Referee 2

In this document text in blue is from the referee, text in black is our response and text in red are modifications for the manuscript.

Review of "The Indonesian Throughflow Circulation Under Solar Geoengineering" by Chen et al

In this manuscript, the authors analyse the changes in the ITF in two sets of GEOMIP6 simulations, with solar dimming and with stratospheric aerosol injection. They find that the major changes are due to upwelling in the Pacific Ocean, and not so much due to changes in wind stress.

This is in principle an interesting result, but I wonder whether it warrants a full manuscript by itself. The results are relatively 'thin', and there is very limited connection to how the changes in ITF impact other parts of the tropical ocean systems. I therefore encourage the Editor to carefully consider whether there is enough 'scientific meat' to the research question of ITF changes under geoengineering scenarios.

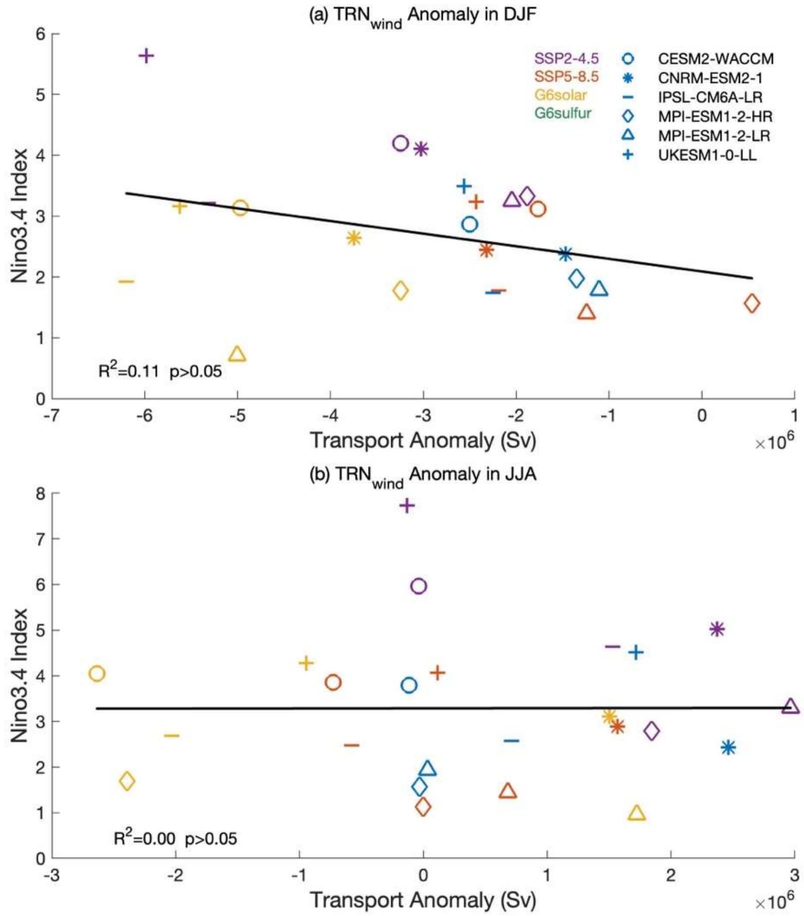
If the Editor does find the Research Question sufficiently relevant, then I have a few major concerns that I think should be addressed before the manuscript is ready for publication

1. The authors state that the ITF flow is too complex to be measured directly, but that is only (to some extent) true in observations. In model simulations, it is fairly trivial to simply integrate zonal and meridional transports, even more so in the coarser-resolution simulations of GEOMIP than in high-res simulations. I therefore really don't understand why the authors need to invoke buoyancy- and wind-stress based proxies of transport, if they could also measure transport directly

Reply: At present, only INSTANT has conducted comprehensive measurements of the ITF transport between 2004 and 2006. Observations are apparently not easy or trivial. In addition, our study focuses on the effects of geoengineering on ITF transport under global warming, which cannot be observed. The models even at 1 degree resolution are too coarse to capture the many small-scale features of the channels and the complex bathymetry. Obviously if it were possible to accurately compute ITF by the referee suggests, then there would be no need of the other methods that are actually used. So, we use accepted methods (wind and buoyancy, etc) to estimate the ITF transport under the future climates.

2. While relations with ENSO and other climate variability modes is discussed in the last section, there is no analysis of it. I'm surprised, as the effect of Geoengineering on ENSO is one of the many outstanding concerns. The argument that ENSO-analysis can't be done because the models are unforced is not very strong; there have been plenty of CMIP ENSO analyses.

Reply: Agreed, and so we added some relevant analysis. There are no statistically significant relationships between the models proxy of ENSO (Nino3.4) and the changes in wind stress. This null result is not very surprising considering that ENSO is driven by more than wind forcing, and indeed the interplay between winds and ocean temperatures are important and various timescales.



