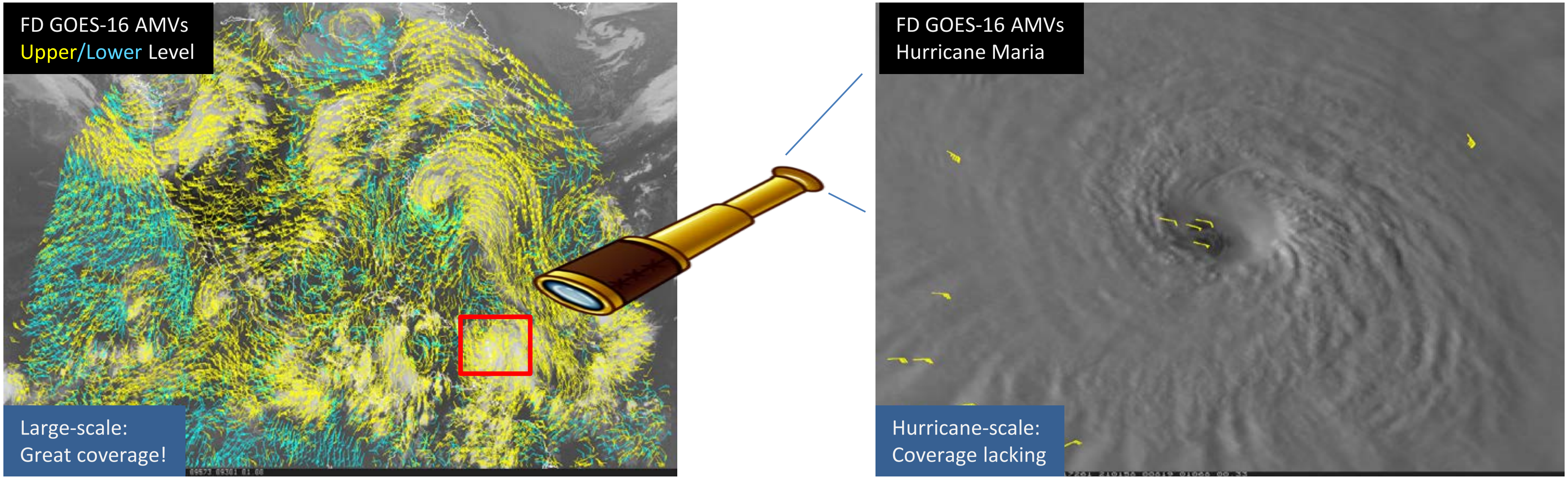
Telescoping In to the Convective Scales: Development of AMV Processing Strategies and Applications



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14th International Winds Workshop (IWW14)
23-27 April, 2018

Motivation

- **Advanced imagers on geostationary satellites are now/soon becoming a reality (e.g., Himawari-8/9, GEO-KOMPSAT-2A/2B, INSAT-3D, EUMETSAT-MTG, GOES-16/17, FY4A/B).**
- **These upgraded sensor capabilities can be exploited for AMV algorithm development and optimized product enhancements (e.g., improvements in signal quality and dynamic range, image scanning rates, spatial resolutions, and spectral options will all translate to enhanced AMV quality and capabilities).**
- **Therefore it is prudent to seek optimal methods to fully exploit the information content of enhanced AMVs in high-impact weather events such as Tropical Cyclones and mesoscale events, where high spatiotemporal observations are needed to resolve the smaller scale flow fields.**
- **Considering hurricane and convective-scale modeling, the divergent part of the wind is no longer considered 'noise', it is the needed 'signal'!**

For advancing hurricane and mesoscale DA/NWP and diagnostics, wind observations at the mesoscale, available at 15-min. or greater frequency around the clock with continuous DA cycling, would be desirable...

Study Parameters

- **Utilizes newly-available GOES-16 Advanced Baseline Imager**
  - **Image data ‘provisional’ during the 2017 Atlantic hurricane season**
  - **In ‘Flex Mode’ scanning operations**
    - **Includes two regional (‘MESO’) scans with 1-min. sampling that can be pointed at targeted regions like hurricanes within view of GOES-16.**

- **Employs NESDIS nested-tracking algorithm: now operational with GOES-16 AMV production (Bresky, Daniels, Bailey, Wanzong 2012).**
  - **Uses GOES-R Algorithm Working Group (AWG) Cloud Height Algorithm (ACHA) for the AMV height assignments**
  - **NO auto-editor used in post-processing**

- **Examines one hurricane case (Maria 2017) and one severe weather event (April tornadic supercells over southern US)**

Strategy

AMV processing modifications for enhanced coverage in hurricane core regions (vs. routine full-disk processing)

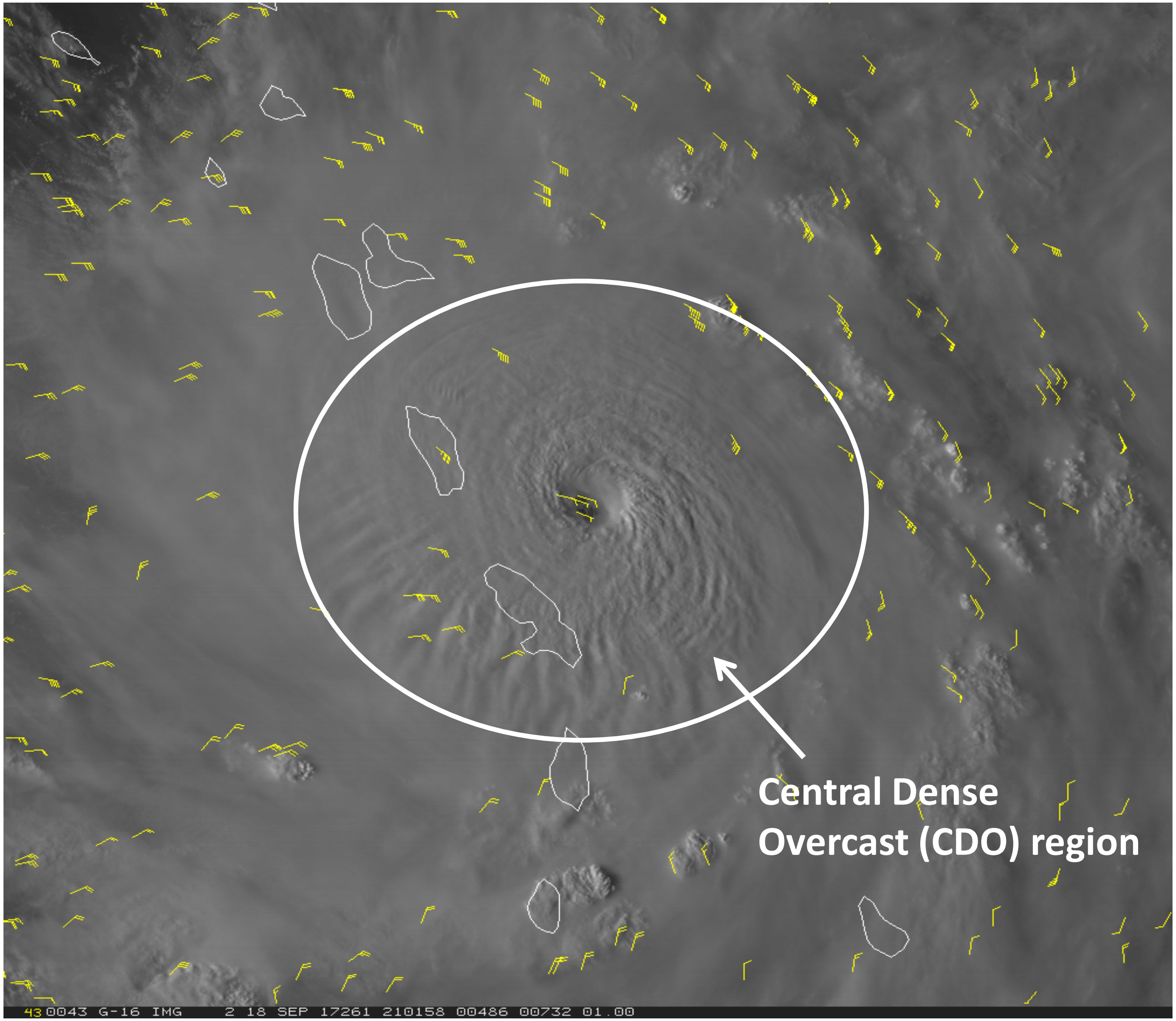
- **Increase AMV target density**
  - **Reduce target spacing and search box size**
  - **Reduce minimum gradient required for target identification**
  - **Disable coherency requirements**
- **Employ image triplets with higher spatiotemporal resolution**
  - **Full-res Vis (0.5km) and IR (2km)**
  - **Utilize 1-min. image triplets (available from GOES-16 MESO scans)**
- **Utilize VIS (0.62 micron) to produce high-level cloud-top AMVs in hurricane Central**

  Dense Overcast (CDO) region
  - **Normally VIS only used for low-level cloud tracking**
- **Relax QC constraints**
  - **Modify required QI in some cases (band dependent thresholds, reduce/eliminate model agreement checks)**

Hurricane Maria—Baseline AMV product

Settings typical for NESDIS operational FD processing (15 min. image triplet)

(only upper-level AMVs plotted)

