Deliverable TN3:

Bio-optical cruise report

BIO-OPTICS FOR OCEAN COLOR REMOTE SENSING OF THE BLACK SEA

BIO-OPT 2019

Research Vessel Akademik, Cruise No. 15AK-2019-298

15-05-2019 04-06-2019, Varna (BG) – Varna (BG)

Leg #1 (15-05-2019 28-05-2019)

ESA contract AO/1-8785/16/NL/SC

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Abbreviation

AOP – Apparent Optical Properties

AWI – Alfred Wegener Institute

CNR – Consiglio Nazionale delle Ricerche

CTD – Conductivity-Temperature-Depth

EC – European Commission

ESA – European Space Agency

HPLC – High Performance Liquid Chromatography

IO-BAS – Institute of Oceanology, Bulgarian Academy of Sciences

IOP – Inherent Optical Properties

ISMAR – Istituto Scienze del Mare

JRC – Joint Research Center

NIMRD – National Institute for Marine Research and Development "Grigore Antipa"

R/V – Research Vessel

ROS – Rosette Sampler

SUN – Sun-Photometry

UkrSCES – Ukrainian Scientific Center of Ecology of the Sea

WS – Water Sampling

1. Summary

The BIO-OPT-2019 cruise aimed at collecting *in situ* bio-optical measurements needed to support remote sensing applications for operational monitoring and climate studies in the Black Sea. This requires a comprehensive bio-optical characterization of the regions of the Black Sea exhibiting the highest environmental variability in bio-optical features. The bio-optical data will be used for assessment of current Sentinel-3A ocean color data products and for implementation of new bio-optical algorithms applied for the quantification of the concentration of seawater optically significant constituents.

The bio-optical oceanographic cruise was carried out from 15th of May to 4th of June 2019 onboard the research vessel Akademik.

The campaign was divided into 2 legs fully covering the 21 days of autonomy of the ship:

- Leg #1 performed from 15th to 28th May 2019 with ship time funded within the framework of a contract between ESA and the Institute of Oceanology of the Bulgarian Academy of Sciences (IO-BAS) (contract #4000123951/18/NL/SC); followed by
- Leg #2 performed from 28th of May till June 4th 2019 with ship time funded through a contract between JRC of EC and IO-BAS (contract #935276 JRC/IPR/2018/D.2/0002/NC-08).

The oceanographic cruise led to the completion of 124 comprehensive measurement stations of which 80 were collected during the first leg and 44 during the second. This report summarizes the BIO-OPT 2019 cruise activities, with specific reference to those performed during the first leg related to the ESA – IO-BAS contract.

