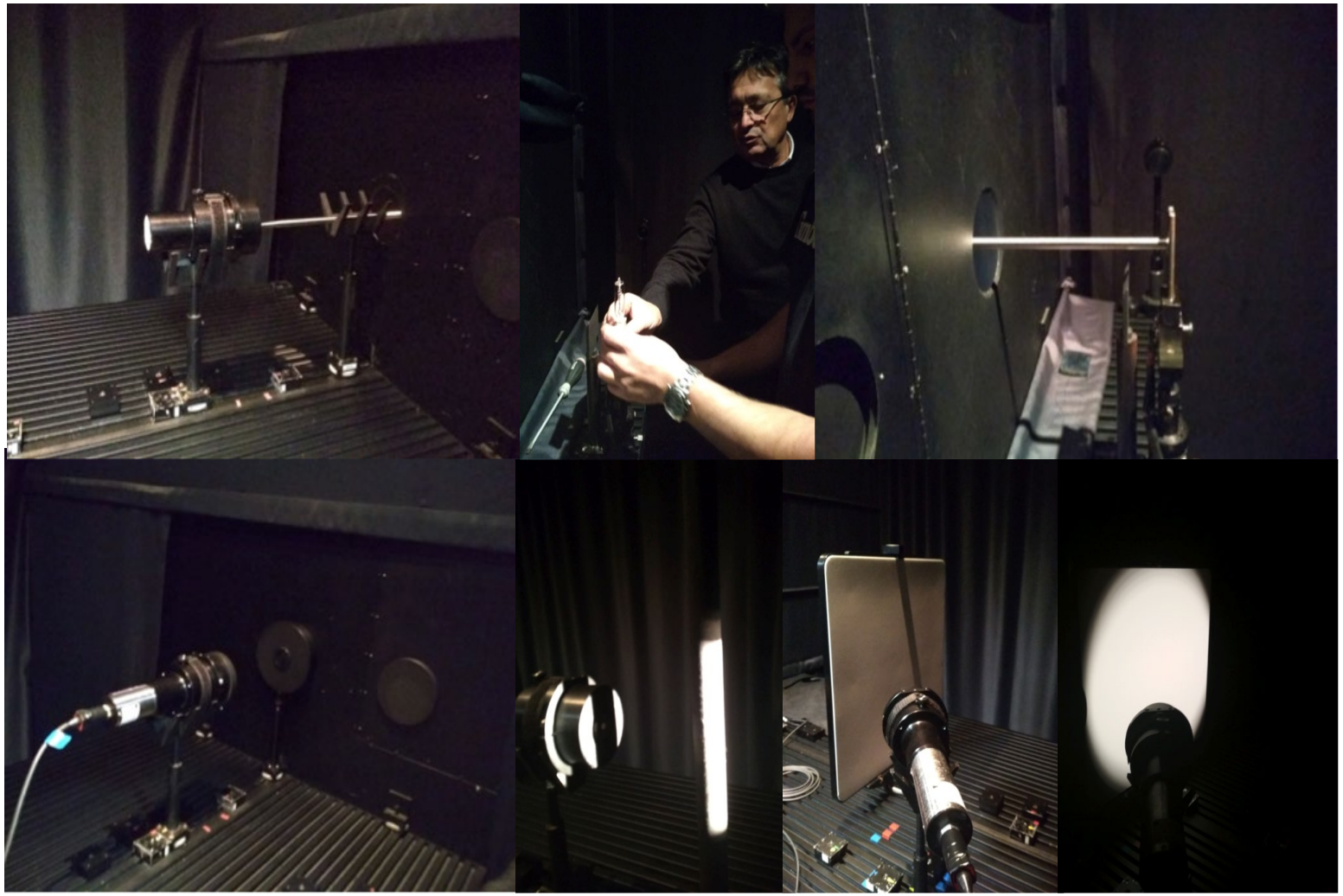
Inherent Optical Properties: Instruments, Characterizations, Field Measurements and Data Analysis Protocols





TOWARDS FRM IN THE EASTERN MEDITERRANEAN
SI traceable radiometric calibration

- ✓ **First recalibrations since 2009 purchase – JRC Nov.2018**
- ✓ Adjustment factors to manufacturers original calibration calculated from these measurements.



