# Response to Committee and USGS Internal Review

# Water circulation/residence time paper

## Libe Washburn

* Line 25: Minor comment: Residence time is not known to 3 significant figures. Suggest rounding down
  + Rounded down
* Line 36: What do you mean by "the influence of stokes drift"? Is support for this statement provided in the manuscript?
  + Stokes Drift increases speed of drifters but it is not accounted for by Eulerian ADCPs. An analysis of Stoke’s drift under assumed wave conditions showed it could cause an increase of ~1-3 cm/s in drifter speeds. Similar to literature (Falter et al. 2008)
* Line 37: It’s not clear what “temporally extensive” means. Do you mean temporally varying?
  + Extending over a longer period of time than drifters moving through an area in several minutes; rewrite

Line 91: I don’t think these methods are used because of difficulties in Eulerian methods. They have their own advantages that motivate their use. Suggest rewriting.

Rewrite

From (Taebi et al. 2011) Most models of setup are for atolls or barrier reefs. As a consequence, existing analytical models of reef circulation developed specifically for barrier reefs and atolls may not be directly relevant to predicting the circulation and flushing of fringing reef systems. Independent from the known morphological controls to reef circulation, analytical solu- tions have furthermore predicted that wave‐driven currents on reefs should be sensitive to variations in the mean sea level over the reef flat; thus changes in water level over a tidal cycle should drive significant modulations in wave‐ driven currents, due to variations in radiation stress forcing and bottom friction [e.g., Hearn, 1999; Symonds et al., 1995].

Models not good in enclosed lagoons with high roughness and complex bathymetry that varies a lot with tide level?

For the Moorea system, maximum reef crest setup values of only ∼0.2 m generate wave‐driven reef currents in excess of 0.5 m/s. In contrast, despite the reef crest setup we observed at Ningaloo being much greater (up to 0.5 m), currents of only 0.2–0.3 m/s were observed. The influence of lagoon morphology on wave‐driven currents has not been considered in existing 1‐D analytical reef circulation models [e.g., Gourlay and Colleter, 2005; Symonds et al., 1995], however, the influence of finite lagoon setup in fringing reefs can be incorporated within these models, (e.g., following Lowe et al. [2009a]).

(Lowe et al. 2009) Fully coupled 3D models are well-validated in smooth sandy environments, not well-validated for shallow, rough, fringing reef systems; Models don’t account for freshwater buoyancy forcing

Need lots of in situ flow data for calibrating model (Lowe et al. 2009)

BIGGEST CONSTRAINT is highly accurate bathymetry (Lowe et al. 2009)

Line 92: Minor point: Here I think you are referring to satellite optical remote sensing approaches. There are other approaches such as active remote sensing, not just from satellites, that work through clouds and have high spatial resolution. Maybe clarify this point.

Changed “Remote sensing” to “Satellite optical remote sensing”

Line 95: Suggest deleting this and adding another requirement of modeling since all methods require significant expertise. Also, this sentence about modeling seems out of place since the rest of the paragraph focuses on Eulerian and Lagrangian observational approaches.

Removed “expertise”, focused on lack of forcing data and bathymetry data.

This sentence is to explain why hydrodynamic modeling was not used, it follows a sentence why satellite remote sensing was not used.

Line 125: Suggest identifying PagoPago Bay in Figure 1.

