We sincerely appreciate the reviewer for her/his constructive comments on the manuscript. Our responses are listed as follows in blue. Text is revised accordingly.

Review from Referee #1

In this paper, the Gaussian Quadrature (GQ) method is used to calculate the spray-mediated heat flux, instead of the current full-size spectrum integral (A92) and the fast algorithm (A15). A global atmosphere-ocean-wave coupled model CFSv2.0-WW3 is employed, and two time periods of 56 days in boreal summer and winter are conducted to test the sensitivities of SST, 10 m wind speed and significant wave height to the new scheme that the authors proposed. Although the improvement on spray-mediated heat flux is not physical, the computational time is about 36 times less than that of A92. In addition, the introduction of this new method improves the simulation of SST, 10 m wind speed (WSP10) and significant wave height (SWH). Based on above reasons, I think this manuscript can be considered for publication if the authors address all my queries and comments below.

Specific comments

1. My first comment is about the title of this manuscript. I think the 'improved' is not appropriate. As I mentioned above, the new method that the author proposed is not physical improvement on spray-mediated heat flux, and it has not been validated against the directly or indirectly observed sea spray heat flux. Although SST, WPSD10 and SWH are has been improved, it can't be said that the sea spay-mediated flux is 'improved'. Perhaps 'Accelerated Estimation of Sea Spray-Mediated Heat Flux Using Gaussian Quadrature method and…….' is more in line with the content of this manuscript.

Response: We agree. The title is revised as suggested.

2. Line 57, I do understand the positive effect of sea spray on tropical cyclone, but what is the 'negative effect of enhanced surface drag'? The author needs to be more specific in the text.

Response: We apologize for the unclear writing. The strong winds and high waves induced by tropical cyclones can enhance sea surface roughness and thus surface drag coefficients. Subsequently, the enhanced surface drag tends to reduce tropical cyclone intensity. In addition, when a sea spray droplet is released into the air, it is accelerated by surface winds, leading to more dissipation of tropical cyclone kinetic energy (Andreas and Emanuel, 2001). So there are negative effects. The text is revised accordingly to clarify.

3. What are the prerequisites for the use of Gaussian-Legendre quadrature for f(x)? just smooth?

Response: Yes, just smooth. According to McClarren (2018), the Gaussian-Legendre quadrature can be used to approximate the integral of any f(x) on [a, b] only when f(x) is a smooth function. Text is revised accordingly to clarify.

4. Line 118, the authors said 'the sorting leads to high complexity of GQ comparable to A92', thereby the authors try to avoid sorting. However, the authors still sort QS and QL from largest to smallest (lines 124-125). Is it contradictory?

Response: We apologize for the unclear writing. In lines 124-125, we sort Q_S and Q_L to derive Eqn. 3-5 to get the corresponding GQ nodes. Afterwards, we don't sort anymore. The newly-derived GQ nodes can be applied directly. Text is revised to clarify.

5. Equations (3) to (5) really make me puzzled. According to the author's description in Appendix C, $r_i = \frac{b-a}{2}x_i + \frac{a+b}{2}$, *if* x_1*=-0.775,* x_2*=0,* x_3*=0.775, and the lower and upper limits of sea spray radius are a=2, b=500, I calculate the values of GQ 3-nodes and get the following results* r_1*=443,* r_2*=251,* r_3*=58, which are almost consistent with the 3-nodes values of* Q_L *given by the authors. How did the authors get the GQ 3-nodes for* Q_S*? Why* Q_S *and* Q_L *use different GQ 3-nodes? Given that the potential users may be interested in this new method, the authors need to clarify how the 3-nodes* $r_{S1}(r_{L1})$*,* $r_{S2}(r_{L2})$ *and* $r_{S3}(r_{L3})$ *are obtained by sorting* Q_S *and* Q_L *as much detailed as possible.*

Response: Yes, according to Appendix C, the three nodes for GQ in this case are m_1=443, m_2=251, m_3=58. Noticeably, the method should be applied only for a smooth function, which is the prerequisite for GQ. So we sort $Q_S(r)$ and $Q_L(r)$ first to obtain the smooth functions, and then calculate the values of r corresponding to their nodes. Since the original Q_L is approximately smooth, the 3-nodes of Q_L in Eqn. 4-5 are almost consistent with the m_1, m_2 and m_3 estimated from Appendix C. On the other hand, the original Q_S is not smooth, as shown in Figure 1. Therefore, after sorting the GQ 3-nodes for Q_S are different with those for Q_L.

After sorting local $Q_S(r)$ and $Q_L(r)$ from the largest to the smallest, we obtain $Q_{S\_sort}(m)$ and $Q_{L\_sort}(m)$, and the corresponding r_{S1} (r_{L1}), r_{S2} (r_{L2}) and r_{S3} (r_{L3}). Note that the independent variable m is not equivalent to the original radius r, but only indicates the position. Under various atmosphere and ocean environments in the globe, the values of r_{S1} (r_{L1}), r_{S2} (r_{L2}) and r_{S3} (r_{L3}) vary. Based on the distribution of global r_{S1} (r_{L1}), r_{S2} (r_{L2}) and r_{S3} (r_{L3}) (Fig. 2&Fig. R1), the approximate values in Eqn. 3-5 are obtained. The text is revised to clarify.

6. Lines 127-128, How can we see that r_{L3} *is related to WSP10 from Figure 2c?*

Response: We apologize that the relation cannot be seen directly from Figure 2c. According to Appendix C, we derived local r_{L3} for each grid point, and its global distribution of occurrence frequency in percentage is shown in Figure 2c. We found that unlike the other nodes (Fig. 2a, b, d-f), the distribution of r_{L3} is not concentrated in a single constant, while there is a 92.53% concentration between 55 and 90 μm. And then we got the relation of r_{L3} (55-90 μm) and WSP10 (Figure R1). It is seen that r_{L3} is related to WSP10. The figure is added to the supplementary, and text is revised accordingly.

