EXPLORING THE BEHAVIOR OF ATMOSPHERIC MOTION VECTOR (AMV) ERRORS THROUGH SIMULATION STUDIES

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Abstract

The expected launch of the GOES-R satellite is 2015. As part of a NOAA/NESDIS risk reduction effort, the Cooperative Institute for Meteorological Satellite Studies (CIMSS), in cooperation with NOAA's GOES-R Algorithm Working Group (AWG), established the GOES-R Analysis Facility for Instrument Impacts on Requirements (GRAFIIR) analysis tool to evaluate potential instrument noise effects on many GOES-R products, including imagery, clouds, derived products, and Atmospheric Motion Vectors (AMVs). GRAFIIR is being used to assess effects due to potential instrument noise on user and product requirements, for considerations by the GOES-R Program Office.

Simulated GOES-R Advanced Baseline Imager (ABI) Top of Atmosphere (TOA) radiances derived from the Weather Research and Forecasting (WRF) model, and the CIMSS fast solar/infrared forward model are used within the Geostationary Cloud Algorithm Testbed (GEOCAT) framework to produce AMVs. The use of GEOCAT is a departure from the current operationally-derived GOES AMVs, but is employed in this study since this framework will mimic what will be in place for the GOES-R ground system data processing after launch. Adaptive changes to the operational feature-tracking algorithms were necessitated for inclusion into GEOCAT. For example, pixel-level cloud heights derived from the AWG cloud team algorithms are used in the AMV height assignment routine.

As a first step, unaltered TOA radiances ("Pure", no noise) are used to derive a baseline set of AMVs. The TOA radiances are then altered at 1- and 3-times the ABI threshold specifications with different induced noise effects, including calibration offsets and navigation shifts. AMV datasets are then derived with the above instrument effects for a selected case study time period, and are compared to the WRF model U and V wind fields ("truth") to assess which effects are most sensitive on the AMV processing software routines within the GEOCAT framework. The results will provide important tolerance guidance to the GOES-R Program Office in the final determination of allowable instrument specification thresholds.

An ABI simulation of Hurricane Katrina is used to explore the sensitivity of the AMV algorithm to temporal and horizontal resolution changes. This is a brief exploration of this dataset as it has just been formatted to work with the AMV software. A detailed analysis will be worked on after these proceedings are published.

INTRODUCTION

In preparation for the launch of the next generation of U.S. Geostationary Operational Environmental Satellites (GOES-R series), the GOES-R AWG is heavily involved in derived product algorithm development and demonstration studies. These algorithms will be required to work in an operational demonstration environment.

AMVs are one of the AWG products, and an AWG team has been formed to ready the AMV algorithms for expected GOES-R inputs. To accomplish this, we employ proxy datasets in the form of simulations produced by numerical weather prediction (NWP) model output. The model output are converted to the form of simulated radiances and images, which can provide the unique opportunity to compare AMVs derived from the simulated image sequence with the “true atmospheric state” model winds for validation of imposed noise effects.

GOES-R ABI SIMULATION

This section details work on a Continental United States (CONUS) simulation which mimics one of the proposed scan segments on the future ABI (Schmit et al 2005). The simulation was performed at the National Center for Supercomputing Applications (NCSA) at the University of Illinois at Urbana-Champaign. Simulated atmospheric fields were generated using the WRF model. It was initialized at 00 UTC on 04 June 2005 with 1° GFS data and then integrated for 30 hours using a triple-nested domain configuration. The outermost domain covers the entire GOES-R viewing area with 6-km horizontal resolution while the inner domains cover the CONUS and mesoscale regions with 2-km and 0.667-km horizontal resolution, respectively (Otkin et al 2009). Prognostic WRF model variables are used as input into the CIMSS Forward Model System (CFMS), which includes modules to compute the optical depth due to gases at each layer of the atmosphere, models and databases to specify surface radiative and cloud scattering properties, and the method used to solve the radiative transfer equation for solar reflectances (ABI Bands 1-6) and IR radiances (ABI Bands 7-16) at the TOA. After an initial 6-hour spin up, TOA radiances/reflectances were calculated every 30 minutes. For a 2-hour period in the middle of the simulation, radiances/reflectances were calculated every 1-minute. The TOA radiance/reflectances were then remapped from the WRF model projection to an ABI like geosynchronous projection. Fig. 1 shows an example of simulated ABI and corresponding real GOES-12 IR/WV images.

