OCI GEOLOCATION EVALUATION AND REFINEMENT USING LANDSAT CONTROL POINTS

Frederick S. Patt, Alexandr V. Semenov, Gwyn F. Fireman, Thomas J. Owens, Corrine Rojas, John G. Wilding
NASA Code 616, Ocean Ecology Lab, Goddard Space Flight Center, 8800 Greenbelt Rd., Greenbelt, Maryland, MD 20771, USA
and
Science Applications International Corporation, 12010 Sunset Hills Rd., Reston, VA 20190, USA

ABSTRACT

The Plankton, Aerosol, Cloud, and ocean Ecosystem (PACE) mission is NASA's next investment in ocean biology, clouds, and aerosol data records. A key feature of PACE is the inclusion of an advanced satellite radiometer, Ocean Color Instrument (OCI), a global mapping radiometer that combines multispectral and hyperspectral remote sensing. The geolocation processing is performed for OCI using spacecraft navigation data and an instrument geometry model. To evaluate the geolocation accuracy for OCI and develop refinements to the processing methods, control point matching using Landsat data has been implemented as a step in the operational processing of OCI data at the Science Data Segment. This processing provides between 200 and 300 high-quality matchups per day with good global and geometric distribution, allowing rapid evaluation of the OCI geolocation accuracy. The results provided an early indication of the overall quality of the geolocation processing and of specific aspects needing improvement. A standard set of granules was identified to support rapid implementation and testing of geolocation refinements, and this approach has been highly successful in improving the geolocation processing accuracy to meet the science requirements. The evaluation will continue throughout the mission to ensure the ongoing accuracy of geolocation. This paper describes the control point matching methodology, the approach to development of the geolocation processing refinements, and the recent results.

Keywords: PACE, OCI, geolocation, control points

1. INTRODUCTION

NASA'S Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission [1] launched February 8th, 2024. Its primary payload is the Ocean Color Instrument (OCI) [2]. OCI provides global top-of-atmosphere (TOA) radiance measurements to support ocean color, aerosol and cloud studies. From 340nm to 895nm, it provides hyperspectral coverage, with multispectral coverage from 940nm to 2260nm. The spatial resolution is 1 km at nadir; the instrument is tilted forward or aft for data collection to avoid Sun glint from the ocean surface.

The OCI science data processing is performed by the PACE Science Data Segment (SDS) at the NASA Goddard Space Flight Center (GSFC). Geolocation is performed as part of the Level 1B (calibrated TOA radiance) processing, using spacecraft navigation data and an instrument geometry model. Accurate geolocation is a key requirement for every Earth science satellite mission; the OCI geolocation requirement is 0.1 pixel (100m at nadir), 1 sigma. To evaluate the geolocation accuracy and develop refinements to the processing methods, control point matching using Landsat data was implemented. This followed the approach developed for the Moderate-resolution Imaging Spectroradiometer (MODIS) on the Terra and Aqua missions [3].

The control point matching is run automatically as a step in the OCI data processing at the PACE SDS. This processing provides between 200 and 300 high-quality matchups per day with good global and geometric distribution, allowing rapid evaluation of the OCI geolocation accuracy. The results provided an early indication of the overall quality of the geolocation processing and of specific aspects needing improvement. A standard set of granules was identified to support rapid implementation and testing of geolocation refinements, and this approach was highly successful in developing and testing improvements to the geolocation processing to meet the science requirements. The evaluation will continue throughout the mission to ensure the ongoing accuracy of geolocation. The following sections describe the control point matching methodology, the approach to development of the geolocation processing refinements and the results to date.

2. METHODS

This section describes the methods implemented for the control point matching and the geolocation processing improvements.

2.1 Control point matching

The method of control point matching with features in Landsat data was originally developed for Terra MODIS [3]. As described in the reference, the method uses Landsat image subsets ("chips") with a spectral band centered at 650 nm; this wavelength provides good land/water discrimination and feature definition. The individual chips have a size of 40x40 km. With a spatial resolution of 28.5 nm, the Landsat data are well suited to assess geolocation accuracy for satellite instruments such as MODIS and OCI. The control point chip library has been steadily evolved over time by the GSFC Terrestrial Information Systems Laboratory (TISL), and currently contains approximately 2500 chips, well distributed globally.

