Reply to ‘RC2: Comment on egusphere-2023-1103' by Referee 2

We are grateful to the referee for his positive and constructive comments. Our reply is as follows.

Major comments:

- Section 3.1: A comparison with the heat fluxes of the previous version of the model would be useful in the main text (similar to section 3.2). Have the heat fluxes improved in the newer version due to the modifications?

To address this topic, we have added global-mean values of fluxes derived from a prescribed-SST ensemble run with the previous model version (v.41), and we have plotted differences between surface fluxes from the two version in the revised Supplementary Fig. S2 (included below). The following text has been added in Sect. 3.1:

When comparing the surface heat fluxes in SPEEDY v.42 with those produced by the previous model version (again in an ensemble with prescribed SST), the main improvements are the reductions of the net solar radiation and sensible heat flux, while in v.41 the global averages of net longwave radiation and latent heat flux were slightly closer to the values by Wild et al. (2015). Overall, the net global balance is much improved in v.42, decreasing from 3.6 W/m^2 to 0.5 W/m^2. Spatial maps of the differences between the fluxes in the two model versions are shown in the right-hand column of Fig. S2.

	SPEEDY v.42	SPEEDY v.41	ECMWF-Ah	Wild et al. (2015)
Net solar radiation (downw.)	167.8	175.0	162.1	160 (154/166)
Net longwave radiation (upw.)	69.8	67.3	58.0	56 (48 / 62)
Sensible heat flux (upw.)	17.3	22.2	17.6	21 (15 / 25)
Latent heat flux (upw.)	80.3	81.9	85.8	82 (70 / 85)
Net surface heat flux (downw.)	0.48	3.57	0.74	0.6 (0.2 / 1.0)

Table 1 Global averages of surface heat fluxes (for the 1981-2010 period) in multidecadal ensemble simulations with SPEEDY v.42, SPEEDY v.41 and the ECMWF atmospheric model (ECMWF-Ah; Roberts et al. 2018), all with prescribed SST, compared with mean estimates and uncertainty ranges from Wild et al. (2015). All data in W/m^2.

- Section 4.1: Figure 10 a and b: I think it would be useful to have similar Figures for the NH extratropical SSWT and extratropical land TAS anomaly. Wondering if the good agreement for the global means are dominated by the tropics - large parts of the tropical SSWT are prescribed.

In response to this comment, and to a similar one from Ref.1, we have added two panels in Fig. 10 (below), showing trends of SST and SAT from the pacemaker ensemble only in the extratropical regions not affected by observational constraints. We have also added a new Supplementary Figure (Fig. S5) showing the global trends from a coupled ensemble without SST relaxation (v.42c). Text added to Sect. 4.1 is as follows:

It should be remarked that, in our pacemaker ensemble, SSWT over most of the Indo-Pacific Ocean and the sea-ice concentration are constrained to follow the ERA5 values. It is therefore appropriate to look at the variability of SSWT and SAT averaged only in the extratropical regions not affected by such constraints. Time series of SSWT and SAT averaged in the extratropical domain (25N-65N and 25S-65S) are shown in Fig. 10c and 10d respectively, using the same format as in the panels for global values. The removal of the tropical domain clearly reduces the signature of ENSO-driven interannual variability in the SSWT time series, but the overall trends are still closely captured over both sea and land. Consistently, a realistic simulation of SSWT and SAT trends was also found in the v.42c ensemble, where SSWT relaxation is not applied (see Supplementary Fig. S5).

- Section 4.3: Figure 14 and corresponding text: My impression is that there are substantial differences between the coupled model and ERA. The coupled model patterns have a structure that reminds me of the NAO, while the ERA patterns remind me more of the East Atlantic pattern. Therefore, the physical processes involved in the COWL-pattern might be different in the model and in the reanalysis data - in particular the importance of a dynamic ocean cannot be ruled out.