Figure; Scattergram of the wind driven ITF transport and Nino3.4 index under the future scenarios (2080-2100).

So we performed a wavelet coherence analysis as well.

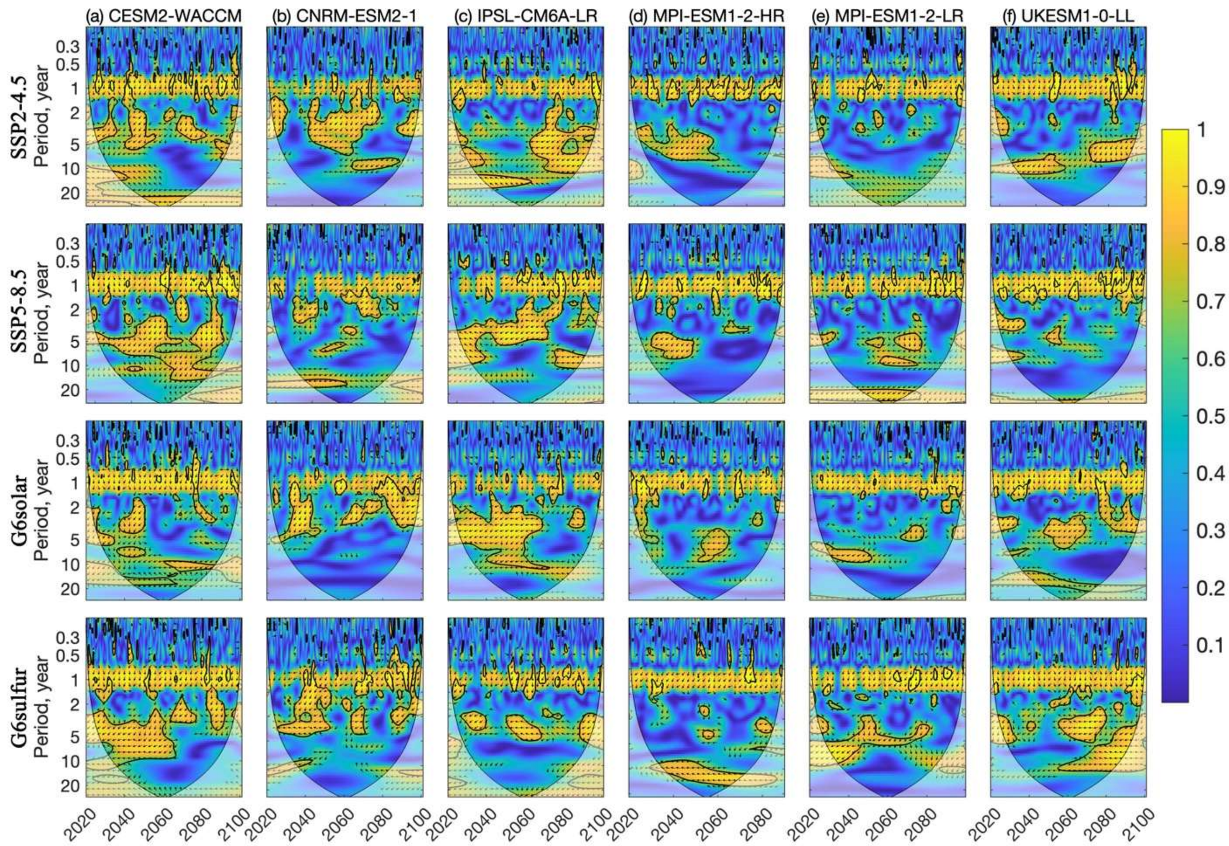


Figure 8. The squared wavelet coherence between the Nino3.4 (representing ENSO) and the wind-driven ITF transport monthly anomalies under the two SSPs (2015-2100) and two G6 (2020-2100) scenarios in six models. The 95% significance level above the background of 1000 Monte-Carlo ensemble of series of identical mean and standard deviation with identical power spectra but phase-randomized Fourier noise (chosen instead of the usual first order autoregressive null hypothesis here because of the strong annual signal; Xia et al. (2023)), is represented by a thick contour line. The arrows indicate the relative phase relationship, that is, in-phase points to the right, anti-phase points to the left, the arrow up indicates that the ITF anomaly leads ENSO by 90°, and a down arrow indicates that the ITF anomaly lags ENSO by 90°.

: From the wavelet coherence analysis (Grinsted et al., 2004) of Nino3.4 and the wind-driven ITF anomaly, the obvious annual power is easily seen, but is not actually significant against the randomized phase Fourier background hypothesis. There are multi-year significant power in all models, though there are no significant differences in power between the scenarios at any band between annual and decadal. The two appear in anti-phase (Figure 8) in line with observed stronger transport during La Niña and weaker transport during El Niña. At the same time, ITF variability also lags behind ENSO on the whole, but there are differences among different models.

