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NEXRAD Dual Polarization Data for FAA Aviation Products*

David J. Smalley, Michael F. Donovan, Betty J. Bennett
Kenta T. Hood, Elaine Griffin, Mark S. Veillette, and Earle R. Williams,
Massachusetts Institute of Technology, Lincoln Laboratory

1. INTRODUCTION*

The dual polarization (hereafter, dual pol) upgrade of the United States' NEXRAD network was completed during 2013. The primary functional benefit of dual pol is the ability to significantly improve estimates of the type of bulk scatterers contributing to the radar returns. Scatterer-typing via dual pol is performed by the NEXRAD Hydrometeor Classification Algorithm – or HCA - (Park et al., 2009) yielding ten classifications. The Federal Aviation Administration (FAA) sponsors MIT Lincoln Laboratory (LL) to develop NEXRAD-based algorithm products for aviation weather systems. Since 2001, eight LL-developed algorithms have entered the operational baseline. Seven products are created to identify convective weather, wind shear, icing, and hail aviation hazards. The algorithms in total have been upgraded over 35 times to improve data quality, address an FAA need, or take advantage of changes introduced to NEXRAD. En route, terminal, and route availability systems utilize these products. The upcoming NextGen Weather Processor will also use some of these products. The current focus is to develop algorithms that derive benefit from the dual pol capability. By utilizing the hydrometeor classifications and the dual pol data itself, new capabilities such as improved data quality and detection of potential hazards are possible.

New FAA hazard products from dual pol icing and hail algorithms are now operationally available that take advantage of two of the hydrometeor classifications. In order to improve the performance of the automated algorithms and maximize the dual pol benefit to the FAA, improvements in the HCA algorithm and data quality of the dual pol parameters are required. This will enable the development of higher fidelity and more robust icing and hail products.

This evolution is underway through the efforts of the NEXRAD community. The NEXRAD Radar Operations Center (ROC) is executing steps in its 23-point recommendation engineering action plan to address dual pol calibration (Ice and Secrest, 2014). LL adapted the NEXRAD Melting Layer Detection Algorithm to utilize grids of meteorological data to produce a higher fidelity melting layer depiction to merge with the radar data that HCA uses in its classification logic (Hallowell et al., 2013). The National Weather Service's Office of Science and Technology (OS&T) has readied for future operational use the National Severe Storms Laboratory's (NSSL) hail size discrimination algorithm (HSDA) for HCA (Ortega and Ryzhkov, 2013). It is the first sub-classification addition to HCA using an innovative coding approach developed by LL and OS&T. For improving dual pol quantitative precipitation estimates, the Cooperative Institute for Mesoscale Meteorological Studies developed MetSignal (Lamb et al., 2014) which is a yes/no precipitation interpreter conjoined with HCA. An approach towards 3D and 4D analyses of dual pol parameters known as Quasi-Vertical Profiles (Ryzhkov et al., 2015) is also in development.

The planned availability of these and future improvements will enable further upgrades to dual-pol-based algorithms for the FAA. The remainder of this paper will describe LL's efforts to contribute further to the evolution of NEXRAD's dual pol

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capability as it pertains to algorithms in development. The intent is to raise awareness to issues, concerns, challenges, and remedies. Particular challenges are addressed regarding truth references. Specific targeted future products or enhancements to products are also discussed.

2. ALGORITHM CHALLENGES ADDRESSED

Each algorithm utilizing NEXRAD data must address and ideally overcome challenges encountered during its development cycle. Is the quality of the necessary input data sufficient? How much radar detection is possible of the meteorological phenomenon? How are algorithm results validated? Is it possible to address NEXRAD shortfalls to benefit the algorithm now or in the future? Are end-user requirements satisfied?

2.1 Icing Hazard Levels (IHL) Algorithm

The goal of the IHL algorithm is to provide radar detection of the icing hazard through the dual pol capability. The operational IHL product provides the top and bottom altitudes (referenced to MSL) within radar view of the icing detection to 300 km range. This range corresponds to the maximum range of dual pol data. The practical range of this single-radar product varies due to the cone-of-silence, beam broadening with range, and overshooting the meteorological phenomenon at far ranges.

Hallowell et al. (2013) describes the IHL methodology. The top and bottom altitudes are determined by the presence of the HCA graupel classification augmented by meteorological model interest based on a combination of temperature and relative humidity data. Graupel by definition is snow (aggregates or ice crystals) rimed by supercooled liquid water droplets or drops and serves as a sentinel that icing hazard conditions have been encountered. The model interest is based on the approach used by the Current Icing Potential product (Bernstein, 2005). For IHL, HCA graupel presence is considered near or at the bottom of the icing hazard. The model interest is used to extend up into the formative graupel region, thus deriving the top altitude.

Validation of IHL performance is a primary challenge. From the surface, LL scientists collect and examine snow in real-time during winter storms to examine for the presence of riming. This method provides clues or “sanity checks” but does not yield riming altitude data. Donovan et al. (2015) report on an extensive validation study of IHL relying on almost 9000 commercial pilot icing and null PIREPs (pilot reports). Reporting of PIREPs is known to have position and time uncertainty as they are provided when possible during flight operations. The study accounts for that, finding IHL has a 78% probability of detection and a 5% false alarm rate. Ironically, in recent major northeast winter storms the airlines pre-emptively canceled all flights. This effectively eliminates useful icing PIREPs as well.

Recall that IHL indicates icing only in the presence of HCA’s graupel classification. The PIREP study determined that the graupel classification only described 14% of the icing situations. Microphysically this seems reasonable. It is suggested that various conditions of mixed phase icing hazard occur defined here as ice crystals or aggregates that coexist in space with supercooled liquid water drops or droplets. But, only sometimes does mixed phase lead to sufficient graupel for the HCA to register as such. The study revealed that HCA-determined non-graupel occurrences were associated with Dry Snow, Ice Crystal, and Unknown classifications. Thus, the current version of HCA does not successfully account for mixed phase conditions.