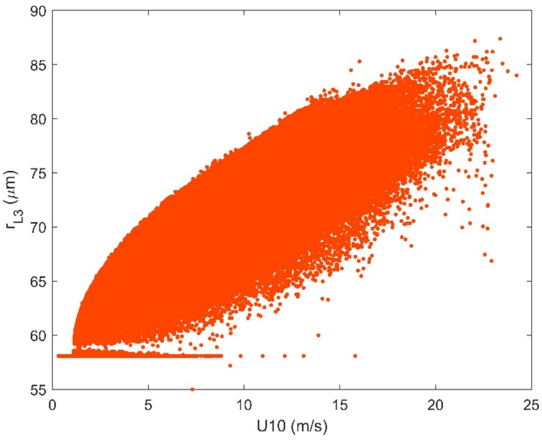

Figure R1. Scatter plots of r_{L3} (y-axis) vs 10-m wind speed (x-axis)

7. Figure 2 is very difficult for me to understand. As far as I can understand from the text, if 3 GQ nodes are determined, then 3 percentage values are determined. But in Figure 2, the authors use $r_{S1}(r_{L1})$, $r_{S2}(r_{L2})$ and $r_{S3}(r_{L3})$ as the name of the x-axis, and there are so many bars in each panel of Figure 2, what do the bars represent? I strongly recommend that the authors devote more space to the introduce the new methods in their manuscript to respond to my comments 5-7.

Response: We apologize for the confusion. As we discussed in comment 5, the 3 nodes for $Q_{S\_sort}(m)$ and $Q_{L\_sort}(m)$ are fixed, but the corresponding radius r for $Q_S(r)$ and $Q_L(r)$ changes under various atmosphere and ocean state. To find out the general law of $r_{S1}(r_{L1})$, $r_{S2}(r_{L2})$ and $r_{S3}(r_{L3})$, using global atmosphere and ocean data, we calculate $Q_S(r)$ and $Q_L(r)$ locally, and thereby $r_{S1}(r_{L1})$, $r_{S2}(r_{L2})$ and $r_{S3}(r_{L3})$ at each grid point. The bars in Figure 2 show the occurrence frequency of different values of $r_{S1}(r_{L1})$, $r_{S2}(r_{L2})$ and $r_{S3}(r_{L3})$. For example, in Fig. 2a, more than 99% of local r_{L1} are about 443.914 μm, therefore we directly set $r_{L1} = 443.914\ \mu m$. As suggested, we add the detailed introduction of the new method.

8. The authors need to briefly describe how the atmospheric and oceanic components of CFSv2.0-WW3 are initialized. I also note that WW3 is not global, then what dataset is used to provide open boundary conditions for WW3?

Response: The initial fields at 00:00 UTC of the first day in each experiment for the atmospheric and oceanic components of CFSv2.0 were generated by the real time operational Climate Data Assimilation System (Kalnay et al., 1996), downloaded from the CFSv2.0 official website (http://nomads.ncep.noaa.gov/pub/data/nccf/com/cfs/prod). The initial wave fields are generated from 10-day simulation starting from rest in a stand-alone WW3 model, forced by ERA5 10-m winds and ice concentration. The open boundary conditions of the wave component are also obtained by the global simulation of the stand-alone WW3 model. Text is revised accordingly.

9. The difference between the spray-mediated heat fluxes calculated by A15 and A92 schemes is so significant. Can the authors comment on what cause this large difference? Extrapolation of VS and VL at high wind speeds? or due to the use of single-radius droplets to represent the full-spectrum integral? As Andreas et al (2015) said, VS &VL in A15 are extrapolated at high wind speeds, while SSGF (sea spray generation function) in A92 are deduced. The lack of discussion on the causes of *this discrepancy will greatly diminish the importance of this article. I am seriously concerned about this.*

Response: In the study, the wind speeds are generally less than 25 m/s (e.g. Fig. R1 & Fig. R4), while extrapolation is required only for wind speeds >25 m/s. So, the difference in heat fluxes calculated by A15 and A92 is mainly due to the use of single-radius droplets. The discussion is added as suggested.

10. It would be better to superimpose the Mean Error onto Figure 6c,7c,8c,9c,10c, and 11c.

Response: The Mean Error (ME) is shown in Fig. R2, which is calculated as ME=$\sum_{i=1}^{n}(\hat{y_i} - y_i)/n$, where $\hat{y_i}$ is simulated value and y_i is OISST/ERA5 data, and n is the total number of grid points. Considering the positive and negative errors (Fig. R2) might cancel out for ME calculation, we also calculate mean absolute errors (MAE=$\sum_{i=1}^{n}|\hat{y_i} - y_i|/n$) in Fig. R3. The MAE is added in Figure 6-11, and it is consistent with the result of RMSE. The ME figure is added to the supplementary. The text is revised accordingly as well.

