AQRP Monthly Technical Report

PROJECT TITLE	Impact of large-scale circulation patterns on surface ozone concentrations in Houston-Galveston-Brazoria (HGB)	**PROJECT #**	14-010
PROJECT PARTICIPANTS	Texas A&M University at Galveston	**DATE SUBMITTED**	6/8/2015
REPORTING PERIOD	**From:** May 1, 2015 **To:** May 31, 2015	**REPORT #**	5

A Financial Status Report (FSR) and Invoice will be submitted separately from each of the Project Participants reflecting charges for this Reporting Period. I understand that the FSR and Invoice are due to the AQRP by the 15th of the month following the reporting period shown above.

Detailed Accomplishments by Task *(Include all Task actions conducted during the reporting month.)*

Task 1: On the basis of the former analysis, we tried other metrics of ozone to quantify the impacts of Bermuda High on ozone (Figure 1). We also tried other indices such as the Bermuda High intensity index, the number of frontal systems, ENSO, and Arctic Oscillation (AO) to capture the interannual variations of HGB ozone (Figure 2).

Task 2: On the basis of the predictors chosen in Task 1 (BH-Lon, BHI1, BHI2, PDSI, AO and HGB mean temperature), we use multiple linear regression (MLR) to predict the interannual variations of HGB ozone (Figure 3-5).

Task 3: The simulation of surface ozone using GEOS-Chem was conducted, and preliminary reanalysis has been done (Figure 6-8).

Preliminary Analysis

Figure 1 shows the time series of monthly mean and median total ozone over HGB, and mean and median background ozone over HGB. The background ozone data were provided by TCEQ. Median total ozone over HGB is calculated as the mean value of median monthly ozone of all the sites. Ozone enhancement is calculated as the difference between mean/median total ozone and mean/median background ozone. The median ozone is relatively lower than the mean, indicating the median value is less sensitive to extremely high ozone events. Monthly mean background ozone shows very similar interannual variations with mean total ozone from June to September, and their correlations are highest in June (r=0.97).

Table 1 summarizes the correlation coefficients between detrended ozone metrics (total ozone and background ozone is detrended, while ozone enhancement is not detrended) and BH-Lon. In June and July, when the correlations between total ozone and BH-Lon are stronger, there are also significant correlations between background ozone and BH-Lon. In August and September, however, there are no significantly positive correlations between BH-Lon with either total ozone or background ozone. Since the correlation coefficients between BH-Lon and mean total ozone are higher than other metrics of ozone from June to September (Table 1), we use mean total ozone in MLR in the later analysis.

