# Differences between the dew point of climate models compared to weather station (and derived) data in coastal cells.


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**Introduction**
We have recently produced a report on the maximum monthly temperatures (Tmax) in coastal cells showing the Tmax of the land in coastal cells is reduced by the Tmax of the water in that cell (B Lemke 2021 Tmax report). Many people live along the coast so this reduction in Tmax of coastal cells will reduce the impact we are studying – the impact of heat on working people. The other component of the heat impact on workers is the humidity so it was suggested that the issues we found with Tmax may also be apparent in the humidity expressed as the dew point temperature (Tdew). One significant issue (B Lemke 2021 TminRH report) we discovered with Tdew was that as it got cooler during the autumn months in the temperate zone, the night time drop in the minimum temperature dragged the Tdew down once the minimum temperature was below Tdew. This did not have a significant effect on Tmin, but Tdew, which taken as constant over 24 hours was at time considerably reduced from the day-time Tdew by the Tdew reduction (up to 5C during the night. Hence the average daily Tdew was reduced up to 5C from what it was at the maximum temperature where the higher impact (WBGT) was calculated. This error appeared in CRU data and weather station data and is not addressed in this paper which is primarily concerned with ISIMIP climate models.

**Method:**
We have developed a table of ½ x ½ degree grid cell Tdew data for various models so they can be directly compared. This table has monthly Tdew data averaged over 10 years 2001 to 2010 for all models we use and weather station (GSOD 2020) data: CRU TS 4.0x (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 data (ISIMIP 2020/21) used for bias correction of ISIMIP3b and based on CRU (land cells) and ERA5 (ocean cells).

Tdew is not directly available for most models so for models GFDL2b, HadGEM2b, EWEMBI and W5E5 Tdew was calculated from RH; Tdew for models GFDL3b and UKesm3b was calculated from Specific Humidity, Tdew from CRU4.04 was calculated from vapour pressure and Tdew was obtained directly from ERA5 models and weather stations. Formulas for these conversions are in Appendix 1.

**Stage 1 coastal grid cell comparison.**
Each grid cell had an associated land percent, 2010 population (CIESIN 2021), altitude, latitude and longitude. It also included the name of the country that occupies the greatest proportion of the grid cell (important when there are two or more countries in a grid cell). As we are not interested in Tdew for colder regions, we excluded all weather stations and grid cells in the polar circle (greater than 66.5 degrees) and above 1000m. We only considered coastal cells that had less than 80% land.
By using weather stations, cells with high populations but no weather stations (eg in large cities that span 2 grid cells), are excluded so in this analysis CRU TS4.0x data was used for comparison with the models. A comparison between CRU data and weather stations that occupied the same grid cell showed good agreement for Tdew except for about 10 grid cells that had obvious CRU errors and are presented in a separate report (B Lemke 2021 CRU report).

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 were used 920 grid cells remained.

**Stage 2: Comparing country wide coastal grid cell data**
As we had country data in our table we could do a country by country analysis to see what country impacts were most affected by any potential errors in the coastal Tdew values.
The difference between the model data and CRU and weather stations for coastal cells in all countries was determined. Out of the total of 245 countries in our table, 199 have a coastline, with about 25% of these being small island states.

As with the previous report some coastal grid cells had a very large difference in Tdew but had a very small population, while others had a small difference in Tdew 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 Tdew(model) deviated by 1C or more from Tdew(CRU) was also recorded.

