Supplementary material for

The Effects of Ocean Surface Waves on Global Forecast in CFS Modeling System v2.0

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Introduction

Figures S1 to S12 show the distribution maps of daily average SST (Fig.S1, S2, S7&S8), SWH (Fig.S3, S4, S9&S10), WSP10 (Fig.S5, S6, S11&S12) in CTRL, their bias and percentage absolute difference of the bias from experiments versus the CTRL, on January 10, 2017, August 10, 2018, January 5, 2019 and July 5, 2018, respectively. All of these simulated data are from the simulations described in the main text, of which the periods span from January 3 to 10, 2017, from August 3 to 10, 2018, from January 1 to 8, 2019 and from July 1 to 8, 2018, respectively. Other settings and processing steps are the same as those in the main text.

Tables S1 shows the correlation coefficient, RMSE and skill score of SWH simulations versus Jason-3 observation at 00:00 on Jan 3, 2017. These simulated data are generated by the single WW3 model (without coupling) with different input-dissipation source terms (ST) and wind forces (CCMP and ERA5).

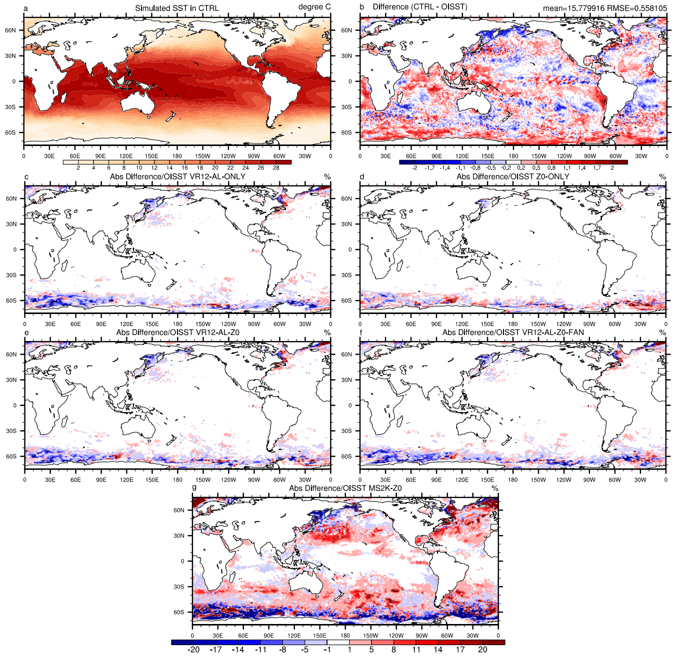

a
Simulated SST in CTRL
degree C
2 4 6 8 10 12 14 16 18 20 22 24 26 28
b
Difference (CTRL - OISST)
mean=15.779916 RMSE=0.558105
-2 -1.7 -1.4 -1.1 -0.8 -0.5 -0.2 0.2 0.5 0.8 1.1 1.4 1.7 2
c
Abs Difference/OISST VR12-AL-ONLY
%
d
Abs Difference/OISST Z0-ONLY
%
e
Abs Difference/OISST VR12-AL-Z0
%
f
Abs Difference/OISST VR12-AL-Z0-FAN
%
g
Abs Difference/OISST MS2K-Z0
%
60N
30N
0
30S
60S
0 30E 60E 90E 120E 150E 180 150W 120W 90W 60W 30W 0
-20 -17 -14 -11 -8 -5 -1 1 5 8 11 14 17 20

Figure S1. The daily average SST (°C) in CTRL, its bias in CTRL and percentage absolute difference of bias on January 10, 2017: a the SST in CTRL, b the SST bias between CTRL and OISST (CTRL minus OISST), c/d/e/f/g the percentage absolute difference between VR12-AL-ONLY/Z0-ONLY/VR12-AL-Z0/VR12-AL-Z0-FAN/MS2K-Z0 and CTRL. The absolute difference is a percentage computed as $\mathbf{PAD} = \frac{|\widehat{y_s}-y|-|\widehat{y_c}-y|}{|y|} \times \mathbf{100}\%$, where y is OISST, $\widehat{y_c}$ is simulated SST in CTRL and $\widehat{y_s}$ is simulated SST in other experiments, so a negative value means that the error is smaller than that of CTRL, and vice versa.

