Thanks for the comments and suggestions that help to improve the quality of this paper. We provide point-to-point responses to the reviewers' comments below with blue texts.

Reviewer #1: Recommendation.

Tides play an important role in the ocean, which plays crucial role in energy transfer and maintaining the thermohaline circulation. Thus, the introduction of tidal processes in global ocean models is necessary. This paper firstly presents a new method for inclusion of tides in a global model via the explicit calculation of the tide-generating force based on the positions of the Sun and Moon is proposed, rather than the traditional method of including about eight tidal constituents with empirical amplitudes and frequencies. Excellent results are demonstrated for the effect on improving simulations of the ocean circulation. This paper has a clear logic and concise structure, which can provide guidance for further improvement of ocean models related to tidal forcing. So, I recommend to accept the MS with the following minor editing.

Reply: We greatly appreciate your detailed summary and excellent comments which helped us clarify our logic and language expression.

L107-109: What is needed in the equation of barotropic modal motion is the horizontal tidal force, so why convert it to the tidal potential in equation (5) after getting the tidal force?

Reply: This is because the direction of the tidal force has not been decomposed into directions along longitude and latitude before being converted to tidal potential. Therefore, it is more convenient and affordable to express the tidal force in the form of the gradient of the tidal potential after converting it into a scalar of the tidal potential.

L132-135: Do the two wave drag terms take exactly the same coefficients as your references?

Reply: Yes, the parameterization of two wave drag terms are exactly following Simmons et al. (2004) as MOM and Schiller and Fiedler (2007).

L118-120: Both φ_m and λ_m are functions of universal time. What is this function?

Reply: Thanks. The projected position and distance of the sun and the moon on the earth are obtained by polynomial expansion, and the specific formula is given by Sun and moon, Satellite Orbits: Models, Methods and Applications (Montenbruck and Gill, 2000). However, because the formula is too large, it is not reflected in the text. We have modified this part of the paper and uploaded supplementary documents.

L187: What's does "large non-closed circular bands" mean?

Reply: This shows that the minimum value of Exp2 in Fig.2 is a circle around the earth without closing, rather than the existence of two closed minimums like Exp1

(Figure R1). Schwiderski (1980) pointed out that when the Earth is an ideal sphere, the equilibrium tide covering the earth's surface exhibits an ellipsoid shape, and distribution of Exp2 is consistent with the ellipsoid's planar expansion.

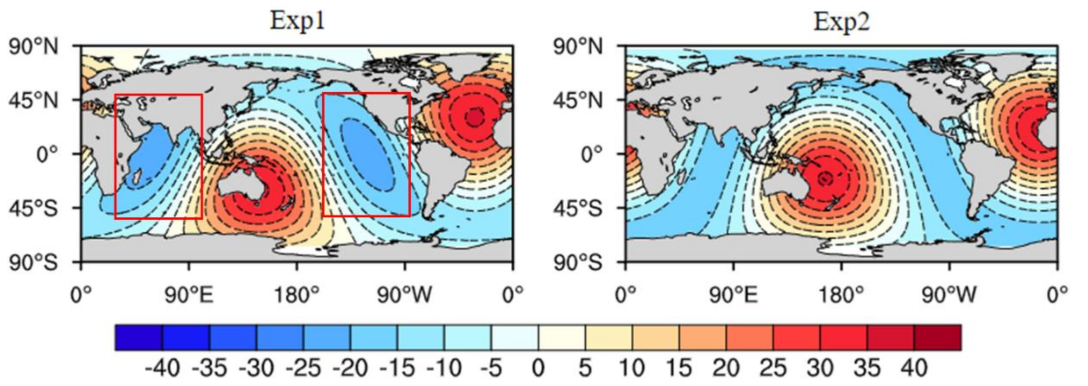

Figure R1. Spatial patterns of the spring tides for Exp1 (left) and Exp2 (right). The red boxes in Exp1 mean the closed minimums. The units are cm.

L211: total errors => total error

Reply: Thanks for your suggestion, we have revised it according to your suggestion.

L212: I don't think phrasing “phase error” is specific enough, especially when it first appears. Instead, “amplitude-weighted phase error (phase error)”.

