ENVRIplus DELIVERABLE

D1.5
REPORT ON OPPORTUNITIES AND APPLICATIONS OF UNMANNED OBSERVATORIES FOR USAGE ACROSS RIS

WORK PACKAGE 1 – NEW SENSOR TECHNOLOGIES: INNOVATION AND SERVICES

LEADING BENEFICIARY: CNR/ANAEE

Author(s):	Beneficiary/Institution
Carotenuto Federico	ANAEE / CNR IBIMET
Delauney Laurent	IFREMER
Dussud Loic	IFREMER
Gioli Beniamino	ANAEE / CNR IBIMET
Turpin Victor	CNRS
Zaldei Alessandro	ANAEE / CNR IBIMET

Accepted by: Laurent Delauney (WP 1 leader)

Deliverable type: REPORT

Dissemination level: PUBLIC

Deliverable due date: 30.04.2018/M36

Actual Date of Submission: 19.06.2019

ABSTRACT

Unmanned vehicles (UVs) are mobile platforms that can be either piloted remotely, either move autonomously using certain degrees of onboard/online intelligence. These kinds of platforms are progressively getting cheaper and accessible and they are penetrating more and more also in the world of scientific research. UVs in fact allow to investigate areas that are hardly accessible (or hazardous) for human researcher, and they are especially relevant for atmospheric, biosphere and marine domains since they allow spatialized sampling in terms of vertical profiles, horizontal transects or a combination of both. Unfortunately, the legislation regulating the usage of these kind of platforms are not moving as fast as their technical development and their spreading in the scientific world. This results in legislation that are often different across different European countries and therefore make transnational research quite difficult: it is often impossible to deploy a platform in a different country without serious legal risks. For UVs research a shared observatory between countries and RIs would be a major boon, allowing to transfer payloads and joint research campaigns between RIs in full compliance with each country own regulations. The aim of this deliverable is threefold:

1. Describe the situation of the usage of UVs in the Atmosphere/Biosphere and Marine domains
2. Describe the main normative constraints acting on the deployment of UVs in the various domains
3. Detail guidelines that can be adopted to create a transnational shared observatory for UVs in research

Project internal reviewer(s):

Project internal reviewer(s):	Beneficiary/Institution
Technical Reviewer	Christophe Waldmann (Marum)
RI Reviewer	Jerome Blandin (EMSO FR)

Document history:

Date	Version
24.10.2018	Draft for comments
04.04.2019	Corrected version
15.05.2019	Accepted by Laurent Delauney

PROJECT SUMMARY

ENVRIplus is a Horizon 2020 project bringing together Environmental and Earth System Research Infrastructures, projects and networks together with technical specialist partners to create a more coherent, interdisciplinary and interoperable cluster of Environmental Research Infrastructures across Europe. It is driven by three overarching goals: 1) promoting cross-fertilization between infrastructures, 2) implementing innovative concepts and devices across RIs, and 3) facilitating research and innovation in the field of environment for an increasing number of users outside the RIs.

ENVRIplus aligns its activities to a core strategic plan where sharing multi-disciplinary expertise will be most effective. The project aims to improve Earth observation monitoring systems and strategies, including actions to improve harmonization and innovation, and generate common solutions to many shared information technology and data related challenges. It also seeks to harmonize policies for access and provide strategies for knowledge transfer amongst RIs. ENVRIplus develops guidelines to enhance transdisciplinary use of data and data-products supported by applied use-cases involving RIs from different domains. The project coordinates actions to improve communication and cooperation, addressing Environmental RIs at all levels, from management to end-users, implementing RI-staff exchange programs, generating material for RI personnel, and proposing common strategic developments and actions for enhancing services to users and evaluating the socio-economic impacts.

ENVRIplus is expected to facilitate structuration and improve quality of services offered both within single RIs and at the pan-RI level. It promotes efficient and multi-disciplinary research offering new opportunities to users, new tools to RI managers and new communication strategies for environmental RI communities. The resulting solutions, services and other project outcomes are made available to all environmental RI initiatives, thus contributing to the development of a coherent European RI ecosystem.

TABLE OF CONTENTS

REPORT ON OPPORTUNITIES AND APPLICATIONS OF UNMANNED OBSERVATORIES FOR USAGE ACROSS RIS

1. INTRODUCTION

Unmanned vehicles (UVs) are seeing a greater and greater usage in scientific applications. A simple research in Web of Science for the terms “unmanned vehicle” for the years 2008-2018 shows an impressive increase of published papers with time (fig. 1).

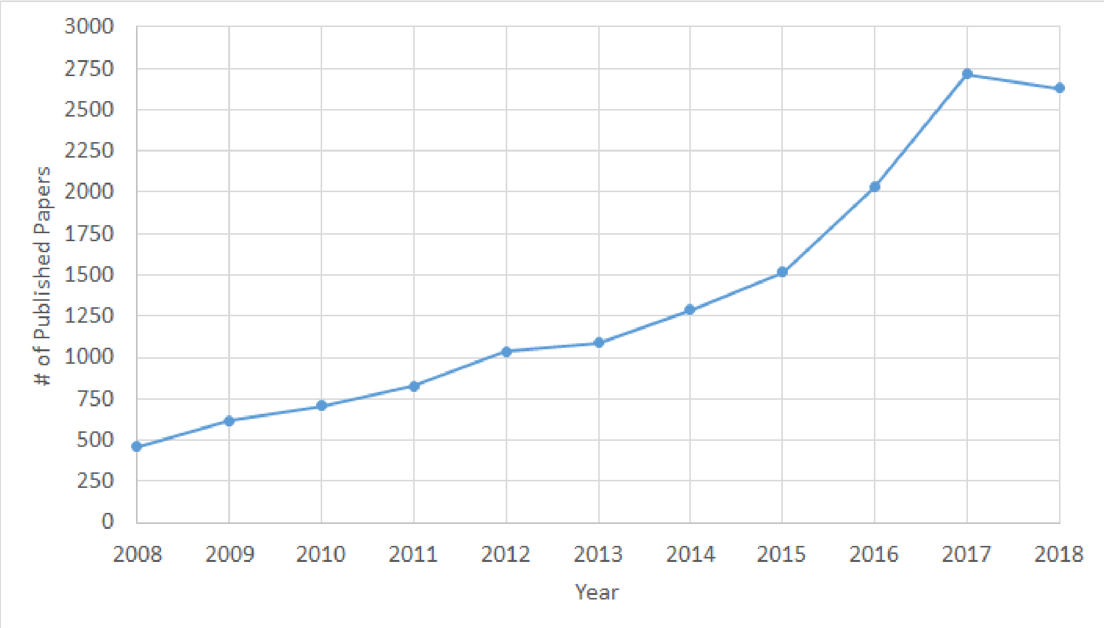

Fig. 1: Number of published papers containing the term “unmanned vehicle” in the past ten years (source: Web of Science, 2018).

This survey reveals how much these kinds of platforms are becoming accessible and pervasive in the scientific world, offering interesting possibilities for investigating even extreme environments in safety and giving the chance to perform wide surveys that would be unfeasible if performed by a human operator. While these platforms are flourishing, their handling is still not straightforward, often requiring a trained pilot (and, eventually, an operator) in order to be operational. This latter issue often restrains research groups that do not possess either the platform, either a way of operating it, even if UV-based surveys would benefit their research purposes. The aim of this deliverable is to investigate which opportunities do exist to create an inter-RIs observatory (or multiple ones) that allows any interested party to access these kinds of platforms for short-term scientific collaborations.

2. OVERVIEW OF UVS APPLICATIONS IN THE BIOSPHERE AND MARINE DOMAIN

2.1 UVS IN THE BIOSPHERE DOMAIN

As the editors noted in the preface of the special issue “Unmanned aerial vehicles for environmental applications” (2017), in the biosphere employed drones are mainly aerial ones that are fit for extremely high-resolution earth observation (EO) methods. Unmanned aerial vehicles (UAVs) equipped with the right kind of cameras and sensors are, in fact, able to perform surveys at a higher spatial resolution and reduced costs if compared with manned aircraft or satellite data. The main limitation in this case is the endurance of the vehicle itself: such high-resolution surveys are often spanning smaller areas than what manned aircrafts or satellites can achieve (Matese et al., 2015). The principal applications of UAVs within the biosphere domain are:

Remote sensing: UAVs equipped with a variety of optical-based sensors are used in research areas such as forestry (see e.g.: Torresan et al., 2017) and precision agriculture (see e.g.: Zhang & Kovacs, 2012) for obtaining high resolution data of the vegetated canopy. Imaging sensors operating in the visible light wavelengths (so called VIS-RGB cameras) as well as in other spectral bands (such as the near infrared or other wavelengths) can be employed to obtain information about the health of the vegetated canopy, to classify the species composing it, to estimate vegetation parameters, to monitor the spread of diseases or fires and finally to yield high-resolution georeferenced maps of the vegetated areas (Torresan et al., 2016; Zhang & Kovacs, 2012). LiDAR (Light Detection and Ranging) systems can also be mounted on UAVs in order to obtain a dense 3D point cloud and reconstruct canopy height and volumetry providing a quick way to estimate biomass production and other physical parameters of the canopy (see for example Wallace et al., 2012; Jaakkola, 2015 and Torresan et al., 2018).

Ecosystem processes investigation: the vertical take-off and landing (VTOL) capabilities of many UAVs, their fine horizontal movement and their capabilities of hovering have made them a cost-effective platform to explore meteorological parameters (see the short review from Anderson & Gaston, 2013). UAVs have been used to explore the turbulent structure of the atmosphere (Martin et al., 2011) on space and time scales that are useful for interpreting, for example, surface-to-atmosphere heat and mass exchanges (i.e.: scales appropriate to study the flux footprint).

