5900 S&P Global Capstone

Group: Climate Solution Consulting

Results:

Summary

Our client S&P Global would like our group to answer three questions. Firstly, what is the relationship between MODIS and NEX datasource ? Secondly, is there a systematic difference between them? Last but not least, how can we estimate the systematic difference between two data sources while taking the seasonal effects into consideration ?

The purpose of this research is to answer the above questions: Visually explore the relationship between Land Surface Temperature (LST) from MODIS and Near Surface Temperature (TAS). Numerically quantify the systematic difference between LST and TAS with RMSE and R^2, under two different SSP scenarios (SSP 126, SSP 585) across four regions selected (Sierra National Forest, US , New South Wales, AU , Xin Jiang, China, Mary, Turkmenistan). And estimate the systematic differences with regression analysis for four seasons.

The results include two parts, visualizations and numerical identification, visualizations include the cross-sectional heat maps that depict the temperature value for each region at pixel level, and the time-series plot of monthly mean temperature values across 6 years (2015 - 2020). The numeric results include RMSE that measures the prediction error and R^2 that suggests the goodness of fit of nex models and estimation is measured with 95% Confidence Interval.

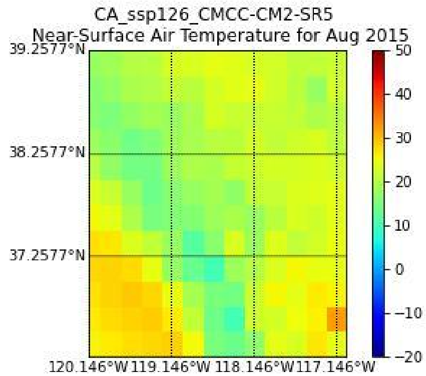
In the exploratory analysis, we observed the pixel color can found that land surface temperature is always higher than near surface temperature, since SSP 585 scenario is based on the

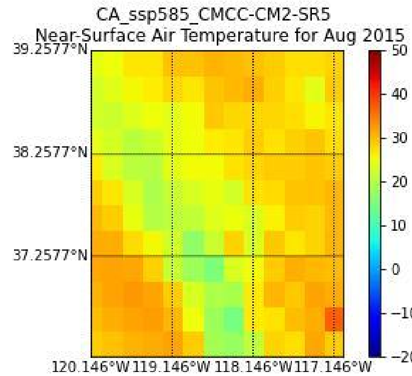
assumption of global warming, consequently it has a smaller gap with land surface temperature when compared with SSP 126, indicating that SSP 585 can potentially be a better estimator for MODIS data. In the time-series plots, we have visually identified an outlier nex model: CMCC_CM2_SR5 which is much closer to the land surface temperature than other models when all the other nex models tend to stack together away from the land surface temperature.From the decomposed trend plot we also found that the 32 trendlines of SSP 126 tend to stack closer compared with SSP 585.

Based on the exploratory analysis, we come up with the hypothesis that there is a systematic difference between MODIS and NEX, and through the calculation of RMSE we do find that all 31 models except for the outlier have similar RMSE which can be the proof for intrinsics difference. For the estimation of systematic difference we used regression to obtain the intercept for each season and the seasonal variation is found especially in summer. In the summer season the gap between land surface temperature and near surface temperature tends to significantly increase or decrease depending on the region of selection.

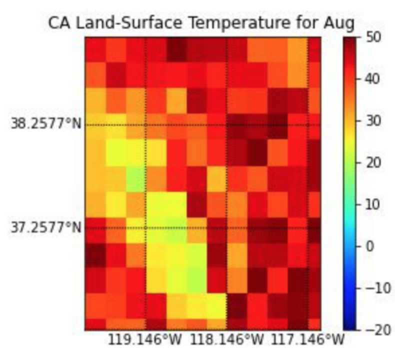
Heat Maps

We built heatmaps to visualize temperature for both NEX and MODIS data. By data preparation, both NEX and MODIS data have the same pixel level with 25km * 25 km.





According to the previous graphs, it visualizes temperature for the NEX model for CA, CMCC-CM2-SR5. The x-axis shows the longitude and y-axis is the latitude. The two graphs represent temperatures at scenarios ssp585 and ssp126. Compared with the ssp126 graph, ssp585 has a deeper color on the graph, which means ssp585 had a higher temperature in August 2015, and it supports one of our hypotheses that under ssp585, predictions on temperature would be higher .

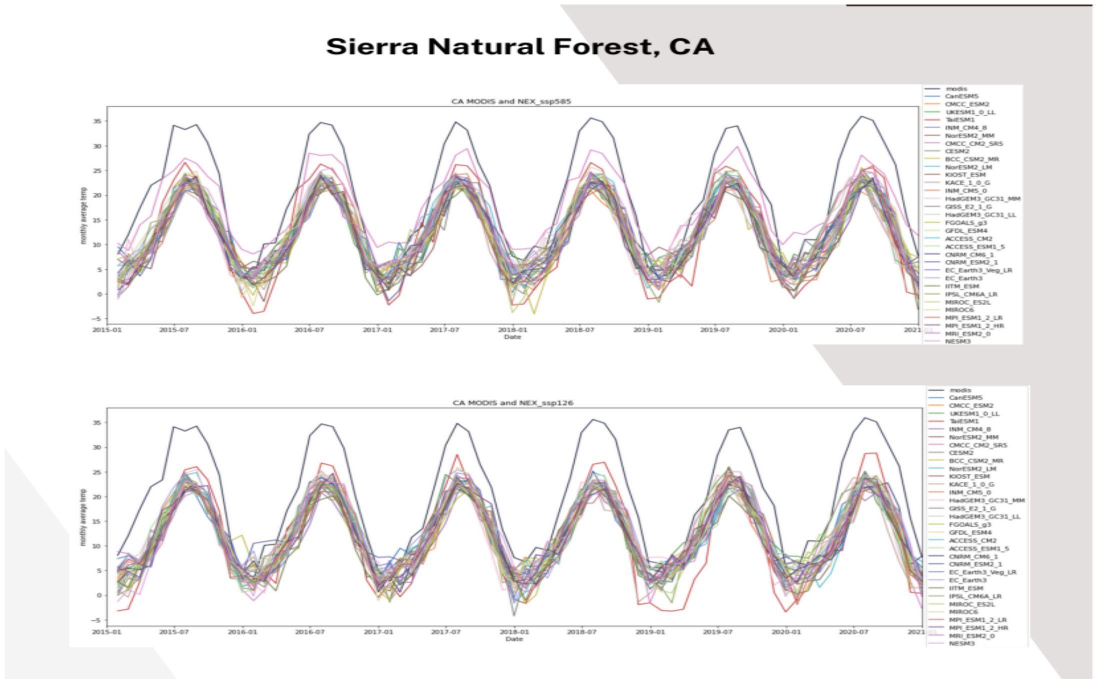


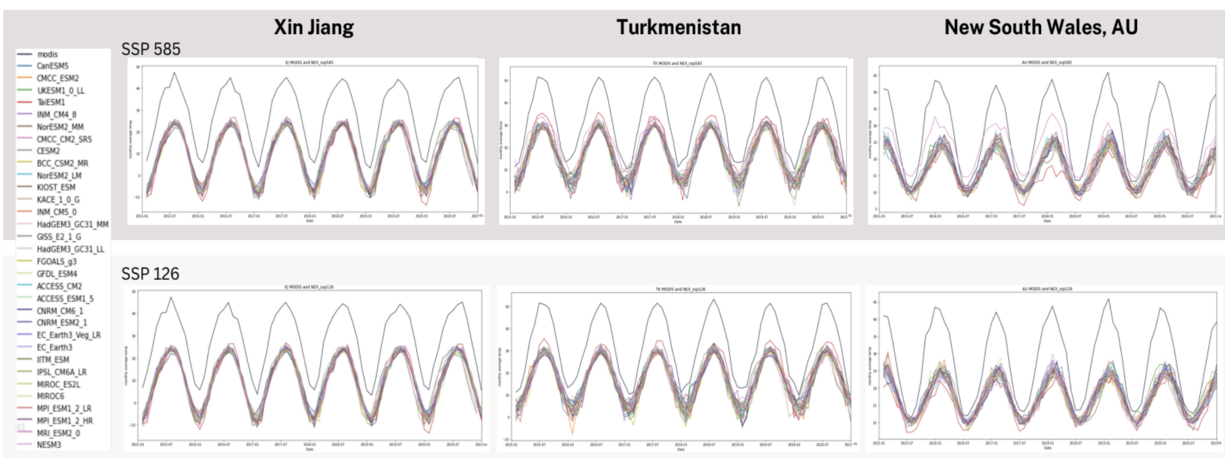
And those graphs visualize the temperature for the MODIS model for CA. Compared with the NEX model, the MODIS model had a higher temperature in Land-Surface Temperature in August 2015. The fluctuation of the temperature is also more significant.