Accounting for mixed phase conditions is not simple (Williams et al., 2015a) – both as a radar detectability problem and as an algorithmic challenge (HCA, independent of HCA, or combined approach). LL has recommended to the FAA that the NEXRAD clear air scanning mode is preferable in winter storms to help with the detectability problem. The algorithmic challenge is best addressed with verification of in situ supercooled liquid water content conditions. LL partnered with the National Research Council of

Canada (NRC) to perform the Buffalo Area Icing and Radar Study (BAIRS) in February 2013 (Williams et al., 2015b). The study is the first and only to rely on an operational dual pol NEXRAD to determine real-time in situ icing mission flight tracks with a fully instrumented research aircraft.

Figure 1 is a scatterplot of the Buffalo NEXRAD reflectivity (Z) and differential reflectivity (ZDR) pairs associated with crystal type as determined by analysis of the particle image data and HCA classifications. The plot covers periods from the three different-condition flights of February 19, 26-27, and 28. A first observation is that quite negative Z with large ZDR is associated with hexagonal flat plate crystals. That observation was only possible through the clear air scanning mode. HCA generally associated these with the Unknown class. Williams et al. (2015b) notes that there is usually a lack of significant mixed phase conditions in such locations.

Needles and dendrites form in conditions of ice and water supersaturation. The sustainment or replenishment of the moisture supply in conjunction with the efficiency of the Bergeron process are two factors that dictate the mixed phase condition associated with these crystal types. The three crystal types identified inhabit generally distinct regions of the Z-ZDR scatterplot. Also distinct in the Z-ZDR space is graupel with its high Z and 0 dB-centered ZDR. The crystal type Z-ZDR separations suggest the potential to advance development of HCA subclasses pertaining to mixed phase icing hazard.

The HCA Dry Snow classification dominates in winter above the melting layer except for near the edges of returns. LL suspects Dry Snow encompasses a broad range of microphysical conditions. The in situ icing missions verified some of that variety with respect to mixed phase. In Figure 1, this classification is shown in shades of blue to indicate conditions of low and high supercooled liquid water content (LWC). Though the data were collected on different days, it seems the high supercooled LWC Dry Snow conditions impinge on some of the needle and dendrite Z-ZDR space – showing a sensible microphysical relationship – suggesting Dry Snow is responsive to those crystal types.

It remains to be determined whether these or the additional findings of BAIRS will lead to future, robust icing hazard detection modules for IHL. The BAIRS in situ database provides a tremendous treasure trove reference to develop and evaluate future concepts. LL plans further analysis of the BAIRS database and has a number of concepts for icing hazard module additions in the evaluation stage of development. It is also important to execute additional in situ icing missions, though costly. Any new missions should target a full exploration of the positive ZDR bright band feature (Williams et al., 2015c) that corresponds to the maximum potential for mixed phase dictated by the microphysical processes.

2.2 Hail Hazard Layers (HHL) Algorithm

The goal of the HHL algorithm is to provide radar detection of the hail hazard through the dual pol capability. Like IHL, the operational HHL product provides the top and bottom altitudes (referenced to MSL) of the hail detection within radar view to 300 km range. This range corresponds to the maximum range of dual pol data. The practical range of this single-radar product varies due to the cone-of-silence, beam broadening with range, and vertical subsampling through the meteorological phenomenon at far ranges.

HHL relies on the HCA Rain/Hail classification to determine altitudes bounds and area coverage of hail. As noted in the Introduction, the NSSL has developed a three-size hail discrimination algorithm (HSDA) that will be replacing the HCA Rain/Hail classification. The next version of HHL will utilize HSDA as a severity indication. The verification and validation challenges arise from the radar sensing hail aloft but only having ground reports to rely on (except for extremely rare reported aircraft encounters with hail). Of course, the HCA classification could be correct aloft except that the hail has reached the surface but transformed to rain.

The challenge is thus twofold: did hail occur and, if it did, what size (diameter) did it have? LL is independently assessing the HCA Rain/Hail classification and, now, HSDA through comparison with hail reports and with the legacy hail algorithm product. The hail reports are provided by National Weather Service trained storm spotters, cooperative observer networks such as the Community Collaborative Rain, Hail, and Snow (CoCoRaHS), and from independent so-called citizen scientists' hail reports. Hail reports are very useful for indicating the location that hail has reached the ground. A lack of a ground hail report does not indicate the HCA or HSDA hail detections were incorrect. The size of the reported hail, though, is only useful to suggest a minimum hail size aloft (i.e. – some melting likely has occurred).

Figure 2a is an example of the HCA Rain/Hail classification with a preliminary HSDA sizing with the legacy hail product overlay for a hail storm event near Chicago. The dual pol hail area coverage (gray/red/orange) depicts a more widespread distribution of hail compared with the legacy (green triangle) overlay. The legacy algorithm examines specific identified storms for hail while the dual pol approach is not storm-centric. LL is not comparing sizing from the two algorithms. It is reassuring, conceptually, that both approaches corroborate each other in this event. The legacy hail product content is used by the FAA's Integrated Terminal Weather System (ITWS). In the future, the ITWS functionality might be the responsibility of the NextGen Weather Processor (NWP). That would present an opportunity for a rethinking of how best to utilize all the available hail information for the FAA.

Figure 2b shows the same event with hail sizing reports indicated by the white circles. The numbers inside represent multiples of ¼ inch diameter hail (i.e. – 4 means 1 inch diameter). In the LL assessment, these are used to examine if the dual pol hail detections were present and in what size range. The search region within the dual pol hail data aloft is broader than the reported time/latitude/longitude to account for non-vertical hail transport to the ground and storm motion vs. spotter arrival at a hail site, etc.

2.3 Data Quality for Algorithms

The FAA NEXRAD algorithms perform automated processing. There is no human-in-the-loop to intercede for these algorithms when the automated processing is challenged with data anomalies. The FAA requires the capability to detect and display weather and chaff (see section 2-6-4: Weather and Chaff Services (Ray, 2014 FAA Order JO7110.65V)). For the past 15 years, the LL-developed Data Quality Assurance (DQA) algorithm has provided quality-controlled reflectivity data to NEXRAD algorithm products such as High Resolution VIL (Vertically Integrated Liquid water) and Enhanced Echo Tops that are used by FAA weather systems. These products depict weather. The dual pol capability is the gateway for development of a chaff detector (see Section 3).

