Improved Monitoring of Rapidly-Evolving Upper-Tropospheric Wind Fields over the Core of Hurricanes from Ultra-High Spatiotemporal Resolution AMVs

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Synopsis

- As presented at IWW14, an effort is underway to optimize the processing and assimilation of ultra-high spatiotemporal AMV datasets around hurricanes by exploiting the rapid-scanning capabilities of the new generation of geostationary satellite imagers such as the ABI on GOES-R series satellites.

- We expect this effort will fill an important observational gap in hurricane analyses, as storm-scale dynamical information at the top of hurricane core and outflow regions is currently lacking and needed to intrinsically tie in convective processes with environmental interactions that can modulate storm intensity.

- The added data will not only improve our observation and understanding of hurricane behavior (e.g. intensity and size fluctuations), but provide key vortex-scale information to rapidly-advancing data assimilation methodologies leading to improved hurricane model predictions (such as the HWRF model).

- These objectives are being accomplished by 1) utilizing the advanced NESDIS operational (enterprise) AMV algorithms and building on novel data processing approaches developed at CIMSS to enhance coverage around hurricanes, 2) demonstrating the end-to-end capabilities via case study and real-time testing, and 3) transitioning the methodologies to NESDIS/STAR (collaborative partner) for seasonal real-time operational testing.

- Concurrently, strategies to assimilate the enhanced AMV datasets are being honed for maximum HWRF model analysis and forecast impact through collaboration between the data providers (CIMSS, STAR) and modeling centers (NOAA/HRD, JCSDA and NCEP/EMC).

- This poster reports on the status and progress of this effort.

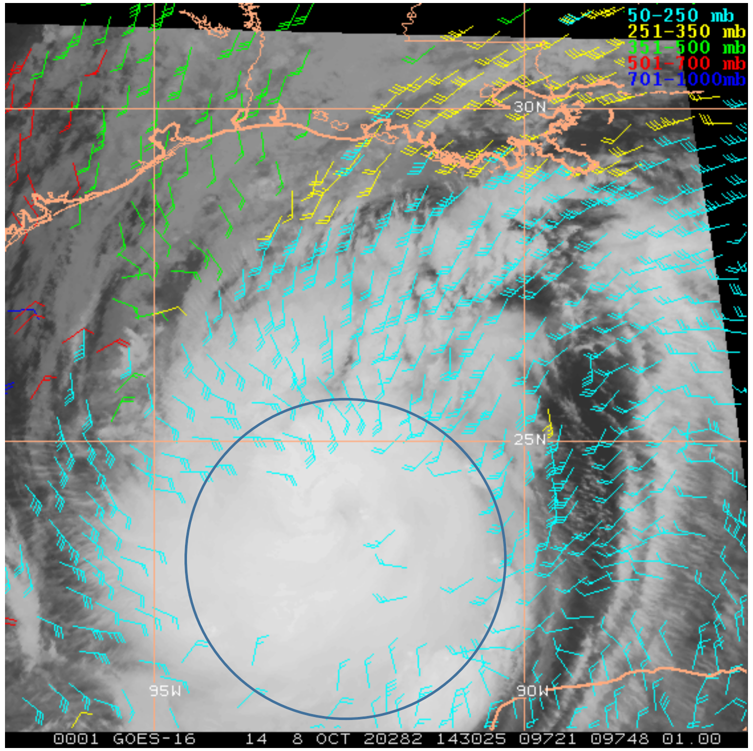
Motivation

➢ **Dynamical information at the top of rapidly-evolving hurricane core and outflow regions is lacking**

