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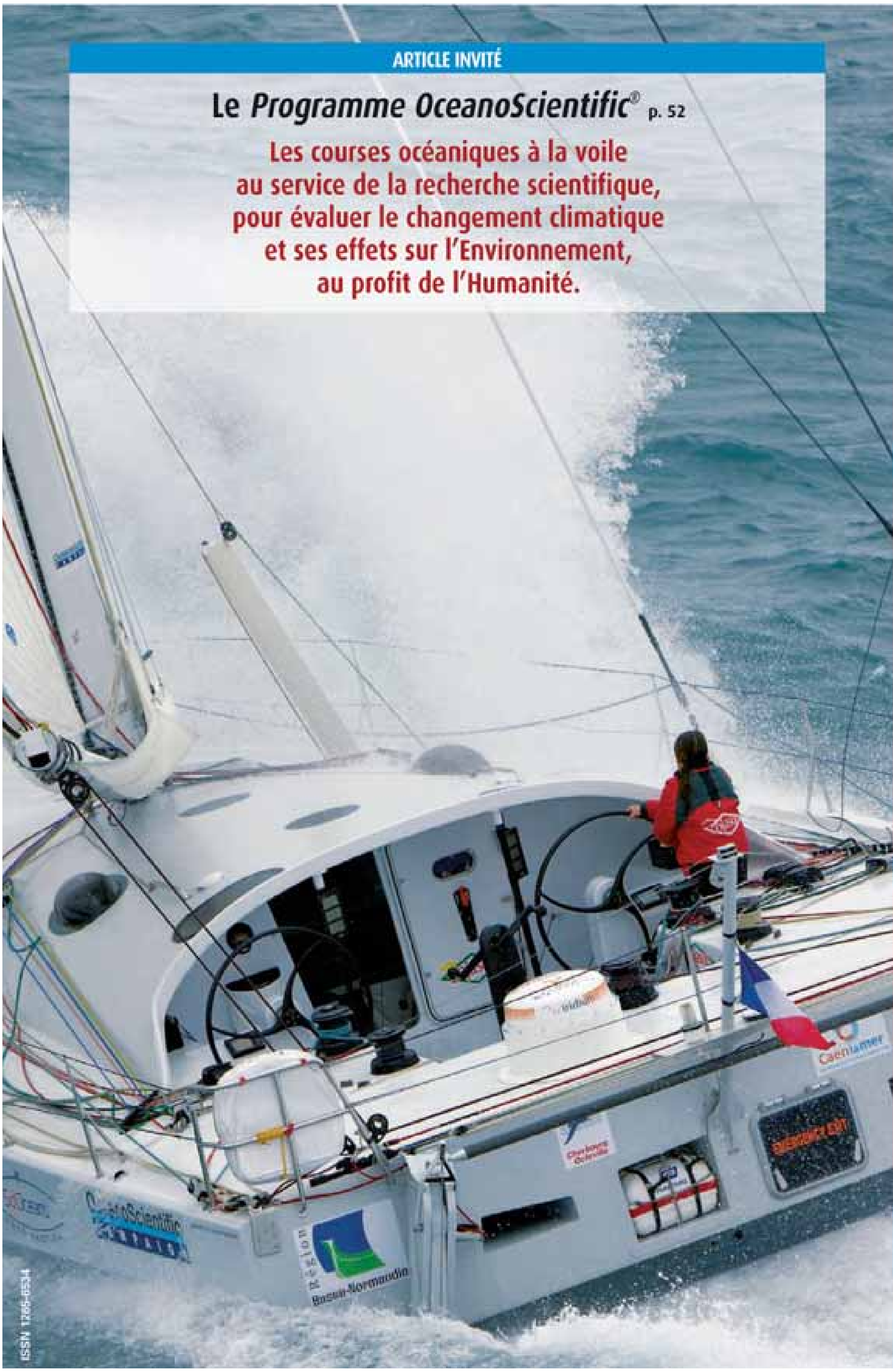

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Scientific data acquisition by ocean-going sailing yachts: The *OceanoScientific®* *Programme*

Mots clés

Oceanography, Meteorology, Sensors, Data Acquisition, Climate Research

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Around-the-world sailing races lead in hardly explored sea areas of high scientific interest and it is now possible to use participating vessels as innovative measurement platforms for climate research.

1. Introduction

The routes of ocean races hardly change and there are regular starts every year. Major parts of those races take place between and south of the continental capes (Horn, Good Hope and Leeuwin) where data from the ocean-atmosphere interface are both, rare and crucial for scientific projects such as CLIVAR (International program on CLImate VARiability and predictability) and GOOS (Global Ocean Observing System). Federating the efforts of scientists from different French institutes (IRD, CNES, CNRS, IFREMER, INSU, IPEV, OMP), the Sea Surface Salinity (SSS) Observation Service gives an overview of regular routes of Ships of Opportunity (SOOP programme) in figure 1. It shows the limited spatial coverage of regular measurements exemplary for the parameter SSS. There is a need for suitable platforms to improve the spatial and temporal collection of scientifically relevant sea surface data, because non ship-bound systems such as the broad-scale global array of more than 3000 drifting temperature and salinity profiling floats, known as *Argo*, deliver data sets that are very limited in the number of parameters and were designed for subsurface operation, i.e. they do not collect real sea surface data.