TOWARDS FRM IN THE EASTERN MEDITERRANEAN
SI traceable radiometric calibration

- ✓ **Second and third calibrations - full absolute radiometric calibrations with per wavelength uncertainties. November 2020 & March 2023 – at Tartu Observatory**

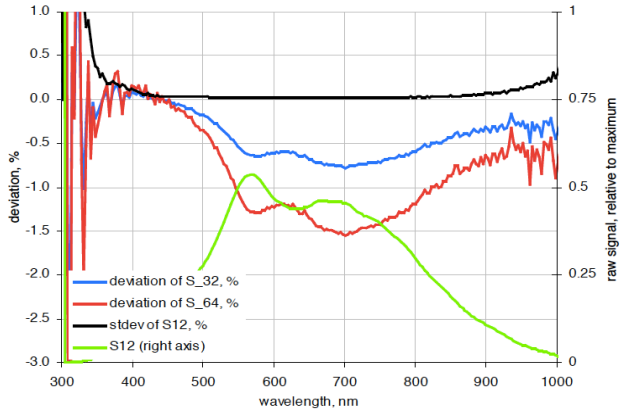

Kalibreerimistunnistus
Calibration certificate

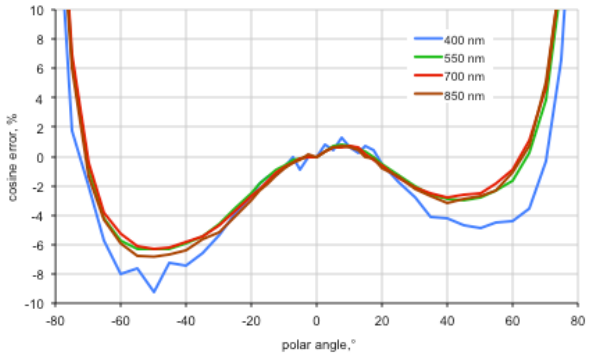
	Irradiance (E) uncertainty (%) at OLCI wavelengths (nm)											
Source	**400**	**412**	**443**	**490**	**510**	**560**	**620**	**665**	**674**	**681**	**709**	**Method**
E radiometer lab calibration	2.1	2.0	1.8	1.8	1.8	1.8	1.8	1.7	1.7	1.7	1.7	TO FEL lamp (k=2)

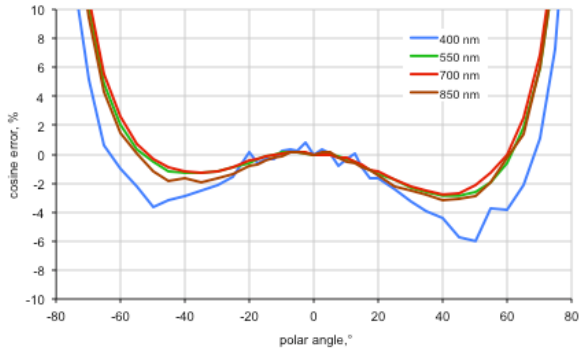
	Radiance (L) uncertainty (%) at OLCI wavelengths (nm)											
Source	**400**	**412**	**443**	**490**	**510**	**560**	**620**	**665**	**674**	**681**	**709**	**Method**
L radiometer lab calibration	2.3	2.0	1.9	1.9	1.8	1.8	1.8	1.8	1.8	1.8	1.8	TO FEL lamp-reflectance panel (0°/45°, k=2)

Towards FRM in the Eastern Mediterranean Characterisations

Linearity & cosine response characterisations – November 2020 and March 2023 at Tartu Observatory