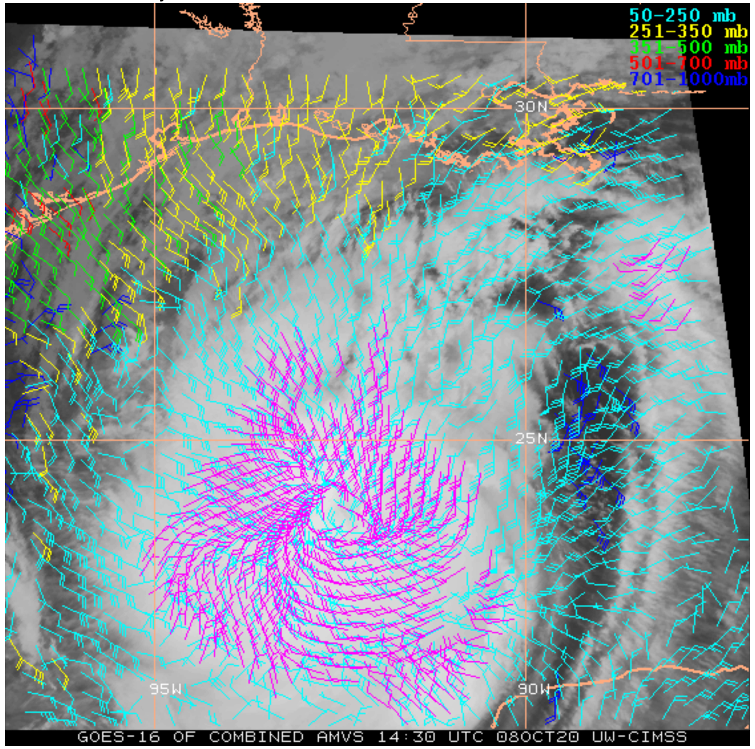
➢ **Ultra-high spatiotemporal AMVs can help fill that important observational gap**

- GOES-16 operational AMVs do not capture the detailed flow fields over the hurricane's Central Dense Overcast (CDO) region (circle in left-hand panel)
- The processing strategies of the enhanced AMV product are tailored to increase vector coverage over the hurricane and fill the observational gap over the CDO region
- A novel optical flow approach to deriving AMVs over the CDO region results in greatly enhanced coverage (magenta vectors in right-hand panel)

Hurricane Delta, 14:30 UTC 8 Oct., 2020



Operational AMVs



Experimental enhanced AMVs (thinned for visualization)

Review of Hurricane-Scale AMV Processing Strategies

- Use image triplets with high spatiotemporal sampling
  - The GOES-16 ABI includes two regional (‘MESO’) scans with 1-min. sampling that can be pointed at targeted regions like hurricanes within view.
  - Utilize full-res Vis (0.5km) and IR (2km)

- Employ NESDIS nested-tracking algorithm for AMV derivation (Bresky et al. 2012).
  - Uses GOES-R Algorithm Working Group (AWG) Cloud Height Algorithm (ACHA) for the AMV height assignments
  - Auto-editor not used in quality control

- Increase AMV target density
  - Reduce target spacing and search box size
  - Reduce minimum gradient required for target identification
  - Disable coherency requirements

Review of Hurricane-Scale AMV Processing Strategies (cont.)

- **Utilize VIS during daylight to enhance high-level cloud-top AMVs in the storm Central Dense Overcast (CDO) region (normally VIS is only used for low-level cloud tracking)**

- **Relax QC constraints to allow highly divergent flow associated with hurricane outflow**
  - **Modify required QI in some cases (band dependent thresholds, lower tolerances)**
  - **Reduce/eliminate model agreement checks**

- **Include additional optical flow (OF) derived AMVs in cold CDO region (for cloud scenes with temperatures of 220 K or colder; approach outlined in next slide)**

- **Generate AMV datasets every 15 minutes (achievable given the limited domain, for real-time/operational processing considerations)**

Optical Flow Approach

- **An alternative to AMV pattern matching is Optical Flow (Horn and Schunk 1981)**

- **Optical Flow uses a fixed image neighborhood to derive motion**
  - Assuming an object with constant brightness I is located at x, y with time t, then, with motion (*u* and *v*)

$$I(x, y, t) = I(x + u, y + v, t + 1) \qquad (1)$$

  - With a Taylor series approximation used on (1), we get:

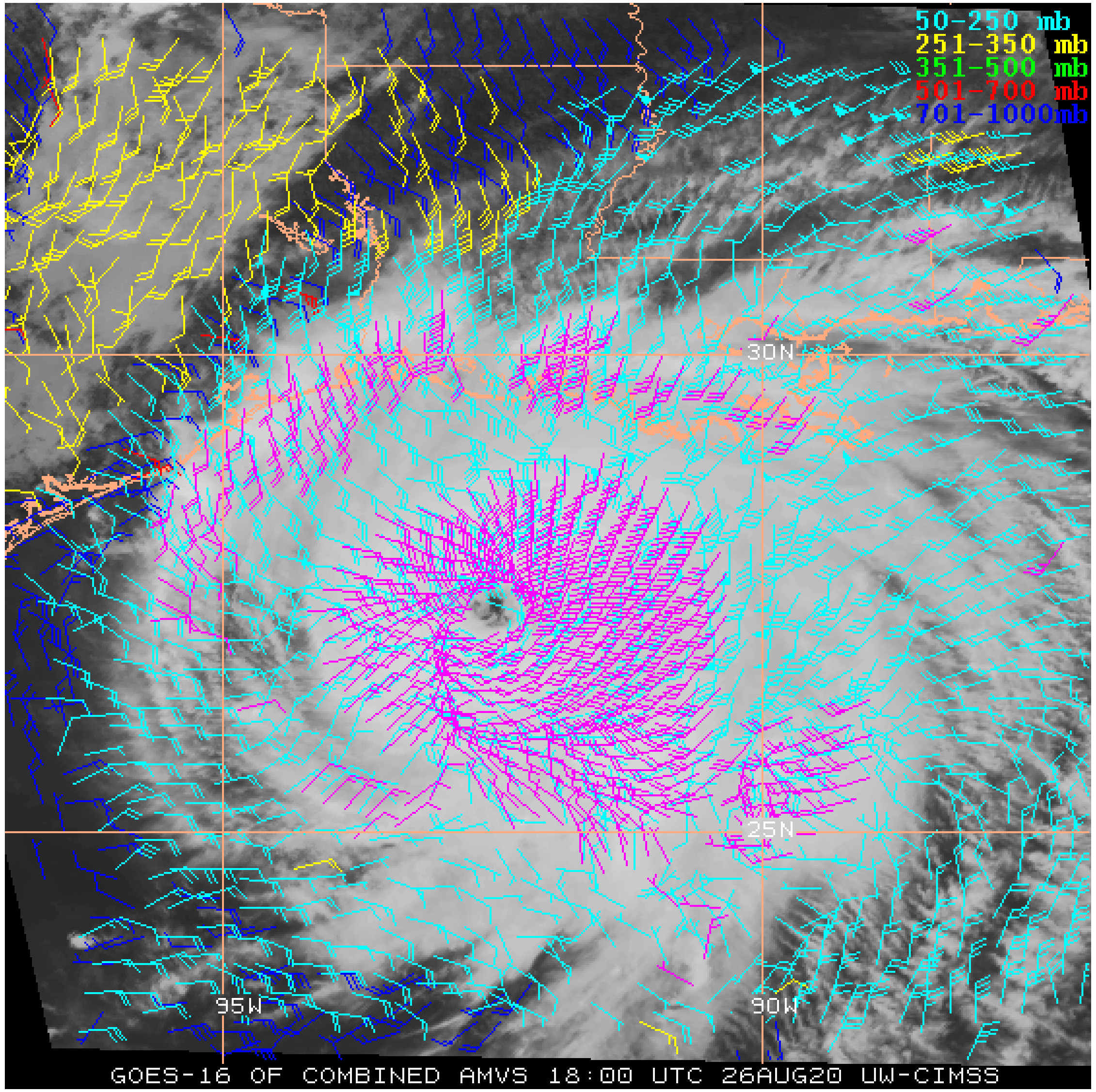
$$-\frac{\partial I}{\partial t} = u\frac{\partial I}{\partial x} + v\frac{\partial I}{\partial y} \qquad (2)$$