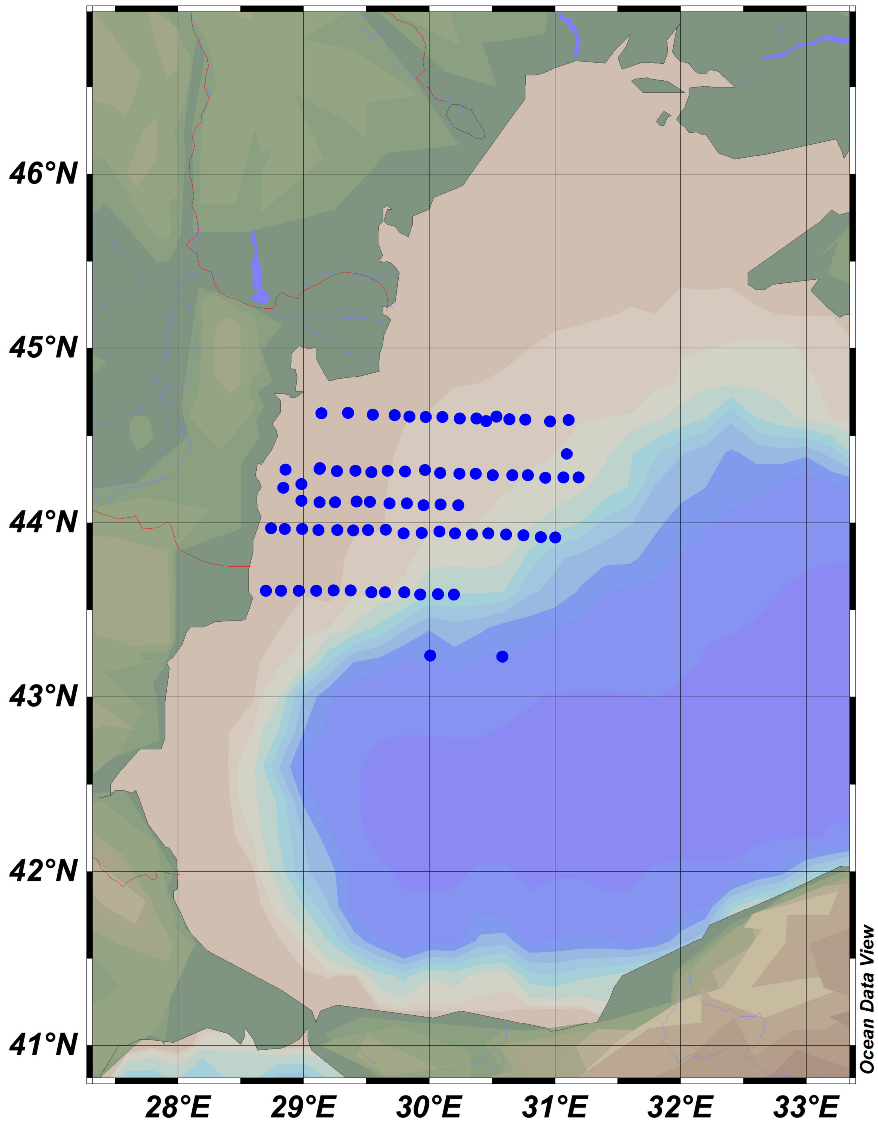

Figure 1. Location of the measurement stations performed during Leg #1 of the R/V Akademik BIO-OPT - 2019 cruise

2. Research Objectives

Objective of the BIO-OPT 2019 cruise has been the production of state of the art measurements including comprehensive apparent and inherent optical properties of seawater, in addition to the concentration of optically significant constituents (see Table 1).

Table 1. Primary bio-optical quantities determined during the BIO-OPT 2019 oceanographic cruise

Quantity	*Symbol*	*Wavelengths range or center-wavelengths*	*Instrument/Method*
Remote sensing reflectance	R_{rs}	412,443,490,510,555,670, 683 nm	JRC and IO-BAS Satlantic micro-profiler
Diffuse attenuation coefficient	K_d	412,443,490,510,555,670, 683 nm	JRC and IO-BAS Satlantic micro-profiler
Total absorption coefficient	A	412,443,490,510,555, 630, 650, 676,715 nm (hyperspectral for AC-S)	JRC WetLab AC-9 and CNR (occasional) AC-S
Absorption coefficient of pigmented particles	a_p	400-750 nm (with 1 nm resolution)	Spectrometry (JRC Perkin-Elmer Lambda 900)
Absorption coefficient of non-pigmented particles	a_{dt}	400-750 nm (with 1 nm resolution)	Spectrometry (JRC Perkin-Elmer Lambda 900)
Absorption coefficient of colored diss. organic matter	a_y	350-750 nm (with 1 nm resolution)	Spectrometry (JRC Perkin-Elmer Lambda 12)
Scattering coefficient	B	412,443,490,510,555, 630, 650, 676,715 nm	JRC WetLab AC-9,CNR AC-S
Backscattering coefficient	b_b	443,490,510,555,620, 670 nm	JRC HobiLabs Hydroscat-6 and CNR (occasional) Web Labs ECOVSF
Salinity and temperature	S&T&FL	Typically down to 25-35 m	JRC , CNR (occasional), IO-BAS SBE Inc. CTDs
Total suspended matter	TSM		JRC filtration and weighting
Pigments concentration	CHL	[$mg.m^{-3}$]	HPLC, Fluorometer, Spectrophotometer
Aerosol optical thickness	τ_a	440, 490, 550, 670, 870 nm	JRC and IO-BAS
Phytoplankton species diversity		Taxonomic structure, abundance[$cell^{-1}$] and biomass [$mg.m^{-3}$]	Inverted microscope