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

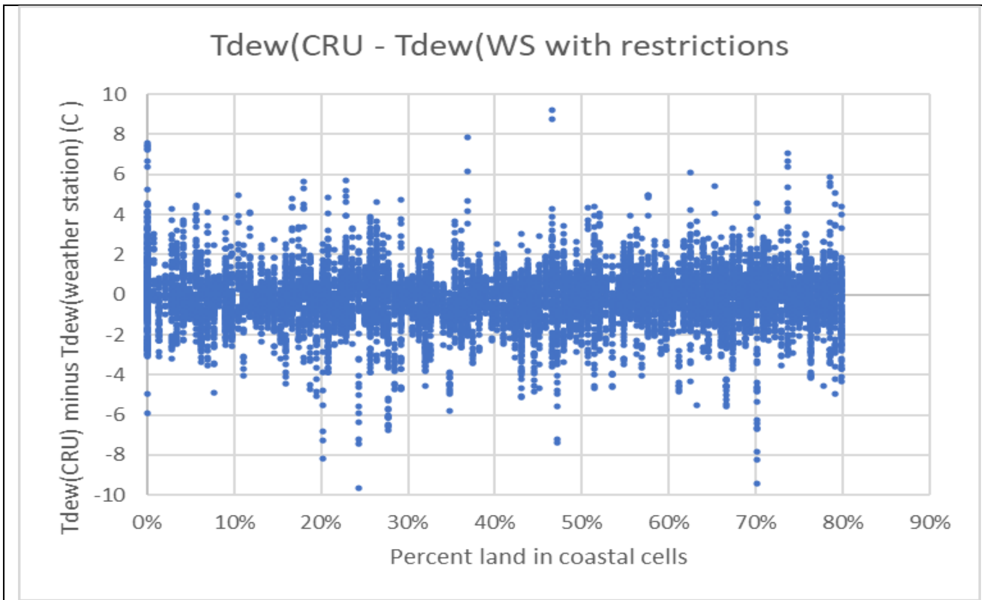


Figure 1 Tdew(CRU) minus Tdew(weather stations) vs percent land cover in coastal cells with the restrictions: no polar weather stations, no weather stations above 1000m only grid cells with weather stations. All grid cells deemed as coastal with less than 80% land in them.

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).

Table 1 shows the comparison of the difference between weather stations and ISIMIP3b models, CRU4.04 and ERA5 in coastal cells. It is clear from the mean values of Tdew(ERA5) does not have the same significant offset as for Tmax(ERA5). In general Tdew has less variation (lower standard deviation) than Tmax and except for CRU, all Tdew values are closer to weather station data than Tmax values.

Table 1 comparison of Tdew and Tmax difference between the ISIMIP3b/ERA5/CRU4.04 and weather stations in coastal cells. Model minus weather station (WS) all months 2001-2010

| Model minus WS all months 2001 to 2010 | Mean | Standard deviation |
|---|---|---|
| Tdew(CRU) minus WS | -0.17 | 1.35 |
| Tdew(GFDL3b) minus WS | 0.09 | 1.40 |

| | | |
|---|---|---|
| Tdew(UKesm3b) minus WS | 0.29 | 1.45 |
| Tdew(ERA5) minus WS | 0.31 | 1.13 |
| Tmax(CRU) minus WS | 0.01 | 1.46 |
| Tmax(GFDL3b) minus WS | -0.39 | 1.95 |
| Tmax(UKesm3b) minus WS | -0.38 | 2.01 |
| Tmax(ERA5) minus WS | -2.15 | 1.67 |

**Stage 1b Coastal grid cells where models and CRU have a significant Tdew difference**

Coastal grid cells had a very large difference in Tdew often had a small population while others had a small difference in Tdew but a high population, so we included a country population weighted Tdew (unit = person-degrees) (see figure 2).
What is immediately apparent from these figures is that the very high population in coastal cells found with Tmax(ERA5) (figure 2b) is not apparent in Tdew(ERA5). Indeed the largest population in coastal grid cells where Tdew(model – CRU4.0x) was 2C or more was in ISIMIP2b which now fortunately has been superseded by ISIMIP3b. ERA5 has even lower populations in all coastal grid cell bins where Tdew(ERA5 – CRU4.0x) was 2C or more.
Note also that the population and percentage land in each cell was exactly the same for all models. The population difference in figure 2 is based on the different Tdew values for those cells in the different models. For example in the 45% to 50% land area bin the cells where Tdew(model) was 2C or lower than Tdew(CRU) has a population of 13M for HadGEM2b, 12.5M for GFDL2b, 1.8M for GFDL3b, 0.8M for HadGEM and 0.2M for ERA5.

