BIO-OPTICS FOR OCEAN COLOR REMOTE SENSING OF THE BLACK SEA (Black Sea Color)

TN1: Bio-optical cruise work programme

(01.12.2018 - 01.03.2019)

Total number of pages: 20

Workpakage:	*2*	***Data collection***
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Document Log

Date	Author	Changes	Version	Status
06.03.2019	Slabakova V.		V0	Draft
07.03.2017	Moncheva S.	Revisions	V1	Draft
08.03.2017	Slabakova V.	Final updated	V2	Complated

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Abbreviations

MODIS- Moderate Resolution Imaging Spectroradiometer

ESA - European Space Agency

JRC –Joint Research Centre

CTD- conductivity temperature depth sensor package

IOP – Inherent Optical Properties

WS- water samples

AOP- Apparent Optical Properties

1. Background and rationale

The Black Sea receives drainage from almost one-third of the continental Europe which includes significant portions of 17 countries, 13 capital cities and some 160 million people. While the physical processes of this highly important socio-economic marine region are relatively well assessed, its trophic and geochemical status is still not fully understood. Within such a framework, optical remote sensing of the sea (satellite ocean color) can provide synoptic information of seawater biogeochemical properties through maps of optically significant seawater constituents (i.e., Nezlin et al. 1999; Barale et al., 2002, Chirilova et al, 2017, Slabakova et al., 2014,) However, satellite derived products (e.g., chlorophyll a concentration commonly used as a proxy for phytoplankton biomass) exhibit large uncertainties in most of the marginal seas as demonstrated by local studies supported by truth data (Kopelevich et al. 2004, 2013, Sancak et al. 2005). Specifically Sancak et al. 2005 showed that the standard ocean color algorithms developed for global applications can be the source of large overestimates (up to hundreds of percent) of chlorophyll a concentration for both the Black Sea and the Eastern Mediterranean Sea. Sancak et al. (2005) recommend the collection of additional in situ data to understand the living and nonliving content of the water column affecting the signal received by satellite ocean color sensors. The works of Kopelevich et al. (2004, 2013) and Suslin et al., 2016 showed the possibility of minimizing the uncertainties in satellite derived products by developing regional algorithms for the Black Seas. This urged the creation of comprehensive data sets of statistically representative *in situ* measurements suitable for the development of specific regional bio-optical algorithms and which is more important to validate these algorithms.

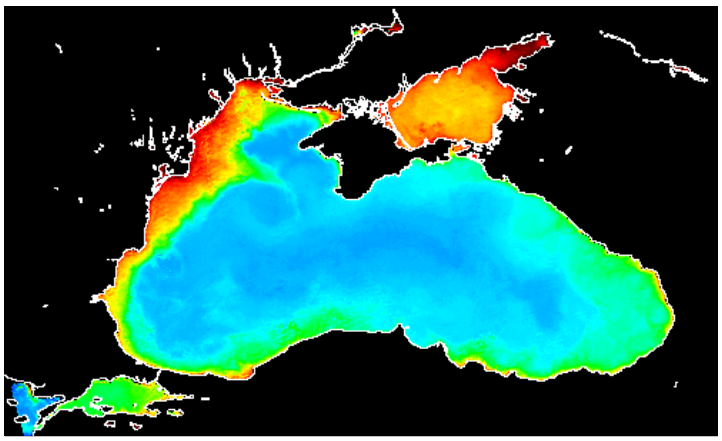

Figure 1. Black Sea monthly composites of May for Chlorophyll a produced from MODIS imagery for the period 2003-2015 applying algorithms proposed for global applications.

2. Methodology

The Bio-opt 2019 cruise will be carried out in the Northwestern Black Sea region exhibiting the highest environmental stress and range of variability in bio-optical features (see Figure 1) during May and June 2019 (15.05-04.06.2019) when biological productivity is high and phytoplankton blooms are likely to occur in the area of interest. The Bio-opt 2019 ESA contract cruise allowing for 14 days of sampling will be complemented by additional 7 sampling days supported by JRC. It is thus that the total 21 sampling days will be performed in two legs that will allow covering both the more complex bio-optical waters in Romanian, Ukrainian, Bulgarian coastal regions, and the less complex bio-optical waters in the offshore region of the Northwestern Black Sea.

