Appendices. Influence of temperature and upwelling intensity on Indian oil sardine (*Sardinella longiceps*) landings

05 September, 2019

Appendix A: Tests for prior season catch as covariate

Table A1. Model selection tests of time-dependency the log catch during spawning months using F-tests of nested linear models. S_t is the catch during the spawning period (Jul-Sep). N_t is the catch during the non-spawning period (Oct-Jun). S_{t-1} and N_{t-1} are the catch during the prior season during and after the spawning period respectively. S_{t-2} and N_{t-2} are the same for two seasons prior. Test A uses catch during the spawning period as the explanatory variable. Test B uses catch during the non-spawning period as the explanatory variable. The numbers in front of the model equation indicate the level of nestedness. For Test C, there are two nested model sets, each with a different model 3. The Naive model is a model that uses the previous data point in the time series as the prediction; thus the Naive model has no estimated parameters.

Model	Residual df	MASE	Adj. R2	F	p value	AIC
Naive Model 1984-2015 data						
$ln(S_t) = ln(S_{t-1}) + \varepsilon_t$	32	1				122.85
Time dependency test A 1984-2015 data						
1. $ln(S_t) = \alpha + ln(S_{t-1}) + \varepsilon_t$	31	0.992	-29			124.83
2. $ln(S_t) = \alpha + \beta ln(S_{t-1}) + \varepsilon_t$	30	0.814	10.3	15.14	0.001	114.14
3. $ln(S_t) = \alpha + \beta_1 ln(S_{t-1}) + \beta_2 ln(S_{t-2}) + \varepsilon_t$	29	0.803	13.6	2.13	0.155	113.88
Time dependency test B 1984-2015 data						
1. $ln(S_t) = \alpha + ln(N_{t-1}) + \varepsilon_t$	31	0.856	14.2			111.78
2. $ln(S_t) = \alpha + \beta ln(N_{t-1}) + \varepsilon_t$	30	0.794	22.2	4.06	0.053	109.59
3. $ln(S_t) = \alpha + \beta_1 ln(N_{t-1}) + \beta_2 ln(N_{t-2}) + \varepsilon_t$	29	0.797	19.6	0.01	0.919	111.57
Time dependency test C 1984-2015 data						
1. $ln(S_t) = \alpha + ln(N_{t-1}) + \varepsilon_t$	31	0.856	14.2			111.78
2. $ln(S_t) = \alpha + \beta ln(N_{t-1}) + \varepsilon_t$	30	0.794	22.2	4.08	0.053	109.59
3a. $ln(S_t) = \alpha + \beta_1 ln(N_{t-1}) + \beta_2 ln(S_{t-1}) + \varepsilon_t$	29	0.804	20	0.16	0.688	111.4
3b. $ln(S_t) = \alpha + \beta_1 ln(N_{t-1}) + \beta_2 ln(S_{t-2}) + \varepsilon_t$	29	0.778	20.8	0.45	0.508	111.09

Table A2. Model selection tests of time-dependency the catch during spawning months using non-linear responses instead of linear responses as in Table A1. See Table A1 for an explanation of the parameters and model set-up.

Model	Residual df	MASE	Adj. R2	F	p value	AIC
Time dependency test A 1984-2015 data						
1. $ln(S_t) = \alpha + \beta ln(S_{t-1}) + \varepsilon_t$	30	0.814	10.3			114.14
2. $ln(S_t) = \alpha + s(ln(S_{t-1})) + \varepsilon_t$	28.2	0.798	19.6	2.74	0.089	111.79
3. $ln(S_t) = \alpha + s_1(ln(S_{t-1})) + s_2(ln(S_{t-2})) + \varepsilon_t$	25.5	0.77	20.7	0.97	0.416	113.23
Time dependency test B 1984-2015 data						
1. $ln(S_t) = \alpha + \beta ln(N_{t-1}) + \varepsilon_t$	30	0.794	22.2			109.59
2. $ln(S_t) = \alpha + s(ln(N_{t-1})) + \varepsilon_t$	28.6	0.761	24.4	1.26	0.287	109.52
3. $ln(S_t) = \alpha + s_1(ln(N_{t-1})) + s_2(ln(N_{t-2})) + \varepsilon_t$	26.4	0.761	21.2	0.28	0.785	112.42
Time dependency test C 1984-2015 data						
1. $ln(S_t) = \alpha + s(ln(N_{t-1})) + \varepsilon_t$	28.6	0.761	24.4			109.52
2. $ln(S_t) = \alpha + s_1(ln(N_{t-1})) + s_2(ln(S_{t-1})) + \varepsilon_t$	26.1	0.698	28.5	1.49	0.242	109.55
3. $ln(S_t) = \alpha + s_1(ln(N_{t-1})) + s_2(ln(S_{t-2})) + \varepsilon_t$	25.9	0.724	26.3	1.09	0.367	110.63

Table A3. Table A2 with 1956-1983 data instead of 1984 to 2015 data. See Table A1 for an explanation of the parameters and model set-up.

Model	Residual df	MASE	Adj. R2	F	p value	AIC
Time dependency test A 1956-1983 data						
1. $ln(S_t) = \alpha + \beta ln(S_{t-1}) + \varepsilon_t$	24	0.633	-0.7			64.69
2. $ln(S_t) = \alpha + s(ln(S_{t-1})) + \varepsilon_t$	22.1	0.614	-0.2	0.78	0.464	65.71
3. $ln(S_t) = \alpha + s_1(ln(S_{t-1})) + s_2(ln(S_{t-2})) + \varepsilon_t$	19.9	0.58	3.1	1.19	0.329	66.35
Time dependency test B 1956-1983 data						
1. $ln(S_t) = \alpha + \beta ln(N_{t-1}) + \varepsilon_t$	24	0.634	-3.8			65.48
2. $ln(S_t) = \alpha + s(ln(N_{t-1})) + \varepsilon_t$	21.6	0.584	8.2	2.24	0.127	63.8
3. $ln(S_t) = \alpha + s_1(ln(N_{t-1})) + s_2(ln(N_{t-2})) + \varepsilon_t$	18.5	0.495	16.9	1.56	0.231	63.13
Time dependency test C 1956-1983 data						
1. $ln(S_t) = \alpha + s(ln(N_{t-1})) + \varepsilon_t$	22.5	0.586	4.3			66.2
2. $ln(S_t) = \alpha + s_1(ln(N_{t-1})) + s_2(ln(S_{t-1})) + \varepsilon_t$	20.7	0.556	4.8	0.91	0.41	67.3
3. $ln(S_t) = \alpha + s_1(ln(N_{t-1})) + s_2(ln(S_{t-2})) + \varepsilon_t$	19.5	0.55	12.9	1.42	0.266	63.79

