REVIEW OF RESEARCH, DEVELOPMENT, AND EVALUATION ACTIVITY OF WSR-88D ALGORITHMS

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I. INTRODUCTION

This report summarizes the development and testing activities of current or potential NEXRAD (WSR-88D) weather algorithms that have transpired since the previous algorithm report of October, 1993. The term "potential" reflects the more recently developed techniques that: (1) are currently being considered as replacements for existing WSR-88D algorithms, (2) in the future may be considered as replacements for existing NEXRAD algorithms, (3) are not currently scheduled for NEXRAD inventory but for which there appears some community interest. Additional references may also be included if they show support or deviation for current concepts/methods, or shed new light on philosophy of approach or adaptation data settings. The broader perspective achieved through incorporation of this range of related efforts will hopefully ensure a more complete understanding of the applicability of WSR-88D techniques previously or currently pursued.

To maintain continuity with previous reports, this document is organized in similar fashion: first by topic (Section II) in summary form, and then by research group (Section III) with specific input. In all instances, the author has attempted to present an objective review, and has occasionally included additional reference material not provided from the surveyed group. All views expressed are those of the author, and are not to be attributed to the government. This is particularly true for this report where there was not always sufficient time to provide respondees summaries for their review before inclusion into this document. Instances where the group activity report (Section III) is included "as received", or "partially as received" by TITAN are noted as such (e.g. AR, PAR). As in the past, activities are coordinated with groups (Appendix B).

Also incorporated into this report is a review of research and findings reported in the literature over this time interval. This review incorporates a standard bibliography (Appendix C) format with both a NEXRAD-relevance rating and a terse summarization of the material. As such, this document is designed to assist the NEXRAD/OSF personnel in monitoring and evaluating activities relevant to NEXRAD algorithms, and potential future efforts. The intent of the rating system is to provide a "quick look" at the broad range of literature, some of which may not be readily accessible to NEXRAD staff, or which without review may not initially be deemed relevant to the NEXRAD program. Assessment of a rating was performed solely by the

author and was guided by the stated TAC NEXRAD technical needs assessment, current NEXRAD algorithm activities, and perceived potential future activities.
As in past reviews, the bibliography contains references to articles for this reporting period, with an occasional exception to older articles of note. Together, with past years' bibliographies, this summarization forms a rather thorough review of recent literature.

II. ACTIVITIES SUMMARY

A. FOREWORD

Significant investigation continues in the areas of algorithm refinement, tuning, and new technique development. In fact, it is quite remarkable to see the level of activity directed towards algorithm modification and possible replacement. The WSR-88D system is a remarkable improvement over the aging weather radar systems, and it has demonstrated time and again its unique ability to detect phenomena, and be used as an integral tool in warning of impending hazardous events. However, as more WSR-88D systems are deployed and experience with the system grows, it is quite clear that many of the current WSR-88D algorithms need improvement. This result should not be unexpected, and in fact is one of the underlying reasons for the existence of the NEXRAD Operational Support Facility (OSF). The OSF, and associated agencies have continually been involved with algorithm improvement.

There are numerous reasons for these algorithmic deficiencies. One is simply that the "potential caveats" associated with simplifying assumptions made during original algorithm development years ago are now being realized as the algorithms are being employed in varying environments and these anomalies are being reported by the growing number of users. A second source is use of non-optimal algorithm thresholds, a reflection of a developers' limited time and data used in algorithm development. The wide variety of storm types and geographical influences were often not known, or not available in statistically robust data cases for algorithm testing. A third source of error is lack of sufficient ground truth information to properly assess algorithm performance. A fourth source is that some algorithms are now being relied upon to recognize storm elements or features that were not included in the original algorithm design.

A simple example is provided by tornado detection as numerous reports arrive about confirmed tornadoes without WSR-88D declaration, presumably due to mesocyclone parameters failing to meet required thresholds. This is "partly" an instance of algorithmic failures not necessarily being failures in the context of what the algorithm "was originally designed to do". For example, tornado detection originally focused upon detecting violent tornadoes (e.g. F3 - F5 Fujita scale) that cause severe surface damage and property loss. The method and thresholds developed for detection of these large circulations were not designed to detect the marginal to moderate tornadic circulations (F1 - F2) that have only recently been observed associated with convergence lines, gust fronts, mini-supercells, etc. Other examples include mesocyclone detection, storm tracking, and turbulence (also implementation problems).

Another example is provided by recent observations from various NWS offices and the OSF indicate the level of error in WSR-88D derived rainfall rate and accumulation estimates could be truly significant. This partly results from not utilizing rain gauge adjustment techniques that will eventually be employed in the WSR-88D. However, it is clear that the whole field bias adjustment originally destined to be implemented will likely not suffice, and concepts of applying "sectorized" bias adjustments are being considered.

The ability to equally calibrate the WSR-88D radars has also come into question, as very large differences are being noted between neighboring WSR-88D systems observing similar storm areas. Accepting that such comparisons need to be performed carefully to integrate beam size, range, altitude, timing, etc., it appears that individual calibration of WSR-88D systems may not be sufficient. The OSF has already begun investigating use of global calibration schemes to mitigate this operational problem.

Perhaps even more interesting are the continuing discussions that focus on fundamental problems such as how a mesocyclone circulation should be modelled, and how to verify algorithm performance without adequate ground truth. The mesocyclone conflict partly arises from increased algorithm and developer sophistication. At first we wanted to be able to "just detect" a strong and symmetric mesocyclone. Having met this "first-order" problem with some success, attention now turns to detection of those non-classic and marginal cases that form the "second-order" problem.

Thus, for many current WSR-88D algorithms, adjustment and modification will be an evolutionary process, as the algorithms are stretched to adapt to new situations as greater amounts of observations bring to focus the wide variations caused by local environmental structure, regional geography and climate, and season. For some, simple threshold tuning may be sufficient, while for a few others replacement, or supplemental algorithms may be considered. This is truly an exciting and significant challenge to the OSF and algorithm developers, one that will not be erased without huge investments in data and ground truth collection, analysis, adjustment, and testing. Finally, as more systems are fielded, NWS observations will play an increasingly valuable and powerful role in validating algorithm performance in the widely varying field environments. Their observations will likely become a significant portion of the input used in tuning algorithm parameters and thresholds. Judging from the response to this document request, the NWS is ready to play its part.

In the arena of NEXRAD algorithmic operation, interesting areas of research are again reflected in the literature. Rainfall estimation continues to receive considerable attention by the radar community, with refinement of methods employing inherent statistical averaging in the spatial, temporal, and microphysical domain. These techniques remove the user from apriori dropsize distribution assumptions, and replace them with derivation of Z-R relationships based upon environmental and gross storm characteristics. Establishment of robust climatological Z-R relationships, as well as guidance for real-time Z-R relationships, appears well underway.

Windfield derivation has seen a resurgence. The use of retrieval techniques for derivation of the 2-D winds from single Doppler radar in clear air, as well as the use of bistatic radar concepts in precipitation environments, are being demonstrated more easily and accurately. These, combined with existing and newly developing image processing approaches to windshift detection (convergence line, gust front, and fronts) point to opportunities for greater specification of the environment that can only assist in the forecasting of storm development and hazard potential.

Again, polarization techniques continue to see refinement as a solid focus on a limited list of parameters demonstrate improved utility in rainfall and attenuation estimation, as well as broad microphysical interpretation of storm features. While many reported studies still suffer from inadequate in-situ ground truth observations, it is quite clear the polarimetry remains perhaps the best approach toward increased understanding of microphysical storm characteristics.

Finally, as noted in past reports, the FAA Terminal Doppler Weather Radar (TDWR) and Integrated Terminal Weather System (ITWS) programs include a number of efforts that should be of interest to the WSR-88D community. These include new signal processing methods for faster data acquisition, detection of anomalous propagation and clutter and their removal, storm tracking, use of image processing techniques, and sensor data fusion. The employment of some methods and concepts developed at Lincoln Laboratory at other labs (e.g. NCAR, NSSL) working within the NEXRAD arena is heartening, indicating a good level of corporation among the agencies.

B. MESOCYCLONE AND TORNADO DETECTION

1. Mesocyclone Detection

Research into the Mesocyclone detection continues at the NEXRAD OSF, NSSL, and PL laboratories. In addition, some initial observations from the NWS field forecasters are also being received. The current WSR-88D mesocyclone algorithm does not currently enjoy a high success rate. An example is provided from results of the study by Burgess on spring 1991 data that found for 326 mesocyclones the Probability Of Detection (POD) was only 54%, the False Alarm Rate (FAR) was 34%, and the Critical Success Index (CSI) only 41%. In addition, reliably estimating rotational strength was considered suspect. This is partly due to the inclusion of contaminated velocity data that can either generate false shear, or mask true shear zones. This first source of error includes range aliased and incorrectly velocity dealiased data. However, the lowered performance also reflects use of the algorithm in those environments where the mesocyclone does not appear to fit traditional mesocyclone structure (shape or strength), and in storms associated with "weak" tornadoes. This second source of error seems more related to the "conceptual model" employed in the existing mesocyclone algorithm. Adjusting this conceptual model may be accomplished through threshold adjustment (e.g. changing the "strength" of the circulation), and/or relaxation of the required structure of the model. The OSF has focused on threshold adjustment, NSSL combines adjustment with some relaxation of the degree of structure, while PL is fully focused on modifying the fundamental structure of the model.

The current OSF adaptation tuning efforts have focused upon detection of mesocyclones associated with weaker tornadic events. Over the past few years, observations have indicated the occurrence of tornadic circulations associated with convergence lines, gust fronts, and developing storms. These are perhaps out of the realm of detectability for the current version of the WSR-88D mesocyclone and tornado detection algorithms, and will be detected by algorithms developed specifically for these phenomena. However, recent observations indicate a significant number of weak (F0 - F2) tornadoes being associated with mini-supercell type storms that contain mesocyclones that are not being detected by the WSR-88D. These storms have been observed in the Eastern and Southern states, may extend only to 20-30 kft, but have storm structure otherwise similar to larger supercells. They have been observed over both land and water (W/SR3) and are possibly not an uncommon occurrence. The OSF has determined that reducing the pattern number threshold from 10 to 6 results in a higher CSI, but at the cost of greater FAR. This threshold reduction "scales down" the required size of the circulation, in line with the "miniaturization" of the storms in general. However, the increased FAR suggests that generalized shear regions are now incorrectly elevated to mesocyclone status.
Although following different paths, both NSSL and PL have been attempting to provide flexibility in the "mesocyclone" (i.e. circulation) model used as the basis for detection. The NSSL approach retains the existing circular flow model, but relaxes various constraints within the model to allow for marginal circulations to be detected. PL, on the other hand has determined that the circular model is not always representative of the circulation flow, and has replaced it with an elliptical model.
As noted, the NSSL approach retains the traditional circular flow model, but the radial length and area thresholds have been reduced, and new classification techniques to quantify the circulation strength have been implemented. NSSL has also installed a capability to monitor these marginal circulations in time, the idea being that evolutionary behavior may provide insight into the potential for development into future mesocyclones. PL also employs time-tracking of marginal circulations. With improved strength estimation capability, better setting of thresholds may be expected; but results with this modified algorithm nor its expected performance with non-circular flows are reported.

PL continues its development of the elliptical mesocyclone flow model in response to observations that mesocyclone attributes often significantly deviate from those expected with the traditional circular model. Rather than requiring a linearly varying radial velocity between oppositely located velocity maxima, uniform divergence and vorticity across the core, the elliptical model allows these fields to vary non-linearly as observed in the Del City storm (Brandes 1984). Application of the elliptical model with reasonable assumptions of divergence and vorticity replicate well the observed velocity maxima placement, elongation of the velocity maximum on the circulations' "right" side, and non-uniform vorticity field that peaks in the Southeast quadrant, in this storm. Use of a non-linear (e.g. sinusoidal) variation of velocity across the core (not performed) is expected to replicate the "S" zero line curve observed in this storm.

Given that observations (Brandes 1984, Wood 1991) suggest the presence of non-circular flows, either as singular circulations or modified via embedded circulations or neighboring flows, the PL approach would seem to offer the best potential for estimating the true rotational strength of the circulation, and thus potentially allowing for a greater level of detection and smaller false alarm rate. The potential trade-off, however, is that the greater flexibility provided by this model may also potentially require a more complex algorithm, requiring additional attributes (e.g. eccentricity, orientation, aspect dependency of measured rotational shear, etc.) to be accounted for before mesocyclone declaration can be made.

A quick decision on the best approach is not yet possible. Meanwhile both NSSL and PL are undertaking additional efforts to further enhance their algorithms. NSSL will investigate using 2-D image processing techniques to better locate circulations, and the use of supporting parameters (e.g. mesocyclone/tornado climatologies, predictor variables derived from soundings and shear (e.g. helicity)), for assisting in declaring mesocyclone existence. PL will attempt to automate the new mesocyclone model into its mesocyclone package by the end of 1995. More testing and analysis are forthcoming from both agencies.

It should be noted that there may be alternative methods for isolating the mesocyclone structures. As reported last year Suzuki et al. (1993) discuss an interesting application of successive filters of varying scale in locating shear zones. While this algorithm obviously operates on a 2-D field, it (or similar pattern recognition schemes) may be a potential candidate for an ancillary processor, or could run on a PUP station, or could be used in validation tests where an additional automated detection algorithm could preview velocity data before human analysis.

Recent literature offers little additional information on mesocyclonic circulations except for limited observations of variations of the classic supercell storm. Jangbluth (1993) reports on a small cluster of storms that produced over 3 in of rain, four tornadoes, and 7 cm hail. The environment was typified as classic supercell, but the storms and attendant mesocyclones remained almost fixed in position during the entire 2+ hr period. Despite the lack of storm movement, helicity calculations indicate supercell values. This report is similar to earlier observations by Johns and Doswell, III (1992) of a non-propagating supercell storm where helicity reached only 50% of that expected necessary to achieve supercell status. That work suggested that helicity calculations may not always be straightforward, and in that case the relative motion of a nearby frontal boundary appeared to supply the additional relative motion necessary to reach the supercell helicity threshold. Some original discussions on the use of helicity can be found in Davies-Jones (1990) and Leftwich (1990).

Another observation of unusual storm motion is reported by Niino et al. (1993). They report on two supercell-type storms with identifiable mesocyclones that move to the NW. The mesocyclones cycle between weak and strong phases. One mesocyclone contained a smaller embedded mesocyclone that was associated with a tornado. These authors suggest a sudden increase in low-mid (1-5 km) level vertical vorticity may be a precursor to mesocyclone strengthening and tornado formation, although the reported 20 min lead time is somewhat lengthy.

Unexpected storm motion can often be tracked to modification of the mesoscale environment. Weaver et al. (1994) provide an example of propagating storms becoming stalled, and new localized tornado-forming storms developing as a result of a localized moisture gradient combined with a cool surface outflow from storms to the East that formed the previous night. Although directed towards MCC events, Lopcheva (1993) discusses the Russian requirement for formation of deep squall lines (MCC events) being tied to earlier MCC development the previous night, suggesting environmental modification is again at work. Finally, in a discussion of an operational method for forecasting mesoscale modification leading to MCC development, Kurz (1993) provides an interesting example of forecasting conditions favorable for convection resulting from large-scale ascent. These observations indicate that there are many factors that affect the development and motion of storms and storm systems, and that we may need to remain cognizant not only of the individual storms of immediate interest, but also the evolving mesoscale environment within which they reside.

