Differences between the maximum temperature of climate models compared to weather station (and derived) data in coastal cells.

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Abstract:
The depression of the maximum temperature in coastal cells of a number of climate models from that of weather station or CRU (Climate Research Unit) maximum temperature is reported here for the first time. CRU was shown to be a good substitute for weather station data that covers more coastal grid cells than weather stations. The maximum temperature deviation for all the models (except ERA5) from the maximum temperature of CRU was less than 0.8C for all months. The deviation of ERA5 (ECMWF Reanalysis 5th Generation) was over 3C for the hottest months when the land temperature is expected to be higher than the sea temperature.

Overall, if ISIMIP3b is being used there are no serious issues with Tmax, Tdew and Tmean in the calculation of population impacts like work hours lost using WBGT (a combination of temperature and humidity). The only exceptions being highly populated island states with proportionally high coastal cells: namely Singapore, Hong Kong and Bahrain. However caution needs to be used when using Tmax(ERA5) for coastal cells when calculating impacts on land based activities as it can be up to 3C cooler on the coast than either coastal Tmax(weather station) or Tmax(CRU)

Introduction:
In this report we use Tmax as the monthly average of the daily maximum temperature in a ½ X ½ grid cell. Tmax is the most important term in determining heat stress for our population impact studies on work hours lost due to heat. Tmax in a global grid also appears difficult to determine accurately as has been seen from three recent versions of Tmax published by PIK (PIK 2021). Tmax is based on one single point in the daily data while Tmean (the monthly average of the daily mean temperature) is based on the average of all the hourly data so it is not surprising that it is more accurate.

This report primarily looks at coastal cells as this is where we found the largest errors in Tmax. Coastal cells are made of part land and part water which also includes inland lakes. The land component warms up much more rapidly than the water component so if any spatial averaging process is used in coastal grid cells, the cooler water (sea) component can seriously decrease the maximum temperature in that coastal cell. Many people live and work in the coastal fringe, so this may affect significant populations in countries that have a large coast-line because most people work on the land component. The land and sea are much more likely to have nearly the same Tmean value and we have not found the same problems with Tmean as we found in the Tmax of coastal cells. This was confirmed in a separate report (B Lemke 2021 Tmean report).

This depression of the coastal Tmax temperature is primarily found in satellite data (ERA5 reanalysis), while land based data originating from weather stations (eg CRU data) is not prone to this depression of Tmax caused by the cooler water temperatures.

Method:
We have developed a table of ½ x ½ degree grid cell Tmax data for various models so they can be directly compared. This table has monthly Tmax data averaged over 10 years 2001 to 2010 for all models we use and for weather stations (GSOD 2020): CRU TS 4.01 (CRU 2020/21), GFDL2b,

HadGEM2b, GFDL3b, UKesm3b (ISIMIP 2020/21) and ERA5 (ERA5 2021). We included the EWEMBI model (ISIMIP 2020/21) used to bias correct ISIMIP2b data and based on the CRU data; and the W5E5 model (ISIMIP 2020/21) used for bias correction of ISIMIP3b and based on CRU (for land cells) and ERA5 (for ocean cells). While EWEMBI also uses an early version of ERA (ERA-interim) for ocean-based cells, it seems to be used much more conservatively for coastal cells than the strong influence ERA5 has on coastal cells in W5E5.

ISIMIP2b is not immune to a lowered coastal Tmax in relation to weather stations, not so much from problems with EWEMBI but issues in the bias correction method where the maximum bias correction used by ISIMIP2b was limited to 3C (S Lange 2020). This issue was discussed in an earlier report that focussed on Tmax errors in ISIMIP2b (B Lemke 2019 ISIMIP 2b report).

Stage 1a coastal grid cell comparison with weather stations

For this first stage all grid cells that did not have a good weather station within them were removed. We deemed a good weather station as one that had over 80% completeness of number of days per annum. Each grid cell had an associated land percent, population, altitude, latitude and longitude. As we are not interested in Tmax for colder regions, we excluded all weather stations in the polar circle (north and south of 66.5 degrees) and all grid cells and weather stations above 1000m. We also excluded cells where the altitude difference between weather stations and the grid cell altitude was more than 500m because of the lapse rate of temperature giving 5-10C of cooling per 1000m altitude increase. We only considered coastal cells that had less than 80% land because we found that the area proportion of water in a cell included water in lakes and large rivers which are not likely to have the same cooling effect as a large body of ocean. Even with the 80% threshold for coastal cells, there are still a few landlocked countries with small shallow lakes where at least one grid cell has less than 80% land: Niger (1 cell), Chad (5 cells), Uganda (3 cells). These landlocked countries were not included in this coastal analysis because lakes (especially shallow lakes) are not likely to have the same cooling effect as large lakes or oceans.

So starting off with 68940 land based grid cells, once all grid cells with more than 80% land were removed we ended with 7475 grid cells. When polar cells (above 66.5 latitude) are removed 6866 coastal cells remained. When all grid cells and weather stations above 1000m were removed 6791 cells remained. With the restriction that only those grid cells that had a weather station in them were used 920 grid cells remained. The final restriction of only using data where the difference between weather station and grid cell was less than 500m difference left us with 900 grid cells with full data for most months of the year.

