NOAA ROSES Semi-Annual Report

Reporting Period: March 2021 – August 2021 (2nd report)

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Project Title: New Fused GEO+LEO Multi-Satellite Product: Stereo-Winds from Collocated ABI and VIIRS Datasets

Executive Summary

This project involves the development, validation, and demonstration of a new GEO-LEO stereo-winds product using an ABI-family imager instrument (aboard GOES-16/17, Himawari-8, and GEO-KOMPSAT 2A) as one eye and the VIIRS instrument (aboard S-NPP, NOAA-20) as the other. This new capability will be an extension of the GEO-GEO stereo winds capability developed by STAR's Winds Science Team that will further extend stereo winds coverage. Use of a stereo approach offers a direct method of cloud height assignment that rely only on the geometric parallax observed from two different vantage points. This approach does not rely on cloud microphysical properties or explicit knowledge of the atmospheric thermal structure, both of which, can challenge infrared-based cloud height retrieval approaches in certain conditions. As a result, the stereo approach produces highly accurate cloud-top heights that enable highly accurate height assignments to be determined for satellite winds. The GEO-LEO stereo winds quality will be quantitatively determined and characterized by comparing them to rawinsonde and aircraft winds observations. GEO-LEO stereo winds will be generated over select time periods and made available to NCEP and other operational Numerical Weather Prediction (NWP) centers for data assimilation experiments aimed at assessing their value to the accuracy of global and regional NWP forecasts.

Progress toward FY20 Milestones and Relevant Findings

Algorithm Development - ABI-VIIRS Stereo Winds Capability

Work this reporting period focused on the development and migration of functions and data associated with the ABI-VIIRS stereo winds capability from the MATLAB prototype to the GEO-GEO stereo winds capability already developed as part of STAR's Satellite Application Processing Framework environment. More specifically, this effort focused on the development of equivalent Fortran-90 software modules and integration of existing software application functions for concatenation and remapping of VIIRS imagery to the GOES-R fixed grid and the creation of a pixel-based time Look-Up Table (LUT) for VIIRS image data.

VIIRS Image Remapping

For the needed VIIRS image remapping function we decided to make use of the existing open source Polar2Grid software *(https://www.ssec.wisc.edu/software/polar2grid/)* developed at the Cooperative Institute for Meteorological Satellite Studies (CIMSS)/University of Wisconsin and funded by NOAA. Our choice to use Polar2Grid software was based on the fact that this open source code library is already being used in NOAA/NESDIS's operational polar wind product processing and we expect its use will minimize a later research to operations effort of the GEO-LEO stereo winds capability and improve the maintainability of the software in the future.

Polar2Grid is a set of command line tools for extracting data from earth-observing satellite instrument files, remapping it to standard or user defined grids, and writing the gridded data to a new file format. For our implementation we needed to use the custom grid utility to define a 2-km GOES-R grid that the VIIRS data could be remapped to. Elliptical Weighted Averaging (EWA) resampling is the default resampling method used. This method uses the size of each instrument scan to determine a weight for each pixel. All input pixels that map to output pixels are weighted and averaged.

We have successfully tested and verified the Polar2Grid functionality against the bicubic resampler function used in the MATLAB prototype software that is slightly different from EWA.

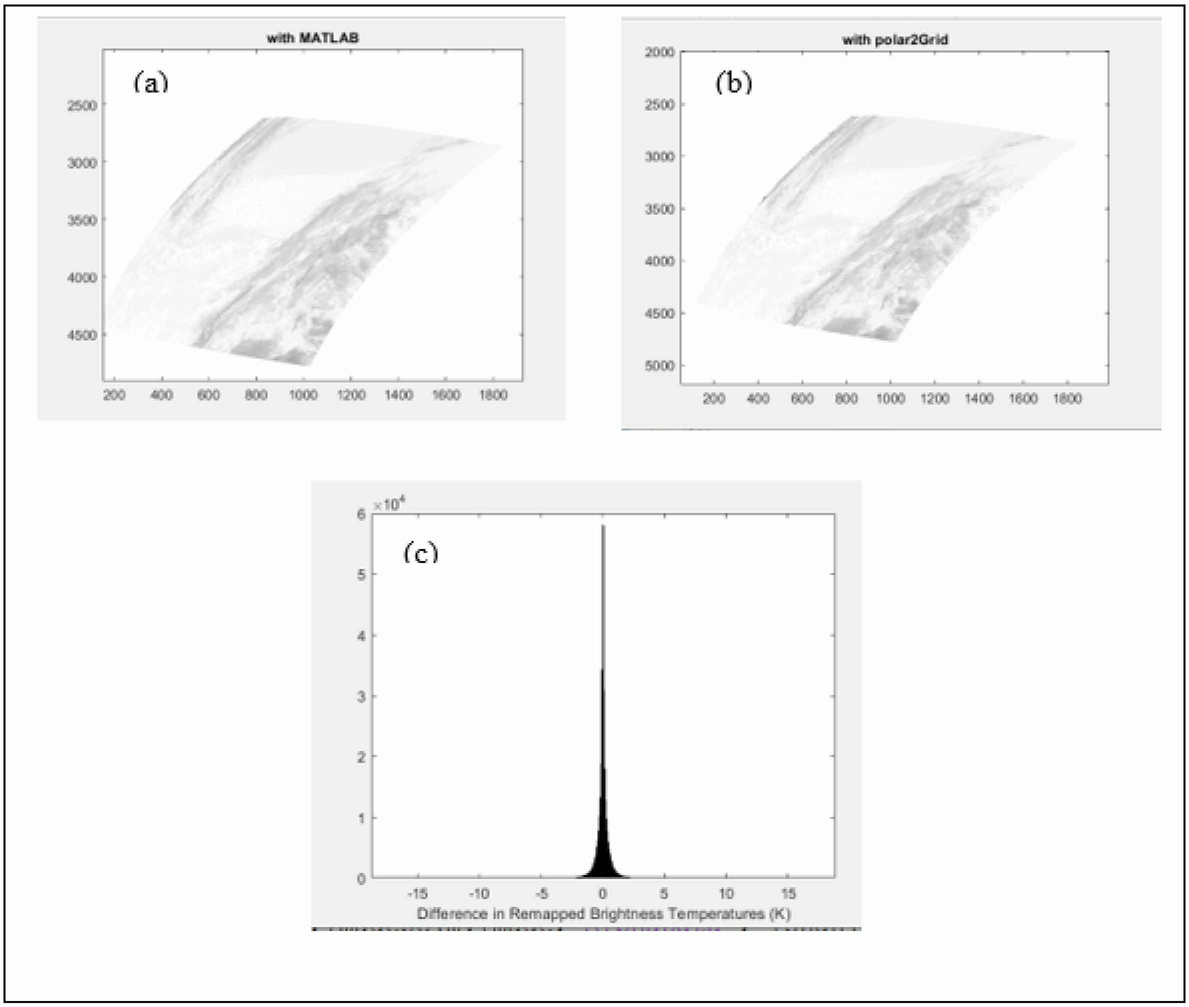

Figure 1. (a) S-NPP/VIIRS Band M15 brightness temperature image granule (2021-04-21; 1029–1035 UTC) remapped to the GOES-16 fixed grid via MATLAB prototype; **(b)** Same as in (a), but via Polar2Grid; **(c)** Histogram of brightness temperature differences from remapped images in (a) and (b).

Figure 1 shows S-NPP/VIIRS Band M15 brightness temperature images for one granule (2021-04-21; 1029–1035 UTC) that are remapped to the GOES-16 2km fixed grid via the MATLAB prototype and Polar2Grid open source tools. A histogram of brightness temperature differences from the two remapped images shows nearly identical results. This is an expected result given the differences in the remapping functions noted above and verifies the correct Polar2Grid implementation.