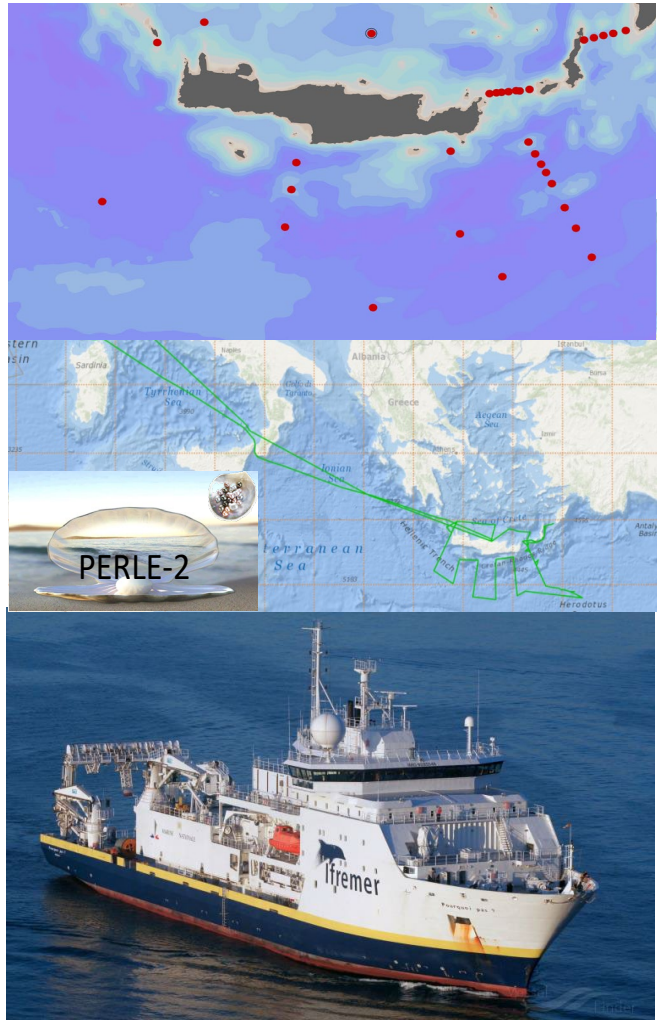




L_{wn} uncertainty budget (%) at OLCI wavelengths (nm)												
Source	**400**	**412**	**443**	**490**	**510**	**560**	**620**	**665**	**674**	**681**	**709**	**Method**
L_u radiometer lab calibration	2.3	2.0	1.9	1.9	1.8	1.8	1.8	1.8	1.8	1.8	1.8	TO lab FEL lamp-reflectance panel (0°/45°, k=2)
L_u instrument characterisation												
Immersion factor	0.2	0.2	-0.6 0.2	0.2	0.2	-0.9 0.2	0.2	-1.2 0.2	0.2	0.2	0.2	Zibordi et al., 2018 Zibordi et al., 2018
Temp. response	0.02 0.4	0.2	0.2 0.01 0.2	0.01 0.2	0.2	-0.3 0.03 0.2	0.2	-0.7 0.09 0.2	0.2	0.2	0.2	Zibordi et al., 2017, 2018 Vabson et al., 2019a (lab) Vabson et al., 2019b (field)
Polarization sens.	0.2	0.2	0.1 0.2	0.2	0.2	0.2 0.2	0.2	0.5 0.2	0.2	0.2	0.2	Talone & Zibordi, 2016, Zibordi et al., 2018 Vabson et al., 2019b (field)
Straylight effects	0.2 0.9	0.2	-1.0 0.2 0.7	0.2 0.3	0.2	0.5 0.2 0.3	0.2	0.4 0.2 0.7	0.2	0.2	0.2	Talone et al., 2016 Zibordi et al., 2018 Vabson et al., 2019a (lab) Vabson et al., 2019b (field)
Nonlinearity	0.11	0.07	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	TO laboratory characterization (k=1).
E_s radiometer lab calibration	2.1	2.0	1.8	1.8	1.8	1.8	1.8	1.7	1.7	1.7	1.7	TO lab FEL lamp (k=2)
E_s instrument characterisation												
Temp. response	0.02 0.4	0.2	0.2 0.01 0.4	0.01 0.2	0.2	-0.3 0.03 0.2	0.2	-0.7 0.09 0.2	0.2	0.2	0.2	Zibordi et al., 2017,2018 Vabson et al., 2019a (lab) Vabson et al., 2019b (field)
Straylight effects	0.2 0.9	0.2	-1.0 0.2 0.7	0.2 0.3	0.2	0.5 0.2 0.3	0.2	0.4 0.2 0.7	0.2	0.2	0.2	Talone et al., 2016, Zibordi et al., 2018 Vabson et al., 2019a (lab) Vabson et al., 2019b (field)
Nonlinearity	0.09	0.06	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.01	TO laboratory characterization (k=1)
Cosine response	1.3	0.8	0.6	0.3	0.2	0.2	0.2	0.3	0.3	0.3	0.2	TO laboratory characterization (k=2)