Reply: Thanks for your suggestion, we have revised it according to your suggestion. It is more standard to use "amplitude-weighted phase error" here.

L225: a similar distribution => similar distributions

Reply: Thanks for your suggestion, we have revised it according to your suggestion.

L311-312: “This is because Exp2, in applying the new formulation of the tidal scheme, can better represent the projection positions of both the Sun and Moon relative to Exp1.”, Why?

Reply: This is because the projection positions of the sun and moon are always in low latitude in Exp2, and tidal potential signal of climatic state is lost caused by simplifying the tidal potential to the form of sine wave in Exp1.

L325-326: modes => constituents

Reply: Thanks for your suggestion, we have revised it according to your suggestion. It should be “constituents” here.

Fig.9: dynamic sea level => DSL

Reply: Thanks for your suggestion, we have revised it according to your suggestion.

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Thanks the reviewer for the suggestions and thorough review for this manuscript. We carefully revised the manuscript according to the suggested comments, including the grammatical issues. Our point-to-point response to the reviewer is as follows.

Reviewer #2: Recommendation.

The authors introduced the direct effect of the gravitation of the Sun and Moon for the external forcing in the tidal model, i.e. the equilibrium tidal potential. This is different from a traditional method which uses a sum of tidal constituents, obtained by spherical harmonics expansion. The authors ran an OGCM by this new tidal forcing, and showed that reproducibility of sea level variations was improved. Although this result could be an important achievement in tidal modeling, the current manuscript is insufficient for explanation, model experiments, and analysis. I encourage the authors to resubmit the paper after a drastic improvement, at least in terms of the points listed in "Major comments".

Major comments

#1
The advantages of the new scheme are not explained clearly. Normally, we treat a tidal potential individually for each tidal constituent specified by the so-called Doodson number, but I think that this paper deals with all the tidal constituents directly from the first principle. In the paper, the advantages of the new method are not theoretically discussed, so the purpose of its introduction is unclear. The traditional method also has advantages, for example, changing the tide parameters such as the love number for each tide, targeting specified tidal constituents, and so on.
Reply: Thanks for your suggestion. We have revised the paper based on your comments and added the theoretical discussion on the advantages of the two schemes in the summary: "The new tidal scheme has some unique advantages: It can accurately provide instantaneous tidal potentials, since both astronomers and oceanographers have well established models for determining the exact position of the sun and the moon by Julian and for calculating the instantaneous tidal potential by their projected positions. Traditional tidal scheme do not guarantee the correct transient tidal potential at any given time, as described in Section 4.1. Traditional method does not cover all tidal constituents, so it is more suitable to study only one specific tidal constituent rather than the full real tidal process in the OGCM. Besides, in the traditional scheme, the tidal potential is introduced in the form of sine wave, so that the climate state of tidal potential is zero at any position. The new tidal method does not impose this particular time variation." in Line 338-347.

#2
I think that the verification approach using an OGCM is not suitable for the purpose

of this paper, which is to propose a new tidal scheme. The authors should first verify it by a barotropic tide model. In addition, as the authors wrote, tide models have various tuning parameters, so the accuracy should be compared after tuning the parameters for the two schemes. Alternatively, the authors may explain theoretically the errors inherent in the traditional method, and show that they would be eliminated.
Reply: Thanks for your suggestion. The aims of this study are to propose a new tidal scheme and investigate the application of the new tidal scheme in OGCM. So, we appreciate your suggestion. We will use the barotropic tide model to verify the tidal scheme in the next step and follow the suggestion in your comment #3.

In addition, the new tidal scheme reasonably simulates the instantaneous tidal potential of spring and neap tide in Section 4.1. Exp1 applying the tradition tidal scheme exhibited larger errors in the amplitude, phase of major tidal constituents compared to Exp2 using the new tidal scheme, which is related with adopting the fixed amplitude for each tidal constituent in traditional explicit tidal scheme. Thus, we think the new tidal scheme reduces errors in the traditional method.

