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COMMENT

Comment on 'The central role of forests in the 2021 European floods'

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Abstract

In July 2021, parts of Germany and Belgium were hit by severe floods. In 'The central role of forests in the 2021 European floods', published in *Environmental Research Letters* (2022 *Environ. Res. Lett.* **17** 064053), Insua-Costa *et al* reported that 'moisture from North American forests was a more important source [of the rainfall contributing to the event] than evaporation over nearby seas'. This suggests that the event was (partly) caused by anomalous contributions from North America. In this comment, we show that this is a misleading interpretation, as: (1) the relative contribution of North American land was below average for the time of year; and (2) rather, the anomalous moisture that contributed to the floods originated mainly from European land. However, consistent with Insua-Costa *et al*, we find no enhanced evaporation from Europe prior to the event and we therefore conclude that there is a lack of evidence for the 'central role' of forests in the 2021 European floods.

In their Letter, Insua-Costa *et al* [1] used the WRF-WVTs model (Weather Research and Forecasting model with Water Vapor Tracers) to study the sources of the heavy rainfall that caused the floods in Germany and Belgium in July 2021. They found that 9.9% of the moisture had evaporated from North America, suggesting that this area, and specifically its forests, had contributed to the floods at the other side of the Atlantic. Here we repeat the simulations from Insua-Costa *et al* using UTrack, a high-resolution Lagrangian atmospheric moisture tracking model [2], for the same event and study area (06:00 UTC 13 July 2021 and 06:00 UTC 15 July 2021 within 49.5°–51.75° N, 4.5°–7.5° E). In addition, we simulate the moisture sources of this area for the first 15 days of July for 2006–2021, and of the Rhine basin and Meuse basins for the July months of the same years.

We find a larger contribution of North American evapotranspiration during the event (13.8%, figure 1) and for the first 15 days of July 2021 (16.6%) to the study area of Insua-Costa *et al* than these authors did (9.9%). However, we show that these are typical values for the time of year: during 2006–2020, for the first 15 days of July, on average 16.8% of the rainfall in the area outlined by Insua-Costa *et al* had evaporated from North America, with a standard deviation of 4.6% (table 1). These results are similar for the Rhine basin as a whole for the entire month of July, where North America contributes 14.9% ± 3.1% (with 17.8% in July 2021), and for the Meuse basin with 17.6% ± 3.7% (17.8% in July 2021). This shows that the moisture resulting in the rainfall that caused the floods was not anomalously contributed by North American land. In contrast, we do find a considerably larger contribution from the North Atlantic Ocean (23.5% for the event) than Insua-Costa *et al* (10.5%), but this is not more than average: the 2006–2020 1–15 July average contribution of the North Atlantic was 35.8% ± 6.6%, with the 2021 value for that period being 29.3% (figure 2).

Expressed in mm of rainfall rather than relative amounts, the North American contribution for 1–15 July 2021 was 22.1 mm, which is 15.1 mm above the 2006–2020 mean (7.0 ± 5.3 mm standard deviation). This is lower than the anomaly for the North Atlantic (contributing 39.0 mm, compared to 14.2 ± 8.3 mm during 2006–2020), and for local land (54.1 mm, compared to 9.9 ± 7.6 mm). The total contribution of land was 78.9 mm (17.9 ± 12.4 mm during 2006–2020) and that of the oceans 54.4 mm (22.0 ± 12.5 mm during 2006–2020). The contribution of the Mediterranean was only 2.3 mm (0.5 ± 0.5 mm during 2006–2020), so we agree with the refutal by Insua-Costa *et al* of media reports that

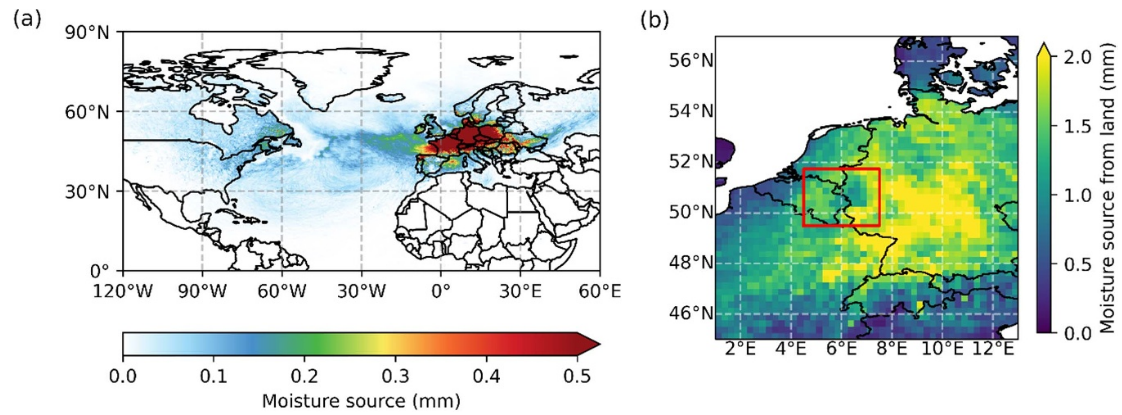

Figure 1. Moisture sources of the July 2021 flooding event. (a) Sources including North America and Europe (mm); (b) land sources in northwestern Europe (mm). Both maps show the evaporation that resulted in rainfall between 06:00 UTC 13 July 2021 and 06:00 UTC 15 July 2021 within 49.5°–51.75° N, 4.5°–7.5° E [1], indicated by the red square in (b).