2. Tornado Detection

Only NSSL reports being actively engaged in "explicit" Tornado Vortex Signature (TVS) detection, although NCAR is involved with detection of tornadoes not associated with mesocyclones (not reported here). Other notable efforts that are not related to algorithm development, but rather the use of existing data to enhance tornado detectability, are underway at the OSF and at NWS offices. Finally, no further efforts on the use of Excess Rotational Kinetic Energy (ERKE) are reported by PL, even though some skill was demonstrated with tornado intensity prediction.

NSSL takes the direct approach to tornado detection via the TVS algorithm. NSSL has modified this algorithm to better estimate the true circulation strength through use of multiple shear thresholds, as well as requiring greater vertical continuity in correlating the rotational shear. An interesting new feature is the tracking of circulation parameters such as low-altitude shear, circulation top and base, and location and value of maximum shear. The use of trend data may be highly useful in this situation where the physical size of tornadic circulations makes direct detection often difficult. In this situation, continuity in time of some aspects of these marginal circulations may be a necessary approach to declare such circulations as tornadoes. This approach is similar to the tracking of substantial shear features to enhance detection of marginal mesocyclones. It would seem, however, that spectrum width would also be a useful parameter to track, particularly when tornadoes are often not resolvable by radar beyond 30 km.

The OSF and NWS sites are attempting to make better use of observations derived from the existing WSR-88D Mesocyclone algorithm. The OSF has been searching for mesocyclone features that correlate with tornadic intensity. It appears that a positive correlation exists between tornadic intensity and the "combined" pair of mesocyclone depth and rotational velocity. There appeared to be no correlation with vertical location within the storm (e.g. base, top, etc.). The OSF will attempt to refine this association with additional data. These results reflect past observations of violent tornadoes associated with strong mesocyclone circulations embedded within strong supercells, and the recent observations reported here (mesocyclone section and below) of numerous marginal tornadic circulations associated with weak or "missed" mesocyclone detections embedded in mini-supercells.

In an alternative form of analysis, various NWS field sites are actively engaged in assessing traditional methods for declaring hazardous weather warnings now that Doppler velocity data are becoming available. As an example, the NWSO Amarillo office conducted an analysis of the applicability of Norman NWSO rules for tornado declaration based on mesocyclone circulation characteristics derived from WSR-88D velocity data. The NWSO Norman mesocyclone criteria for tornado warning are (1) rotational velocity greater than 45 kn (35 kn) for ranges less than 100 nm (greater than 100 nm), (2) time continuity, and (3) a vertical extent no less than 10 km. The analysis reviewed 11 tornadic (F0 - F2, one F3) events that failed these criteria. All mesocyclone depths were near 10 kft, and had at least a 2-scan continuity. Analysis indicated the mesocyclone depth threshold was missed 3 times (e.g. actual values were between 9-10 kft), the velocity threshold (45 kts) for < 100 nm range was missed 6 times, the velocity threshold (35 kts) for > 100 nm range was missed 1 time, and for a tornado at range > 100 nm no discernible mesocyclone was observed at all. The F3 tornado was associated with a shallow mesocyclone of 9.2 kft depth, failing the depth threshold. These marginal situations are instructive, not only because they document cases of failure, but also because they suggest new threshold values that would allow successful forecaster warning (all depths > 9.2 km, nearly all rotational velocities between 30 - 45 kn). Thus, such information may expedite the adaptation threshold tuning process, and become a valuable source of information for the OSF.
Other than observations on the larger focus of tornado-producing storms, and the generation of environments that can support them (see literature discussion in Mesocyclone Section), very few recent tornado observations are reported in the literature. Niino et al. (1993) suggest that forecasting tornado development may be linked to the weak-strong cycling of the parent mesocyclones. Earlier work at PL has also tied the forecasting of tornadic development to mesocyclone behavior. Finally, an example of a marginal tornadic circulation that would be difficult for WSR-88D detection, despite the very close range (15 km) from the radar, is reported by Wakimoto and Lew (1993). The velocity data for this circulation (max width < 200 m) presented in the article suggests that even a trained observer would likely not have detected much of this circulation. Such marginal events may always elude detection.

C. HYDROLOGICAL APPLICATIONS

A wealth of activity exists in the hydrologic arena. Input was received from FSL, HRL, NMSFC, NSSL, OSF, and NWS regional offices. Observations of the performance of the WSR-88D algorithms using field WSR-88D systems are now filtering in, with initial results disappointing. Assessment of algorithm performance must be tempered with the knowledge that the gauge-derived bias correction is not currently being applied to final accumulation estimates. Regardless, the observations clearly suggest that the originally planned implementation (e.g. a single whole field bias adjustment), will often result in considerable error.

Observations by the NWS/WR3 and OSF for a limited number of storm periods in Oklahoma noted that the WSR-88D storm total accumulation estimates can be significantly different from resident gauge network measurements, as well as between neighboring WSR-88D systems. While one storm period showed good agreement, two other observational periods are particularly notable. Both could be generally characterized as convective to the NW and stratiform to the SE. During a December (12-13) storm the Twin Lakes WSR-88D (KTLX) radar measured typically 40 - 80% of gauge totals to the NW with a limited region of over-estimates to 120%, while towards the SE the WSR-88D estimates were generally between 20-40% of gauge values. The Norman WSR-88D registered 40-100% and 100->200% of gauge totals in the Northern and Western portions of the NW sector, respectively. To the SE, the Norman WSR-88D estimates ranged from 20-100% of gauge values. Neither WSR-88D measured more than 20% of gauge totals beyond about 90 km range. During a September (12-14) storm the KTLX radar measured about 50-75% of gauge values to the NW and again only 30-50% to the SE. These are only very limited cases, but further discrepancies should be expected with routine WSR-88D observations in the Southern and Rocky Mountain regions.
These results reflect a number of potential problems, including; (1) the inability of the WSR-88D Z-R relationship to adequately reflect the range of precipitation environments during these two storms, (2) beam elevation and storm top mismatch, and (3) potential WSR-88D mis-calibration.

Discrepancies (3) between the measured reflectivities from the KTLX and neighboring Norman (KOUN) and Frederick (KFDR) systems have suggested the KTLX reflectivities are often between 3-10 dBZ lower than the two neighboring WSR-88D's. This supports the drastically lower storm total accumulations noted for this radar. While reflectivity patterns were not available for this report, the accumulation patterns suggest (NWSO Appendix) that any under-estimation due to attenuation probably would have been primarily to the NW in the convective zone, and not to the SE where under-estimation was in fact prevalent, thus attenuation is not considered a relevant factor.

Finally, these combined convective/stratiform cases suggest that the whole field gauge bias adjustment (2) will not return better performance across the field when very dissimilar storm systems are being simultaneously observed. Such correction would seem to require a sectorized gauge adjustment capability, as suggested by these two agencies. Correction of these calibration and reflectivity-to-accumulation (i.e. Z-R) problems is crucial for both real-time and projected (e.g. flash flood) hazard detection.

In response to such observations, the OSF is undertaking comparisons of WSR-88D estimates of rainfall against raingauge amounts to better ascertain the mismatch noted between the radar and raingauge estimates. Also, the OSF, together with FSL and NCAR, are evaluating the WSR-88D calibration routines, noise estimation and solar check routines, to determine potential sources for error and alternative methods where possible. Methods to acquire an effective "global" calibration are being considered.

As noted, the use of a single Z-R relation and the whole field bias adjustment would appear unsuitable in many instances of mixed storm environments. As a potential alternative approach, FSL is investigating the applicability of the Window Probability Matching Method (Rosenfeld et al., 1994) to the WSR-88D. This method is a member of the class of techniques that employs only gross storm and environmental characteristics in determining a Z-R relation to be used in estimating rainfall. This family of approaches offers flexibility to adjust with storm type, season, and geography. Development of the method, however, requires significant investment in data collection both from radar, environmental sounding, and validation sources such as raingauges. This itself is a considerable undertaking, given that sounding and raingauge data have often been shown to have inadequate spatial or temporal resolution to be meaningful as validation measurements. In addition, maintenance (Zevin, 1994) of gauge networks and the recurring problem of gauge-to-gauge discrepancy are always of concern.

The variability in measurements capable of being generated by spatially separated raingauges is truly highlighted by the observations of Huff (1994) where over 6 in of rain fell in 3 hr.

This analysis, although focused upon determining more representative rainfall climatologies, demonstrates the wide rainfall variations that can occur over km length-scales, and again points to the difficult problem of radar-raingauge validation. In addition, although in "general" agreement, the various rainfall measuring devices all have inherent limitations (Sheppard and Joe, 1994), and may result in significant differences depending on what "type" of rain is present.

Nonetheless, these methods (e.g. WPMM) that remove the reliance on a single Z-R relation have been shown to be quite robust. The non-linearity (log-log plots) typically seen in the data-derived Z-R relations from these techniques, as well as the variation with range and storm type, attest to the potential inadequacy of a single Z-R power law based technique. The utility of gross-average techniques have also been extended to rainfall climatology development as reported by Morrissey et al. (1994). Here, with less variability in rain "type", use of Fractional Time Raining (FTR) is discussed as a method for estimating rainfall amounts. Use of a gross-observational method (e.g. ATI, WPMM, etc.) will likely utilize the data WSR-88D data archiving activities at the OSF and NMSFC. To be most useful, however, the WPMM technique must be capable of being employed on a sector basis to account for the spatial variations in storm type that may occur during single volume scan periods.

Other non-algorithmic sources of error also potentially exist, and HRL continues data collection and algorithm testing efforts to determine the extent of some of these "fundamental" sources of error that may arise with "implementation". To assess the performance of the gauge data acquisition process, HRL is developing the capability to acquire field raingauge data and apply this to real-time adjustment. A second effort is a study of the effect of the raingauge data posting time to assess the potential error for a raingauge measurement improperly falling into the previous, or next period accumulation (posting) period. These investigations will attempt to quantify the degree of error that may be expected in the field.

Bright band (BB) identification also remains a potential source of error. Both its automated identification and correction are required. Both HRL and HSTX have investigated automated BB detection. The HSTX technique is part of a larger methodology that forms the HSTX freezing rain algorithm. However, no additional activity on this algorithm was reported. The HRL BB algorithm will also identify BB presence and then allow the Precipitation Preprocessing algorithm to provide corrective measures. This algorithm has also not yet been fully tested. The NWS/OSF observations of occasional accumulation over-estimates that are generally embedded within a field of overall storm total under-estimation may reflect inclusion of bright band effects in the observations noted above.

There still remain a host of other areas that can affect the precipitation algorithms and that require further investigation. These include occultation, topography, and partial beam filling effects (particularly in the Western mountainous regions), high hail signature returns, high rain reflectivity (> 60 dBZ) with no hail (e.g. Florida), mixed phase rain and ice events, and snow tracking and accumulation. Some of these are truly basic problems that must be accounted for if successful use of the precipitation algorithms is to occur. The first three elements are highly geographically dependent, and rapid resolution of these problems is unlikely. Adjustment for orographic effects lies outside the realm of the WSR-88D algorithm suite, and implementation on an ancillary workstation has been suggested.

Mixed phase identification and resultant adjustment is a difficult problem to tackle with the WSR-88D, and such decisions often depend on noting relative placement to storm features. Precipitation discrimination and bias adjustments suggest use of polarimetric methods, which actively continue at CSU, NCAR, and NSSL. The various reports (e.g. Gorgucci et al., (1994); Vivekanandan et al., 1993; Zrnic et al., 1994, etc.) reinforce the strength of these approaches (e.g. Z and ZDR) in deriving estimates of rainfall, more accurate and stable than obtainable from the WSR-88D reflectivity alone. It is also quite clear that capability for microphysical classification is improving. Notable success has been achieved in estimating rainfall in mixed phase environments, and as noted earlier, discriminating between heavy rain and hail environments. However, identification of actual "microphysical" evolution through the BB can be very difficult, even with polarimetric observations (Meneghini et al. 1994). Polarimetric methods remain far from automated, however, and their applicability in all storm environments is not uniform. Thus, although important results are continually obtained via polarimetric methods, installation of modest polarization capability on WSR-88D systems still appears unlikely in the near future.

Snowfall is receiving some attention as NCAR analyzes winter storm data acquired during the past two years and begins investigation of tracking and forecasting schemes for low-gradient reflectivity fields commonly observed in snow storms. Snow accumulation has traditionally received little attention. The accumulation of snow at the surface is dependent upon crystal types and the degree of aggregation and riming. The radar reflectivity is somewhat type dependent (bulk orientation, etc.), and may very substantially with degree of aggregation, riming, water coat and "mushiness", and to a lesser extent the amount of enclosed air (if near surface layer). Since these characteristics are not well delineated by traditional nor polarimetric observations, snow Z-R relationships are few in number.

Some, albeit limited, insight into snow crystal and aggregate structures that pertain to radar reflectivity is reported by Hogan (1994). With knowledge of the crystal/snow type being observed, these observations of typical mass-to-size values may aid in explaining some of the evolution of reflectivity and velocity profiles observed as snow falls to the ground. However, without in-situ sampling or precise knowledge of the temperature regime of crystal development, perhaps only polarimetric methods may be able to utilize such information. It would appear that gross-observational methods such as the ATI/FAR/WPPM, etc. that include realistic sounding information will probably be required here also. An additional source of concern is verification, since gauge measurements of snowfall are often unreliable. It should be expected that new VCPs will be required to improve data collection in these low-level stratiform-type situations.

Finally, on a separate note, NSSL has investigated another occasion of reflectivity mismatch, this time between the Twin lakes WSR-88D radar and the NSSL Cimarron polarimetric radar. It appeared that the Cimarron radar reflectivity was about 10 dBZ lower than the WSR-88D through an extended squall line (increasing to an estimated 15 dBZ difference at 120 km range). Calculation of potential attenuation via polarimetric measurements from Cimarron suggested this range (10-15 dB)/(3 dB) of attenuation was possible in the reflectivity/(Z_{DR}) measurement during a special case of alignment of storms along a viewing radial. Further calculations suggested as much as 3 dB (1 dB) of 2-way attenuation was possible at the radome during a heavy (light) rain event. Measurements also suggest that 3-4 dB of attenuation may be frequently occurring at S band in such extensive systems. These high estimates are somewhat surprising. It is also not known whether the KTLX WSR-88D was suffering any calibration bias error at this time, which could have separated the measurements between the two radars by another 5-10 dB.

D. STORM MOTION AND FORECASTING

This element receives considerable attention, partly due to the need for better tracking capability, and partly due to the wide variety of storm environments now of interest to weather data users and forecasters. The WSR-88D Storm Sequence algorithm has enjoyed some success with isolated cells, areas that usually define positions of storms and their hazardous regions. This algorithm often encounters problems with newly developing or rapidly evolving storm cells, as well as those that merge or split. While capable of tracking the individual cells that remain isolated within lines, it was not really designed for tracking lines, systems (squalls and organized systems), and regions (e.g. more stratiform rain or snow) as now desired. These environments are replete with opportunities for cell misidentification as one cell dissipates and a neighboring cell develops. This is demonstrated nicely by observations by Westcott (1994) that indicates storm "merging" appears to result primarily as a result of horizontal storm expansion. Statistics indicated 65% of the observed mergers were between a parent and daughter storm, 25% were between two young echoes, and only 10% from merging individual cells from different storms. It must be remembered that these statistics are a function of the definition of a "cell", and different statistics will be obtained with varying reflectivity threshold levels. Nonetheless, these data suggest that cell merging is primarily an "internal" storm phenomenon, and it is unclear whether threshold tuning would much improve the performance of the current WSR-88D algorithm. Its use of reflectivity cells defined in 3-D would suggest that tracking VIL (still using 1 threshold value) would probably not offer much improvement. For these reasons, the various agencies are attempting to supplement this algorithm, or develop alternative methods to make it more suitable to the wider variety of environments of interest today.