Towards FRM in the Eastern Mediterranean
Recent OCR validation cruises

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

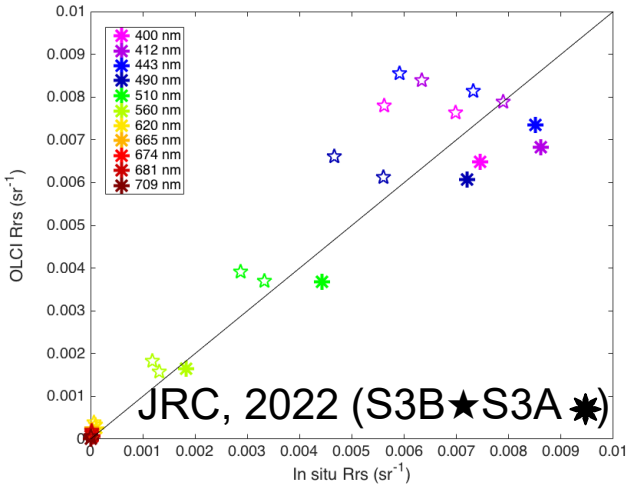


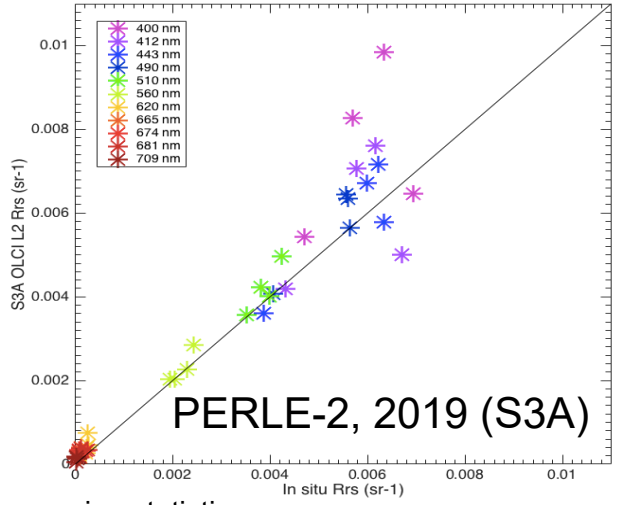
2. MARine monitoring system of the Hellenic Seas using REmote sensing satellite data and in-situ measurements (**MARRE**) cruise 25 – 28 Sept 2020

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

TOWARDS FRM IN THE EASTERN MEDITERRANEAN
Processing & matchup protocols

Following NASA protocols (Mueller et al., 2003) since 2007, IOCCG protocols (Zibordi et al., 2019) since 2020 (and now starting to adopt EUMETSAT matchup protocols)





Regression statistics

Sensor	No. obs.	R	R^2	RMSE	Slope	Intercept
JRC cruise	33	0.960	0.921	0.00096	0.993	0.0003
PERLE 2	44	0.966	0.933	0.00084	1.106	0.0001