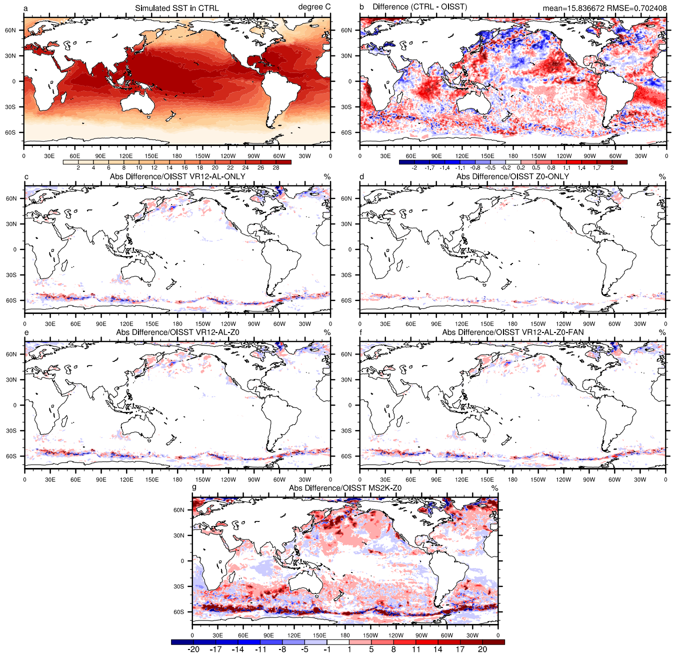

a
Simulated SST in CTRL
degree C
2 4 6 8 10 12 14 16 18 20 22 24 26 28
b
Difference (CTRL - OISST)
mean=15.836672 RMSE=0.702408
-2 -1.7 -1.4 -1.1 -0.8 -0.5 -0.2 0.2 0.5 0.8 1.1 1.4 1.7 2
c
Abs Difference/OISST VR12-AL-ONLY
%
d
Abs Difference/OISST Z0-ONLY
%
e
Abs Difference/OISST VR12-AL-Z0
%
f
Abs Difference/OISST VR12-AL-Z0-FAN
%
g
Abs Difference/OISST MS2K-Z0
%
60N
30N
0
30S
60S
0 30E 60E 90E 120E 150E 180 150W 120W 90W 60W 30W 0
-20 -17 -14 -11 -8 -5 -1 1 5 8 11 14 17 20

Figure S2. As Fig. S1, but for the daily average SST (°C) in CTRL, its bias in CTRL and absolute difference of bias on August 10, 2018.

