Technical Report
University Of Wisconsin-Madison

<table>
<tr><td>Project Title:</td><td>Investigation of mesoscale flow fields in severe storm environments enabled by the development and multiple-application of high-resolution (space and time), research-quality Atmospheric Motion Vector fields derived from GOES-R multi-spectral imagery</td></tr>
</table>

Award Number: **NNX15AR61G (ROSES-2014 / Severe Storms Research)**

UW Internal IDs: **MSN184900 / AAA4745**

For the Period of: **7/31/2015 through 7/30/2018**

Principal Investigator: **Christopher Velden**

Collaborators:
Robert Rabin, NOAA/National Severe Storms Laboratory
John Mecikalski, University of Alabama in Huntsville
Kristopher Bedka, NASA/Langley Research Center
Jason Otkin, University of Wisconsin
Daniel Cecil, NASA/Marshall Space Flight Center
Thomas Jones, OU-Cooperative Institute for Mesoscale Meteorological Studies
Timothy Lang, NASA/Marshall Space Flight Center

Date Submitted: **5/30/2017**

Location:
University of Wisconsin - Madison
Space Science and Engineering Center
1225 West Dayton Street
Madison, WI 53706

Reports will be sent to:
Technical Officer: Ramesh Kakar
Ramesh.k.kakar@nasa.gov
Grants Office: NSSC-Grant-Report@mail.nasa.gov
New Technology Office: hq-ntsr@lists.nasa.gov

SSEC Number (Internal)   *1457*

Inventions Report:

☒ No Inventions resulted from this award
☐ Yes

Inventory Report:

☒ No federally owned equipment is in the custody of the PI
☐ Yes

Publications:
Griffin, S., K. M. Bedka, and C. S. Velden, 2016: A Method for Calculating the Height of Overshooting Convective Cloud Tops Using Satellite-Based IR Imager and *CloudSat* Cloud Profiling Radar Observations. Journal of Applied Meteorology and Climatology 2016 55:2, 479-491.

Summary of Technical Effort:
The work plan for the past year's effort was amended due to the delay in the field experiment to 2018 or 2019. This included two major milestones:

Year	Task/Milestone	Success criteria
2	Participate in field campaign feasibility study team	Report outlining feasibility and strategies of potential NASA-led severe weather field campaign was submitted
2	Using simulated and real GOES-R/16 image datasets, begin research and development of meso-AMV processing and sampling strategies for optimal data impacts and mesoscale analyses of severe weather events	Development and tuning of AMV algorithms to provide high-density and quality AMV fields and products for severe weather applications

With regards to Task/Milestone 1, the PI directly participated in two workshops last year held to discuss and report on the feasibility of a NASA-led severe weather field campaign. The proposed project collaboration team, led by Dr. Amber Emory, delivered a final report with our findings and recommendations to Dr. Kakar. Briefly summarizing the report, the team has crafted a field campaign feasibility study that emphasizes the synergistic use of ground-based, airborne, and high-resolution GOES-R (now GOES-16) measurements to develop an improved three-dimensional understanding of the evolution of tornadic storms and their manifestation in GOES-R/16 products. Several experimental design and flight scenario options are described. The proposed campaign has the capability to improve the understanding of storm processes and provides an opportunity for NASA to play a role in basic and applied research using a spaceborne asset (GOES-R/16) that it played a leading role in developing. PI Velden was also on the GOES-R/16 team recently awarded the prestigious 2017 NASA Agency Honor Award.

Regarding the second milestone, our research team is actively collaborating with Prof. John Mecikalski's group at the University of Alabama-Huntsville, Dr. Kris Bedka at NASA-Langley, and Dr. Robert Rabin at NOAA/NESDIS/NSSL. The Bedka collaboration has already resulted in a publication, which examines a new and improved method to estimate overshooting cloud top heights in strong convective systems. In collaboration with Mecikalski, we are exploring advanced methods to derive high-resolution atmospheric motion vectors (AMVs) that can also be used to diagnose the cloud-top structure evolution in severe weather events. Structures in the anvil cirrus canopy can be tracked in super rapid scan imagery (which will be routinely available with GOES-R/16) to deduce features such as cloud-top kinematic features, ageostrophic motions, developing blocked flow, canopy-level divergence and vorticity trends. Collaborator Mecikalski and associate Apke have done preliminary diagnostic studies relating some of these features to severe weather occurrences using heritage tracking methods. An example was shown in the last report. While encouraging in terms of