Table A4. Model selection tests of time-dependency the N_t model using F-tests of nested models fit to 1984 to 2014 log landings data. The years are determined by the covariate data availability and end in 2014 since the landings data go through 2015 and N_{2014} includes quarters in 2014 and 2015. N_t is the catch during the non-spawning period (Qtrs 4 and 1: Oct-Mar) of season t (Jul-Jun). S_{t-1} and N_{t-1} are the catch during the prior sardine season during and after the spawning period respectively. S_{t-2} and N_{t-2} are the same for two seasons prior. Test A uses catch during the spawning period as the explanatory variable. Test B uses catch during the non-spawning period as the explanatory variable. Test C uses both. The numbers next to the model equations indicate the level of nestedness. The Naive model is a model that uses the previous data point in the time series as the prediction; thus the Naive model has no estimated parameters.

Model	Residual df	MASE	Adj. R2	F	p value	AIC
Naive Model 1984-2014 data						
$ln(N_t) = ln(N_{t-1}) + \varepsilon_t$	31	1				90.87
Time dependency test A 1984-2014 data						
1. $ln(N_t) = \alpha + ln(S_{t-1}) + \varepsilon$	30	1.363	-20.3			107.36
2. $ln(N_t) = \alpha + \beta ln(S_{t-1}) + \varepsilon_t$	29	1.018	26.2	19.99	0	93.17
3. $ln(N_t) = \alpha + \beta_1 ln(S_{t-1}) + \beta_2 ln(S_{t-2}) + \varepsilon_t$	28	1.009	26.6	1.15	0.292	93.92
Time dependency test B 1984-2014 data						
1. $ln(N_t) = \alpha + ln(N_{t-1}) + \varepsilon_t$	30	0.999	24.7			92.87
2. $ln(N_t) = \alpha + \beta ln(N_{t-1}) + \varepsilon_t$	29	0.978	37	6.63	0.016	88.28
3. $ln(N_t) = \alpha + \beta_1 ln(N_{t-1}) + \beta_2 ln(N_{t-2}) + \varepsilon_t$	28	0.97	34.8	0.04	0.843	90.24
Time dependency test C 1984-2014 data						
1. $ln(N_t) = \alpha + \beta ln(N_{t-1}) + \varepsilon_t$	29	0.978	37			88.28
2a. $ln(N_t) = \alpha + \beta_1 ln(N_{t-1}) + \beta_2 ln(S_{t-1}) + \varepsilon_t$	28	0.964	35	0.12	0.729	90.15
2b. $ln(N_t) = \alpha + \beta_1 ln(N_{t-1}) + \beta_2 ln(S_{t-2}) + \varepsilon_t$	28	0.978	34.7	0.01	0.919	90.27

Table A5. Model selection tests of time-dependency the N_t model using non-linear responses instead of linear responses as in Table A4 See Table A4 for an explanation of the parameters and model set-up.

Model	Residual df	MASE	Adj. R2	F	p value	AIC
Time dependency test A 1984-2014 data						
1. $ln(N_t) = \alpha + \beta ln(S_{t-1}) + \varepsilon_t$	29	1.018	26.2			93.17
2. $ln(N_t) = \alpha + s(ln(S_{t-1})) + \varepsilon_t$	27.3	0.992	30.2	1.83	0.185	92.61
3. $ln(N_t) = \alpha + s_1(ln(S_{t-1})) + s_2(ln(S_{t-2})) + \varepsilon_t$	24.4	0.94	36.4	1.79	0.177	91.62
Time dependency test B 1984-2014 data						
1. $ln(N_t) = \alpha + \beta ln(N_{t-1}) + \varepsilon_t$	29	0.978	37			88.28
2. $ln(N_t) = \alpha + s(ln(N_{t-1})) + \varepsilon_t$	27.6	0.874	45.3	3.88	0.047	84.75
3. $ln(N_t) = \alpha + s_1(ln(N_{t-1})) + s_2(ln(N_{t-2})) + \varepsilon_t$	25.4	0.805	45.6	0.87	0.441	86.11
Time dependency test C 1984-2014 data						
1. $ln(N_t) = \alpha + s(ln(N_{t-1})) + \varepsilon_t$	27.6	0.874	45.3			84.75
2. $ln(N_t) = \alpha + s_1(ln(N_{t-1})) + s_2(ln(S_{t-1})) + \varepsilon_t$	25.1	0.856	43.8	0.53	0.634	87.37
3. $ln(N_t) = \alpha + s_1(ln(N_{t-1})) + s_2(ln(S_{t-2})) + \varepsilon_t$	24.8	0.743	56.6	3.39	0.036	79.53

Table A6. Table A5 with 1956-1983 data instead of 1984 to 2014 data. See Table A4 for an explanation of the parameters and model set-up.

Model	Residual df	MASE	Adj. R2	F	p value	AIC
Time dependency test A 1956-1983 data						
1. $ln(N_t) = \alpha + \beta ln(S_{t-1}) + \varepsilon_t$	24	0.641	-1.7			44.98
2. $ln(N_t) = \alpha + s(ln(S_{t-1})) + \varepsilon_t$	22.1	0.534	16.2	3.53	0.052	41.11
3. $ln(N_t) = \alpha + s_1(ln(S_{t-1})) + s_2(ln(S_{t-2})) + \varepsilon_t$	19.9	0.502	18.1	1.09	0.362	42
Time dependency test B 1956-1983 data						
1. $ln(N_t) = \alpha + \beta ln(N_{t-1}) + \varepsilon_t$	24	0.681	-4.2			45.61
2. $ln(N_t) = \alpha + s(ln(N_{t-1})) + \varepsilon_t$	21.6	0.507	29.1	5.69	0.009	37.12
3. $ln(N_t) = \alpha + s_1(ln(N_{t-1})) + s_2(ln(N_{t-2})) + \varepsilon_t$	18.5	0.471	32.2	1.14	0.36	37.87
Time dependency test C 1956-1983 data						
1. $ln(N_t) = \alpha + s(ln(N_{t-1})) + \varepsilon_t$	21.6	0.507	29.1			37.12
2a. $ln(N_t) = \alpha + s_1(ln(N_{t-1})) + s_2(ln(S_{t-1})) + \varepsilon_t$	19	0.45	34.4	1.49	0.251	36.74
2b. $ln(N_t) = \alpha + s_1(ln(N_{t-1})) + s_2(ln(S_{t-2})) + \varepsilon_t$	19.5	0.465	33.4	1.54	0.24	36.84

