Analysis of subsurface currents in the West Arm of Glacier Bay, Alaska

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Abstract

Acoustic Doppler current profiler measurements in the West Arm of Glacier Bay, Alaska indicate barotropic tides and a persistent stratified flow pattern. Data from the University of Hawaii data acquisition system (UHDAS) auto formatting was used to calculate the net volume transport and current structure for this geographic region. ADCP data shows tidal currents at depths greater than 300m in this region. CTD casts indicate very weak density stratification due to salinity alone, and an increase in temperature with depth. Despite the weak stratification, well-defined shear was observed at approximately 150m and 35m depth. With the barotropic tidal signal removed from the data, currents below 150m were observed to flow NW into the channel while currents above 150m flowed SE out towards the sea. The residence time for a water parcel in the West Arm was calculated to be 130 days.

Introduction

By definition most of the dynamics of a fluid system occur beneath the surface. Many techniques have been developed to track fluid flow. One of the more clever devices engineered to do so is the acoustic Doppler current profiler (ADCP). This device bounces sound waves off small particles entrained in seawater to measure current velocity. The R/V Thompson is equipped with such a device, which coupled with the opportunity to participate in the UW senior research cruise presented the possibility of a study of the currents in Glacier Bay. The project described below represents an attempt to use the ADCP data collected in Glacier Bay to describe the structure of tides and currents in the region. The task proved difficult as the data points vary temporally and spatially and few geographic regions were sampled more than once. Despite this, there are interesting physical phenomena evidenced in this dataset, which have been explored to the furthest extent that time has allowed.

Methods

The R/V Thompson's ship mounted acoustic Doppler current profiler (ADCP) was be used to measure currents. The ship is equipped with the Teledyne RD Instruments Ocean Surveyor 75KHz model ADCP mounted 6m below the water surface in the keel of the ship. This model ADCP has a measurement range of 10m to 1000m, meaning that measurements of currents within 10m of the ADCP cannot be resolved. These factors limit the upper current measurement to a depth of approximately 21m below the surface. ADCP measurements are limited at bottom boundaries by a 6% of water depth plus one depth bin. For example, the bottom boundary data gap for a 200m (the approximate depth for this study) deep area would be 20m. This limits the ADCP's ability to measure currents in waters less than 30m deep. The data is grouped into 8m depth averaged bins. Although the ADCP can record up to 128 bins, 79 bins were recorded on this cruise. The R/V Thompson uses UHDAS software to interface with the ADCP. This is the R/V Thompson's default software and operates within the UNIX operating system.

The ADCP data was processed on board by the UHDAS system into 15-minute time averaged data points. The unprocessed data from the ADCP was not used as processing this data once on shore proved too time intensive for this project. A thorough analysis of the raw data would be required to validate any conclusions made based on the auto formatted data used in this study. Although the ADCP does measure currents in x, y, and z (depth) directions; due to time constraints, the z measurement was not included in this analysis of the data. For each 15-minute interval the R/V Thompson spent in Glacier Bay, a column vector of current data was recorded in the u(east-west) and v(north-south) directions. The length of the vector was determined by the depth of the water column minus the fractional loss described above. Each element in this vector represents an 8m depth averaged current reading. The result of this data collection was four matrices. The u and v matrices are 79×518 representing the number of depth bins and time steps respectively. The x and y matrices store longitude and latitude, they are both 1×518 with one entry per time step. This allowed any subset of the data to be selected based on the time and depth or by latitude and longitude.

All measurements of currents were viewed with respect to the tidal phase in which they were observed. The tidal information used in this analysis comes from the National Oceanic and Atmospheric Administration (NOAA) tidal height predictions for Composite Island. Tide times were converted to Greenwich mean time (GMT) from Alaska daylight time (ADT) to agree with UHDAS data. These tides were used to make rough estimates of currents through the mouth of the West Arm by calculating the expected change in volume dived by the time span of the tidal phase.