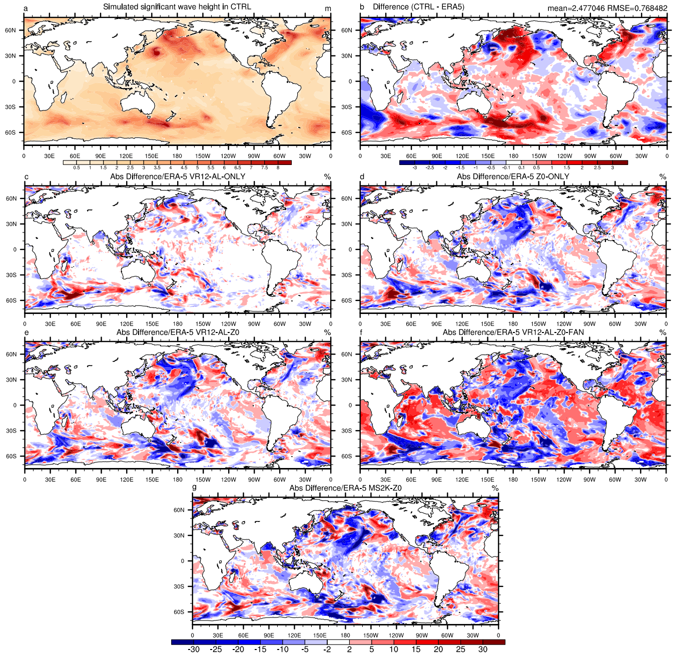
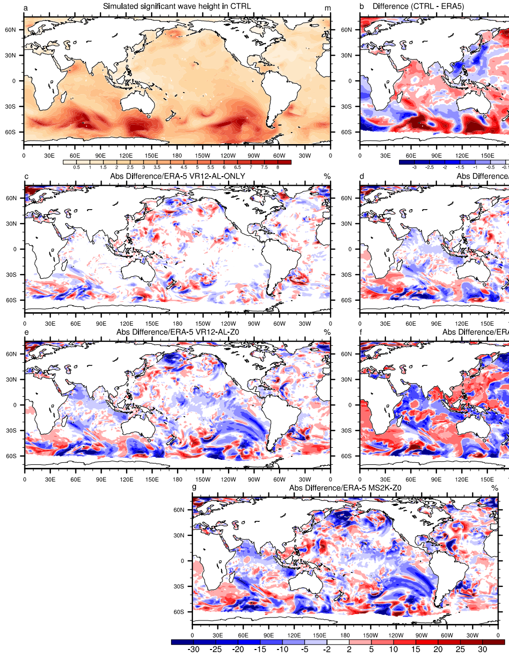

a
Simulated significant wave height in CTRL
m
0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8
b
Difference (CTRL - ERA5)
mean=2.477046 RMSE=0.768482
-3 -2.5 -2 -1.5 -1 -0.5 -0.1 0.1 0.5 1 1.5 2 2.5 3
c
Abs Difference/ERA-5 VR12-AL-ONLY
%
d
Abs Difference/ERA-5 Z0-ONLY
%
e
Abs Difference/ERA-5 VR12-AL-Z0
%
f
Abs Difference/ERA-5 VR12-AL-Z0-FAN
%
g
Abs Difference/ERA-5 MS2K-Z0
%
60N 30N 0 30S 60S
0 30E 60E 90E 120E 150E 180 150W 120W 90W 60W 30W 0
-30 -25 -20 -15 -10 -5 -2 2 5 10 15 20 25 30

Figure S3. The SWH (m) in CTRL, its bias in CTRL and percentage absolute difference of bias on January 10, 2017: a the SWH in CTRL, b the SWH bias between CTRL and ERA5 (CTRL minus ERA5), c/d/e/f/g the percentage absolute difference between VR12-AL-ONLY/Z0-ONLY/VR12-AL-Z0/VR12-AL-Z0-FAN/MS2K-Z0 and CTRL. The absolute difference is a percentage computed as $\mathbf{PAD} = \frac{|\widehat{y_s}-y|-|\widehat{y_c}-y|}{|y|} \times \mathbf{100}\%$, where y is the SWH from ERA5, $\widehat{y_c}$ is simulated SWH in CTRL and $\widehat{y_s}$ is simulated SWH in other experiments, so a negative value means that the error is smaller than that of CTRL, and vice versa.



a
Simulated significant wave height in CTRL
m
b
Difference (CTRL - ERA5)
mean=2.788791 RMSE=0.779439
c
Abs Difference/ERA-5 VR12-AL-ONLY
%
d
Abs Difference/ERA-5 Z0-ONLY
%
e
Abs Difference/ERA-5 VR12-AL-Z0
%
f
Abs Difference/ERA-5 VR12-AL-Z0-FAN
%
g
Abs Difference/ERA-5 MS2K-Z0
%
60N
30N
0
30S
60S
0
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W
0
0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8
-3 -2.5 -2 -1.5 -1 -0.5 -0.1 0.1 0.5 1 1.5 2 2.5 3
-30 -25 -20 -15 -10 -5 -2 2 5 10 15 20 25 30

Figure S4. As Fig. S3, but for the SWH (m) in CTRL, its bias in CTRL and absolute difference of bias on August 10, 2018.