  - Constraint 1 (and eq. 2) can be calculated at any image pixel box, however, the equation for one pixel is underdetermined, so only flow in the direction of the gradient can be resolved (aperture problem)
  - The aperture problem is solved by applying (1), among other possible constraints, to an image neighborhood (rectangular group of pixels) and finding *u* and *v* in the field that minimizes a cost function (e.g. Lucas and Kanade 1981; Bresky and Daniels 2005)

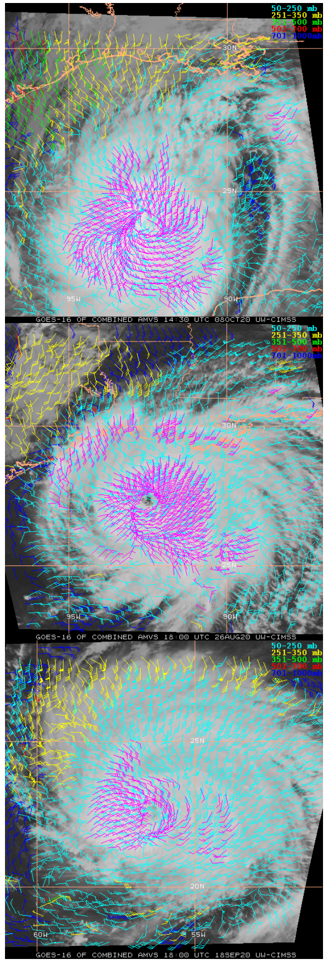
- **Clouds within a fixed small satellite image neighborhood can often evolve too fast to be coherently tracked**
  - With GOES-16 ABI 30-60 sec data, small-scale optical flow derivation is now possible

Example: Hurricane Laura, 18:00 UTC 26 Aug., 2020

- Employing the steps outlined in the processing strategy results in greatly enhanced AMV coverage over Hurricane Laura, especially in the CDO region
- The OF AMVs are plotted in magenta and are only kept for the coldest cloud regions
- This dataset was produced on a medium capacity computer in about 10 minutes



Examples with animations to view the evolving windfields during Hurricanes Laura, Teddy, and Delta as provided by 15 min. AMV datasets