Racing yachts have been equipped with scientific sensors before, but the possibilities were always very limited because of the competition and onboard conditions. In 2006, the French Sailing Federation (FFVoile) launched the *SolOceans* race, which from the beginning combined the sportive aspects of a sailing race in the Southern Ocean with the scientific need for data from said areas.

A new type of yacht, the *SolOceans One-Design*, was designed for this challenge by the famous Finot-Conq Group (Vannes, France) for a serial production of 15 vessels. Fully in carbon, these 16 meters long high-tech yachts for single-handed racing allow for the deployment of various oceanographic and atmospheric sensors (see figure 2), following French Grenelle de la Mer's commitments of *Tomorrow's Ship* (*Navire du Futur*) [2].

At the fifth session of the Ship Observations Team (SOT) of the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) of the World Meteorological Organization (WMO) and the Intergovernmental Oceanographic Commission (IOC) of the United

L'ESSENTIEL

L'objectif du *Programme OceanoScientific®* et de la classe *Monotype SolOceans* est d'acquérir et de transmettre des données scientifiques de l'interface océan-atmosphère lors de courses océaniques à la voile. Les données acquises à bord de la première unité du *Monotype SolOceans* ont prouvé leur bonne qualité. Ainsi, la première étape pour l'introduction des plateformes acceptées pour l'acquisition des données océanographiques et météorologiques à la surface de l'océan est bouclée. La production en série peut commencer.

SYNOPSIS

The aim of the *OceanoScientific® Programme* and of the *SolOceans One-Design Class* is to collect and transmit scientific data from the ocean-atmosphere interface during regularly starting offshore sailing races. Data collected on board the first *SolOceans One-Design* proved to be of good quality. Thus the first important step towards the introduction of accepted platforms for ocean surface and atmospheric parameter acquisition has been taken. The serial production can begin.

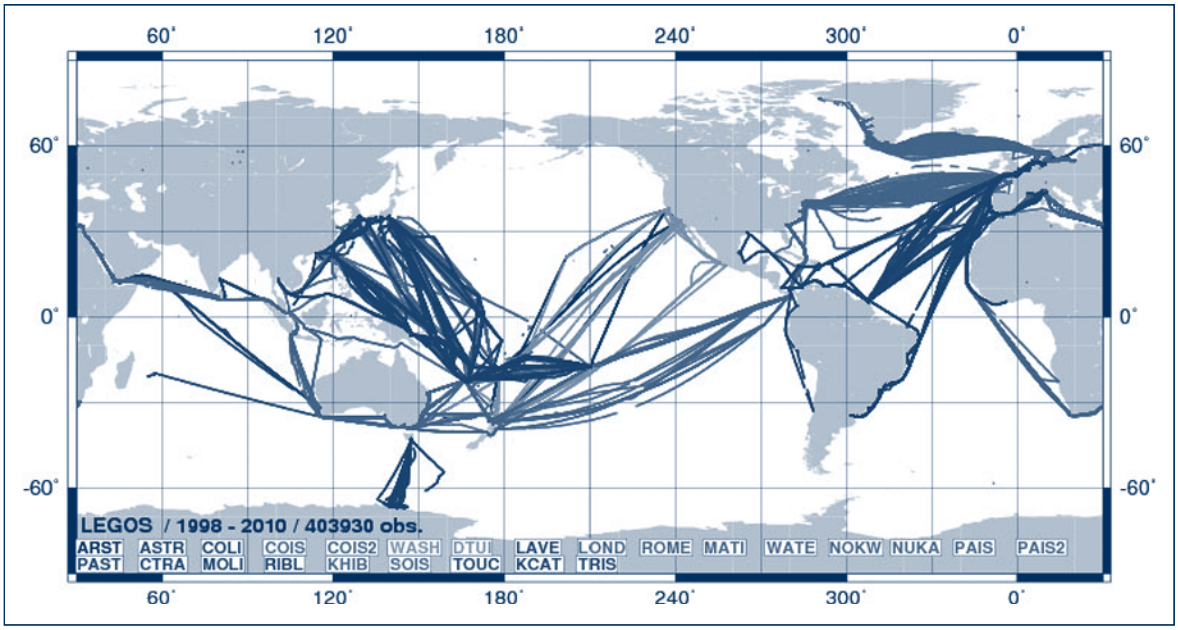

Figure 1. Spatial distribution of SSS observations, 1998-2010 [1]: *Data from the southern ocean are rare.*

Nations Educational, Scientific and Cultural Organization (UNESCO), the *OceanoScientific® Programme* was introduced to the international scientific community [3].

The fleet of completely identical *SolOceans One-Designs* forms its own class and will take part not only in the *SolOceans*, but also other major offshore races.