vector density and coverage, the AMV fields are likely not yet optimized to capture all of the flow features pertinent to the storm scales. We are investigating this aspect using novel AMV derivation approaches being developed in collaborations with the GOES risk reduction program. These new methods are exploratory, and the effort now is to evaluate algorithm processing trade-offs, tuning of parameters that can affect the vector quality, and careful validation studies with the end goal of providing high-quality, GOES-R produced meso-AMV datasets to the mix of observations for the proposed field campaign in 2018 or 2019.

One proposed new method is the feasibility of using an optical flow technique to obtain AMVs at the top of thunderstorms, and this is being been tested using imagery from the GOES-14 satellite (SRSOR mode), and from GOES-16 Mesoscale sectors operating in both 1-minute and 30-seconds mode. Wind vectors are estimated using a "Classical Variational Optical Flow algorithm" obtained courtesy of the Computer Vision Group, Feiburg, Germany. The algorithm is derived from that described in *High accuracy optical flow estimation based on a theory for warping* by T. Brox, A. Bruhn, N. Papenberg, J. Weickert. *T. Pajdla and J. Matas (Eds.), European Conference on Computer Vision (ECCV) Prague, Czech Republic, Springer, LNCS, Vol. 3024, 25-36, May 2004.* Visible image pairs of 1 minute or 30 second time separation have been utilized in this approach. The images have been remapped to equal latitude longitude grids before applying the algorithm. In the case of GOES-16 band 2 (visible) data, the grid spacing is .005 deg, approximately 0.5km. For GOES-14 band 1 data, the grid spacing is .01deg (1km). A parallax correction has not yet been applied. Wind vectors are computed at each grid point from the computed displacement along the eastward and southward directions between image times.

Cloud top pressure estimates are assigned to the AMVs at each grid point. The cloud top pressure and wind data are converted to McIDAS MD format files (point data) for further analysis. The MDs files will be used to provide an objective analysis of winds in 3 dimensions using a recursive filter analysis. The cloud top pressures are currently assigned using the CLAVR-x (Clouds from AVHRR Extended) product. We have been assessing the spatial characteristics of the cloud top/height pressure in the vicinity of thunderstorm anvils and overshooting tops for selected cases. There appear to be some limitations in the derived cloud top pressures at the resolution needed for the optical flow derived winds. We plan on assessing the applicability of the GOES-R cloud top product when output becomes available. Dave Stettner and Steve Wanzong (UW-CIMSS) have provided valuable support and guidance for the tasks described above.

From the analysis of a few supercell storms, high speed winds were observed to develop rapidly downwind of overshooting tops within minutes of tornado formation. The high speed winds downwind of those regions may be indicative of strong outflow above the equilibrium level of intense updrafts. Another interpretation could be stronger environmental winds near the summit of the overshooting tops. From GOES-14 data, peak velocities of approximately 80 ms-1 developed rapidly near the times of EF3 and EF4 tornado formation on 09 May 2016 in Oklahoma. Recent analyses from GOES-16 revealed a similar signature in a storm producing an EF2 tornado near Elk City, Ok. The strength of these winds may signal the intensity of the updrafts as they penetrate into the stratosphere and divergence flow intensifies. Ultimately, this information could be combined with GLM-enhanced lightning flash rate and 3-dimensional winds from weather surveillance Doppler radars to provide a multi-sensor analysis product.

Preliminary comparisons indicate little significant difference in AMVs derived from image pairs 30 seconds and 1 minute apart. These were based on analyses from GOES-16 above thunderstorms in west Texas on 28 March 2017. Time continuity of derived winds from cloud movement above storms appears to be quite good with the use of both 30 seconds and 1 minute time intervals. AMVs derived from the displacement of small cumulus clouds in the thunderstorm environment near the top of the boundary exhibit more variability between successive analyses. This may be related to the slower wind speeds and limited displacement lengths of these clouds over such short intervals. Some improvement in this regard was noted in using image pairs 2 minutes apart.

