

Response to Review B

Thank you for your thoughtful and helpful review of our paper. It has helped us to craft a more precise and readable paper. Below we list your comments (in red) and our responses (in black).

1) try to put some words of cautions in comparing the present-day, forced and non-steady data from CERES and other instruments with control runs in pre-industrial conditions. I think that is definitely correct, since the authors are considering VERY robust features of the climate system (cfr Lucarini and Ragone 2011 cited for a long discussion on this), but I would spend some words for the unexperienced reader; the literature is full of comparisons between apples and oranges.

We have added a discussion (where we first introduce the observations) regarding the instrumental errors in the observations, the short duration of the observational period and, the differences in atmospheric forcing agents between the observations and the PI simulations. We have also added caveats whenever the inter-model average and the observations are compared.

2) the authors assess the relevance of the "dynamic" vs the "radiative" feedback (nice formulation) by computing the covariance among models of the relative contributions to the meridional transport and of the shortwave and longwave contributions. This tells, in my opinion, what is more relevant to explain the difference among models (good to know). To assee this in physical terms, the authors should compute the same correlations on the yearly time series model by model. This would be quite informative.

This is an excellent suggestion and we present the results below.

For each model we compute annual mean ASR* and OLR* for each year during the last 100 or 200 years of the PI simulation (depending on data availability). On annual time scales, the extratropics are not in energetic equilibrium and can store a sizeable amount of energy in the ocean. To account for this energy imbalance, we also calculate the net surface energy flux integrated over the extratropics (SHF -- defined as positive to the atmosphere). Our analysis below does not distinguish between temporal changes in ocean heat transport and ocean heat storage. As such, we will analyze the inter-annual variability in atmospheric heat transport into the extratropics (AHT_{MAX}). The revised extratropical energy budget solved for AHT_{MAX} is:

$$AHT_{MAX} = ASR^* - OLR^* - SHF \quad (B1)$$

Figs. B1 and B2 summarize the relationship between the inter-annual variability of the variables in Eq. B1 for the Northern Hemisphere and Southern Hemisphere respectively. The inter-annual anomalies from the climatological values of quantities on the right hand side of Eq. B1 are plotted against AHT_{MAX} anomalies in panels A-C with each symbol type/color corresponding to a different model. The linear regression between variables is shown by the colored dashed line (one for each model). By construction the sum of the

regression slopes in panels A-C (with the appropriate sign as per Eq. B1) sum to unity for each model. Therefore, the regression slopes indicate the terms that dominate the balance with AHT_{MAX} in the inter-annual problem (Fig. B1 and B2, panel D).

The relationship between the variables in Eq. B1 varies significantly from year to year (the correlations in Panels A-C are far from perfect). In the bulk statistics, the dominant inter-annual extratropical balance is between AHT_{MAX} and -SHF in both hemispheres (and in all models). This result is purely statistical and the question of causality is interesting, but beyond the scope of the present work. Either the inter-annual variability of AHT_{MAX} is dynamically driven and the anomalous atmospheric heat flux convergence is preferentially downwelled into the ocean as opposed to radiated out the TOA as an OLR^* anomaly (the latter result is expected based on the work of Donohoe, 2011) or the extratropical SHF anomaly is driven by other processes (i.e. sea ice or cloud variability) and causes the extratropical atmosphere to warm or moisten, thereby reducing the equator-to-pole moist static energy gradient and reducing the AHT. We hope to further pursue these ideas in future work. But the key result is that, on inter-annual timescales, the tight relationship between ASR^* and MHT_{MAX} that was found in the inter-model spread is not found. However, we note that the relationship between ASR^* and AHT_{MAX} is stronger than the (almost negligible) relationship between $(-)OLR^*$ and AHT_{MAX} similar to the inter-model spread case.

3) the authors find that the "radiative" feedback is not so relevant: this matches very nicely with what found in Lucarini et al. (2011, arXiv:1002.0157v4 [physics.ao-ph], JAS, in press) when analysing the contributions to the entropy production due to the meridional heat transport. The transport and the meridional gradient of the emission temperature are (time-wise) weakly correlated in all IPCC models.

We have added a discussion and reference to the Lucarini et al. result to the discussion section of the revised manuscript.