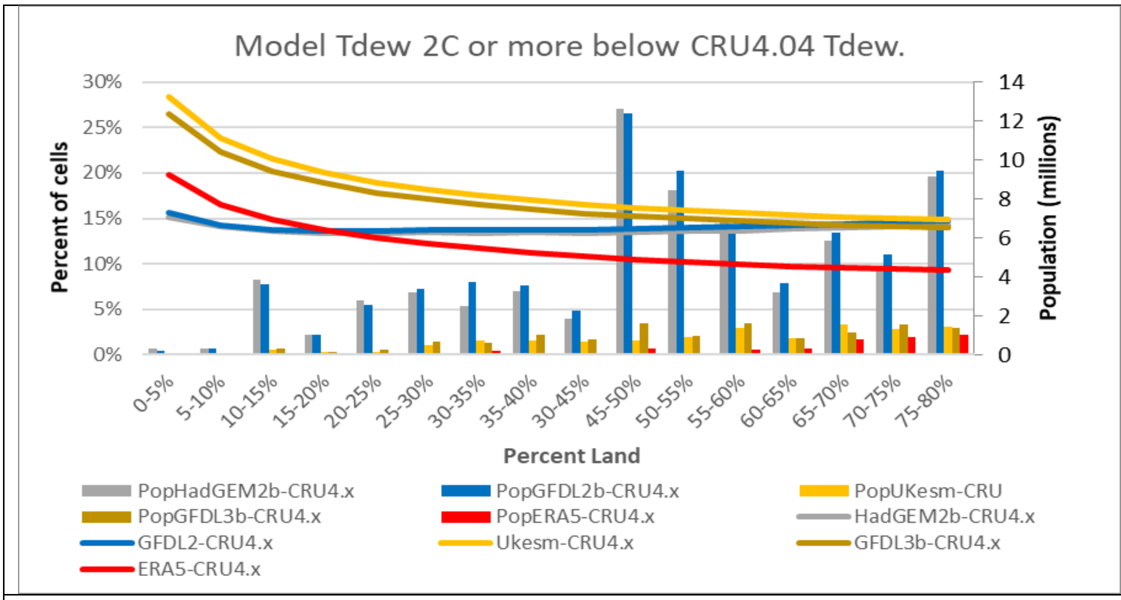


Figure 2a Tdew Comparison Left axis: Percentage of coastal cells in each 5% cell land area bin where Tdew(model) is more than 2C below Tdew(CRU). Note that the HadGEM2b line is behind the GFDL2b line. Right axis: Population in each percent land bin as shown by the vertical clustered column bars.