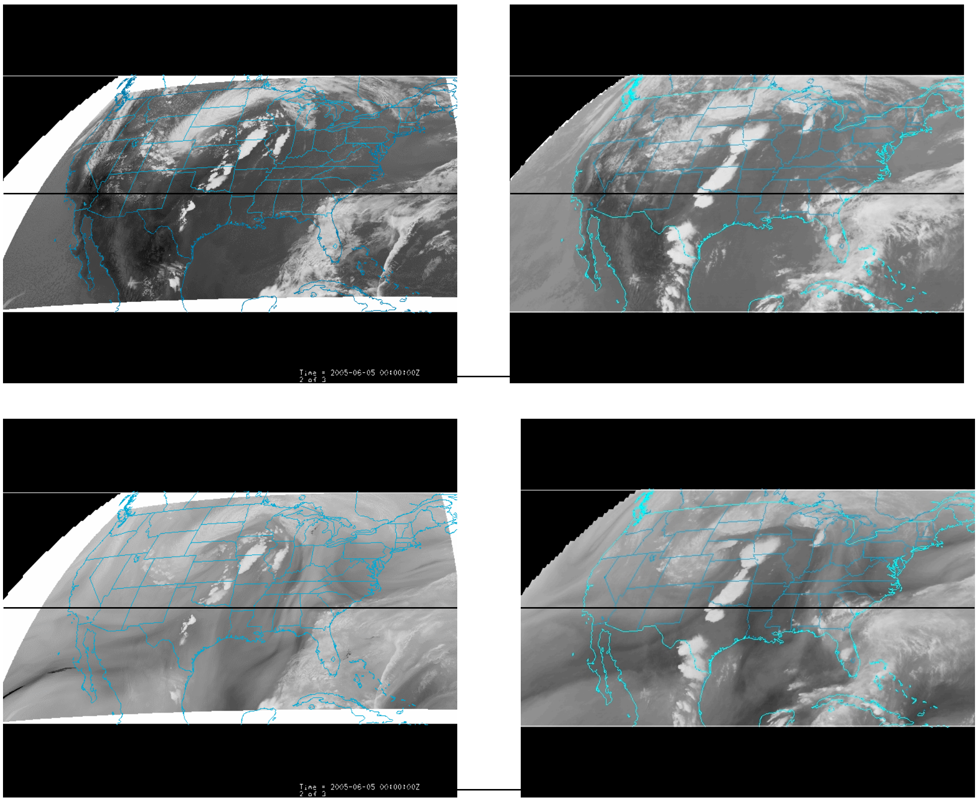


***Figure 1*: At left and top, simulated 11.2 μm imagery from the GOES-R ABI. At right and top, 10.7 μm imagery from the GOES-12 imager. Bottom left, simulated 6.19 μm imagery from the ABI. Bottom right, 6.5 μm imagery from the GOES-12 imager. The simulated data captures the general features and locations well. Differences can be observed in some of the cloud structures.**

SIMULATED AMVs: RETRIEVAL AND ANALYSIS STRATEGY

The use of GEOCAT is a departure from the current operationally derived GOES AMVs, but is still grounded within the NESDIS/CIMSS AMV algorithms (Nieman et al, 1997, Velden et al, 2005). A set of 3 precisely calibrated, navigated, and co-registered simulated images from the WRF model output for selected spectral channels are used as initial inputs to the AMV algorithm, and this comprises the unaltered “pure” or “baseline” AMV dataset. The automated GEOCAT algorithm is used to target, height assign, track, and quality control (QC) the AMV fields from these simulated images. This procedure is then repeated, except the simulated images are altered with various noise effects including striping and navigation offsets at 1 and 3 times the proposed GOES-R satellite specifications. Finally, a quantitative error analysis on the resultant AMV field is performed using an objective toolkit called GRAFIIR to deduce the effects of the imposed instrument noise on the derived AMV products.

EXPLANATION OF GRAFIIR

The GRAFIIR data analysis tool was developed to facilitate the potential impacts of instruments not meeting specifications on derived product requirements. As of now, it is a loose collection of individual tools used to assess GOES-R data products (i.e. imagery, clouds, soundings, winds, etc.) in a consistent way to ensure that instrument noise effects on the products can be adequately characterized. See the flow chart in Fig. 2 for a more detailed look at GRAFIIR.