Both NEX and MODIS models for the CA show the border between California and Nevada. Nevada is primarily desert and flat, and the right side of the image also shows that this part is warmer. In the lower-left corner is the mountainous area. The average temperature difference between this part and the lower right corner is about 30 degrees in both models.

Time Series Analysis

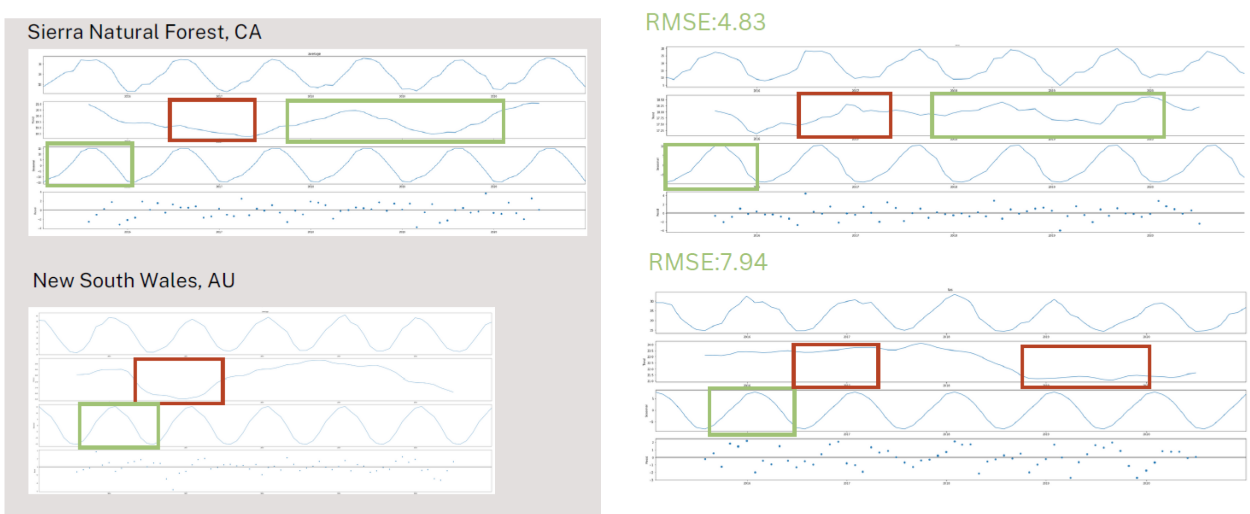
We generated the time series plots to better visualize the differences between NEX models in two SSP scenarios and MODIS during the time period from 2015 to 2020. It also allows us to compare the differences between SSP126 and SSP585 performance against MODIS at each region. Here, we showcase the combined time series plot for 32 NEX models in the Sierra National Forest region in California, the upper one is ssp585 scenario and the bottom one is ssp126 scenario. Based on the graphs, we concluded that the hypothesis is that there are systematic differences between NEX models: near surface temperature and the MODIS data: land surface temperature. However, the differences between SSP 126 and SSP 585 for the same NEX model is minimal compared to their gap against MODIS. For the hypothesis testing, we tested the proposed hypothesis by applying the same time-series analysis across the other regions, and we found consistent results compared to what we found in the Sierra Natural Forest region in California. For New South Wales in Australia, Turkmenistan, Xinjiang, there are systematic differences between NEX models and MODIS since we can see that there's a big gap between the 32 NEX model and the MODIS on the graph. Similarly, the differences between SSP126 scenario and SSP 585 scenario for the same NEX model is minimal compared to their gap against MODIS since they all overlapped a lot.



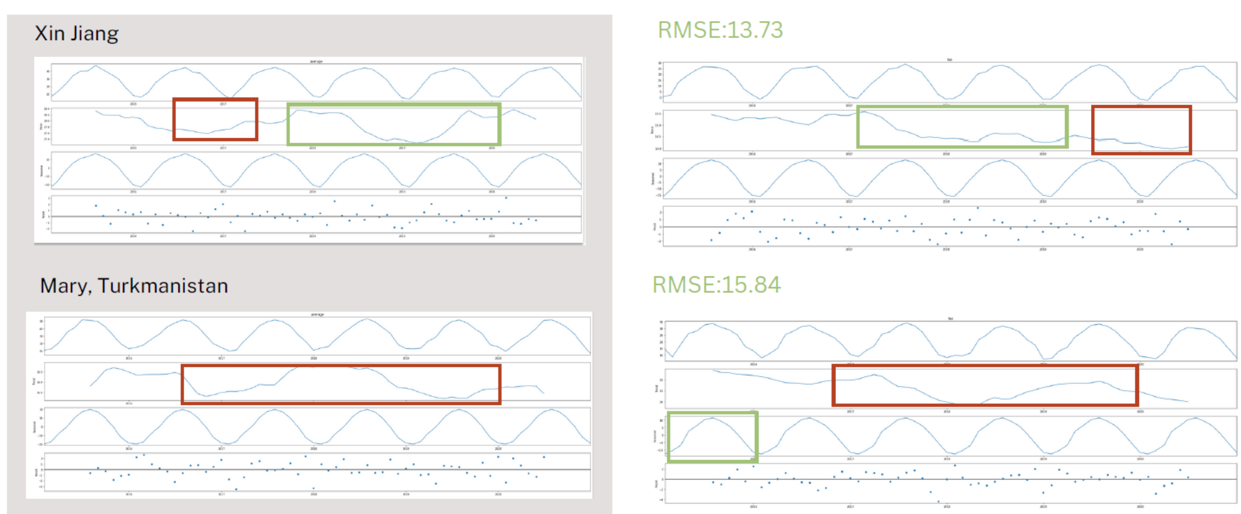


For the decomposition analysis we performed on 4 regions, we used Seasonal-Trend Decomposition, which divides the time series data into three portions: seasonal, trend, and residual to search for periodical patterns in the data. We can't make any conclusions just by looking at the decomposition analysis of the MODIS data. Instead, we compared them side by side to the NEX models in the same region to generate meaningful insights on the performance of each model.

We select the NEX model CMCC-CM2-SR5 under SSP 585 scenario (lowest RMSE NEX model and compare it with MODIS side by side across all the regions. We have Identified that major differences between MODIS and CMCC-CM2-SR5 occur in the trend component.

