Jet Propulsion Laboratory
California Institute of Technology

Wax Lake Water Level Data Overview

Version 1.0

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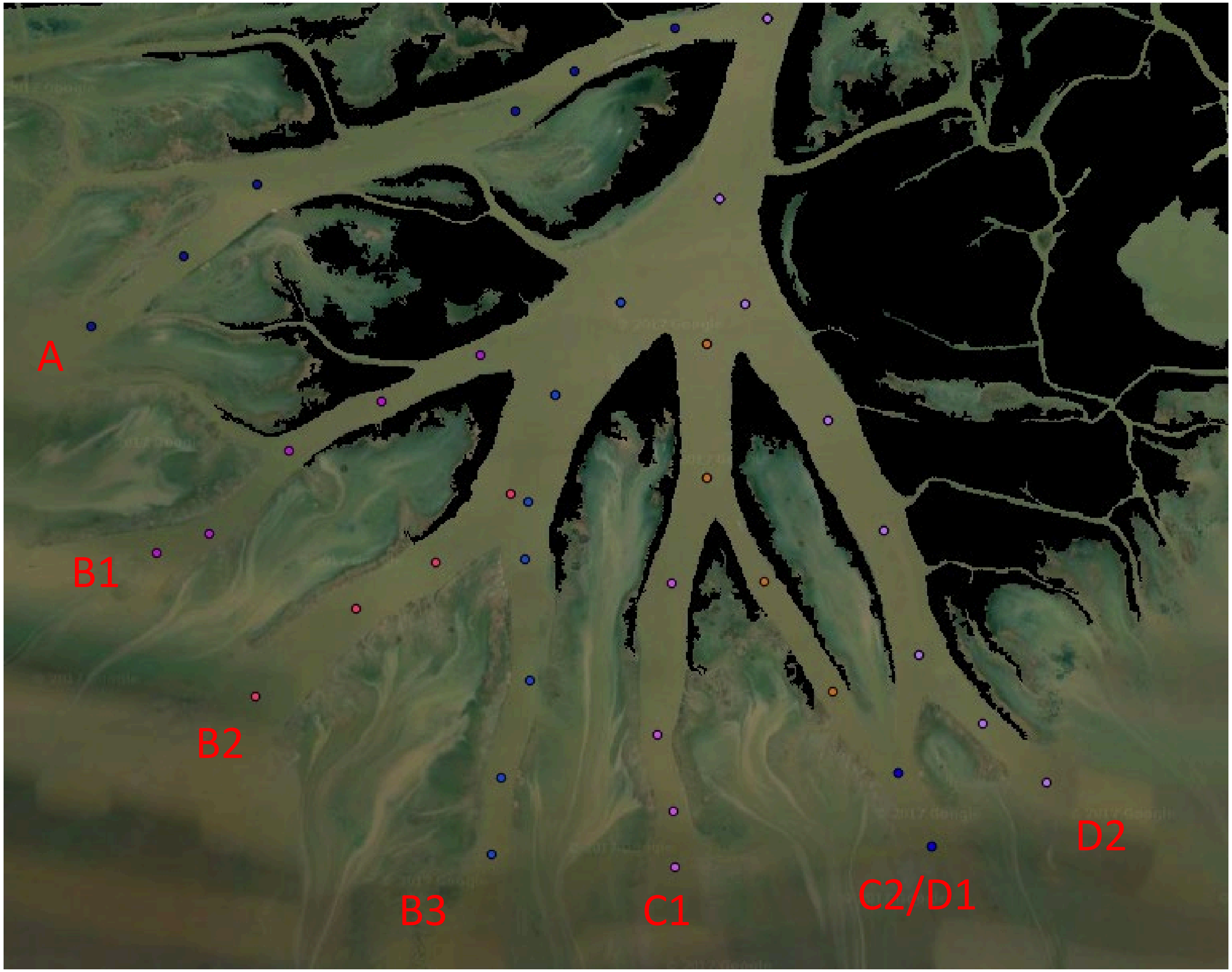
January 3, 2017

Data Format

Lidar Water Surface Elevation Profile Processing

Wax Lake Delta ASO Lidar Channel IDs



The letter denotes the main branch, and the number denotes sub-branch after splitting from the Wax Lake Outlet.

Letters and numbers increase sequentially from West to East.

Dots are channel center line coordinates.

Lidar Profile Plotting Example (Python)

```
# Plot lidar WSE vs. along-channel distance for WLO, flight ID 23.
import pandas
import matplotlib.pyplot as plt
lidar = pandas.read_csv('Wax_Lake_Lidar_Profiles_NAVD88.csv')
index = (lidar['Channel ID'] == 'WLO') & (lidar['Flight ID'] == 77)
plt.plot(lidar['Distance'][index], lidar['WSE (NAVD88)'][index])
plt.xlabel('Along-Channel Distance (m)')
plt.ylabel('WSE (m, NAVD88)')
plt.ylim([0.8, 1.2])
plt.savefig('lidar_profile.png')
```

LAS Files

- Profiles are generated using the .LAS files delivered by the Airborne Snow Observatory (ASO) team. The ASO lidar instrument is a RIEGL LMS-Q1560.
- LAS files contain lidar point cloud information containing X, Y, Z, time, intensity, and other parameters for each lidar return.
- The RIEGL LMS-Q1560 is a dual-channel lidar (only difference is viewing angle), and the two channels are contained in separate LAS files. We combine the dual-channel LAS files into a single lidar point cloud before processing.

Definition of Channel Coordinate System

- Each channel (the Wax Lake Outlet, as well as each channel in the Wax Lake Delta) is defined by a set of manually drawn coordinates.
  - The Wax Lake Outlet was defined by Ke Liu. We use the same channel coordinates in order to match his results. The channel line points are on the West bank of the channel.
  - The Wax Lake Delta branches were defined by Michael Denbina, as no pre-existing channel line was available. These channel line points are in the approximate center of the channel.
- The UTM coordinates of the lidar point cloud are transformed to along-channel (S) and cross-channel (N) coordinates. Lidar returns not on the channel are excluded from the processing.

Water Masking

- Used a water mask derived from UAVSAR backscatter data.
- Drew manual polygons to refine and improve the mask, particularly over the Wax Lake Delta.
- Manual polygons were drawn using Google Earth and the lidar intensity data as reference.
- Lidar returns with (X,Y) coordinates located over areas masked as land are excluded from processing.

Lidar Outlier Filtering

- Of the lidar points remaining after channel coordinate transformation and water masking, we discard any lidar returns with a height outside the bounds of +/- 5 meters (with respect to the EGM96 geoid).
- We apply a median absolute deviation (MAD) filter to the remaining points with a z-score threshold of 2 (e.g., points with one-sided z-score > 2 will be removed). The MAD filter is robust to data that is asymmetrical, which is ideal since we are more likely to observe positive biases than negative biases (due to water vapor effects).
- The remaining points are used to calculate the water profile.

