Phytoplankton Of Warming Ocean Waters (POWOW#2)

Cruise Report

10 January– 8 February 2013

Honolulu, Hawaii (round trip)

R/V Kilo-Moana
(KM1301)

Zackary Johnson (Duke University), Chief Scientist
Erik Zinser (University of Tennessee)
Steve Wilhelm (University of Tennessee)

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vJanuary 2014

Abstract

The POWOW#2 cruise was the second in a series cruises to study the influence of temperature and other environmental variables on *Prochlorococcus*, its viruses and other members of the microbial community. The primary goal of this cruise was to measure the abundance, diversity and activity of *Prochlorococcus* and associated bacterial and viral communities across temperature (and other environmental) gradients to understand how climate change may impact ocean ecology and biogeochemistry. There are many additional scientific and broader impact goals including characterizing oxidative stress and investigating nitrogen uptake/utilization molecular diversity. The official title of the project is "Collaborative Research: Seasonal and decadal changes in temperature drive *Prochlorococcus* ecotype distribution patterns" and it is part of NSF #1031064 (Duke) and 1030518 (UTK). The abstract from the grant is:

The two numerically-dominant ecotypes of the marine cyanobacterium *Prochlorococcus* partition the surface ocean niche latitudinally, with ecotype eMIT9312 dominant in the 30°N-30°S region and eMED4 dominant at higher latitudes. These ecotypes may account for 25-50% of primary production in open ocean ecosystems, but this percentage is dependent on which ecotype dominates. The relative abundance of the two ecotypes follows a log-linear relationship with temperature, with the transition from eMIT9312 to eMED4 occurring at ~18 °C. From these descriptive data, it has been hypothesized that temperature is the primary driver of relative abundance. Their contribution to net primary production, however, appears to be independent of temperature, suggesting temperature regulates ecotype dominance through photosynthesis-independent mechanisms. To test these hypotheses, the PIs are undertaking a series of field and lab studies to investigate the effect of temperature change on the distribution of these ecotypes. Two cruises in the North Pacific will trace the transitions from eMIT9312- to eMED4-dominated regions, with one cruise during the winter and the other during summer. They have hypothesized that the ratio of ecotype abundance will move latitudinally with the seasonal shift in temperature gradient: migration of the 18° C isotherm northward in the summer will be matched by a similar migration of the 1:1 ecotype transition point. Multiple crossings of the 18° C isotherm are proposed, and the summer cruise will also follow the isotherm to the Western US coast to gain insight on physical and geochemical influences. Environmental variables such as nutrient concentrations, light/mixing depths, and virus /grazing based mortality, which may impinge on the relationship between temperature and ecotype ratio, will be assessed through a series of multivariate analyses of the collected suite of physical, chemical and biological data. Seasonal comparisons will be complemented with on-deck incubations and lab competition assays (using existing and new isolates) that will establish, for the first time, how fitness coefficients of these ecotypes relate to temperature. As latitudinal shifts in temperature gradient and migration of ecotypes during seasonal warming likely share common features with high latitude warming as a consequence of climate change, the investigator's analyses will contribute important biological parameters (e.g., abundances, production rates, temperature change coefficients) for modeling biological and biogeochemical responses to climate change. This research will be integrated with that of committed collaborators, generating data sufficient for ecosystem-scale characterizations of the contributions of temperature (relative to other forcing factors) in constraining the range and seasonal migration of these numerically dominant marine phototrophs.

Disclaimer

All data and findings in this report are to be considered preliminary and subject to change without notice following instrument calibration and other data quality checks. Please contact the PIs for the most recent version of the data referenced in this report.

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Participants

Scientists (Total = 17)

Name	Group	Role
Dr. Zackary Johnson	Duke-PI	Chief Scientist (of paper work), ISUS, PE curves, CTD
Tristan Ballard	Duke	DIC/pH
Catherine Henry	Duke	Experimental (temperature shift → flow cytometry) / frozen nutrients
Molly Reichert	Duke	Size fractionated chlorophyll (profiles)
Carrie Schmaus	Duke	at sea flow cytometry (FACSCalibur) – profiles
Jennifer Walker	Duke	Experimental (temperature shift → chlorophyll)
Samantha Rose	Duke	NH_4
Yajuan Lin	Duke	Ap / FIRe (profiles + incubations) / frozen flow cytometry
Alyse Larkin	Duke	RNA + DNA
Maria de Oca	Duke	Primary production / Flow cytometry lead
Dr. Erik Zinser	UTK-PI	Chief Mate Scientist / qPCR
Lanying Ma	UTK	Prochlorococcus vs. HOOH
Jackson Gainer	UTK	Virus, Het. Bacteria
Marty Szul	UTK	*Prochlorococcus* metabolic profiling
Dr. Steve Wilhelm	UTK-PI	Virus, Bacterial productio, large chlorophyll size fraction
Dr. Jennifer DeBruyn	UTK	Bacterial production
Helena Pound	UTK	Bacterial production, large chlorophyll size fraction

Captain

Name	Group	Role
Rick Meyer	UH	Captain

Marine Technicians (University of Hawaii / Ocean Technology Group)

Name	Group	Role
Vic Polidoro	OTG	Lead Marine Technician
Ben Colello	OTG	2nd Marine Technician

Friends of the Cruise (non-cruise participants)

Name	Group	Role
Dr. Elizabeth Steffen	NOAA/PMEL	ARGO
Jules Hummon	University of Hawaii	ADCP

Figure 1: Group Photo

Contact Information

Johnson Lab
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Wilhelm Lab
University of Tennessee
Dept. of Microbiology
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Knoxville, TN 37996

Research Objectives / Data

Johnson Lab - Duke (chief scientist, co-PI)

1. *Prochlorococcus* abundance, diversity and activity and environmental variables
2. DNA, RNA
3. nutrients (NO_2, NO_3, $SiOH_4$, PO_4, NH_4)
4. ISUS NO_3
5. flow cytometry– het. Bacteria, *Prochlorococcus*, *Synechococcus*, photosynthetic picoeukaryotes
6. size fractionated chlorophyll (0.22 and 0.8 µm)
7. pH (spectrophotometric), DIC
8. *Prochlorococcus* isolations
9. Temperature shift incubations
10. Size fractionated (0.22 and 0.8 µm) C-14 Primary production
11. Size fractionated (0.22 and 0.8 µm) C-14 photosynthesis-irradiance curves
12. Fluorescence induction and relaxation (FIRe)

Zinser Lab – UTK (co-PI)

1. Depth profiles of the *Prochlorococcus* ecotypes at each station along the transect
2. Isolation of new *Prochlorococcus* strains, especially of the eMED4 ecotype, using liquid and semisolid media enrichments (live and DMSO frozen)
3. Metabolomic profiles of whole community- and Prochlorococcus-specific-carbon flux, with 13C bicarbonate substrate additions (deck incubations)
4. Impacts of HOOH on Prochlorococcus and the rest of the microbial community (deck incubations)

Wilhelm Lab – UTK (co-PI)

1. To determine the distribution and productivity rates of cyanomyoviridae along the available temperature gradient and within the water column
2. To determine the distribution of N4-like roseoviridae along the transect
3. To test out our Turner Designs Phytoflash on both profiles and in underway mode
4. To collect samples for DNA analyses of microbial community structure.

Steffen & Johnson Groups - UW/NOAA

1. ARGO floats

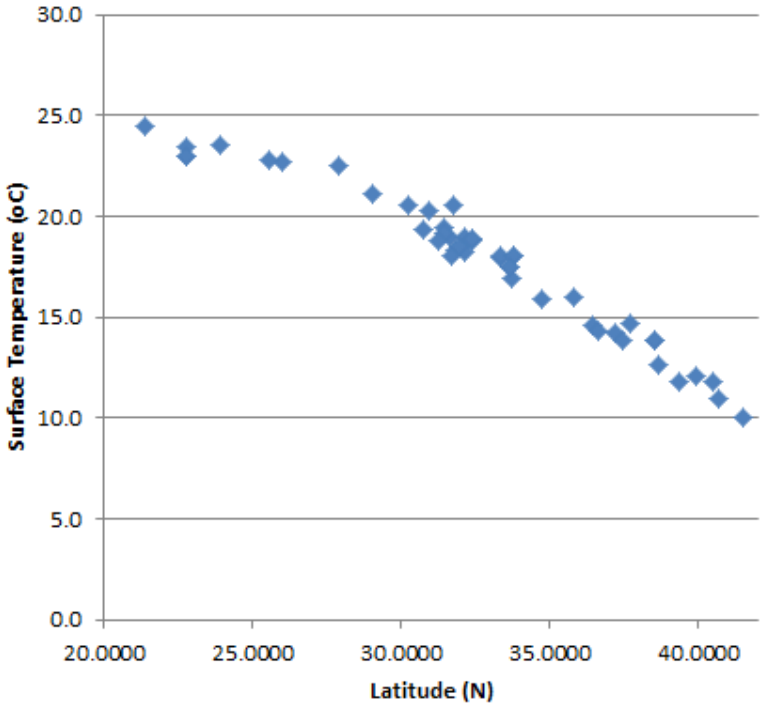
Outcomes

Johnson Lab

The Johnson group analyzed samples for numerous physical, chemical and biological variables along the meridional transects across gradients in sea surface temperature. Many of the physical and chemical variables are plotted below as part of the cruise hydrography although there are numerous additional samples that will be analyzed in the laboratory. Specifically, using a flow cytometer at sea, samples were taken throughout the water column (down to 200 m) and were analyzed for the abundance of *Prochlorococcus*, *Synechococcus* and other picophytoplankton across the temperature gradient in the North Pacific. Preliminary results show that as sea surface temperature decreased, so did the abundance of *Prochlorococcus*. Additional frozen and preserved samples from the water column were collected for flow cytometry (536 samples in total) on shore for total bacterioplankton. Samples from 4 temperature shift experiments (300 samples in total, see below) were also collected. Size fractionated chlorophyll (0.22 and 0.8 μm) was collected to determine the total and "*Prochlorococcus*"-specific biomass of phytoplankton along temperature and other environmental gradients. Active fluorescence (FIRe) was used to measure parameters of photosynthesis for both water column profiles and temperature shift experiments. pH was measuring using a fixed-temperature colorimetric analytical method and the data show a strong decrease in seawater pH—increase in acidity—with both increasing latitude and depth. Ammonium (NH_4) was measured in triplicate at all of the sampling stations using a fluorometric technique. Initial analyses show relatively consistent and low ammonium concentrations at latitudes below 36°N and higher values at increasing latitudes—which also correlates to two separate storms that likely caused mixing/upwelling. Ammonium concentrations were also measured for temperature shift experiments. Frozen samples for nitrate, nitrite, phosphate, urea and silicate were taken for all profiles. An ISUS was used to estimate nitrate concentration *in situ.* *Prochlorococcus* DNA and RNA samples were collected from environmental CTD casts and from onboard temperature shift experiments using 0.2 μm polycarbonate filters. In total, we collected 1,500 samples, which will be analyzed using qPCR and next generation sequencing (NGS) when we return to the Duke University Marine Laboratory. Size fractionated (0.22 and 0.8 μm) C-14 based primary production (on-deck incubations at 8 depths) and photosynthesis-irradiance curves (2 depths) were made for most early morning (i.e. ~4 am local) stations to estimate the contribution of *Prochlorococcus* and total phytoplankton to carbon cycling. Stations sampled for primary production covered sea surface temperatures from 10 to 21°C. Within these temperatures, the subsurface peak values of total production were highest in stations with the lowest sea surface temperature. We found the same patterns for the small (<0.8 μm) size fraction. As for the larger size fraction (>0.8 μm), subsurface peak values were consistently high throughout the transect. Higher total primary production values seemed to be associated with physical forcing, as evidenced by shallow deep chlorophyll maximum (DCM) and nitracline depth values. A comparison of profiles from the most eutrophic station (Station 29) and one of the most oligotrophic stations (Station 26) showed that in eutrophic conditions the smaller size fraction dominated at the surface and peaked at less than 20 m depth. On the other hand, for Station 26, the larger size fraction dominated at the surface and the peak of the smaller size fraction appeared bellow 40 m depth.

In addition to measuring natural variability, four temperature shift experiments were performed whereby water from ~18°C was placed in control or -2 and +2°C incubators and various

physical, chemical and biological variables tracked. The goal of these experiments was to determine how temperature affects the abundance, diversity and activity or *Prochlorococcus*. Each experiment lasted 4 days and was sampled daily, except for the last one, which was only sampled on days 2 and 4. Flow cytometry was used to determine changes in populations incubated at three different temperatures. In general, population size was augmented most greatly in the temperature increase environment, as compared to both the control and the temperature decrease. Overall, the several 4-day temperature shift experiments generally showed decreases in chlorophyll in the beginning, with an increase by the end of the 4 days. The rates of change varied between each incubator (one control, one warm, one cool) and variability between sample bottles was also observed.



Zinser Lab

The Zinser group worked on three different projects for KM1301. The first project was to collect for molecular characterization of the Prochlorococcus populations along the transect. For this purpose we collected cells via filtration, which we will process back in the lab at the University of Tennessee and assay by quantitative PCR, which will allow us to quantify the different genetic lineages of Prochlorococcus. In a similar way we sampled the temperature shift incubation experiments. In addition, for the first time, we brought on board our thermocycler which allows us to perform quantitative PCR. This instrument was used successfully to quantify two of the numerically-dominant lineages of *Prochlorococcus* during the cruise, giving us real-time information on the population structure over the transects. While only a preliminary study, it nonetheless confirmed our hypothesis that the dominant lineages switch dominance at the surface at approximately 19 °C: the "eMED4" lineage dominated colder waters, while the "eMIT9312" lineage dominated the warmer ones.

The second project was to collect samples to investigate the "metabolome" of the microbial community in general and the *Prochlorococcus* community specifically. Cells were collected on filters and stored for analysis back at UT. We will use a mass-spectrophotometric approach to quantify 100s or even 1000s of small metabolites, and with our deck incubation studies assess the impacts of nitrogen and/or phosphorus starvation on the flux of carbon and nitrogen through the *Prochlorococcus* cells.

The third project was to assess the ability of the microbial community to protect *Prochlorococcus* from hydrogen peroxide-mediated oxidative stress. Prochlorococcus is highly sensitive to peroxide, and our laboratory studies suggest a protective function for the other members of the marine microbial community. We used a dilution technique to vary the ability of the community to deal with a peroxide challenge, and assayed for changes in peroxide levels. We also collected samples of *Prochlorococcus* and the microbial community for further analysis back at UT.

Wilhelm Lab

We were able to complete most of our research objectives on the cruise. Approx. 680 bacterial production samples were processed at sea – sample processing stopped with about 10 days left in the cruise due to a catastrophic failure of the refrigerated microcentrifuge (see comments in cruise report on power issues in the radiation van). The group was also able to collect and process size fractionated chlorophyll from each cast (data available in swap filter), ~ 400 samples for the enumeration of *Prochlorococcus* phage by qPCR, ~ 800 samples for total virus enumeration. We completed about 25 experiments to measure the production rate of total viruses as well as cyanomyoviruses and *Prochlorococcus*-specific viruses. Nucleic acids were collected throughout the cruise (210 total samples) for metagenomic community analyses.

From our data we see anticipated trends in the north/south distribution of phytoplankton biomass. One note is that the second trip north encountered much higher chlorophyll concentrations and much of this was in a larger (> 20 um) size class consistent with the presence of a small diatom bloom. This might be tied to spikes in surface N noted by the Johnson lab in the preceding days and is potentially tied to storm events leading to upwelling of nutrient rich deeper waters.

ARGO Deployment

Seven ARGO floats. all from UW, were deployed on the cruise. All are successfully transmitting and details of the deployment are listed below.

Data

CTD Locations & Times

Station #	Cast	Event ID	UTC Day	UTC Time	Lat	Lon	Bottom Depth (m)
1	1	CTD01	11	00:16	21.3428	-158.2736	1544
2	1	CTD02	11	14:10	22.7498	-158.0002	4740
3	1	CTD03	11	22:09	23.8718	-158.0005	4495
4	1	CTD04	12	13:59	26.0011	-158.0001	4258
5	1	CTD05	12	21:59	27.8603	-157.9964	5660
6	2	CTD06	13	22:17	31.7307	-158.7325	5498
7	1	CTD07	14	17:28	33.3330	-159.0005	5663
7	2	CTD08	14	19:17	33.3330	-159.0026	5687
8	1	CTD09	14	22:03	33.6839	-158.9997	5978
9	1	CTD10	15	14:05	36.4552	-159.0026	5786
10	1	CTD11	15	22:03	37.6944	-159.0006	5379
11	1	CTD12	16	14:05	40.4740	-158.9992	5367
12	1	CTD13	16	22:01	39.9043	-159.2782	5444
12	2	CTD14	16	22:09	39.9043	-159.2948	5446
13	1	CTD15	17	13:59	38.5321	-160.6166	5532
13	2	CTD16	17	21:59	38.5276	-160.6105	5570
14	1	CTD17	18	22:23	39.3723	-159.8699	5551
15	1	CTD18	19	14:00	36.6536	-158.7330	5784
17	1	CTD19	19	21:55	35.7747	-158.3265	5877
18	1	CTD20	20	13:56	33.7511	-157.3052	6055
18	2	CTD21	20	18:48	33.7493	-157.3022	6054
19	1	CTD22	21	13:58	31.6056	-156.2510	5918
20	1	CTD23	21	21:57	30.9014	-155.9089	5852
21	1	CTD24	22	13:53	29.0000	-155.0035	5693
22	1	CTD25	22	21:56	30.2547	-154.8415	5718
24	1	CTD26	23	15:59	33.6521	-154.4219	5627
24	2	CTD27	23	17:47	33.6520	-154.4216	5628
27	1	CTD28	24	13:56	37.1968	-153.9533	5833
29	1	CTD29	25	16:10	41.5004	-155.2819	5436
30	1	CTD30	25	21:50	40.6849	-154.9993	5425
31	1	CTD31	26	13:54	38.6667	-154.0006	5061
32	1	CTD32	26	21:51	37.4186	-153.9972	5602
33	1	CTD33	28	21:54	32.1726	-154.0024	5321
34	1	CTD34	29	13:54	32.1252	-154.0280	5480
35	1	CTD35	30	05:43	34.6991	-154.0042	5729
36	1	CTD36	30	21:48	32.4117	-154.2499	-
37	1	CTD37	31	13:51	32.4119	-154.2498	-
37	2	CTD38	31	15:37	32.4115	-154.2499	-
38	1	CTD39	31	21:50	32.1561	-154.9074	-
39	1	CTD40	32	05:54	31.8231	-155.8880	5718
40	1	CTD41	32	13:51	31.9168	-156.8779	5736
41	1	CTD42	32	21:49	31.6948	-157.7786	5563
42	1	CTD43	33	13:49	31.4435	-158.7515	5809
42	1	CTD44	33	15:39	31.4438	-158.7499	5808

43	1	CTD45	33	21:49	31.2463	-158.0160	5919
44	1	CTD46	34	13:48	30.7507	-156.2010	5796
45	1	CTD47	36	03:56	25.5345	-155.8707	4946
46	1	CTD48	36	21:48	22.7704	-157.9356	-
47	1	CTD49	37	00:30	22.7512	-158.0005	-

Note: some stations not shown here correspond to ARGO deployment only stations.