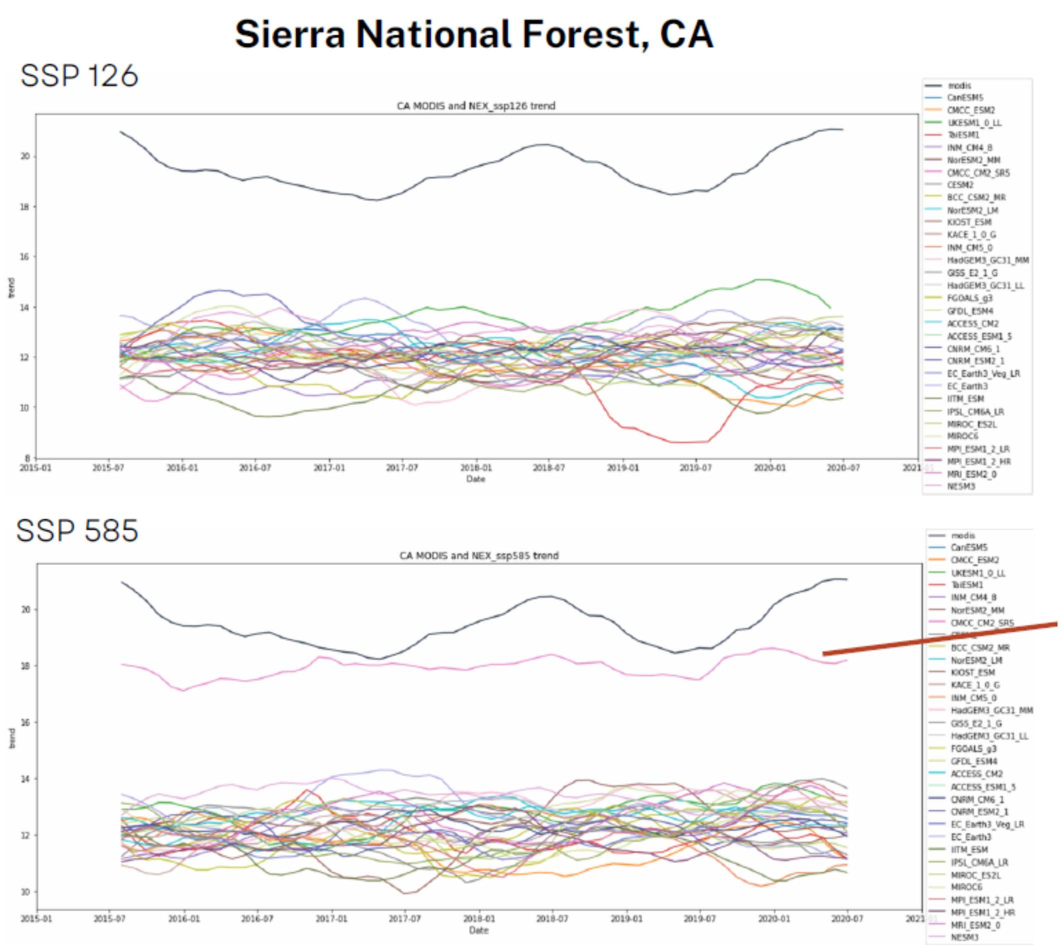


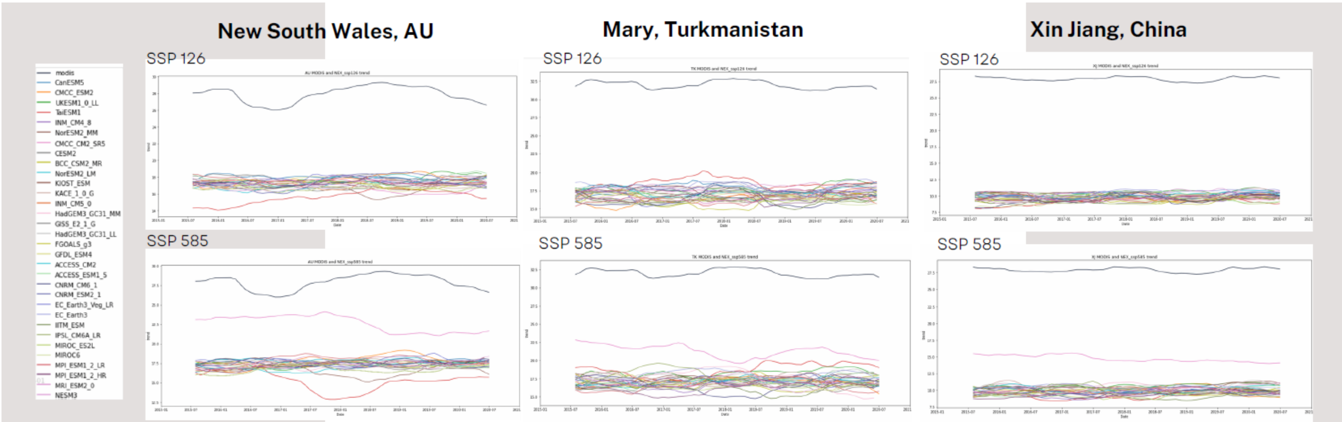
MODIS CMCC-CM2-SR5: SSP 585



MODIS CMCC-CM2-SR5: SSP 585

For the hypothesis testing, we also tested the proposed hypothesis by applying the same trend analysis across all four regions, and we found consistent results in the Sierra National Forest region in California. ,New South Wales in Australia, Turkmenistan,and Xinjiang. As we can see from the graph, The trend components of Nex Models are mostly stacks within an upper and lower bound with only a few outliers such as CMCC-CM2-SR5 model of ssp585 scenario in all regions.Although the boundary of two SSP scenarios do not differ significantly, we found that SSP126 tend to stack tighter than SSP585 across al the regions.





Results Tables

Next, we need to use the results of the analysis of the data to identify changes in the systematic differences between the MODIS and NEX models in four different regions.

In the first step, we calculate the root mean square error (RMSE) of each model, which allows us to measure the difference between the predicted monthly near-surface temperature (NEX) and the observed monthly surface temperature (MODIS). RMSE results are positively correlated with forecast error. Next, we calculate R^2, which shows the goodness-of-fit of each NEX model as a percentage. Likewise, there is a positive relationship between R^2 and the proportion of variance in MODIS that can be explained by the NEX model.

