Responses to reviewers' comments on the manuscript "Effect of tidal stream power generation on the region-wide circulation in a shallow sea", by G. I Shapiro. Submitted to Ocean Science Discussions (OS-2010-47).

REFEREE #2.

In principle, this is an interesting paper, quantifying the way in which an array of turbines in a laterally unbounded flow will reduce the tidal current, thus leading to less power production than if the current were unaffected. There are however, a number of points that need clarification and improvement, so that major revision is recommended prior to publication.

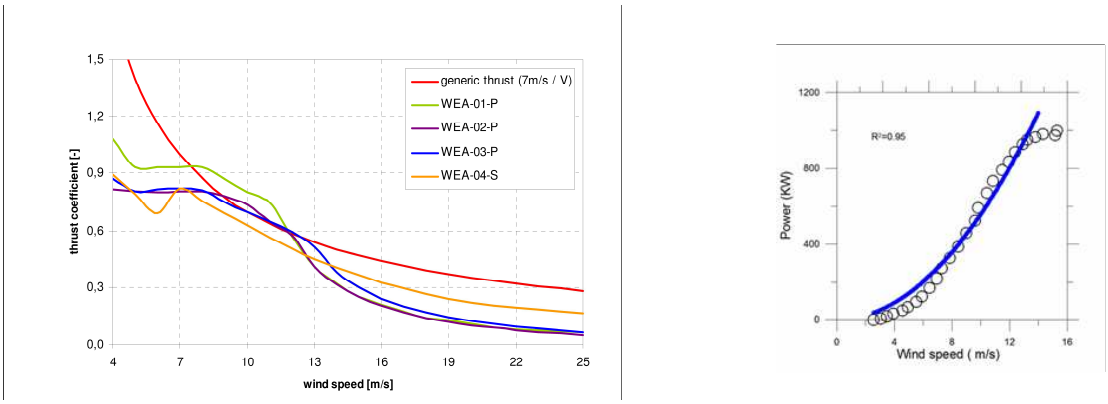
Major comments:

COMMENT: The results of the paper depend critically on having the drag coefficient associated with the turbines independent of the vertical coordinate. This seems very unrealistic in water some tens of metres deep. Isn't it more likely that the turbines would be moored near the sea bed? If so, there is the likelihood that the bottom boundary layer would be modified, with the tidal current flowing over the turbines and leading to even more reduction in power than estimated in this paper. The author uses a 3D model and so could examine this question. It at least needs to be mentioned.
RESPONSE: The in-stream tidal farms are still in their juvenile state and we do not know what the final design of the tidal farms will be. Current prototype turbine (by SeaGen) has a diameter of 16m , the supporting column extends from the seabed to above the surface and the rotors can be raised above the sea surface. It well might be that the engineers would wish to use as much water column as possible to maximise the input within the licensed area of operations (as they do in Uldolmok, South Korea, see picture below from http://gcktechnology.com/GCK/pg2.html). As we do not know the exact vertical structure of future tidal farms , the uniform approximation seems to be a logical first step. The modification of the bottom boundary layer due to reduced current flow is automatically taken into account by POLCOMS. The paper aims at providing estimates of disruption to the patterns and parameters of the flow rather than going into technical details of the design of the energy devices. Some explanation added to this effect in the 2nd para of Section3.

COMMENT: Even with the assumption of depth-uniform drag coefficient, the value of this needs to be related to the type and spacing of turbines that might give the assumed drag coefficient. The quantitative results of the paper would be more useful if they were related to a realistic array of turbines.
RESPONSE: As we do not know the density of the turbines in the tidal farms of the future, a set of thrust (aka drag) coefficients are explored to give a reasonable range of power generation (80-600MW), see Figs.3,4,5,6 and the new Fig.8. The most powerful tidal plant of today (of barrage type), La Rance, has a peak rating of 240 MW somewhere in the middle of this range**.**

COMMENT: Choosing a linear, Rayleigh, drag, rather than a more realistic quadratic drag, seems curious and unnecessary.
RESPONSE: I cannot agree that a quadratic drag 'is more realistic'. Quadratic drag (and hence the assumption of the constant drag coefficient) is commonly used for

description of flow around static objects, but such an assumption is not suitable for the flow dynamics through turbines. In this case the thrust coefficient (a term used instead of drag in the fluid dynamics of turbines) decreases as speed increases resulting in a linear drag law. More details are given in response to referee #1, and a new sub-section, literature references and a sub-figure to Fig.1 are added to the manuscript to clarify this issue. Basically the difference is that in a turbine the loss of pressure (retarding force) is mainly caused by transfer of momentum to the rotation of blades rather than by creating turbulence.



New Fig1. Thrust coefficient (left) and generated power (right) vs flow speed

COMMENT: A number of reductions of the estimated power need to be made. For a start, there are the wake losses described by Corten (ECN Report ECN- RX–01-001, 2001) and further by Garrett and Cummins (J. Fluid Mech. 588:243–51, 2007). Beyond this, there is the drag on supporting structures and internal losses in the turbines.
RESPONSE: This is correct. The short range effects of the downstream wakes and internal losses are not resolved by the ocean model, instead they are implicitly parameterised by the Rayleigh coefficient. This is why the paper quotes 'extracted' or 'lost' energy rather than the values of 'generated' electric power. Electric power is unavoidably less due to these losses (and hence the power coefficient C_p is smaller than the thrust coefficient C_T), clarification is added to the text between Eqs(10) and (11).