Stage 1b coastal grid cell model comparison with CRU grid cells

The comparison of weather stations with CRU was to see if CRU could be used as a substitute for climate model comparisons. CRU is more useful, because it covers more cells especially in large cities because often the NOAA weather station is in one city grid cell and there is no weather station in the neighbouring highly populated grid cells.

Once we confirmed that CRU data was able to be used, we compared the gridded CRU data with gridded data from all models. This gave us more datapoints and captured highly populated areas that did not have a weather station in the grid cell.

Again starting off with 68940 land based grid cells, once all grid cells with more than 80% land were removed we ended with 7475 grid cells. When polar cells (above 66.5 latitude) are removed 6866 coastal cells remained. When all grid cells above 1000m were removed, 6791 cells remained.

We wanted to see which months were most affected and by how much. We have monthly data, but we cannot mix climate data from the northern hemisphere (summer months = June, July, August) and southern hemisphere (summer months = December, January, February) and the tropics (hottest months = March, April, May or September, October, November) so we divided the global data into the three zones and focussed on the hottest months.

Stage 2 Comparing Country-wide coastal cell data
Country coastal cell data was compared because we were concerned that some countries – especially those like Indonesia with a long highly populated coast-line was subject to large impact errors (B Lemke 2019 ISIMIP2b report). The names of the country occupying a grid cell was stored in our table in an approximate form: for boundary cells, the cell was assigned to the country with the largest area in the boundary cell.

Some coastal grid cells had a very large difference in Tmax but had a very small population, while others had a small difference in Tmax but a high population so a country population weighted Tdew was included in this report (unit = person-degrees). The number of coastal cells in each country where the Tmax(model) deviated by 1C or more from Tmax(CRU) was recorded.

RESULTS

Stage 1a results: coastal cell Tmax from models compared to Tmax from weather stations.
A quick check of this data is shown in Figure 1 which shows the Tmax(CRU) minus Tmax(weather station) for 5% bins from 0 to 80% land cover.

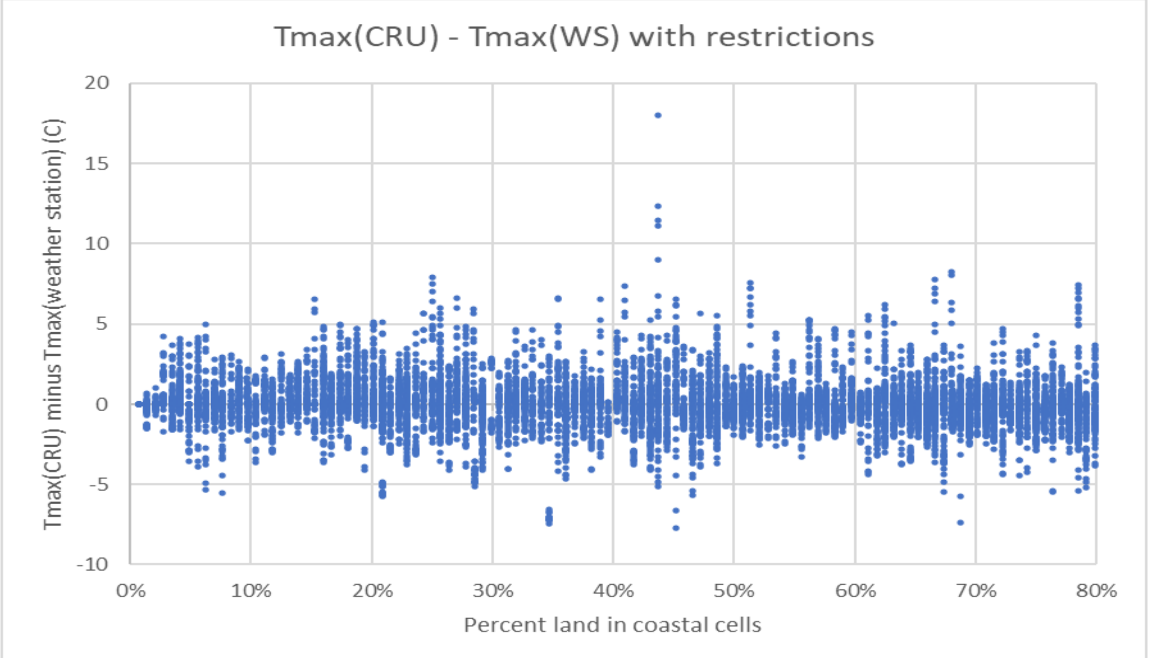

Figure 1 Tmax(CRU) minus Tmax(weather stations) vs percent land cover in coastal cells with the restrictions: no polar weather stations, no weather stations above 1000m only grid cells with weather stations and where the weather station altitude differed by less than 500m from the grid cell altitude. All grid cells deemed as coastal with less than 80% land in them.

As can be seen in Figure 1 there are some very strong outliers in this scatter plot. These were investigated and are documented in a separate report (B Lemke 2021 CRU report).

We studied the deviation of the models from weather station Tmax by subtracting the weather station Tmax from the model Tmax. The mean difference and the scatter is shown in table 1 which shows the comparison of the difference between the models (including CRU) and weather stations.