CTD Notes – niskin mis-trips

CTD 28 niskin 6 (125 m) is likely a mis-trip based on flow cytometry data
CTD 33 niskin 17 (25 m) is likely a mis-trip based on pH data

ARGO deployment

UW Float #	WMO ID#	Latitude	Longitude	Deployment UTC Date	Deployment UTC Time
F0204	4901549	36.0008	-158.4387	2013-01-19	19:00
F0207	4901547	32.0000	-154.6283	2013-01-23	07:29
F0171	4901546	33.6519	-154.4224	2013-01-23	18:25
F0206	4901548	35.3933	-154.1950	2013-01-24	03:57
F0208	4901522	37.1081	-153.9648	2013-01-24	13:03
F0137	4901499	38.8000	-154.3467	2013-01-25	01:58
F0153	4901515	40.6848	-154.9993	2013-01-25	22:30

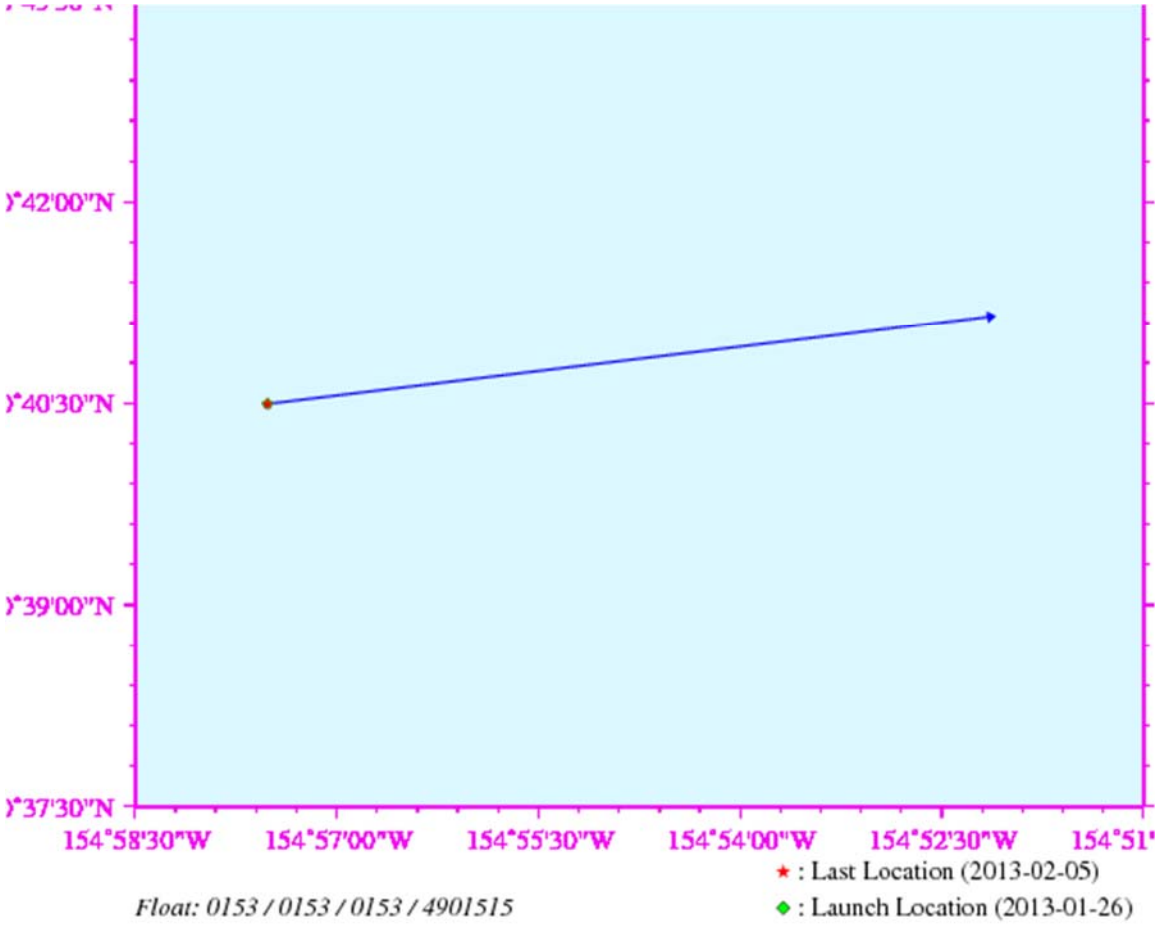


Figure 2: Sample Float Trajectory: WMO ID#4901515

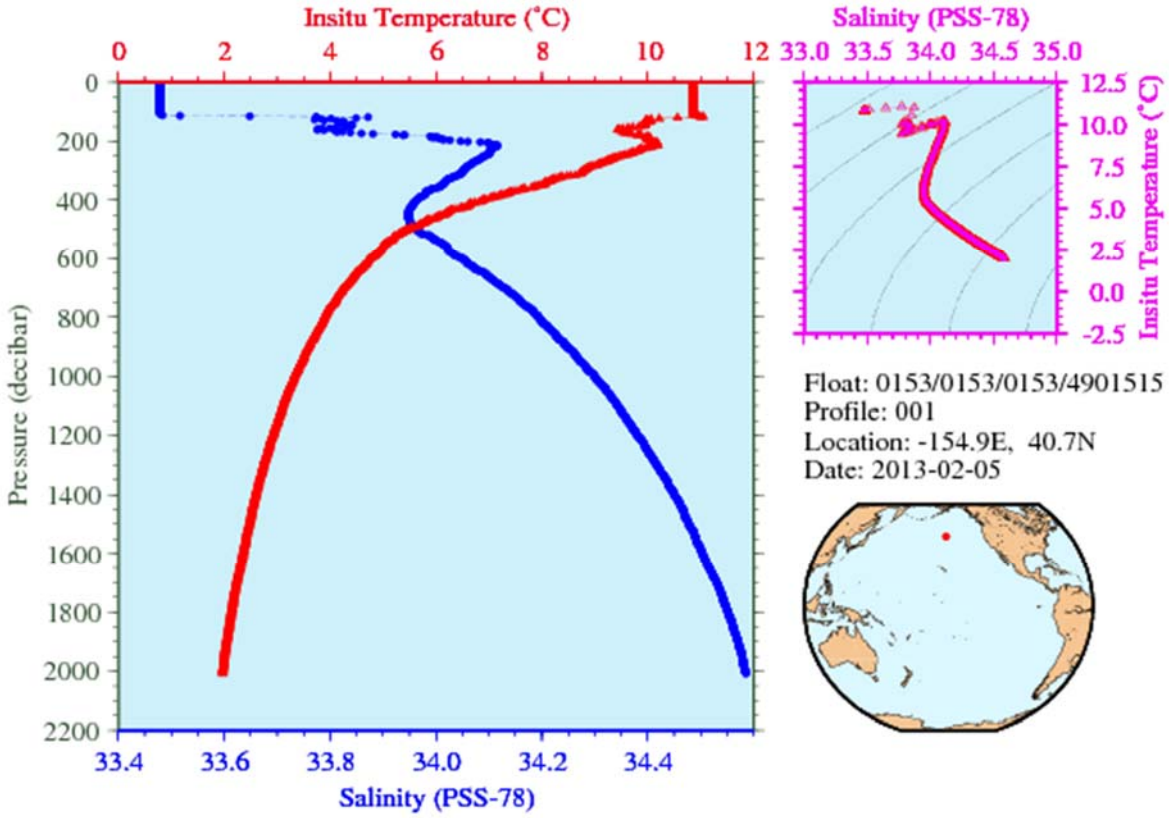


Figure 3: Sample profile for ARGO float (WMO ID#4901515)

Maps

Satellite Images

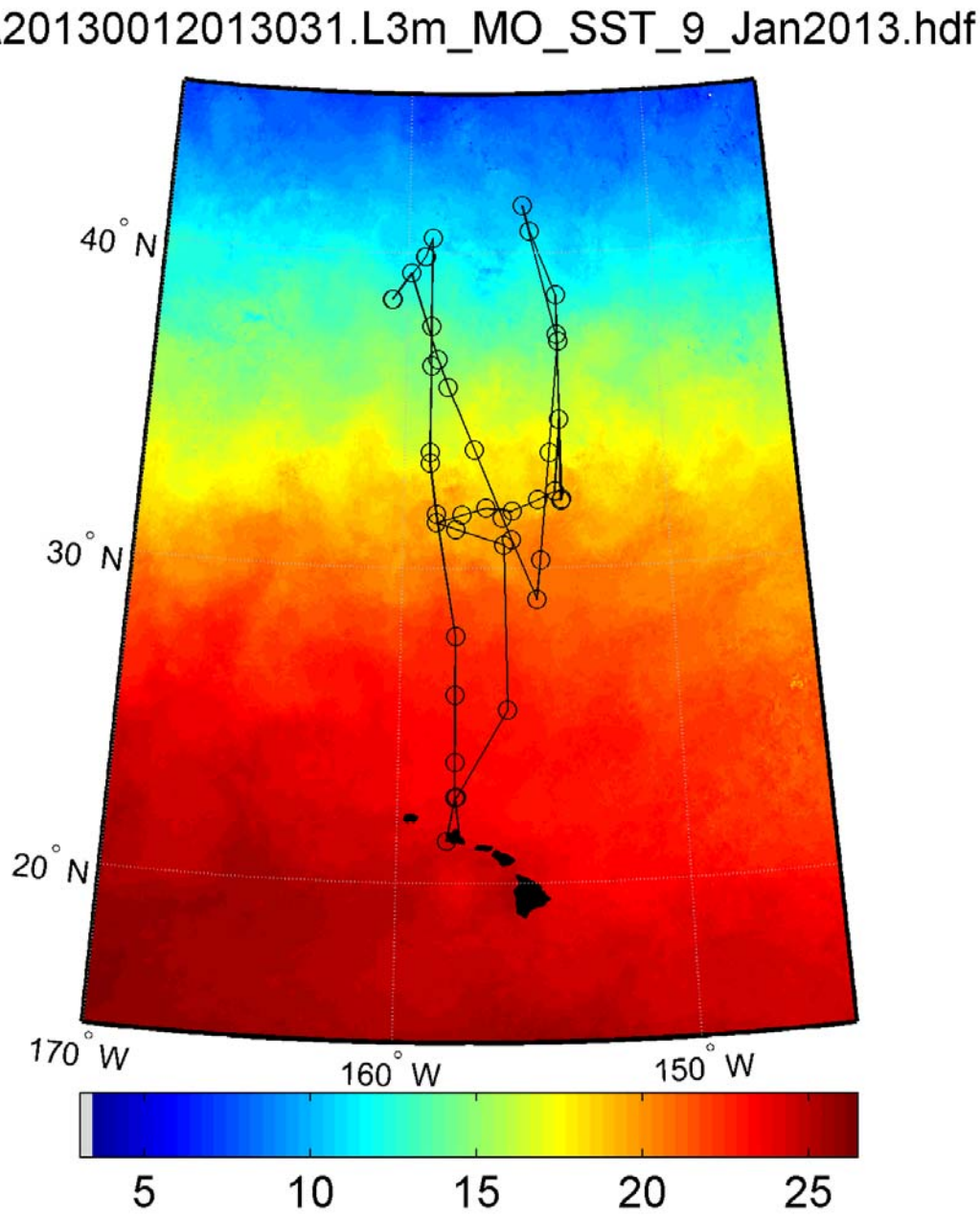


Figure 4: NASA Aqua MODIS estimated day time (11μ) sea surface temperature (January 2013 composite) with overlaid cruise track and stations. SST interpolated for pixels where data not available (e.g. clouds).

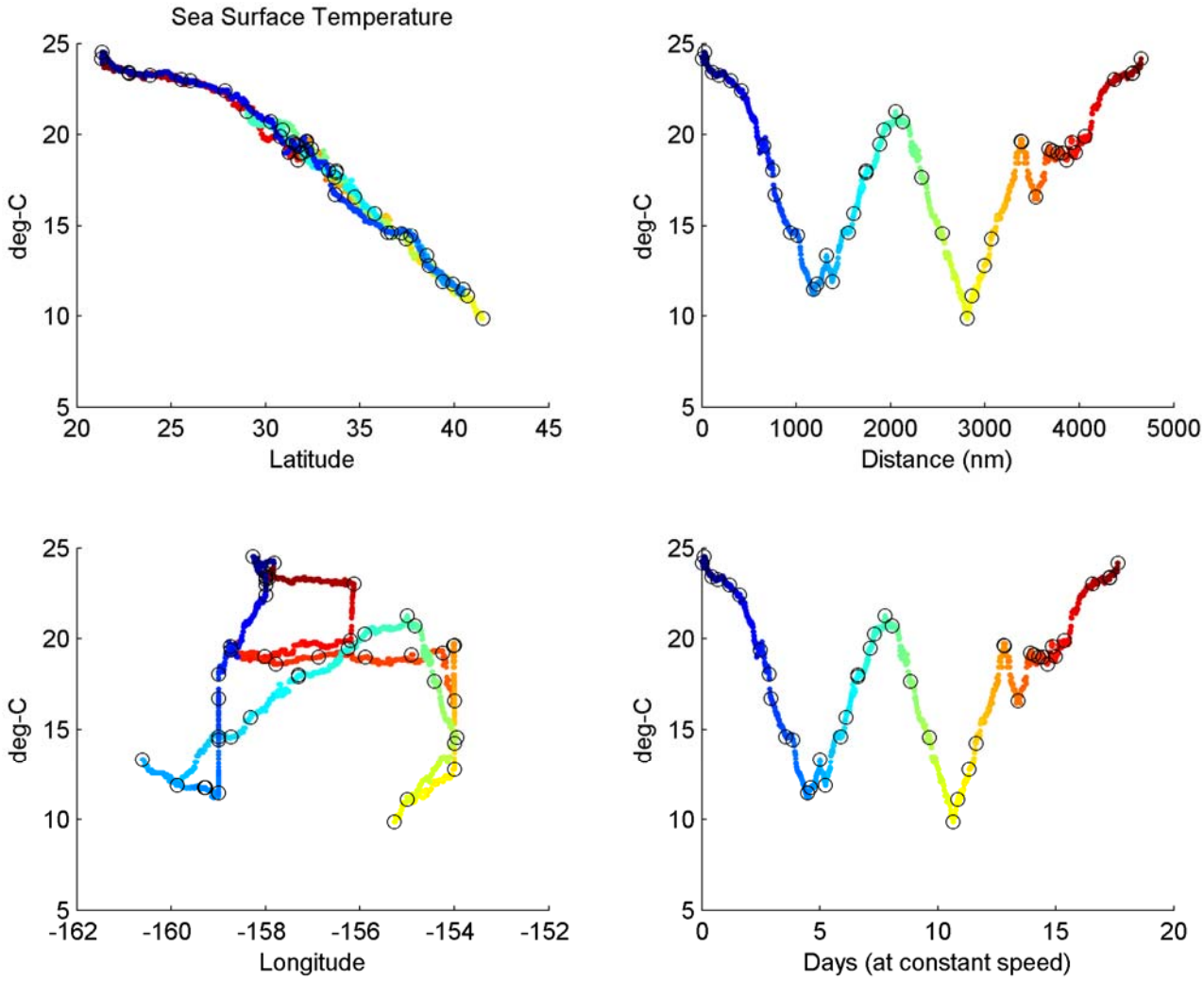


Figure 5: NASA Aqua MODIS estimated day time (11µ) sea surface temperature (January 2013 composite) along the cruise track as a function of latitude, distance, longitude and days at sea (assuming constant 11.5 knots). Circles denote station locations.

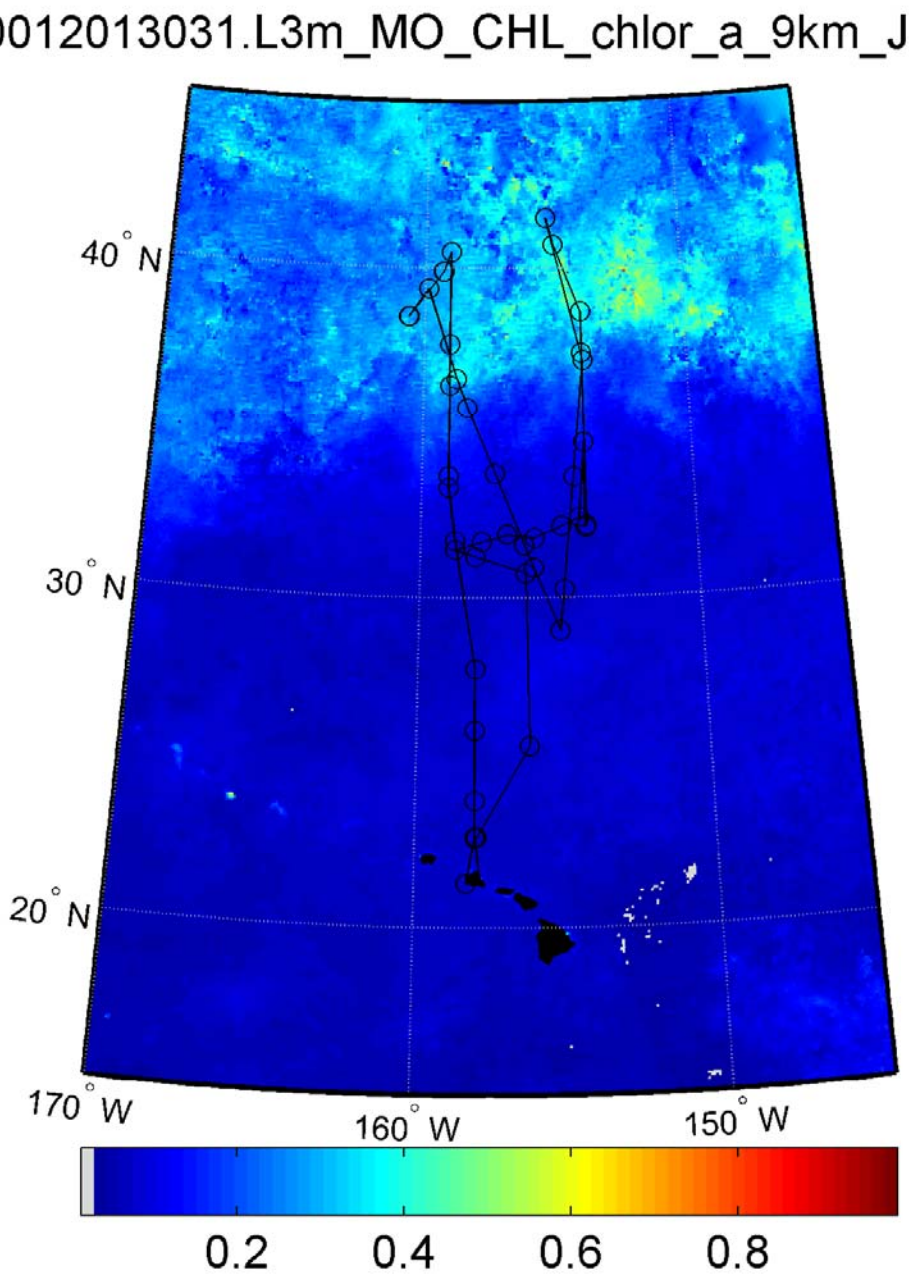


Figure 6: NASA Aqua MODIS estimated chlorophyll concentrations (January 2013 composite) with overlaid cruise track and stations. Chlorophyll interpolated for pixels where data not available (e.g. clouds).