Biological agents monitoring: UAVs have been recently used also to sample airborne biological particles suspended in the atmosphere. For collection purposes multiple sensors have been employed: from simple impaction onto Petri dishes (Lin et al., 2014; Powers et al., 2018) and spore collectors (Gonzalez et al., 2011) up to more complex and specific methods for quasi-real-time monitoring such as surface plasmon resonance (Palframan et al., 2014) and immunoassays (Anderson et al., 1999). The idea behind this kind of sampling is not only the detection of a potential pathogen, but also tracing its sources. Also, some microorganisms are potentially relevant to surface-atmosphere precipitation feedbacks (the bioprecipitation hypothesis, Morris et al., 2014) and it is therefore important to characterize and quantify them. The development of reliable sampling of biological agents via UAV is also of paramount importance as a potential response to bio-terroristic threats allowing the survey of an area without endangering human operators.

Wildlife survey: Imaging sensors alongside imaging classification procedures can be used also to track, count and classify wildlife (Gonzalez et al., 2016) with minimal disturbance for the animals and higher safety for the ecologists who don't have to get close to elusive but dangerous predators.

For the 4 research applications in the biosphere domain multiple kind of flying platform can be employed. A detailed classification of all the existent kinds and sizes of UAVs can be found in the excellent review from Hassanalian & Abdelkefi (2017), but from the point of view of biosphere research the main distinction is between fixed-wing and rotary-wings UAVs. Fixed-wing UAVs have a rigid fuselage and wings and resembles manned aircraft in their aerodynamic profiles; rotary-wing UAVs instead are propelled by one or more rotors generating lift due to the quick spinning of airscrews in a more helicopter-like fashion. Fixed-wings UAVs require space for take-off and landing and higher flight speeds compared to rotary-wings UAVs (Hassanalian & Abdelkefi, 2017), while rotary wings UAVs are VTOL platforms that can perform extremely slow flights in all directions and even hover in the air. The trade-off between fixed- and rotary-wings is endurance: fixed-wing platforms require less power to fly (Hassanalian & Abdelkefi, 2017) and are therefore able to cover larger areas compared to rotary-wings UAVs. Also, the distinct positioning between the nose of the platform and its propellers generates a relatively disturbance free area where instruments can be placed and this is especially important if atmospheric parameters (such as turbulence) needs to be measured: The M^2AV drone employed by Martin et al. (2011), for example, was a fixed-wings platform and not a rotary-wings one for this reason.

Given the number of platforms and sensors flooding the market each year is not straightforward to do a survey of the "most common" ones used in biosphere research. This is also because the choice of platform strongly depends, for example, on the area that needs to be covered, on the specific type of sensor that needs to be employed and on the technical expertise of the user who can, in fact, come up with custom built solutions. In the review from Torresan et al. (2017) about forestry applications of UAVs, for example, fixed- and rotary-wings platforms were equally distributed in the studied cases and off-the-shelf solutions were preferred to custom ones. In a meta-analysis and review of UAVs imagery for terrestrial system, instead, Singh & Frazier (2018) found a preference for rotary-wings platforms (65%) versus fixed-wings ones (30%) and noted that several studies reported building a custom platform tailored to the specific application. Nevertheless, concerning fixed wings operations the UAVs most reported in surveys and reviews are various model either from the Sensefly or Trimble manufacturers (Torresan et al., 2017; Colomina & Molina, 2014; Toth & Jóźków, 2016). As for rotary-wings UAVs most common manufacturers are Mikrokopter, Microdrones and DJI

(Torresan et al., 2017; Colomina & Molina, 2014; Toth & Jóźków, 2016; Singh & Frazier, 2018). Some platforms for the cited manufacturers are summed up in Table 1 and figure 2.

Model	Manufacturer	Type	Endurance (mins.)
SwingletCAM	SenseFly	Fixed Wings	30
EBee RTK	SenseFly	Fixed Wings	40-45
UX5	Trimble	Fixed Wings	50
X100	Trimble	Fixed Wings	45
Phantom 2	DJI	Rotary Wings	25
MD4-1000	Microdrones	Rotary Wings	90
MD4-200	Microdrones	Rotary Wings	30
HexaKopter	Mikrokopter	Rotary Wings	36
Okto 2-26	Mikrokopter	Rotary Wings	21

Table 1: list of "common" UAVs platform following Torresan et al., 2017; Colomina & Molina, 2014; Toth & Jóźków, 2016

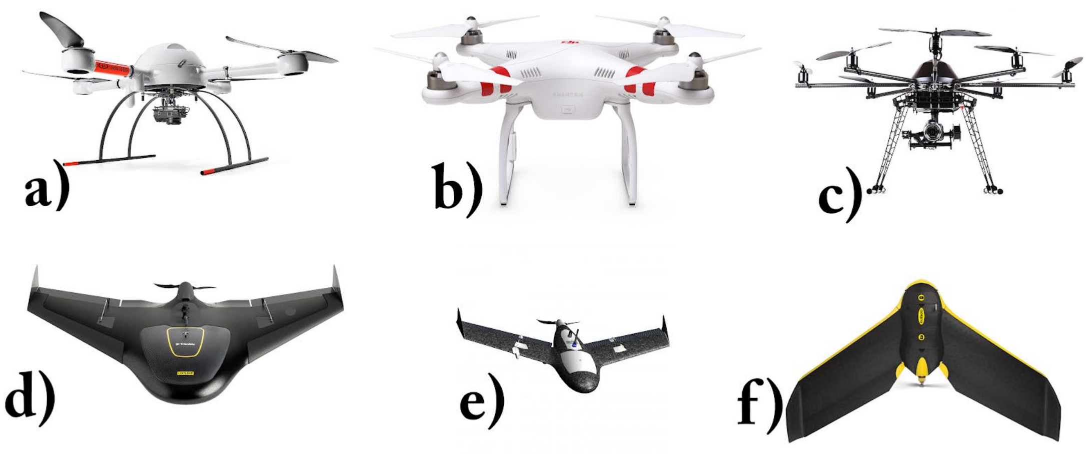

Fig. 2: Examples of "common" UAV platforms, from top to bottom and left to right: MD4-1000 Microdrones (a), Phantom 2 DJI (b), Okto Mikrokopter (c), UX5 Trimble (d), X100 Trimble (e), eBee Sensefly (f).

Heterogeneity is found also on the choice of deployed sensors: Torresan et al. (2017) found that for remote sensing applications above forest the majority of examined works either employed cameras operating in the visible spectrum (VIS-RGB, 40%), either multi-spectral cameras encompassing both the visible and the near infrared spectrum (MS-VNIR, 35%). Nowadays there's almost no limit to the kind of VIS-RGB cameras that can be mounted on a drone and researchers have employed almost anything ranging from commercial off-the shelf GoPro cameras (Singh & Frazier, 2018) up to proprietary cameras (such as Trimble ones, Colomina & Molina, 2014). Singh & Frazier (2018) in their meta-analysis report Canon-branded cameras as a popular choice, due to the possibility of incorporating custom scripts in the camera itself. The latter seems to be a recent trend: Canon cameras are not mentioned in the summary tables of Colomina & Molina in 2014, but they are present in Singh & Frazier (2018) and in Torresan et al. (2017). Other manufacturers that are consistently mentioned in recent reviews are Ricoh and Sony (Colomina & Molina, 2014; Torresan et al., 2017). For cameras recording in multiple spectral bands (multi- or hyper-spectral depending on the number of recorded bands) consumer-level market is more restricted leaving a relative number of manufacturers. Most models of multi and hyperspectral cameras work in the range between 350/400 and 900/1000 nm (i.e.: they are MS-VNIR cameras operating within the visible and near infrared spectra), independently from the manufacturer. Brands reported in review study include Headwall Photonics, Quest Innovations, MosaicMill and SPECIM (but for detailed lists see Colomina & Molina, 2014 and Adão et al., 2017). For thermal cameras, FLIR is one of the major players in the market for both consumer and research grade-equipment. Contrary to other multispectral cameras, thermal cameras tend to work in the regime above the near infrared (i.e.: with wavelenghths > 1 micrometer and < 1000 micrometers) allowing to explore different aspects of the vegetated canopy. LiDAR instruments (mainly produced by Ibeo, Velodyne and Riegl, Colomina & Molina, 2014) work as light-based radars: LiDARs use pulsed light sources and measure reflected pulses, thus measuring the distance between the sensor and the targets. Combining distance information in a 2D scanning matrix with attitudinal and positional information on the sensor itself it is thus possible to obtain 3D reconstruction of whatever the scanner is illuminating.

2.2 UAVS IN BIOSPHERE RESEARCH CASE STUDY: CNR IBIMET/ANAEE FLEET

IBIMET UAV fleet consists of three different platforms. All three are rotary wings UAVs tailored for different payloads and purposes. Two drones have been designed and built by IBIMET in collaborations with external partners (CNR-IBIMET-001 and CNR-IBIMET-002), while the third one is a commercial platform (DJI Spreading Wings S900). Main characteristics of the UAVs are summed up in Table 2

Characteristic	CNR-IBIMET-001	CNR-IBIMET-002 "EFESTO"	DJI Spreading Wings S900	CNR-IBIMET-001 "HORUS"
# Engines	12	6	6	12
MTOW (Kg.)	12	6	8.3	16
Max. Endurance* (mins.)	17	14	18	25
Max. Flight Altitude (m)	150	150	150	150
Flight Radius (m)	<500	<500	<500	<500

*: Endurance is payload-dependent. Heavier payloads reduce endurance.

Table 2: Main characteristics of the IBIMET UAV fleet.

Each of the UAVs is registered to the Italian Civil Aviation Authority (ENAC) and follows all the Italian regulations for unmanned vehicles. Each drone has its own operation manual, it has technical instrumentation onboard that complies with the required standards and follows all the required maintenance procedures. A new version of the CNR-IBIMET-001 UAV ("Horus") is currently in the assemblage phase by Sigma Ingegneria and is adopting bleeding-edge design innovations based on genetic design algorithms to maximize weight reduction in the chassis (figure 3 shows both the original version of the CNR-IBIMET-001 and some details of the new design).

