FRM4SOC Field Inter-Comparison Exercise (FICE) Implementation Plan D-200 (FICE-IP).

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Plymouth Marine Laboratory, Remote Sensing Group

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CONTENTS

APPLICABLE DOCUMENTS

Ref. No.	**Version / Issue**	**Document Title**
1-8500 SoW	1	Fiducial Reference Measurements for Satellite Ocean Colour (FRM4SOC) Statement of Work (SOW)

ACRONYMS AND ABBREVIATIONS

ESA	European Space Agency
FRM	Fiducial Reference Measurements
IR	Infra-Red
IOCCG	International Ocean Colour Group
ISO	International Organization for Standardization
JRC	Joint Research Centre
LCE	Laboratory Calibration Exercise
NMI	National Metrology Institute
PML	Plymouth Marine Laboratory
OCR	Ocean Colour Radiometry
RBINS	Royal Belgian Institute Natural Science
TO	Tartu Observatory
TR	Technical Report

1 INTRODUCTION

To underpin the validation of satellite OCR, it essential that above and in water radiometers used to collect FRM's, to ascertain the accuracy of Sentinel 2 & 3 products, are inter-compared to assess data consistency and characterise uncertainties between instruments. In the absence of such field inter-comparisons, the use of a wide range of instruments, methods and laboratories may only add to the uncertainty in the accuracy of Sentinel 2 & 3 products. The primary data product in satellite ocean colour used to generate biogeochemical concentrations of chlorophyll a (Chl a) and total suspended matter (TSM) that are widely distributed to the user community for monitoring the marine environment, is the spectral remote sensing reflectance (R_{rs}) measured from the satellite sensor as the top of atmosphere radiance. Measurements of this parameter in situ are generally obtained through the deployment of in-water and above water optical measurement systems (OMS). OMS include fixed platforms, ships and tethered buoys.

2 OBJECTIVES

The FICE will address the following Objectives:

A. A range of different OMS methods will be deployed, including above water radiometry, underwater profiling, underwater measurements at fixed depths or combined above/underwater measurements from floating systems.
B. The same processing schemes will be applied to the data from these systems and differences between radiometers will be quantified.
C. The same calibration sources and methods for the absolute radiometric calibration of field instruments will be used and uncertainty budgets for each sensor will be estimated.

3 ORGANIZATION

3.1 PILOT

Repetition of the errors reported in these previous NASA SIRREX and SIMRIC and ESA MVT field inter-comparisons will be reduced by:

- Calibrating all sensors at the same reference laboratory using the same plaques and and radiation sources traceable to SI standards prior to the AAOT.
- Use of SeaPRISM (*above-water*) and WiSPER (*in-water*) as reference sensors.
- Reducing environmental effects including tilt and roll and illumination geometry by using the stable AAOT platform.
- Reducing environmental effects as a result of heterogeneous conditions by conducting continuous above-water radiometry measurements throughout daylight hours for a period of ~5 weeks.

The FICE experiments will be conducted at two principal platforms:

A. The Acqua Alta Oceanographic Tower (AAOT).
B. The Atlantic Meridional Transect (AMT).

These have been chosen as they both have a long history of use for satellite ocean colour validation and development during recent NASA and ESA missions (e.g. O'Reilly et al. 1998;

Zibordi et al. 2006). Both platforms offer excellent deployment conditions for above water, floating and underwater profiling systems (e.g. Hooker et al. 2005), provide a range of oceanographic conditions to characterise measurement uncertainties and allow a large number of measurements to be taken per day (Brewin et al. 2014; Zibordi et al. 2002). Good agreement between radiometric sensors was achieved at the AAOT under ARC MERIS MVT because of the stability of the platform and the near ideal deployment conditions experienced at its location. The use of multi- sensor and method comparisons at the AAOT and long track above water radiometric comparison on the AMT will provide the volume and quality of data for a stand-alone publication in potentially high impact factor journal.

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A. FICE-AAOT.