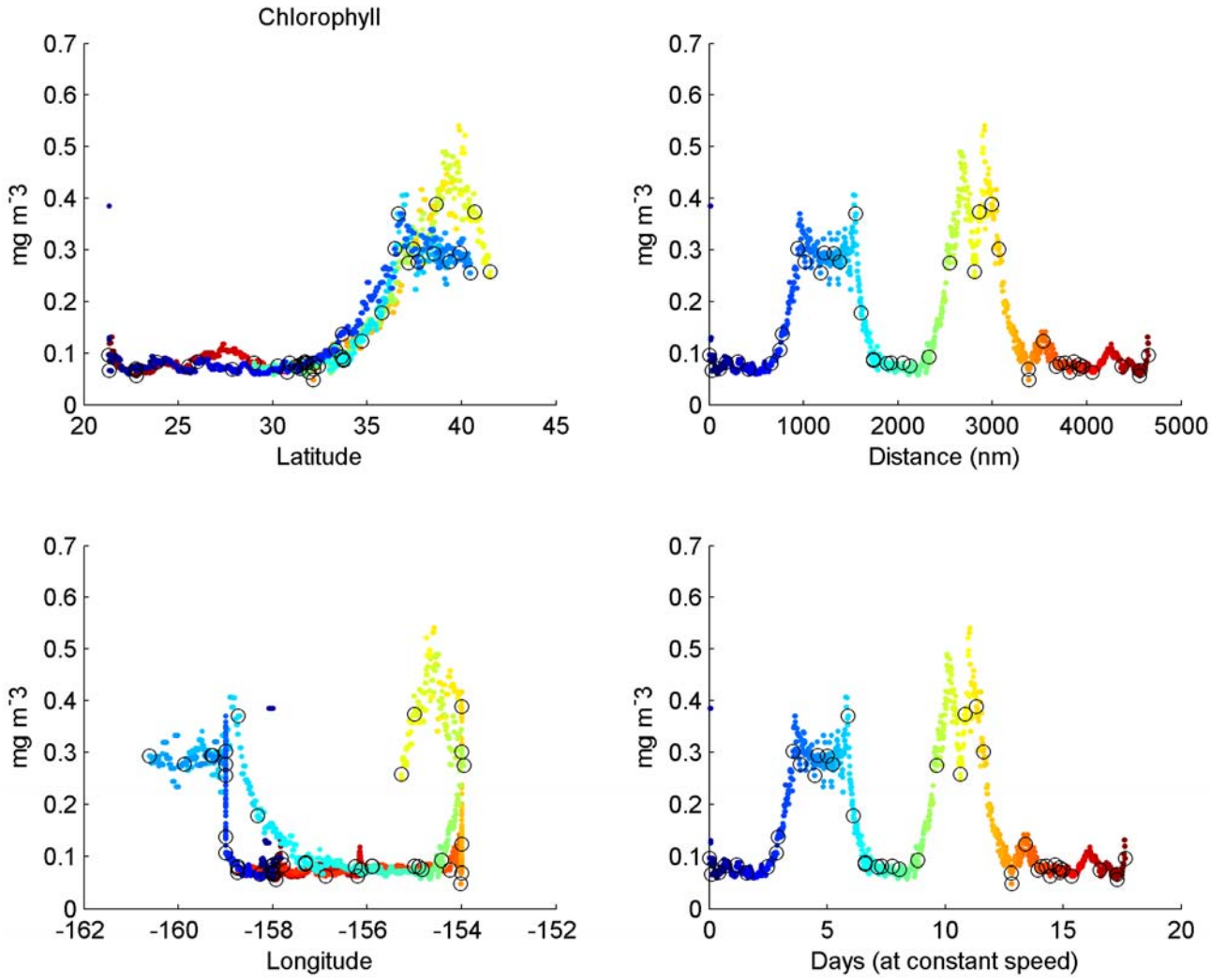
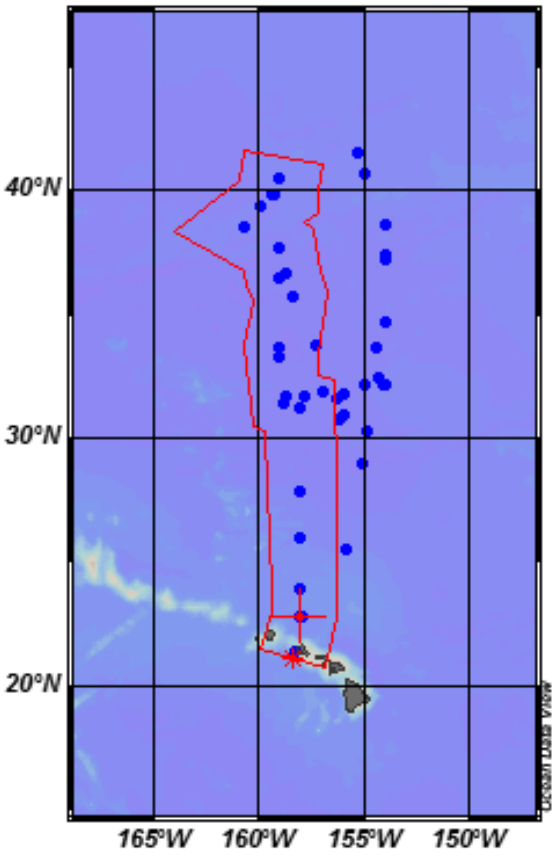
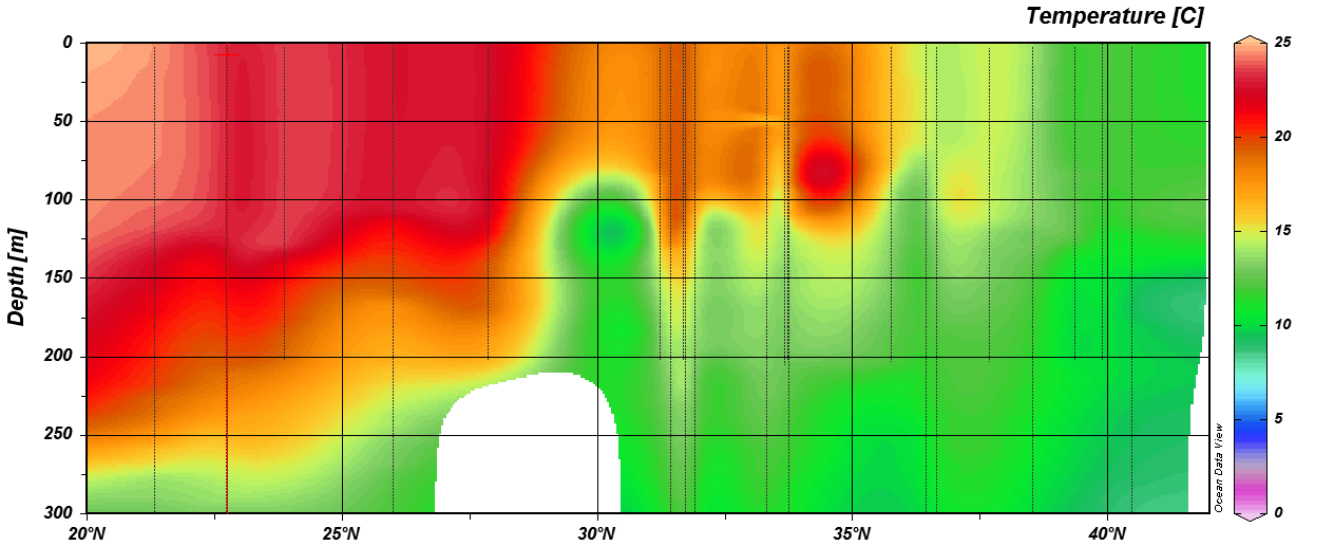


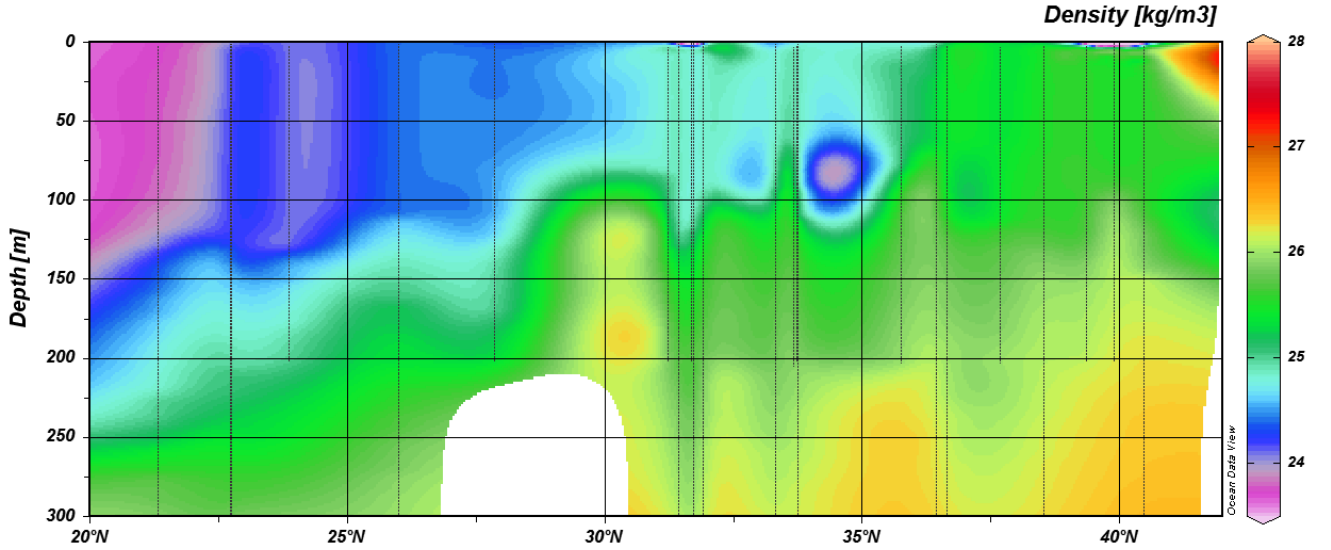
Figure 7: NASA Aqua MODIS estimated chlorophyll concentrations (January 2013 composite) along the cruise track as a function of latitude, distance, longitude and days at sea (assuming constant 11.5 knots). Circles denote station locations.

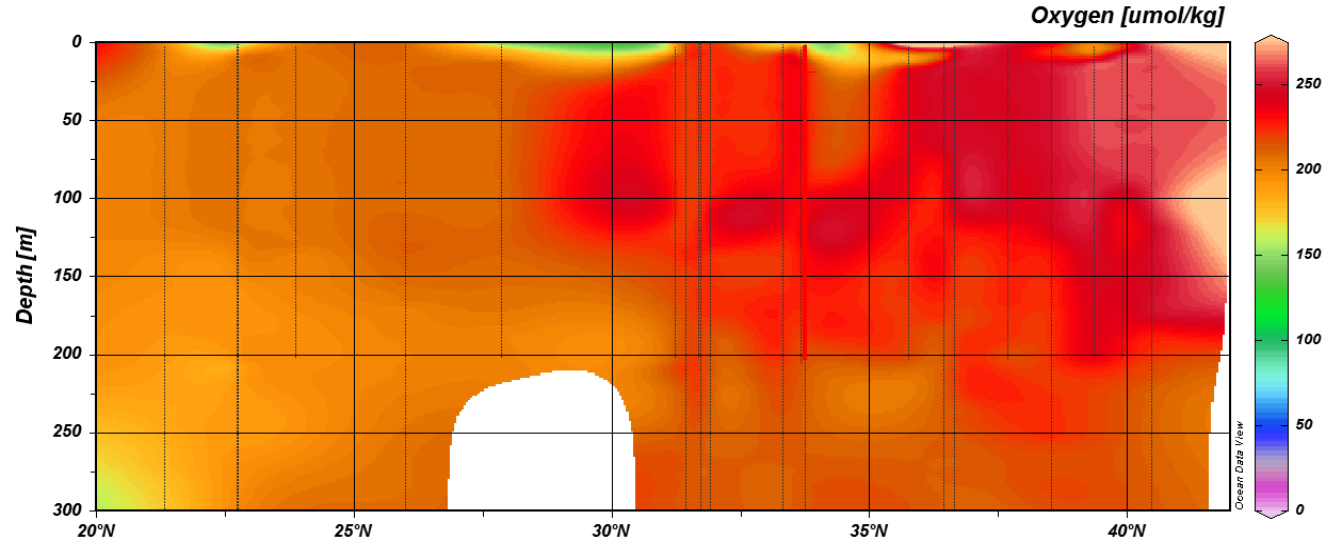
Hydrography: Sectional Data

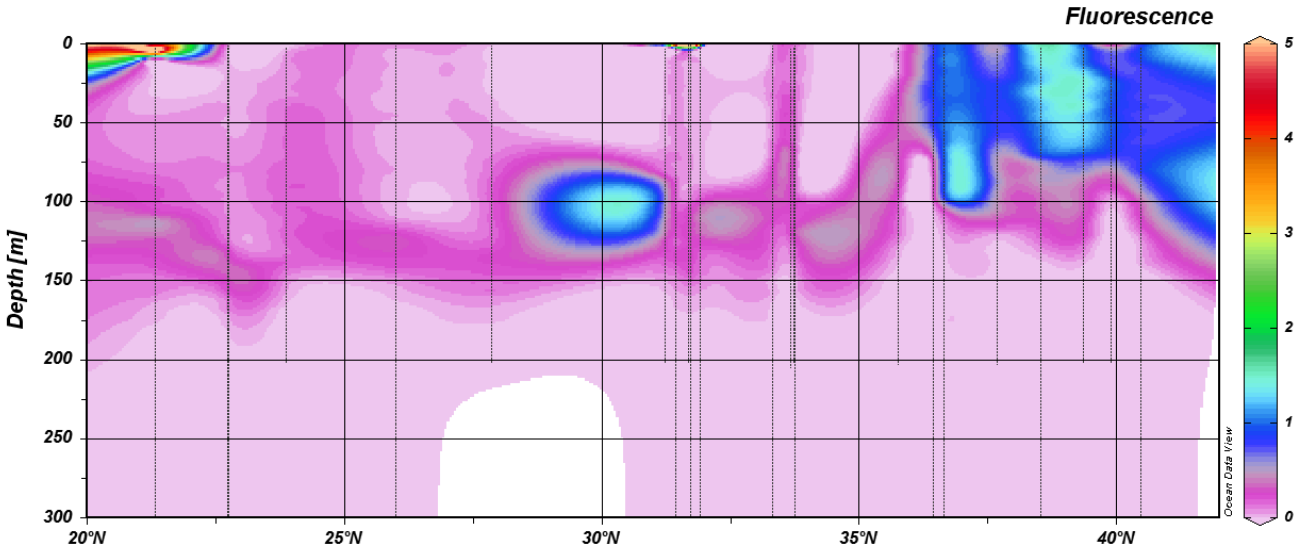
Section #1

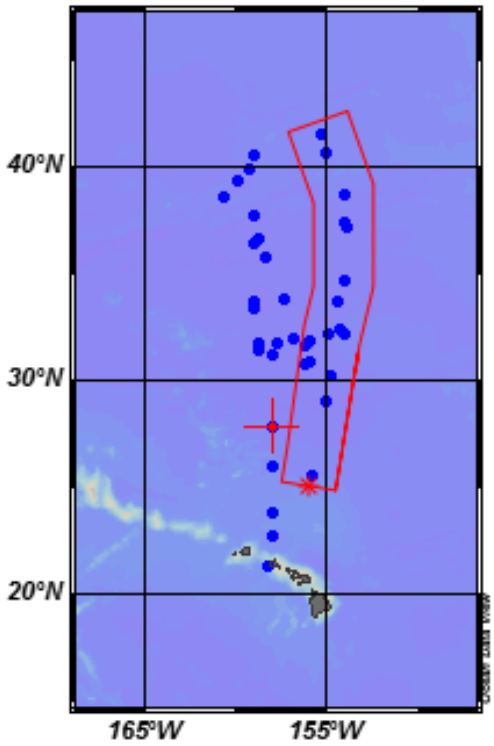



Temperature [C]
Depth [m]
0
50
100
150
200
250
300
20°N
25°N
30°N
35°N
40°N
25
20
15
10
5
0
Ocean Data View

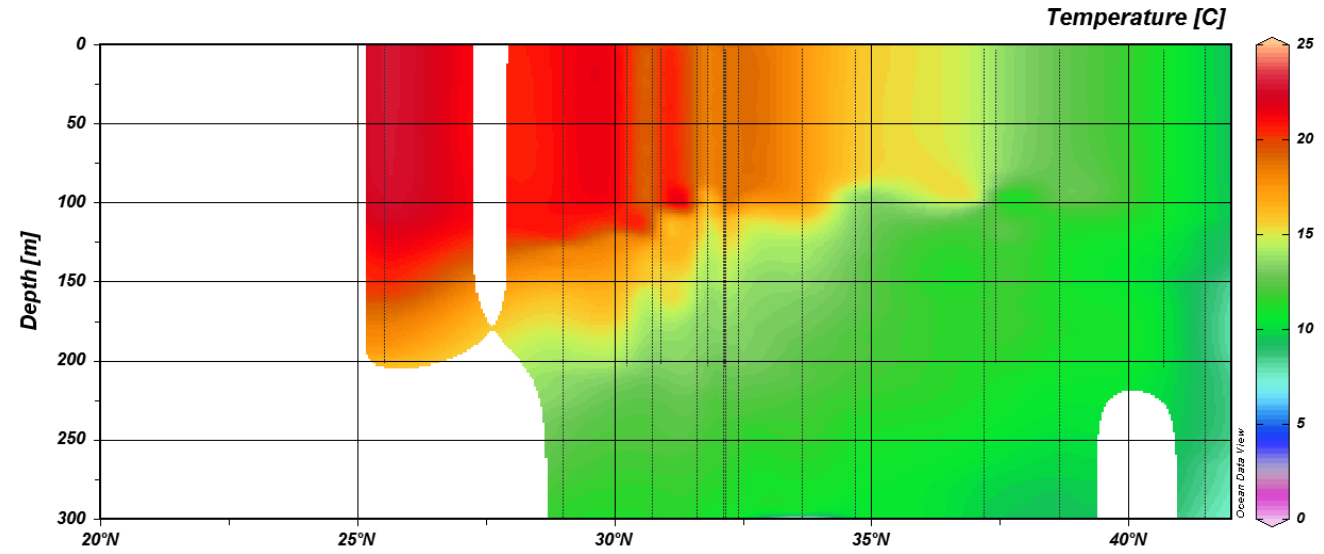

Density [kg/m3]
Depth [m]
0
50
100
150
200
250
300
20°N
25°N
30°N
35°N
40°N
28
27
26
25
24
Ocean Data View

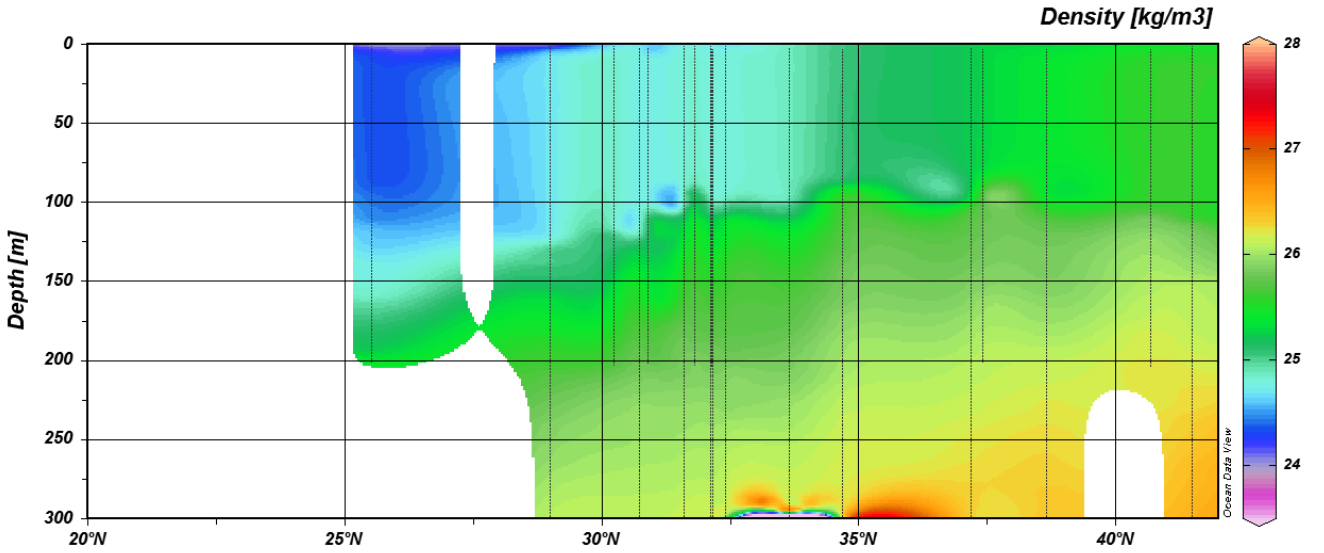

Oxygen [umol/kg]
Depth [m]
0
50
100
150
200
250
300
20°N
25°N
30°N
35°N
40°N
250
200
150
100
50
0
Ocean Data View