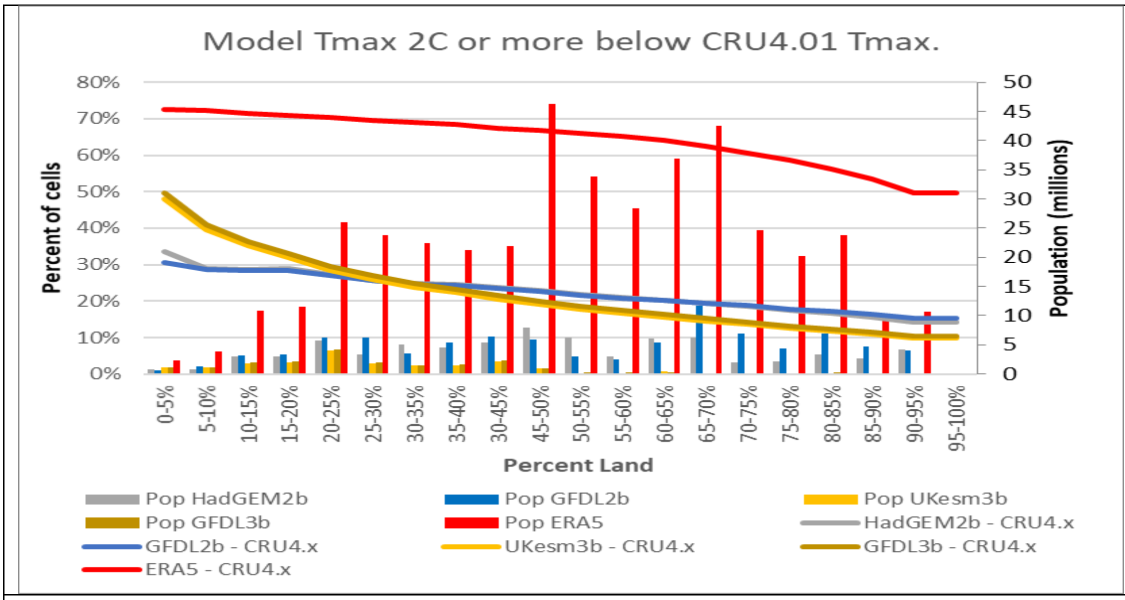


Figure 2b Tmax comparison. Same left and right axis units as for figure 2a.

From the above analysis it appears that Tdew(ISIMIP3b) has less problems than Tmax(ISIMIP3b) Tdew(ERA5) has very much less problems than Tmax(ERA5). Indeed the above results show that in general Tdew(ERA5) is much closer to Tdew(CRU) than is Tdew(ISIMIP).

Table 2 Comparing coastal grid cell Tdew from models with CRU for summer months in the northern and southern hemisphere and tropics. The table shows the mean difference from Tdew(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 Tdew(model) in excess of Tdew(CRU) and "Min" means the largest Tdew(CRU) in excess of the Tdew(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 | 10.08 | 12.02 | 9.71 | 12.65 | 16.59 | 11.67 | 11.47 |
| 90Perc | 1.42 | 2.24 | 1.50 | 2.51 | 3.53 | 2.11 | 2.18 |
| Average | -0.51 | 0.27 | -0.60 | 0.63 | 0.68 | 0.21 | 0.23 |
| 10Perc | -2.31 | -1.45 | -2.32 | -1.01 | -1.21 | -1.47 | -1.49 |
| Min | -18.14 | -13.23 | -25.17 | -13.90 | -4.30 | -13.38 | -11.05 |
| SD | 2.00 | 1.77 | 2.21 | 1.74 | 2.51 | 1.75 | 1.81 |
| Latitude= -66.6 to -23.4 (South of Tropics) | | | | January, February, December | | | n=2100 |
| Max | 9.38 | 10.91 | 8.57 | 11.18 | 11.44 | 10.74 | 10.69 |
| 90Perc | 2.18 | 2.84 | 1.87 | 3.03 | 4.83 | 2.68 | 2.53 |
| Average | -0.16 | 0.68 | -0.61 | 0.96 | 1.69 | 0.63 | 0.62 |
| 10Perc | -2.29 | -1.00 | -2.90 | -0.94 | -0.80 | -1.20 | -0.85 |
| Min | -7.91 | -8.64 | -16.02 | -9.24 | -3.67 | -9.01 | -9.02 |
| SD | 1.95 | 1.72 | 2.20 | 1.76 | 2.34 | 1.76 | 1.65 |
| Latitude= -23.4 to 23.4 (Tropics) | | | | March, April, May | | | n=7977 |
| Max | 5.41 | 7.98 | 5.50 | 8.43 | 19.85 | 8.22 | 7.98 |
| 90Perc | 1.71 | 2.14 | 1.61 | 2.31 | 3.12 | 2.05 | 1.80 |
| Average | -0.03 | 0.62 | -0.23 | 0.78 | 0.90 | 0.48 | 0.33 |
| 10Perc | -2.19 | -0.66 | -2.34 | -0.49 | -0.92 | -0.83 | -0.82 |
| Min | -17.50 | -14.24 | -25.18 | -13.19 | -4.31 | -14.60 | -13.04 |
| SD | 1.87 | 1.42 | 2.45 | 1.40 | 2.06 | 1.44 | 1.32 |