4) What is the impact of higher CO₂ concentration on the mechanisms discussed here? Of course I suggest just a physical discussion, not an extensive re-analysis of the IPCC data!

We have added a paragraph of qualitative discussion about how we expect the mechanisms discussed in the manuscript to respond to global warming. Quantitative analyses of the CO₂ perturbation experiments in the CMIP3 ensemble are underway and we anticipate submitting a manuscript on this work in the future.

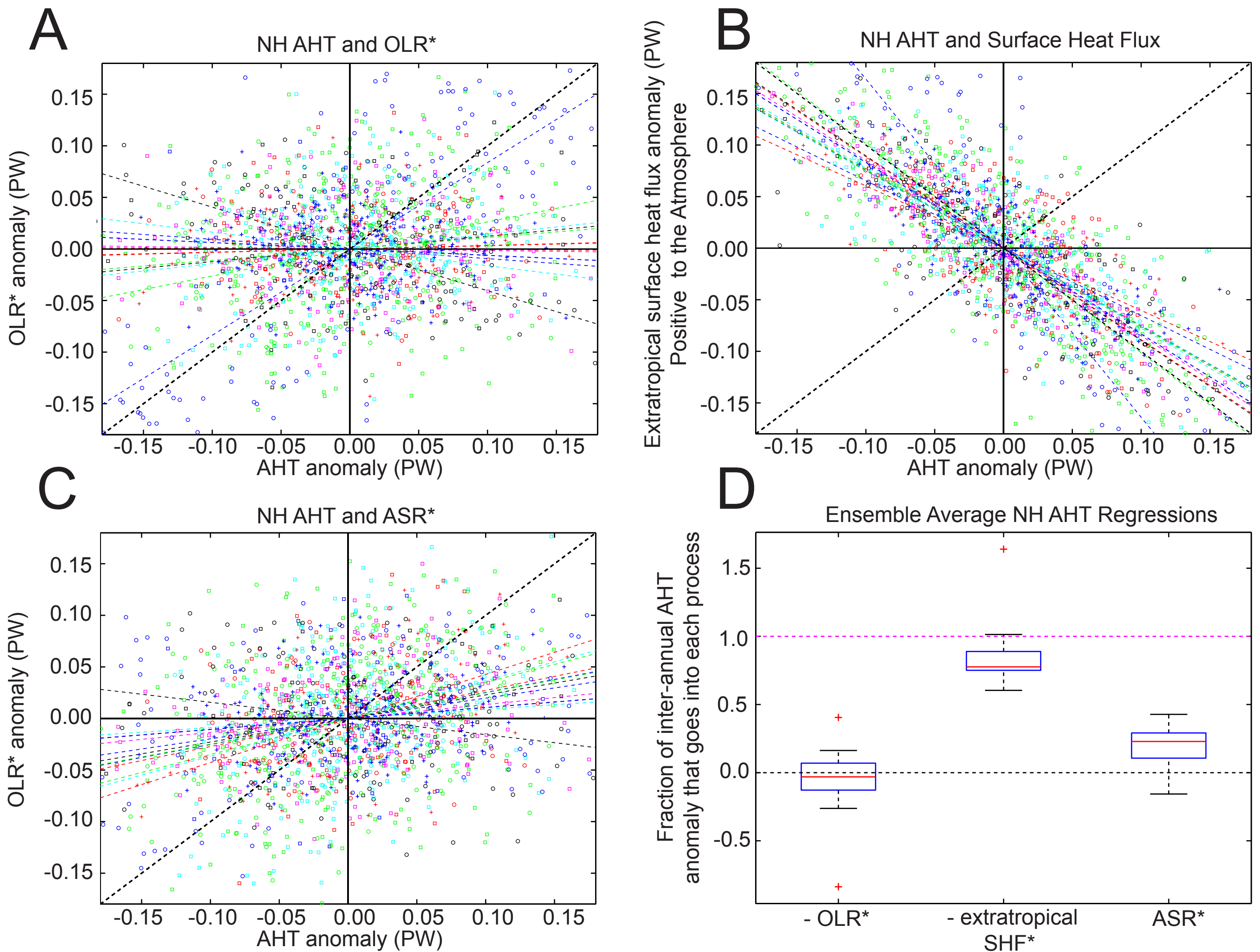


Figure B1. Northern Hemisphere inter-annual anomalies of (A) OLR*, (B) SHF and, (C) ASR* plotted against AHT_{MAX} anomalies in the CMIP3 PI simulations. Each symbol color/type corresponds to a different model. All anomalies are calculated relative to the climatology in that model. The dashed colored lines represent the linear best fits for the model with the same marker color. The dashed thick line is the 1:1 and all axes have a 1:1 scaling. (D) Summary of the CMIP3 ensemble regression statistics in panels A-C. By construction, the sum of the regression coefficients in panels A-C sum to unity for each model according to Eq. B1. The red line represents the inter-model median regression coefficient for each term, the blue box bounds the upper and lower quartile of regression values and, the whiskers include all models except the outliers (given by the red crosses).