Table 1 comparison of the difference between the ISIMIP/ERA5/CRU and weather stations (WS) for all months averaged over 2001-2010		
Model minus WS all months 2001 to 2010	Mean	Standard deviation
Tmax(CRU) minus WS	0.01	1.46
Tmax(HadGEM2b) minus WS	-0.38	2.01
Tmax(GFDL2b) minus WS	-0.39	1.95
Tmax(UKesm3b) minus WS	-0.07	1.95
Tmax(GFDL3b) minus WS	-0.26	1.93
Tmax(ERA5) minus WS	***-2.15***	1.67

It is clear from the mean values in table 1 that for coastal cells Tmax(ERA5) has a significant offset (average of 2.15C less than weather stations) from the Tmax(weather station) in the same coastal grid cell. Also note that the average Tmax(CRU) has almost no offset from the Tmax(weather station) and that the Tmax(CRU – weather stations) has the smallest scatter.

As table 1 shows the largest errors occur when Tmax(models) are less than Tmax(CRU) so we focussed on Tmax(models)<Tmax(weather stations) in Figure 2 where we show the difference when the Tmax(weather stations) is subtracted from the Tmax(models). Tmax in coastal cells for ISIMIP3b, has the land portion derived from CRU while the ocean portion derived from ERA5 so Tmax(ISIMIP3b) approaches Tmax(ERA5) when the land percentage is low and approaches Tmax(CRU) at high land percentages. See Figure 2.

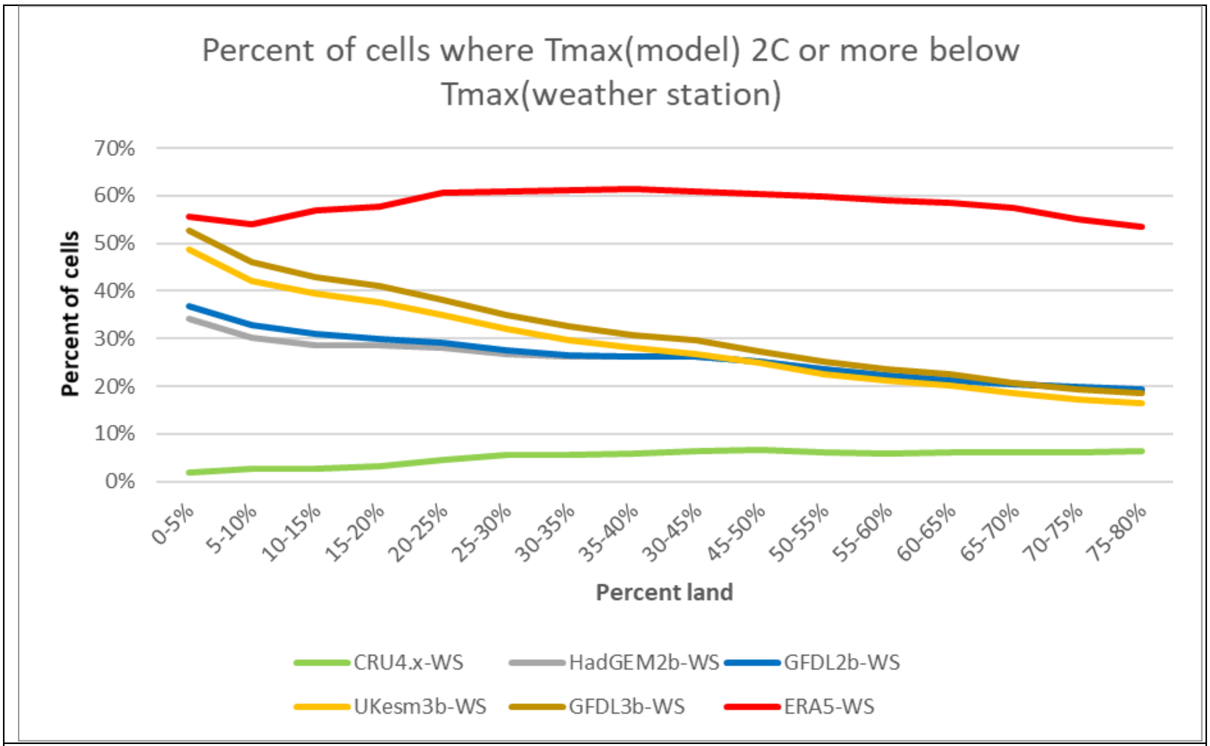

Figure 2 Percentage of coastal cells in each 5% land area bin where model Tmax is more than 2C below weather station Tmax. All data 10 year monthly averages 2001 to 2010

It is clear from figure 2 that about 60% of coastal cells have Tmax(ERA5) 2C or more cooler than Tmax(weather stations). On average only 5% of coastal cells have their Tmax(CRU) 2C or more below Tmax(weather stations).

Stage 1b results: Comparing the coastal cell Tmax monthly variation.

From the results in stage 1a, it is clear that CRU 4.01 is a good substitute for weather station data with about 5% of CRU cells where Tmax(CRU) is 2C or less below Tmax(weather stations). As we are interested in global coastal grid cells, not just those with a weather station, analysis in stage 2 is comparing Tmax(models) with Tmax(CRU).

In this global coastal grid cell analysis we also included the EWEMBI and W5E5 models that are used by PIK to bias correct the ISIMIP climate models. We did this to determine how strong the effect of ERA5 was on EWEMBI used to bias correct ISIMIP2b and on W5E5 used to bias correct ISIMIP3b. Figure 3 clearly shows that Tmax(ERA5) is at least 2C less than Tmax(CRU) in most coastal cell bins ranging up to 80% land cover.

