frontiers

Supplementary Material

Observations of shallow methane bubble emissions from Cascadia Margin

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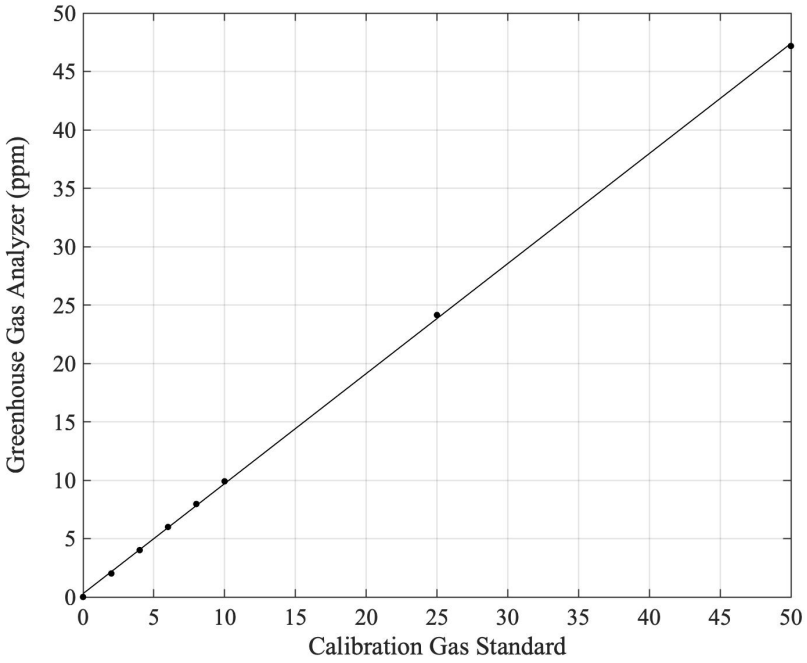

Figure S1. Calibration of the greenhouse gas analyzer. The zero point was measured by using pure nitrogen. Calibration gas standards (Mesa Gas) of 10 ppm, 25 ppm, and 50 ppm were used. 2 ppm, 4 ppm, 6 ppm, and 8 ppm gas standards were made by mixing 10 ppm methane with pure nitrogen gas using a gas mixer (Monkey Industrial Supply MCQ GB100). The calibrations at 2 ppm showed a standard deviation of measurement of 0.03 ppm.

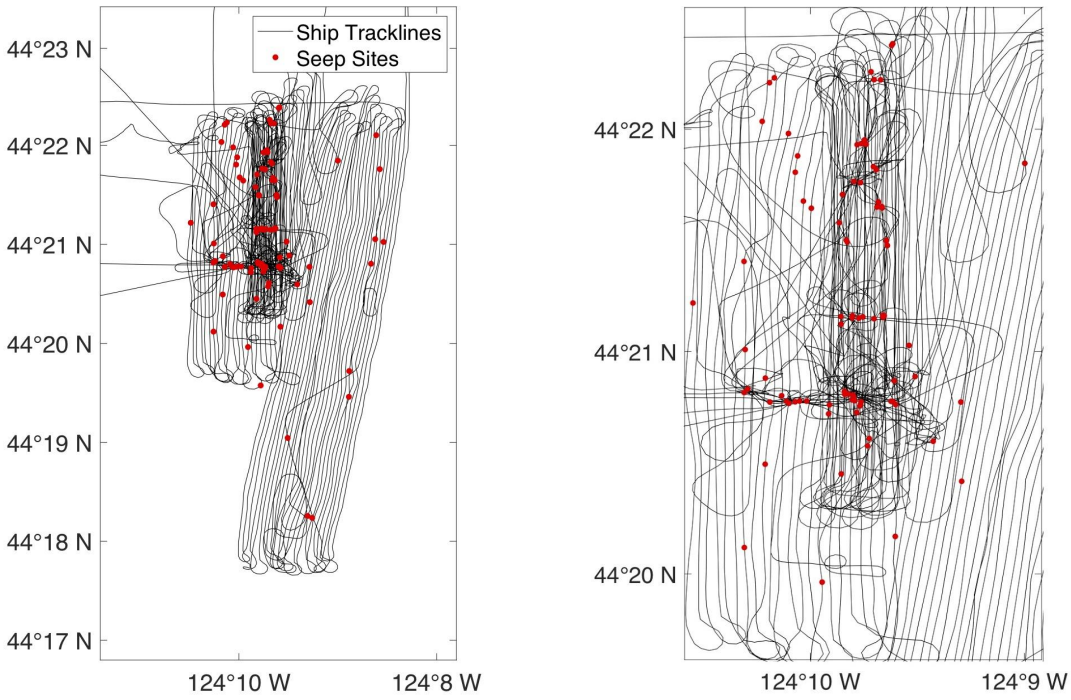

Figure S2. Locations of plume sites in the Yachats area (red dots) and the tracklines of the R/V Falkor. The panel on the right shows the panel on the left zoomed in.