| Latitude= -23.4 to 23.4 (Tropics) | | | | September, October, November | | | n=7977 |
|---|---|---|---|---|---|---|---|
| Max | 7.16 | 10.19 | 8.17 | 9.37 | 13.83 | 9.33 | 11.60 |
| 90Perc | 1.93 | 2.25 | 1.90 | 2.37 | 3.33 | 2.16 | 2.12 |
| Average | 0.06 | 0.75 | -0.09 | 0.91 | 1.01 | 0.64 | 0.48 |
| 10Perc | -2.06 | -0.66 | -2.35 | -0.50 | -0.76 | -0.82 | -0.79 |
| Min | -15.70 | -10.54 | -25.03 | -11.32 | -3.99 | -12.16 | -11.61 |
| SD | 1.85 | 1.45 | 2.49 | 1.44 | 1.89 | 1.47 | 1.44 |

What stands out in table 2 is very much larger extreme values (Max and Min) for all models for Tdew compared to Tmax (see Tmax Report). The Standard deviation of the Tdew values is also approx. 0.5C higher than it is for Tmaxat all values. The mean value is also somewhat higher than that for Tmean in many of the models. This time the EWEMBI model is not the best and the ERA5 models is as good as any of the other models so highlighting the very great depression of the ERA5 Tmax in the previous report.

The monthly variation of Tmax for all the models is shown graphically in Figure 3a, 3b and 3c.