#3
If the authors still want to introduce the new tidal forcing into an OGCM, the introduction method should be reconsidered. As discussed in detail in Arbic et al. (2010) and Sakamoto et al. (2013, DOI:10.5194/os-9-1089-2013), replacing the barotropic equation in an OGCM by Eq.(10) in the paper leads to disrupt the dynamical balance of the ocean circulation in the original OGCM. There is no point in verifying the model results in such a situation.
Reply: Thanks for your suggestion, which has given us great inspiration. According to your suggestion, we conducted experiments by also adopting the practical scheme following Sakamoto et al. (2013). This scheme decomposes the barotropic process including tides into a linear component caused by tides and the original barotropic component that maintains the original dynamical balance in the ocean. The experiment was integrated for one year, initialized from the quasi-equilibrium state (300th year) of the spin-up experiment under the same CORE I forcing fields. We found the errors (including the phase error and total error) of all the eight tidal constituents of Exp2 using the new tidal scheme are less than Exp1 that applies the tradition tidal scheme (Table R1). When we apply the practical scheme of Sakamoto et al. (2013), the distribution and amplitude of tidal constituents in Exp1 and Exp2 (Figures R1 and R2) are very similar to the original method. The conclusions of the new tidal scheme on improvement of the tidal constituents remain unchanged. Therefore, we added "Furthermore, we conduct two experiments (one using traditional tidal scheme, the other applying new tidal scheme) by also adopting the practical scheme following Sakamoto et al. (2013), we found the errors (including the phase error and total error) of all the eight tidal constituents of the experiment using the new tidal scheme are less than that applies the tradition tidal scheme (Table R1)." in Lines 303-307.

The traditional formula of the eight tidal constituents by Griffies et al. (2009) is incorporated directly in barotropic equation in many OGCMs including MOM, MPI-OM, HYCOM and LICOM (Schiller, 2004; Arbic et al., 2010; Müller et al., 2012, Yu et al. 2016). Based on the above two points, we decide to use the same method to introduce the tidal forcing in this paper, i.e. introducing the tidal forcing directly in barotropic equation in OGCM.

Besides, Arbic et al (2010) pointed out the global tidal simulations must include parameterized topographic wave drag in order to accurately simulate the tides, we added a drag term τ_{tide} in barotropic equation (Eq.(10) in the paper), including parameterized internal wave drag due to the oscillating flow over the topography and the wave drag term due to the undulation of the sea surface (Jayne and Laurent, 2001; Simmons et al. 2004; Schiller and Fiedler, 2007), which is the same drag term with MOM to deal with the traditional tidal method. Therefore, we did not see evidence of the disruption of the dynamical balance by the introduction of our method. We revised the paper by adding a discussion about the dynamical balance: "Introduction of tidal forcing leads to disrupt the dynamical balance of the ocean circulation in the original OGCM (Sakamoto et al., 2013), and Arbic et al (2010) pointed out the global tidal simulations must include parameterized topographic wave drag in order to accurately simulate the tides, we added a drag term τ_{tide}, in barotropic equation, including parameterized internal wave drag due to the oscillating flow over the topography and the wave drag term due to the undulation of the sea surface (Jayne and Laurent, 2001; Simmons et al. 2004; Schiller and Fiedler, 2007)." in Lines138-144

Sakamoto et al. (2013) provides a guarantee for the dynamical balance of tidal dissipation, we will use the decomposition method of Sakamoto et al. (2013) to quantitatively compare the effects of tidal forcing on large scale ocean circulation and the sensitivity of bottom friction due to the tidal component in our future work.

