NEXRAD TAC - April 29, 2019
Meeting called to order at 11am Central

TAC Members in Attendance: John Snow, Mike Istok, Rich Ice, Jim Evans, Dan Miller, Tammy Weckwerth, Mike Jain, Todd Pattison

12 Informational Presentations; 0 Decision Briefs:
- Low Angle Elevation Angle Update - Jessica Schultz, ROC
- SLEP Update - Dan Hoffman, ROC
- Product Improvement Update - Mike Istok, ROC
- Improving Quality of Polarimetric Variables Using Hybrid-Scan Estimator - David Schvartzman
- Update on Range Oversampling - Sebastian Torres and Chris Curtis, CIMMS/NSSL
- Update on Staggered PRT and Ground Clutter Mitigation - David Warde, CIMMS/NSSL
- Progress in Polarimetric Snow Measurements - Alexander Ryzhkov, CIMMS/NSSL
- Calibrating ZDR on Nonlinear 88D Receivers - Valery Melnikov, CIMMS/NSSL
- Update on MRMS - Ken Howard, NSSL
- Chaff Detection Algorithm - Jim Kurdzo, MIT/LL
- The Crystal Sandwich - Earle Williams, MIT/LL
- Regression Filters for Clutter Mitigation - John Hubbert, NCAR

Low Angle Elevation Angle Update

- Implementing low angles at sites for a few years.
- NWS is funding the environmental assessments only at this time.
- Sites determined by requirements from NWS Regions and/or Congressional Interest
- Finding of No Significant Impact (FONSI) from the environmental assessment is required prior to implementation
- So far all low angles are in addition to 0.5 angle, not a replacement.
- Current site list: KLGX (+0.2), KICX (+0.2), KBUF (+0.3)
- Field Test ongoing: KMUX and KMAX
- Build 18.2 New Sites: KMUX, KGSP, KDGX, KMBX, KSHV, KRAX
- Build 19 New Sites: KMAX, KCLE, KMSX, KRGX, KMTX, KCLX, KDLH, KGJX, KFSX
- Congressional interest has been based on complaints from constituents as a result of severe weather events

SLEP Update

- Signal Processor - Fully Deployed as of Dec 2017
- Transmitter Refurbishment: Includes Backplane/CCA Modernization (Deployed 2018), Transmitter Chassis (67% complete), Transmitter Modulator (85% shipped, 83% installed), Anticipate completion February 2020

- Pedestal SLEP - Contract awarded August 2018. First task order was KCRI and then 18 additional radars task order started Aug 2018. Average time of completion is about 14 days. Contractor refurbishes pedestal at their refurbishment facility, and they remove radome and old pedestal at site before putting refurbished back on. Have completed one night lift in order to remain within 18 mph limit for radome removal. 8 Sites remain on the current task order which ends August 15, 2019. Next task order runs from August 2019-August 2020, which will include five OCONUS sites)
- Shelter Maintenance and Repair SLEP - Contract was awarded to 2 vendors in September 2018. Completed first task order for 13 DOD sites March 2019. Second task order for 13 NWS Central Region awarded April 2019, and a third task order is anticipated for NWS Eastern Region. FAA is not participating in this SLEP.
- Addition of Generator, Automated Transfer Switch (ATS), and Diesel Fuel Tank Replacement SLEP. FAA is not participating in this SLEP.

Chaff Detection Algorithm

- Chaff Detection Algorithm developed by MIT/LL
- False Weather Returns are issue particularly for air traffic controllers
- Differential Phase is a useful discriminator between weather and chaff signals
- Current HCA classifies chaff as a variety of biological, big drops, unknown, and then dry snow in melting layer
- MIT has developed the “Aviation Classification Algorithm” (ACA) that is similar to HCA but adds an “inanimate” class that identifies things like chaff, sea clutter, smoke
- They cluster the inanimate class into clusters and use a trained Support Vector Machine to classify the chaff clusters.
- In the ORPG, ACA is inserted downstream of the DP Preprocessing
- Kurdzo showed some case studies that illustrate the chaff delineation of nearby weather.
- Some image processing is performed to smooth the classes to get operable clusters
- SVM is a machine learning algorithm for classification with the classes defined here as chaff and non-chaff, which helps to remove sea clutter from the chaff detection.
- A de-flickering algorithm is applied to keep the classifications consistent in time
- CDA can have issues close to the radar where false detections from ground clutter can show up and the image processing/filtering struggles
- Sea clutter is also detected and subclassified in the inanimate class. Differential Phase is useful for discriminating it from weather similarly to chaff. Sea clutter can trigger false alarms in CDA in extreme ducting cases where sea clutter is widespread.
- Exploring adding sea clutter as a new class to ACA.
- POD measured as 92%, FAR below 7%
- Smoke is difficult to classify because measured values vary significantly based on what is burning, can trigger false alarms in CDA
- CDA is not intended as a QC product to filter out echoes from the other products