Region	SSP Senarios	Systematic Difference Estimation ("Delta")																			
	SSP Senarios	SSP 126										SSP 585									
	Seasons	Winter		Spring		Summer		Fall				Winter		Spring		Summer		Fall			
	Metrics	coef.	INTCP	coef.	INTCP	coef.	INTCP	coef.	INTCP	RMSE	R^2	coef.	INTCP	coef.	INTCP	coef.	INTCP	coef.	INTCP	RMSE	R^2
Sierra National Forest, CA	UKESM1-0-LL	0.37	4.68	0.90	5.49	-0.29	40.03	1.01	9.14	8.44	0.82	0.31	4.87	1.06	4.37	0.11	31.29	1.12	8.97	8.99	0.83
	TaiESM1	0.12	6.58	0.64	11.51	0.40	23.92	0.72	13.00	9.20	0.88	0.25	6.60	0.69	10.39	0.36	24.91	0.83	10.72	8.60	0.90
	NorESM2-MM	0.97	2.74	1.07	5.65	0.26	28.11	1.20	6.00	8.78	0.91	0.13	5.96	1.19	5.01	0.62	20.57	1.16	7.15	8.93	0.91
	NorESM2-LM	0.35	4.98	1.05	7.49	0.53	22.33	1.30	5.10	9.16	0.90	0.49	4.33	1.37	3.16	0.34	26.42	1.18	6.06	8.82	0.91
	NESM3	0.03	6.46	0.61	10.66	0.23	28.70	1.21	4.82	8.84	0.84	0.02	6.47	1.28	3.62	0.56	21.05	1.06	6.31	8.05	0.89
	MRI-ESM2-0	0.27	5.44	1.29	3.89	0.51	22.47	1.09	6.87	8.53	0.90	0.08	6.19	1.17	4.67	0.39	25.16	1.29	5.12	8.86	0.86
	MPI-ESM1-2-LR	0.47	4.81	1.32	4.31	0.36	25.92	1.23	7.37	9.46	0.90	-0.49	8.38	1.11	5.59	0.53	22.28	1.19	6.59	9.01	0.90
	MPI-ESM1-2-HR	-0.04	6.74	1.09	5.80	0.41	25.04	1.19	5.90	9.01	0.88	0.41	5.03	0.86	8.88	0.41	25.20	1.17	7.53	9.71	0.86
	MIROC6	0.32	5.29	1.30	2.83	0.45	23.42	1.33	4.33	8.32	0.92	0.71	4.39	1.07	6.00	0.35	26.12	1.34	4.16	8.16	0.93
	MIROC-ES2L	0.44	4.76	1.21	4.73	0.64	20.17	1.20	6.36	9.04	0.91	0.10	6.26	0.93	7.26	0.72	18.02	1.33	4.97	8.93	0.90
	KIOST-ESM	-0.44	8.39	1.12	5.75	0.32	26.84	1.23	7.08	9.36	0.89	0.11	6.04	0.96	7.49	0.62	20.40	1.26	6.43	9.16	0.86
	KACE-1-0-G	-0.28	7.44	0.77	7.77	0.20	29.29	0.91	12.46	9.74	0.77	-0.17	7.25	0.89	6.41	-0.03	34.21	1.12	10.09	9.66	0.78
	IPSL-CM6A-LR	-0.10	6.87	0.89	7.59	0.30	27.13	0.91	12.46	9.15	0.86	0.05	6.39	1.13	5.72	0.48	23.35	1.42	3.88	9.08	0.91
	INM-CM5-0	0.92	2.64	1.39	3.30	0.48	23.36	1.27	5.98	8.98	0.93	0.21	5.74	1.10	6.84	0.61	20.44	1.13	8.03	9.32	0.88
	INM-CM4-8	0.13	6.01	1.15	6.03	0.29	27.82	1.30	6.66	9.81	0.87	-0.34	7.95	1.17	5.06	0.39	25.57	1.44	3.11	9.25	0.89
	IITM-ESM	-0.48	7.82	1.24	6.17	0.52	23.27	1.20	8.27	10.32	0.89	-0.18	7.01	1.01	7.89	0.40	25.43	1.12	8.03	9.68	0.90
	HadGEM3-GC31-MM	0.11	6.07	1.14	3.94	0.02	33.19	1.05	11.28	9.44	0.82	0.49	4.07	0.76	7.45	-0.16	37.05	1.24	8.79	9.10	0.79
	HadGEM3-GC31-LL	0.67	3.93	0.95	7.63	0.76	17.32	1.18	6.12	8.89	0.90	0.39	4.55	1.04	4.34	-0.18	37.52	1.13	9.32	9.17	0.80
	GISS-E2-1-G	0.67	3.93	0.95	7.63	0.76	17.32	1.18	6.12	8.89	0.90	0.61	3.82	1.17	4.49	0.55	21.73	1.26	5.16	8.68	0.91
	GFDL-ESM4	0.03	6.49	1.25	4.70	0.54	21.86	1.12	7.41	8.85	0.91	0.36	5.30	1.38	2.32	0.37	25.65	1.23	6.14	8.86	0.91
	FGOALS-g3	0.46	4.81	1.24	4.90	0.42	24.92	1.20	0.37	9.55	0.88	0.08	6.19	1.22	4.81	0.51	23.23	1.35	3.42	9.13	0.88
	EC-Earth3-Veg-LR	-0.42	8.23	0.93	8.11	0.63	20.51	1.12	7.15	9.43	0.85	0.22	5.64	1.16	5.37	0.32	26.97	1.25	6.29	9.32	0.89
	EC-Earth3	-0.09	7.02	1.00	6.30	0.18	29.58	1.27	3.76	8.38	0.87	0.43	4.39	1.15	4.79	0.47	23.58	1.47	2.47	8.85	0.89
	CanESM5	0.33	5.13	1.13	5.12	0.45	23.81	1.34	4.90	8.87	0.90	0.29	5.26	1.11	5.94	0.48	23.08	1.29	4.71	8.82	0.88
	CNRM-ESM2-1	0.00	6.56	0.87	8.67	0.46	24.01	1.44	2.35	9.06	0.84	0.53	4.47	0.92	7.88	0.58	21.37	1.26	5.13	9.06	0.89
	CNRM-CM6-1	0.12	5.95	0.97	7.74	0.48	23.55	1.27	5.64	9.22	0.86	0.18	5.81	1.53	0.49	0.59	20.87	1.16	8.12	8.92	0.91
	CMCC-ESM2	0.12	6.07	1.08	6.40	0.68	19.49	1.19	7.43	9.44	0.89	0.15	5.99	1.27	4.57	0.35	26.54	1.18	7.66	9.65	0.89
	CMCC-CM2-SR5	0.18	6.15	1.22	5.80	0.21	29.17	1.16	7.57	9.62	0.89	0.23	4.40	1.16	-1.48	0.42	22.39	1.27	-2.67	4.83	0.92
	CESM2	0.07	6.40	1.10	6.40	0.56	21.66	1.31	6.10	9.43	0.91	0.01	6.54	1.11	5.70	0.38	25.66	1.37	4.94	9.49	0.86
	BCC-CSM2-MR	-0.34	7.93	1.14	4.28	0.28	27.80	1.14	7.20	9.22	0.83	-0.11	7.05	0.98	7.78	0.49	23.30	1.19	6.92	9.32	0.85
	ACCESS-ESM1-5	0.88	2.97	1.35	2.65	0.52	22.63	1.12	7.81	9.00	0.91	0.18	5.81	1.53	0.49	0.59	20.87	1.16	8.12	8.92	0.91
	ACCESS-CM2	0.16	5.91	1.11	5.01	0.67	18.80	1.23	5.60	8.50	0.91	0.71	3.67	1.04	5.69	0.53	21.81	1.04	8.05	8.35	0.91
	Mean	0.19	5.79	1.08	6.07	0.41	24.80	1.18	6.83	9.12	0.88	0.20	5.68	1.11	5.28	0.41	24.75	1.22	6.24	8.90	0.88

Through the table, we can compare the differences between the various models and find out the maximum and minimum values, as shown in the figure.In Sierra National Forest, CA
NEX model with the lowest RMSE is 'CMCC-CM2-SR5', NEX mode with highest R^2 is 'MIROC6'.

