Review of "A practical scheme to introduce explicit tidal forcing into OGCM" Sakamoto et al. (2013, Ocean Sci. Discuss.):

General comments:

- This explicit introduction of tides into an OGCM is a good idea and appears to be promising as a way to simulate tides and the non-tidal circulation together. According to the way you described your new scheme, it appears that your explicit tidal scheme, when simulated concurrently with the "basic" component of the circulation, does not violate the dynamical balances in the OGCM. Your root-mean-squared error is impressively small for such a coarse resolution model without several pieces of physics that are known to improve tidal simulations (e.g., the full self-attraction and loading computation and a topographic internal lee wave drag scheme). You focused on showing that the self-attraction and loading scalar approximation decreases the errors in tidal phasing, as previous studies have shown using other schemes to implement tides, and on showing similar-looking tidal energy flux maps with those from previous studies.

Specific comments:

- However, I would like to see the results of some additional calculations before the discussion component of the review process is complete. The calculations I would like to see include the following: **1)** Do a comparison of your scheme using your manuscript's Eq. (22) with use of your scheme using your manuscript's Eq. (21). That is, I would like to see a comparison of your scheme with that of Arbic et al. (2010) since the latter is the scheme you are trying to improve upon. Your reported root-mean-squared error values with your scheme in your model are compared against the NAO.99b dataset. Your results can only be fairly compared with root-mean-squared error values using the Arbic et al. (2010) scheme in your model against the NAO. 99b dataset, not the Arbic et al. (2004) results. It is probably correct to argue that the all of the SSH deviation is not always the tidal height, as you do, but you have the opportunity to show evidence that you are correct in this assertion here. I understand that the computational expense to implement the Arbic et al. (2010) is greater than that of your scheme, but because you are using a coarse-resolution model, it should not be prohibitive. Local machines where I am, for example, can perform this computation without asking for additional computer resources, and I doubt that's specific to my institution.

- **2)** You argue that the differences in the vertical velocities between your full tidal simulation, using your new scheme, and your simulation without tides are due to the presence of internal tides caused by the interaction of tides and the bottom topography. It is unclear how the internal tides would be generated from the interaction of tides and the bottom topography when

you're using a relatively coarse resolution (particularly in the horizontal). (Also, use of a topographic internal lee wave drag parameterization would influence your results.) You need to explain how the internal tides arise in your simulations with tides. At the very least, you should show a time series of the isopycnal vertical displacements (not just the vertical velocities) to demonstrate the presence of greater undulations in the internal wave field when tides are included. Also, if you were to run your model at a different resolution, you would expect that there would be an effect on the vertical velocities (Niwa and Hibiya, 2011, J. Oceanogr.) in your model, which would be best to show explicitly. Since you're implementing tides differently from previous studies, you need to show this.

- **3)** It's unclear whether the **X** term, which includes the winds, in the momentum equations and the freshwater flux in the continuity equations should be absent from the differential equations you derive, your Eqs. (11) and (12), for the primary barotropic response of the ocean to the equilibrium tidal potential. It's clear that those two terms should be present in the "basic" circulation equations, your Eqs. (13) and (14), and that the sum of those equations, your Eqs. (11) + (13) as well as (12) + (14), should yield **X** and the freshwater flux term. However, studies such as Xing and Davies (1997, J. Phys. Oceanogr.) have shown that the winds have an influence on the tides and studies such as Lee (2006, Ocean Modelling) have shown that the freshwater flux is not independent of the tides. Your scheme allows for a connection between these variables through coupling of the "basic" and tidal flows, but I think you need to further justify your 100% separation of **X** and/or the freshwater flux term out of the aforementioned tidal equations. Alternatively, you could perform another simulation showing the sensitivity of this assumption by putting in one/two new parameters: one/two different fractions between zero and one on X and/or the freshwater flux term in the "basic" equations and one minus each of those fractions in the tidal equations.

Technical corrections:

The grammar needs work. Specific suggestions follow:

- Title: "A practical scheme to introduce explicit tidal forcing into **an** OCGM."
- Abstract, Line 5: "…original barotropic equations of **an** OGCM."
- Abstract, Line 8: "…balances in **an** OGCM."
- Abstract, Line 10: "That is, this scheme drives **the** OGCM…"
- Abstract, Line 15: "…the model can simulate both **the** non-tidal circulations…"
- Abstract, Line 17: "…error in the tidal heights **is found to be** as small as…"
- Abstract, Line 18: "In addition, analysis of **the** speed and energy…"
- Abstract, Line 19: "…currents **is found to be** consistent with past tide studies."

