S1 Drought based groundwater model validation: drought duration

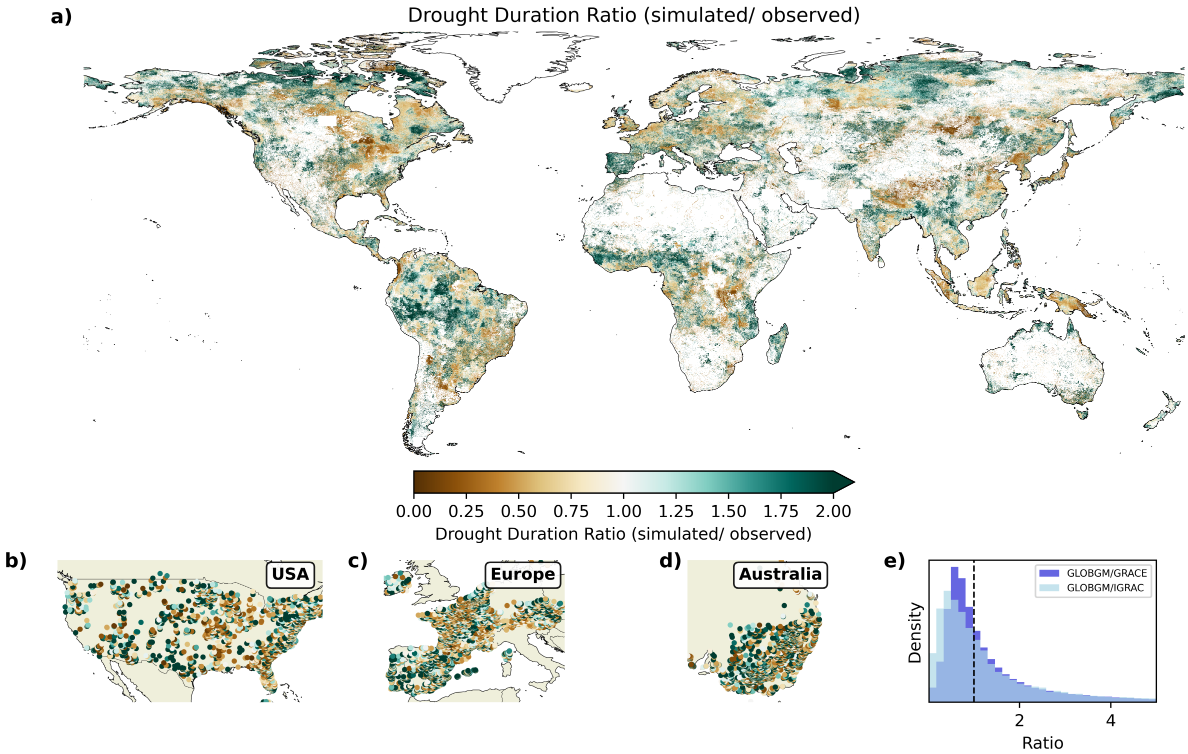

Figure S1: Ratio of average drought duration between a) observed GRACE and simulated groundwater data and b,c,d) point observations from the IGRAC data base and simulated groundwater data. 90% of all point observations in the IGRAC database (with sufficient data) are displayed in sub figures b, c, and d. e) compares the distribution of the drought duration ratio computed with GRACE and IGRAC datasets.

Figure S1 plots the ratio of the average drought duration as simulated by GLOBGM and the average drought duration calculated from the observed groundwater data. Figure S1a compares GLOBGM droughts to GRACE droughts and Figure S1b, c and d compare GLOBGM to observed point data from IGRAC. Values more than 1 imply that GLOBGM simulates longer droughts than those seen in the observational record, and visa versa, values less than one imply that the GLOBGM droughts are shorter than observed. Figure S1e shows the distribution of the drought duration ratio across the two observed datasets. The drought duration ratio is very varied across both observational datasets and there is no obvious global pattern. The distribution of drought duration ratios is also similar across both observational datasets. As mentioned in the main manuscript, the mean drought duration across the IGRAC observational data is 5.4 months and the median drought duration is 3.4 months. At the same locations, the simulated groundwater data has drought events with a mean duration of 6.4 months and a median duration of 2.9 months suggesting that the model records a greater number of long groundwater droughts at these locations which are not seen in the observational record. When comparing the global GRACE observational data to the simulated groundwater droughts, we see that GRACE records a mean drought duration of 5.5 months and a median of 4.3. Comparatively, in the regions which overlap with the GRACE coverage, the model simulates a mean drought duration of 9.9 months and a median of 5.4 months (note that this value differs from above because of only including data which overlaps with the observed data) suggesting that again the model simulates a greater number of long groundwater droughts.

S2 Meteorological drought duration (SPEI-12)

Figure S2 displays the global pattern of the average meteorological drought duration (calculated using SPEI-12). There is much less variation in this metric than observed in the groundwater (see Figure 2b in the main manuscript). The mean length of a meteorological drought is 6.7 months and the median is 6.3 months.