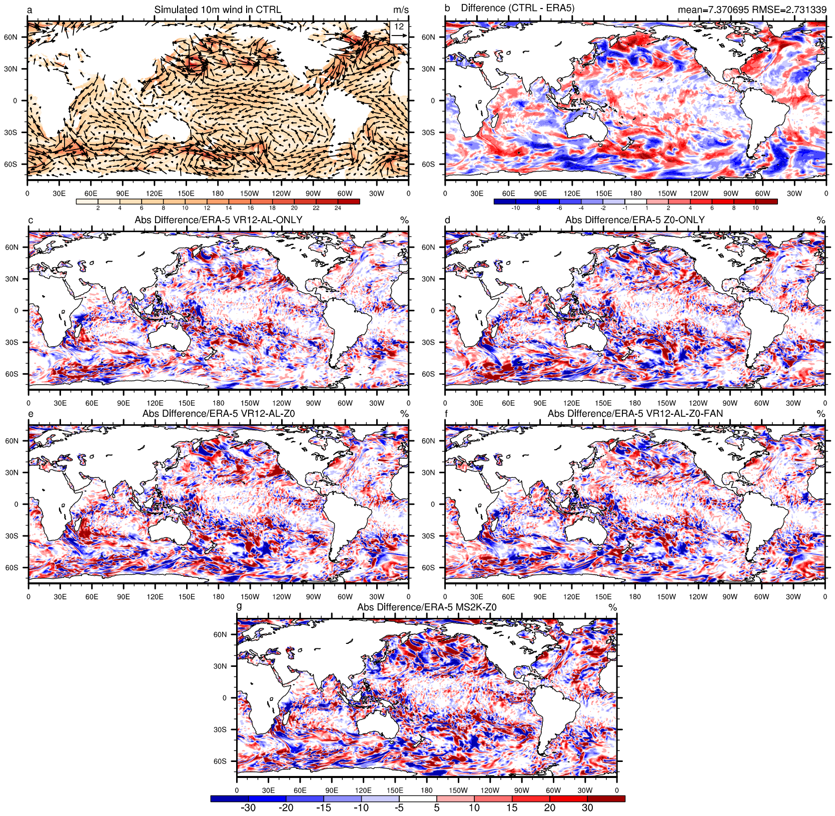

a
Simulated 10m wind in CTRL
m/s
12
b
Difference (CTRL - ERA5)
mean=7.370695 RMSE=2.731339
c
Abs Difference/ERA-5 VR12-AL-ONLY
%
d
Abs Difference/ERA-5 Z0-ONLY
%
e
Abs Difference/ERA-5 VR12-AL-Z0
%
f
Abs Difference/ERA-5 VR12-AL-Z0-FAN
%
g
Abs Difference/ERA-5 MS2K-Z0
%
60N
30N
0
30S
60S
0
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W
0
2 4 6 8 10 12 14 16 18 20 22 24
-10 -8 -6 -4 -2 -1 1 2 4 6 8 10
-30 -20 -15 -10 -5 5 10 15 20 30

Figure S5. The WSP10 (m/s) in CTRL, its bias in CTRL and percentage absolute difference of bias on January 10, 2017: a the 10-m wind in CTRL, b the 10-m wind bias between CTRL and ERA5 (CTRL minus ERA5), c/d/e/f/g the percentage absolute difference between VR12-AL-ONLY/Z0-ONLY/VR12-AL-Z0/VR12-AL-Z0-FAN/MS2K-Z0 and CTRL. The absolute difference is a percentage computed as $\mathbf{PAD} = \frac{|\widehat{y_s}-y|-|\widehat{y_c}-y|}{|y|} \times \mathbf{100\%}$, where y is WSP10 from ERA5, $\widehat{y_c}$ is simulated WSP10 in CTRL and $\widehat{y_s}$ is simulated WSP10 in other experiments, so a negative value means that the error is smaller than that of CTRL, and vice versa.