L_{wn} uncertainty budget (%) at OLCI wavelengths (nm)												
Source	**400**	**412**	**443**	**490**	**510**	**560**	**620**	**665**	**674**	**681**	**709**	**Method**
L_u radiometer lab calibration	2.3	2.0	1.9	1.9	1.8	1.8	1.8	1.8	1.8	1.8	1.8	TO lab FEL lamp-reflectance panel (0°/45°, k=2)
L_u instrument characterisation												
Immersion factor	0.2	0.2	-0.6 0.2	0.2	0.2	-0.9 0.2	0.2	-1.2 0.2	0.2	0.2	0.2	Zibordi et al., 2018 Zibordi et al., 2018
Temp. response	0.02 0.4	0.2	0.2 0.01 0.2	0.01 0.2	0.2	-0.3 0.03 0.2	0.2	-0.7 0.09 0.2	0.2	0.2	0.2	Zibordi et al., 2017, 2018 Vabson et al., 2019a (lab) Vabson et al., 2019b (field)
Polarization sens.	0.2	0.2	0.1 0.2	0.2	0.2	0.2 0.2	0.2	0.5 0.2	0.2	0.2	0.2	Talone & Zibordi, 2016, Zibordi et al., 2018 Vabson et al., 2019b (field)
Straylight effects	0.2 0.9	0.2	-1.0 0.2 0.7	0.2 0.3	0.2	0.5 0.2 0.3	0.2	0.4 0.2 0.7	0.2	0.2	0.2	Talone et al., 2016 Zibordi et al., 2018 Vabson et al., 2019a (lab) Vabson et al., 2019b (field)
Nonlinearity	0.11	0.07	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	TO laboratory characterization (k=1).
E_s radiometer lab calibration	2.1	2.0	1.8	1.8	1.8	1.8	1.8	1.7	1.7	1.7	1.7	TO lab FEL lamp (k=2)
