Validation and modification of bio-optical and biogeochemical algorithms developed for Oceansat-3 OCM as a requisite pre-launch activity

Expedition Report: ORV SK-364

(December 16, 2019 to January 7, 2020)

Scientific Participation:

PRL, Ahmedabad
SAC (ISRO), Ahmedabad
Annamalai University, Chidambaram
CSIR-CSMCRI, Bhavnagar
Gujarat University, Ahmedabad

Co-ordinating Institute

NCPOR, Goa

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Overview

The scientific expedition on SK-364 was successfully conducted during December 16, 2019 to January 7, 2020 in the Arabian Sea. During this cruise, water sampling at fourteen stations and sediment coring at two stations was performed to fulfil the scientific objectives of different research groups which are mentioned further in the report.

Activities

The research objectives and experiments performed onboard by the research teams are described below:

SAC, Ahmedabad

Measurements of Optical and Biological Properties by Space Applications Centre (SAC), Ahmedabad onboard Sagar Kanya Cruise (SK-364)

Objectives

The following are the objectives of SAC, Ahmedabad participants for ORV Sagar Kanya 364:

1) Oceansat-3 pre-launch validation and algorithm finalisation: Algorithms that are being developed for operational, evaluation and test products of Oceansat-3 will be tested and validated using satellite derived geophysical products and *in-situ* data.
2) Characterization and spatio-temporal variation of winter blooms in northern Arabian Sea.
3) Comparing and developing arelation between chlorophyll derived from spectrophotometer and flourometer.
4) Characterisation of marine aerosol optical properties.

Introduction

Indian Space Research Organization (ISRO) is going ahead with its next satellite mission for the Remote Sensing of oceans with Oceansat-III, tentatively scheduled for launch in March-April, 2020.Oceansat-III will be the third in the series of Indian Remote Sensing satellites for oceanographic applications. This satellite will carry three ISRO built payloads, viz., a Radar Scatterometer (OSCAT-3), an Infrared Imager (SSTM) and an Ocean Colour Monitor (OCM-3). Data from OCEANSAT-1 OCM and Oceansat-II OCM, has been operationally utilized for PFZ forecast by INCOIS and for various biological and geo-physical science applications. Unlike OCM1 and OCM2, OCM3 is an advanced sensor with 13 spectral channels in the region of 0.407 to 1.020 microns with a targeted signal to noise ratio (SNR) greater than 1000 and ≤10 nm bandwidth for visible region and 20nm bandwidth for the IR region. It also has a marching orbit and ± 20° tilt to avoid sun-glint. SSTM will have two thermal channels: TIR-1 & TIR-2 with 500m (at Nadir) footprint size and 1400 km wide swath. The main objective of this sensor will be to provide highly accurate SST over global oceans along with ocean colour information.

Utilization of Oceansat-3 data essentially consists of three major components: (1) geophysical parameter retrieval, (2) calibration/validation, and (3) applications. Geo-physical products of Oceansat-3 have been identified in three categories as operational, evaluation and R&D products.Operational products are Remote sensing reflectancesRrs(λ), Chlorophyll*a*, aerosol optical depth, diffuse attenuation (Kd_{490}), total suspended sediments, photosynthetically available radiation(PAR), SST, LST, sigma0, wind speed, wind direction, wind stress curl etc. Evaluation products envisaged are IOPs, FLH, $CDOM_{abs}$. (λ), ocean primary production. R&D products are PSC, POC, Sea surface nitrate(SSN), algal bloom detection etc.

Under ISRO's Meteorology & Oceanography (MOP-III) programme many projects were formulated to develop algorithms and methods for the products mentioned above in collaboration with many academic and research institutes. These algorithms need to be validated rigorously in both Case-1 and Case-II waters and their uncertainty budget estimated before integrating into the data processing chain of Oceansat-3. Hence, as a pre-launch activity, it is required to have ship campaigns in Case-I waters of both the Arabian Sea and the Bay of Bengal during cloud free inter-monsoon and winter monsoon seasons for validation and fine tuning of algorithms.