Fig. 3: CNR-IBIMET-001 taking off (left) and 3D schematics of CNR-IBIMET-001 “Horus” (right). CNR-IBIMET-001 shows the LiDAR payload with the laser scanner in clear sight (black box underneath the drone). The two poles extending from the side of the laser scanner are the GPS antennas.

CNR-IBIMET-002 and the commercial DJI drone are lighter drones, with a reduced payload capacity and are shown in figure 4.

Fig. 4: CNR-IBIMET-002 “EFESTO” (left) and
DJI Spreading Wings S900 (right).

IBIMET UAVs are mainly tailored for precision agriculture research and as such mount commercial visible, thermal and multispectral cameras to investigate characteristics of the crop canopy and health (fig. 5), but IBIMET has designed two extra payloads for air-quality and 3D volume reconstruction.

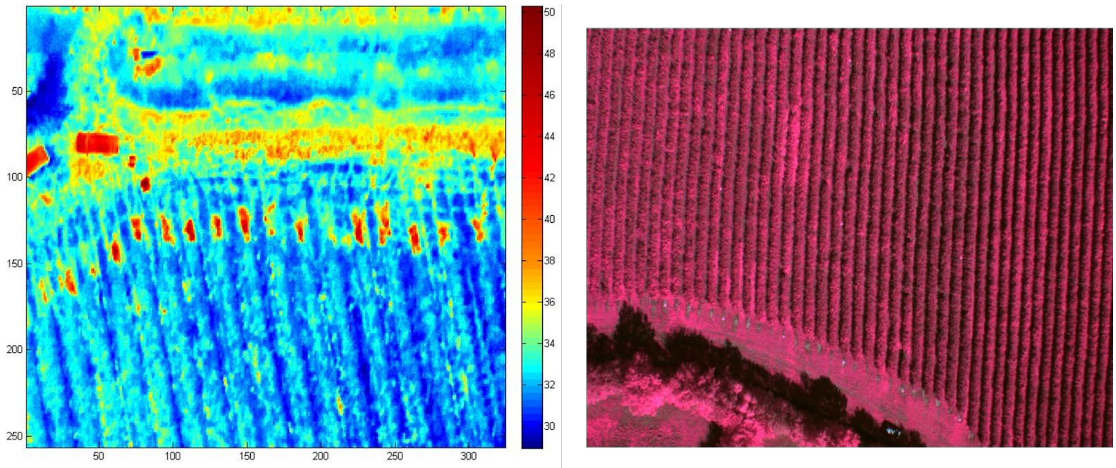

Fig. 5: Thermal (left) and multispectral (right) imaging in precision agriculture

The air quality payload is based on the low-cost air quality sensors (AIRQino) that have been presented in the Deliverable 1.6 of the same ENVRIPlus WP that has been modified with the inclusion of a pressure sensor to evaluate the altitude of the measurements (fig. 6).

Fig. 6: AIRQino airworthy air-quality payload.

3D volume reconstruction has been achieved by combining low-cost sensors to create a full-fledged LiDAR system with differential GPS correction to improve the precision in the position of the point-cloud. The system combines an automotive LiDAR (Ibeo automotive) with a VN-300 inertial navigation system (VectorNav) and a Reach RS+ (Emlid) differential GPS system (figure 3, left panel). IBIMET has developed a MATLAB-based post-processing routine that can reconstruct the volumes that the UAV is scanning both offline and in real-time (the outputs of this routine can be seen in figure 7).

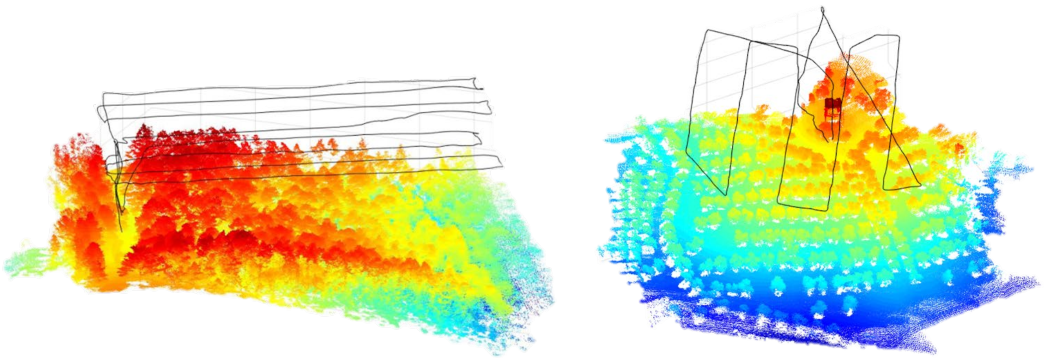

Fig. 7: 3D volume reconstructions from point-clouds:
coniferous forest (left) and olive grove (right).

IBIMET, following Italian regulations, has dedicated personnel for fleet responsibility, operational responsibility and on-site UAV piloting and maintenance and as such can readily address any deployment in the Italian area.

2.3 UVS IN THE MARINE DOMAIN

Unmanned Surface Vehicle (USV) is a growing trend for ocean in situ monitoring. However, the use of such medium for in-situ automated measurement is not without problems and questions. In addition, the diversity of possibilities for USV platforms

At first, some acronyms must be defined. Vehicles without anybody on board for marine applications are described as Unmanned Marine Vehicle (UMV). We can consider 3 types of UMV, Autonomous Underwater Vehicle (AUV), Remotely Operated Vehicle (ROV) and the subject of this section, Unmanned Surface Vehicle (USV). Sometimes USVs are qualified as Unmanned Ocean Vessel (UOV) that emphasized the fact that the vehicle is designed to run in open ocean and should behave well in rough ocean condition. UOVs are not huge unmanned vessel but transportable systems by two persons. The “Ocean” aspect is defined by their navigation capabilities and their unsinkable abilities.

Actual market and commercial catalogue is mainly oriented to lake application and gas/petroleum offshore services. Scientific surface vehicle is growing little by little and few systems are available for ocean deployment. Actual medium can be categorized in function of their purpose and capability in term of autonomy, navigability, payload capacity, energy availability, adaptability to in situ measurement; real time data transfer possibility, maintenance frequency for the embedded instrumentation, and, in some extent, global operation cost.

2.3.1 USV NEEDS

Many areas of study of the ocean and atmosphere require acquiring in-situ measurements in the vicinity of the ocean interface. Recent advances in the miniaturization of sensors and on-board electronics as well as in communication and localisation have led the development of new observational tools dedicated to this layer: microstructure profiler, fixed buoys, drifters, electric propulsion or sailing vehicles.

Among them, the platforms able to move in a controlled manner with a certain autonomy and equipped with substantial scientific equipment payload capacity have significant potential for process studies.

These vehicles can be deployed from shore for any specific area studies. In a periodic manner for area evolution trend studies or, for example, in an emergency situation for environmental assessment after a natural or industrial disaster.

Some other specific usages can be imagined. For example, during oceanographic campaigns in addition to classic tools related to oceanographic ship, USV can be used to acquire in-situ measurement outside the route of the ship in undisturbed surface water layers.

Various prototypes do exist and were used by the concepts described above. However technological choices need to be well chosen to comply with objectives and observation strategies: their propulsion systems, energy management, communications technology, control unit, and the on-board sensors. Sensors are a key point, which parameter can be measured by such systems and how the sensors are arranged on-board?

In the ocean, the main parameters identified are: temperature, salinity, pH, but also: fluorescence, O2, turbidity and at mid-term, nutrient and pCO2.

The temperature and salinity measurements collected by USV have similar use to those obtained with ocean drifters. Drifters are unmanned surface devices that drift on the ocean surface up to the surface ocean current. Both, drifter and USV, give information on the horizontal structure of the vertical gradient of temperature and salinity. More specifically, they can give information on rainfall events and assess their impact on satellite measurements (Reverdin et al., 2012). The advantage to use autonomous vehicle is the control of the path of the vehicle with greater speed than ocean drifters.

The collection of bio-geochemical parameters at several levels in the first meter layer and over a long distance (hundreds of kilometres) would be a considerable progress in understanding the role of organic matter in the carbon cycle (Gorgues et al., 2011). Indeed, a part of the accumulated surface organic material may upon degradation produces CO_2 and feed a surface ecosystem. At large-scale, by not taking into account this badly known process, this can (i) lead to an underestimation of the flow based on measurements below 2 meters depth, (ii) interfere with the measurement of the 'ocean colour' by satellites.

For the atmosphere and specifically to the problems of studies of ocean-atmosphere exchanges it is necessary to sample the different physical parameters for determining the flow at the interface. This type of autonomous and reduced size platform allows access to finest part of the atmospheric boundary layer without being too intrusive, where the exchanges are badly known and often parameterized in models. In particular, the variability of the ocean-atmosphere exchanges close to ocean frontal structures is imperfectly documented while it is the subject of many studies (see Small et al., 2008).

These approaches make it necessary to sample high frequency measurements, from various instruments and autonomously. The reliability and the adaptation of these instruments to USV are therefore relevant. Finally, in order to better understand the first meters of the marine atmospheric boundary layer, original instrumental approaches need to be developed and tested on USV.

2.3.2 UNMANNED SURFACE VEHICLES CATEGORIES

Surface vehicle for oceanographic in-situ measurements can be categorized in function of their purpose and capability. Actual market and commercial catalogue are mainly oriented to lake application and gas/petroleum offshore services. Scientific surface vehicles availability is growing little by little. For ocean applications only 3 or 4 systems with TRL above 7 (Technology Readiness Level 7: System technology prototype demo in an operational environment) are now available.

The proposed categories to be presented hereby are:

- Unmanned surface vehicle for shallow water (lagoon) (USV).
- Autonomous self-mooring vehicle (ASMV).
- Unmanned coastal Surface Vehicle (USV)
- Unmanned Ocean Vessel (UOV).
- Unmanned Hybrid Ocean Vehicle (UHOV).