NCAR, LL, OSF, NSSL, and TDL are all actively engaged, directly or indirectly, in this area. Both NCAR and NSSL have cell tracking algorithms. Stratiform/precipitation forecasting algorithms are also being developed at NCAR and TDL. PL is undertaking a study of tracking supercell storms via the WER/BWER regions, including an investigation of the potential for forecasting severe weather like hail or tornadoes. The level of activity on this effort was not reported.

TITAN (Dixon and Wiener, 1993) remains the primary storm cell tracking algorithm at NCAR. It is typically applied to existing cells, identifying 3-D reflectivity and volume attributes that are used for maintaining cell identification, tracking, and forecasting. Unlike other methods that track storms individually, this algorithm determines the new positions of all storms simultaneously via a cost function approach that retains information of each storms position and volume. For identification of merging and splitting an ellipsoidal representation of the cells is combined with geometric tests (overlap) to determine the association of current cells with those from the past scan. The algorithm is widely used in the community, and forms a component of the NCAR storm initiation and forecasting sequence for storms initiated by convergence line intersection. While primarily designed to track convective-type cells, it does have adjustable reflectivity thresholds to allow for tracking of more subtle features as typically observed in stratiform and wintertime storms. Typical TITAN statistics for storm cell tracking decrease with length of forecast, with typical values of POD near .8 - .6, FAR near .3 - .6, and CSI near .6 - .3 for 6 - 30 min forecasts.

The NSSL Storm Cell Identification and Tracking (SCIT) algorithm has been shown to be quite superior to the existing WSR-88D algorithm. While the WSR-88D method follows one reflectivity threshold, the NSSL SCIT employs 7 thresholds from 30 - 60 dBZ. This approach essentially allows for tracking of cells that may be developing or dissipating in time, where the range of thresholds exceeded by the cell may be changing in time. It also provides additional information about parent and daughter cells during merging and splitting events. These enhancements provide some flexibility in maintaining cell identification between scans that is not found in the single threshold WSR-88D algorithm. Use of a range of thresholds also allows for tracking more stratiform features for which the current WSR-88D algorithm was not designed. This algorithm has been delivered to the NEXRAD OSF and is available for testing.

The LL tracking method is a 2-D correlation tracker, less focused upon cell identification and designed to track in both cellular and stratiform-type environments. This approach appears to make it less susceptible to cell misidentification during merging and splitting events. Similar to the other techniques, it provides individual storm track forecasts, and the implementation employs a limited visual boundary (e.g. leading edge) to show the forecasted placement of the storm leading edge; other display options have also been explored. A potential upgrade to storm motion assessment will be to establish the storm motion from a consensus of partially correlated neighboring sub-storm motions. This should enhance even further the greater track stability already noted with this algorithm when compared to rival techniques. The implementation employs only five (5) reflectivity thresholds in the display, thus not heavy on meteorological content, but provides the user (e.g. FAA) a simpler display designed for ease of interpretation in a hectic work environment. A comparison of the NSSL, WSR-88D, and LL tracking algorithms found the NSSL method more accurate and consistent than the WSR-88D algorithm, but the LL approach produced the most stable tracks (at computational expense). No comparisons with TITAN are known to have been performed.

After achieving some success in severe storm tracking, attention now also turns to those less dramatic environments of stratiform and snow fields. In support of a snowfall forecasting program NCAR is testing both the existing TITAN (with reduced thresholds) method and a new 2-D TREC-type approach termed Radar Echo Prediction (REP). The TITAN technique, as discussed previously, is basically a cell tracking method that has adjustable thresholds to allow application to more stratiform environments. However, it still attempts to identify, track, and forecast "cells", an attribute that is often misleading when being applied to the low-gradient fields typical of snow and stratiform situations. The REP technique, on the other hand, is more TREC-like, correlating small (e.g. 10 x 10 km) regions (may be overlapping) from one scan to the next. Determining optimal tracks for the regions essentially generates a 2-D flow field as in TREC. Correlation of regions between scans can be either through divergence minimization (current) over a small field of neighboring regions, or minimization of whole field error (in development). Efstratiadis and Katsaggelos (1993) describe a similar method that operates on sub-regions, generating high definition 2-D flow fields through error minimization. Hamill and Nekhorn (1993) also employ a TREC-type method that attempts to correct trajectories in conditions of curved flow.

It is likely the NSSL SCIT algorithm will replace the current WSR-88D algorithm, since it employs features that could not be duplicated through threshold tuning of the WSR-88D algorithm. What is unclear is whether two different techniques should be employed for cellular versus stratiform tracking. The correlation approach is naturally more applicable to varied environments, but the use of multiple thresholds within SCIT also provides it significant flexibility if the thresholds are adjustable.

A wealth of other techniques remain available for storm identification, tracking, and forecasting. Use of Kalman filters

(Burl, 1993) in a 2-D technique to determine feature motion is of interest since this filter can self-adjust the relative weights applied to old versus new positions. The method of Wamazi et al. (1993) seems particularly robust for use in low SNR environments. At the extreme end of complexity, use of 2-D tracking to study 3-D motion and evolution using finite elements is reported by Cohen and Cohen (1993). However, the authors suggestion that tracking in 3-D is visually easier to understand is well taken.

The image-processing literature abounds with countless methods for identification of "features, segments, etc." of 2-D and 3-D data fields. Many of these techniques employ sophisticated transforms (e.g. Fourier or wavelet), or polynomial representation. Fitting cells to polynomials (Keren et al. 1994) may provide a method by which contour evolution can be tracked and forecast, if the polynomial parameters are themselves tracked in time. However, as stated earlier, tracking on a 2-D plane is difficult since the reflectivity contour is not a conserved quantity. These are quite interesting and offer potential for robust tracking and forecasting in "evolving" systems.

However, there are numerous simpler techniques employing variable templates and median (and other) filters, as well as "texture-based" schemes using multiple lags of observables, that are also quite robust. These techniques identify feature characteristics that are not normally included in traditional radar meteorology methods. Only the NCAR neural network clutter approach that uses simple "texture" features to discriminate between clutter and precipitation, and the template approaches of LL and HSTX to isolate shear or reflectivity gradients (GF detection, both very successful) apply such image processing concepts. It is this authors' feeling that these "image-processing" techniques are far under-utilized within the radar meteorology community, and provide opportunities for enhanced storm tracking, 2-D flow field generation, velocity dealiasing, and feature detection (mesocyclone an tornado). A discussion of these "texture" techniques can be found in the discussions on anomalous propagation and clutter detection.

E. HAIL DETECTION

Hail detection remains a somewhat elusive capability for the WSR-88D system. A number of agencies, including NCAR, the OSF, NSSL, PL, TDL, and the NWS offices are in some way involved with hail detection. The existing WSR-88D hail algorithm suffers from a high FAR and low POD, and does not actually quantify hail size.

These results suggest additional attributes may need to be considered to improve algorithm reliability. While there is still some activity with the existing WSR-88D algorithm, little activity on some other alternative algorithms is reported. For example, PL reports no further work on the use of ERKE as a hail forecast tool, although it previously appeared to demonstrate some skill. In its place, PL will investigate the existence of correlations between WER/BWER's and hazardous phenomena (e.g. hail and tornadoes). Similarly, TDL reports no further work on a scheme based on VIL and environmental parameters that appeared to offer some potential. Most recent efforts appear to be taking place at NCAR and NSSL, with some observations arriving from the OSF and NWS sites as well.

The most recent organized program to acquire coordinated hail data was conducted by NCAR during the summers of 1992 and 1993. One prime focus of this effort was to obtain very accurate data on hailfall locations, time, and size categories. This process is critical if comparisons are to be made to radar observations. That is, precisely known (as well as possible) verification data (hail on ground) are required if accurate correlations are to be made. NCAR reports that over 100 storms were observed. Both the WSR-88D hail algorithm and polarimetric techniques were under test, however, no results were received to provide further details in this report.

While NSSL will begin modification of the hail algorithm to determine relations between hail presence and size with the volume extent of the hail, upper divergent level outflow, and relative placement to the freezing level, most recent efforts have turned to algorithm evaluation. Evaluation of the Probability Of Severe Hail (POSH) on Southern Plains, Midwest, and Florida data
showed significant reduction in performance when compared to results from the Southern Plains alone. This should not be totally unexpected for more tropical locations such as Florida where environmental conditions are favorable for generation of very high reflectivity (e.g. 60 - 70 dBZ) with no hail observed. NSSL is attempting to determine whether the variance is meteorological or due to other factors such as poor ground truth validation. While validation is a cause of concern in the lightly populated Western regions (e.g. NCAR program), it should not be quite such the problem in Florida, and it is likely the deviations are primarily a result of geography. Also reported was an analysis of the optimum warning threshold (max CSI) for four warm season days in Florida. The thresholds were found similar, or lower than, that observed in Oklahoma.

Some interesting observations are reported by Auer, Jr (1994), who related hail to radar reflectivity and cloud top temperature. Although these results are for New Zealand, and the method somewhat reminiscent of the technique of Kitzmiller (1993), the results are quite remarkable in ability to delineate between hail/no hail/heavy rain environments. This technique would be easily adaptable to the WSR-88D if sounding data were made available from which to estimate cloud top temperature (e.g. 15 dBZ level). Some hail size discrimination is also provided via this relation.

Finally, with the placement of WSR-88D systems into the field, NWS observations will play a vital role in validating and tuning the hail detection approach. A quick example is provided by a WSR3 site that performed a limited analysis of VIL versus hail size. Some discrimination between small and large hail could be achieved via a data-derived nonlinear relation (applicable at 300 and 500 mb heights), providing support for the use of daily VIL as a predictive tool as previously suggested (e.g. TDL). VIL, however, can be misleading since a "VIL of the day" may not truly be representative of the full region under radar coverage for extended periods of time, nor be correctly estimated in the presence of water and ice environments.

Whether it is reflectivity, VIL, or some feature related to environmental convective potential or storm structure, all methods reported here are indirect. Radar reflectivity is usually considered direct, however use of a simple reflectivity threshold is generally not a good discriminator between hail and heavy rain, as shown in Florida. This brings into question the feasibility of employing limited polarimetric capability as these techniques demonstrate increasing capability to perform such discrimination in storms. For example, a study of hail growth is reported by Conway and Zrnic (1993), providing information on the growth regimes of the hail embryos as they traverse the storm structure.

F. FREEZING RAIN AND ICING

There is no current activity in automated detection of freezing rain. As reported previously, the observations reported by Prater and Borho (1993) indicated identifiable signatures in the radar reflectivity and velocity fields that could form the basis of an algorithm during these frontal situations. A more recent set of observations by Martner et al. (1993) nicely demonstrate the applicability of the suggested freezing rain algorithm. HSTX implemented the algorithm, with modifications, and had begun testing on limited data sets, with promising initial results. However, lack of funding has resulted in termination of this work at both UND and HSTX. An interesting variation on a freezing rain event is presented by Rauber et al. (1994) where the falling rain hindered surface warming and thus the recovery from a surface icing event.

No current work is reported in the radar identification of icing conditions. Data from the Winter Icing and Storms Program (WISP) of NCAR and FSL have indicated that the most severe icing occurred with the presence of stratocumulus clouds containing no precipitation. Obviously, this environment will not be routinely detected by the WSR-88D, thus there appears little hope for a WSR-88D approach in identifying these conditions.

G. TROPICAL STORMS

Development of tropical algorithm techniques came to conclusion for both HSTX, and the PARAMAX/Florida State University group. Both PARAMAX/FSU and HSTX have encountered some difficulties in maintaining support for development and testing of these algorithms over the past few years. At this time, the PARAMAX algorithm appears the most complete as an automated package suitable for testing in a WSR-88D environment.

Last year, PARAMAX halted testing of the final version of its suite of algorithms consisting of the four categories; (1) storm identification, (2) eye location and intensity estimation, (3) tracking and forecast, (4) and storm surge forecast. However, testing was resumed this year, using both simulated and limited real data. At this time PARAMAX is waiting for the opportunity to test the package with WSR-88D data.

The HSTX tropical package, also previously reported, consists of techniques to locate and quantify hurricane circulations. Hurricane center positioning employs the spiral reflectivity rainbands to "point" to the center (accuracy of 10 km with limited data). Tracking the trend in hurricane intensity is done by fitting the flow to a Potential Vortex Fit (PVF) model. PVF is calculated from a VAD analysis and indicates increasing intensity (PVF > 1) or decreasing (PVF< 1) intensity. Testing on only limited real data was completed and no further work is currently planned.

Recent reports suggest that the water/reflectivity distribution within these storms may be asymmetric and suggests that use of the spiral bands must be done with care. Gamache et al. (1993) found condensation occurring mostly on the side opposite to the inflow, thus generating a nonuniform distribution of spiral bands. Also, Franklin et al. (1993) discuss the asymmetric reflectivity structure of Hurricane Gloria. This observation is quite true if all bands are considered, however, if one restricts themselves to the inner bands then symmetry is quite well preserved. Thus, use of spiral bands for locating hurricane centers and tracking perhaps must include a discrimination function that emphasizes use of only the inner bands circulating about the storm center.

This past year may be remembered for its' unprecedented large number of hurricane-related journal articles. For example, a new velocity-based technique for locating hurricane circulations and the hurricane eye was reported by Wood (1994). The Doppler radial velocity is used to locate velocity "pattern vectors". These pattern vectors are then fit to a model of the expected "envelope" of vectors for a typical hurricane circulation. Here it is the "pattern" of these pattern vectors as well as the trend of velocities that is of interest. Once the pattern vector envelope is identified, its symmetry allows for identification of the hurricane center position. The technique appears to require at least half of a hurricane to be detectable. The limited testing to date shows reasonable results, but further development and testing is required to bring it to a stage comparable to portions of the PARAMAX algorithm.

Most other reports dealt with tracking and forecasting, rather than with identification. The studies by Chan et al. (1993) and Peng et al. (1993) suggest that persistence best describes future tracks except for erratically moving storms (e.g. very young, weak, or near landfall). A discussion of the Climatology and Persistence model (CLIPER) is provided by Neuman and Pelisser (1981). Franklin et al. (1993) found an interesting correlation between hurricane direction and speed with the 700 mb winds at roughly 50 and 650 km from the eye. This method may be compared with the Beta drift method of Smith (1993) that provides a simple relation to the Coriolis force for hurricane drift before they undergo curvature.
All these results would appear less substantial, though, than those reported by Hodanish and Gray (1993). They tackled the more difficult problem of tropical cyclone track curvature through analysis of 21 years of data. They developed at set of rules for forecasting hurricane tracks during all phases of motion, including linear, curvature, and recurvature conditions.