The mixture of scientific expeditions and ocean races offers new opportunities to report on climate change and other environmental challenges beside the fact that high-quality data is collected. It enhances public awareness for scientific questions, not only within the race villages at departure and arrival or during virtual races, but also by educational programs.

2. Partners

The project already has various partners from both science and industry, who come together for general meetings twice a year. The number of partners and the constitution of the project are not restricted and it is hoped to welcome further partners in the future.

2.1. Science

In France IFREMER [4], INSU-CNRS, Météo-France and the University of Caen are partners of the project, together with IFM-GEOMAR in Germany, the University of Maine in the United States and MetService in New Zealand. It is also supported by the French and European space agencies CNES and ESA [5], the French Ministry of Higher Education and Research (MESR), the French Ministry of Ecology, Sustainable Development, Transport and Housing (MEDDTL) and was recently recognized by the *Explorers Club* (*Club des Explorateurs* - Grenelle de la Mer).

Together, these partners define the parameters of the *OceanoScientific® Programme*, share their expertise to design the equipment, validate the emerging data and contribute it to international data networks such as the Global Telecommunication System (GTS) of the WMO.

2.2. Industry

SailingOne (Caen, France), based in the Lower Normandy Region, is specialized in ocean racing. SailingOne equips all *SolOceans One-Designs* (hulls being built by nearby JMV Industries, Tourlaville, France), manages all maintenance services and organizes the *SolOceans* races.

SubCtech (Osdorf, Germany), a recently founded spin-off of CONTROS Systems & Solutions (Kiel, Germany), is specialized in complex flow-through-systems with years of experience in underway technology. SubCtech participates in the project by a micro-version of its *OceanPack*, which suits the racing conditions.

Mer Agitée (Port-la-Forêt, France) is the technical team of world-class sailor Michel Desjoyeaux. Together with Mer Forte (Port-la-Forêt, France), Mer Agitée participates in the project by its new hydro generator (HydroGnautiC), source of emission-free energy onboard the *SolOceans One-Design Class*.

3. Finance

Until the end of 2008, French Veolia Propreté (Veolia Environnement Group, Paris, France) was main sponsor of the *OceanoScientific® Programme*. Afterwards, at the peak of the worldwide financial crisis, the other partners continued to invest in the development of the project and the association ROSS (Research-*OceanoScientific®*-