http://tropic.ssec.wisc.edu/archive/data/stettner/Laura/AllLaura.gif

http://tropic.ssec.wisc.edu/archive/data/stettner/Teddy/AllTeddy.gif

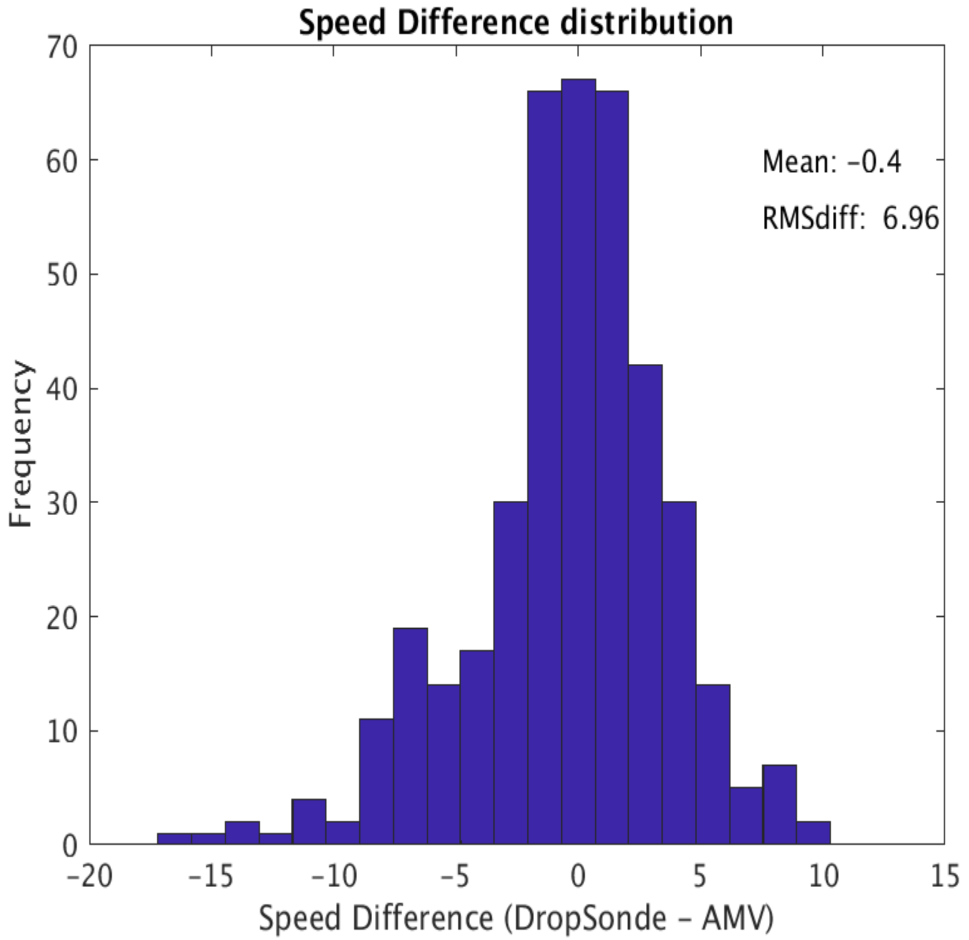
http://tropic.ssec.wisc.edu/archive/data/stettner/Delta/AllDelta.gif