Appendix B: Tests for environmental variables as covariates

Table B1. Model selection tests of GPCP precipitation as an explanatory variable for the catch S_t during spawning months (Jul-Sep) using 1984 to 2015 data. The data range is determined by the years for which SST was available in order to use a consistent dataset across covariate tests. The base model (M) with prior catch dependency was selected independently (Appendix A). To the base model, covariates are added. V_t is the covariate in same calendar year as the Jul-Sep catch. The specific hypothesis (Table 1) being tested is noted in parentheses. The models are tested as nested sets. Thus 1, 2a, 3a is a set and 1, 2b, 3b is another set. MASE is the mean absolute square error (residuals).

Model	Residual df	MASE	Adj. R2	F	p value	AIC
base model (M) 1984-2015 data						
1. $ln(S_t) = \alpha + s(ln(N_{t-1})) + \varepsilon_t$	28.6	0.761	24.4			109.52
V_t = Jun-Jul Precipitation (S1)						
2. $ln(S_t) = \text{M} + \beta V_t$	27.6	0.743	23.5	0.67	0.42	110.78
3. $ln(S_t) = \text{M} + s(V_t)$	26	0.734	27	1.51	0.241	110.28
V_t = Apr-May Precipitation (S2)						
2. $ln(S_t) = \text{M} + \beta V_t$	27.6	0.756	23.8	0.72	0.403	110.65
3. $ln(S_t) = \text{M} + s(V_t)$	25.6	0.748	21.1	0.24	0.792	112.98

Table B2. Model selection tests of sea surface temperature off the Kerala coast (up to 80km offshore in boxes 2-5 in Figure 1), upwelling and ONI as the explanatory variables (V_t) for the catch during monsoon months (Jul-Sep) using 1984 to 2015 data. The hypothesis tested (Table 1) is noted in parentheses. Two upwelling indices were tested. The nearshore-offshore temperature diferential (UPW), which is the offshore (box 13) minus nearshore (box 4) SST, and the average nearshore SST along the Kerala coast (boxes 2-5). These are highly correlated but not identical. The ONI index is the average over all months in the calendar year. The 2.5-year average SST is the average for Jan-Jun in the current calendar year and the prior 2 calendar years (30 months total). Thus the average does not include any months during the Jul-Sep catch (response variable). See Table B1 for an explanation of the models.

Model	Residual df	MASE	Adj. R2	F	p value	AIC
base model (M) 1984-2015 data						
1. $ln(S_t) = \alpha + s(ln(N_{t-1})) + \varepsilon_t$	28.6	0.761	24.4			109.52
V_t = Ave Mar-May SST (S4)						
2a. $ln(S_t) = \mathrm{M} + \beta V_t$	27.6	0.772	23.3	0.59	0.449	110.87
3a. $ln(S_t) = \mathrm{M} + s(V_t)$	25.5	0.753	26.4	1.26	0.303	110.8
2b. $ln(S_t) = \mathrm{M} + \beta V_{t-1}$	27.6	0.754	22.8	0.39	0.533	111.07
3b. $ln(S_t) = \mathrm{M} + s(V_{t-1})$	25.7	0.723	26.1	1.35	0.275	110.74
V_t = Ave Oct-Dec SST (L1)						
2. $ln(S_t) = \mathrm{M} + \beta V_{t-1}$	27.6	0.759	21.8	0	0.952	111.5
3. $ln(S_t) = \mathrm{M} + s(V_{t-1})$	26.1	0.768	21.8	0.66	0.482	112.32
V_t = Ave. Jun-Sep UPW (S4 and L2)						
2a. $ln(S_t) = \mathrm{M} + \beta V_t$	27.6	0.706	33.5	5.01	0.034	106.32
3a. $ln(S_t) = \mathrm{M} + s(V_t)$	25.5	0.682	34.1	0.83	0.455	107.24
2b. $ln(S_t) = \mathrm{M} + \beta V_{t-1}$	27.6	0.748	22.6	0.33	0.568	111.15
3b. $ln(S_t) = \mathrm{M} + s(V_{t-1})$	25.1	0.724	26.2	1.28	0.3	111.16
V_t = Ave. Jun-Sep SST (S4 and L2)						
2a. $ln(S_t) = \mathrm{M} + \beta V_t$	27.6	0.745	33.3	5.53	0.027	106.4
3a. $ln(S_t) = \mathrm{M} + s(V_t)$	25.9	0.683	41	2.85	0.084	103.43
2b. $ln(S_t) = \mathrm{M} + \beta V_{t-1}$	27.6	0.742	23.2	0.54	0.468	110.89
3b. $ln(S_t) = \mathrm{M} + s(V_{t-1})$	25.5	0.715	22.2	0.54	0.599	112.57

Model	Residual df	MASE	Adj. R2	F	p value	AIC
V_t = 2.5-year average SST (A1)						
2. $ln(S_t) = \mathrm{M} + \beta V_t$	27.6	0.723	33.2	5.52	0.027	106.43
3. $ln(S_t) = \mathrm{M} + s(V_t)$	26.2	0.653	41	3.22	0.07	103.26
V_t = ONI (A2)						
2. $ln(S_t) = \mathrm{M} + \beta V_{t-1}$	27.6	0.758	22	0.08	0.77	111.4
3. $ln(S_t) = \mathrm{M} + s(V_{t-1})$	26.6	0.733	23.6	1.16	0.294	111.28

Table B3. Model selection tests of GPCP precipitation as an explanatory variable for the catch (N_t) during post-monsoon months (Oct-May) using 1984 to 2014 data. The data range is determined by the years for which SST was available in order to use a consistent dataset across covariate tests. The base model (M) with prior catch dependency was selected independently (Appendix A). N_{t-1} is the post-monsoon catch in prior season, and S_{t-2} is the catch during Jul-Sep two seasons prior. To the base model, covariates are added. V_t is the covariate in the calendar year, and V_{t-1} is the covariate in the prior calendar year. The specific hypothesis (Table 1) being tested is noted in parentheses. The models are tested as nested sets. Thus 1, 2a, 3a is a set and 1, 2b, 3b is another set.