Turkmenistan

Region	SSP Senarios	Systematic Difference Estimation ("Delta")																			
	SSP Senarios	SSP 126										SSP 585									
	Seasons	Summer		Fall		Winter		Spring				Summer		Fall		Winter		Spring			
	Metrics	coef.	INTCP	coef.	INTCP	coef.	INTCP	coef.	INTCP	RMSE	R^2	coef.	INTCP	coef.	INTCP	coef.	INTCP	coef.	INTCP	RMSE	R^2
Mary,TK	UKESM1-0-LL	0.19	12.58	1.26	6.98	0.54	34.08	1.48	9.23	15.76	0.87	0.17	12.46	1.07	10.52	0.47	36.32	1.40	9.72	15.41	0.88
	TaiESM1	0.16	12.58	1.07	14.66	0.48	34.24	1.30	4.86	14.09	0.92	0.63	10.68	1.11	15.93	0.32	35.21	1.12	20.27	13.93	0.93
	NorESM2-MM	0.09	12.82	1.44	9.08	0.57	33.30	1.66	1.92	15.91	0.93	0.61	10.46	1.39	8.81	0.44	37.13	1.97	-3.07	15.72	0.96
	NorESM2-LM	0.16	12.41	1.16	13.01	0.70	29.15	1.71	1.32	15.42	0.95	-0.09	13.72	1.29	10.90	0.51	35.21	1.51	5.13	15.78	0.95
	NESM3	0.05	13.03	1.12	14.04	0.42	37.71	1.45	5.68	15.64	0.93	-0.14	13.83	1.40	9.44	0.30	41.25	1.45	4.69	15.75	0.92
	MRI-ESM2-0	-0.19	13.97	1.37	8.45	0.24	43.02	1.47	6.31	15.96	0.93	-0.19	14.08	1.21	12.72	0.35	39.66	1.58	4.48	15.88	0.94
	MPI-ESM1-2-LR	-0.11	13.66	1.21	12.44	0.52	35.02	1.52	6.86	16.52	0.93	0.01	13.25	1.44	7.64	0.52	35.19	1.47	8.05	16.46	0.94
	MPI-ESM1-2-HR	0.17	12.57	1.13	13.97	0.79	27.44	1.61	4.33	16.30	0.93	-0.09	13.64	1.08	15.24	0.65	31.53	1.61	4.12	16.44	0.93
	MIROC6	-0.39	14.58	1.36	10.30	0.60	32.97	1.76	2.50	16.63	0.95	0.15	12.55	1.37	9.90	0.55	34.11	1.51	4.87	15.90	0.94
	MIROC-ES2L	0.11	12.82	1.20	12.89	0.40	38.37	1.61	3.96	16.15	0.95	0.10	12.86	1.28	11.43	0.62	32.08	1.62	3.50	16.09	0.95
	KIOST-ESM	-0.12	13.91	1.38	7.76	0.82	25.99	1.71	2.07	15.44	0.95	0.06	13.37	1.35	8.40	0.66	30.51	1.33	8.47	15.34	0.96
	KACE-1-0-G	0.16	12.92	1.17	9.86	0.47	36.54	1.29	13.35	16.50	0.86	0.04	13.42	1.25	7.87	0.49	35.74	1.45	11.24	16.16	0.87
	IPSL-CM6A-LR	0.21	12.51	1.18	13.20	0.53	34.62	1.82	0.27	16.13	0.94	0.03	13.11	1.48	7.04	0.43	37.24	1.72	1.40	15.59	0.92
	INM-CM5-0	0.42	11.59	1.31	10.93	0.42	37.70	1.82	-0.02	16.10	0.94	0.01	13.58	1.26	11.57	0.53	34.70	1.52	6.32	16.16	0.93
	INM-CM4-8	-0.03	13.43	1.39	8.41	0.71	29.76	1.65	2.93	15.96	0.92	-0.15	13.84	1.28	10.92	0.52	34.97	1.63	3.19	15.94	0.95
	IITM-ESM	-0.06	13.54	1.08	14.64	0.61	32.42	1.47	7.88	16.40	0.93	-0.17	13.85	1.44	8.14	0.79	27.53	1.56	5.22	16.53	0.91
	HadGEM3-GC31-MM	0.25	12.11	1.03	13.47	0.34	40.24	1.66	7.57	16.34	0.88	0.16	12.77	1.41	4.30	0.41	37.95	1.51	9.00	15.87	0.88
	HadGEM3-GC31-LL	0.30	12.17	1.36	5.78	0.60	32.27	1.47	8.93	15.65	0.93	0.20	12.37	1.08	10.88	0.47	36.44	1.36	11.58	15.95	0.85
	GISS-E2-1-G	0.41	10.73	1.21	13.02	0.45	36.96	1.47	6.16	15.89	0.94	0.45	11.39	1.23	11.99	0.33	40.52	1.44	7.59	16.32	0.94
	GFDL-ESM4	0.03	13.15	1.31	11.62	0.42	37.62	1.41	7.99	15.96	0.95	0.34	11.45	1.31	11.14	0.62	31.93	1.76	0.77	15.79	0.96
	FGOALS-g3	-0.08	13.63	1.12	14.40	0.61	32.56	1.44	7.82	16.46	0.92	0.35	11.24	1.29	10.52	0.49	36.13	1.56	5.61	16.13	0.95
	EC-Earth3-Veg-LR	0.22	12.24	1.31	10.63	0.51	35.39	1.67	2.98	16.11	0.94	0.13	12.66	1.35	9.12	0.49	35.99	1.85	-1.28	15.89	0.94
	EC-Earth3	0.18	12.22	1.23	11.64	0.86	24.03	1.56	2.03	14.97	0.94	0.19	12.07	1.30	10.03	0.40	38.30	1.70	0.47	15.17	0.94
	CanESM5	-0.08	13.80	1.20	11.05	0.80	25.95	1.33	8.80	15.23	0.95	-0.08	13.63	1.49	5.43	0.99	20.85	1.47	6.36	15.57	0.95
	CNRM-ESM2-1	0.29	11.51	1.21	12.12	0.59	32.59	1.59	2.78	15.34	0.94	0.17	12.40	1.36	9.33	0.50	35.63	1.45	7.38	15.89	0.95
	CNRM-CM6-1	0.04	13.12	1.67	4.58	0.66	31.72	1.56	5.08	16.64	0.92	0.18	12.44	1.29	11.73	0.90	24.13	1.57	5.16	16.30	0.93
	CMCC-ESM2	-0.22	13.98	1.20	11.70	0.50	35.65	1.35	9.34	16.32	0.91	0.36	11.57	1.47	6.17	0.85	25.95	1.27	11.24	16.20	0.93
	CMCC-CM2-SR5	-0.09	13.80	1.48	6.37	0.74	28.74	1.48	5.90	15.79	0.93	-0.02	13.45	1.13	7.81	0.46	35.29	1.57	-2.89	12.37	0.92
	CESM2	0.19	12.57	1.49	7.49	0.61	32.09	1.48	7.11	16.13	0.95	-0.19	13.93	1.32	10.17	0.54	34.09	1.40	8.76	16.22	0.94
	BCC-CSM2-MR	0.23	12.28	1.20	12.96	0.67	30.85	1.67	3.14	16.25	0.95	0.53	9.85	1.18	13.03	0.57	33.47	1.56	4.84	15.68	0.95
	ACCESS-ESM1-5	-0.18	14.04	1.18	12.97	0.81	25.91	1.53	5.76	15.81	0.95	-0.15	13.92	1.30	10.44	0.95	22.10	1.64	1.85	15.66	0.93
	ACCESS-CM2	0.02	13.19	1.37	8.98	0.46	36.59	1.59	4.15	15.80	0.94	0.20	12.23	1.37	10.70	0.47	36.06	1.43	7.47	15.94	0.94
	Mean	0.07	12.92	1.26	10.92	0.58	33.17	1.55	5.28	15.92	0.93	0.12	12.69	1.30	9.98	0.55	33.85	1.53	5.67	15.75	0.93

In Mary, Turkmenistan, NEX model with the lowest RMSE is 'CMCC-CM2-SR5', NEX mode with highest

R^2 is 'KIOST-ESM'.