Fig.1. GOES-14 visible image of supercell storm in south central Oklahoma at 21:07 UTC 09 May 2016. The location of the high speed maximum at anvil top just downwind of the overshooting top is indicated by the "X". "T" is the approximate location of the EF-4 tornado.
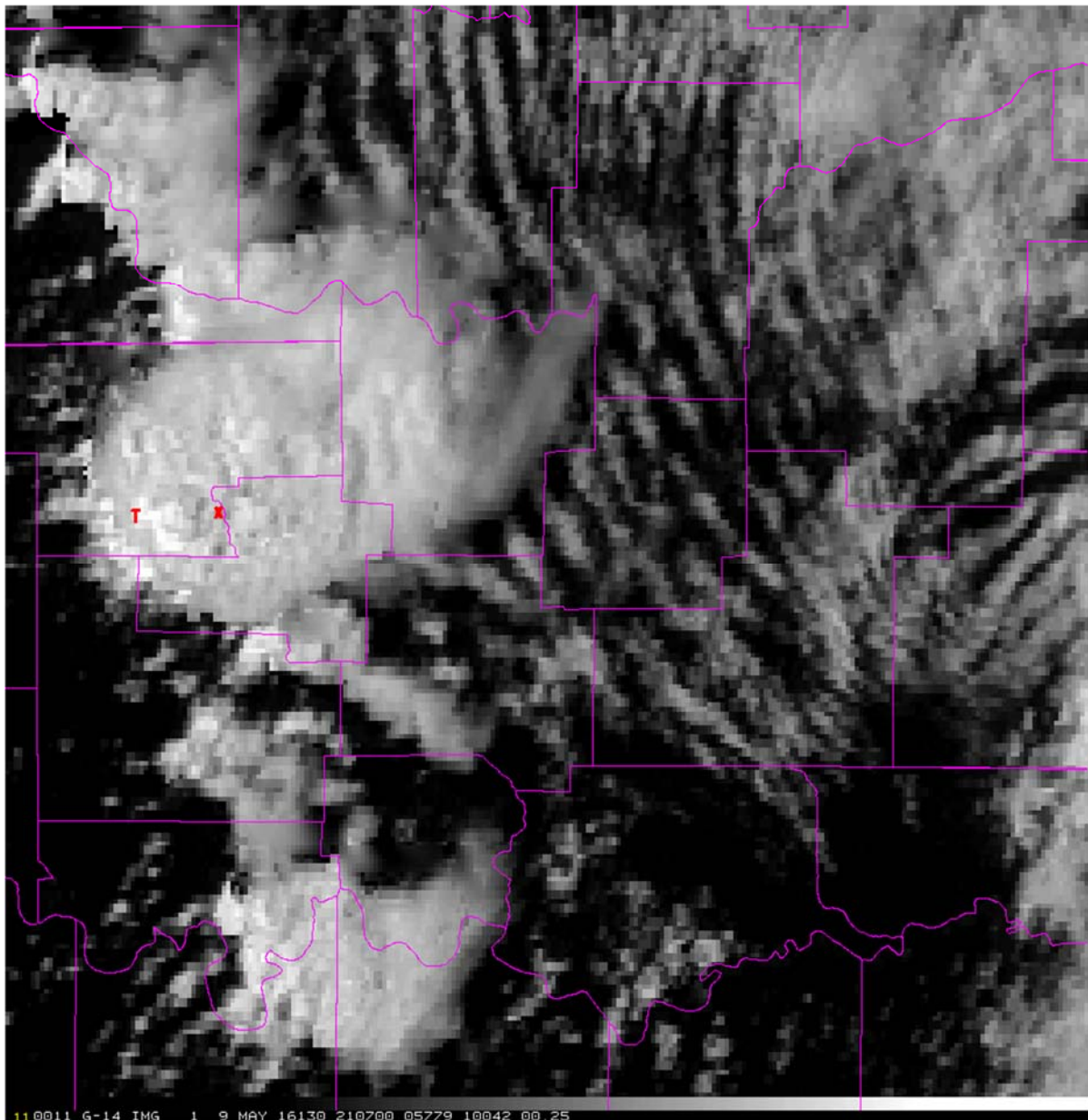