The MODIS control point matching code and chip library were provided by the TISL. The matching method was recoded in Python before the PACE launch, with options to process both OCI and MODIS data. The method was tested using MODIS data before the PACE launch because the available OCI simulated data did not have adequate feature definition to support the control point matching.

The OCI Level 1 science data products are generated by the SDS in five-minute granules. The Level-1B processing (geolocation and calibration) [4] is run as the second processing step for each granule. The control point matching is run using the Level-1B granules as input.

The first step is to determine whether any Landsat chips fall within the granule boundaries. For each chip identified for a granule, the error estimation is performed as follows:

- A 60x60 km subset of the OCI granule is selected, centered over the Landsat chip.
- The Landsat image data are resampled to OCI resolution using the computed geolocation from both sensors.
- The normalized correlation coefficient (NCC) is computed using the OCI 650-nm data covering the chip area and the resampled Landsat data.
- This process is repeat by shifting the chip data over a specified range of Landsat pixels and recomputing the NCC.
- The two-dimensional peak of the NCC is located. The OCI geolocation error for this match is computed by converting the pixel shifts corresponding to the peak to latitude and longitude differences.
- If the NCC exceeds a threshold, the results are output to a text file.

This method is illustrated in the figures below. Figure 1 shows the 60x60 km OCI image subset centered on the Landsat chip, the subset cropped to match the chip boundaries, and the chip date resampled to the OCI resolution. Note that both the OCI and Landsat data have been false-colored using a rainbow palette to emphasize the features.

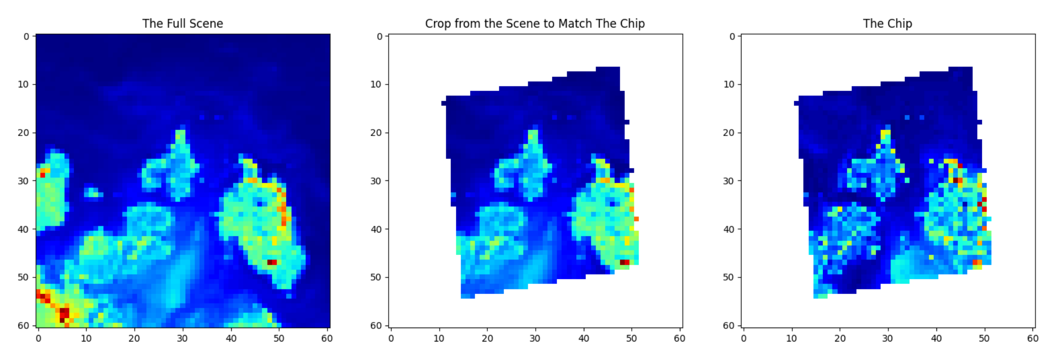

Figure 1. OCI 60x60 km subset, crop to match Landsat chip, and resampled Landsat chip for a sample control point matchup.

Figure 2 shows the two-dimensional NCC for this chip matchup. In this case, the NCC peak corresponds to a pixel shift corresponding to -0.000842 degree in latitude and 0.000286 degree in longitude.