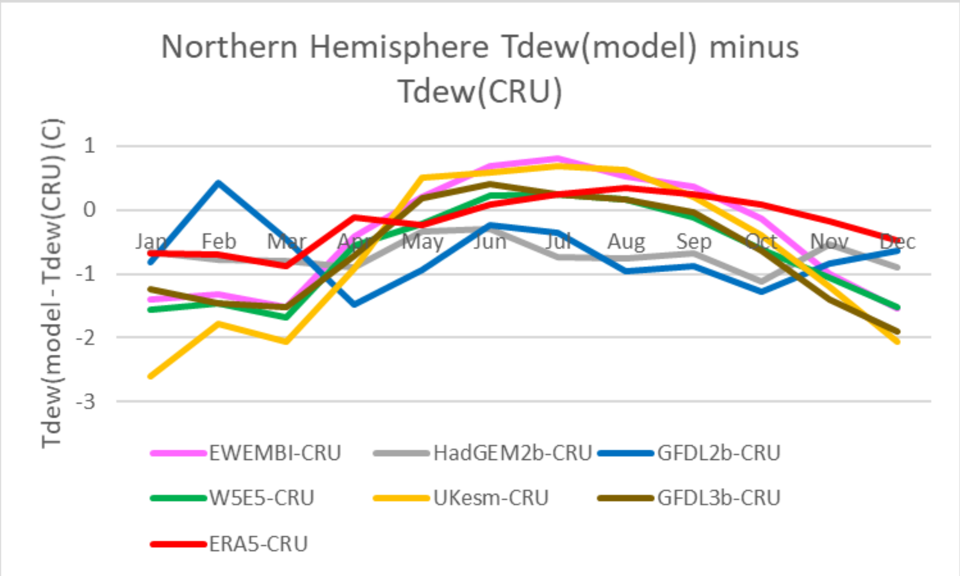


Figure 3a Northern Hemisphere Tdew difference of the 7 models from CRU

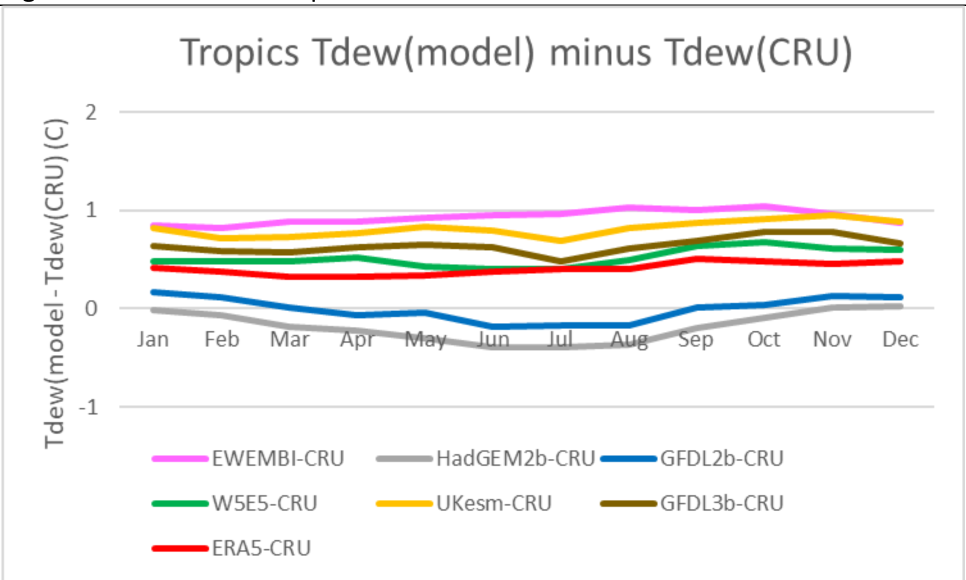


Figure 3b Tropics Tdew difference of the 7 models from CRU

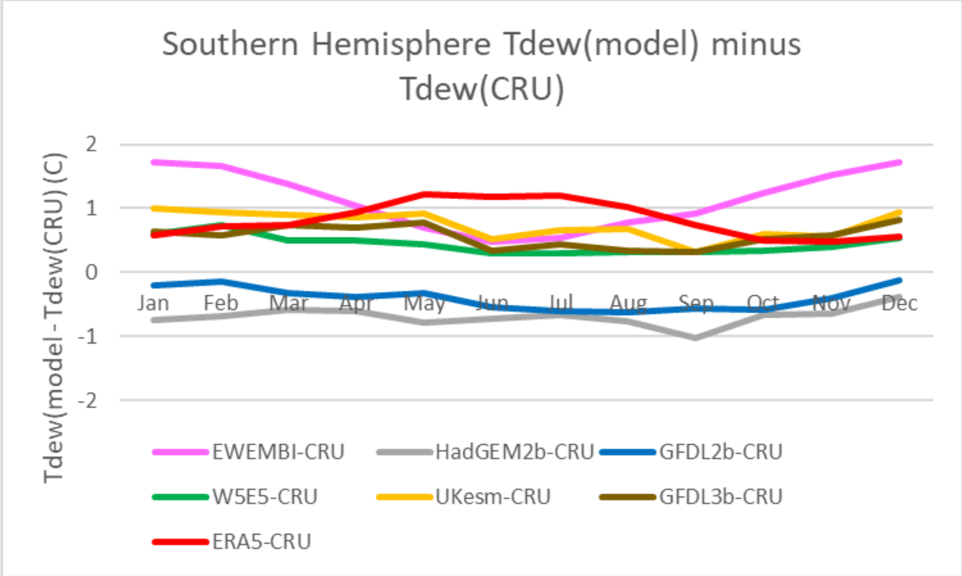


Figure 3c Southern Hemisphere Tdew difference of the 7 models from CRU

It is clear from figures 3a-3c that for all months the deviation of Tdew for all the models from the Tdew of CRU is mostly less than +/- 1 except for EWEMBI which is 1.8 higher than Tmax(CRI) for the Southern Summer. For the northern hemisphere summer all Tdew(models) are +/- 1C from Tdew(CRU) but for the winter months, many models have the average cell Tdew(models) up to 3C below the Tdew(CRU).

**Results Part 2 Tdew in country coastal cells**

**2a Tdew difference only**

The number of countries where Tdew(model) was different from Tdew(CRU) on **average** by 2C or more for all that country's coastal cells was 27 for GFDL2b, 18 for GFDL3b, 35 for HadGem2b and 23 for UKesm3b. 2C was chosen rather than 1C not because this was an acceptable limit, but because 1C difference resulted in too many cells to list in the table 3.