Lidar Profile Generation

- To calculate the profile WSE, we slide a moving window along each channel, and take the moving average of the Z coordinates of the lidar points within the window dimensions.
- For the data in this release, the moving window had a size of 1 km, with 50 m between along-channel profile samples.
- The data can be re-processed with different moving window size, or channel distance sampling, by request.

Water Level Gauge Filtering

Water Level Gauge Locations

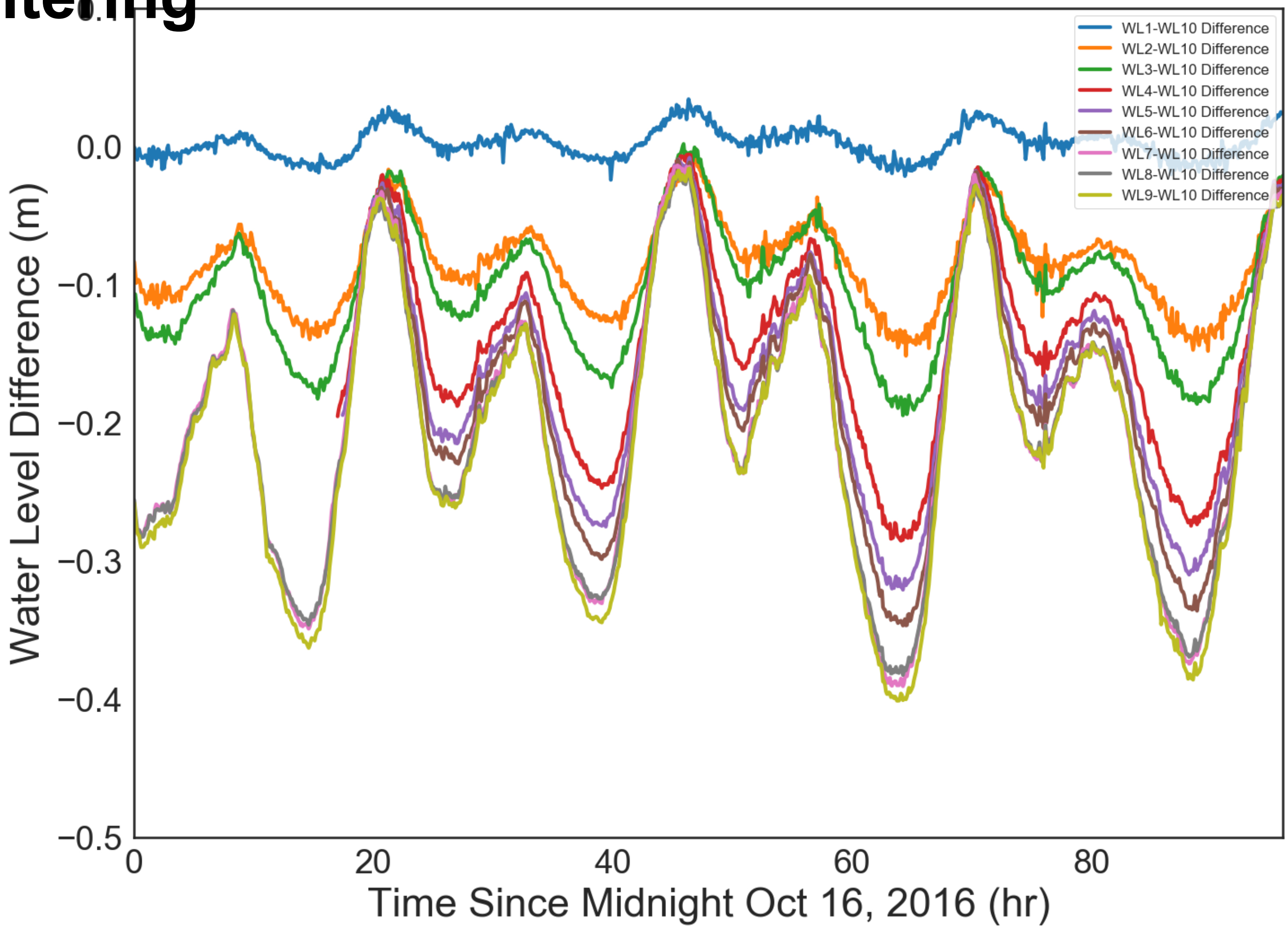
Gauge Data Plotting Example (Python)

```
# Plot gauge water level vs. time for gauge WL1 (near Calumet).
import pandas
import matplotlib.pyplot as plt
gauge = pandas.read_csv('Wax_Lake_Filtered_Gauge_Data_NAVD88.csv')
index = (gauge['Gauge ID'] == 'WL1')
time_adjusted = (gauge['UTC Time'] + (gauge['Day'] - 14)*86400)/3600
plt.plot(time_adjusted[index], gauge['WSE (NAVD88)'][index])
plt.xlabel('Hours After 12:00 AM October 14, 2016')
plt.ylabel('WSE (m, NAVD88)')
plt.savefig('gauge_profile.png')
```