The primary steering influence appears to be the upper level (300 - 200 mb) winds to the W, N, and NW of the storm center. Although the rules do not include much interpretation as to "why" they work, they appear reasonably well substantiated via the wealth of data included in the study. Again, however, applying similar rules in a WSR-88D setting would require ingestion of upper level wind data, and thus is perhaps best relegated to an ancillary processor.
The difficulty in forecasting cyclone movement upon landfall is demonstrated by the modeling results of Yeh and Elsberry (1993, I & II). The complex interaction between cyclone flow and land results in cyclones approaching Taiwan's Northern end deflecting towards the south, those approaching the Southern half deflecting towards the north (but not symmetrical deflection). Results also suggest that landfall could result in deflection or termination of the cyclone track. The final track appears dependant upon the location of the cyclone relative to land, the relative sizes of both features, and the land topography.

Finally, a non-applicable, but very interesting report on use of an OTHR for mapping hurricane flow near the sea surface level is presented by Georges et al. (1993). After some modification, the OTHR demonstrated a very nice capability to detail hurricane surface winds on a scale of a few 10's of km. Apparently, this report was a desperation move to acquire additional funding for the OTHR systems and their personnel. Sadly, this does not go without parallel in the radar meteorological community.

H. VELOCITY DEALIASING AND RANGE UNFOLDING

While there probably exist nearly as many velocity dealiasing routines as radar meteorologists, the primary routines under consideration for "automated" use with the WSR-88D reside at PARAMAX, NCAR, NSSL, LL, and the OSF. The successful detection of kinematic-based storm features is dependent upon the ability to correctly dealias the measured Doppler radial velocities. Often dealiasing failure occurs where least desired, in the high shear regions associated with mesocyclones, updraft boundaries, and outflows. Dealiasing failures can often be attributed to velocity data contamination from multi-trip echo, anomalous or clutter return, low SNR, non-representative reference field velocity, or occasionally multiply-aliased velocities.

To date, the algorithms (e.g. WSR-88D, NSSL, FSL) tested have demonstrated rather comparable performance, with about a 3 % failure rate when the Nyquist velocity lies within the range 20 -

30 m/s, but with performance degrading quickly at lower Nyquist velocities (NSSL best). This low failure rate, however, must be tempered with the knowledge that such rates are typically measured relative to the total number of good range gates available for dealiasing. With the vast majority of velocities not aliased, and most remaining aliased velocities residing in regions that are amenable to the simplest form of radial dealiasing, it is then recognized that a 3% failure rate often represents a sizeable portion of the "more difficult" dealiased velocity cases under consideration, and often they are embedded within those shear features we most dearly wish to detect. From this perspective, it becomes clear why so many continue to wage battle against so few remaining incorrectly dealiased gates.

Moderate to high Nyquist rates are usually considered necessary to achieve adequate performance. However, high Nyquist rates implies increased potential for multi-trip contamination, the old velocity-range ambiguity problem. It is reported (TAC Summary Feb 1994) that range folding effects account for about 80% of undetected mesocyclones. The velocity algorithm must be a real-time algorithm. Post real-time 2-D image processing techniques are not usually considered viable replacements since they would eventually impede the processing flow, and the few available for comparison have not demonstrated enough improvement in skill to warrant such a major software revision. Because of the similarities between the WSR-88D and NSSL routines, modification of the existing WSR-88D routine using NSSL improvements is considered the most efficient path for improvement.

A major concern with the WSR-88D method was the tagging of some valid data as "missing". OSF staff are adjusting parameters to reduce this number of "missing" values. Further retesting indicated a slight performance improvement in CSI (82% to 84%). Testing on limited data from a high tornado activity day showed about a 5% improvement (79 to 83) in mesocyclone detection and an increase in tornado detection (2 to 4). Unfortunately, the number of falsely dealiased gates also increased. The OSF testing demonstrated the NSSL algorithm handled better those gates that were potential candidates as "missing". Investigation continues with this difficult problem.

NSSL is widening its scope of investigation by also studying the effects of sounding data inaccuracies, and modified scanning strategies with multiple PRFs to untangle the unambiguous range and velocity problem. NSSL expects to have available next year an algorithm incorporating the results from some of these pursuits. Although further details are not available at this time, NSSL has a demonstrated history for aggressively investigating new techniques to mitigate the range-velocity ambiguity problem. A very successful demonstration of a limited use of paired PRFs, optimized to reduce dealiasing ambiguities, may be found in the operational TDWR systems.

PARAMAX has also reviewed the existing WSR-88D algorithm and has reportedly developed refinements that reduce range aliasing effects. While no further details are available, PARAMAX feels significant improvement has been achieved and wishes to further develop and test the improved algorithm with the OSF on WSR-88D systems.

Finally, NCAR has developed, and is testing, a new Two Dimensional Dealiasing (TDD) algorithm (Jing and Wiener, 1993) that is not yet quite real-time. However, with higher performance hardware and perhaps some code tweaking this algorithm is expected to become a real-time processing algorithm. The technique is somewhat reminiscent of the Ray and Ziegler (1977) method that performed "regional" dealiasing. The TDD processes a whole scan subset by subset, each subset being as small as 6 gates to as large as 7200 gates. The method determines all velocity differences between adjacent (using 4 neighbors only) gate pairs, generates a parameter proportional to this sum (effectively a sum of all differences), and then attempts to minimize this parameter, recognizing that minimizing the sum should minimize all velocity pair differences. Thus, the method dealiases all valid gates within the sub-region simultaneously. The process is repeated on the next sub-region, and so on until all sub-regions are processed. Although all sub-regions are "internally" dealiased, they may still may in error by multiples of 2 x Nyquist velocity. At this point a reference wind field (sounding, VAD, etc.) is used to perform global dealiasing of the sub-regions. Each sub-region is checked against the "local" wind estimate derived from the reference field, and then the correct multiple (0,1,2, etc.) of $2*V_{NY}$ is applied to all gate velocities within the sub-region.

The TDD technique assumes all data within a sub-region are "connected", that there is some string of continuous valid data linking all valid gates. The current version also assumes the maximum difference between adjacent dealiased gates is limited to V_{NY}. As with most 2-D approaches, one advantage of this technique is that dealiasing failures are generally limited in area, and do not show the often-noted radial or arc appearance of dealiasing failure associated with real-time radial-based methods. Results so far have been quite impressive, with failures typically limited to small disconnected regions or small portions of storm boundaries, with high shear regions being handled quite well. Currently, the method is employed on the Mile High Radar (MHR) and CP-2 radars, and is used both in post-analysis as well as in occasional real-time tests. This algorithm is running on a SUN SPARC II workstation, and reportedly processes 7200 gates in 0.2 sec in this configuration.

LL is faced with a slightly different problem, how to increase the rate of volumetric data acquisition while still retaining good data quality and the high spatial resolution required for detection of hazardous phenomena in the airport terminal area. One approach is to increase the scanning rate while maintaining moderate to high PRF's. To reduce the velocity-range ambiguity problems, LL is also investigating multi-PRF techniques. This includes the multi-PRF signal waveforms as well as new clutter filters by which to remove the clutter in these sample-number limited estimates. LL is also developing frequency domain techniques to resolve mixed clutter and weather signals in order to obtain accurate velocity data at both low and high PRF. Working in the frequency domain will always be superior to the time domain if one is required to identify and remove artifacts from the spectrum moment estimates. Even here, however, correction for biases may not always be straightforward when there is overlap among the various spectral sources. In the past, frequency domain techniques were relegated to the research environment where real-time application was of no concern, or performed in real-time on only a limited number of range gates. However, with the rapid increase in hardware capability, application to nearly all range gates appears feasible in the near future.

Increasing the efficiency of the dealiasing methodology in a real-time algorithm is a difficult prospect. Given the standard WSR-88D system configuration, the 2-D approaches could likely achieve the greatest success, but it is unclear whether such methods could run in a real-time WSR-88D algorithm suite. With the WSR-88D MicroFive processor upgrade, however, reconsideration for 2-D approaches may be in order. There are many robust schemes for locating discontinuities, regional features, etc. in the image processing and pattern recognition literature, and perhaps these could be adapted to the dealiasing problem. The TDD, REP, MIGFA, and HSTX techniques are examples of very successful applications of image processing methods to varied radar problems.

Another possible method is suggested after simple observation of the 2-D velocity field after application of the dealiasing routine. Incorrectly dealiased regions are often small areas, containing portions of a few successive radials, or arc-like in appearance. Their typically easy detection via visual inspection suggests it may be possible to remove such features with a simple "second pass" through the 2-D dealiased field. Use of the simplest radial shear detection methods could likely realias the majority of these incorrectly dealiased regions with little difficulty. Such an addition would be simple to implement, and require the least in algorithm modification.

The literature has a couple of interesting entries in this area. First, there is a description of how to access the Internet signal processing database by Johnson and Shami (1994). Not only references and "how too's", but actual software may be retrieved from this source. Secondly, there are two discussions that may have implications for the velocity-range ambiguity problem. Uppala and Sahr (1994) discuss use of the DFT and aperiodic samples series to remove this ambiguity, whereas Sahr and Grannan (1993) discuss efficient methods to speed up the binary code search for use with pulse compression methods. Both authors open the door for "potential" applicability for mitigating the velocity-range ambiguity problem.

I. ARCHIVING

The Level II archive data from the WSR-88D systems will likely become an invaluable resource to a wide variety of users. With nearly the entire country under surveillance, an enormous variety of weather types and regimes become available for study. These data will become invaluable in algorithm tuning and modification efforts. Perhaps one of the greatest obstacles to research and development will no longer be the acquisition of "any" data, but rather "which" data to request and use from the wealth of interesting cases becoming available. Surely, as the OSF has recognized, a major effort will be required to maintain this invaluable and continually growing resource. Development of routines for browsing, reading, and manipulating these data are required. Similarly, some form of automated cataloging of the contents of these data will be required, including not only the traditional items such as times and coverages, but hopefully some classification of storm types and characteristics (tops, volumes, max reflectivities, VILS, convective or stratiform, etc.).

With the realization of the Level II Data Collection Plan and budget support from the NWS, the collection and archiving of these Level II data is well underway. Level II recorders are scheduled for installation in 1995, with the National Climatic Data Center designated the data repository and the OSF providing documentation support. The NSSL is also providing software for reading and display (UNIX) of these data. These supportive efforts should be commended and should be developed further. Community interest in using WSR-88D Level II data was well demonstrated during 1993 with the NCDC filling over 150 requests. To provide further support to data users a Level II users conference is scheduled for spring of 1995 in Asheville.

Specialized data sets of Level II archive data, for use in algorithm development, are also maintained at the NSSL and OSF. These data are generally specific in that they provide useful test cases for algorithm refinement, testing, and development. These may also be of interest to other agencies employed in WSR-88D algorithm development.

Another source of reflectivity data is being developed at the NMSFC. This database is derived from the reflectivity data as composited by the WSI corporation and consists of WSR-54, WSR-74, and WSR-88D observations. WSI has developed the capability to merge individual radar data into both regional and national composites. The data will be available from NMSFC DAAC. Although being developed for non-WSR-88D purposes, these data will be available in an electronic browse mode. This resource may be quite useful in identifying weather periods of interest and help make selection of specific WSR-88D archive data sets more efficient.

Not to be forgotten are the older WSR-54 and WSR-74S datasets. These RADAP II archive data are held at TDL. While only representing digitized reflectivity data, these data span 8 years of data collection, and can still provide valuable information on seasonal trends and climatologies of storms. In the past, these data have been useful in developing severe storm index algorithms, tracking and forecast routines, and hydrology-related methods. To assist users in locating relevant datasets and use of these data, the TDL has issued a new users guide that may be acquired upon request.

Finally, not only should the expected use of Level II archive data grow rapidly, but use of commercially available data distributed by NIDs vendors is also expected to grow as the commercial community becomes familiar with the NID's products. Within this community, one may expect that industry will also become involved in development of algorithmic solutions oriented towards their specialized needs. Quite possibly, this may eventually be an additional source for algorithm concepts. One interesting application of the NID's data has already been demonstrated with the NMSFC composite database.

J. OPERATOR-MACHINE INTERFACE & INTERPRETATIVE TECHNIQUES

These two Technical Needs express the desire to develop techniques that not only increase the information content offered by the various data products, but also user-system interfaces that provide for easier and more efficient use of data. Sometimes this requires new hardware, often only new concepts in software. Some of the new capabilities desired include display of time trends, product overlays, contoured data fields, greater use of symbols, and product manipulation such as display thresholding and simple mathematical operations. The various laboratories have developed a number of interesting software packages that address some of these issues. The host for this added capability is expected to be the WSR-88D PUP, the current user interface with the WSR-88D system, or possibly an ancillary processor. Once upgraded with the Microfive processors, the PUP processing capability is increased by roughly 200%, and thus may be able to support additional tasks.

One example of a user-oriented system designed for display and manipulation of WSR-88D radar data is the NSSL RADS system. It incorporates some interesting features such as displays of time trends of parameters (e.g. storm tops), and point and click zoom. It allows for incorporation of some additional data (e.g. mesonet and lightning) that is relevant for storm research and characterization. A post-analysis capability to edit data, for example, realiasing to correct for dealiasing failures, is also provided. Because of its combination of algorithm outputs, overlays, and additional data, the system is very useful for program support as well as research.

A software package that strives to provide flexibility (to user) in integrating varied data sets and present them in a synergistic manner is the ZEB system developed at NCAR. This system is capable of incorporating a very large number of different sensor data types, and provides routines for their manipulation, display, and overlay. Generously employing menus and icons, the system is quite user friendly. The resident software allows the user to tie-on additional modules for integration of data not already incorporated into the package. Once into the system, the data are retained in a standard format, and thus may be manipulated freely. This software is freely available and is distributed on CD-ROM. Its versatility and ease-of-use has resulted in it being widely used in universities for the purpose of teaching and data analysis, as well as in field experiments for decision support, and for real and post-time data analysis.

A system that is still under development, not specifically designed as a WSR-88D display system, but that "employs" WSR-88D data is the FSL Dissemination Project. This system is designed to provide decision-making support to emergency management centers, state offices, and similar agencies. The FSL effort utilizes LAPS model output products and WSR-88D imagery to focus on watershed management problems. The system resides on a PC workstation, utilizes graphics, text, overlays, and icons to maximize information content.

In the area of man-machine interface the OSF Human Factors Group (HFG) has been involved with programs at both the OSF and NSSL facilities. The purpose of this effort is to enhance information content and ease-of-use through use of optimal layout, color, labels (e.g. data presentation), etc. Some affects and uses of color may be found in Hoffman et al. (1993). The human factors approach is applicable to a wide range of areas including algorithm product displays, menus, user interfaces, and even documentation. Areas of activity at the OSF have included refinements to the rotational velocity display, "status" of precipitation menus, identification of range blanking on products, and HELP screens. At the NSSL the HFG assisted in revisions to the software and documentation for Level II archive data distributed by the NCDC. More recent activities have been centered around enhancing the NSSL RADS system that was employed at the Phoenix, AZ WFO. The Phoenix program was used by the HFG as a testbed to validate changes, as well as determine deficiencies and areas for further enhancement.

Other data systems are also being developed. For, example, Baumgartner and Apfel (1994) discuss a GIS-based system integrating various data sources for tracking snowstorms and determining snow cover. Integrating a mesoscale numerical model into a workstation environment for snow forecasting has been attempted by Cotton et al. (1994). This capability may be of great interest to NWS or other personnel responsible for making forecasts over limited domains, particularly prior to their detection via radar.

Finally, of potential interest are the numerous commercial packages for data analysis and display manipulation.