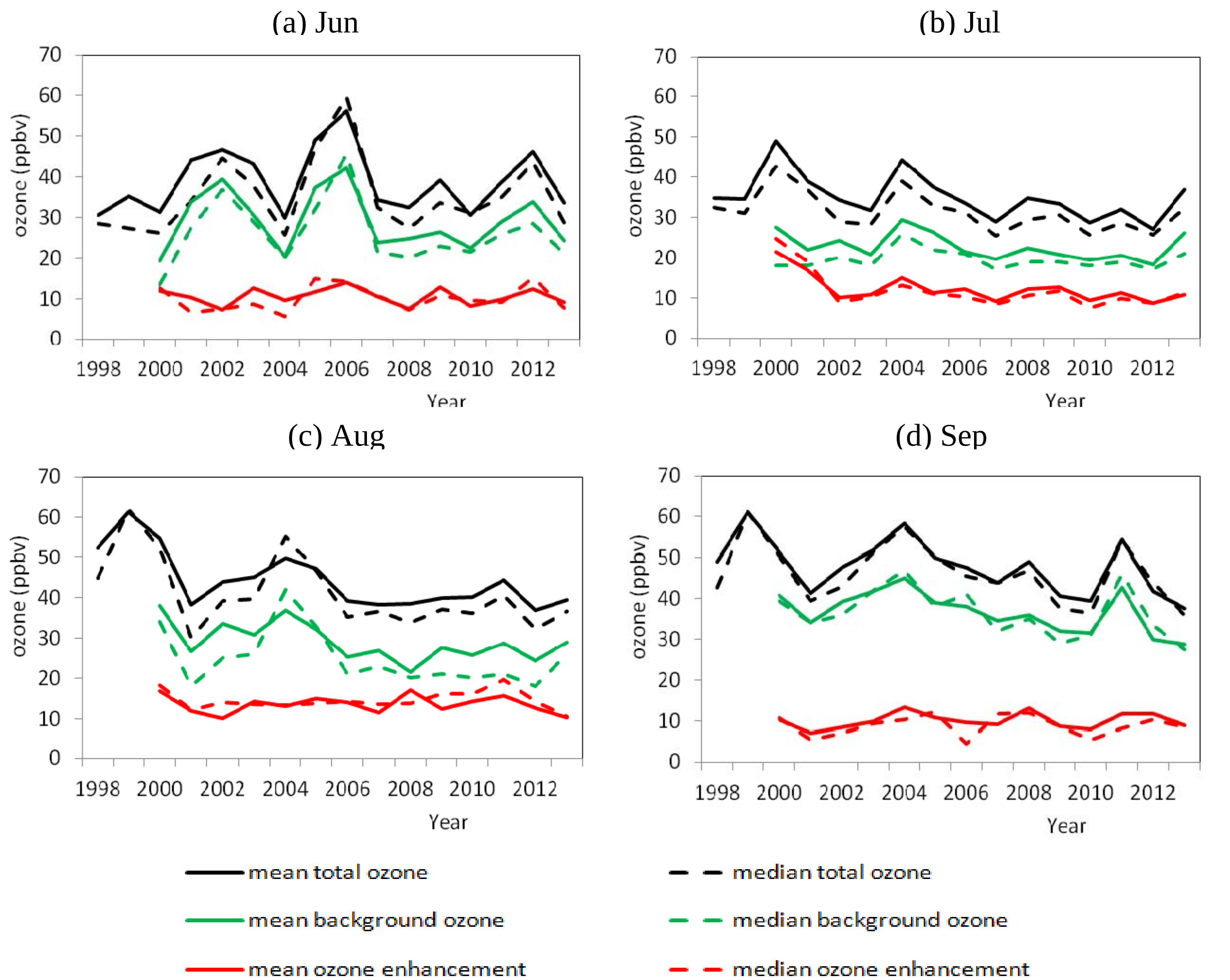

Figure 1. Time series of mean and median total ozone, mean and median background ozone and ozone enhancement.

Table 1. Correlation coefficients (r^2) between BH-Lon and different metrics of ozone. Bold numbers indicate significant correlations ($p<0.1$).

r^2		Jun	Jul	Aug	Sep
total ozone (detrended)	mean	**0.49**	**0.58**	0.20	0.20
	median	**0.35**	**0.55**	0.15	0.21
background ozone (detrended)	mean	**0.30**	**0.28**	0.00	0.10
	median	0.19	0.22	0.06	0.06
ozone enhancement	mean	**0.29**	**0.44**	**0.40**	0.12
	median	0.23	-0.11	0.01	0.00

Besides BH-Lon and PDSI, we also tried other indices including the intensity indices of BH and the number of frontal systems, AO, and regional mean temperature. BHI1 is adopted from Zhu et al. (2013), which is defined as the mean SLP difference between two different places (black box 1 and 2 in Figure 2): the Gulf of Mexico (25.3°–29.3°N, 92.5°–87.5°W) and the southern Great Plains (35°–39°N, 105.5°–100°W). According to Zhu et al., SLP over the two black boxes 1 and 2 correlates well with LLJ (Figure 2), which captures the strength of the southerly flow along the west edge of the Bermuda high. BHI2 is an index developed by this project. BHI2 is defined as the mean SLP difference between the red box over northeast Texas (31°-36°N, 91°-96°W) (box 3 in Figure 2) and the box 1 in the Gulf of Mexico. Because BHI2 is defined as the SLP difference between two different latitudes, the intention of BHI2 is to capture the strength of meridional winds over HGB which are expected to influence ozone concentrations. Previous studies have shown that both easterly and northerly clusters are favorable circulation patterns for the exceedance of the 8-h ozone standard over HGB (Ngan et al., 2011). BHI1 is expected to represent the strength of northerly clusters, while BHI2 is for the easterly circulation patterns.