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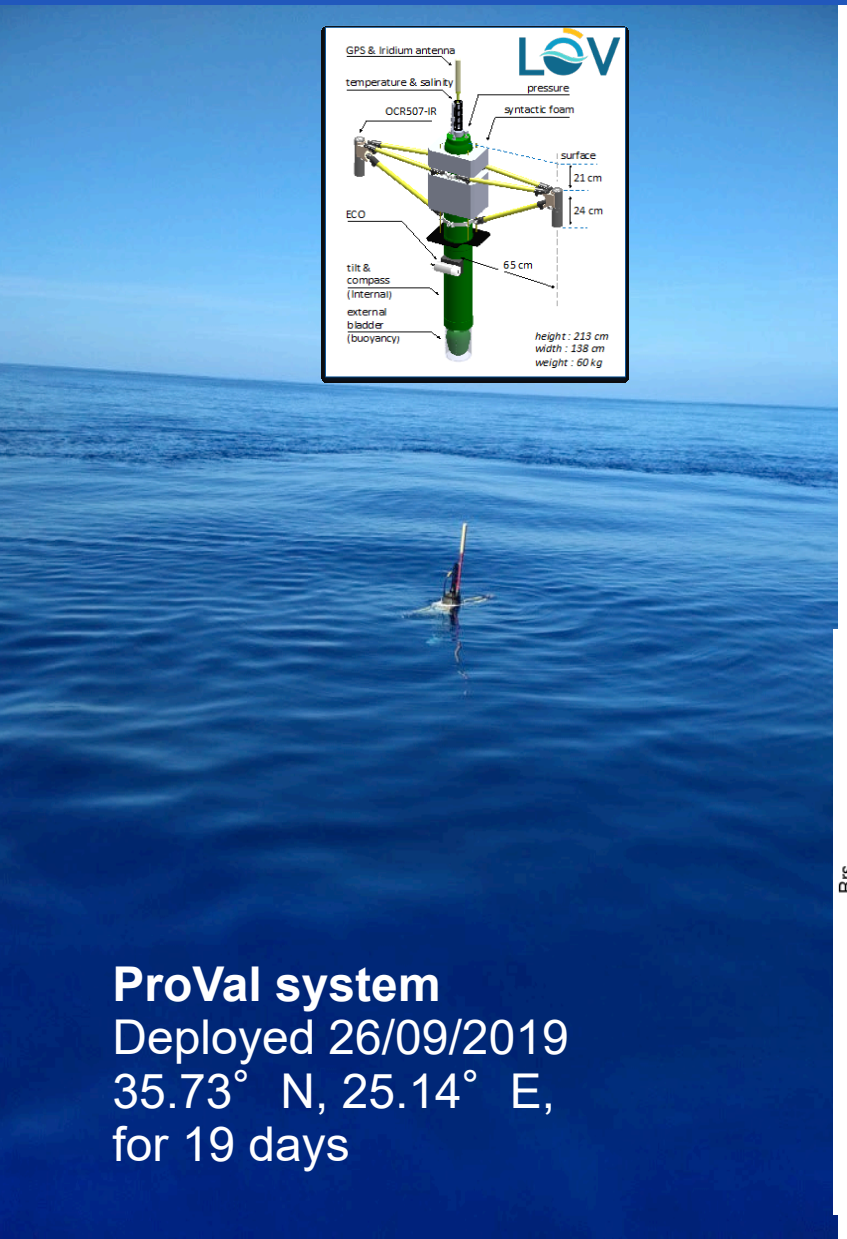
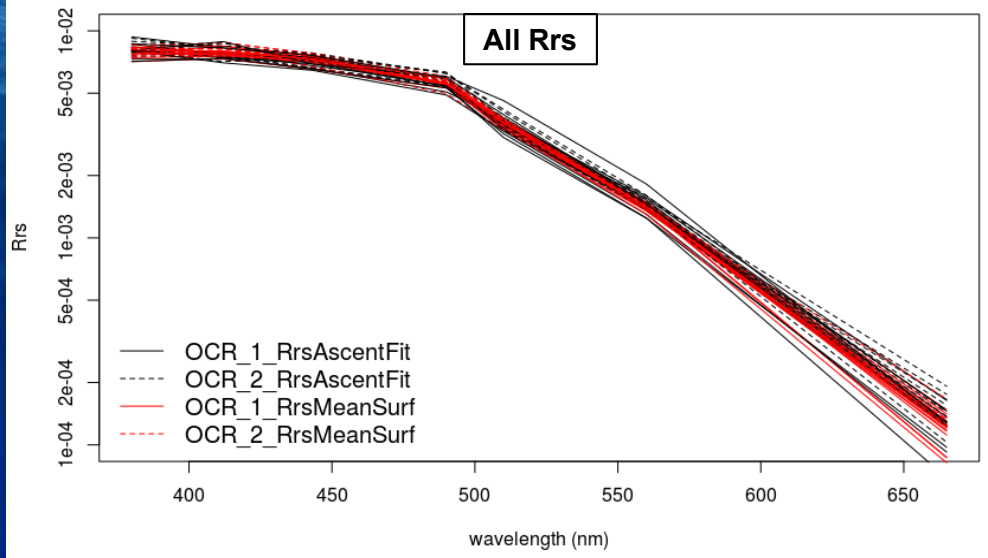
Temp. response	0.02 0.4	0.2	0.2 0.01 0.4	0.01 0.2	0.2	-0.3 0.03 0.2	0.2	-0.7 0.09 0.2	0.2	0.2	0.2	Zibordi et al., 2017,2018 Vabson et al., 2019a (lab) Vabson et al., 2019b (field)
Straylight effects	0.2 0.9	0.2	-1.0 0.2 0.7	0.2 0.3	0.2	0.5 0.2 0.3	0.2	0.4 0.2 0.7	0.2	0.2	0.2	Talone et al., 2016, Zibordi et al., 2018 Vabson et al., 2019a (lab) Vabson et al., 2019b (field)
Nonlinearity	0.09	0.06	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.01	TO laboratory characterization (k=1)
Cosine response	1.3	0.8	0.6	0.3	0.2	0.2	0.2	0.3	0.3	0.3	0.2	TO laboratory characterization (k=2)
Field / environmental / other												
Self-shading correction	0.3	0.3	-1.2 0.3	0.3	0.1	-0.9 0.1	0.8	-3.2 0.8	0.8	0.8	0.8	Zibordi et al., 2018 Zibordi et al., 2018
Anisotropy corr.	0.4	0.4	0.4	0.4	0.9	0.9	0.5	0.5	0.5	0.5	0.5	Zibordi et al., 2019
E_0 determination	1.9	1.9	1.9	1.9	0.8	0.8	0.2	0.2	0.2	0.2	0.2	Zibordi et al., 2019
Environ. effects	2.1	2.1	2.1	2.1	2.2	2.2	3.2	3.2	3.2	3.2	3.2	Zibordi et al., 2018
Combined (k=2)	5.1	5.1	**5.1**	5.1	3.8	**3.8**	6.1	**6.1**	6.1	6.1	6.1	