Sophisticated systems are now available that allow for various filtering, decomposition, and analysis routines of 1-D, 2-D, and 3-D data. They can perform all sorts of manipulations and analyses (zoom, scroll, stretch, overlay, filter, gradient detection, regression, etc.) on data, and some allowing viewing data fields and their attributes in 2-D and 3-D from a user-selected perspective. Assuredly, all would enjoy watching an evolving thunderstorm, bright band, or frontal region in 3-D. While these packages typically require high-end UNIX or PC machines, the advances in computer hardware make it quite apparent that these types of software will come into common use in the near future. These applications may provide opportunities for understanding the kinematic and microphysical processes in a way not allowable from the display formats in common use today. Perhaps a proper scenario would see such a capability as a user-selected tool integrated into one of the existing data display packages discussed above.

K. FLASH FLOOD PREDICTION

The Flash Flood Prediction algorithms are a component of the overall suite of precipitation algorithms. The HRL is planning to test these algorithms on Archive Level II data. One component of these algorithms is the forecast of expected precipitation location and amount. Also, TDL continues to develop the extrapolative-statistical forecast technique, while NCAR is now developing a method for snowfall forecasting. These methods basically forecast a single low-level reflectivity field. Because these fields often respond to influences not observed in the plane of observation such as unseen vertical motions of precipitation cores and storm development, extrapolative forecasting may remain a difficult task. This is also particularly true in areas such as land-water boundaries and regions of strong topographic effects where rapid change in storm structure or motion are possible. In this instance, specific "local adjustments" may need to be included into the forecast process.

While the extrapolative-statistical approach of TDL focuses on forecasting zero tilt reflectivity (ZTR) fields, the forecast process attempts to employ additional information (e.g. VIL, tops) from storm observations to mitigate the difficulties of this type of method. The implementation of this technique makes it neither a cell (WSR-88D, SCIT, TITAN) nor a correlation (REP, TREC) tracker, but more similar to the approach of Belon and Zadwadzki (1993) for forecasting precipitation accumulation fields on large scale grids. The forecasted VIL and storm top parameters are used in lieu of actual volumetric reflectivity observations to provide additional (e.g. in vertical) information not available from ZTR alone. This process generates forecasts of reflectivity within 144 (400) km^2 gridded regions for 30 (60) min later. The use of such a large grid, combined with the fact that VIL and tops may not really reflect activity at the lowest storm levels, results in ZTR variability that is often too great for statistically meaningful forecasts. Currently, TDL is investigating the use of parameters other than ZTR that may be better conserved, and that may better be related to forecastable storm parameters.

L. ANOMALOUS PROPAGATION AND CLUTTER

Only LL, the OSF, and NCAR report activity in clutter rejection technique development. The WSR-88D employs real-time clutter filtering which can often remove significant amounts of isolated clutter. While robust, however, unacceptable amounts of clutter may still leak through such filters. This results in contaminated data which can negatively impact the velocity dealiasing algorithm, and all subsequent algorithms that detect structures, especially those that identify feature "strings or vectors" in their pattern recognition schemes. Thus, an enhancement to remove residual clutter is of interest. One demonstrated approach that is quite effective is the use of Clutter Residue Editing Maps (CREM) as applied by LL in the Terminal Doppler Weather Radar (TDWR) program. Both LL and NCAR continue to investigate the application of CREM maps. Other approaches receiving interest include the use of the spatial behavior (i.e. texture) of the clutter signal, image processing, and modelling techniques.

As noted, LL, via the TDWR program, has previously demonstrated the significant improvement over real-time filtering that can be achieved through the addition of CREM maps following real-time filtering. More recently, LL has been investigating the use of WSR-88D data as one of its data sources for the ITWS program. It has been observed that unacceptable amounts of residual clutter often pass through the WSR-88D real-time clutter filters. To circumvent this difficulty in an operational setting, LL has removed the contaminating effects of this clutter by only using data above 2 km in its various products. However, LL recognizes the deleterious effects the loss of the lower altitude data can have on many WSR-88D algorithms, and urges the use of CREM techniques with the WSR-88D. The generation and use of CREM maps is quite straightforward, with only few adjustable parameters such as SNR, velocity, and clutter residue breakthrough thresholds to be applied. NCAR is investigating the use of TDWR-like CREM maps with the WSR-88D system.

NCAR is working on an approach that involves two techniques not often found in radar studies, neural network (NN) and "texture" analysis. The philosophy of this approach is to distinguish between signals that are "more clutter than weather" or "more weather than clutter". This approach relies on statistical estimators as parameters within a neural network algorithm. This form of approach is more commonly found in image processing literature. The parameter, "radial texture" or roughness, is related to the difference of a radar value (e.g. V, SNR, etc.) between range cells separated by a lag distance along a specified radial. NCAR has reported the results for SNR and spectrum width (velocity found not as reliable) over lags 1-3. The texture estimates were derived using single gates, and blocks of gates (provides some statistical filtering). To date, single gate differences have been found too noisy to clearly distinguish between weather-like or clutter-like signals. However, use of block (block = 9 gates) differences showed clear distinction between gates filled with clutter versus gates filled with weather. Test results appeared essentially independent of lag number. This is perhaps a result of the rather large blocks of data employed, the potentially smaller texture scale lengths being strongly filtered.

The NN system was trained on limited sets of clutter data, then weather data, and then tested on larger sets of clutter, weather, and mixed clutter and weather data. The system correctly identified at least 90% of the clutter and 88% of the weather, with investigations continuing. It would be hoped that this investigation be continued, using different block sizes, lags, and data combinations. The results of this NN test are perhaps quite good considering other studies (Chang et al., 1993) that indicate NN detection failures can result from unexpected differences in global properties (there SNR of data field) between the training and test data sets. The potential offered by the neural network approach, however, is the possibility of the NN system finding and employing correlations within the data that may be difficult for the observer to detect.

The OSF is working with NCAR and FSL in developing methods for data quality enhancement that potentially employ parallel signal processing and the "spatial behavior" of data. The clutter removal scheme would potentially use both clutter filtered and clutter unfiltered data, and a measure of spatial behavior of the data to estimate when data are biased by the presence of clutter. If a clutter bias were suggested, then a correction could be applied to the filtered data. The form of "spatial behavior" was not reported here.

The use of "spatial behavior" or "texture" to discriminate between clutter and weather can be understood after plotting the distribution of texture "values" (frequency versus value) for clutter and weather. Experience has shown that the statistical modelling of clutter and weather variables (Z, SNR, V, W, etc.) at a single range gate generally follow different distribution functions, but in practice it is often difficult to distinguish which distribution is being observed (too few samples, mixed weather and clutter, etc.). However, texture, employing a 2-point spatial decorrelation function generally results in the two different probability distributions being separated as a function of lag distance. Thus, even though the distributions of clutter and weather may actually appear similar (e.g. small data samples), this separation often provides a "threshold" to use in discriminating clutter from weather. Because the false detection rate is related to the "overlap" of these two distributions, it may be expected that performance of texture based methods may also be related to the weather "type" used in technique development and encountered in operation. Since it should be expected that some overlap will always exist for simple differences of base data, some false detection will always arise. However, there are other texture parameters that may be employed that may increase the discrimination capability.

The NCAR approach employs a "radial" texture approach to enable possible real-time processing. If processing can be applied to the 2-D field instead, for example because of upgrade of the RPG processor or operation on an associated processor, there are a wealth of methods that can be employed in clutter removal, as are discussed below.

Bankert (1994) discusses an automated technique used in cloud classification that combines texture, spectral characteristics, and physical parameters. Some fundamental analysis on the form of texture probability distribution functions is provided by Behar and Lee (1994). Use of alternative parameters as texture variables is discussed in Chou et al. (1994). This very nice presentation employs means, variances, and other moments of the data field in the texture analysis, and as an aside provides a nice overview of the more traditional (e.g. segmentation, open-close, etc.) image processing techniques. The entire August 1994 issue of the International Journal Of Remote Sensing deals with scaling and texture and provides numerous references. Determining "what" the terrain characteristics are, that then can be employed in texture analysis, is presented by Laine on Fan (1993). This investigation employs wavelets, the rapidly emerging scale analysis tool that is replacing the FFT in many applications. How image texture can vary with "beam size" is presented by Roy and Dikshit (1994). Their study, however, reports results in terms of energy properties of the fields, but remains interesting.

A common alternative to texture analysis is field filtering. A direct method to remove clutter from 2-D field data is provided by Onural et al. (1994) who employ filters over a large domain to adjust filter parameters applied to a smaller internal domain for removing the clutter contained therein (more like speckle clutter). A truly simple and fast technique for removing non-extended (random, speckled type, etc.) clutter is provided by Roberti and Perona (1993). Here, simply classifying features by a highly limited set of variables (e.g. area-to-perimeter ratio) appears to provide sufficient information to remove significant amounts of clutter. Also, a nice discussion of the "physical interpretation" of filter action on data fields is presented by Tucenyan (1994).

It is thus quite obvious that a wealth of information is available from image analysis that could be applicable to WSR-88D operation. However, clearly, these techniques (if 2-D) would not run radial by radial, but only after completion of full scan processing. Depending upon the application, some consideration could be given to operate such algorithms on an upgraded RPG, or an associated processor rather than the RPG.

M. TURBULENCE STUDIES

Some work is being undertaken by NCAR in reviewing methods to estimate turbulence via radar. One effort includes a limited revaluation of the WSR-88D Turbulence Algorithm at NCAR. A very limited comparison of the eddy dissipation rates returned from this existing algorithm against in-situ aircraft measurements has indicated good agreement.

The original PL algorithm performed quite well on developmental data sets, showing relatively high POD and low FAR for the "collocated" estimates of eddy dissipation rate derived from radar and in-situ aircraft. However, its transfer to the WSR-88D system has not been satisfying. The unfortunate track record of the WSR-88D version of the Turbulence Algorithm results primarily from three reasons. The first (1) is that algorithm output is in terms of eddy dissipation rate, a parameter that by itself does not directly indicate aircraft hazard. A second (2) is that it appears to generate intensity estimates that are routinely too high. Third (3), the algorithm was originally designed for precipitation-only environments, and not for the entire clear and cloudy observation volume interrogated by the WSR-88D.

The reason for choosing eddy dissipation rate (1) as the algorithmic output was simply that this parameter represents well the "basic" measure of turbulence intensity. Eddy dissipation rate is a meteorological variable, is independent of aircraft type, and would not change as aircraft designs changed with time. Thus the algorithm would not require updating or modification for the innumerable and evolving types of aircraft designs to be encountered. A measure of its effect upon aircraft could be simply determined given the critical load/lift parameters of the aircraft encountering the turbulence. This translation to aircraft response had not been automated into the algorithm.

As noted, the second (2) major area of concern was the propensity for the intensity estimates to typically be "high" with very few "low" to "moderate" turbulence observed. This potentially results from a number of factors including; (a) the algorithm was incorrectly coded or PDL supplied to UNISYS was in error, (b) the bias in the spectrum width estimates from clutter and other parameters is significant, (c) the PL interpretation of thresholds of eddy dissipation rate separating low, moderate, and high intensity turbulence was in error, (d) the layer composite display is inappropriate, or (e) the developmental dataset was not sufficiently representative of different environments.

Incorrect coding or PDL (a) is unlikely, however, it was always noted that the values obtained on the Norman test WSR-88D were significantly higher than those observed in all data sets upon which the algorithm was developed at PL. The developmental datasets (e) included a number of quite energetic East Coast thunderstorms, containing vertical draft, high shear and stratiform-like regions, and is considered reasonably representative of conditions to be encountered by aircraft in thunderstorms. As a check, limited analysis was performed on NSSL Doppler and non-collocated in-situ aircraft measurements, with results very similar to those obtained from the East Coast data.

Bias in the spectrum width (b) is highly expected for a number of reasons. At PL, the many components of the turbulence algorithm were not implemented in a continuous automated fashion, but consisted of a series of separate processing steps. The most critical of these was a major data quality editing procedure. The time series data from the closest "clean" gate within 300m of the penetrating aircraft were used to estimate the base data values through both pulse pair (time domain) and power spectrum (frequency domain) methods. Algorithms were employed to identify signal contamination from multi-trip echo, ground clutter, radar system problems, etc. which were then removed from the power spectrum estimate by automated means. Low SNR data were also identified for potential disqualification. These clean spectrum width estimates were then reduced by the estimates of the contributions from large scale shear (azimuthal and radial), rotation, precipitation fallspeed, etc. Finally, it was these quality controlled spectrum width estimates that were used in estimating the eddy dissipation rate from radar. Deriving some of these non-turbulent contributions required 2-D fields of radial velocity data, a prospect not considered reasonable at the time of WSR-88D implementation. Thus, none of these quality control steps were included in the WSR-88D Turbulence Algorithm, rather the WSR-88D algorithm relies on being supplied "clean" data.

Misinterpretation of turbulence intensity thresholds (c) is quite possible since classifications (low, moderate, high) were drawn from voice recordings of pilot conversations during storm penetration, and available journal data. Unfortunately, both provided little comment from which to infer the "quality" of ride from the aircraft-derived estimates of eddy dissipation rate.

Layer composites (d) were never employed by PL, since the only Doppler radar data were from the six (6) Dopplerized NASA SPANDAR radar gates centered about the penetrating aircraft. Thus, the PL algorithm only compared collocated radar and aircraft values and no assessment was available concerning the utility of the product as implemented within the WSR-88D.

The original reason for employing Doppler spectrum variance, rather than performing power spectrum analysis (PSA) on the Doppler velocities resulted from the fact that turbulence generally occurs in "patches" (Sikora and Young, 1994, and Turner and Leclerc, 1994). To get any meaningful results from PSA, one is usually forced to use radial data of many km in length, and then average over many successive radials to reduce the noise. Quite often, this results in data sets from different (e.g.

scales, intensity, 2-D versus 3-D, etc.) "patches" of turbulence to become merged, the resultant data not representative of either local region. One can employ techniques (Gluhovsky and Agee, (1994) and Lenschow et al.,1994) to attempt to isolate areas to be combined into individual PSA's, but a real-time application may not be straightforward. The other difficulty is the requirement to perform inverse filtering on the PSA to remove the pulse volume averaging effects (i.e. partitioning of turbulent energy between spectrum width and fluctuation of the Doppler velocity). These operations do not lend themselves easily to automated detection.

Spectrum variance, on the other hand, is a single pulse volume estimate. While the estimates among neighboring pulse volumes may be noisy, experience shows that the trend of turbulence intensity can be seen when viewing the "neighborhood" trends. Using the variance of neighboring estimates to set 2-D filter size and weights, perhaps similar in flavor to Pedder (1993), may be an appropriate way of smoothing the field and showing the up/down trends in turbulence intensity as a function of location. VAD and similar analyses will generally result in a "whole field" averaged intensity estimate, which may often be sufficient in the boundary layer or in well-behaved stratiform precipitation systems, but often becomes meaningless when any convective activity is present. If the desire is to understand the variability of the turbulence intensity, then a "local" estimate technique seems most appropriate.

The TAC committee has suggested the findings of the 1989 Turbulence Group be considered in determining the potential applicability of this algorithm. Implementation of the most relevant recommendations (e.g. data quality editing), as performed within the PL algorithm methodology, would require significant new code development. Prior to that, however, it must be determined whether estimating turbulence only within precipitation regions, and potentially the clear air boundary layer (not yet demonstrated), is of sufficient interest to warrant this effort. If the answer is yes, serious consideration should be given to using the algorithm as is with perhaps limited data quality checking, and modification of the threshold values and their interpretation, as experience is gained with aircraft passing through turbulent regions observed by the WSR-88D.