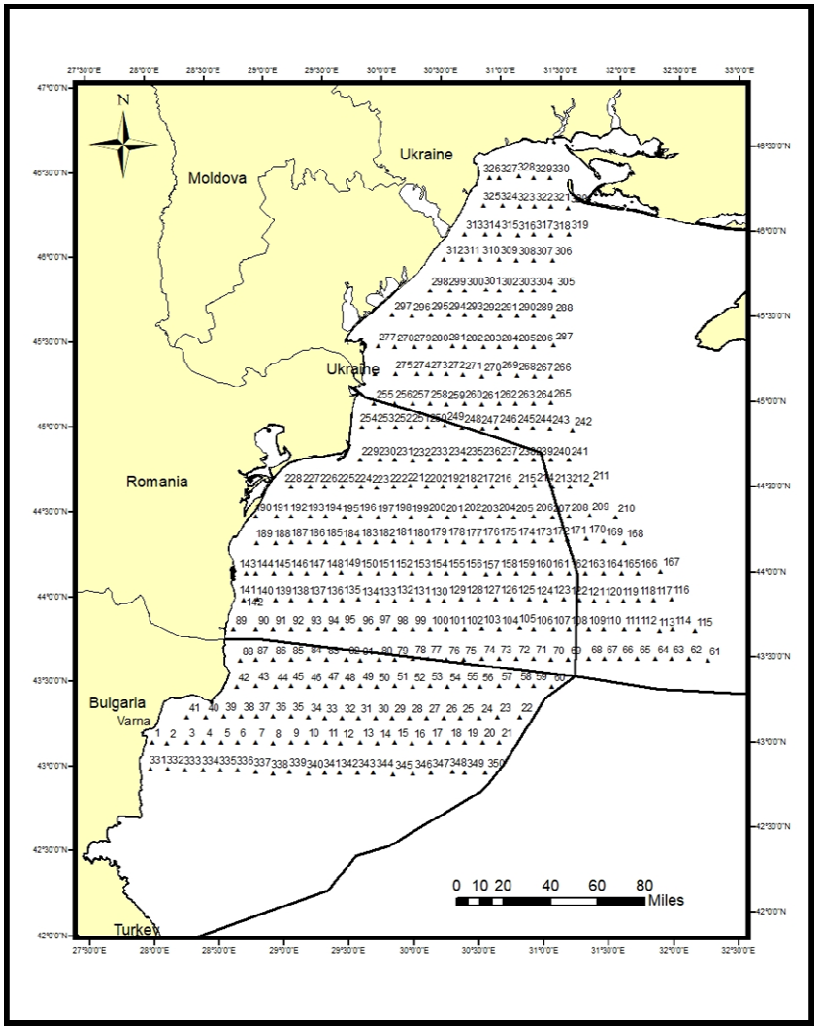

Figure 2. Tentative grid of desirable measurement stations in the Northwestern Black Sea. The target objective of the BIO-OPT -2019 ESA contract cruise is the collection of 105 stations while for the JRC cruise it comprises 54 stations (out of total 350 identified). Actual measurement plan will be adjusted on a daily basis accounting for local weather conditions and bio-optical state of the investigated area