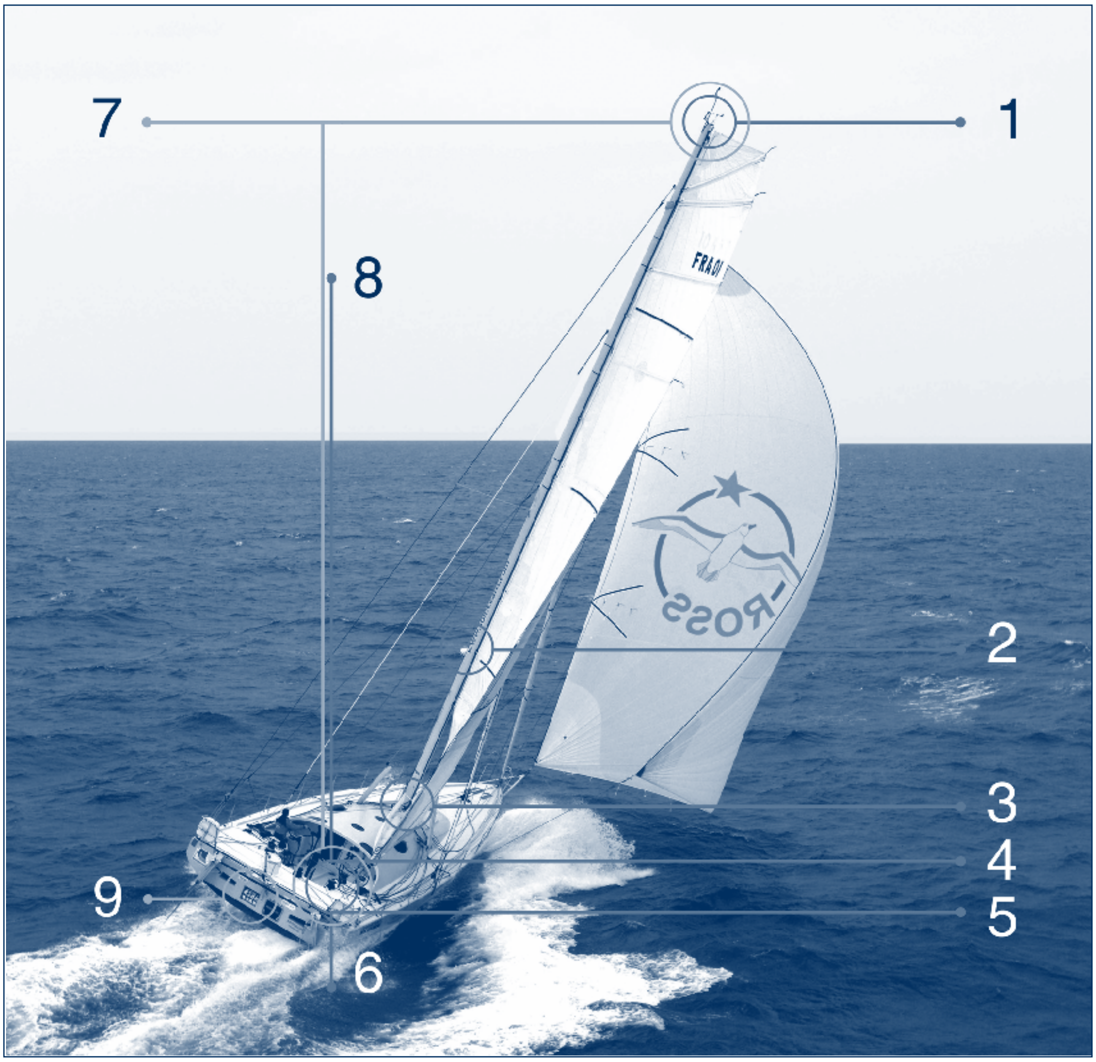

***Figure 2. The first unit of the SolOceans One-Design Class**. Indicated are the positions of the already installed (dark grey) and future sensors (until 2012, light grey): 1. wind direction and speed, 2. air humidity and temperature and 3. atmospheric pressure. The flow-through system (6.) includes the sensors for sea surface salinity and temperature (4.) as well as sea surface pCO_2 (5.). In the future it will also host a fluorescence and a pH sensor; the mast top will also be equipped with a radiation measuring device (7.). 8. denotes the satellite transmission of the collected data and 9. marks the position of the hydro generator.*

Sport) also supports the project. All emerging data are made public and are available free of charge.

The *OceanoScientific® Programme* is one part of the main author's PhD thesis that deals with new partnership models in sport sponsoring, following the concept of Corporate Social Responsibility (CSR).

4. Parameters

The idea guiding the selection of parameters by the scientists is the availability of qualified, stable, compact and low power sensors and the possibility of integrating the *OceanoScientific®* data set in an existing or intended worldwide observing system. The system development is conceived of several steps of increasing complexity.

Step One - Initialization (in 2006)

- Wind direction
- Wind speed
- Atmospheric pressure
- Air temperature
- Air humidity
- Sea surface temperature
- Sea surface salinity
- Sea surface partial pressure of carbon dioxide - *p*CO_2

Step Two - Additional parameters (Starting 2010)

- Radiation
- Sea surface fluorescence
- Sea surface power of hydrogen - pH

Step Three - Additional parameters (Starting 2012)

- Plankton
- Nutrients

The technical infrastructure is very flexible and further parameters can be added or exchanged with others.

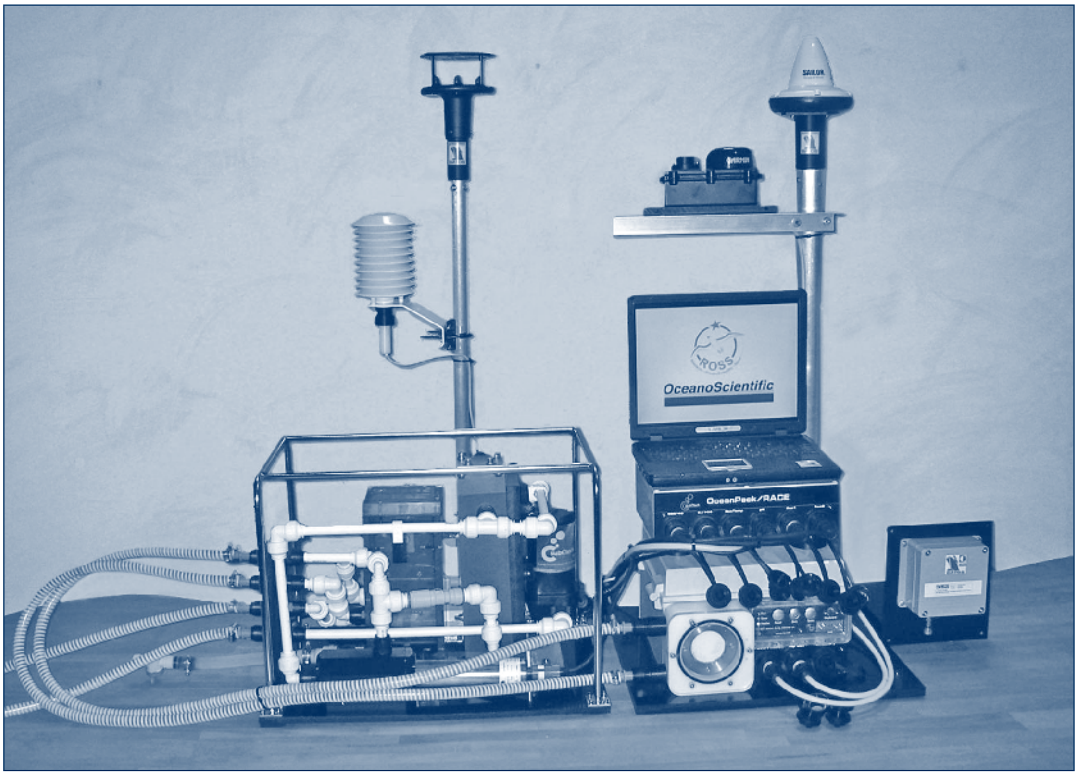

Photo: SailingOne

Figure 3. The OceanoScientific® Kit. Latest configuration (step 2) from 2010.