The left panel of Figure 3 shows a reflectivity PPI without any data quality control. Other than the legitimate weather returns east of the radar, this PPI shows typical additional returns that are undesirable for automated algorithms that DQA should remove. DQA is effective with clutter removal around the radar unless that clutter is intense and has motion (such as post thunderstorm and bug bloom). Additionally, DQA also removes solar sun strobes, constant power function returns, anomalous propagation returns, azimuthal spikes, and general speckle. Cell phone tower returns are now handled well with radial noise logic that the NEXRAD ROC implemented in radar data processing prior to DQA receiving data.

LL is exploring the preferred approach to integrate the dual pol advantage toward addressing the remaining shortfalls with DQA. The focus has been to augment the DQA-edited reflectivity with the HCA Ground Clutter and Biologicals classifications. At times, this yields very acceptable results. The right panel in Figure 3 shows such a result of the prototype DQA with HCA. Unfortunately, those two HCA classes have enough false alarm potential (due to varying reasons such as non-uniform beam filling) that LL is now modifying our approach.

DQA debuted in 2003 and to-this-day continues to process legacy resolution data (1^{o} x 1 km). For the NextGen Weather Processor, the highest resolution reflectivity data per tilt is required with data quality editing – the so called Super-resolution Reflectivity: Data Quality Edited (SRQ) product. LL's modified approach to support SRQ is to likely expand the DQA modular-format algorithm by adding new modules for those HCA classifications as well as some related to the dual pol parameters. Through analysis and/or applying machine learning approaches the new DQA will ideally be better integrated and perform at its highest level possible to support both SRQ and legacy resolution requirements.

Independent of algorithm-based data quality control is the overarching issue of requiring the dual pol NEXRAD network to be calibrated and stable. One measure that the ROC monitors by various means is the differential reflectivity (ZDR) calibration bias. Their data suggests that at any given time only about two-thirds of the network is within double the target 0.1 dB specification. Another assessment metric could be the comparison of like-scanned weather from two or more adjacent radars. Figure 4 shows an example of ZDR comparisons between neighboring NEXRADs through the Radar Reflectivity Comparison Tool (RRCT). This is a handy snapshot for quick assessment between adjacent radars. Unfortunately, it is difficult to use RRCT to determine which radar(s) are properly within calibration. It does highlight the challenge to algorithms when such variability is present within the network.

The NEXRAD ROC's 23-point engineering action plan is intended to address dual pol calibration on multiple levels (Ice and Secrest, 2014). The plan is the logical progression from guidance provided in the NEXRAD ZDR Calibration Subcommittee Recommendation Report. There is acknowledgement of the inability to attain consistently a ZDR calibration accuracy of 0.1 dB throughout the NEXRAD network (Cunningham et al., 2013) and that should be addressed and solved. The primary concern to the ROC is the inferred degradation in the dual pol Quantitative Precipitation Estimates that occurs when the stated accuracy is not maintained. Logically, other dual pol algorithms such as IHL and HHL might have sub-optimal performance for compromised radars.

Some challenges are hardware-based. 30 dB couplers are found to have improper settings in some of the radars due to mistakes in manual data entry. The couplers at all radars suffer from uncertainty introduced in the "cross-straight calibration" technique due to use of snap connections. Some radars do not point accurately enough to perform the Sun box check reproducibly. Sun checks are typically part of calibration procedures for many radars. Williams et al. (2015d) discuss the pulse processing necessary to drive down the high pulse-to-pulse variability from the Sun (+/- 8 dB) to a value near the calibration target. The NEXRAD Surface Life Extension Program (SLEP) might address the pointing accuracy.

A proposed solution as described in the plan relies on Sun box checks and ZDR bias estimates through monitoring of external targets - light rain, dry snow, or Bragg scatter conditions. This monitoring assumes exclusive scanning of each of the singular conditions. The suggested outcome is either to adjust the magnitude of ZDR or to flag the ZDR as suspect. Notable is the lack of any implementation of an absolute calibration standard such as a calibration sphere.

As the plan is executed and knowledge gained, a suggested list is proposed of items that should be considered in the decision-making process:

a. What is the acceptable temporal tolerance for a NEXRAD identified to be out of ZDR calibration (1 hour, 1 day, 1 week, 1 month, etc.)?

b. Should the live feed of any out-of-ZDR-tolerance radar be pulled from the network (as is done with some maintenance procedures)?

c. As the plan is executed, is consideration given for the ability of a site electrical technician to routinely perform a particular calibration task in the field?

d. What determines the amount of acceptable down time to support ZDR calibration (Sun box check, special-request sphere calibrations on clear nights)?

e. If 0.1 dB accuracy is not achievable:

i. How will the new level of accuracy be determined without an absolute calibration standard?

ii. What is the backup plan (such as rethink or recalibrate the Hydrometeor Classification Algorithm)?

It would be useful to have a real-time, web-based notification system of suspect out-of-ZDR-tolerance radars available to all external users of NEXRAD data (similar to the ROC's current web-based status utility).

3. TARGETED FUTURE BENEFITS TO AVIATION WEATHER ALGORITHM PRODUCTS

Improved fidelity of the icing and hail products and the overall data quality of dual pol data used by the algorithms is achievable. Through validation and verification actions, MIT LL has designed "living blueprints" for the algorithms to implement in the coming years. The development of improved techniques will be influenced by the NEXRAD environment as it evolves and requires periodic reevaluation of the blueprints. One change coming is the new VCP (volume coverage pattern) scanning strategies that will be deployed beginning sometime in 2017. These will include a new general surveillance VCP that combines the best advantages of VCPs 11 and 21 while eliminating the physical scanning gap of VCP 21. A new clear air VCP will retain the benefit of improved sensitivity but complete a volume about 20% faster and include more elevation scan angles. Many of the VCPs will be enabled to augment with additional within-volume surface scans. This supports the tri-agency need for better surveillance of rapidly evolving weather in any season. It is expected that the radars will be better calibrated in future years. This will support final determination of NEXRAD dual pol capabilities regarding distinction of mixed phase regions especially. The following subsections discuss some of the near-term aspects of the blueprints for the icing and hail algorithms and the overall data quality of dual pol data.