Experimental procedure

Experiments were performed to do validation expedition in the Arabian Sea. We deployed under water radiometer to analyze the submarine light field and water leaving radiances at various hydrographic stations as per the cruise track. Radiometer operations were carried out around 12 noon when solar zenith angle was less than 30 degrees. Incoming surface irradiance was measured using Es sensor of radiometer which was mounted on a raised platform away from any shadow. The radiometer was operated in profiling mode, measuring upwelling radiance and downwelling irradiance from surface upto euphotic depth (1% light saturation). In total 14 stations were covered during the cruise expedition. Radiometer was deployed at allthe 14 stations. In two stations, the radiometer was operated in floating mode due to overcast and cloudy conditions.

Water samples were collected using CTD rosette sampler at surface, depth corresponding to DCM (deep chlorophyll maxima) and euphotic depth. DCM was obtained from flourometer sensor attached to CTD whereas euphotic depth was obtained from radiometer. From each depth, 55 to 60 litres of water were sampled for pigment and taxonomy studies. For chlorophyll and pigment measurements water samples were filtered on 25 mm Whatman GF/F filters (pore size 0.7 μm) onboard and immediately preserved in freezer at -20°C. Additional parameters like SST (Sea surface temperature), wind speed, wind direction, sea state (currents) were taken for studies related to physical forcing of ocean biology. Water samples were preserved for phytoplankton taxonomy as well. For this purpose, sea water was fixed with 1% of lugol'sIodin and preserved with 4% formaldehyde solution. Phytoplankton species would be identified and enumerated from the solution using inverted microscope. Ocean optics protocols was followed for *in-situ* measurements of bio-optical parameters for validation of ocean colour products. Table 1 lists the station locations and the depths from which water was sampled for lab-based analysis.

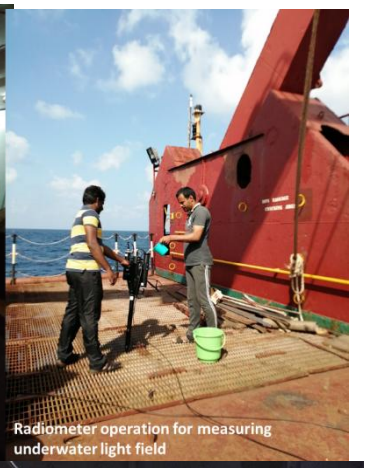
Table 1. *Radiometer operation details*

Station	Date	Latitude	Longitude	Depths (meter)	
				DCM	Euphotic
1	17/12/2019	15^0 56.34’	73^0 8.31’	35	45
2	19/12/2019	19^0 58.45’	69^0 30.20’	28	48
3	21/12/2019	20^0	65^0	22	46
4	22/12/2019	18^0	65^0	25	45
5	23/12/2019	16^0	65^0	25	40
6	24/12/2019	14^0	65^0	20	40
7	26/12/2019	12^0	65^0	20	30
8	27/12/2019	10^0	65^0	40	60
9	28/12/2019	8^0	65^0	58	76
10	30/12/2019	6^0	65^0	68	80
11	31/12/2019	4^0	65^0	78	95
12	02/01/2020	8^0	68 24.9’	85	110
13	04/01/2020	11^0 02’	71^0 02.5’	85	100
14	05/01/2020	13^0 30.67’	72^0 19.8’	50	65

Aerosol optical depth (AOD) was measured at every half hour between 9 am to 4:30 pm using sun photometer. The AOD values, which is measured at four wavelengths in VIS-NIR region of electro-magnetic spectra, is useful for characterising marine aerosol optical properties and validation of satellite derived AOD products.

One of the Scientist from SAC operating Sun-photometer: A device to measure Aerosol Optical Depth (AOD)

Scientist Performing Filteration using Water collected from Niskin Sampler at Surface, Deep-Sea Cholorphyll and Euphotic depths



Radiometer operation for measuring underwater light field

PRL, Ahmedabad

C:N:P stoichiometry, N_2 fixationand other biogeochemical parameters measurement in the Arabian Sea during winter monsoon

The Arabian Sea is one of the twin basins of the northern Indian Ocean, characterized by upwelling of subsurface water mostly during summer monsoon.Upwelling of subsurface water to surface facilitates easy exchange of temperature and other properties in these layers. In addition, low river discharge into the basin doesn't affect the upwelling. This process is mostly dominant in the southwest monsoon; meanwhile convection is significant during winter in this basin. This results the ocean as hotspot for biological and physical processes. Such processes affect the distribution and composition of phytoplankton by influencing the circulation and mixing of ocean water and in turn the redistribution of nutrients. Whereas the seasonal study is foremost required to understand the changing biogeochemistry of the ocean.