ABI and VIIRS Pixel Time Tags

Accurate time tagging of pixels is essential for the stereo wind application. Pixel times for the ABI are modelled based on the ABI observational mode and timeline version. For VIIRS, each center-of-scan time is used to tag the mid scan and a linear rate is used to tag pixels within each scan. Horizontal scan lines are assumed. Polar2Grid is used to remap these VIIRS pixel times to the GOES 2km fixed grid. Pixel-based Look-Up Tables (LUT) are dynamically generated for the VIIRS image data and input to the stereo model along with information on the position of the S-NPP or NOAA-20 spacecraft. Figure 2 shows an example of a S-NPP VIIRS pixel-based time LUT associate with a S-NPP/VIIRS Band M15 brightness temperature (K) image (2021-05-01; 20:10–20:24 UTC) remapped to the GOES-16 fixed grid.

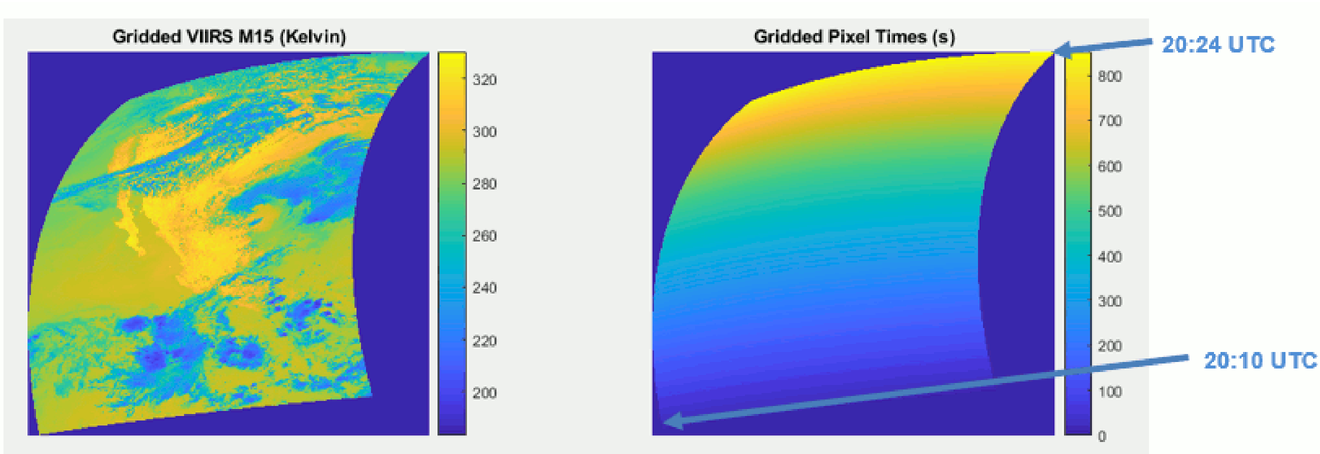

Figure 2. S-NPP/VIIRS Band M15 brightness temperature (K) image granule (2021-05-01; 20:10–20:24 UTC) remapped to the GOES-16 2km fixed grid (left) and the associated pixel times (s) (right).

ABI-VIIRS Test Cases

Here we present results of two cases where VIIRS M-band 15 data were used together with the corresponding GOES-16 CONUS ABI data to generate GOES-VIIRS stereo winds on 01 May 2021 20 UTC. The first case is a single VIIRS case involving only S-NPP and GOES-16 imagery where *STAR's Satellite Application Processing Framework software* was used to derive stereo winds. Exhaustive testing was done with this case to ensure that the remapped VIIRS imagery application and VIIRS time LUT were correct. The second case is a tandem VIIRS case involving the use of both S-NPP and NOAA-20 imagery and GOES-16 imagery where an updated version of the MATLAB prototype software was used to derived stereo winds. In each case, the GOES-VIIRS stereo winds are verified against clear-sky ground points and GOES16-GOES-17 stereo winds.

Single VIIRS Case

- GOES16-ABI/SNPP-VIIRS Stereo Winds Generated via STAR's Satellite Application Processing Framework Software
- **Day/Time:** 05-01-2021; 20 UTC
- **GEO Data:** GOES-16 band 14 image triplet (20:10, 20:20, 20:30 UTC)
- **LEO Data:** S-NPP VIIRS band M15 band (20:10 UTC – 20:24 UTC)

The composite GOES-16 ABI band 14 and remapped S-NPP VIIRS M15 band imagery used in this test case is shown in Figure 3. The imagery overlap between the ABI and VIIRS imagery is depicted in the violet color and is where the stereo winds are retrieved. Figure 4 shows the times of the ABI and VIIRS data used in the stereo retrieval process and are plotted versus the row number in the remapped image. For GOES-16, there are three lines (yellow, orange, and blue) showing the times of data from each FD image in the image triplet – note that 10 minutes separates these lines reflecting the ABI Mode 6 timeline. The GOES-16 times progress as the row number increases from north to south with a staircase signature indicative of the ABI swath transitions. The VIIRS times (purple) progress as the row number decreases south to north indicating an ascending orbit.

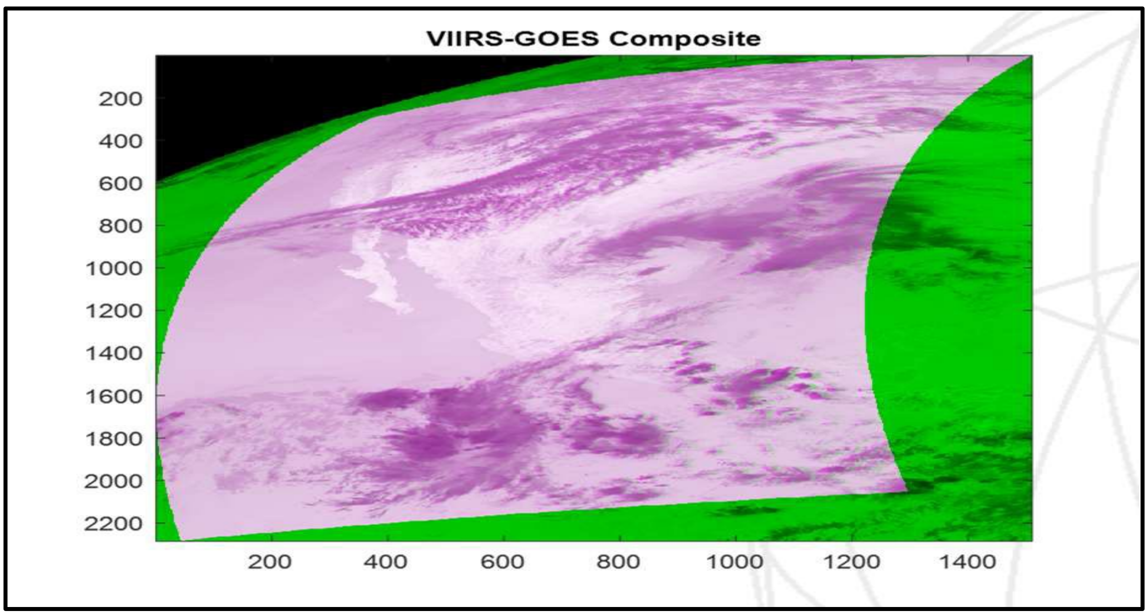

Figure 3. SNPP/VIIRS-GOES16/ABI composite image where the green color shows GOES-16 FD image at 20:20 UTC and the violet shows the overlapping SNPP image (20:10–20:24 UTC).