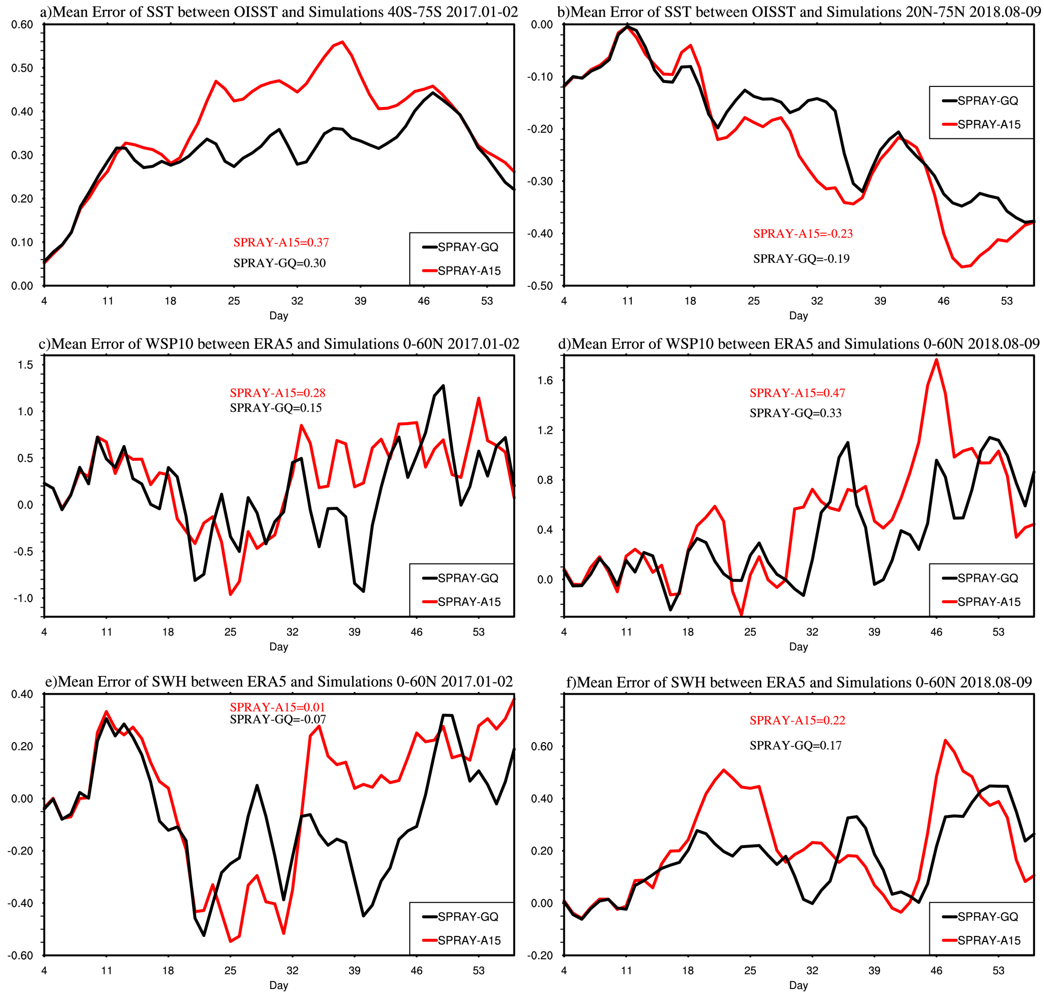

Figure R2. The Mean Error of SPRAY-A15 (red) and SPRAY-GQ (black) in Jan-Feb, 2017 (a, c, e) and Aug-Sep, 2018 (b, d, f): (a) SST of 0-360°E, 40-75°S; (b) SST of 0-360°E, 20-75°N; (c&d) WSP10 of 0-360°E, 0-60°N; (e&f) SWH of 0-360°E, 0-60°N.

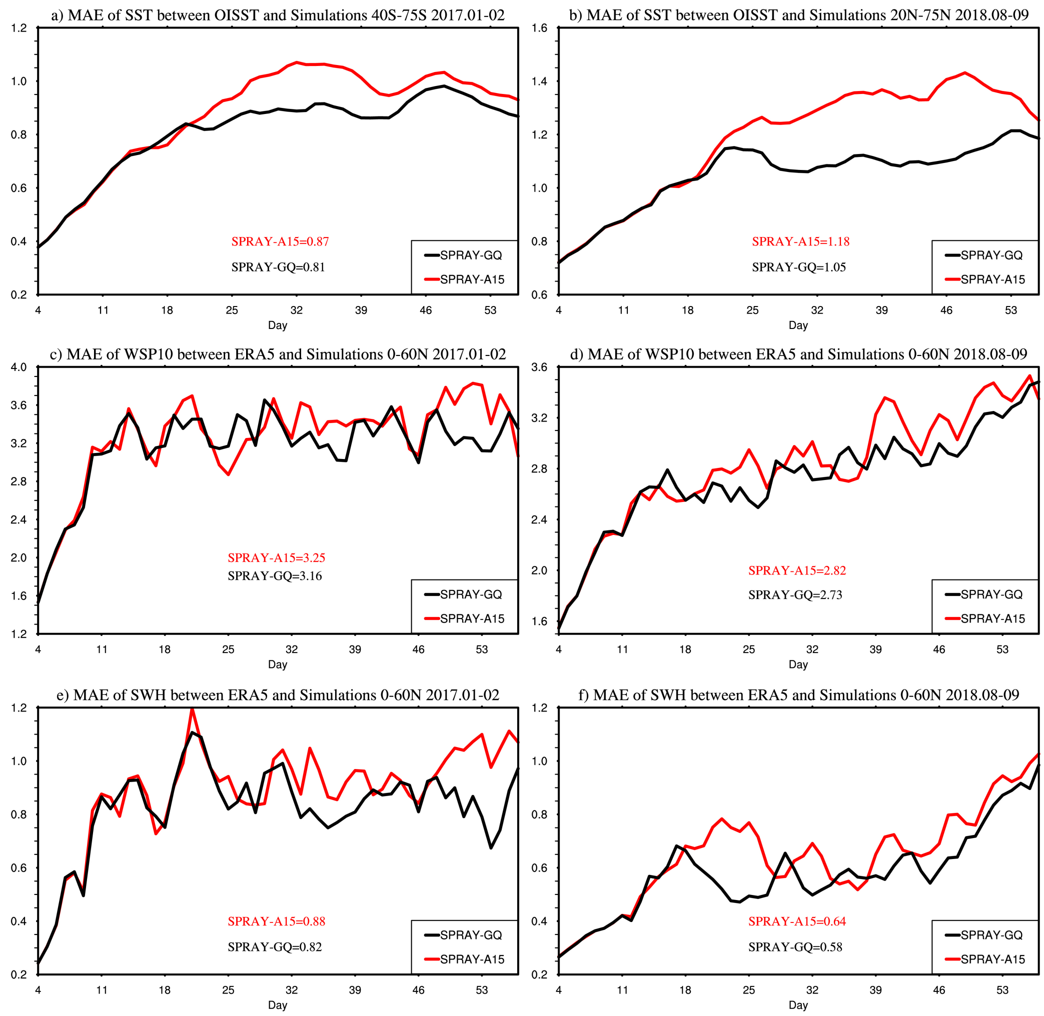

Figure R3. The MAE of SPRAY-A15 (red) and SPRAY-GQ (black) in Jan-Feb, 2017 (a, c, e) and Aug-Sep, 2018 (b, d, f): (a) SST of 0-360°E, 40-75°S; (b) SST of 0-360°E, 20-75°N; (c&d) WSP10 of 0-360°E, 0-60°N; (e&f) SWH of 0-360°E, 0-60°N.

11. According to Andreas et al. (2015), the effect of sea spray become significant at wind speed of 10-13 ms-1. How strong can the simulated WSP10 be? Therefore, I would like to see the global distribution of WSP10 simulated by CFSv2.0-WW3.