The countries with coastlines that figured on this list were Albania, Algeria, Angola, Azerbaijan, Bahrain, Bermuda, Botswana, Chad, Croatia, Cyprus, Dominica, Egypt, Eritrea, Georgia, Greece, Guinea, Guyana, Iran, Iraq, Kuwait, Montenegro, Namibia, Niger, Oman, Pakistan, Palestinian Territory, Qatar, Saint Helena, Saudi Arabia, Sierra Leone, Sudan, Syria, Turkmenistan, United Arab Emirates, Yemen. It should be noted that while Bahrain had a Tmax(model) that was much lower than Tmax(CRU) (see previous report), it had a much higher Tdew(model) than Tdew(CRU). ERA5 had 20 countries where average coastal Tdew(ERA5) was different from Tdew(CRU) by 2C or more (see table 3).

Table 3. Number of countries with coastlines where the average Tdew difference from CRU data for all coastal cells is greater than 2C. Name of the countries where the difference is 2C or more.

| | Tdew(GFDL 2b-CRU) | Tdew(GFDL 3b-CRU) | Tdew(HadGEM2b-CRU) | Tdew(UKesm 3b-CRU) | Tdew(ERA5 -CRU) |
|---|---|---|---|---|---|
| Number of countries | 26 | 17 | 31 | 21 | 20 |
| Countries 2C or more average Tdew difference of all cells Excluding small island states and countries with 5 or less coastal grid cells | Angola<br>Eritrea<br>Iran<br>Namibia<br>Oman<br>Pakistan<br>Qatar<br>Saudi Arabia<br>Sierra Leone | Azerbaijan<br>Guinea<br>Namibia<br>Oman<br>Qatar<br>Saudi Arabia | Angola<br>Eritrea<br>Iran<br>Namibia<br>Oman<br>Pakistan<br>Qatar<br>Saudi Arabia<br>Sudan | Algeria<br>Azerbaijan<br>Cyprus<br>Egypt<br>Greece<br>Guinea<br>Namibia<br>Oman<br>Qatar | Algeria<br>Croatia<br>Cyprus<br>Egypt<br>Georgia<br>Greece<br>Qatar<br>Saudi Arabia |

| | | | | | |
|---|---|---|---|---|---|
| | Turkmenistan<br>UAE<br>Yemen | | Turkmenistan<br>UAE<br>Yemen | Saudi Arabia<br>Sierra Leone | |

**2b Population weighted Tdew difference.**

For population weighting we multiplied the Tdew(model) minus Tdew(CRU) by the population IN EACH grid cell and then repeated the averaging of all coastal cells in each country.

We identified countries where the country average of all coastal cells when Tdew(CRU)*Population was over 100000 greater than Tdew(model)*Population. This resulted in 61 countries for GFDL2b, 59 for GFDL3b, 66 for HadGem2b and 64 for UKesm3b and 54 for ERA5. Person-degrees is a difficult term to comprehend, we have listed those countries where the coastal person-degree data was the greatest and then included the population of that country in the coastal cells where the person-degrees is above 1M. Note the 1M threshold was chosen because of the space limitation in listing countries using a lower threshold.

Table 4. Name of countries including their affected coastal populations where the coastal cell population weighted average Tdew(model) differed from Tdew(CRU) by over the 1M person-degree threshold. The values in models*Population are shown in bold-italic where the person-degree is higher than 1 million. Data expressed as Tdew(model **-** CRU)*Population so a positive number indicates Tdew(model)>Tdew(CRU) and negative when Tdew(CRU)>Tdew(model) when population weighted. Country population for 2010. The World Bank Group 2020.