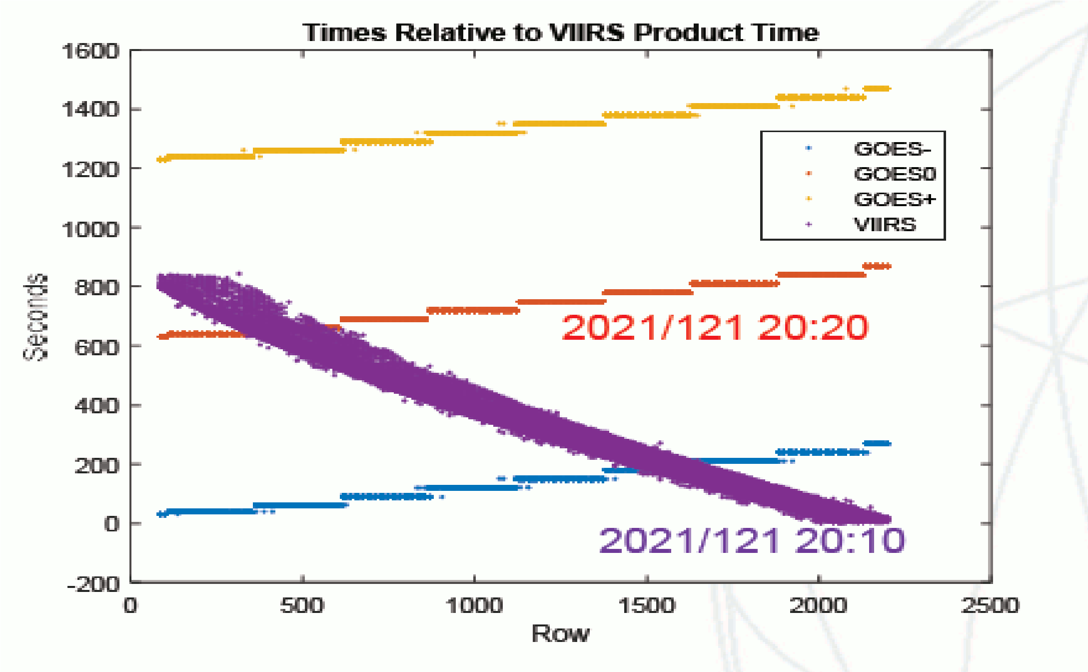

Figure 4. Pixel times of the collocated ABI and VIIRS data used in the stereo retrieval process.

The retrieved GOES16/S-NPP stereo winds are illustrated in Figure 5. Qualitatively, the retrieved stereo winds nicely capture the mid and upper levels circulation around the low pressure system in south-eastern Texas and the fleet of fast (> 50kts) upper levels winds associated with a frontal boundary oriented southwest to northeast and extending from the California coast to Montana.

Quantitative verification of the stereo approach involves validating tracked stationary ground points under clear-sky conditions. The clear-sky ground-point stereo retrievals provide an excellent indication of the accuracy of the stereo retrievals since the expected velocities (zero) and elevations of tracked ground points from terrain models are known. Figure 6 shows the locations of the clear-sky ground-point stereo retrievals and shows the verification plots associated with these. All stereo ellipsoid-height retrievals locations that are over land are plotted versus the underlying terrain height. The separation of truly clear scenes and other scenes that may not be totally free of clouds is obvious with the truly clear scenes falling on and around the one-to-one line. Retrieved height errors associated with these clear-sky ground scenes are estimated by differencing the retrieved height from the known terrain height. Retrieved u- and v- wind component errors are estimated by differencing the retrieved u- and v- wind components from zero. The histograms are well behaved and resemble a normal distribution with mean bias errors of 47m, 0.11 m/s, and -0.06 m/s for the height, u-wind component, and v-wind component, respectively.

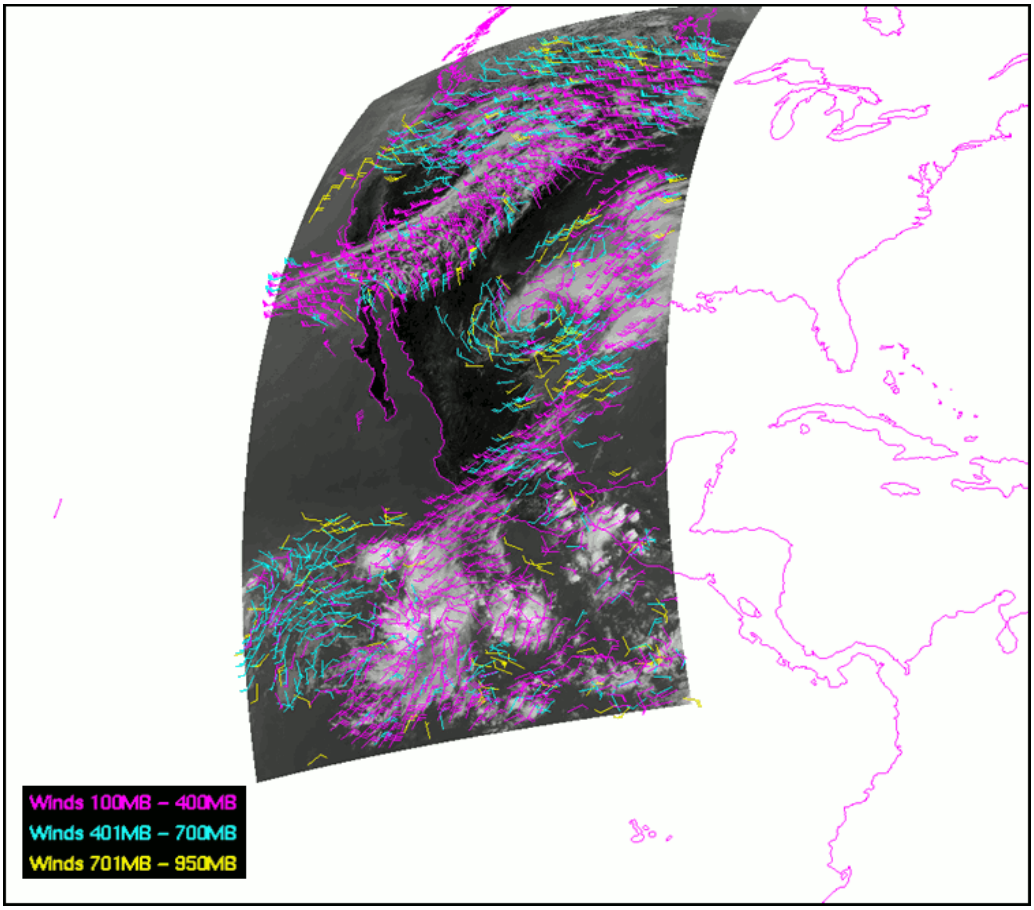

Figure 5. Retrieved GOES16/S-NPP stereo winds (05-01-2021; 20:20 UTC) illustrated as wind barbs (top), histograms of u and v components of the winds (lower left), and histogram of stereo heights associated with the retrieved winds (lower right).

Further verification of the retrieved GOES16-ABI/SNPP-VIIRS stereo winds for this case can be done by comparing them against GOES16 ABI/GOES17 ABI stereo winds for the same time. The retrieved heights and the u-/v- wind components associated with these winds are shown in Figure 7. Comparisons between the collocated (to within 4km) GOES16-ABI/SNPP-VIIRS and GOES16 ABI/GOES17 ABI stereo winds are shown in Figure 8.