N. WIND ANALYSIS TECHNIQUES

The realm of wind analysis techniques embodies those algorithms that utilize data from a single radar to derive information of the 2-D flow field throughout a volume. There is interest in whether there are alternative methods that may provide more information than the current processing schemes in the WSR-88D (Modified Volume Velocity Processing (MVVP) and Velocity Azimuth Display (VAD)). The current WSR-88D algorithms require the wind field to vary linearly, or be uniform, and are thus often not applicable to the meteorological environment. The primary approaches for deriving 2-D fields from single radar fall into such categories as (1) VAD-type analyses including sectors, single level or volumetric, and (2) correlation methods such as TREC and REP. More complex methods may include the (3) fusion-like techniques that incorporate multiple data sources, and finally (4) the retrieval methods employing parameter conservation and thermodynamic constraints.

An example of a typical problem encountered is provided by the OSF investigation into reasons for the VAD Wind Profile algorithm to occasionally derive soundings in disagreement with local soundings. To study this problem both sounding and VWP data are being acquired from 12 forecast sites (and 3 profiler) for this comparison. Some potential reasons for discrepancies include anomalous 2-D winds (e.g. nearby low level jets), biologic targets (birds and insects) in migratory travel, and unexpected signal path refraction. As reported previously, the OSF has achieved some increased accuracy in radar derived soundings by utilizing shorter range and higher elevation angles in the VAD analyses, thus mitigating some of the effects of nonuniform horizontal winds and refraction. The frequency and severity of this problem may vary with geography and season, thus better problem resolution may require further data collection and analysis. In fact, an analysis program is being supplied to NWS offices willing to participate in this effort. This is a very worthwhile undertaking, allowing for development of a large database with widely varying meteorological environments, and generating increased involvement with forecast office personnel who are typically intimately familiar with the specifics of their local environment.

It is quite possible that additional information may be derived from VAD-type (1) analyses. Increased use of VAD derived parameters (divergence, deformation, dilation, etc.), as well as observation of the time evolution of such parameters, has been applied by HSTX in deriving information beyond that provided from the simple VAD application. The Sectorized Uniform Windfield is another approach that relaxes windfield constraints, requiring uniformity over only a limited portion of the observed windfield.

When the local windfields are quite disturbed, however, methods that do not place any significant constraints upon the windfield are preferred.

A rather complex single-radar Dual-Doppler conical scan approach is reported by Scialom and Lemaitre (1994). Termed the "QVAD", it employs quadratic fitting of data from two different volume scans, either from nearby radars, or time-separated volume scans from a single radar where the assumption of windfield stationarity is required over the encompassing (2*vol-time + wait) period. This method performed quite well in a disturbed situation, but seems computationally heavy. This method perhaps should be compared with the somewhat simpler implementation of Bluestein et al. (1994) that also utilizes successive volume scans and stationarity assumptions, but that has also demonstrated some skill in a complex wind environment.

Another interesting variant is the LL gridded wind technique that can utilize multiple data sources (3) such as WSR-88D, TDWR, aircraft, and other observations. The method can work with sparse data, employs a 2 km grid, and effectively accomplishes interpolation and multiple-radar combination to generate 2-D winds over much of the interrogated volume. Use of multiple data sources increases data density, timeliness, and effectively introduces a consensus check where multiple data observations exist. Although the majority of WSR-88D systems could not invoke a multiple radar option, the augmentation of WSR-88D data with other observations could be helpful.

Also worthy of note is the bistatic method currently under investigation at NCAR. It is quite useful in precipitation environments, but system sensitivity of the passive elements does currently introduce some limitations on coverage, and this method is not yet useful in clear air environments. This result, combined with the extra hardware and maintenance requirements, will likely relegate this highly useful technique to research efforts.

As previously discussed in the storm tracking section, correlation trackers (2) such as TREC and REP can be quite useful. While still requiring a good deal of conservation of the tracked quantity, these techniques make no further assumptions about the 2-D windfields and can provide information in high spatial detail. They can operate on any 2-D plane (e.g. be vertically stacked) on which there is sufficient data, and individual flow field vectors can always be "averaged" to return information on a larger scale. The penalty is the increased time for computation. These "types" of approaches have been suggested as possible additions to the WSR-88D algorithm set. Note that other similar methods (e.g. Efstratiadis and Katsaggelos, 1993; Lvettgen et al., 1994, and Wamazi et al., 1993) have been reported within this document in discussions concerning snow fields. Numerous methods have also been reported in past NEXRAD Algorithm Reviews.

Finally, and although more limited (e.g. in vertical) in applicability and not considered currently feasible for the WSR-88D operational setting, retrieval (4) offers a robust method for accurate and detailed description of the windfield in the boundary layer. Both OU and NCAR are investigating such methods. A number of different approaches have been reported, such as the method by Gal-Chen et,. al. (1993), and the adjoint methods of Sun et al. (1991) and Xu et al. (1994, I & II). These methods have demonstrated significant ability to derive the "state" of the environment. They are powerful, but necessary assumptions currently make them of limited use in many environments of interest, and they would appear to be somewhat difficult to implement for unattended automated use. Any such implementation could likely run on a workstation "supplied" with WSR-88D and other supporting data.

O. BOUNDARY LAYER WIND SHIFT ANALYSIS

The WSR-88D boundary layer wind shift problem arises out of a need for NWS forecasters to be able to forecast new storm initiation and development. This primarily reflects the extensive work performed at NCAR on thunderstorm initiation resulting from convergence line interactions, a phenomenon not currently forecast operationally. However, it also implies more timely knowledge of the presence and structure of gust fronts, and fronts in general, since these are also generally associated with storm development. The WSR-88D has a Combined Shear Algorithm that attempts to estimate the two components of shear by combining a component of vorticity with the measured radial shear. However, this technique has been found somewhat lacking in estimation of shear intensity.

A number of candidate approaches to enhance windshift detection are available; (1) the traditional shear detection method represented by the NSSL Gust Front Algorithm that is based on locating patterns of radial shear, (2) the line detection algorithm of NCAR that locates lines of enhanced field gradient via 2-D least squares fitting, and (3) a pair of "template" based approaches employed by LL and HSTX that invoke 2-D image processing techniques to locate strong, localized gradients within the 2-D fields of reflectivity and/or velocity.

All these techniques rely on detection of a restricted region of shear, where the along-shear dimension is much smaller than the cross-shear dimension, essentially a classic 2-D image processing problem. As noted, one of the parent methods is the shear "pattern vector" gust front algorithm of NSSL. When working in a real-time setting, data are typically analyzed one radial at a time, thus the radial pattern vector becomes the primary analysis tool. This algorithm has enjoyed some success with the TDWR system (Hermes et al., 1993), but has been surpassed by the more recent LL Machine Intelligent Gust Front Algorithm (MIGFA) algorithm. The LL algorithm is similar in many respects to the earlier HSTX shear detection algorithm. Both the LL and HSTX approaches to line-feature detection employ the more classic image processing approach of passing 2-D templates (e.g. matrices) over the 2-D data field. By altering the values of template components, a wide variety of texture and other field characteristics may be derived. One of the most straightforward and useful applications are the gradient field operators, used to locate and quantify the 2-D gradients of reflectivity and velocity (i.e. gust fronts).

The template-based techniques generally appear to offer superior performance to the pattern vector approaches in detecting these discontinuities, with the more recent LL method somewhat more robust than the older HSTX version. The LL algorithm has, on occasion, performed better than a human using the same basic data fields. Even MIGFA, however, has demonstrated some difficulty in the dry air environment of Albuquerque, NM. A preliminary NEXRAD version of MIGFA has been developed and is undergoing testing. The original MIGFA algorithm has been distributed to both NSSL and NCAR. Meanwhile, HSTX is extending their template approach to the problem of detection and interpretation of fronts. This newer HSTX version employs more robust detection and combination logic and will be used to interpret the 3-D nature of the frontal regime. PL/HSTX have acquired a powerful visualization system that may, in the future, allow for observation of frontal evolution over time in 3-D. It should also be noted that the OSF is investigating 3-D visualization.

An approach currently under use at NCAR is the Convergence Line Analysis and Detection Algorithm (CLADA). Designed to work in these clear air situations, this algorithm employs filtering operations to reduce data fluctuation and enhance feature detection. The algorithm then employs a 2-D least squares fitting procedure to locate those areas that provide a characteristic gradient structure common to clear air lines. In a common manner to LL and HSTX, line segment building routines then develop the convergence line. A comparison of CLADA and MIGFA has not been reported, but with NCAR in possession of both algorithms, perhaps such a comparison will be made to identify the relative strengths and weaknesses of the curve fitting and template approaches.

Again, some observational studies are worthy of note. First, and foremost, the source of these reflectivity thin lines "appears" to have been undisputedly shown to be insects. This truly notable report of Wilson et al. (1994) once and for all attempts to bring this minor controversy to a close; its just bugs, bugs, and more bugs! Also reported are the observations of Wakimoto and Atkins (1994) of a seabreeze front that interacts with other boundary layer circulations to generate preferential regions for convection. Enhancement of shear due to seabreeze opposition to environmental flow (Ohno and Suzuki, 1993) is another case where preferential locations for convective activity may occur. Also, downburst observations producing significant gusts are reported by Ghno et al. (1994). This paper summarizes well the microburst conditions, findings, and observations from previous studies, and provides a useful reference list. Finally, the unexpected stratospheric air intrusion resulting in gusts greater than 70 kn at the surface is reported by Browning and Reynolds (1994).

Lastly, it must be noted that automated detection of "lines" and "discontinuities" have long been subjects of great interest in pattern recognition and image processing circles. This topic has been discussed in previous algorithm reviews and a few techniques are noted here. The histogram approach of Krishnamurthy et al. (1994) appears to locate edges and line features, even when the field gradients are minor. Such a case may result from utilization of a boundary layer field that is filtered to reduce the noise content, but that also has had the gradients of the observed gust front, line, and microburst events relaxed in the process. Also of note is the very fast and simple method of Lea and Lybanon (1993), where some knowledge of the feature characteristics allows for use of this simple open/close routine.

III. ACTIVITIES ACCORDING TO GROUP

A. COLORADO STATE UNIVERSITY

The Colorado State University (CSU) efforts remain focused upon two primary areas, storm morphology, and radar polarimetry. Extensive participation in field studies are noted. With the basic polarimetric variables quite well understood and accepted, the radar polarimetry efforts are now becoming application oriented. This tool is proving very beneficial in understanding microphysical development, and when combined with Doppler-derived information is providing new insight into hail growth processes, storm electrification and lightning, and microburst initiation. These efforts may be highly useful in better understanding many storm processes and provide valuable information in algorithm tuning and new algorithm development.

1. Polarimetric Methods

The reported CSU polarimetric efforts have demonstrated the utility of polarimetric variables in estimating rain rate in mixed rain-ice environments. A comparison of estimating rain rate and rain accumulation from specific differential phase K_{DP} , specific attenuation at x-band A_3, and traditional reflectivity Z_{HH} (with NEXRAD 55 dBZ cutoff) was performed. With specific differential phase most sensitive to oriented non-spherical raindrops (hail often has an effective axial ratio near 1 (or equivalent via tumbling)), and A_3 being somewhat insensitive to hail over a range of sizes (e.g. 3.9-6 mm, also see Jameson), this is an interesting intercomparison of parameters either quite insensitive (K_{DP}), potentially insensitive (A_3), and strongly sensitive (Z_{HH}) to the presence of hail. Rain rate estimates via the three parameters were compared against raingauge data. Somewhat surprisingly, all three methods returned estimates of rainrate and accumulation within about +/- 10% of that measured at the ground. This result however, may be fortuitous. Rerunning the Z_{HH} method with 50 and 60 dBZ hail cutoffs resulted in errors ranging from 30 -60%, indicating the extreme sensitivity to the cutoff values chosen. The rainrate varied between about 20 - 160 mm/hr and rainfall accumulation was about 70 mm. These results suggest that K_{DP} may be quite reliable in rainfall estimation, allowing use of a single method in both rain and rain-ice environments.

The polarimetric data also provided information of an atypical multi-cellular storm case this same day. A storm complex was advancing with new cells developing along an outflow that was advancing ahead of the complex. Of interest were the detection of columns of positive Z_{DR} located within the NE sections of the updrafts developing along these convergence lines. The columns extended from near the freezing level (0 deg C up to -15 deg C), and were often capped by a layer of enhanced L_{DR}. With enhanced L_{DR} also observed in the hail shaft, a hail signal (HS) no greater than 5 dB, combined with a high rain rate (up to 200 mm/hr) and no large hail observed at the ground, the interpretation was that the positive Z_{DR} columns represented regions of heavy rain (verified at 0 deg C level by T-28 penetrations) capped by a mixed-phase layer. The column appeared to be derived from a warm rain (collision-coalescence) process more typical of high moisture (e.g. Florida) environments. These flanking updraft cells appear to be sources of hail embryos that may be passed into rearward located major updrafts. This detailed interpretation would have been difficult without multiparameter measurements.

2. Storm Studies

CSU is also extensively involved with storm study programs. One study noted a cyclic bow echo development that formed in response to alteration of the flow at mid-levels through the interaction with locally developed vortices. The modified flow appeared to sweep precipitation particles around the updraft region, thus forming the bowed appearance. Observations indicate that series of developing cores often combine into a characteristic echo core with a bowed appearance. The primary reason appears tied to development of mid-level vorticity couplets. The particular storm observed also demonstrated a modulation of hail output in concert with mesocyclone development, and maximum surface hail during the bow phase.

B. NOAA FORECAST SYSTEMS LABORATORY

The Forecast Systems Laboratory (FSL) is undertaking two projects that may effect WSR-88D algorithm development and use of WSR-88D products. FSL is investigating a new method for obtaining better rainfall estimates, and secondly, continuing research into development of a prototype workstation that will assist users of weather data in decision making processes.

1. Rainfall Estimation

The FSL is investigating the utility of employing the Window Probability Matching Method (WPMM) with the WSR-88D system. This method has been demonstrated in Australia and Israel with some success. The method relies on classifying a "region" under observation into a storm "type", and then employing a specific Z-R relationship for that storm type. The method lies within the class of gross-observational methods that do not attempt to estimate the Drop Size Distribution (DSD) and its variation with space and time, but rather employs gross measures of the storm and environment to deduce rainfall estimates. Somewhat similar techniques employing this gross-observational concept include the Area-Time Integral and Cumulative Probability methods.

The WPMM may actually be considered an attempt to tune such methods to better represent the storm type and environment. The technique requires a variety of data to both develop the storm classifications and ultimate Z-R relationships, as well as final selection and use of appropriate Z-R relation in the operational setting. Examples of these include horizontal reflectivity gradients, cloud depth, freezing level, bright band fraction, radar range, and accurate high spatial and temporal raingauge measurements. The resultant Z-R relationships may vary with geography, season, and stage of storm cycle. Thus, adequately testing the applicability of the WPMM approach for the United States requires significant data collection and analysis.

The FSL investigation suggests that the WSR-88D provides ample information to derive the radar reflectivity-related variables. The major concern lies in the representativeness of standard sounding data to classify the state of the environment, as well as validation by ground measurements of rainfall via gauges. FSL and others have previously found that the 12 hour temporal resolution, as well as spatial resolution, of the sounding network are often inadequate in quantifying the true storm environment. Thus, it is proposed that some environmental parameters be obtained from model systems such as the Mesoscale Analysis and Prediction System (MAPS) and the Local Analysis and Prediction System (LAPS). Obtaining accurate ground truth data on the spatial and temporal scales utilized in the published works describing the WPMM method (Rosenfeld et.al. 1994), however, remains a significant obstacle.