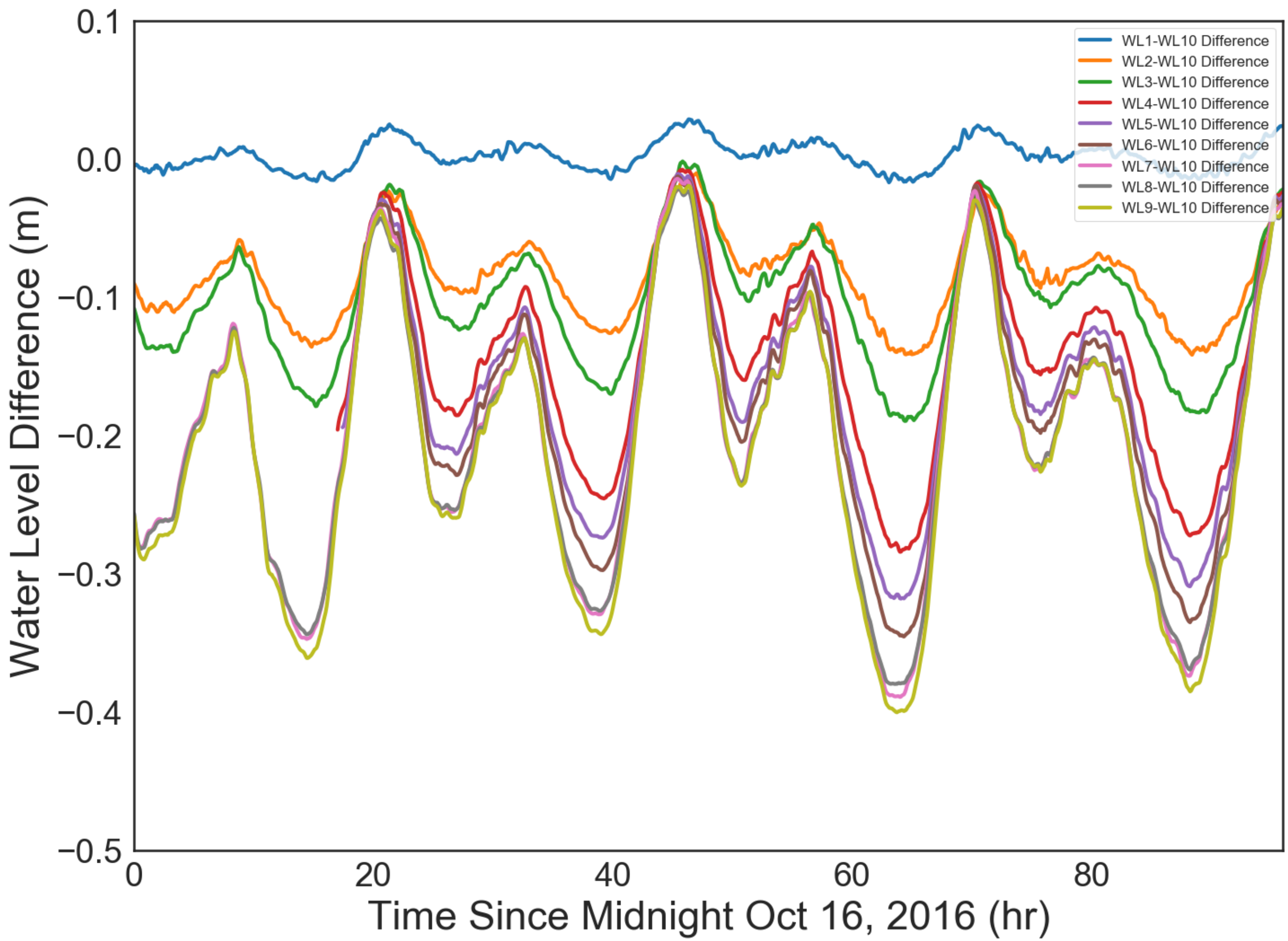
Water Level Gauge Filtering

- Some of the gauges needed to be moved part way through the experiment. Therefore, some water level gauges cover a smaller range of time than others.
- The water level gauge data exhibited some small jitters in water level, generally less than 1 cm.
- To mitigate this, we smoothed the data in time using a 3rd order Savitzky-Golay filter with a window of 11 samples (55 minutes).
- On the next two slides, the difference in water level between the various gauges (using WL10, the most upstream gauge, as reference) are shown for the unfiltered and then filtered data.

Water Level Gauge Differences, Before Filtering



Water Level Gauge Differences, After Filtering



Lidar and Gauge Data Absolute Height Correction

Absolute Height Correction (1)

- Both the lidar profiles and gauge data were originally biased with respect to the true water level.
  - Height bias of lidar data varies for different acquisition dates and aircraft altitudes, and is likely due to a combination of IMU/GNSS errors, potential errors in the intensity-based range correction of the lidar data, and geophysical error sources such as water vapor.
  - Water level gauges measure the gauge height, and are not referenced to any true vertical datum. The offset between each gauge height and the desired vertical datum therefore needed to be estimated.

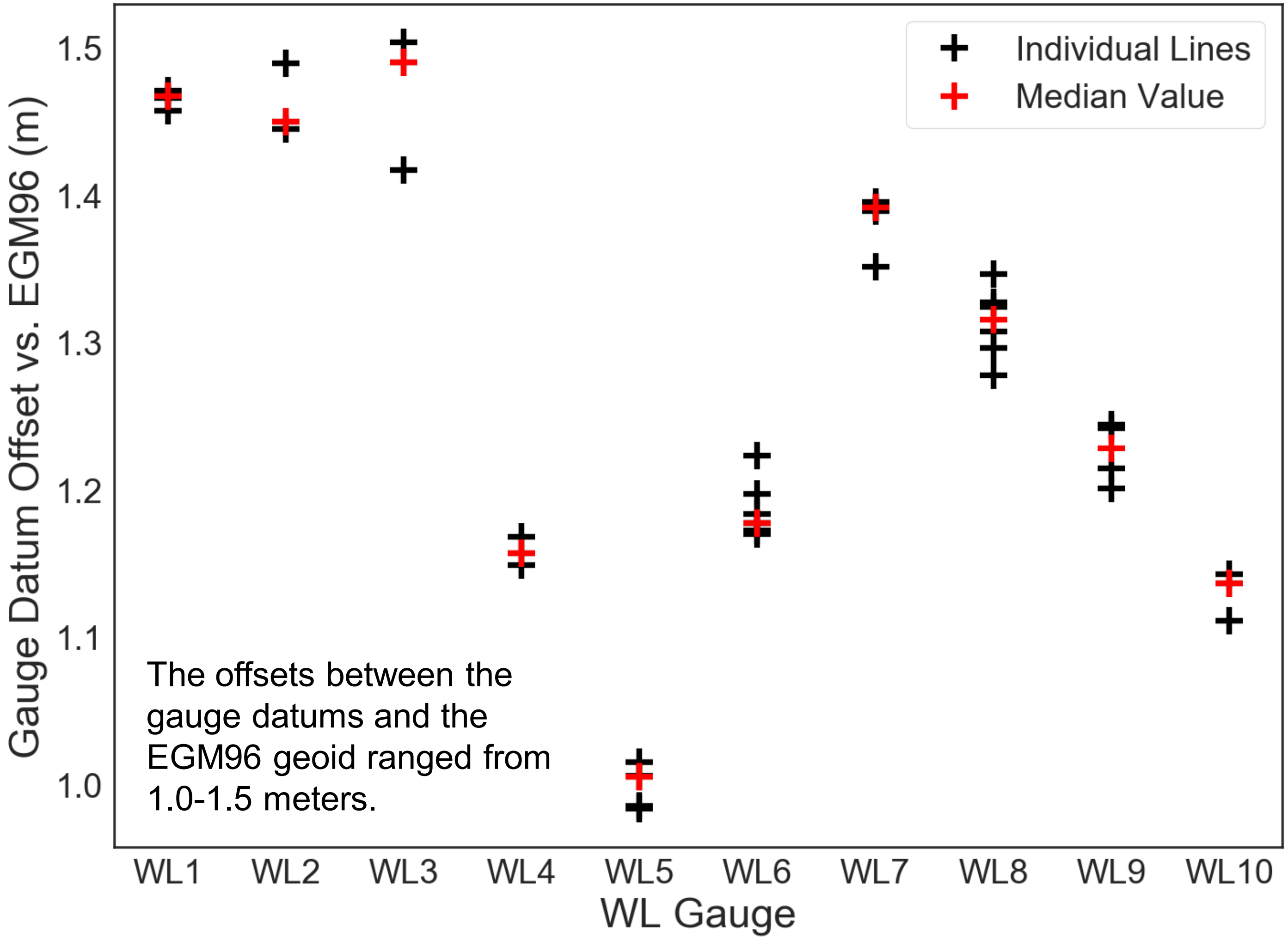
Absolute Height Correction (2)

- We jointly estimate height correction values for the lidar data and the water level gauges using an iterative approach.
- The USGS station at Calumet is used as an absolute water level height reference. All of the height corrections applied to the data are ultimately based on the USGS Calumet water level.
- Five lidar flight lines (out of 32) were manually flagged and excluded from the height correction process. These flight lines are not included in the released data. Later in this slide package, stats comparing the flagged and non-flagged data are shown.