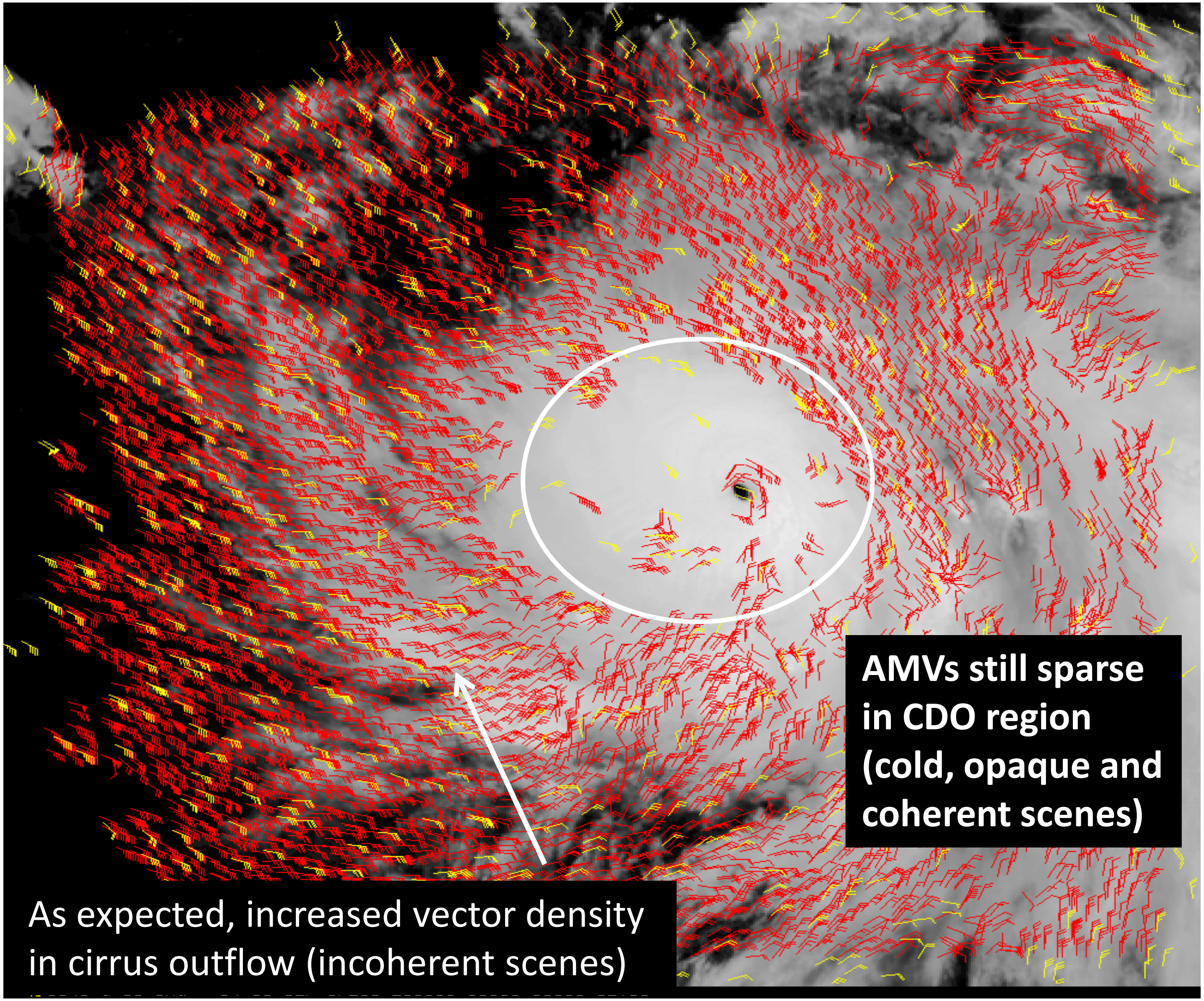


Central Dense Overcast (CDO) region

Hurricane Maria—enhanced IR+CTWV

Reduced target spacing by factor ~2 and image sampling to 5 min.

(only upper-level IR (11.2) + CTWV (6.2) AMVs plotted)



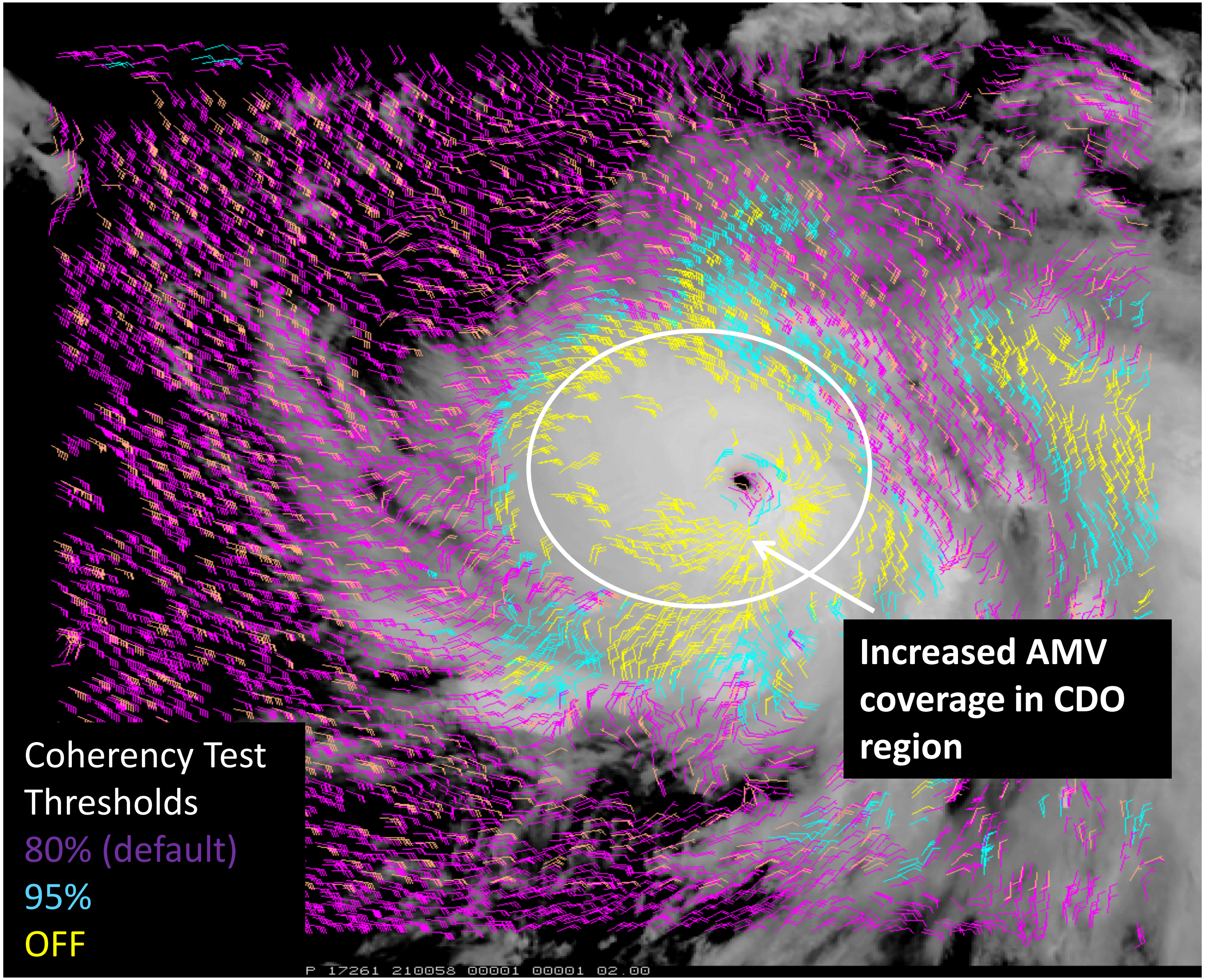
AMVs still sparse in CDO region (cold, opaque and coherent scenes)

As expected, increased vector density in cirrus outflow (incoherent scenes)

Hurricane Maria—enhanced IR+CTWV

Relaxed target scene coherency test requirements

(only upper-level IR (11.2) + CTWV (6.2) AMVs plotted)



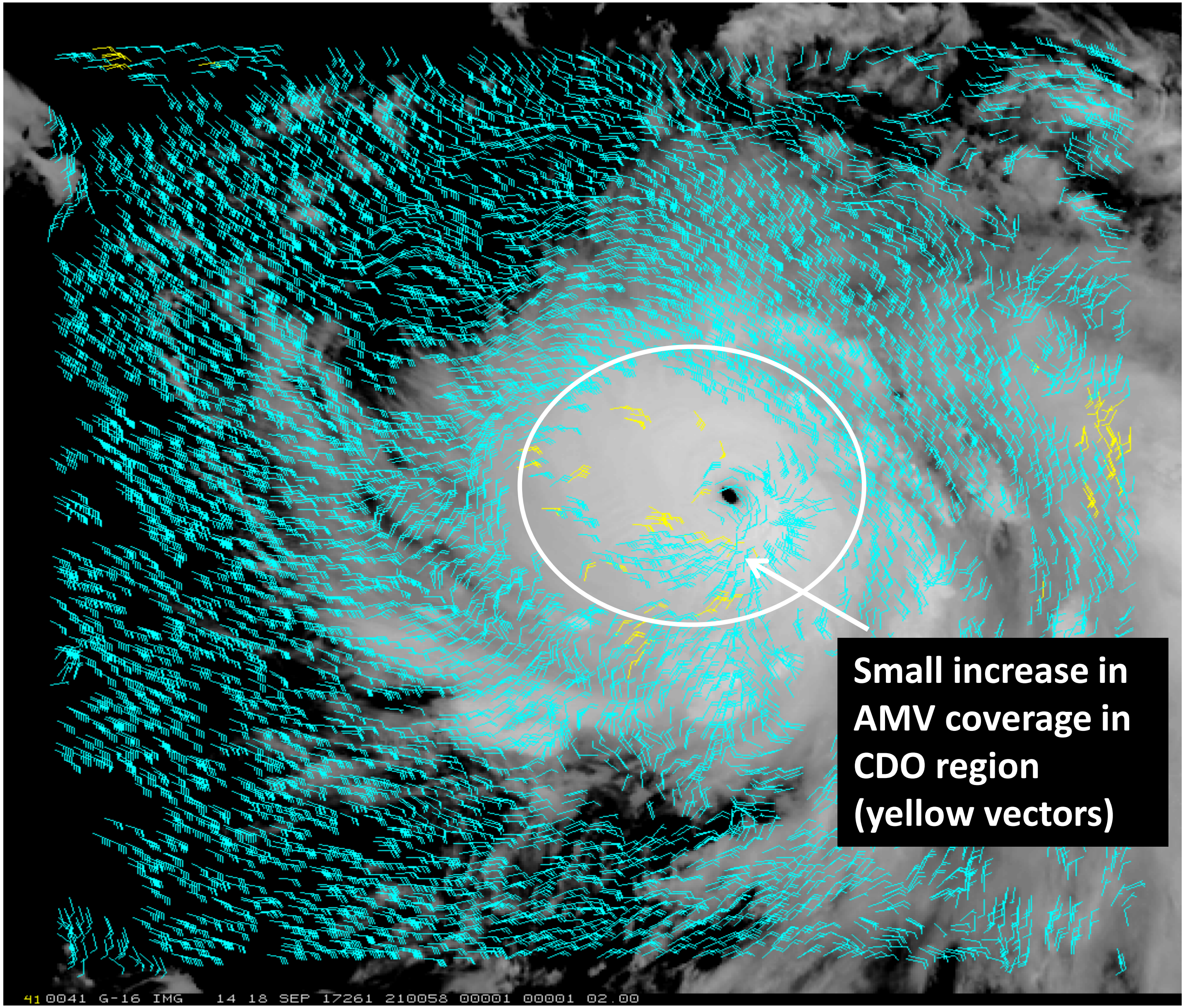
Increased AMV coverage in CDO region

Coherency Test Thresholds
80% (default)
95%
OFF

Hurricane Maria—enhanced IR+CTWV

Reduced target scene gradient threshold requirements

(only upper-level IR (11.2) + CTWV (6.2) AMVs plotted)