3.1 Icing Hazard

The goal for the Icing Hazard Levels (IHL) algorithm product is to provide the highest fidelity depiction of the radar-sensed aviation icing hazard. MIT Lincoln Laboratory developed the first version of the IHL algorithm to provide an icing hazard product based on analysis of NEXRAD dual pol graupel classification from single radars. Hallowell et al. (2013) details the initial version of the product. Extending the product requires new techniques designed to support mixed phase detection through context and inference.

There could still be a bit more use for graupel in IHL. Graupel specifically results from riming of ice crystals by supercooled liquid water. For IHL purposes, the HCA determines graupel. The HCA yields the singular, most-likely hydrometeor. If the riming process does not yield sufficient graupel to be the dominant singular type, HCA will likely return Dry Snow as the hydrometeor type. It would be useful for IHL to know whether HCA determined that graupel is the secondary or tertiary classification. This would be especially useful in the context of the interpretation of the interplay of adjacent areas of graupel vs. secondary or tertiary graupel as IHL builds area coverage of the icing hazard.

A few dual pol radar winter weather features are evident repeatedly. In Williams et al. (2015c), two often-observed features are dubbed Category A and Category B. Category A, the positive ZDR "bright band", is a suspected area of mixed phase icing potential. It is observed as a relative increase in positive ZDR at altitudes with temperature in the -10° C to -15° C range. This region is favored for crystal generation in conditions of ice and liquid water supersaturation. Category B refers to the trailing edges and cap to the weather where it is suspected that single crystals predominate. The amount, if any, of icing hazard is generally thought to be minimal. LL is testing a positive ZDR "bright band" module for future incorporation into IHL.

Without question, the in situ icing missions have been invaluable towards informing approaches to mixed phase detection. Additional in situ missions are recommended with focus on in-depth probing of the ZDR bright band. Results in Figure 5 from one of the February 2013 in situ icing missions corroborates the finding of the icing PIREP study and follows microphysical expectations. The PIREP study revealed that the favored non-graupel HCA classifications coincident with pilot reports of icing were Dry Snow, Ice Crystal, and Unknown. The red bar segments beneath the HCA classification bar show there is ample evidence of these classifications during flight conditions of notable (supercooled) liquid water content (LWC). These observations are not unexpected as mixed phase icing conditions often will not be sufficient to yield graupel for many reasons. The collected evidence studied (not shown here, refer to BAIRS (Williams et al., 2015b) is that the supercooled LWC coexisted with needle crystals and dendrite crystals as dictated by temperature as shown in crystal habit diagrams. It will take novel concepts to reliably detect some portion of the mixed phase icing hazard.

3.2 Hail Hazard

The goal of Hail Hazard Layers (HHL) algorithm product is to provide the highest fidelity depiction of the radar-sensed aviation hail hazard. The primary method is to automate interpretation of the three-hail-size subclassification from HCA. The current HHL utilizes HCA's rain/hail classification and does not provide any "severity" measure such as will be possible with the three-size subclassification. As noted earlier, the Hail Size Detection Algorithm (HSDA) provides the subclassification logic for small (up to 1 inch dia.), large (to 2 inch dia.), and giant (beyond 2 inch dia.) hail. The National Severe Storms Laboratory developed the HSDA logic based on observations collected for SHAVE (the Severe Hazards Analysis and Verification Experiment).

The HHL product includes the top and bottom altitudes that any size hail is found within "columns" within the radar volume presented in polar coordinate format. The HCA rain/hail classification is used currently but, in the future, HSDA will be used. Similarly, HHL "severity" and "confidence" data fields are provided. Currently, they are not populated with data. The HSDA subclassification will be the basis for determining "severity". The "confidence" measure will be developed as LL independently evaluates hail size performance from storm data reports. As with IHL and graupel, knowledge of whether HCA's secondary or tertiary classifications are identified to be hail could be of use.

The recent case of Delta flight 1889 (August 10, 2015) provided a diagnostic opportunity for the development of HHL but was certainly not pleasant for those onboard. That flight encountered damaging hail en route at about 34 kft flight level near the Nebraska/Kansas/Colorado border. The damage was sufficient to cause an unscheduled landing in Denver. Figure 6a shows a notional hail severity depiction based on HSDA sizing for the event. Note the starburst just right of the center of the image showing the aircraft location for the closest scan from the Goodland, KS dual pol NEXRAD. The aircraft is just at the edge of small hail with a sharp gradient to giant hail. Not shown is that the flight location is in the HCA graupel zone that typically envelopes the strong hail columns. This area typically includes lightning activity. A likely enhancement will be to augment the “severity” depiction with some portion of the area of the surrounding graupel envelope in proximity to large and/or giant hail.

Figure 6b shows the top altitude for this hail case. The yellow ranges from 45 to 50+ kft altitude. The bottom altitude is not shown but the lowest that this product is able to show is that associated with the lowest elevation scan in the VCP. With increasing range, it is possible hail will exist below the lowest elevation scan. Model data might be used in conjunction with hail melting approximations to determine the presence of hail beneath the lowest elevation scan. For “severity” associated with the top altitude, the hail size maximum anywhere within the vertical column will be represented. The “severity” for the bottom altitude would be the size determined for the lowest altitude by HSDA. A size difference between the two might be useful to indicate the presence of melting.

3.3 Data Quality

Data quality is a key prerequisite for the automated NEXRAD algorithms for the FAA. Currently, the NEXRAD Data Quality Assurance (DQA) algorithm is used to quality control reflectivity data before use by product algorithms such as High Resolution VIL and High Resolution Enhanced Echo Tops that serve FAA weather systems. DQA is over 10 years old and pre-dates the dual pol NEXRAD era. Due to uncertainties with HCA’s Biologicals and Ground Clutter classifications, they cannot be directly used as a second-pass quality control step. Instead, LL is testing methods to mitigate weaknesses with those classes before they can be used effectively in this capacity.