Hybrid Scan Estimators: Using split cut data to improve the quality of polarimetric variables

- CS/CD runs split cut on lowest angles. For Dual Pol variables, only data from the surveillance scan is kept and used. The algorithm proposed here is to incorporate data from the doppler scan
- The HSE algorithm goes bin-by-bin to select the “better estimate” between the surveillance and doppler scans. The result is smoother fields and better clutter filter performance near the radar.
- HSE takes data from surveillance scan and range-unfolded data from the doppler scan. It computes expected bias and SD of CS Data nad CD data. If CD has better bias and SD, then the CD data is used. Otherwise the CS data is kept.
- The HSE processing improves over conventional processing in regions of low-to-medium SNR or relatively high CC or wide spectrum width.
- Lookup tables are used for SNR, CC, and spectrum width parameter space to select CS/CD data
- Examples shown for tornadic supercell events, snow storm events, and light rain events. The improvement of CC field in region of suspected tornado debris was highlighted.
- HSE is designed to “do no harm” such that it only choose the new CD data when it improves on CS bias/standard deviation
- The HSE algorithm was delivered to the ROC in the FY18 RPI MOU final report.
- Question raised regarding time shifts for rapidly moving storms: difference between scans is around 10-20 seconds, developers have not seen major differences between surveillance/doppler scans in that short amount of time.

Update on Range Oversampling

- This is the fifth presentation on range oversampling to the TAC
- Three data characteristics to improve: Spatial sampling, Data precision, and update time. Improving one of these characteristics comes at the expense of the other two.
- Range oversampling can overcome this.
- Conventional sampling leads to range gates of 250 m that do not overlap
- With range oversampling, you get overlapping radar volumes to get more granular estimates
- Conventional sampling period is reduced due to the number of range samples. Dwell time does not change, and transmitter pulse and receiver do not change.
- Range oversampling reduces noises in the base data without losing details or spatial resolution, which indicates more precision in data.
- Range Oversampling concept originally conceived in 1997. Oversampling and whitening and adaptive pseudowhitening techniques developed since then up to 2009.
- Whitening transformation ignores the effects of noise and leads to optimal performance in high SNR. The conventional matched filter maximizes the SNR and leads to optimal

performance at low SNR. Propose using different transformations at different SNR ranges.

- Adaptive pseudowhitening includes the effects of noise and leads to optimal performance at all SNRs. Uses a different transformation for each radar variable.
    - Implementation of adaptive pseudowhitening is split into two parts that allows them to only apply the transformation once to the I/Q data, which is more efficient that doing it separately for all radar variables.
- Was implemented in real time on the NWRT PAR in 2009 and was integrated with RBRN, CLEAN-AP, and traditional single-pol estimators.
- On NWRT PAR, dwell time was reduced from 99.2 ms to 56.8 ms with adaptive pseudowhitening and data quality was not degraded.
- From 2013-2019, have focused on addressing a wide range of practical implementation issues (see presentation slides)
- Accurate range correlation is important for unbiased estimates. Range correlation may change due to environmental changes (temperature), hardware drift from wear-and-tear and hardware changes.
- Lookup tables are used to apply the adaptive pseudowhitening when the theoretical variance expressions are not available.
- Implementation on the WSR-88D requires producting IQ data with L-time faster sampling. Vaisala provided a software mod to support up to 8168 bins per pulse on the 88D. The system would need to support 7536 bins per pulse to support L=4 range oversampling factor.
- Recommend focusing on improving data quality of radar variables on 88D without reducing scan times. Developers feel it is mature and ready to transition to WSR-88D

