Supplementary Material: regional marine ecosystem projections for Southeast Asian seas

This supplementary material presents some further comparison of the regional model outputs to observations and to global climate models outputs.

1 Comparison to observations.

Figure S1 shows boxplots of monthly mean sea surface temperatures at each model point from satellite-based observation, the regional model and 11 global models from the CMIP5 set (Coupled Model Intercomparison Project Phase 5). A direct year-to-year match is not expected for a climate model, so a 20 year mean, 1997-2018, has been used in each case. Observations are from the OSTIA multi-sensor satellite and in situ product (Good et al., 2020, https://doi.org/10.48670/moi-00168), POLCOMS-ERSEM is the regional model presented in the main paper, HadGEM2-ES is its parent global model and the other model names are as used in CMIP5. In Figure S1 the RCP8.5 version was used for the regional and global models for years after 2005, but the results are very similar if RCP4.5 is used. The observation and global model data were regridded to match the regional model using a nearest-neighbor method and masks applied for the whole domain and for each sub-region. The linear trend for each dataset was calculated and removed before the median and range were calculated. The boxplots show the statistics for all points within the specified sub-region for 12 monthly time points: the red line shows the median, the box the inter-quartile range, the whiskers extend by 1.5 times the inter-quartile range, points beyond this are shown as blue dots.

The regional model (POLCOMS-ERSEM) has a wider spread and lower median than its parent model (HadGEM2-ES) in most regions. Its median is in better agreement with observations than the parent global model in most sub-regions, but it is lower than observed in Box A and Palawan. The global model medians vary by up to 3-4°C within each sub-region, with the satellite value generally near the middle of the range and the regional model central or below average. There is some difference in variability between the models, but this is less than the variability within each model.

Figure S2 shows a similar set of plots for surface log10-chlorophyll. In this case the observations are the ESA Ocean Colour CCI product (Sathyendranath et al., 2019; https://doi.org/10.48670/moi-00283). The model data was masked to match the mask on the chlorophyll data (cloud points removed) and trends were small so were not removed; otherwise the processing and plotting was as for Figure 1. There is much more variability between models than for sea surface temperature, though there is some consistency between them when averaged over the whole domain. The regional model (POLCOMS-ERSEM) has consistently higher values than the parent global model (HadGEM2-ES) and the general pattern is that HadGEM2-ES is closer to satellite values in open waters (Boxes A-D) while POLCOMS-ERSEM is closer at the coastal sites.