3. Cruise plan

Measurement stations are chosen to represent seawaters likely characterized by different bio-optical regimes in the Romanian, Ukrainian and Bulgarian waters. Selected sampling regions comprising as waters that exhibit significant variability of bio-optical properties like Western Black Sea shelf area as well as very clear offshore waters of the Northwester Black Sea. Regular gridding is not a requirement for bio-optical activity: variability and statistical representativeness of bio-optical regional regimes are the basic requirements. Because of this, relying on the pre-defined stations grid, actual measurement stations can be fixed on a daily basis to account for weather conditions or bio-optical features of the area. In the case of very poor weather, measurement stations will be carried near the coast (while waiting for improvement of sea state). Station sampling time will be of approximately 30 minutes while travel time between stations is expected to vary between 1 and 1.5 hours. The bio-optical measurements are only possible on daylight conditions. Transects of 6-8 stations per day ideally equally spaced and aligned on transects, are likely possible. Any transit required to reach relatively distant regions, which might provide different/better measurement conditions, will be made overnight. Actual measurement stations will be decided on a day-by day basis accounting for changes in the bio-optical properties of seawater, sea-state and cloud cover forecasts. Target for the BIO-OPT-2019 ESA contract bio-optical campaign are 105 stations out of the 350 potential. A detailed list of stations (including positions) and transects is presented in Table.1.

Measurement sequence during each station will comprise:

A. Deployment of the CTD and IOP instrumental packages to characterize the near surface: i. salinity and temperature and ii. spectral absorption, attenuation and back-scattering, all within the first 30-50 meters (which are those of interest for ocean color remote sensing);

B. Collection of surface seawater samples (WS) to determine: i. absorption coefficients of pigmented, non-pigmented and colored dissolved organic seawater components through spectro-photometric techniques; ii. total suspended matter and pigments concentrations through, iii. identification of phytoplankton species composition through microscopic image analysis.

C. Deployment of free-fall optical radiometer systems (specifically two Satlantic profiling systems equipped with multispectral radiometers measuring upwelling radiance and, downward and upward irradiance) and a multispectral sun-photometer to determine: i. subsurface values of seawater AOP; and ii. atmospheric aerosol optical thickness (SUN).

Assuming a sea state lower than 3, measurements A and C can be carried out in approximately 15 minutes by a skilled team of five scientists (two handing the CTD and three the IOP packages). Equivalent time is required for measurements indicated at point B using two free-fall profilers operated by a skilled team of five/six scientists. Conditioning of water samples (i.e., seawater filtration) generally starts on spot/stations and is completed during travel time to next station by three scientists. Simultaneously to water filtration the sunphotometric measurements are performed during travel time to the following station by two scientists. Clearly, some scientists will sequentially operate different measurement systems.

Table 1. Details of r/v Akademik BIO-OPT 2019 measurement stations.

Station ID	Longitude, [DD]	Latitude, [DD]	Operation/measurments
1	27.99	43.14	AOP/IOP/CTD/ WS/SUN
2	28.11	43.13	AOP/IOP/CTD/ WS/SUN
3	28.27	43.13	AOP/IOP/CTD/ WS/SUN
4	28.40	43.13	AOP/IOP/CTD/ WS/SUN
5	28.54	43.13	AOP/IOP/CTD/ WS/SUN
6	28.67	43.13	AOP/IOP/CTD/ WS/SUN
7	28.81	43.13	AOP/IOP/CTD/ WS/SUN
8	28.94	43.12	AOP/IOP/CTD/ WS/SUN
9	29.09	43.12	AOP/IOP/CTD/ WS/SUN
10	29.21	43.12	AOP/IOP/CTD/ WS/SUN
11	29.36	43.12	AOP/IOP/CTD/ WS/SUN
12	29.48	43.11	AOP/IOP/CTD/ WS/SUN
13	29.63	43.11	AOP/IOP/CTD/ WS/SUN
14	29.77	43.10	AOP/IOP/CTD/ WS/SUN
15	29.91	43.10	AOP/IOP/CTD/ WS/SUN
16	30.04	43.10	AOP/IOP/CTD/ WS/SUN
17	30.18	43.10	AOP/IOP/CTD/ WS/SUN
18	30.32	43.09	AOP/IOP/CTD/ WS/SUN
19	30.45	43.09	AOP/IOP/CTD/ WS/SUN
20	30.59	43.09	AOP/IOP/CTD/ WS/SUN
21	30.72	43.08	AOP/IOP/CTD/ WS/SUN