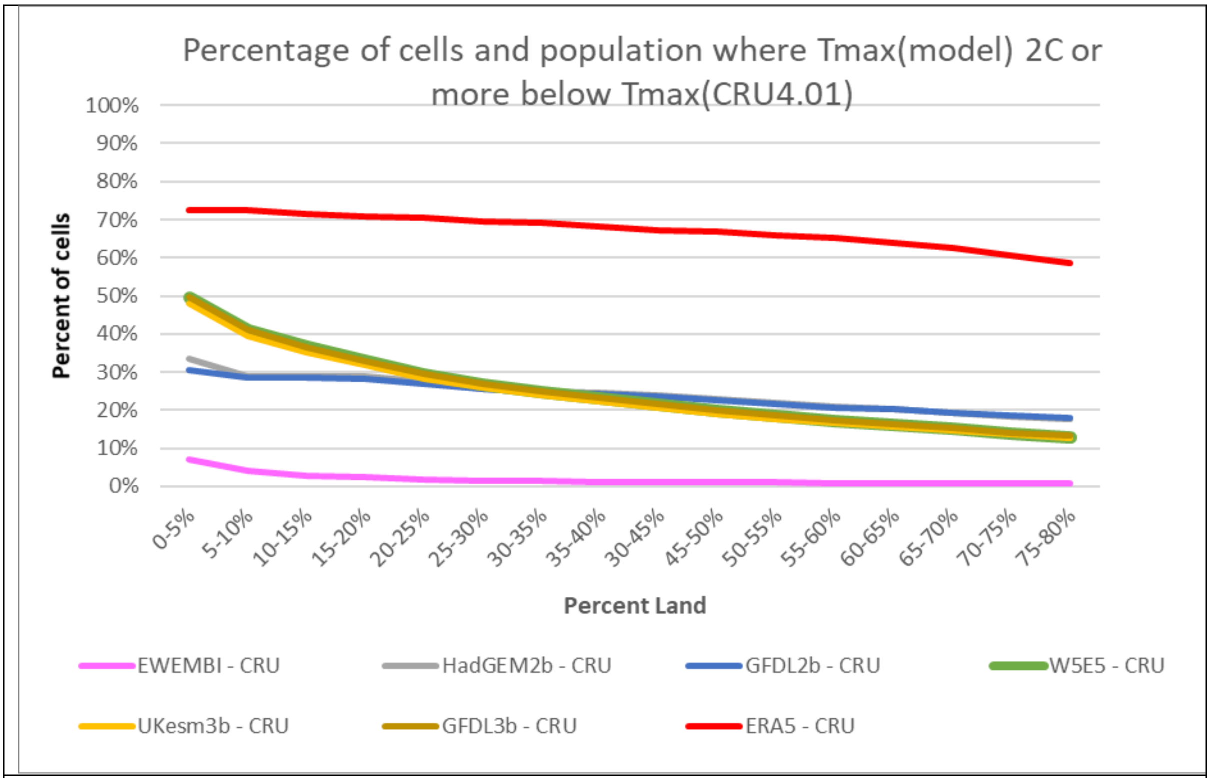

Figure 3 Percentage of coastal cells in each 5% land area bin where model Tmax is more than 2C below CRU Tmax. All data 10 year monthly averages 2001 to 2010

It is also striking that EWEMBI does not seem to have a problem with coastal cells except for very low land cover. This indicates that the influence of the sea temperatures of ERA-Interim on EWEMBI is minimal. The Tmax(W5E5) curve closely tracks Tmax(GFDL3b) and Tmax(UKesm3b) indicating that for 2001-2010 the bias correction of ISIMIP3b against W5E5 is excellent for coastal cells. However, even though the Tmax(EWEMBI) is almost the same as Tmax(CRU) for most coastal cells, the bias correction of ISIMIP2b against EWEMBI is not good, as shown by the large difference between ISIMIP2b comparisons and EWEMBI comparisons in Figure 3.

The main answer we were seeking was whether ISIMIP3b was better than ISIMIP2b in relation to the impact on population. As population 2001-2010 average had been assigned to each grid cell, we were able to do an impact study of the number of people affected by the coastal cell issue for the various models. This population has now been included in Figure 4. Our impact studies only involved ISIMIP data, so the ERA5, EWEMBI and W5E5 climate data has been removed in Figure 4 to allow for an expanded population scale for the remaining models.