Model	Residual df	MASE	Adj. R2	F	p value	AIC
base model (M) 1984-2014 data						
1. $ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + \varepsilon_t$	24.8	0.743	56.6			79.53
V_t = Jun-Jul Precipitation (S1)						
2a. $ln(N_t) = \text{M} + \beta V_t$	23.8	0.755	56.7	1.03	0.318	80.23
3a. $ln(N_t) = \text{M} + s(V_t)$	22.3	0.75	55.3	0.19	0.767	82.02
2b. $ln(N_t) = \text{M} + \beta V_{t-1}$	23.8	0.744	54.9	NA	NA	81.5
3b. $ln(N_t) = \text{M} + s(V_{t-1})$	22.3	0.701	56.4	1.32	0.28	81.18
V_t = Apr-May Precipitation (S2)						
2a. $ln(N_t) = \text{M} + \beta V_t$	23.8	0.742	55.1	0.11	0.735	81.34
3a. $ln(N_t) = \text{M} + s(V_t)$	21.7	0.73	53.7	0.36	0.707	83.39
2b. $ln(N_t) = \text{M} + \beta V_{t-1}$	23.8	0.723	56.2	0.74	0.397	80.6
3b. $ln(N_t) = \text{M} + s(V_{t-1})$	22	0.692	55.6	0.5	0.587	81.87

Table B4. Model selection tests of sea surface temperature off the Kerala coast (up to 80km offshore in boxes 2-5 in Figure 1), upwelling and ONI as the explanatory variables (V_t) for the catch during post-monsoon months (Oct-May) using 1984 to 2014 data. The hypothesis tested (Table 1) is noted in parentheses. Two upwelling indices were tested. The nearshore-offshore temperature diferential (UPW), which is the offshore (box 13) minus nearshore (box 4) SST, and the average nearshore SST along the Kerala coast (boxes 2-5). These are highly correlated but not identical. The ONI index is the average over all months in the calendar year. The 2.5-year average SST is the average for Jan-Jun in the current calendar year and the prior 2 calendar years (30 months total). Thus the average does not include any months during the Oct-Mar catch. See Table B3 for an explanation of the models.

Model	Residual df	MASE	Adj. R2	F	p value	AIC
base model (M) 1984-2014 data						
1. $ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + \varepsilon_t$	24.8	0.743	56.6			79.53
V_t = Ave Mar-May SST (S5)						
2a. $ln(N_t) = \mathrm{M} + \beta V_t$	23.8	0.701	59	2.84	0.107	78.53
3a. $ln(N_t) = \mathrm{M} + s(V_t)$	22	0.682	63.2	2.29	0.13	76.01
2b. $ln(N_t) = \mathrm{M} + \beta V_{t-1}$	23.8	0.762	57.1	1.33	0.26	79.93
3b. $ln(N_t) = \mathrm{M} + s(V_{t-1})$	22	0.747	57.4	0.79	0.455	80.61
V_t = Ave Oct-Dec SST (L1)						
2. $ln(N_t) = \mathrm{M} + \beta V_{t-1}$	23.8	0.748	54.9	NA	NA	81.5
3. $ln(N_t) = \mathrm{M} + s(V_{t-1})$	22.5	0.736	56	1.13	0.318	81.37
V_t = Ave. Jun-Sep UPW (L2)						
2a. $ln(N_t) = \mathrm{M} + \beta V_t$	23.8	0.759	62.2	4.91	0.038	76
3a. $ln(N_t) = \mathrm{M} + s(V_t)$	21.4	0.733	62.3	0.74	0.513	77.2
2b. $ln(N_t) = \mathrm{M} + \beta V_{t-1}$	23.8	0.742	54.9	0	0.979	81.49
3b. $ln(N_t) = \mathrm{M} + s(V_{t-1})$	21.4	0.711	56.5	1.12	0.351	81.6
V_t = Ave. Jun-Sep SST (L2)						
2a. $ln(N_t) = \mathrm{M} + \beta V_t$	23.8	0.717	62.7	5.27	0.033	75.57
3a. $ln(N_t) = \mathrm{M} + s(V_t)$	21.9	0.714	61.8	0.39	0.67	77.33
2b. $ln(N_t) = \mathrm{M} + \beta V_{t-1}$	23.8	0.744	55.3	0.23	0.626	81.18
3b. $ln(N_t) = \mathrm{M} + s(V_{t-1})$	21.8	0.76	54.6	0.49	0.616	82.72

Model	Residual df	MASE	Adj. R2	F	p value	AIC
V_t = 2.5-year average SST (A1)						
2. $ln(N_t) = \mathrm{M} + \beta V_t$	23.8	0.667	64.7	7.68	0.012	73.9
3. $ln(N_t) = \mathrm{M} + s(V_t)$	22.7	0.594	67.5	2.58	0.12	71.88
V_t = ONI (A2)						
2. $ln(N_t) = \mathrm{M} + \beta V_{t-1}$	23.8	0.744	54.9	NA	NA	81.46
3. $ln(N_t) = \mathrm{M} + s(V_{t-1})$	23	0.748	55.5	0.99	0.313	81.46

Appendix C: Tests for Chlorophyll-a as a covariate

Table C1. Model selection tests of Chlorophyll-a (CHL) as an explanatory variable for the Jul-Sep catch (S_t) using 1998 to 2014 data. The data range is determined by the years for which CHL was available. V_t is CHL in the current season which spans two calendar years from July to June in the next year. V_{t-1} is CHL in the prior Jul-Jun season. Only CHL in Oct-Dec and Jan-Mar in the prior season is used since for the current season, these months are after the Jul-Sep catch being modeled. Non-linearity is modeled as a 2nd-order polynomial due to data constraints and appears as $p()$ in the model equations. The Jul-Sep catch is modeled as a function of Oct-Jun catch in the prior year only, without Jul-Sep catch 2-years prior as in the other covariate analyses (Appendix B). This is done due to data constraints. The models are nested; the Roman numeral indicates the level of nestedness. Models at levels II and higher are shown with the component that is added to the base level model (M) at top.