Apparent Optical Properties (AOPs) are the remote sensing reflectance and the diffuse attenuation coefficient determined through in-water radiometry. Inherent optical properties (IOPs) are the absorption, scattering, back-scattering coefficients and volume scattering function determined through in-water profiling and laboratory analysis of water samples. Concentrations of seawater suspended constituents include those of pigments and total suspended matter determined from laboratory analysis.

3. Narrative of the Cruise

Measurement stations have been chosen to represent seawaters likely characterized by different bio-optical regimes in the Bulgarian and Romanian waters (the planned stations in Ukrainian waters could not be performed due to safety issues related to military operations). Regular gridding is not a requirement for bio-optical modeling: variability and statistical representativeness of bio-optical regional regimes are the basic requirements. Because of this, actual measurement stations have been fixed on a daily basis to account for weather conditions or bio-optical features of the area.

Station time has been approximately 60 minutes while travel time between stations has also been kept within approximately 60 minutes. The bio-optical measurements are only possible on daylight conditions, transects of 5 - 7 stations per day were likely possible. Any transits required to reach relatively distant regions, which might provide better or alternative measurement conditions, have been made overnight.

Measurements were performed using the instruments and the methods listed in Table 1. Measurement sequence during each station comprised:

A. Deployment of free-fall optical radiometer systems (specifically two Satlantic optical profilers equipped with multispectral radiometers measuring *i.* upwelling radiance, downward and upward irradiance) to determine subsurface values of seawater apparent optical properties; and *ii.* atmospheric aerosol optical thickness (this latter quantity is only measured in view of future validation exercises for satellite derived products which generally require comprehensive characterizations of both marine and atmospheric optical quantities);

B. Deployment of the CTD and IOP instrumental packages (the latter include: *i.* the JRC WetLabs AC-9 absorption and attenuation meter, and a HobyLabs Hydroscat-6 back-scattering meter; *ii.* the ISMAR-CNR WetLabs AC-S absorption and attenuation meter, WetLabs ECOVSF volume scattering function meter within the first 25-30 meters which are those of interest for ocean color remote sensing (these measurements were only performed occasionally during the first and last stations of the day);

C. Collection of surface seawater samples to determine: *i.* absorption coefficients of pigmented, non-pigmented and colored dissolved organic seawater components through spectro-photometric techniques *ii.* total suspended matter concentration through dry-weighting and pigments concentrations through HPLC, fluorometry and spectrophotometry *iii.* phytoplankton species analysis through inverted microscope.

Measurements B were carried out in approximately 30 minutes by a team of eight scientists (three handling the CTD and five the IOP packages). Equivalent time was required for measurements indicated at point A using two free-fall profilers operated by a team of six scientists. Conditioning of water samples (i.e. seawater filtration) was generally started during stations and completed during travel time to next station by four scientists. Additionally, measurements of the indirect sun irradiance were performed by two scientists during clear sky conditions between stations using two hand held Microtops-II sun-photometers. Clearly, some scientists sequentially operated different measurement systems.

4. Measurements and Sampling

4.1 Apparent Optical Properties

Apparent Optical Properties of seawater are determined from multispectral free-fall systems which simultaneously measure the upwelling radiance Lu (z, λ), the downward irradiance Ed (z, λ) and the upward irradiance Eu (z, λ) as a function of depth z and wavelength λ, in addition to the above–water downward irradiance Ed (0+, λ). While the in–water profile measurements are used to extrapolate to 0− depth (i.e. just below the water surface) radiometric quantities which cannot be directly measured because of wave perturbation, the above–water downward irradiance measurements allow to minimize the effects of illumination variations on in–water data during profiling. All applied sensors (i.e. radiometers of the OCR-507) have equivalent spectral channels with 10 nm bandwidth centered at the nominal wavelengths 412, 443, 490, 510, 555, 665, and 683 nm, close to those of satellite ocean color sensors.