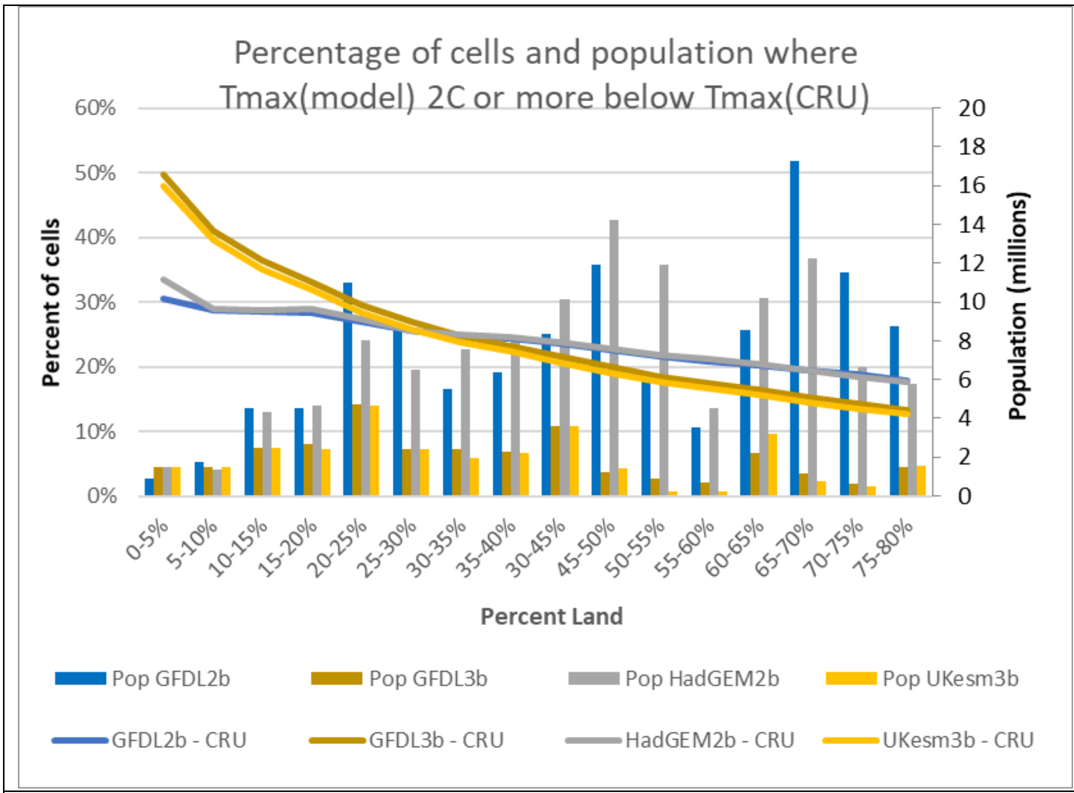

Figure 4 Left axis: Percentage of coastal cells in each 5% cell land area bin where Tmax(model) is more than 2C below Tmax(CRU). Right axis: Population in each land percent bin with Tmax(model) 2C or more below Tmax(CRU) shown by the vertical clustered column bars.

What is immediately obvious from Figure 4 is that while the percentage of ISIMIP3b cells is above the ISIMIP2b cells with less than 30% land, the population in the cells with more than a 2C difference between Tmax(ISIMIP3b - CRU) is much higher in ISIMIP2b especially when the land cover of the cell is greater than 45%. Adding the population in all coastal bins, the total population of the ISIMIP2b grid cells which have Tmax(ISIMIP2b) more than 2C lower than Tmax(CRU) is about 118M, while for ISIMIP3b there are only about 50M people in coastal cells where Tmax(ISIMIP3b) is 2C or more lower than Tmax(CRU). This can be explained because the 2C lowering of Tmax(ISIMIP2b) occurs predominantly in cells with a larger land area which are able to sustain higher populations. In particular one of the grid cells in the 65-70% land area bin was Chennai. In an earlier report (B Lemke 2019 ISIMIP2b report) there are 3-4M million people living in just one coastal cell where Tmax(GFDL2b) was 4C less than Tmax(CRU). This was caused by a faulty bias correction process used in ISIMIP2b where the maximum allowable bias correction was 3C (Lange S 2018).

Table 2 shows the result when Tmax(CRU) is subtracted from the models, including EWEMBI and W5E5. The Tmax when the Tmax(model) has the highest difference from Tmax(CRU) is indicated in the table as “Max” because we are subtracting the Tmax(CRU) from the Tmax(model). When Tmax(CRU) has the highest difference from the Tmax(model) it is labelled “Min”. The 90 percentile is the Tmax value where 10% of the largest model Tmax values are higher than the Tmax(CRU) and the 10 percentile value has 10% of the highest Tmax(CRU) less than the Tmax(model).

Table 2 Comparing coastal grid cell Tmax from models with CRU for summer months in the northern and southern hemisphere and tropics. The table shows the mean difference from the Tmax(CRU), the maximum and minimum difference, the 90 percentile and 10 percentile and the standard deviation for each of the climate zones. Note that "Max" means the largest Tmax(model) in excess of Tmax(CRU) and "Min" means the largest Tmax(CRU) in excess of the Tmax(model)							
Coastal cells	GFDL2b-CRU	GFDL3b-CRU	HadGEM2b-CRU	UKesm3b-CRU	EWEMBI-CRU	W5E5-CRU	ERA5-CRU
Latitude= 23.4 to 66.6 (North of Tropics)				June, July, August			n=10296
Max	2.87	2.91	3.22	3.27	1.87	1.93	4.65
90Perc	0.94	0.94	1.04	1.41	0.7	0.59	-0.06
Average	-0.38	-0.48	-0.38	-0.21	0.1	-0.48	-3.02
10Perc	-2.05	-2.84	-2.39	-2.49	-0.52	-2.89	-6.58
Min	-6.13	-11	-6.77	-11.7	-5.79	-11.27	-15.11
SD	1.22	1.82	1.4	1.9	0.54	1.71	2.61
Latitude= -66.6 to -23.4 (South of Tropics)				January, February, December			n=2100
Max	1.97	2.1	1.96	2.77	1.49	1.19	3.78
90Perc	1.06	1.03	1.05	1.19	0.71	0.65	-0.18
Average	0.1	-0.05	-0.12	0.08	0.24	-0.16	-3.03
10Perc	-1.18	-1.85	-1.74	-1.74	-0.23	-1.94	-6.29
Min	-5.05	-10.42	-5.73	-9.76	-5.22	-10.04	-10.7
SD	1.01	1.69	1.19	1.67	0.5	1.65	2.36
Latitude= -23.4 to 23.4 (Tropics)				March, April, May			n=7977
Max	2.17	2.67	2.48	3.39	1.94	1.87	7.68
90Perc	1.02	1.27	1.07	1.54	0.93	0.84	-0.49
Average	-0.76	-0.04	-0.58	0.13	0.44	-0.22	-2.92
10Perc	-3.22	-3.19	-2.96	-3.12	0.02	-3.28	-5.25
Min	-6.97	-15.36	-6.26	-14.98	-9.5	-15.24	-16.33
SD	1.67	1.8	1.59	1.85	0.59	1.73	2.09
Latitude= -23.4 to 23.4 (Tropics)				September, October, November			n=7977
Max	2.7	3.05	3.03	3.7	1.74	1.96	6.35
90Perc	1.03	1.3	1.1	1.58	0.94	0.86	-0.5
Average	-0.75	-0.04	-0.57	0.15	0.47	-0.21	-2.85
10Perc	-3.22	-3.09	-2.95	-3.06	0.04	-3.15	-5.23
Min	-6.52	-9.87	-6.38	-9.36	-6.33	-9.74	-11.7
SD	1.7	1.81	1.62	1.87	0.55	1.72	1.96