The Acqua Alta Oceanographic Tower in off the Gulf of Venice, Italy, in the northern Adriatic Sea is a purpose built steel tower with a platform containing an instrument house to facilitate the measurement of ocean properties under exceptionally stable conditions. The platform has a long history of optical measurements to support and validate both NASA and ESA ocean colour missions (Zibordi et al. 2006; 2009b). An autonomous OMS has been developed at the tower, the data from which are widely used and accessed by the ocean colour community for satellite validation (Zibordi et al. 2004b, 2009c). Both *in*- and *above-water* optical measurements at the AAOT are taken under near ideal conditions due to the stability of the platform which has a fixed geometry, the frequency of clear sky conditions, the relatively low sun zenith angles and moderate to low sea states that are experienced at the tower. The water type at the tower can vary from clear open sea to turbid coastal. The atmospheric conditions are mostly dominated by continental and occasionally maritime, aerosols. This variability offers the opportunity perform field inter-comparisons under a wide range of environmental conditions. Continuous data acquisition of above water radiometry coupled with field campaigns to characterise the in water optics makes this site unique in the ability to inter-compare an array of sensors and methods at any one time.

The AAOT-FICE will be undertaken in June-July 2017 (KO+12 tbd) over eight days for simultaneous deployment of *in-* and *above-water* water radiometers listed in **Table 1**. All optical sensors will be inter-calibrated against the same standards and methods prior to the FICE. The data products listed in **Table 2** will be inter-compared. Data analysis will be conducted on centre wavelengths for Sentinel 2 & 3 (400, 412, 442, 510, 560, 620, 665, 673, 681, 708 nm). Uncertainty budgets will be quantified for each system and method.

PARTICIPANTS

PML, JRC, RBINS, and TO will take part in the FICE-AAOT, plus a further 3-4 laboratories from the candidate laboratories given in **Table 1**. To extend the FICE-AAOT to an International level, we have budgeted for major US and Australian laboratories, as representatives of the NASA and ESA ocean colour vicarious calibration and validation community, to participate in this FICE. In addition, further European Laboratories who played an active role in the validation and development of MERIS products will also be invited to participate. The range of laboratories will not only provide a broad cross section of the International Ocean Colour community, but also offers comparisons between different optical sensors and methods.

PARTICIPANTS’ DETAILS

Table 1. Candidate laboratories, including radiometric sensor type and method (viewing angle) for participation in the FICE-AAOT. (Information based on *Zibordi et al. 2012*). (N.B. PML, JRC, RBINS will also participate in the FICE-AMT - see below).

Laboratory (representative)	Measurement type: spectral range; resolution (viewing angle of radiance)	Sensor type
Plymouth Marine Laboratory (Dall’Olmo)	Above-water manned: hyperspectral Data; 400– 900 nm; 10 nm resolution (7 °)	SATLANTIC HyperSAS
EU Joint Research Centre (Zibordi)	In water manned: Continuous profiles of multispectral data; 400–700 nm; 10 nm resolution (18°)	WiSPER
EU Joint Research Centre (Zibordi)	Above water: multispectral data; 400–1020 nm; 10 nm resolution (1.2°)	SeaPRISM
Royal Belgium Institute of Science (Ruddick)	Above-water manned: hyperspectral Data; 400– 900 nm; 10 nm resolution (7 °)	TRIOS RAMSES Hyperspectral Radiometers
Tartu Observatory (Ligi)	Above-water manned: hyperspectral data; 400–900 nm; 10 nm resolution (7 °)	TRIOS RAMSES Hyperspectral Radiometers
University of Miami (Voss)	In water manned: hyperspectral 350 to 700 nm; 3.3 nm resolution.	HPLSeries of radiance radiometers and the HSE series of irradiance radiometers