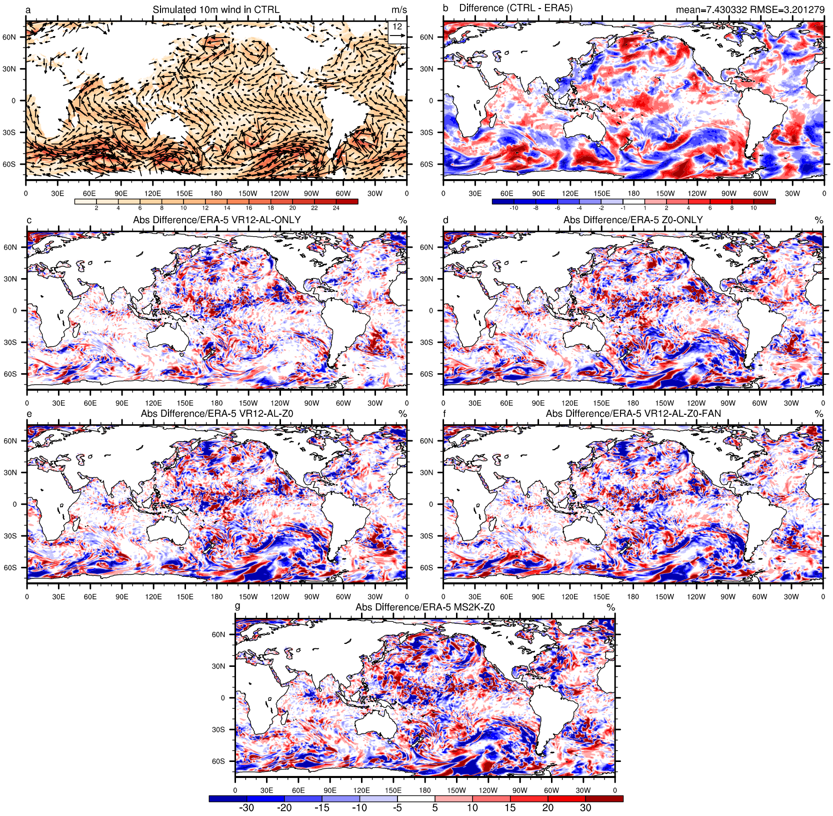

a
Simulated 10m wind in CTRL
m/s
12
b
Difference (CTRL - ERA5)
mean=7.430332 RMSE=3.201279
c
Abs Difference/ERA-5 VR12-AL-ONLY
%
d
Abs Difference/ERA-5 Z0-ONLY
%
e
Abs Difference/ERA-5 VR12-AL-Z0
%
f
Abs Difference/ERA-5 VR12-AL-Z0-FAN
%
g
Abs Difference/ERA-5 MS2K-Z0
%
60N
30N
0
30S
60S
0
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W
0
2
4
6
8
10
12
14
16
18
20
22
24
-10
-8
-6
-4
-2
-1
1
2
4
6
8
10
-30
-20
-15
-10
-5
5
10
15
20
30

Figure S6. As Fig. S5, but for the WSP10 (m/s) in CTRL, its bias in CTRL and absolute difference of bias on August 10, 2018.