What stands out in table 2 is that all values (Mean, Max, Min, 10 percentile and 90 percentile) are about 2-3C less then CRU data for the ERA5 model. The EWEMBI model has the least difference from the CRU data except in the tropics where it is about 0.45C higher than the CRU data.

The monthly variation of Tmax for all the models is shown graphically in Figure 5a, 5b and 5c.

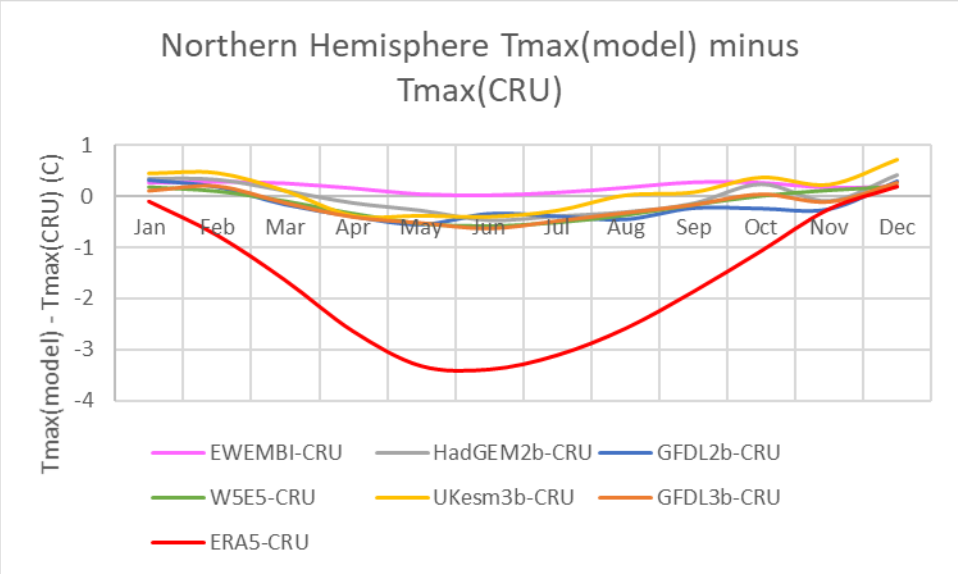

Figure 5a Northern Hemisphere Tmax difference of the 7 models from CRU

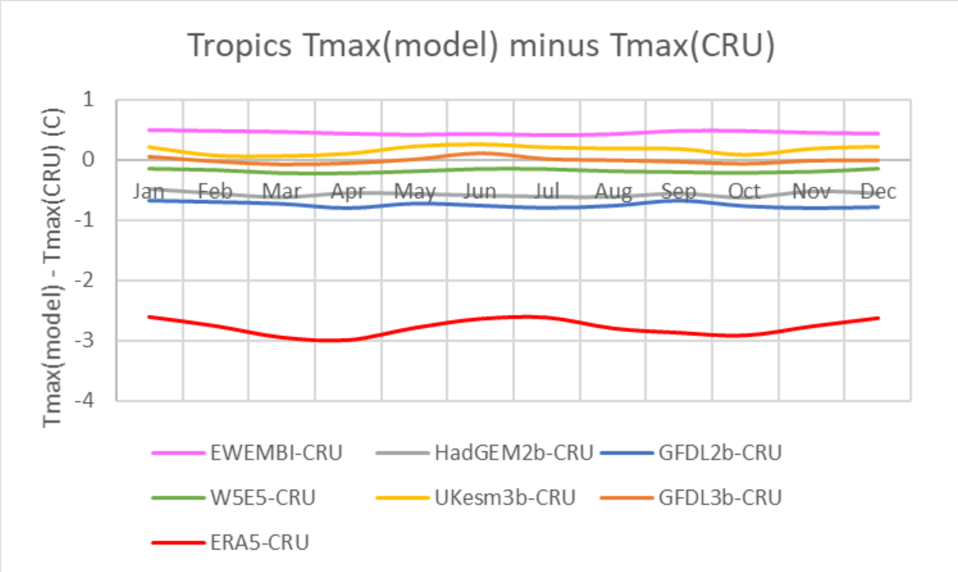

Figure 5b Tropics Tmax difference of the 7 models from CRU

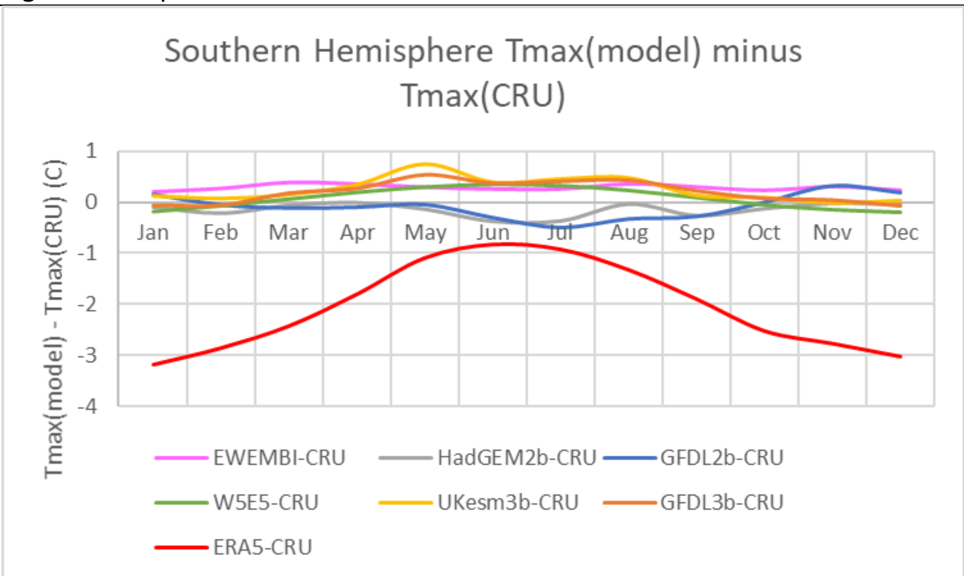

Figure 5c Southern Hemisphere Tmax difference of the 7 models from CRU

It is clear from figures 5a-5c that for all months the deviation of Tmax for all the models from the Tmax of CRU is less than 0.8C except for ERA5. Note that during the cooler months in the non-tropical regions ERA5 is close to that of the other models but when the land warms up the deviation becomes large, with Tmax(ERA%) lower than Tmac(CRU) by 3C or more in the hottest months.

Results Stage 2 Comparing Tmax for Coastal Grid cells in countries.

The difference between the model data and CRU for coastal cells in all countries was determined in this section. While 202 countries have a coastline, about 25% of these are small island states. The previous section shows that in coastal cells Tmax(models) were generally lower than Tmax(CRU) for warmer months. However, in this report, while data is available for each month separately, the results shown are for all global coastal cells for all months. This is because some countries (eg tropical countries) have all 12 months where the Tmax difference is high so by limiting to only some months is unlikely to give a good representation of the overall