Fig. 2. Same as in Fig. 1, except the image shown covers a larger area, and AMVs derived from the optical flow are plotted at every 5km (every 5th grid point).
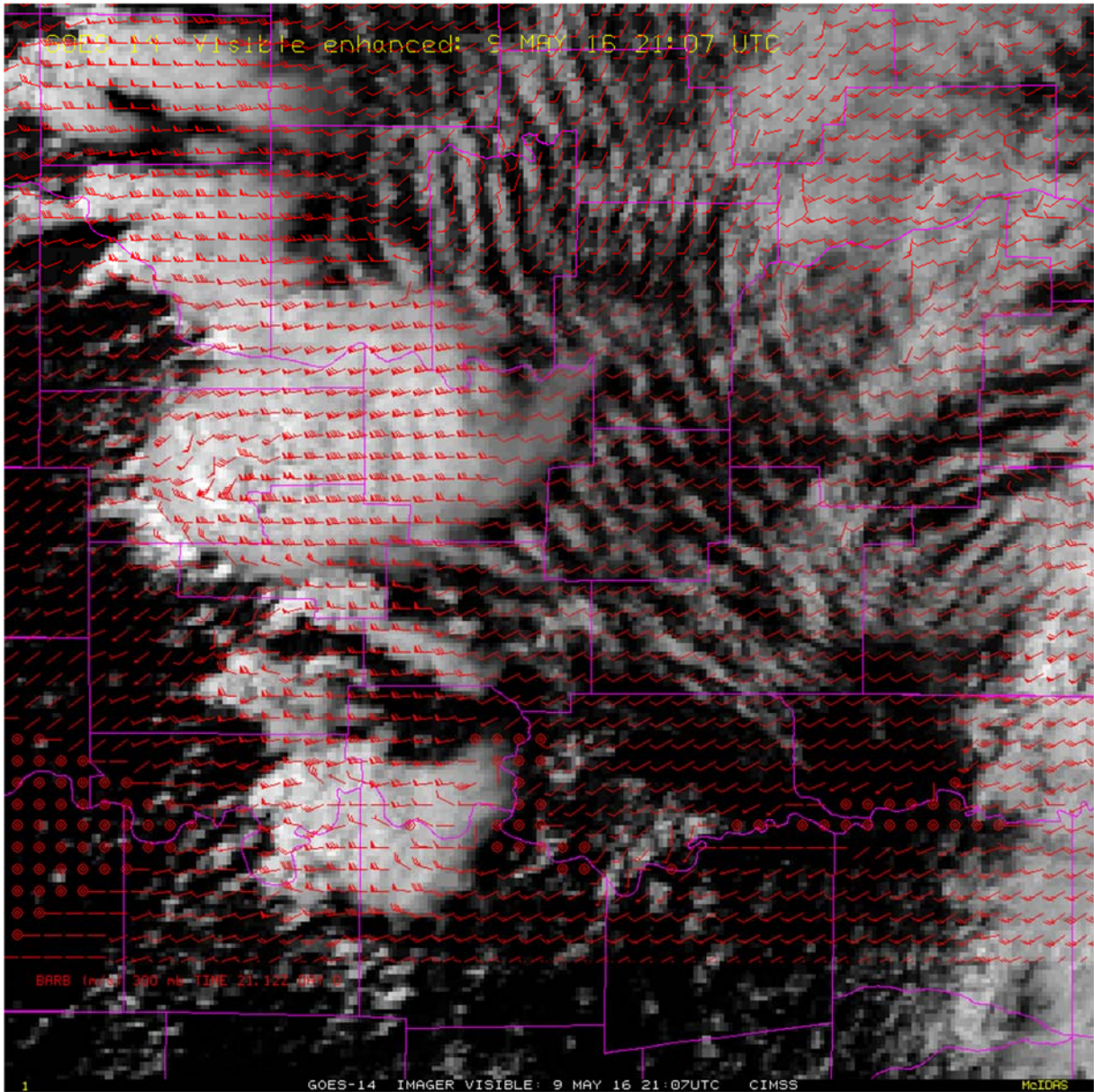
Fig. 3. Color enhancement to indicate wind speed (m/s) of the AMV field from Fig. 2, on a 1km analyzed grid. Note the local