		(HyperPRO II, Satlantic Inc.)
University of Curtin & Villefranche-Sur-Mer (Antoine)	In water autonomous: two fixed depths; Multispectral - 412, 443, 490, 510, 560, 670,681nm. 10 nm resolution (7 º)	SATLANTIC 200-series radiometers
University of Curtin & Villefranche-Sur-Mer (Antoine)	Above water autonomous: Multispectral - 412, 443, 490, 510, 560, 670,681nm. 10 nm resolution (20 º)	SATLANTIC Multichannel Visible Detector System (MVDS) 200-series radiometers
Bigelow Laboratory for Ocean Sciences (Balch)	Above water autonomous: Multispectral (412, 443, 490, 510, 531, 555, 670 nm); 10 nm resolution (7 º)	SATLANTIC MicroSAS on automated pointing system with rotating gimble to track sun position & reduce tilt and roll
Helmholtz-Zentrum Geesthacht (Krasseman)	Above-water manned: hyperspectral Data; 400– 900 nm; 10 nm resolution (7 º)	TRIOS RAMSES Hyperspectral Radiometers
Laboratoire d'Océanographie de Villefranche-sur-Mer (Claustre)	In water: ProVal float system; multispectral data; 400– 900 nm; 10 nm resolution (20º)	SATLANTIC Multichannel radiometers
Institute of Oceanology of the Polish Academy of Sciences (Darecki)	Above-water manned: hyperspectral Data; 400– 900 nm; 10 nm resolution (7 º)?	TRIOS RAMSES Hyperspectral Radiometers?
Norwegian Institute for Water Research (Sorensen)	Above-water manned: hyperspectral Data; 400– 900 nm; 10 nm resolution (7 º)	TRIOS RAMSES Hyperspectral Radiometers
Stockholm University & Bio-Optika (Kratzer)	In-water autonomous fixed depth multispectral data; 400–700 nm; 10 nm resolution (20º)	TACCS: Tethered Attenuation Coefficient Chain Sensor
Sagremarisco Lda & Bio-Optika (Icely)	In-water autonomous fixed depth hyperspectral data; 350–800 nm; 11 nm resolution (18º)	TACCS

3.2 QUANTIFYING DIFFERENCES BETWEEN METHODS.

In-water radiometric continuous profiles are usually made by winch or freefall. The accuracy of the resulting radiometric products depends on the sampling depth interval and on the depth resolution (D'Alimonte et al., 2010; Zibordi et al. 2004a, 2012). In some environments (particularly coastal, case 2 waters), the heterogeneous nature of the optical properties, a high accuracy in in water radiometric products can only be determined by sampling close to the surface (e.g. TAACS in **Table 1**) and / or by producing a large number of measurements per unit depth (Zibordi et al., 2004b) as long as the variance in sensor tilt resulting from waves and currents is eliminated or reduced.

In-water fixed-depth profiles are normally obtained from the deployment of optical sensors on buoys at fixed depths (e.g. Antoine et al. 2008) or from buoys with autonomous profiling systems (e.g. Laurenco et al. 2000; Zielinski et al. 2006). These OPMs are capable of measuring L_u and E_d simultaneous at multiple depths. Assuming that tilt is negligible, the accuracy of the radiometric products is a function of the fixed depths used for the optical sensors, the acquisition rate and duration of logging interval (Zibordi et al., 2009a; 2012).

Above-water methods use measurements of total radiance from above the sea (L_T), sky radiance L_i and above water $E_d(0+)$ which are used to determine L_w. The measurement geometry is determined by the sea-viewing angle, the sky-viewing angle and the difference between sun and sensor azimuth angles (Deschamps et al., 2004; Hooker et al., 2004; Zibordi et al., 2004b). The accuracy of L_w is dependent on the degree to which sun glint can be minimized which is normally done by choosing suitable measurement geometries (nominally +135° viewing angle; Mobley, 1999). The application of statistical filtering schemes on L_T (Hooker et al., 2002a; Zibordi et al., 2002), correction methods based on known reflectance properties of seawater in the near-infrared (Ruddick et al., 2006), or polarisers to directly reduce sky- and sun glint (Fougnie et al., 1999) can also be used to minimise glint effects.