The ship spent over half of the on-site cruise time in the West Arm of Glacier Bay. 204 of 396 data points taken in Glacier Bay come from this region. A deep channel, 450m in spots, runs from the mouth of the West Arm to the southeast tip of Russell Island. This channel was selected as the geographic subset of the West Arm region to study because it is relatively uniform in depth and width, with little change in the along channel (NW/SE) direction. The ship passed though this channel five times during the cruise. The first four of these transits show data from this deep channel over flood and ebb tidal cycles. The fifth transit in the area was used to map bathymetry near Composite Island; this track varies spatially to such a degree that the corresponding current data could not be incorporated into this study. The current matrices u and v were rotated element wise such that each vector had an along channel component and a cross channel component. The resulting along channel component matrix u' was used in the analysis of the West Arm region. Data points within the chosen region were selected from the u' matrix and organized into tracks 1, 2, 3, and 4. Analysis of along channel flow in the West Arm used these subsets of u' exclusively. Shear and depth averaged currents were calculated in the along channel direction from u'. Shear is reported as the absolute value of du/dz, which was calculated using a second order accurate centered differencing Taylor approximation. Depth averages were calculated by averaging all measurements at a given time step. The currents were said to be represented by some u where $u = u(x,y,z,t)$. It was assumed $du/dx = du/dy = 0$, due to the limited size of the chosen domain, thus yielding $u = u(z,t)+C$. To further simplify the problem, the following *ansatz* was made: $u(z,t) = u(z) + u(t)$. This provided mathematical justification to remove the time dependent portion of u, revealing the