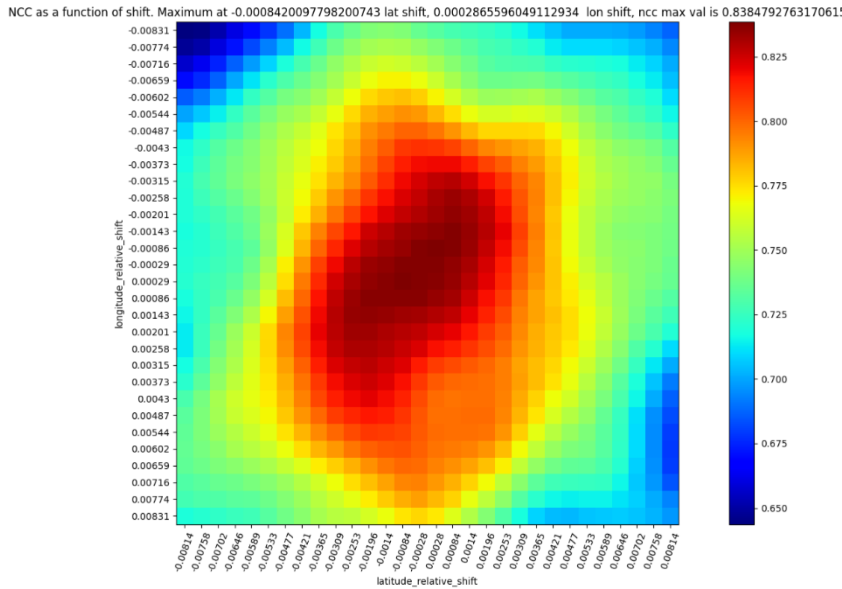

Figure 2. Two-dimensional normalized cross-correlation for sample control point matchup.

For each successful matchup, the following information is output:

- The OCI scan time, science pixel number and tilt angle corresponding to the center of the image subset
- The OCI granule and Landsat chip IDs.
- The center latitude and longitude of the chip
- The differences in latitude and longitude corresponding to the NCC peak.
- The NCC peak value

These result for all the matchups found for each OCI granule are output to a text file.

2.2 Development of geolocation improvements

As stated in the introduction, the use of the control point matchup results is twofold: to evaluate the accuracy of the OCI geolocation processing throughout the mission, and to develop improvements to the geolocation processing that are applied to both the forward processing and periodic reprocessing. The method for developing improvements follows the approach originally developed for the Sea-viewing Wide Field-of-view Sensor [5].

The control point matching process described above generates results as errors in latitude and longitude. To develop geolocation improvements from these results, the geolocation errors from expected sources (e.g., spacecraft-to-sensor misalignments) are modeled, to determine the partial derivatives of latitude and longitude with respect to each source. Modeling the derivatives as a function of error source and observing geometry (i.e. orbit position, scan angle and OCI tilt) is performed numerically. For a sample orbit-based swath, a look-up table of derivatives for each error source is computed by perturbing the sources individually and computing the differences in the geolocated latitudes and longitudes.

The derivatives are then interpolated from the table for each matchup using the center latitude and pixel number for the matchup. The results are arrays of partial derivatives in latitude and longitude with respect to the error sources. These arrays are used to estimate the error in each source for a set of matchups using least-squares estimation. The partial derivatives with respect to the along-scan and along-track directions in the sensor frame are also calculated to convert the latitude and longitude errors to OCI pixel units, to allow the errors to be compared with the OCI geolocation requirement.

3. RESULTS

The geolocation matchup processing has been run for all OCI Level-1B granules since routine data collection was started at the end of February 2024. The processing is performed automatically by the Ocean Data Processing System (ODPS). Matchups are found for 20 to 35 granules per day, with a total of between 230 and 400 total matchups.

The matchups have been typically analyzed for periods of 10 days, in order to provide sufficient numbers for valid statistics and outlier rejection. The global distribution of matchups for a sample 10-day period (April 1 through 10, 2024) is shown in Figure 3, with a total of 3,288 matchups.