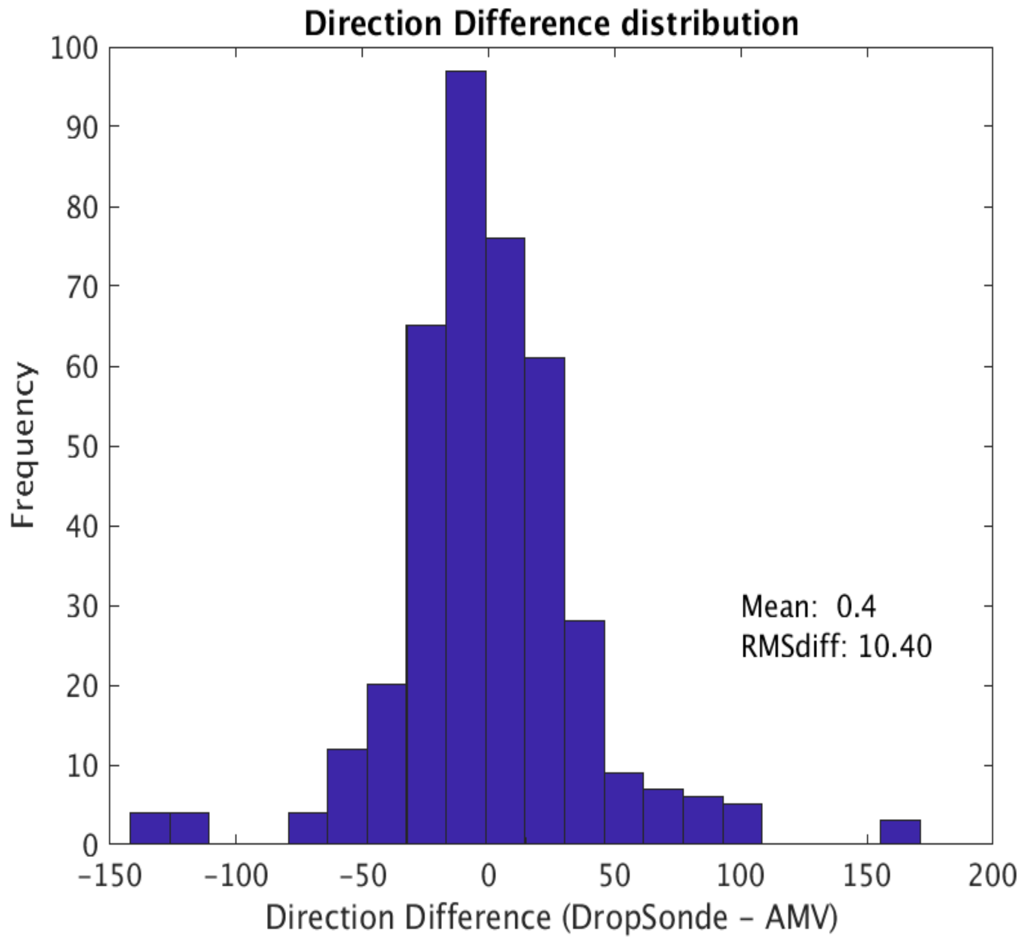
Meso-sector AMV Quality Assessment

- **Validating the quality of AMVs in hurricanes is difficult due to the sparsity of independent observations**
- **During the 2020 hurricane season, NOAA G-IV research flight missions (FL 40-45 kft) penetrated near the core of Hurricanes Laura and Delta and their dropwindsonde data provided some validation of storm-top AMVs**
- **Despite a relatively small sample size, the comparison results shown on the next slide are encouraging, with the mean (bias) and RMS dropwindsonde-AMV differences similar to quality-controlled operational AMV values despite the dynamic/divergent flow environment over hurricanes**

Meso-sector AMV Quality Assessment

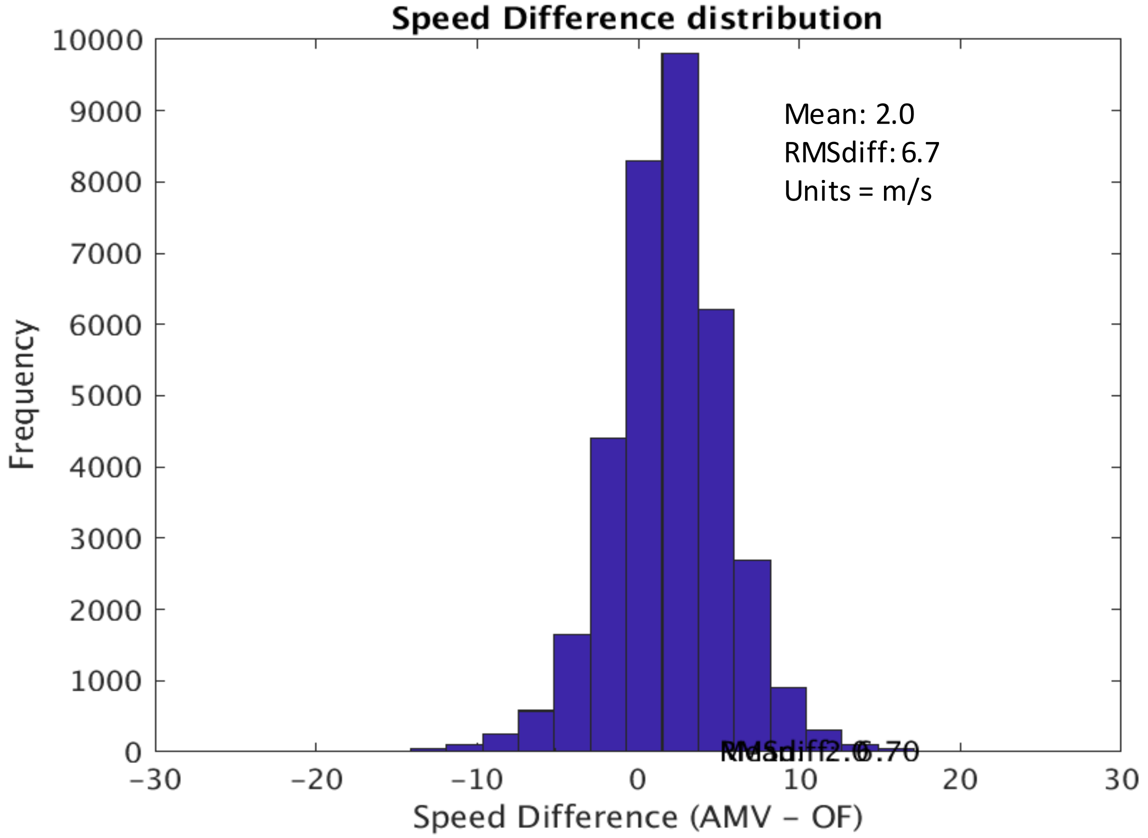
Collocated dropsonde-AMV matches contributing to the distributions and statistics below are constrained to <u>non-OF</u> AMVs above 300 hPa, delta-t of 5 min., delta-x,y of 10 km, and delta-p of 0.1 hPa. Units are m/s (speed) and degrees (direction).