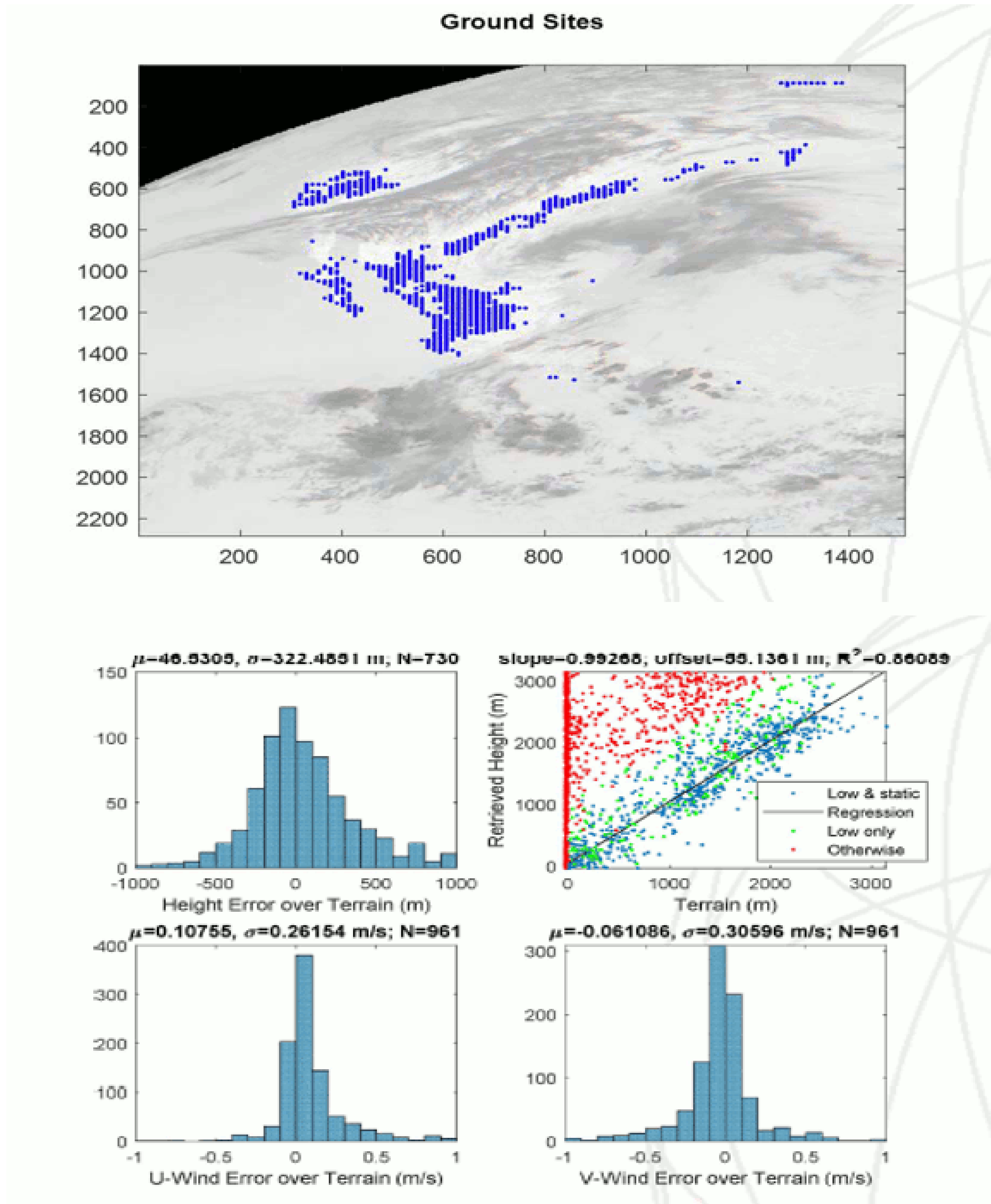

Figure 6. Location of clear-sky ground-point stereo retrievals (top) and verification of retrieved heights, u-wind component, and v-wind component.

The retrieved heights and wind components between the two sets of stereo winds compare quite well. We expect that even closer agreement between the retrieved height and wind components can be achieved if we ensure that the target scenes between the two datasets are identical. We plan to pursue this in future tests. These comparison results, together with the clear-sky ground point comparisons discussed earlier, provide a clear indication that the newly developed image remapping and pixel time LUT are working correctly, thus enabling good stereo winds to be generated from a GOES16-ABI triplet and VIIRS swath.

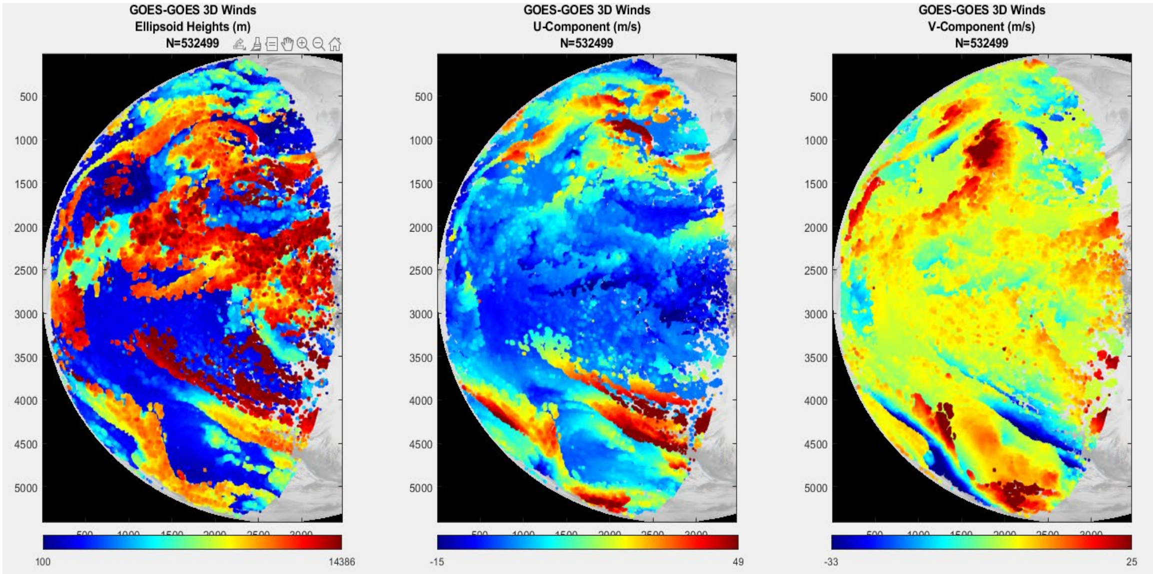

Figure 7. GOES16 ABI/GOES17 stereo winds (05-01-2021; 2020 UTC)