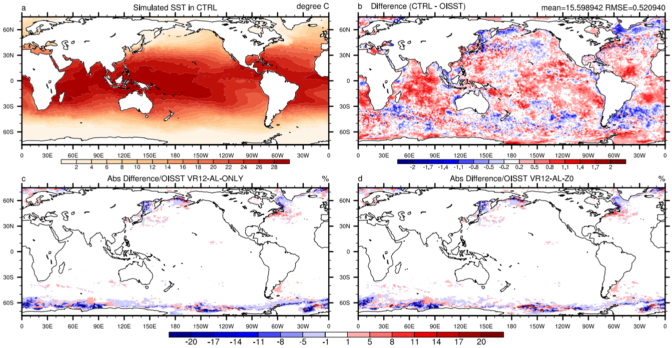

a
Simulated SST in CTRL
degree C
2 4 6 8 10 12 14 16 18 20 22 24 26 28
b
Difference (CTRL - OISST)
mean=15.598942 RMSE=0.520940
-2 -1.7 -1.4 -1.1 -0.8 -0.5 -0.2 0.2 0.5 0.8 1.1 1.4 1.7 2
c
Abs Difference/OISST VR12-AL-ONLY
%
d
Abs Difference/OISST VR12-AL-Z0
%
-20 -17 -14 -11 -8 -5 -1 1 5 8 11 14 17 20
60N 30N 0 30S 60S
0 30E 60E 90E 120E 150E 180 150W 120W 90W 60W 30W 0

Figure S7. The daily average SST (°C) in CTRL, its bias in CTRL and percentage absolute difference of bias on January 5, 2019: a the SST in CTRL, b the SST bias between CTRL and OISST (CTRL minus OISST), c/d the percentage absolute difference between VR12-AL-ONLY/VR12-AL-Z0 and CTRL. The absolute difference is a percentage computed as $\mathbf{PAD} = \frac{|\widehat{y_s}-y|-|\widehat{y_c}-y|}{|y|} \times \mathbf{100}\%$, where y is OISST, $\widehat{y_c}$ is simulated SST in CTRL and $\widehat{y_s}$ is simulated SST in other experiments, so a negative value means that the error is smaller than that of CTRL, and vice versa.

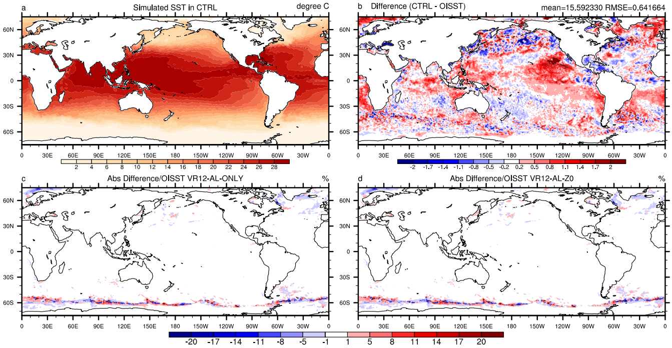

a
Simulated SST in CTRL
degree C
2 4 6 8 10 12 14 16 18 20 22 24 26 28
b
Difference (CTRL - OISST)
mean=15.592330 RMSE=0.641664
-2 -1.7 -1.4 -1.1 -0.8 -0.5 -0.2 0.2 0.5 0.8 1.1 1.4 1.7 2
c
Abs Difference/OISST VR12-AL-ONLY
%
d
Abs Difference/OISST VR12-AL-Z0
%
-20 -17 -14 -11 -8 -5 -1 1 5 8 11 14 17 20
60N 30N 0 30S 60S
0 30E 60E 90E 120E 150E 180 150W 120W 90W 60W 30W 0

Figure S8. As Fig. S7, but for the daily average SST (°C) in CTRL, its bias in CTRL and absolute difference of bias on July 5, 2018.