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References

Grinsted, A. J. C. Moore, S. Jevrejeva 2004 Application of the cross wavelet transform and wavelet coherence to geophysical time series, Nonlinear Processes in Geophysics, 11, 561-566

Xia, Y D.E. Gwyther, B. Galton-Fenzi, E.A. Cougnon, A.D. Fraser, J.C. Moore, 2023 Eddy and tidal driven basal melting of the Totten and Moscow University Ice Shelves, Frontiers in Marine Science, 10 https://doi.org/10.3389/fmars.2023.1159353

3. There is very little mention of the fidelity/skill of the GeoMIP simulations in this region. Only the mean transport is compared, but what about other EOVs like SST etc?

Reply:Yes we have not discussed this in any detail because we always look at anomalies and relative changes in ITF, winds, upwelling etc. There are certainly differences between models and observations that could be bias corrected e.g. as in Kuswanto, et al. (2021), but here we discuss relative differences in future scenarios rather than between compound indices such as apparent temperature.

Reference

Kuswanto, H., B. Kravitz, B. Miftahurrohmah, F. Fauzi, A. Sopahaluwaken, **J.C. Moore** 2021 Impact of solar geoengineering on temperatures over the Indonesian Maritime Continent *International Journal of Climatology* JOC-20-0686.R3 https://doi.org/10.1002/joc.7391

4. On line 238, the authors compare the wind-driven ITF of Fig 2a to the INSTANT observations of Sprintall et al; but these direct observations also include the buoyancy component so should be compared to Fig 2c; in which case the agreement is much poorer.

Reply: The comparison is between ITF estimated by the Island rule forcing and observations. The buoyancy model is entirely a separate method of estimating ITF, and it can been seen that the ITF estimated using buoyancy is far lower than using the Island rule (cf. 2b or 2c with 2d). The buoyancy method (2d) is not designed to be used together with wind (2a, the Island rule) or wind+upwelling (2c, Amended Island rule), and so the panels in figs 2a,c and 2d represent different models of how the observations can be simulated.

Added text: The multi-mean ITF transport simulated by buoyancy forcing is 7.3 Sv in the historical period, which is less than that by wind driven and only half the transport observed during INSTANT (Sprintall et al., 2009), and there is large across-model variability (Figure S2).

1. The explanation of the results in terms of climate physics is relatively limited. Most of the arguments in e.g. lines 313-334 are fairly handwaving and/or descriptive and could be substantiated by more careful and quantitative analysis.

Reply: We added some quantitative analysis, such as trend values and significance of differences between scenarios. We also discuss the results in terms of seasonal changes in forcing such as wind stress curl finding consistent relationships, and upwelling. These are the model fields used that can be tested. We find no significant relationships with ENSO, but that is not surprising considering the large differences across models in fidelity of ENSO variability.

Minor comments:

-line 19L state that this is the ITF water transport

Reply: Done

- line 19: in which way 'similar'?

Reply: The wind-driven ITF transport under the G6sulfur scenario shows a significant downward trend, and starting from about 2050, the transport is even lower than that under the SSP5-8.5 scenario, where the ‘similar’ is the reduced transport.

: … But stratospheric sulfate aerosols affects winds more than simply “shading the sun” and hence reduces the water transport similar as we simulate for unabated greenhouse gas emissions..

- line 57: the word 'compensating' is very confusing here. Agulhas leakage and ITF don't compensate each other

Reply: rephrased to " The ITF helps supply the Agulhas current leakage from the Indian Ocean to the South Atlantic Ocean,”

- line 58: is 'flush' the best word here?