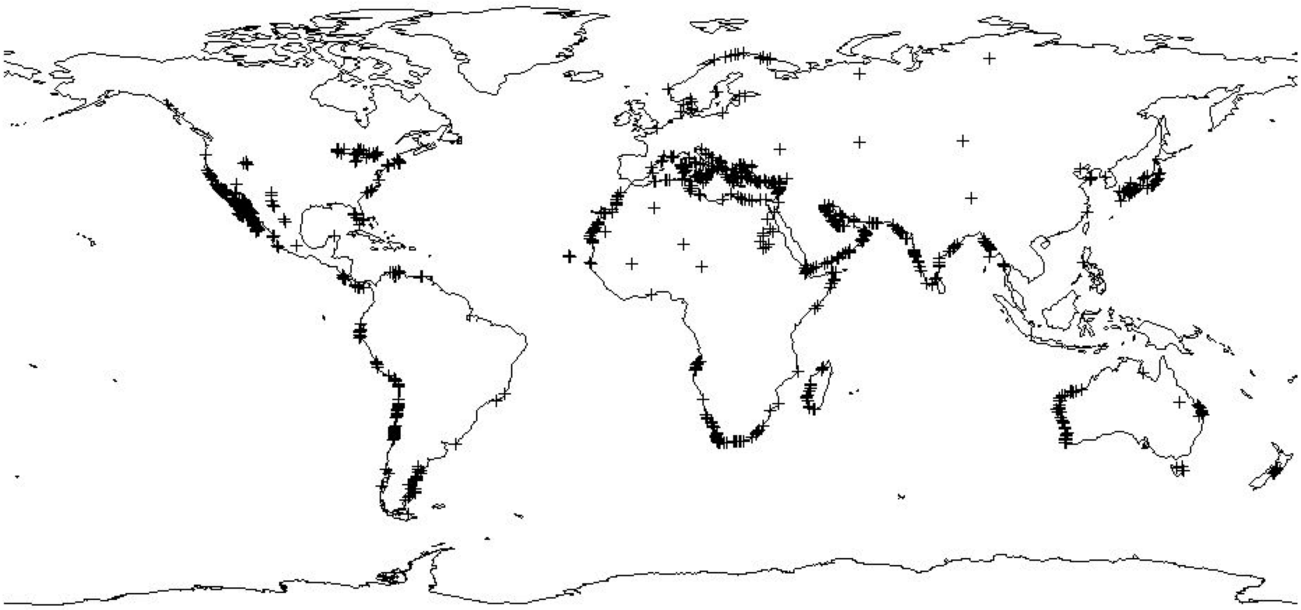

Figure 3. Global distribution of matchups for April 1 through 10, 2024.

In addition to the automated processing, a set of granules was selected from the early part of the mission (February 25 through March 12, 2024) for testing geolocation improvements. This set consisted of all of the granules from that period that produced matchups. A total of 437 granules are included in this set containing approximately 2900 matchups.

The geolocation evaluation results with the test granule set and the at-launch geolocation processing configuration are shown in Figure 4 as errors in longitude and latitude vs. scan angle. The figure shows that the initial error significantly exceeded the requirement, with longitude errors of up to 0.1 degree (about 10 km) and latitude errors up to 0.05 degree. The plot symbol colors indicate the matchups at the forward (blue) and aft (red) tilt angles. There is an obvious difference in the latitude errors at the two tilt angles, indicating an error in the difference between the tilt angles.

The monotonic, nonlinear dependence of both the longitude and latitude errors on the scan angle was a clear indicator of an error in the OCI scan angle calculation, specifically the per-pixel scan angle increment. The OCI scan angle calculation [5] includes a correction based on prelaunch characterization test results. It was quickly determined that the behavior of the errors was consistent with a sign error in the application of the correction. This was corrected in the geolocation parameter look-up table (LUT) and the test granule set was reprocessed.

The results with the scan angle correction are shown in Figure 5. The errors, although reduced, still significantly exceeded the requirement. The large, monotonic scan angle dependence of the longitude errors was removed, as expected. There were still correlations with both scan and tilt angle that indicated a combination of alignment, tilt angle and tilt axis errors. For comparison with the geolocation requirement that is written in terms of OCI science pixels, these results were converted to along-scan and along-track errors in pixel units as described in Section 2 (Figure 6).