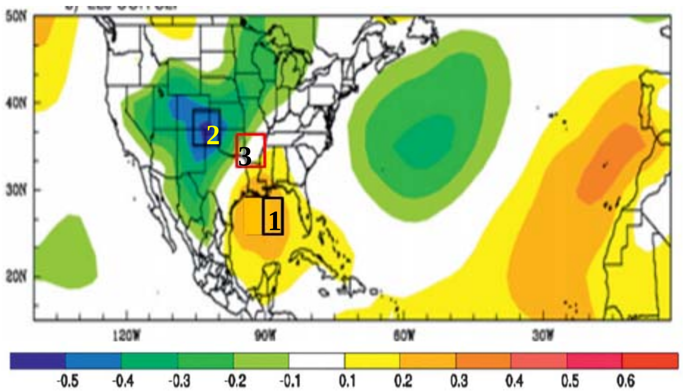

Figure 2. The summer interannual correlation coefficients of SLP with the LLJ (Zhu et al., 2013). The boxes 1, 2, 3 indicate the regions over which mean SLP is used to define BHI1 and BHI2.

We obtained the data of frontal system numbers for June-September from 2005 to 2013 at the site Sugar Land Regional Airport from the NOAA website. There is a moderate correlation between frontal system number and HGB ozone in August (r=0.35) but not for other months. However, when frontal system number is included in MLR, no improvements are shown in August. Thus, we excluded frontal system number in the final MLR. We tried monthly mean observed maximum temperature (T_{max}) over HGB and monthly mean reanalysis temperature in MLR separately. Since the predictive R^2 shows more improvements when reanalysis monthly mean temperature over HGB is included, we choose reanalysis temperature rather than observed T_{max} in MLR.

Furthermore, to elucidate any connection of the BH-Lon variability with known climate modes, we examined the relations of BH-Lon with ENSO and AO on a longer time scale (1991-2010). The AO and Bivariate ENSO time series were obtained from NOAA (http://www.esrl.noaa.gov/psd/data/climateindices/list/). We tested the correlation of BH-Lon with the ENSO index for the same month as well as up to a 2-month lag. The only significant correlation is found between the BH-Lon of June and the Bivariate ENSO index in April and that correlation is only moderate. This suggests that ENSO may not play a significant role in affecting the variability of HGB ozone and therefore it is not included in the MLR. However, there is a significantly negative correlation between AO and HGB ozone in August. Thus, AO is included in the final MLR.

Finally, we applied a multiple linear regression (MLR) model to construct the statistical relationship between HGB ozone and the six indices (BH-Lon, PDSI, BHI1, BHI2, AO and HGB temperature). Time series of mean total ozone over HGB and MLR-predicted ozone are shown in Figure 3. The correlation coefficients (R^2) for these four months are all higher than 0.65. The extremely high and low ozone events are also well captured by MLR-predicted ozone.