coastal Tmax depression. Figure 4 also shows that some coastal grid cells have a very large difference in Tmax but had a very small population, while others have a small difference in Tmax but a high population (Mumbai is a good example). A country population weighted Tmax was therefore included below.

Part 2a Tmax difference values only

The number of countries where Tmax(model) was less than Tmax(CRU) on **average** by 1C or more for all that country's coastal cells was GFDL2b=65, GFDL3b=54, HadGem2b=66 and UKesm3b=56.

ERA5 had 184 countries (out of 202) with the average coastal Tmax(ERA5) lower than Tmax(CRU) by 1C or more.

There were no countries where the average difference of Tmax(model) minus Tmax(CRU) was greater than 1C.

Note that the 1C difference indicate an acceptable difference for our impact work.

The countries that figured on this list were almost all Island countries (see also table 3): Aruba, Aland Islands, American Samoa, Antigua and Barbuda, Bahrain, Bonaire, Saint Eustatius and Saba, Bahamas, Bermuda, Barbados, Cocos (Keeling) Islands, Cook Islands, Comoros, Cape Verde, Curacao, Christmas Island, Cayman Islands, Cyprus, Dominica, Federated States of Micronesia, Guernsey, Grenada, Guam, Jamaica, Jersey, Kiribati, Saint Kitts and Nevis, Saint Lucia, Saint-Martin (French part), Maldives, New Caledonia, Northern Mariana Islands, Montserrat, Malta, Mayotte, Nauru, Palau, Puerto Rico, Solomon Islands, Saint Pierre and Miquelon, Seychelles, Singapore, Turks and Caicos Islands, Tokelau, Tuvalu, Saint Vincent and Grenadines, US Virgin Islands, Wallis and Futuna Islands, Samoa.

Table 3. Countries with coastlines where the average (for all coastal cells) of Tmax(model) was lower than Tmax(CRU) by 1C or more. Country list excludes any small island cells listed above.