22	30.89	43.23	AOP/IOP/CTD/ WS/SUN
23	30.72	43.23	AOP/IOP/CTD/ WS/SUN
24	30.58	43.23	AOP/IOP/CTD/ WS/SUN
25	30.43	43.24	AOP/IOP/CTD/ WS/SUN
26	30.30	43.24	AOP/IOP/CTD/ WS/SUN
27	30.16	43.24	AOP/IOP/CTD/ WS/SUN
28	30.03	43.25	AOP/IOP/CTD/ WS/SUN
29	29.89	43.25	AOP/IOP/CTD/ WS/SUN
30	29.76	43.26	AOP/IOP/CTD/ WS/SUN
31	29.63	43.26	AOP/IOP/CTD/ WS/SUN
32	29.49	43.26	AOP/IOP/CTD/ WS/SUN
33	29.36	43.26	AOP/IOP/CTD/ WS/SUN
34	29.23	43.27	AOP/IOP/CTD/ WS/SUN
35	29.09	43.28	AOP/IOP/CTD/ WS/SUN
36	28.95	43.28	AOP/IOP/CTD/ WS/SUN
37	28.82	43.28	AOP/IOP/CTD/ WS/SUN
38	28.70	43.28	AOP/IOP/CTD/ WS/SUN
39	28.56	43.29	AOP/IOP/CTD/ WS/SUN
40	28.42	43.28	AOP/IOP/CTD/ WS/SUN
41	28.27	43.29	AOP/IOP/CTD/ WS/SUN
42	28.67	43.46	AOP/IOP/CTD/ WS/SUN
43	28.82	43.46	AOP/IOP/CTD/ WS/SUN
44	28.97	43.45	AOP/IOP/CTD/ WS/SUN
45	29.10	43.46	AOP/IOP/CTD/ WS/SUN
46	29.24	43.45	AOP/IOP/CTD/ WS/SUN
47	29.37	43.45	AOP/IOP/CTD/ WS/SUN
48	29.50	43.44	AOP/IOP/CTD/ WS/SUN
49	29.65	43.44	AOP/IOP/CTD/ WS/SUN
50	29.78	43.44	AOP/IOP/CTD/ WS/SUN
51	29.92	43.44	AOP/IOP/CTD/ WS/SUN
52	30.06	43.43	AOP/IOP/CTD/ WS/SUN

53	30.20	43.43	AOP/IOP/CTD/ WS/SUN
54	30.34	43.42	AOP/IOP/CTD/ WS/SUN
55	30.47	43.42	AOP/IOP/CTD/ WS/SUN
56	30.60	43.42	AOP/IOP/CTD/ WS/SUN
57	30.74	43.41	AOP/IOP/CTD/ WS/SUN
58	30.89	43.41	AOP/IOP/CTD/ WS/SUN
59	31.02	43.40	AOP/IOP/CTD/ WS/SUN
60	31.16	43.40	AOP/IOP/CTD/ WS/SUN
61	32.40	43.50	AOP/IOP/CTD/ WS/SUN
62	32.25	43.51	AOP/IOP/CTD/ WS/SUN
63	32.11	43.52	AOP/IOP/CTD/ WS/SUN
64	31.99	43.53	AOP/IOP/CTD/ WS/SUN
65	31.84	43.53	AOP/IOP/CTD/ WS/SUN
66	31.71	43.54	AOP/IOP/CTD/ WS/SUN
67	31.59	43.54	AOP/IOP/CTD/ WS/SUN
68	31.47	43.55	AOP/IOP/CTD/ WS/SUN
69	31.30	43.55	AOP/IOP/CTD/ WS/SUN
70	31.16	43.55	AOP/IOP/CTD/ WS/SUN
71	31.03	43.57	AOP/IOP/CTD/ WS/SUN
72	30.89	43.57	AOP/IOP/CTD/ WS/SUN
73	30.75	43.57	AOP/IOP/CTD/ WS/SUN
74	30.62	43.58	AOP/IOP/CTD/ WS/SUN
75	30.47	43.58	AOP/IOP/CTD/ WS/SUN
76	30.34	43.58	AOP/IOP/CTD/ WS/SUN
77	30.20	43.59	AOP/IOP/CTD/ WS/SUN
78	30.07	43.59	AOP/IOP/CTD/ WS/SUN
79	29.93	43.59	AOP/IOP/CTD/ WS/SUN
80	29.80	43.60	AOP/IOP/CTD/ WS/SUN
81	29.65	43.60	AOP/IOP/CTD/ WS/SUN
82	29.54	43.60	AOP/IOP/CTD/ WS/SUN
83	29.38	43.61	AOP/IOP/CTD/ WS/SUN