* + Added to Fig 1
* Line 140: Minor point: Suggest using “were” since “data” is considered plural. Suggest being consistent throughout paper.
  + Ok
* Line 146: Not clear what is an “insular shelf”, but maybe this is specialized terminology.
  + Curt?
  + As opposed to continental shelf
* Line 149: Are these the same as the “Backreef Pools” identified in Figure 1? If so, I suggest clarifying that. The black text is difficult to see against the dark background in Figure 1.
  + Yes, clarified by adding (“Backreef Pools” in Figure 1)
* Line 150: Is this shown in Figure 1? If so I suggest indicating its position. Also it would be helpful to identify Faga'alu Stream in Figure 1.
  + Yes, clarified in text by adding (“Channel” in Figure 1)
  + Added Faga’alu Stream to Figure 1
  + Added “Pago Pago Bay” and arrow to Figure 1
* Line 154: In Figure 1 you identify “North Reef” and “South Reef”. Are these what you refer to here. If so, I suggest using consistent terms
  + Ok, clarified in text. Changed “southern reef” to “South Reef (Figure 1)”
* Line 170: Not clear what you mean by “resampled”. For example, did you compute a 1-minute running mean and then sub-sample to 1 point per minute?
  + Average Lat/Lon calculated over 1 min interval
* Line 181: Suggest adding more details here about the ADCP measurements. This could aid readers who may want to use ADCPs in similar environments. Maybe give bin widths, blanking distance from the transducer head, distance from surface where you cut off velocity data due to surface reverberation, standard deviation of velocity noise, etc. When you say “580 current samples at 2 Hz every 10 min”, does this mean that you computed a current profile every 10 minutes by ensemble-averaging 580 profiles from 580 pings?
  + Curt? Olivia
* Line 189: I couldn’t see this in Figure 1.
  + It was removed from Figure 1 since it wasn’t used in any analyses.
* Line 200: It’s not clear what you mean here. Suggest re-writing. The caption of Figure 3 indicates NDBC station NSTP6 data are shown. Why not also show data from the Davis weather station? It would be interesting to compare them.
  + Yes, data are from NSTP6 (also added location to Figure 1). I actually took that language from another paper so I thought it would be acceptable.
  + Data from the Weather Station had a gap of about two days, and it didn’t seem like an important result since they were mostly similar.
  + Rewrite?

Line 210: I wasn’t clear why you used the term EOF here and elsewhere. Principal axis currents can be obtained from an EOF approach, but they can also be computed directly without using EOFs.

(Emery and Thomson 2004) say that “In oceanography, the method is commonly known as empirical orthogonal function (EOF) analysis.”

(Taebi et al. 2011) calls them EOF’s. “A spatial EOF analysis was applied….”

Should they just be called Principal Components (PC’s)?

* Line 211: Suggest discussing why 100 m by 100 m bins were selected. I assume it is because you need areas that encompassed sufficient numbers of drifters.
  + Added: “Spatial bins were sized to include sufficient drifter tracks while capturing small scale flow changes”
* Line 214: Minor point: I don’t think it’s necessary to point out that your study demonstrates the usefulness of Lagrangian methods. Their utility is well known as you describe above. Your study also clearly shows their usefulness. Suggest restating why you employed Lagrangian measurements here, which, BTW, was an excellent choice in approach.
  + Ok cut out: “to demonstrate the usefulness of Lagrangian methods for describing spatial flow patterns compared to projected flow from Eulerian methods, and”
* Line 226: I suggest also identifying these time periods (WIND, TIDE, WAVE) more precisely in Figures 3 and 4. Giving just the YD is not quite right since, for example, small and large waves occur on YD 48.