- Abstract, Lines 21-22: "…and precise introduction of tides into **an** OGCM is a significant step toward **the improvement** of ocean **models**."

Main body:

- Pg. 3, Line 5: "…mixing affects **the** ocean circulation **on** a basin scale."
- Pg. 3, Lines 12-13: "These studies **suggest an influence of tides on the general circulation**."
- Pg. 3, Lines 14-15: "**Only recently have tides begun to be** sufficiently taken into account in ocean general circulation models (OGCM**s**)."
- Pg. 3, Lines 21-22: "… into OGCM**s** is classified into two types**: an** implicit one and **an** explicit one."
- Pg. 3, Line 27-28: "Bessieres et al. (2008) proposed a**n implicit parameterization for** the tidal…"
- Pg. 4, Line 1: "… into free-surface OGCM**s** directly**; i.e., through introduction of tidal forcing in the momentum equations**."
- Pg. 4, Line 12: "Development of **an** OGCM, when simultaneously **simulates the** time evolution…"
- Pg. 4, Line 16: "… independently of OGCM**s**…"
- Pg. 4, Line 27: "…of barotropic **velocities,**…"
- Pg. 5, Line 6: "…approximation of **the** SAL **term, which has been traditionally referred to as the "scalar approximation" (Hendershott, 1972, Geophys. J. R. Astr. Soc.),** the pressure gradient…"
- Pg. 5, Lines 15-16: "…usual for OGCM**s** have been proposed for tid**al** modeling, such as body tide**s, which are included here,** and atmospheric tide**s**."
- Pg. 5, Line 17: "The knowledge obtained by tid**al** modeling studies…"
- Pg. 5, Line 19: "… in the basic field of OGCM**s** are…"
- Pg. 5, Line 23: "…for the geostrophic currents in OGCM**s** either,…"
- Pg. 5, Line 25: "Therefore, we cannot simply **replace** the governing equations of OGCM**s** by…"
- Pg. 5, Line 27: "…means **to introduce** tides into **an** OGCM."
- Pg. 5, Line 29: "…explicitly into OGCM**s,** the equilibrium tid**al** potential is given directly **through** the…"
- Pg. 6, Line 4: "(geostrophic **and eddying**) characteristics…"
- Pg. 6, Line 13: "… the SAL term **so** that the SAL **would** not…"
- Pg. 6, Line 17: "As a solution **to** the **aforementioned** problem…"
- Pg. 6, Line 21: "…are given by the same…"
- Pg. 6, Lines 25-26: "… in the OGCM will be presented briefly."
- Pg. 7, Line 14: "… is the surface **fresh**water flux. **Introduction** of…"
- Pg. 7, Line 20: "If the **scalar** approximation…"
- Pg. 8, Line 5: "This scheme works well in modeling tides **without the basic circulation. However,** in modeling…"
- Pg. 8, Line 7: "…unintentionally. **In fact**, Eq. (6)…"
- Pg. 8, Line 13: "The **violation of the dynamical balance in the basic fields arises from the fact** that…"