Each of these factors in the different methods will be considered in the FICE and the uncertainties arising from them will be calculated.

3.3 COMPARISON OVERVIEW

Table 2. FRM products that will be inter-compared during the FICE-AAOT and FICE-AMT.

Fiducial Reference Measurement	**Abbreviation**	**Units**
Above water Apparent Optical properties	**AOPs**	
Remote sensing reflectance	$R_{rs} = L_u/E_d$	sr^{-1}
Normalised water leaving radiance	nL_w	mW cm^{-1} µm^{-1} sr^{-1}
In water Apparent Optical properties	**AOPs**	
Photosynthetically active radiation	PAR	µE m^{-2} s^{-1}
Attenuation coefficient	K_d	m^{-1}
Euphotic depth	Z_{eu}	m
Downwelling Irradiance	E_d	mW cm^{-1} µm^{-1}
Upwelling radiance	L_u	mW cm^{-1} µm^{-1}
Upwelling irradiance	E_u	mW cm^{-1} µm^{-1}

Overview of AAOT:

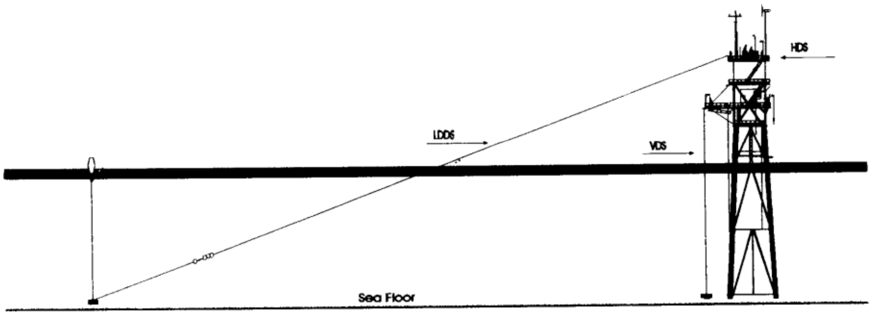
Methods of deployment from AAOT:

In-water measurements (from Zibordi et al. 2012)

