Review of "*Quantifying the Impacts of Atmospheric Rivers on the Surface Energy Budget of the Arctic Based on Reanalysis*" by Zhang et al.

In this paper, authors aim to analyze the contribution of atmospheric rivers (ARs) to the seasonal surface energy budget (SEB) in the Arctic using ERA5 reanalysis data for 1980-2019. ARs are detected using the 85th percentile of IVT and components of the seasonal SEB are anomalies are assessed for times when ARs are detected. The aim of improving understanding the importance of ARs in net SEB in the Arctic is important and interesting, and the authors provide a very detailed analysis with discussion of implications and connections to previous work. Analysis regarding absolute anomalies is thorough, but I am unsure of the appropriateness of the metric used to quantify the contributions of ARs to seasonal SEB (detailed in Major Comment 1).

Major Comments:

1. The metric used for evaluating the contribution of ARs to net SEB may not be appropriate for the conclusions drawn. It is difficult to interpret the physical meaning of the contributions when the seasonal net SEB is very small. Based on the description of the calculation, it appears that the contribution is being calculated as (using downwelling longwave (LWD) as an example):

$$\frac{(LWD_{AR} - LWD_{All})*\left(\frac{t_{AR}}{t_{All}}\right)}{|SEB_{All}|} = \frac{(LWD_{AR} - LWD_{All})*t_{AR}}{|SEB_{All}|*t_{All}} \quad \text{(Equation 1)}$$

where t_{AR} and t_{All} represent the number of 3-hr time intervals when ARs are present and the total number of 3-hr time intervals in the season, respectively. The physical meaning of that quantity is unclear because of how the times are used to scale the flux ratio.

Considering the net SEB to be

$$SEB = LWD - LWU + SWD - SWU + SH + LH \quad \text{(Equation 2)}$$

where LWU and SWU are upwelling long- and shortwave radiation, respectively, and SH and LH represent the sensible and latent heat fluxes (assuming turbulent fluxes are positive downwards). It's quite possible for the total balance to nearly cancel each other out (as seen in Greenland in Spring, Table 1). This means that comparing, for example, $LWD_{AR} – LWD_{All}$ to $|SEB_{All}|$ could yield very large percentages (over 1000%) even if the difference between LWD_{AR} and LWD_{All} is much less than 100% (e.g., if SEB_{All} is 0.4 W m^{-2}, LWD_{All} is 177.2 W m^{-2}, and LWD_{AR} is 221.0 W m^{-2}). In this case, the % difference for LWD is only about 25%, but Equation 1 suggests a results of 1292%. That is not physically meaningful.

To yield more physically meaningful results, the anomaly for each component (F) can be compared to the mean values of that component;

$$\frac{(F_{AR}*t_{AR})-(F_{All}*t_{All})}{(F_{All}*t_{All})} \quad \text{(Equation 3)}$$

where F may represent any SEB component or net SEB. This would provide an estimate of the magnitude of the anomaly relative to the average value for each component. Using this option instead of the current construction would be clearer and more easily justified.

However, since a main goal of this paper is to estimate the relative contribution of different components to net SEB, the net SEB can be decomposed for each flux relative to SEB by looking at the total energy (E_{tot}) over the season as the sum of the net SEB during ARs and net SEB during times without ARs;

$$E_{Tot} = SEB_{All} * t_{All} =$$
$$(LWD_{AR} - LWU_{AR} + SWD_{AR} - SWU_{AR} + SH_{AR} + LH_{AR}) * t_{AR} +$$
$$(LWD_{NoAR} - LWU_{NoAR} + SWD_{NoAR} - SWU_{NoAR} + SH_{NoAR} + LH_{NoAR}) * (t_{All} - t_{AR})$$

(Equation 4)

Then, replacing a single term in the AR portion of the equation with a NoAR value in a hypothetical calculation (E_{Hyp}) can provide an estimate of the difference due to that single term. Using LWD as an example:

$$E_{Hyp} =$$
$$(LWD_{NoAR} - LWU_{AR} + SWD_{AR} - SWU_{AR} + SH_{AR} + LH_{AR}) * t_{AR} +$$
$$(LWD_{NoAR} - LWU_{NoAR} + SWD_{NoAR} - SWU_{NoAR} + SH_{NoAR} + LH_{NoAR}) * (t_{All} - t_{AR})$$

(Equation 5)

The difference between E_{Tot} and E_{Hyp} can tell you the absolute impact of LWD during ARs, and the relative impact can be found by dividing by E_{Tot}:

$$\frac{E_{Hyp} - E_{Tot}}{E_{Tot}} \qquad \text{(Equation 6)}$$

This is another potential solution that would result in more physically meaningful results in representing the ARs' contribution to the seasonal energy budget that might be preferable to the authors since it maintains an overall energy value as the denominator. However, note that there is no simultaneous changing of the flux and the amount of time here.

Regardless of how the authors proceed, the equation used to calculate this metric should be included, rather than only described in words to make sure it is very clear what is being shown.

2. I am unable to reproduce the "contribution to SEB" values shown in Table 1 using the description of how it was calculated in Section 2.3. Since the AR frequencies, anomalies and net SEB values are provided for each region, the contribution should be able to be calculated without any further information (based on Section 2.3). For example, I get the following for spring in the Central Arctic:

$$\frac{(LWD_{AR} - LWD_{All}) * \left(\frac{t_{AR}}{t_{All}}\right)}{|SEB_{All}|} = \frac{(32.9\ W\ m^{-2}) * (0.108)}{|-19.6\ W\ m^{-2}|} = 0.181 = 18.1\%$$

(Equation 7)

Whereas Table 1 shows 45.1%. Please ensure methods are described clearly so the results can be reproduced.

3. Consider performing statistical testing to determine if the absolute anomalies during ARs are statistically different from the mean conditions (which could be shown in the b rows of Figures 2-7). Since ARs exist in a location likely for more than one timestep, there is some temporal autocorrelation which may be accounted for by randomly selecting a smaller sample of AR timesteps to compare to a randomly selected sample of non-AR timesteps. Determining the statistical significance of these anomalies may help to identify SEB components that are more important with more confidence.

Minor Comments:

- 45-46: ARs typically being associated with extratropical cyclones is mentioned here, but isn't discuss it again. I think more discussion regarding the linkage between cyclones and ARs would be valuable here for context of when/how ARs occur in the Arctic.

- 100: It is mentioned that times are only used during neutral or weak El Niño-Southern Oscillation. I assume it's because of IVT anomalies associated with strong ENSO events, but it is worth briefly stating in the text for clarity.

- 123-125: Is it necessary to give multiple names for these first 3 ERA5 variables?

- 147-149: This sentence uses both "three-hourly" and "3-hourly" referring to the data – I suggest picking one to remain consistent.

- 287-289: What is meant by "ARs make their most significant relative contribution to the average net SEB in spring, accounting for at least 45% of the net SEB, surpassing the corresponding AR frequency by more than 34%"? I don't think subtracting the frequency from the contribution has a physical meaning since they are percentages of different things.

- 358: I suggest starting a new paragraph at "The results over the central Arctic" as this is a long paragraph, and a new topic is being introduced here.

- Section 3 is titled "Analysis and Results" and Section 4 "Discussion", but Section 3 includes a lot of discussion (i.e., discussing potential impacts of the anomalies, comparing to previous work) and Section 4 still discusses some results (particularly temperature). A potential solution for this would be to rename Section 3 to focus on SEB and Section 4 to focus on impacts, and perhaps create another section for limitations/uncertainties (for 4.3 and 4.4).