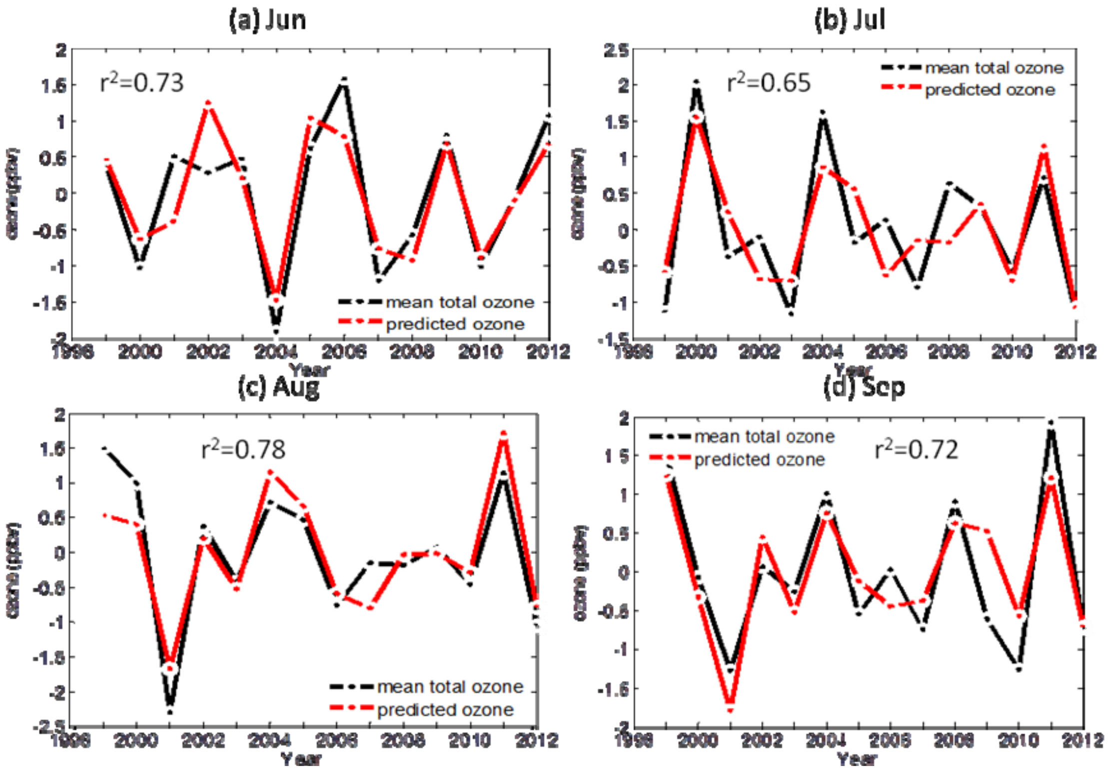

Figure 3. Time series of mean total ozone over HGB and predicted ozone with the indices.

The regression equations for each month are as follows,

$$y_{Jun} = 0.43 \times x_1 - 0.10 \times x_2 - 0.45 \times x_3 + 0.16 \times x_4 - 0.19 \times x_5 + 0.68 \times x_6$$

$$y_{Jul} = 0.60 \times x_1 + 0.08 \times x_2 - 0.21 \times x_3 - 0.03 \times x_4 - 0.30 \times x_5 + 0.09 \times x_6$$

$$y_{Aug} = 0.64 \times x_1 + 0.87 \times x_2 - 0.87 \times x_3 - 0.43 \times x_4 - 0.32 \times x_5 - 0.19 \times x_6$$

$$y_{Sep} = 0.50 \times x_1 - 0.14 \times x_2 - 0.50 \times x_3 - 0.23 \times x_4 + 0.32 \times x_5 + 0.15 \times x_6$$

where y represents detrended mean total ozone; x1 represents BH-Lon; x2 and x3 represent BHI1 and BHI2; x4 represents PDSI; x5 represents AO; x6 represents HGB mean reanalysis temperature.

Figure 4 shows the improvements of correlation coefficients (R^2) in MLR when the predictors are added successively. In June and July, BH-Lon is the most important predictor, while BHI1 and BHI2 in combination play a more important role in August and September. AO is important for July-September, and the largest effect of AO on the prediction R^2 is at 15% in September. However, the mechanism by which HGB ozone correlates with AO has not been determined. We also examined the correlations between individual predictors for each month (table not shown), and found that temperature and PDSI are negatively correlated in each month, which is expected given the dependence of PDSI formulation on temperature. We will conduct statistical tests on the significance of individual predictors for each month in the subsequent report.

Figure 5 shows the correlation coefficients (R^2) between MLR-predicted ozone and detrended mean total ozone at individual HGB sites. Since the predictors used in the MLR are not site specific, the MLR-predicted ozone is meant to represent the HGB-mean ozone rather than ozone at site levels. However, we can still find significant correlations at a number of sites, indicating those sites may be representative of regional ozone than others. As expected, R^2 on the sites near Houston Ship Chanel is relatively lower, probably because of the influence of local emissions not included in MLR. We will test the impact of site-specific predictors in MLR in the subsequent report.

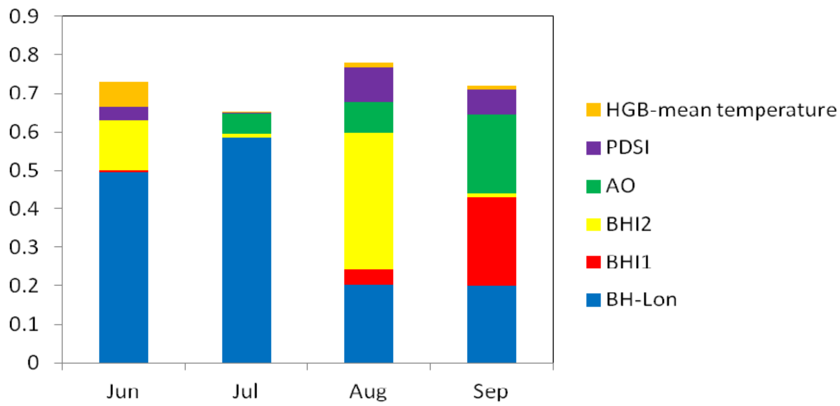

Figure 4. Improvements of R^2 in MLR when individual predictors are added in sequence.