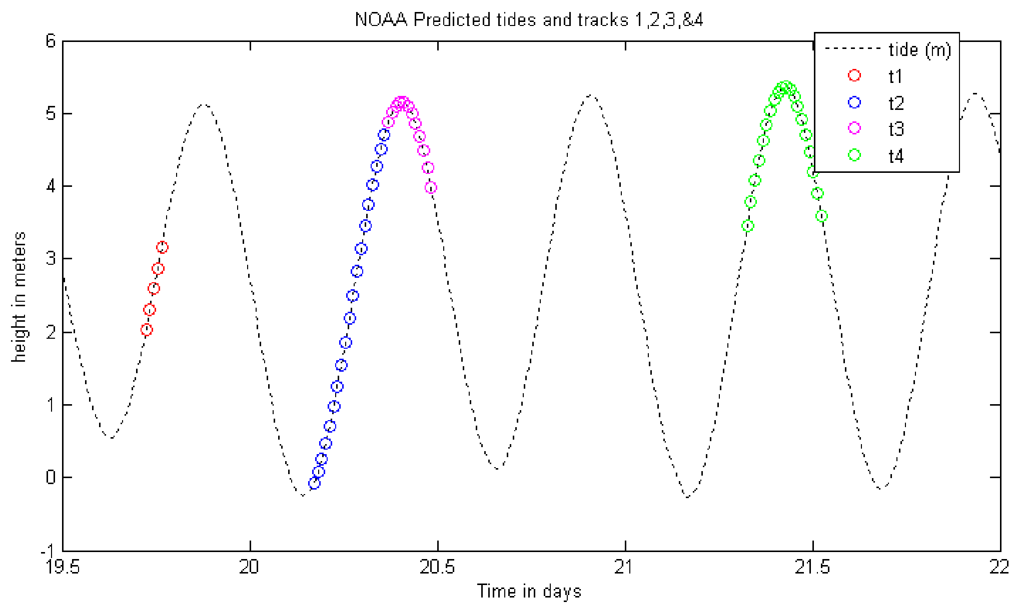

Figure 1: Tidal height predictions and the times sampled in this study

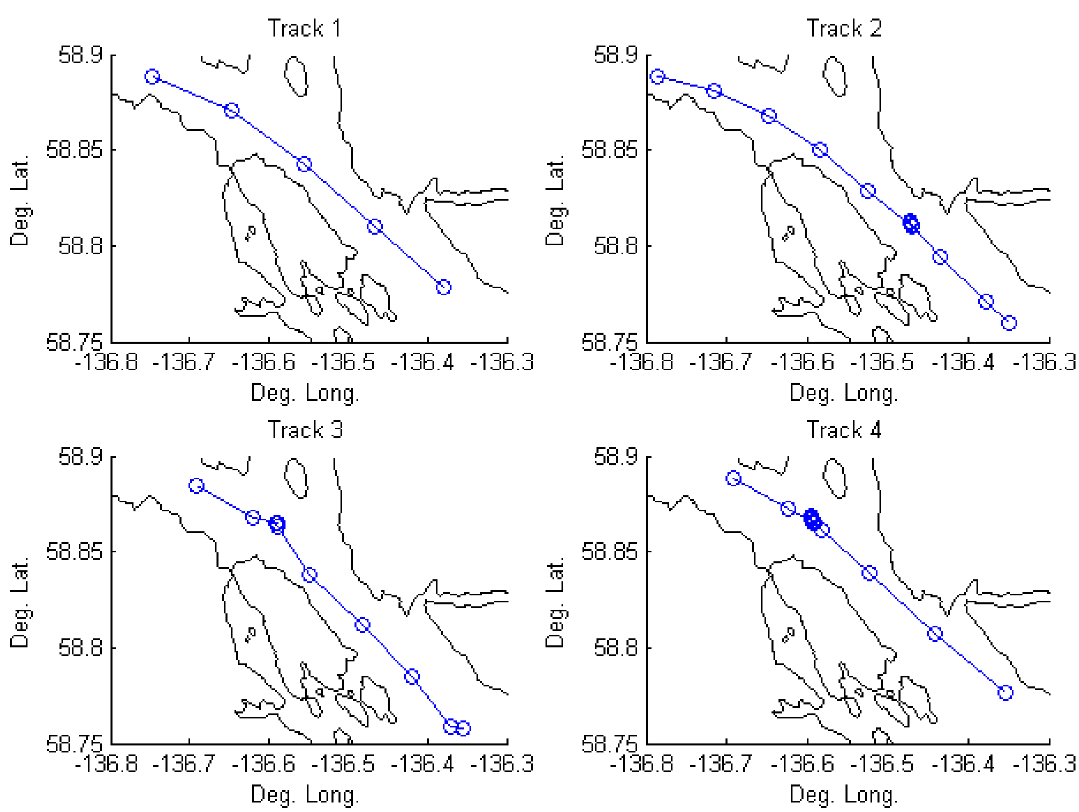

Figure 2: Ship tracks 1, 2, 3, and 4 through the West Arm

depth, and thus density, dependent circulation pattern. The tides were observed to be largely barotropic (Mickett 542), thus the best way to remove the tidal signal was to subtract the depth mean from each data point, at each time step.

Results

The resulting data from the above methods is a series of four data sets along the main channel in the West Arm. These datasets are referred to as tracks 1, 2, 3, and 4. All times are given in decimal days beginning with March 1 0001 GMT, and are stepped forward in fifteen minute time intervals. Track 1 runs SE to NW from day 19.725 to 19.765. This initial pass transits through the area of interest without pausing, on a flood tide. Track 2 runs NW to SE from day 20.17 to 20.36 on a flood tide. Track 3 runs SE to NW from day 20.36 to 20.48. Track 3 begins at the end of a flood tide and into ebb tide. Track 4 runs NW to SE from day 21.33 to 21.52 over the end of a flood tide and into ebb tide.

The data from track one does not fit well into the overall theoretical analysis to be presented in the discussion, so it will receive less attention here. This data was measured on a flood tide. The tides appear to be barotropic, thus the currents are expected to flow into the channel. The data shows currents flowing out to sea, which is in opposition to this expectation. This contradiction is left as a topic for further study.

Tracks 2 and 3 are the primary datasets for this project. These tracks show a clear signal of currents flowing NW into the West Arm and then SE out to sea. The observed signal correlates well to the tidal phase in which these data were taken. These tracks show the tidal currents are primarily barotropic, as the magnitude and direction of currents is similar throughout the water column. Track 2 shows currents flowing NW on the flood tide. Track 3 shows currents flowing SE on the ebb tide. Taken together the data from these tracks shows periodic and smooth transition from flood to ebb tide in the West Arm. With the tidal signal removed from this dataset, the density dependent flow becomes visible. A steady flow of roughly 2 cm/s NW was observed below 150m. Above 150m the net flow is less uniform, but shows a subsurface maximum at ~100m. This steady current flows SE, out of the West Arm. Calculations of shear indicate this transition with noticeably increased shear at 150 m. The near surface layer at approximately 35m also indicates significant shear, however there is little data above 30m so this shear layer is left as a subject of further investigation.