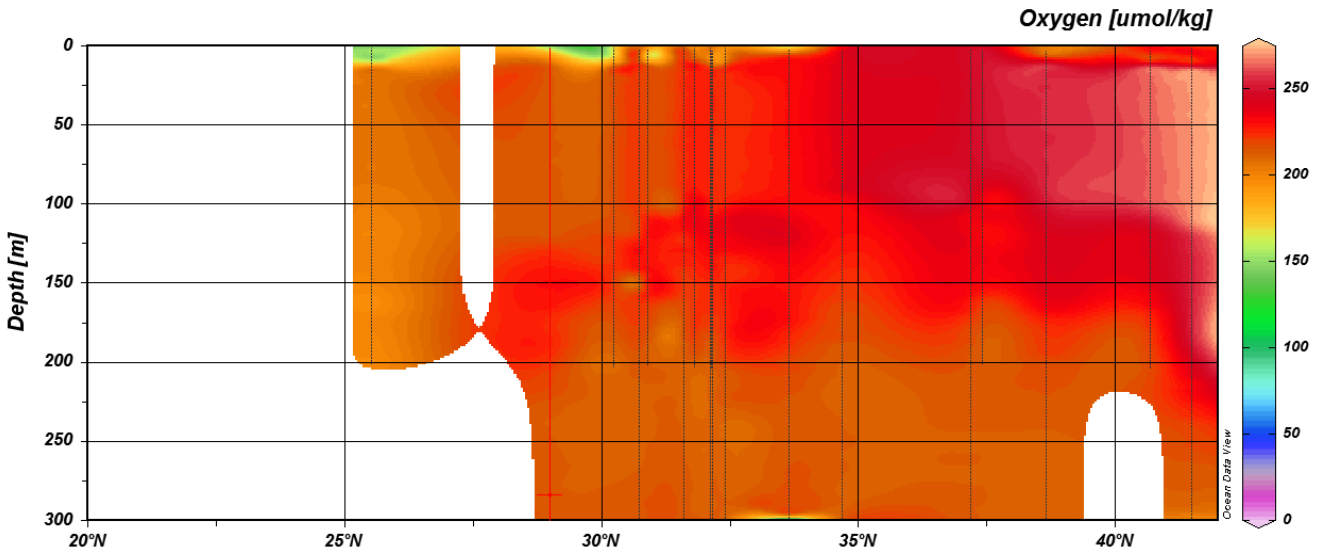

Fluorescence
Depth [m]
0
50
100
150
200
250
300
20°N
25°N
30°N
35°N
40°N
5
4
3
2
1
0
Ocean Data View

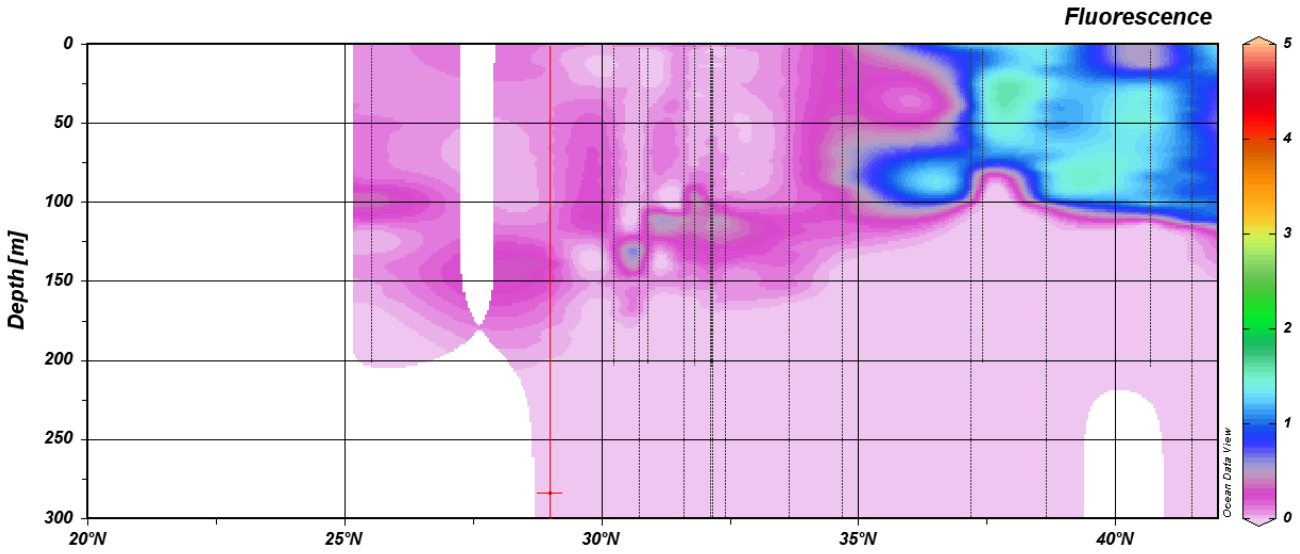


Section #2


Temperature [C]
Depth [m]
0
50
100
150
200
250
300
20°N
25°N
30°N
35°N
40°N
25
20
15
10
5
0
Ocean Data View

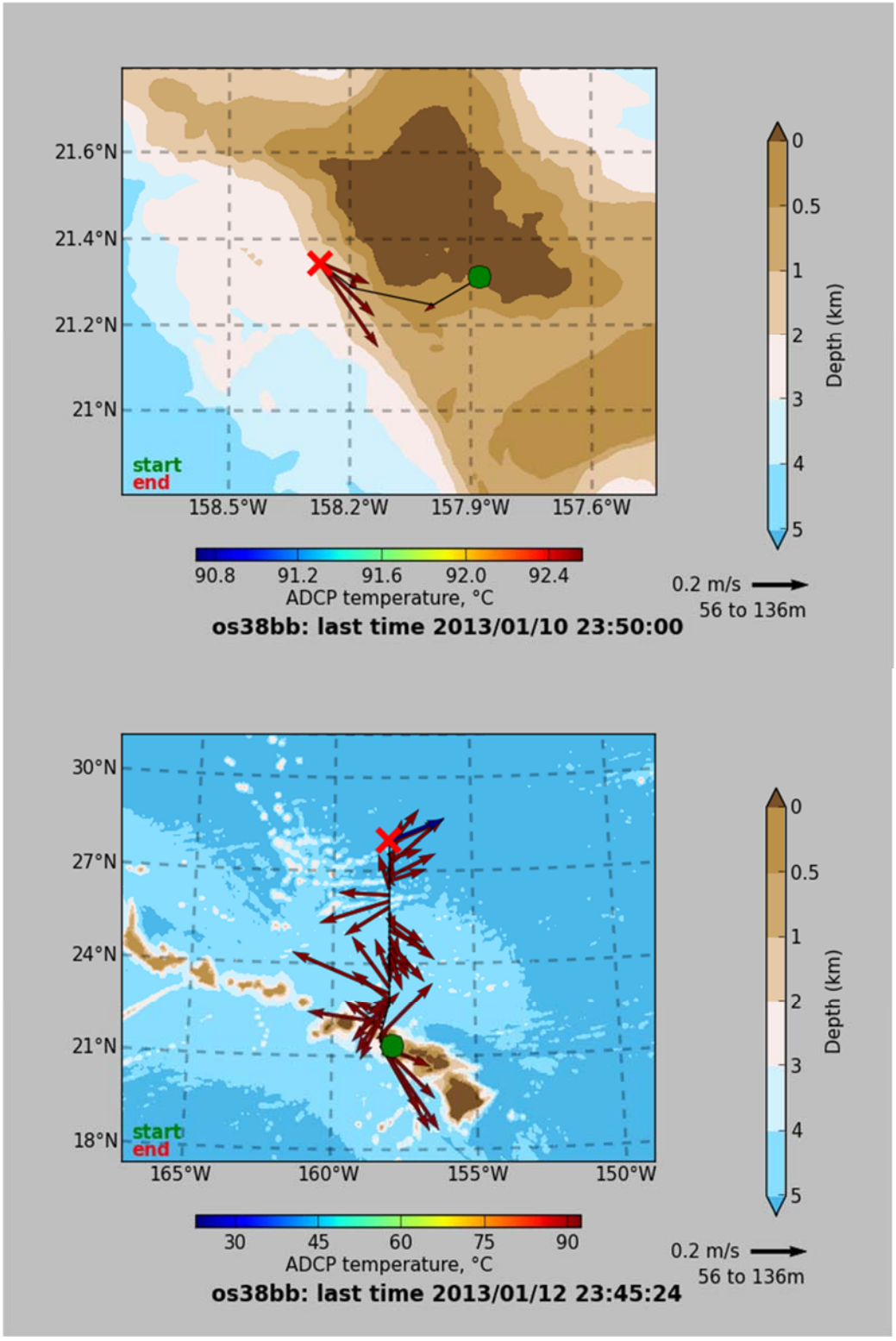

Density [kg/m3]
Depth [m]
0
50
100
150
200
250
300
20°N
25°N
30°N
35°N
40°N
28
27
26
25
24
Ocean Data View

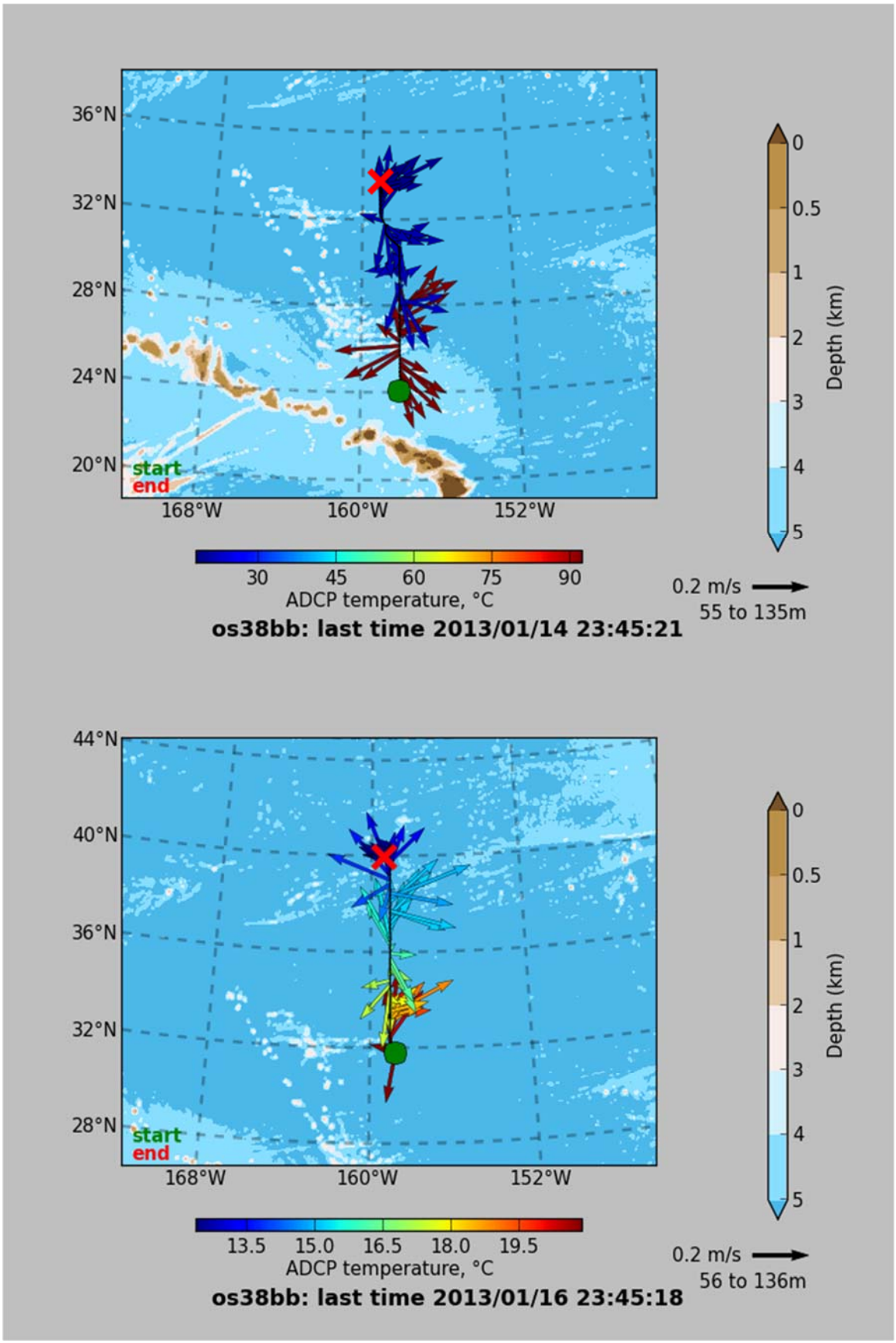

Oxygen [umol/kg]
Depth [m]
0
50
100
150
200
250
300
20°N
25°N
30°N
35°N
40°N
250
200
150
100
50
0
Ocean Data View

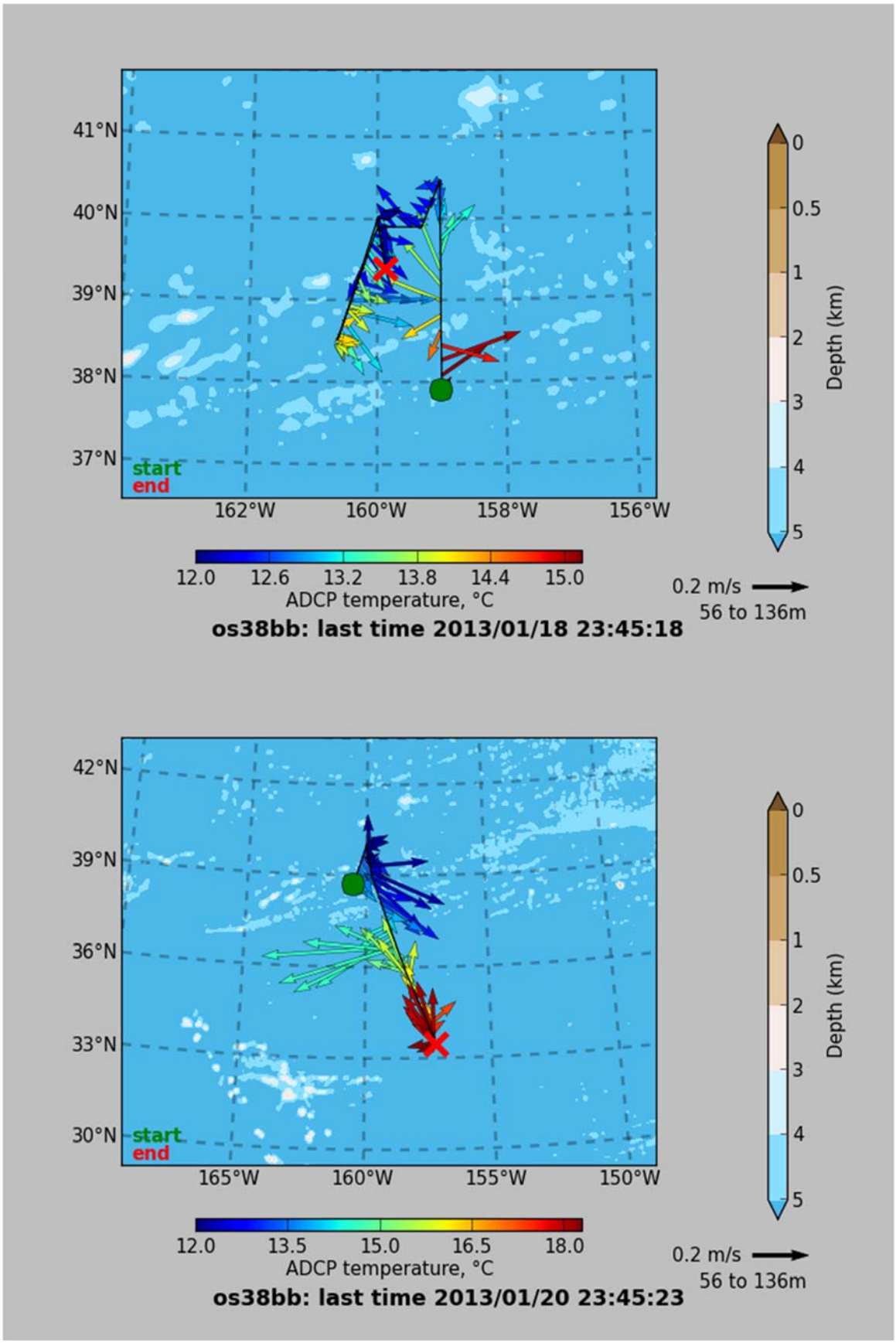

Fluorescence
Depth [m]
0
50
100
150
200
250
300
20°N
25°N
30°N
35°N
40°N
5
4
3
2
1
0
Ocean Data View