Response: The global distributions of SPRAY-GQ WSP10 in Jan-Feb, 2017 are shown in Fig. R4. At middle and high latitudes, WSP10s can exceed 10 m/s. Overall, the wind speeds in the simulation are in the range of 0-25 m/s.

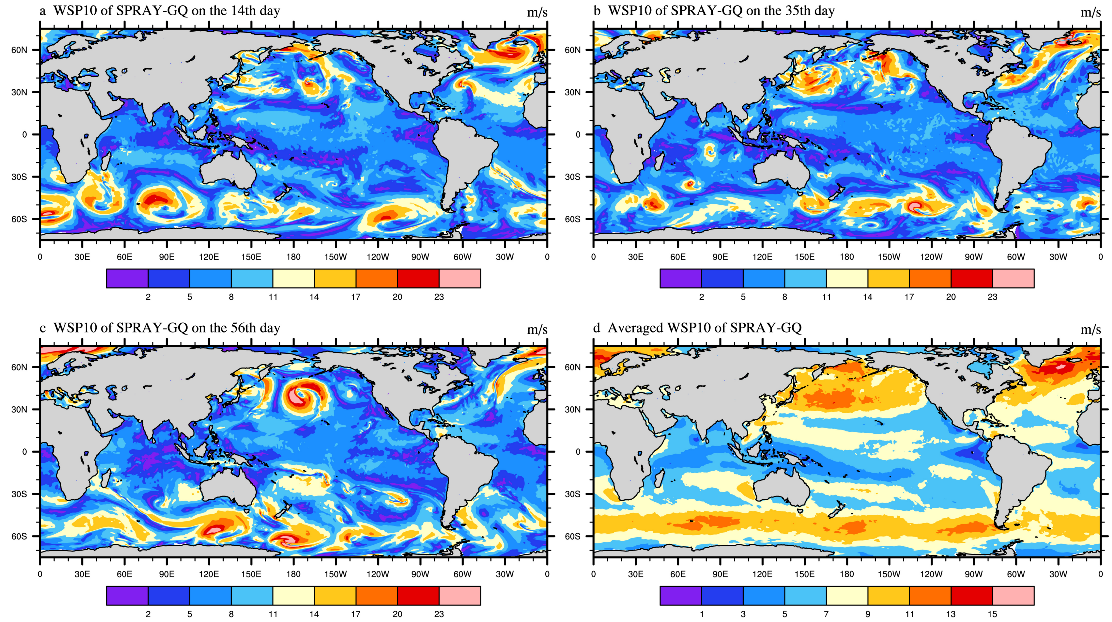

Figure R4. The WSP10 (m/s) of SPRAY-GQ in Jan-Feb, 2017: (a) the 14th day; (b) the 35th day; (c) the 56th day; (d) the 53-day average, with the first 3-day simulation discarded.

12. Line 178, what does equivalent neutral wind mean? Do the authors mean that the equivalent neutral winds in OAFLux are larger than those in ERA5?

Response: We apologize for the confusion. OAFLux only provides neutral wind, calculated from wind stress and the corresponding roughness by assuming air is neutrally stratified. Previous studies (Seethala et al., 2021; Lindemann et al., 2021) indicated the neutral winds from OAFlux are larger than those in ERA5. Text is revised to clarify.

13. Lines 230-231, The expression is not accurate, the reduced wind and weaker mixing can lead to warmer SST?

Response: The reduced wind can weaken the upper ocean mixing, so the water becomes more stratified, then the SST tends to be warm, and vice versa. Text is revised accordingly.

14. As we know, satellite scatterometer and altimeter data are usually used to validate WSP10 and SWH for short term weather forecast. I don't know why the authors use ERA5 reanalysis as validation data for seasonal prediction.

Response: As suggested, we compare our simulation results with the monthly global ocean RSS Satellite Data Products (https://data.remss.com/wind/monthly_1deg/) for WSP10 and the Reprocessed L4 Satellite Measurements for SWH (https://doi.org/10.48670/moi-00177). Due to the spatial and temporal limitations of satellite data, we compare the differences of averaged WSP10 and SWH over the periods between simulations and satellite data (e.g., Fig. R5&R6 in Aug-Sep, 2018). The averaged WSP10 and SWH differences compared with satellite data (Fig. R5a&c; Fig. R6a&c) are consistent with those compared with ERA5 (Fig. R5b&d; Fig. R6b&d). Besides, the differences between ERA5 and satellite data are slight (Fig. R5e&6e). Since ERA5 provides daily data for comparison and the differences between ERA5 and satellite data are small, we use ERA5 and add the following figures in the supplementary for references.

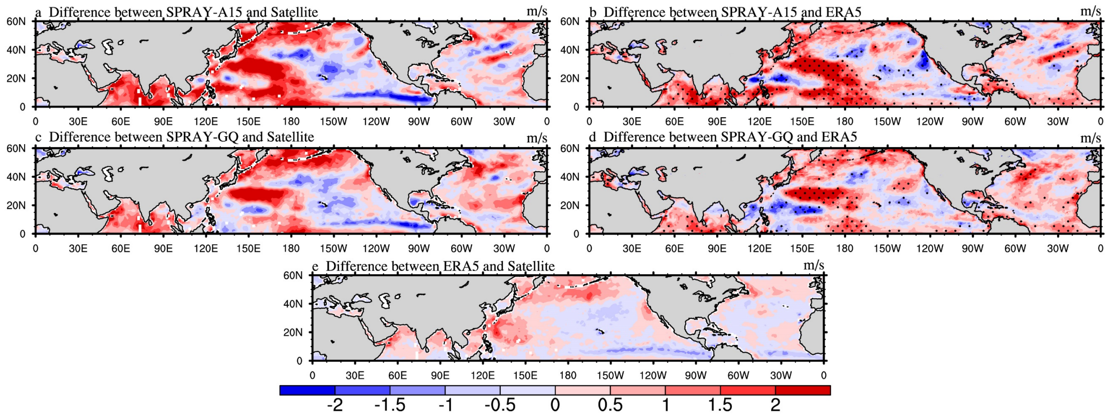

Figure R5. The average WSP10 (m/s) differences between SPRAY-A15/SPRAY-GQ and satellite data (a/c; SPRAY-A15/SPRAY-GQ minus satellite data), differences between SPRAY-A15/SPRAY-GQ and ERA5 (b/d; SPRAY-A15/SPRAY-GQ minus ERA5), and differences between ERA5 and satellite data (e; ERA5 minus satellite data) in Aug-Sep, 2018. The dotted areas are statistically significant at 95% confidence level.