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Table S1. Plume sites at Yachats Seep Site. All sites were identified in UTC time on cruise FK180824 using a Kongsberg EM710 multibeam system. All Yachats seep sites are between 40 and 55 meters depth.

Latitude	Longitude	Date Located	Time Located
44° 20' 46.9788" N	124° 9' 46.3386" W	9/11/18	1:39:27
44° 20' 46.9896" N	124° 9' 45.8886"W	9/11/18	1:39:31
44° 20' 46.4706" N	124° 9' 43.9194"W	9/11/18	1:47:41
44° 20' 34.5588" N	124° 9' 42.2202"W	9/11/18	1:53:07
44° 20' 45.3012" N	124° 9' 44.2686"W	9/11/18	1:55:38
44° 20' 45.8694" N	124° 9' 44.0634"W	9/11/18	1:55:50
44° 21' 9.3492" N	124° 9' 43.4802"W	9/11/18	2:00:48
44° 21' 55.911" N	124° 9' 42.5916"W	9/11/18	2:09:16
44° 21' 57.0996" N	124° 9' 43.0302"W	9/11/18	2:18:27
44° 21' 45.8994" N	124° 9' 45.9"W	9/11/18	2:21:06
44° 21' 9.6906" N	124° 9' 46.2996"W	9/11/18	2:27:01
44° 21' 9.0894" N	124° 9' 46.3494"W	9/11/18	2:27:07
44° 20' 48.2598" N	124° 9' 46.1478"W	9/11/18	2:30:24
44° 20' 26.9988" N	124° 9' 49.2804"W	9/11/18	2:48:20
44° 20' 49.2792" N	124° 9' 48.3978"W	9/11/18	2:56:14
44° 21' 7.3902" N	124° 9' 49.32"W	9/11/18	2:59:09
44° 21' 9.45" N	124° 9' 49.3812"W	9/11/18	2:59:23
44° 21' 29.5308" N	124° 9' 47.6706"W	9/11/18	3:02:35
44° 21' 55.7994" N	124° 9' 45.0288"W	9/11/18	3:06:46
44° 22' 13.3716" N	124° 9' 40.4382"W	9/11/18	3:09:42
44° 21' 42.3684" N	124° 9' 48.96"W	9/11/18	3:18:30
44° 21' 34.7112" N	124° 9' 49.8378"W	9/11/18	3:19:45
44° 19' 34.4892" N	124° 9' 46.7316"W	9/11/18	3:40:16
44° 19' 57.7812" N	124° 9' 54.4206"W	9/11/18	3:45:48
44° 20' 43.1982" N	124° 9' 52.6896"W	9/11/18	3:53:08
44° 20' 45.6282" N	124° 9' 52.4694"W	9/11/18	3:53:31
44° 21' 38.6604" N	124° 9' 57.33"W	9/11/18	4:57:37
44° 21' 40.5894" N	124° 9' 59.4792"W	9/11/18	5:12:16
44° 20' 46.6506" N	124° 10' 0.4908"W	9/11/18	5:21:20

Latitude	Longitude	Date Located	Time Located
44° 20' 46.0104" N	124° 10' 3.3492"W	9/11/18	5:46:30
44° 21' 48.3798" N	124° 10' 1.6392"W	9/11/18	5:57:06
44° 21' 52.7898" N	124° 10' 1.0086"W	9/11/18	5:57:52
44° 20' 48.0906" N	124° 10' 5.3034"W	9/11/18	6:18:42
44° 20' 29.601" N	124° 10' 9.7284"W	9/11/18	6:40:22
44° 21' 58.8312" N	124° 10' 3.4782"W	9/11/18	6:55:21
44° 20' 52.8288" N	124° 10' 9.681"W	9/11/18	7:14:16
44° 20' 7.119" N	124° 10' 15.3408"W	9/11/18	7:34:35
44° 20' 48.9402" N	124° 10' 15.384"W	9/11/18	7:41:09
44° 21' 0.5394" N	124° 10' 15.1212"W	9/11/18	7:43:01
44° 21' 24.321" N	124° 10' 15.24"W	9/11/18	7:46:58
44° 22' 2.0994" N	124° 10' 10.5234"W	9/11/18	8:09:56
44° 22' 12.5292" N	124° 10' 8.601"W	9/11/18	9:03:23
44° 22' 13.8684" N	124° 10' 7.2588"W	9/11/18	9:03:47
44° 21' 13.0896" N	124° 10' 29.1612"W	9/11/18	10:50:16
44° 20' 49.9092" N	124° 10' 14.4516"W	9/11/18	11:24:00
44° 20' 46.3704" N	124° 10' 8.49"W	9/11/18	11:26:51
44° 20' 46.5678" N	124° 10' 3.99"W	9/11/18	11:28:26
44° 20' 46.4382" N	124° 10' 1.668"W	9/11/18	11:29:17
44° 20' 46.6182" N	124° 9' 58.5792"W	9/11/18	11:30:10
44° 20' 48.4584" N	124° 9' 48.312"W	9/11/18	11:33:26
44° 20' 48.5484" N	124° 9' 47.4474"W	9/11/18	11:33:42
44° 20' 46.5786" N	124° 9' 35.8884"W	9/11/18	11:36:34
44° 20' 46.4886" N	124° 9' 35.3694"W	9/11/18	11:36:40
44° 20' 36.5382" N	124° 9' 41.76"W	9/11/18	11:43:27
44° 21' 8.8482" N	124° 9' 40.4712"W	9/11/18	12:12:18
44° 21' 38.991" N	124° 9' 39.6792"W	9/11/18	12:16:51
44° 21' 49.0602" N	124° 9' 39.8592"W	9/11/18	12:18:22
44° 22' 15.4992" N	124° 9' 41.2698"W	9/11/18	12:22:24
44° 21' 30.0204" N	124° 9' 37.1412"W	9/11/18	12:38:47
44° 21' 9.7986" N	124° 9' 38.0988"W	9/11/18	12:41:54
44° 21' 9.2196" N	124° 9' 38.0082"W	9/11/18	12:42:00