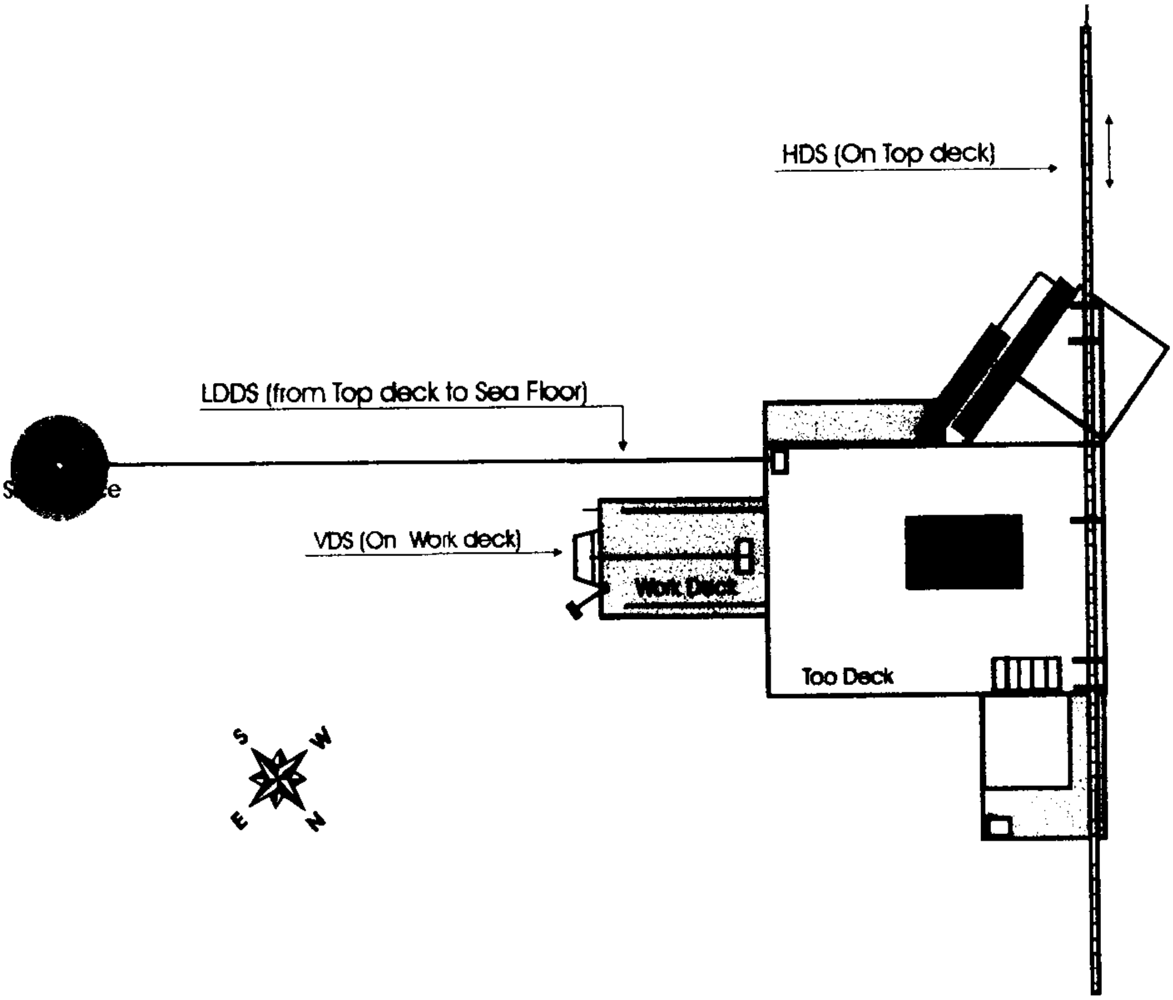
In-water radiometry relies on subsurface continuous or fixed depth profiles of upwelling radiance Lu(z,λ, t), downward irradiance Ed(z, λ, t) and occasionally also upward irradiance Eu(z, λ, t) at depth z, wavelength λ and time t . The above-water downward irradiance Ed(0+,λ, t) is also measured to complement the in-water data. These latter data are used to extrapolate to 0− (i.e. just below the water surface) the radiometric quantities which cannot be directly measured because of wave perturbations. Above-water downward irradiance data are used to minimize the effects of illumination, changes on in-water radiometric measurements during data collection.

In-water continuous profiles of radiometric quantities result generally from measurements performed with optical sensors operated on profiling systems (e.g. winched or freefall). Due to wave focusing and defocusing, the accuracy of sub-surface radiometric products largely depends on the sampling depth interval and on the depth resolution (Zaneveld et al., 2001; D'Alimonte et al., 2010). Thus, highly accurate in water radiometric products can only be determined by sampling near the surface (especially in coastal regions due to possible vertical non-homogeneities in the optical properties of seawater), and by producing a large number of measurements per unit depth not significantly affected by tilt (Zibordi et al., 2004a).