With particular reference to optically complex waters like those encountered in the Black Sea, the determination of highly accurate in−water radiometric products often requires profiling near the surface to minimize the perturbing effects of non-homogeneities in the vertical distribution of optically significant constituents and to account for the rapid decrease of light signal with depth in highly attenuating waters. An additional requirement is the capability of producing a number of measurements per unit depth not significantly affected by the tilt of the profiling system to lessen the effects of wave perturbations. As a consequence, the accuracy of derived sub-surface radiometric products is a function of the sampling depth interval and of the depth resolution as defined by the system acquisition rate and deployment speed (6Hz and 0.3-0.4 m s^{-1}, respectively, for the considered free-fall radiometer systems). BIO-OPT 2019 radiometric measurements used to determine sub-surface products have thus been performed by profiling in the near-surface layers and applying the multicast method that relies on the combination of measurements from successive and independent profiles to increase the number of samples per unit depth.
Pre- and post-campaign absolute calibration data were and will be determined at the JRC using NIST traceable irradiance standards to verify the stability with time of each radiometer.

Data products from the free-fall optical profilers include spectral values of: irradiance reflectance, remote sensing reflectance, normalized water–leaving radiance, diffuse attenuation coefficient and the so called Q-factor. The processing and quality assurance of data products are made using the Optical Processor developed at the JRC. The various processing steps, defined in agreement with consolidated protocols are fully documented in Zibordi et al. (2011).

Figure 3. Free-fall optical profilers deployed during the BIO-OPT 2019 cruise

4.2 Inherent Optical Properties (IOP)

Measurements of the seawater inherent optical properties include vertical profiles of:
i. total (except water) beam attenuation and absorption coefficients c (λ) and a (λ), performed with a WET Labs (Philomath, USA) "AC-9" at the nominal wavelengths (λ) 412, 440, 488, 510, 555, 630, 650, 676 and 715 nm, and a WET Labs hyperspectral "AC-S" (where the particulate scattering coefficient b(λ) is determined as c(λ)-a(λ)).
ii. back-scattering coefficient b_b (λ) at the nominal wavelengths 442, 488, 510, 555, 620, and 665 nm made with a HobiLabs (Bellevue, USA) "HydroScat-6" (HYD-6). Measurements and processing of AC-9 and HYD-6 data were performed as described in Berthon et al. (2007).