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Latitude	Longitude	Date Located	Time Located
44° 20' 10.1112" N	124° 9' 34.7508"W	9/11/18	13:04:31
44° 20' 52.101" N	124° 9' 35.0274"W	9/11/18	13:11:00
44° 20' 45.7002" N	124° 9' 34.6602"W	9/11/18	13:20:00
44° 22' 22.6092" N	124° 9' 35.73" W	9/11/18	13:25:12
44° 22' 23.07" N	124° 9' 35.4306" W	9/11/18	13:25:18
44° 22' 13.3212" N	124° 9' 38.7102" W	9/11/18	13:32:35
44° 21' 56.091" N	124° 9' 43.848" W	9/11/18	13:40:00
44° 21' 49.881" N	124° 9' 40.6296" W	9/11/18	13:42:55
44° 21' 40.3698" N	124° 9' 39.276" W	9/11/18	13:59:31
44° 21' 29.8398" N	124° 9' 37.1808" W	9/11/18	14:01:44
44° 21' 28.5984" N	124° 9' 36.8604" W	9/11/18	14:11:05
44° 21' 38.7282" N	124° 9' 38.2788" W	9/11/18	14:15:17
44° 21' 39.099" N	124° 9' 38.3796" W	9/11/18	14:15:27
44° 21' 45.6012" N	124° 9' 44.1396" W	9/11/18	14:20:19
44° 21' 1.5084" N	124° 8' 32.2506" W	9/11/18	22:26:14
44° 19' 2.661" N	124° 9' 30.3834" W	9/11/18	22:47:49
44° 21' 3.1608" N	124° 8' 37.2912" W	9/12/18	2:24:13
44° 19' 43.2294" N	124° 8' 53.016" W	9/12/18	2:48:21
44° 21' 45.6192" N	124° 8' 34.5006" W	9/12/18	3:48:38
44° 18' 14.2092" N	124° 9' 15.48" W	9/12/18	4:35:57
44° 18' 15.3612" N	124° 9' 18.291" W	9/12/18	4:48:44
44° 22' 6.2004" N	124° 8' 36.636" W	9/12/18	5:25:05
44° 20' 24.9894" N	124° 9' 16.8984" W	9/12/18	15:18:02
44° 21' 50.781" N	124° 8' 59.9274" W	9/12/18	15:31:35
44° 20' 46.3704" N	124° 9' 16.92" W	9/12/18	16:57:52
44° 21' 9.021" N	124° 9' 44.5674" W	9/13/18	16:11:42
44° 21' 1.6488" N	124° 9' 30.9954" W	9/13/18	17:19:39
44° 20' 35.7894" N	124° 9' 24.5592" W	9/13/18	18:09:34
44° 20' 46.7298" N	124° 9' 45.669" W	9/14/18	5:36:00
44° 21' 9.6798" N	124° 9' 37.692" W	9/14/18	6:52:15
44° 20' 43.5402" N	124° 9' 45.108" W	9/14/18	14:30:34

CTD022		CTD023		CTD024	
Depth (m)	**CH_4 (nM)**	**Depth (m)**	**CH_4 (nM)**	**Depth (m)**	**CH_4 (nM)**
2	6.1	3	5.9	3	3.5
5	5.5	5	6.1	8	4.5
8	8.3	8	7.2	20	12.1
12	17.1	12	8.8	25	13.5
20	22.2	20	12.5	30	12.7
25	19.3	25	15.5	35	16.6
30	21.3	30	22.5	40	23.6
45	27.3	37	66.1	44	21.0

Table S2: Methane concentrations measured in Niskin bottles for the casts at the Yachats seep site.