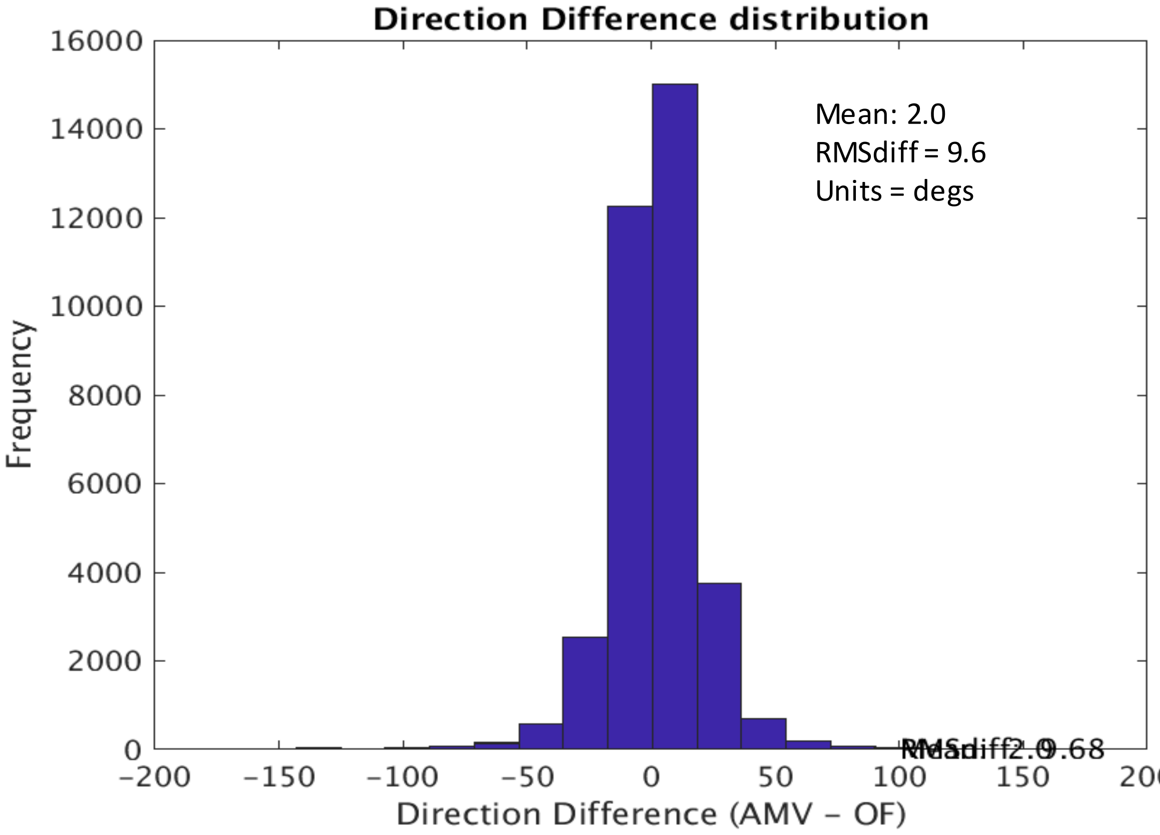




Meso-sector AMV Quality Assessment

- The Optical Flow AMVs retained only over the coldest core of the hurricane have pressure values above the uppermost dropsonde data (<100 hPa); no direct independent comparisons are possible
- However, assessment of hurricane-top OF AMV quality vs collocated non-OF AMVs yields reasonable differences, with a small slow speed bias (2 m/s) noted with the OF AMVs