84	29.24	43.61	AOP/IOP/CTD/ WS/SUN
85	29.10	43.61	AOP/IOP/CTD/ WS/SUN
86	28.96	43.61	AOP/IOP/CTD/ WS/SUN
87	28.82	43.62	AOP/IOP/CTD/ WS/SUN
88	28.70	43.61	AOP/IOP/CTD/ WS/SUN
89	28.65	43.80	AOP/IOP/CTD/ WS/SUN
90	28.83	43.79	AOP/IOP/CTD/ WS/SUN
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92	29.11	43.79	AOP/IOP/CTD/ WS/SUN
93	29.25	43.79	AOP/IOP/CTD/ WS/SUN
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98	29.94	43.77	AOP/IOP/CTD/ WS/SUN
99	30.08	43.77	AOP/IOP/CTD/ WS/SUN
100	30.21	43.76	AOP/IOP/CTD/ WS/SUN
101	30.35	43.76	AOP/IOP/CTD/ WS/SUN
102	30.49	43.75	AOP/IOP/CTD/ WS/SUN
103	30.63	43.75	AOP/IOP/CTD/ WS/SUN
104	30.76	43.75	AOP/IOP/CTD/ WS/SUN
105	30.93	43.75	AOP/IOP/CTD/ WS/SUN
106	31.04	43.74	AOP/IOP/CTD/ WS/SUN
107	31.19	43.73	AOP/IOP/CTD/ WS/SUN
108	31.31	43.73	AOP/IOP/CTD/ WS/SUN
109	31.48	43.72	AOP/IOP/CTD/ WS/SUN
110	31.59	43.72	AOP/IOP/CTD/ WS/SUN
111	31.76	43.71	AOP/IOP/CTD/ WS/SUN
112	31.86	43.70	AOP/IOP/CTD/ WS/SUN
113	32.04	43.69	AOP/IOP/CTD/ WS/SUN
114	32.14	43.69	AOP/IOP/CTD/ WS/SUN

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119	31.76	43.88	AOP/IOP/CTD/ WS/SUN
120	31.64	43.88	AOP/IOP/CTD/ WS/SUN
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219	30.37	44.60	AOP/IOP/CTD/ WS/SUN
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233	30.27	44.76	AOP/IOP/CTD/ WS/SUN
234	30.41	44.76	AOP/IOP/CTD/ WS/SUN
235	30.55	44.75	AOP/IOP/CTD/ WS/SUN
236	30.68	44.75	AOP/IOP/CTD/ WS/SUN
237	30.83	44.74	AOP/IOP/CTD/ WS/SUN
238	30.97	44.74	AOP/IOP/CTD/ WS/SUN