The referee is correct in pointing out these differences, although it is difficult to attribute them to a specific cause. We speculate that in ERA5 meridional advection of polar air over the Western North Atlantic may play a bigger role, as stated in the modified text of Sect. 4.4:

… However, in the pacemaker ensemble the position of the ocean lows is shifted north-westwards, in a NAO-like pattern, and the regions of increased ocean heat loss correspond to increased westerly (or north-westerly) flow. Therefore, in the SPEEDY coupled runs, heat fluxes from the ocean are enhanced not only because the air above is colder, but also because the positive westerly anomaly increases the average surface wind speed (see similar results from a seasonal forecast model in Molteni et al. 2017). In ERA5, the increase in surface heat fluxes on the western North Atlantic is likely to be due to increased meridional advection of polar air on the western side of the negative geopotential anomaly.

Minor comments:

- *line 401 fi g 7b => Fig. 7b*

corrected

- *line 686 Using data from both our coupled and ensembles => Using data from both our coupled and uncoupled ensembles?*

Corrected

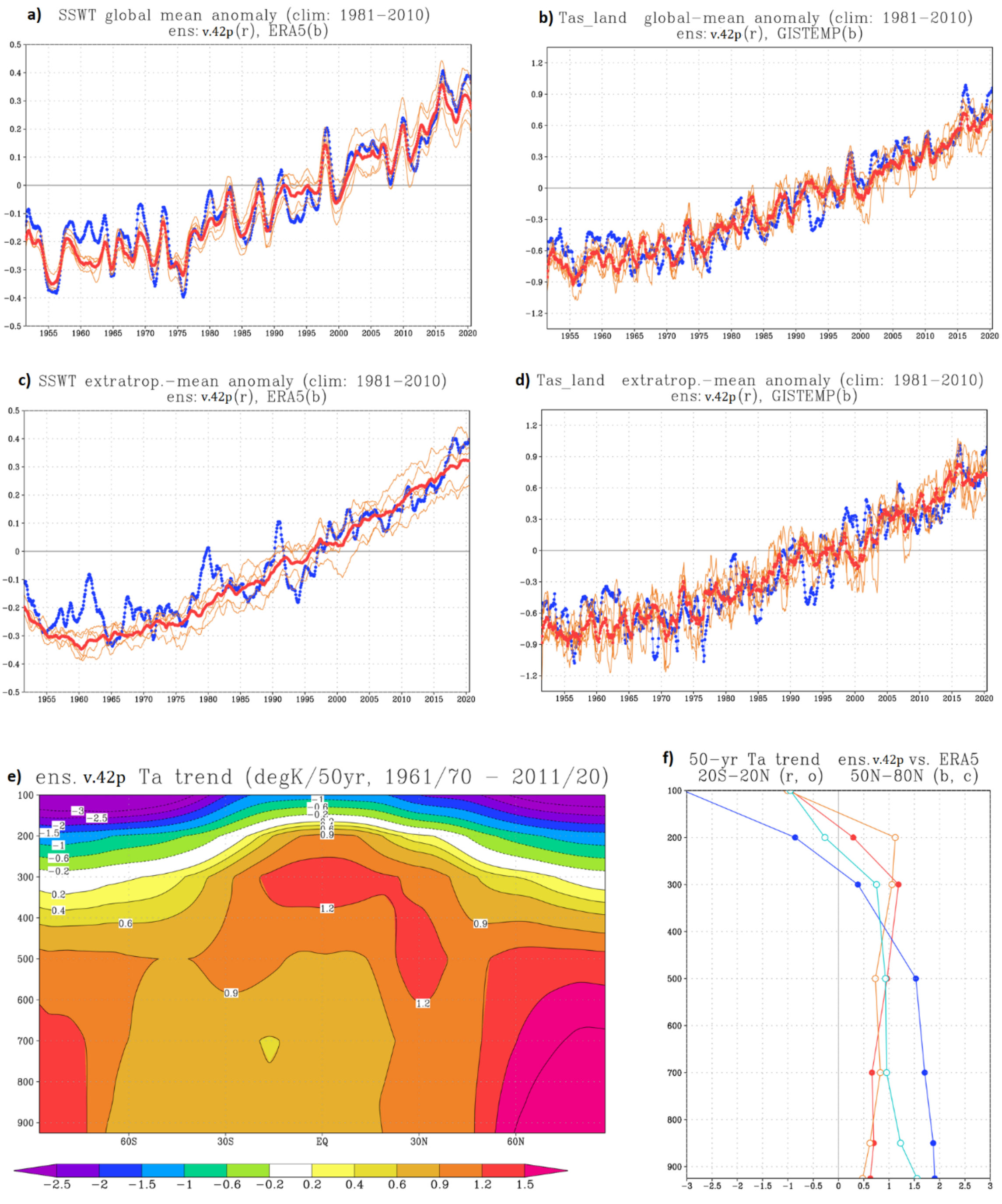

Figure 10: Top row: time series of global and annual-mean variability of **a)** surface sea-water temperature (SSWT), and **b)** SAT over land, from the SPEEDY-TOM3 pacemaker ensemble for 1951-2020 (v.42p). All data are anomalies from a 1981-2010 climatology, in ºK. Red curve: ensemble mean; orange curves: individual ensemble members; blue curve: observational data from ERA5 (for SSWT) and GISTEMPv4 (for land SAT). Middle row: **c)** and **d)** as in a) and b) respectively, but only for the extratropical domain (25N-65N, 25S-65S) where no observational constraint is applied. Bottom row: linear trends of atmospheric temperature computed from overlapping 10-yr means, from 1961/70 to 2011/20. Units: ºK/(50 yr). **e):** vertical cross section from the pacemaker ensemble (v.42p); **f)**: vertical profiles of trends integrated in two latitudinal bands, from the ensemble in 20S-20N (red curve) and 50N-80N (blue curve), and from ERA5 in 20S-20N (orange curve) and 50N-80N (cyan curve).