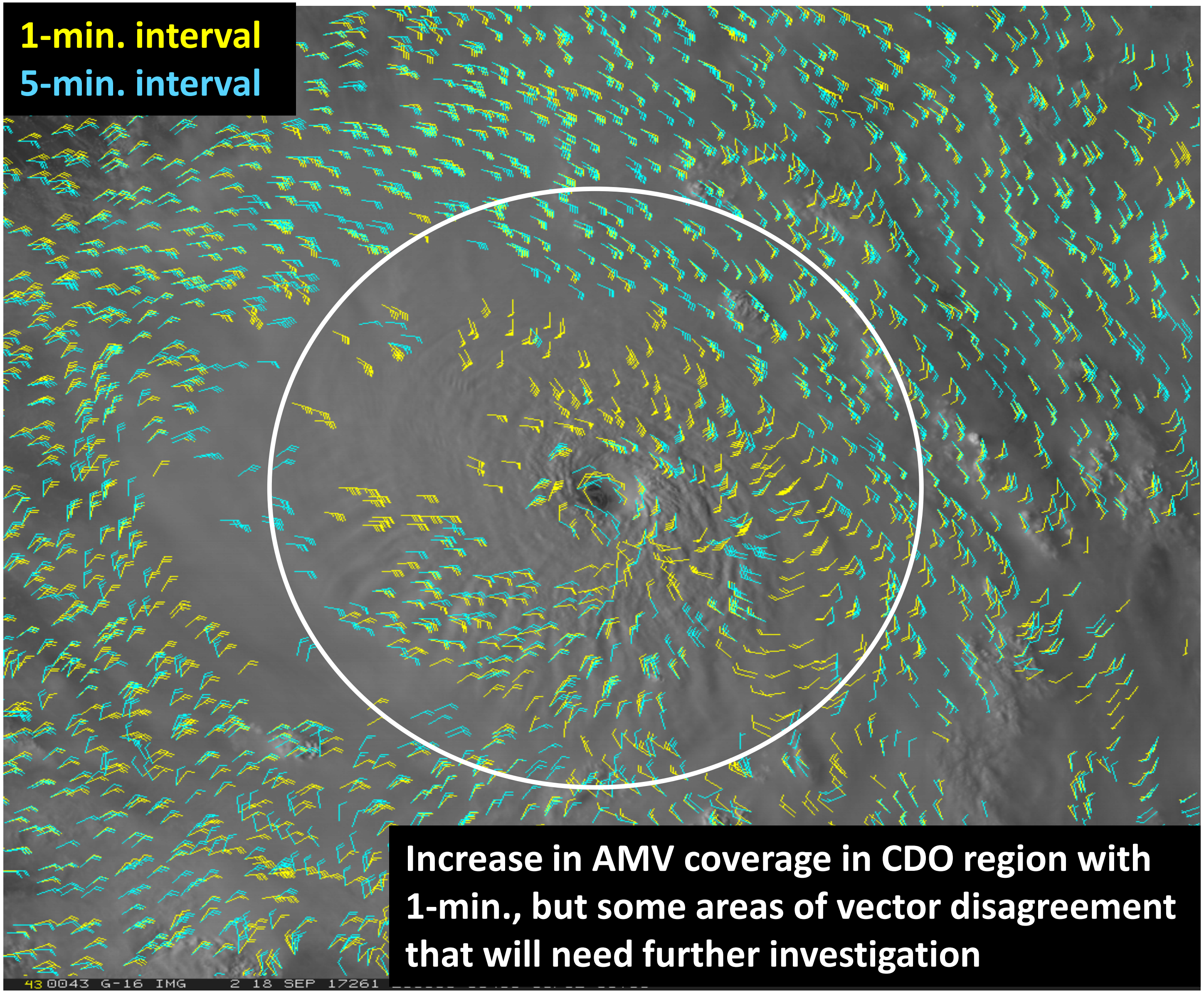


Small increase in AMV coverage in CDO region (yellow vectors)

Hurricane Maria—enhanced IR+CTWV

Use 1-min. image triplet (vs. 5-min.)

(only upper-level IR (11.2) + CTWV (6.2) AMVs plotted)

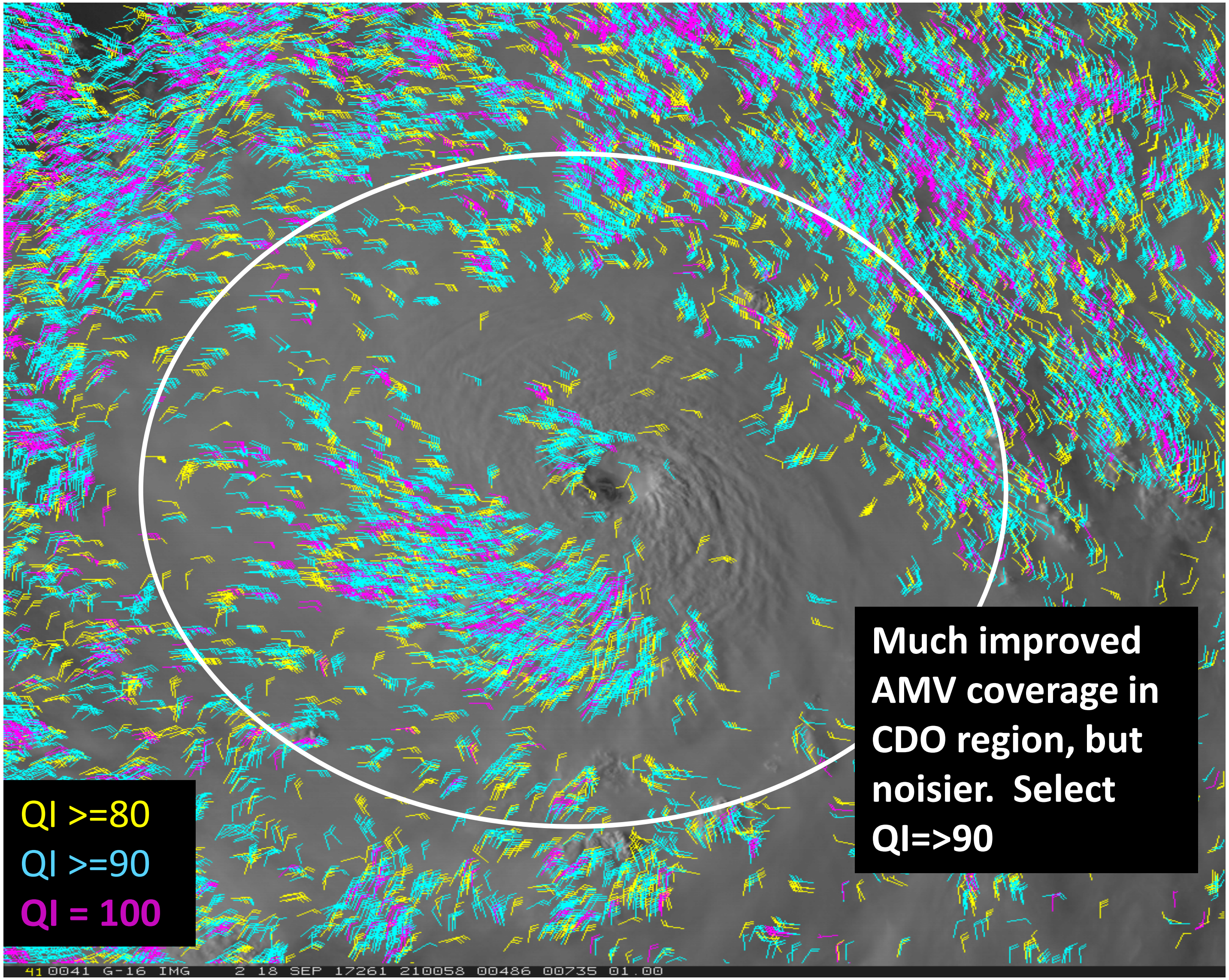


Increase in AMV coverage in CDO region with 1-min., but some areas of vector disagreement that will need further investigation

Hurricane Maria—enhanced VIS

Reduced target spacing and search box size, relaxed target scene gradient/coherency threshold requirements, 3-min. image spacing

(only upper-level VIS (0.64) AMVs plotted--zoomed in on CDO region)