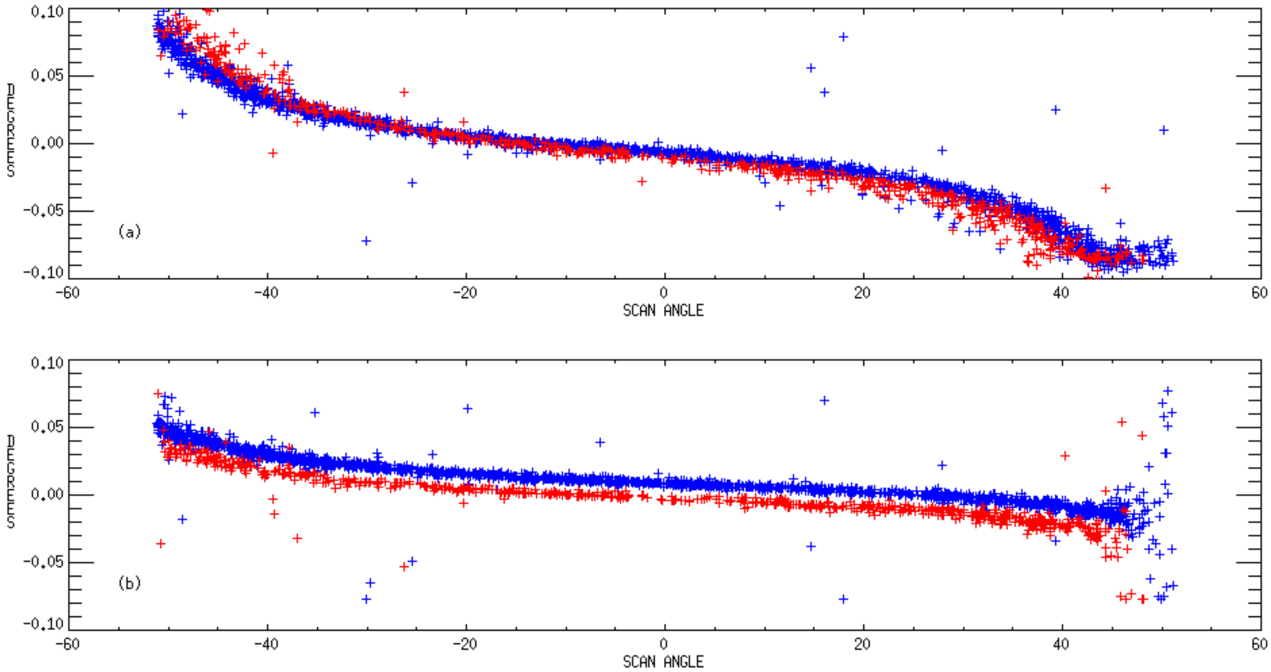

Figure 4. OCI geolocation errors vs. scan angle with at-launch processing configuration: longitude (a) and latitude (b). The errors are plotted in blue for the forward tilt and red for aft.