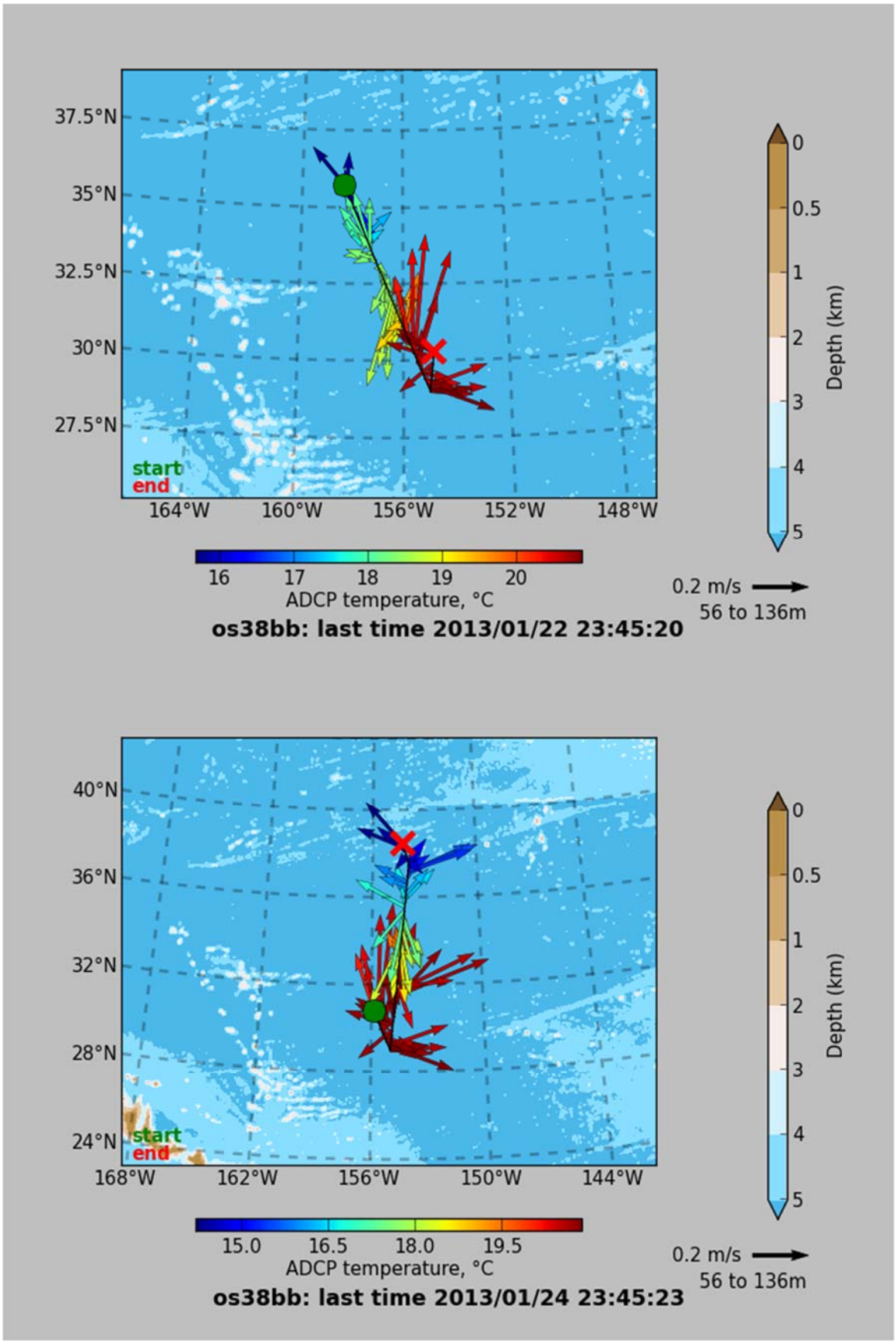
ADCP (OS38BB):

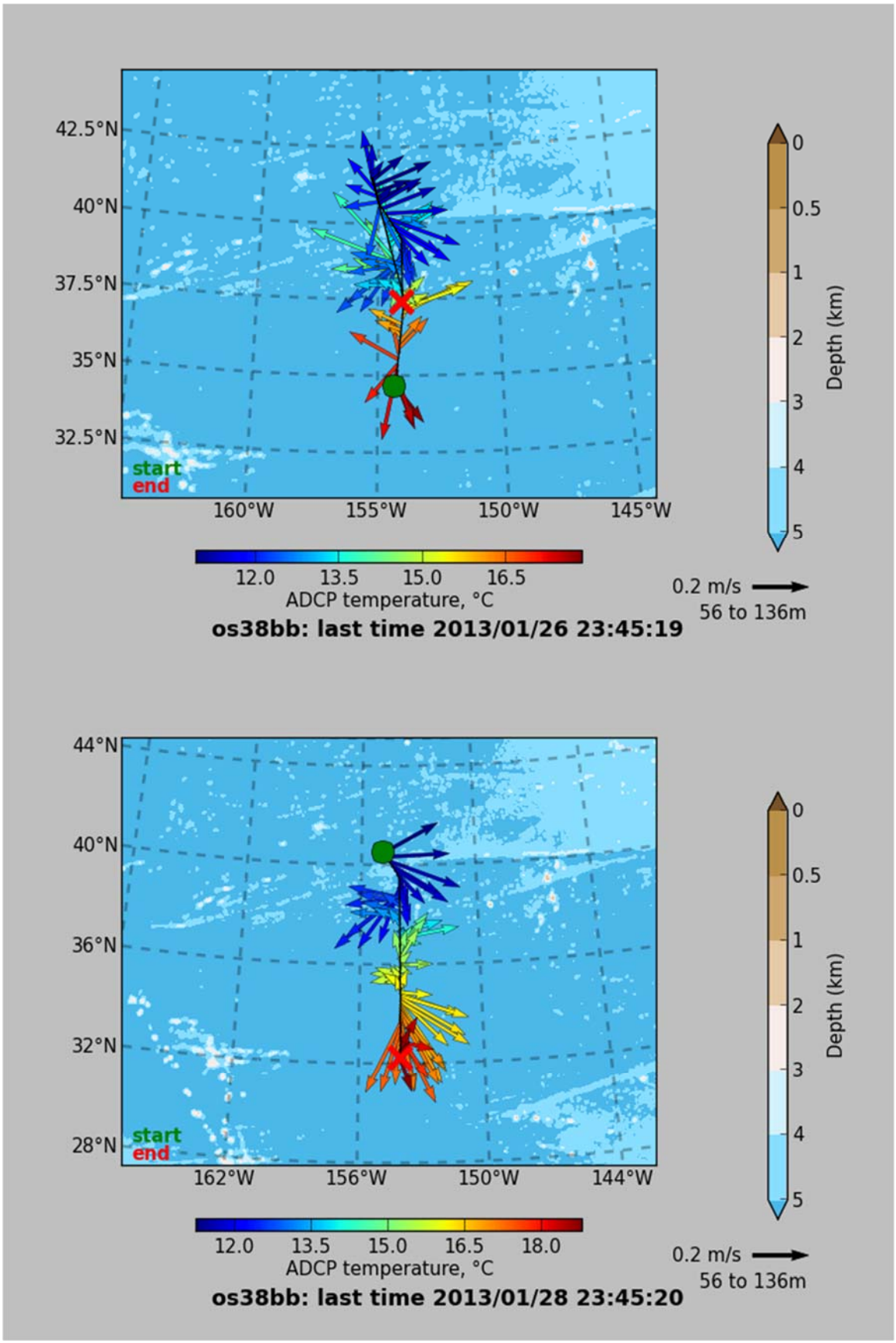
Surface Vectors

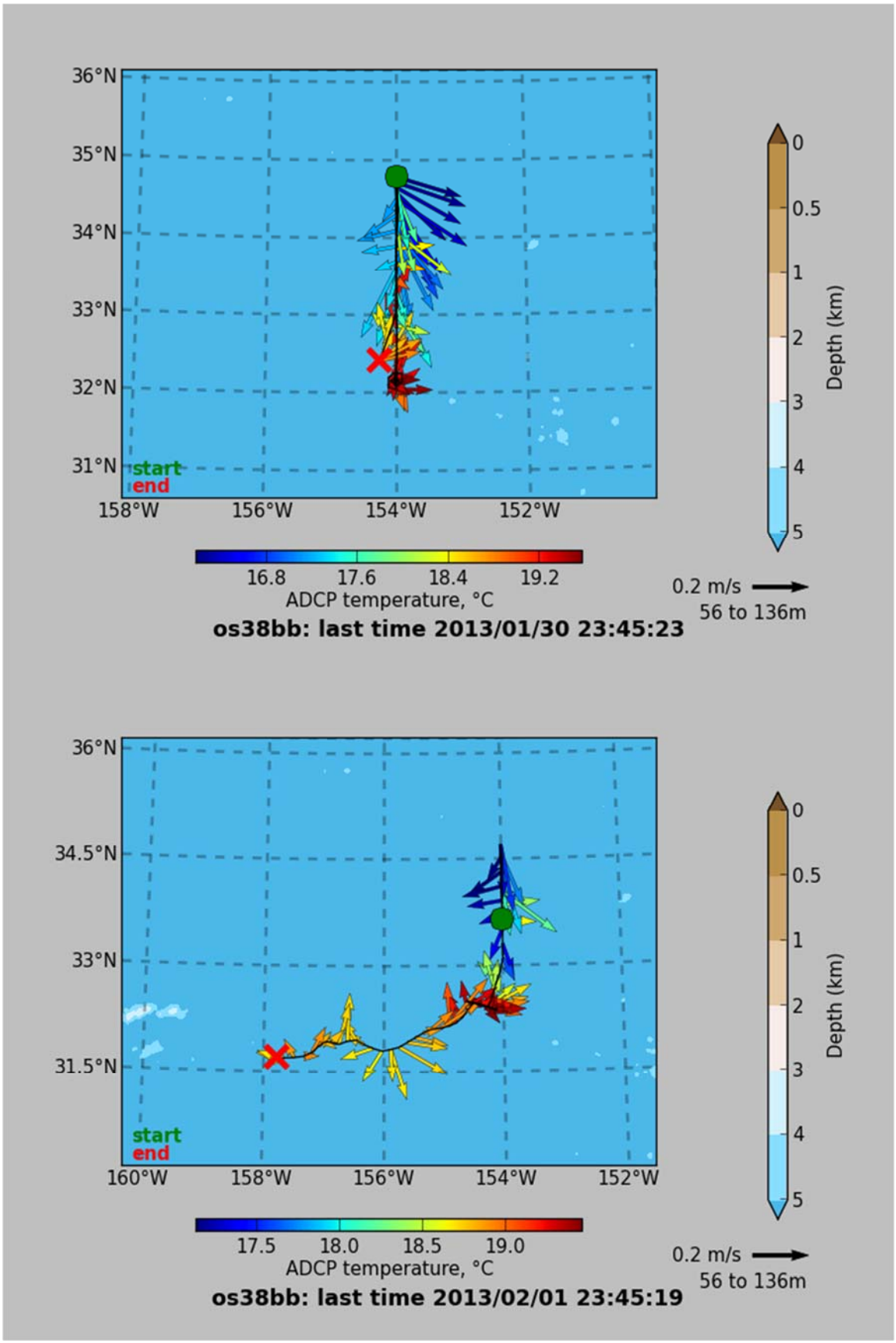


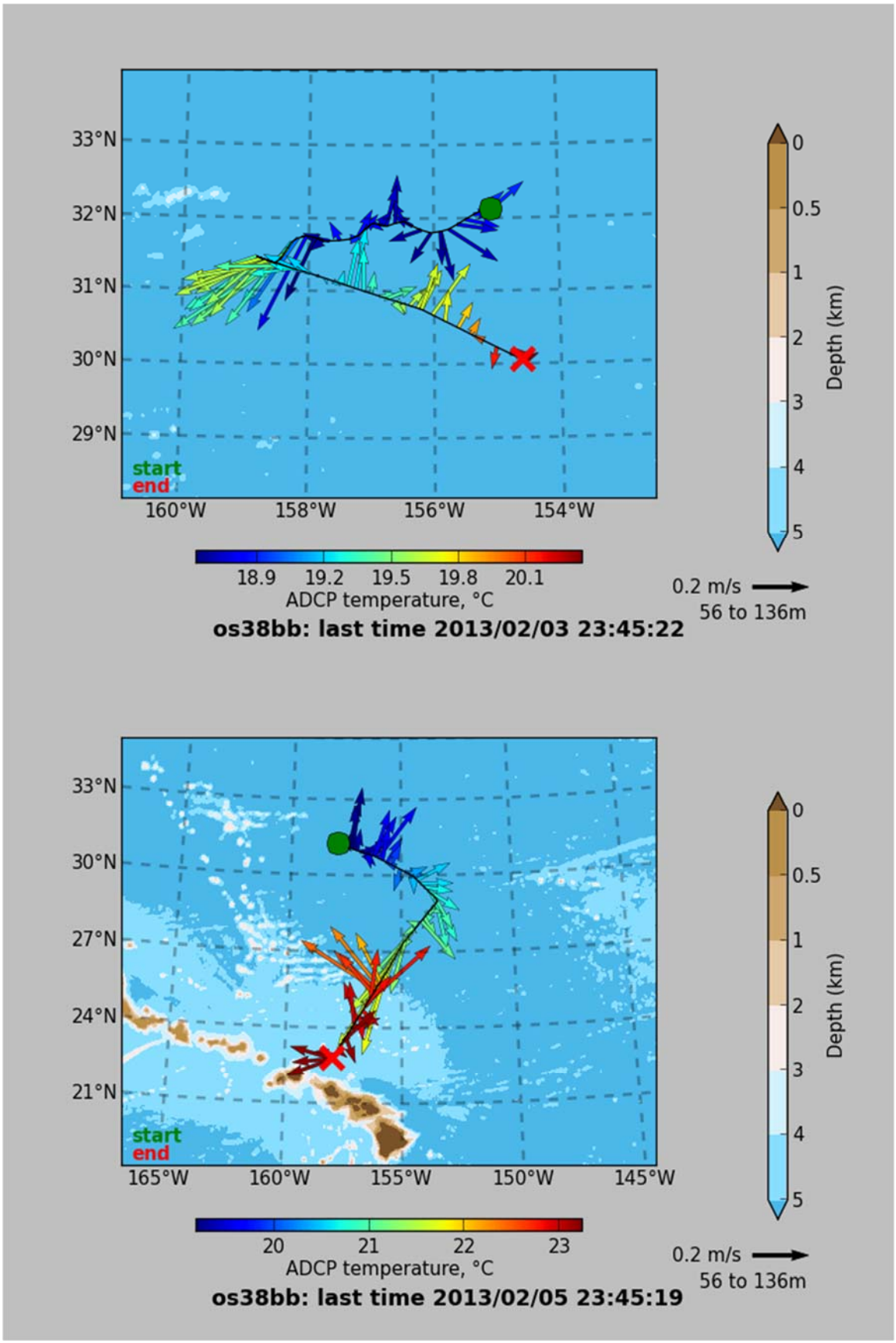

36°N
32°N
28°N
24°N
20°N
start
end
168°W
160°W
152°W
30
45
60
75
90
ADCP temperature, °C
0
0.5
1
2
3
4
5
Depth (km)
0.2 m/s
55 to 135m
os38bb: last time 2013/01/14 23:45:21
44°N
40°N
36°N
32°N
28°N
start
end
168°W
160°W
152°W
13.5
15.0
16.5
18.0
19.5
ADCP temperature, °C
0
0.5
1
2
3
4
5
Depth (km)
0.2 m/s
56 to 136m
os38bb: last time 2013/01/16 23:45:18

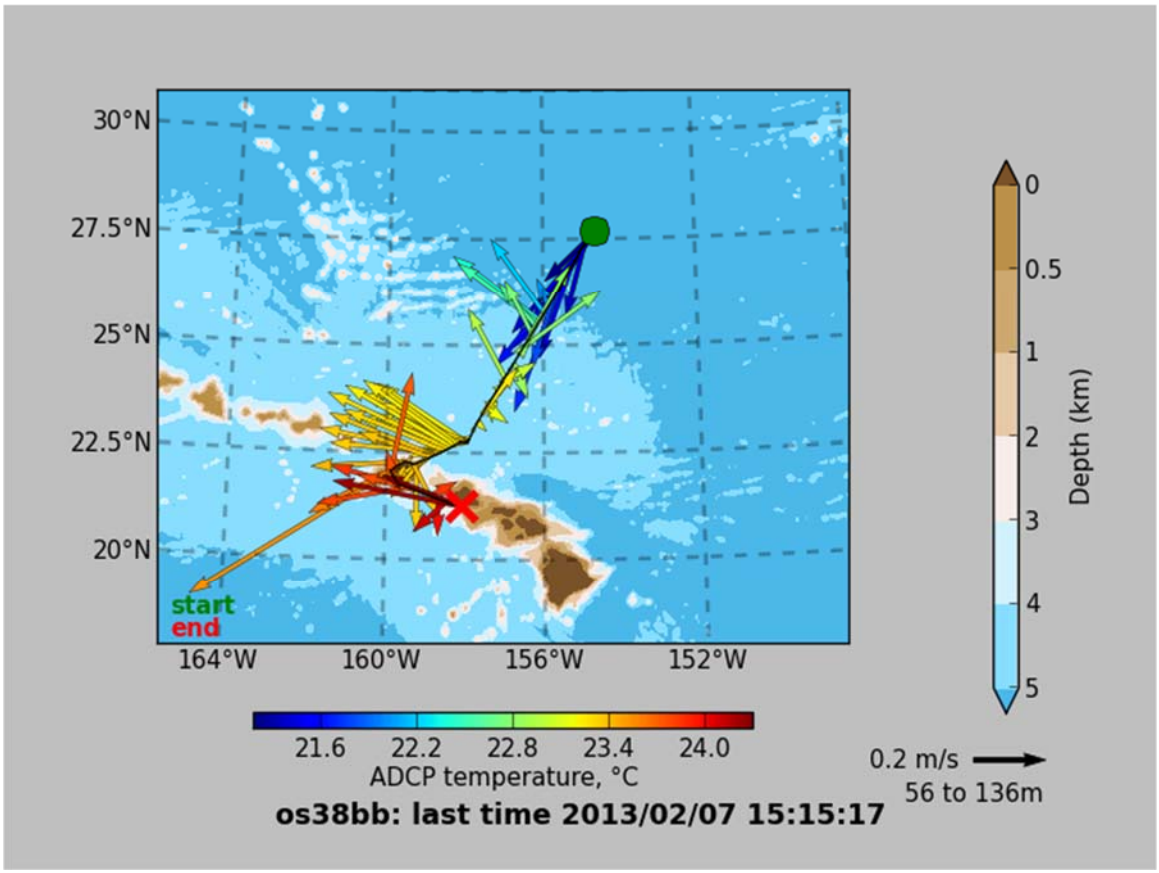

41°N
40°N
39°N
38°N
37°N
start
end
162°W
160°W
158°W
156°W
12.0
12.6
13.2
13.8
14.4
15.0
ADCP temperature, °C
0
0.5
1
2
3
4
5
Depth (km)
0.2 m/s
56 to 136m
os38bb: last time 2013/01/18 23:45:18
42°N
39°N
36°N
33°N
30°N
start
end
165°W
160°W
155°W
150°W
12.0
13.5
15.0
16.5
18.0
ADCP temperature, °C
0
0.5
1
2
3
4
5
Depth (km)
0.2 m/s
56 to 136m
os38bb: last time 2013/01/20 23:45:23


37.5°N
35°N
32.5°N
30°N
27.5°N
start
end
164°W
160°W
156°W
152°W
148°W
16
17
18
19
20
ADCP temperature, °C
0
0.5
1
2
3
4
5
Depth (km)
0.2 m/s
56 to 136m
os38bb: last time 2013/01/22 23:45:20
40°N
36°N
32°N
28°N
24°N
start
end
168°W
162°W
156°W
150°W
144°W
15.0
16.5
18.0
19.5
ADCP temperature, °C
0
0.5
1
2
3
4
5
Depth (km)
0.2 m/s
56 to 136m
os38bb: last time 2013/01/24 23:45:23