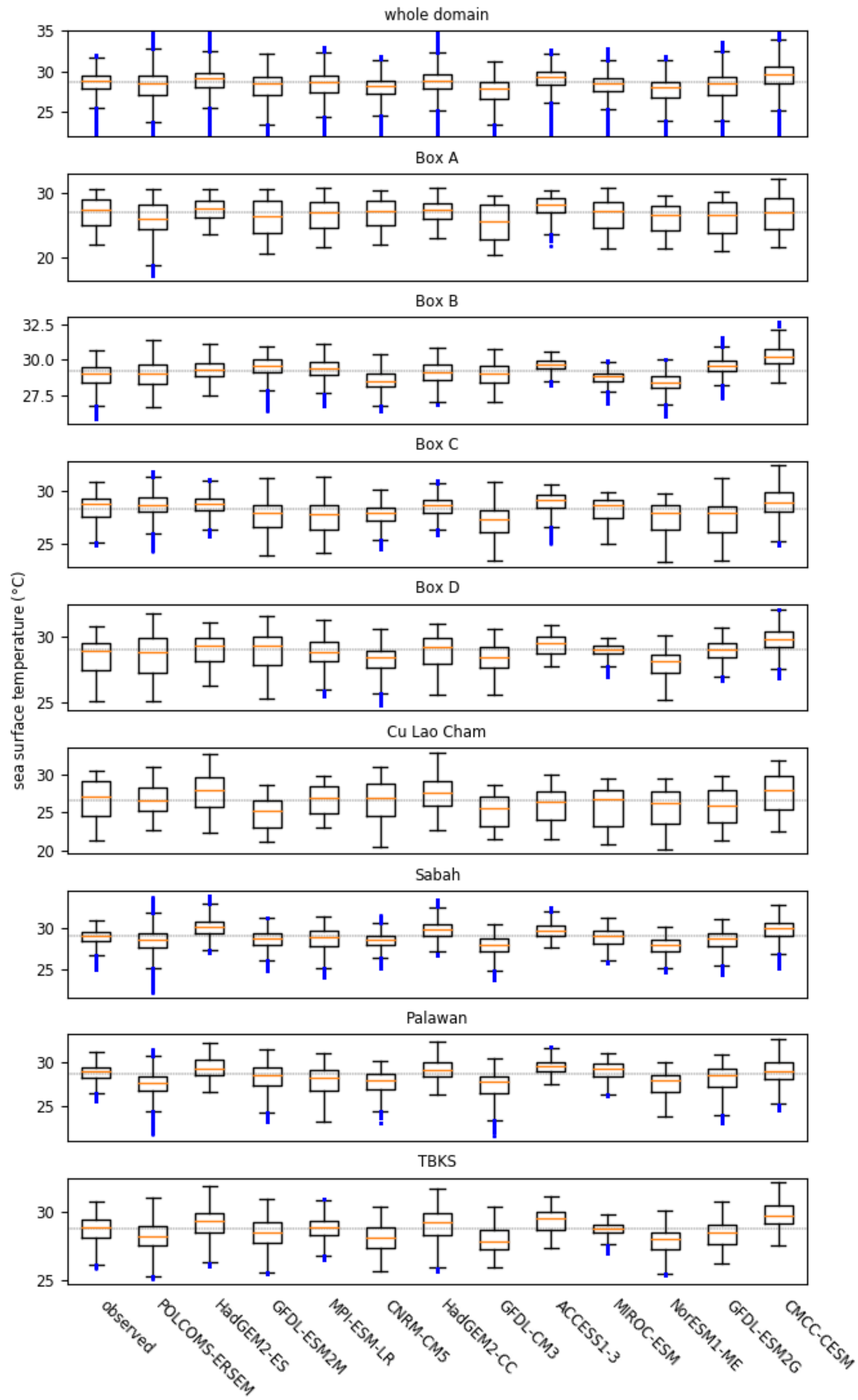

Figure S1. Distribution of detrended monthly mean sea surface temperature at each point, averaged over 1998-2017, from satellite-based observations, the regional model (POLCOMS-ERSEM) and 11 CMIP5 global models, for the whole domain and sub-regions; see Figure 1 in the main text for the sub-region locations. Red line=median, box=inter-quartile range, whisker=1.5*IQR, blue points=outliers. The grey line shows the average regional median for the global models. For the whole domain plot the range has been restricted to aid visibility: some extreme points are not shown.