- Pg. 8, Line 14: "Therefore, **our**…"
- Pg. 8, Line 15: "… and basic fields by two different…"
- Pg. 8, Lines 16-17: "The **objective** of **our new** scheme is to simultaneously **achieve** both accurate modeling of **the** tides…"
- Pg. 8, Line 25 or so: You need to specify the units of each of the variables in Eqs. (7)-(10) because it is not conventional for modelers to write the momentum equations using the depth-integrated velocities in units m^2/s.
- Pg. 8, Line 25: "The linear tidal component**,** indicated by the subscript**, 'lt,'** corresponds…"
- Pg. 8, Lines 26-27: "The basic component**, indicated by** the subscript**, 'b,' corresponds to** the other…"
- Pg. 9, Line 3: "… is calculated **using** its own governing equation."
- Pg. 9, Lines 4-5: "… for tid**al** modeling**;** i.e.**, a modified** Eq. (5) and continuity **equation**."
- Pg. 9, Line 9 or so: Explain that the SSH gradient term on the right hand side of Eq. (11) represents the coupling between the basic and tidal fields. Also, explain why **X** and the freshwater flux term should be omitted from Eqs. (11) and (12) or include small fractions of **X** and the freshwater flux term (the fraction of which can be estimated with tuning experiments). Justify use of these fractions by citing Xing and Davies (1997, J. Phys. Oceanogr.) and Lee (2006, Ocean Modelling) and showing whether the model is further improved in a root-mean-squared error sense. Of course, introducing more parameters will likely improve a model, but if you can justify it by arguing more than just the coupling between the basic fields and tidal fields in Eq. (11) is not enough (e.g., the continuity equation does not include a coupling term and could use a fraction of the freshwater flux term), then proceed with this. If you cannot justify it, then say why.
- Pg. 9, Line 21: "… to calculate **the** time evolution of U_lt and eta_lt **separately from U_b and eta_b**."
- Pg. 9, Line 25: "… the next step is **determined** by **their** summation."
- Pg. 10, Line 3: "… the non-linear terms **need to** be treated **more** carefully. In **our** scheme,…"
- Pg. 10, Lines 6-7: "… the three**-**dimensional velocity field**,** given by **the** summation of all **of their** components (*u* in Fig. 1), and **their sums** are…"
- Pg. 10, Line 15: "… (**Taylor, 1919;** Weatherly et al., 1980)…." and it would be useful to emphasize the units once again here (in particular, that C_D and **T**_theta are dimensionless). Also, don't mention what value you use for C_D or theta until you state them in Sec. 2.3.
- Pg. 11, Line 1: "… coefficient part)**, but** each component for **U**/(H+eta) (the vector part) **is given by**…"
- Pg. 11, Lines 6-7: "To show this achievement **more** clearly, we assume the SAL term **has** a linear form, eta_SAL ~ (1-alpha) eta_lt**,** and sum Eqs. (11) and (13) **to find that**…"
- Pg. 11, Line 11: "… works **on** eta_lt only**, the body tide effect works on the equilibrium tide only,** and the expressions…"
- Pg. 11, Line 15: "Eq. (3). **Thus,** introduction of **our** tide scheme…"

- Pg. 11, Line 17: "From **the** point of view of tid**al** modeling, **our** scheme…"
- Pg. 11, Lines 18-20: "The value of alpha**, the formulation of tau^btm_lt,** and the parameterization of **D**_lt can be selected **independently**."
- Pg. 11, Line 20: "For example, the constant, theta, in Eq. (15)…" Don't mention C_D because, unless the parameterization first derived by Taylor (1919, Philos. Trans. R. Soc. London Ser. A) is unphysical/inadequate, it doesn't make a lot of physical sense to me that tidal velocities would have a different coefficient for bottom drag from the basic field's velocities.
- Pg. 11, Lines 21-22: "… even a bottom friction formulation **for tides can be set to be** different from **that of** the basic **circulation**." It is perfectly fine to use a different formulation for bottom drag, as you say, but once you stick with a given parameterization, it doesn't make much sense to me for the bottom boundary layer to act as a greater sink for a tidal velocity of some magnitude than a basic field velocity of the same magnitude. Since tidal velocities tend to have a different spatial structure from the basic field velocities, each influencing the bottom boundary layer differently, and the bottom boundary layer parameterization is likely inadequate, tuning the theta parameter is more acceptable.
- Pg. 12, Lines 2-3: Take out the second sentence on this page and then say something like: "**S**trictly speaking, a part of the basic component **of** eta is used in **Eqs. (11) and (12) so the linear tidal component is not strictly independent of the basic component. However, the linear tidal component is treated separately from the basic component**."
- Pg. 12, Line 7: "… the linear tidal component can be referred **to** as an…"
- Pg. 12, Line 11: "… the practical approximation used by **our** new scheme…"
- Pg. 12, Line 15: "… order to introduce tides into OGCM**s** realistically."
- Pg. 12, Line 16: "… decomposition of the two components in **an** OGCM."
- Pg. 12, Line 19: "… Hereafter, we call them "the…"
- Pg. 13, Line 2: "…straightforward**ly** under…"
- Pg. 13, Line 9: "In **an** OGCM with **the Arbic et al. (2010)** tide scheme,…"
- Pg. 13, Lines 17-18: "**It is because of this** approximation **that** tidal fields can be reproduced **with less** numerical resources **and be** accurate enough to represent tidal effects **in an** OGCM,…"
- Pg. 14, Lines 1-3: Given this admission, it would be nice to see a computation of the root-mean-square error in coastal areas (within some distance of the coasts) in Table 2, for example, and some discussion about confounding factors (e.g., no wave breaking on shelves) as well as future directions.
- Pg. 14, Line 4: "Though **relatively** small,…"
- Pg. 14, Line 14: "coordinate**s [Murray, 1996, J. Comp. Phys.]**)"
- Pg. 14, Line 17: "The model settings **?** are ordinary…" I'm not sure what model setting you're referring to, so you have to elaborate a bit more.
- Pg. 14, Line 19: "… the Second Order Moment tracer advection **(?)**…" A reference is needed here.
- Pg. 14, Line 28: "…Love numbers **(?)**.) A simple harmonic horizontal viscosity is used for the diffusivity term**, D**_lt**,** with…"