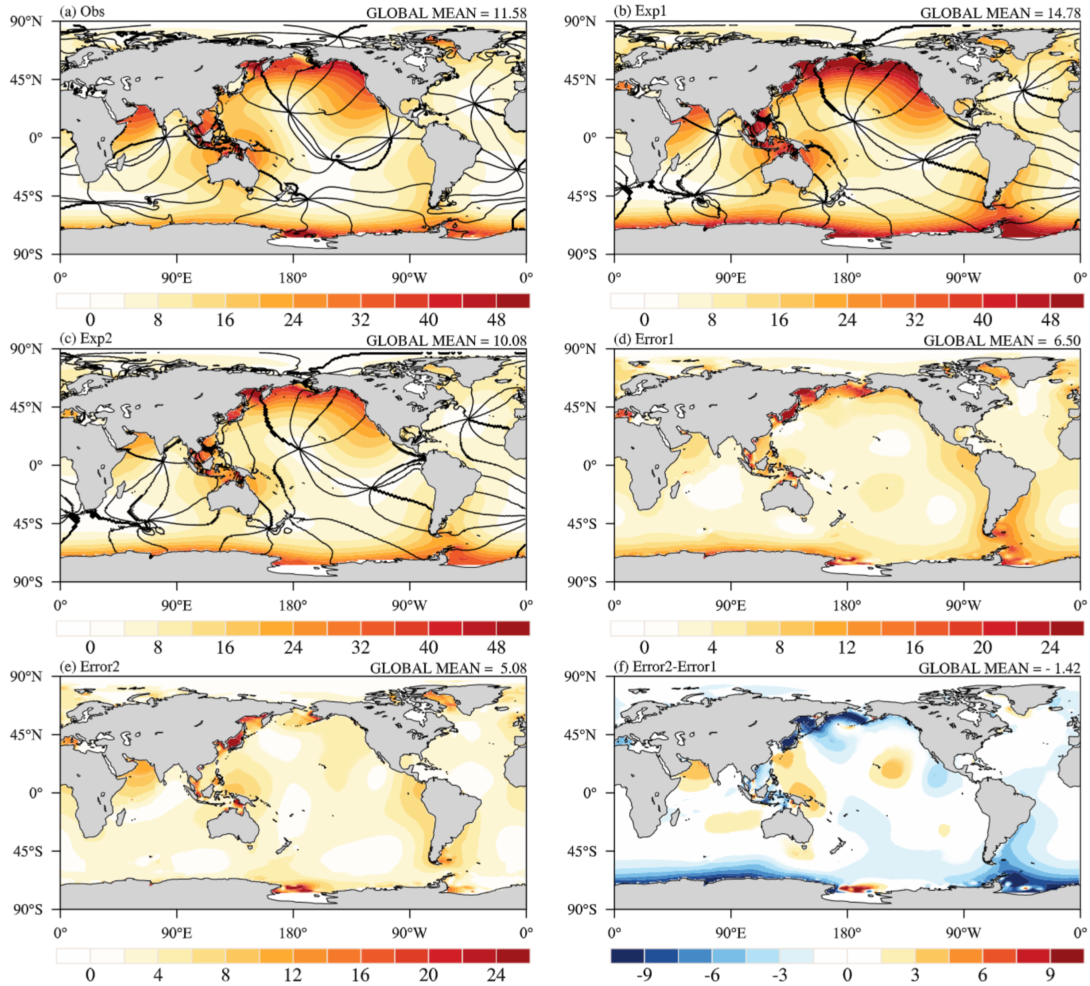

Figure R1. Spatial patterns of the amplitude and phase of K1 for (a) the observation (Obs), (b) Exp1, (c) Exp2, (d) the total error for Exp1, (e) the total error for Exp2, and (f) the difference in error between Exp2 and Exp1. The observation is from TPXO9v2 (Egbert and Erofeeva, 2002). The units are cm, and the lines of the constant phase are plotted every 45° in black.