high wind maximum in purple (greater than 80 ms^{-1},155 knots).
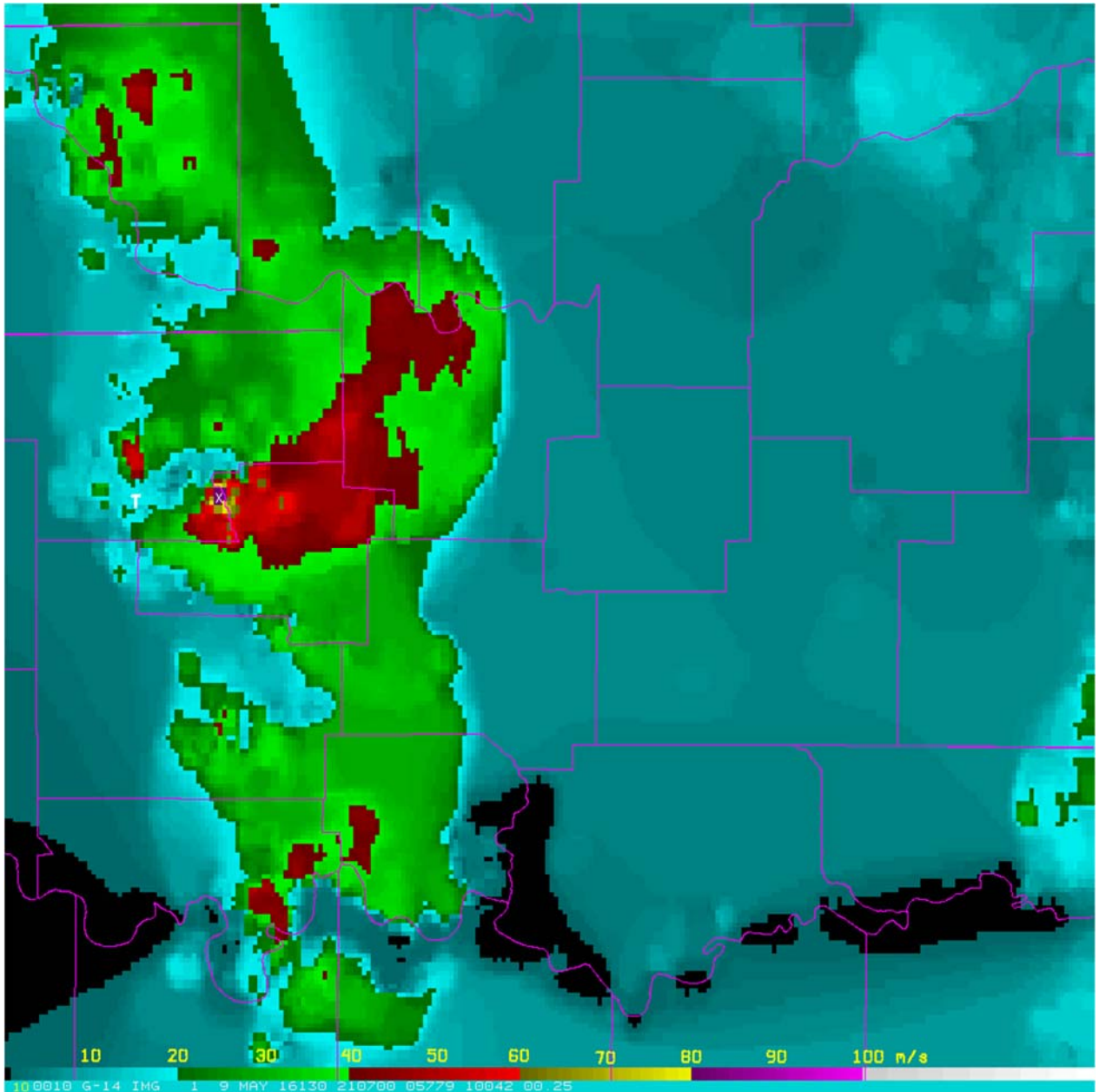
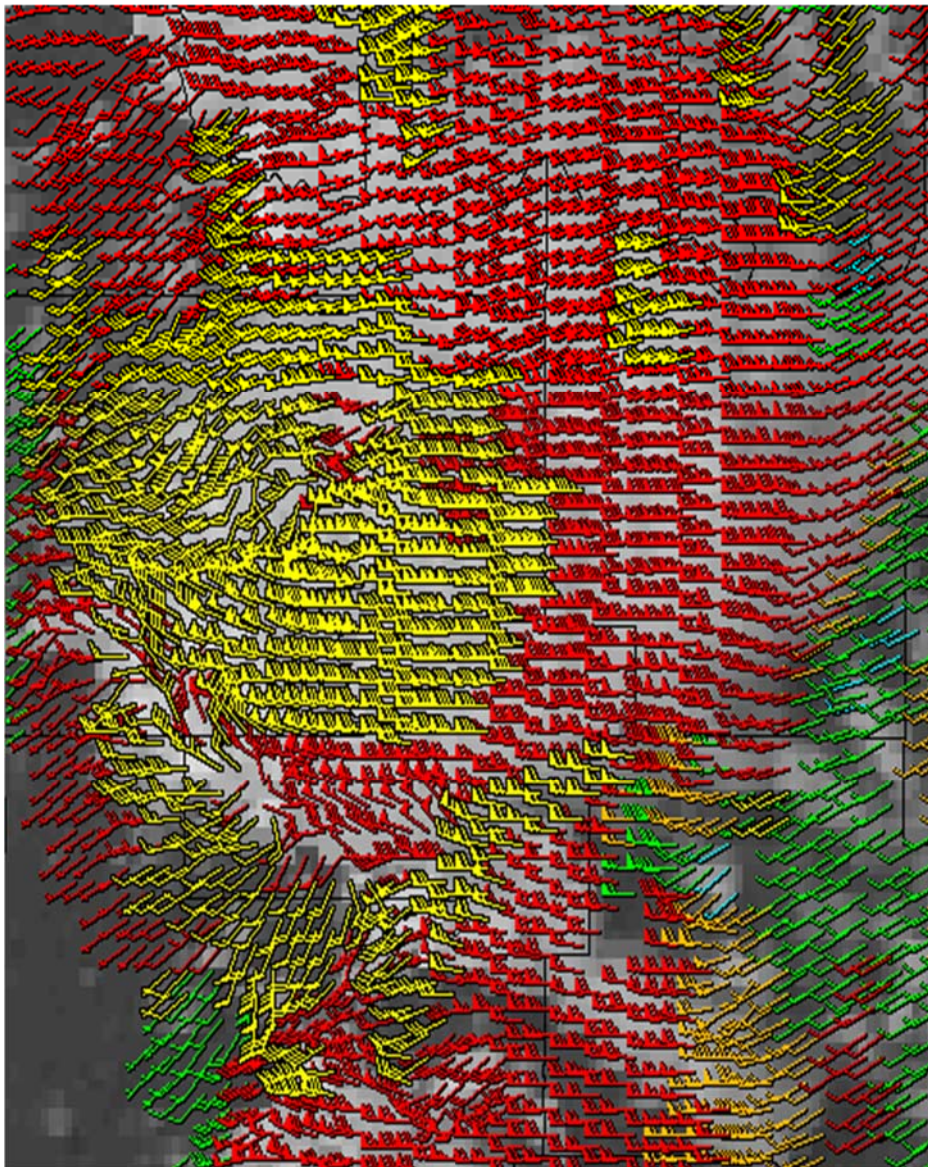Fig. 4. Same as in Fig. 2, except color coding of the wind flags indicates pressure level.

Fig. 5. Comparison of wind vector density over a tornadic supercell, 21:33 UTC 09 May 2016. Top panel: optical flow technique (winds plotted at every 5th grid point). Lower panel: from legacy AMV technique developed at UW-CIMSS (WINDCO), courtesy of Jason Apke, University of Alabama-Huntsville. Vector enhancement is clearly indicated over regions of the storm anvil using the optical flow method.