  + Ok, added some lines and labels to Figs 3 and 4 to delineate end members
* Line 234: Figure 4d shows the maximum wave height was just under 1.4 m at the beginning of YD 50. It’s lower on YD 50.
  + Added text:
  + “Large waves predicted by WW3 during WIND and TIDE were from a northerly direction that is blocked by the island and wave-breaking was not observed at the study site; on YD 52 the swell direction moved to the southeast causing large breaking waves on the reef crest”
* Line 238: I suggest finding another title for this section that summarizes what scientific result or process you are trying to describe here. Maybe something like “Flow variability on the reef flat”. But I’m sure could think of a better title!
  + I like this suggestion but couldn’t come up with a much better title
  + New title:
  + Spatial flow variability during end member conditions - Eulerian Measurements
* Line 239: As mentioned above, give blanking distance in methods section.
  + Moved this part to Methods
* Line 239: This paragraph seems more appropriate for the methods section.
  + Moved to Methods
* Line 252: By eye there may be correlation, but the relationship between winds & waves and currents at AS2 could be explored more quantitatively with your data.
  + Trent brought up this same point.
  + I don’t have the data to do this. Curt/Olivia?
  + (Taebi et al. 2011) gives R square values in text and Figure; good example
* Line 262: I also suggest changing this section title, maybe to something like “Spatial structure of flow trajectories”. But I’m sure you can improve on this. In this section you could group and describe all the results from the drifter component of your experiment.
  + That title works for me
  + “Spatial structure of flow trajectories – Lagrangian measurements”
* With all of the drifter data you have, you could make some estimates of particle diffusion based on changes in drifter separations during individual deployments of multiple drifters. Have you considered this? It could add a new, quantitative direction to the paper. There is extensive literature that describes how this is done. With the 5-drifter clusters that you released, you seem to be in a good position to do such an analysis. Colleagues of mine here at UCSB have MATLAB code that you could use for this. But this is just a suggestion. I know you’re working on multiple topics in your dissertation.
  + Not sure I understand. Drifters weren’t deployed near each other though, isn’t particle diffusion analysis used when drifters are deployed near each other, and separate over time? Curt?
  + Not possible with the deployments we did
* Line 270: Was the tide beginning to ebb when these higher current speeds were observed?
  + They weren’t necessarily higher current speeds, just that when the tide was high and waves were small they could go to sea over the reef crest
* Line 275: I don’t think the discussion of progressive vectors adds much to the paper. Given the many factors including complex bathymetry and coastline variability, it’s not surprising that the progressive vectors don’t match well the drifter trajectories or occasionally extend past the shoreline. I suggest finding another title for this section or combining it with the previous section.
  + Maybe should cut it or reduce the text on Progressive Vectors? Curt?
* Line 276: Figures 4 b,e clearly show this consistency of flow so it’s not surprising the progressive vectors look like the do.
  + Ok, but I can also see someone else saying that is only obvious to someone familiar with these methods
* Line 306 tradwinds: Separate and capitalize?
  + Dictionary says just separate, no capitalize
* Line 308: I suggest consistently using the names of the three categories of end-member forcing that you identify above.
  + Liv made the same comment. Changed all “wind forcing” etc to WIND