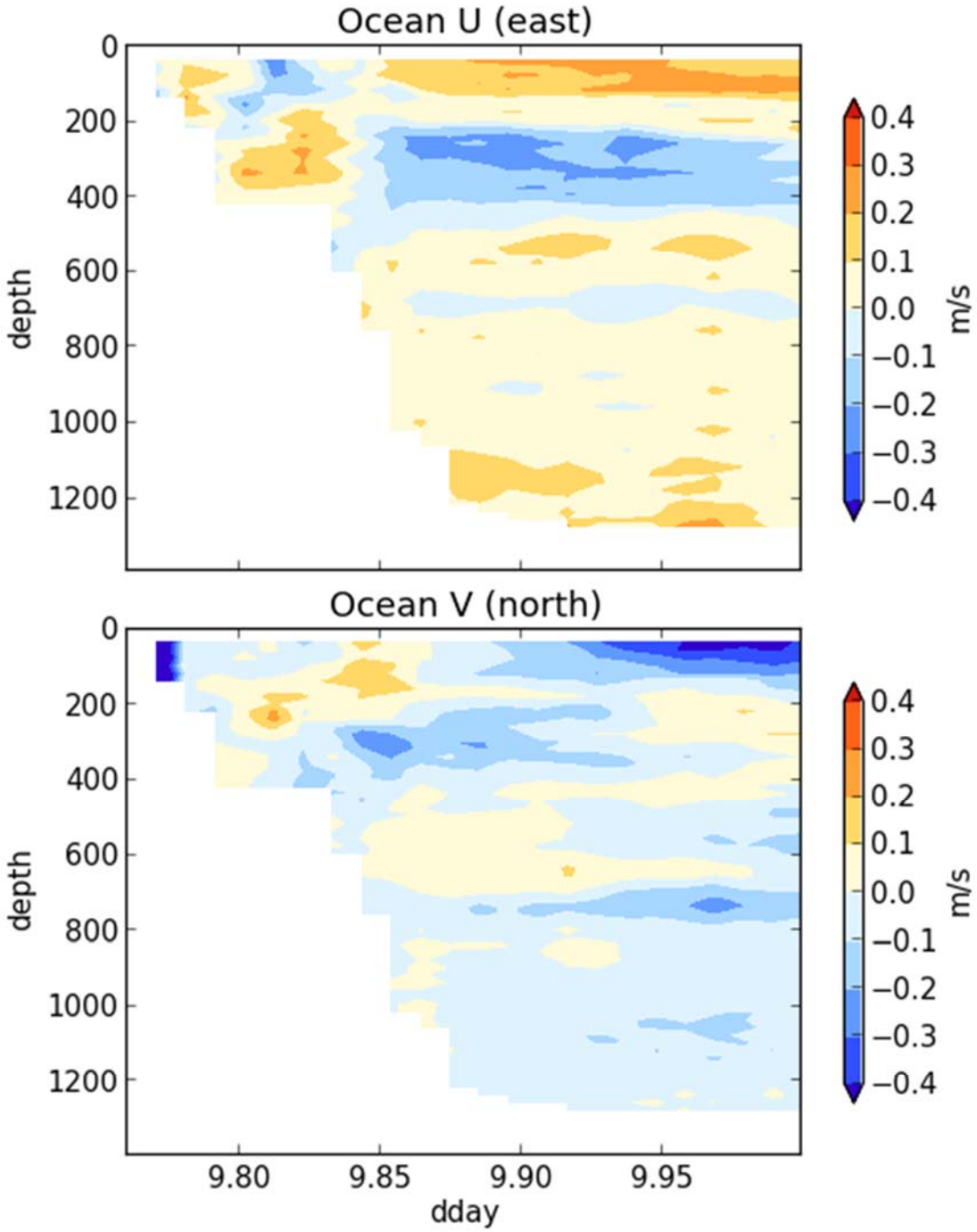

42.5°N
40°N
37.5°N
35°N
32.5°N
start
end
160°W
155°W
150°W
145°W
12.0
13.5
15.0
16.5
ADCP temperature, °C
0
0.5
1
2
3
4
5
Depth (km)
0.2 m/s
56 to 136m
os38bb: last time 2013/01/26 23:45:19
44°N
40°N
36°N
32°N
28°N
start
end
162°W
156°W
150°W
144°W
12.0
13.5
15.0
16.5
18.0
ADCP temperature, °C
0
0.5
1
2
3
4
5
Depth (km)
0.2 m/s
56 to 136m
os38bb: last time 2013/01/28 23:45:20


36°N
35°N
34°N
33°N
32°N
31°N
158°W
156°W
154°W
152°W
start
end
16.8
17.6
18.4
19.2
ADCP temperature, °C
0
0.5
1
2
3
4
5
Depth (km)
0.2 m/s
56 to 136m
os38bb: last time 2013/01/30 23:45:23
36°N
34.5°N
33°N
31.5°N
160°W
158°W
156°W
154°W
152°W
start
end
17.5
18.0
18.5
19.0
ADCP temperature, °C
0
0.5
1
2
3
4
5
Depth (km)
0.2 m/s
56 to 136m
os38bb: last time 2013/02/01 23:45:19

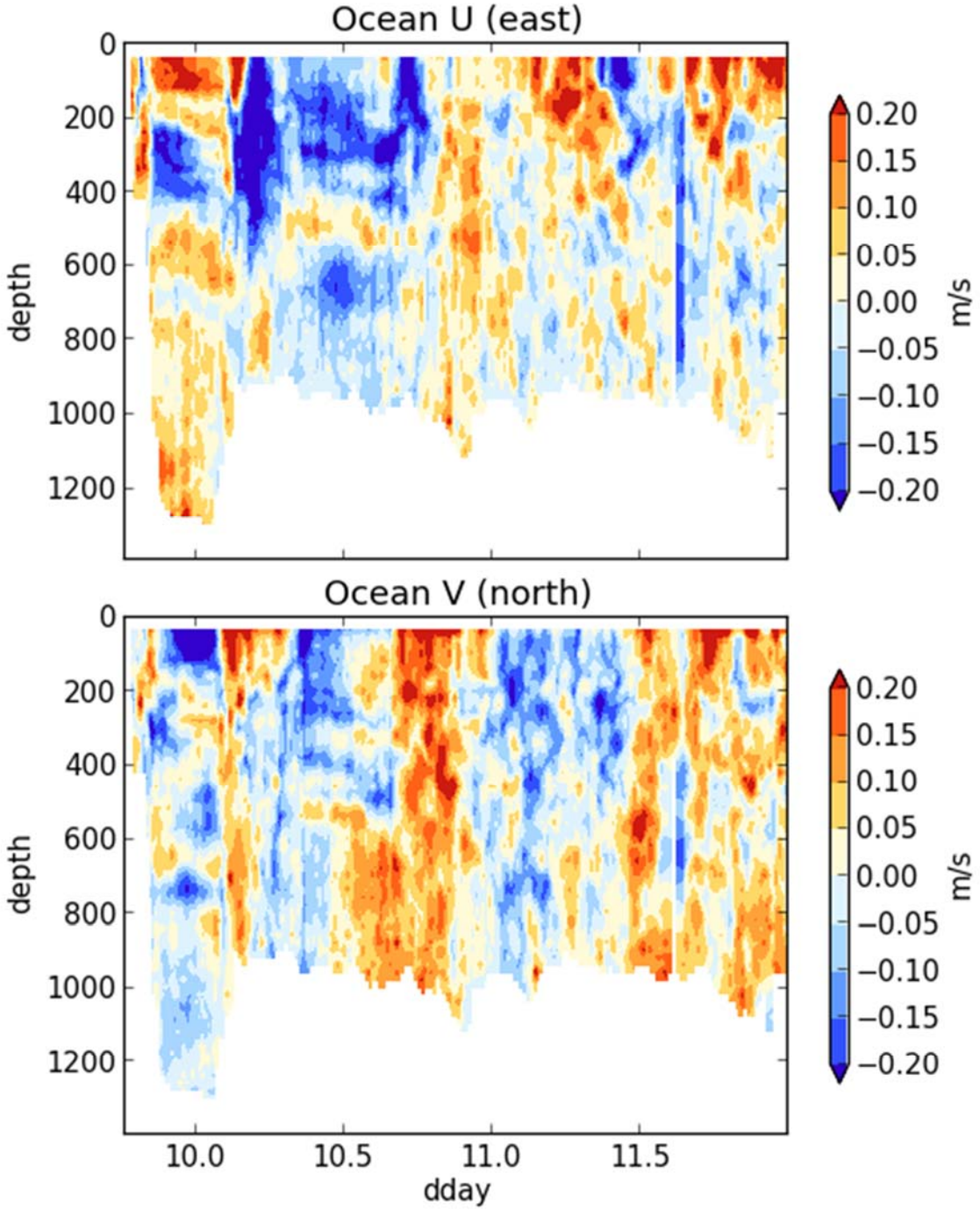

33°N
32°N
31°N
30°N
29°N
start
end
160°W
158°W
156°W
154°W
18.9
19.2
19.5
19.8
20.1
ADCP temperature, °C
0
0.5
1
2
3
4
5
Depth (km)
0.2 m/s
56 to 136m
os38bb: last time 2013/02/03 23:45:22
33°N
30°N
27°N
24°N
21°N
start
end
165°W
160°W
155°W
150°W
145°W
20
21
22
23
ADCP temperature, °C
0
0.5
1
2
3
4
5
Depth (km)
0.2 m/s
56 to 136m
os38bb: last time 2013/02/05 23:45:19


30°N
27.5°N
25°N
22.5°N
20°N
164°W
160°W
156°W
152°W
start
end
21.6
22.2
22.8
23.4
24.0
ADCP temperature, °C
0
0.5
1
2
3
4
5
Depth (km)
0.2 m/s
56 to 136m
os38bb: last time 2013/02/07 15:15:17

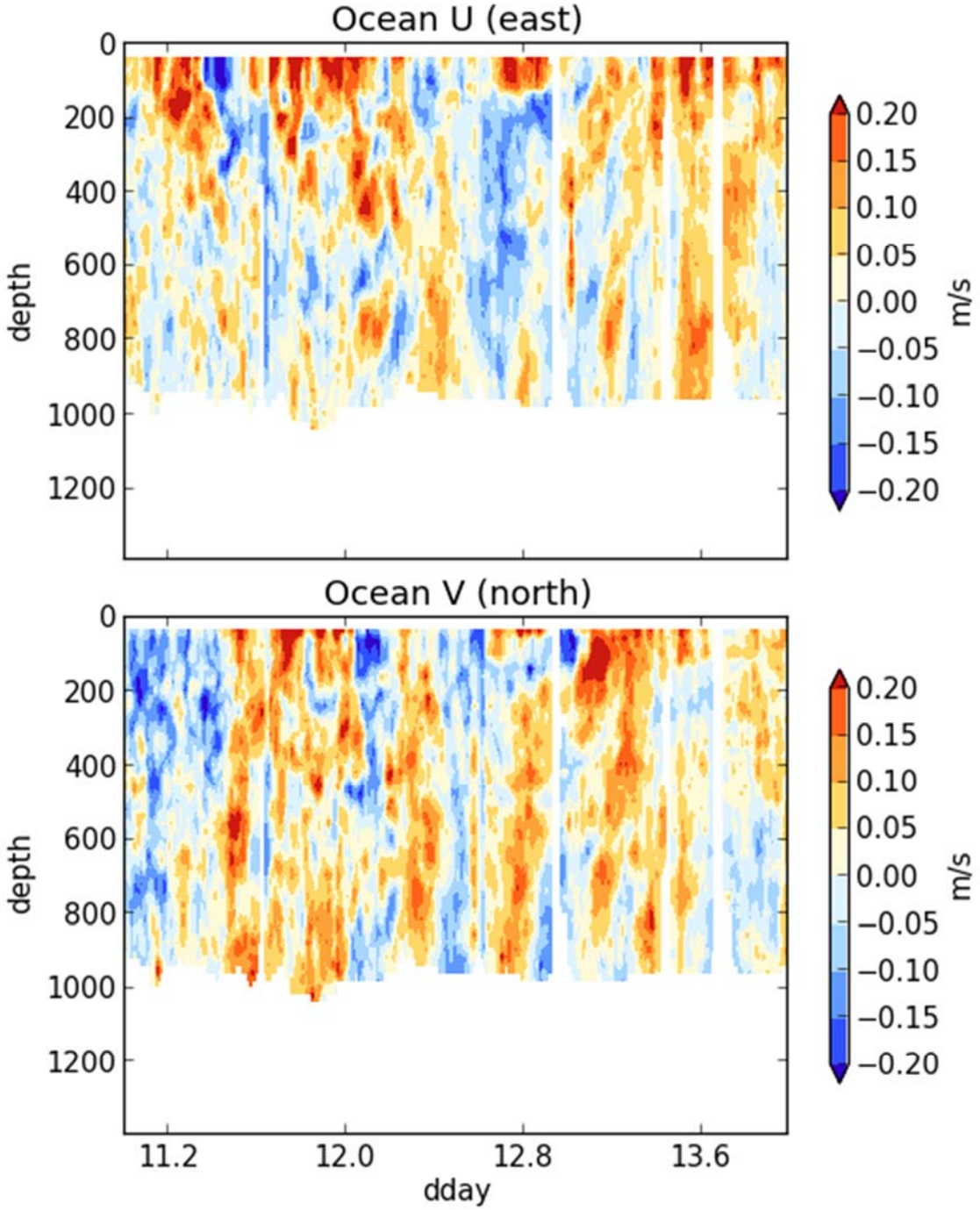
Depth Vectors (decimal day)