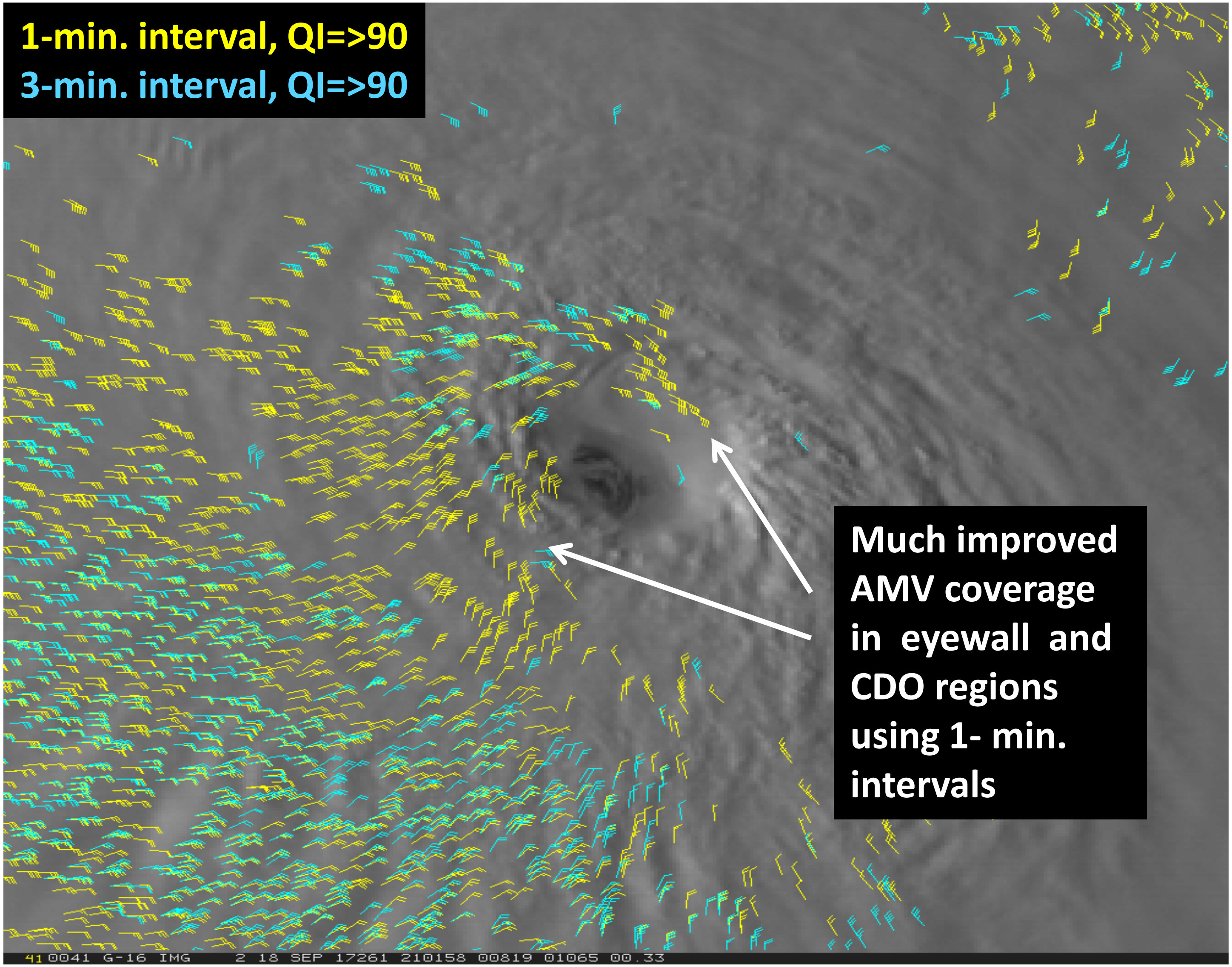


Much improved AMV coverage in CDO region, but noisier. Select QI=>90

Hurricane Maria—enhanced VIS

Use 1-min. image triplet (vs. 3-min.)

(only upper-level VIS (0.64) AMVs plotted--zoomed in on CDO region)

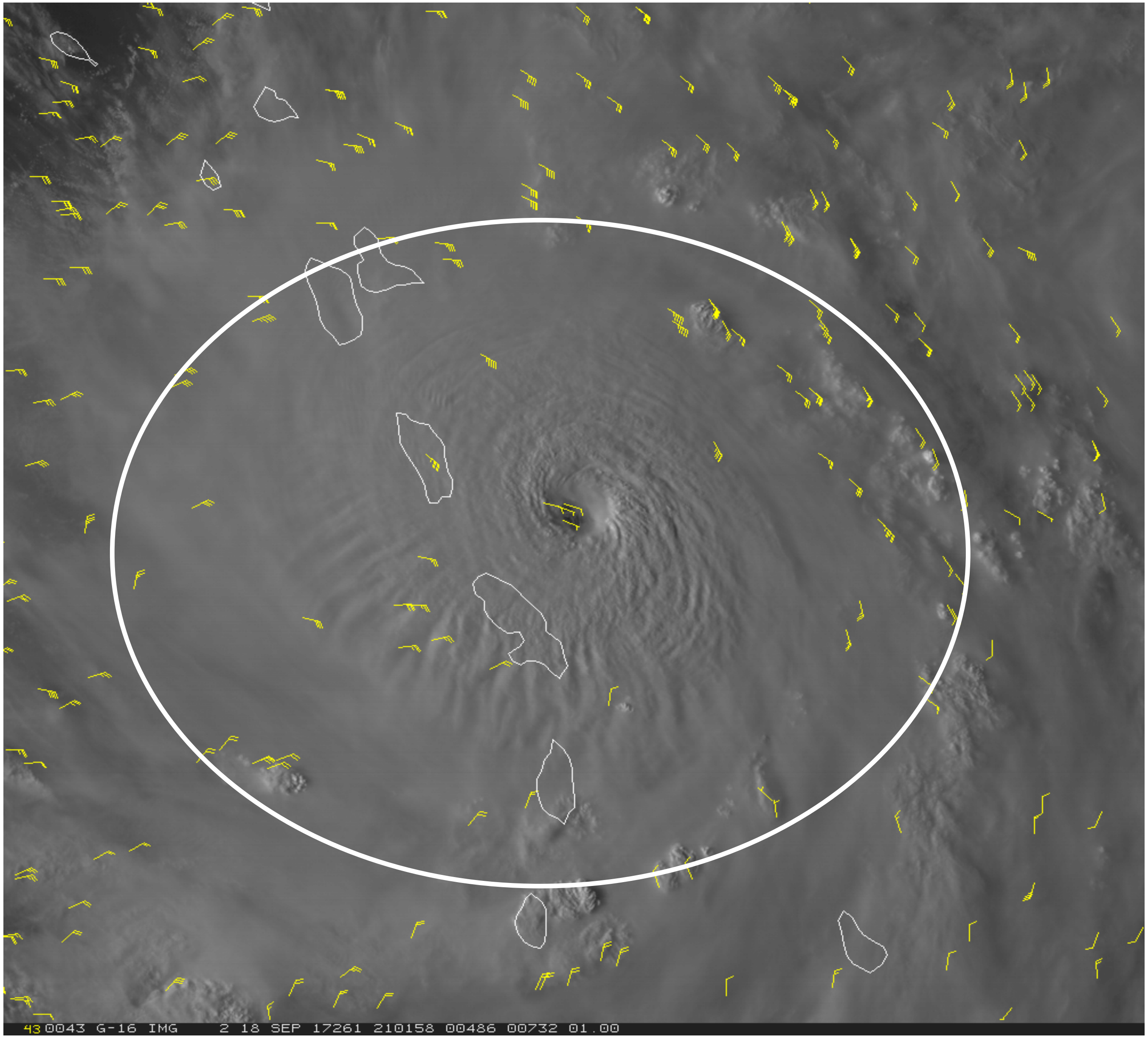


1-min. interval, QI=>90
3-min. interval, QI=>90

Much improved AMV coverage in eyewall and CDO regions using 1- min. intervals

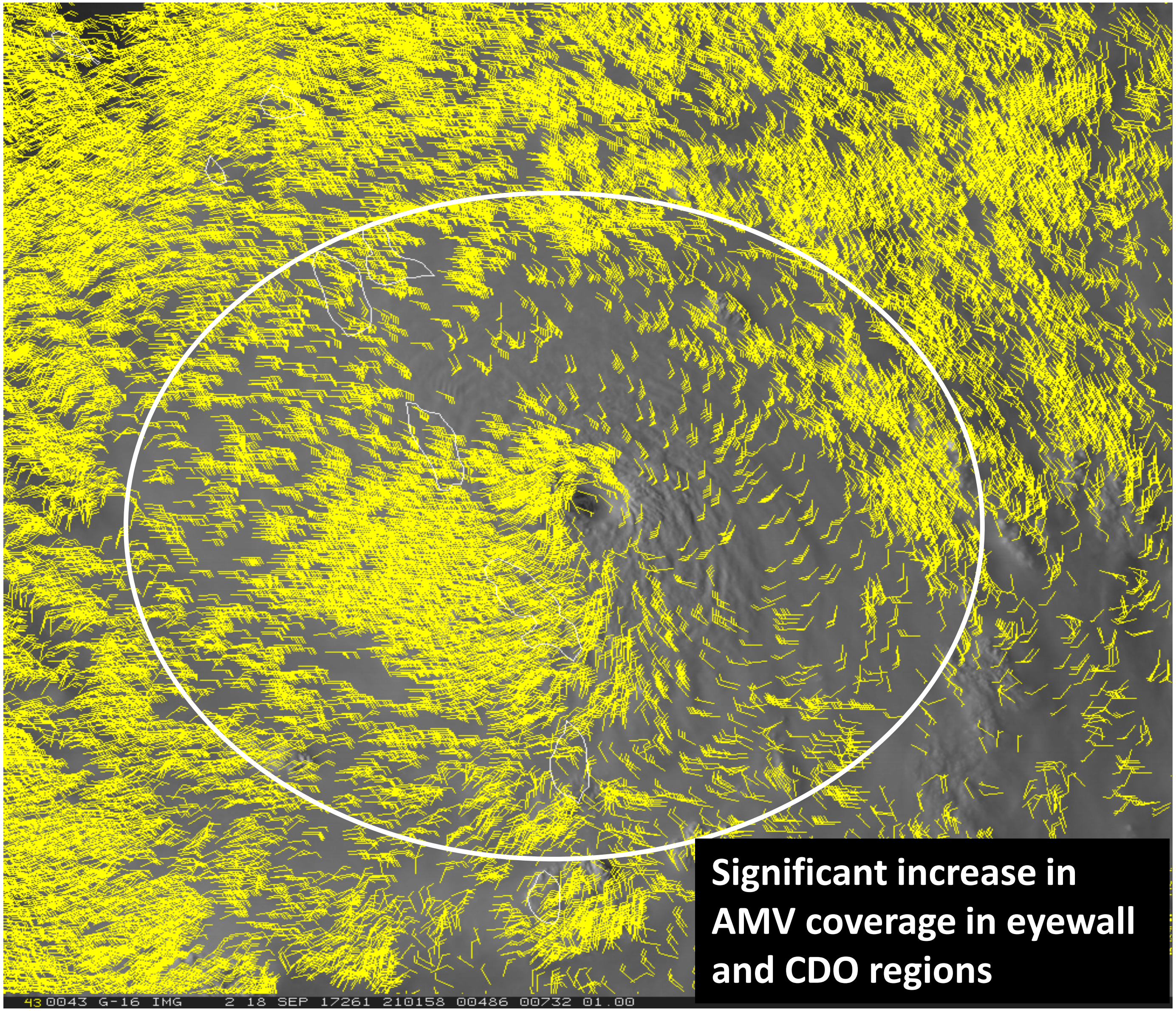
Hurricane Maria—Baseline

(only upper-level AMVs plotted)