Absolute Height Correction (3)

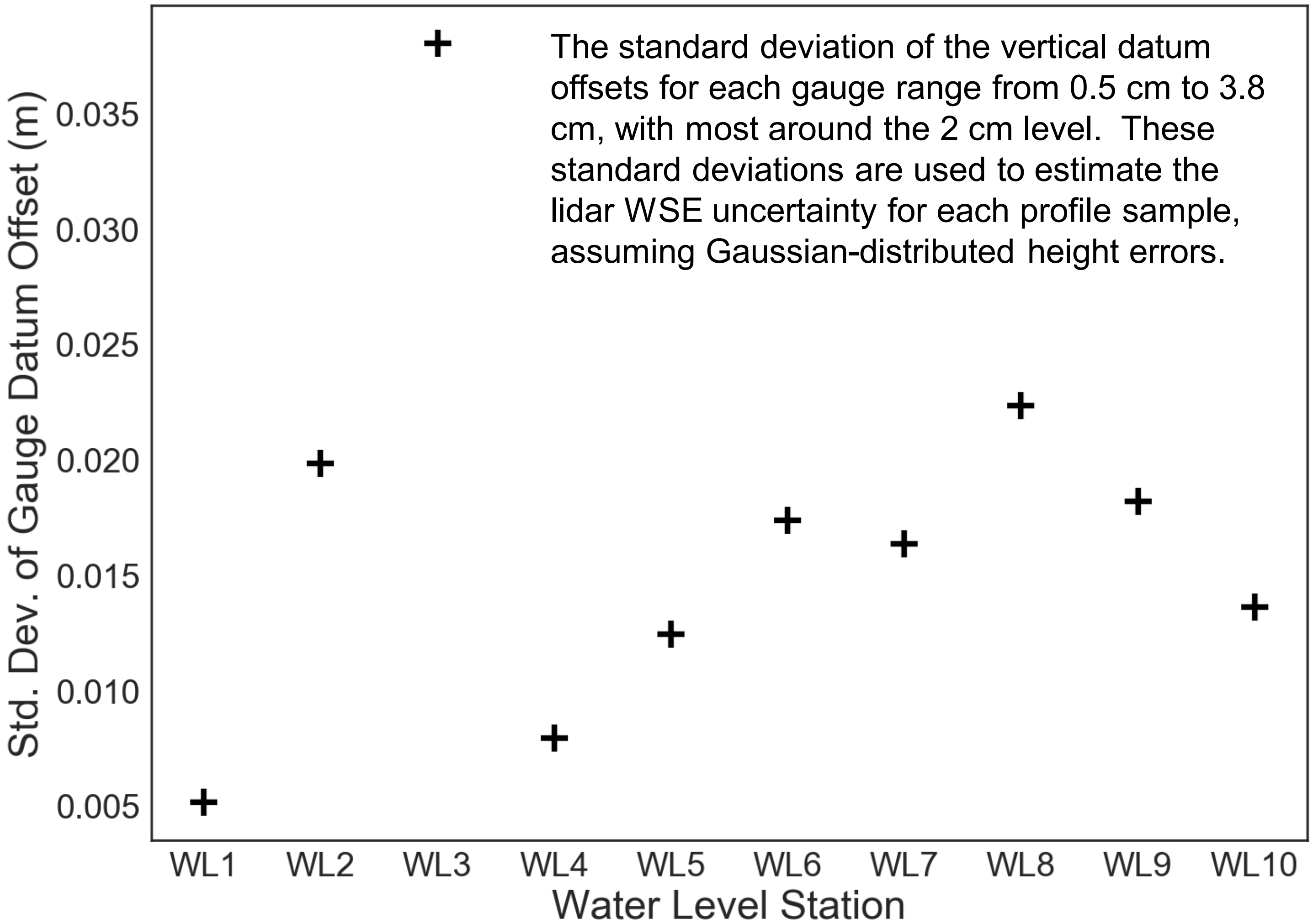
- **Step 1**: Use the Calumet USGS water level to height correct all lidar flight lines which overlap with the station.
- **Step 2**: Use corrected lidar flight lines to estimate the gauge vs. vertical datum offset for the first gauge within the coverage area of the corrected lidar data. The gauge offset is taken as a median of the gauge offsets estimated from each individual lidar flight line. We use the median in order to reduce the effect of outliers considering the small sample size.
- **Step 3**: Use the corrected gauge to correct any uncorrected lidar flight lines which overlap with the gauge.
- **Step 4**: Return to step 2, estimating vertical datum offsets for the next gauge, repeating until all gauges have had offsets estimated, and all lidar data which overlaps with any of the gauges or Calumet has been corrected.