Staggered PRT Update

- The staggered PRT algorithm results in less “purple haze”, less velocity dealiasing than the velocity currently available on the 88D in batch mode.
- Current mitigation strategy for velocity ambiguities is to use phase coding at low levels (SZ-2), Batch PRT in midlevels, and Uniform PRT in upper tilts.
- Batch mode can have range obscuration throughout entire radar field. With staggered PRT improves this within certain ranges from radar. For dual pol variables, similar range obscuration is possible in batch mode but staggered PRT can eliminate this completely.
- Project started originally in 2003 in single-pol, was expanded to dual-pol in 2010. CLEAN-AP was introduced in 2012, and CLEAN-AP/WET in 2015. “Matched autocorrelation” spectrum width estimators was introduced in 2017.
- Recently implemented a velocity dealiasing enhancement called “1DVDA” that removes a lot of the dealiasing issues that still show up in the velocity with staggered PRT.
- Future work includes supporting implementation of SPRT on the ORDA, support engineering evaluation of SPRT, and supporting ORPG 2DVDA modifications for SPRT.
- Conclusion is that staggered PRT is a mature technique and is expected to replace Batch mode in all VCPs.

CLEAN-AP/WET Update

- CLEAN-AP/WET = Clutter Environment Analysis using Adaptive Processing/Weather Environment Threshold
- CLEAN-AP is a real-time automated integrated technique for ground clutter mitigation. WET is integrated with CLEAN-AP to assist with the data quality improvement
- Start by computed unfiltered radar variables. WET determines if there is weather present without contaminants, and if so, it uses the unfiltered data. If contaminants present, CLEAN-AP clutter filter is applied.
- Unfiltered version of CC really shows ground clutter contamination near the radar site for KDLH for a case from 2013, and CLEAN-AP removed it completely.
- CLEAN-AP originally proposed in Spring 2008 and implemented real-time on the NWRT PAR in Fall 2008. It was compared with 88D ground clutter data in 2009 and results were presented to TAC in November 2009
- CLEAN-AP was extended to dual pol in 2010 and results of that were presented in Fall 2010 to TIM
- Delivered CLEAN-AP algorithm description to ROC in Fall 2010, and delivered staggered PRT CLEAN-AP algorithm to ROC in Spring 2012
- Baron Services licensed CLEAN-AP from OU and deployed it in 2014
- Delivered SPRT and new SZ-2 CLEAN-AP algorithm descriptions in Spring 2017 and are currently assisting ROC engineers with implementation

Progress in Polarimetric Snow Measurements

- Many different Z-S relationships have been proposed and used both worldwide and in the U.S., with parameters varying by an order of magnitude. Little progress has been made in radar measurements of snow.
- Size distributions vary significantly, and snow density and habit are highly variable, which makes accurate estimation with a single equation difficult using reflectivity alone. Equations are typically parameterized by snow distribution parameters.
- Using dual pol variables, the best hope for improved snow QPE is specific differential phase (KDP). KDP is proportional to first moment of snow size distribution rather than the fourth moment for reflectivity (i.e., KDP is less sensitive to variation than Z). However, KDP is also sensitive to shape and orientation of snow particles
- Aircraft measurements support equations of IWC(KDP) and IWC(KDP,ZDR) in ice clouds
- Proposed snow QPE equations using dual pol use KDP and ZDR. However, KDP can be very noisy for light snow. Additional spatial averaging is required to obtain robust estimates of KDP and ZDR
- Case studies were presented for KLWX, KOUN, and KGJX. KDP can range up to 0.2 deg per km but is noisy and requires filtering as was already mentioned

- Examples of Quasi-Vertical Profiles (QVPs) were presented to show time evolution of vertical profiles of dual pol variables for the KLWX case.
- KLWX: ZDR is enhanced within the dendritic growth layer, while KDP shows enhancement just below the dendritic growth zone.
- KLWX: Dual pol signatures within the dendritic growth layer provide the closest estimate of what it will be at the ground, so measurements below that level may not add much value, which is useful when measurements below the dendritic zone are not available
- KLWX: Verification was done vs snow gauges, with the dual pol equations providing better performance to the S(Z) evaluated ($S(Z) = 0.088Z^{0.5}$)
- KOUN: Column Vertical Profile (CVP) was shown for KOUN, with the column centered over Kessler's Farm approx 29 km from KOUN.
- Pristine crystals show up as enhanced ZDR whereas aggregates have ZDR closer to zero.
- KOUN results similar to KLWX with dual pol equations performing better than S(Z) relative to gauges.
- KGJX: Snow is orographically induced which provides somewhat different dual pol characteristics from other cases. Despite orographic difference, dual pol equations also outperformed S(Z) for the event shown
- Ground validation of snow with gauges is difficult. One way to mitigate this challenge is to examine stratiform rain events with low melting layers where the gauges measure rain at the surface while the radar beam is sampling snow aloft.
- Ka-band radars can provide better estimates of KDP than S-Band radars, so they can be useful to validate dual pol snow equations.
- Jim Evans recommended evaluating atmospheric river events along the west coast
- Dan Miller commented that snow ratios can vary significantly for low temperature environments over just a few degrees