- Pg. 15, Line 3: The topographic internal lee wave drag parameterization tends to induce an enhanced vertical diffusivity when it is implemented in the momentum equations, but this does not seem like an appropriate place to mention it because you're talking about vertical/horizontal viscosity parameterizations. Although, Polzin (2009, Ocean Modelling) and Melet et al. (in press, J. Phys. Oceanogr.) enhance the diffusivity instead of inserting an extra term in the momentum equations to parameterize topographic internal lee wave drag. I would just end the sentence after citing (Schwiderski, 1980).
- Pg. 15, Line 6: This is an appropriate place to explain why different values of C_D and theta are used on the tidal velocities than on the basic field velocities. Again, doing this in order to improve a model suggests that this bottom drag parameterization is inadequate (for tides) more than anything.
- Pg. 15, Lines 9-11: The sentence in parentheses should be a footnote.
- Pg. 15, Line 25: "…NOTIDE **were run** with the eight tidal constituents and without tide, respectively, and are analyzed…"
- Pg. 15, Lines 26-27: "… is used for comparison **with a case in which** the SAL term…"
- Pg. 16, Line 1: "… is ignored **without violating** dynamical balances…"
- Pg. 16, Lines 2-4: The sentence in parentheses should be a footnote.
- Pg. 16, Line 4: The M2 **case, which uses the** M2 constituent **only,** and the K1 **case, which uses the K1** constituent **only,**…"
- Pg. 16, Line 6: "… and M2d10 **use a** tidal horizontal viscosity **of** 2 x 10^4 m^2/s and 10 x 10^4 m^2/s,…" Again, it seems like more parameters are being added by using different values for the horizontal viscosity for the tides as opposed to basic field in order to improve the performance of the model without much physical justification. Polzin (2008) has an interpretation of horizontal viscosity as a way to parameterize the interaction of mesoscale eddies and internal waves, so I suppose using different values for horizontal viscosities for the tidal as opposed to basic fields just means that mesoscale eddies interact differently with internal waves that result from geostrophic adjustment (for instance) than with internal tides. It is worth elaborating on this point here.
- Pg. 16, Lines 12-13: I'm not sure what you mean by "… the dataset is referred as true in this study". Do you mean "… the NAO.99b dataset is assumed to be the actual tidal heights in this study."?
- Pg. 16, Lines 16-17: "… with **our** tid**al** scheme successfully **reproduced many of the large-scale features known to be in the tidal field as well as basic field**."
- Pg. 16, Lines 18-19: "… along with **the geostrophic circulation on** a large scale…"
- Pg. 16, Line 24: "… show eta_t and eta_lt…"
- Pg. 16, Line 26: "… while the latter **is the** primary…"
- Pg. 17, Line 2: "…they are almost identical **globally** (Fig. 2d)."
- Pg. 17, Line 3: "… tidal component**s, U**_lt and eta_lt, represent most…"
- Pg. 17, Line 5: "… for tides in **our** new scheme, which **here is suggested to**

be enough…"