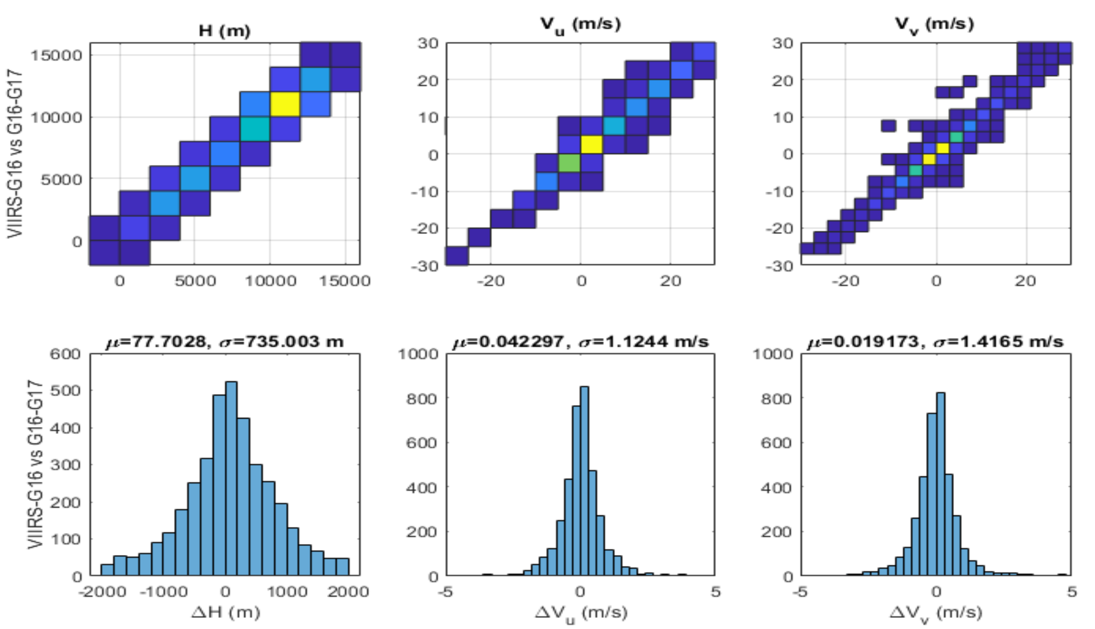

Figure 8. Comparison of retrieved GOES16/S-NPP and GOES16 ABI/GOES17 stereo winds (H, u, v) (05-01-2021; 2020 UTC)

Tandem VIIRS Case

- GOES16-ABI/SNPP-VIIRS Stereo Winds Generated via MATLAB Prototype Software
- **Day/Time:** 05-01-2021; 19:50 UTC
- **GEO Data:** GOES-16 band 14 image triplet (19:40, 19:50, 20:00 UTC)
- **LEO Data:** S-NPP VIIRS band M15 (20:10 UTC – 20:24 UTC);
  NOAA-20/VIIRS band M15 (19:20 UTC – 19:37 UTC)

The composite GOES-16 ABI band 14, remapped S-NPP VIIRS M15 band, and NOAA-20 VIIRS M15 band imagery used in this test case is shown in Figure 9. The imagery overlap between the ABI and the tandem VIIRS imagery is depicted in the violet color and is where the stereo winds are retrieved. Figure 10 shows the pixel times of the collocated GOES16/ABI, SNPP/VIIRS, and NOAA20/VIIRS data used in the stereo retrieval process for this case. The orbital tracks of SNPP and NOAA-20 and the locations of the retrieved ABI and tandem VIIRS stereo winds are also visualized for reference in this figure.

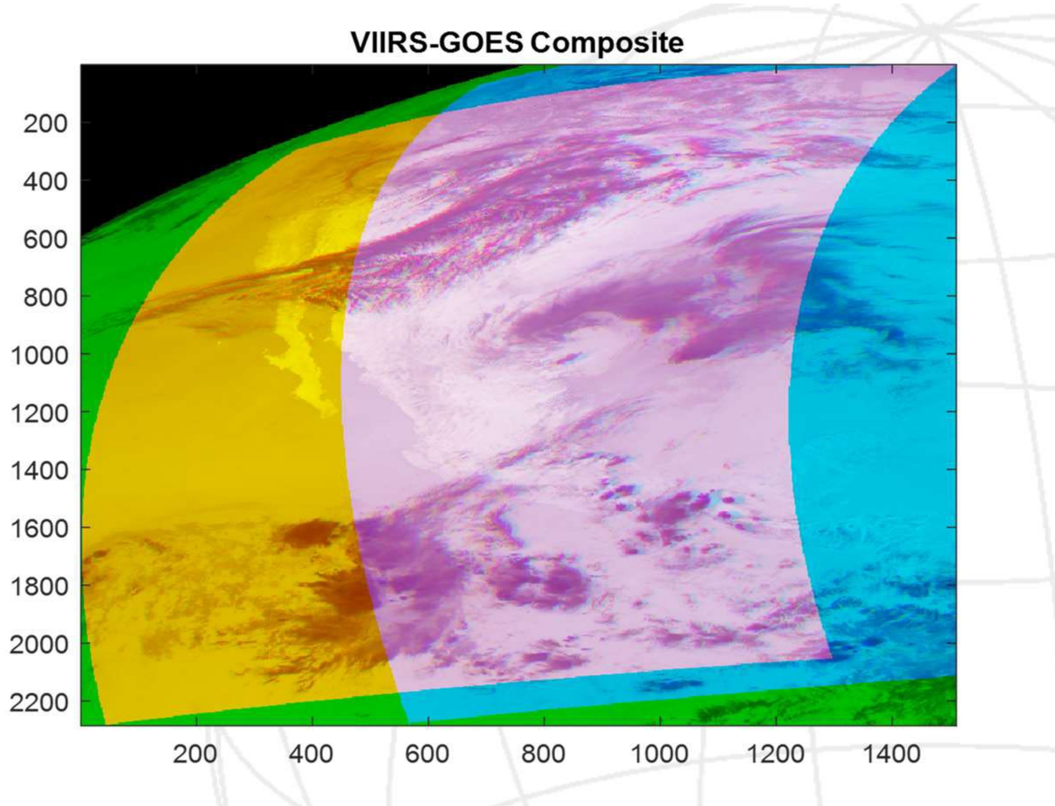

Figure 9. Composite image GOES-16/ABI FD (green), SNPP/VIIRS (gold), and NOAA20/VIIRS (blue). The violet shows the overlap among these images.

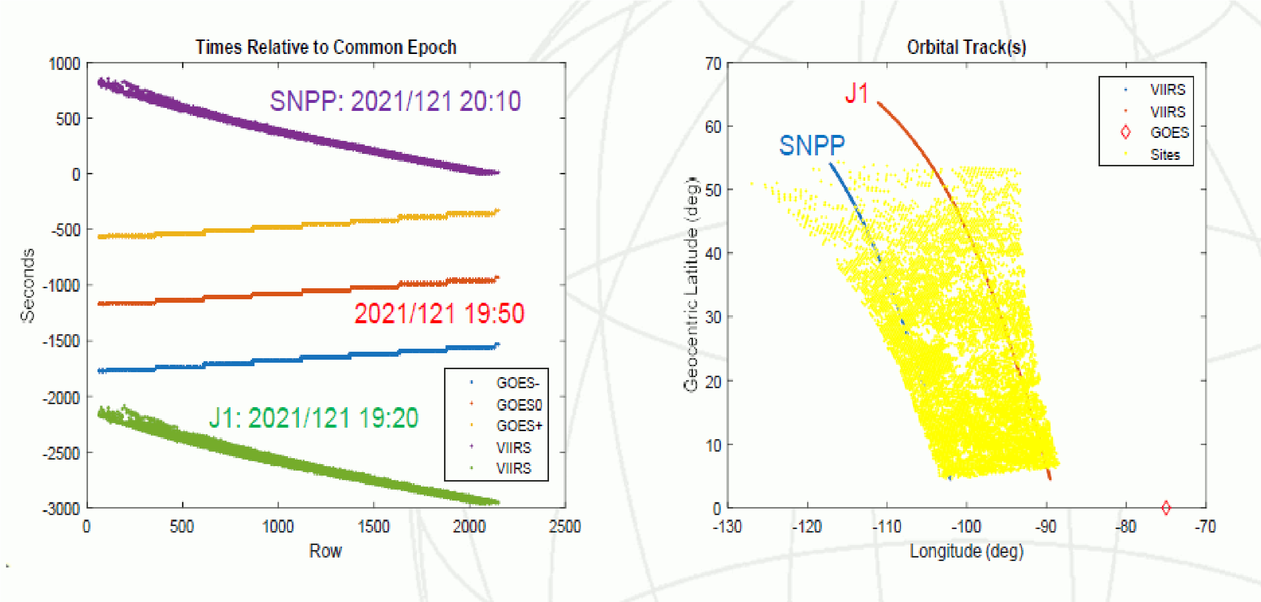

Figure 10. Pixel times of the collocated GOES16/ABI, SNPP/VIIRS, and NOAA20/VIIRS data (left). Orbital tracks of SNPP and NOAA20 and stereo retrieval locations (right) for the tandem VIIRS test case.