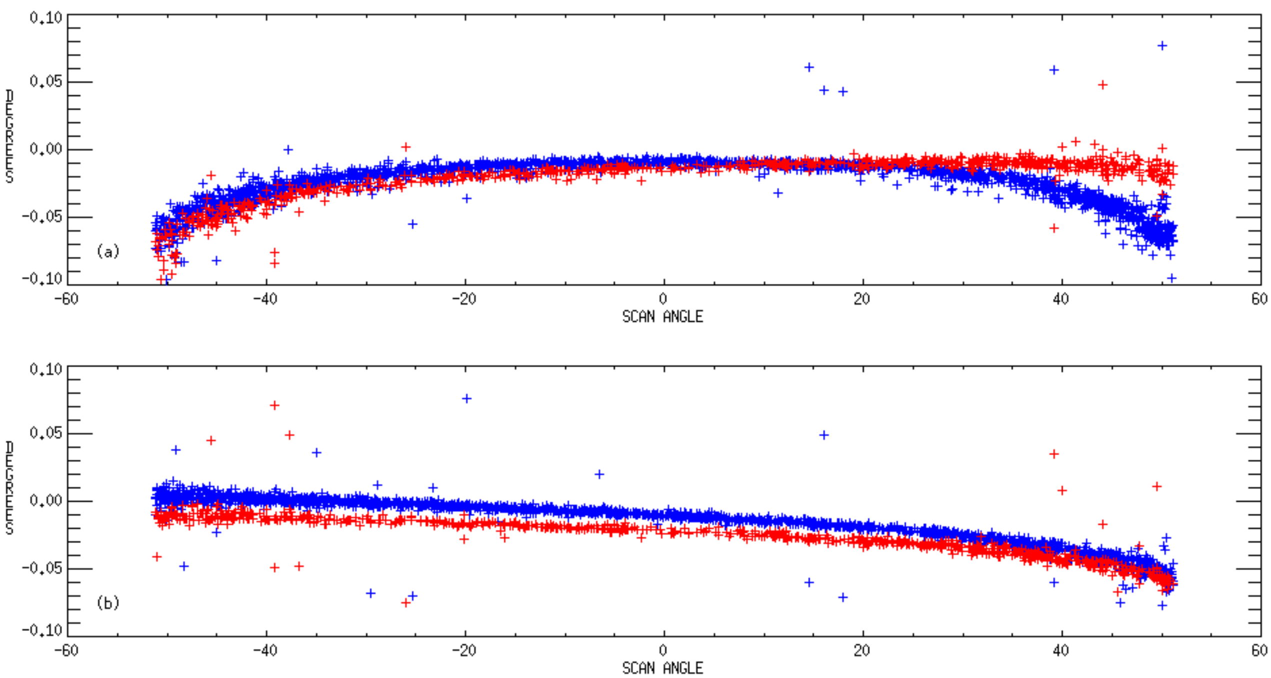

Figure 5. OCI geolocation errors vs. scan angle with the scan angle correction: longitude (a) and latitude (b). The errors are plotted in blue for the forward tilt and red for aft.

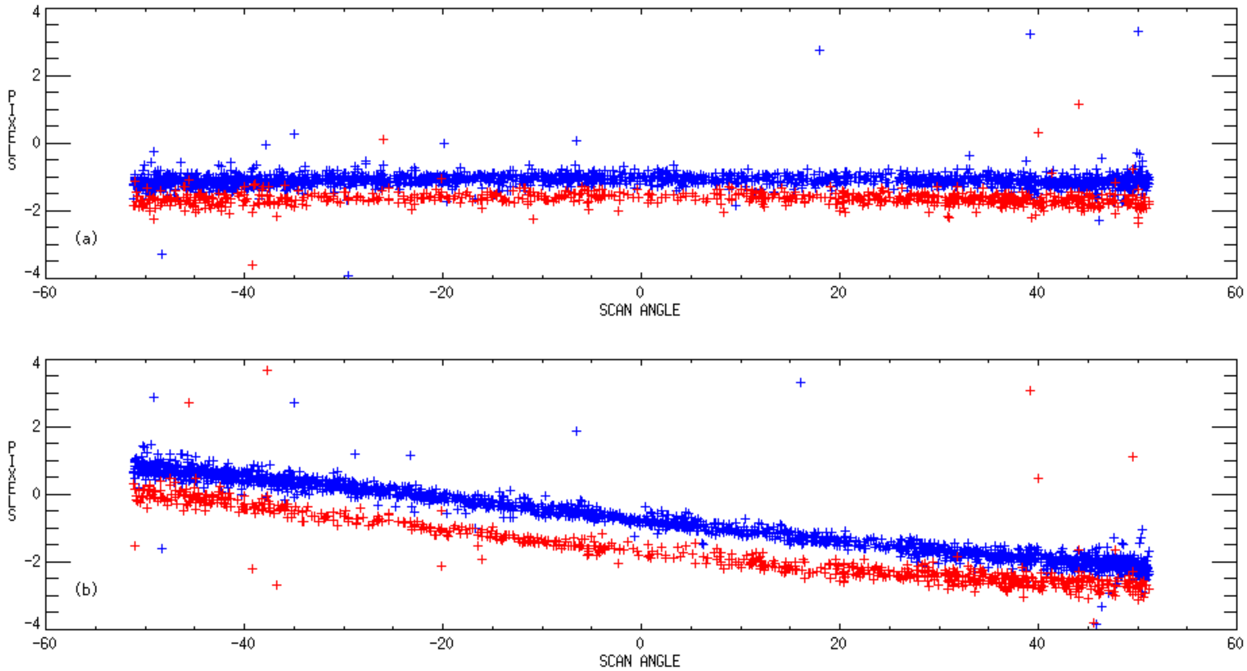

Figure 6. OCI geolocation errors vs. scan angle in pixel units with the scan-angle correction: along-scan (a) and along-track (b). The errors are plotted in blue for the forward tilt and red for aft.

These results showed that significant improvements were still needed to meet the requirement. The along-track errors were as large as -3 pixels; both the along-scan and along-track errors had systematic scan angle dependencies; and there were obvious differences between the results at forward and aft tilt.