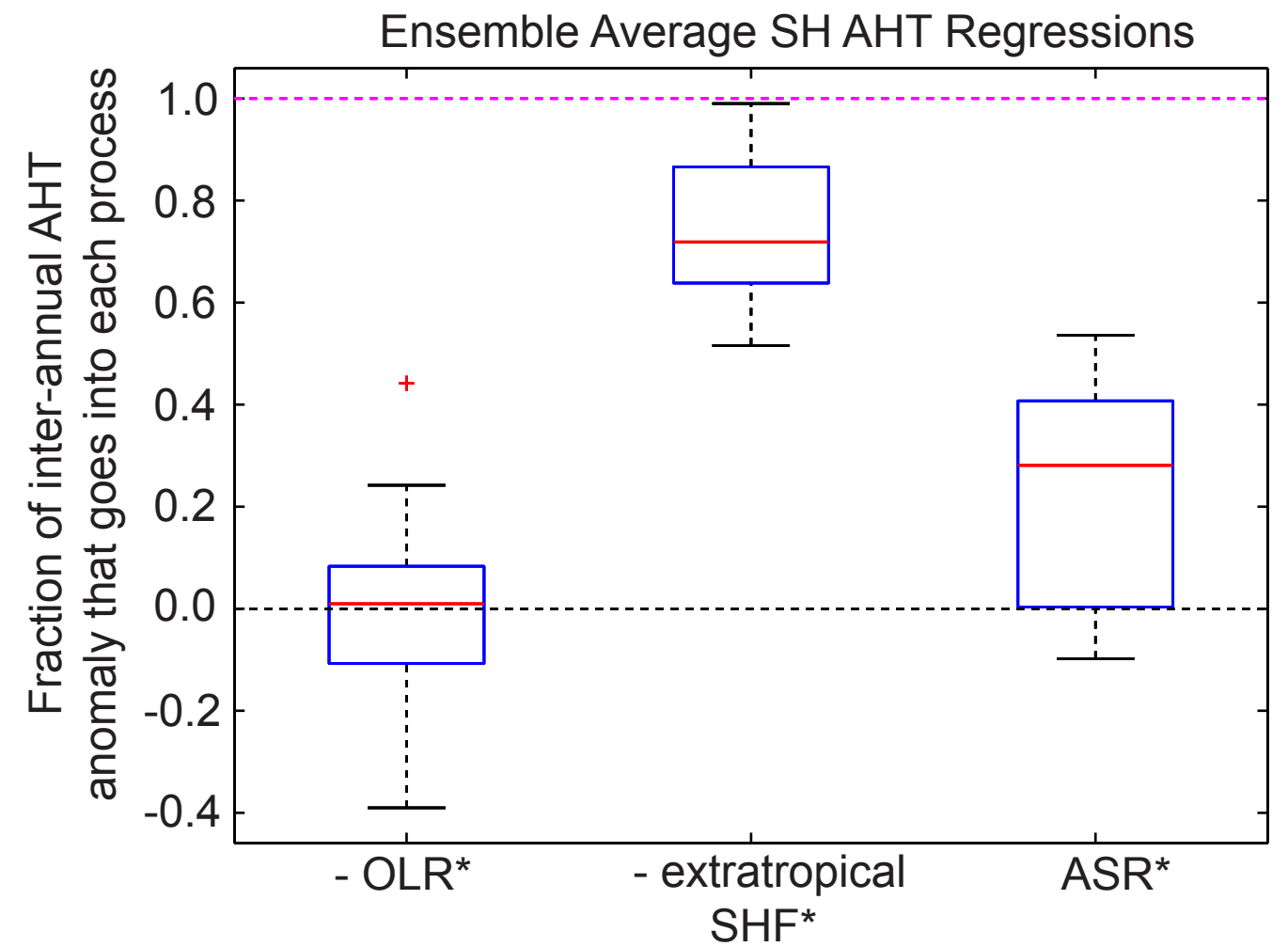