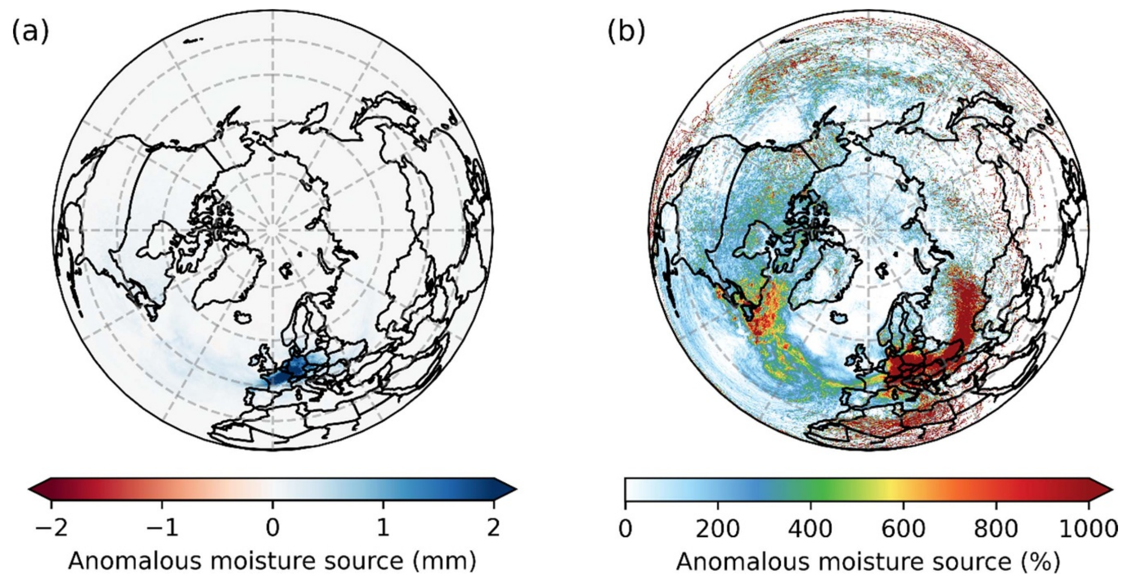

Figure 2. Anomalies of the evaporation that resulted in rainfall in the study area of Insua-Costa *et al* during 1–15 July 2021 compared to the average 2006–2020 1–15 July average. (a) Absolute anomalous moisture source (mm); (b) relative anomalous moisture source (%).

the event was because the low-pressure system that caused it picked up large amounts of moisture from the warm Mediterranean Sea.

The exceptional relative and absolute contribution from local land warrants a closer look at anomalous conditions there. We focus on the areas within the local land region from which at least 2 mm of evapotranspiration more than usual precipitated in the study area during the first half of July 2021 (figure 2). During 1–15 July 2021, this area tended to evaporate less moisture than usual for the same period of the year: 41.8 mm compared to 45.5 ± 4.7 mm normally. This result strongly suggests that nothing unusual happened at the (evaporation) sources of the moisture, but rather at its sink. In other words, not its moisture sources but the event itself was the anomaly, as is expected to become more likely with climate change [3].

To generate the above results we used the UTrack model, which is a Lagrangian atmospheric moisture tracking model that utilizes ERA5 forcing data [2]. For every mm of rainfall (in either the Insua-Costa *et al* study area, or the Rhine or Meuse basins) we released 100 parcels of moisture, which were released randomly within the area of interest weighted by the rainfall during each hour. We tracked the parcels back in time, where at every time step of 15 min, each parcel was transported through the atmosphere based on hourly three-dimensional wind speeds. The horizontal resolution of the ERA5 forcing data [4] is 0.25° and wind data for 25 different pressure layers were used. At every time step, a parcel has a probability of replacement within the atmospheric column such that on average it redistributes once every 24 h, where the probability of its new vertical location scales with the vertical moisture distribution. Also at every time

Table 1. Comparison of moisture sources in Insua-Costa *et al* and our simulation, and the recent history of rainfall levels and moisture sources during 1–15 July for the study area of Insua-Costa *et al* (49.5°–51.75° N, 4.5°–7.5° E). 'Event' refers to the simulations of this paper for the same two-day period (06:00 UTC 13 July 2021 and 06:00 UTC 15 July 2021) as in Insua-Costa *et al*. The means and standard deviations apply to the period 2006–2020.