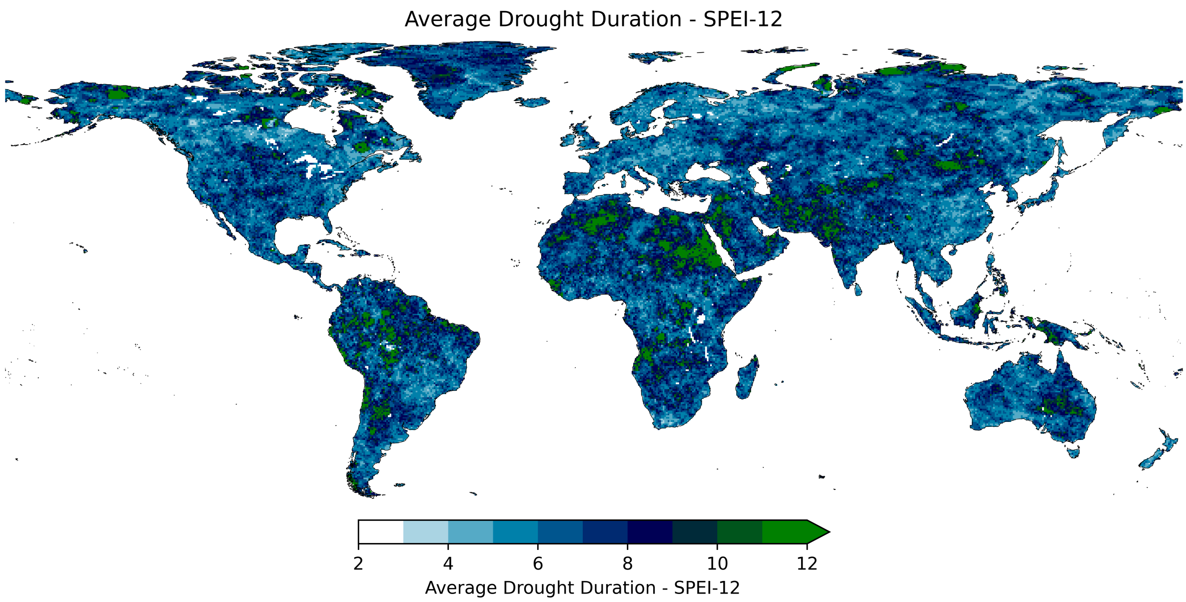

Figure S2: Global pattern of the average meteorological drought duration (calculated from SPEI-12).

S3 Distance to surface water

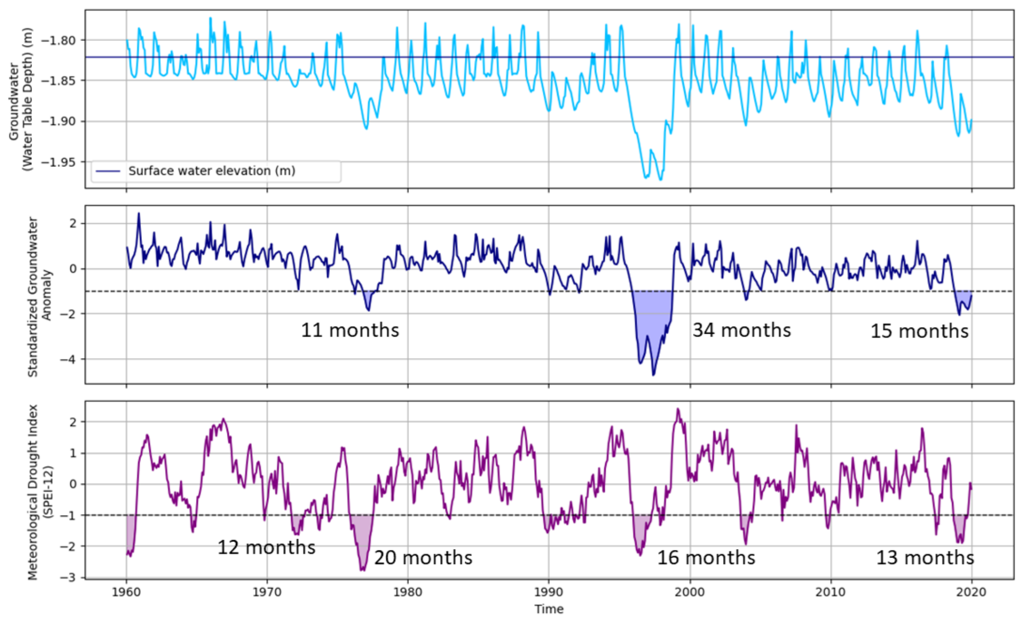

Figure S3: Timeseries displaying the raw groundwater water table depth (top), monthly standardized groundwater anomaly (middle) and SPEI-12 (bottom). The length of drought events has been annotated on. The timeseries in the top panel is accompanied by a line which shows the surface water elevation.

Figure S3 plots a representative timeseries from a location where the average groundwater drought duration is not multi-year despite spending more time in multi-year drought than normal drought. In the top panel, we observe the groundwater table depth rising above the surface water elevation annually. However, when there is a long meteorological drought, occasionally the groundwater table depth does not reach this threshold and instead the groundwater levels become disconnected from the surface water and we observe a long and often more intense groundwater drought. This is the same process as observed in Figure 4b in the main manuscript, but here the surface water elevation has been plotted alongside the raw groundwater timeseries. These long, more intense droughts are punctuated with several very short droughts which skew the average drought duration down.