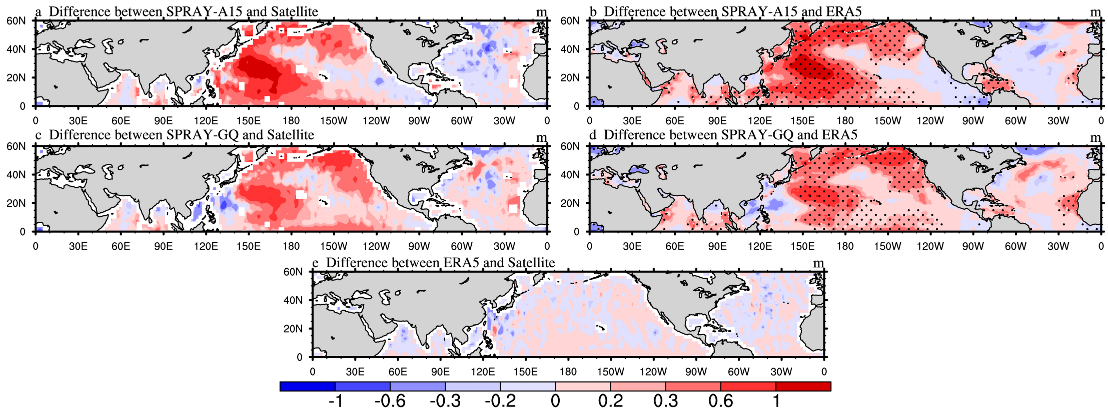

Figure R6. The average SWH (m) differences between SPRAY-A15/SPRAY-GQ and satellite data (a/c; SPRAY-A15/SPRAY-GQ minus satellite data), differences between SPRAY-A15/SPRAY-GQ and ERA5 (b/d; SPRAY-A15/SPRAY-GQ minus ERA5), and differences between ERA5 and satellite data (e; ERA5 minus satellite data) in Aug-Sep, 2018. The dotted areas are statistically significant at 95% confidence level.

15. Does the introduction of sea spray can improve the simulation of other elements? For example, air temperature and humidity.

Response: To check, we compare the simulated 2-m air temperature (T02) and specific humidity (SPH) with ERA5 as well. The differences between CTRL (without sea spray effect) and SPRAY-GQ in Jan-Feb, 2017 are shown in Fig. R7.

Compared with CTRL experiment, the introduction of sea spray cannot reduce the global total errors, while it can reduce errors in some regions (blue in Fig. R7e&f). For example, T02 and SPH in CTRL are underestimated in the Northwest Pacific (blue in Fig. R7a&b), and SPRAY-GQ experiment improves them by increasing temperature and moisture (Fig. R7c-f). The reduced errors are related to relatively large WSP10s over these areas (Fig. R4), since the effects of sea spray become significant at wind speeds larger than 10 m/s. The results of Aug-Sep, 2018 are also compared and added to the supplementary, and text is revised accordingly.