Calibrating ZDR on Nonlinear 88D Receivers

- ZDR is a measure of non-sphericity of scatterers. Theoretically it is a simple measurement but practically it requires high accuracy and precision from the radar.
- For the snow event example shown for KDIX the ZDR values were entirely between 0 and 1 dB. Light rain is similar, and both require ZDR accuracy of 0.2 dB
- ZDR values in Bragg scatter areas are close to 0 dB and should be measured with accuracy better than 0.2 dB
- In an ideal radar, the system ZDR offset does not depend on the input signal power (i.e., Signal to Noise Ratio, SNR). However, on real systems, the system ZDR offset can vary with SNR. Examples from WSR-88Ds were shown.
- ZDR calibration examples using the Sun, Bragg Scatter, and radar signal sources try to measure ZDR at different SNR ranges with different intrinsic ZDR offset values
- Plots shown that illustrate SNR varying over wide ranges even for rain in a single volume scan

- ZDR equation for a nonlinear receiver contains the channel amplification factors Qh,v which are nonlinear functions of the power Pout. The purpose of the factor is to make nonlinear factors more linear for ZDR
- Future work is that the ZDR calibration procedure should be revised to take into account receiver nonlinearities. The receiver is used in calibration of the transmitter and in solar ZDR calibration. Therefore, all calibration procedures should be revised.
- ZDR responses should be obtained from multiple radars, including both “good” and “bad” radars with respect to ZDR calibration

Update on MRMS

- Fourth presentation to TAC in 15 years
- MRMS an operational system running NCO’s IDP hardware. It is the integration of multiple data sources, including the WSR-88D network, GOES satellite, NWP analysis fields, rain gauge data, and lightning networks into derived operationals products
- MRMS produces and disseminates via SBN and LDM 100+ products to NWS WFOs and other users
- MRMS’s development platform is used for evaluations and refinements for new severe weather and hydrological applications and to facilitate their transition into operations. The R&D system’s products are accessible to field offices in order to get feedback of product performance
- Current MRMS version is 11.6 at IDP for QPE. QPE products include precip rate, quality index, accumulations over various time scales, and gauge-corrected QPE accumulations. Resolution is ~1 km over CONUS and many products update every 2 minutes
- MRMS has an operational product viewer website for IDP products
- MRMS version 12 QPE will include a new dual-pol QPE (Q3DP), evaporation correction, and a multisensor QPE that integrates satellite QPE, HRRR-based QPF, and the radar QPE in order to fill radar coverage gaps
- OCONUS MRMS domains have been created for Alaska, Caribbean, Hawaii, and Guam, which will operational with V12
- Q3DP uses specific attenuation rain rates for rain, R(KDP) for hail, and R(Z) with VPR correction for all other areas
- MSQPE shows significant improvement in performance over radar based QPE over western CONUS
- One major project now is improving QPE for OCONUS domains where finding data sources can be more challenging than over CONUS, and tuning algorithms over OCONUS that were originally developed for CONUS environments
- V12 is currently scheduled to be operational on IDP in Q2 FY2020

Product Improvement Update

- ROC has three main efforts for R20 Transition projects for NEXRAD: Improving Data Quality (with NCAR), Radar Product Improvement (with NSSL), and Technology Transfer (with NSSL)
- Scope of projects include base data coverage, bias, variance, and resolution; radar-meteorological algorithms and products
- Improving Data Quality Project Areas:
    - Dual polarization calibration
    - Hybrid Spectrum Width Estimator
    - Clutter Mitigation Decision (CMD) based clutter filtering
- Radar Product Improvement Project Areas:
    - Ground Clutter Mitigation
    - Range-and-Velocity Ambiguity Mitigation
    - Meteorological Variable Estimators
    - Radar Data Quality Control
    - Range Oversampling
    - Investigate Impacts of System Differential Phase upon Transmission
    - Identify Areas and Sources of Reduced Radar Data Quality
    - Hydrometeor Classification of Winter Precipitation (WsHCA)
    - Identify Features in Convective Storms
    - Quasi-Vertical Profiles and Column Vertical Profiles
    - Nowcasting Cold Season Precipitation using Polarimetric Signatures Aloft
    - Quantitative Precipitation Estimation in Pure Rain or Rain Mixed with Hail
    - QPE in Snow and Mixed Precipitation
- Technology Transfer Project Areas:
    - Dual Polarization QPE Improvements
    - Mesocyclone Detection Algorithm, Tornado Detection Algorithm, and Hail Detection Algorithm refresh
    - Assess Echo Tops and Vertically Integrated Liquid Products
    - Bird Detection Algorithm
    - Develop Applications to use Expanded Scale ZDR Data