Track 4 is a SE transit over the end of a flood and beginning of an ebb tidal phase. The ship was stopped south of Composite Island for over half of this dataset, yielding a rare opportunity to observe time evolution of these currents at a fixed location. The data from this track is the least noisy of the four tracks examined in this study. Track 4 clearly shows ebb tide currents developing in time. Data from this track shows shear at 150m. Below this depth the current varies from strong to very weak in the NW direction. Above 150m the current varies from weakly NW to strongly SE. A stratified flow pattern becomes clear when the tidal signal is removed. Above 150m the flow is continuously to the SE, while below the flow is NW. These current measurement tracks were averaged over time. The average outflow in the 35m to 150m layer was found to be 0.015 m/s giving an estimated residence time for the West Arm of 130 days.

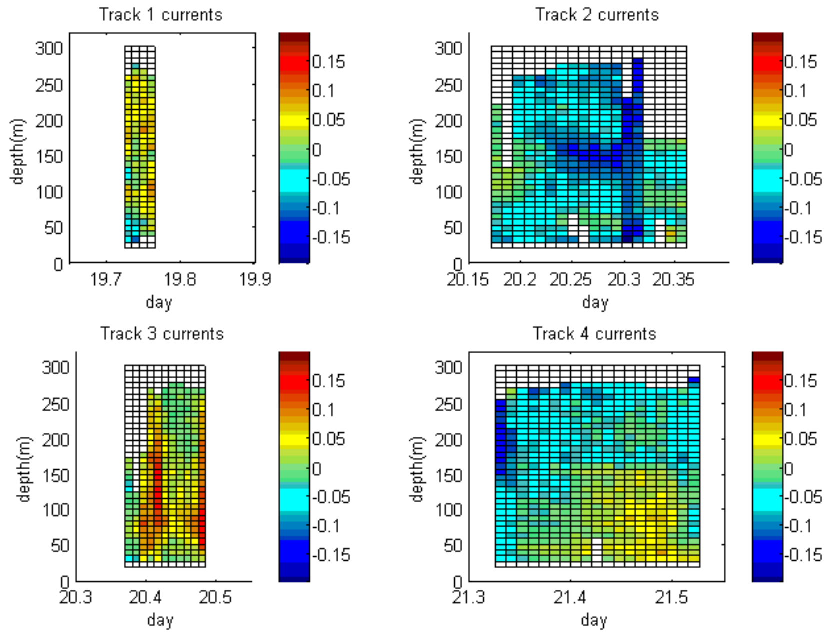

Figure 3: Currents in m/s as measured by the ADCP for the 4 tracks. Positive values flow SE.

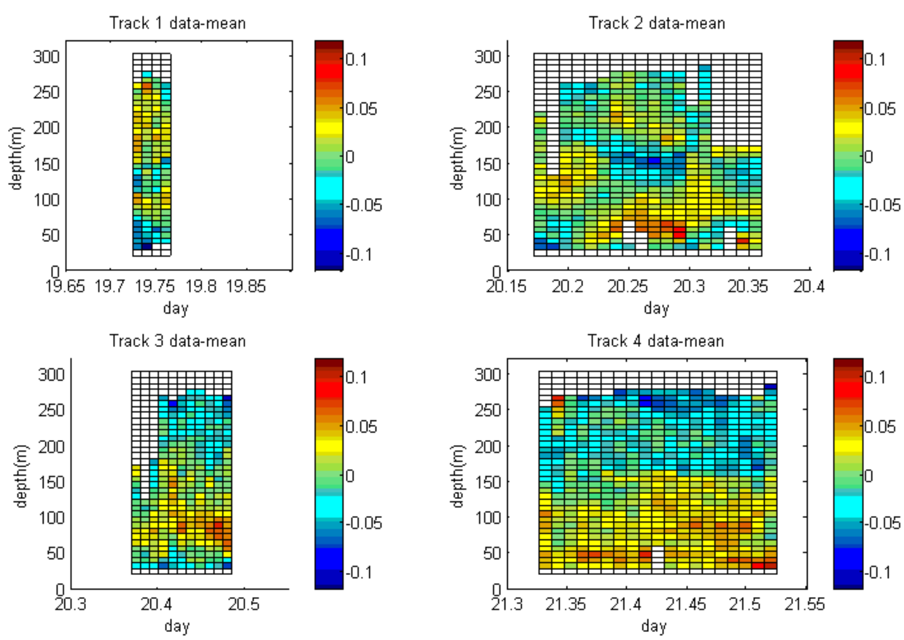

Figure 4: Currents in m/s with the barotropic tidal signal removed. Positive values flow SE.