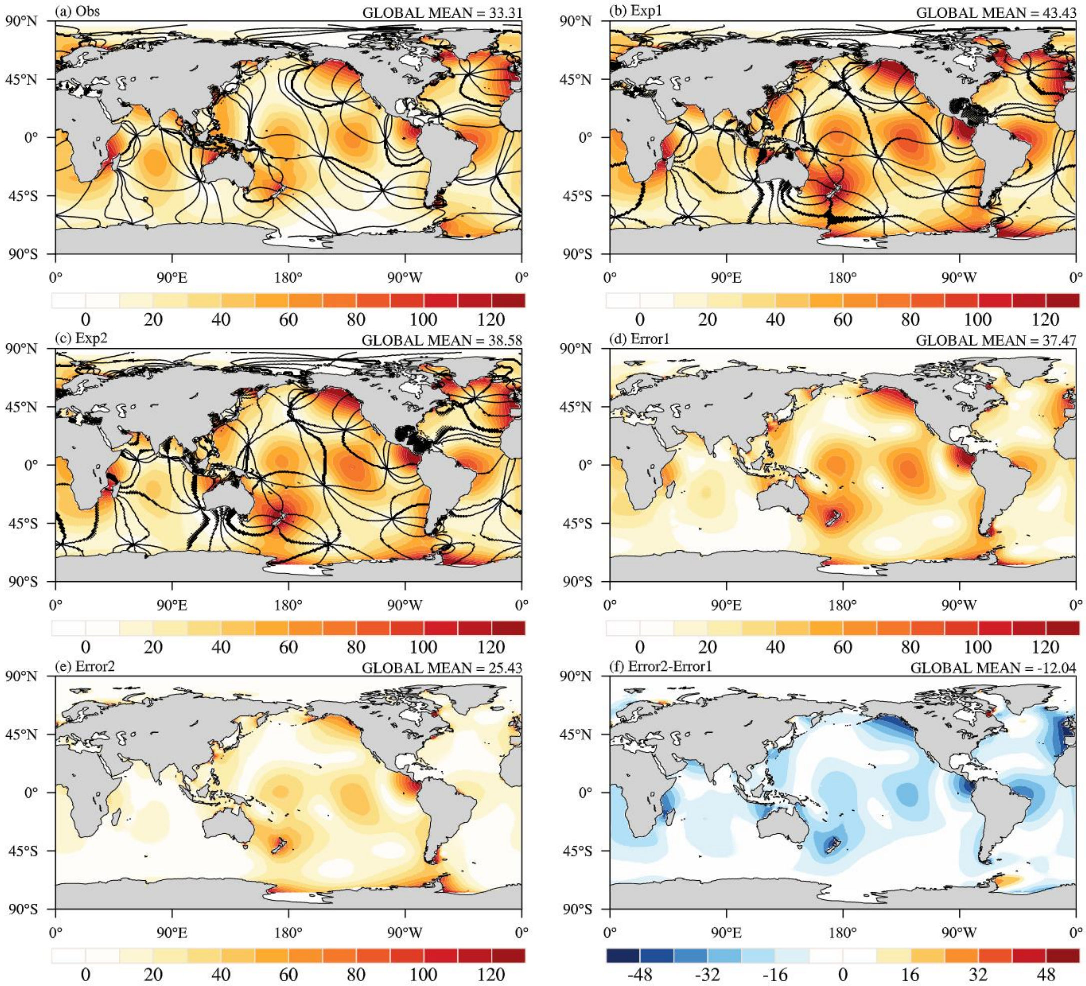

Figure R2. Spatial patterns of the amplitude and phase of M2 for (a) the observation (Obs), (b) Exp1, (c) Exp2, (d) the total error for Exp1, (e) the total error for Exp2, and (f) the difference in error between Exp2 and Exp1. The observation is from TPXO9v2 (Egbert and Erofeeva, 2002). The units are cm, and the lines of the constant phase are plotted every 45° in black.

Table R1. Global mean values of the amplitudes of the eight tidal constituents during observation, Exp1 and Exp2, and the amplitude, phase, and total errors of the eight tidal constituents in Exp1 and Exp2. The units are cm. The better amplitude and lower errors in Exp2 relative to Exp1 are marked by bold font.

	Global mean			Amplitude Error		Phase Error		Total Error	
	Obs	Exp1	Exp2	Exp1	Exp2	Exp1	Exp2	Exp1	Exp2
M2	33.31	43.43	**38.58**	15.18	**13.11**	34.26	**21.78**	37.47	**25.43**
S2	13.35	13.70	11.46	5.30	5.44	7.71	**5.79**	9.35	**7.94**
N2	7.08	11.29	**6.91**	4.34	**1.99**	8.35	**3.03**	9.41	**3.62**
K2	3.75	7.5	**7.01**	3.92	**3.54**	7.60	**6.26**	8.56	**7.19**
K1	11.58	14.78	**10.08**	5.05	**3.78**	4.09	**3.40**	6.50	**5.08**
O1	8.34	11.65	**9.92**	3.94	**3.18**	9.22	**4.04**	10.02	**5.14**
P1	3.62	11.65	**8.25**	7.53	**4.50**	4.98	**4.12**	9.03	**6.10**
Q1	1.76	2.91	**1.80**	1.14	**0.50**	2.20	**0.51**	2.48	**0.71**

Minor comments

#4 Abstract

Quantitative evaluations are necessary when discussing accuracy.