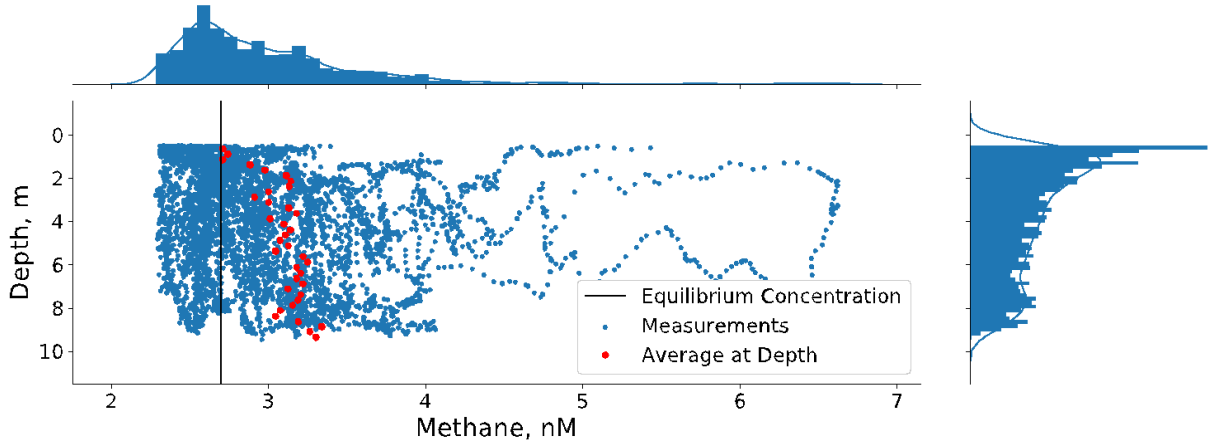

Figure S3. Distribution of methane concentration measurements made at each depth at the Yachats Seep site using the ChemYak.

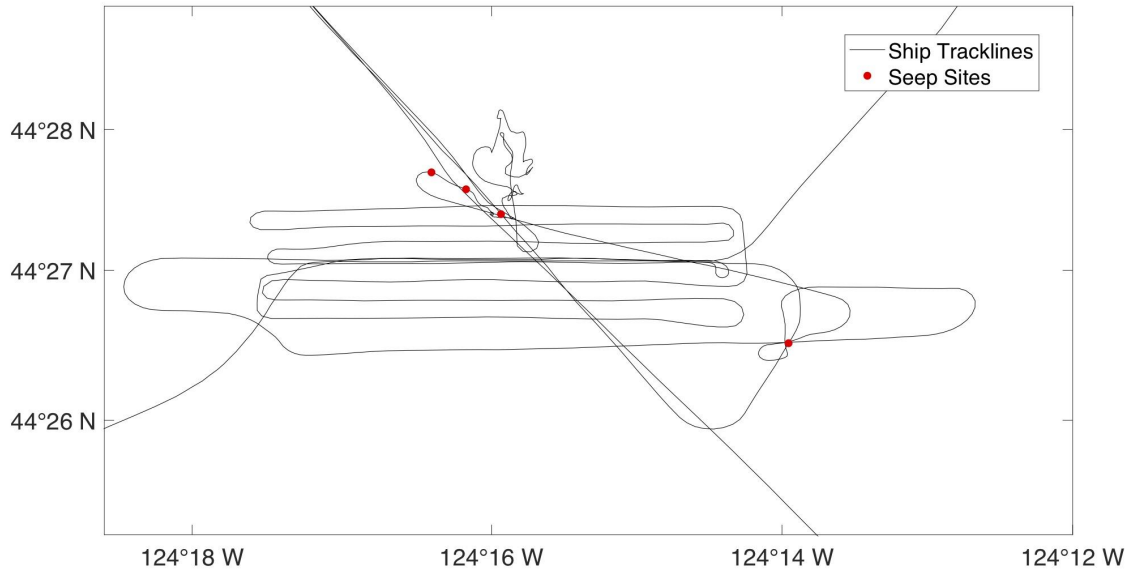

Figure S4. Locations of plume sites in the Stonewall Bank area (red dots) and the track lines of the R/V Falkor.

Table S3. Plume sites at Stonewall Bank. All sites were identified in UTC time on cruise FK180824 using a Kongsberg EM710 multibeam system. All Stonewall Bank seep sites are between 65 and 75 meters depth.