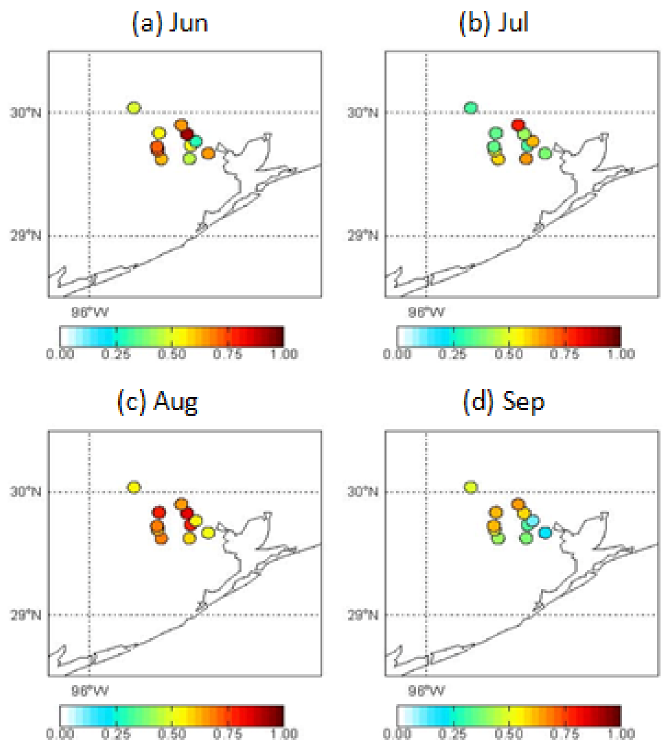

Figure 5. Correlation coefficients (R^2) between regressed ozone and detrended mean total ozone on HGB sites. (Only sites with full observations from 1998 to 2013 are used to calculate R^2)

GEOS-Chem simulations have been conducted for June from 2004 to 2012 using the GEOS-5 assimilated meteorology and EPA NEI inventory with year-to-year changes of emissions. The model resolution is 0.5° x 0.667°. Figure 6 shows the observed and simulated surface ozone in June from 2004 to 2012. The main model bias is the overestimation of surface ozone over Galveston and Brazoria coastal regions, which have lower local emissions. This overestimation is more obvious in the year 2007, 2008 and 2010 (Figure 7). Compared to observed ozone, the simulated ozone has a weaker interannual variation. Figure 8 shows the time series of simulated

HGB mean surface ozone and BH-Lon in June. There is a positive correlation between simulated ozone and BH-Lon, but the correlation coefficient is lower than that between the observed ozone and BH-Lon.