XinJiang

Systematic Difference Estimation ("Delta")

Region	SSP Senarios	SSP 126									
	Seasons	Winter		Spring		Summer		Fall			
	Metrics	coef.	INTCP	coef.	INTCP	coef.	INTCP	coef.	INTCP	RMSE	R^2
	UKESM1-0-LL	0.60	11.10	1.26	13.05	0.18	38.47	1.06	21.07	18.24	0.91
	TaiESM1	0.53	12.98	1.22	19.23	0.37	33.73	0.98	18.36	19.05	0.95
	NorESM2-MM	0.80	12.72	1.23	17.62	0.93	21.71	1.27	15.50	18.43	0.97
	NorESM2-LM	1.27	14.12	1.13	19.08	1.18	15.64	1.21	15.84	18.16	0.97
	NESM3	0.90	13.22	1.03	20.47	0.86	22.56	1.16	16.61	18.30	0.96
	MRI-ESM2-0	0.90	13.49	1.17	18.31	1.33	11.56	1.17	16.27	18.22	0.97
	MPI-ESM1-2-LR	1.23	15.44	1.06	20.47	1.19	15.42	1.21	16.61	18.71	0.96
	MPI-ESM1-2-HR	1.26	15.96	1.08	19.92	0.81	24.25	1.21	16.53	18.74	0.97
	MIROC6	0.57	12.55	1.18	18.47	1.20	16.20	1.20	16.45	19.06	0.97
	MIROC-ES2L	0.58	11.59	1.18	19.14	1.30	13.87	1.23	16.27	18.84	0.96
	KIOST-ESM	0.82	12.74	1.05	19.21	0.47	31.56	1.25	15.13	17.88	0.97
	KACE-1-0-G	0.57	11.72	1.17	15.48	0.27	36.56	1.04	21.72	18.86	0.92
	IPSL-CM6A-LR	1.08	14.56	1.14	18.55	0.70	26.77	1.32	13.90	18.21	0.97
	INM-CM5-0	1.01	13.03	1.10	19.62	1.38	11.16	1.21	15.84	18.40	0.96
	INM-CM4-8	0.89	13.29	1.06	19.70	0.76	25.37	1.25	15.78	18.45	0.97
	IITM-ESM	0.85	12.91	1.08	19.84	0.78	25.61	1.17	17.46	18.87	0.96
Xin Jiang, China	HadGEM3-GC31-MM	0.73	11.27	1.01	18.46	0.38	33.87	1.17	20.08	18.50	0.92
	HadGEM3-GC31-LL	0.67	11.65	1.12	16.26	0.17	38.84	1.15	19.84	18.46	0.93
	GISS-E2-1-G	0.99	13.13	1.21	18.40	0.85	23.80	1.18	16.71	18.59	0.97
	GFDL-ESM4	1.43	15.40	1.10	19.68	0.94	21.24	1.15	17.34	18.54	0.96
	FGOALS-g3	0.71	12.49	1.09	20.13	1.17	16.17	1.08	17.84	18.79	0.96
	EC-Earth3-Veg-LR	0.96	13.61	1.27	16.77	1.40	10.80	1.20	16.20	18.30	0.97
	EC-Earth3	0.99	12.90	1.13	18.47	0.81	23.50	1.12	16.28	17.75	0.96
	CanESM5	0.88	11.98	1.09	18.92	0.70	26.73	1.38	15.08	18.15	0.97
	CNRM-ESM2-1	0.94	12.59	1.20	17.94	1.02	19.98	1.29	15.81	18.42	0.97
	CNRM-CM6-1	0.53	11.89	1.06	20.14	0.51	31.39	1.28	15.01	18.87	0.96
	CMCC-ESM2	1.06	14.85	1.08	19.21	1.09	17.89	1.25	16.58	18.65	0.97
	CMCC-CM2-SR5	0.99	13.59	1.14	17.95	0.83	23.84	1.15	17.48	18.32	0.97
	CESM2	0.94	13.52	1.46	14.95	1.31	12.74	1.16	17.13	18.50	0.97
	BCC-CSM2-MR	0.94	13.37	1.01	20.88	0.85	23.80	1.12	17.42	18.74	0.96
	ACCESS-ESM1-5	1.11	14.48	1.06	20.67	1.58	4.48	1.17	16.28	18.27	0.96
	ACCESS-CM2	1.07	14.06	1.15	18.79	0.89	22.02	1.20	16.25	18.24	0.97
	Mean	0.90	13.19	1.14	18.62	0.88	22.55	1.19	16.90	18.48	0.96

SSP Senarios	SSP 585									
Seasons	Winter		Spring		Summer		Fall			
Metrics	coef.	INTCP	coef.	INTCP	coef.	INTCP	coef.	INTCP	RMSE	R^2
UKESM1-0-LL	0.63	10.68	1.11	15.93	0.32	35.21	1.12	20.27	18.06	0.92
TaiESM1	0.59	13.67	1.00	21.19	0.19	37.93	0.87	19.95	18.98	0.95
NorESM2-MM	0.98	12.76	1.24	17.22	0.81	23.91	1.29	14.62	17.89	0.97
NorESM2-LM	1.14	13.09	1.15	18.51	1.48	8.67	1.20	15.54	17.90	0.97
NESM3	1.06	14.04	1.11	19.53	0.52	30.44	1.21	15.03	18.09	0.95
MRI-ESM2-0	1.01	13.94	1.04	20.69	1.01	18.99	1.13	16.69	18.37	0.96
MPI-ESM1-2-LR	1.30	14.59	1.21	18.64	0.81	24.31	1.18	16.90	18.60	0.97
MPI-ESM1-2-HR	0.99	14.65	1.17	19.73	0.80	24.46	1.19	16.48	18.91	0.97
MIROC6	0.87	13.52	1.52	13.96	0.92	21.88	1.17	16.95	18.62	0.97
MIROC-ES2L	0.88	13.06	1.17	19.62	0.94	21.72	1.16	16.77	18.84	0.96
KIOST-ESM	1.15	13.69	1.20	17.31	0.94	20.57	1.23	15.66	17.76	0.97
KACE-1-0-G	0.59	11.19	1.13	15.75	0.27	36.54	1.12	21.09	18.60	0.90
IPSL-CM6A-LR	0.64	12.07	1.05	19.70	0.85	23.25	1.22	15.69	18.40	0.96
INM-CM5-0	1.01	13.03	1.10	19.62	1.38	11.16	1.24	16.39	18.40	0.96
INM-CM4-8	0.52	11.54	1.08	20.63	1.14	16.94	1.17	17.30	19.02	0.96
IITM-ESM	0.99	14.59	1.19	17.77	0.97	20.42	1.14	18.08	18.70	0.97
HadGEM3-GC31-MM	0.82	11.79	1.17	15.53	0.34	34.87	1.04	20.64	18.25	0.93
HadGEM3-GC31-LL	0.70	11.22	1.01	17.69	0.28	36.08	1.05	20.41	18.08	0.92
GISS-E2-1-G	1.16	14.88	1.23	17.51	1.17	16.24	1.20	16.96	18.60	0.98
GFDL-ESM4	0.94	13.60	1.05	19.66	0.98	20.26	1.15	17.00	18.41	0.97
FGOALS-g3	1.02	13.32	1.16	18.34	1.73	2.97	1.18	16.59	18.19	0.97
EC-Earth3-Veg-LR	0.81	13.06	1.22	17.48	0.67	27.71	1.26	15.80	18.60	0.97
EC-Earth3	0.96	13.10	1.10	18.97	1.06	17.80	1.19	15.49	17.85	0.97
CanESM5	1.21	14.74	1.22	17.83	0.57	29.69	1.23	16.63	18.54	0.96
CNRM-ESM2-1	0.84	12.59	1.15	18.80	0.97	20.59	1.23	16.11	18.38	0.97
CNRM-CM6-1	0.33	10.35	1.09	19.51	0.71	26.77	1.27	15.19	18.55	0.96
CMCC-ESM2	0.40	10.59	1.27	16.68	1.10	18.32	1.15	17.63	18.65	0.96
CMCC-CM2-SR5	1.23	7.77	1.20	11.12	0.69	24.54	1.16	11.52	13.73	0.97
CESM2	0.87	13.39	1.16	17.56	0.96	20.76	1.12	17.92	18.41	0.97
BCC-CSM2-MR	1.09	14.28	1.11	19.56	0.84	23.72	1.18	16.51	18.56	0.97
ACCESS-ESM1-5	0.77	12.56	1.12	19.64	0.92	21.27	1.32	14.47	18.32	0.96
ACCESS-CM2	1.09	14.45	1.27	17.37	0.41	33.26	1.23	15.51	18.27	0.97
Mean	0.89	12.87	1.16	18.09	0.84	23.48	1.18	16.81	18.27	0.96

In Xin Jiang, NEX model with the lowest RMSE is 'CMCC-CM2-SR5', NEX mode with highest R^2 is 'GISS-E2-1-G'.