Line 310: See previous comment.

* + Changed all to TIDE WIND WAVE
* Line 315: Good, clear result
  + Thanks
* Line 319: I suggest finding another title that summarizes what scientific results you are describing in this section. As above, I suggest not using the term EOF to describe this analysis which uses variance ellipses and principal axis currents.
  + Curt? EOF?
  + Changed to: “Spatial Variation in Mean Flow and Variability during end-member conditions “
* Line 322: Some variance ellipses are hard to see, especially for those from the current meters. The blue ellipses on the black background are also hard to see. Can you use some color other than black in Figure 7? Maybe use an all white background with the reef features and channel indicated by lines.
  + Can be changed but will take a lot of time
  + Curt?
* Line 330: Here and elsewhere, suggest using “eccentric” or “has higher eccentricity” since eccentricity this is a parameter for ellipses that can be quantified.
  + Ok, changed all to eccentric/eccentricity
* Line 339: Suggest incorporating these into Table 1. If you keep the text as is, I would use the names of your end-member forcing regimes.
  + Incorporated the mean flow speeds into Table 1 and moved text to different section.
  + Also did some significance tests

Line 346: Do you mean they had higher eccentricity?

* + Yes, as above, changed all to eccentricity
* Line 350: Here and elsewhere do you mean the WIND end-member regime? I suggest being consistent throughout in doing this.
  + Changed all to WIND TIDE WAVE
* Line 361: Awkward sentence
  + Rewritten, split into two sentences.
* Line 370: Maybe retitle to something like “Spatial structure of residence times”.
  + Changed to “Spatial structure of residence times”
* Line 372: This seems like too many significant figures for a residence time estimate. Furthermore, you resampled the drifter data to 1 minute intervals = 1/60 hr. Here you are specifying residence time to 1/100 hr which is smaller than your drifter time interval.
  + Changed to 1 significant figure
  + 0.1-2.8 hr, 0.1-2.8 hr, and 0.04-0.6 h
* Line 376: Computing residence time from single current meters seems somewhat arbitrary since it depends strongly on what you assume for the control volume or control area in this case. For drifters residence time is better defined since you can measure the time the drifters are in a particular area.
  + Sort of arbitrary but its mostly to compare with estimates from drifters. The same 100m length is used to standardize methods.
* Line 376-380: Did you used the same 100 m x 100 m bins that you used for the drifters? You might show whatever area you used in Figures 7a,c,e.
  + Residence time from ADCP = 100m/mean velocity
* Line 389: Define here on first use.
  + Defined Root Mean Square Difference
* Line 389: Do you really mean “difference” here? It’s not clear how to attribute errors between the drifters and ADCPs.
  + Yes, changed to Difference
* Line 402: Is this true? Do you mean these are the most drifters released during a Lagrangian study in a coral reef system? You certainly conducted a lot of drifter deployments!
  + As far as I know this is the highest number of drifter deployments (30), a high number of drifters (5), and more importantly a high coverage of the study area.
* Line 413: This is a good point. Can you elaborate on how the far the sediment might be carried given the flow speeds you observed with the drifters in the pools, North Reef, and channel? It seems relevant to somehow connect flow paths, likely sediment settling velocities, to distances from the stream mouth where settling is likely to occur. Elsewhere you state the importance of sediment deposition to this system. Therefore it would strengthen the paper if you could more clearly link your results to sediment patterns or other aspects of sediment deposition.
  + I’d like to leave this for the third paper since we have the sediment accumulation data to support these kinds of calculations.
  + Curt? Trent?
* Line 415: Do you mean water-borne sediment concentration in this context?
  + Yes, need to explain?

Line 420: Again, the inability of current meters to predict current trajectories far from their measurement locations in a complex coral reef system is not surprising.

Should this be cut? Curt?

* Line 428: Good point. The consistent difference in flow direction between AS1 and AS2 is surprising and interesting.
  + I thought so too

Line 445: Suggest rewriting to explicitly state the inadequacy of using a single current meter for estimating residence time.

Rewritten:

Either way, the increase is notable for illustrating the inadequacy of using a single current meter in the channel to estimate water residence or flushing time from the bay.

* Line 456: There is also the limitation of ADCPs in measuring currents near the sea surface due to reverberation. In this case the depth where ADCP data is unavailable due to reverberation may nearly coincide with the depth range over which the drifters extend.
  + Curt?
* Line 475: Suggest rewriting this sentence for clarity. For example, is “surfing” the same as “wave induced deflection”?
  + Rewritten:
  + Another potential error could be wave-induced deflection or “surfing” ; however, Falter et al. (2008) concluded the wave-induced deflection was low, so although this may explain some of the discrepancy, it likely was not the dominant process.
* Line 516: This is sentence is vague and the overall point is unclear. I suggest deleting or rewriting it. Drifters seem to be an excellent approach for estimating RTs over space. To do this with current meters would be very difficult as you point out above.
  + Split into two sentences:
  + It is important to note that the spatially-distributed residence times calculated from Lagrangian drifters likely represent an underestimation since the mean flow speed from drifters was consistently higher than Eulerian methods. Further application of the residence times presented here must be appropriate to the research question, whether the interest is in residence time of near-surface water or total volumetric flux.
* Line 532: I can see that your study may be relevant to sediment dynamics on this reef system. Is there a way you can more strongly tie the results of your study to observed patterns of sediment distribution over the reef areas in this system?
  + I want to save that for the third paper

## Liv Herdman USGS

* My main two comments are that **if the eulerian/ lagrangian discrepancies are from Stokes Drift then it could be good to be more quantitative about** it. In my experience the  wave-driven flow has become a mostly eulerian flux once it passes the wave breaking zone so I would be surprised if that is contributing much. It could be drift from the tidal wave or wind generated waves, which I don't know as much about, but just providing some quantitative estimate using the stokes drift formula and the relevant wave conditions would help support  this point.
  + I computed Stokes Drift for the possible range of conditions. Not sure how much to include on this
  + Stokes Drift could be important but is likely not the only source of difference
* Also, it looks like your drifters sit really low in the water and don't protrude much, so wind slip probably isn't much of an issue, but, given that you are specifically looking at high wind conditions I think it **could be good to provide some demonstration of the drifters accuracy despite wind slip**. Either recalculate some of the drifter tracks with an adjustment for wind slip ( some estimates are out there in the literature and I talk about them in the thesis appendix I sent you a while back) and show that they aren't that different. Or discuss the expected changes in velocity. I think some estimate of this would be good to show that the differences in current being attributed to wind are actually from the current and not drifter error.