Estimated Water Level Gauge Offsets

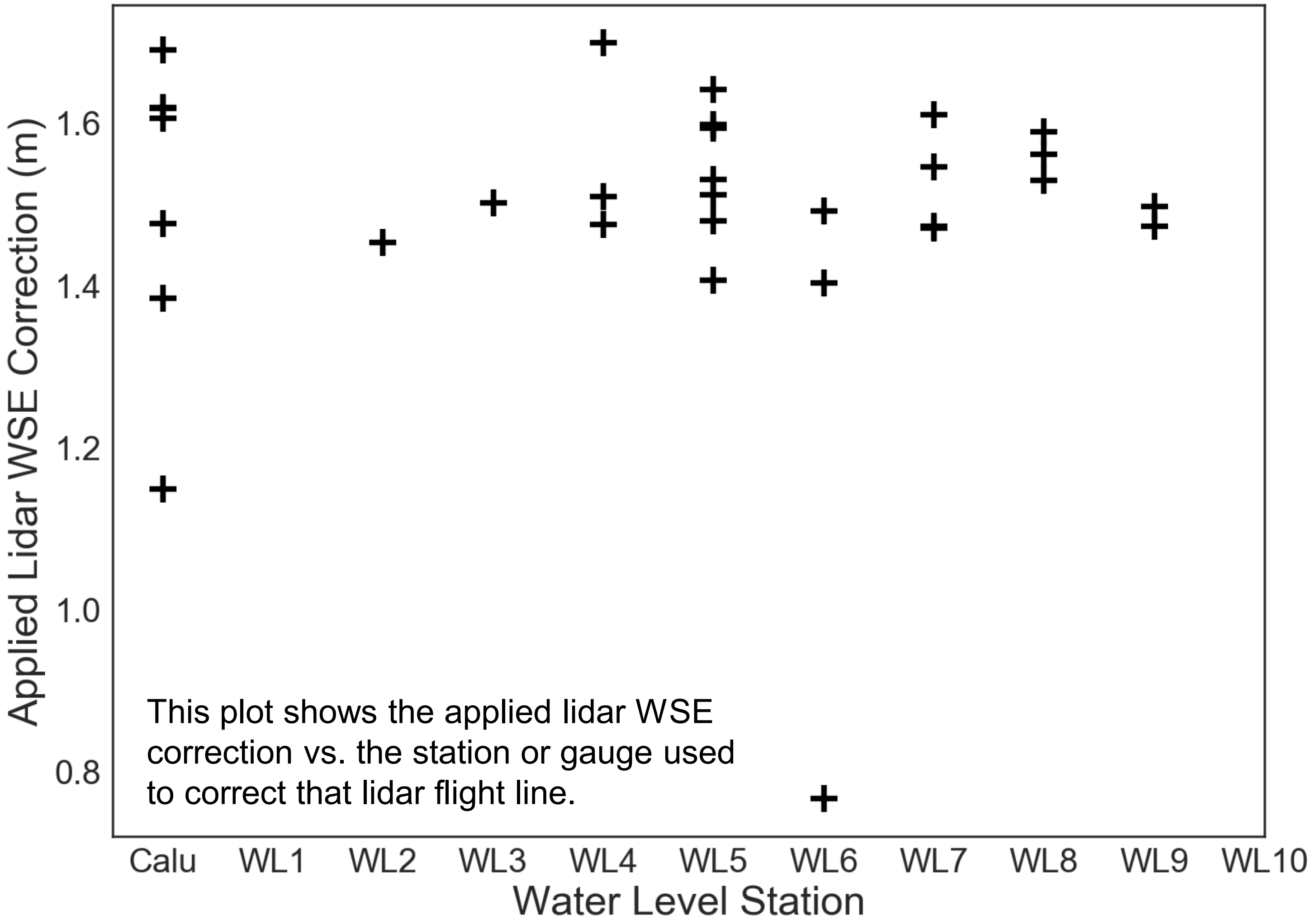


The offsets between the gauge datums and the EGM96 geoid ranged from 1.0-1.5 meters.

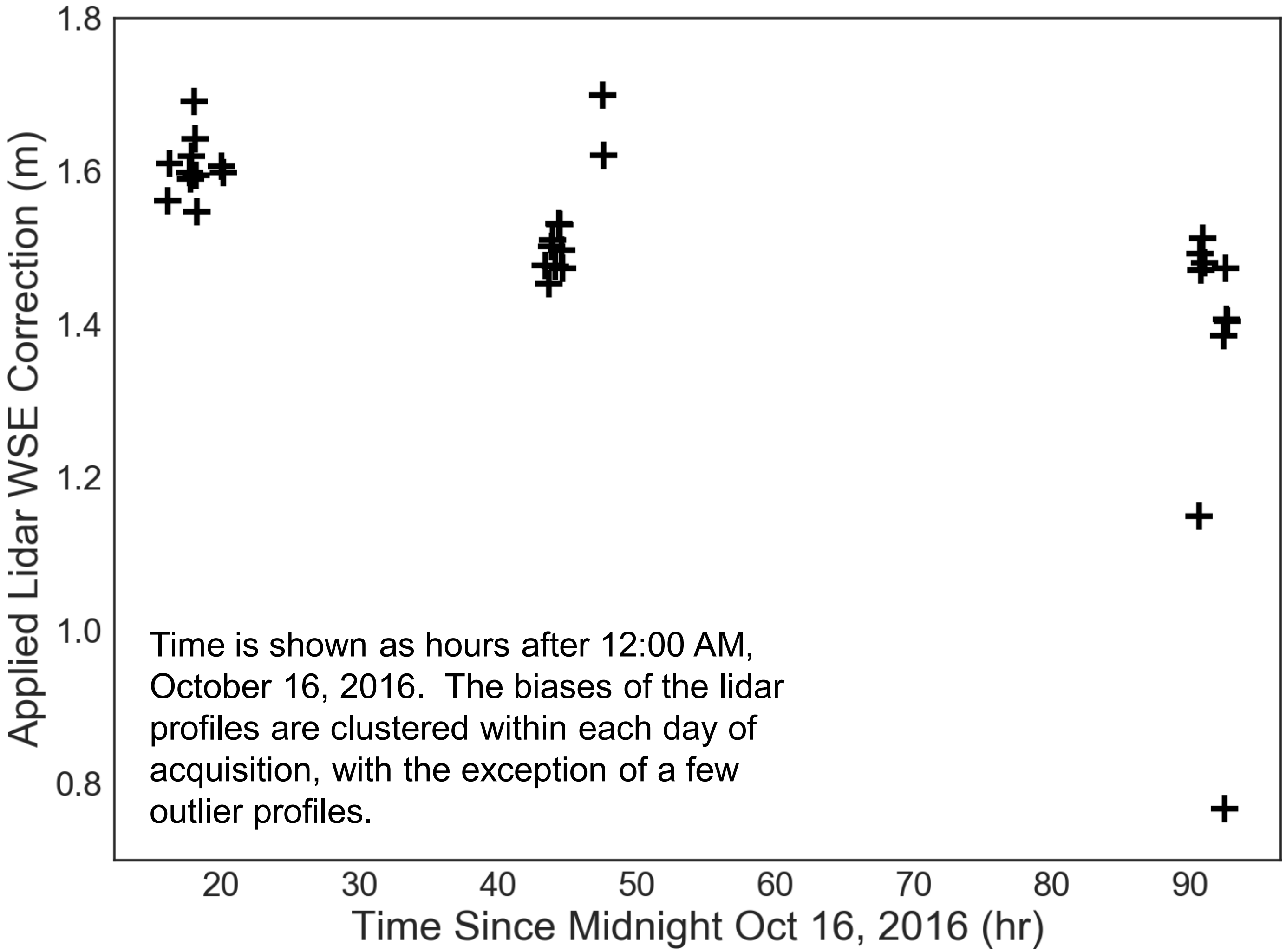
Water Level Gauge Offset Standard Deviation



Lidar Profile Corrections vs. Station



Lidar Profile Corrections vs. Time



Absolute Height Correction (4)

- Note that each lidar flight line is corrected using the same bias, even when it overlaps with multiple channels and was therefore used to generate multiple profiles. This was done in order to apply the height corrections in a systematic way, and because we expect that the error sources that cause the height bias are relatively stable within a given flight line.
- The following slides compare the lidar data with the gauge data. When calculating the errors, lidar data is not compared with the gauge used to correct it—it is only compared to other gauges which also overlap the lidar data. (If we compared the lidar data to the gauge used to correct it, the error would always be zero.)

