Comment on essd-2023-166: '*Indicators of Global Climate Change 2022: Annual update of large-scale indicators of the state of the climate system and the human influence*' by Forster et al.

Forster et al. present a nice and worthwhile effort to keep large-scale climate indicators up to date in order to provide an up-to-date status on Earth's climate. I have a few comments about it.

Traditional sets of global climate indicators have ignored hydro-climatological aspects (e.g. the WMO, GCOS, and Copernicus), but such hydro-climatological indicators are sorely needed, for instance the global total mass of H_2O falling on Earth's surface on a typical day and the fraction of Earth's surface area that receives precipitation on a typical day[1]. These may also be refined to cover land-only, oceans and different hemispheres. They can be related to both the frequency of extreme rainfall (flooding) as well as drought. One important aspect is that Earth is a closed system where the integrated moisture flux from the surface equals the total global precipitation in the long run (in a steady state).

The typically narrow emphasis on the temperature in the past is perhaps one explanation for the said incomplete set of global climate indicators (e.g. estimates of the climate sensitivity only involves temperature, but ignores the response in the global hydrological cycle to an increased greenhouse effect). L178-179 underscores this point: "*Observations of global surface temperature change (Sect. 5) and Earth's energy imbalance (Sect. 6) are key global indicators of a warming world.*" We also need to be concerned about how a strengthened greenhouse effect changes rainfall patterns and the global water budget. This aspect is often under-communicated, but extremely important (e.g. floods, droughts, water management, agriculture, health, nature).

I think that our research community should broaden out beyond the temperature focus when discussing the strengthened greenhouse effect (e.g. L790 "While total warming …"), as it is conceivable that a climate change also can involve an accelerated atmospheric overturning where increased latent heat transport keeps the temperature more in check[2]. Again, changes in

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[1] Benestad, R.E., Lussana C., Lutz J., Dobler A. Landgren O.A., Haugen, J.E. Mezghani A., Casati B. Parding K.M. (2022) "Global hydro-climatological indicators and changes in the global hydrological cycle and rainfall patterns", PLOS Climate, PCLM-D-21-00079R1, DOI: 10.1371/journal.pclm.0000029
[2] Benestad, R.E. (2016) A mental picture of the greenhouse effect: A pedagogic explanation Theoretical and Applied Climatology. May 2017, Volume 128, Issue 3–4, pp 679–688, DOI: 10.1007/s00704-016-1732-y

rainfall patterns have consequences that should not be swept under the carpet. I wonder if this aspect is too invisible, even in the IPCC reports. It is absolutely relevant for adaptation (mentioned in L792), and I think it's appropriate to acknowledge this in this paper.

In addition, there have been some issues concerning the estimation of the global mean temperature which involves an ad-hoc geographical sampling of thermometer data with a subtle effect on global trend estimates, purely due to the way there are sampled[3] - in addition to the points made in the paper about GSAT and GMST (Section 7.1.2). I recommend a greater emphasis on the *global mean sea level* (easier to explain than EEI or OHC), which is a true integrator of the heat accumulation on earth, both in terms of thermal expansion of sea water and added contribution to oceans' volume from melting land ice. A stronger emphasis on the global sea level could perhaps avoid misplaced discussions on so-called 'hiatuses'.

For the polar regions, an interesting additional index is the *fractional area with above-freezing daily temperatures*, which may be correlated (e.g. aggregated over a season or a year) with the fraction snowfall/rainfall, area of snow-cover, or area with thawing permafrost. The global fractional area may be of interest also for other observations in addition to the common area-based indicators involving sea-ice and snow-cover, e.g. cloud-cover, glaciers/ice-caps area (also their volume or numbers?), total area burned by wildfires, forest area, area with declared state of drought. In addition, I think that globally aggregated albedo, longwave radiation, and (incoming) short-wave radiation, measured from space and at the surface, provide useful indicators for the closed system that Earth represents. We are now getting more global data from satellite observations and reanalyses that enable us to look at a new set of global indicators.

There may also be opportunities to give a broader account on changes in extreme events e.g. based on the statistics of record-breaking events[4] or through a (searchable map-based with moving time windows) global catalogue of historical extreme events (tropical cyclones, tornadoes, derechos, major droughts, major floods, glacial lake outflow (GLOFs), polar lows, major mid-latitude cyclones, atmospheric rivers, etc.).

In summary, I recommend expanding the set of already existing indicators with especially ones describing the evolution in the global hydrological cycle (e.g. total mass of H_2O falling on Earth's surface on a typical day and the fraction of the global area on which it falls). Also, I will recommend a thorough search through the literature to capture past work that is relevant - sometimes I get the impression that we are lazy and only cite works from friends and peers from our close circles (it would be nice if we could ask ChatGPT to suggest relevant work and

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[3] Benestad, R.E., Erlandsen, H.E., Parding, K.M, Mezghani, A. (2019) "Geographical distribution of thermometers gives the appearance of lower historical global warming", GRL, DOI:10.1029/2019GL083474.

[4] Benestad, R.E.(2008) 'A Simple Test for Changes in Statistical Distributions', Eos, 89 (41), 7 October 2008, p. 389-390. DOI: 10.1029/2008EO410002

references for our manuscripts). We have learned that missing out relevant work increases the risk of drawing misleading conclusions[5].

[5] Rasmus E. Benestad, Dana Nuccitelli, Stephan Lewandowsky, Katharine Hayhoe, Hans Olav Hygen, Rob van Dorland, John Cook (2015), 'Learning from mistakes in climate research', Theoretical and Applied Climatology, 126(3), 699-703, DOI:10.1007/s00704-015-1597-5