Seasonal trends of ACSPO VIIRS SST product characterized by the differences in orbital overlaps for various waters types

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ABSTRACT

The uncertainty of the Advanced Clear-Sky Processor for Oceans (ACSPO) Sea Surface Temperature (SST) products from the Visible Infrared Imaging Radiometer Suite (VIIRS) satellite is examined using consecutive orbital overlaps in coastal waters of the Gulf of Mexico. The overlapping region on the left and right side of the VIIRS swath at 23-35 degree latitude covers approximately 500 pixels, which occur within 100 minutes and can provide a total of 4 SST products (2 day and 2 night) per day. By assuming the ocean SST should be similar on each side of the swath in this short time period, diel changes are examined and the uncertainty of SST retrieval is determined by comparing with buoy-derived SST. The VIIRS ACSPO product from NOAA STAR was used to determine the difference in SST within the overlapping regions. These SST changes are evaluated between consecutive orbits to validate the accuracy of SST algorithms on each side of the swath at high sensor angles. The SST product differences across the swath can result from surface glint, sensor angular impacts and sensor characteristics such as half angle mirror side (HAM) and calibration. The absolute diurnal SST changes that can occur within 100 minutes are evaluated with the buoy and VIIRS-derived SST. Sensitivity of the SST to water types is evaluated by measuring diurnal differences for open ocean, shelf and coastal waters. The 100 minute VIIRS SST overlap shows the capability to monitor the diurnal ocean heating and cooling which are associated with water mass optical absorption. The seasonal trends of the difference in SST at the overlaps for these water masses were tracked on a monthly basis. The unique capability of using the same VIIRS sensor for self-characterization can provide a method to define the uncertainty of ocean products and characterize the diurnal changes for different water types.

Keywords: Sea Surface Temperature, Satellite, SNPP VIIRS, Coastal, Validation, Algorithms,

1. INTRODUCTION

The Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi National Polar-orbiting Partnership (SNPP) satellite was launched in October 2011 and produces ocean products of sea surface temperature (SST) and color. The VIIRS sensor is planned for the two follow-on Joint Polar Satellite System (JPSS) satellites, J1 and J2, scheduled for launch in 2017 and 2023, respectively. The VIIRS SST products have been evaluated on a global scale (Liang et al., 2011, Cayula et al., 2014) and have been shown to be comparable with the AVHRR and MODIS SST products. Advancements to the VIIRS SST algorithms have been developed and have proven to extend the present SST coverage and accuracy. These developments have been integrated in the NOAA STAR ACSPO (Advanced Clear Sky Processor for Oceans) SST product, and have been continuously monitored in the NOAA SST Quality Monitor (SQUAM; *Dash et al.* 2010)). The ACSPO SST product has been shown to perform very well on a global scale (Petrenko et al., 2014; Gladkova et al., 2014). The ACSPO SST algorithms have been tested and evaluated against other SST algorithms, as described in Petrenko et al. (2014), along with the details of the day and night algorithms. A significant advancement with the ASPCO SST algorithms included the ability to derive SST signal from the full swath of VIIRS observations (sensor angles from $|\theta| \leq 70°$). Also ACSPO VIIRS processing is done at the full 750 m resolution (Petrenko et al. 2014, McBride et al. 2013).

The coefficients used in the SST algorithms for the present ACSPO processing are based on comparisons with global buoy SSTs. Only drifter and tropical moored buoy matchups were used with the algorithms, with match-up windows within 2 hour time interval between *in situ* and satellite measurements, and the a minimum distance of < 10 km between the buoy location and the nearest clear-sky VIIRS pixel. Our objective is to evaluate the ACSPO VIIRS SST product in coastal and shelf waters to determine their accuracy, using a different approach for evaluation of the SST VIIRS performance. The evaluation will determine if the SST algorithms which were developed using open ocean waters with large spatial homogeneity, can be applied to coastal areas with enhanced temporal and spatial variability. Additionally our approach will evaluate the consistency of VIIRS SST products from the right and left side of the swath. This approach will assess the sensor calibration for each side to the half angle mirror (HAM) (Xiong et al., 2014) in addition to the impact of sensor zenith angle of the SST. We have assembled the ACSPO SST data products from the PO.DAAC site (https://podaac.jpl.nasa.gov/dataset/VIIRS_NPP-OSPO-L2P-v2.3), where the ACSPO product has been archived. The ACSPO SST products are processed using cloud mask flags to determine the confidently clear sky (Petrenko et al. 2010). A time series of these SST products is used to determine the trend in SST product accuracy and if the sensor calibration has been maintained.