The FSL concludes that a sufficient number of precipitation events exist in the various geographic and seasonal regimes. However, with the wide range of storm types, their often multistage evolutionary cycles, and frequent contamination via hail and ice, classification of storm types may not be a trivial task. To date, classifications have been based mainly on stratiform versus convective, shallow versus deep, and near versus far range criteria. Further classification is likely required for operational use. Nonetheless, as with all these methods that attempt to remove themselves from interpretation of actual DSD changes, the method attempts to bridge these uncertainties via using the gross characteristics of the storms and environments, and the data acquisition, analysis, and validation efforts offer a much higher probability of success. To date FSL has focused upon identifying whether sufficient data (quality and quantity) exist, if WPMM offers solutions to the main uncertainties in the current PPS package, and whether WPMM can address problems posed by adaptable parameter uncertainty.

2. The FSL Dissemination Project

The FSL Dissemination Project does not represent an algorithm or approach to be applied to the WSR-88D system. Instead, it is a system designed to assist weather data (e.g. WSR-88D products) users in data interpretation and decision making. The project, begun in 1992, is in a second major iteration. The end user is an integral component of the iterative developmental process of design, test, redesign and test, etc. The project involves both University, city and county, and NWS personnel. The precipitation guidance are derived from the WSR-88D and related algorithms within the LAPS. Radar rainfall estimation is used in river models locally to assist emergency preparedness agencies. Radar intensity images are used to enhance the forecast information during periods of significant convection. The hardware platform is a PC multimedia workstation. Data are presented in both color imagery, graphical overlays, text, and uses sound and color to highlight significant events.

FSL is developing two components of this system, the MeteoAssert and Basin Rainfall Monitoring System (BRMS). MeteoAssert employs data from LAPS and presents both a graphic and textual depiction of weather events as they affect a particular problem of interest to the user. BRMS uses both model and WSR-88D data to provide information about rainfall, again with special emphasis to areas of concern (watersheds, basins, etc.) to the user. The third version will attempt to investigate the utility of integrating feedback from users to the NWS forecasters. Efforts next year will focus on including the user base, and various engineering projects to make the system more compliant with future data sources such as AWIPS.

C. NOAA HYDROLOGIC RESEARCH LABORATORY (AR)

The Hydrological Research Laboratory (HRL) reports three NEXRAD related activities, the PPS algorithm, bright band identification, and the Flash Flood Prediction algorithm.

The NWS Office of Hydrology's Hydrologic Research Laboratory (OH/HRL) has been monitoring the performance of the WSR-88D Precipitation Processing System (PPS) algorithms at a number of WSR-88D sites around the country. It is the OH/HRL mission to monitor the operational radar-derived rainfall products from the WSR-88D and improve the operational algorithms.

OH/HRL has dialed up various WSR-88D radars from the Principal User Processor (PUP) at NWS headquarters and is retrieving precipitation products on a daily basis. This has aided OH/HRL to identify case studies in which the PPS performed either well or poorly and which therefore might be worthy of ordering Archive Level II base data for follow-on research and algorithm testing. HRL has ported the operational PPS software code to a UNIX workstation with an 8mm Exabyte tape drive and developed the functionality to run the PPS algorithms using Archive level II base data as input, and display the products with custom-developed X-Windows graphics displays. HRL is able to play back base radar data through the algorithms for various case studies and optimize adaptable parameters. HRL develops new algorithms which interface with the existing code and mitigate problems such as the bright band contamination of rainfall estimates. HRL is in contact with both the Weather Forecast Office and River Forecast Center field offices who provide information events when the PPS performs well or poorly.

1. Algorithm Performance Evaluation

HRL is currently working on adjusting the bias adjustment algorithms of the PPS which use rain gauge data to calibrate the radar rainfall estimates. The Bias Adjustment algorithm has received limited testing using real-time gauge data since the algorithms were first developed at HRL in the early 1980's, but their tests did not use the UNISYS code that is part of the WSR-88D baseline software or the operational gauge data that will be routinely available to the RPG. HRL has access to real-time rain gauge data from the NWS gauge networks obtained from the various River Forecast Centers around the country. This is the actual data which will be input into the Rain Gauge Data Acquisition computer. It is important to determine potential problems with the rain gauges themselves and the associated data communication schedules. The results of the performance tests to be performed will hopefully instill greater confidence among forecasters in the gauge bias adjustment algorithm and/or identify deficiencies either with the algorithm logic or software implementation that can be fixed.

The Rain Gauge Data Acquisition Function collects gauge data into an RPG-compatible database in a real-time environment. However, it is not a trivial task to imitate the gauge data acquisition function in a case study environment. HRL is writing code to unload the archived gauge data and insert it into the PPS gauge database for use in the bias adjustment algorithm.

HRL has been running the PPS bias adjustment algorithm (along with the other algorithms) for varying amounts of gauge data and studying the effect of the gauge posting time window. HRL will first determine the performance of the bias adjustment procedure for a number of cases using the entire set of gauge data regardless of posting time. This will assume a perfect scenario in which all gauge data comes in simultaneously. Once the robustness of the algorithm is established for a wide range of events, HRL will investigate the sensitivity to a smaller set of gauge data (i.e. real-world situation).

2. Bright Band

HRL is resurrecting its version of the PPS written in the mid 1980's to run on the HRL Prime computer. This HRL version has not been running for over a year because the Prime computer was not operating in 1993. HRL is in the process of porting that code to the HP workstations. HRL is porting this code partly because the HRL code developed in 1991-2 detects the bright band and is a part of the HRL version of the PPS.

HRL plans to get this version of the PPS running and able to ingest WSR-88D data. Once running, HRL will test the bright band detection algorithm for multiple cases. Ultimately, HRL plans to incorporate the bright band algorithms into the UNISYS version of the PPS that will be the HRL baseline code.

This, however, is only the first step in removing the deleterious effects of the bright band on the rainfall estimates. The real challenge lies in the actual removal or correction of the abnormally high rainfall once the bright band has been identified.

3. FFP

Over the next few months HRL is planning to begin testing the WSR-88D Flash Flood Potential algorithms using Archive Level II data. The algorithms are being ported from the Prime computer to the HP workstations.

D. HUGHES STX

Hughes STX (HSTX) has been conducting algorithm development in three specific areas, including severe weather precursors based upon storm structure, lightning precursors, and frontal structure. The common thread for these efforts is the development of techniques quantifying the structure from Doppler weather radar data. The detection and assessment of gradient fields form part of each development effort.

1. Storm Structure

HSTX is focusing on the automated detection and characterization of the Bounded Weak Echo region (BWER), in an attempt to relate these features to occurrences of severe weather. The BWER has been chosen since it typifies the mature stage of the supercell storm (classic, LP, HP), the period of highly destructive tornadoes, hail, and wind. While its actual form may vary between supercell storm types, its attributes (size, shape, longevity, etc.) may provide valuable information on the strength and organization of the parent storm, and likely the potential for severe weather.

Image processing techniques have been developed to extract BWER boundaries from the 2-D reflectivity gradient fields. The approach combines aspects of traditional and machine intelligent (MI) concepts such that multiple derivative fields are extracted from the base data and combined into an "interest field" that delineates the BWER. The traditional component derives "pattern vectors" to locate reflectivity field gradients from which reflectivity extrema can be found. The MI component is loosely patterned after the LL MIGFA (Troxel and Delanoey, 1993) algorithm and employs multiple passes with varying 2-D templates to determine field attributes. Currently, the MI approach has been used to locate the reflectivity maxima, as well as attributes relating to the gradient values and directions. These various attributes are combined (weighted) via scoring functions, and then joined to delineate the WER. Limited testing on simulated 2-D data appears quite promising.

HSTX has also begun developing methods for quantification (area, compactness, height, etc.) of the physical dimensions and structure of the BWER. Parameters such as water deficit in the BWER are being examined to determine relationships with potential severity of associated weather.

2. Automated Front Detection And Quantification

HSTX is in the process of developing an automated technique for detection of fronts, to include details of their 3-D structural and intensity characteristics. The 3-D structure will be monitored with time to assess the development of hazardous weather such as that associated with wind shear and precipitation. HSTX is currently focusing on deriving this information through use of velocity and reflectivity gradient vectors.

The basis for the method is again an extension of the successful 2-D gradient detection technique previously employed by HSTX in gust front detection. The method employs templates (e.g. 3 x 3 matrix operator) that are passed over the 2-D data domain of interest. Variation of the weight values allows alteration of the mathematical operation being performed on the 2-D data field. One of the most useful is the measure of field gradients in the two orthogonal dimensions. The template method is accurate and efficient, and is well suited for detection of large gradients within the data field, such as reflectivity and velocity "lines".

While the approach retains some of the same algorithms used in the prior gust front detection algorithm (e.g. noise filtering, data editing, etc.), HSTX has extended the previous 2-D detection technique in two significant ways. First, the template technique has been modified to operate in the polar reference frame in which the data are obtained. This change increases the speed of operation by removing the intermediate interpolation process from polar to Cartesian space, necessary when operating in the Cartesian frame. HSTX plans to perform an analysis on test data to ascertain the differences in gradient field estimates resulting from use of the templates within the two different reference frames. The second change includes processes (e.g. Hough) to organize the fields of gradient values from the template process to form the line segments. The advantage of this technique is that the data are fitted to a form similar to the true variation in nature, but with adaptable constraints on scale and intensity.

This effort will be accomplished in the four phases of (1) front detection, (2) 2-D structure definition, (3) 3-D structure definition via correlation of 2-D structures, and (4) correlation of frontal "structures" and their variations to meteorological events.

3. Lightning Precursors

A lightning precursor study has also been initiated by HSTX with a focus on lightning development within air mass thunderstorms. Several case studies in Florida and New Mexico have identified a relationship between the development of convection relative to various temperature levels and the onset of lightning. Here, the measure of convection is often tied to an aspect of radar-observed storm reflectivity such as storm top, maximum reflectivity, or reflectivity centroid. Examples include Buechler and Goodman (1991) who noted in Florida storms that cloud to ground (CG) activity was correlated to extension of the 30-40 dBZ region above 7 km (-10 deg C) level; Lhermitte and Krehbiel (1979) who detected intracloud (IC) initiation when the storm top reached 8 km (-20 deg C) and a maximum in IC flash rate when reflectivity at the -10 deg C level exceeded 50 dBZ. Other studies have also correlated lightning initiation with the freezing level. Shchukin et al. (1993) noted a relationship with the maximum reflectivity 2 -3 km above the 0 deg C level, and Petersen et.al. (1993) related the occurrence of echo centroid height rising above the 0 deg C level.

Maximum forecast lead time could be attained if lightning initiation could be tied to forecasts of convection initiation such as employed by Wilson an Mueller (1993), who have demonstrated the forecasting of the onset of convection by interaction of boundary lines among themselves or with different air mass environments. This approach however, requires further quantification of boundary layer convergence strength and thermodynamic distributions.

The high spatial and temporal resolution offered by the WSR-88D, combined with the systems excellent sensitivity provide opportunity for an automated lightning analysis. Based upon these observations HSTX will also focus on identification of lightning precursors via (1) identification of new convection via locating favorable convergent lines in the boundary layer, and (2) the detection of moderate reflectivity just above the freezing level in developing storms.

E. **MIT LINCOLN LABORATORY** (AR)

The MIT Lincoln Laboratory (LL) is not directly testing WSR-88D algorithms. However, in support of the FAA LL is conducting an extensive research and development program that incorporates Doppler radar meteorological algorithms similar to those in the WSR-88D suite, and some that may utilize WSR-88D output. These investigations have led to the uncovering of some deficiencies in WSR-88D data processing (e.g. clutter removal). This, and related radar methodologies are of interest to the NEXRAD OSF. The following material summarizes the LL activities of potential interest to the OSF.

NEXRAD-Related Research

TN-2 Data Acquisition Rate Needs And Strategies

1. Observations Of Clutter and Dealiasing Problems

The FAA's Integrated Terminal Weather System (ITWS) (under development by Lincoln Laboratory) utilizes NEXRAD data in the generation of a number of graphical and alphanumeric "products" for air traffic control supervisors, traffic planning specialists and airline operations personnel. These include precipitation reflectivity maps, real-time "dual-Doppler" gridded winds, and information on severe storm features such as hail and mesocyclonic circulations.

One significant issue encountered in the use of NEXRAD data by has been high levels of ground clutter residue present near the radar and broad-area clutter breakthrough on the low-elevation angle tilts during conditions of anomalous super-refractive propagation conditions (anomalous propagation (AP)). While NWS meteorologists utilizing NEXRAD data can recognize these artifacts and ignore them, the ITWS automated algorithms are not designed to cope with time varying levels of clutter residue and clutter breakthrough in their input data streams. Similarly, non-meteorologist aviation users such as Flight Service Station (specialists advising general aviation pilots have found this clutter contamination (especially that due to AP) to be a significant operational problem at times.

Since the current LL ITWS prototypes utilize wideband communications links to ingest NEXRAD base data, LL has been able to generate surrogate NEXRAD "products" that include appropriate clutter breakthrough prevention. For the ITWS 1994 Demonstration/Validation (DemVal) testing at Memphis and Orlando, LL excluded one or two low-elevation tilts from "layered" or "composite" reflectivity products on a range-dependent basis so as to effectively establish a lower bound of 2 km (above ground level (AGL)) for reflectivity data used to create the layers.

Although this "reflectivity aloft" approach was operationally adequate for the ITWS DemVal, it would be far better if NEXRAD could flag the clutter contaminated data before it is incorporated into the NEXRAD precipitation and velocity products. Options which appear viable include:

a. Use of a clutter residue map to "flag" resolution cells where NEXRAD's clutter filters are unable to suppress clutter returns below the intensity of meteorological echoes. This approach has been validated extensively during LL testing of FAA systems such as the Terminal Doppler Weather Radar (TDWR) and the Wind Shear Processor (WSP);

b. Flagging of echoes with low mean-Doppler and spectrum width as likely ground clutter breakthrough caused, for example, by AP conditions. This technique has proven successful in eliminating AP-induced clutter breakthrough from reflectivity maps generated by the ASR-9 WSP; and

c. Requiring that high-reflectivity returns exhibit physically plausible vertical continuity.

LL believes that other remote users of NEXRAD base data or products (e.g., other FAA programs such as the Weather and Radar Processor (WARP) supplying NEXRAD data to Air Route Traffic Control Center (ARTCC) controllers, River Forecast Centers and the NIDs users (e.g., the FSS specialists)) will also find unacceptable the degree of clutter contamination that is currently present. LL is recommending strongly to the Operational Support Facility (OSF) and the various NEXRAD program oversight offices that planned system upgrades include more robust clutter suppression for data provided to remote, non-meteorologist and/or largely automated users. Further refinement, testing and implementation of the above clutter suppression techniques would, LL believes, largely address this significant problem.

TN-11 Wind Analysis Techniques

2. Gridded Winds Analysis

LL is developing a 3-D gridded winds analysis for ITWS (Cole and Wilson, 1994). This product provides wind estimates on a grid with a horizontal resolution of 2 km and an update rate of five minutes. Data from surface stations and aircraft are used, but the data that support such a high-resolution analysis are the Doppler radar data from TDWR and NEXRAD.