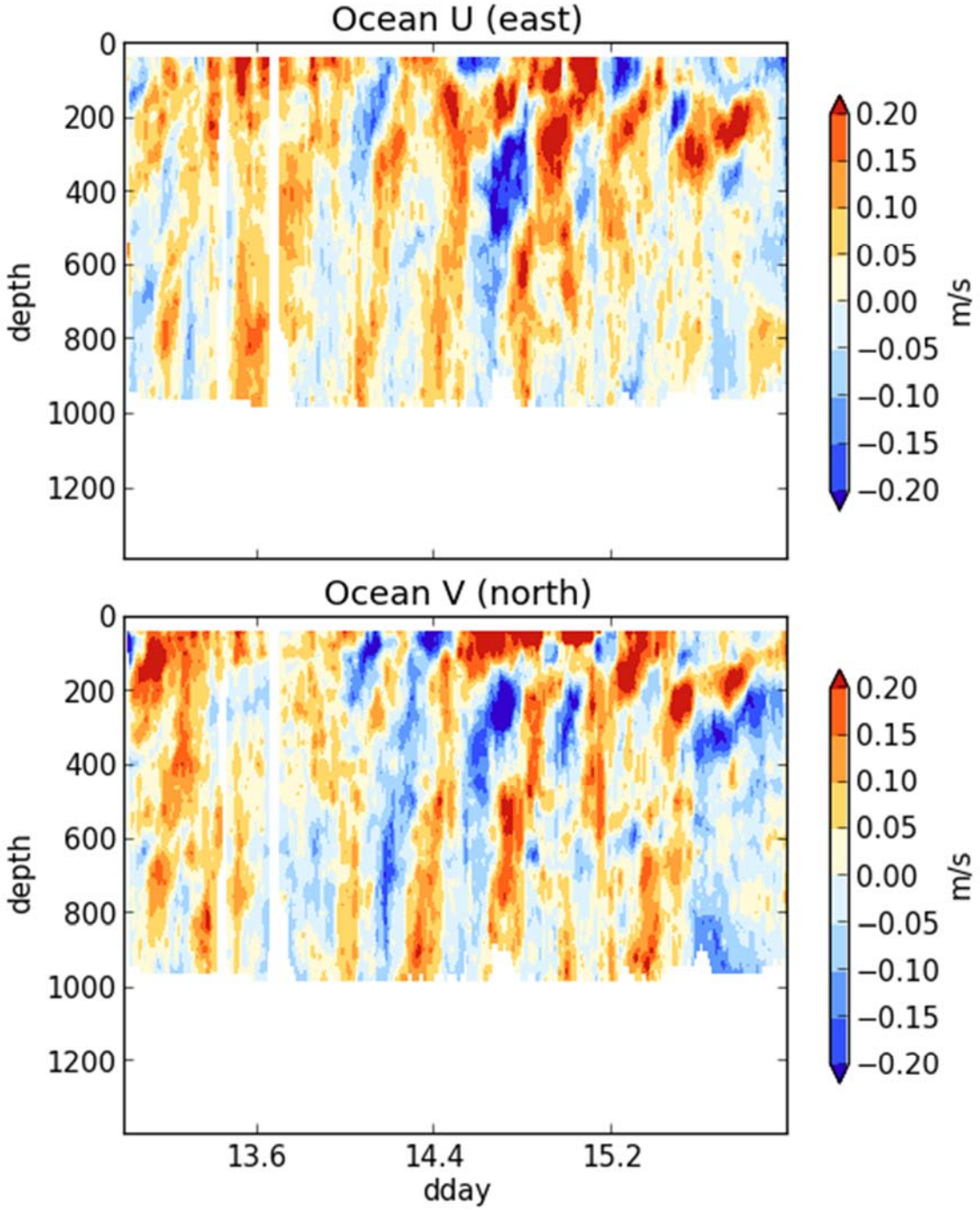
os38bb: last time 2013/01/10 23:59:37



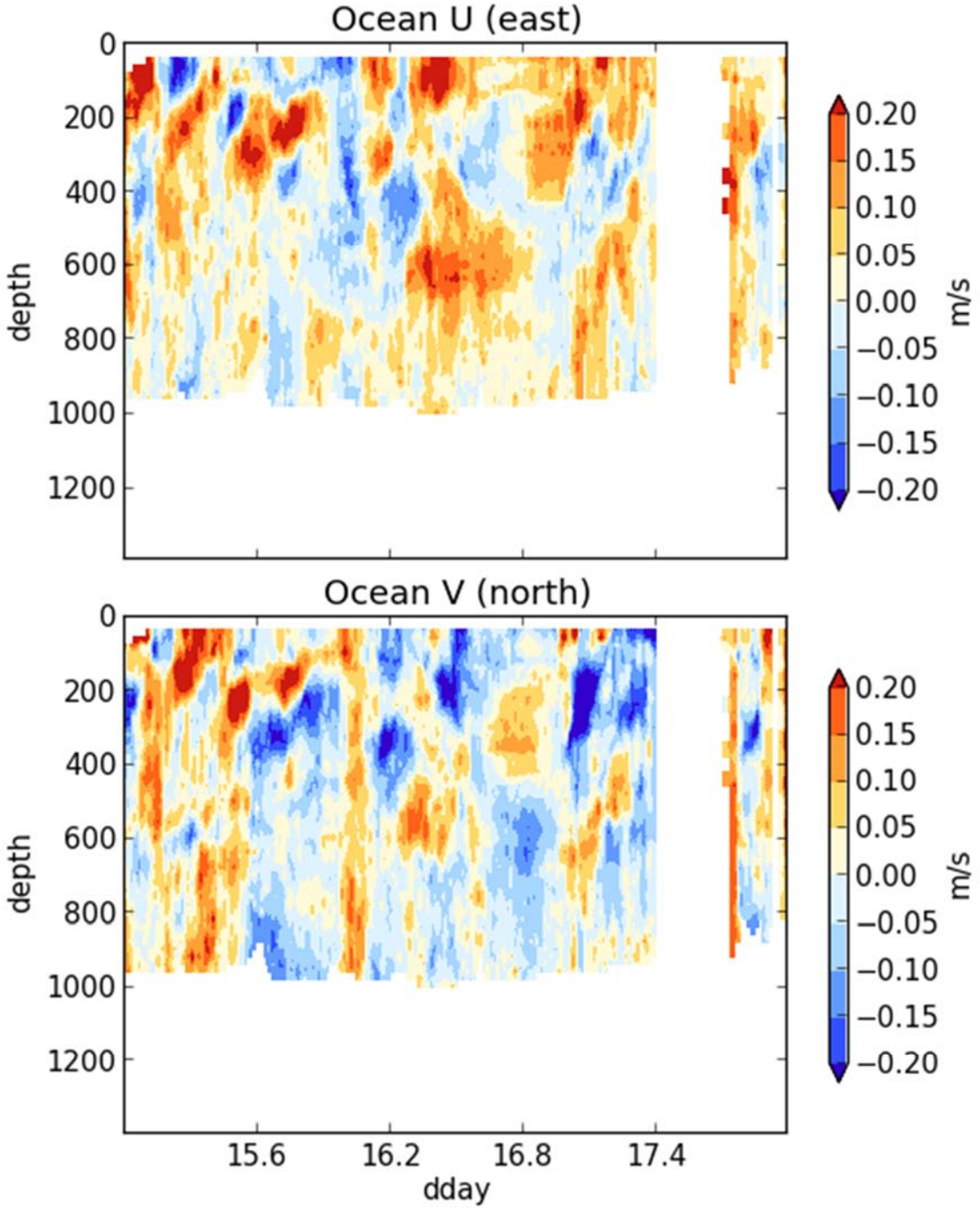
os38bb: last time 2013/01/12 23:59:37



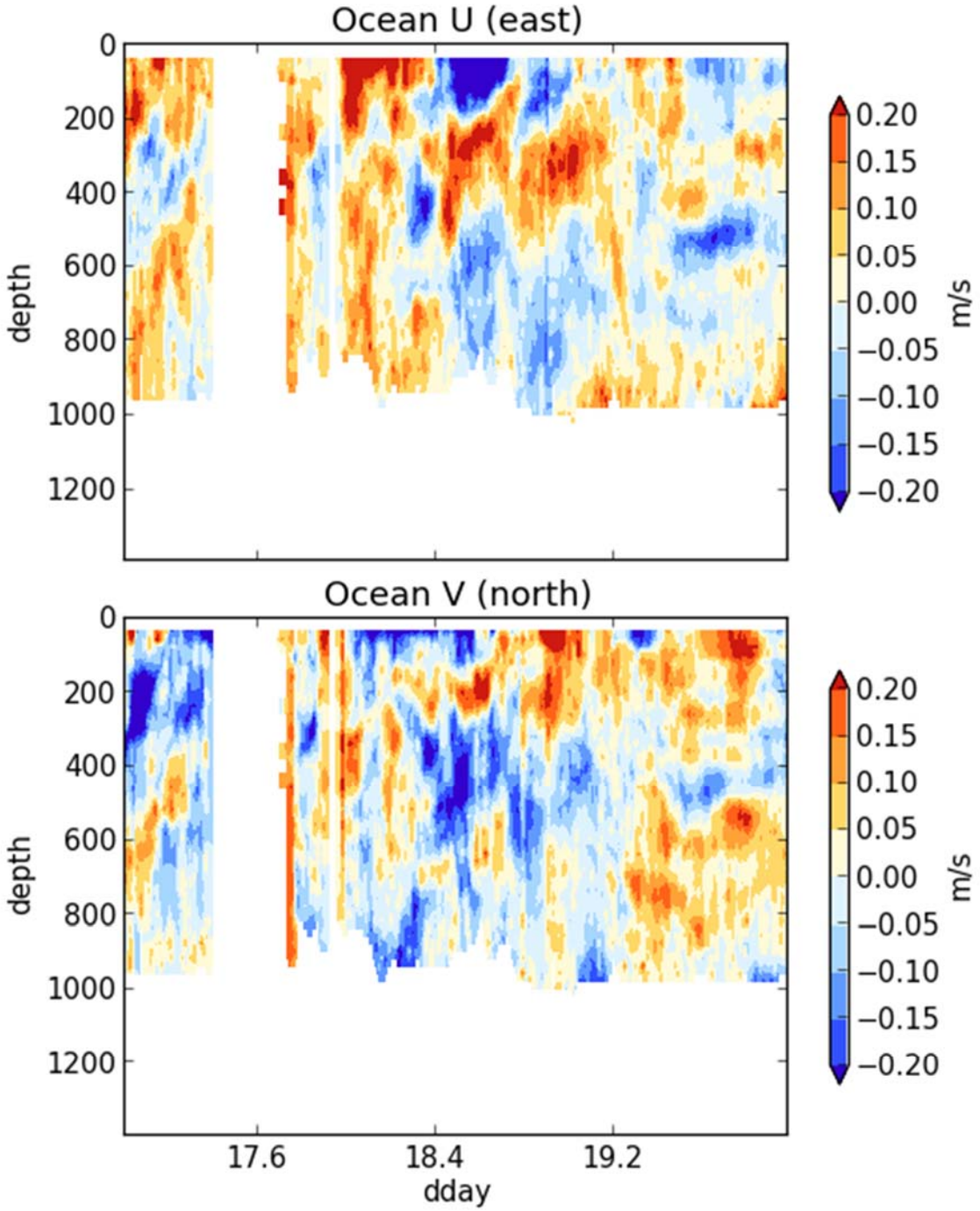
os38bb: last time 2013/01/14 23:49:56



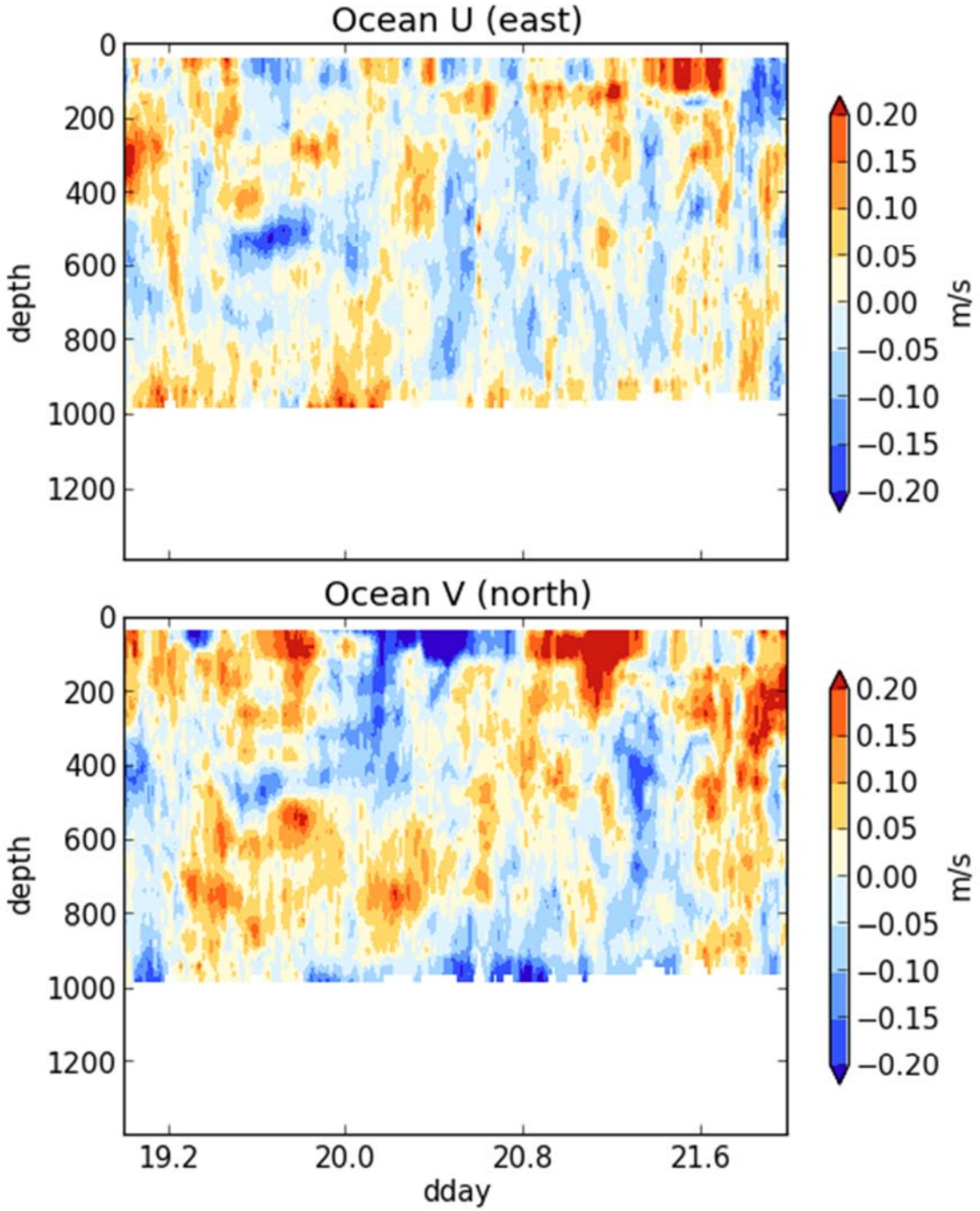
os38bb: last time 2013/01/16 23:50:19



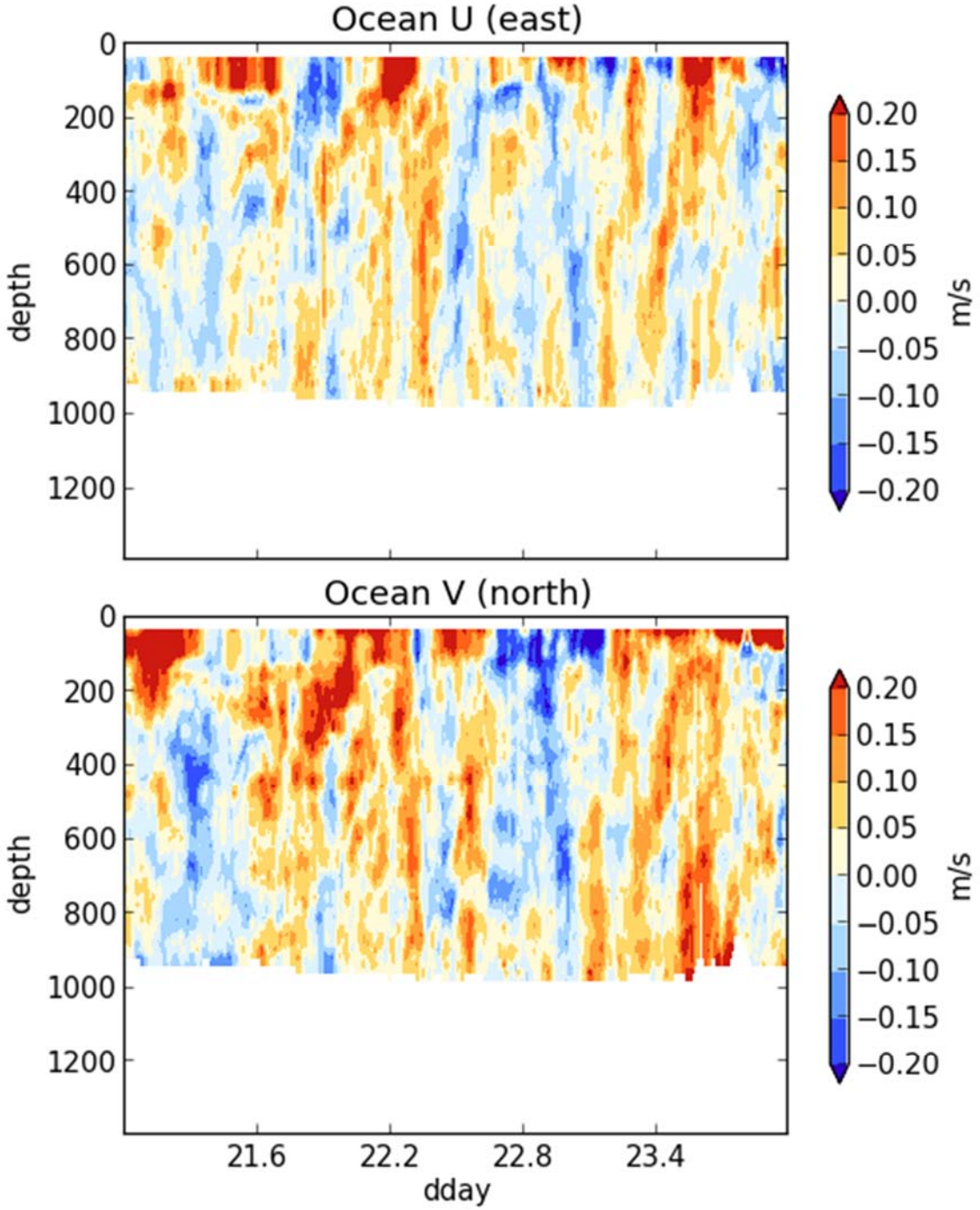
os38bb: last time 2013/01/18 23:45:23



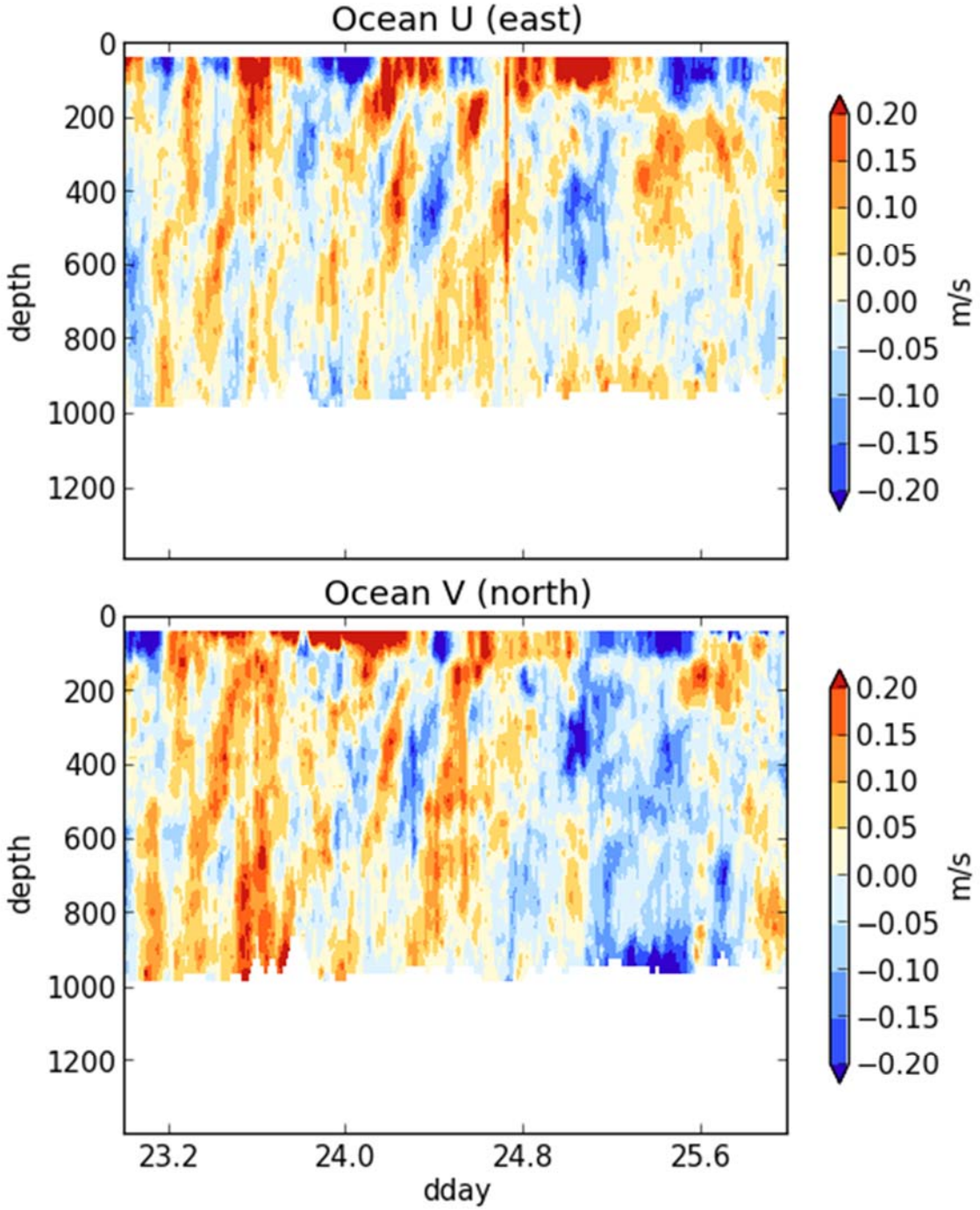
os38bb: last time 2013/01/20 23:45:23



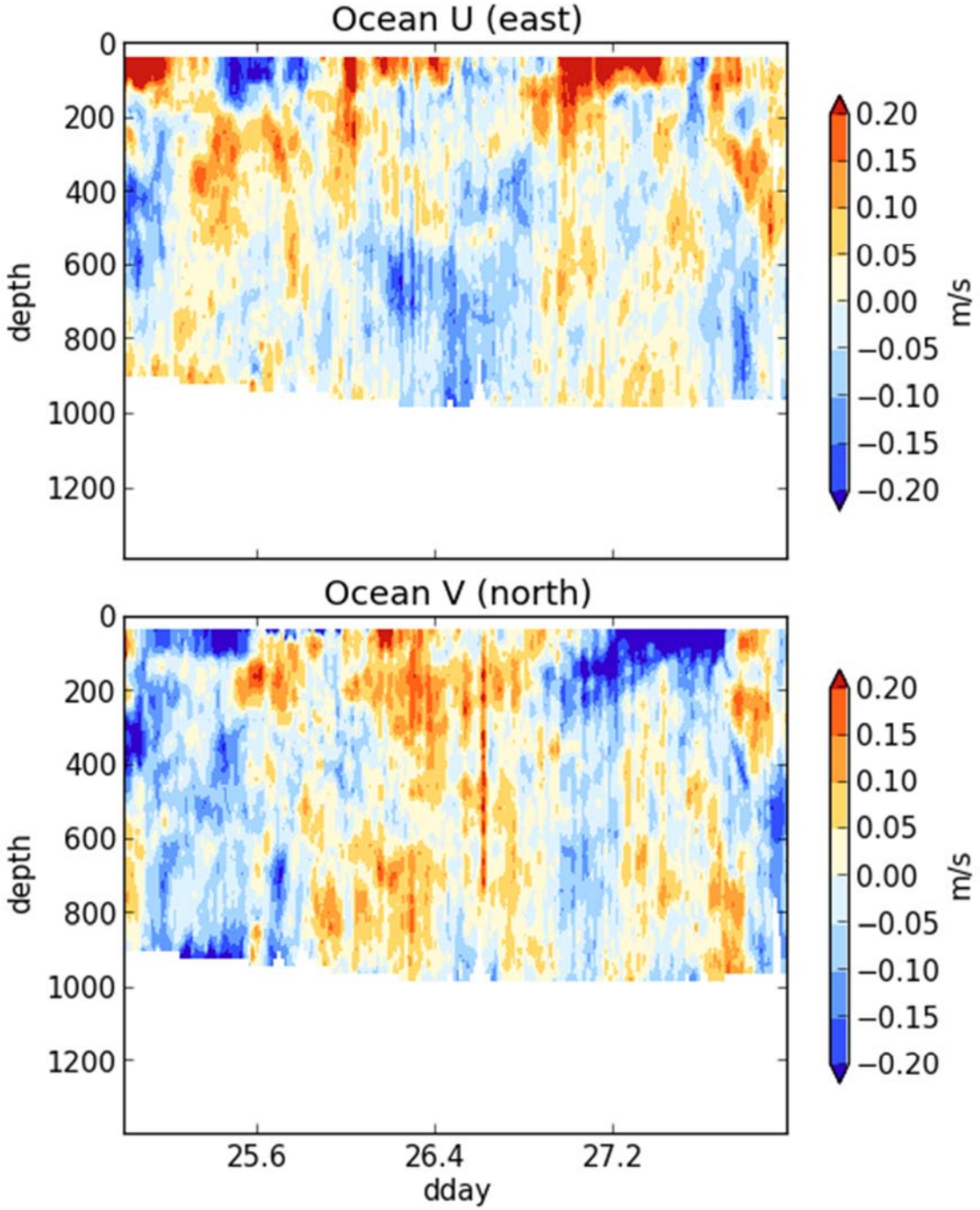
os38bb: last time 2013/01/22 23:45:22



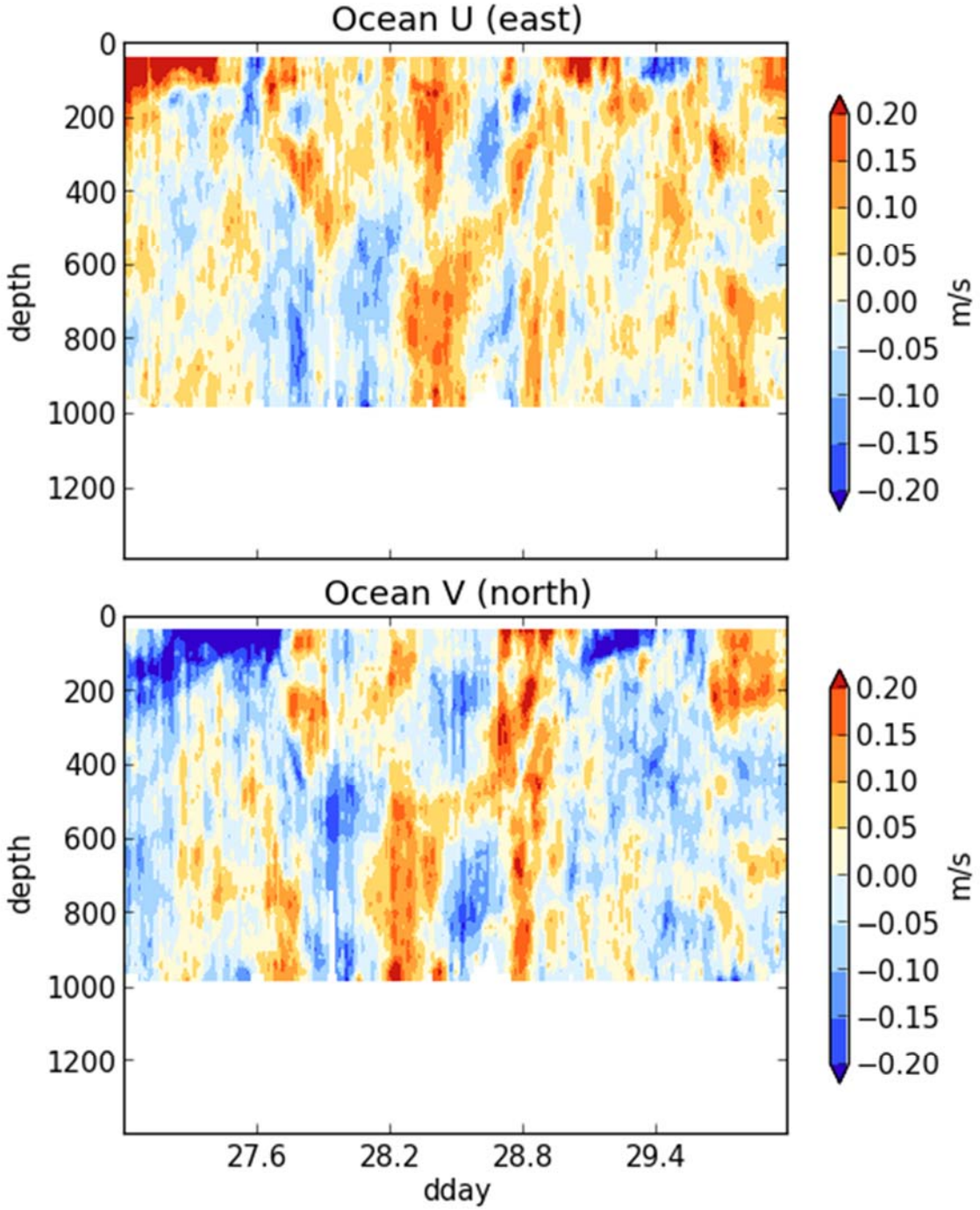
os38bb: last time 2013/01/24 23:50:19



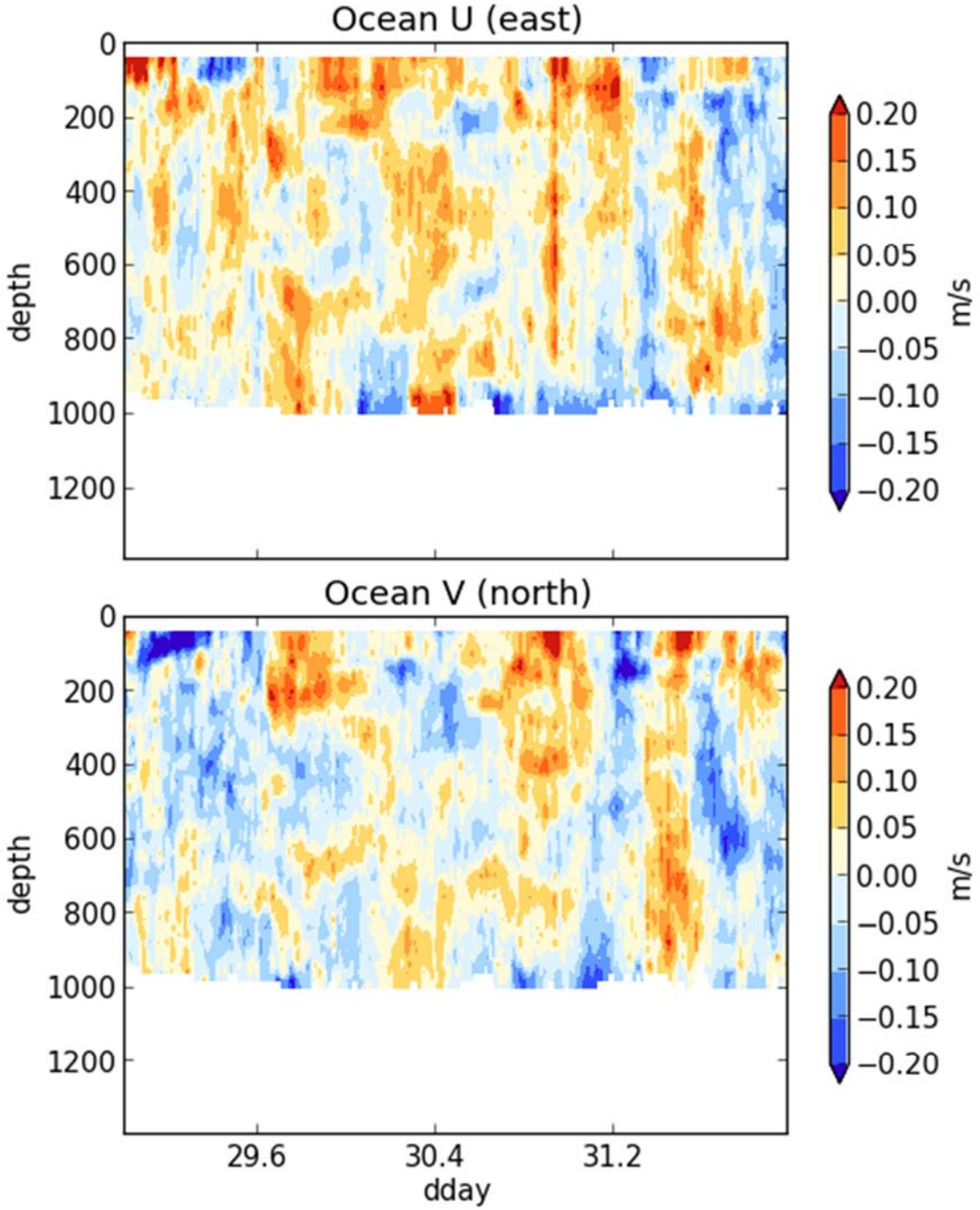
os38bb: last time 2013/01/26 23:45:21



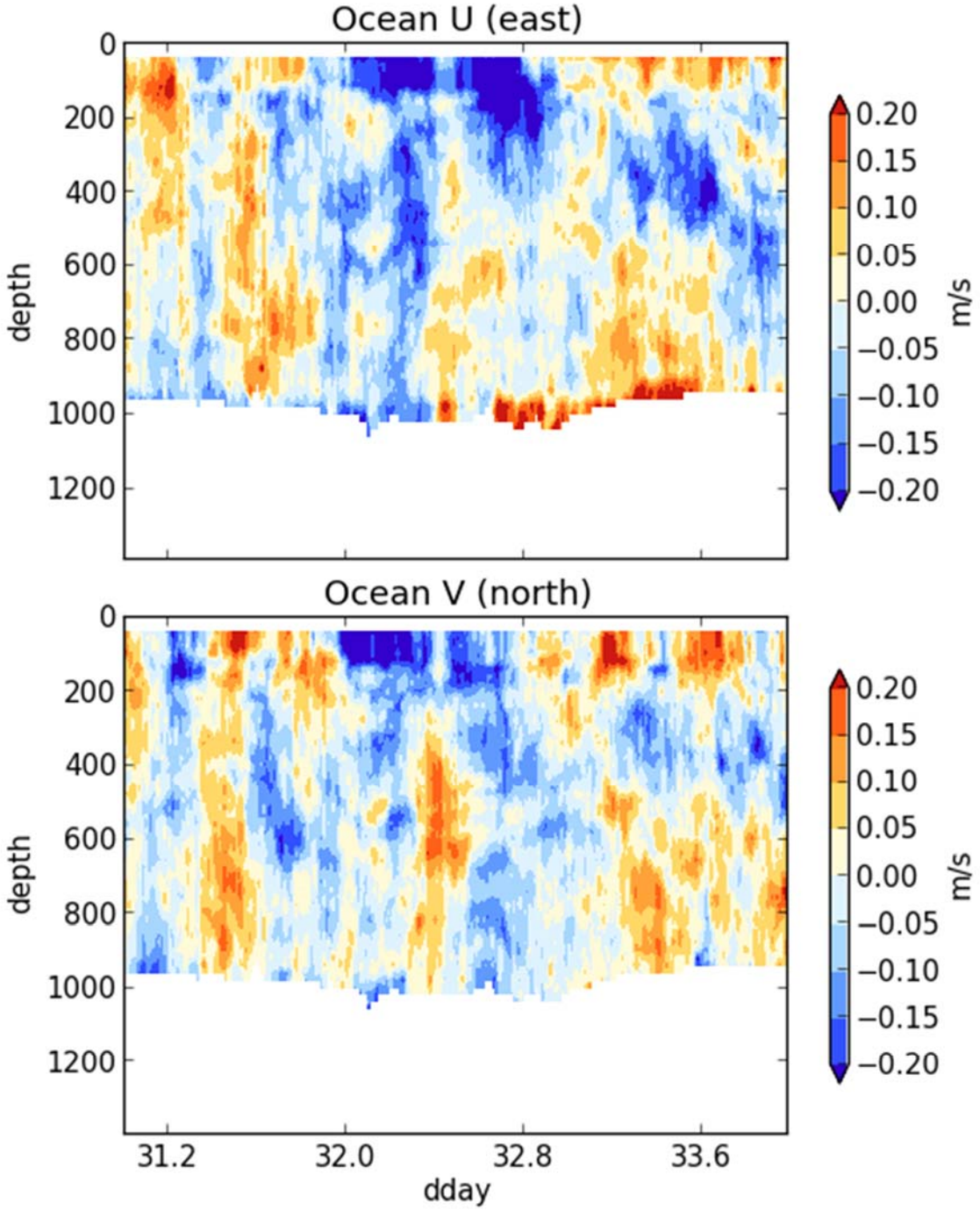
os38bb: last time 2013/01/28 23:45:20



os38bb: last time 2013/01/30 23:50:19



os38bb: last time 2013/02/01 23:45:22



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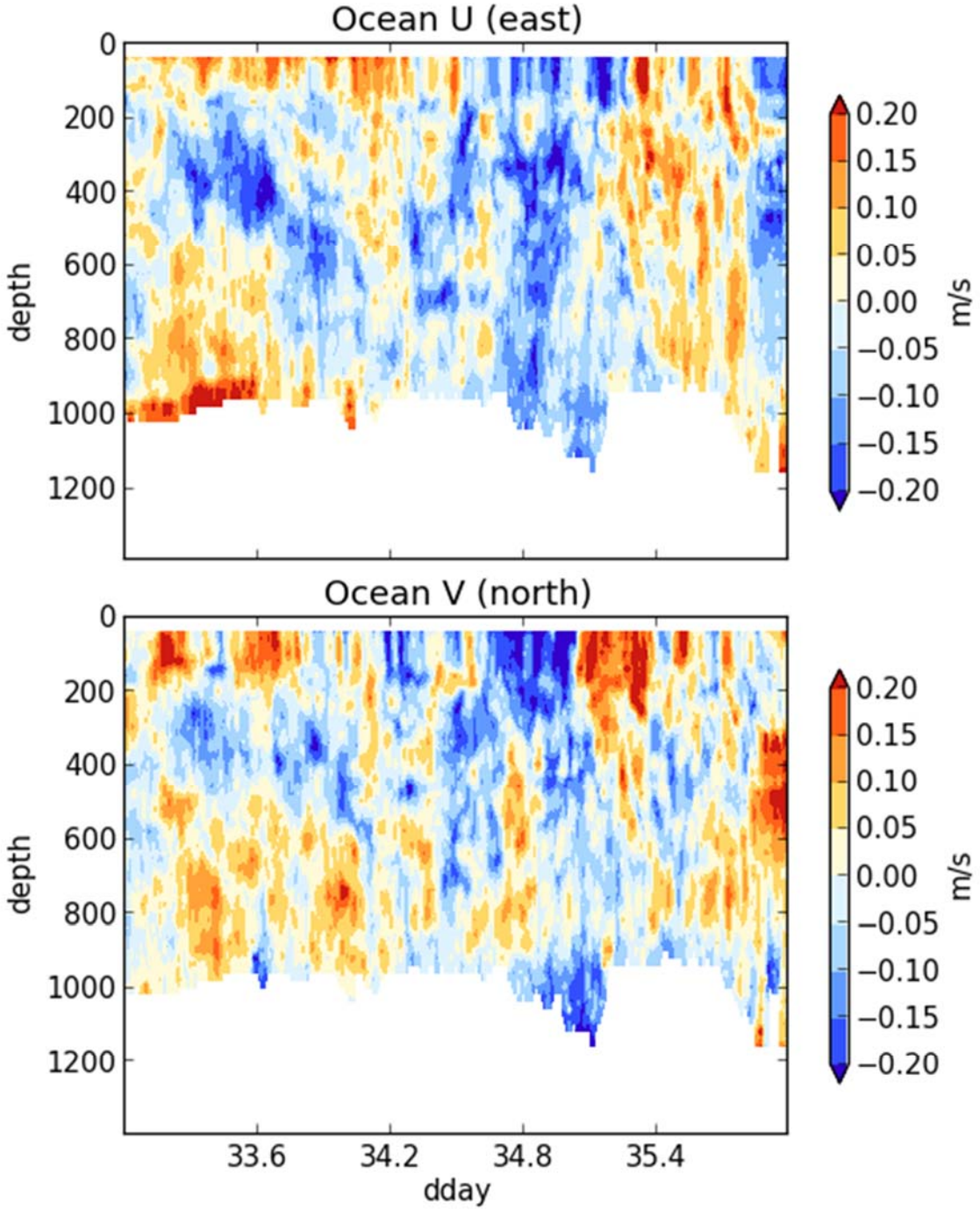