- Pg. 17, Line 11: "**This** result **suggests** that **our** new…"
- Pg. 17, Line 13: "… ignored the SAL term, is different…"
- Pg. 17, Line 17: "The contrasting results **between** TIDE…"
- Pg. 17, Line 18: "… modeled in **an** OGCM…"
- Pg. 17, Lines 19-20: "… developed for tides. **Even the scalar approximation for the SAL term, for example, improves simulations of the tides**."
- Pg. 17, Line 27: "…the assimilation dataset. **Comparing** eta_RMS(TIDE) and…"
- Pg. 18, Lines 4-8: Replace the sentences, "Thus, it can be concluded… See Sect. 3.2.)" with "It is discussed in Sect. 3.2 how the viscosity parameterization influences the performance of TIDE as opposed to TIDEa1."
- Pg. 18, Line 9: "As a **representative** result,.."
- Pg. 18, Line 16: "This is **one important** reason **for** the difference…"
- Pg. 18, Line 22: "… of the tidal phase**, which ultimately affects the tidal amplitudes**."
- Pg. 18, Lines 23-24: This seems like an orphan sentence. Elaborate to save it from being sent to an orphanage.
- Pg. 18, Lines 25-26: "… evaluated quantitatively **here**."
- Pg. 19, Line 6: "… in most regions **such** that it reaches **values** comparable…"
- Pg. 19, Line 16: Define what A is. Is A the World Ocean?
- Pg. 19, Line 17: "**T**he tide reproducibility is very low…"
- Pg. 19, Line 18: "… level as **a** tuned tide model, due to taking into account **an approximation of** the SAL…"
- Pg. 19, Line 20: "… increase **further** by…"
- Pg. 20, Lines 13-14: "**For both the M2 and K1 cases, t**he tidal currents are strong in coastal areas, especially **near** Great Britain**,** Ireland**,** and far east Asia."
- Pg. 20, Lines 14-16: "In **the M2 case**, |u_ltl^t is large over the Mid Atlantic Ridge**, and in** the equatorial Pacific. **In the K1 case, |u_ltl^t is large** in the Indian Ocean and the North Pacific. **These results** agree will with…"
- Pg. 20, Line 19: "… is supplied to be **interior** ocean **regions,** and…"
- Pg. 20, Line 22: "… the work the tid**al** forcing does **on** the…"
- Pg. 21, Line 1: "… the linear tidal component **using**…"
- Pg. 21, Lines 8-9: "… model reproduced **both** the tidal heights **and the** tidal dynamics**,** such as…"
- Pg. 21, Lines 12-14: You should show P and W for experiments M2v2 and M2v10, or at least say that P and W are relatively insensitive, consistent with how insensitive the precision of your model is to horizontal viscosities. Instead of the sentence, "Also in our model experiments,… the horizontal viscosity, nu.)," say something like: "Here, we verify that this is the case using our scheme and demonstrate that P and W are relatively insensitive to the viscosity and friction used in our model. We show this by varying the

horizontal viscosity, nu."