239	31.11	44.73	AOP/IOP/CTD/ WS/SUN
240	31.25	44.73	AOP/IOP/CTD/ WS/SUN
241	31.39	44.72	AOP/IOP/CTD/ WS/SUN
242	31.43	44.90	AOP/IOP/CTD/ WS/SUN
243	31.25	44.91	AOP/IOP/CTD/ WS/SUN
244	31.11	44.92	AOP/IOP/CTD/ WS/SUN
245	30.99	44.93	AOP/IOP/CTD/ WS/SUN
246	30.82	44.93	AOP/IOP/CTD/ WS/SUN
247	30.71	44.93	AOP/IOP/CTD/ WS/SUN
248	30.54	44.94	AOP/IOP/CTD/ WS/SUN
249	30.40	44.96	AOP/IOP/CTD/ WS/SUN
250	30.26	44.96	AOP/IOP/CTD/ WS/SUN
251	30.13	44.96	AOP/IOP/CTD/ WS/SUN
252	30.00	44.97	AOP/IOP/CTD/ WS/SUN
253	29.87	44.97	AOP/IOP/CTD/ WS/SUN
254	29.73	44.97	AOP/IOP/CTD/ WS/SUN
255	29.83	45.11	AOP/IOP/CTD/ WS/SUN
256	30.01	45.10	AOP/IOP/CTD/ WS/SUN
257	30.15	45.10	AOP/IOP/CTD/ WS/SUN
258	30.29	45.09	AOP/IOP/CTD/ WS/SUN
259	30.42	45.09	AOP/IOP/CTD/ WS/SUN
260	30.57	45.09	AOP/IOP/CTD/ WS/SUN
261	30.71	45.08	AOP/IOP/CTD/ WS/SUN
262	30.85	45.08	AOP/IOP/CTD/ WS/SUN
263	30.98	45.07	AOP/IOP/CTD/ WS/SUN
264	31.13	45.07	AOP/IOP/CTD/ WS/SUN
265	31.27	45.07	AOP/IOP/CTD/ WS/SUN
266	31.29	45.22	AOP/IOP/CTD/ WS/SUN
267	31.15	45.23	AOP/IOP/CTD/ WS/SUN
268	31.01	45.24	AOP/IOP/CTD/ WS/SUN
269	30.86	45.25	AOP/IOP/CTD/ WS/SUN

270	30.72	45.24	AOP/IOP/CTD/ WS/SUN
271	30.57	45.26	AOP/IOP/CTD/ WS/SUN
272	30.43	45.26	AOP/IOP/CTD/ WS/SUN
273	30.31	45.27	AOP/IOP/CTD/ WS/SUN
274	30.19	45.27	AOP/IOP/CTD/ WS/SUN
275	30.02	45.27	AOP/IOP/CTD/ WS/SUN
276	29.85	45.28	AOP/IOP/CTD/ WS/SUN
277	29.88	45.44	AOP/IOP/CTD/ WS/SUN
278	30.02	45.44	AOP/IOP/CTD/ WS/SUN
279	30.18	45.43	AOP/IOP/CTD/ WS/SUN
280	30.31	45.43	AOP/IOP/CTD/ WS/SUN
281	30.49	45.43	AOP/IOP/CTD/ WS/SUN
282	30.59	45.42	AOP/IOP/CTD/ WS/SUN
283	30.74	45.41	AOP/IOP/CTD/ WS/SUN
284	30.87	45.41	AOP/IOP/CTD/ WS/SUN
285	31.01	45.40	AOP/IOP/CTD/ WS/SUN
286	31.16	45.40	AOP/IOP/CTD/ WS/SUN
287	31.32	45.40	AOP/IOP/CTD/ WS/SUN
288	31.33	45.57	AOP/IOP/CTD/ WS/SUN
289	31.17	45.58	AOP/IOP/CTD/ WS/SUN
290	31.04	45.59	AOP/IOP/CTD/ WS/SUN
291	30.89	45.59	AOP/IOP/CTD/ WS/SUN
292	30.74	45.60	AOP/IOP/CTD/ WS/SUN
293	30.60	45.61	AOP/IOP/CTD/ WS/SUN
294	30.47	45.61	AOP/IOP/CTD/ WS/SUN
295	30.33	45.62	AOP/IOP/CTD/ WS/SUN
296	30.17	45.62	AOP/IOP/CTD/ WS/SUN
297	30.01	45.63	AOP/IOP/CTD/ WS/SUN
298	30.33	45.76	AOP/IOP/CTD/ WS/SUN
299	30.49	45.76	AOP/IOP/CTD/ WS/SUN
300	30.61	45.75	AOP/IOP/CTD/ WS/SUN