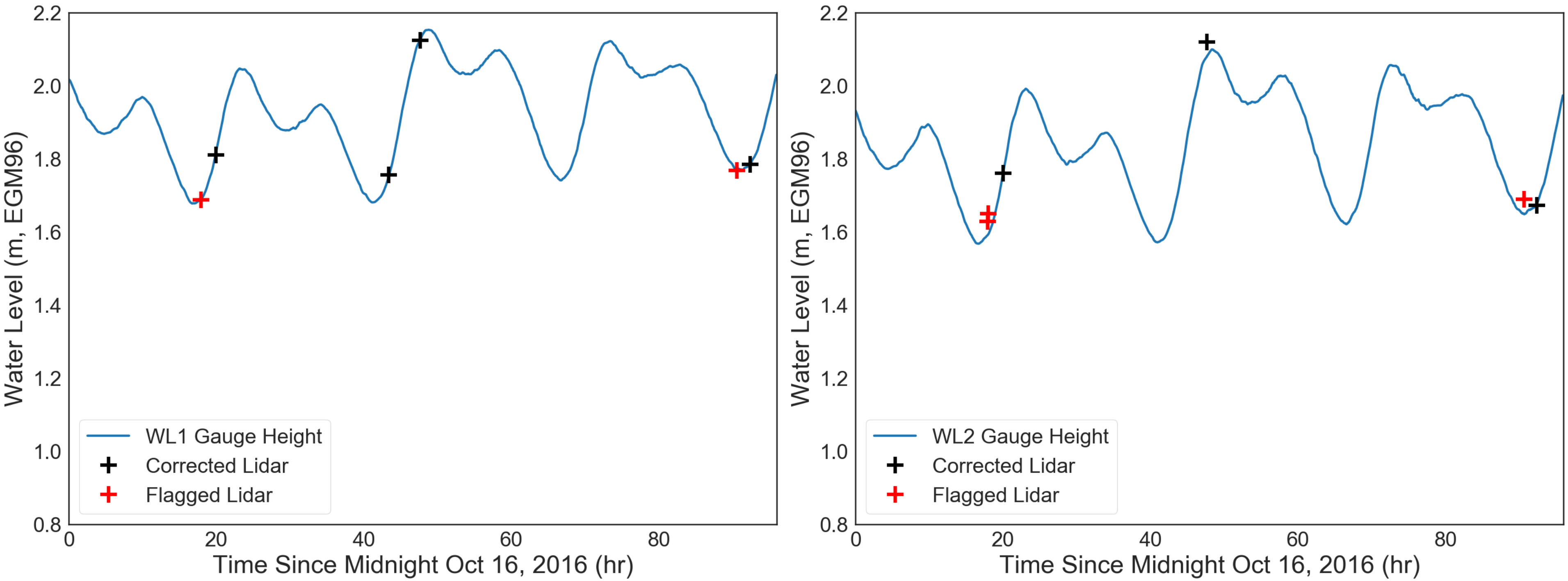
Overall Error Statistics (Incl. All Data)

Gauge ID	Mean Diff. (cm)	Std. Dev. (cm)	RMS (cm)	Number of Profiles
WL1	-0.19	0.42	0.46	6
WL2	2.84	2.27	3.64	6
WL3	1.22	4.74	4.89	6
WL4	2.25	3.81	4.42	6
WL5	1.42	4.29	4.52	8
WL6	1.09	1.76	2.07	13
WL7	1.80	3.93	4.32	14
WL8	-2.67	10.02	10.36	16
WL9	-13.82	27.44	30.73	10
WL10	0.18	1.83	1.84	6
ALL DATA	**-1.17**	**11.88**	**11.94**	**91**

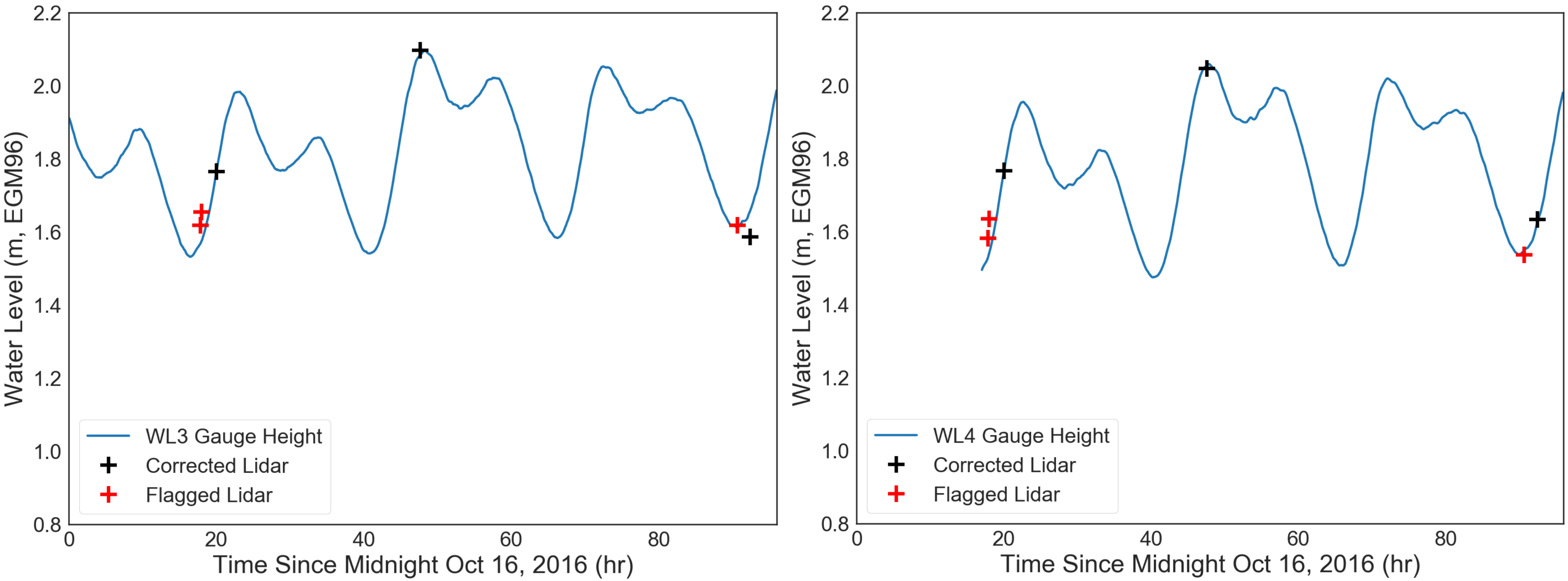
Overall Error Statistics (Excl. Flagged Data)

Gauge ID	Mean Diff. (cm)	Std. Dev. (cm)	RMS (cm)	Number of Profiles
WL1	-0.15	0.52	0.54	4
WL2	1.15	1.98	2.29	3
WL3	-1.99	3.80	4.29	3
WL4	0.09	0.79	0.80	3
WL5	-0.61	1.24	1.38	5
WL6	0.84	1.74	1.93	11
WL7	-0.42	1.25	1.32	10
WL8	-0.25	2.25	2.26	12
WL9	-0.13	1.94	1.95	8
WL10	-0.62	1.36	1.50	3
ALL DATA	**-0.18**	**1.96**	**1.97**	**62**