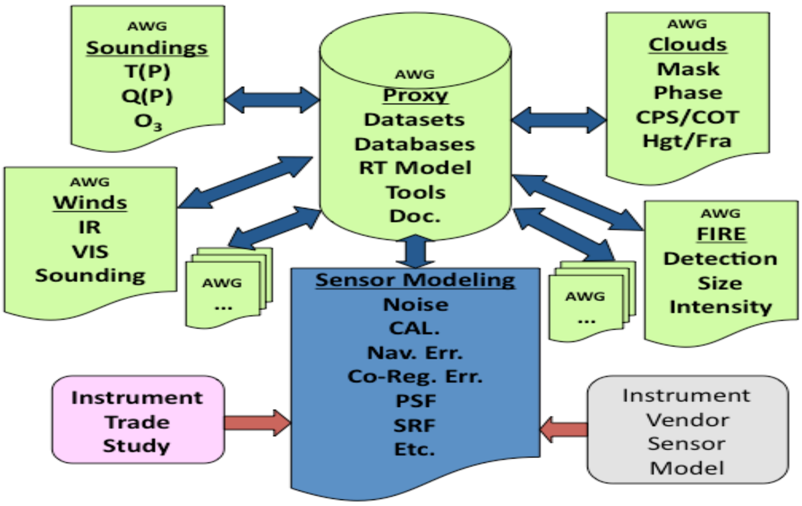


Figure 2: **Flow chart for the GOES-R Facility for Instrument Impacts on Requirements (GRAFIIR) concept.**

EVALUATION

The GOES-R program office has selected the mean vector difference (MVD) and standard deviation (SD) as the quality metrics for GOES-R AMVs. The vector difference between an AMV and “truth” (in this case the AMVs are compared to the WRF model U/V wind fields) is defined as:

$$(VD)_i = \sqrt{(U_i - U_r)^2 + (V_i - V_r)^2}$$

Where U_i/V_i are the AMV wind components, and U_r/V_r are the truth wind components. The MVD is simply the mean of all of the vector differences in an AMV set.

$$MVD = \frac{1}{N}\sum_{i=1}^{N}(VD_i)$$

The standard deviation follows:

$$SD = \sqrt{\frac{1}{N}\sum_{i=1}^{N}((VD_i) - (MVD))^2}$$

For a given AMV field to be within 100% spec, the MVD has to be less than or equal to 7.5 m/s, and the SD has to be less than or equal to 3.8 m/s (as determined by the GOES-R Performance and Operational Requirements Document (PORD) specifications).

EXAMPLE 1: IMPOSED ABI NAVIGATION ERROR – METHODOLOGY AND RESULTS

The PORD specification for navigation error is +/- 21 microradians (~0.75 km). This error is simulated in a random pixel-by-pixel manner. Each pixel is given a random compass direction between 0 and 359.99 degrees, and a random, normally distributed (about 0) shift equivalent of 21 microradians. New pixel positions are generated using the random shift and direction. Finally, the radiances are then linearly interpolated to these new positions. This is done at 1 times and 3 times the specifications. The resulting effect is a new image, on the original grid, but with an altered radiance field (Fig. 3). The largest impact is observed in the cloud edges.

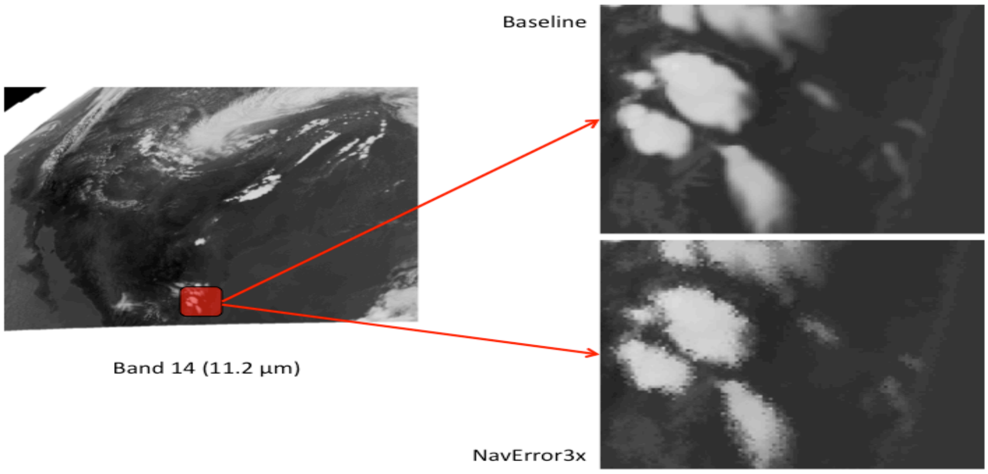


Figure 3: **Example of 3 times spec navigation error applied to the simulated ABI band 14 TOA. Note the large changes in the cloud edges of the NavError3X image.**