Unmanned surface vehicle for shallow water (USV) are small systems (2 meters long at maximum) dedicated to hydrographic survey in harbours and inland water. Commonly, these vehicles are equipped with sonar for measurement of sediment thickness, object search (munitions, archaeological artefacts, wrecks). They are also dedicated to inspection of underwater constructions and infrastructure (pipes, cables, walls, etc.) and then equipped with camera (underwater and/or aerial).

A typical illustration of such equipment is the “Evo Logics Sonoboat” (fig. 8), that proposes 10 hours of operation, can be operated in auto routing or radio controlled. Such USV is approximately 35 kg and is commonly equipped with Echo sounders, GPS and cameras. The vehicle is propelled by hydro jet thrusters and data communication can be real time by WIFI connection (GPRS/UMTS) or stored on board.

Fig. 8: Evo Logics Sonoboat (Source: Evo Logics).
https://www.evologics.de/en/products/sonobot/index.html

Autonomous self-mooring vehicle (ASMV) is a specific category that is an hybrid system between USV and the fixed platforms (buoys). The vehicle can move between waypoints and is specifically designed to remain stationary like a fixe buoy to perform observations and measurement. Since these systems are dedicated for unattended long deployment from one days to several days, they are equipped with energy harvesting equipment like wind turbine and solar panels. Such system is for example the **C-Enduro** from ASV Limited company (fig. 9). This ASMV weights 350 kg and can move up to 6.5 knots. Commonly the deployment duration is about 30 days, the possible payload is quite important and can be keel mounted sensors, CTD (Conductivity, Temperature, Depth) lowered by winch, meteorological sensors, ADCP (Acoustic Doppler Current Profiler), MBES (Multi Beam Echo Sounder), side-scan sonar, PAM sensor (Pulse Amplitude Modulation), acoustic modem, ASW (Anti-Submarine Warfare) and electronic warfare.

Fig 9: ASV Limited (UK) – C Enduro Platform (Source : ASV Limited).
https://www.asvglobal.com/product/c-enduro

Unmanned coastal Surface Vehicle (USV) are systems designed to be deployed in coastal areas and under continuous supervision. The vessel can be autonomous in terms of navigation thanks to a GPS (Global Positioning System) and a routing software. The routing software can be embedded or on a shore station. The ground control station can be mobile (e.g. in a van) or fixed. In the case of onshore routing the vessel must be permanently connected by a robust data link that can be long distance WIFI, data GSM or other. This principle is known as M2M (Machine to machine) technology.

Such an arrangement for this application was developed as part of the **MOBESENS** EU project (MOBile watEr quality SENsor System) on a marine electrical propelled Kayak (c.f. fig 10). The kayak was customised for coastal marine in situ measurements and equipped with two winches designed to place down to forty meters deep a multi-parameter probe and a water sampler. The Mobesens Kayak has been designed to be operable by two persons and transportable on a trailer and a light vehicle. The MOBESENS Kayak can be piloted by the mean of a radio-controlled unit and a pilot able to see the USV. As well, the MOBESENS Kayak can be programmed in advance for the route, the waypoints and the *in-situ* measurements to perform. This allow to perform unattended missions if necessary.

Fig. 10: Ifremer MOBESENS Kayak (Source : Ifremer).
https://www.youtube.com/watch?v=FBSbjiZZFp0

Another particular Unmanned coastal Surface Vehicle is the **Vaimos** (Voilier Autonome Instrumenté de Mesures Océanographiques de Surface) sailing boat (c.f. fig 11).

Fig 11: Vaimos autonomous sailing boat (Source: Ifremer).
https://www.youtube.com/watch?v=PJWlKkKgAsc

The ocean surface mixed layer presents surface singularities for biogeochemical parameters. Those question the common view of a homogeneous mixed layer. However, the degree of ubiquity of these surface singularities and their horizontal structures remain largely unknown because of the lack of adequate instruments to sample the first centimetres of the ocean. So in order to be able to document the gradients of several parameters between the top centimetres and the sub-surface of the ocean, an autonomous sailboat able to sample the ocean surface at two depths (the first 10 cm and nearly 1 m) was developed in 2010 by Ifremer. The Vaimos USV is completely autonomous in terms of energy, navigation (except obstacle avoidance up to now), and measurement. It can perform very long mission and the autopilot has been very well proved at sea. The hull is derived from a standard mini-J which is a 1/10th scale model of the famous America's cup Class J and is equipped with a rig adapted from a "balestron" concept.

Consequently, the **Vaimos** USV is very efficient in open sea sailing condition. Vaimos USV can be controlled on sight by a remote control through a long distance WIFI link and a high-level Human Machine Interface (HMI): both keyboard and joystick controls are available. Offshore communications are possible via Iridium system. The Vaimos USV is equipped with a MPx NKE multi-parameter probe that can provide measurements for turbidity, fluorescence, dissolved oxygen, conductivity and temperature. The measuring system has been designed mostly like a "Ferrybox" system, sea water is pump thru a tubing system and the multi-parameter probe is placed in a specific measuring cell. The main difficulty is to avoid bubbles trapped in the circuit and to minimize bubble formation at the inlets. Two inlets have been arranged, one on the hull itself and one at the bottom of the keel, a two-way valve allows to select one inlet or the other and consequently to perform the measurement at two depths (10 cm and nearly 1 m) with the same multi-parameter probe. This insure at its best the inter-comparability of the measurements and save money in terms of measuring instrument on board.

IFREMER employs the USV **Speedoo** (fig. 12). Speedoo meets a specific need: Quickly and easily perform water extraction at sea, to 500 meters from the coast. It is a multifunction precision machine which measures 1 meter long and 30 cm wide. The device that weighs less than 15 kg, is transportable by one person and has multiple devices that enable it both to carry water samples but also to measure in situ the basic physicochemical elements (temperature, salinity, etc.).

Fig. 12: Speedoo supplied by Hydronalix - A sampling USV

Unmanned Ocean Vessel (UOV) are systems designed to be deployed in coastal areas and open sea without full time supervision. The vessel is autonomous in terms of navigation thanks to a GPS (Global Positioning System) and an embedded routing software. The supervision of the UOV is comparable to the supervision for gliders, it can be a specific technical/scientific team dedicated to the scientific project or an external operational entity dedicated to supervised many UOVs deployments. The companies that are providing such equipment commonly propose the supervision service. These systems are autonomous in term of energy needed to progress, they commonly use wind similarly to a sailing boat and one of them is using the swell.

The one using swell harvesting for motion is the Wave Glider from Liquid Robotics company. The originality of the concept is to propose an autonomous navigating system with a free platform optimized to expose on a wider as possible surface solar panels to gather energy for sensors and data transmission and if needed, additional motion. Moreover, the less equipment you have above the sea surface the more robust the system will in open ocean navigation. The concept used to gather swell energy is based on the fact that, as explain on Liquid Robotics website, “wave energy is greatest at the water’s surface, decreasing rapidly with increasing depth”. Consequently, the Wave Glider is made of a two-part architecture that exploits this difference in energy to provide forward propulsion as shown below in figure 13. The drawback of such design is the resulting size that makes more complex its handling, when, for example, it is launched at sea.

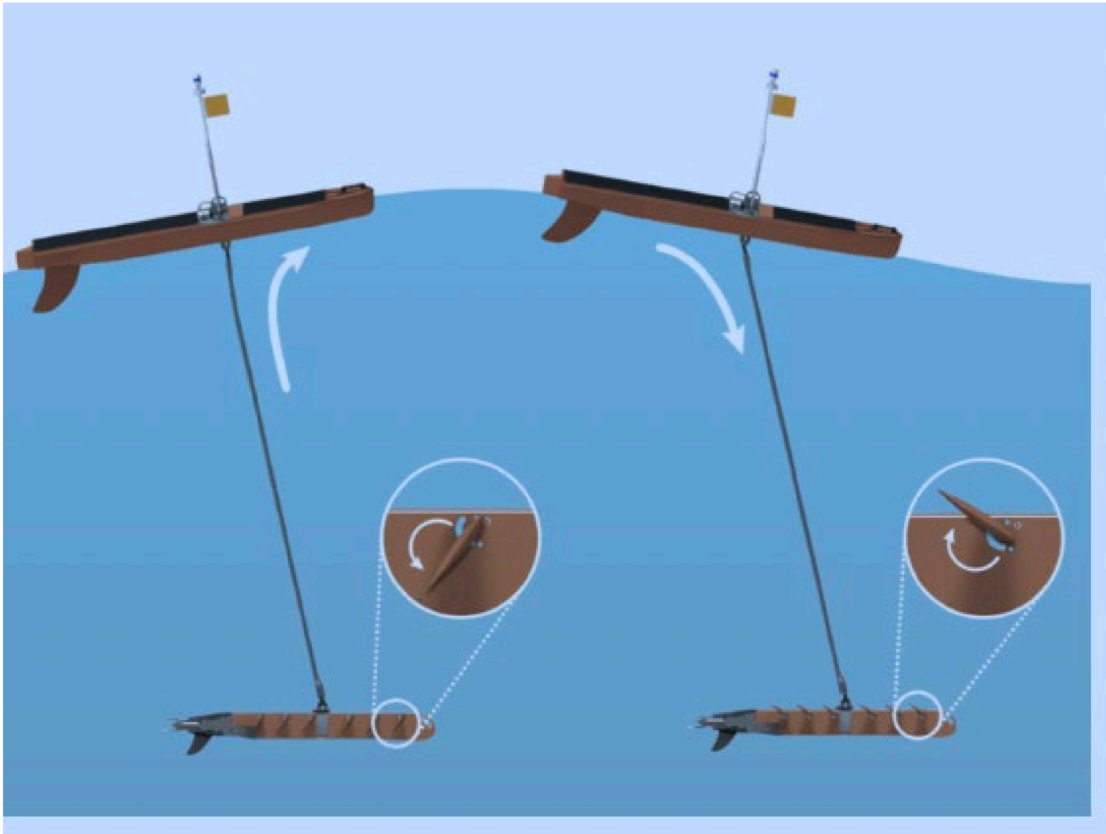

Fig. 13 Wave Glider (Liquid Robotics) swell harvesting concept.
Source: Liquid Robotics website. https://youtu.be/77Wg1MFsLpQ

The main advantage of such system is the autonomy that it provides. Indeed, the performances of the Wave Glider is a water speed between 1kt to 3kts with an endurance of up to 1 year. The Wave Glider has a payload capability of up to 500 kg mass and can provide an average continuous power of 5W to 20W. The battery storage capability proposed is between 0.9kWh and 6.8kWh. Data communications can be handled by satellite, cell or Wi-Fi. This allow to take on board a large range of measurement instruments.