Model	Residual df	MASE	Adj. R2	F	p value	AIC
base model (M) 1998-2014 data						
1. $ln(S_t) = \alpha + p(ln(N_{t-1})) + \varepsilon_t$	14	0.516	25.3			18.29
V_t = Jul-Sep Chlorophyll						
2. $ln(S_t) = M + \beta V_t$	13	0.503	24.6	0.69	0.427	19.2
3. $ln(S_t) = M + p(V_t)$	12	0.48	19.5	0.16	0.699	20.94
4. $ln(S_t) = M + p(V_t) + \beta V_{t-1}$	11	0.5	13.7	0.17	0.688	22.65
5. $ln(S_t) = M + p(V_t) + p(V_{t-1})$	10	0.497	5.1	0.01	0.935	24.64
V_t = Oct-Dec Chlorophyll						
2. $ln(S_t) = M + \beta V_{t-1}$	13	0.516	19.6	0	0.99	20.29
3. $ln(S_t) = M + p(V_{t-1})$	12	0.456	21.5	1.33	0.272	20.51
V_t = Jan-Mar Chlorophyll						
2. $ln(S_t) = M + \beta V_{t-1}$	13	0.522	20.6	0.16	0.697	20.08
3. $ln(S_t) = M + p(V_{t-1})$	12	0.526	16.7	0.4	0.541	21.52

Table C2. Model selection tests of Chlorophyll-a (CHL) as an explanatory variable for Oct-Jun catch (N_t) using 1998 to 2014 data. The data range is determined by the years for which CHL was available. V_t is CHL in the current season which spans two calendar years from July to June in the next year. V_{t-1} is CHL in the prior Jul-Jun season. Non-linearity is modeled as a 2nd-order polynomial due to data constraints and appears as $p()$ in the model equations. The Oct-Jun catch is modeled as a function of Oct-Jun catch in the prior year only, without Jul-Sep catch 2-years prior as in the other covariate analyses (Appendix B). This was done due to data constraints. The models are nested; the numeral indicates the level of nestedness. Models at levels 2 and higher are shown with the component that is added to the base level model (M) at top.

Model	Residual df	MASE	Adj. R2	F	p value	AIC
base model (M) 1998-2014 data						
1-M. $ln(N_t) = \alpha + p(ln(N_{t-1})) + \varepsilon_t$	14	0.875	26.5			18.94
V_t = Jul-Sep Chlorophyll						
2. $ln(N_t) = M + \beta V_t$	13	0.893	23.1	0.32	0.587	20.45
3. $ln(N_t) = M + p(V_t)$	12	0.874	17.9	0.15	0.709	22.21
2. $ln(N_t) = M + \beta V_{t-1}$	13	0.86	25	0.69	0.422	20.03
3. $ln(N_t) = M + p(V_{t-1})$	11.7	0.839	21.7	0.27	0.677	21.36
V_t = Oct-Dec Chlorophyll						
2. $ln(N_t) = M + \beta V_t$	13	0.883	23.9	0.59	0.458	20.29
3. $ln(N_t) = M + p(V_t)$	12	0.744	29.5	2.22	0.167	19.62
4. $ln(N_t) = M + p(V_t) + \beta V_{t-1}$	11	0.679	40.8	2.99	0.114	17.16
5. $ln(N_t) = M + p(V_t) + p(V_{t-1})$	10	0.68	34.9	0	0.976	19.16
2. $ln(N_t) = M + \beta V_{t-1}$	13	0.764	39.4	3.87	0.074	16.41
3. $ln(N_t) = M + p(V_{t-1})$	11.3	0.728	37.7	0.49	0.595	17.62
V_t = Jan-Mar Chlorophyll						
2. $ln(N_t) = M + \beta V_t$	13	0.901	23.6	0.4	0.541	20.34
3. $ln(N_t) = M + p(V_t)$	12	0.829	23.9	0.89	0.367	20.92
2. $ln(N_t) = M + \beta V_{t-1}$	13	0.866	21.2	0.05	0.829	20.88
3. $ln(N_t) = M + p(V_{t-1})$	11.1	0.873	15.2	0.23	0.791	22.97

Table C3. Model selection tests of Chlorophyll-a as an explanatory variable for the catch during the non-spawning months (Oct-Jun) using box 5.

Model	Residual df	MASE	Adj. R2	F	p value	AIC
base model (M) 1998-2014 data						
1. $ln(N_t) = \alpha + p(ln(N_{t-1})) + \varepsilon_t$	14	0.875	26.5			18.94
V_t = Jul-Sep Chlorophyll						
2. $ln(N_t) = M + \beta V_t$	13	0.865	22.5	0.24	0.635	20.6
3. $ln(N_t) = M + p(V_t)$	12	0.904	20.4	0.61	0.451	21.69
2. $ln(N_t) = M + \beta V_{t-1}$	13	0.839	28.5	1.33	0.271	19.22
3. $ln(N_t) = M + p(V_{t-1})$	12	0.837	25.2	0.07	0.789	20.42
V_t = Oct-Dec Chlorophyll						
2. $ln(N_t) = M + \beta V_t$	13	0.864	28.4	1.4	0.265	19.25
3. $ln(N_t) = M + p(V_t)$	12	0.844	24	0.26	0.62	20.91
4. $ln(N_t) = M + p(V_t) + \beta V_{t-1}$	11	0.666	35.6	2.9	0.119	18.62
5. $ln(N_t) = M + p(V_t) + p(V_{t-1})$	10	0.649	29.9	0.11	0.743	20.42
2. $ln(N_t) = M + \beta V_{t-1}$	13	0.739	35.5	2.88	0.116	17.48
3. $ln(N_t) = M + p(V_{t-1})$	11.7	0.732	34.2	0.52	0.534	18.39
V_t = Jan-Mar Chlorophyll						
2. $ln(N_t) = M + \beta V_t$	13	0.847	29.5	1.56	0.24	18.98
3. $ln(N_t) = M + p(V_t)$	12	0.804	31.6	1.33	0.276	19.11
2. $ln(N_t) = M + \beta V_{t-1}$	13	0.89	21.4	0.09	0.769	20.84
3. $ln(N_t) = M + p(V_{t-1})$	8.9	0.682	27.9	1.07	0.427	20.97