As expected, the increased navigation error has an impact on AMV fields. Figure 4 below shows AMV fields derived from images at 5-minute intervals produced from unaltered “pure” radiances (yellow) and 3 times the navigation error spec (blue). The image on the left shows low-level IRW (IR-Window channel) AMVs. A noticeable decrease in density is observed with the NavError3X AMVs when compared to the “baseline” field. A bit subtler is the general slowing and bending away from the baseline field. The image on the right shows upper level IRW AMVs. Again, there is a decrease in density from NavError3X to “baseline”. The biggest difference is the inability of the NavError3X AMV field to adequately define the closed upper level low.

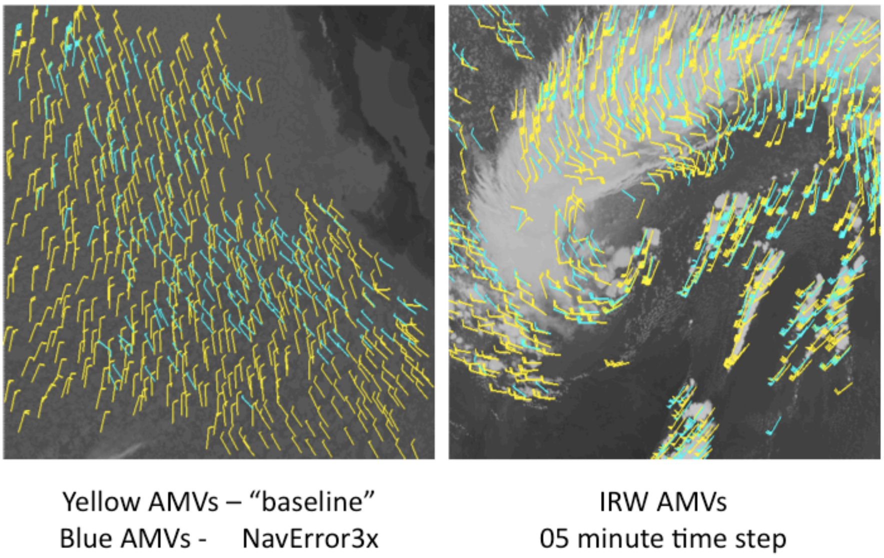


Figure 4: **Example AMV fields using images at 5-min. intervals produced from unaltered TOA (yellow) and 3 times the navigation error spec (blue). The image on the left side shows low-level IRW AMVs. The image on the right side shows upper level IRW AMVs.**

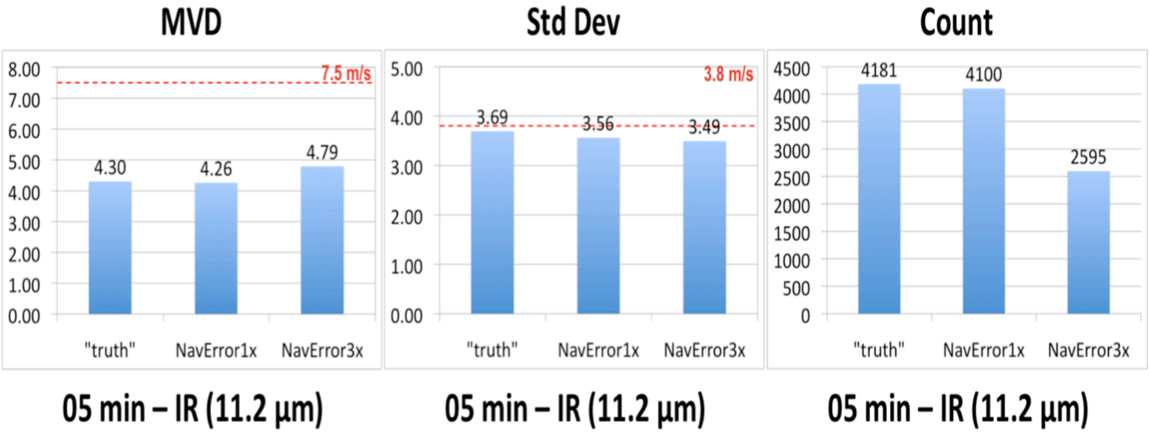


Figure 5: **MVD, SD, and match count for IRW AMV fields using images at 5-min. intervals produced from unaltered TOA, 1 times the navigation error spec, and 3 times the navigation error spec, compared to WRF model U/V "truth".**