A parallel effort involves using dual pol data to detect the presence of chaff. The FAA has a mandate to report the presence of weather and chaff. Since chaff releases are often not publicized, chaff appears as weather in FAA weather systems such as the Corridor Integrated Weather System (CIWS). Figure 7a shows a regional snapshot of CIWS centered on the North Carolina coastal area. Off-shore weather returns are evident (this is a mosaic of High Resolution VIL used as the weather severity and area extent indicator along with High Resolution Enhanced Echo Top tags). Inland, chaff is indicated. Chaff can linger and drift in such scenes for over 12 hours.

Through visual inspection and experience, chaff has this appearance. Without dual pol or official notification, an automated algorithm or product end-user might be cautious with such a classification. Figure 7b shows reflectivity along with two dual pol parameters: differential reflectivity and cross-correlation coefficient. The former is a measure of the horizontal (positive) or vertical (negative) orientation of the scatterer. For this instance from Key West, the chaff is very positive (fluttering down with horizontal preference). The cross-correlation coefficient is a measure of similarity. The chaff has very low values indicating multiple sizes and fluttering. Combining this information leads to a notional chaff (red)/clutter (gray) capability. Additional methods are being considered to determine the preferred method for a robust chaff detector that could potentially reside in the HCA as a classification or part of a new subclassification grouping for Ground Clutter, Biologicals, and Chaff.

4. SUMMARY

The initial benefit from dual pol from the FAA perspective began with low-hanging-fruit. This has led to operational fielding of Icing Hazard and Hail Hazard products based upon decent performance of the HCA graupel and rain/hail classifications. Taking advantage of the NEXRAD HCA for data quality purposes has been more difficult. Essentially, mitigating the uncertainty (though relatively small) with some of the HCA classifications that could benefit FAA data quality objectives is challenging with respect to the standard currently achieved by DQA.

Further benefit requires thorough vetting of more sophisticated techniques outside of HCA (possibly to be incorporated within a future HCA).

The final version of HHL likely coincides with completion of integration/interpretation of HSDA and its performance vetting. Incorporating the mixed phase capability will be a major step forward for IHL. The fullness to which that is accomplished will likely define the limits of icing hazard detection by dual pol S-band radars. The quality of the dual pol data remains essential. A solution is likely to combine the merits of DQA with a dual pol contribution. The development and routine implementation of a fleet-wide dual pol calibration program will solidify the use of dual pol data for the future and likely spur more confident development of algorithms within the entire NEXRAD community.

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Figure 1. In situ measurements from the National Research Council of Canada's Convair 580 enabled dual pol NEXRAD data from Buffalo, NY to be matched against crystal type and NEXRAD Hydrometeor Classification Algorithm classes.

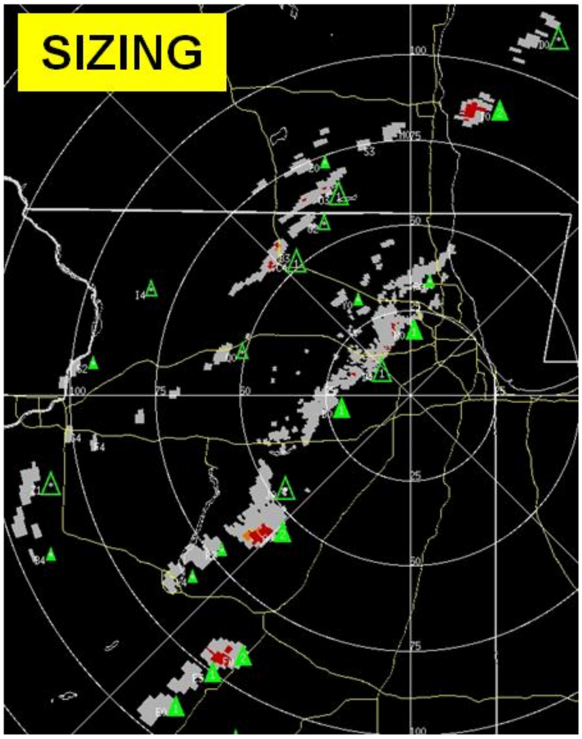

Figure 2a. Verification of hail presence and validation of the Hail Hazard Layers (HHL) algorithm are challenging. Unless hail is encountered aloft and reported (rare), the reliance is on ground-based observations of hail. Those observations are limited to conditions that allow preservation of hail to the surface and define the minimum size of the hail when aloft. Refer to the text for discussion of the comparison of legacy hail detection (green triangles) vs. HHL area coverage and sizing (gray/orange/red).

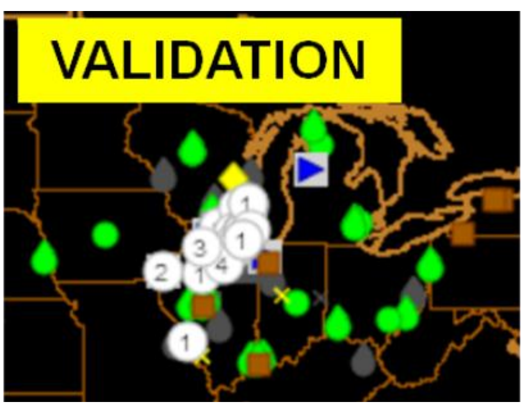

Figure 2b. Verification of hail presence and validation of the Hail Hazard Layers (HHL) algorithm are challenging. Here validation uses citizen scientists' reports of hail (numbered white circles) to compare against HHL. The numbers represent ¼ inch diameter multiples for hail size (i.e. – 4 = 1 inch).