Latitude	Longitude	Date Located	Time Located
44° 27.3836' N	124° 15.8959' W	9/16/18	15:57:24
44° 26.5045' N	124° 13.9357' W	9/16/18	16:23:59
44° 27.6683' N	124° 16.3695' W	9/16/18	19:05:21
44° 27.5528' N	124° 16.1334' W	9/16/18	19:08:09

CTD025	
Depth (m)	**CH_4 (nM)**
2	2.8
5	3.1
8	3.5
18	3.9
30	5.3
40	5.7
50	5.8
60	7.0
65	7.7

Table S4: Methane concentrations measured in Niskin bottles for the cast at the Stonewall Bank seep site.

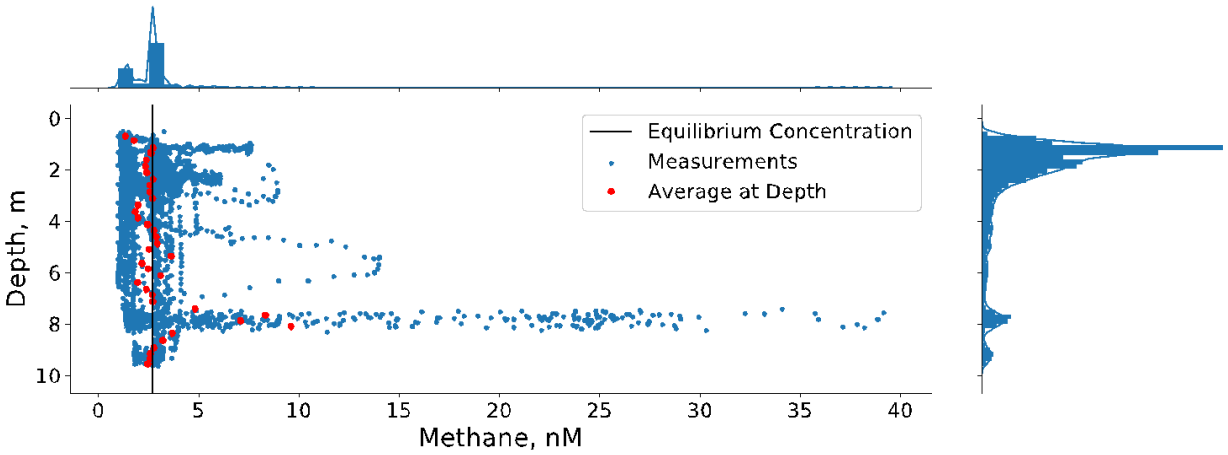

Figure S5. Distribution of methane concentration measurements made at each depth at the Stonewall Bank Seep site using the ChemYak.

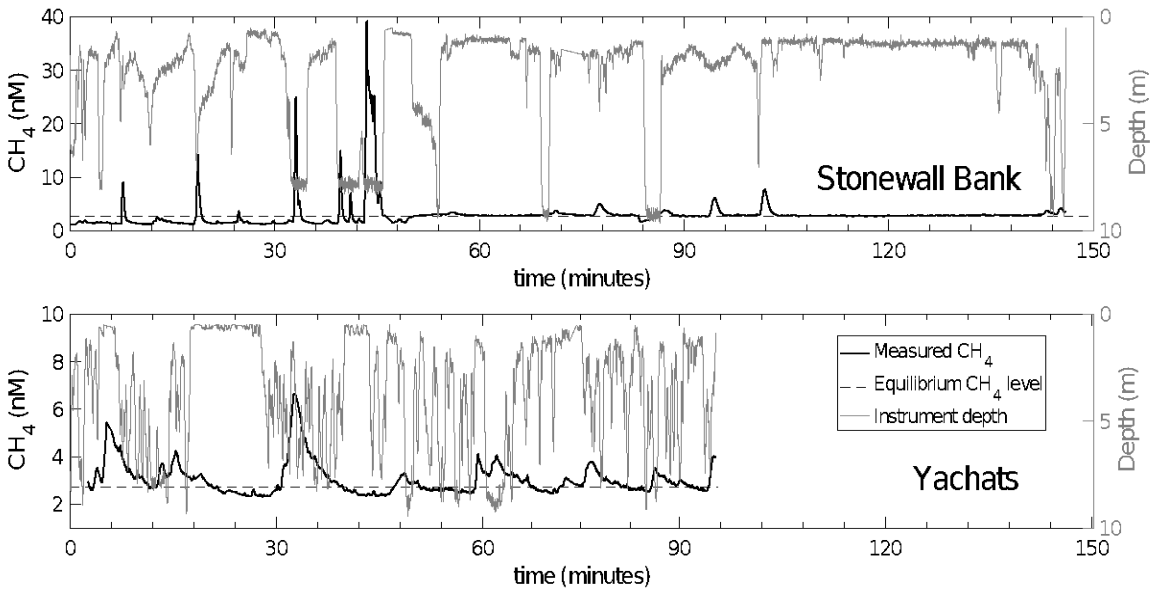

Figure S6. Time series measurements of dissolved methane measured by the ChemYak (Yachats seep site data from 9/13/18 – start time of 23:54 GMT and Stonewall Bank seep site data from 9/16/18 – start time of 23:25 GMT). These data show the dissolved methane measurements made from the start to end of the ChemYak deployments and the depth that the data were taken at as measured by the CTD collocated with the sampling line and deployed using the ChemYak's onboard winch. A dashed line in each figure shows the equilibrium methane level calculated based on temperature and salinity at these sites. A slight baseline shift of background level methane is seen in the Stonewall Bank seep site Data at 50 minutes which we hypothesize is due to the clogging of the inlet tubing.