Figure 5 shows the mean vector difference, standard deviation, and number of IRW AMVs for datasets produced from 5-min sequence images, compared against the WRF model U/V fields. The red dashed line is 100% spec. Although the NavError3X AMVs quality degrades, it is still within specification. However, 40% of the AMVs are lost when compared to the "baseline".

EXAMPLE 2: IMPOSED ABI STRIPING ERROR – METHODOLOGY AND RESULTS

The GOES-R PORD specification for striping error is that it should be less than specification instrument noise (0.1 K at 300 K for IR bands 7 - 15, 0.3 K for band 16). If we assume a detector array consists of 100 detectors in the north/south direction, 1 detector is chosen to be bad. Every 100th line has striping error applied by adding a radiance offset equal to the specification noise to the chosen bad scan line. This was done at 1 times and 3 times the specification value for instrument noise. Figure 6 shows a differenced image of the brightness temperature values between the unaltered band 8 (6.19 µm) and 3 times the striping specification in band 8.

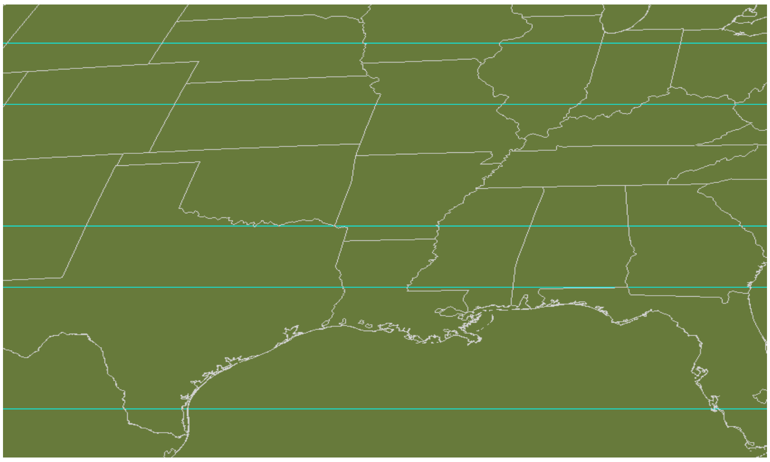


Figure 6: **Difference image between a simulated field of band 8 unaltered data, and the same field but with 3 times the striping specification for selected scan lines. The stripes at the selected scan lines show radiance differences. Green background represents no difference.**

Figure 7 shows the effect of 3 times the striping spec on simulated images to derive clear sky water vapor AMVs (band 8). The image to the left shows the AMVs derived from a 15-minute image triplet produced from unaltered radiances. The image to the right shows the AMVs derived from a 15-minute image triplet using radiance fields with 3 times the striping effects. The highlighted ovals contain extra AMVs that are the result from tracking the striping.