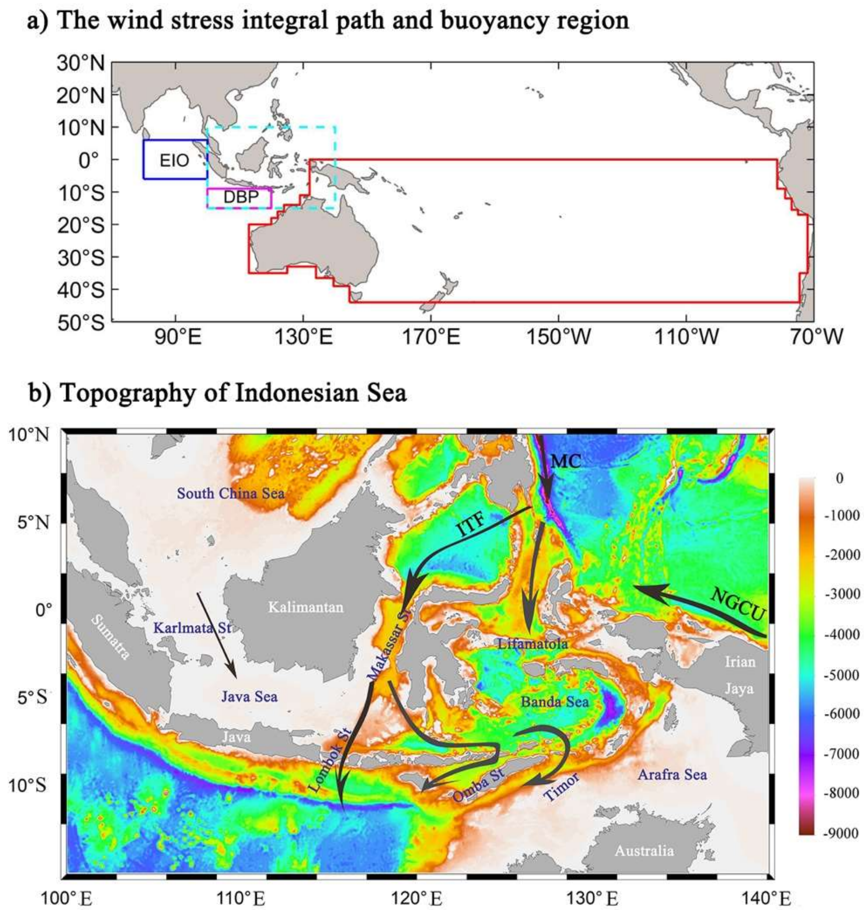
Reply: Yes, it's an abstract expression, but it doesn't affect understanding.

- line 65: the use of 'flux' and 'transport' in one sentence raises the question whether these concepts are the same or not

Reply: The ITF transport can also be said to be the mass or volume flux, and its units are the same.

- line 80: The flow in the ITF is grossly simplified here. I strongly encourage the authors to be a bit more specific about the different pathways; and/or to show a model domain?

Reply: Yes, here we mainly mark the pathways mentioned in this paper, but have added some other pathways.



- line 84: which simulations are meant here?

Reply: Done, I have added the citation.

: Analyzing the water flux through the many shallow channels in the Indonesian archipelago is challenging, and many of these channels are not resolved in simulations with resolutions of a degree or so (Gordon et al., 1999) (Figure 1).

- line 99: how is this transport observed?

Reply: the INSTANT use the mooring placed at major inflow and outflow passages, and the ITF transport was estimated to be around 15 Sv during the 3-year period (2004-2006).

: INSTANT uses moorings deployed at the major inflow (Makassar Strait, Lifamatola Strait) and outflow passages (Lombok Strait, Ombai Strait and Timor Passage) of the ITF to estimate the ITF transport, resulting in a value of 15 Sv during 2004-2006.

- line 112: why are these particular methods unlikely to be ever done?

Reply: Reworded as:

These styles of SRM are known to produce over-cooled tropical oceans and under-cooled poles relative to global mean temperatures. However, other styles of injection strategies than the simple tropical site specified by G6 can produce simulated climates without these temperature biases (MacMartin and Kravitz, 2016)

- Lin 159: why are the G6 scenarios not particularly realistic?

Reply: Reworded as:

These styles of SRM are known to produce over-cooled tropical oceans and under-cooled poles relative to global mean temperatures. However, other styles of injection strategies than the simple tropical site specified by G6 can produce simulated climates without these temperature biases (MacMartin and Kravitz, 2016)

- line 185: is 'dormant' the right word?

Reply: Yes we think the 'dormant' is right, implies that at a certain depth the sea is no motion.

- line 224: It's unclear whether these variables are calculated as a function of time, or using time-mean fields

Reply: we use the monthly oceanic temperature and salinity to calculate the ITF transport as stated just before Table 1: We used monthly data from the first realization in each scenario

- line 227: is this lever of 1200 m also an appropriate choice here?

Reply: We follow the analysis of Andersson and Stigebrandt, (2005), we do not make a novel method.

- line 229: is this the difference in spatially averaged densities?

Reply: Yes, as we say "… the density difference between the DBP region (9° S–15° S, 100° E–120° E) and the EIO region (6° N–6° S, 80° E–100° E).

- line 268: what is meant with a 'scheme' here?

Reply: Rephrased as "where ITF is much closer that from the wind driven estimation method."

- line 448/449: refer to where this is shown in the analysis

Reply: In Fig 2 and table 2, it is clear that ITF slows significantly in all scenarios.

Modified text :The six ESM we use concur on weakening of ITF transport in all future scenarios. That is SRM cannot restore the ITF to its historic levels (Table 2, Fig 2). This contrasts somewhat to the changes simulated in the AMOC under SRM with GHG forcing, where it seems that SRM can partly reverse the slow down in AMOC induced by GHG forcing, reducing impacts from around 35% to 24% (Muri et al., 2018; Tilmes et al., 2020; Xie et al., 2022). This illustrates the important regional variability in responses to SRM.