The analyses evaluate the SST products using both the VIIRS orbital overlaps and ocean buoys. The study will address SST accuracy at several time scales from the monthly trends and the short term diurnal SST. The analyses will evaluate the day and night algorithms over these time periods as well as the left and right side of the sensor swath. The monthly trends of the SST overlaps will be used to determine the consistency of the products over seasons. The evaluation will include the capability of VIIRS to resolve the hourly short term SST changes that occur with diurnal surface heating. Rapid SST changes can occur with low wind speeds and mixing. Additionally, the ocean optical properties can impact the diurnal heating and cooling rates of surface waters (Rochford et al., 2002, Arnone et al., 1999) through heat absorption and scattering in turbid waters. Waters with high optical absorption coefficients show strong diurnal changes compared to waters with high optical scattering coefficients. These rapid SST changes can impact the accuracy and uncertainty of the VIIRS SST products. These spatial and temporal SST products will be evaluated in different water masses including a coastal estuary (Mobile bay), shelf and open ocean waters of the Gulf of Mexico.

2. ORBITAL OVERLAPS

The VIIRS onboard the SNPP has a capability to retrieve SST with the entire swath of the sensor out to +/- 70 degrees from nadir. This sensor capability can be used to retrieve SST in overlapping ocean regions from one orbit to the next. With the orbit progression, the consecutive orbital overlap occurs within 100 minutes and provides SSTs at the same location for both day and night, providing up to four scenes per day at the left and right side of the orbit. Figure 1 shows an example of overlap that occurs in the Gulf of Mexico.

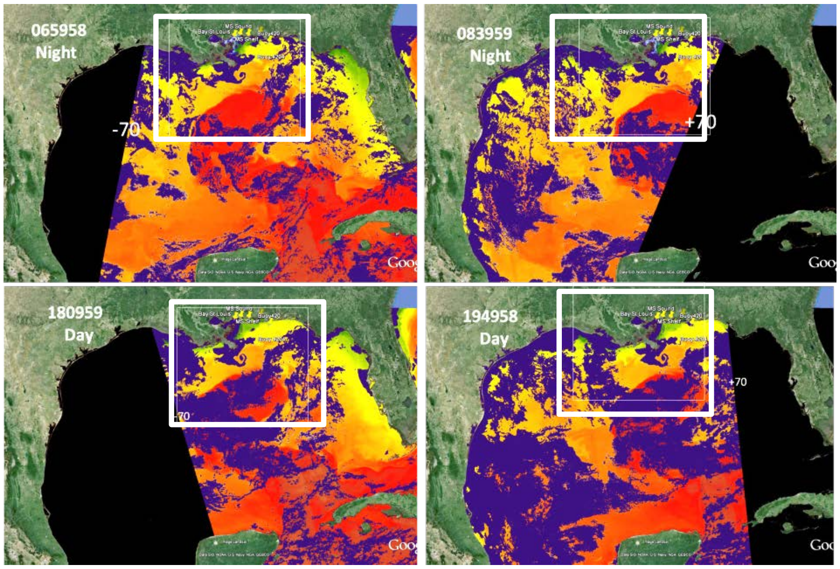


Figure 1 : An example of the orbital Overlap for Jan 21, 2015 for the Gulf of Mexico shows the 2 night passes (at 0659 and 0839 GMT) and the 2 day passes (at 1809 and 1949 GMT). For each orbit, the overlap region represents the right and left side of the sensor swath out to + and – 70 degree sensor zenith angle. The box shows the location of overlaps used in this study.