Globally, C:N:P ratio of 106:16:1 (Redfield ratio) became a cornerstone in the field of biogeochemistry[1], the regional studies on particulate organic matter elemental ratio have reported deviation from the canonical Redfield ratio[2]. Despite of diverse plankton community distribution the C:N:P in particulate organic matter (POM) and in dissolved inorganic matter (DOM) in the Arabian Sea have not been studied. In the present study, estimates ofC:N:P of the POM and DOM during winter monsoon was carried out. In addition, it is believed that the diazotrophic activity enhances in this season, therefore the study of autotrophic and heterotrophic N_2 fixation in this basin will be helpful to understand the biogeochemistry of the Arabian Sea in this season.

The Arabian Sea contains diverse biogeochemical features e.g. eutrophic, oligotrophic, and oxygen deficient zone (ODZ). The latter lies between 150 and 1000 m depth and represents the thickest oxygen deficient zone (ODZ) found in the world's oceans today. The OMZ of the Arabian Sea is the site of intense denitrification processes and thus plays a major role in the global nitrogen cycle.

Scientific Objectives

a. To estimate the C:N:P in particulate and dissolved organic matter in the Arabian Sea during the winter monsoon season as a part of our seasonal study and its variation from the canonical Redfield ratio.
b. To understand the effect of environmental factors and nutrient supply on the distribution of plankton community, can provide possible evidences for growth limitations in this basin.
c. To estimate the autotrophic and heterotrophic N_2 fixation in the Arabian Sea.
d. To estimate the taxon specific N_2 fixation and to quantify the cell counts of different phytoplankton species.
e. To estimate the C fixation in surface by phytoplankton at five different PAR percentage.
f. To estimate the greenhouse gases flux from the Arabian Sea and to understand nitrous oxide production pathways.

Materials and methods

Water samples were collected using Seabird CTD Niskin sampler from the surface, deep chlorophyll maxima (DCM), oxycline, 100 m, 200 m, 300 m, 500 m, 1000 m, 1500 m and 2000 m from the 14 locations situated in the coastal and open ocean (Fig 1). For particulate matter such as particulate organic carbon (POC), particulate organic nitrogen (PON) and particulate organic phosphorous (POP) analysis, water samples were filtered on pre-combusted (400°C, 4 h) Whatman GF/F filters (pore size 0.7 μm) in the cruise and were preserved in deep freezer at -20°C until analysis. The filtered matter for POP analysis were rinsed with Na_2SO_4 solution before freezing in order to remove the inorganic phosphates present if any.

Water samples were collected in HDPE, centrifuge bottles and preserved in freezer at -20°C until analysis of dissolved nutrients such as nitrate (NO_3^-), nitrite (NO_2^-), phosphate (PO_4^{3-}), silicate (SiO^{-2}) and total organic carbon (TOC), total nitrogen (TN) measurement respectively.In addition, samples were collected for flow cytometric study of phytoplankton including cell sorting.

lIn order to identify and quantify the autotrophic and heterotrophic N_2fixation in the Arabian Sea, twenty-four-hour incubation experimentswere performed at six stations where water samples were filtered onboard on GTTP filter for DNA studies. This will be the first ever studied experiment in this region.Also, water samples were collected for the study of abundance of marine microorganisms especially picophytoplankton.

Additionally, water samples from the strong OMZ regions were collected at every alternate station for^{15}N isotope pairing experiments to quantify denitrification and anammox rates in the water column.