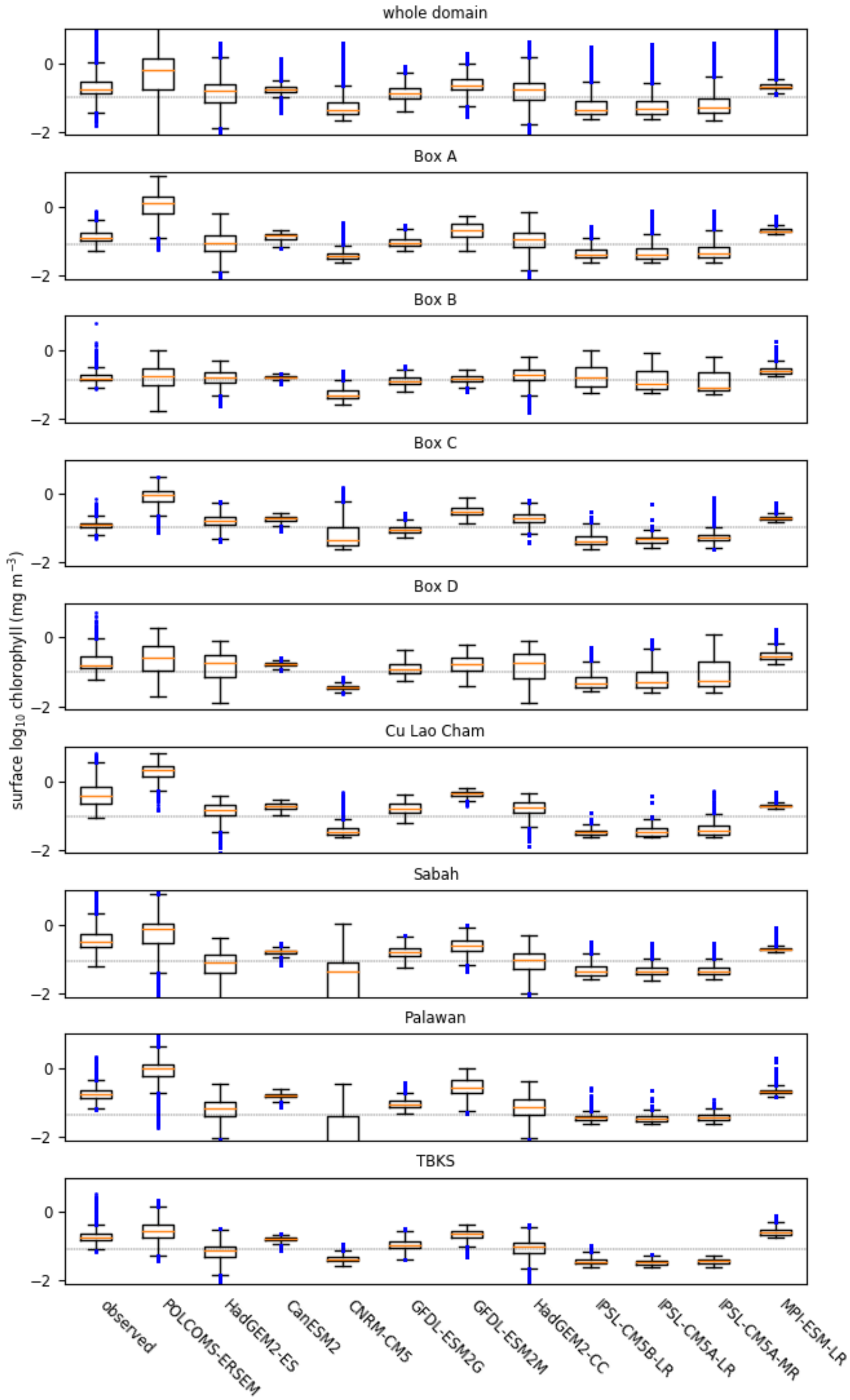

Figure S2. Distribution of monthly mean surface log10-chlorophyll at each point, averaged over 1998-2017, from satellite-based observations, the regional model (POLCOMS-ERSEM) and 11 CMIP5 global models, for the whole domain and sub-regions; see Figure 1 in the main text for the sub-region locations. Red line=median, box=inter-quartile range, whisker=1.5*IQR, blue points=outliers. The grey line shows the average regional median for the global models. Points below -2.1 and above 1.0 are not shown.

Figure S3 shows boxplots comparing model outputs to observations of temperature, salinity, nitrate, phosphate and oxygen at all depths from the World Ocean Database (Boyer et al., 2018). Observations are sparse in some parts of the region so a dataset was compiled by matching each observation for 1980-2019 to the model output for the same month and location averaged over the same period. The coastal sites were not included as very few observations were available there. The model shows a reasonable match to the range and median of observations. Agreement is worst for Box A, where temperatures and oxygen are underestimated and nitrate is overestimated. Nutrients are also overestimated in Box C.