Collocated non-OF and OF AMV matches contributing to the distributions and statistics above are constrained to AMVs above 100hPa, delta-t of 0 min., delta-x,y of 5 km, and delta-p of 5 hPa (high freq of matches due to OF wind values at each pixel)

Operational Transition of the Hurricane-scale GOES AMV Product Processing

- **Product ‘proof-of-concept’ with GOES-16 ABI meso-scan data has been completed through case study R&D at CIMSS**

- **Completed a successful real-time demo of the GOES-16 product during the full (and active) Atlantic hurricane season in 2020**

- **Fine tuning of processing strategy and scripts is underway**

- **Testing with GOES-17 ABI meso-scans for East Pacific hurricanes is planned this summer**

- **Next step is to transfer methodology and processing code/scripts to NESDIS STAR for integration into the Enterprise system and testing**

- **Final goal: Operational processing at NESDIS**

Experimental Data Assimilation Studies with the Hurricane-scale GOES Meso-scan AMV Product

- **Several studies have been conducted with the GSI DA and HWRF model aimed at examining the analysis impact of the enhanced AMV data and optimizing the influence of the information on subsequent model forecasts of hurricane track and intensity**
  - **Velden et al. 2017, *Wea. & Fore*; Li et al. 2020, *J. Geo. Res.*; Lewis et al. 2020, *Atmos***
- **Advanced DA methods such as EnKF are being explored (Xuguang Wang at U. Oklahoma; Zhan Zhang at NOAA/EMC and Jason Sippel at NOAA/HRD)**
- **Operational potential being assessed by NOAA/EMC; full hurricane season trials are needed and planned (Agnes Lin at U. Wisc/JCSDA; Li Bi at NOAA/EMC)**

Summary

- Ultra-high resolution AMVs produced from GOES meso-sector 1-min. imagery targeted on hurricanes and tailored to storm scales can depict the detailed evolution of flow fields at the outflow level and provide critical dynamical information on storm behavior

- A novel optical flow tracking method can enhance AMV coverage of coldest cloud tops in the hurricane central dense overcast region where traditional AMV derivation methods can struggle

- Initial quality assessments of the hurricane-scale AMV product via qualitative analyses and statistical comparisons with dropsondes are encouraging, and further independent verification studies will be conducted

- It has been demonstrated that these enhanced AMV datasets can be produced at 15-min. intervals in real time for the duration of a targeted hurricane

- Initial Hurricane model assimilation studies have shown favorable analysis and forecast impact results, and efforts to optimize the information content with advanced DA are ongoing

Work in Progress/Future Directions

- Complete the refinement and testing of the tailored processing strategies (presented at IWW14) that have been optimized to extract maximum AMV information content in hurricane environments from GOES-16 meso-sector scans

- Test the processing strategies to operate with GOES-17 and possibly Himawari-8/9 which also provide meso-sector imaging modes that can target Pacific storms

- Assist in the transition of this research to NESDIS and NCEP for operational testing and implementation in collaboration with STAR, JCSDA and EMC colleagues

- With NWP collaborators, continue to investigate approaches to more effectively assimilate the enhanced AMV data into operational hurricane prediction models (i.e. HWRF, HAFS) to maximize the information content getting into the initialized analyses and leading to improved forecasts

- Provide the enhanced AMV datasets to the hurricane research community (already several papers published or in press), and to NOAA/HRD hurricane flight planners to help direct missions

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