- Pg. 21, Line 21: "… than **on the** interior currents…"
- Pg. 22, Line 2: "… tides and topography, **without altering** the original…"
- Pg. 22, Line 5: "As noted in Sect. 2.2, **our** new tid**al** scheme…"
- Pg. 22, Line 9: "… we expected some changes **would occur** in the velocity…"
- Pg. 22, Line 11: "… impacts of **our** tid**al** scheme,…"
- Pg. 22, Lines 17-18: "In NOTIDE, **with the exception of the equatorial regions,** *w* was O(10^-3) cm/s, while **w in TIDE was** more than 10^-2 cm/s over large areas."
- Pg. 22, Lines 21-22: As stated above, you need to suggest a mechanism in our model, show the time series of vertical displacements of isopycnals, and/ or run another model simulation to support your hypothesis that this occurs in your model, given that you're implementing tides in a different way from previous studies.
- Pg. 23, Line 9: "… resulted in **a** SST decrease **of** 0.1-0.5^oC over…"
- Pg. 23, Lines 10-11: "… the surface layer **(0-15 m)** became cooler, while the subsurface layer **(20-40 m) became** warmer,…"
- Pg. 23, Line 13: "… Northern Hemisphere **during its summertime** was hampered,…"
- Pg. 23, Line 16: "… scheme. **T**he mixing scheme **only intermittently** predicted large vertical diffusivities."
- Pg. 23, Line 17: "Delta T^t was **relatively** small in the Southern Hemisphere**'s** winter."
- Pg. 23, Line 18: "… mixing hardly **affected the** vertical temperature…"
- Pg. 23, Line 19: "… well**-**mixed **via** surface cooling**. B**oth temperature…"
- Pg. 23, Line 20: "… to the depth of 80m."
- Pg. 23, Line 21: "**The** SST decrease **with the inclusion of tides** was especially large in shallow coastal regions**; e.g.,** more than…" Non-linear tidal effects?
- Pg. 23, Line 23: "… stratification in **the** open oceans…"
- Pg. 24, Line 1: "**is consistent with the findings of previous** studies**,** which…"
- Pg. 24, Line 4: "The **differences between the** currents **in TIDE and NOTIDE** were…"
- Pg. 24, Line 7: "… scheme did not generate **spurious** currents."
- Pg. 24, Line 10: Is it apparent that the differences between the currents are getting larger (asymptoting to some values) as your simulation goes on?
- Pg. 24, Lines 11-12: "Though plausible**, impacts on tidal currents** were obtained by the new scheme, it should be noted that **our** experiment…"
- Pg. 24, Line 20: "(OGCM**s**)."
- Pg. 24, Line 22: "… barotropic equations of **the** OGCM."
- Pg. 24, Line 25: "… balances in **an** OGCM."
- Pg. 24, Line 26: "… of tides in **an** OGCM."
- Pg. 24, Line 27: "…drives **an** OGCM…"
- Pg. 25, Line 1: "… a tuned tide model, **in lieu** of **using** the equilibrium…"

- Pg. 25, Line 6: "The root**-**mean**-**square**d** error…"
- Pg. 25, Line 7: "… reference of a data-assimilation result, **suggesting**…"
- Pg. 25, Line 10: "… significantly**,** as the error was up to 31.3 cm. **This suggests that the SAL scalar** parameterization must…"
- Pg. 25, Line 11: "… to introduce tides into **an** OGCM…"
- Pg. 25, Line 18: "… independently of **which** OGCM **is used**."
- Pg. 25, Line 22: "… out model **generally** reproduced **similar** amplitudes…"
- Pg. 25, Lines 23-24: "…and the tid**al** energy **conversions when compared with previous** tid**al** modeling studies."
- Pg. 25, Lines 24-25: "In addition, enhancement of vertical mixing **was found** in the model,…" You didn't show that the internal tides were excited (only found suggestive evidence), nor did you show they were necessarily realistic.
- Pg. 25, Line 26: "…40 days. **Our** scheme generated realistic tidal…"
- Pg. 25, Lines 27-28: "… in the model. **We did this through an explicit tidal scheme,** in contrast to the indirect…"
- Pg. 26, Lines 1-2: "…vertical diffusivity. Usage of **our** scheme…" (Take out the sentence starting with "Advection…" and ending with "… scheme.")
- Pg. 26, Line 4: A reference is needed after "… chemical and biological processes."
- Pg. 26, Line 5: "…into **an** OGCM is a…"
- Pg. 26, Lines 9-10: "… the basic field**,** as shown in Sect. 3.3, and **in turn**, the basic field modifies **the** tides."
- Pg. 28, Lines 9-10: "…for **X**. **M**odeling the barotropic tides **as** dissipated by excitation of the internal tides due to **a** combination…"
- Pg. 28, Line 13: "… with unit**s** of s^-1."
- Pg. 28, Line 14: "…as Eq. (A6) to give…"
- Pg. 28, Line 16: "…we obtain **a** modification…"
- Pg. 28, Line 17: "…secondary interaction, **X, to be**…"
- Pg. 29, Lines 14-15: "…situation, **the** interaction between the tidal and basic fields emerges **through** a driving term…"
- Pg. 29, Line 16: "… as modification of tides if its frequency is **the** same as…"
- Pg. 29, Line 17: "Otherwise, the change is **an** excitation…"

Tables and Figures:

- Pg. 34: "Experimental cases **simulated using our new scheme with MRI.COM**"
- Pg. 34: "NOTIDE without tide**s**"
- Pg. 41: "… and the unit**s are** in cm/s."
- Pg. 42: Say what the unit length of the vectors is explicitly (200 kW/m?)