# Eulerian and Lagrangian measurements of flow and residence time on a fringing reef flat embayment, American Samoa

From Curt April 1, 2014:

Basically, what is the goal of the manuscript? Lay out the background of the problem in the beginning of the Introduction, move into the more specific gap in our understanding that we're trying to pursue, then state because of this, we did X to learn Y at the end of the Introduction. The Study Area is background information on the specific study area - both subaerial and subsurface. Methods outline the methods used - both instruments and specific calculations; you don't need the detail of your proposal - just give a reference for methods like progressive vectors and EOFs. Results are the data - not methods. You can compare the results to other studies to put them in context, but don't explain why you think you're seeing the patterns you're seeing - that's for the Disucssion. Break it out by oceanographic and meteorologic forcing, ADCP data, and drifter data. The Discussion is where you first discuss how well the Lagaranian and Eulerian methods compare, then characterize the findings by the different types of forcing and why you think you're seeing these patterns you see in the data. You then can discuss the relevance to residence times and what they mean for sediment, nutrient uptake, etc. Wrap it all up with the big take-away message. Coral Reefs does not have a "Conclusions" section.

# Outline:

*Goal for the manuscript:*

This manuscript describes how Eulerian and Lagrangian methods were used to map water circulation and the resulting water residence times over a shallow, fringing reef experiencing sediment stress.

## INTRODUCTION

**Background of the problem:** Water residence time is important for biological processes like sediment dynamics but spatially distributed flows are hard to quantify.

* Hydrodynamic conditions control sedimentation by limiting deposition and resuspension/flushing
* Water residence time is controlled by wave, wind and tidal forcing, modulated by tide height at the reef crest.
* Description of Lagrangian, Eulerian, other methods (models, remote sensing etc.)
  + Eulerian measurements capture long term conditions but difficult to get a lot of spatial info since expensive
  + Hydrodynamic models need too much detailed data and expertise, remote sensing is inadequate
  + Lagrangian good for spatial coverage ; GPS drifters are smaller, and cheaper now, can use lots of them to observe flows; Others have used them in deep ocean, surf zones, haven’t used drifters on reef flats yet;
* Drifters are short term, uncertainty of sampled conditions; Storlazzi (2006) combines them to get best of both worlds. How Eulerian and Lagrangian are combined

**Specific knowledge gap:** Since water residence time is critical to sediment dynamics and coral heath, what is the water residence time over the Faga’alu reef flat and how does it change under wave, wind and tidal forcing?

**So we did “X” to learn “Y”:** We compared the spatially extensive Lagrangian measurements with the longer term Eulerian measurements to calculate spatially distributed water residence time under different “end-member” forcing conditions: tide, wind, wave.

## MATERIALS AND METHODS

### Study Area

Figure 1. Map of Faga’alu reef

*Background info on specific study area: subaerial and subsurface*

* Location, size, layout, depths, physical and biological characteristics of reef
* Description of seasonality and prevailing waves, winds, and tides
* Previous studies/data: Not much except for ACOE 2002 wave climate, and Vetter (unpublished), and none is published in journals
* Flood plume dynamics from Faga’alu Stream to Faga’alu Reef, and referring to other papers in Faga’alu
  + Figure 2. Flood plume pictures in the bay
* Other on-going work includes sediment yield monitoring from watershed, sediment accumulation on the reef, and larger restoration efforts of USCRTF

### Methods

O*utline the methods used - both instruments and specific calculations; you don't need the detail of your proposal - just give a reference for methods like progressive vectors and EOFs*

Figure 3. Pictures of ADCPs and drifters

**Eulerian measurements**

* ADCP deployed for one week at three locations in Faga’alu and recorded data like…

**Lagrangian measurements: drifters**

* Drifters were designed for reef flat conditions and made on-island
* Drifters were deployed to coincide with end-member conditions and ADCP deployment; at the same five launch sites;
* collected data at 5 sec interval, resampled to 1 min; tracks limited to 1 h for comparison with ADCP data

**Ancillary data**

* Data used to define forcing conditions: Wave, Wind, Tide; Forcing end-members are determined post-deployment, using the recorded data
* Wave data was recorded by a DOBIE, then modeled from WW3 for the ADCP week
* Wind data recorded with weather station in Faga’alu, NOAA NDBC station at DMWR
* Tide data recorded by NOAA NDBC station at DMWR

**Analytical methods**

* Data is subset by end-member forcing conditions and analyzed using:
  + Progressive vectors
  + EOF’s
    - mean flow velocity
    - residence times
* Progressive vectors are used to compare flow at ADCP to flow tracks from drifters, show if flow directions and speeds are variable away from ADCPs;
* EOF’s show major and minor axes of flow at the ADCP points, and for binned drifter data;

Mean velocity also calculated and put on EOF; mean velocity of binned drifter data is calculated and compare with ADCP mean velocity to see if short Lagrangian measurements compare to long term ADCP (are mean velocities similar between methods);

* Mean velocity is used to calculate residence times;

## RESULTS

*Results are the data - not methods. You can compare the results to other studies to put them in context, but don't explain why you think you're seeing the patterns you're seeing - that's for the Discussion. Break it out by oceanographic and meteorologic forcing, ADCP data, and drifter data.*

**Oceanographic/meteorologic forcing data-Tide, Wind, Wave (Figure 4, Table 1)**

* Tide, wind and wave conditions during the study period showed three distinct periods, allowing study of forcing end members: wind, tide, wave (Table 1)
* Wind forcing: 2014 Year Day (YD) 47-49, mean wind speed/direction and max gust
* Tide forcing: YD 50-51, tide range?, wind speed, wave height?
* Wave forcing: YD 52- 55, max wave height
* Compared these conditions to range of annual measurements