The other USV for open ocean that is well established on the market is the Sail-Buoy from Offshore Sensing AS company (fig. 14). The principle of the system is similar to the Vaimos USV presented previously but here the design has clearly been driven by robustness and compactness. The Sail-Buoy can stand rough sea condition, announced operational on 9+ sea state (Beaufort wind force scale). The sail is made of a solid material, the size is very limited as well as the global weight (2m long and 1.13m height, 60 kg), then the equipment can be carried by two persons quite easily. The drawback of this design is the limited speed of the Sail-Buoy announced at 1-2 knots with a maximum of 3 knots.

Fig 14: Sail-Buoy USV from Offshore Sensing AS company
(Source: Sail-Buoy website - http://www.sailbuoy.no)

Futuristic Unmanned Hybrid Ocean Vehicle (UHOV): Announces are made by companies about futuristic unmanned ocean vehicle for environmental monitoring or multipurpose usages. Two of them are of prime interest.

The first one can be categorized as a Hybrid Unmanned Ocean Vehicle. It gathers the functionality of a USV (surface), of a AUV (underwater), and of a Profiler. The Submaran™ from the Ocean Aero company (USA) is declared as the first hybrid wind and solar-powered surface and subsurface vessel designed for extended ocean observation and data collection. The project seems to be at qualifying tests so as TRL6 (System/sub-system technology model or prototype demo in relevant environment).

The other examples that can be found are at even more low TRL level. Prototypes exists and demonstrations are performed, but only their motion capacities are demonstrated. The vehicles are designed for surface and underwater explorations but as well with flying capacities. The trendy technologies that are evaluated are based on multicopter scheme. The one that seems the most mature is the Naviator developed by Rutgers University. This looks promising but we must keep in mind that our concern hereby is monitoring of the surface of the ocean with in situ instrumentation. With multicopter, autonomy and payload capacity is too much limited for such objectives. That doesn't mean that this flying vehicle can be used for coastal measurement, by using cameras and telemetry equipment.

2.4 UVS IN MARINE DOMAIN CASE STUDY: EXAMPLES OF DEPLOYMENT

We reviewed many examples of unmanned surface vehicles with categorization to help the reader understand the purpose and capability of exposed systems. There are many other systems offered by companies and academic institutes, and almost every one of them would find a place in the proposed categorization. However, we must keep in mind that there is not a large amount of systems used in a systematic manner by the research teams. It's coming little by little but a tremendous work needs still to be performed to allow scientific teams to use these systems routinely. These systems are still a specialist job to operate, a dedicated team needs to be part of the operation and no every research laboratory can afford it. Including these systems in a Coastal Research Infrastructure organisation is one of the solutions, as it is for example, for the gliders. As well, private companies making USVs are proposing this service, but only for the models they build and sell.

Integration of instrumentation on board of such autonomous platforms is not an easy job. On the MOBESENS Kayak or on the C-Enduro, the instrumentation integration is more straight forward and based on a conventional commercial multi-parameter probe that is deployed in the water column by a winch and when the USV is stationary. Since the deployment of the instrument from the USV is very conventional, then the metrology approach can be very similar as described in the ad hoc best practices. When the instrumentation is included in a pumping system (Vaimos, Wave Glider, Sail-Buoy, Speedoo) the metrology approach is more complicated. The bias induced by the pumping system from the inlet to the outlet must be evaluated. It can be for example temperature elevation, pressure effect (due to pumping), bubbles and hydrodynamic effect. This metrology approach is similar than the one needed when measurements are performed with a Ferrybox system or a buoy equipped with a pumping system, the global uncertainty of the measurements produced must then consider the whole platform system. This is a heavy work to properly performed.

Biofouling is an important limitation when in situ measurement is performed in the ocean, especially close to the surface where biofouling pressure is the most severe. The biofilm on the transducing interfaces of the sensors can produce a bias and ruined the measurement produced much more than the expected uncertainties. For USV applications, as long as deployment remains limited to few days, biofouling should not be a problem and conventional biofouling protection (copper screens, wipers) should be efficient enough. For deployment longer than 3 or 5 days, adapted fouling protection should be involved. Unmanned Ocean Vessel (Wave Glider and Sail-Buoy) normally dedicated to multiple week deployment should use biofouling protection like the one used for example for Ferrybox, that are acid injection or seawater electrolysis. This is another important point to consider when studying the integration of instrumentation to a USV. The biofouling on the hull of the USV is another matter and is less a problem for a 2 or 3-week deployment duration. And it's rather better not to try to get rid of biofouling with antifouling paint on the hull of a surface *in situ* measurement platform, this, to prevent "pollution» of the sampled sea water.

And finally, deploying USV in coastal zone or open ocean area cannot be performed without considering the local legislation (military area, harbour area, natural area, touristic area).

3. NORMATIVE CONSTRAINTS FOR THE USAGE OF UVS IN RESEARCH

3.1 CONSTRAINTS ON UAVS EMPLOYMENT

UAVs are airborne vehicles that, as such, interact with civil and military airspaces. Also, UAVs flights might result in injuries in case of accidents and, since many UAVs carry cameras, they might also invade a third-party privacy. While regulations on unmanned airborne vehicles do exist since the Chicago convention of 1944 (ICAO, 1944), it was only in 2006 (when UAVs systems became widespread) that the International Civil Aviation Organization (ICAO) declared the need for harmonized regulations of such kind of vehicles (ICAO, 2015). Europe started a task force for integrating UAVs in European airspace already in 2002, a joint effort between the Joint Aviation Authorities (JAA) and the European Organization for the Safety of Air Navigation (EUROCONTROL). This effort has been continued by EASA from 2008 onwards as a successor of JAA. Finally, in 2012 the European commission created a steering group tasked with generating a roadmap for the integration of civil UAVs in European aviation normative (Stöcker et al., 2017). In parallel with supranational regulations each European nation is adopting its own specific set of rules for UAVs operations. The fact that a de-facto standard set of rules does not really exist is clearly highlighted in the excellent review of Stöcker et al. (2017) and it's clearly summed up in the following table (table 3), drawn from their paper.

	Applicability			Technical Requirements		Operational Limitations (Distances)								Administrative Procedures			Human Resources	Ethical Constraints	
Country Issued and/or Last Updated [Reference]	Applicable for MA/UAVs	Classification (Weight, Purpose, Area, Visibility)	Weight Limits (*Max*)	Special Technical Requirements	Collision Avoidance Capability	Airports/ Strip	People	Congested Areas	Prohibited Areas	Additional	Max Height	VLOS/Lateral Distance	BVLOS	Application and Operational Certificate	Need for Registration	Insurance	Qualification of Pilots	Data Protection	Privacy
United Kingdom 05/2002 03/2015 [73]	MA/UAV	W, P	7/20/*150* kg		for special operations		50 m	150 m		N/A	122 m	500 m, EVLOS possible	need for special approval	various approval requirements for different flight operations	N/A	N/A	**pilot competency**	refer to Data Protection Act, CCTV Code of Practice	advice to respect personal privacy
Australia 07/2002 09/2016 [74]	MA/UAV	W, P	2/25/*150* kg	N/A	N/A	5.5 km	30 m			emergency situation	120 m		need for special approval	>2/25 kg	N/A	**recommended**	license > 2 kg	advice to respect personal privacy	
Malaysia 02/2008 [75]	no distinction	W, P	20 kg	Request equivalent level of compliance with rules for manned aircraft			N/A	N/A	N/A	N/A	122 m		if ATC capable	flight authorization and airworthiness certification	>20 kg		license for pilot and commander	UAV operation shall comply with civil requirements	
United States 08/2008 06/2016 [76]	MA/UAV	W, P	0,25/25/*150* kg	N/A	N/A	8 km		N/A		N/A	122 m	EVLOS possible	need for special approval	>25 kg	registration number	depending on purpose	certificate	N/A	refer to related laws
Canada 2010 05/2015 [77]	MA/UAV	W, P	2/25 kg	N/A	>25 kg	9 km	150 m			forest fires	90 m		N/A	>25 kg	N/A	depending on weight	pilot competency	advice to respect personal privacy	
France 2012 12/2015 [78]	MA/UAV	W, A, V	2/8/*150* kg	>2 kg	in populated areas and BVLOS		not over crowds	N/A		emergency situation	150 m	100 m/200 m/EVLOS		for specific operation procedures	depending on flight scenario		depending on flight scenario	Commercial use: ask for permission to use data	advice to respect personal privacy
The Netherlands 2012 07/2016 [79]	MA/UAV	W, P	1/4/25/*150* kg	N/A	N/A	no fly zones	50 m			moving cars	120 m	100/500 m	N/A	operational certificate			license	refer to related regulations	
Germany 12/2013 07/2016 [80]	UAV	W	10/25 kg	>10 kg	**May help to get BVLOS permission**		not over crowds	N/A		emergency situation	100 m		need for special approval	general permission, single operational approval for >10–25 kg	N/A		**pilot competency**	emphasize that actions might be subject to other laws	
Italy 12/2013 12/2015 [81]	UAV	W, A	2/25/*150* kg	For critical flights	N/A	5 km	50 m	150 m		N/A	150 m	500 m/EVLOS	in segregated airspace	for critical operations and/or >25 kg	plate and electronic ID		0–25 kg certificate, >25 kg license	refer to Italian Data Protection Code	N/A
Austria 01/2014 08/2015 [82]	no distinction and if >500 m from pilot	W, A	5/25/*150* kg	depending on scenario	depending on scenario		not over crowds	N/A		N/A	150 m		need for special approval	general permission, single approval for risky operations	registration needed		depending on scenario	N/A	N/A
Spain 10/2014 [83]	MA/UAV	W	2/25/*150* kg	N/A	N/A	8/15 km	not over groups			N/A	120 m	500 m for 2–25 kg	0–2 kg or special approval	flight authorization, NOTAM notification	registration and ID plate		0–25 kg certificate, >25 kg license	N/A	N/A
Azerbaijan 01/2015 [84]	no distinction	W	20/*150* kg	N/A	for BVLOS		50 m	150 m		N/A	122 m		in segregated airspace	for critical operations and/or >20 kg	>20 kg		**pilot competency**	N/A	N/A
Chile 04/2015 [85]	no distinction	W	6 kg	many special demands	N/A	2 km	30 m	N/A		<60 min	130 m	500 m	N/A	flight authorization		N/A	license	N/A	N/A
Colombia 07/2015 [86]		W	25 kg	many special demands	N/A	5 km				intern. border	152 m	750 m	N/A	flight authorization			license	not allowed to violate the rights of privacy	
South Africa 09/2015 [87]	N/A	W, V	7/20 kg		N/A	10 km	50 m			N/A	122 m	EVLOS possible	need for special approval	air service license, letter of approval and operation certificate	registration marks		license	N/A	N/A
Japan 12/2015 [88]	no distinction and if heavier than 200 g	N/A	N/A	N/A	N/A	no fly zone	30 m			N/A	150 m		N/A	for restricted areas	N/A	N/A	N/A	N/A	N/A
Nigeria 12/2015 [89]	no distinction	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	special authorization	N/A			flight authorization	N/A	N/A	manned aircraft license	**license**	N/A
Rwanda 05/2016 [90]	not for toy aircraft	N/A	25 kg	N/A	N/A	10 km	50 m			N/A	100 m	300 m		flight authorization, operational certificate	registration marks		license	respect privacy of others, surveillance of people and property without their consent is prohibited	