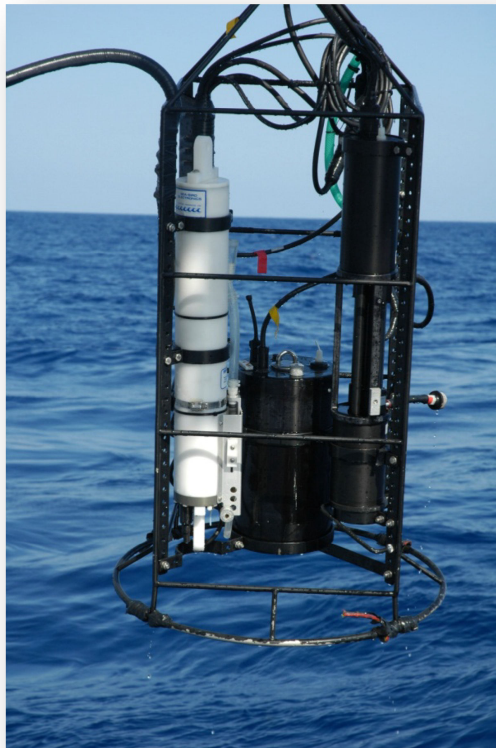

Figure 4. JRC IOP package deployed during the BIO-OPT 2019 cruise

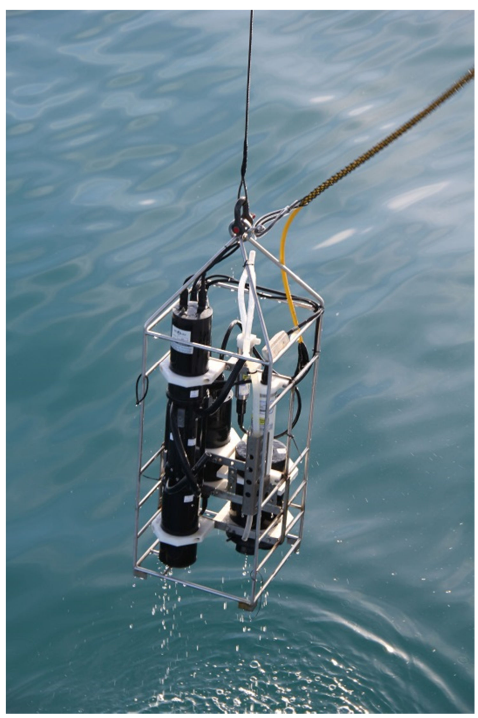

Figure 5. CNR IOP package deployed during the BIO-OPT 2019 cruise

4.3 Water Sampling (WS)

Subsurface water samples (at approximately 1 m depth) were collected at each station at the same time of IOP profiling using a sampling bottle. These discrete water samples were conditioned between stations for successive laboratory analysis of:

i. Pigments concentration (specifically total Chlorophyll a, Chla) through High Performance Liquid Chromatography according to the methodology described in Canuti and Berthon (2011) and spectrophotometrically according to Jeffrey and Humphrey (1975);

ii. Total suspended matter (TSM) through dry-weighting (see Zibordi et al. 2002);

iii. Absorption coefficients of pigmented, aph (λ), and non-pigmented, adp (λ), particulate matter between 400 and 750 nm through filter-pads and spectrophotometric techniques (see Berthon et al. 2007, and references therein);

iv. Absorption coefficient of colored dissolved organic matter, ays (λ), between 350 and 750 nm of filtrated (0.22 mm) seawater (see Berthon et al. 2007, and references therein).

v. surface water samples were collected at all stations for phytoplankton species analysis;

Additional water samples were taken at selected stations and depths with 5 L Niskin bottles positioned in a rosette over the CTD system of the ship. These samples were specifically performed to determine the coccolithophore by inverted microscope, particularly targeting the *Emiliania huxleyi* blooms that take place normally during May and June and are interacting with the optical properties of surface Black Sea waters.

4.4 CTD Profiling and Rosette Sampling (CTD and ROS)

Conductibility, temperature and depth (CTD) measurements were performed during each IOP cast using a CTD operated in conjunction with the IOP packages. These profiles were restricted to the near-surface layer (i.e. generally 25-35 meters). Additional casts were performed with the CTD system operated on the ship together with a rosette (ROS).

4.5 Sun-Photometry (SUN)

Sun-photometric measurements were performed at stations and between stations during clear sky conditions. Measurements of the direct sun-irradiance were carried out with hand held Microtops II sun-photometers equipped with five spectral channels within the spectral range 340–1020 nm. Instruments calibration and data processing procedures comply with requirements of the international Maritime Aerosol Network (MAN) traceable to the Aerosol Robotic Network (AERONET). Instruments and data analysis details are described in Smirnov et al. (2011).

5. Participants

R/V Akademik hosted 14 scientists. Names, affiliations and duties during the measurement campaign are provided in Table 2.