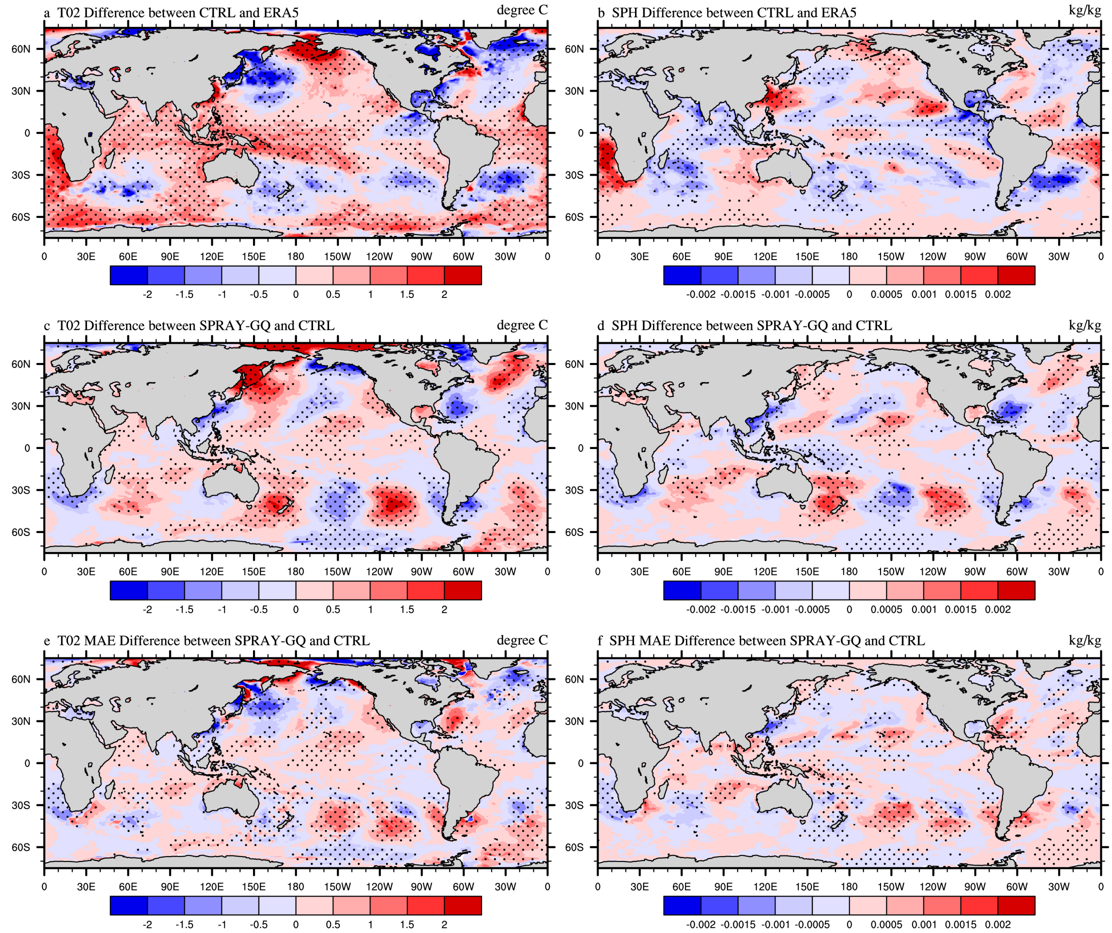

Figure R7. The 53-day average T02 (a, c, e) and SPH (b, d, f) differences between CTRL and ERA5 (a&b; CTRL minus ERA5), differences between SPRAY-GQ and CTRL (c&d; SPRAY-GQ minus CTRL), and MAE differences between SPRAY-GQ and CTRL (e&f) in Jan-Feb, 2017. The first 3-day simulation is discarded. The dotted areas are statistically significant at 95% confidence level.

16. Line 246, there is a grammatical mistake in this sentence. And Fig10b&11b do not support 'The SWHs in SPRAY-GQ improve compared with those in SPRAY-A15'. Do the authors mean that there is a significant difference between SPRAY-GQ and SPRAY-A15?

Response: Yes, thanks. The text is corrected to "The SWHs in SPRAY-GQ show significant differences with those in SPRAY-A15".

17. As far as I know, the sea spray algorithm codes of Andreas are open source, please upload the author's modified A92 codes to a repository so that others can repeat the author's results.

Response: The codes of our modified A92 (SPRAY-GQ) can be found in https://zenodo.org/record/7100345#.Y66vRtVByHt.

18. Lines 255-259, the authors try to discuss the physical mechanism that responsible for the accelerated surface wind. However, the citation does not seem to support the author's conclusions. I can understand that the increase of air-sea heat flux could promote air convection in the vertical, but how does it promote the downward transmission of momentum from the upper layer of *atmosphere? By affecting the large-scale atmospheric circulation? Please provide appropriate citations or give your own analysis to support your points.*

Response: We apologize for the unclear writing. The air-sea heat flux influences the sea level pressure (SLP) distribution, and thus influences surface winds. For example, compared with SPRAY-A15, the decreased heat flux of SPRAY-GQ in the Northwest Pacific in Aug-Sep, 2018 leads to higher SLP and smaller pressure gradient (Fig. R8), and thus decreased WSP10; while the increased heat flux in the Gulf of Alaska leads to lower SLP and larger pressure gradient (Fig. R8), and thus enhanced WSP10. Text is revised to clarify.

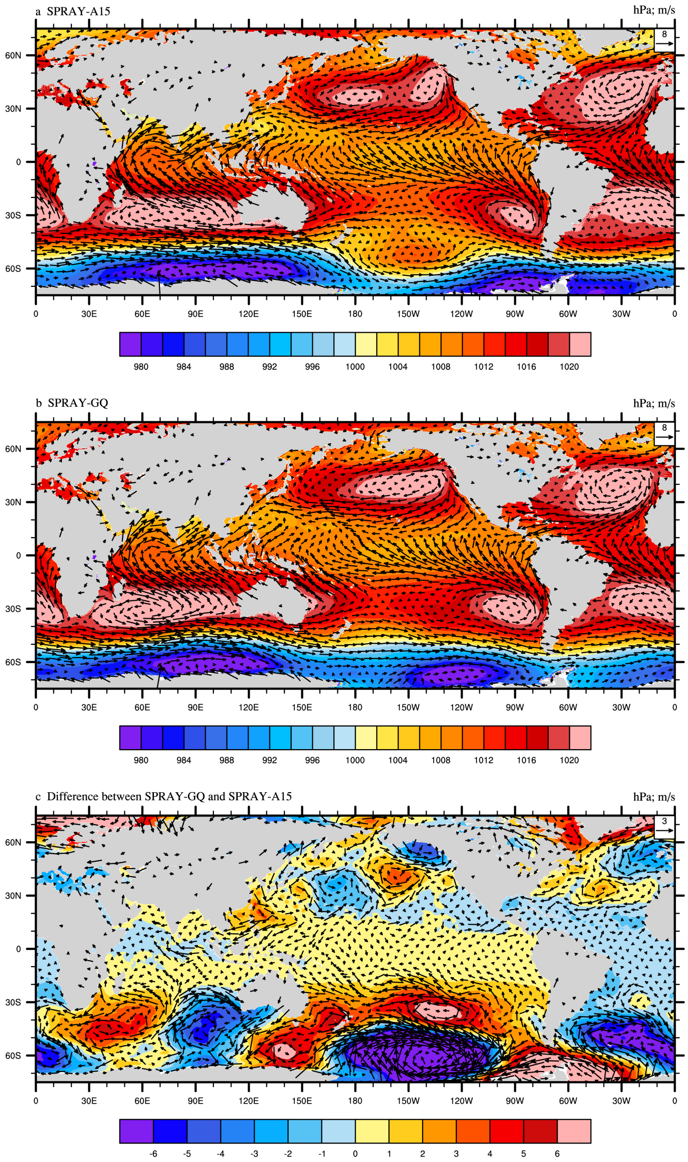

Figure R8. The 53-day average wind (m/s) and sea level pressure (hPa) of SPRAY-A15 (a) and SPRAY-GQ (b), and their differences (c; SPRAY-GQ minus SPRAY-A15) in Aug-Sep, 2018.

19. Lines 263-264, again, without verification by direct/indirect observation, we can't say that SPRAY-GQ is more accurate than A15. All we can say is that the difference between SPRAY-GQ and A92 is smaller than that between A15 and A92.

Response: We agree. The text is revised as suggested.

20. Finally, I think the current experimental design is insufficient, a reference experiment without sea spray effect is missing in manuscript. Although it may be expensive to conduct a new set of experiment, it makes sense for the scientific community to understand the importance of spray-mediated heat flux for seasonal and intra-seasonal prediction.