Hurricane Maria—All enhancements

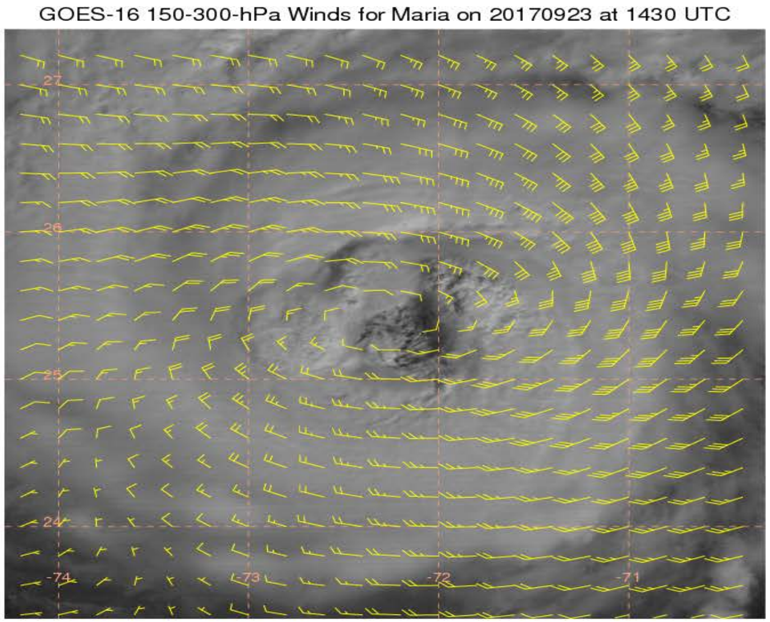
(only upper-level AMVs plotted)



Significant increase in AMV coverage in eyewall and CDO regions

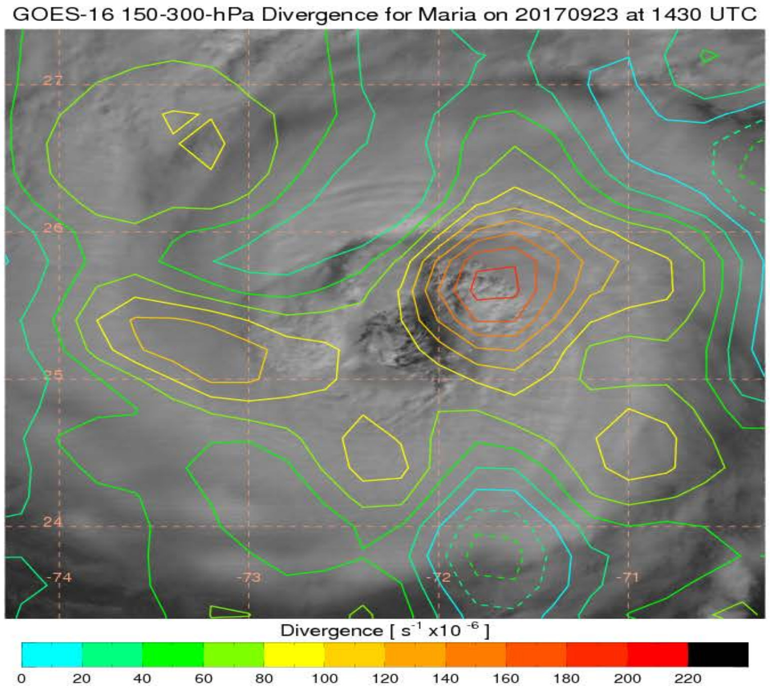
Hurricane Maria—Enhanced AMVs

Tropical Cyclone research and high-res modeling applications

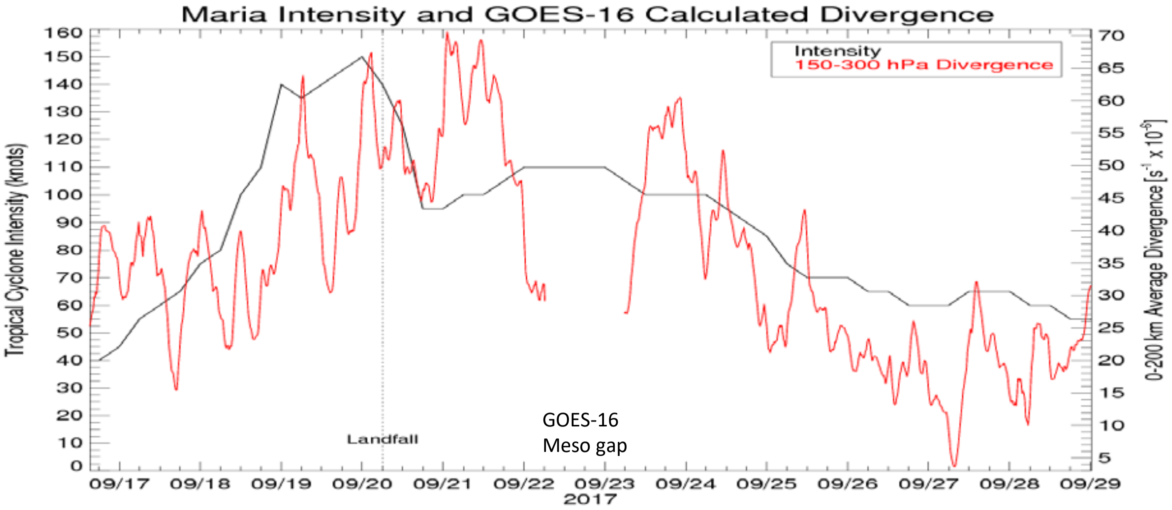


GOES-16 150-300-hPa Winds for Maria on 20170923 at 1430 UTC

Analyzed and gridded AMVs



GOES-16 150-300-hPa Divergence for Maria on 20170923 at 1430 UTC



Maria Intensity and GOES-16 Calculated Divergence

GOES-16
Meso gap

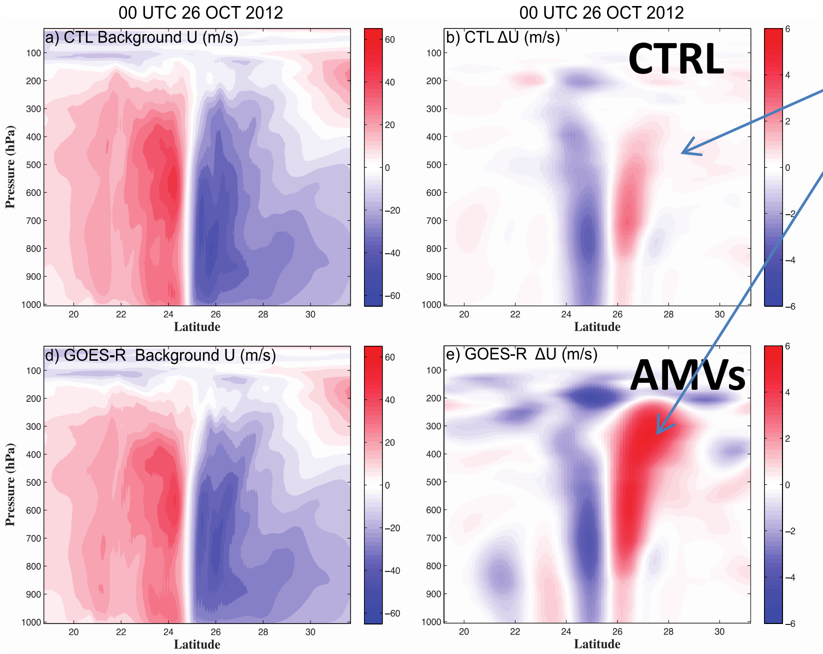
Upper-level flow fields over the TC core region are generally divergent, as expected, but localized regions of more intense divergence are also identifiable as illustrated in Maria, likely associated with intense eyewall convective bursts.

Velden, C., D. Stettner and S, Griffin, 2018: Improved Monitoring of the Evolving Upper-Tropospheric Wind Fields Over the Core of Tropical Cyclones Aided by High Spatiotemporal Resolution GOES-16 Atmospheric Motion Vectors. 33rd AMS Hurricane Conf.

Hurricane Maria—Enhanced AMVs

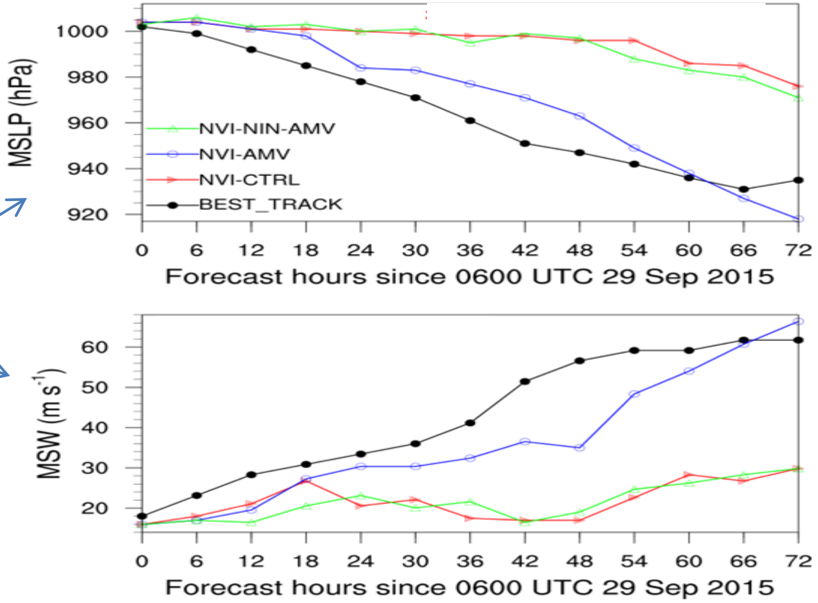
Tropical Cyclone research and high-res modeling applications

Two recent studies using enhanced AMVs in the Hurricane WRF (HWRF) model



Assimilated enhanced AMVs lead to stronger vortex zonal wind component increments in the HWRF cycle during Hurricane Joaquin (2014), and subsequently improved intensity forecasts.

Velden, C., W.E. Lewis, W. Bresky, D. Stettner, J. Daniels, and S. Wanzong, 2017: Assimilation of High-Resolution Satellite-Derived Atmospheric Motion Vectors: Impact on HWRF Forecasts of Tropical Cyclone Track and Intensity. *Mon. Wea. Rev.,* 145, 1107–1125.