At the latitude of ~ 30 degree north, the overlap region represents a sensor zenith from 40 to 70 degrees which represents approximately 500 pixels at ~ 1km resolution. The SST algorithms compensate for these angular impacts and the passage through a larger water vapor depth with larger angles (*Petrenko et al. 2014).* These VIIRS overlap regions can be used to evaluate the SST products at the same location which occur within 100 minutes. This data set, in turn, can be used to determine the difference in the SST within 100 minutes and enables the examination of what is responsible for the difference. These data will be used to define the following: How much does the SST change from the first orbit to the second orbit? Does the SST for the one side of the HAM different from the other side? How do the SST retrievals at night compare with the daytime SST at these locations? \

2. DATA SETS

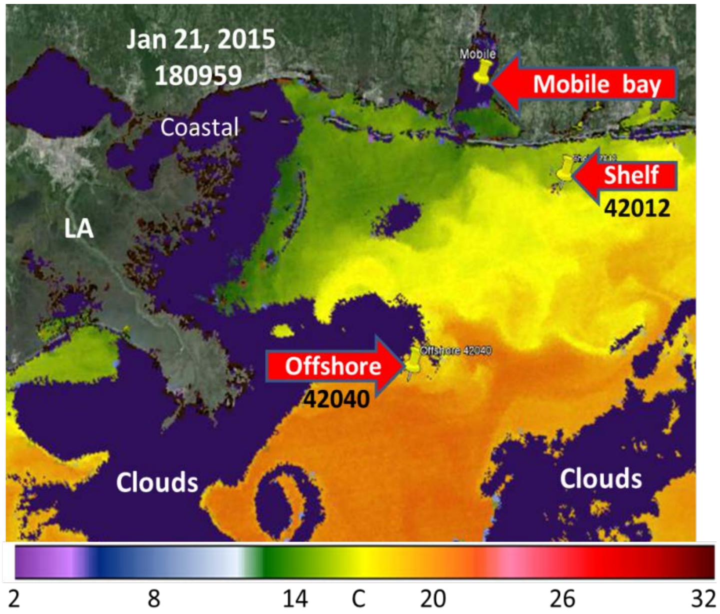
The VIIRS SST data in these analyses used NOAA ACSPO processing, including the cloud mask flags (Petrenko et al. 2010). We used only the most accurate retrievals for perfectly clear values in the analyses. Figure 1 shows the confidently clear SST values with the cloud mask applied.

The ACSPO data set selected in the Gulf of Mexico extends from May 2014 through January 2015 and represents 19 days with overlapping orbits (Table 1) which are spaced monthly and were selected based on cloud free conditions.

Table 1 –Date of SST overlaps

5/21/14	6/17/14	7/8/14	7/13/14	7/30/14	8/20/14	9/21/14	10/6/14	10/7/14
10/17/14	10/23/14	11/2/14	11/18/14	11/19/14	12/9/14	12/25/14	1/21/15	1/26/15

The analyses for these coastal areas was performed using VIIRS SST values that were extracted as single pixel locations at the specific locations at a resolution of 750m (full resolution). Additionally, the SST matchups with all buoy data were within 1 hour. This matchup criteria is much more constrictive than typical global buoy data sets but is required in these coastal type waters to evaluate the diurnal temperatures changes and high spatial variability occurring from temperature fronts.



SST from three National Data Buoy Center ocean mooring buoys were used, which recorded hourly SST to define diurnal changes (figure 2). 1) Shelf - Station 4210 Orange beach - water depth 27 m 44nm SW of Mobile Bay 2) Offshore - Station 42040 – Luke Offshore Platform 64 Nm South of Dauphin Island AL. water depth 165 m, and 3) Estuary - Middle Bay Light, Mobile Bay, Al – water depth 3.3 m.

Figure 2- Buoy locations at Mobile Bay, Shelf 42012, and Offshore 24040 showing the different water masses.

4. RESULTS

The comparison of the VIIRS SST from each of the overlaps of the first and second orbit is shown in figure 3a. The scatter represents the changes in the VIIRS SST retrieved within 100 minutes. These results are for all three water types representing 100 points and show that both day and night orbits have a similarly high R^2 correlation of 0.9816 and 0.9925, respectively.

The comparisons of VIIRS SST with the Buoy SST are shown in Figure 3b to determine if the first or second orbit has better accuracy. All matchups are within one hour of the satellite SST. The regressions shows the R^2 correlation coefficients of the first pass, right side of the swath (0.9702) and the second orbit, left side of the swath (0.968) with the buoy SST. Both orbits show similar high correlations, indicating both provide excellent matchups.