The retrieved GOES16/SNPP/NOAA20 stereo winds are illustrated in Figure 11. Histograms of the retrieved u-wind components, v-wind components, and stereo heights associated with the retrieved winds are also shown. The first thing to note is that the coverage of these winds corresponds to the overlap area involving all of the sensors as indicated by the violet area in Figure 9. Qualitatively, these retrieved stereo winds look quite good and nicely capture the winds associated with the low pressure system in south-eastern Texas and the fleet of fast (> 50kts) upper levels winds associated with a frontal boundary oriented southwest to northeast and extending from the California coast to Montana.

Figure 12 shows the locations of the clear-sky ground-point stereo retrievals and shows the verification plots associated with these. As discussed before, all stereo retrievals locations that are over land are plotted versus the underlying terrain height. The separation of truly clear scenes and other scenes that may not be totally free of clouds is obvious with the truly clear scenes falling on and around the one-to-one regression line. Retrieved height errors associated with these clear-sky ground scenes are estimated by differencing the retrieved height from the known terrain height. Retrieved u- and v- wind component errors are estimated by differencing the retrieved u- and v- wind components from zero. The histograms are well behaved and resemble a normal distribution with mean bias errors of 91m, 0.07 m/s, and 0.03 m/s for the height, u-wind component, and v-wind component, respectively.

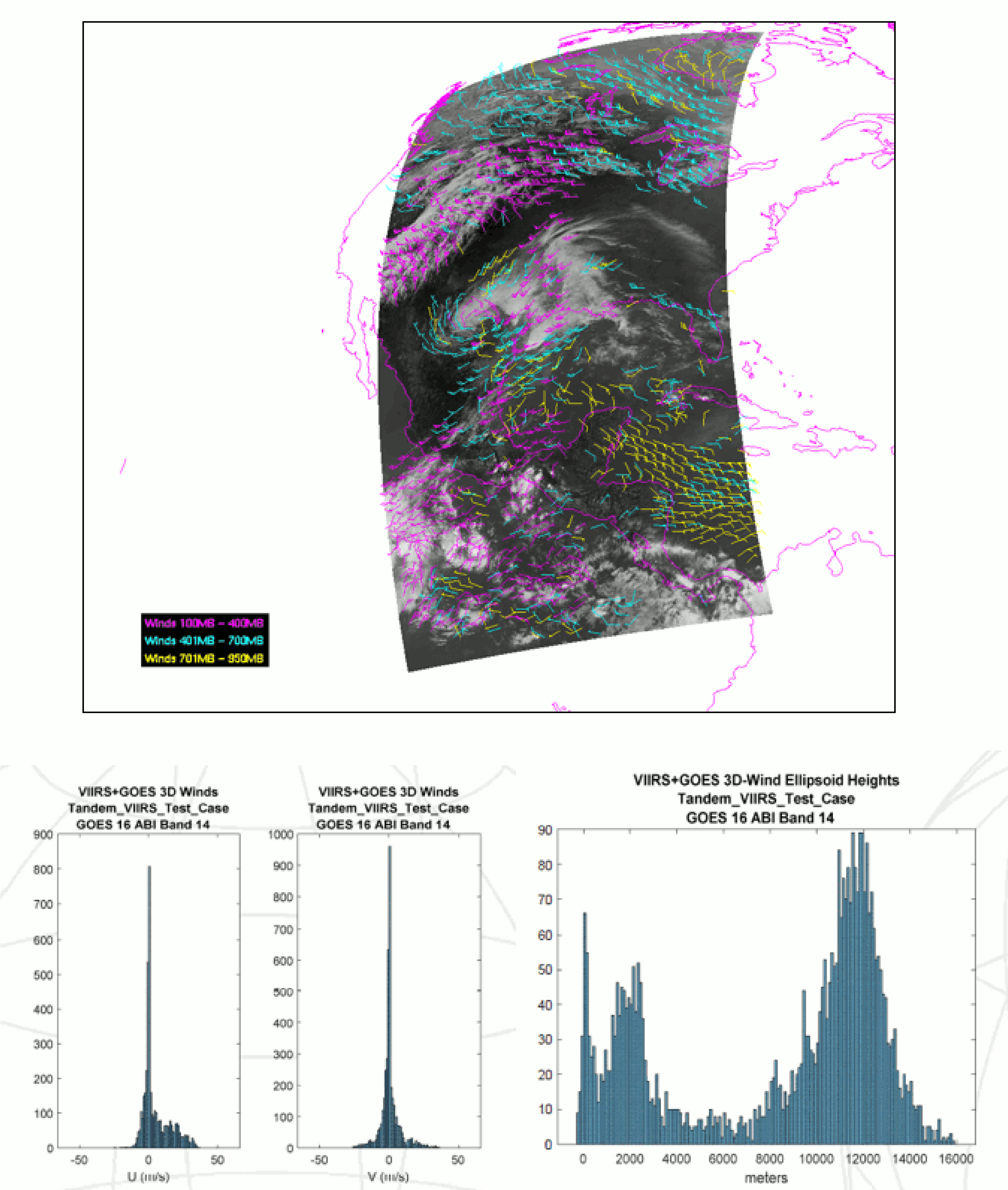

Figure 11. Retrieved GOES16/SNPP/NOAA20 stereo winds (05-01-2021; 19:50 UTC) illustrated as wind barbs (top), histograms of u and v components of the winds (lower left), and histogram of stereo heights associated with the retrieved winds (lower right).