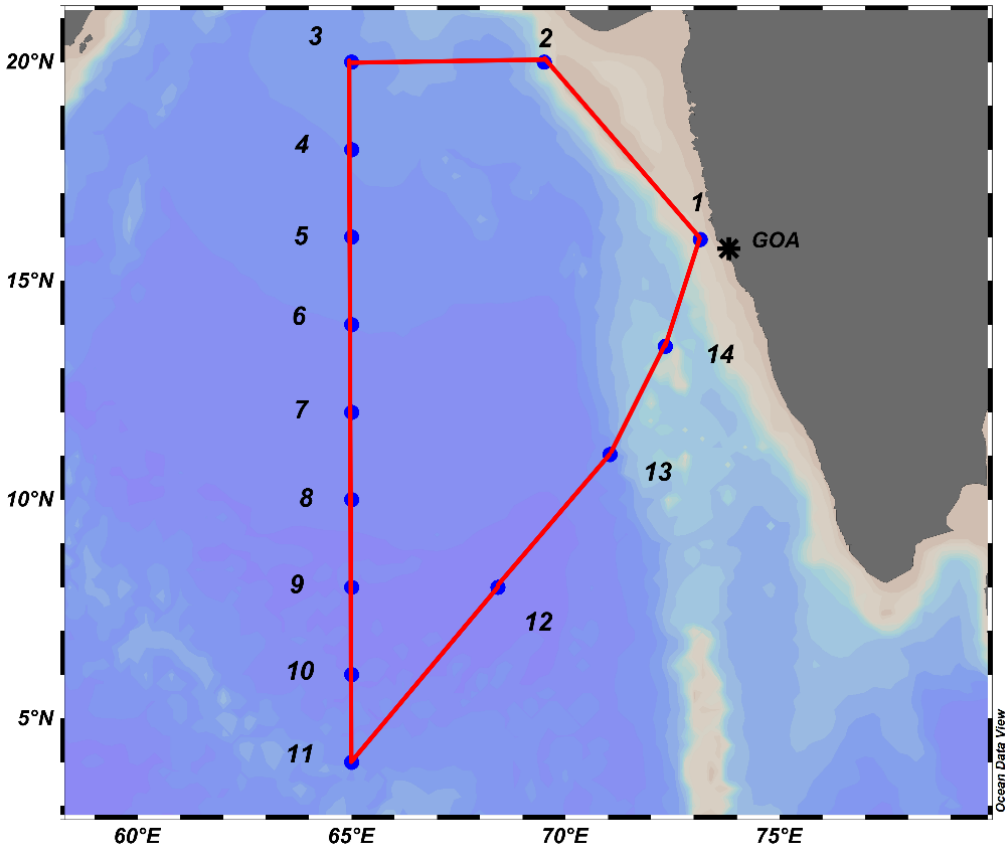


Figure 1. *Sampling locations in the Arabian Sea during 17 December 2019 - 6January 2020*

Aliquots of seawater sample were also collected for various other parameters. Details are given in following table.

Table 2.*List of Sample collection and preservation methodology*

Sampling Parameter	**Sample volume (ml)**	**Description**
Dissolved oxygen (Winkler Method)	120	Bubble free samples collected in BOD bottles till neck and fixed with reagents at the time sampling. Sample analysis was performed onboard using 865 Dosimat Plus titration unit just after sample collection.
Dissolved greenhouse gases	120	Sample collected in serum bottles, sealed using rubber septum and aluminium cap and preserved at room temperature adding supersaturated $HgCl_{2.}$
^{15}N and ^{18}O in dissolved nitrous oxide	250	Sample collected in serum bottles, sealed using rubber septum and aluminium cap and preserved at room temperature adding supersaturated $HgCl_{2.}$
$DIC^{13}C$ and DIC concentration	60	Sample collected in serum bottles, sealed using rubber septum and aluminium cap and preserved at room temperature adding supersaturated $HgCl_{2.}$
DOC	40	Samples were collected in glass vials and frozen immediately.
$DOC^{14}C$	1000	Samples were collected in glass PP bottles and frozen immediately.
$DIC^{14}C$	500	Samples were collected in PP bottles and treated with $HgCl_2$ for preservation at room temperature and sealed using Teflon tape
$\sum CO_2$	60	Bubble free samples were collected in glass bottles till neck and preserved by adding $HgCl_{2,}$ sealed with brown tape.
Water Isotopes (H & O)	15	Sample collected in Tarson narrow mouth bottle with tight cap.

