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Interactive comment on "Flow dynamics around downwelling submarine canyons" *by* J. M. Spurgin and S. E. Allen

J. M. Spurgin and S. E. Allen

jspurgin@eos.ubc.ca

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We would like to thank reviewer #2 for their thoughtful response, some very important points were raised.

The reviewer asked for quantitative results. We have calculated two sets:

The first set is transport values calculated across 5 planes within the canyon: 1) along-shore transport over the canyon, 2,3) onshore/offshore transport over the canyon in the upstream and downstream (respectively) and 4,5) vertical transport at shelf break depth in the upstream and downstream (respectively).

These values reveal 2 patterns across the upstream and downstream planes. In 6 model simulations, transport is downwards (negative) across both shelf break planes.

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In 3 of these cases (OW, SF, LRC) upstream transport is larger than downstream transport. While the 3 other simulations (UW, BLRB, KHRB) show the opposite pattern, downstream transport is larger than upstream transport. Eight model simulations exhibit downwards transport across the upstream plane, but upwards transport across the downstream planes. In all of these cases, downwards transport is stronger than upwards transport. Meridional (cross-shore) transport shows flow to be onshore in the upstream and offshore in the downstream.

Just as strength of net vertical flux is affected by canyon Rossby number and Burger number, so too is transport pattern. Simulations with a canyon Rossby number to Burger number ratio of approximately 0.1 or lower exhibit negative transport across both vertical planes. However, simulations with a canyon Rossby number to Burger number ratio of approximately 0.1 or higher exhibit upwards flow in the upstream and downwards flow in the downstream.

The second set is values of average density anomaly in 9 regions within and around the canyon. These values were averaged over the approximate advection dominated phase (averaged over model days 4–10). The nine regions are:

- US_can, DS_can: width: from canyon axis to upstream rim or downstream rim, respectively, length: from the shelf break to the coast and depth: from shelf break depth to bottom depth.
- US_shallow, DS_shallow: same as above, but depth: from surface to shelf break depth.
- US_shelf, DS_shelf: width: from upstream rim or downstream rim, respectively to 10 km away from canyon, length: from shelf break to coast and depth: from surface to shelf depth.
- Lower_can: width: from upstream rim to downstream rim, length: offshore of shelf break to 15 km offshore and depth: surface to shelf break depth.

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- US_off, DS_off: width: from upstream rim or downstream rim, respectively to 10 km away from canyon, length: offshore of shelf break to 15 km offshore depth: surface to shelf break depth.

These values are negative everywhere within (US_can and DS_can) and over the submarine canyon (US_shallow and DS_shallow), as well as along the shelf in the upstream (US_shelf) and downstream (DS_shelf) for all model simulations. Four simulations (UW, OW, She, SF) exhibit negative density advection everywhere near the canyon (all nine regions). Eight simulations (ST, KL, SK, US, HB, LRC, SHR, KHRB) exhibit positive anomalies everywhere offshore of the canyon (Lower_can, US_off and DS_off), while 2 simulations (OBC and BLRB) display a positive density anomaly only in the upstream and downstream offshore regions.

Similar to pattern 1/2 density anomalies, location of incoming zonal jet impacts density advection within the model domain. Simulations with an outer shelf or coastal jet exhibit negative density anomalies over the lower canyon. Simulations with a shelf break or offshore jet exhibit positive anomalies offshore of the canyon.

These values will be included in tables and this discussion will also be included in the revised manuscript.

The reviewer asked about the relative importance of downwelling seen in the present study relative to upwelling seen in previous studies of left-bounded flows and upwelling canyons. The upwelling flux through submarine canyons can be estimated using a scaling analysis based on the strength of flow, stratification, Coriolis parameter and topographic shape parameters including the slope of the continental shelf (Howatt and Allen, 2013). Using this scaling analysis, an approximate upwelling flux was estimated for all canyon scenarios in the present study and was compared to the downwelling flux found from the numerical simulations. The OBC simulation is an outlier because of the very small downwelling flux in this scenario (Fig. 15). Considering the other cases, for low Rossby numbers (She and SF) we find similar upwelling and downwelling fluxes,

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consistent with a large role for time dependence in these cases. As the Rossby number increases, the downwelling flux increases approximately linearly (Fig. 15). However, the upwelling flux increases much more quickly (Howatt and Allen, 2013) as it is an advection dominated process. For the high Rossby number cases (UW, OW, ST, US, HB, KHRB) we estimate upwelling on the order of $10\times$ the size of downwelling. As the upwelling and downwelling fluxes are measured differently, we cannot give exact values, but upwelling is clearly stronger than downwelling for Rossby numbers greater than about 0.04.

The reviewer asked for details on the implications of downwelling canyons on biological productivity and provided several helpful citations. Previous observational studies in the NW Mediterranean Sea have shown that physical transport processes affect planktonic and particle distributions within and around submarine canyons (Alvarez et al., 1996; Granata et al., 1999), respectively. In Palamòs Canyon, an intruding filament of cold, salty oceanic water at 50 m depth correlates to a high density distribution of planktonic larvae at the same depth (Alvarez et al., 1996). In Blanes Canyon, concentrations of total particulate matter are highest in downwelling zones, particularly within anticyclonic cores (Granata et al., 1999).

One numerical model coupled a hydrodynamic model and a coastal plankton ecosystem model to further investigate the impacts submarine canyons have on primary production (Skliris and Djenidi, 2006). Upwelling of deep water rich in nitrate upstream and downstream of the canyon was found to enhance primary production, while cyclonic circulation in the canyon lead to an accumulation of plankton biomass in the canyon [ibid.].

All canyon simulations in the present study exhibited net downwards nitrate advection, which suggest that, in nitrate limited regions, steady downwelling canyons lead to a reduction of primary productivity in the region of canyons. Net downwelling occurring in the canyon will focus sinking particulate matter. Reasonably strong vertical flows, particularly on the downstream side of canyons, could lead to a concentration of vertical

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migrating zooplankton (Ianson et al., 2011). Particle tracks (Spurgin, 2014) showed that simulations with anticyclonic circulation (UW, OW, OBC, ST, HB, KHRB) produced a looping flow for particles, suggesting that, in these simulations, the canyon is generally a retention region.

These discussions will be added to the discussion in the revised manuscript.

The reviewer also raised issues of 1) a missing reference and a 2) clarification of density anomaly patterns. These will be addressed in the revised manuscript.

Further references

Granata, T. C., Vidondo, B., Duarte, C. M., Satta, M. P., and Garcia, M.: Hydrodynamics and particle transport associated with a submarine canyon off Blanes (Spain), NW Mediterranean Sea, Cont. Shelf Res., 19, 1249–1263, 1999.

Howatt, T. M. and Allen, S. E.: Impact of the continental shelf slope on upwelling through submarine canyons, J. Geophys. Res.-Oceans, 118, 5814–5828, 2013.

Ianson, D., Allen, S. E., Mackas,D. L., Trevorrow, M. V., and Benfield, M. C.: Response of Euphausia pacifica to small-scale shear in turbulent flow over a sill in a fjord, J. Plank. Res., 2011.

Skliris, N. and Djenidi, S.: Plankton dynamics controlled by hydrodynamic processes near a submarine canyon off NW corsican coast: A numerical modelling study, Cont. Shelf Res., 26, 1336–1358, 2006.

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