5. Technology

The ensemble of systems installed onboard the *SolOceans One-Designs* was named *OceanoScientific® Kit*. It consists of the sensors and their necessary infrastructure. During the maintenance service of the vessel, which occurs at least once a year, all scientific instruments are regularly replaced or calibrated, which is crucial for constant high quality data. Figure 2 shows the *SolOceans One-Design* and the sensor positions onboard. Figure 3 shows the *OceanoScientific® Kit* in detail, without its hydro generator.

5.1. Ocean

Realizing a suitable water intake for the *SolOceans One-Designs* was the first challenge to meet. Similar measurements from buoys and floats are performed with the sensor submerged at the measurement depth, but most of the time *SolOceans One-Designs* are moving very quickly with top speeds exceeding 25 nautical miles per hour and operate at the uppermost ocean layer. External buoy systems were found to be too vulnerable and penalizing for the ship's speed.

On other SOOP or research vessels, the water is taken at a depth of several meters (2 to 20) and pumped to the sensor installed inside the ship. This internal solution was chosen, but the type and size of the *SolOceans One-Designs* imposes technical limits on weight, size and power-consumption, even if those are not an issue in terms of competition within the one-design concept (i.e. all starting vessels carry the same instrumentation package).

Taking water through the keel using the pressure generated by the speed was considered at first, but in order to reduce the list of the vessel to a minimum and optimize the performance, its canting keel can be moved up to 40° to the windward side. That results in the usual draft of more than 4 meters being reduced to almost zero in certain conditions with a hardly submerged intake for the seawater flow-through system.

Tests performed with IFREMER and INSU-DT in November 2008 invalidated this concept: There was either no flow at all or the rate was not stable enough. As soon as the vessel accelerated, listed or pitched in the waves, the circuit was taking in great amounts of air, which is fatal for the data quality of most ocean sensors.

An industrial partner finally realized the development of a pumped flow-through system that suits the *SolOceans One-Designs*. With a weight of less than 30 kg and a power consumption of less than 50 Watts, SubCtech's *Micro-OceanPack* Race comes with:

- Pump
- Debubbler (including a sediment trap)
- Flowmeter
- Datalogger
- Plug & Play interface for various sensors
- Transmission option (Iridium or Inmarsat)

The self-priming pump and a new debubbler design with bypass enable an efficient debubbling-procedure (using several bubble traps) at the beginning of the circuit and a stable flow (adjustable rate, up to 10 liters per minute) of bubble-free water inside the sensor-section. Even in very

rough offshore conditions, lists of more than 20° and even while the vessel is surfing at full speed, these conditions can be maintained. With a second bypass, the flow-rate can be reduced for one or several sensors if necessary.
The first ocean sensors deployed are:
- Sea-Bird (Bellevue, Washington, USA) *SBE45* (salinity and temperature, bypass flow-rate of approximately 1.5 liters per minute)
- CONTROS *HydroC*™/CO_2 (pCO_2, mainstream flow-rate of approximately 4.5 liters per minute)

Additional sensors will be installed from 2010, such as a modified CARbon Interface Ocean Atmosphere system (CARIOCA) [6] [7] for measurement redundancy and intercomparison with the HydroC™/CO_2 unit [8]. Partly the new instruments are still under development, such as an outside sea temperature sensor designed especially for this application.

5.2. Atmosphere

Météo-France's department for ocean observing systems (DOS-OCE) tested positively that the Automated Weather Station (AWS) BATOS could be installed onboard the *SolOceans One-Designs* in November 2008. Since then, Météo-France is the partner for the atmospheric part of the programme and responsible for the choice, installation and maintenance of the concerned sensors as well as for the acquisition, storage, transmission, monitoring and reporting of the data to the GTS. Within the *OceanoScientific® Programme* the idea to acquire and transmit salinity data with BATOS was also successfully implemented.

The BATOS system deployed today uses the following sensors:
- Gill (Lymington, England) *Windsonic* (wind speed and direction)
- Rotronic (Bassersdorf, Switzerland) S3CO3 (air humidity and temperature)
- Vaisala (Vanta, Finland) PTB 220 (atmospheric pressure)
- Sea-Bird *SBE45* (sea temperature and salinity)

A Young (Traverse City, Michigan, USA) *41003* radiation shield protects the air humidity and temperature sensor.