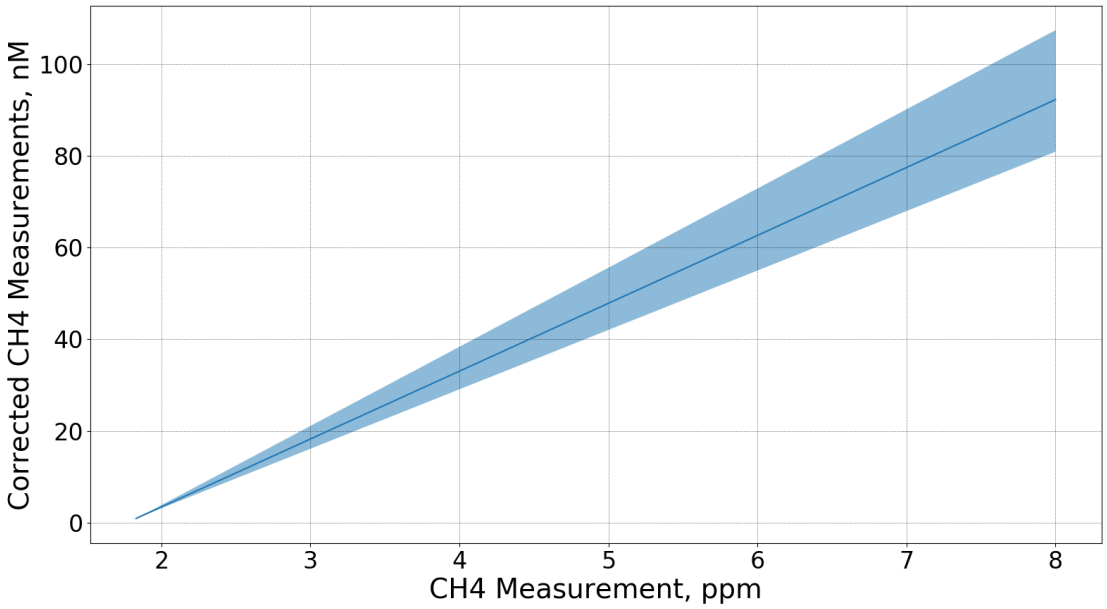

Figure S7. The confidence level of the measurements of methane from the greenhouse gas analyzer coupled to the gas extractor were determined to see how changes in the environmental parameters impact the dissolved concentration calculated (nM). 50,000 Monte Carlo samples of salinity, temperature, and efficiency were used to generate the interval. Samples of salinity and temperature were drawn from the empirical distributions of salinity and temperature as observed by the ChemYak. Samples of the extraction efficiency were drawn from a Gaussian distribution centered at 0.05 with 0.01 standard deviation. The posterior samples of corrected methane measurement are plotted, with the solid line being the median of the distribution, and the shaded region representing the interquartile range. Based on these data, the lowest value measured was 0.972nM +/- 0.001 nM and the highest value measured was 66 nM +/- 10 nM, providing the bounds of detection limits.