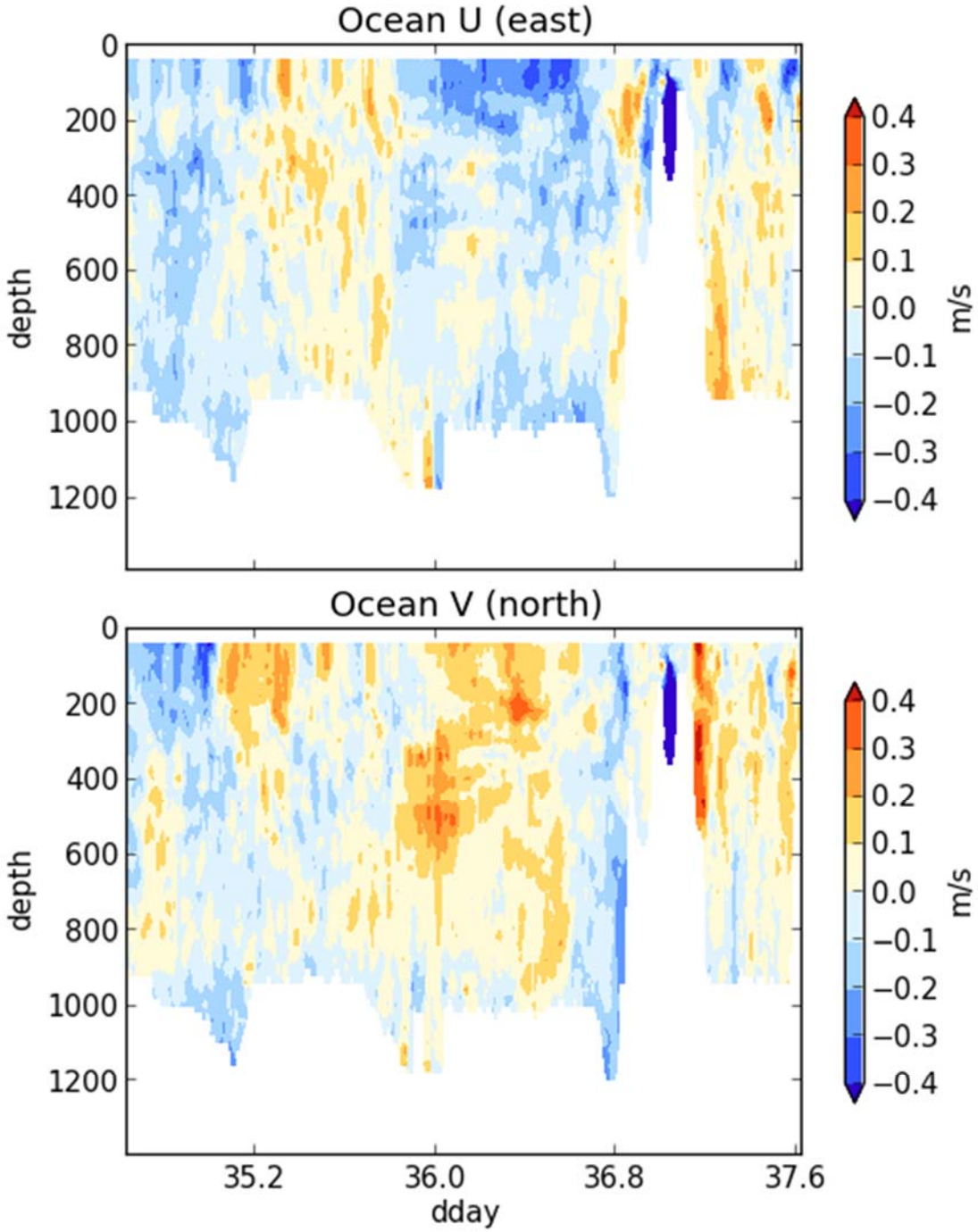


os38bb: last time 2013/02/05 23:45:20



os38bb: last time 2013/02/07 15:00:19

References

Project Website:
http://oceanography.ml.duke.edu/johnson/research/powow

Cruise Blog:
http://www.nicholas.duke.edu/insider/trips/researchatsea

Data Archive
http://bcodmo.org (Oceanographic)
http://www.ncbi.nlm.nih.gov/ (Molecular)

Major Funding Agency:
National Science Foundation
4201 Wilson Boulevard
Arlington, VA 22230
http://www.nsf.gov

University of Hawaii Marine Operations (R/V Kilo Moana)
http://www.soest.hawaii.edu/UMC/cms/kilo-moana/

Satellite Imagery Data (NASA MODIS)
http://modis.gsfc.nasa.gov/

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http://odv.awi-bremerhaven.de/

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ARGO project description
http://www.usgodae.org/argo/argo.html
ARGO data storage site
http://www.usgodae.org/cgi-bin/argo_select.pl
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