The sailor can regularly add visual meteorological observations. Météo-France's special training for sailors on Voluntary Observing Ships (VOS) and BATOS's graphical user interface enable them to easily add the extra information on the sea state, clouds, precipitation and further observations.

The data are transferred to shore on an hourly basis by an Inmarsat-C data reporting system that also delivers GPS position and speed over ground data. This is necessary to calculate true wind data. The measuring frequency of the atmospheric data depends on the sensor and is between 0.2 and 2 Hz.
The data transmitted to shore are:
- Wind averages from h-10 to h+00
- Air humidity and temperature at h+00
- Atmospheric pressure averages from h-03 to h+00
- Sea salinity median from h-02 to h+00
- Sea temperature corresponding to salinity index
- Position, course and speed over ground
- Optional: visual meteorological observations

In addition to the transmission all atmospheric data are stored onboard at a flexible sample rate. Sea surface salinity and temperature data are stored every 6 seconds.

6. Evaluation and Validation

From October 16th to December 20th, 2009, the first *OceanoScientific®* Kit was put through a thorough testing period on a *SolOceans One-Design* that sailed the French waters between Caen (Lower Normandy) and Brest (Brittany). After the first successful trial it was put to strain in violent storms and heavy seas during a challenging voyage to Portugal.

The Laboratoire de Physique des Océans (LPO) was in charge of the sea temperature (T) and salinity (S) validation and took part in the tests in Brest from October 23rd to 28th.

The validation included: A visual inspection of the Sea-Bird system, water sampling for laboratory analysis and checking of the temperature and salinity data transmission by BATOS (reduced hourly dataset) and storage (full dataset sampled at 6 seconds).

The additional water samples were not taken in via the water inflow. They were collected with a bucket directly over the railing on October 26th at several locations and stored in OSIL (Havant, England) type bottles. They were analyzed for salinity back in the laboratory at LPO. Temperature was measured on board with a thermometer Ebro (Ingolstadt, Germany) *TFX 392*. The stated accuracy of this temperature probe (0.1 °C) is lower than the one of the *SBE45* (0.001 °C). Therefore only a very coarse comparison is possible and the data is given just for sake of completeness.

The comparison of the water samples with the corresponding *OceanoScientific® SBE45* measurements (see tables I and II) indicates a deviation between the two independently measured salinities of about 0.02 PSS (Practical Salinity Scale).

	Time	Latitude (N)	Longitude (W)	Description
1	14h15	48°21.5'	004°31.3'	Between naval base and lighthouse
2	14h37	48°19.9'	004°36.2'	Near Petit Minou
3	16h03	48°17.64'	004°38'	Near Toulinguet
4	16h36	48°20.99'	004°33.62'	Near Marel buoy

Table I: Data comparisons (S and T), Time and Position (Oct. 26th, 2009).

	SBE 45 T (°C)	TFX 392 T (°C)	Δ T (°C)	SBE 45 S (PSS)	LPO S (PSS)	Δ S (PSS)
1	14.863	14.8	$0.0<\Delta<0.1$	35.267	35.288	-0.021
2	14.854	14.8	$0.0<\Delta<0.1$	35.269	35.295	-0.026
3	14.854	14.8	$0.0<\Delta<0.1$	35.338	35.350	-0.012
4	14.846	14.7	$0.1<\Delta<0.2$	35.268	35.287	-0.019

Table II: Data comparisons (S and T), Results (Oct. 26th, 2009).

Figure 4. Sea surface salinity measured from the 12/12 to the 20/12/2009.
Salinity with quality flags (grey scale (*)) and external data (salinity from co-localized Argo floats (circle) and water samples (triangle)). Only good quality external data are shown. There was no data recorded around December 16th because of technical modifications. (*) quality flag: reliable data (black), bad data (light grey).

Given the rapid space and time variability and the non-optimal sampling conditions for the discrete samples, the achieved accuracy is very good, and complies with the scientific requirements for sea surface salinity. In order to monitor the possible drift of the salinity (conductivity) sensor, water samples are taken regularly (if possible every three days).

During the test the water temperature inside the thermosalinograph (jacket temperature) did not show any warming, but this point will be validated on a more representative voyage in the near future using an external temperature sensor.

The datasets both transmitted and stored have been analyzed over the period from December 12th to 20th (figure 4 and 5).

It appears that there is very little signal loss for the salinity measurements (much less than usually seen on SOOP), although the data were taken in very heavy seas and under rough wind conditions. The comparison of the *SBE45* data with the water samples taken underway as well as with data from nearby Argo floats indicates little deviation: the maximum deviation observed was inferior to 0.07 PSS. We can thus conclude that the *OceanoScientific® Kit* will gather high quality, near surface salinity and temperature data that will be e.g. extremely valuable for the calibration of the recently launched SMOS (ESA) and future Aquarius (NASA/CONAE) satellites.