The seasonal time trends of the SST VIIRS overlaps were evaluated to determine if the accuracy of the SST products changed during the 7 months. These analyses evaluated the differences of the SST with 100 minutes from the first and second orbit for each overlap (Figure 4).

The consistency in the SST between the first and second orbit is shown by the difference (figure 4). The red box shows the + / - 0.5 degree C range. The average absolute difference is 0.41 degree C for all points which is within the requirements and overall accuracy for these coastal regions.

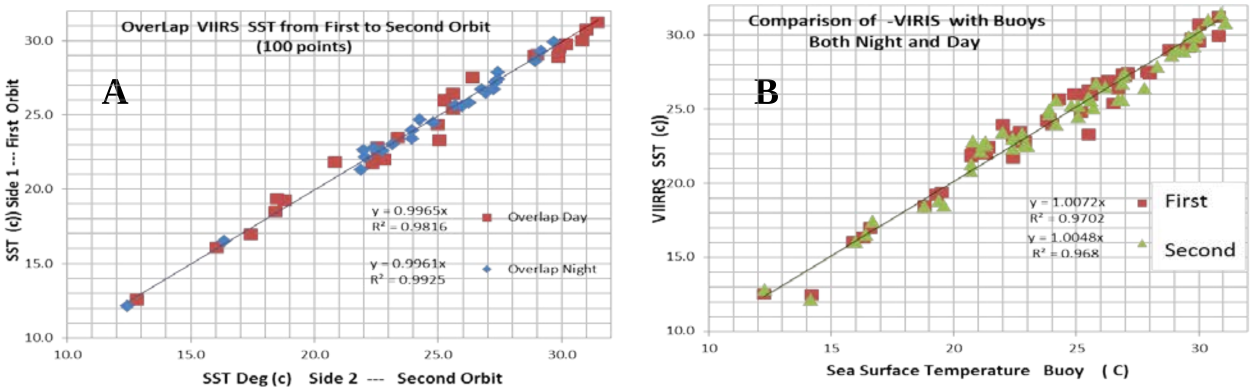


Figure 3- A. The correlation of SST from the first orbit and the second orbit for the day and night VIIRS. B. The correlation of the buoy SST with the VIIRS SST first (red) and second (green) orbits.

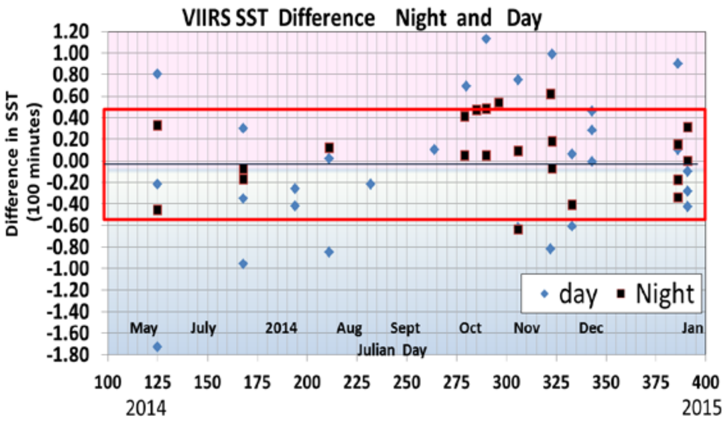


Figure 4- Seasonal trend of the SST difference in the VIIRS SST overlap at the 3 buoy locations, for the night and day scenes.

These SST differences can result from: 1) impacts of sensor channel calibration for either side of the Half Angle Mirror 2) SST algorithms accuracy in defining the angular effects for atmospheric thickness for each orbit and 3) diurnal heating or cooling of the waters within 100 minutes. Figure 4 shows the night (black) differences are closer to the zero difference compared to the day (blue) differences. This suggests that the night SST products may be more consistent with the 100 minutes and that the day differences are subject to diurnal heating.

The accuracy in the VIIRS SST retrievals was examined for these different water types to determine any biases associated with coastal type waters, such as water turbidity, proximity to land, etc. The seasonal trend of the SST difference within the 100 minute orbits was examined for the three water types.