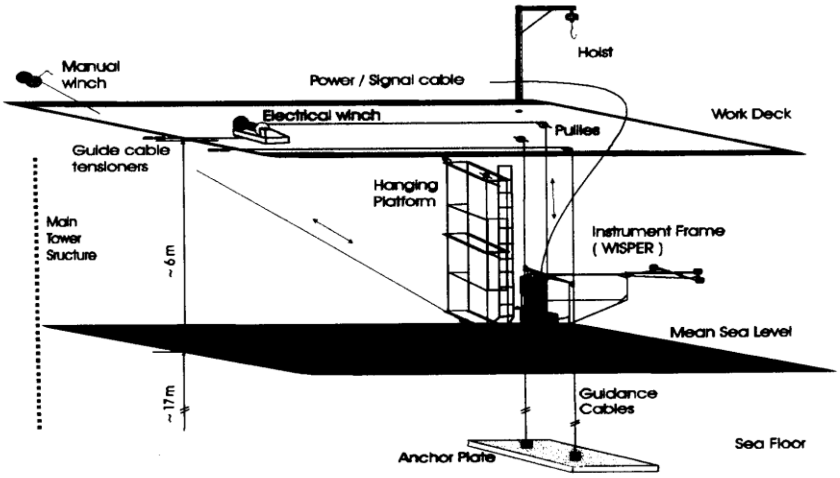
In-water fixed-depth profiles mostly result from the use of optical sensors operated on buoys at nominal depths. These buoy-based systems generally provide the capability of measuring Lu(z, λ, t), Ed(z, λ, t) and possibly also Eu(z, λ, t) at multiple depths (typically between 1 and 10m), in addition to Ed(0+, λ, t). By neglecting the effects of system tilt, the accuracy of radiometric products determined with buoy-based systems is a function of the discrete depths selected for the optical sensors, the acquisition rate and the duration of logging intervals (Zibordi et al., 2009).



Overview of AAOT:



Vertical deployment system of AAOT:



A. FICE-AMT.

The Atlantic Meridional Transect (AMT) has been operated by the Plymouth Marine Laboratory (PML) in collaboration with National Oceanography Centre (NOC) Southampton for the past two decades. The cruise is conducted between the UK and the sparsely sampled South Atlantic during the annual passage from October to November of a NERC ship (*RRS James Clark Ross, RRS James Cook or RRS Discovery*). The transect covers several ocean provinces where key physical and biogeochemical variables such as chlorophyll, primary production, nutrients, temperature, salinity and oxygen are measured. The stations sampled are principally in the North and South Atlantic Gyres, but also the productive waters of the Celtic Sea, Patagonian Shelf and Equatorial upwelling zone are visited, which therefore offers a wide range of variability in which to conduct FICE for the FRM4SOC.

There are few calibration / validation sites in the blue water oligotrophic gyres of the global oceans, because of the cost of accessing and maintaining measurement platforms in such remote locations. The NOAA moored buoy MOBY (off Hawaii) has been used during the US Sea viewing Wide-Field-of-view Sensor (SeaWiFS), Moderate-resolution Imaging Spectroradiometer (MODIS) and Visible Infrared Imaging Radiometer Suite (VIIRS) missions to provide vicarious calibration data to monitor and reference to satellite Level2 Reflectance (L2R) data. Both MOBY and BOUSSOLE (the CNRS, France optical moored buoy) provided this capability for MERIS, but there were few independent sites in deep blue, case 1 waters that are used for ocean colour validation. AMT therefore offers an excellent opportunity to conduct field inter-comparisons at these sites.

The AMT has an excellent heritage for ocean colour (OC) satellite calibration and validation. At IOC in 2014 and 2015, AMT was heralded as one of NASA SeaWiFS 10 greatest highlights and it was recommended this ocean observing platform be funded to provide vital calibration / validation data for future satellite missions. AMT not only provided vital FRM data for the duration of the SeaWiFS mission but also served as a developmental and inter-comparison platform for selecting the most accurate ocean colour algorithm for SeaWiFS.

Many of the early AMTs in the late 1990s were financially supported by NASA for the early pre- and post-launch work on the SeaWiFS. This work included in-situ radiometric measurements to compare against the satellite derived values of water leaving radiance and coincidental measurements of chlorophyll for vicarious calibration and algorithm development. Recent AMTs have renewed the optical drive with continuous, highly accurate and well calibrated measurements of hyperspectral absorption, attenuation and backscatter (Inherent Optical Properties – IOPs) using an established optical flow-through set-up (WET Labs ECO-BB3 meter and WET Labs ACs; see Dall'Olmo et al. 2012) working from seawater from the ship's clean flow-through system. Measurements of particulate absorption are calibrated with discrete HPLC chlorophyll measurements to derive continuous along-tack estimates of chlorophyll concentration (Brewin et al. 2014). This has resulted in unprecedented numbers of data points (e.g. 400 per cruise) for use in satellite validation work (e.g. **Figure 1**). PML have opportunistically taken coincident with hyperspectral radiometer measurements of water leaving radiance (SATLANTIC HYPERSAS; see **Figure 2**).