Since salinity measurements are sensitive to bubbles within the water stream and the conductivity cell respectively and since the signal loss was small, we can also conclude that the flow-through setup with its specialized water intake, the pump and the debubbler i.a. successfully fulfils the requirements onboard the *SolOceans One-Designs*.

Beside temperature and salinity, sea surface pCO_2 data was successfully recorded during the testing period as well. The measuring frequency was 20 seconds and a zero-point drift correction of the NonDispersive Infra-Red (NDIR) detector within the HydroC™ unit, the so-called zeroing, was carried out regularly every 12 hours. A detailed analysis of the HydroC™ technology and its emerging data is planned within further publications (IFM-GEOMAR) from 2011. Intercomparison measurements onboard the *SolOceans One-Design* as well as the collection of reference samples for the determination of carbon system parameters such as total Dissolved Inorganic Carbon (DIC), Total Alkalinity (TA) and hence pCO_2 are scheduled for 2011.

For the validation of the atmospheric sensors, the observations of the BATOS AWS were compared to those of other platforms - two moored buoys and a light vessel - as well as to analysis outputs of two weather models – French Arpège and ECMWF (European Centre for Medium range Weather Forecasts).

For instance, on October 26th, 2009, the *SolOceans One-*

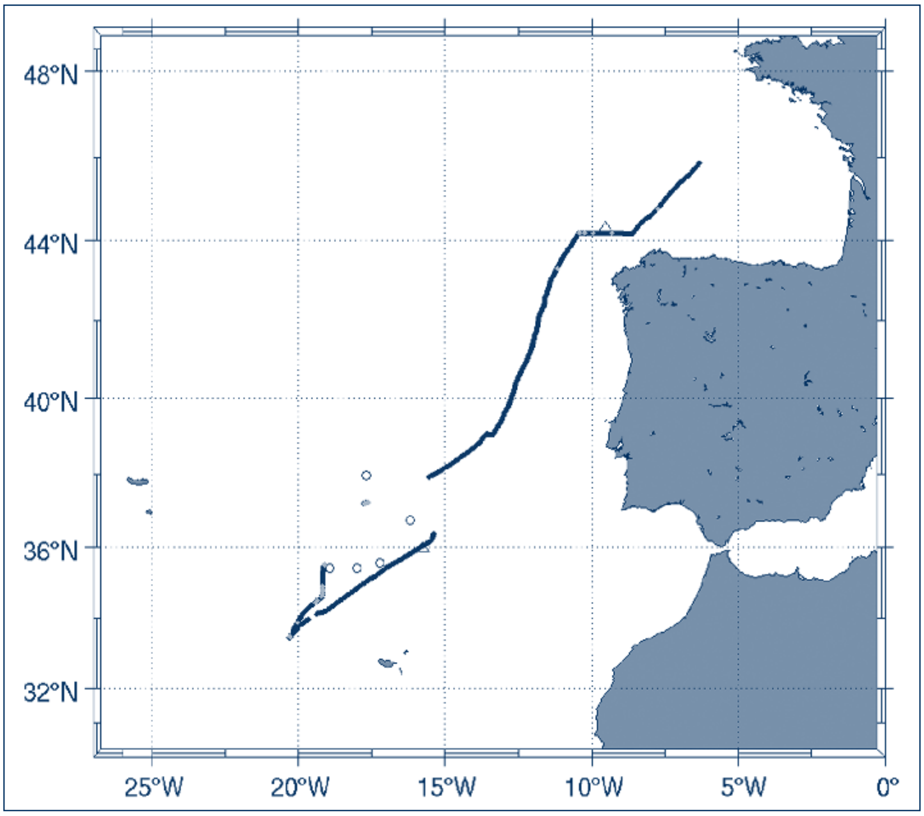

*Figure 5. **Map of the offshore test.** Measurement positions with salinity quality flags (grey scale (*)), good external data (salinity from co-localized Argo floats (circle) and water samples (triangle)). Same period as Figure 4. (*) Quality flag: reliable data (black), bad data (light grey).*

Design kept sailing for a couple of hours in the vicinity of a navigation buoy (Swansea Vale – 48°19.3'N-4°38.7'W) equipped with an AWS. The data of the BATOS AWS were compared to those of the moored buoy.

The wind velocities measured by the buoy at 3.50 m height were corrected to 22 m (height of the anemometer above the *SolOceans One-Design* waterline), with

$$W = Wref * \ln(z/z0)/\ln(zref/z0) \qquad (1)$$

which assumes that the neutral atmospheric stability conditions are met [9]. In (1), W is the wind velocity at height z above the sea level, Wref is the reference speed (i.e. measured by the buoy) at height zref and z0 is the roughness length.

With a roughness length of 0.001 m currently used at the sea surface [9], (1) becomes

$$W = 1.225 * Wref \qquad (2)$$

which has been used here in all wind corrections and comparisons.