From (MacMahan et al. 2010): Assuming wind slippage similar to that of Murray, (1975), who used a similar drifter with a longer mast of the same diameter, the maximum bias error for the experiment is estimated at 0.01 m/s per m/s of wind (MacMahan et al., 2009). Max wind was ~8 m/s so at most wind slip would be 0.08 m/s or 8 cm/s. Typical wind speed was 2-5 m/s so wind slip could be on the order of 2-5 cm/s. Could be significant but that would be for tall masted drifters

(Austin and Atkinson 2004) determined wind slip was insignificant for cruciform drifters

I don’t have the thesis appendix she mentions. Curt?

* Line 49: A great reference for residence time and temperature is also Herdman et al 2013 ;-)
  + Couldn’t find a ref for 2013. Dissertation?
  + Herdman 2015 Heat balances and thermally driven lagoon-ocean exchangeson a tropical coral reef system(Moorea, French Polynesia)
* Line 62: remove the word actual, implies there is some interest in "fake patterns"
  + Removed
* Line 155: Does density vary spatially wihtin the southern reef ie more dense near the reef crest? Or are there mini- channels created by the reef growth? If it is a fairly even and random distribution of corals in the Acropora thickets then this descprition is adequate. But, channels and these types of features would be important to describe in terms of drifter flow paths and would be a big part of the cause of the spatial heterogeneity you are investigating
  + Reply: Not sure how much to add here.
* Line 163: How big is the housing?
  + 2 inch pipe, 5 cm dia.
* Line 165: How much of the housing stuck up out of the top of the water.
  + They’re about 7 cm tall, above the fins but generally only ~3 cm is above water, see Figure 2 b
* Line 170: by resampled do you mean averaged or smoothed some how? Resampling sounds like you have removed a lot of data, which doesn't usually reduce signal to noise ratio.
  + Yes 1 min. average location

Line 174: Did they never get stuck? How did you handle this?

* + If they got stuck I didn’t use that drifter track; this only occurred in early deployments before the ADCP period. If the tide was low I followed the ones in the shallow reef areas to make sure they didn’t get stuck. I quickly learned how low the tide could be for them to not get stuck.
* Line 186: I would like a little more description of this end-member business, but maybe the rest of your audience is more familiar with this approach
  + Not to be snarky but the reference provided (Yamano et al. 1998) clearly outlines the approach
  + Changed to/added: The instrument deployments were timed to capture “end-member” hydrodynamic forcing conditions that characterize the study area, such as high winds, high waves, or calm conditions (Yamano et al. 1998). This approach isolates the influence of wind-driven and wave-driven forcing to determine the dominant flow patterns caused by these forcings.

Line 192: Why not show it?

Not an important result. Trying to keep it short.

Line 234: It might be helpful for the reader if you point out that although large waves also occured earlier in the record they came from a direction that did not hit the reef, this briefly caused me some confusion.

Added text:

“Large waves predicted by WW3 during WIND and TIDE were from a northerly direction that is blocked by the island and wave-breaking was not observed at the study site; on YD 52 the swell direction moved to the southeast causing large breaking waves on the reef crest”

Line 289: I am confused, if there are 6 drifter releases during the wind case shouldn't there be six different progressive vectors from each ADCP location to compare to the releases?

there are only 2 progressive vectors

Curt/Olivia?

Line 294: Does this correspond to TIDE ie panel b? Reference figure panesl for these descriptions and stick to the TIDE, WIND , WAVE nomenclature you have already established. ( I think it is the mentioning waves that confused me and made it seem not to follow the topic sentence of being about the tidal conditions)

Yes TIDE. Tried to clarify this and use the nomenclature throughout

Line 296: Some indication of direction on the figure would be helpful to follow these statements, either start and end points indicated or arrows like on the other figure

Strat of the progressive vectors is indicated by the black dot.

Changing drifters to arrows can be done but will require a lot of time

Curt?

