



EGUsphere, author comment AC3
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Reply on RC3

Alizée Chemison et al.

Author comment on "Impact of an acceleration of ice sheet melting on monsoon systems" by Alizée Chemison et al., EGU sphere, <https://doi.org/10.5194/egusphere-2022-197-AC3>, 2022

The manuscript "Impact of an acceleration of ice sheet melting on monsoon systems" uses the AOGCM IPSL-CM5A to investigate the impact of fresh water input from ice sheet melting over Greenland or the Antarctic on top of RCP8.5 scenario, with a particular focus on the response of global major monsoon systems. It is found that the Antarctic fresh water input has moderate global impact due to dilution by the circumpolar current. However, Greenland ice sheet melting fresh water input is able to significantly slow down the AMOC and shift ITCZ southward due to energy constraint (Schneider et al. 2014). As a result, some regional monsoons closely linked to ITCZ shift are greatly impacted, which include later (earlier) onset of North (South) American monsoon and drying (wetting) North (South) African monsoon. However, the response of the Asian and Australian monsoons, which are weakly linked to ITCZ shift, is not clear.

Monsoon variability and response to external forcings are very important topics in climate science given its impact on a large number of population and yet it is a great challenge due to the complexity of the system that involves interaction of various components. Overall, this is an interesting study and highlights one important driver (fresh water input from ice sheet melting) in the future warming climate that is often neglected in model simulations and projections. I recommend publication after concerns from the reviewer being addressed.

Answer: We thank the reviewer for his/her positive and constructive comments that helped improving the scientific quality of the manuscript.

Major comments:

- The spatial resolution of the atmospheric component (3.75 deg longitude x 1.875 deg in latitude) is relatively low and might not be able to capture some key effect of high orography, which is crucial for some monsoons (e.g the Asian monsoon in Boos and Kuang 2010 and the North American monsoon in Boos and Pascale 2021). The authors need to discuss if the major results are sensitive to the spatial resolution.

Answer: The low spatial resolution of IPSL-CM5A-LR is indeed a caveat. We have added

the following paragraph in discussion.

Lines: 453-472 "The spatial resolution of the IPSL-CM5A-LR climate model is coarse. The slowing trend of the AMOC, the associated decrease in temperature and the southward shift of the rain belt in response to the addition of fresh water into the North Atlantic Ocean are robust results. These changes were found in other studies and they are related to large-scale parameters (Mulitza et al., 2008; Kageyama et al., 2013, Jackson et al., 2015, Liu et al., 2020). Concerning freshwater inputs in West Antarctica, a higher resolution ocean model (at 0.1° spatial resolution) could represent oceanic eddies that are not represented in our low-resolution simulations (Kirtman et al. 2012). These eddies occur in the Southern Ocean around Antarctica. These eddies are important sinks of energy between the ocean and the atmosphere, and this sink is more important the further east the wind is (Jullien et al., 2020). Thus, the representation of realistic surface winds in the atmospheric model is also an important issue. These eddies contribute to a global warming signal of about +0.2°C according to Kirtman et al. 2012. This eddy effect is significant but moderate compared to the temperature changes simulated in our ice-melt simulations (global cooling between GrIS3m and RCP8.5 of about 0.6°C on average, and may reach a maximum of 1.15°C over the period 2041-2070). Jackson et al (2020) also show that finer spatial resolution can have an impact on the AMOC weakening. Both high and low-resolution models have significant biases (Chassignet et al., 2020, Jackson et al., 2020). Additional simulations on the impact of horizontal model resolution and bias improvement will be very valuable and useful for improving future climate projections. The impact of the spatial resolution is more important at regional scale. Therefore, for the Asian and AUSMC regions it is difficult to simulate reliable trends. The presence of the Himalayas, which has a strong impact on the Asian monsoon (Boos and Kuang, 2010), is poorly represented in our model simulations due to a too coarse resolution and very few island grid boxes are available in the AUSMC region to obtain reliable results. Our findings based on low spatial resolution model still simulate realistic monsoon dynamics and simulated future changes are in agreement with other published studies (Mulitza et al., 2008; Kageyama et al., 2013, Jackson et al., 2015, Liu et al., 2020)."