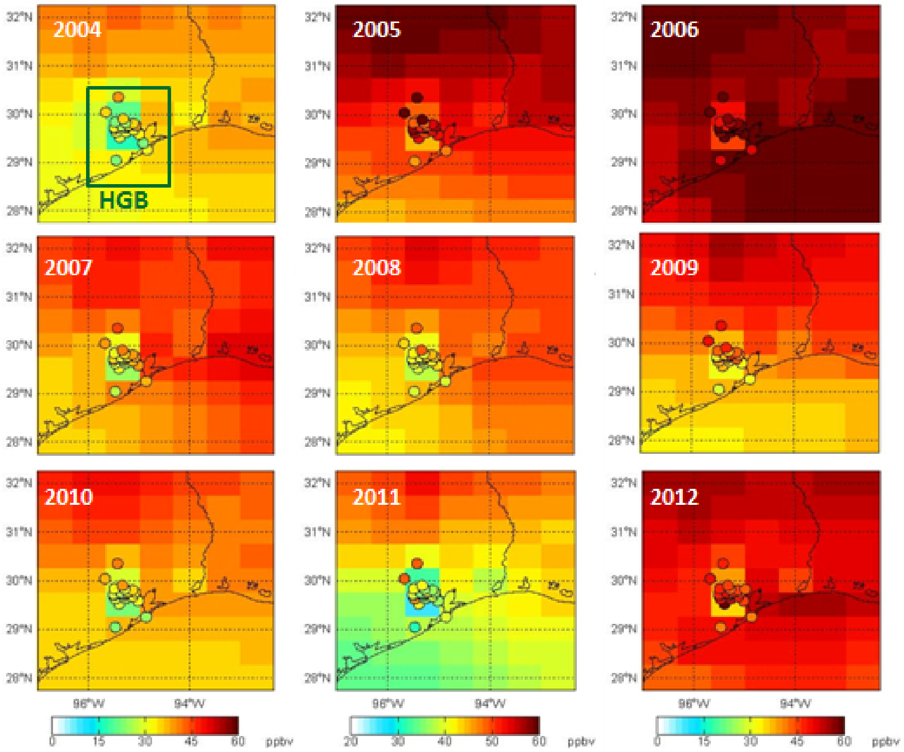

Figure 6. Observed surface ozone (filled circles) and GEOS-Chem simulated surface ozone over HGB region in June.

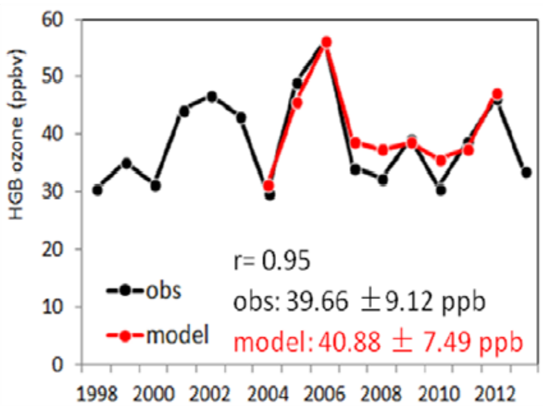

Figure 7. Time series of observed and simulated HGB mean surface ozoen in June.

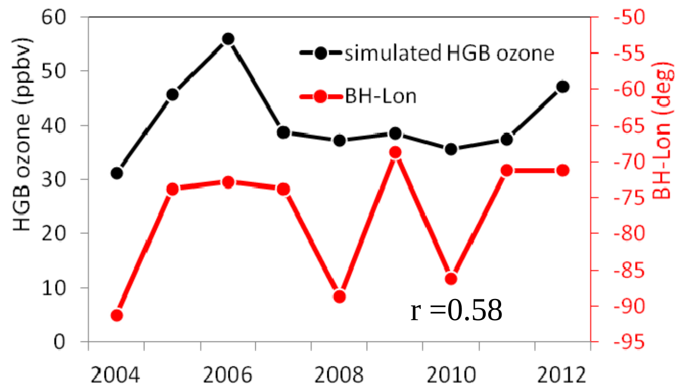

Figure 8. Time series of simulated HGB mean surface ozoen and BH-Lon in June.

Data Collected

We collected the number of frontal system for June, July, August and September from 2005 to 2013 on the site Sugar Land Regional Airport (12977), Houston, TX (29.621°N, 95.656°W) from NOAA website (http://www.ncdc.noaa.gov/qclcd/QCLCD).

Monthly mean time series of Arctic Oscillation (AO) is obtained from NOAA website (http://www.esrl.noaa.gov/psd/data/climateindices/list/).

Monthly mean reanalysis temperature with the spatial resolution of 0.5°x0.5° is downloaded from ECMWF website. Monthly mean HGB T_{max} is calculated from observed NCDC dataset.

Identify Problems or Issues Encountered and Proposed Solutions or Adjustments

None this period.

Goals and Anticipated Issues for the Succeeding Reporting Period

We will test the importance of each predictor in MLR.

Since BH-Lon is the most important predictor in June and July, we will go on analyzing the impacts of BH-Lon on HGB ozone on the daily time scale.

Detailed Analysis of the Progress of the Task Order to Date*(Discuss the Task Order schedule, progress being made toward goals of the Work Plan, explanation for any delays in completing tasks and/or project goals. Provide justification for any milestones completed more than one (1) month later than projected.)*

Progress on the project is ongoing.

Submitted to AQRP by:

Principal Investigator: Yuxuan Wang