The Crystal Sandwich

- The Buffalo Area Icing and Radar Study (BAIRS) is FAA-supported work on CONVAIR-580 validation of in situ icing conditions
- The “Crystal Sandwich” is the layers of Plate-like crystals in -9 to -16C and needle crystals in -4 to -6 C, both of which have higher ZDR, and the layer in between is expected to be supercooled water with lower ZDR values
- Crystal habit is dependent on Temperature and Humidity
- Flat plate crystals tend to exhibit oblate ZDR values (<1), whereas ice needles tend to exhibit prolate ZDR values (>1)
- Airplane had access to radar data in real time and would preferentially fly to areas of high ZDR

- Dendrite layer tends to show up as a “positive ZDR brightband” in NEXRAD data
- Aggregation of the dendrites aloft cause them to fall out into the lower layers and “destroys” the horizontal continuity of the layer signatures
- Showed case examples from 88Ds of concentric “brightbands” representing the conventional brightband, a needle bright band above it, and a dendrite bright above the needle brightband

Rethinking Clutter Filtering and Improving Signal Statistics

- Spectra-Based Clutter filtering has been the standard since the advent of fast digital receivers (e.g., GMAP)
- Discrete Fourier Transform (using FFT algorithm) turns a finite length time series into a periodic repeating function. In order to create a sum of sinusoids that can replicate a jump discontinuity, many higher frequency sinusoids are required. Solution to this is the Hanning Window filter
- Regression filtering (originally proposed by Torres in 1999) - apply a polynomial regression fit to the data and subtract out the ground clutter signal to get weather only
- Fit lines to real and imaginary parts separately and subtract to get residuals
- Regression vs. Window and Notch: there is 4-5 dB of attenuation (signal lost) with the Blackman and Hanning windows. This level of signal is not lost with the regression filter.
- Case examples shown for S-Pol radar in Colorado.
- Similar performance between regression and window/notch for clutter rejection
- Impacts on dual pol data shown with different filtering techniques. Dual pol variables look much better and smoother with the regression filter vs. the blackman window
- Blackman-Nuttall window can spread ground clutter spectra across a wider range of velocities, requiring a larger notch filter to remove it. This is not the case with regression filtering

Supplemental Notes by TAC Members:

TAC Meeting notes provided by Mike Istok:
Improving quality of polarimetric variables using hybrid-scan estimator. Presentation delivered by David Schvartzman, NSSL.

This technique improves dual pol data used by algorithms and displayed by users by blending split cut surveillance scan data with better quality data from the Doppler portion of the split cuts. Several cases were evaluated and were shown to be smoother, had less invalid RHOhv (aka CC) data bins, and had better clutter filter performance. The technique uses the expected bias and variance which is primarily based on the number of pulses, SNR, spectrum width, and RHOhv. Data with low-to-medium SNR and high RHOhv or wide spectrum width is improved most. Comments and questions asked included:

1) What happens if the surveillance and Doppler data provides equivalent quality data -- should they both be used and averaged? Answer: Would look at that case as a separate project – it is complicated when both estimates have a bias.

2) Are there any downsides with fast moving storms? Answer: Typical time between precip VCP scans is less than 20 seconds, so motion is insignificant. Also, quasi uniform data regions have similar quality so discontinuities are not expected

3) Is there any reason to retain which scan the data came from? Answer: Not sure of the use -- batch scans currently derive estimates from either the surveillance or Doppler pulses, the one chosen is based on quality, and we don't retain which was used. MPDA VCPs also combine data from multiple scans (up to 3 scans) and we don't retain knowledge of which scan each bin came from.

4) It was stated that operations folks in the southeast provided favorable feedback as it improves identification of small debris signatures.

5) Noted that images shown were of Level 2 data and curious to see how it would look on AWIPS. The difference is primarily due to azimuthal recombination and radial filtering done within the RPG, so it should look even better. The TAC agreed that it would be good to verify AWIPS images look okay.