The AMT-FICE will inter-compare the *above-water* measurements listed in **Table 2**, and the sensors and methods deployed by PML, JRC and RBINS (see **Table 1**) along a 4000 mile transect in both productive and coastal waters as well as the clearest waters in the Atlantic Ocean and under Sentinel 2 and 3 swaths additionally allowing multi-sensor comparisons at the time of satellite match-ups. Uncertainty budgets on instrument calibration, measurement platform and measurement processing will be computed to ensure measurement traceability to NIST/NPL standards based on calibrations before, during and after the cruises. This will contribute to quantification of the errors in these FRMs and also in level 2 OLCI products in open ocean Atlantic environments.

The AMT-FICE will be conducted early in the project on AMT26 from 4 September to 11 October 2016 so that these initial ship-borne comparisons can be used to guide the main FICE at AAOT in 2017. The AMT-FICE will enable the consortium to develop knowledge of potential biases between measurements made by instruments under a range of operational and in water optical conditions. The AMT is costly and would be beyond the resources available to a single task and Lead within this ITT. PML will provide the ship time, personnel (both scientific, technical and ship) and additional data (CTD, biogeochemical concentrations, IOPs) at no cost to the project. Small resources are sought to cover the travel expenses of RBINS to and from the ship.

APPROACH TO DATA & AUTHORSHIP AGREEMENT.

3.4 TIMETABLE

There are four phases of the FICE, which are illustrated in Table 3. The first phase prepares for the measurements; the second phase is the measurements themselves and the third phase the analysis and report writing.

Table 3. FICE Implementation Plan Schedule

PHASE 1: PREPARATION	
International invitation to participate	September, 2016
Application form available on web site	September, 2016
Applications open until	January 2017

Selection of participants??	January 2017
Announcement of participation	January 2017
PHASE 2: AAOT Inter-comparison	
Radiometer shipment from TO to participants by	May, 2017
Participants to ship radiometers to AAOT by	June 2017
FICE AAOT 8 days excl travel. Dates pending confirmation from ISMAR	June-July, 2017 tbd
PHASE 3: AMT Inter-comparison	
Current dates for AMT27	4 Sept to Oct 2017
BoL's, CARs, COSHH, RA to be completed by July 2017	July 2017
Embarkation on RRS DISCOVERY	31 August 2017
Disembarkation in Azores	19 Sept 2017
Disembarkation in Falkland Islands	Oct 2017
PHASE 4: ANALYSIS AND REPORTS	
Calibrated sensors returned to participants	May, 2017
Participants to send raw data from AAOT inter-comparison	July, 2017
Draft A (results circulated to participants)	May, 2018
Final draft report circulated to participants	June, 2018
Data loaded to database	July, 2018
Final Report published	August, 2018

3.5 TRAVEL ARRANGEMENTS FOR FICE

Plymouth Marine Laboratory will be arranging all travel and hotel arrangements. The point of contact for this is:

Christina Devereux
Plymouth Marine Laboratory
Prospect Place
West Hoe
Plymouth
UK
PL1 3DH

Email: chpb@pml.ac.uk

Tel: 01752 633100

3.6 FLIGHTS TO VENICE & DIRECTIONS TO THE AAOT

The "acqua alta" research tower was installed on january 1970 off the gulf of venice, italy, by micoperi for the cnr. this tower consists of a platform containing an instrument house, supported by a steel pipe structure, similar to that of an oil well derrick. the pipe structure is hammered 22 m into the bottom through each of its four hollow legs. the tower is situated in 16 m of water (mllw). the gulf of venice site was chosen because it provided the best combination of desirable oceanographic features and practical operating convenience.