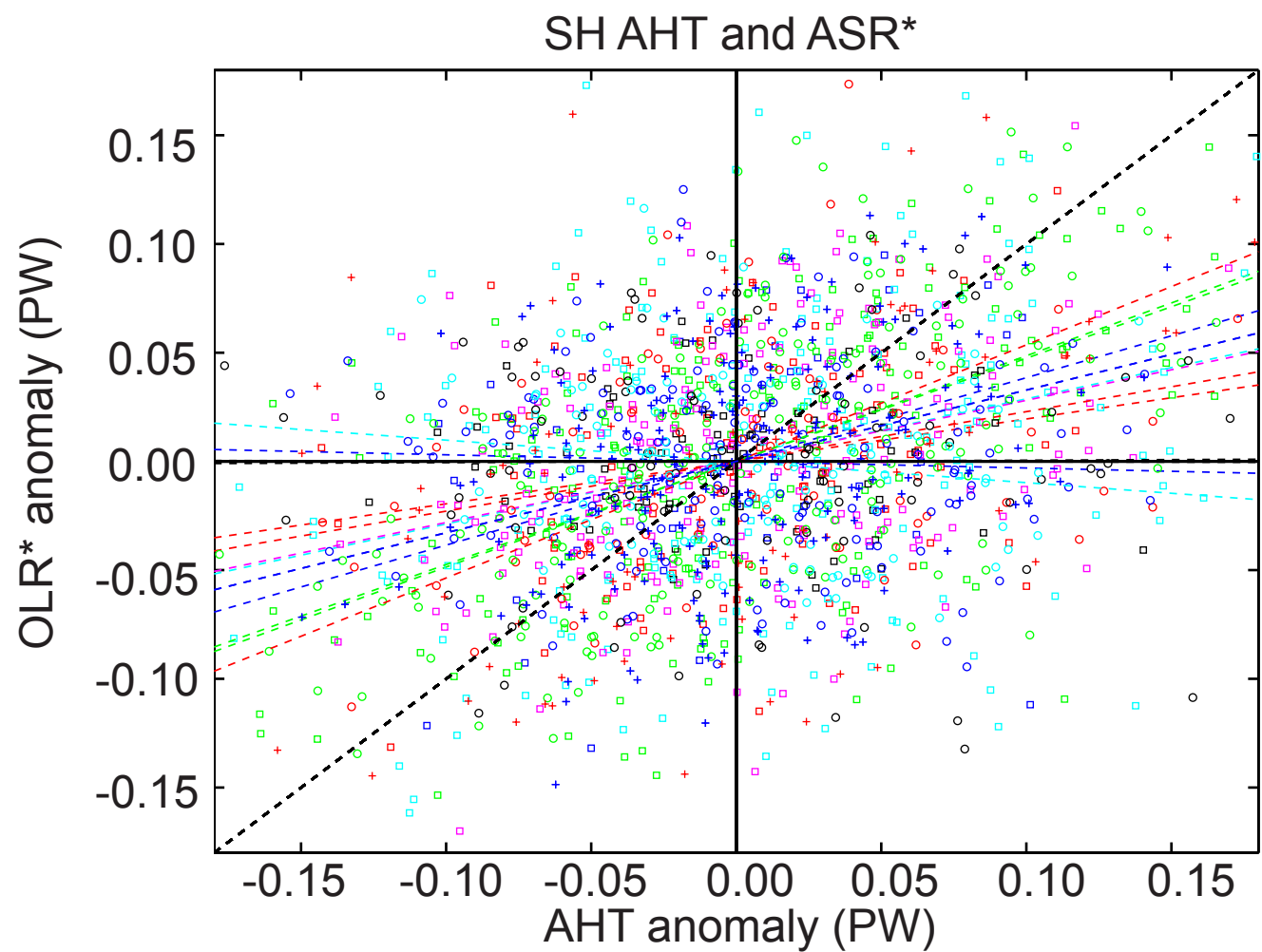
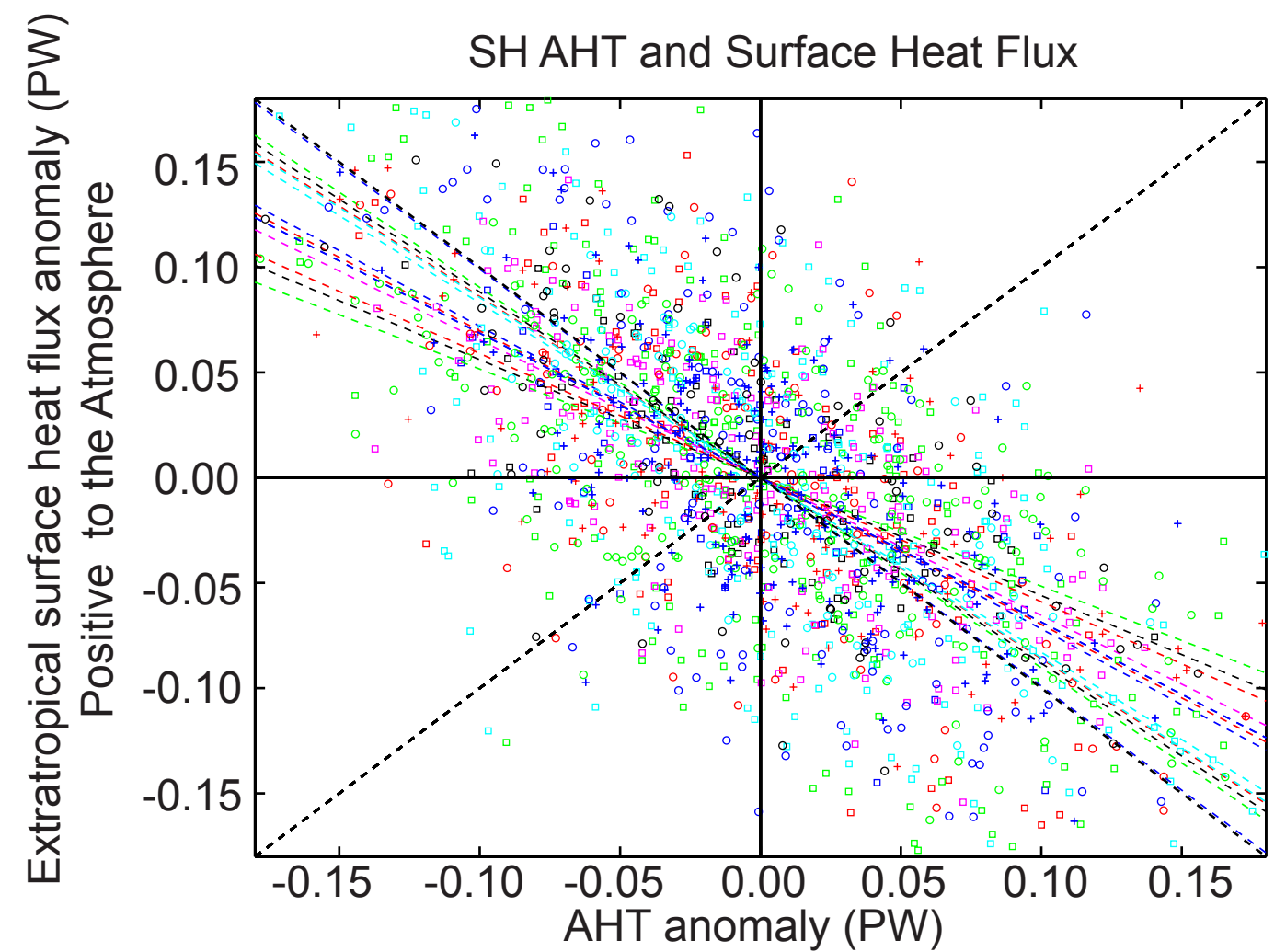