Table 2. Names, affiliation and duties of the scientists participated in the BIO-OPT 2019 cruise

No	Name	Gender	Affiliation	Main scientific task
1	Giuseppe **ZIBORDI**	M	JRC	Apparent and Inherent Optical Properties
2	Jean-Francois **BERTHON**	M	JRC	Apparent and Inherent Optical Properties
3	Marco **TALONE**	M	JRC	Apparent and Inherent Optical Properties
4	Violeta **SLABAKOVA**	F	IO-BAS	Chief Scientist, Apparent Optical Properties and Sun-Photometry
5	Nataliya **SLABAKOVA**	F	IO-BAS	Water Sampling and Sample Conditioning
6	Nina **DZHEMBEKOVA**	F	IO-BAS	Water Sampling and Sample Conditioning
7	Yavor **VEKOV**	M	IO-BAS	Apparent Optical Properties
8	Anatoli **APOSTOLOV**	M	IO-BAS	CTD
9	Asen **KRASTEV**	M	IO-BAS	CTD
10	Hristo **IVANOV**	M	IO-BAS	CTD, Water sampling
11	Gianluca **VOLPE**	M	ISMAR CNR	Inherent Optical Properties
12	Elena **PANTEA**	F	NIMRD	Water Sampling and Sample Conditioning
13	Svitlana **KOVALYSHYNA**	F	UkrSCES	Water Sampling and Sample Conditioning
14	Marvin **WELLKAMP**	M	AWI	Training of water sampling collection and filtration

7. Stations List

The Akademik BIO-OPT 2019 cruise led to the completion of 80 measurement stations. Details on station position, time and measurements are listed in Table 4.

Table 4. Details on R/V Akademik BIO-OPT LEG 1 measurement stations

Station №	Date	Latutude Deg (North)	Longitude Deg (East)	Bottom Depth	Station Start (UTC)	Station End (UTC)	GEAR
K11-001	15.5.2019	43°36.600’	28°42.000’	56	04:00	05:10	AOP,IOP,WS
K11-002	15.5.2019	43°36.600’	28°49.200’	59	07:00	07:43	AOP,IOP,WS
K11-003	15.5.2019	43°36.600’	28°57.600’	67	08:43	09:15	AOP,IOP,WS
K11-004	15.5.2019	43°36.600’	29°06.000’	64	11:45	12:20	AOP,IOP,WS
K11-005	15.5.2019	43°36.627’	29°14.294’	67	13:06	13:35	AOP,IOP,WS
K11-006	15.5.2019	43°36.666’	29°22.413’	70	15:03	16:12	AOP,IOP,WS
K11-007	16.5.2019	43°36.033’	29°32.357’	99	04:00	09:32	AOP,IOP,WS
K11-008	16.5.2019	43°36.000’	29°38.901’	370	06:32	07:09	AOP,IOP,WS
K11-009	16.5.2019	43°36.000’	29°48.000’	255	08:23	09:10	AOP,IOP,WS
K11-010	16.5.2019	43°35.313’	29°55.611’	590	10:15	10:52	AOP,IOP,WS
K12-011	16.5.2019	43°35.381’	30°03.994’	685	12:29	12.59	AOP,IOP,WS
K13-012	16.5.2019	43°35.331’	30°11.667’	936	14:20	15:30	AOP,IOP,WS
K14-013	17.5.2019	44°06.131’	30°13.766’	98	04:00	05:25	AOP,IOP,WS
K15-014	17.5.2019	44°06.391’	30°05.300’	84	06:18	06:52	AOP,IOP,WS
K15-015	17.5.2019	44°06.122’	29°57.241’	65.5	08:45	08:23	AOP,IOP,WS
K11-016	17.5.2019	44°06.674’	29°49.270’	65.5	09:17	10:00	AOP,IOP,WS
K11-017	17.5.2019	44°06.763’	29°40.902’	61	11:00	11:41	AOP,IOP,WS
K11-018	17.5.2019	44°07.203’	29°31.568’	58	12:55	13:26	AOP,IOP,WS
K11-019	17.5.2019	44°07.322’	29°25.202’	54.8	14:20	16:05	AOP,IOP,WS