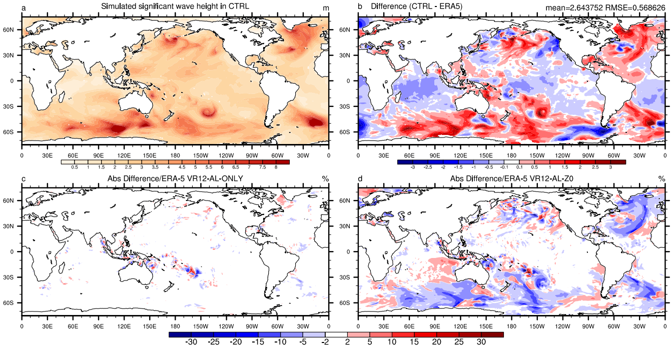

a
Simulated significant wave height in CTRL
m
b
Difference (CTRL - ERA5)
mean=2.643752 RMSE=0.568626
c
Abs Difference/ERA-5 VR12-AL-ONLY
%
d
Abs Difference/ERA-5 VR12-AL-Z0
%
60N
30N
0
30S
60S
0 30E 60E 90E 120E 150E 180 150W 120W 90W 60W 30W 0
0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8
-3 -2.5 -2 -1.5 -1 -0.5 -0.1 0.1 0.5 1 1.5 2 2.5 3
-30 -25 -20 -15 -10 -5 -2 2 5 10 15 20 25 30

Figure S9. The SWH (m) in CTRL, its bias in CTRL and percentage absolute difference of bias on January 5, 2019: a the SWH in CTRL, b the SWH bias between CTRL and ERA5 (CTRL minus ERA5), c/d the percentage absolute difference between VR12-AL-ONLY/VR12-AL-Z0 and CTRL. The absolute difference is a percentage computed as $\mathbf{PAD} = \frac{|\widehat{y_s}-y|-|\widehat{y_c}-y|}{|y|} \times \mathbf{100\%}$, where y is the SWH from ERA5, $\widehat{y_c}$ is simulated SWH in CTRL and $\widehat{y_s}$ is simulated SWH in other experiments, so a negative value means that the error is smaller than that of CTRL, and vice versa.

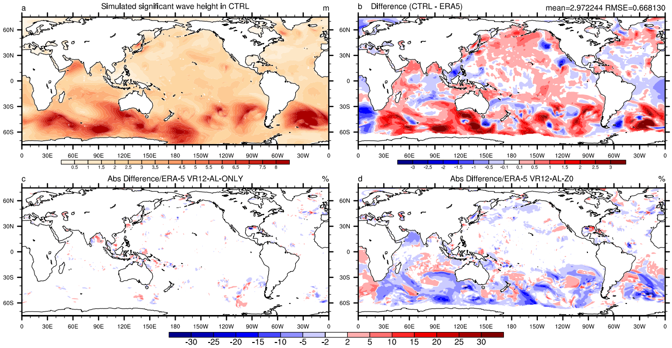
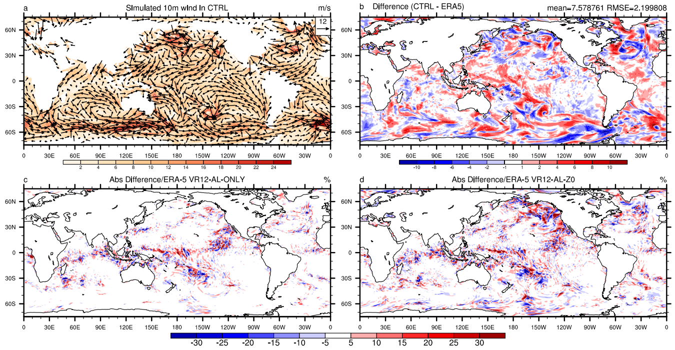

a
Simulated significant wave height in CTRL
m
b
Difference (CTRL - ERA5)
mean=2.972244 RMSE=0.668130
c
Abs Difference/ERA-5 VR12-AL-ONLY
%
d
Abs Difference/ERA-5 VR12-AL-Z0
%
60N
30N
0
30S
60S
0 30E 60E 90E 120E 150E 180 150W 120W 90W 60W 30W 0
0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8
-3 -2.5 -2 -1.5 -1 -0.5 -0.1 0.1 0.5 1 1.5 2 2.5 3
-30 -25 -20 -15 -10 -5 -2 2 5 10 15 20 25 30