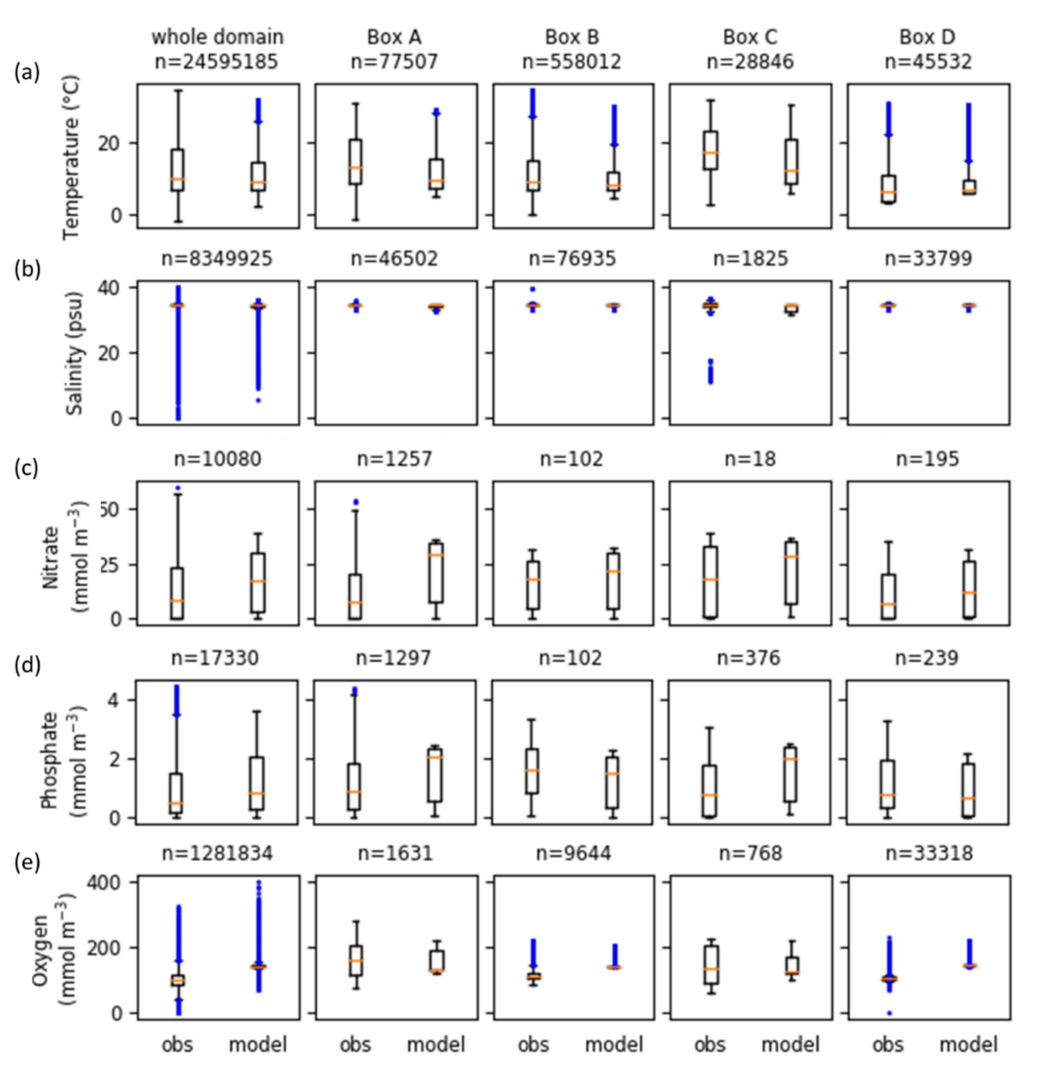

Figure S3. Distribution of observations at all depths from the World Ocean Database (obs) and matched values from a climatology of the regional model (model) for the whole region and boxes A-D. All available observations are included for (a) temperature, (b) salinity, (c) nitrate, (d) phosphate and (e) oxygen. See Figure 1 in the main text for the locations of boxes A-D. n is the number of observations, red line=median, box=inter-quartile range, whisker=1.5xIQR, blue points=outliers.