	Tmax(GFDL 2b – CRU)	Tmax(GFDL 3b – CRU)	Tmax(HadGEM 2b – CRU)	Tmax(UKesm 3b – CRU)	Tmax(ERA5 – CRU)
Number of countries	65	54	66	56	184
Countries with Tmax difference of all cells > 1C excluding small island states	GuineaBissau Equat.Guinea Brunei Cameroon Iceland Mozambique Papua-NG Timor-Leste	Greece GuineaBissau Senegal	Azerbaijan Brunei Greece Indonesia Pakistan Portugal Qatar South Korea	Germany Denmark Estonia Finland Greece Sweden	Too many to list but include: Australia Brazil, Greece Indonesia India, Mexico Turkey South Africa

Part 2b Population weighted Tmax difference.

When population weighting is introduced, many of these small island countries were not significant in their impact because of their low population. So we multiplied the Tmax(model - CRU) by the population IN EACH grid cell and then repeated the averaging of all coastal cells in each country. For example, if the Tmax difference is 2C then a population of 100,000 in a grid cell will give a 200,000 person-degrees difference.

If the country average of all coastal cells when Tmax(model-CRU)*Population was less than -100,000 the number of countries were as follows: GFDL2b=66, GFDL3b=64, HadGem2b=63, UKesm3b=83. The country with the largest difference was Bahrain. See table 4 for more detailed data but where a 1M criteria was used so the table did not become too large.

For ERA5 there were 121 countries where the country average of all coastal cells when Tmax(ERA5 - CRU)*Population was less than -100,000.

Table 4. Name of countries including their affected coastal populations where the coastal cell population weighted average Tmax(model) differed from Tmax(CRU) by over the 1M person-degree threshold. The values in the models*Population columns are in bold-italics where for the models where the 1M person-degree threshold is exceeded. Positive values of Tmax(model **-** CRU)*Population indicates Tmax(model)> Tmax(CRU) while a negative values indicates Tmax(CRU)>Tmax(model) when population weighted. Country population for 2010. (The World Bank Group 2020).

Country	Coastal Populat^n	Country Populat^n	GFDL2bDiff *Populat^n	GFDL3bDiff *Populat^n	HadGEM Diff *Populat^n	Ukesm Diff *Populat^n	ERA5 Diff *Populat^n
Bahrain	0.83	1.241	-0.27	***-2.88***	***-1.99***	***-2.79***	***-3.07***
Bangladesh	0.58	147.575	-0.04	0.00	-0.10	0.27	***-2.11***
Benin	1.50	9.199	***1.25***	0.78	***1.47***	0.80	***-6.20***
Côte d'Ivoire	0.63	20.533	0.53	0.28	0.65	0.41	***-1.62***
El Salvador	0.39	6.184	-0.16	0.35	0.22	0.44	***-1.06***
Gambia	1.12	1.793	0.99	0.75	0.58	***1.06***	***-6.42***
Hong Kong	4.46	7.024	***1.32***	0.47	***1.61***	***1.53***	***-7.50***
India	9.23	1234.28	-0.19	0.35	0.26	0.43	***-2.42***
Israel	1.18	7.624	-0.21	0.25	***1.05***	***1.02***	***-1.61***
Kuwait	0.71	2.992	-0.52	-0.20	-0.27	0.06	***-2.21***
Lebanon	0.59	4.953	-0.24	-0.15	-0.06	0.15	***-1.84***
Nigeria	0.53	158.503	0.36	0.22	0.29	0.25	***-1.31***
Pakistan	0.45	179.425	0.01	0.08	0.18	0.28	***-1.57***
Palestinian Territory	0.40	3.786	0.14	0.04	0.34	0.27	***-2.27***
Senegal	0.80	12.678	0.28	0.36	0.20	0.45	***-1.63***
Singapore	3.09	5.077	***1.40***	***2.54***	***-5.84***	***2.95***	***-12.14***
Togo	1.22	6.422	***1.07***	0.54	***1.25***	0.61	***-2.29***

From table 4, it is apparent that there is no country where the threshold is exceeded by any model and not exceeded in ERA5. Indeed for the newer ISIMIP3b models the 1M threshold is only exceeded in two countries for GFDL3b and in five countries for UKesm while the 1M threshold is exceeded for all 15 of the listed countries for ERA5.

Conclusion.

The first part of this report showed that Tmax(CRU) was a good substitute for Tmax(weather stations) in comparing model data to the best real (historical) data. CRU covers more coastal grid cells (6791) than just weather station data (909 grid cells). This included grid cells with high populations that did not contain a weather station. CRU has a very minimal mean offset from weather station data (0.01C) and a lower standard deviation (1.46C) than other models.
The Tmax deviation of all the models (except ERA5) from the Tmax of CRU was less than 0.8C for all months. While the deviation of ERA5 was over 3C for the hottest months when the land temperature is expected to be higher than the sea temperature.

When models are compared with CRU or weather stations at a country level, Tmax(ISIMIP – CRU) is better for all ISIMIP models than is for Tdew(ISIMIP – CRU) (B Lemke 2021 Tdew report). On the other hand ERA5 is decidedly worse for Tmax(ERA5 – CRU) than for Tdew(ERA5 – CRU).

Overall, if ISIMIP3b is being used there are no serious issues with Tmax, Tdew and Tmean in the calculation of population impacts like work hours lost using WBGT (a combination of temperature and humidity). The only exceptions being highly populated island states with proportionally high coastal cells: namely Singapore, Hong Kong and Bahrain. However caution needs to be used when using ERA5 for coastal cells when calculating impacts on land based activities.

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