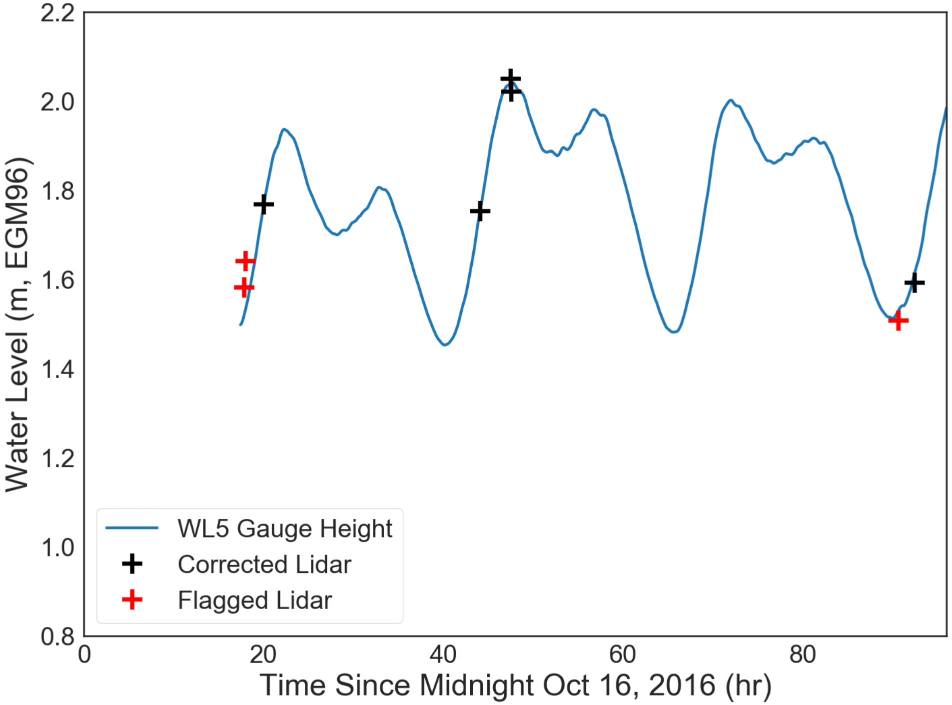
Lidar vs. WL1 and WL2 Gauge Data

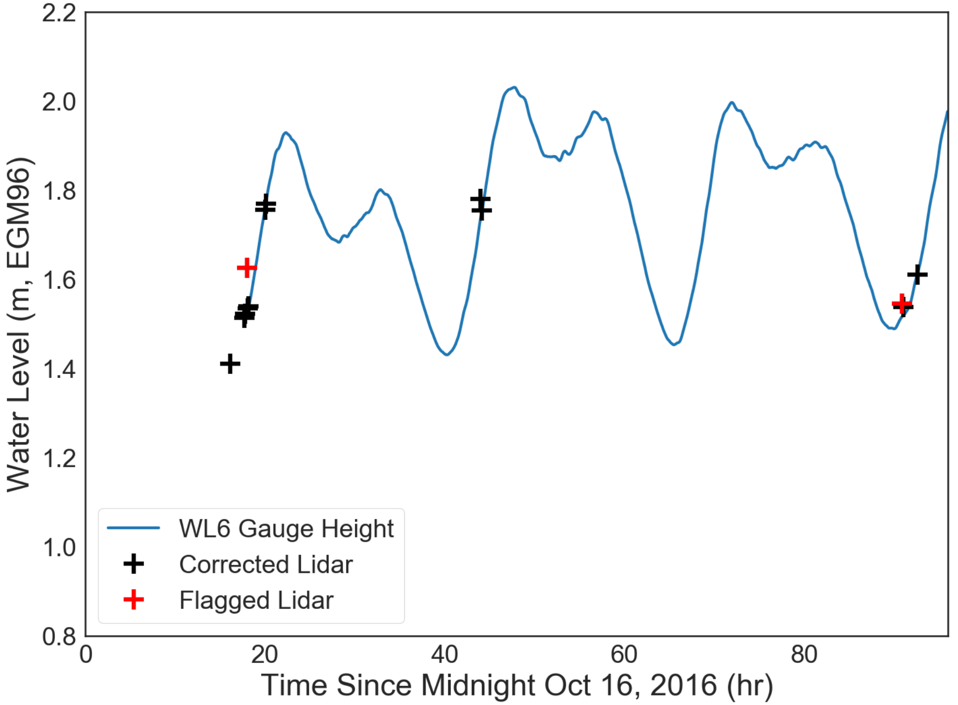


Lidar vs. WL3 and WL4 Gauge Data

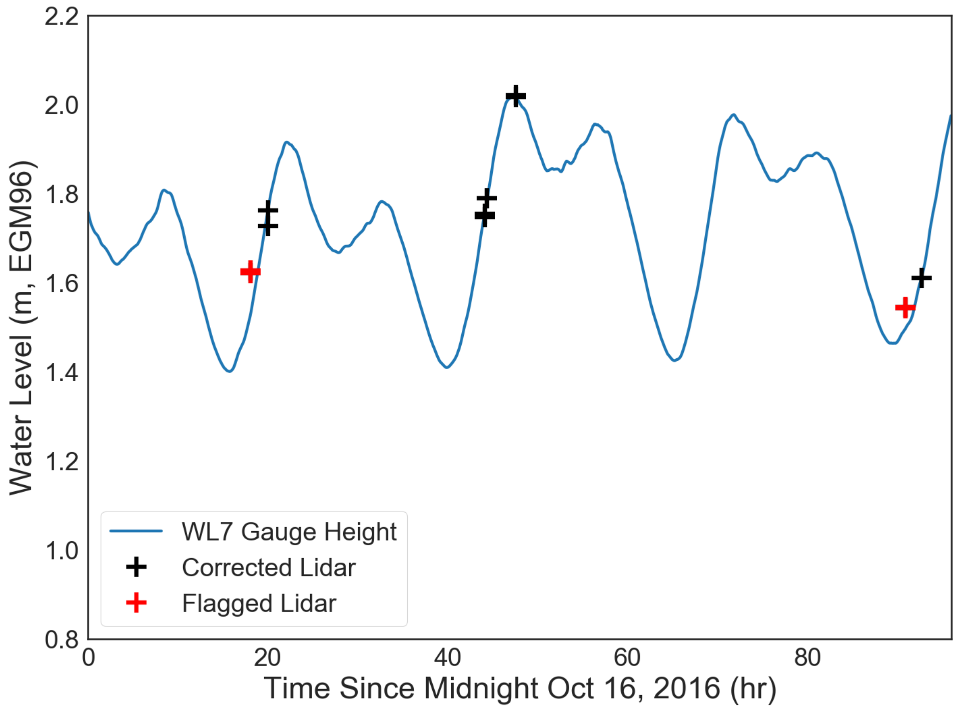


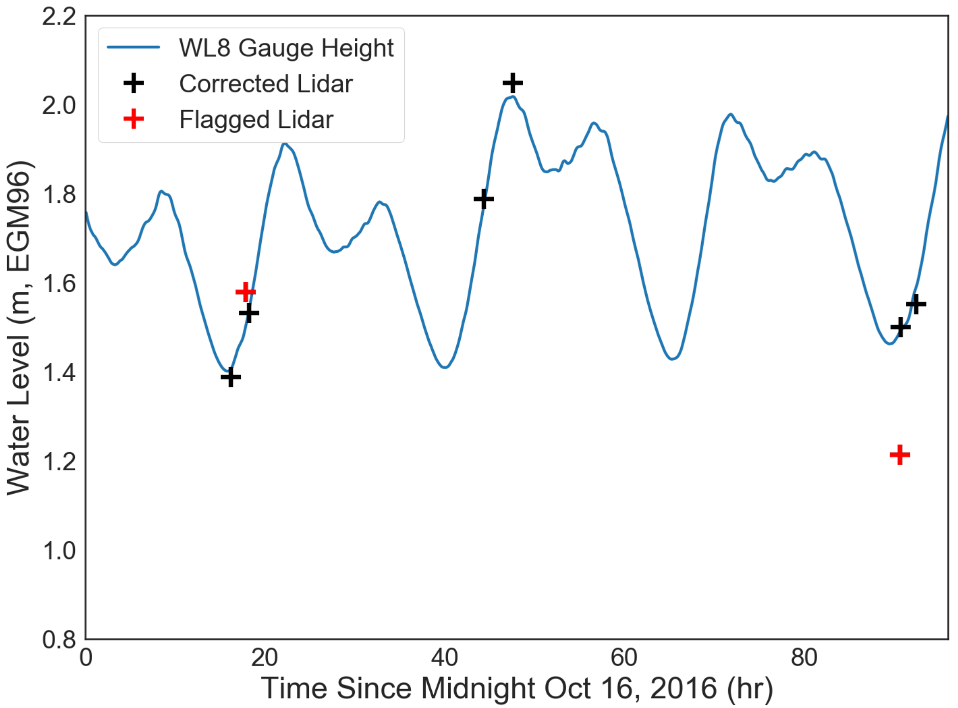
Lidar vs. WL5 and WL6 Gauge Data



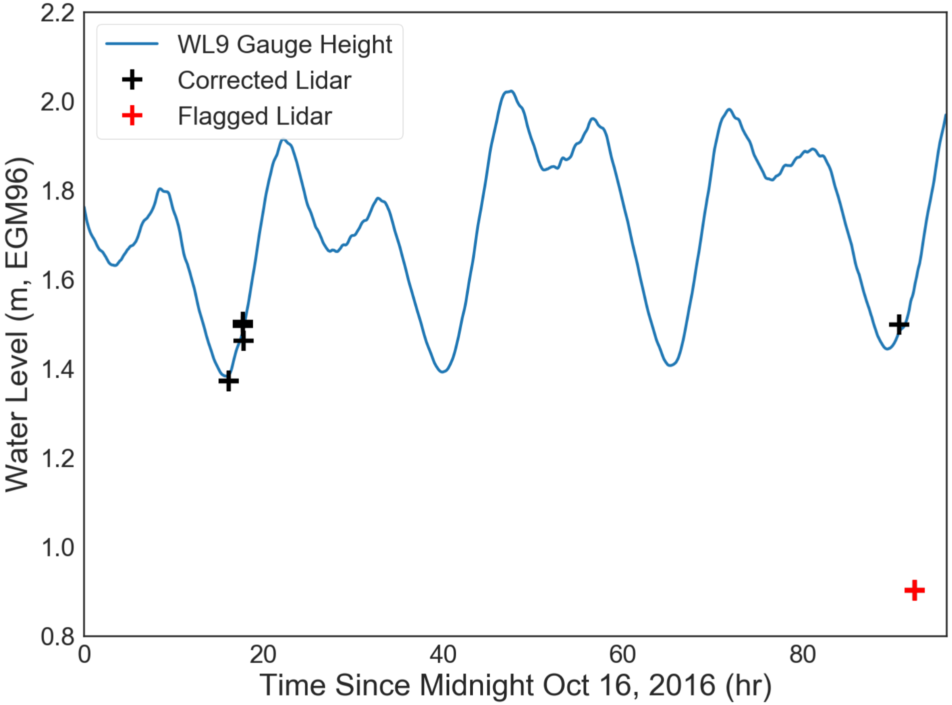


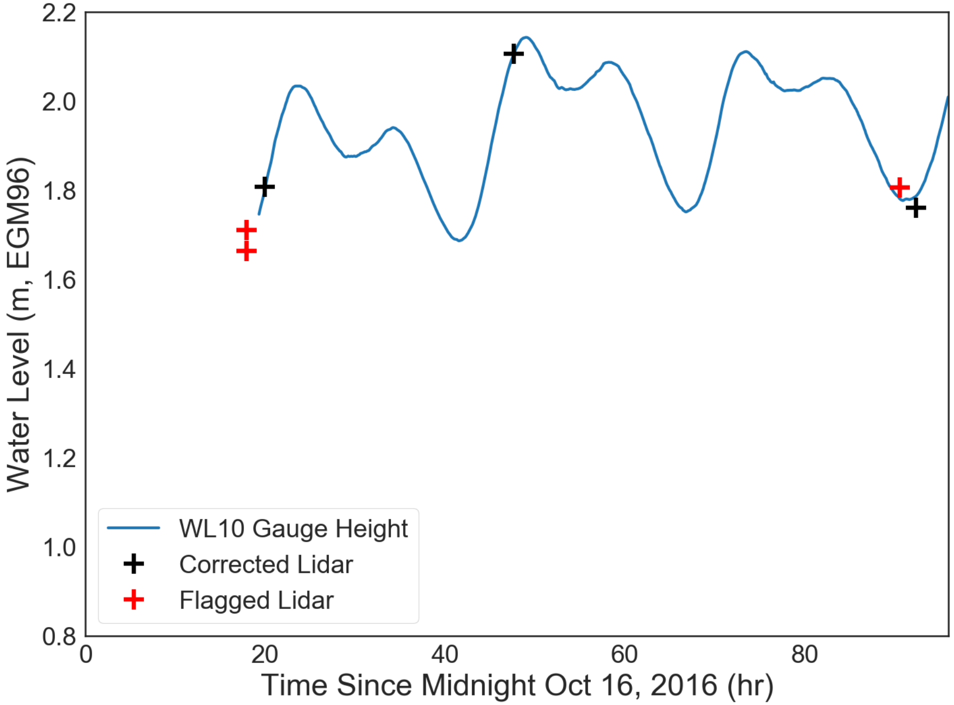
Lidar vs. WL7 and WL8 Gauge Data





Lidar vs. WL9 and WL10 Gauge Data





Summary

Summary

- Water surface elevation (WSE) data released for Wax Lake Outlet and channels in the Wax Lake Delta.
  - WSE profiles from 27 lidar flight lines.
  - Stationary WSE data from 10 in situ gauges.
- WSE biases were corrected using Calumet USGS station and an iterative procedure to estimate height offsets for each lidar flight line and water level gauge.
- Lidar-derived WSE profiles include uncertainty in the form of an estimated standard deviation for each profile sample. Uncertainty was estimated assuming Gaussian-distributed height errors, based on the variance of the water level gauge offsets and the lidar height returns.

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