Table 3. *Details of CTD sampler operations*

Sr. No.	Date	Station No.	Location		No. of casts	Duration of operation	Sampling Depths
			Lat (N)	Lon (E)			
1	17.12.2019	1	15˚ 56.82’	73˚9.22’	6	07.35 to 14.10	50, 25, 10, 45, 35, 5
2	19.12.2019	2	20˚0.00’	69˚30.00’	6	06.10 to 13.10	140, 100, 75, 50, 48, 35, 25, 5
3	21.12.2019	3	20˚00.00’	65˚00.00’	8	05.00 to 16.00	3000,2500,2000,1500,300,1000, 500, 200, 150,120, 70, 50, 25,10, 46, 22, 5
4	22.12.2019	4	18˚00.00’	65˚00.00’	7	07.50 to 15.00	2000,1500,950, 500, 300 200, 150, 75, 50, 45 25, 5
5	23.12.2019	5	16˚00.00’	65˚00.00’	7	06.35 to 15.00	2000,1500,1000, 600, 300 200, 140, 75, 50, 40 25, 5
6	24.12.2019	6	14˚00.00’	65˚00.00’	8	05.36 to 15.50	3000, 2500, 2000,1500,1000, 800500, 300 200, 150, 100 75, 50, 40 25, 20, 5
7	26.12.2019	7	12˚00.00’	65˚00.00’	6	05.15 to 12.00	2000,1500,1000, 600, 300, 190, 140, 100 75, 50, 25, 5
8	27.12.2019	8	10˚00.00’	65˚00.00’	7	5.27 to 13.00	2000,1500,1000, 800, 500, 300, 180, 130, 100 75, 50, 25, 5, 40, 60
9	28.12.2019	9	08˚00.00’	65˚00.00’	2	05.18 to 14.00	3000, 2500,2000, 1500, 1000, 5 (all casts could not be completed due to error in CTD)
10	29.12.2019	9	08˚00.00’	65˚00.00’	7	05.16 to 12.00	2000, 1500,1000, 500, 300, 200, 150, 100, 75, 58, 25, 5
11	30.12.2019	10	06˚00.00’	65˚00.00’	8	05.12 to 14.00	2000, 1500, 1000, 800, 500, 300, 190, 140, 100, 80, 70, 68, 25, 5
12	31.12.2019	11	04˚00.00’	65˚00.00’	7	06.10 to 14.30	2000, 1500, 1000, 500, 300, 100, 150, 100, 95, 50, 78, 25, 5
13	02.01.2020	12	08˚00.00’	68˚25.00’	7	05.20 to 16.00	2000, 1500, 1000, 500, 300, 200, 100, 150, 107, 100, 85, 75, 50, 25, 5
14	04.01.2020	13	11˚02.00’	71˚02.50’	7	04.50 to 14.00	2000, 1500, 900, 500, 300, 200, 100, 140, 90, 85, 75, 50, 25, 5
15	04.01.2020	14	13˚30.48’	72˚19.92’	7	10.00 to 16.00	1000, 500, 300, 200, 100, 150, 100, 85, 75, 53 ,50, 25, 5

Sediment Core Sampling

Theobjective to collect sediment core was to understand thepaleo-nitrogen cycling in the Arabian Sea. For this purpose, sediment core samples from two locations were collected using gravity corer. Prior to each coring, multibeam eco-sounder was used to perform bathymetry survey to identify the precise location of coring.

Table 4.*Sediment core sample details*

Sr. No.	Date	Station No	Location	Water depth (m)	Core Length recovered (m)
1	20.12.2019	3	20˚00.00' N, 64˚59.50' E	3164	4.10
2	03.01.2020	13	11˚02.00' N, 71˚02.50' E	2827	5.16

Aerosol Sampling

Timely sampling of the ambient air for aerosol concentrations was conducted to understand the atmospheric chemistry of the Arabian Sea during winter-monsoon. These samples were collected only when the cruise was running to avoid any contamination from the engine exhaust. Details of the aerosol sampling is provided in Table 5.