Table 3: Details of various national regulation for UAVs from Stöcker et al. (2017)

As the table clearly show both around the world and within Europe there's no clear standard regulations on how to operate an UAV. The main variables that are generally included into the regulatory framework could be summed up in three broad groups:

a. **Platform specific regulations:** these rules affect the technical requirements of the UAV itself. Many countries, for example, classify UAVs depending on the maximum take-off weight (MTOW) and implement different regulations on such a basis (in some cases under a certain MTOWs the regulations do not apply altogether). Some countries may ask for specific technical solutions to be implemented on the vehicle in case of risky flights: UAVs exceeding a given MTOW or flying in populated areas must, for example, have onboard special failure and safety instrumentation that's not required for non-risky flights. Depending on the country, the platform itself might have to be registered to a specific national registry, requiring therefore a univocal registration number as per manned aircrafts.

b. **Flight specific regulations:** Many countries distinguish between commercial and leisure flights, applying different regulations to each of them. Some countries implement complex risk matrices based on the different flight areas and, therefore, different flight scenarios. Some areas might be designed as no-fly zones, will some other areas are considered "risky" due to the presence of population or buildings and as such may require additional equipment or authorizations. More or less every country applies a ceiling to the maximum height that an UAV can reach as well as a minimum horizontal distance between the platform and other people. Depending on the country and on the flight area more or less communication needs to happen between the pilot and the authorities: local/national flight authorities should either be informed of the flight happening or authorize the flight itself. The flexibility of this communication changes, again, from country to country: Italy, for example, does not require formal flight applications with MTOWs < 25 Kg, while Spain requires a notification to airman (NOTAM) for each and every UAV flight. Generally, for UAVs that fly within visual line-of-sight (VLOS) of the pilot no further requirements are made, but if flights should extend beyond that (BVLOS) further regulations can apply (or it can be even forbidden). Independently of the specific flight conditions most countries also do require an insurance in order to assess liability and compensation in case of unfortunate accidents.

c. **Pilot specific regulations:** depending on the country UAVs pilot must have a higher or lesser degree of training. While, for example, Germany only requires basic confirmation of the pilot skills, most other countries require a certification/license.

The future of this forest of regulations seems to be, as noted by Stöcker et al. (2017), a streamlining following a risk-based approach that is currently in line with EASA harmonization initiatives and that has been already pioneered by France, Italy and Austria. Also, given the growth of the market and the penetration of UAVs in multiple professional and recreational fields, will most probably result in a future increase of the necessity of notify flight requests to appropriate organizations (Stöcker et al., 2017). Related to this aspect it might also become necessary for UAVs operating out of segregated airspace to mount specific communication devices for safer BVLOS flights and coordination with other airspace users (Stöcker et al., 2017). Accountability will also be a key aspect of the increased UAV activities and, as such, the influence of insurance companies on these kind of operation is also expected to grow (Stöcker et al., 2017). While at the moment privacy and data protection remained a gray area in most regulations, sometimes barely suggested, it is also expected to become a bigger concern in the future.

While this ever-evolving jungle of country-specific regulations might seem a hindrance to establish a pan-European UAV observatory, they are actually one of its greatest strengths. Being able to rely on operators rooted in each country's regulations, in fact, will make the development of transnational research much easier than to have to adapt platforms and certifications anytime a flight mission is required in a different country. This would greatly increase the strength of research consortia in performing science that requires UAVs already from the project writing phase thanks to the presence of a reliable framework for accessing different kind of platforms and sensors.

3.2 CASE-STUDY: THE EUFAR EXPERIENCE, A POSSIBLE GUIDELINE FOR AN EUROPEAN UAV OBSERVATORY

EUFAR (from 2008 to 2013) and its follow-up EUFAR2 (from 2014 to 2018) were two FP7 projects dedicated to airborne research in geoscience (for a total project cost of 16 836 068.02 € and an EU contribution of 14 000 000 €). These projects, to which CNR IBIMET participated SkyArrow 650 manned aircraft between 2008 and 2013, aimed to create a central network for the airborne research community in Europe, helping scientists to access aircrafts and instrumentation that would have been otherwise unavailable. The original EUFAR project involved "*32 European legal entities, comprising 14 operators of airborne facilities operating 20 instrumented aircraft and providing access to 6 specialised instruments, and 18 institutions expert in airborne research*" (https://cordis.europa.eu/result/rcn/160997_en.html). These entities were divided into 9 Networking activities (N1-N9) with different leaders and different tasks. N2 was dedicated to transnational access (TAC) (figure 15).

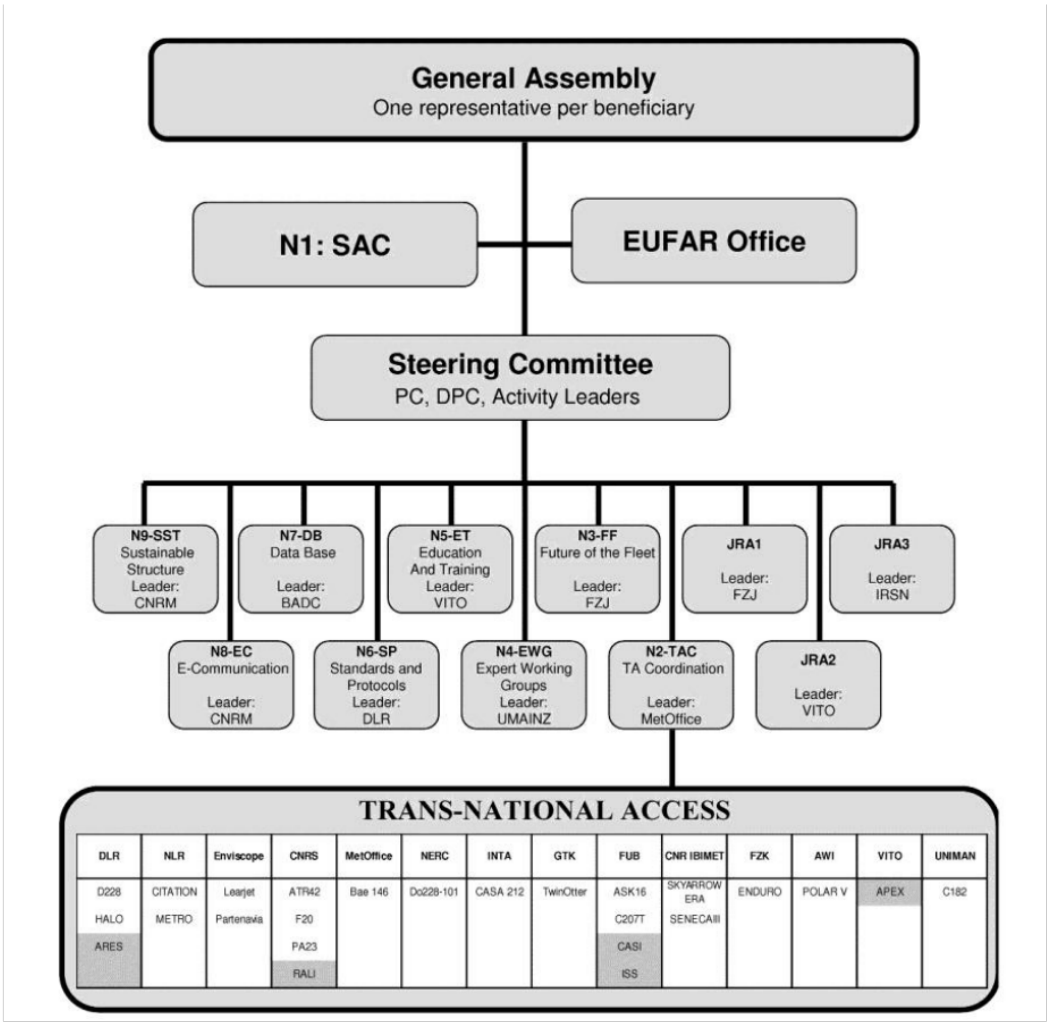

Fig. 15: Structure of the EUFAR Project

EUFAR TNA proved to be quite effective, having "*coordinated 20 research flight campaigns, funding 225.25 fully-funded flight hours*" (https://www.eufar.net/eufar-achievements/).