THE AAOT is located near to INSTITUTE OF MARINE SCIENCES - NATIONAL RESEARCH COUNCIL ADDRESS:

PML | Plymouth Marine Laboratory

ISMAR-CNRARSENALE - TESA 104, CASTELLO 2737/F 30122 VENEZIA, ITALY. TEL (+39) 041 2407927; FAX (+39) 041 2407940

Venice is connected to the mainland (Venezia Mestre) by the **“Ponte della Libertà”**, 4 km long, which allows road vehicles and trains to travel to the lagoon. The bridge leads to the **Cruise Terminal,** to the **“Tronchetto”** and **“Piazzale Roma” terminals** and to the **Railway Station**. **Vehicles cannot pass beyond these terminals**, so those arriving by car must park and those arriving by train must alight at Venezia Saint Lucia Railway Station.

By air:

If you are arriving at **“Marco Polo” airport**, located in Tessera (Venice mainland) take:

- the ALILAGUNA lines (public waterbus transportation) according to your destination. You can buy your tickets at the ticket offices located **a)** in the arrival hall; **b)** just in front of the waterbus stop or **c)** on board, with an additional fare of 1 EUR;

- the ACTV AERObus n. 5 to Piazzale Roma (20 minutes’ ride);

- the ATVO airport bus to Piazzale Roma (20 minutes’ ride);

- the car taxi (approximately 20 minutes’ ride);

- the boat taxi (approximately 90,00-100,00 EUR, 30-40 minutes’ ride).

If you are arriving at “**Canova” airport**, near Treviso, catch the ATVO bus-express (1 hour ride) to Piazzale Roma.

By train:

If you arrive by train, at the railway station of **Venezia Santa Lucia**, take the **boat** (**line 5.2** just in front of the railway station) and stop at **BACINI**. For the water bus service timetable please refer to the following **link**.

Hence walk according to the paths given in the map.

The entrance of the Institute of Marine Sciences is located at **Tesa 104** (“Tesa” is the name of the single attached building where ships were originally built).

By car:

When you drive to Venice and **park your car at Piazzale Roma** or **at the Tronchetto Terminal**, it is possible within walking distance to reach **Actv landing stages for the main public transport waterbus routes.**

Parking places here are limited and expensive, but other car parking facilities are available on the mainland and are linked with the city through public transport.

Check availability and rates from VeneziaUnica website by clicking on "PARKING"**.**

From Piazzale Roma, take the **boat** (**line 5.2** at the waterbus stop located in front of the Railway Station) and stop at **BACINI**. For the water bus service timetable please refer to the following **link**.

Hence walk according to the paths given in the map.

The entrance of the Institute of Marine Sciences is located at **Tesa 104** ("Tesa" is the name of the single attached building where ships were originally built).

Tickets

An ordinary ticket for the in town navigation service costs **7,50 EUR*** and you can travel on any route (except Alilaguna lines, ACTV routes n. 16, 19, 21 and Casino) with route changes in the same direction, for 75 minutes from the moment of ticket validation.

You can buy conveniently-priced tourist tickets for trips with a minimum length of 24 hours to a maximum of 7 days. Another convenient solution is to buy "Carta Venezia" (Venice card) at the ACTV (boat ticket) office located in Piazzale Roma (this service is available only here and requires to provide a valid identity document). The cost is of 50,00 EUR* and allows to buy tickets at the local reduced fare (1,50 EUR* per ride). The card lasts for 5 years.

For more information on ACTV ticket prices, please refer to the **VeneziaUnica website.**

*** Please consider that costs are provided as a reference. Fares may change in time. For any updated information please refer to the VeneziaUnica website.**

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APPENDIX 1

HOTEL arrangements at AAOT

HOTEL	COMMENTS / FACILITIES
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