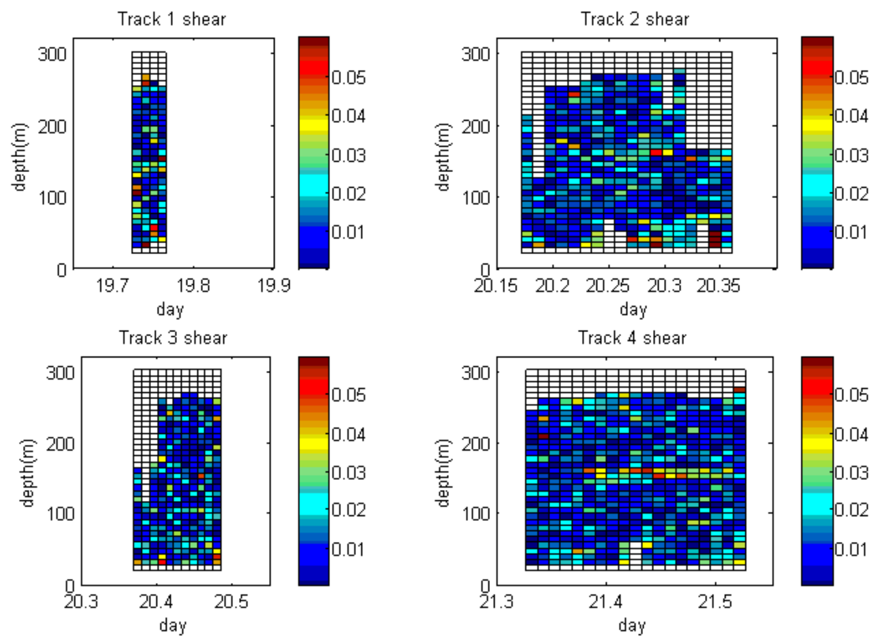

Figure 5: Shear |du/dz| for the 4 tracks.

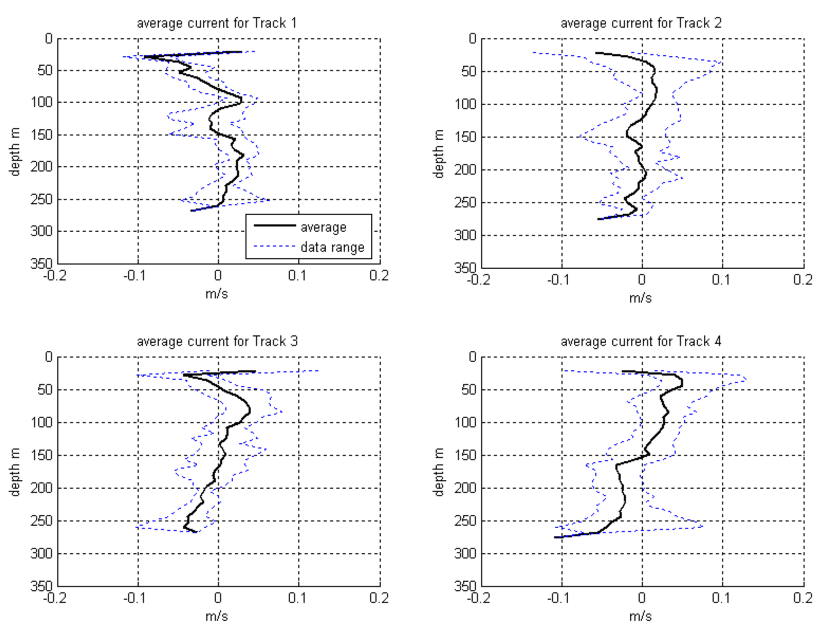

Figure 6: Time averaged currents for each track. Positive values flow seaward (SE).