Assimilating enhanced AMVs in all HWRF nested domains including the inner vortex region yields better Hurricane Joaquin intensity forecast impacts (blue) vs. CTRL (no enh AMVs, red) and assimilation of AMVs only in the outer HWRF domains (green)

Zhang, S., Z. Pu and C. Velden, 2018: Impact of Enhanced Atmospheric Motion Vectors on HWRF Hurricane Analyses and Forecasts with Different Data Assimilation Configurations. Accepted in Mon. Wea. Rev.

Mesoscale AMV Applications--Early Demonstrations

AMV processing modifications for enhanced coverage in mesoscale severe weather scenarios (versus routine full-disk processing)

- **Same basic modifications as with hurricane applications**
- **Rapid-scans critical: 1 min. desirable for VIS AMVs**
- **Employ full spatial resolution VIS (0.5km for GOES-16) in order to increase the density of coherent trackable features (Upper-level: convective anvil tops, Lower-level: cumulus clouds)**

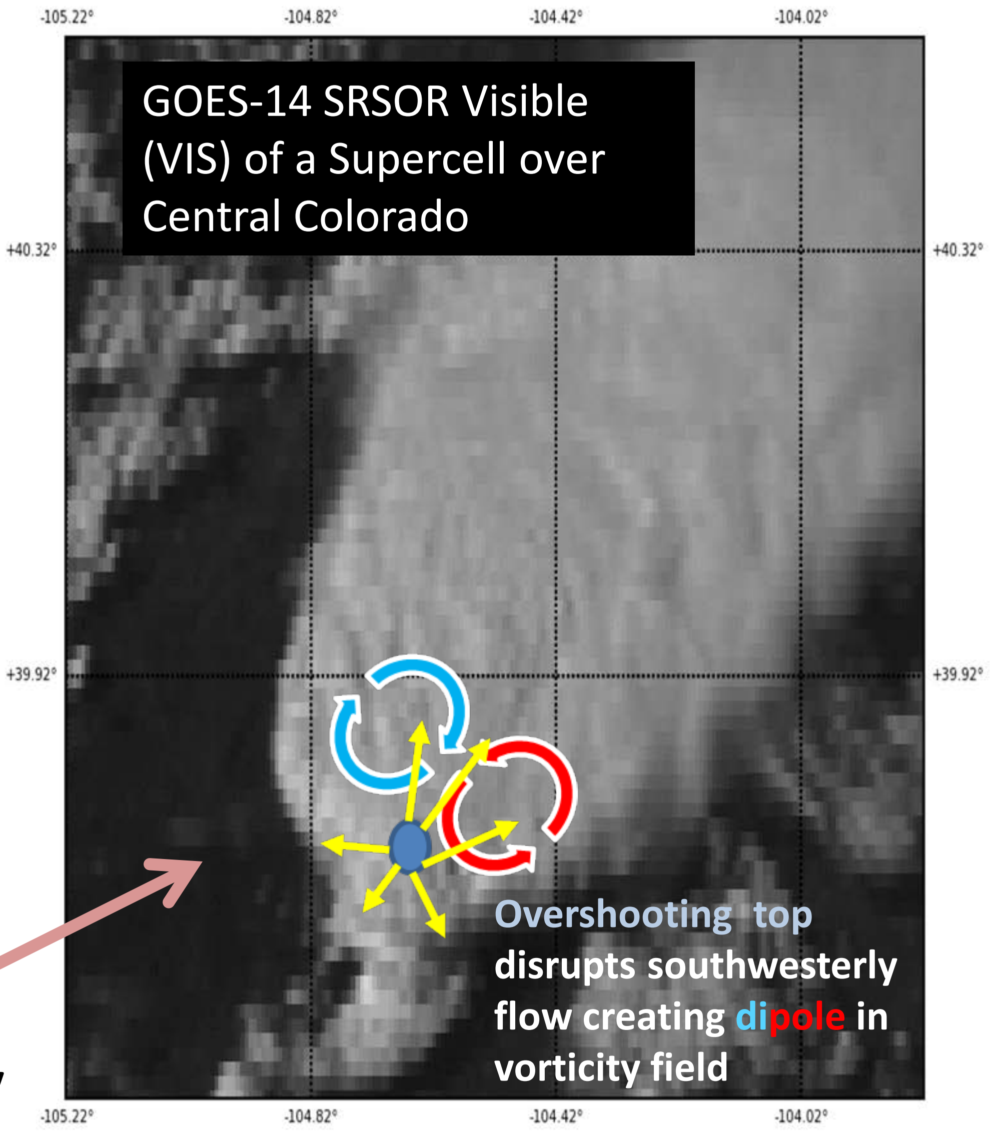
Supercells

Supercell thunderstorms produce severe weather hazards that are considerable threats to life and property.

Understanding and predicting these mesoscale events can prove challenging.

Can we quantify the strength of an observed thunderstorm from space?

Recent techniques have been developed to derive cloud-top kinematics to diagnose storm intensity (Apke et al. 2016, JAMC), and these analyses can be aided by meso AMVs (Apke et al. 2018, submitted to MWR).



GOES-14 SRSOR Visible (VIS) of a Supercell over Central Colorado

Overshooting top disrupts southwesterly flow creating dipole in vorticity field

Case Study using GOES-16 AMVs

Severe weather outbreak over the southeastern US on 5 April 2017

Multiple supercells and reports of tornados and severe winds were observed

GOES-16 was not yet operational, but was in beta test mode and providing 1-min. meso sector scans over this region

AMVs were processed over the tornadic supercell in the red box at right using two methods: 1) Derived Motion Vectors (DMVs) from enhanced processing using the NESDIS algorithm, and 2) Optical Flow

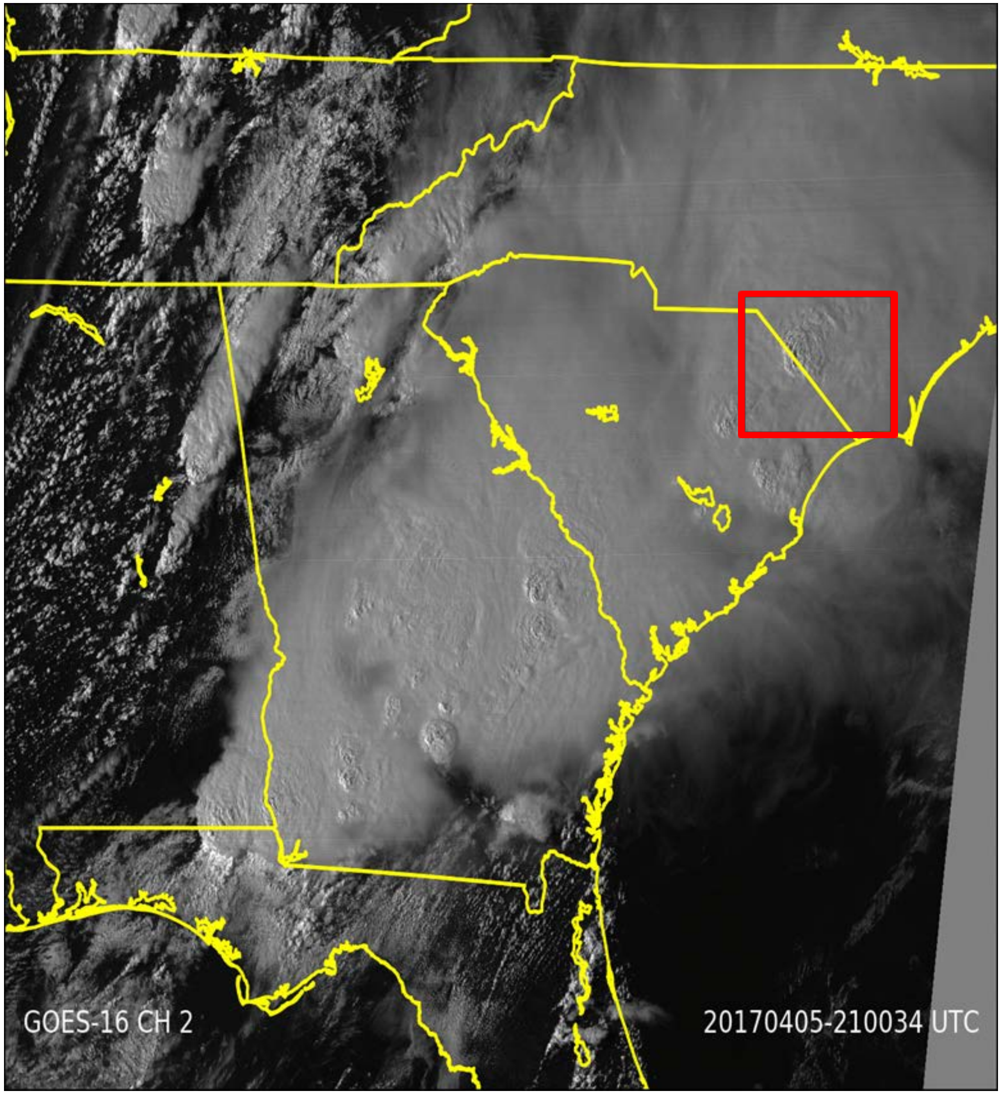
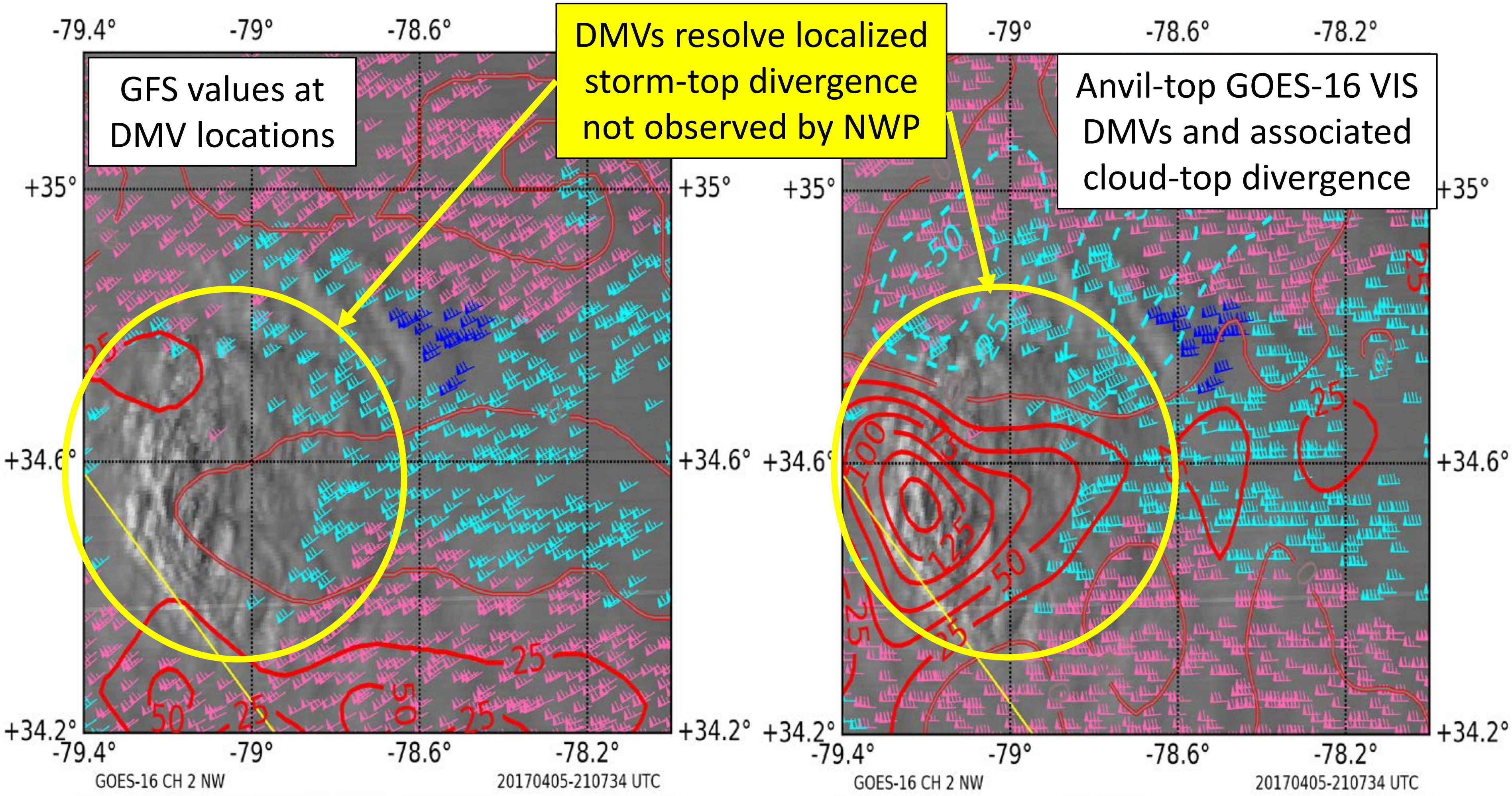