K11-020	18.5.2019	44°07.154’	29°15.005’	49	04:00	05:21	AOP,IOP,WS
K11-021	18.5.2019	44°07.078’	29°07.544’	44.8	06:18	07:01	AOP,IOP,WS
K11-022	18.5.2019	44°07.579’	28°58.977’	42.1	08:16	09:10	AOP,IOP,WS
K11-023	18.5.2019	44°13.378’	28°58.932’	34.8	10:00	10:44	AOP,IOP,WS
K11-024	18.5.2019	44°12.005’	28°50.210’	34.8	11:57	13:44	AOP,IOP,WS
K11-025	18.5.2019	44°18.235’	28°51.235’	29	14:40	15:40	AOP,IOP,WS
K11-026	19.5.2019	44°18.808’	29°07.748’	32.9	04:00	05:17	AOP,IOP,WS
K11-027	19.5.2019	44°18.555’	29°07.554’	36.8	06:00	06:44	AOP,IOP,WS
K11-028	19.5.2019	44°17.789’	29°15.918’	43.1	07:45	08:21	AOP,IOP,WS
K11-029	19.5.2019	44°17.876’	29°24.761’	52.6	09:23	10:11	AOP,IOP,WS
K11-030	19.5.2019	44°17.390’	29°32.253’	55	11:06	12:18	AOP,IOP,WS
K11-031	19.5.2019	44°17.965’	29°40.026’	58	13:31	14:22	AOP,IOP,WS
K11-032	20.5.2019	44°17.679’	29°48.433’	63	04:30	06:05	AOP,IOP,WS
K11-033	20.5.2019	44°18.172’	29°57.895’	68	07:00	07:55	AOP,IOP,WS
K11-034	20.5.2019	44°17.155’	30°05.072’	71	09:00	09:48	AOP,IOP,WS
K11-035	20.5.2019	44°16.927’	30°14.395’	82	11:14	11:50	AOP,IOP,WS
K11-036	20.5.2019	44°16.866’	30°22.154’	89	13:01	13:46	AOP,IOP,WS
K11-037	20.5.2019	44°16.343’	30°30.170’	96	14:40	15:32	AOP,IOP,WS
K11-038	21.5.2019	44° 16.337’	30° 39.509’	114	04:25	05:39	AOP,IOP,WS
K11-039	21.5.2019	44° 16.353’	30° 46.932’	112	06:30	07:27	AOP,IOP,WS
K11-040	21.5.2019	44° 15.551’	30° 55.318’	179	08:25	09:10	AOP,IOP,WS
K11-041	21.5.2019	44° 15.571’	31° 3.884	392	10:12	10:43	AOP,IOP,WS
K11-042	21.5.2019	44° 15.594’	31° 11.137’	582	11:53	12:28	AOP,IOP,WS
K11-043	21.5.2019	44° 23.749’	31° 5.532’	380	13:50	14:57	AOP,IOP,WS