Appendix D: Covariates along the SE India coast

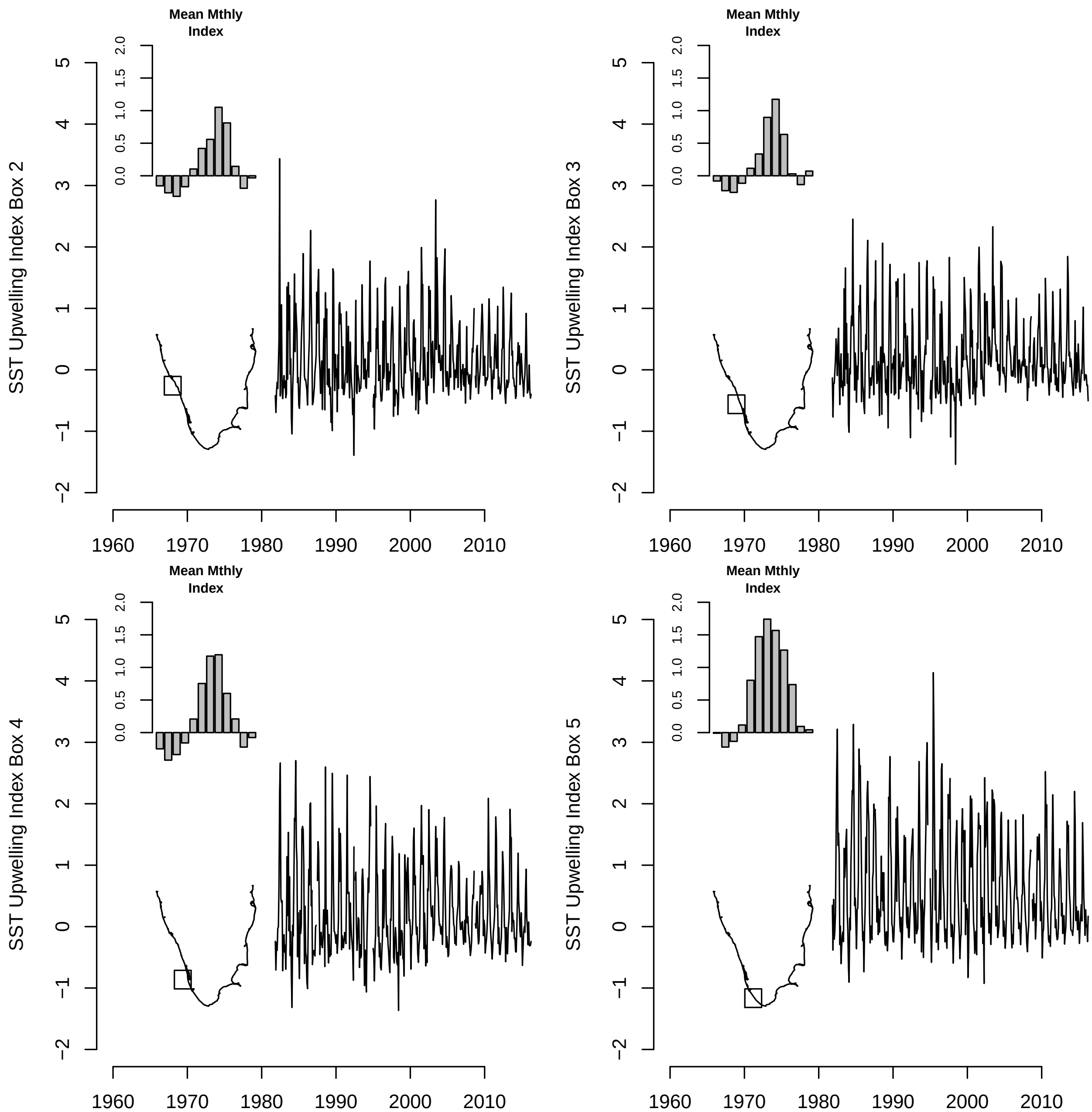

Figure D1. Upwelling index.