By observation we found that mean RMSE of Mary,Turkmenistan: 15.92, 15.75 and Xin Jiang, China: 18.48, 18.27. Their regional characteristics are also similar: Low Vegetation, low humidity, extended daylight and sun exposure.

AU

Systematic Difference Estimation ("Delta")

Region	SSP Senarios	SSP 126										SSP 585									
	Seasons	Summer		Fall		Winter		Spring		RMSE	R^2	Summer		Fall		Winter		Spring		RMSE	R^2
	Metrics	coef.	INTCP	coef.	INTCP	coef.	INTCP	coef.	INTCP			coef.	INTCP	coef.	INTCP	coef.	INTCP	coef.	INTCP		
New South Wales, AU	UKESM1-0-LL	0.28	34.46	1.95	-5.20	0.46	8.43	1.71	-2.45	11.70	0.91	0.81	22.02	2.03	-6.15	0.80	4.68	1.94	-6.07	12.03	0.94
	TaiESM1	-0.27	46.87	1.82	-3.01	0.77	6.99	1.77	1.82	13.89	0.87	-0.08	42.84	1.53	1.42	0.11	12.76	1.41	8.32	14.19	0.77
	NorESM2-MM	0.00	41.14	2.02	-8.45	0.87	4.56	2.31	-8.64	12.42	0.89	-0.07	42.91	1.70	-3.94	0.70	6.43	1.81	0.18	12.35	0.85
	NorESM2-LM	-0.26	47.39	1.85	-5.85	0.92	3.68	2.82	-16.83	12.40	0.87	-0.19	45.55	1.98	-7.68	0.39	9.50	2.42	-10.49	12.60	0.89
	NESM3	0.18	36.85	1.62	-2.15	0.61	7.07	1.90	-2.11	12.19	0.87	0.06	39.71	1.51	-0.36	0.40	9.12	1.84	-2.62	12.14	0.86
	MRI-ESM2-0	0.11	38.57	2.16	-11.05	0.88	3.99	2.04	-4.73	12.31	0.90	-0.24	47.01	2.10	-10.22	0.94	3.53	1.66	1.59	12.21	0.91
	MPI-ESM1-2-LR	-0.18	45.46	1.63	-4.23	1.33	-0.45	1.93	-3.48	11.89	0.86	-0.03	41.94	1.80	-6.09	0.78	4.94	1.89	-2.75	11.88	0.87
	MPI-ESM1-2-HR	-0.12	44.16	2.00	-9.64	0.43	9.13	2.13	-5.78	12.16	0.88	-0.36	49.80	1.97	-8.43	0.81	4.83	1.78	0.19	12.30	0.83
	MIROC6	-0.32	48.68	2.09	-9.91	0.34	10.09	2.54	-11.62	12.78	0.88	-0.53	53.33	2.16	-11.73	0.28	10.70	2.20	-6.74	12.70	0.89
	MIROC-ES2L	-0.17	45.40	1.90	-8.53	0.64	6.59	2.14	-8.35	11.42	0.90	-0.16	45.07	1.91	-8.24	0.36	9.84	1.89	-2.96	11.83	0.88
	KIOST-ESM	-0.18	45.61	2.07	-9.91	0.43	9.15	1.72	2.28	12.57	0.90	-0.31	48.55	1.89	-5.97	0.20	11.47	1.41	6.24	12.69	0.88
	KACE-1-0-G	0.38	32.09	1.71	-1.27	0.71	5.72	1.84	-3.78	12.03	0.90	0.82	21.14	1.85	-3.96	0.56	7.42	1.82	-3.44	11.78	0.88
	IPSL-CM6A-LR	0.23	35.64	1.94	-8.11	0.32	10.32	2.10	-5.29	12.27	0.89	0.07	39.55	1.92	-7.50	0.57	7.54	2.19	-6.51	12.41	0.88
	INM-CM5-0	-0.28	47.91	1.98	-8.20	1.05	2.30	1.76	-0.41	12.32	0.90	-0.33	49.23	1.97	-8.68	0.87	4.22	2.05	-6.65	11.91	0.88
	INM-CM4-8	0.12	38.33	2.21	-12.83	0.78	5.27	2.31	-9.28	12.27	0.89	0.01	40.89	1.91	-7.81	0.18	11.69	2.33	-8.49	12.20	0.86
	IITM-ESM	0.64	25.87	1.82	-6.89	1.31	-0.82	2.25	-9.64	12.77	0.88	0.08	39.26	1.90	-6.49	1.84	-6.31	2.06	-5.76	12.78	0.87
	HadGEM3-GC31-MM	0.46	30.31	1.76	-1.58	1.04	2.10	2.61	-18.14	12.05	0.91	0.91	19.74	1.96	-4.27	0.57	7.39	2.07	-8.39	12.19	0.92
	HadGEM3-GC31-LL	0.52	28.94	1.88	-4.87	1.03	2.24	1.95	-5.33	12.09	0.92	0.24	35.48	1.76	-2.59	0.54	7.47	1.69	-1.47	11.87	0.89
	GISS-E2-1-G	0.08	39.20	1.62	-4.77	0.04	13.24	1.87	-3.10	11.52	0.88	-0.20	45.99	1.92	-7.35	0.65	6.75	1.92	-4.10	11.97	0.90
	GFDL-ESM4	0.01	40.95	1.75	-3.88	0.50	8.21	1.93	-2.14	12.31	0.86	-0.09	43.32	1.74	-4.20	0.74	5.67	2.06	-5.09	12.33	0.89
	FGOALS-g3	-0.49	53.04	2.11	-11.03	0.68	6.19	1.70	0.94	12.13	0.89	0.49	29.55	1.97	-8.43	0.27	10.77	2.35	-10.45	12.13	0.93
	EC-Earth3-Veg-LR	0.08	39.16	1.99	-8.97	0.35	10.00	1.63	2.40	12.05	0.87	0.19	36.64	1.83	-7.20	0.38	9.46	2.00	-4.65	11.77	0.86
	EC-Earth3	0.45	30.05	2.09	-9.81	0.73	5.65	2.48	-13.04	12.77	0.88	-0.05	42.28	1.67	-3.95	0.84	4.51	1.88	-2.43	12.78	0.87
	CanESM5	0.64	25.87	1.82	-6.89	1.31	-0.82	2.25	-9.64	11.83	0.92	0.08	39.26	1.90	-6.49	1.84	-6.31	2.06	-5.76	12.28	0.92
	CNRM-ESM2-1	0.38	31.89	1.81	-6.68	0.62	6.89	2.51	-12.58	11.98	0.88	-0.11	43.94	1.90	-8.38	0.58	7.41	1.70	1.61	12.18	0.85
	CNRM-CM6-1	-0.26	47.51	1.99	-9.32	0.73	5.63	2.14	-6.12	12.20	0.87	0.10	38.80	1.61	-2.55	0.50	8.25	2.14	-5.56	11.98	0.87
	CMCC-ESM2	0.10	38.67	1.86	-6.19	0.78	5.02	1.70	-0.24	11.79	0.87	0.24	35.40	1.83	-5.98	0.73	5.51	1.87	-2.23	11.97	0.90
	CMCC-CM2-SR5	-0.16	44.88	1.86	-5.20	0.44	9.13	1.63	1.66	12.39	0.90	0.36	30.54	1.53	-8.40	0.99	-1.40	1.23	2.07	7.95	0.87
	CESM2	0.07	39.48	1.78	-4.39	0.36	10.02	2.20	-6.79	12.40	0.89	-0.15	44.77	1.88	-6.82	0.15	12.12	2.27	-7.91	12.43	0.87
	BCC-CSM2-MR	0.29	34.53	1.97	-8.19	1.20	0.70	2.14	-5.98	12.63	0.88	-0.40	50.79	2.16	-11.07	0.36	9.64	2.08	-4.55	12.35	0.86
	ACCESS-ESM1-5	0.12	38.19	1.61	-2.19	0.98	2.82	1.53	3.40	11.90	0.86	-0.33	49.08	2.32	-14.27	0.40	9.29	2.08	-4.61	12.49	0.87
	ACCESS-CM2	-0.29	48.29	1.85	-6.29	1.05	2.74	2.08	-5.94	11.97	0.89	-0.28	48.04	1.90	-7.15	0.73	5.68	1.78	-1.74	11.65	0.89
	Mean	0.07	39.54	1.89	-6.73	0.74	5.68	2.05	-5.28	12.23	0.89	0.02	40.70	1.87	-6.59	0.63	6.71	1.93	-3.48	12.14	0.88