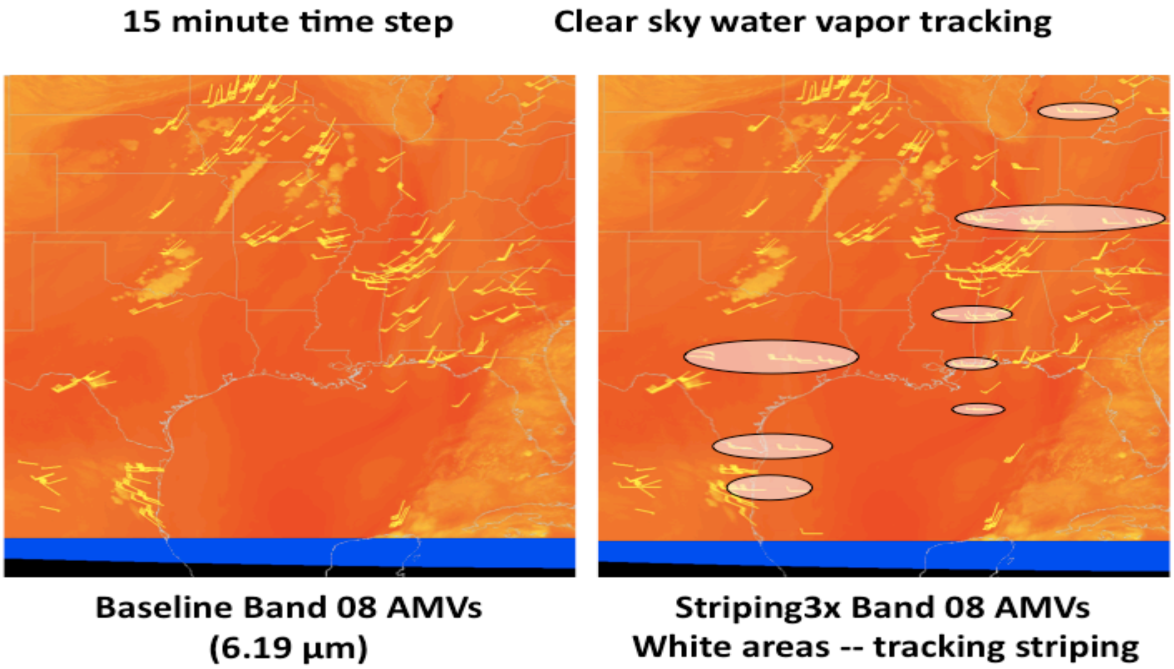


Figure 7: **Simulated clear sky water vapor AMVs showing the results of modifying the radiances with 3 times striping spec. Left image shows unaltered TOA radiance AMVs. Right image is identical to the unaltered, but highlights regions that include extra AMVs, which have erroneously tracked the imposed striping.**

The imposed 3X striping does have an impact on the AMV quality, as shown in the statistical comparisons in Figure 8. Again, the MVD is within specification, even for the 3 times striping dataset. However, the SD is out of the 100% specification range. The AMV algorithms are currently at 80% maturity. By the time of 100% maturity delivery (September 2011), the SD will need to be under the 3.8 m/s limit, and this is being investigated.

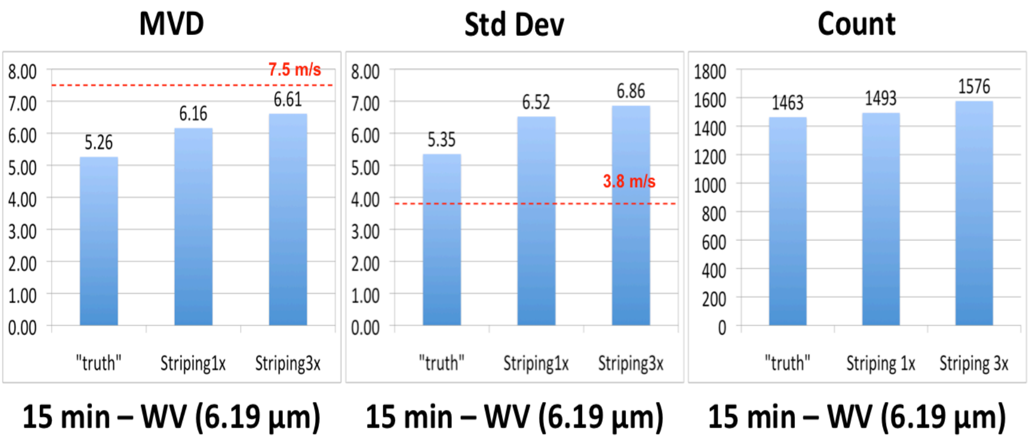
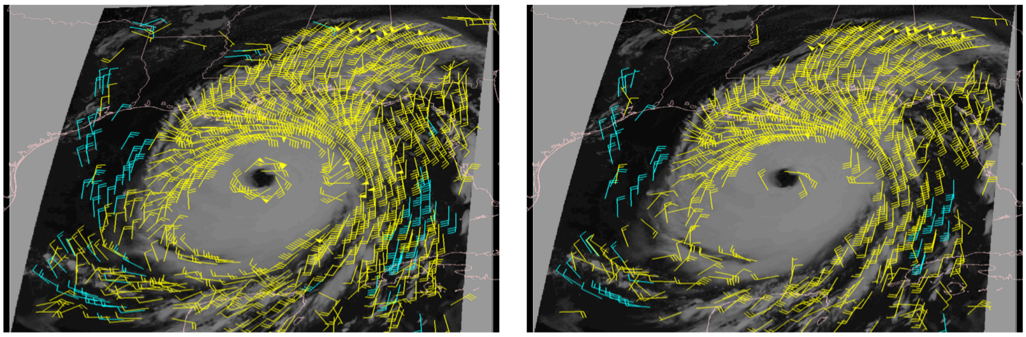