Discussion

There are two stories to tell from the data analysis. The first is the existence of barotropic tides. The second is a density stratified flow pattern. Observed tidal currents did not agree well temporally with the NOAA tidal predictions. This is not unexpected, the NOAA predictions are an extrapolation from Bartlett cove tides, and there are many topographic features to delay and distort the propagation of the tides into further reaches of the bay (Thorpe 332), including the West Arm. In this study the tide height used to analyze the data came from these predictions, and as such any conclusions that rely specifically on that information are subject to the propagation of error between the predicted and observed tides.

Tracks 1, 2, and 3 show that tidal currents through the full depth range. This observation is an indication that the tides are primarily barotropic (Mickett 543), meaning in this case that the isopycnals are parallel to the surface. In track 1 the maximum tidal currents are centered on a depth of 200m. The depth profile of the track 1 currents is not exactly uniform, but a consistent pattern of tidal currents was observed at depth. Tracks 2 and 3 clearly show tidal currents throughout the water column as well.

A three layer current profile was observed in the West Arm. The surface layer, 0m to 35m, currents appear to change direction, possibly due to baroclinic tides and wind stress. The middle layer, 35m to approximately 150m, shows consistent transport out to sea. Below 150m the flow is NW, into the channel. Figure 6 shows the time averaged current profile for each of the tracks. The currents cross zero in each plot near 150m depth. Based on this information it would appear that the West Arm has a depth dependent circulation pattern $u(z = (35m, 150m)) = 0$, as shown in figure 7. Surface currents were extrapolated from the data using forward differencing on the first three data points of each vector; the result is shown in figure 7. Although the ADCP is expected to lose ˜6% of the depth at each measurement, in the West Arm the data represents approximately 60% of the water column. It was desired to extrapolate to the bottom using the data in a similar way as for the surface; however this was not possible as the last depth measurements in the ADCP data are very noisy. Thus it is assumed that the flow pattern below the measurements is consistent with the data and flows NW.

Conclusions

Data from this research created more questions than answers. Little progress was made toward the larger goal of studying Glacier Bay and its circulation patterns. This project focused solely on the West Arm region and did not produce any reliable quantitative measure of net volume transport for Glacier Bay as a whole. The largest scientific contribution from this project is to identify specific areas where further research is necessary. For example, the disagreement between tidal predictions and observations could be investigated by the placement of a tide gauge at Composite Island. This would yield information on the wave distortion and phase shift of tidal waves as they propagate through the bay. Continuous ADCP data over several tidal cycles for a fixed geographic location would greatly increase the usefulness of any further study of these currents. The original plan for this research involved the use of a moored ADCP. This report and its tentative findings underscore the importance of such equipment for this type of study.

References

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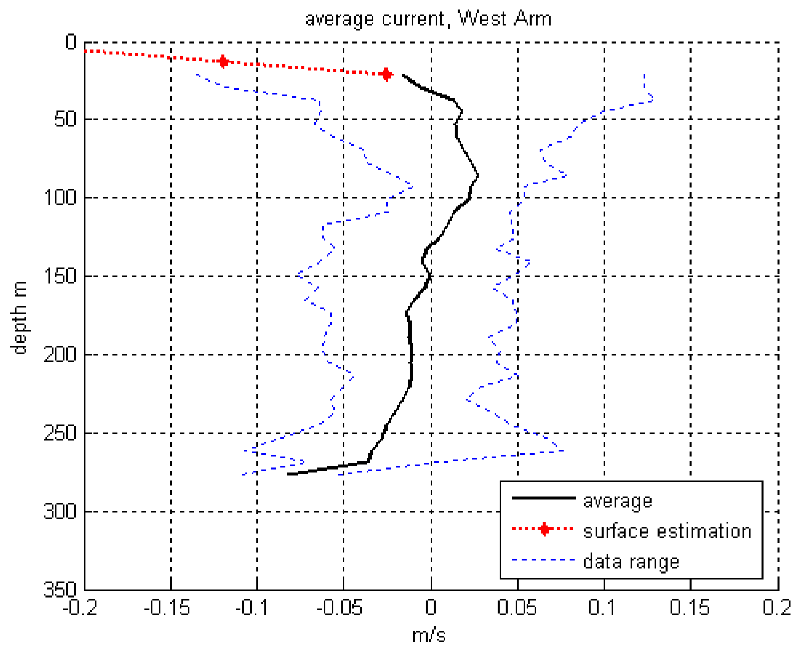

Figure 7: Time averaged current profile for all data in the West Arm

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