COMMENT: Whatever form of turbine drag is used, it would be helpful if the model could be run for more values so that the absolute maximum power can be estimated. Figure 3 of the present paper shows a power that seems to be levelling out with increasing drag coefficient, but has not quite reached a maximum. Or maybe the maximum is between the last two points!
RESPONSE: The purpose of the paper is to show the patterns and orders of magnitude of the effects of the tidal farm on the currents in the far field. More case studies with more values of parameters is a good plan for future, which would also include variations in the vertical distribution of turbines, shape of the farm, location of the farm on the shelf, different seasons etc. However detailed analysis of such an array of hypothetical parameters will be unmanageable for a single paper.

COMMENT: Unless these problems are addressed, there is a danger that the estimated available power will be taken too seriously by proponents and politicians.
RESPONSE: One of the messages of this paper is ' DO NOT TAKE TOO SERIOSLY EXISTING ESTIMATES RELATED TO THE TIDAL FARMS'. I hope that this paper sets more questions than answers and shows that an approach of simply taking tidal resource from the tidal energy atlas and multiplying it by an arbitrary' extraction coefficient' is not the end of the scientific challenge.

Other comments (Lxx for line xx):

COMMENT: L41: Saying that "tidal energy is almost inexhaustible" is true but misleading as the possible rate of extraction, the power, is very constrained.
RESPONSE: Yes, this paper aims to show what the limitations of extractable amounts of energy are.

COMMENT: L54: "high levels of tidal energy fluxes from the ocean". This is irrelevant. The natural energy flux could be zero but not rule out the extraction of tidal power.
RESPONSE: Tidal energy in shelf seas often has 'foreign origin', i.e. comes from the deep ocean.

COMMENT:L55: "deemed to become a stable source … for the future". Hmm, and the Severn Barrage project has just been cancelled?!
RESPONSE: May be it is good time for less expensive and less damaging in-stream tidal farms? I am not a politician to judge.

COMMENT:L61-68: Some inaccuracies here. The Uldolmok scheme is not a barrage. Please check all this.
RESPONSE: Thank you, I amended the text. With some difficulty I managed to find out that Uldolmok is a fence type in-stream scheme utilising a Russian invented Gorlov Helical Turbines. It is actually designed to occupy nearly the whole water column – close to my assumption of the vertical distribution of alpha (http://gcktechnology.com/GCK/pg2.html):

COMMENT:L78: “the velocity through the device itself may increase”. Because of ducting? In general, the flow has to slow to build up the head required to overcome the resistance of the turbine.
RESPONSE: Yes this is how I understand Garrett and Cummins (i.e. effect of ducting).

COMMENT: L81: Garrett and Cummins (2008) was a review with some new material. The relevant original paper on the effect of a complete fence in a channel was Garrett and Cummins (Proc. R. Soc. A 461:2563–72, 2005).
RESPONSE: I refer the more recent paper by the same authors as it is more updated and it gives the reference to the earlier paper.

COMMENT: L125-135: This seems muddled. There are two effects. The first is the reduction factor due to the nature of turbine operation, with results dating back to the work of Lanchester and Betz. The second is the reduction in regional flow due to the presence of turbines. Using a drag coefficient in models such as the present one is okay, but see point 4) above about wake losses.
RESPONSE: reference to Betz and Blade Element Momentum theory removed to avoid confusion.

COMMENT: L153: The result of equation (4) was for quasi-steady flow. The numerical factor varies a little with the importance of acceleration.
RESPONSE: Yes this is correct.

COMMENT: L253-255: Please give the units of alpha (s^{-1}).
RESPONSE: Introduced between Eqs(8) and (9)

COMMENT: L299-300: Please explain this alleged factor of 3. Also, the 14-fold reduction seems very specific to the situation in the present paper.

RESPONSE: Yes, the concrete figures are dependent on the specific situation, however the tendency is general – more powerful farms have lower efficiencies as some energy has already been extracted by the neighbouring devices . This fact mirrors the situation with individual turbines –their efficiency represented by power coefficient Cp decreases as the flow speed increases, see e.g. Fig.2 in R. J. Barthelmie et al, Wind Energy , 10, 517–528, 2007. The factor of 3 for the bounded flow in a channel comes from the statement in Garrett and Cummins (2008) 'the maximum power is just… 38% of the kinetic energy flux evaluated at the exit', p2487, between Eqs. (6) and (7).

COMMENT: L305: Lateral diversion of the flow was a factor in the two-channel study of Sutherland et al. (J. Power Energy 221:147–57, 2007).
RESPONSE: Agreed.

COMMENT: The figures are generally very poor. Please show the farm location on all the maps (and tell us in the text how deep the water is in that location) and make the figure labels legible.
RESPONSE: The original high resolution figures will be uploaded at the production stage. The .pdf files for Ocean Discussion are automatically generated and I have no control over resolution of the figures. Location of the farm is now shown in Figs.2 and 8, the centre of the farm coincides with the label #7 in Fig.7- explanation is added to this effect, location is obvious in Figs.5.and 6.

COMMENT: Many statements in the abstract will need to be modified once the main parts of the paper have been revised.
RESPONSE: Abstract has been updated as advised

COMMENT: A little more attention is needed to the English and to correct typos.
RESPONSE: Done.

COMMENT: While I appreciate that the present study is for a specific area with specific assumptions about the form of the turbine array, it would be nice if the author or others could undertake a more generic study.
RESPONSE: This is my plan for future work.