TAC Meeting notes provided by Michael Jain:
Main Points of TAC Presentation: Oversampling (Torres)

· R&D for Range Oversampling has been ongoing for a number of years (as early as 1997) and has been presented to the TAC on multiple occasions

· Over this time, the technique has reached a high level of maturity

o Demonstrated to effectively run in a real-time environment on the NWRT PAR for seven years

o The technique has undergone a number of adaptations and extensions that address practical implementation issues specific to the WSR-88D

· The technique has demonstrated the generation of more precise estimates of radar variables with the same scan times … or reduced scan times with the same precision of radar variable estimates … or a combination of both. Side note: Shown to improve quality of DP variables

· Operational considerations were postponed due to a limitation in the RVP-900 regarding the number of bins per pulse. However, Vaisala has recently provided a modification that will allow up to an oversampling factor of 4. This new capability would allow the oversampling technique to execute on the RDA and produce the beneficial results mentioned above.

· Algorithm description was provided to the ROC in 2018

· Proposing initial implementation would target improving quality of all radar variables and would not require any VCP or hardware changes

· WSR-88D implementation considerations

o ROC should confirm RVP-900 has sufficient computational capacity

o ROC should confirm system has sufficient throughput capacity

· The TAC members reacted positively to the information presented in the briefing and there were no concerns, objections nor any further qualifications stated.

TAC Meeting notes provided by John Snow:
Low Elevation Angle Update/Schultz

Good presentation. This is an important effort, one that has long been needed. It was noted that the FAA is not participating (is this a correct statement?)
ACTION: TAC should monitor. In about a year, the TAC should hear from some of the WFO's where elevations below 0.5º are in use. Some of the questions to be addressed: Is having use of lower elevation angles positively influencing forecasting and warnings? Specific examples of impacts on coverage, longer lead times, initial detection/tracking of mesocyclones… Any impact on WDTD?
If there are sites were the required environmental assessment has found a significant impact, let us have details. Are there reasonable/practical fixes, like elevating the radar antenna assembly? Are there any FAA concerns re adding lower elevation scans to some VCPs (since VCP completion times will increase)?

Update on MRMS/Howard

From this briefing, it appears that MRMS has reached a level of maturity and so is ready to move from NSSL, where both continued development and early implementation are currently

taking place, to the NWS. However, this presentation gave only the OAR/NSSL side of the story.
While NSSL would continue to develop MRMS, it appears that the NWS and OAR need to implement an R2O program to transition the early implementation of MRMS to a more permanent arrangement within the NWS.
This could be a case study/exemplar of the "transition of research to operations (R2O)" of a piece of new technology (software).
Who are the "customers" for the MRMS product suite? It sounds like MRMS is really targeted to an audience well beyond NWS forecasters. Is this the case?
Is there a business plan showing costs (investments)/benefits (ROI) of a R2O for an MRMS Build 1.0? Assuming that MRMS will be transitioned to operations, is there a long term development plan to guide future builds that, a plan that reflects NWS/other customers' needs?
ACTION: TAC should monitor. Let us hear about the R2O effort at the next TAC meeting from presenters from both NSSL and the NWS.

TAC Meeting notes provided by Jim Evans:

Notes and discussion on the presentation "Calibrating ZDR on nonlinear 88D receivers" by Valery Melnikov

Calibration of the WSR-88D ZDR components has been an ongoing problem for a number of years that was discussed by the TAC as early as 2015. There are a number of operational uses of dual polarization NEXRAD products that are drivers for the ZDR calibration requirements:

1. Quantitative precipitation estimates require accurate measurements of reflectivity (Z) and differential reflectivity (ZDR).

2. Identification of regions of super cooled water droplets is a significant operational safety concern due to the possibility of very rapid airline airframe icing. The super cooled water regions are also a major safety concern for helicopter EMS.

3. Delineation of the rain/snow boundary is important for airport and road operations. This also may at times require fairly accurate ZDR measurements.

4. By contrast, identification of regions of large hail (a hazard to aircraft) does not necessitate highly accurate ZDR measurements.

Accurate measurements of ZDR depend on its calibration, i.e., obtaining the system ZDR (ZDRsys) sometimes also called system ZDR bias. According to the WSR-88D's specifications, ZDRsys should be obtained with accuracy of 0.1 dB.

A ZDR accuracy of 0.1 dB is not that important for identification of large hail. But, it is important for identification of super cooled water regions and rain/snow discrimination.