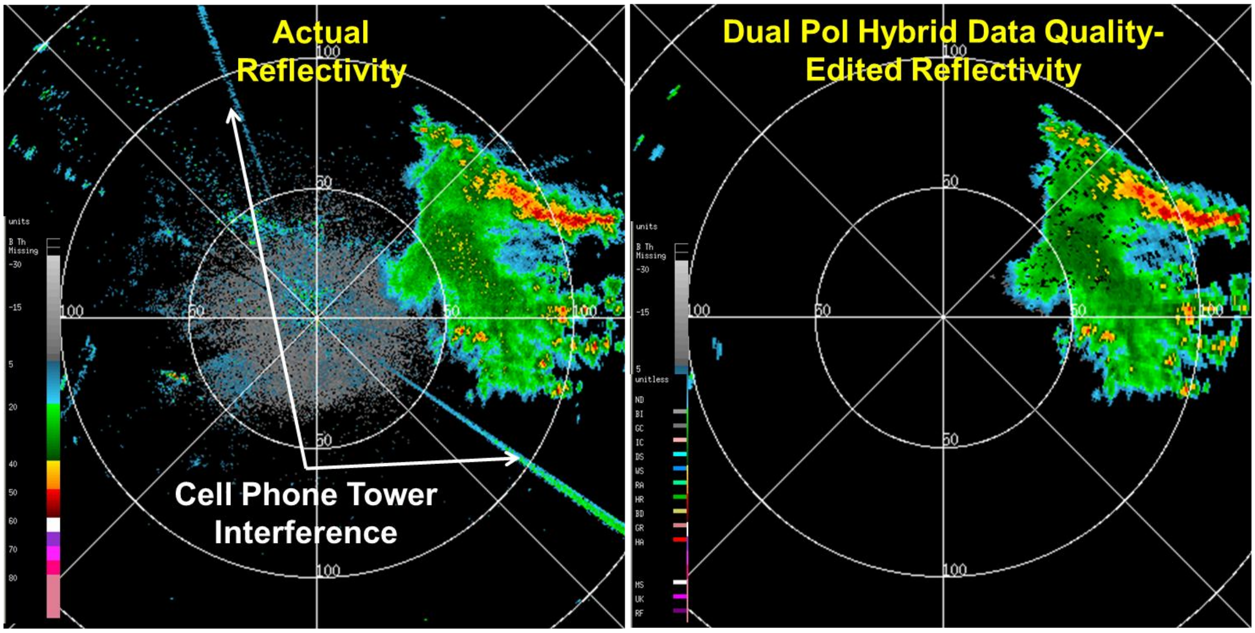

Figure 3. MIT Lincoln Laboratory began addressing the data quality of NEXRAD data for automated FAA NEXRAD algorithms in 2003. The dual pol capability allows for further tweaking to identify and remove remaining clutter.

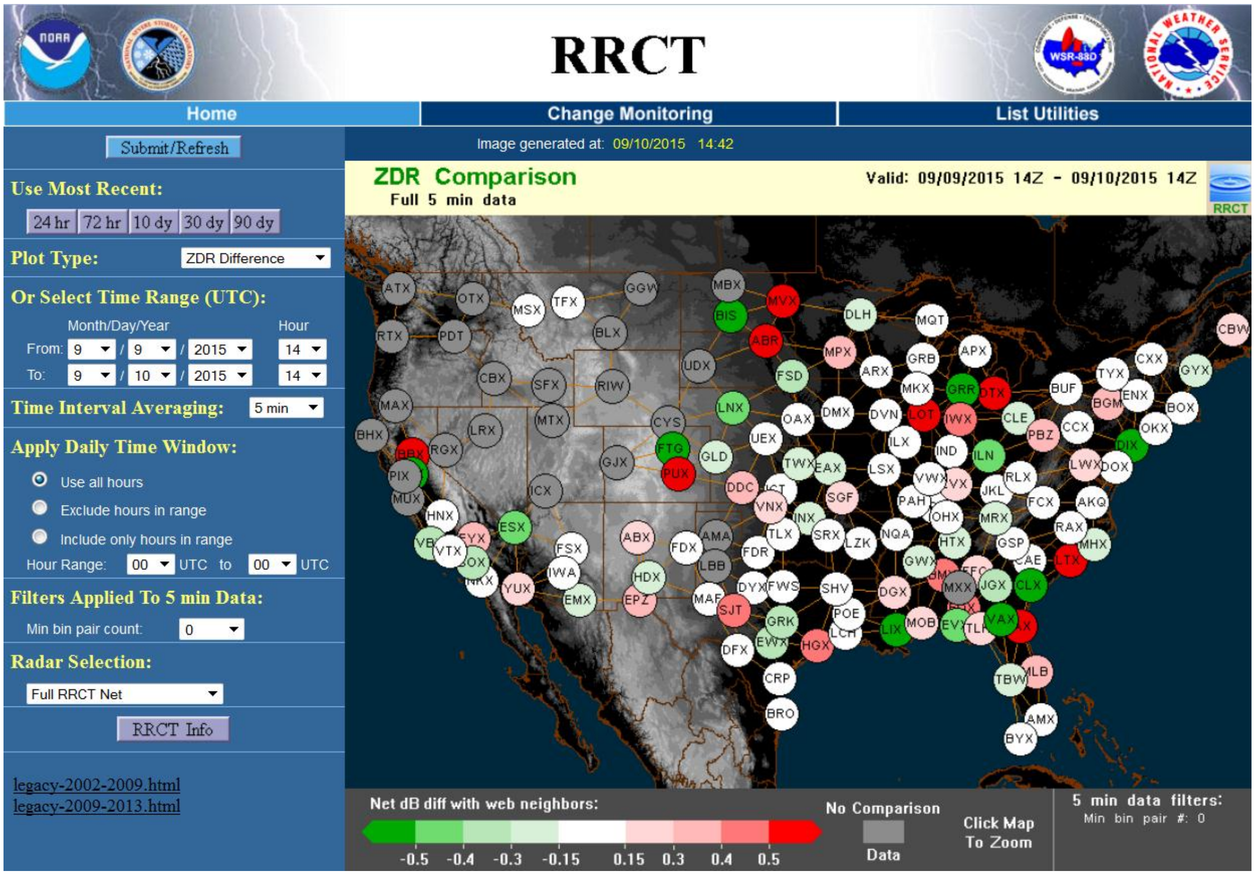

Figure 4. This is an example of differential reflectivity ZDR comparisons (in dB) between neighboring radars during the 24 hours ending Sept. 10, 2015 at 14 UTC. These comparisons are available through the Internet at http://rrct.nwc.ou.edu/.