Reply: Thanks for your suggestion. Quantitative improvements for M2 and K1 are briefly supplemented in the abstract: “It significantly reduces the total errors of eight tidal constituents (with the exception of N2 and Q1) in the traditional explicit tidal scheme, in which the total errors of K1 and M2 are reduced by 21.85% and 32.13%, respectively.” in Line 29-31.

“Compared with Exp1, the total errors of K1 and M2 in Exp2 are reduced by 21.85% and 32.13% respectively.” in Line 268-269.

#5 Section 2.

Add some appropriate references for the gravitation of celestial bodies (a textbook?). Description of variables is also insufficient.

Reply: Thanks very much. When introducing Eq.(1), we have added some references for the gravitation of celestial bodies: “Assuming that the Earth is a rigid body, the horizontal tide-generating force is (Cartwright, 1999; Boon, 2004):” in Lines 99-100.

We have added the description of the variable in Section 2, for example, "r is the angle between the Moon pointing to the center of the Earth and point X, L and θ_m are the distance and zenith angle of the Moon and an arbitrary position X on the Earth (Fig. 1)." in Lines 106-108.

#6 Eq. (4)
I cannot follow derivation of Eq.(4).
Please give a supplement or reference for readers.
Reply: Thanks. We have modified this part of the paper and uploaded supplementary documents.

#7 Eq. (9)
There is no need to separate cases, since the value of "cos Tm" is the same.
Reply: Thanks very much. We have deleted the Eq. (9) according to your suggestion.

#8 L.187 "the negative regions of the spiring tide..."
The meaning is not clear. What part of Schwiderski (1980) do you refer to?
Reply: This shows that the minimum value of Exp2 in Fig.2 is a circle around the earth without closing, rather than the existence of two closed minimums like Exp1 (Figure R3). Schwiderski (1980) pointed out that when the Earth is an ideal sphere, the equilibrium tide covering the earth's surface exhibits an ellipsoid shape, and distribution of Exp2 is consistent with the ellipsoid's planar expansion.

#9 L.199-201 "The different distribution..."
Enrich arguments to support the conclusion.
Reply: Thanks for your suggestion. We have added the relationship between the position of solar projection and the tidal potential distribution of neap tide, which will more clearly illustrate the advantages of the new scheme in the simulation of solar projection position, we have revised to "There are pronounced differences in neap tides between Exp1 and Exp2 (Fig. 3). The neap tide simulated in Exp2 shows a larger meridional variation, the positive regions are mainly concentrated in the middle and low latitudes, the negative regions are mainly concentrated in the high latitudes of the two hemispheres, because the projection positions of the Sun and Moon are located in the middle and low latitudes, resulting in the relatively weaker tidal potential in the high latitudes farther away from the projection position, which is consistent with the results of Gill (2015). However, Exp1 presents a larger zonal variation (positive-negative-positive-negative pattern), and the negative regions are concentrated in the middle and low latitudes rather than the high latitudes, and the tidal potential in the polar regions is even higher than the negative regions in low latitudes, which means that the projection position of the sun is incorrect, locating at high latitudes rather than at low latitudes. Therefore, the new tidal scheme can better represent the position of the Sun compared to the traditional scheme." in Line 199-210 according to your suggestion.

#10 Section 4.3
The definition of "Dynamic sea level" is required.
Reply: Thanks for your suggestion. We have added the following definitions: “that is defined as the sea level associated with the fluid dynamic state of the ocean (Griffies and Greatbatch, 2012; Griffies et al., 2016)” in Line 309-310.

#11 L.313-315 "Therefore, compared to Exp 1..."
Why does the Exp 2 improve? The reason should be discussed.
Reply: Thanks. We have added the following discussion: “This is because Exp2 applying the new formulation of the tidal scheme can reasonably consider the positions of both the Sun and Moon relative to Exp1, which makes the higher DSL in low latitude compared to that in high latitude due to the effect of gravity.” in Line 330-333.

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