Response: As suggested, we add a new experiment without sea spray effects (CTRL). The introduction of sea spray cannot significantly reduce the global overall errors of simulations, but it leads to regional improvements (e.g., Fig. R7, Fig. R9-11). For example, compared with CTRL in Jan-Feb, 2017, SST MAE of SPRAY-GQ in the southeast of Australia decreases (blue in Fig. R9e), because of warmer SST (Fig. R9c) related to reduced wind (Fig. R10c). The reduced wind here also leads to lower SWH (Fig. R11c) and thus reduced SWH overestimation (Fig. R11e). The related content is added in the text and the following figures are added in the supplementary for references.

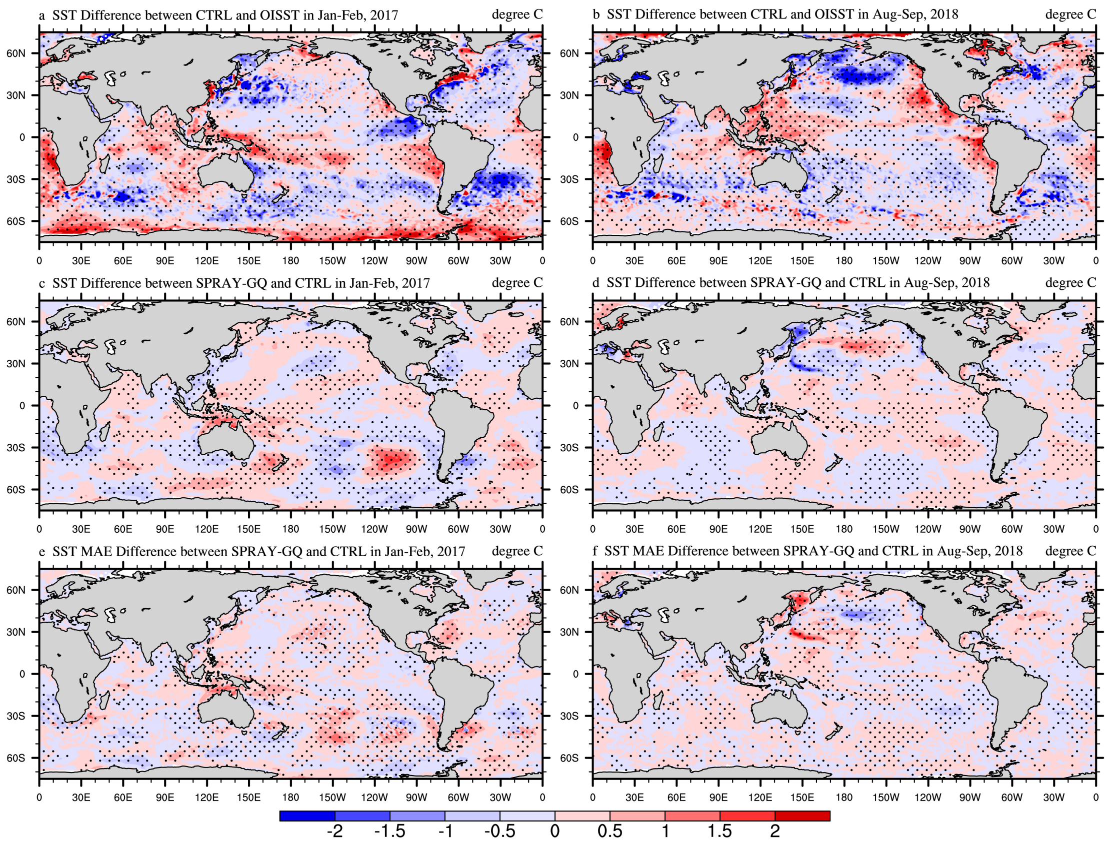

Figure R9. The 53-day average SST differences between CTRL and OISST (a&b; CTRL minus OISST), differences between SPRAY-GQ and CTRL (c&d; SPRAY-GQ minus CTRL), and MAE differences between SPRAY-GQ and CTRL (e&f) in Jan-Feb, 2017 (a, c, e) and in Aug-Sep, 2018 (b, d, f). The first 3-day simulation is discarded. The dotted areas are statistically significant at 95% confidence level.