| **Country** | Coastal Populat$^n$ | Country Populat$^n$ | HadGEM Diff *Population | GFDL2b Diff *Population | UKesm Diff *Populat$^n$ | GFDL3b Diff *Population | ERA5 Diff *Populat$^n$ |
|---|---|---|---|---|---|---|---|
| Bahrain | 1.11M | 1.24M | -0.35M | -0.71M | ***2.52M*** | ***2.38M*** | ***2.42M*** |
| Bangladesh | 2.22M | 147.6M | 0.41M | 0.24M | ***1.08M*** | 0.97M | 0.83M |
| Benin | 1.50M | 9.20M | ***1.87M*** | ***1.89M*** | ***1.87M*** | ***1.74M*** | 0.18M |
| Gambia | 1.12M | 1.79M | ***-2.84M*** | ***-2.61M*** | 0.62M | 0.43M | 1.09M |
| Hong Kong | 4.59M | 7.02M | ***1.69M*** | ***1.44M*** | ***4.27M*** | ***3.18M*** | 4.29M |
| India | 0.98M | 1234M | -0.27M | -0.40M | 0.91M | ***1.02M*** | 0.39M |
| Kuwait | 0.62M | 2.99M | ***-3.69M*** | ***-4.04M*** | -0.03M | -0.30M | 1.41M |
| Pakistan | 2.27M | 179.4M | -0.31M | -0.27M | -0.34M | 0.27M | 0.33M |
| Palestinian Territory | 0.40M | 3.79M | 0.91M | 0.94M | ***1.59M*** | ***1.45M*** | ***1.17M*** |
| Senegal | 3.80M | 12.68M | ***-1.33M*** | ***-1.24M*** | 0.30M | 0.25M | 0.22M |
| Singapore | 5.08M | 5.08M | ***1.42M*** | ***1.53M*** | ***1.90M*** | ***1.25M*** | ***-3.22M*** |
| Taiwan | 1.79M | 23.19M | 0.49M | 0.30M | 0.48M | 0.29M | ***1.07M*** |

From Table 4, it can be seen that for Bahrain, Bangladesh and Hong Kong the Tdew(model-CRU)*Population have substantially increased for the ISIMIP3b versions. For the newer ISIMIP3b there are now no countries where Tdew(CRU)*Population is larger than Tdew(models)*population by the 1M person degree criteria we have used. For ERA5 only Singapore has Tdew(CRU)>Tdew(ERA5). For country-wide analysis the Tdew(ISIMIP3b/ERA5-CRU) difference is only significant for small population countries: Bahrain, Benin, Hong Kong, Palestine Territories and Singapore.

**Conclusion**

From this analysis the difference between Tdew(models) and Tdew(CRU) in coastal cells, while still significant, is generally less of a problem than the difference of Tmax(models) from Tmax(CRU). Coastal

Tdew(ISIMIP3b) results are better than for Tdew(ISIMIP2b) but the population affected by the difference from CRU is less for Tdew(ISIMIP3b) than for Tdew(ISIMIP2b). Tdew(ERA5) data compared favourably with Tdew(CRU). This is most likely due to the minimal difference of Tdew over the ocean compared to over the land for the coastal cells while for Tmax there will be significant land heating during the day compared to the ocean. These results give us confidence that Tdew values from all models are reasonable to use given the large scatter (standard deviation) in the data from which they were derived.

**Appendix:**

**Calculatiing Tdew from vapour pressure, RH and Specific Humidity**

In the following all pressures are in hPa.

Saturated vapour pressure of water e(s) <-> Ta where Ta = ambient temperature

e(s) = 6.112 exp ( 17.67 Ta / ( Ta +243.5 ) ) ……………………..equation 1

(Bolton, D (1980) eqns (10) and (11))

By definition Tdew is the temperature at which the vapour pressure of water in air (e) is saturated,

ie e = e(s)

Hence e = 6.112 exp ( 17.67 Td / ( Td +243.5 ) ) ………………equation 2

By definition RH = ( e / e(s) ) * 100.0 ………………………………equation 3

**So to calculate Tdew from Vapour Pressure (e)** we use the inverse of (1) with T = Tdew

Tdew =243.5 * Ln(e/0.6112)) / (17.67 - Ln(e/0.6112))) …….. equation 4

**And to calculate Tdew from RH** we use the two step process

x = log( RH ) +17.67 * Ta / (242.5 + Ta) -4.6051

Tdew = 243.5 * x / (17.67 - x )

For P = atmospheric pressure (hPa) and SH = specific humidity

e = SH * P / ( 0.622 + 0.378 * SH ) …………………………………. equation 5

(Davis, ER (2016) eqn (2) inverted)

**So to calculate Tdew from specific humidity** we first use equation 5 to get the vapour pressure, then equation 4 to get the dew point.

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