301	30.79	45.75	AOP/IOP/CTD/ WS/SUN
302	30.90	45.74	AOP/IOP/CTD/ WS/SUN
303	31.08	45.74	AOP/IOP/CTD/ WS/SUN
304	31.18	45.73	AOP/IOP/CTD/ WS/SUN
305	31.35	45.73	AOP/IOP/CTD/ WS/SUN
306	31.35	45.90	AOP/IOP/CTD/ WS/SUN
307	31.19	45.91	AOP/IOP/CTD/ WS/SUN
308	31.05	45.91	AOP/IOP/CTD/ WS/SUN
309	30.91	45.93	AOP/IOP/CTD/ WS/SUN
310	30.75	45.93	AOP/IOP/CTD/ WS/SUN
311	30.60	45.94	AOP/IOP/CTD/ WS/SUN
312	30.46	45.94	AOP/IOP/CTD/ WS/SUN
313	30.63	46.08	AOP/IOP/CTD/ WS/SUN
314	30.80	46.08	AOP/IOP/CTD/ WS/SUN
315	30.92	46.07	AOP/IOP/CTD/ WS/SUN
316	31.08	46.06	AOP/IOP/CTD/ WS/SUN
317	31.21	46.06	AOP/IOP/CTD/ WS/SUN
318	31.35	46.05	AOP/IOP/CTD/ WS/SUN
319	31.49	46.05	AOP/IOP/CTD/ WS/SUN
320	31.50	46.21	AOP/IOP/CTD/ WS/SUN
321	31.36	46.22	AOP/IOP/CTD/ WS/SUN
322	31.22	46.23	AOP/IOP/CTD/ WS/SUN
323	31.10	46.23	AOP/IOP/CTD/ WS/SUN
324	30.96	46.24	AOP/IOP/CTD/ WS/SUN
325	30.80	46.25	AOP/IOP/CTD/ WS/SUN
326	30.86	46.41	AOP/IOP/CTD/ WS/SUN
327	30.94	46.41	AOP/IOP/CTD/ WS/SUN
328	31.11	46.41	AOP/IOP/CTD/ WS/SUN
329	31.23	46.40	AOP/IOP/CTD/ WS/SUN
330	31.37	46.39	AOP/IOP/CTD/ WS/SUN
331	27.98	42.98	AOP/IOP/CTD/ WS/SUN

332	28.11	42.98	AOP/IOP/CTD/ WS/SUN
333	28.25	42.97	AOP/IOP/CTD/ WS/SUN
334	28.39	42.97	AOP/IOP/CTD/ WS/SUN
335	28.53	42.97	AOP/IOP/CTD/ WS/SUN
336	28.66	42.97	AOP/IOP/CTD/ WS/SUN
337	28.81	42.95	AOP/IOP/CTD/ WS/SUN
338	28.94	42.94	AOP/IOP/CTD/ WS/SUN
339	29.07	42.95	AOP/IOP/CTD/ WS/SUN
340	29.22	42.94	AOP/IOP/CTD/ WS/SUN
341	29.35	42.94	AOP/IOP/CTD/ WS/SUN
342	29.46	42.94	AOP/IOP/CTD/ WS/SUN
343	29.60	42.93	AOP/IOP/CTD/ WS/SUN
344	29.73	42.93	AOP/IOP/CTD/ WS/SUN
345	29.88	42.92	AOP/IOP/CTD/ WS/SUN
346	30.04	42.92	AOP/IOP/CTD/ WS/SUN
347	30.18	42.92	AOP/IOP/CTD/ WS/SUN
348	30.35	42.92	AOP/IOP/CTD/ WS/SUN
349	30.44	42.91	AOP/IOP/CTD/ WS/SUN
350	30.60	42.91	AOP/IOP/CTD/ WS/SUN

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