Table 5.*Details of aerosol samples*

Sample ID	Date (start)	Date (end)	From Location	To Location	Duration(hours)
SK-364/01	17-12-2019	18-12-2019	16^{o}31.30'N 72^{o}41.68'E	18^{o}00.24'N 71^{o}21.43'E	19.56 to 10.22
SK-364/02	19-12-2019	20-12-2019	19^{0}57.50'N 68^{0}43.73'E	19^{o}58.86'N 66^{o}34.61'E	19.48 to 10.16
SK-364/03	21-12-2019	22-12-2019	19^{0}39.60'N 64^{0}55.91'E	18^{o}00.86'N 64^{o}59.89'E	18.26 to 05.46
SK-364/04	22-12-2019	23-12-2019	17^{0}48.95'N 64^{0}59.33'E	16^{o}02.18'N 64^{o}59.94'E	17.37 to 05.53
SK-364/05	23-12-2019	24-12-2019	15^{0}39.47'N 64^{0}58.38'E	14^{o}02.80'N 64^{o}59.59'E	17.20 to 04.58
SK-364/06	24-12-2019	25-12-2019	13^{0}31.33'N 64^{0}56.80'E	12^{0}00.88'N 64^{0}59.50'E	18.40 to 08.57
SK-364/07	26-12-2019	27-12-2019	11^{0}57.95'N 64^{0}59.19'E	10^{0}20.71'N 64^{0}59.83'E	13.53 to 02.21
SK-364/08	27-12-2019	28-12-2019	9^{0}25.39'N 64^{0}59.36'E	7^{0}59.93'N 65^{0}00.43'E	17.11 to 05.25

SK-364/09	29-12-2019	30-12-2019	$7^0$24.54'N $64^0$58.95'E	$6^0$00.98'N $64^0$59.95'E	17.10 to 04.30
SK-364/10	30-12-2019	31-12-2019	$5^0$30.90'N $64^0$57.53'E	$3^0$59.97'N $64^0$59.61'E	18.08 to 06.30
SK-364/11	31-12-2019	01-01-2020	$4^0$21.16'N $65^0$11.50'E	$5^0$49.54'N $66^0$29.28'E	17.56 to 08.08
SK-364/12	02-01-2020	03-01-2020	$8^0$19.49'N $68^0$38.09'E	$9^0$42.52'N $69^0$51.37'E	12.58 to 10.47
SK-364/13	02-01-2020	03-01-2020	$8^0$19.49'N $68^0$38.09'E	$9^0$42.52'N $69^0$51.37'E	20.25 to 10.10
SK-364/14	04-01-2020	05-01-2020	$11^0$44.01'N $71^0$26.03'E	$13^0$14.37'N $72^0$12.84'E	19.54 to 07.43

Annamalai University, Chidambaram and CSIR-CSMCRI, Bhavnagar

Objectives

- To measure new production by using N15 tracers
- To measure primary production by using C13 tracers
- To measure chlorophyll PON/POC and SPM

Water samples were collected from surface into Polycarbonate Nalgene bottle. for Nitrate, ammonium and Urea uptake experiments N15 tracers are added similarly for primary production C13 tracer is added. Tracer-added bottles were kept in a crate tub on the main deck and seawater from a depth of 6 m was circulated during the incubation for twenty-four hours at each sampling station. At the end of incubation, all samples were filtered sequentially through pre-combusted (4 h at 400 °C) 47 mm diameter and 0.7 μm pore size Whatmann GF/F filters, washed with filtered sea water. After the filtration, the samples were stored in hot air oven for drying overnight to preserve it for further analysis.

In addition to nitrate(NO_3^-), ammonium(NH_4^+) and urea uptake measurements, chlorophyll *a*measurementwas concurrently carried out. 10 L of water sample from surface was collected for chlorophyll a measurement and filtered on 47 mm diameter and 0.7 μm pore size Whatmann GF/F filters under low vacuum and the samples were stored at -20◦C in refrigerator. POC/N and SPM measurements were concurrently carried out. 10 L of water sample from

surface was collected for POC/N measurement and filtered pre-combusted on 47 mm diameter and 0.7 μm pore size Whatmann GF/F filters under low vacuum and the samples were stored at hot air oven.

Aliquot of seawater samples for inorganic micronutrients (Nitrite (NO_2^-), NO_3^-, NH_4^+, inorganic phosphate (PO_4^{3-}) and silicates (SiO_4^{4-}) stored in pre-cleaned polyethylene bottle (HDPE grade). The filtered subsamples were poisoned by adding 0.5ml of mercuric chloride ($HgCl_2$) to prevent any organic reaction.

At each sampling stations, phytoplankton and zooplankton samples were collected using a standard phytoplankton and zooplankton net. The volume of water filtration was quantified with aid of a flow meter attached to the net.After sample collection, the concentrated phytoplankton and zooplankton samples from the collecting chamber of the net was transferred to a pre-cleaned polyethylene bottle (HPDE grade) and preserved with formalin.

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