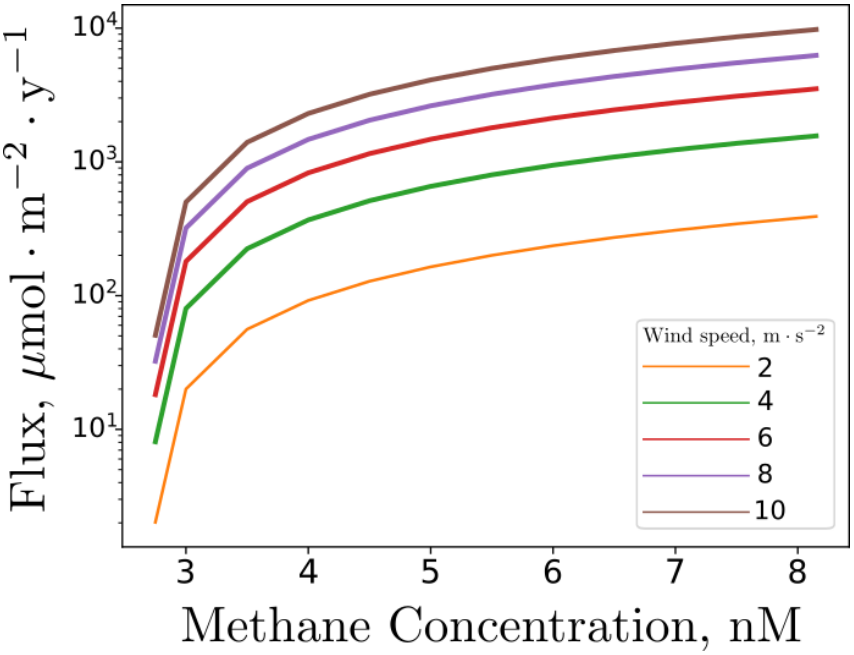

Figure S8. The relationship between methane concentration in water in nM, wind speed in meter second^{-1}, and diffusive methane flux in µmol m^{-2} y^{-1} is represented, assuming water with 32.96 PSU salinity, 12.7 C temperature, and 1.86 µatm of methane in the atmosphere. For low sustained wind speed, the diffusive flux is negative, indicating that the water could be a sink of methane from the atmosphere for some surface concentrations. For sustained wind speeds of greater than 2 m s^{-1}, the flux is typically positive. This estimate does not consider seasonal variations in surface temperature or changing wind conditions.

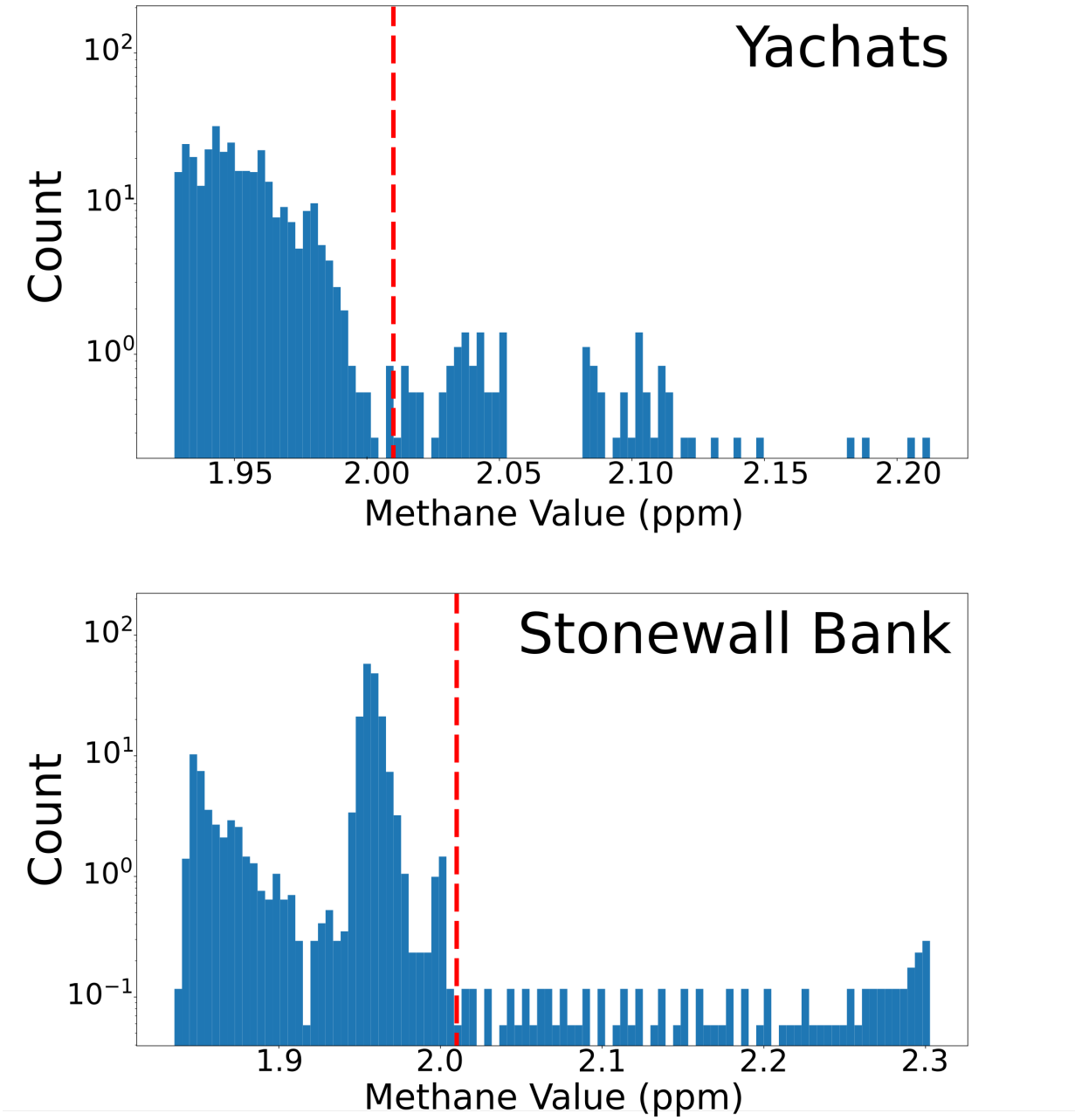

Figure S9. Distribution of raw (i.e., uncorrected), observed values at each of the sampling sites. The red dashed line represents the empirical threshold for identifying observations to be part of the background (to the left) or hotspots (to the right). For each site, this value was selected to be 2.01 ppm (uncorrected for extraction efficiency).