Parameter	Time	*SolOceans One-Design*	*Swansea Vale*	Required uncertainty
Atmospheric pressure	14:00	1019.8 hPa	1019.7 hPa	±0.1 hPa
	15:00	1019.6 hPa	1019.5 hPa	
Sea temperature	14:00	14.9°C	14.8°C	±0.1°C
	15:00	14.9°C	14.8°C	
Wind direction	14:00	180°	180°	±5°
	15:00	170°	170°	
Wind speed (22 m)	14:00	8.2 m/s	8.1 m/s	±0.5 m/s (10% for > 5 m/s
	15:00	8.2 m/s	8.5 m/s	
Air temperature	14:00	15.9°C	16.0°C	±0.1°C
	15:00	15.9°C	15.9°C	
Air humidity	14:00	88%	88%	±1%
	15:00	88%	90%	

Table III: Data comparisons between SolOceans One-Design and Swansea Vale moored buoy (Oct. 26th, 2009).

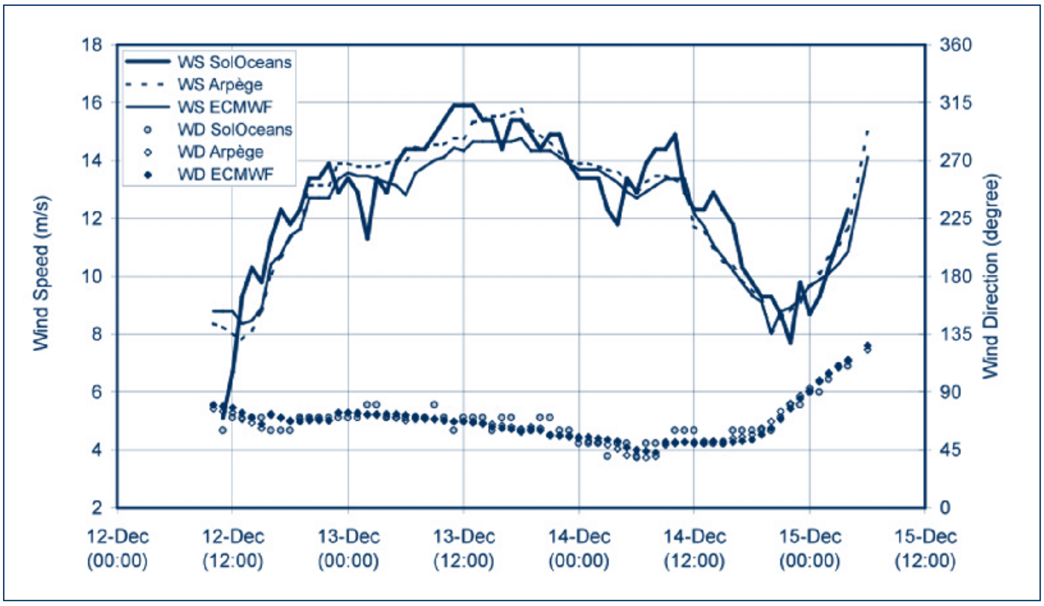

***Figure 6. Comparisons between wind observations**, carried out by the BATOS AWS and co-located weather model outputs corrected to 22 metres from the 12th to the 15th of December, 2009.*

Table III shows the values of different parameters measured by the two platforms as well as the recommended measurement uncertainty requirements for general operational use in meteorology [10]. It must be noted that the resolution for wind direction is still in tens of degrees as previously recommended by the WMO.

Table III also shows the very high compliance between the measurements of the two stations. It clearly appears that the measurements carried out by the BATOS AWS of the *SolOceans One-Design* meet the WMO requirements.

The observations of the *SolOceans One-Design* have also been compared to model outputs during all navigations at sea. Figure 6 shows the wind speeds and directions reported by the BATOS AWS, compared to co-located model outputs. The concordance confirms that the BATOS data of the *SolOceans One-Design* are reliable.

7. Conclusion

The fully automatic acquisition and transmission of underway data from aboard the *SolOceans One-Design* Class has been demonstrated as feasible and efficient within extensive testing onboard the first vessel for all the measured parameters. The *OceanoScientific® Programme* with international scientific as well as industrial partners will provide full sets of information of the ocean-atmosphere interface in hardly explored sea areas. Like data of VOS and SOOP, or non ship-bound systems such as Argo floats, all *OceanoScientific®* data are available free of charge from international data networks such as GTS and GOOS, for climate and ocean research, for operational oceanography, meteorology and for the public.

Regular sensor maintenance and calibration guaranty stable data quality. Optional visual observations and additional water samples can be added to complement the automatic sampling.

The regular acquisition of data on identical routes by the whole fleet of the *SolOceans One-Design Class* make this programme a new partner for the Global Ocean Surface Underway Data (GOSUD) project of the International Oceanographic Data and Information Exchange Programme (IODE) and JCOMM.

Whilst the *SolOceans One-Designs* remain the best platforms for the *OceanoScientific® Kit* in its totality, parts of the system could also be used on other sea-going sailing vessels to increase even more the amount of scientific data from hardly explored areas of the oceans. First tests have been run successfully in August 2010 on German research sailing vessel *Aldebaran*.

8. Acknowledgment

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