While EUFAR per-se did not include any UAV platform, in EUFAR2 there was a beginning of a collaboration with the International Society for Atmospheric Research using Remotely piloted Aircraft (ISARRA). These first steps could form the basis and the framework for a pan-European UAV observatory. The structure of the observatory should follow what already delineated in the EUFAR experience which can apply in a 1:1 fashion to UAVs as well. In the case of the UAV observatory the N6-SP ("Standards and Protocols") should be in contact (and possibly include members from) with EASA, JAA and any other major supranational stakeholder for the harmonization and streamlining of UAV regulation (such as the European Commission RPAS steering group and the ICAO JARUS group, Stöcker et al., 2017). Such integration in the context of an UAV observatory would generate a two-way feedback between users and regulatory authorities, fostering the introduction of a future standardized regulation for civil and scientific UAVs. One of the main difficulties in EUFAR activities was that many platforms required an intermediate private handler for the manned aircraft operations, a situation that would be easily bypassed when the UAV platforms are fully managed inside each adherent RI. For example, the IBIMET fleet is entirely managed "in-house" without the requirement to interact with third parties for the platform handling, piloting and maintenance. This situation would allow for more streamlined transnational access procedures as well as an easier organization of practical training activities. One of the milestones of Task 1.3 of the ENVRIPLUS project was, in fact, the organization of a workshop on the usage of unmanned vehicles in RIs. The workshop was attended by multiple RIs as well as research institutes not part of ENVRIPLUS and it was a clear manifestation of the interests the research world has in constituting such a common network for a scientific tool that's becoming more and more relevant in many fields.

3.3 CONSTRAINTS ON UV USAGE IN THE MARINE DOMAIN

Access to the maritime world is governed by the International Maritime Organization via numerous international conventions; the best-known being:

- Convention sur le Droit de la Mer (https://treaties.un.org/pages/ViewDetailsIII.aspx?src=TREATY&mtdsg_no=XXI-6&chapter=21&Temp=mtdsg3&clang=_fr),
- Load Lines (LL 1966, http://www.imo.org/en/About/Conventions/ListOfConventions/Pages/International-Convention-on-Load-Lines.aspx),
- Regulation for Preventing Collision at Sea (COLREG 1972, http://www.imo.org/en/About/Conventions/ListOfConventions/Pages/COLREG.aspx),
- Safety of Life at Sea (SOLAS 1974, http://www.imo.org/en/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-(SOLAS),-1974.aspx),
- Standards of Training, Certification and Watchkeeping for Seafarers (STCW 1978, http://www.imo.org/en/About/Conventions/ListOfConventions/Pages/International-Convention-on-Standards-of-Training,-Certification-and-Watchkeeping-for-Seafarers-(STCW).aspx),
- Prevention of Pollution at Sea (MARPOL 73/78, http://www.imo.org/en/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-(MARPOL).aspx),
- Removal of Wrecks (WRC 2007, http://www.imo.org/en/About/Conventions/ListOfConventions/Pages/Nairobi-International-Convention-on-the-Removal-of-Wrecks.aspx),

These agreements make it possible to have at the international level a set of common tools and rules widely accepted and recognized by the signatory countries of the said conventions. It should be noted that these conventions apply to all the seas and oceans of the planet (international waters - high seas) and are supplemented by national regulations for waters over which the sovereignty of the riparian state is recognized and applied.

The introduction of new vectors called surface, underwater, aerial or even hybrid drones poses many problems of adaptation of regulations and cohabitation. As an example, some questions to which no authority can today provide answers accepted by all:

- Can the surface drone be qualified as a ship?
- Is an unmanned vessel still a ship and conversely can drone operators qualify as seafarers?
- The 'Only master on board after God' is the Commander, what about onboard of the drone?
- How to implement the marine « sense » to a machine?

- Can cameras and other sensors replace the mandatory visual and auditory « watch »?
- Can autonomous ships be considered 'in sight of each other' if no one is on board?
- What becomes of the concept of assistance at sea with autonomous ships or drones?
- And, probably the most complex; Who is responsible for damages and / or losses?

At an international level

Maritime drones are becoming increasingly important in the maritime economy and their introduction into the marine environment for a variety of uses poses many economic, legal and technical challenges. Constrained both by a rapid evolution of technologies (energy, communications, ...) and a need to have a formal working environment for professionals (designers, architects, builders, ship-owners, insurers, lawyers, ...), some countries took the initiative to develop regulatory frameworks for the development of these disruptive technologies. For example, the European Defense Agency, through the SARUMS Working Group, has issued recommendations, which have been adopted by the Society of Maritime Industries in the form of a Code of Practice. Certification companies such as Lloyds Register or Bureau Veritas have issued recommendation codes for the design and manufacture of maritime drones.

For its part, Great Britain (MSC 95/20) relayed by 8 countries (MSC 98/20/2) proposed to study how the safe and environmentally sound operation of autonomous surface vessels could be integrated into the IMO instruments. Internationally, the IMO at the Maritime Safety Committee (MSC 98) of 13 June 2017 recognized the need to clarify a regulatory framework for surface drones and their interaction with manned ships to ensure safety of the operations of these machines. This proposal was favorably received and each member was asked to escalate their needs. This work is expected to prepare the next meeting (MSC 99) scheduled for early 2019.

On a national level

In France, from 2015, the French Maritime Cluster (CMF), recognizing the importance of the introduction of drones at sea has set up a working group on the subject to feed the reflections and propose to the legislator tracks regulation in order to support the harmonious and ecological development of the economy of the sea. Thus, in 2016, the law for the blue economy introduced for the first time in French law the notion of maritime drone and set the regime liability for their use from a ship.

Continuing its action of animation, the CMF set up in 2017 a working group on the drones maritime with two subgroups synergy, one devoted to the "autonomous surface ships" intended to support the French recommendations to the IMO, the other dedicated to the introduction of "maritime drones" in French regulations. This second group is currently working on a good practice guide. This guide is intended for use by maritime stakeholders involved in the introduction of surface and submarine UAVs into the marine environment. Established by a group of professionals from the world of the sea, it aims to set recommendations for the design, manufacture, marketing, implementation, use, maintenance and operation of drones at sea and on the sea. Waterways. This guide should inspire the legislator in the near future. In particular, it is intended to supplement the Maritime Safety Directorate's Maritime Safety Regulations, particularly without Divisions 222 (Cargo ships under 500 gross tonnage) and 233 (underwater vessels). "Maritime drone" means any surface or submarine floating craft on which no crewmember is embarked and has maneuverability, whether or not the craft has the quality ship within the meaning of the regulations. The scope of this guide excludes non-floating gears and non-maneuvering gears, such as fixed pontoons or buoys and / or drifting floats in use for scientific research. Flying vehicles are concerned only if they are hybrid, i.e. if, in addition to their aeronautical capacity, they can operate on the surface or under the sea, without prejudice to the application of other recommendations related to their mobility

3.4 CASE-STUDY: THE JERICO NEXT TRANSNATIONAL ACCESS (TNA) PROGRAMME

JERICO (Joint European Research Infrastructure network for Coastal Observatories) and its follow-up JERICO-NEXT are H2020 projects including work packages (WPs) that emulate what EUFAR did for the biosphere/atmosphere domain for the marine domain. JERICO NEXT is coordinated by IFREMER and has as a main aim to foster the cooperation between European oceanic observatories in order to better study and unravel ocean's complexity. In order to reach said objectives JERICO NEXT implements a TNA programme in its WP7 allowing EU (and associated countries) researchers to access both specific oceanic facilities and unmanned vehicles such as gliders (see both http://www.jerico-ri.eu/project-information/work-packages/wp7/ and http://www.jerico-ri.eu/project-information/work-packages/wp7/observing-systems/). More specifically there are 3 facilities within the TNA programme that offer access to marine UVs (http://www.jerico-ri.eu/download/jerico-next-deliverables/JERICO-NEXT-Deliverable_7.1_V1.1.pdf and summed up in the map of figure 15):

a. **Glider National Facility (GNF).** This facility is managed by CNRS and operates 10 gliders as well as the facilities needed for all gliders operations. The facilities can mount sensors such as CTD, oxygen optode and fluorimeters and it generally works in a remote fashion, executing missions without direct presence of the user group.
b. **Coastal Observing System for Northern and Arctic Seas (COSYNA).** This facility is managed by the Helmholtz-Zentrum Geestacht (HZG) and operates 2 gliders capable of mounting CTDs, fluorimeters and turbidometers.
c. **Balearic Islands Coastal Observing and Forecasting System Glider Facility (SOCIB-GF).** This facility is managed by SOCIB and operates 7 Slocum gliders and 2 Seagliders equipped for collecting both physical and biogeochemical data. The SOCIB-GF also manages a series of facilities for UVs operations

Figure 15: Locations of TNA facilities offering
marine UVs access in JERICO NEXT project
(SOCIB glider facility, COSYNA glider, CNRS-INSU Glider National Facility

This formula allows researchers from Europe or associated countries to access platforms, deploy payloads and conduct experiments in different locations overcoming the limitations detailed in the preceding paragraphs and proved quite successful in the course of the project. At the present date, in fact, 3 TNA calls were opened in the context of JERICO NEXT (between May 2nd 2016 and March 12th 2018) for a total of 30 approved TNA proposals (6 in the first call, 15 in the second and 9 in the third one).