Line 377: How do you calculate this residence time from a point measurement? Please explain

RT is 100m / mean speed of ADCP; 100m corresponds to drifter spatial grid cell

Line 482: be more quantitative about this discussion. How big would Stokes drift be based on the wave conditions? Also, what about wind slip?

I’ve calculated possible Stoke’s, how much to include? Curt?

From (MacMahan et al. 2010): Assuming wind slippage similar to that of Murray, (1975), who used a similar drifter with a longer mast of the same diameter, the maximum bias error for the experiment is estimated at 0.01 m/s per m/s of wind (MacMahan et al., 2009). Max wind was ~8 m/s so at most wind slip would be 0.08 m/s or 8 cm/s. Typical wind speed was 2-5 m/s so wind slip could be on the order of 2-5 cm/s. Could be significant but that would be for tall masted drifters

(Austin and Atkinson 2004) determined wind slip was insignificant for cruciform drifters

Curt?

Figure 3 caption, line 692: Are these peak or average periods, wave heights or directions?

(significant wave height, average wave period, peak wave direction); added to caption

Figure 4 caption, line 699: It would be helpful if there were colored bars or something indicating the three different forcings on this figure

Added lines to delineate periods

Figure 5 caption, line 701: It might be helpful to have specific symbols to mark the start and end of drifter tracks, to help with following the arrows... or maybe that would be too cluttered

I think it would be too hard to see. Launch zones/starting points are shown in Fig 1

Figure 5 caption, line 701: Are these the full drifter tracks or are they cut to 1 hr

These are full drifter tracks

## Trent

* Line 1: Ocean circulation is an important control on nutrient and sediment dynamics in coral reefs, but determination of circulations patterns often requires expensive data collection and modeling. Or water circulation? Circulation could mean of the atmosphere.
  + Not sure
* Line 19: embayment fringed with coral reef in American Samoa
  + Rearrange to be be shorter? Too many modifiers in front of ‘embayment”
* Line 29: Is the channel incised or relic? Not necessarily important
  + Not sure. Changed to “deep channel” since it’s not important
* Line 120: The research questions are:
  + Research questions:
  + How do flow speeds and residence times vary spatially on the reef flat, and How are flow speeds and residence times influenced by high waves, high winds, or calm conditions?
* Line 153: reword
  + Reworded
* Line 182: Depth of deployment was xx m (AS1), xx m (AS2),…
  + Curt: What tide stage should be used?
  + Olivia will compute depths from ADCPs
* Line 248: Why “AS”, why not ADCP1 or A1?
  + That’s how they were labeled by Curt/Olivia. I assumed AS stood for American Samoa?
* Line 248: It would be helpful to indicate AS1-5 on the maps in Figure 4 since it’s hard to visually align them using Fig 1.
  + ??
* Line 252: I don’t clearly see the correlation between speed at AS2 and wind speed/wave height. IS there a statistically significant correlation between them?
  + I think it is clear AS2 and waves are correlated. For winds it is less clear.
  + I don’t have the raw ADCP flow speed data to make test the significance.
  + Curt/Olivia?
* Line 257: This seems like an important conclusion? Or old news to oceanographers?
  + Unfortunately it is old news, but it’s cool to see in our study site too
* Line 263: I think this goes in methods.
  + It was a recap of methods. Moved it to Methods
* Line 276: And directions?
  + Yep
* Line 294: Better than AS2? Does this need to be quantified?
  + It could be. Length of drifter/mean speed vs. Length of progressive vector?
  + Not sure this is such an important result
  + Curt/Olivia?
  + Add something about meaning of this result
* Line 336: Are they statistically significantly different? ANOVA.
  + Did an ANOVA and they are all statistically significantly different
* Line 338: Why is there a range—can’t you calculate mean flow speeds over the whole domain?
  + Calculated a mean over the bay for each end member
* Line 339: The mean gridded velocity was xx, xx and xx cm s-1 under wave, wind, and tidal forcing..
  + Calculated these and added to Table 1
* Line 366: Need?
  + I think this is interesting for sediment export. Would a sediment plume be advected permanently to sea or could it be recirculated over either the northern or southern reef