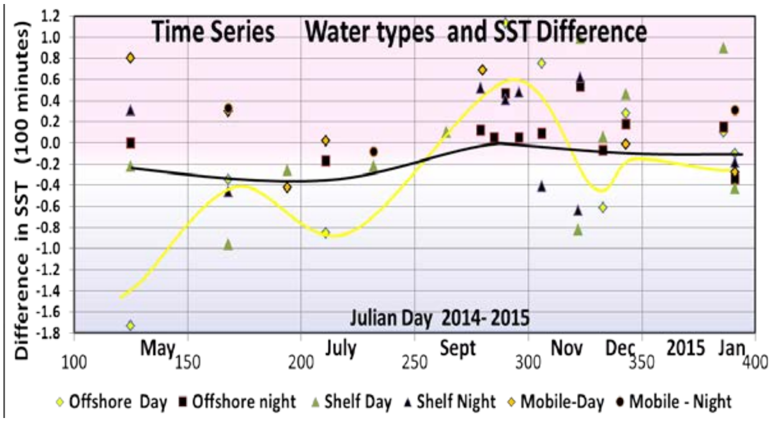


Figure 5 shows the time series for 7 months of the SST difference (first minus second orbit) within 100 minutes for the 3 water masses (Offshore, Shelf, Coastal) for day and night.

Notice the Offshore Day (yellow) has a high variability compared to the night (black). The Offshore day waters appear to have a negative bias (where the second orbit SST are larger) compared to the Shelf and Mobile areas, which are positive and the second orbit SST are lower. This suggests the first orbit SST is cooler than the second orbit in offshore waters whereas the first orbit is warmer than second in coastal waters. Offshore waters may be responding to diurnal heating differently than coastal waters, which can result from increased turbidity and shallow water depth. The night orbits (black) have less diurnal heating and are more stable, as shown by the all 3 water masses, and show similar differences in the SST variability.

The SST difference of the first to second orbit for the Jan 21 Day orbital overlaps is shown in Figure 6. The positive difference indicates that the first orbit is warmer than the second, and has a cooling trend. A negative difference indicates a warming trend. Note this is during the winter season. The spatial variability of temperature changes are shown to identify the different water masses.

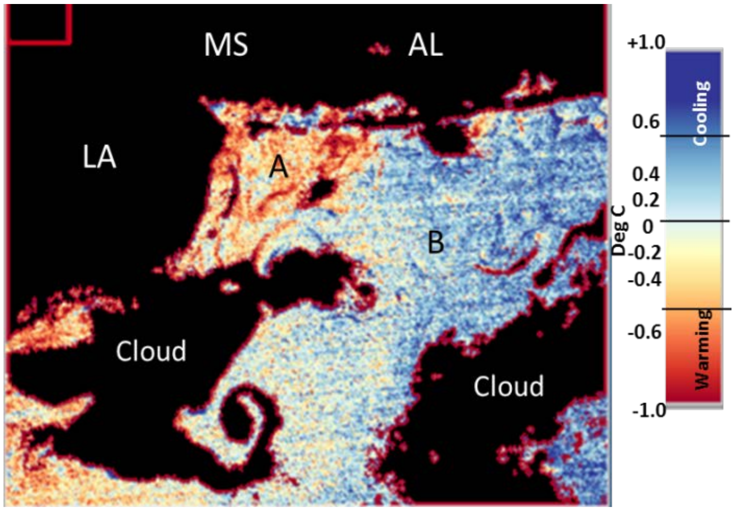


Figure 6: Northern Gulf of Mexico SST Difference with 100 minutes of the Day. The image represents the first orbit minus the second orbit for Jan 21, 2015 (Fig 1c,d). Clouds and land are masked.

The locations of SST differences were compared with the VIIRS derived optical water absorption coefficient (Lee et al. 2002, Arnone et al. 2014). Location B shows a cooling trend (Blue) and represents clear ocean waters with low absorption. Location A shows a warming trend (red) with higher absorption waters characteristic of coastal water masses. This suggests the VIIRS SST overlaps can monitor diurnal changes and surface heat associated with different water masses.