**ADCP data (Figure 5)**

* Data was collected YD 47-55; water level fell below on AS3
* Overall:
  + Tide forcing showed slower flow speeds, more variable direction
  + Wind forcing showed slower flow speeds, more variable direction
  + Wave forcing showed faster flow speeds, more constant direction
* Max velocity was at AS1, YD ## in NW direction
* AS1 showed more constant flow direction and high flow speeds
* AS2 showed fairly constant flow direction except during TIDE; flow speed was responsive to wind and wave forcing, highest during high wave conditions
* AS3 showed extremely variable directions and slow flow speeds
* AS1 shows modulating effect of tide stage on wave-forced flow YD 52-55

**Drifter data (Table 2 and Figure 6)**

* 30 deployments were made, 22 coinciding with ADCP deployments YD 47-55 (Table 2 of deployments)
* Drifter tracks covered nearly the whole bay (Figure 6)
* several examples of cross-reef transport and re-entrainment were observed
* higher flow speeds over southern reef, especially near the reef crest and seaward of ‘ava channel
* lowest speeds clustered around northwest corner of bay, near streammouth

**Progressive Vectors (Figure 7)**

* ADCP showed little variation in flow direction, going ashore in many cases (AS1) but drifters followed the contours of the shore, and slowed at deep pools on south reef
* Drifters on northern reef showed much more variable flow than ADCP’s; travel much farther distances than predicted by ADCP Progressive Vectors
* Tide: Drifters on northern reef went onto southern reef during Tide, and cross-reef at D3; drifters traveled in erratic patterns, and much farther than ADCP’s, especially on the northern reef; ASthree compares poorly with Lagrangian drifter, AS2 is better but still shows short, constant flows, AS1 pretty good
* Wind: Drifter 2 during lost at sea; shorter shows slower flows than Tide forcing; AS1, AS2 and AS3 compare pretty closely with drifters in travel distance and direction, but fewer observations; everything kind of piles up in northwest corner
* Wave: longer progressive vectors show faster flow speeds at all locations; Drifters show overall coherent flow pattern flushing the bay but ADCPs go ashore or straight onshore; AS1 shows transport into ‘ava channel, flow coming all the way from AS1 to flush out that area? All drifters out of ava channel after 1 h = flushing time?

**EOF’s/Mean vector (Figure 8)**

* Some spatial bins have more observations than others, especially in the ‘ava channel, some none at all; ADCP many more observations so more certain, weird EOF’s where observations are few, like southeast corner on Tide and farther out of Bay
* Overall patterns:
  + ADCP more ellipsoid at AS1 and AS2, more circular at AS3, same as drifters
  + ADCP mean vectors pretty similar directions for all forcings, mean speed much higher for Wave
  + Drifters, mean directions capture the overall flow pattern including the seaward flow through the ava; ADCP’s show only shoreward transport
  + Flow speeds of drifters, flow speeds of ADCP under different forcings
* Tide: ADCP less ellipsoid EOF’s, short mean vector shows slow speeds; drifters show overall clockwise flow across southern reef into ‘ava and out to sea, EOF’s more ellipsoid near reef crest, more circular in deep pools and ‘ava
* Wind: ADCP EOF’s more ellipsoid than Tide, but slower mean speed; drifter EOF’s same flow pattern (directions) but EOF’s are smaller which means slower flows in deep pools; flow piles up in northwest corner or just low data density and short drift times?
* Wave: Faster mean speeds for all, except AS3; EOF’s pretty similar pattern to others, clockwise coherent flow; clearly flowing out ava channel. Flow at AS2 and backreef pools increased from breaking waves on reef crest near ava

**Residence Times (Figure 9)**

* Overall:
  + Tide: highest residence time, highest over the northern reef
  + Wind: high residence time on northern reef
  + Wave: lowest residence times over pretty much the whole reef, a few spots of higher residence times on northwest corner of the bay
* Mean flow speeds from ADCP for AS1 during Tide, Wind and Wave forcing were: ; for AS2 they were: , for AS3 they were: ; and they compare to Drifters…. Table with RMSE, % difference?

## DISCUSSION

*The Discussion is where you first discuss how well the Lagrangian and Eulerian methods compare, then characterize the findings by the different types of forcing and why you think you're seeing these patterns you see in the data. You then can discuss the relevance to residence times and what they mean for sediment, nutrient uptake, etc.*

**Observations**

* Highest speed at AS1 for all forcings due to breaking waves, even small ones
* Flow directions more variable on northern reef
* Lowest speeds, highest res time in northwest corner

**How well did Lagrangian and Eulerian compare?**

* Both Eulerian and Lagrangian methods showed the main differences between the north and south reefs: flow speeds are slower and flow directions more variable over the north reef than the south reef; but Lagrangian methods resolved the general flow pattern of the bay much better. Eulerian shows all flow shoreward, Lagrangian shows flow across reef into ava and out to sea. Several unique flow features shown by Lagrangian measurements
* Contrary to study in Molokai, flow was slower in deep pools and ava. However ava flow speeds not constant; compare to Hench ADCP in channel
* Lagrangian measured higher flow speeds than Eulerian, possibly because Eulerian measures deeper flows
  + d

**Relevance to residence times, sediment and nutrient uptake**

* Residence times are much higher on the north reef and deep pools of south reef, which are also closest to the stream mouth, increasing influence of sediment and nutrient inputs in these areas

*Wrap it all up with the big take-away message* *No Conclusion in “Coral Reefs”, give big take-away message*

**Take-away message**

Residence time is mainly controlled by wave forcing, and is much higher on the northern reef flat than the southern reef flat, increasing the impact of land-based sources of pollution from the river.