Table S1 shows the Pearson correlation coefficients for the model and observation datasets presented in Figures 1-3. Correlations for temperature are high except for surface temperature at Box A in the north of the region. Correlation is low for surface chlorophyll at Box A and for the coastal sites, where ocean color chlorophyll estimates are less reliable, otherwise there is reasonably good correlation. Correlation for salinity is good for boxes A, B and D but less than 0.5 for Box C and for the region as a whole: this could be associated with inter-annual variation in fresh water inputs from river discharge that the model climatology was not able to capture (see Figure S3). Correlations above 0.6 for nitrate, phosphorus and oxygen are satisfactory for a biogeochemical model.

Table S1. Pearson correlation coefficient for the observation and regional model datasets in Figures S1, S2, and S3. See the text for details of the content of each dataset. SST is sea surface temperature; unless surface is specified the observations come from a range of depths.

	SST	Surface log-chl	Temper-ature	Salinity	Nitrate	Phosph-orus	Oxygen
whole domain	0.86	0.32	0.95	0.44	0.77	0.76	0.63
Box A	0.69	0.23	0.93	0.73	0.70	0.64	0.69
Box B	0.90	0.66	0.94	0.84	0.98	0.86	0.85
Box C	0.94	0.64	0.96	0.38	0.97	0.82	0.66
Box D	0.93	0.84	0.97	0.89	0.93	0.95	0.84
Cu Lao Cham	0.92	0.71	-	-	-	-	-
Palawan	0.70	0.15	-	-	-	-	-
Sabah	0.77	0.24	-	-	-	-	-
TBKS	0.87	0.13	-	-	-	-	-

2 Projected future conditions

Figures S4 and S5 show annual mean sea surface temperature and column total net primary production from the regional model and a range of CMIP5 global models; the main text gives anomaly plots based on the same data. These plots put the regional model outputs into the context of other modelling, showing:

- Surface temperatures are lower in the regional model than in the parent global model especially in the north (Box A) and at the coastal sites. Satellite values are closer to the regional model than the global model for most sub-regions.
- Global model annual average sea surface temperatures vary by about 2°C; the regional model is higher than average in some sub-regions, lower in others but always within the inter-model spread.
- Primary production is much higher in the regional than the parent global model.
- For primary production, variation between global models is much greater than inter-annual variation or any long-term trend.