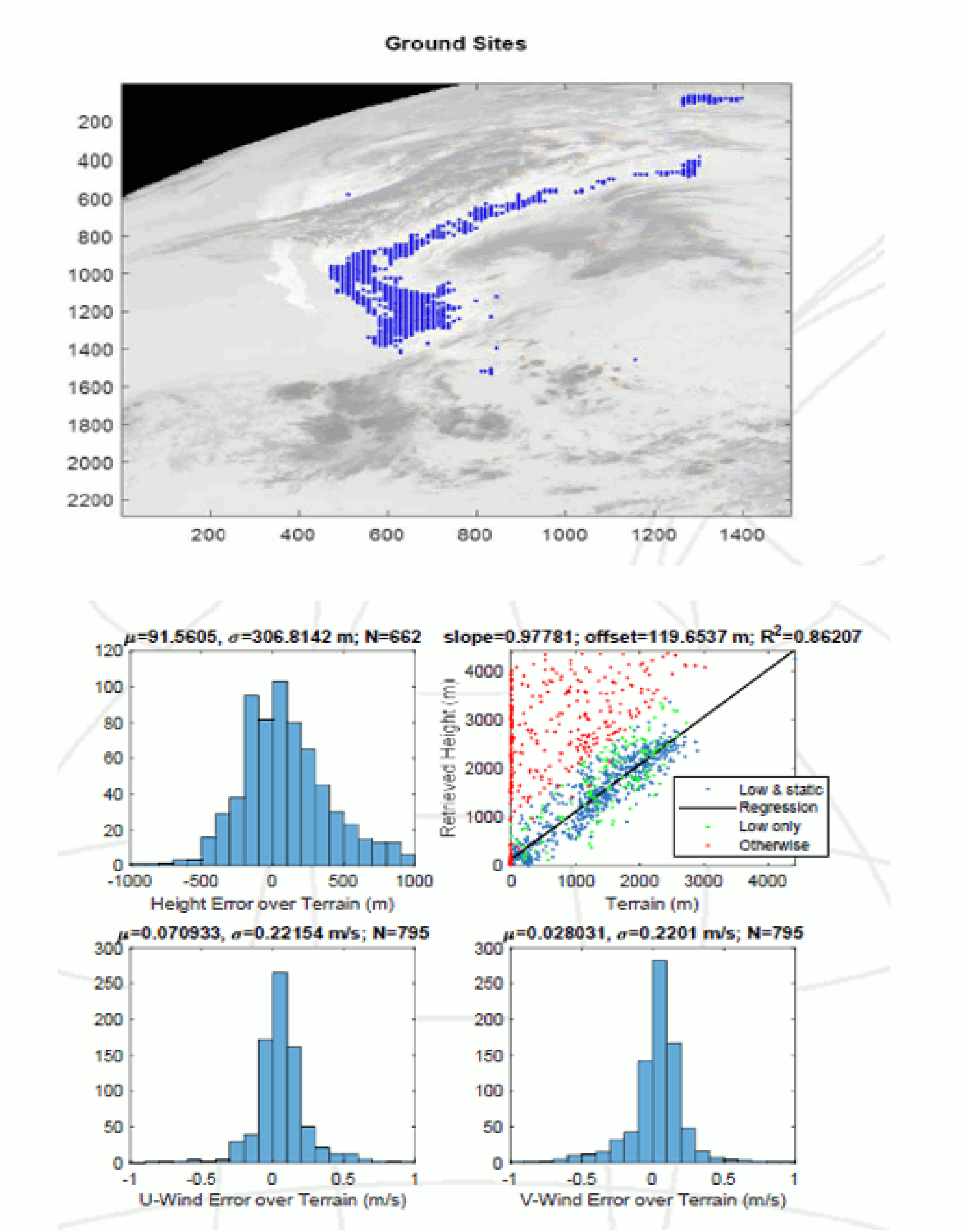

Figure 12. Location of clear-sky ground-point GOES16/SNPP/NOAA20 VIIRS stereo retrievals (top) and verification of retrieved heights, u-wind component, and v-wind component.

Direct Broadcast 3D Stereo Winds Test Case via MATLAB Prototype

As a first step in the development of a capability to use VIIRS data obtained from NOAA's Direct Broadcast Network (DBNET), we acquired a Direct Broadcast (DB) VIIRS M15 band dataset, updated the ABI-VIIRS MATLAB prototype stereo winds software to process the DBNET VIIRS data, and successfully generated a NOAA20/VIIRS-GOES17/ABI stereo wind product from these data.

The DB NOAA20/VIIRS M15 band SDR and geolocation datasets for 09-24-2021 21 UTC were provided by Louis Nguyen (NASA/LaRC). These DB datasets were captured through an Amazon Web Service (AWS) Ground Station and the VIIRS SDR dataset was created with the Community Satellite Processing Package (CSPP). We also acquired the corresponding NOAA20/VIIRS SDR data from NOAA's Comprehensive Large Array-data Stewardship System (CLASS) to use it as a reference to verify the correct processing of the slightly different (highlighted in Table 1) DB VIIRS data by the ABI-VIIRS MATLAB prototype software. We compared the DB and CLASS VIIRS M15 band radiances and pixel geolocations and verified that they were identical. We also verified that the stereo winds software correctly identified and processed missing radiance data correctly. Composite NOAA20/VIIRS M15 band SDR (violet)

	CSPP Direct Broadcast (DB)	**NOAA CLASS**
SDR data	Single granules (86s of data)	Aggregates 4 consecutive granules with geolocation (approximately 6 minutes of data) into a single file (HDF-5 format)
Geolocation Files	Ellipsoid Terrain Corrected (TC) GITCO (I-Band) and GMTCO M-band) geolocation files	Ellipsoid GIMGO (I-band) and GMODO (M-band) geolocation files
Missing Data (bowtie data deletions)	DQF=2	bitand(DQF,2)=1

Table 1. Differences between VIIRS SDR data collects from CSPP DB and NOAA CLASS.

and GOES17/ABI Band 14 (green) imagery for DB and CLASS acquired VIIRS data is shown in Figure 13. Retrieved GOES17/ABI-NOAA20/VIIRS Stereo heights, u-wind components, and v-wind components using the DB acquired VIIRS data are displayed in Figure 14. When compared to same retrieved data (not shown), but using the CLASS acquired VIIRS data, very similar results are achieved. These comparisons are shown in Figure 15. Exact results are not expected since the retrieval site locations are different between DBNET and CLASS given differences in the VIIRS footprints.

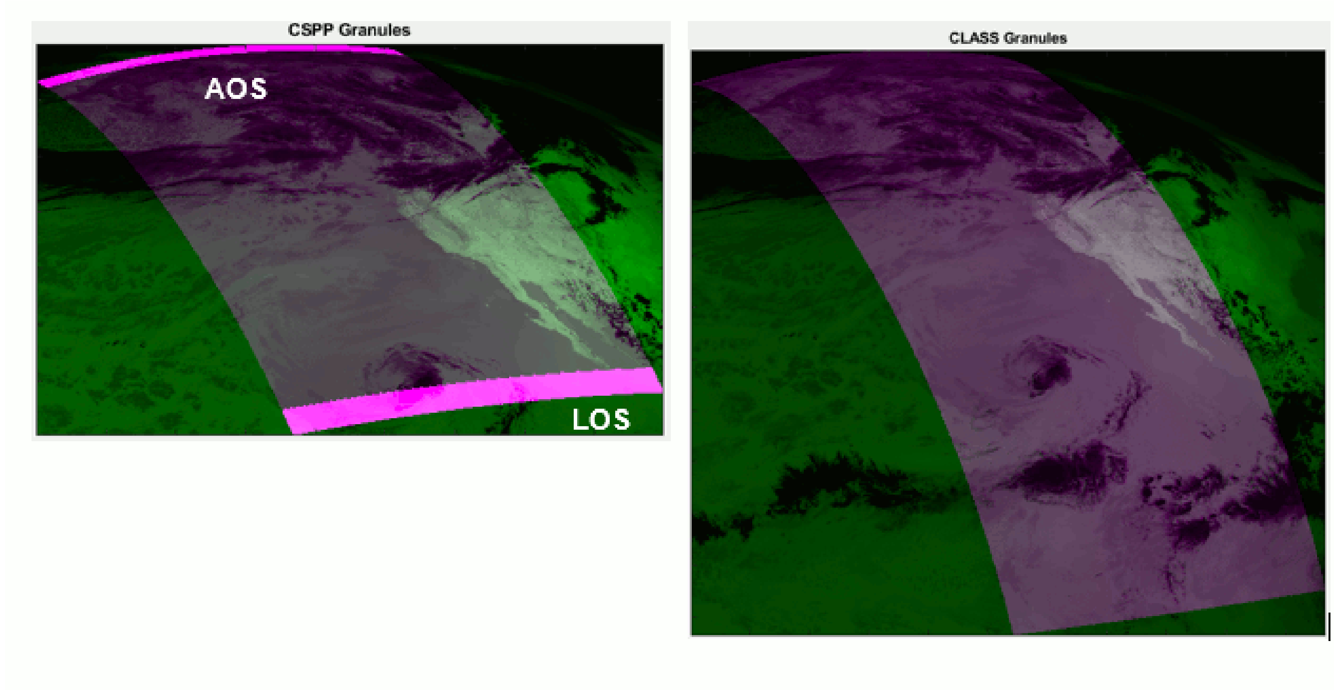

Figure 13. Composite NOAA20/VIIRS M15 band SDR (violet) and GOES17/ABI Band 14 (green) image on 09-24-2021 21 UTC. DB collected VIIRS data is on the left and from NOAA CLASS on the right.