Figure 3. GOES-16 Channel 2 VIS imagery for 5 April 2017 from 21-22 UTC over the southeastern United States.

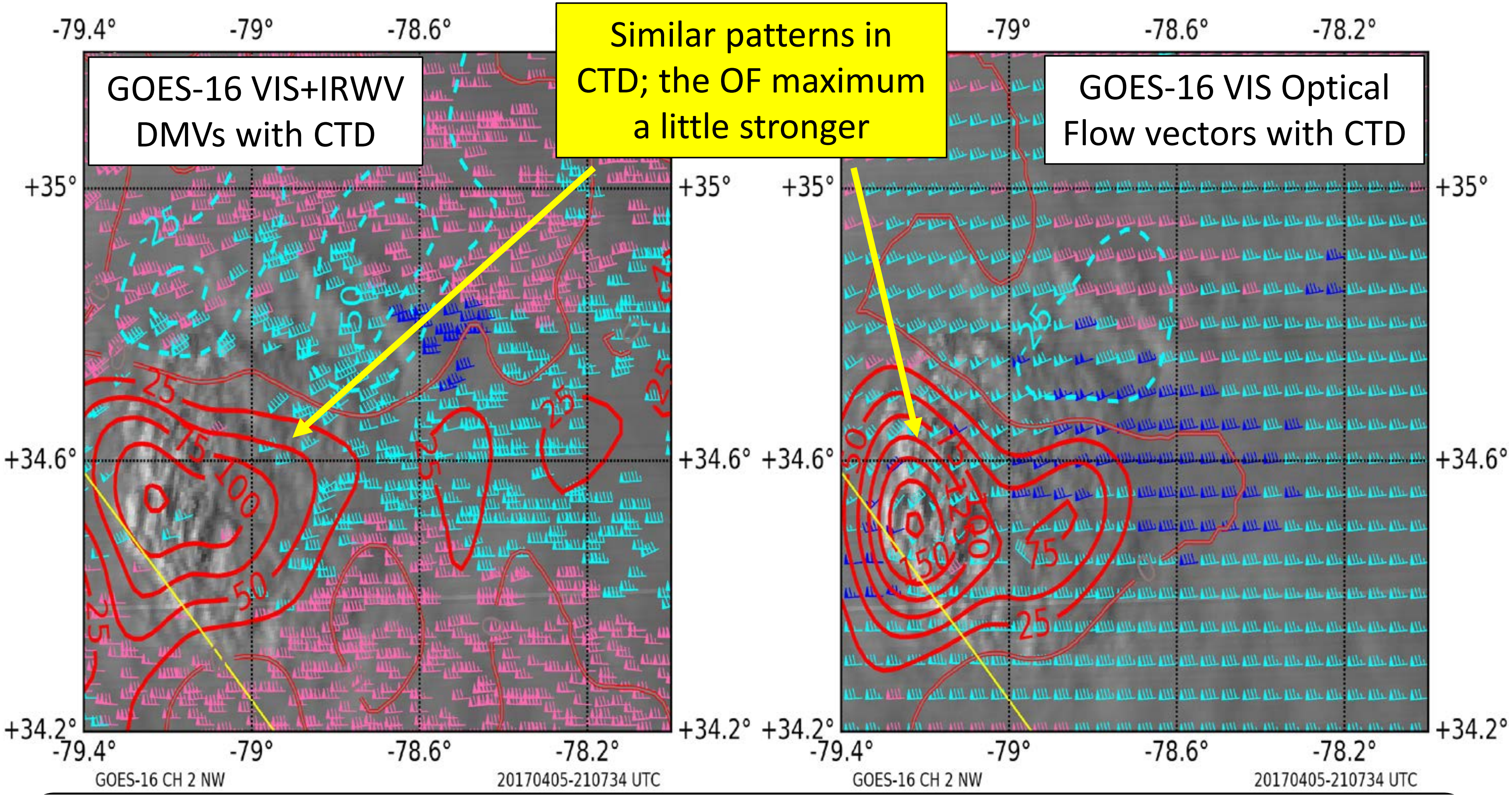


GFS values at DMV locations

DMVs resolve localized storm-top divergence not observed by NWP

Anvil-top GOES-16 VIS DMVs and associated cloud-top divergence

GOES-16 channel 2 VIS imagery of a storm over North Carolina on 5 April 2017 shown with GFS 6- hr forecast winds and associated calculated cloud-top divergence (*Left*) ,and derived GOES-16 VIS DMVs with divergence field (*Right*). The cloud-top divergence (CTD) is contoured with positive (negative) values in red (blue dash) every 25x10^{-5} s^{-1}, and vectors are colored by pressure, with pink representing vectors at pressure (p) 300 hPa > p ≥ 200 hPa , cyan at 200 hPa ≥ p > 175 hPa, and blue at 175 hPa ≥ p > 150 hPa.


GOES-16 VIS+IRWV DMVs with CTD

Similar patterns in CTD; the OF maximum a little stronger

GOES-16 VIS Optical Flow vectors with CTD

GOES-16 channel 2 VIS imagery of a storm over North Carolina on 5 April 2017 shown with GOES-16 VIS, IR and CTWV DMVs and associated CTD analysis (*Left*) and VIS Optical Flow vectors with CTD (*Right*). CTD is contoured with positive (negative) values in red (blue dash) every 25×10^{-5} s^{-1}, and vectors are colored by pressure, with pink representing vectors at pressure (p) 300 hPa > p ≥ 200 hPa , cyan at 200 hPa ≥ p > 175 hPa, and blue at 175 hPa ≥ p > 150 hPa.

Findings

- **Tracking of cloud motions with DMV and Optical Flow methods at high spatiotemporal imagery such as from the GOES-16 meso sector scans allows for detailed diagnoses of deep convection cloud-top flow kinematics**

- **The Optical Flow method produces more vectors over turbulent deep convection tops and results in stronger divergent flow than the DMV method, but the validity of these winds needs to be confirmed through more extensive radar and aircraft comparisons, etc.**

- **Work is underway (Apke et al. 2018) to experiment with finer detail analyses of the meso AMVs (down to ~5 km features will be resolved), and the potential use of even finer temporal resolution data (30 sec) from overlapping GOES-16 meso sector data**

Overall Summary

Retrieving AMVs in mesoscale flow environments offers unique challenges, but these are often dynamic regions associated with hazardous weather events

And regional (e.g., mesoscale/hurricane) weather forecast models and their associated data assimilation systems are now becoming convective-scale, demanding observations on these scales

Advanced and recently-available satellite imagers that offer increased spatiotemporal sampling and <u>solid navigation/co-registration</u>, along with customized AMV processing, can help meet these challenges

Future Directions

- **Further exploit the new Himawari-8/9 and GOES-R series super-rapid-scanning opportunities to continue the advancement of AMV processing methodologies towards the enhancement of AMV quantities and quality for mesoscale applications.**
  - **Document the quality of the 1-min. AMVs (band-dependent RMSE)**

- **Expand investigations to multiple mesoscale events, and seasonal hurricane impact studies**

- **Can novel dynamic initialization (HWRF) or hybrid DA (meso models) techniques be employed to better exploit the high spatiotemporal resolution AMV observations? Is correlated error a barrier to improvement?**

Future Directions

- **For operational centers, consider a multi-tiered, scale-dependent approach to AMV processing (already some elements of this in NESDIS, EUMETSAT and JMA processing streams)**

  - **Large-scale AMV processing at reduced time and spatial resolutions to support global analysis and NWP (i.e. hourly, full-disk, relaxed target spacing)**

  - **Telescoped or nested enhanced AMV processing based on targeted regions of interest**
    - **Utilize rapid-scans and enhanced processing methods**
    - **Provide at ~15-min intervals using full res imagery**

- ***Recommendation: IWW to take an action item to work with NWP community (global and meso NWP centers) to determine the optimal configurations of such an observing strategy***