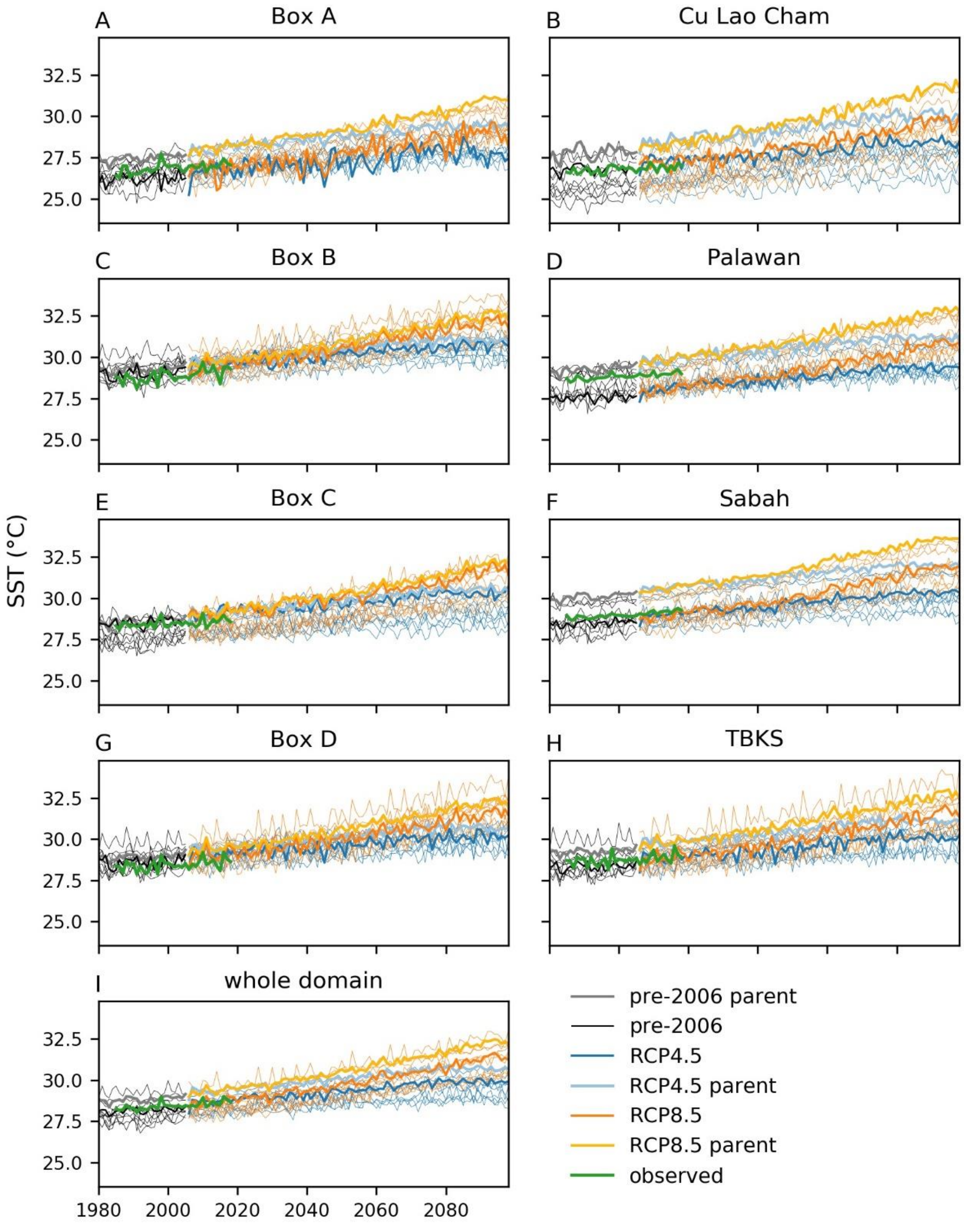

Figure S4. Annual mean sea surface temperature for 1980-2098 averaged over sample regions and the whole domain. The darker lines show the regional model outputs, the paler colors show the parent global model, the thinner lines show a range of other CMIP5 models. In each case the black lines show the historical period, 1980-2005, the blue line RCP4.5 and the orange line RCP8.5. The green line shows satellite-based values, (OSTIA, Good et al., 2020, https://doi.org/10.48670/moi-00168). See Figure 1 in the main text for the location of the regions.