K11-044	22.5.2019	44° 35.541’	31° 6.374’	230	04:37	05:48	AOP,IOP,WS
K11-045	22.5.2019	44° 34.973’	30° 57.638’	98	06:40	07:34	AOP,IOP,WS
K11-046	22.5.2019	44° 35.550’	30° 45.775’	88	09:00	09:42	AOP,IOP,WS,SUN
K11-047	22.5.2019	44° 35.700’	30° 38.183’	80	10:52	11:57	AOP,IOP,WS,SUN
K11-048	22.5.2019	44° 34.649’	30° 32.055’	77	13:10	13:55	AOP,IOP,WS,SUN
K11-049	22.5.2019	44° 35.053’	30° 26.973’	74	14:50	15:52	AOP,IOP,WS,SUN
K11-050	23.5.2019	44° 35.997’	30° 22.522’	70	04:30	05:53	AOP,IOP,WS,SUN
K11-051	23.5.2019	44° 35.990’	30° 14.568’	61	07:10	08:14	AOP,IOP,WS,SUN
K11-052	23.5.2019	44° 36.526’	30° 6.114’	62	09:36	10:45	AOP,IOP,WS,SUN
K11-053	23.5.2019	44° 36.547’	29° 58.299‘	58	11:45	12:26	AOP,IOP,WS,SUN
K11-054	23.5.2019	44° 36.594’	29° 50.453’	54	13:26	14:06	AOP,IOP,WS,SUN
K11-055	23.5.2019	44° 37.110'	29° 43.448’	52	15:00	16:54	AOP,IOP,WS
K11-056	24.5.2019	44° 37.271'	29° 33.077'	45	04:30	05:20	AOP,IOP,WS
K11-057	24.5.2019	44° 37.809'	29° 25.264’	35	06:40	07:11	AOP,IOP,WS
K11-058	24.5.2019	44° 37.957’	29° 21.076’	29	07:50	08:29	AOP,IOP,WS
K11-059	24.5.2019	44° 38.041’	29° 17.590’	24	09:10	09:40	AOP,IOP,WS
K11-060	24.5.2019	44° 37.748’	29° 8.515’	18	11:17	12:25	AOP,IOP,WS
K11-061	25.5.2019	43° 58.178’	28° 44.450’	36	04:27	05:11	AOP,IOP,WS
K11-062	25.5.2019	43° 57.915’	28° 50.933’	45	06:12	07:08	AOP,IOP,WS
K11-063	25.5.2019	43° 57.944’	28° 59.265’	45	08:00	08::31	AOP,IOP,WS
K11-064	25.5.2019	43° 57.542’	29° 7.026’	51	09:38	10:10	AOP,IOP,WS
K11-065	25.5.2019	43° 57.530’	29° 16.122’	52	11:30	12:06	AOP,IOP,WS
K11-066	25.5.2019	43° 57.433’	29° 23.661’	59	13:10	14:00	AOP,IOP,WS
K11-067	25.5.2019	43° 57.552’	29° 30.703’	62	14:40	15:40	AOP,IOP,WS

K11-068	26.5.2019	43° 57.613'	29° 39.111'	60	04:28	05:54	AOP,IOP,WS
K11-069	26.5.2019	43° 56.429'	29° 47.637'	69	07:21	08:22	AOP,IOP,WS,SUN
K11-070	26.5.2019	43° 56.493'	29°56.2783'	75	09:45	10:47	AOP,IOP,WS,SUN
K11-071	26.5.2019	43° 56.996'	30° 4.738'	80	12:01	13:02	AOP,IOP,WS,SUN
K11-072	26.5.2019	43° 56.445'	30° 12.272'	98	13:45	15:40	AOP,IOP,WS
K11-073	27.5.2019	43° 55.964'	30° 20.396'	203	04:35	05:50	AOP,IOP,WS
K11-074	27.5.2019	43° 56.398'	30° 28.046'	200	06:58	07:46	AOP,IOP,WS
K11-075	27.5.2019	43° 55.981'	30° 36.510'	580	09:00	09:56	AOP,IOP,WS,SUN
K11-076	27.5.2019	43° 55.784'	30° 44.899'	582	11:04	11:54	AOP,IOP,WS
K11-077	27.5.2019	43° 55.130'	30° 53.257'	861	13:00	13:34	AOP,IOP,WS,SUN
K11-078	27.5.2019	43° 55.023'	31° 0.156'	996	14:24	16:45	AOP,IOP,WS
K11-079	28.5.2019	43° 14.025'	30° 34.746'	1897	04:28	05:26	AOP,IOP,WS
K11-080	28.5.2019	43° 14.428’	30° 25.409’	1757	06:15	07:01	AOP,IOP,WS

8. Training

Basic training activities were carried out onboard of Akademik between stations. During the cruise training included tutorials on:

1. Water sampling and filtration (led by Dr. Nina Dzhembekova and Nataliya Slabakova)
2. AOP measurements (led by Dr. Giuseppe Zibordi)

9. Acknowledgements

We thank to the Captain and the Crew of the Research Vessel Akademik for professional support of daily adjustments in the cruise plan making possible the successful completion of the BIO-OPT-2019 activities.

10. References

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