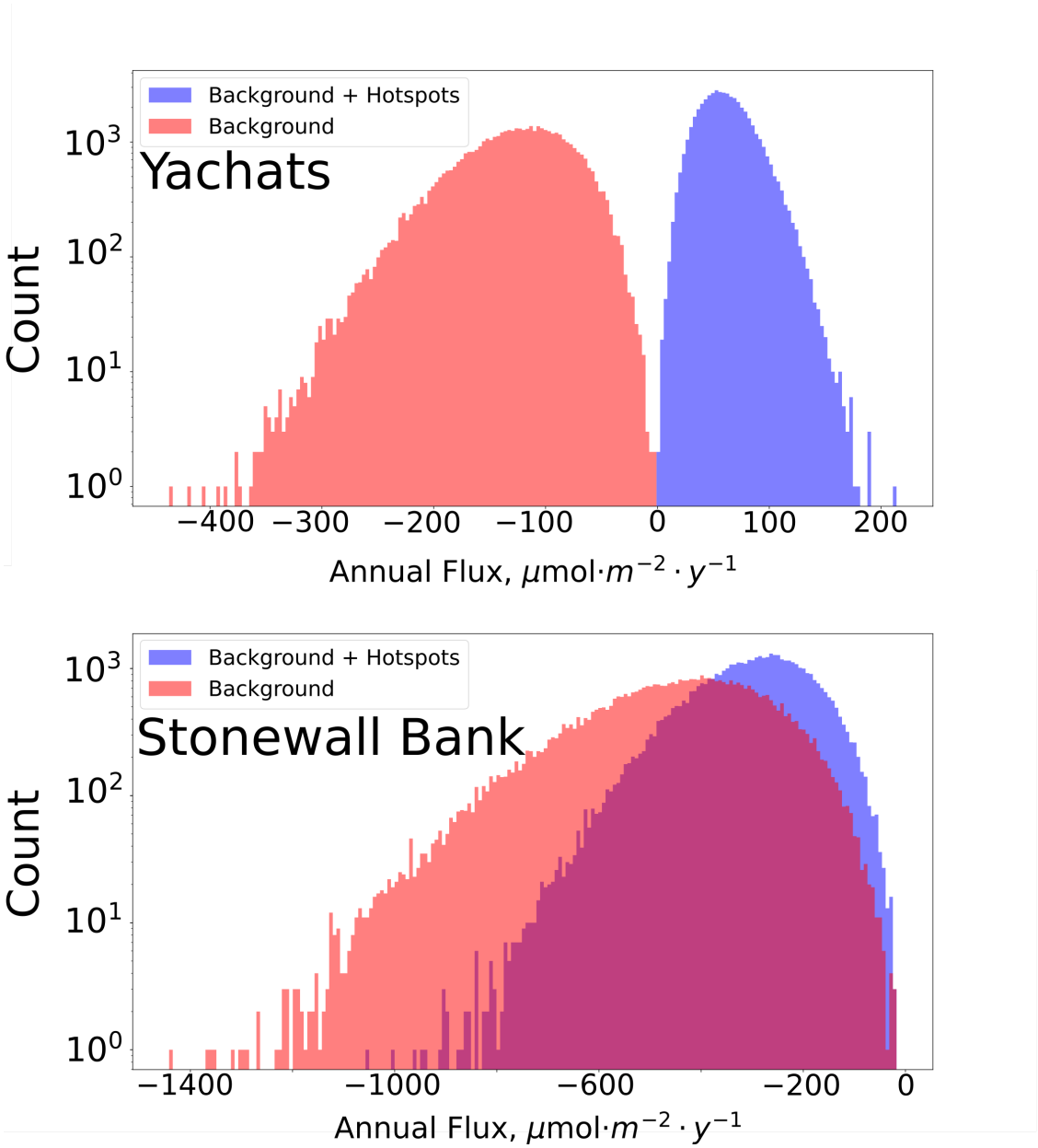

Figure S10. Distribution of simulated annual methane flux values from empirical distributions of salinity, temperature, and wind. The average methane value for each dataset (e.g., just background or background with hotspots) is used as the representative surface methane concentration in the simulations. 50,000 Monte Carlo samples are utilized to draw each distribution.