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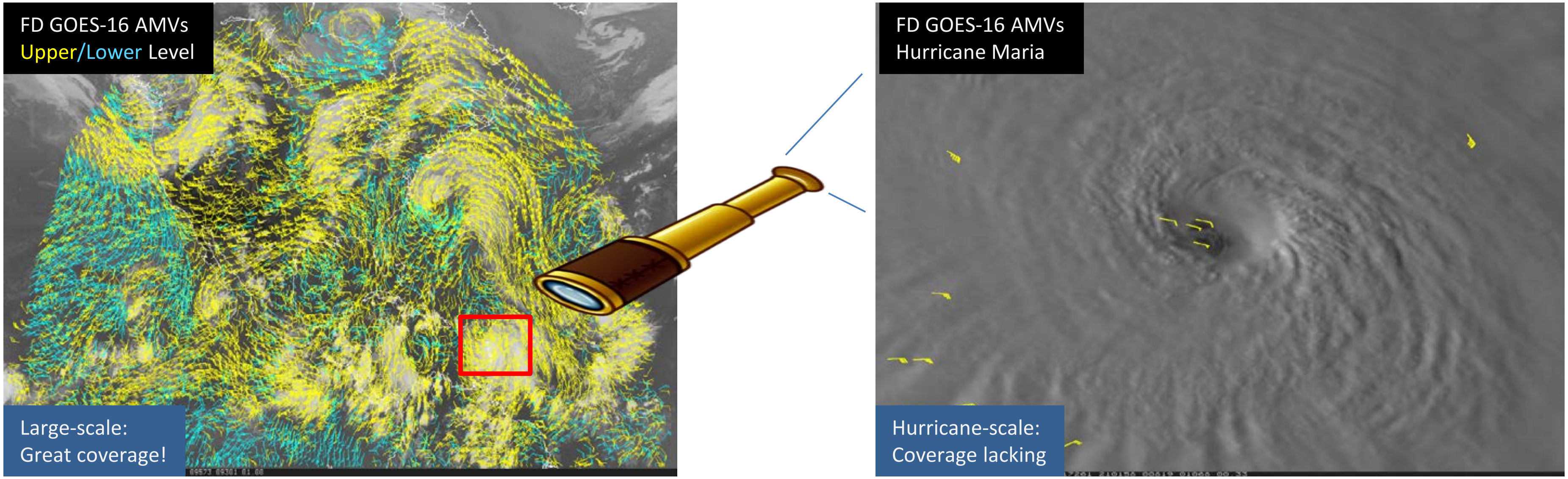

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Extra Slides

Optical Flow Approach

- An alternative to DMV 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)
- Normally, clouds within a fixed small satellite image neighborhood move too fast to be tracked
- With GOES-16 ABI 30-60 sec data, mesoscale optical flow derivation is now possible!

References

Apke, J. M., J. R. Mecikalski, K. Bedka, E. W. McCaul Jr., C. Homeyer, and C. P. Jewett, 2018: Relationships between deep convection updraft characteristics and satellite based super rapid scan mesoscale atmospheric motion vector derived flow. Mon. Wea. Rev., Submitted.

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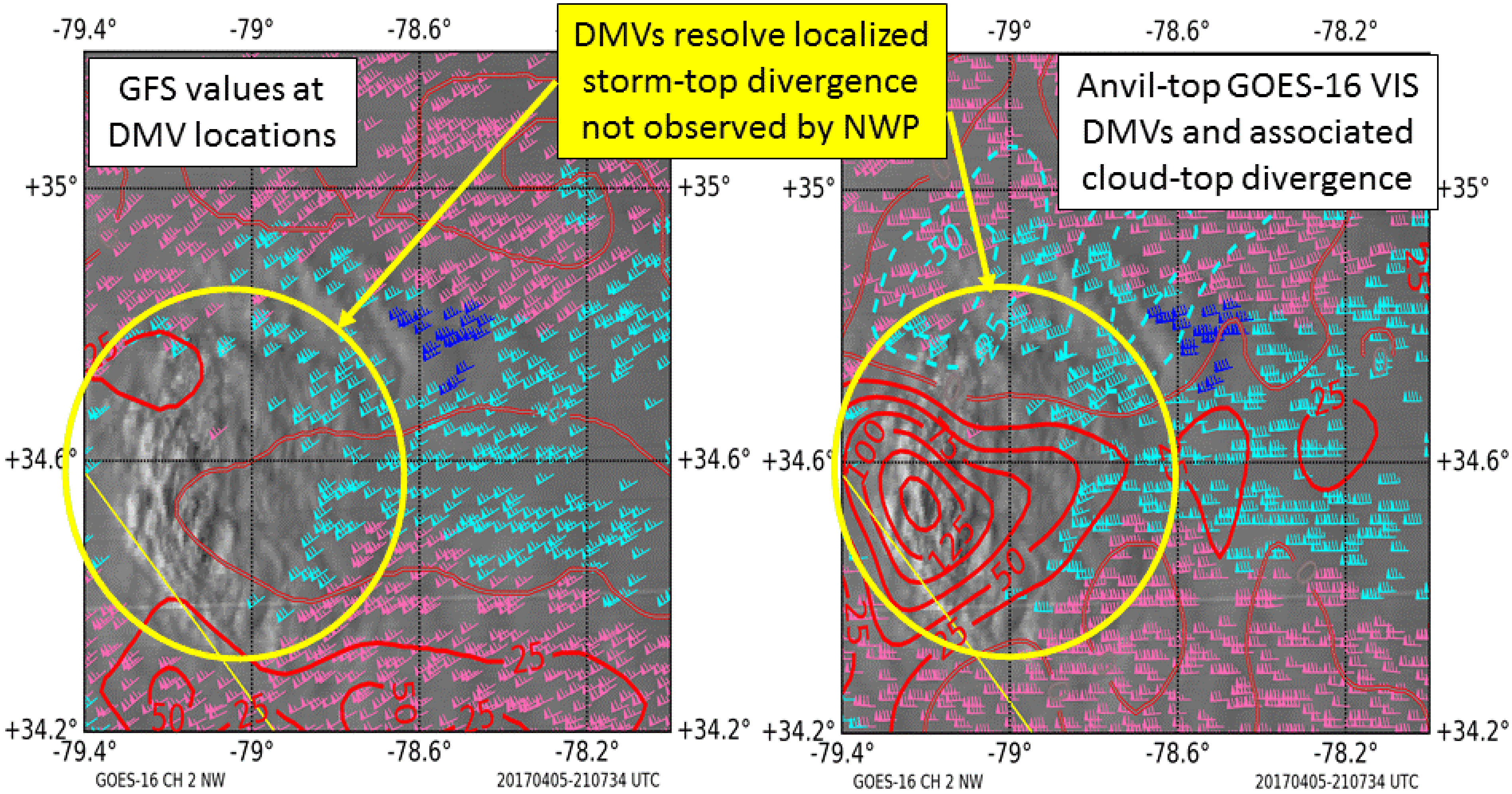

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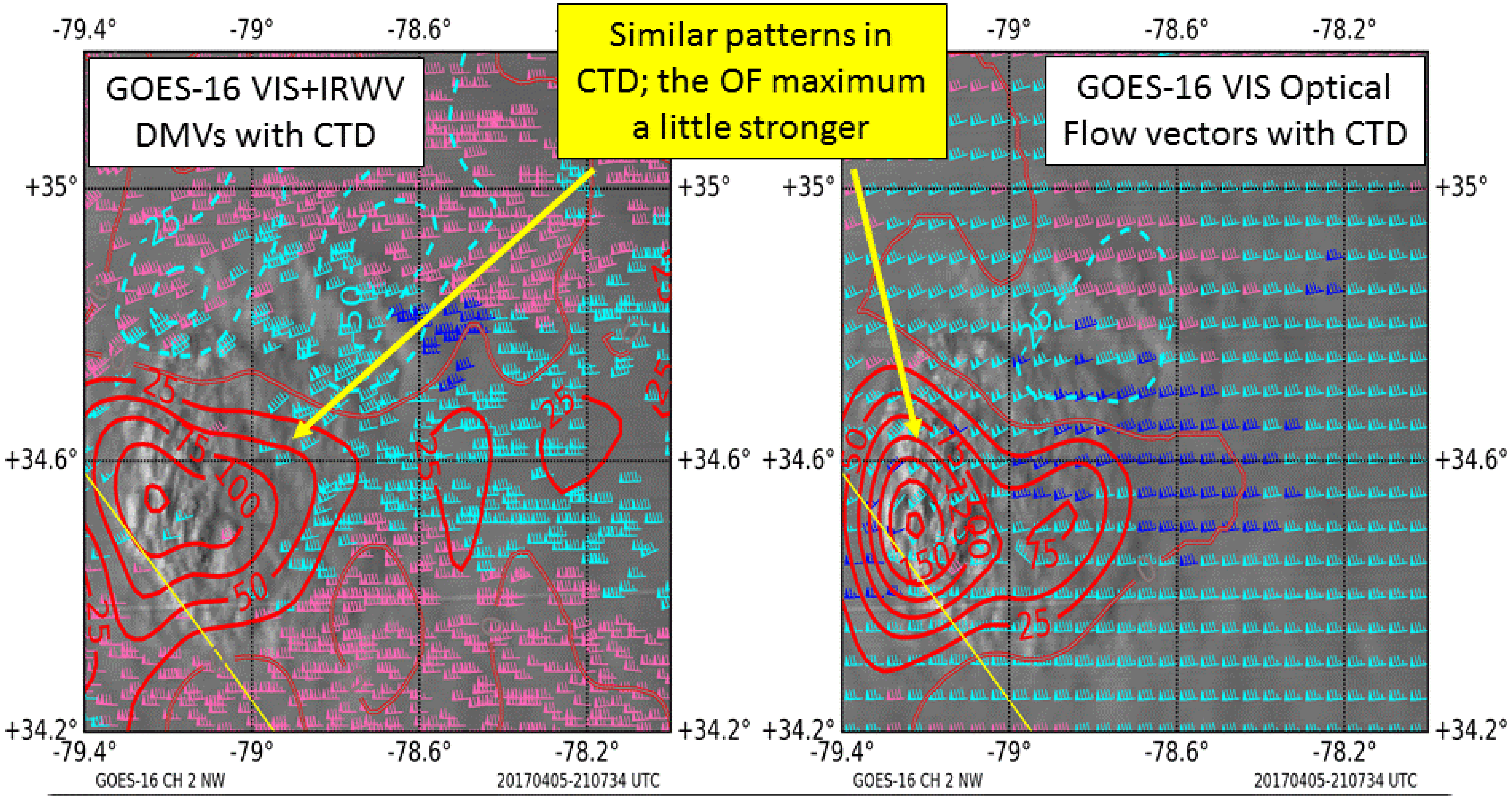

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