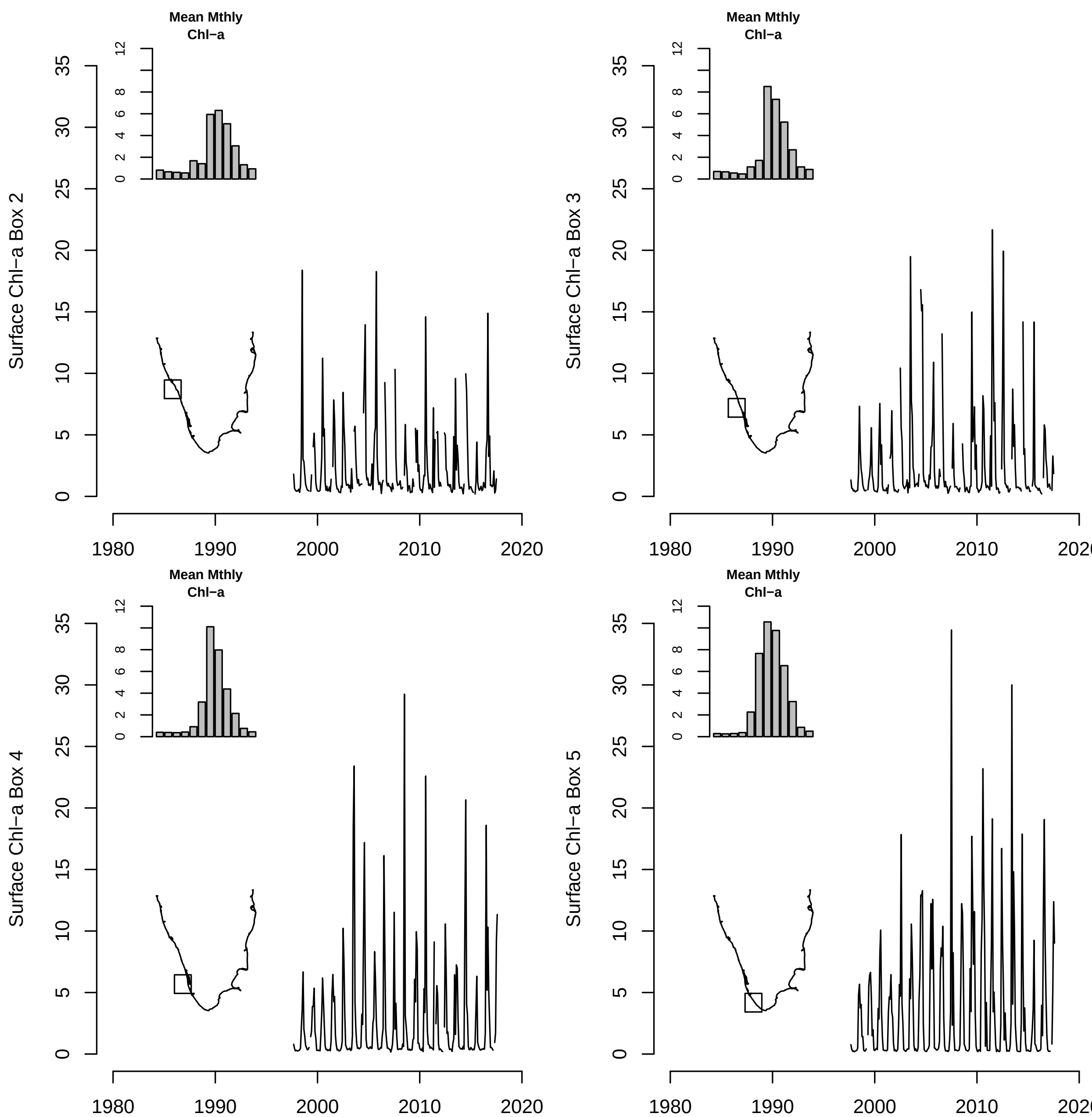

Figure D2. Chlorophyll-a.

Appendix E: Comparison of land and oceanic rainfall measurements

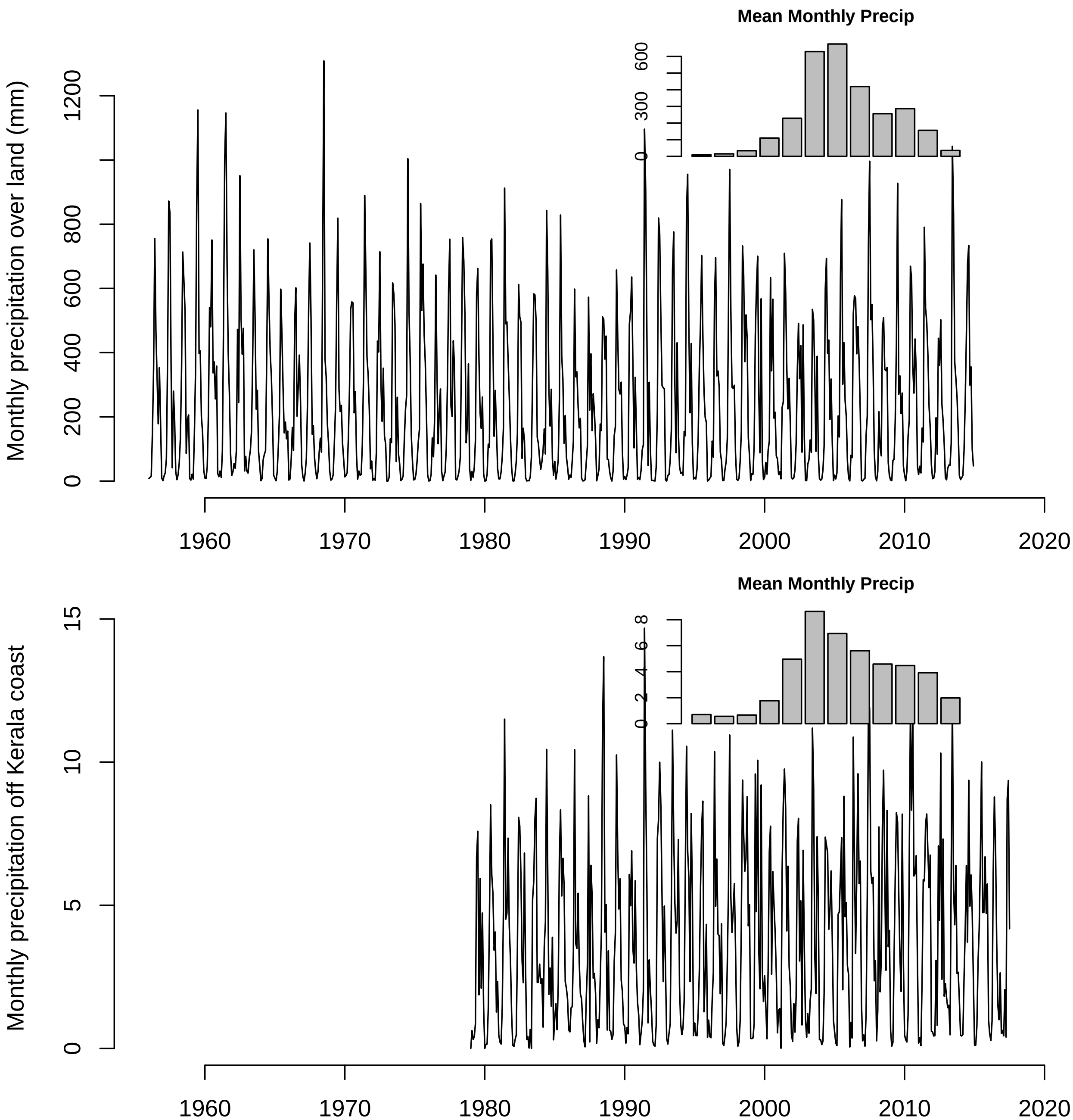
Mean Monthly Precip
0
300
600
Monthly precipitation over land (mm)
0
200
400
600
800
1200
1960
1970
1980
1990
2000
2010
2020
Mean Monthly Precip
0
2
4
6
8
Monthly precipitation off Kerala coast
0
5
10
15
1960
1970
1980
1990
2000
2010
2020