New South Wales, AU,NEX model with the lowest RMSE is 'CMCC-CM2-SR5', NEX mode with highest R^2 is 'UKESM1-0-LL'.Despite that this region is in Southern hemisphere and the area size is 600*600km, we found the outlier model to be same.

Systematic Difference Estimation ("Delta")

Region	SSP Senarios	SSP 126										SSP 585									
	Seasons	Winter		Spring		Summer		Fall		RMSE	R^2	Winter		Spring		Summer		Fall		RMSE	R^2
Mean Predictions across 32 models	Metrics	coef.	INTCP	coef.	INTCP	coef.	INTCP	coef.	INTCP			coef.	INTCP	coef.	INTCP	coef.	INTCP	coef.	INTCP		
Sierra National Forest, CA		1.21	1.93	1.40	2.76	0.72	18.14	1.32	5.19	8.90	0.94	1.11	1.90	1.46	1.54	0.76	17.11	1.35	4.53	8.65	0.94
Mary,TK		0.43	11.25	1.42	8.18	1.20	14.94	1.74	2.12	15.76	0.98	0.64	10.01	1.45	7.15	1.22	14.52	1.71	2.46	15.57	0.98
Xin Jiang, China		1.60	16.91	1.23	17.48	1.52	7.89	1.23	16.55	18.39	0.98	1.59	16.40	1.45	17.01	1.49	8.24	1.22	16.45	18.18	0.98

Region	SSP Senarios	SSP 126										SSP 585									
	Seasons	Summer		Fall		Winter		Spring		RMSE	R^2	Summer		Fall		Winter		Spring		RMSE	R^2
Mean Predictions across 32 models	Metrics	coef.	INTCP	coef.	INTCP	coef.	INTCP	coef.	INTCP			coef.	INTCP	coef.	INTCP	coef.	INTCP	coef.	INTCP		
New South Wales, AU		0.18	36.88	2.10	-10.30	1.87	-6.37	2.53	-13.24	12.17	0.94	-0.06	42.55	2.09	-10.40	1.56	-3.40	2.36	-10.76	12.07	0.93

95% Confidence Interval

Region	SSP Senarios	SSP 126				SSP 585			
	Seasons	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Mean Predictions across 32 models	95% Confidence Interval								
Sierra National Forest, CA		(5.24, 6.33)	(5.33, 6.81)	(5.86, 7.81)	(23.11, 26.48)	(5.25, 6.11)	(4.39, 6.17)	(5.30, 7.18)	(23.09, 26.41)
Mary,TK		(4.39, 6.98)	(-7.27, -3.29)	(-7.82, -5.65)	(36.95, 42.14)	(5.07, 8.34)	(-5.03, -1.92)	(-7.74, -5.45)	(37.64, 43.77)
Xin Jiang, China		(12.75, 13.63)	(17.99, 19.25)	(16.27, 17.52)	(19.45, 25.64)	(12.30, 13.44)	(-5.03, -1.92)	(16.08 17.53)	(20.55, 26.40)

Region	SSP Senarios	SSP 126				SSP 585			
	Seasons	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring
Mean Predictions across 32 models	95% Confidence Interval								
New South Wales, AU		(4.38, 6.97)	(-7.27, -3.29)	(-7.82, -5.65)	(36.95, 42.14)	(5.07, 8.34)	(-5.03, -1.92)	(-7.74, -5.45)	(37.64, 43.77)

Finally, we use a 95% confidence level to estimate the systematic difference between surface and near-surface temperatures.

Recommendation:

In this project, we use a geographical approach backed by data science to help S&P Global understand how climate change is affecting the operation of the company. The systematic difference estimation helps understand the gap between land surface temperature and near surface temperature. What's more important,the estimation gives us insight about how do we predict one from another. For example, if the specific region we would like to obtain the land surface temperature (MODIS) has thousands of rows of missing value(which can occur in cloudy regions), we can estimate it using near surface air temperature from NEX. When choosing the NEX model, in most cases, two SSP scenarios return similar predicted values but when it comes to the outliers it is important to take the SSP scenarios into consideration because the prediction from SSP 585 is significantly higher than SSP 128.

S&P Global can visualize climate change specifically where and when it might occur through visualization, such as heatmap and time series plot. Our findings provide S&P Global insights to identify potential damages, forecast different scenarios, and make sound decisions in future business plans. What’s more, when S&P Global’s consultants provide advice for their clients, they could translate climate science insights such as a hazard metric into potential physical and financial impacts. For example, we observe California has a number of extremely hot days within a year, which means the financial budget of cooling costs of a company located in California's are likely to rise due to this hazard.

What are the **implications for the organization,** its customer base, competitors, or other constituencies?
(Xin Zou 2 paragraphs)

How do you recommend that the organization use the results from the analysis, and what are the **potential obstacles** to watch out for? **(Jianglan shi 2 paragraphs)**

Based on this result, we can conclude that although the NEX SSP585 CMCC-CM2-SR5 model has the closest trend prediction compared to the MODIS, the accuracy results of 32 NEX models still have a huge gap between the outcomes. The NEX model can be used as a prediction tool toward the research of the MODIS but may need to explore other optimized choices at the same time. According to the RMSE and R square tables for the four different regions, seasonal elements and geographical location will still be a big consideration in the future search for the organization.

In a word, Some recommendations for the S&P Global company will be to pay attention to the elements that influence the accuracy of the result. The place with low vegetarians and low humility may cause a big gap of outcome so choose the model wisely in those drought places. Furthermore, research about the target places' climates will be necessary for those research people to start up their work. To determine the areas to research may need to try best to avoid the land that is covered with much water or clouds. Both water and clouds will have higher reflections on the satellite image which gives a huge impact on the efficiency and accuracy of the original dataset. Employees need to put in more effort to remove or set up those elements to 0 so that to minimize their influences. This may bring people's attention during the data cleaning process and cause troubles which the organization may need to take care of. And also, to know that models are influenced by seasonal changes will be another consideration for the research people. Summer will be the season I need to pay most attention to. The high surface temperature, the strong convection weather, and the change in precipitation may be the causes of variety results.

For this component of the research project, include an Appendices as needed, as well as a Bibliography that sets forth your sources**. The Bibliography should be formatted in the academically-accepted Modern Language Association (MLA) style<u>. FInal edit: Xin Zou</u>**

Submission Format: File upload**, 6-9 pages, double-spaced, 12 pt font,** not including any Appendices; note, **y<u>ou may submit this document in outline format using bullet points, tables and/or charts; please consult with your instructor on his/her preferred format</u>**