Reply

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In his comments regarding the open-ocean artificial upwelling experiment described by White et al. (2010), Kithil (2011, hereafter PK), the Chief Executive Officer (CEO) of Atmocean, Inc., states that 1) the Atmocean wave pumps utilized in the experiment may have failed prematurely as a result of the deployment procedure, 2) the authors (White et al. 2010) have not aptly presented the efficiency of measured upwelling rates in these early prototypes, and 3) a new ''tubeless'' Atmocean pump design (yet to be rigorously tested to our knowledge) has overcome some of the challenges inherent to early prototypes (PK).

Our experiment was the first of its kind in terms of pump dimensions and duration of deployment. Hence, no true deployment strategies had been previously developed by the manufacturer. Nevertheless, each of the three wave pumps deployed in the North Pacific operated properly for a brief period. This fact, coupled with the metal fatigue observed at the time of recovery (Fig. 1), leads us to conclude that the deployment procedure was appropriate and that additional work is required to design and engineer wave pumps capable of withstanding the stresses experienced in the open ocean. As with the development and implementation of any new technology, periods of trial and design improvement are to be expected.

With regards to the efficiency at which these pumps operated in the ~17-h period that upwelling was recorded, we acknowledge that we presented the absolute efficiency and did not attempt to estimate the impact of the inherent inefficiencies of these pumps. We compared the range of measured upwelling velocity to mean wave height divided by the dominant wave period. PK suggests that this calculation should take into account factors such as cable stretch and the load limit of the buoy. Effectively, PK points out that these pumps will not operate below a minimal threshold of wave height as a result of inefficiencies inherent to the system. We agree with this assessment.

Finally, in response to the description of the next generation of Atmocean wave pump technology, it is not possible to evaluate the utility or durability of this new tubeless Atmocean design on the sole basis of the GPS data presented in PK's comments. Nonetheless, if these pumps, like their predecessors, are to be marketed for geoengineering applications, we encourage PK to continue to seek the participation of objective parties not financially vested in the experimental outcome and to publish the full results in peer-reviewed journals.

REFERENCES

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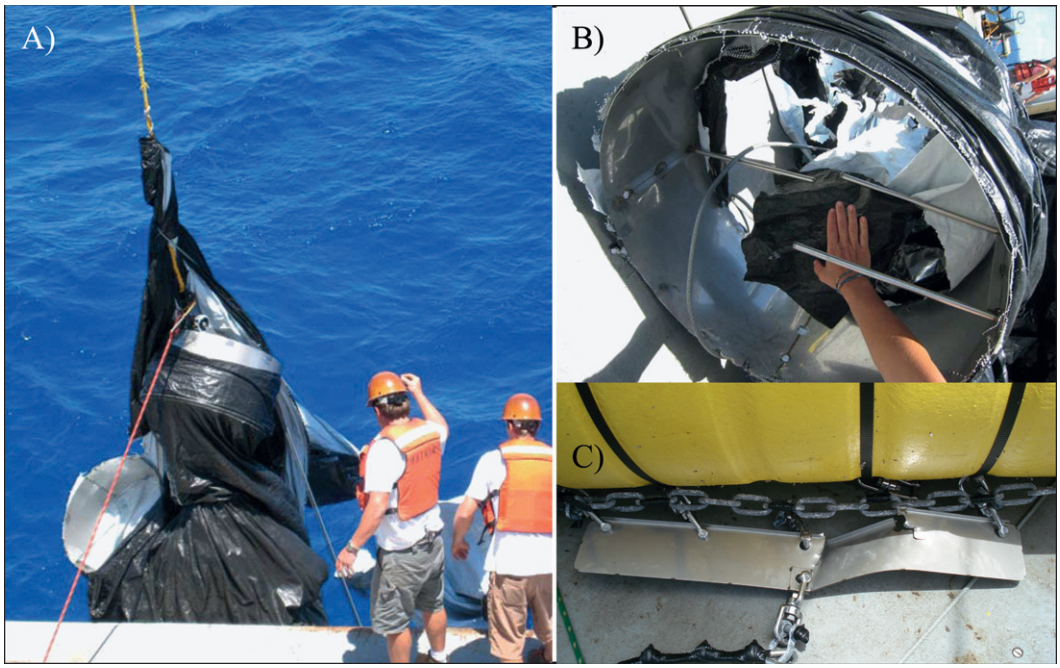


FIG. 1. Images of (a) the recovery of the single pump: torn, tangled, and irreparable; (b) the midcoupler, which had broken free from the tube and sank to the depth of the valve, which was still attached by a central cable; and (c) the bent and torn Atmocean, Inc., keel of the single pump after a 2-week deployment.