Melnikov et al. measured the contributions of every component in the chain, specifically at RF and IF separately. The IFD (Intermediate Frequency Digitizer) is separated out from the rest of

the components in the RF chain in order to determine individual components of introduced bias. By sending a CW signal at different powers through the chain and measuring at each point, they were able to determine the total system ZDR bias based on power/SNR, and found that there was a strong dependence on SNR, which has not previously been shown.
Specifically at SNR values below 50 dB, the separation of the channels becomes not only larger than .1 dB, but rather stochastic in nature, making this a very difficult problem to solve.
When corrected for noise, the bias is more predictable above 0 dB SNR, but still often exceeds 0.1 dB. They found that at all points in the chain, low bias was present at SNR values > 50 dB, and below this, values were highly dependent on SNR. One issue was that of the radars they looked at, there were somewhat significant differences between the chains. In a general sense, this indicates that any "forced" offsets that are the same from radar to radar may need to be tweaked from system to system.
This presentation makes a major contribution to addressing a significant operational problem with the operational use of dual pol for NEXRAD.
The TAC supported near term follow up action that takes account of the very good work by Melnikov, et. al.

<u>TAC Meeting notes provided by Rich Ice:</u>

Alexander Ryzhkov and Petar Bukovcic: "Progress in Polarimetric Snow Measurements"

Dr. Ryzhkov reminded the group of 18 different Z(S) relations for dry snow and summarized the challenges related to obtaining accurate results. The problem is the order of magnitude variability of the multiplier in the power-law relations. Also, the variability of snow habits is an issue. Very little progress has been made in the past decades.

He presented several radar snow relations based on the polarimetric variables of ZDR and KDP. Due to the noisy nature of KDP estimates, additional spatial averaging is necessary. His research makes use of Quasi-vertical Profiles (QVP), range defined QVP (RD-QVP), and Column Vertical Profiles (CVP) to provide the necessarily aggressive spatial averaging.

Petar Bukovcic presented results comparing four methods using the spatial averaging to gauge measurements. The methods are S(KDP,Z), S(KDP, ZDR) and two S(Z) method based on power law (Eastern and Western US). Radars were KLWX, KGJX and KOUN. Results varied between the radars. There was a brief mention of results between the S band KOKX and a Ka band radar, KASPR where KDP estimates were well matched.

Conclusions are that the "variability of the S(Z) relations is prohibitively large" and that "aggressive spatial averaging is required to obtain robust estimates of polarimetric variables in snow at S band".

Dan Miller, NWS committee member, mentioned that including column profiles in lower temperatures would be useful, citing the significant impacts on winter operations in his area of

Duluth MN. Mike Isok, NWS committee member, asked about possible use of the KDP proxy under investigation at NSSL. Ken Howard mentioned deployment of C band dual pol radars in Durango and Alamosa CO as potentially useful to these studies.

Earle Williams: “The Crystal Sandwich”

This talk described observation of layers of snow crystals above and below layers of super cooled liquid water. Dr. Williams talk focused on ways to use polarimetric variables, especially ZDR, to identify crystal types. He presented observations of distinct types of bright bands associated with dentrites, needles, and the conventional bright band of the melting layer. He showed results that observed super cooled liquid water between an upper layer of plate like crystals and a lower layer of needle shaped crystals. He compared vertical profiles of liquid water content and differential reflectivity compared to in situ observations of crystal types using an aircraft.

Dr. Williams presented radar scans from the KBOX, KMRX, KRAX, and KMHX radars showing these separate bright bands.

Dan Miller cited research from Cal Tech and agreed to provide the reference.

John Hubbert: “Rethinking Clutter Filtering and Improving Signal Statistics”

Dr. Hubbert’s talk focused on new activity related to potential use of regression filtering as an alternative to spectral clutter filtering. Regression filtering is done in the time domain, and used polynomial function fits to the slowly varying parts. The fitted curve is used to remove the part of the signal contribution from clutter and allows retention of the weather signal. This work makes use of Forsythe Polynomials for the curve fits.

The main advantage of regression filtering is that data windows are not required. Windowing is an essential part of spectral processing and results in significant loss of signal. This loss can be as high as 5 dB and increases the variance of the estimates as it essentially reduces the effective number of independent samples.

Dr. Hubbert presented data from NCAR’s S-Pol research radar as well as data from KFTG. The results show that regression filtered data does exhibit much lower standard deviations than spectral processing based filtered data.

Dusan Zrnic asked about the method for choosing the order of the polynomials. The order is chosen based on experience with test cases. Dr. Hubbert proposed that the order could be adaptable based on scan strategies.