- The study focuses on multiple regional monsoons in response to ice sheet melting fresh water input but lacks some process-based analysis to answer the question of why the response is way it is. Examples of such analyses include moisture static energy (MSE) budget analysis as in Seth et al. 2013, Hill et al. 2017 and Jacobson et al. 2020, which may provide deep insight into the response of monsoons. I recommend the authors conduct similar analysis, or add some discussion on the limitation of the scope of current manuscript if the authors would like to leave such analysis in future study.

Answer: This is a good point. Following your comment, we carried out a moisture static energy (MSE) analysis similar to the one presented by Seth et al. 2013 (in figure 4). Our analysis is based on the MSE difference between 200 and 850 hPa (proxy of atmospheric stability/instability). Then, we show future differences of this MSE vertical gradient on Figures 7-8-9 and Figure B1 in Supplementary materials. Theoretically, when the MSE anomaly increases, the stability between the surface and the upper atmospheric layers increases, which leads to a decrease in simulated precipitation. Conversely, a decrease in the MSE anomaly causes a reduction in vertical stability and thus an increase in precipitation (Seth et al., 2013).

We have added the following paragraph in Methodology:

Lines 206-227: "Monsoon areas consist of any land grid point corresponding, in at least one of the simulations, to the aforementioned criterion (Lee and Wang, 2014). Thus, the selected monsoon areas include monsoon regions for historical and scenario simulations (RCP8.5, GrIS1m, GrIS3m, WAIS3m). All land grid points per monsoon region were retained to derive spatial averages, except for the AUSMC box for which one outlier

(southernmost point) was removed. Only Land data was considered. To better understand simulated precipitations changes, we calculated Moist Static Energy (MSE) in $J.kg^{-1}$ as follows:

$$MSE = cpT + gZ + Lq$$

C_p ($J.kg^{-1}.K^{-1}$) is the the specific heat at constant pressure, T (K) is the layer temperature, g ($m.s^{-2}$) is the gravity constant, Z (m) is the geopotential height, L ($m^2.s^{-2}$) is the latent heat of evaporation and q ($kg.kg^{-1}$) is the specific humidity.

Hovmöller diagrams were derived for each land monsoon region. Rainfall was averaged longitudinally. They represent the average monthly precipitation over our 30-year study period. Then, the difference between the future period (2041-2070) and the historical period (1976-2005) was calculated. The statistical significance of this difference was evaluated using the Wilcoxon-Mann-Whitney test for p -values greater than 0.05 (Seneviratne et al., 2013). For each land monsoon area, Δ MSE, the difference between the MSE at 200 hPa and 850 hPa, was calculated following Seth et al., 2013.

$$\Delta MSE = MSE_{200} - MSE_{850}$$

Then, the Δ MSE difference between the future and historical period is calculated for each future simulation and for each region (Δ MSE anomaly hereafter). Δ MSE anomaly was averaged longitudinally and monthly and overlaid on the Hovmöller precipitation diagrams.

Hovmöller diagrams are shown for NAMS, SAMS, NAF, SAF and SAS. Diagrams for AUSMC and EAS are presented in Appendix C. It is noteworthy that changes for AUSMC and EAS are mostly non-significant and too few land pixels were available for the AUSMC region."

Supplementary information was added in results:

Lines: 360-367 "Changes in rainfall seasonality are linked to changes in the Δ MSE anomaly. When Δ MSE anomaly increases, atmospheric stability increases and precipitation decrease. Conversely, when the Δ MSE anomaly decreases, atmospheric destabilization and precipitation increase. This relationship between precipitation and MSE is shown for the American (Fig. 7), Southern African (Fig. 8 d-f-h-j), Southern Asian (at high latitudes, see Fig. 9) and South-east Asian monsoons (Fig. C1 c-e-g-i). In some regions, an increase in MSE occurs without an associated decrease in precipitation. This is related to the fact that MSE increases during the dry season, when precipitation is already close to zero, as is the case for Southern Africa (Fig. 8 d-f-h-j), for the North American monsoons at high latitudes (Fig. 7 c-e-g-i) and for the South American monsoon for the RCP8.5 and WAIS3m scenarios (Fig. 7 d-f)."

A more detailed regional analysis of future changes in MSE at 850 hPa and 200 hPa is provided below for the NAMS region:

For the NAMS region, a delay in the rainy season is simulated in spring with the standard scenario RCP8.5 (Fig 3A.c) and is associated with an increase in MSE. Then, during the wet season, larger rainfall is simulated further south during the rainy season and is associated with a decrease in MSE.