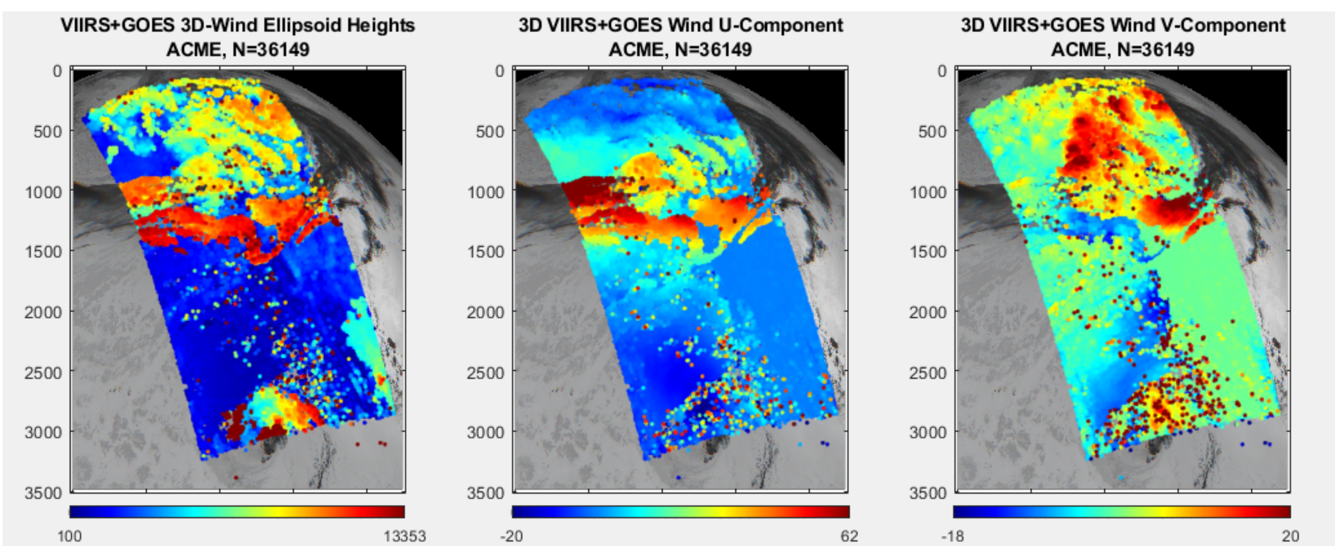

Figure 14. Retrieved GOES17/ABI-NOAA20/VIIRS Stereo heights (left), u-wind component (center), and v-wind component (right) on 09-24-2021 21 UTC.

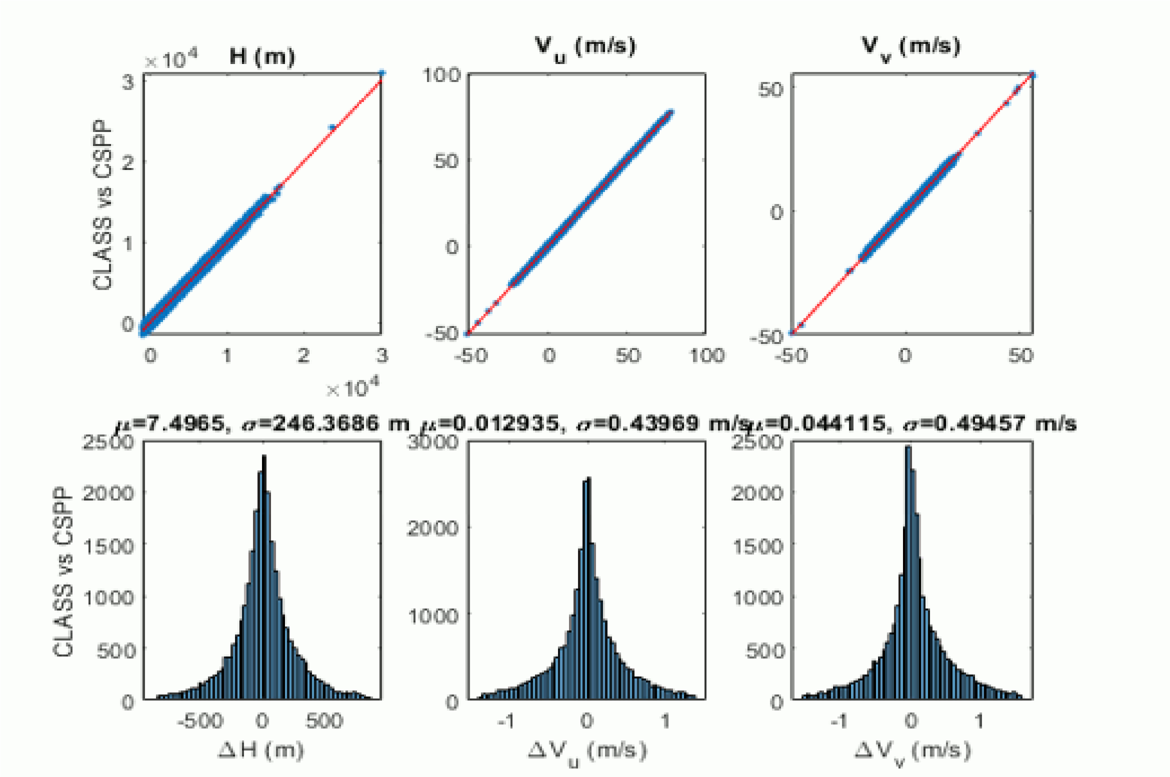

Figure 15. Scatter plots (top) and histograms of differences of retrieved GOES17/ABI-NOAA20/VIIRS Stereo heights, u-wind components, and v-wind components on 09-24-2021 21 UTC when using VIIRS data acquired from DB versus when acquired from CLASS.

While we have demonstrated that we can correctly generate GOES-VIIRS stereo winds using VIIRS data acquired from a DB site, the following things to be considered if and when VIIRS DB data is used for the operational production of GOES-VIIRS stereo winds.

- Need awareness of satellite overpasses to schedule antennas
- Minimize latency by organizing processing around granules
- Need to buffer content from prior granule to complete templates at boundaries of current granule being processed.

Plans for Next Reporting Period

- Complete development and testing of GOES-VIIRS stereo winds software in STAR's Satellite Application Processing Framework environment
- Generate GOES-VIIRS stereo winds in STAR's Satellite Application Processing Framework environment for several case studies and verify results.
- Complete scripting to enable an end-to-end demonstration of the GOES-VIIRS stereo winds in STAR's Satellite Application Processing Framework environment

- Generate GOES-VIIRS stereo winds over a period of a month or more and validate quality of retrieved stereo winds against spatially and temporally collocated NESDIS operational GOES winds and rawinsonde winds.