S4 Dominant groundwater lag

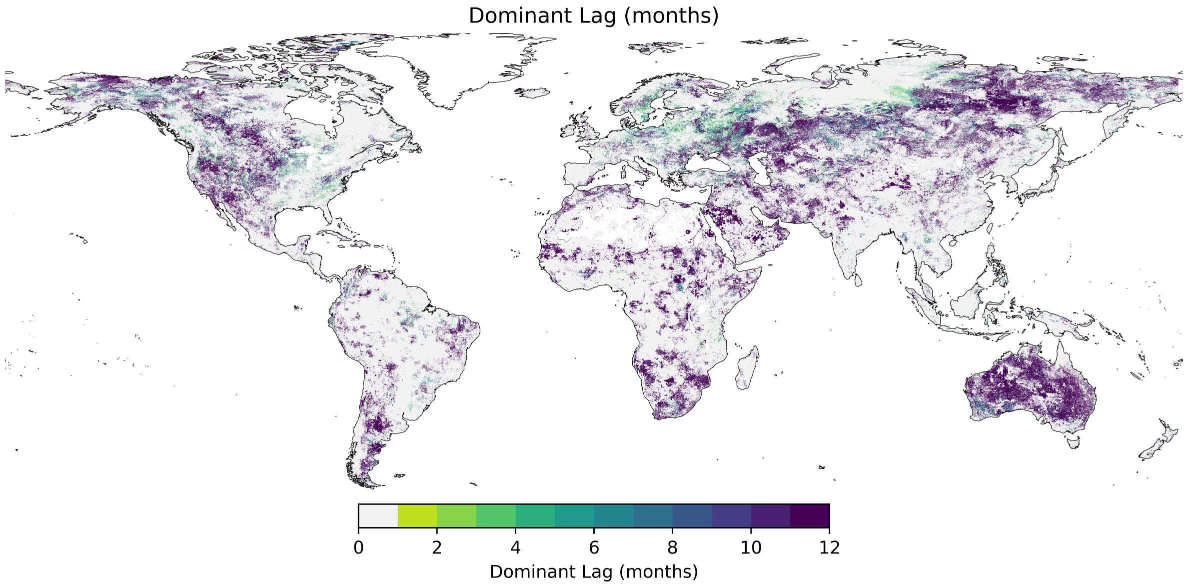

Figure S4: Global map demonstrating the spatial pattern in the dominant groundwater lag. The lag is calculated based on the anomaly correlation.

Figure S4 displays the global pattern of dominant groundwater lag. In 77% of the world, the groundwater does not have a significant lag, but where this is accounted for, the most common lag is 12 months (15% of global data). The regions with the dominant lag tend to be those which also have a multi-year groundwater drought duration, where the DDR is high.

S5 ROC AUC score relationships

Figure S5a plots the distribution of ROC AUC values, grouped based on the groundwater lag. We compare data from lag 0 - lag 12 and find that places with a higher lag tend to also have lower ROC AUC scores. Figure S5b demonstrates that points with a DDR closer to 1 also tend to have a high ROC AUC score. Points in the meteo>GW category tend to have higher ROC AUC scores than those in the meteo<GW category.

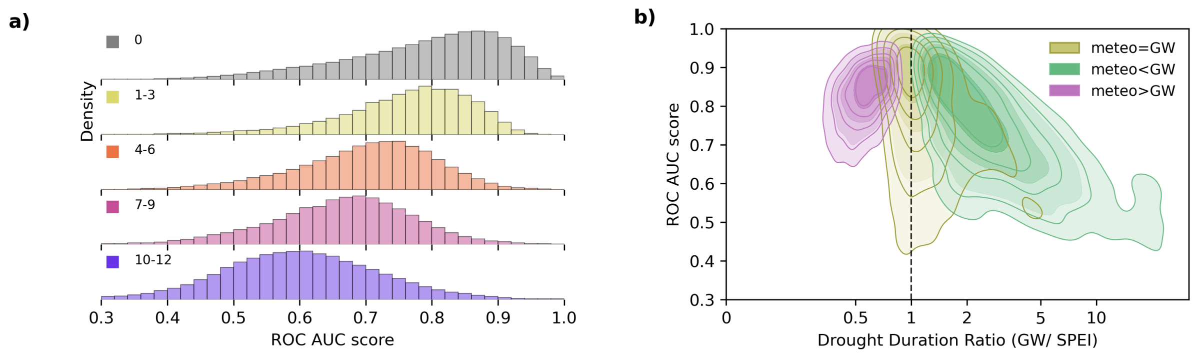

Figure S5: a) histogram displaying the distribution of ROC AUC scores for groundwater data with lags between 1 and 12 months. b) density plot representing the relationship between the ROC AUC score and the Drought Duration Ratio, plots are coloured based on their Drought Duration Ratio.