Figure S10. As Fig. S9, but for the SWH (m) in CTRL, its bias in CTRL and absolute difference of bias on July 5, 2018.


a
Simulated 10m wind in CTRL
m/s
12
b
Difference (CTRL - ERA5)
mean=7.578761 RMSE=2.199808
c
Abs Difference/ERA-5 VR12-AL-ONLY
%
d
Abs Difference/ERA-5 VR12-AL-Z0
%
60N
30N
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30S
60S
0
30E
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90E
120E
150E
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150W
120W
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60W
30W
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-10
-8
-6
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-25
-20
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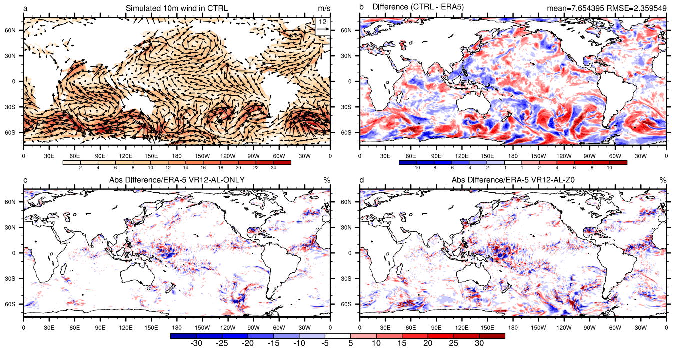
Figure S11. The WSP10 (m/s) in CTRL, its bias in CTRL and percentage absolute difference of bias on January 5, 2019: a the 10-m wind in CTRL, b the 10-m wind bias between CTRL and ERA5 (CTRL minus ERA5), c/d the percentage absolute difference between VR12-AL-ONLY/VR12-AL-Z0 and CTRL. The absolute difference is a percentage computed as $\mathbf{PAD} = \frac{|\widehat{y_s}-y|-|\widehat{y_c}-y|}{|y|} \times \mathbf{100\%}$, where y is WSP10 from ERA5, $\widehat{y_c}$ is simulated WSP10 in CTRL and $\widehat{y_s}$ is simulated WSP10 in other experiments, so a negative value means that the error is smaller than that of CTRL, and vice versa.


a
Simulated 10m wind in CTRL
m/s
12
b
Difference (CTRL - ERA5)
mean=7.654395 RMSE=2.359549
c
Abs Difference/ERA-5 VR12-AL-ONLY
%
d
Abs Difference/ERA-5 VR12-AL-Z0
%
60N
30N
0
30S
60S
0
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W
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16
18
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22
24
-10
-8
-6
-4
-2
-1
1
2
4
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-30
-25
-20
-15
-10
-5
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Figure S12. As Fig. S11, but for the WSP10 (m/s) in CTRL, its bias in CTRL and absolute difference of bias on July 5, 2018.

Table S1. Correlation coefficient, RMSE and skill score of SWH in WW3 simulations versus Jason-3 observation at 00:00 on Jan 3, 2017. The RMSE and skill score (SS) are calculated as RMSE=$\sqrt{\sum_{i=1}^{n}(\hat{y}_i - y_i)^2/n}$ and SS=$1 - \frac{\sum_{i=1}^{n}(\widehat{y_i}-y_i)^2}{\sum_{i=1}^{n}(|\widehat{y_i}-\overline{y_i}|+|y_i-\overline{y_i}|)^2}$, respectively, where $\hat{y}_i$ is simulated value, y_i is Jason-3 data and $\bar{y}_i$ is the average, i=1,n and n is the total number of measurements in the Jason-3 orbit.

Experiments	Correlation Coefficient ($P<0.01$)	RMSE	Skill Score
ERA-5 ST2	0.76	0.42	0.85
ERA-5 ST3	0.77	0.41	0.86
ERA-5 ST4	0.82	0.37	0.89
ERA-5 ST6	0.82	0.49	0.86
CCMP ST4	0.69	0.54	0.78
CCMP ST2	0.68	0.59	0.76