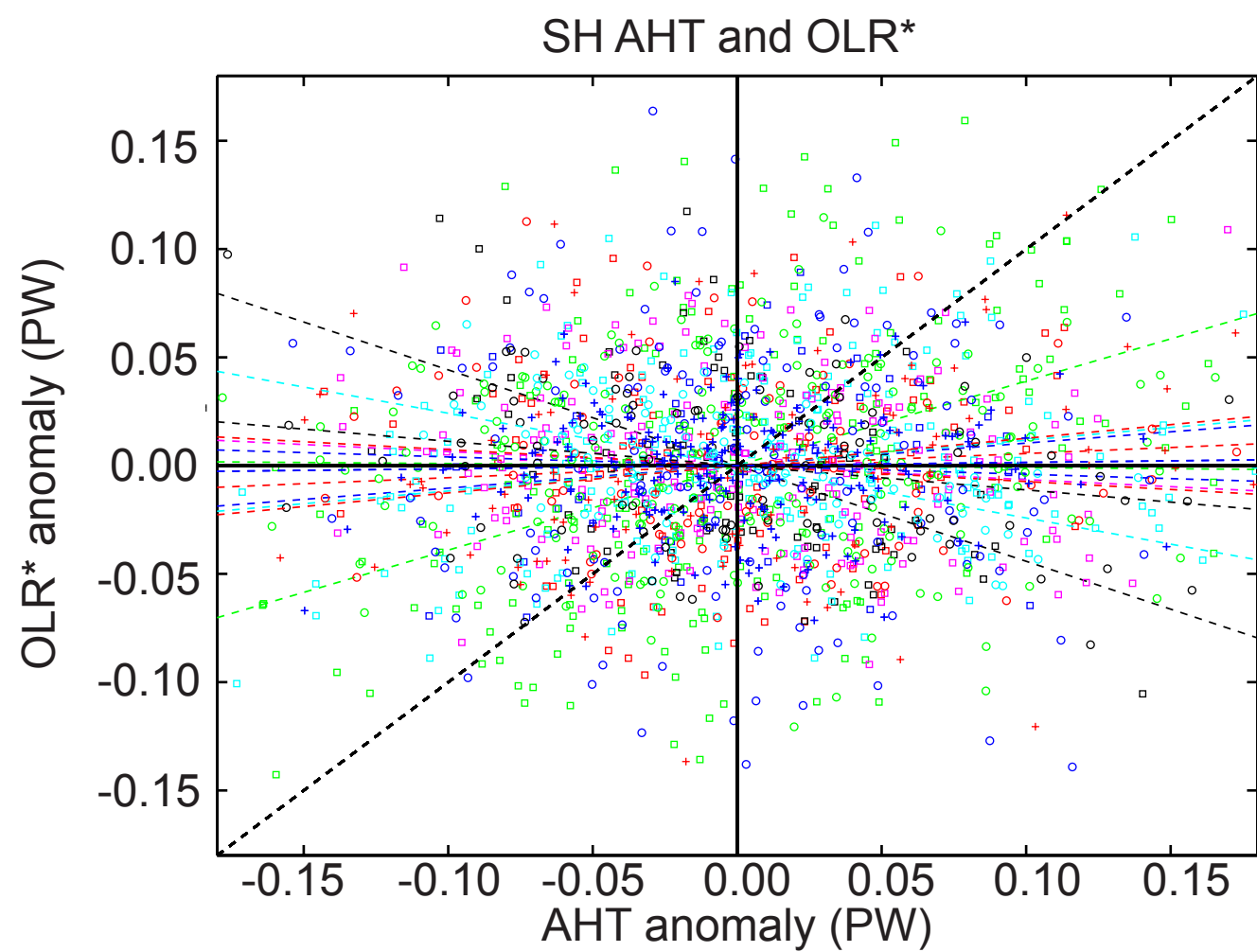


Figure B2. As in figure B1, except for the Southern Hemisphere.