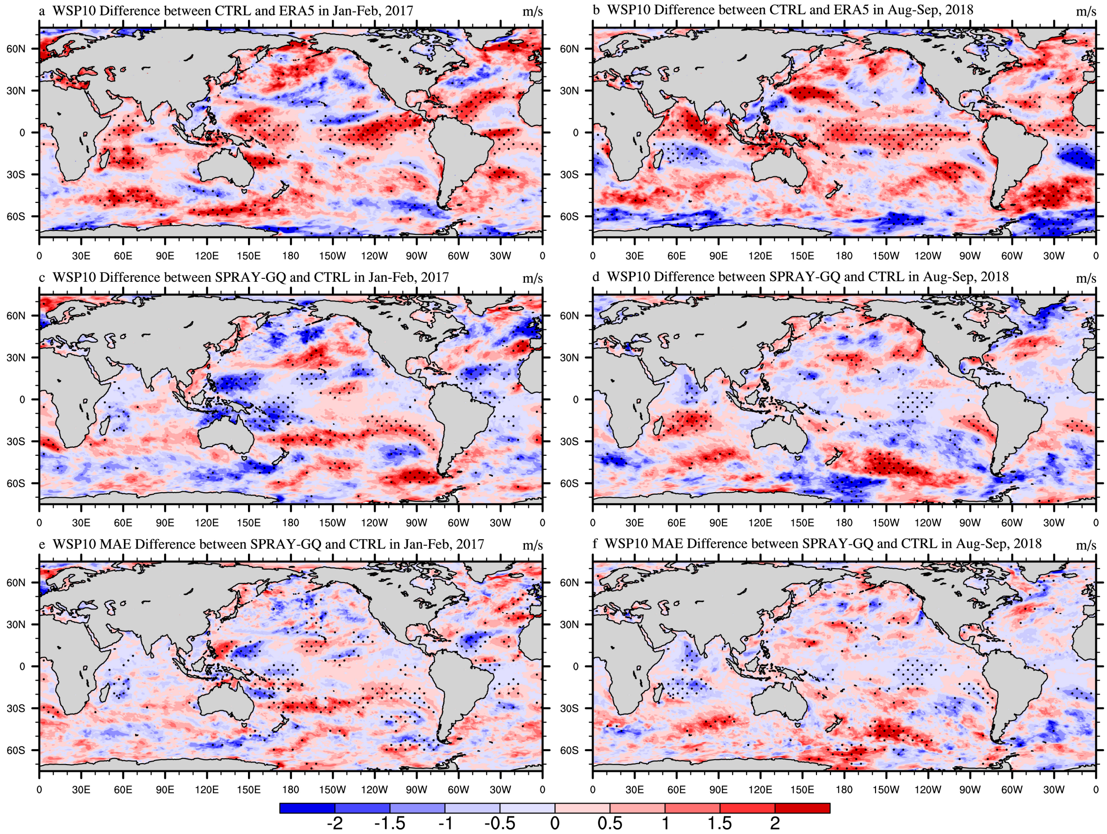

Figure R10. The 53-day average WSP10 differences between CTRL and ERA5 (a&b; CTRL minus ERA5), differences between SPRAY-GQ and CTRL (c&d; SPRAY-GQ minus CTRL), and MAE differences between SPRAY-GQ and CTRL (e&f) in Jan-Feb, 2017 (a, c, e) and in Aug-Sep, 2018 (b, d, f). The first 3-day simulation is discarded. The dotted areas are statistically significant at 95% confidence level.

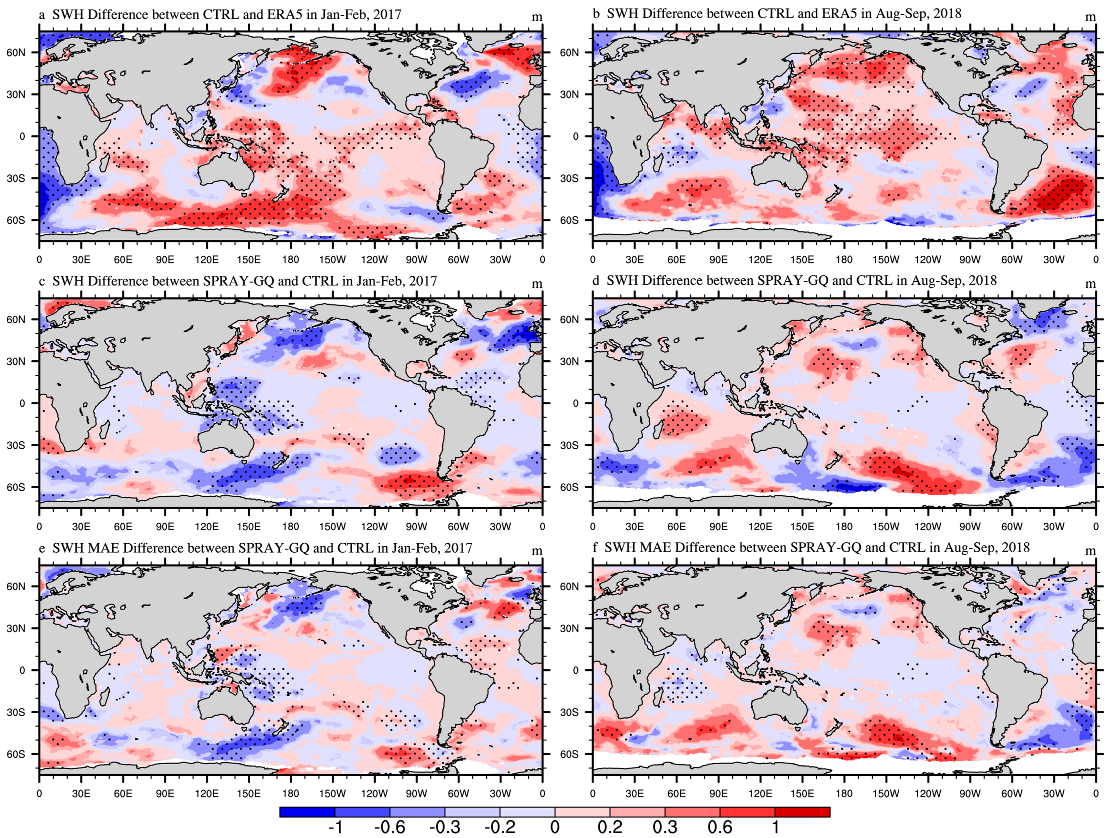

Figure R11. The 53-day average SWH differences between CTRL and ERA5 (a&b; CTRL minus ERA5), differences between SPRAY-GQ and CTRL (c&d; SPRAY-GQ minus CTRL), and MAE differences between SPRAY-GQ and CTRL (e&f) in Jan-Feb, 2017 (a, c, e) and in Aug-Sep, 2018 (b, d, f). The first 3-day simulation is discarded. The dotted areas are statistically significant at 95% confidence level.

References

Andreas, E. L., and Emanuel, K. A.: Effects of sea spray on tropical cyclone intensity, Journal of the atmospheric sciences, 58, 3741-3751, 2001.

McClarren, R.: Gauss Quadrature and Multi-dimensional Integrals, Computational Nuclear Engineering and Radiological Science Using Python; Academic Press: Cambridge, MA, USA, 287-299, 2018.

Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W. D., Deaven, D. G., Gandin, L. S., Iredell, M. D., Saha, S., White, G. H., and Woollen, J.: The NCEP/NCAR 40-Year Reanalysis Project, Bulletin of the American Meteorological Society, 77, 437-471, http://dx.doi.org/10.1175/1520-0477(1996)077%3C0437:TNYRP%3E2.0.CO;2, 1996.

Andreas, E. L., Mahrt, L., and Vickers, D.: An improved bulk air–sea surface flux algorithm, including spray-mediated transfer, Quarterly Journal of the Royal Meteorological Society, 141, 642-654, 2015.

Lindemann, D., Avila-Diaz, A., Pezzi, L., Rodrigues, J., Freitas, R. A., Coelho, L., Alonso, M., and Cerón, W. L.: The Surface Wind Influence on the Heat Fluxes Variability on the South Atlantic, 2021.

Seethala, C., Zuidema, P., Edson, J., Brunke, M., Chen, G., Li, X. Y., Painemal, D., Robinson, C., Shingler, T., and Shook, M.: On assessing ERA5 and MERRA2 representations of cold-air outbreaks across the Gulf Stream, Geophysical research letters, 48, e2021GL094364, 2021.