Figure E1

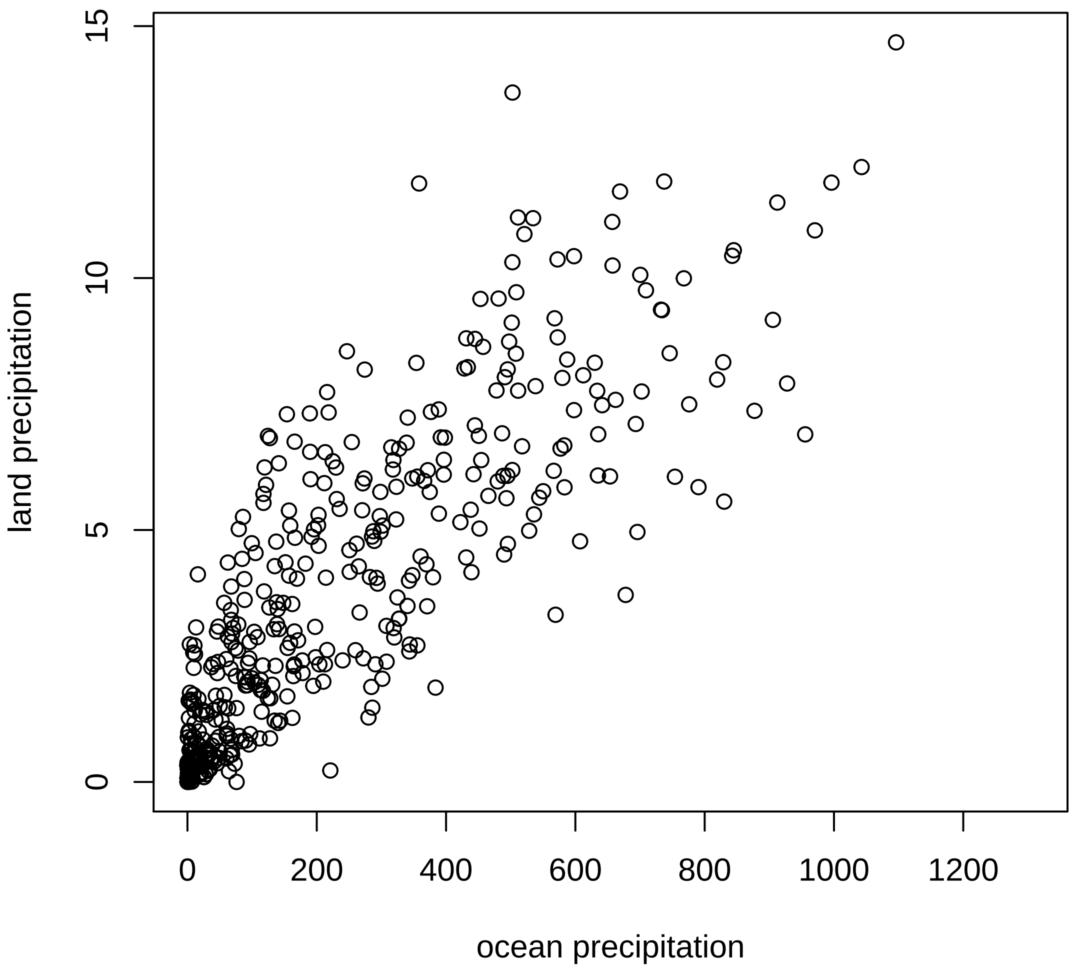

Figure E2. Monthly precipitation measured over land via land gauges versus the precipitation measured via remote sensing over the ocean.

Appendix F: Chlorophyll-a images in 2016

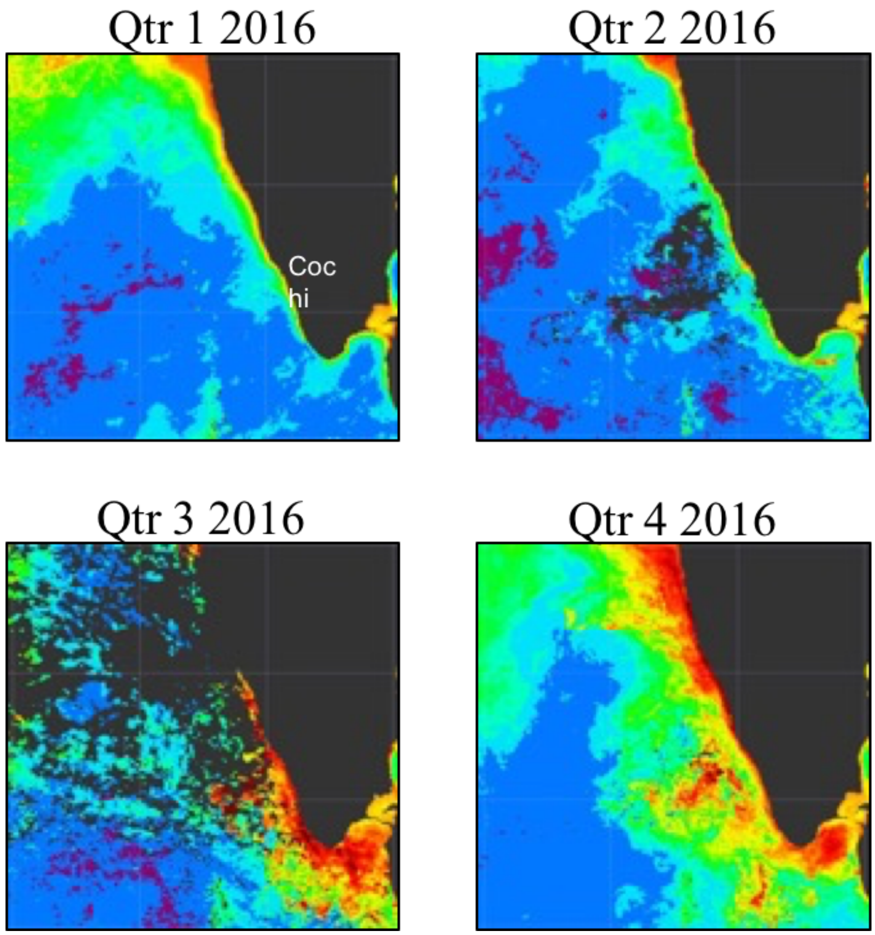

Figure 1