	Rain (mm)	Local (%)	Trop. (%)	N. Atl. (%)	Amer. (%)	Med. (%)	North/ Balt. (%)	Asia (%)	Pacific (%)	Arctic (%)
I-C *ea*	—	51.4	14.6	10.5	9.9	5.7	2.9	2.0	0.5	0.3
Event	70	49.5	3.4	23.5	13.8	2.6	3.3	1.9	0.4	1.6
2021	133	40.6	4.5	29.3	16.6	1.7	3.3	1.7	0.5	1.8
2020	33	7.7	25.3	46.0	14.1	0.2	2.1	1.2	0.5	3.1
2019	19	16.2	13.6	40.7	17.3	0.2	4.5	3.0	0.6	3.8
2018	11	41.5	3.8	22.0	14.2	0.7	10.8	2.3	0.6	4.0
2017	55	20.7	11.2	28.3	27.3	1.7	3.5	1.5	1.5	4.4
2016	26	15.9	5.6	40.8	21.6	0.4	4.2	3.1	1.3	7.0
2015	35	21.7	8.5	41.7	19.3	3.2	1.3	0.9	0.7	2.7
2014	97	34.4	7.9	28.3	16.4	2.1	6.2	0.4	0.6	3.7
2013	11	20.8	18.4	40.0	16.5	0.2	0.5	0.9	0.7	2.0
2012	78	22.1	4.6	37.0	23.3	1.0	2.5	1.3	1.3	5.9
2011	27	28.3	5.0	30.8	10.3	0.4	13.8	2.6	0.4	8.4
2010	31	38.5	10.2	32.4	14.7	1.4	0.6	0.4	0.6	1.2
2009	42	29.9	5.1	34.0	8.1	1.4	7.0	5.6	0.9	8.0
2008	50	23.1	11.7	41.2	15.8	0.7	1.4	1.2	0.5	4.4
2007	64	19.1	6.3	43.0	17.1	0.5	2.3	5.0	0.7	6.1
2006	17	35.9	11.7	30.7	16.2	1.8	0.9	0.6	0.5	1.5
Mean	46	25.1	10.0	35.8	16.8	1.1	4.1	2.0	0.8	4.4
SD	34	9.1	5.6	6.6	4.6	0.8	3.8	1.6	0.3	2.2

step, the rainfall in the study area and period was allocated to evaporation at the location of the parcels, proportional to the evaporation in the respective grid cells during that hour. We tracked each parcel until 99% of its moisture had been allocated to evaporation, with a maximum of 30 d. For the definitions of the source areas (table 1), we used those of Insua-Costa *et al*, with the exception that we kept tracking moisture when it was transported south of 30° N. This means that moisture from the source area 'tropics' has been allocated to evapotranspiration there rather than referring to all moisture that was transported south of 30° N (the 'three-dimensional source' in Insua-Costa *et al*). Therefore, unlike in Insua-Costa *et al*, moisture parcels could enter the tropics and subsequently return north of 30° N. This difference between the two approaches is likely an important reason why we estimate a smaller moisture contribution of the tropics to the event and a larger contribution of especially the North Atlantic. Apart from this, our results agree well with those of Insua-Costa *et al*.

The Letter by Insua-Costa *et al* implies that the extreme floods in northwestern Europe in July 2021 were related to North American sources of moisture and specifically the role of forests there. Although we applaud their effort to study an impactful event, we showed that the exceptional nature of the event cannot be attributed to anomalies in North American moisture sources and—consistent with figure S3 in Insua-Costa *et al*—that there was no anomalous evaporation from the local areas that contributed most moisture to the flooding event. This is important, as it may otherwise be concluded that forests (specifically those in North America) may be responsible for hydroclimatic extremes, whereas the evidence rather points in the opposite direction. At local scales, by retaining moisture, forests mitigate floods [5]. Furthermore, at regional scales across the globe, moisture provisions by forests are associated with relatively low levels of variations in precipitation, pointing at a regional buffering effect of forests [6]. Naturally, part of the moisture in extreme rainfall events will be provided by evapotranspiration from forests [7–9], and there is strong observational evidence that western European forests enhance cloud formation [10]. Nevertheless, the hypothesis that forests are responsible for floods is not supported by current evidence. Instead, forests could be a solution to floods rather than the problem.

Data availability statement

The data generated for this study can be downloaded from Zenodo: https://doi.org/10.5281/zenodo.7707637. ERA5 data can be downloaded from the Copernicus Climate Data Store: https://cds.climate.copernicus.eu.

Code availability statement

Code for the UTrack model can be downloaded from https://github.com/ObbeTuinenburg/UTrack-atmospheric-moisture.

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