If we focus on MSE changes at different altitudes:

- RCP85 (Figure 3B.a-b): At low level (850 hPa) there is an increase in MSE from June to December. At the top of the troposphere (200 hPa), there is a major increase in MSE from August to December. The difference between 200 and 850 hPa is therefore negative in June and July with an associated increase in precipitation at low latitudes. The MSE

increase is almost zero at 850 hPa from January to May, which leads to an increase in Δ MSE anomaly associated with a drying that is not apparent because it occurs during the dry season. However, such changes in MSE may lead to a slight rainfall delay during the wet season at low latitudes.

- WAIS3m (Figure 3B.c-d): At 850 hPa, MSE mainly increases in March, April and May. At high latitudes this increase mostly occurs during the wet season. Decrease in Δ MSE is associated with a slight increase in precipitation and an earlier start of the wet season.

- GrIS3m (Figure 3B.e-f): At 850 hPa, the MSE increase is located between the equator and 10°N from June to December. At high altitude the MSE increase is mostly located between the equator and 20°N and during the dry season. At high altitude the decrease in MSE does not impact precipitation because the changes at both low and high levels are almost zero. At about 20°N the increase in MSE (linked to the simulated increase at 200 hPa, thus linked to the increase in temperature) leads to a slight drying. Largest changes are simulated between the equator and 10°N. From March to May (and from May to August at higher latitudes) the increase in MSE leads to a decrease in precipitation and thus to a delay in the wet season. On the other hand, from June onwards, there is a very strong increase in surface MSE (latent heat flux, hence moisture input) which leads to a negative MSE anomaly associated with a strong increase in precipitation during the wet season which extends until November.

Specific comments:

Page 1, lines 16-17: add some references to this statement.

Answer: We added references to Wang and Ding, 2006 & Moon and Ha, 2020:

Lines: 17-19 "Monsoons influence tropical regions without perennial rain regime, providing the vast majority of rainfall in one season (Wang and Ding, 2006). Consequently, monsoons have a significant impact on two thirds of the world's population (Wang and Ding, 2006; Moon and Ha, 2020)."

Page 3, lines 69-71: add some references to the statements. Also notice that the confidence on the future projection of East African rainfall can be greatly reduced given the bias of simulation in the current climate (see Yang et al. 2015).

Answer: Following comments from other reviewers we have shortened this paragraph that describe the evolution of regional rainfall. Following your advice, we have added references Ongoma et al., (2018), Yang et al., (2015), Biasutti et al., (2009), Biasutti, (2013), Seth et al., (2013) to:

Lines: 65-74 "Over eastern Africa, two rainy seasons occur: the so-called short rains from October to December and long rains from March to May. A significant increase in future rainfall during the long rainy season is usually simulated over East Africa, (Ongoma et al., 2018), although important biases exist in this region (Yang et al., 2015). For the West African monsoon, there are large rainfall differences simulated across GCMs (Biasutti et al., 2009; Monerie et al., 2020). However, simulated trends for CMIP3 and CMIP5 are similar with drying simulated during spring and an increase in precipitation simulated in summer (Biasutti and Sobel, 2009; Christensen et al., 2013; Biasutti, 2013; Seth et al., 2013). Dunning et al. (2018) show a later onset of the monsoon season with a northward shift of the rainbelt between August and December. The study of Biasutti and Sobel (2009), based on CMIP3 models, projects a shorter rainy season with a late start of the semi-arid African Sahel. A delayed start of the rainy season has also been demonstrated

by Song et al. (2021) using observed precipitation data. An extension of the dry season is simulated over the southern part of Africa (Mariotti et al., 2014)."

Table 2:

The equation of Pavj: "I" doesn't appear in the equation. Do you mean $\sum_{I=1}^I$ by $\sum_{n=1}^I$?

The equation of SDIIj: Is "W" instead of "w" the last value in the sigma notation, i.e. $(\sum_{w=1}^W PRwj)W^{-1}$ instead of $(\sum_{w=1}^w PRwj)W^{-1}$?

Answer: Yes, you are right, we have modified this table accordingly.

Figure 2:

Use consistent latitude format as in other figures (e.g. 20S and 20N instead of -20 and 20).

Answer: Corrected

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Please also note the supplement to this comment:

<https://egusphere.copernicus.org/preprints/2022/egusphere-2022-197/egusphere-2022-197-AC3-supplement.pdf>