The next step was to interpret these results in terms of expected error sources, specifically misalignments between the spacecraft and instrument. This was accomplished using the numerical partial derivatives computed as described in Section 2. These and the errors were input to a least-squares regression to estimate the alignment errors. The alignments were computed separately for the results at the forward and aft tilt positions, to allow the contributions from the tilt to be separated from other sources. Based on these calculations, the following updates were made to the geolocation processing:

1. Roll (+X) and yaw (+Z) components of the spacecraft-to-tilt alignment.
2. Tilt angles at the forward and aft position. Note that the tilt angle and pitch (+Y) alignment are degenerate, so any pitch adjustments were absorbed into the tilt angles.
3. Tilt axis. The at-launch configuration aligned the tilt axis with the spacecraft +Y axis; the update introduced small components in +X and +Z.

The design of the geolocation software [4] allowed all of these updates to be made with the geolocation parameter LUT. They were implemented and evaluated successively with the test granule set to verify the effectiveness of each update. The final results are shown, converted to pixel units, in Figure 7; the plot scale has been reduced compared to Figure 6. The results show no significant differences between the two tilts or trends with scan angle.

The statistics of the errors shown in Figure 7 were computed for comparison with the geolocation requirement of 0.1 pixel. The median and inter-quartile range (IQR) were used as they are insensitive to outliers; note that the IQR is equivalent to 1.33 times the standard deviation for normally distributed data. The results are shown in Table 1. The medians indicate small, residual biases in both directions that are nearly the same for the forward and aft tilts. The IQRs are below the requirement along-scan and very close along-track. It should be noted that the control point matching algorithm does contribute uncertainty that increases the calculated geolocation errors, although the magnitude is unknown at this time.