Jim Evans asked about performance where clutter is not necessarily stationary, such as wind blown trees. Dr. Hubbert believes that antenna motion actually contributes more to the induced variability of the clutter components than wind blown trees.

Terry Clark asked if this would be useful to remove wind turbine clutter. The general consensus is that it would not as turbine clutter is mostly weather like in nature.

During the executive session, Rich Ice mentioned that the regression filtering approach, applied separately to the horizontal and vertical channel data, could be an improvement over the current method used in the WSR-88D.

TAC Meeting notes provided by Dan Miller:

This presentation was on a chaff (or perhaps more accurately stated - inanimate non-MET echo classification) detection algorithm developed at Lincoln Labs/MIT.

One of the primary needs/benefits for something like this is for the FAA and air traffic, as it is common to have chaff interspersed with meteorological echoes - and some chaff can look very similar to thunderstorms in traditional reflectivity displays - which can be confusing and potentially dangerous to pilots and air traffic controllers. The primary focus of this talk was identification of chaff.   The current WSR-88D HCA is useless regarding chaff detection.

Lincoln Labs has developed an algorithm that has it's roots in a "Aviation Classification Algorithm" that includes several classes of inanimate non-MET radar echoes, including chaff (their primary goal), sea clutter, and smoke

Their algorithm is fairly complex with many steps, but seems to still have sufficiently short processing time to be useful in real-time

The algorithm is human-truthed with over 1000 cases, that are constantly being used for machine learning to improve the algorithm

There are some issues with false detections, or with false alarms, but missed detection clusters can be recovered at a later step in the data processing by a process called "deflickering" Specific details of the data processing were not provided.

Examples Jim showed in his talk showed that the methodology shows a lot of promise with a POD of ~92%, and a FAR ~7%.

The biggest issues with proper detection and identification seem to be in instances where chaff is ingested or overtaken by precip echoes where MET/non-MET echoes become interspersed, or close to the RDA site where contamination from the ground clutter pattern is present.

Algorithm is also useful in detecting and classifying other non-MET echoes such as sea clutter and wildfire smoke - Jim showed some examples of sea clutter. There can be instances of false detection of sea clutter in strong super-refraction or ducting conditions.

Algorithm has been tested in real-time on live RPGs and seems to work as designed.

Questions that were asked + Discussion:

1) Any speculation on why we see such large ZDR values in chaff (upwards of +8.0 db)?

A: There is speculation and theory suggesting that some of this may be due to differing size/shapes of chaff resulting in differing fall speeds and perhaps some dielectric contributions as well, especially at levels closer to Earth's surface, but we really don't know for sure.

2) What about smoke detection - you mentioned it several times but didn't really talk about it - seems as though that would be important to many users?

A: Algorithm seems to do a decent job in identifying smoke - especially from biomass burning. No data will be removed - so users can still see where echoes are - even if the algorithm doesn't properly identify smoke.

Comment - if Jim wants a good smoke case not from a wildfire - check out smoke plume from Husky Energy Oil Refinery explosion and fire in Superior. WI as sampled from KDLH: ~1700 UTC 4/25/2018 to ~01 UTC 4/26/2018. Primary contributor was burning asphalt, with smaller amounts of other chemicals and debris.

TAC Meeting notes provided by Tammy Weckwerth:

Here are my notes from David Warde, SPRT:

- Last TAC update Nov 2013
- Added matched autocorrelation in July 2017
- Provides less purple haze and greater data coverage and larger Nyquist interval
- Uses different techniques for different elevation angles, starting with phase coding (SZ2); then batch PRT at middle elevation angles; then uniform PRT aloft
- Provides polarimetric variables at increased range
- Provides more pulses to resolve Ze
- There's better range coverage for SW, Vr, rho_hv, Zdr, phi_dp
- There's better de-aliasing for Vr
- 1D dealiasing helps; 2D dealiasing will soon be tested

- SPRT is mature capability that improves range coverage, V measurements and data quality
- Jim Kurdzo made the point that this will help his chaff detection algorithm which doesn't work in purple haze.

David Warde, CLEAN-AP/WET:

- This is a technique for ground clutter mitigation
- Started in 2008
- Extended to SPRT in 2010
- Endorsed by TAC in 2011
- Integrated into McGill C-band radar in 2013
- UK Met Office collaboration 2015-present
- Several reports describing technique are confidential
- ERAD 2018 conference paper shows improved QPE with CLEAN-AP/WET
- Not yet ready for operations at split cut level
- There will be a systematic comparison with CMD with rho_hv test