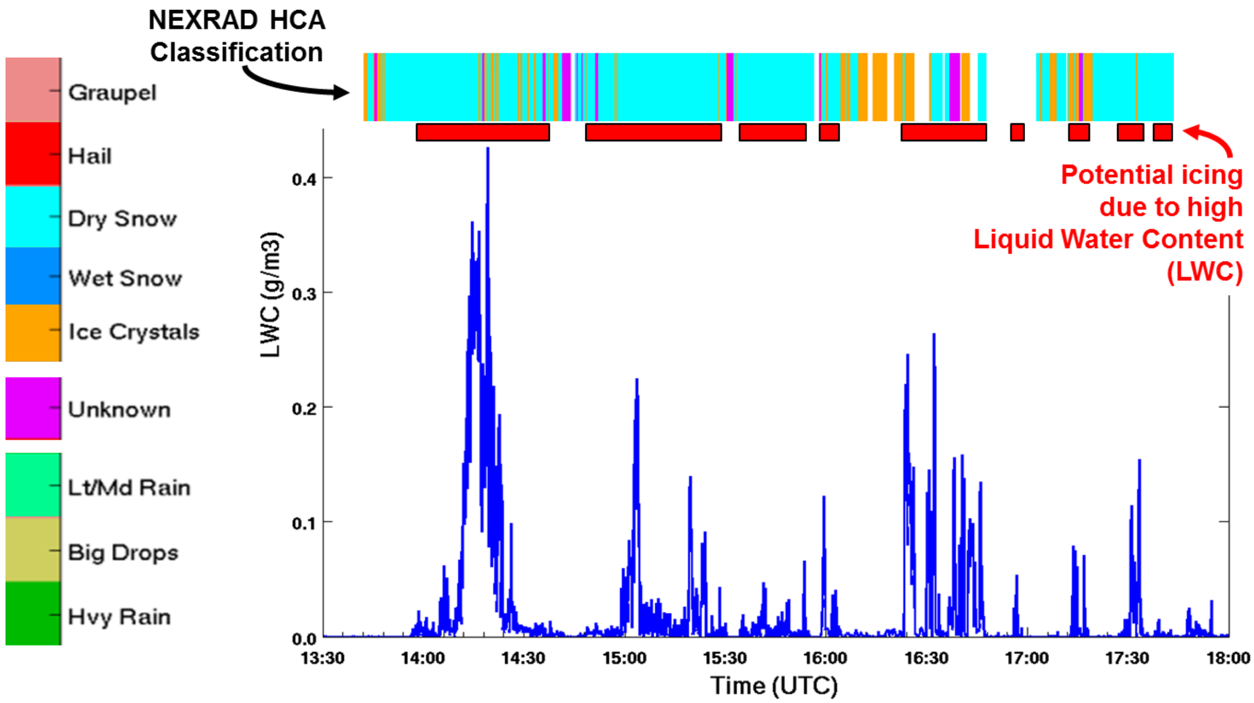

Figure 5. The Icing Hazard Levels algorithm can be expanded to provide icing hazard detection beyond use of the NEXRAD Hydrometeor Classification Algorithm graupel class. The in situ icing missions identified conditions of supercooled liquid water corresponding to the HCA classes of dry snow, ice crystals, and the unknown class.

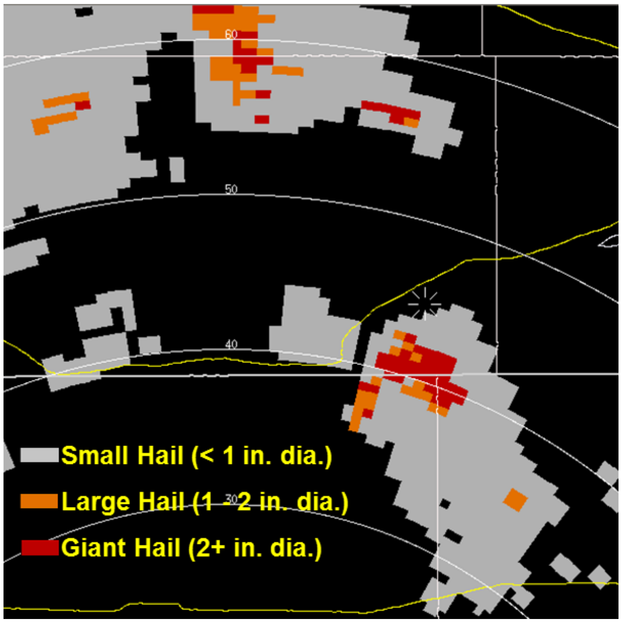

Figure 6a. Delta flight 1889 on August 10, 2015 provided a diagnostic opportunity for the development of the Hail Hazard Layer algorithm by encountering giant hail at 34 kft flight altitude. This shows the "severity" as determined by HSDA. Refer to the text for additional detail.

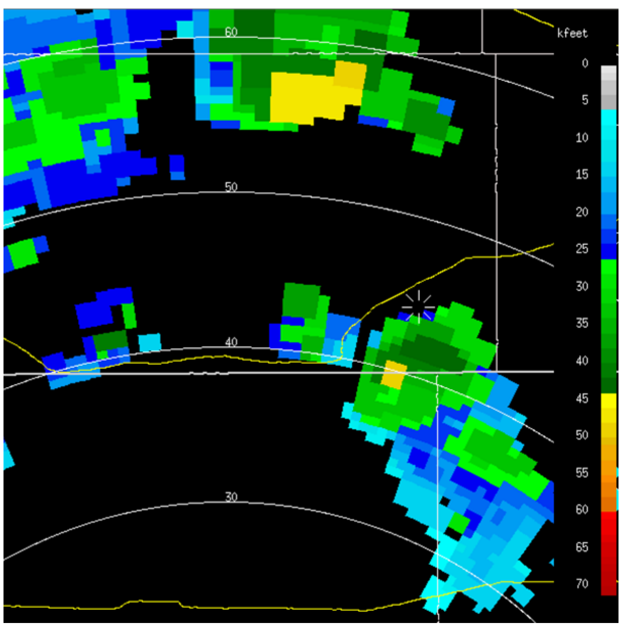

Figure 6b. Delta flight 1889 on August 10, 2015 provided a diagnostic opportunity for the development of the Hail Hazard Layer algorithm by encountering giant hail at 34 kft flight altitude. The HCA rain/hail classification is used to determine the top altitudes of hail. Refer to the text for details.