The angular impacts on the SST (figure 7) were evaluated to determine how the difference between the buoy and the VIIRS SST changes with sensor zenith angles. The higher angles will have thicker atmosphere, and reduced emissivity to compensate for. Figure 7 shows that night and day difference between VIIRS and the buoy from 50 to 70 degrees (satellite zenith angle) which were used in the overlaps data set. The trends lines of the difference for day (red) and night (black) are shown. The day (red) differences show a slightly higher difference at around 60 – 65 degrees than the night differences. The night appears more consistent with zenith angle with slight negative bias of -0.43 degree C.

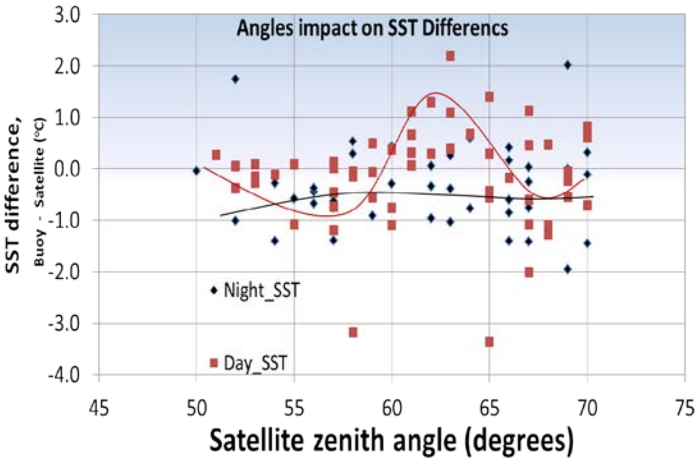


Figure 7 – Angular impacts on the SST difference between VIIRS and buoy.

Diurnal heating: As described in Figure 4, the diurnal heating and cooling of the SST can change rapidly in different water masses. We examined the hourly diurnal buoy SST at the 3 buoy locations and compared with the VIIRS overlap SST to see if changes in the 100 minute difference are attributed to these diurnal changes. As expected, the 24 hour diurnal SST changed in the 7 month periods from summer to winter and is shown in the SST differences in the 100 minute orbits. Three examples of the hourly diurnal buoy SST with the night and day VIIRS SST overlaps are shown in Figure 8 for the Mobile Bay, shelf and offshore buoy. The changes in diurnal heating in day afternoon are quite high (> 1 degree C) compared to the more stable SST at night. Notice the SST changes in VIIRS SST for the first and second orbit for both the night and day follows the similar changes in the buoy hourly changes. This is observed at all three locations and suggests the SST difference we observed (figures 4, 5) from the first to second orbit can be attributed to actual diurnal heating and not inconsistency between overlaps. The hourly diurnal SST is different at each location and, as expected, changes in the different seasons as a response to solar elevation and heating. This indicates that in evaluating the accuracy of the SST algorithms, the constraints of closely matching time between buoy and satellite SSTs is important.

Maintaining calibration of the VIIRS channels is critical for monitoring the SST changes. To evaluate the SST consistency, we examined the difference in the SST from buoy and VIIRS overlaps for the day and night SST for the 7 months. The average monthly comparison of the difference of the VIIRS SST and the buoys for all the water masses does not show any obvious trend (Figure 9) and indicates consistency in the SST differences.

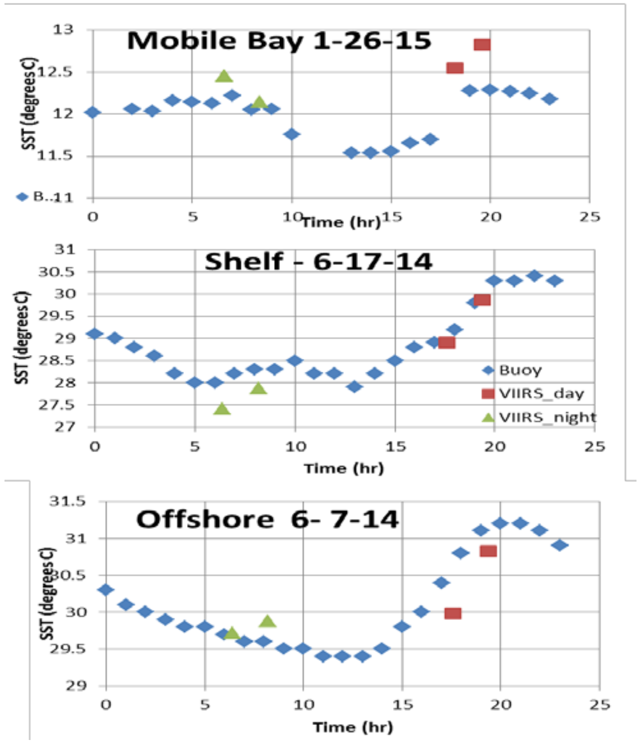


Figure 8- The hourly changes in the SST at three buoy locations Mobile, Shelf and Offshore. Blue (Buoy) Green (night VIIRS) and Red (day VIIRS) shows the hourly response.