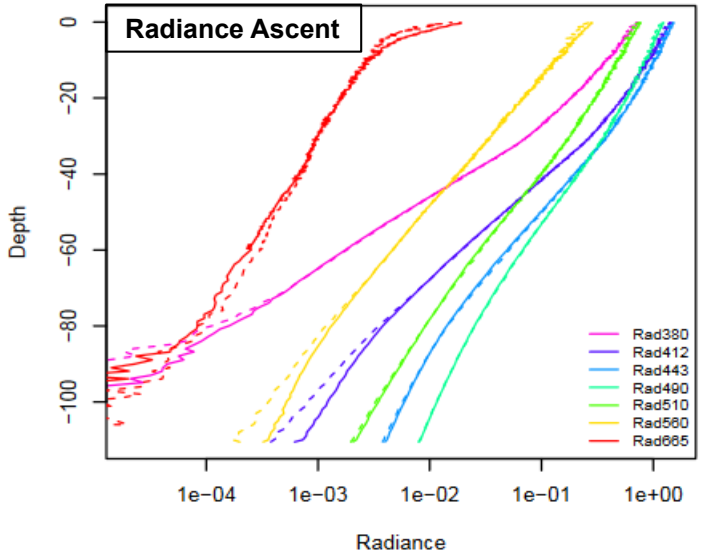
TOWARDS FRM IN THE EASTERN MEDITERRANEAN
Other advanced OCR in-water systems deployed in Crete