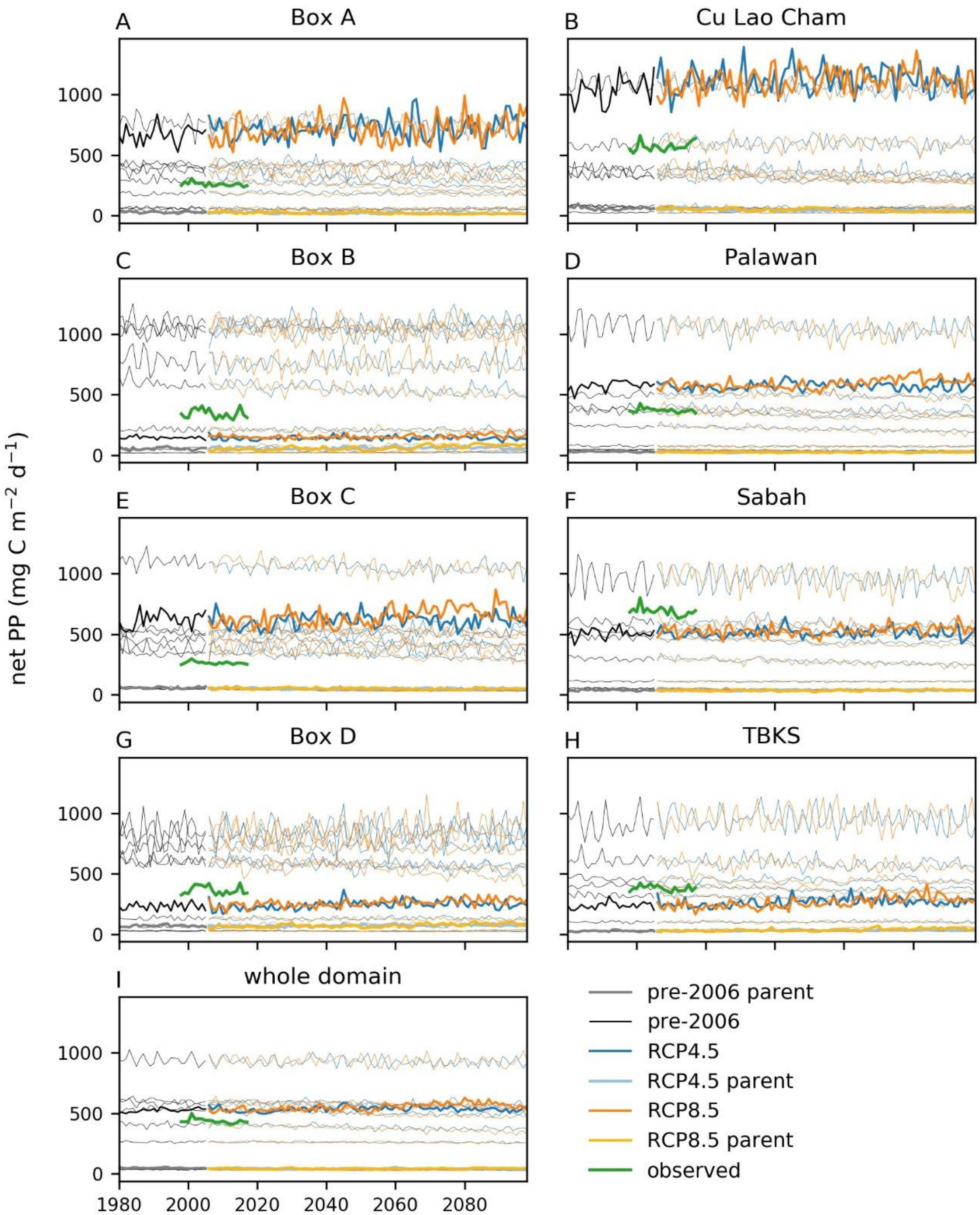

Figure S5. Annual mean column total net primary production for 1980-2098 averaged over sample regions and the whole domain. The darker lines show the regional model outputs, the paler colors show the parent global model, the thinner lines show a range of other CMIP5 models. In each case the black lines show the historical period, 1980-2005, the blue line RCP4.5 and the orange line RCP8.5. The green line shows satellite-based values (Copernicus GlobColour, https://doi.org/10.48670/moi-00100). See Figure 1 in the main text for the location of the regions.

References

Boyer, T.P., Baranova, O.K., Coleman, C., Garcia, H.E., Grodsky, A., Locarnini, R.A., Mishonov, A.V., Paver, C.R., Reagan, J.R., Seidov, D., Smolyar, I.V., Weathers, K., Zweng, M.M., (2018). World Ocean Database 2018, NOAA Atlas NESDIS 87. Silver Spring, MD.

Good, S., Fiedler, E., Mao, C., Martin, M. J., Maycock, A., Reid, R., et al. (2020). The Current Configuration of the OSTIA System for Operational Production of Foundation Sea Surface Temperature and Ice Concentration Analyses. Remote Sensing, 12(4), 720. https://doi.org/10.3390/rs12040720

Sathyendranath, S., Brewin, R. J. W., Brockmann, C., Brotas, V., Calton, B., Chuprin, A., et al. (2019). An Ocean-Colour Time Series for Use in Climate Studies: The Experience of the Ocean-Colour Climate Change Initiative (OC-CCI). Sensors, 19(19), 4285. https://doi.org/10.3390/s19194285