4. CONCLUSIONS

Unmanned vehicles are becoming more and more ubiquitous in research activities and across research domains. The main issue that the adoption of UVs in research is facing is mainly a policy one: there is still not a European consensus on how to handle UVs and, as a result, each country is adopting local rules that can be quite different even from the ones of neighboring states, making difficult the interoperability of UVs between countries as well as joint research activities. While Europe is moving forward towards a more harmonized policy framework, the best option for the creation of unmanned observatories for usage across RIs remains the one trailblazed by European projects such as EUFAR and JERICO (NEXT), i.e.: the creation of massive TNA platforms joining various local research entities in different countries. This has been proven to be a viable solution both for manned aerial platforms (EUFAR) as well as for gliders (JERICO NEXT) and is the only framework within which is possible to overcome the aforementioned policy limitations. There are still some obstacles to the formation of this new TNA platform and namely:

a. **Monetary Investment**: both EUFAR and JERICO NEXT are projects that required investments in the order of magnitude of 10 million euros. While the costs of the single platform (i.e.: drone) itself can be relatively cheap, a TNA platform should take in account personnel and material costs necessary for the operation of each single platform as well as reimbursement plan for researchers travelling across RIs.

b. **Flexibility in Platform-Sensor Interactions**: both EUFAR and JERICO NEXT tend to offer a fixed set of sensors mountable on a given platform. But the experience of CNR ANAEE within the ENVIPlus project (highlighted by the ENVRIPlus workshop on unmanned vehicles held in Livorno) is that RIs are also developing in-house sensors that are deployable on a mobile platform. While efforts towards standardization and harmonization between platform and sensors are being made, there is still clearly a necessity for great flexibility in this field. UVs can accommodate a vast array of sensors from cameras to temperature probes up to sensors that are developed within one or more RIs and is not realistic to think that they can all share a common interface or data format.

c. **Delineation of Clear Joint Objectives**: what did emerge from the Livorno ENVRIPlus workshop is that there is a clear interest of having shared UVs facilities within the same domain, but the across-domain initiatives and linkages are still unclear. EUFAR and JERICO NEXT are a prime example, being projects clearly focused toward a specific community. This does not mean that such necessities aren't present: for example CNR IBIMET and CNR ISSIA have conducted campaigns in the Arctic that made used of both UAVs and marine surface UVs in order to fully map conditions on the face of a glacier in Svalbard (Ferretti et al., 2018). These kind of interactions (that were also fostered by an ENVRIPlus EoP application) are still in their infancy and they should be developed in a clear common agenda in order to maximize the scientific power and efficacy of a UV TNA platform.

5. REFERENCES

Adão, T., Hruška, J., Pádua, L., Bessa, J., Peres, E., Morais, R., & Sousa, J. J. (2017). Hyperspectral Imaging: A Review on UAV-Based Sensors, Data Processing and Applications for Agriculture and Forestry. Remote Sensing, 9(11), 1110. https://doi.org/10.3390/rs9111110

Anderson, G. P., King, K. D., Cuttino, D. S., Whelan, J. P., Ligler, F. S., MacKrell, J. F., Bovais, C., Indyke, D., & Foch, R. J. (1999). Biological agent detection with the use of an airborne biosensor. Field Analytical Chemistry & Technology, 3(4-5), 307–314. https://doi.org/10.1002/(SICI)1520-6521(1999)3:4/5<307::AID-FACT9>3.0.CO;2-M

Anderson, K., & Gaston, K. J. (2013, April 1). Lightweight unmanned aerial vehicles will revolutionize spatial ecology. Frontiers in Ecology and the Environment. John Wiley & Sons, Ltd. https://doi.org/10.1890/120150

Colomina, I., & Molina, P. (2014, June). Unmanned aerial systems for photogrammetry and remote sensing: A review. ISPRS Journal of Photogrammetry and Remote Sensing. https://doi.org/10.1016/j.isprsjprs.2014.02.013

Gonzalez, F., Castro, M. P. G., Narayan, P., Walker, R., & Zeller, L. (2011). Development of an autonomous unmanned aerial system to collect time-stamped samples from the atmosphere and localize potential pathogen sources. Journal of Field Robotics, 28(6), 961–976. https://doi.org/10.1002/rob.20417

Gonzalez, L., Montes, G., Puig, E., Johnson, S., Mengersen, K., & Gaston, K. J. (2016). Unmanned Aerial Vehicles (UAVs) and Artificial Intelligence Revolutionizing Wildlife Monitoring and Conservation. Sensors, 16(1), 97. https://doi.org/10.3390/s16010097

Gorgues, T., Ménage, O., Terre, T., & Gaillard, F. (2011). An innovative approach of the surface layer sampling. Journal Des Sciences Halieutique et Aquatique, 4, 105–109.

Hassanalian, M., & Abdelkefi, A. (2017). Classifications, applications, and design challenges of drones: A review. Progress in Aerospace Sciences, 91, 99–131. https://doi.org/10.1016/J.PAEROSCI.2017.04.003

International Civil Aviation Organization (ICAO). Convention on International Civil Aviation; ICAO: Chicago, IL, USA, 1944.

International Civil Aviation Organization (ICAO). Manual on Remotely Piloted Aircraft Systems (RPAS); ICAO: Montréal, QC, Canada, 2015.

Jaakkola, A. (2015). Low-cost Mobile Laser Scanning and its Feasibility for Environmental Mapping. PhD diss., Aalto University. ISBN 978-952-60-6197-9 (printed), ISBN 978-952-60- 6198-6 (pdf), ISSN-L 1799-4934, ISSN 1799-4934 (printed), ISSN 1799-4942 (pdf). http://urn.fi/ URN:ISBN:978-952-60-6198-6

Lin, B., Ross, S. D., Prussin, A. J., & Schmale, D. G. (2014). Seasonal associations and atmospheric transport distances of fungi in the genus Fusarium collected with unmanned aerial vehicles and ground-based sampling devices. Atmospheric Environment, 94, 385–391. https://doi.org/10.1016/j.atmosenv.2014.05.043

Martin, S., Bange, J., & Beyrich, F. (2011). Meteorological profiling of the lower troposphere using the research UAV "M2AV Carolo." Atmospheric Measurement Techniques, 4(4), 705–716. https://doi.org/10.5194/amt-4-705-2011

Matese, A., Toscano, P., Di Gennaro, S. F., Genesio, L., Vaccari, F. P., Primicerio, J., Beli, C., Zaldei, A., Bianconi, R., & Gioli, B. (2015). Intercomparison of UAV, aircraft and satellite remote sensing platforms for precision viticulture. Remote Sensing, 7(3), 2971–2990. https://doi.org/10.3390/rs70302971

Morris, C. E., Conen, F., Alex Huffman, J., Phillips, V., Pöschl, U., & Sands, D. C. (2014). Bioprecipitation: a feedback cycle linking Earth history, ecosystem dynamics and land use through biological ice nucleators in the atmosphere. Global Change Biology, 20(2), 341–351.

Palframan, M. C., Gruszewski, H. A., Shmale III, D. G., & Woolsey, C. A. (2014). Detection of a surrogate biological agent with a portable surface plasmon resonance sensor onboard an unmanned aircraft system. Journal of Unmanned Vehicle Systems, 2(October), 103–118. https://doi.org/10.1139/juvs-2013-0015

Powers, C. W., Hanlon, R., Grothe, H., Prussin, A. J., Marr, L. C., & Schmale, D. G. (2018). Coordinated Sampling of Microorganisms Over Freshwater and Saltwater Environments Using an Unmanned Surface Vehicle (USV) and a Small Unmanned Aircraft System (sUAS). Frontiers in Microbiology, 9, 1668. https://doi.org/10.3389/fmicb.2018.01668

Reverdin, G., Morisset, S., Boutin, J., & Martin, N. (2012). Rain-induced variability of near sea-surface T and S from drifter data. Journal of Geophysical Research: Oceans, 117(C2), n/a-n/a. https://doi.org/10.1029/2011JC007549

Singh, K. K., & Frazier, A. E. (2018). A meta-analysis and review of unmanned aircraft system (UAS) imagery for terrestrial applications. International Journal of Remote Sensing, 39(15–16), 5078–5098. https://doi.org/10.1080/01431161.2017.1420941

Small, R. J., deSzoeke, S. P., Xie, S. P., O'Neill, L., Seo, H., Song, Q., Cornillon, P., Spall, M., & Minobe, S. (2008). Air–sea interaction over ocean fronts and eddies. Dynamics of Atmospheres and Oceans, 45(3–4), 274–319. https://doi.org/10.1016/J.DYNATMOCE.2008.01.001

Stöcker, C., Bennett, R., Nex, F., Gerke, M., & Zevenbergen, J. (2017). Review of the Current State of UAV Regulations. Remote Sensing, 9(5), 459. https://doi.org/10.3390/rs9050459

Torresan, C., Berton, A., Carotenuto, F., Chiavetta, U., Miglietta, F., Zaldei, A., & Gioli, B. (2018). Development and Performance Assessment of a Low-Cost UAV Laser Scanner System (LasUAV). Remote Sensing, 10(7), 1094. https://doi.org/10.3390/rs10071094

Torresan, C., Berton, A., Carotenuto, F., Di Gennaro, S. F., Gioli, B., Matese, A., Miglietta, F., Vagnoli, C., Zaldei, A., & Wallace, L. (2017). Forestry applications of UAVs in Europe: a review. International Journal of Remote Sensing, 38(8–10), 1–21. https://doi.org/10.1080/01431161.2016.1252477

Toth, C., & Jóźków, G. (2016). Remote sensing platforms and sensors: A survey. ISPRS Journal of Photogrammetry and Remote Sensing, 115, 22–36. https://doi.org/https://doi.org/10.1016/j.isprsjprs.2015.10.004

Unmanned aerial vehicles for environmental applications. (2017). International Journal of Remote Sensing, 38(8–10), 1–8. https://doi.org/10.1080/01431161.2017.1301705

Wallace, L., Lucieer, A., Watson, C., & Turner, D. (2012). Development of a UAV-LiDAR system with application to forest inventory. Remote Sensing, 4(6), 1519–1543. https://doi.org/10.3390/rs4061519

Zhang, C., & Kovacs, J. M. (2012, December 31). The application of small unmanned aerial systems for precision agriculture: A review. Precision Agriculture. https://doi.org/10.1007/s11119-012-9274-5