ProVal system
Deployed 26/09/2019
35.73° N, 25.14° E,
for 19 days

Initial (very promising) results: 20 cloud free S3A-OLCI matchups over 3 weeks



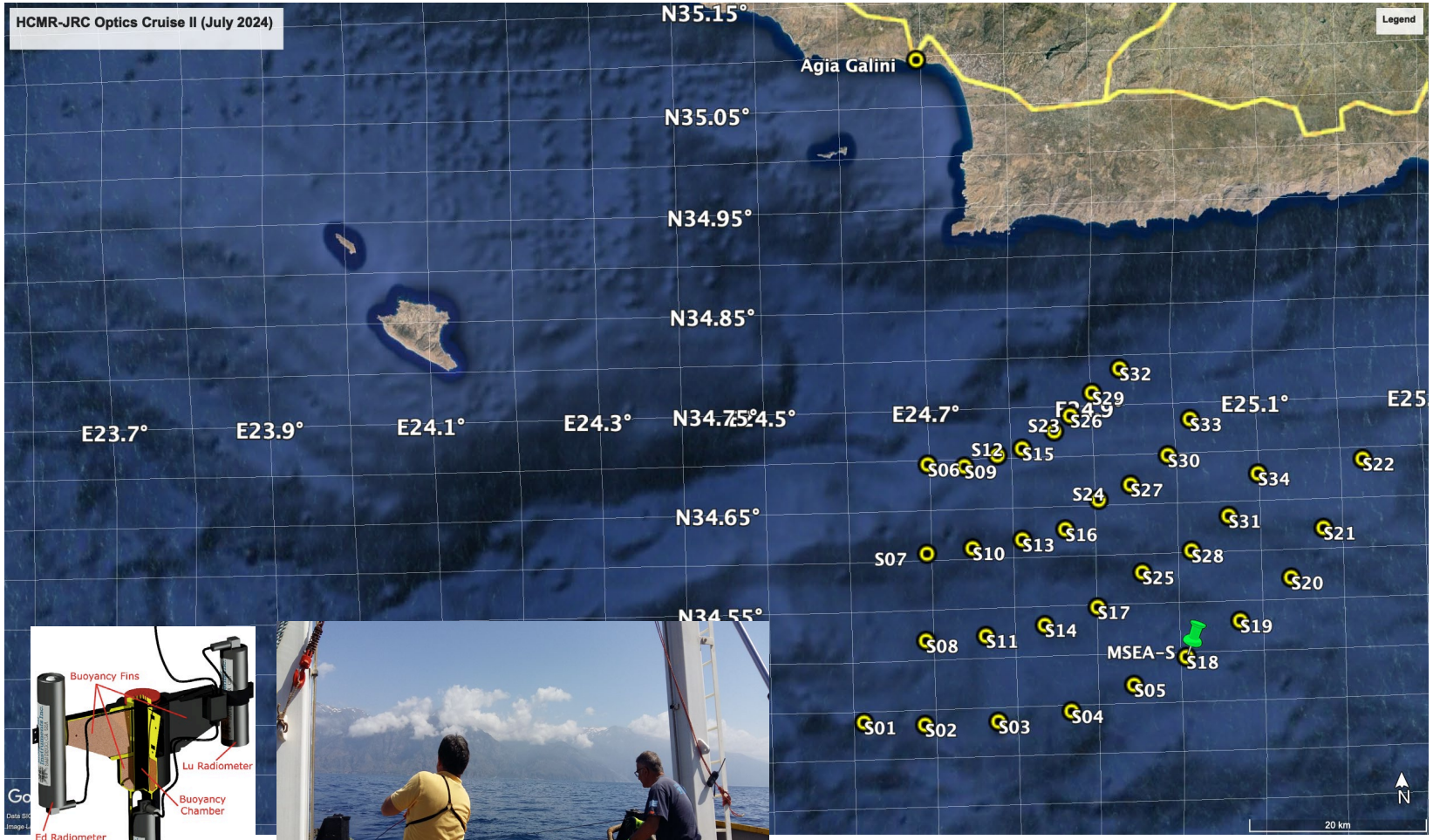


TOWARDS FRM IN THE EASTERN MEDITERRANEAN
Key upcoming cruise – JRC-HCMR optics cruise II, July 2024

JRC-HCMR optics cruise II in Crete, 15-30 July 2024

Planned sampling:

- 4 sets of radiometry data, JRC Satlantic, Biospherical and TriOS in-water profilers; HCMR above water TriOS system.
- IOP profiles from JRC AC-9 and Hydroscat-6 to 35m; HCMR AC-S and ECOBB3 + LISST-Deep & LISST-Holo 2 particle measurements to 150-200 m.
- Surface water sampling and Niskin bottle sampling down to 150-200 m for filtration and lab analysis – HPLC, aCDOM, aph, adt, adg.
- CTD profiles with fluorescence to 150-200m



Towards FRM in the Eastern Mediterranean
A few lessons learnt

Calibrations / characterisations

- Allow a substantial budget in projects and enough time before cruises for this. It is expensive and time consuming – FRM4SOC free calibration offer very welcome.
- More OCR calibration labs needed in Europe but building your own lab is a long and expensive process – guidelines / advice from FRM4SOC, NPL, TO and JRC invaluable.
- Applying characterisation corrections on your own takes considerable effort and is complex – thank goodness for class based work by JRC and FRM4SOC.

Measurement and processing

- Carefully follow FRM4SOC and IOCCG protocols – have checklist onboard.
- Keeping exact relative azimuth angle to sun on an R/V very difficult (captains attention, prevailing weather direction etc.). Always record angle away from ideal orientation relative to sun. Simple indicator for captain very useful.
- Try to evaluate your own environmental uncertainties for your cruise setup.

Uncertainty budgets

- Evaluating an uncertainty budget on your own takes considerable effort and is complex. Thank goodness for FRM4SOC and the community processor!
- Need a standardized way of evaluating the in situ and satellite uncertainties in the validation process – coming in ThoMaS?

Comparisons

- Try to get involved in field intercomparison exercises.

TOWARDS FRM IN THE EASTERN MEDITERRANEAN
Lessons learnt – quality assurance

Contact: andyb@hcmr.gr