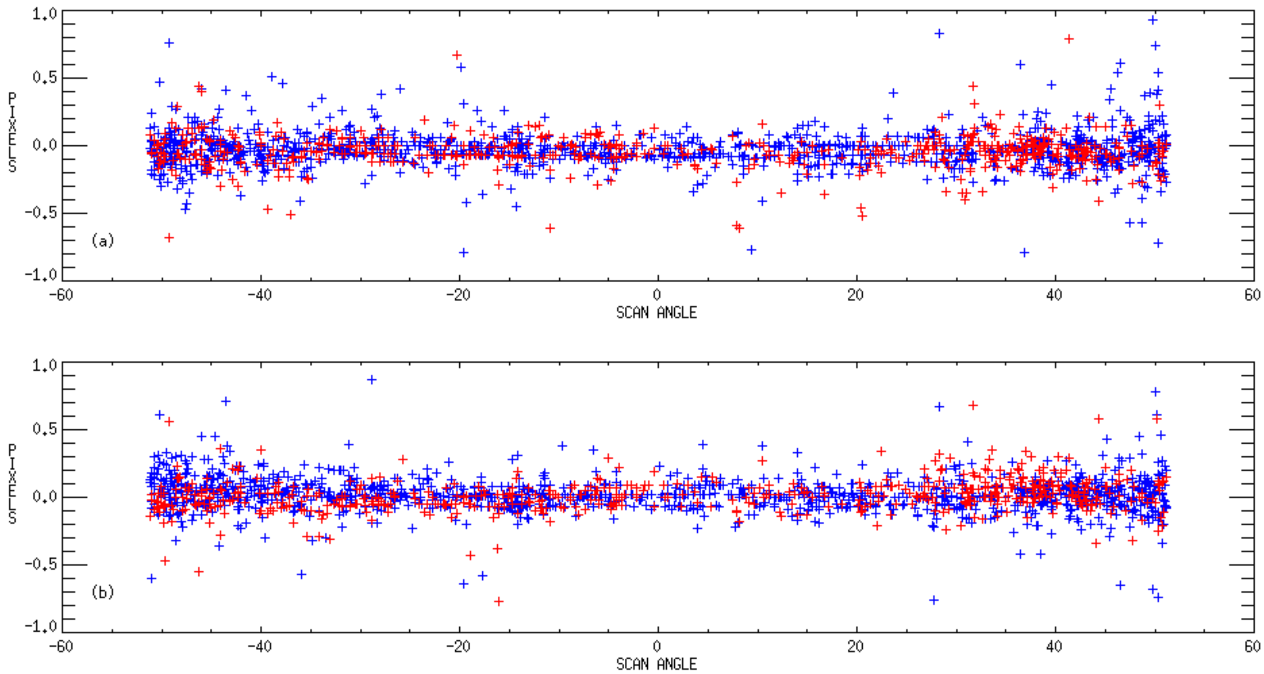

Figure 7. OCI geolocation errors vs. scan angle in pixel units with all current corrections: along-scan (a) and along-track (b). The errors are plotted in blue for the forward tilt and red for aft.

Table 1. Error statistics in pixel units for geolocation evaluation with all current corrections.

Direction	**Forward Tilt Median**	**Forward Tilt IQR**	**Aft Tilt Median**	**Aft Tilt IQR**
Along-scan	-0.032	0.115	-0.044	0.108
Along-track	0.015	0.135	0.013	0.129

These results are sufficiently good that further geolocation refinements will await the evaluation results over time with the OCI mission data. In the near term, the focus of the evaluation will be on monitoring and reporting the geolocation results. These results will be analyzed as described above for consistent or systematic (e.g. seasonal) errors.

4. SUMMARY

Geolocation evaluation has been implemented for the PACE OCI, using a method of land control point matchups previously developed and proven for other Earth remote sensing instruments with similar characteristics. The results of this evaluation on early mission data have been used to identify and correct for sources of error in the PACE geolocation processing. The results with the latest corrections show that OCI geolocation is meeting, or very close to, the accuracy requirement. The matchups and evaluation are performed automatically for all OCI science data. These results will be used for ongoing evaluation of the geolocation accuracy and possible further refinements.

ACKNOWLEDGEMENTS

The authors wish to acknowledge Guoqing Lin and the MODIS/VIIRS geolocation team of the NASA/GSFC Terrestrial Information Systems Laboratory for providing the Landsat control point matching code and chip library.

REFERENCES

[1] Werdell, P. J., Behrenfeld, M. J., Bontempi, P. S., Boss, E., Cairns, B., Davis, G. T., Franz, B. A., Gliese, U., Gorman, E. T., Hasekamp, O., Knobelspiesse, K. D., Mannino, A., Martins, J. V., McClain, C. R., Meister, G., Remer, L. A., (2019). “The Plankton, Aerosol, Cloud, Ocean Ecosystem Mission: Status, Science, Advances.” Bull. Am. Meteorological Soc. 100 (9), 1775–1794. doi:10. 1175/bams-d-18-0056.1

[2] [2] G. Meister, Joseph J. Knuble, Ulrik Gliese, R. Bousquet, L. H. Chemerys, H. Choi, R. E. Eplee, R. H. Estep, Jr., E. T. Gorman, S. Kitchen-McKinley, D. Kubalak, S. Lee, C. McClain, J. W. McIntire, F. S. Patt, Z. Rhodes, P. Jeremy Werdell, "The Ocean Color Instrument (OCI) on the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) Mission: System Design and Prelaunch Radiometric Performance," in IEEE Transactions on Geoscience and Remote Sensing, doi: 10.1109/TGRS.2024.3383812

[3] Wolfe, R. E. and M. Nishihama, “Accurate MODIS global geolocation through automated ground control image matching,” in *Image Registration for Remote Sensing*, J. Le Moigne and N. S. Netanyahu, eds., Cambridge University Press, New York. ISBN:978-1-108-44575-7

[4] Patt, F.S. (2024). PACE Technical Report Series, Volume 13: PACE OCI Calibration and Geolocation Operational Algorithm Description (NASA/TM–2024-219027/Vol. 13.). Eds. I. Cetinić, C. R. McClain,P. J. Werdell, NASA Goddard Space Flight Space Center Greenbelt, MD; https://ntrs.nasa.gov/api/citations/20240007962

[5] Patt, F. S, “SeaWiFS operational geolocation assessment system,” in *Image Registration for Remote Sensing*, J. Le Moigne and N. S. Netanyahu, eds., Cambridge University Press, New York. ISBN:978-1-108-44575-7