***Figure 8:* MVD, SD, and match count for clear-sky water vapor AMV fields produced from 15-min images using unaltered TOA, 1 times the striping error spec, and 3 times the striping error spec, compared to WRF model U/V "truth".**

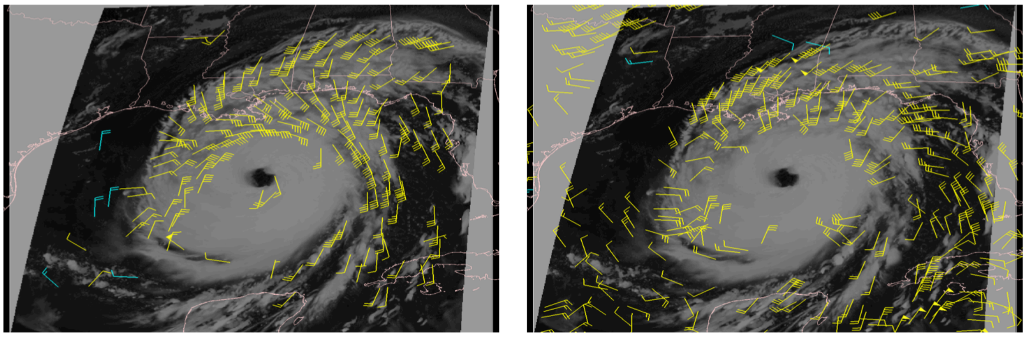
EXAMPLE 3: HURRICANE KATRINA SIMULATION

The ABI instrument will have 2 km resolution in the IR bands (7-16) with 5-min image scan rates over CONUS region. The current GOES imager has 4 km resolution, and its nominal scan time is 15 minutes (unless in rapid scan mode). To characterize the potential effects of improved spatial resolution and time scales expected from the ABI data, an AMV set was run using 2 km resolution WRF data at 5 and 15 minute sequences. The data was then reduced to 4 km resolution, with AMVs run using a 15-minute time step. For comparison purposes, real operational GOES-12 AMVs (4 km resolution, 15 minute time step) are shown. The results can be seen in Figure 9.



(a) 2 km resolution; 05 minute time step

(b) 2 km resolution; 15 minute time step



(c) 4 km resolution; 15 minute time step

(d) 4 km resolution; 15 minute time step – GOES-12 AMVs

***Figure 9*: IRW AMV observations over Hurricane Katrina for: (a) simulated ABI AMVs at 2 km resolution and a 5 minute time step, (b) simulated ABI AMVs at 2 km resolution and a 15 minute time step, (c) simulated ABI AMVs at 4 km resolution and a 15 minute time step, and (d) real GOES-12 IRW AMVs plotted over the simulated ABI image.**

Fig. 9a is representative of the potential AMV coverage from the ABI imager. The increased resolution and time scale should make superior AMV coverage like this possible as the storms progress into the CONUS scan segment. As we move away from ABI and towards the current GOES capability (Fig. 9b-c) the affects of resolution and time sampling scales becomes apparent. Even at 2 km and 15 minute scanning (Fig. 9b) we lose many of the eyewall AMVs and the detail in the inflow region. The outflow is still well captured. Fig. 9c is 4km and 15-minute sampling, close to what the current GOES imagers would sense. Fig. 9d are the actual operational GOES-12 AMVs for comparison, and the coverage looks similar to the 4 km simulated product.

SUMMARY

To prepare for the GOES-R era, simulated datasets are being employed to ready the NESDIS AMV algorithms for Day-1 products. Early results indicate that simulated GOES-R proxy datasets using numerical model TOAs are an effective way to study the potential effects of various imposed “noise” sources and processing choices on AMV quality and quantities. Unaltered radiance fields were used as the baseline (“truth”) AMV product. Imposed navigation/registration errors have the greatest negative impact on IRW and Visible channel AMVs when compared to the baseline product and these are documented. Imposed striping effects are troublesome for clear sky water vapor AMVs. Examples shown above are effectively quantified using the GRAFIIR analysis framework. Since these simulations are at native ABI resolution (at least for the IR bands), they enable us to test the potential impact of resolution and time scales on Day-1 products such as AMVs.

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