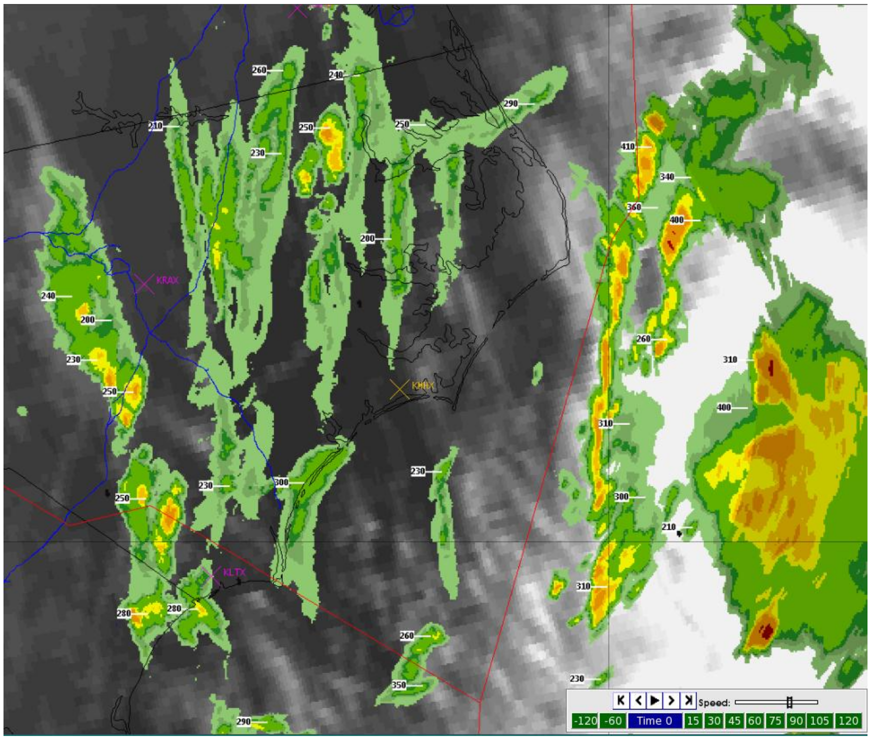

Figure 7a. The FAA has an interest in the identification of chaff. Dual pol data make the identification possible. This image shows the Corridor Integrated Weather System weather coverage in the North Carolina area. Over water, returns are from weather but over land the returns actually are from chaff.

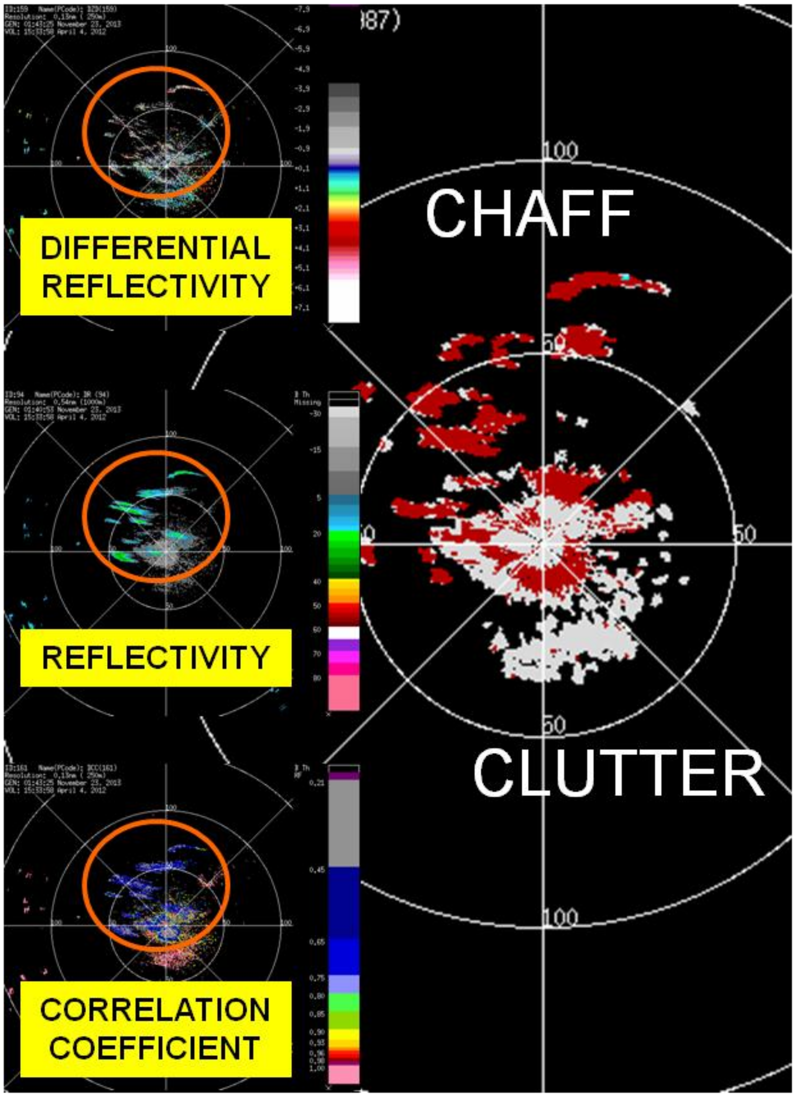

Figure 7b. This image depicts a notional chaff detection algorithm with yes (red)/no (gray) chaff based on dual pol data such as differential reflectivity and cross-correlation coefficient (this is an event from Key West, FL).