Monitoring the difference in these hourly matchups using orbital overlaps provides an accurate approach for tracking the SST consistency. We note that in the last 2 months of the data set, Dec 2014 and Jan 2015, the differences were less than 0.5 degree C, suggesting the accuracy may be improving and requires continuing through the spring and summer seasons.

5. CONCLUSIONS

The ACSPO SST for confidently clear cloud free retrievals for VIIRS overlaps orbits were compared with the moored buoy data in the coastal waters in the Gulf of Mexico for a 7 month period. Results show that the SST retrievals within the 100 minutes between orbits compared quite well. The data set used in the analyses represents the difficult high sensor angle retrievals on the other limbs of the satellite swath. We assume that near nadir SST retrievals will have similar or better accuracy. Results indicate the APSCO SST algorithms and the sensor calibration are maintaining the SST accuracy out to the high sensor zenith angles and different Half Angle Mirror Sides. There was no observed sensor zenith angular impact on the SST accuracy. Larger SST differences within the 100 minute overlaps were observed in the day scenes compared to night retrievals. Results suggest that these 100 minute day differences appear to be related to the diurnal changes in actual SST at the buoy locations. The ACSPO VIIRS SST can resolve the rapid diurnal changes using the VIIRS overlapping locations. This also suggests that changes in the SST can occur in short time scales so that accurate validation of SST from VIIRS requires using coincident buoy and satellite matchups within an hour. Results suggest that the VIIRS diurnal SST retrieval can be used to determine how surface heating from solar radiation is impacted by water turbidity, such as absorption.

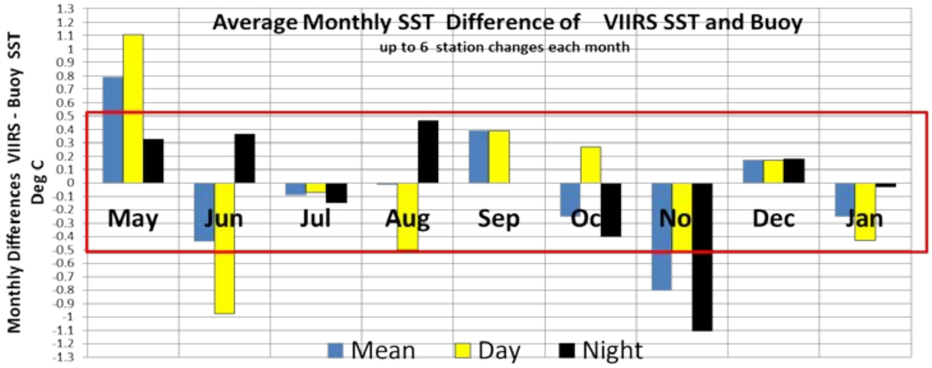


Figure 9: Monthly trends of the SST Difference of the buoy and VIIRS.

The ACSPO VIIRS SST retrievals were validated in coastal areas, including estuaries and near shelf waters and offshore waters. The results indicated that the validation in all water masses was similar and that the ACSPO SST retrievals provide similar accuracy in all water masses. The study supports the use of the VIIRS products in coastal areas that have been properly identified as confidently clear sky conditions.

Future efforts will address the using the 100 minute VIIRS orbital overlaps for evaluation the VIIRS cloud mask. The VIIRS SST data used in this study come from ACSPO version 2.30. As of this writing, next ACSPO version 2.40 is being promoted to operations. Work is also underway at NOAA to reprocess all VIIRS record back to Jan 2012 using ACSPO 2.40. We plan to refine the methodology of analysis used here, and apply it to longer time series of the more presumably more accurate ACSPO 2.40 data.

6. ACKNOWLEDGEMENTS

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