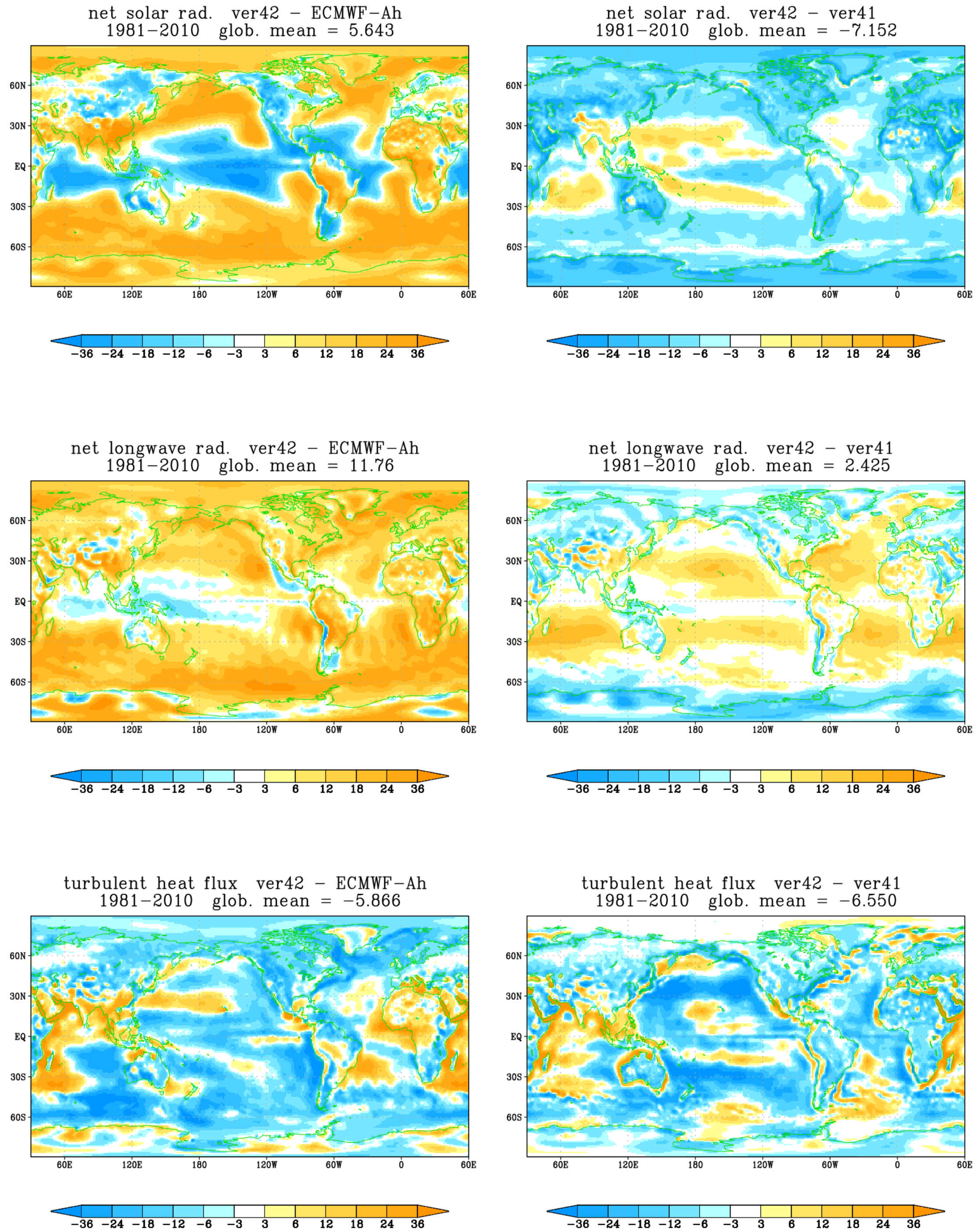

Figure S2: Difference between annual-mean surface heat fluxes from SPEEDY and ECMWF ensembles with prescribed SST. Left: SPEEDY v.42 minus ECMWF historical ensemble (Roberts et al. 2018); right: SPEEDY v.42 minus SPEEDY v.41. Top: net solar radiation; centre: net longwave radiation; bottom: turbulent (sensible + latent) heat flux. Global-mean values are listed above each panel. Unit: W/m^2.

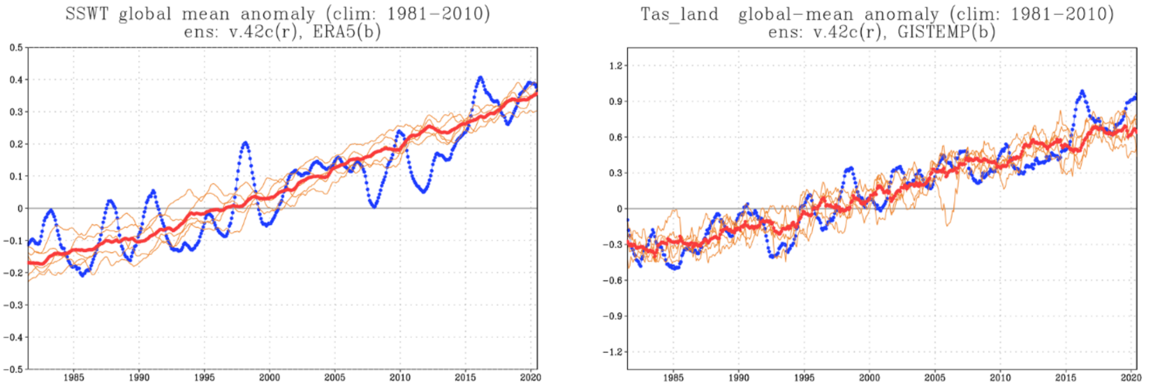

Figure S5: Time series of global and annual-mean variability of surface sea-water temperature (SSWT, left), and SAT over land (right), from a SPEEDY-TOM3 coupled ensemble for 1980-2020 without relaxation to observed tropical SST (v.42c). All data are anomalies from a 1981-2010 climatology, in ºK. Red curve: ensemble mean; orange curves: individual ensemble members; blue curve: observational data from ERA5 (for SSWT) and GISTEMPv4 (for land SAT).