An analysis technique was designed for the ITWS gridded winds analysis using a least squares technique that directly analyzes Doppler data to extract a maximum amount of information from Doppler data sets. This technique is closely related to both Optimal Interpolation and standard multiple Doppler analysis. This technique has the potential to produce a quality VAD-like wind estimate from data sets which are too sparse to produce useful wind estimates from traditional (velocity azimuth display) algorithms.

TN-13 Boundary Layer Wind Shift Analysis Techniques

3. Machine Intelligent Gust Front Detection

The Machine Intelligent Gust Front Algorithm (MIGFA) is now in its third year of operational testing. A version of MIGFA built for the Airport Surveillance Radar with Wind Shear Processor (ASR-9 WSP) was tested in Orlando, FL (1992) and in Albuquerque, NM (1993). The high-clutter environment around Albuquerque and the very dry air typical of the Southwest proved to be a significantly more difficult test than Orlando had been: during 1993 in Albuquerque, MIGFA provided warning for about 30 percent of gust fronts that impacted the airport as compared to about 75 percent during 1992 in Orlando.

A TDWR version of MIGFA was also tested in 1993 in Orlando, running in parallel with the existing TDWR gust front detection algorithm (GF88). MIGFA did much better than GF88 over all means of scoring (Troxel and Delanoy, 1994).

Despite the overall good performance for both versions of MIGFA, several weaknesses were discovered during 1993 operations that were subsequently improved in time for 1994 operations. The most significant changes include:

a. Improved detection of gust fronts embedded in precipitation.

b. Development of a consensus-based approach to wind shift and wind shear estimation, averaging the results of several estimation techniques. Individual estimates are weighted according knowledge of the conditions under which that estimate is likely to be inaccurate.

c. Elimination of false alarms caused by high-altitude weather in the ASR-9 WSP version of MIGFA. By decreasing false alarms, LL was then able to increase the sensitivity of MIGFA. Consequently, LL was able to detect and track more faint gust front signatures, resulting in an increased probability of detection.

Although scoring results are not yet available for 1994, preliminary results and the impressions of site personnel and users indicate that both the ASR-9-WSP and TDWR versions of MIGFA are performing more accurately than they had in 1993.

Eventually LL intends to develop an ITWS version of MIGFA that will assimilate the outputs of feature detectors for multiple radar sources. As part of this effort, LL has implemented and conducted limited testing on a preliminary NEXRAD version of MIGFA. When completed, the new NEXRAD feature detectors will be able to perform either as part of ITWS MIGFA or as a stand-alone (i.e., single radar) NEXRAD MIGFA.

Copies of MIGFA software have been distributed to Mike Eilts' group at the NSSL and to the Research Applied Programs (RAP) group at NCAR. Both groups are interested in the development of a NEXRAD version of MIGFA.

TN-16 Structure Analysis Detection and Feature Tracking Techniques

4. Comparison of Storm "SCIT" Algorithms

An intercomparison of three promising Storm Cell Information and Tracking (SCIT) algorithms on one challenging storm case was carried out by LL. The SCIT algorithms were NSSL's Centroid Tracker, the NCAR TITAN algorithm, and the ITWS Correlation Tracker. The comparison provided useful but limited information about the trackers, and the results were briefed to the NEXRAD Technical Advisory Committee (TAC) in July 1994. LL concluded that the NSSL tracker was far better than the current WSR-88D algorithm because of the use of multiple threshold levels, but that it can still be confused by centroid motions in growing cells. The correlation tracker was very stable and resistant to spurious centroid motions but required more CPU time to run.

A more rigorous comparison, including cases with non-cellular and banded precipitation (stratiform rain, snow, hurricane, etc.), should be performed. NEXRAD currently has no correlation tracker, but it is in precisely these cases that such a tracker should perform well, while a centroid tracker might give erratic storm motions. Also, if the NEXRAD system had both centroid and correlation trackers, some synergism would be possible. This would need to be explored to provide not only the best storm track but the best prediction of future precipitation fields.

5. Storm Tracking

LL has ongoing research in the area of local-area correlation tracking. This should be particularly of interest regarding NEXRAD Technical Need 16. Since LL work has been directed at the creation of automated algorithms for TDWR and ITWS, LL research has focused on developing a robust area-correlation technique. Some of the recent work regarding estimation accuracy has been described previously (E.S. Chornoboy and A. Matlin, 1994). Recently LL combined the correlation tracking method with the 460 km NEXRAD Composite Reflectivity Product to produce a long-range Storm Motion product for ITWS. Real-time demonstrations in both Memphis and Orlando proved the combination both effective and reliable.

6. Thunderstorm Evolution

As part of the development of a Microburst Prediction algorithm for the FAA, LL has discovered very effective ways of mapping regions of storm growth and decay and of producing an accurate 10-15 min forecast of the precipitation field. This algorithm also provides estimates of the damaging surface winds produced by the outflow of these storms. This algorithm is complete, has undergone operational testing in Memphis, TN and Orlando (summer 1994), and is undergoing specification for the ITWS program (fall 1994). LL believes that further improvements in lead time for storm prediction can be gained by coupling this work with MIGFA, also developed at LL, and by developing further precipitation and Doppler velocity structure analysis detection capability. This work is ongoing.

7. Signal Processing

a. Optimal Doppler Estimation

LL has continuing active research in the areas of improved Doppler estimation, unambiguous Doppler range extension, and clutter filtering. A number of new developments are particularly relevant to NEXRAD Technical Need TN-28: Velocity Dealiasing and Range Folding.

b. Clutter Filters For Multi-PRI Signals

There has been new progress in the area of clutter-filter design for multi-PRI signals. The need for clutter suppression with low-altitude scanning limits the use of multi-PRI techniques for unambiguous Doppler extension. A viable clutter suppression method and dealiasing technique were previously reported (E.S. Chornoboy, 1993). These new ideas have been extended further and successfully applied in conjunction with new frequency-domain work (E.S. Chornoboy and M.E. Weber, 1994).

c. Coherent Processing For Multi-PRF Signals

New results in multi-PRI coherent processing were published (E.S. Chornoboy and M.E. Weber, 1994). This work focuses on frequency-domain Doppler estimation and includes a new and innovative approach to unambiguous Doppler estimation.

d. Frequency-Domain Doppler Estimation

LL has taken a more direct approach to the problem of range unfolding. The initiation of work in the area of Doppler spectrum decomposition has been reported previously. In particular, that LL has been exploring the use of low-PRF data, like the NEXRAD low-PRF tilt, to decompose range-ambiguous high-PRF spectra. If successful, this approach could provide NEXRAD velocity estimates for <u>both</u> the first and second trips whereas the current NEXRAD algorithm can, at best, provide a velocity estimate for one of the trips. This is a potential cost-effective solution for NEXRAD because it does not require transmitter modification. LL work in this area is yet unpublished but has continued with progress and shows promise through simulation results.

F. NASA MARSHALL SPACE FLIGHT CENTER

The NASA Marshall Space Flight Center (NMSFC) is investigating two areas that do not have direct applicability to current WSR-88D algorithms, but may be used in conjunction with WSR-88D data and may assist in better understanding of storm characteristics. A separate effort utilizing layer composite reflectivity maps may facilitate use of WSR-88D archive data.

1. Data Fusion

Data fusion investigations have been on the agenda at NMSFC over the past few years. Currently NMSFC is undertaking two efforts pertaining to incorporation of lightning data with radar data.

First, NMSFC is examining the information content and algorithm improvement that can be derived by integrating National Lightning Network Data with WSR-88D data. The focus is to better understand storm morphology (e.g. growth, evolution, and decay). The second effort will be the use of in-cloud lightning and ground discharge data from a new NASA/MSFC prototype lightning sensor destined for application during the Tropical Rainfall Measuring Mission (TRMM). These data, combined with additional surface measurements, are also to be used to examine storm morphology and fusion possibilities with the WSR-88D network.

2. Precipitation Algorithms

The second effort is supportive of precipitation/hydrologic algorithm development and consists of the creation of a national composite rainfall data set from the WSI, Inc. NOWRAD composite reflectivity maps. The WSI composites utilize the various WSR radars in the U.S. The intent is to make precipitation maps useful for comparison and validation studies with the Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave/Imager (SSM/I). It also provides an electronic browse product for scientists interested in WSR-88D Level II archive tapes available from NOAA archives. The rainfall data set will be available from the NASA Distributed Active Archive Center (DAAC) located at NMSFC for studies of the global hydrologic cycle.

G. NATIONAL CENTER FOR ATMOSPHERIC RESEARCH (PAR)

1. Winter Storms And Snowfall Forecasting

Two analysis efforts are underway at NCAR/RAP in support of providing accurate current, and 0-30 min forecasts of snowfall in the airport environment in support of ground de-icing operations. The first effort involves a study to determine the feasibility of using real-time radar reflectivity factor (Z) and liquid equivalent snowfall accumulation. Important factors include the numerical stability of the real-time algorithm and the proper correlation of radar and snowgauge measurements. Current results show that horizontal advection of snowfall has to be taken into account.

The second effort involves the development and evaluation of snow echo tracking techniques. Two techniques are currently being evaluated; (1) a technique named Radar Echo Prediction (REP) (Peter Neilley) based on cross-correlation methods, and (2) a cell tracking technique named TITAN (Mike Dixon).

The TITAN program, as previously reported, is a storm cell identification and tracking methodology that locates reflectivity cells, quantifies various attributes, and then tracks and forecasts the cell motions over time. This method has been used in tracking developing thunderstorm cells as part of the methodology recently developed at NCAR for identifying and forecasting new storm development via convergence line interaction. TITAN is discussed further in the storm tracking and forecasting section.

The REP method uses a TREC-type approach by determining propagation velocities for sub-image portions of the entire image. A localized 2-D correlation technique, each sub-image (10 x 10 km) may partially overlap adjacent sub-images to increase the density of estimated vectors. Each sub-image is correlated with the new image to find possible "best fit" solutions. Performing this process for all sub-images provides a 2-D field of potential motion vectors. Identification of the "best fit" solution for a sub-image is currently determined by requiring the divergence of a region of sub-images to be a minimum. A new method under development includes minimizing the whole image RMS error field at one time. The method has an array of tunable parameters. As expected, the quality of the derived motion vectors is correlated with the definition (e.g. strength of field gradients) of the reflectivity. With knowledge of the sub-image advection, the reflectivity trend is also tracked and forecast.

RAP is currently performing a statistical evaluation of these two techniques using data from the Mile High Radar and Denver WSR-88D data. Results from an initial evaluation using Mile High Radar data from the winter of 1992/93 will be completed by the end of September 1994.

2. Hail Studies

NCAR/RAP has been analyzing hail-related data collected from Northeast Colorado during the summer months of 1992 and 1993. The dataset includes hail reports (Denver NWS, Mountain States Weather Services, and a Volunteer Hail Network), observations from chase vehicles, measurements from a research aircraft, and radar measurements from both a NEXRAD-like radar (NCAR's Mile High radar) and NCAR's CP-2 multiparameter radar. Currently, the data are being used to evaluate the NEXRAD hail algorithm and a suggested replacement developed by the NSSL. A report of this work will be submitted to the FAA (for potential use with TDWR) by the end of

September 1994. Standard Statistical probability measures such as Probability of Detection (POD), False Alarm Rate (FAR) and Critical Success Index (CSI) are computed for hail categories of any hail, hail GE 0.25 in, GE 0.5 in, and GE 0.75. Over 100 hail storms and numerous rain storms are included in the study. Future efforts will concentrate on multiparameter radar techniques for hail detection. The principal investigators for this study are Ed Brandes and Cathy Kessinger.

3. Turbulence Studies

A "quick look" evaluation of the WSR-88D turbulence algorithm has been performed. Spectral width estimates from the Mile High Radar have been used to compute eddy dissipation rates using the NEXRAD methodology. These turbulence estimates have been compared to aircraft measurements of turbulence computed from fluctuations in indicated air speed and center of gravity accelerations. For a small number of cases good agreement was found between NEXRAD turbulence estimates interpolated to the aircraft location and in-situ turbulence. Plans call for expanding the study to other data sets and investigating the influence of the coarse grid on the utility of the NEXRAD product. The investigators for this study are Ed Brandes and Larry Cornman.

4. Wind Retrieval And Model Initialization

NCAR is actively involved in developing methods for retrieval of the 3-D wind and thermodynamic structure using single Doppler radar data. One approach, loosely patterned after Liou et al. (1991) involves deriving the 3-D wind field from single Doppler radar observations and thermodynamic retrieval as done by Gal-Chen (1978), with these data then used for model initialization. The second approach is the adjoint method of Sun et.al. (1991) that also uses single Doppler data, forward integration of the numerical model combined with backward integration of a "cost" (error) function in deriving the wind and thermodynamic fields.

The first method was tested with simulated and real gust front cases. It involved derivation of the 2-D boundary layer winds via TREC (or use any other suitable method). The data are then interpolated onto a 3-D Cartesian grid, then interpolated onto the model terrain-following grid, and followed by calculation of the buoyancy terms from thermodynamic retrieval (Gal-Chen (1978)). The tendency term used in the retrieval is determined from a least squares fit to three time periods centered within the data assimilation period. The method is applied in a dry environment to ensure conservation of tracked quantity (e.g. reflectivity).

In the first study involving TREC-only winds, reasonable accuracy in predicting gust front speed and propagation was achieved only for a limited range of initialization times. Model reliability was then improved with TREC vector editing by deleting wind data where the reflectivity was greater than 15 dBZ (i.e. removing cells that move with higher level winds), and supplementing assimilation data with surface wind and temperature data. Using these supplemented TREC winds with the remaining two cases, the motion of most convergence lines and the resulting localized strong surface convergence, were forecast. Some sources of error were noted, including range aliased velocities, ground clutter, and unrepresentative sounding data. Modification of standard sounding data via surface observations typically improved the accuracy of the forecasts. The results suggest the radar data assimilation process requires supplementation via surface observations to remove data artifacts.

The adjoint method, applied to a gust front case study from Phoenix II, indicates this non-hydrostatic, dry model can successfully retrieve the wind and thermodynamic fields from single Doppler radar velocity and reflectivity. Results indicated the method was not very sensitive to the amount of information at inflow boundaries, and that reflectivity data was only needed if the radial velocity data behind the front was poorly observed. This second effect could result from the geometry of the front relative to the radar position (only small components of actual winds are measured), or from the velocity data being sparse or of poor quality.

5. Velocity Dealiasing

NCAR is currently testing a new two-dimensional dealiasing (TDD) scheme being developed for real-time application. The approach operates over a sub-region (currently 7200 gates max) of the full PPI scan. For this sub-region, it solves a linear system of relations via minimizing a "smoothing" function to establish the corrections to be applied to individual gate velocity data. The technique has been applied to both simulated and real data. The range gates within the sub-region must be "connected", that is, gates further in range are connected by valid gate data to gates closer in range. Under this scheme, small isolated data regions become individual sub-regions. Within each sub-region standard threshold techniques are used to locate velocity discontinuities between each range gate and its four primary neighbors. A smoothing function is determined for this sub-region. This function is simply related to the sum of all these velocity differences with place-holders for the "true" correction for each gate. Minimizing this function for all gates simultaneously determines "intermediate" correction factors to be applied to each gate of the sub-region. These are "intermediate" values, since they may be noisy and not whole multiples of $2*V_{NY}$.

Next a histogram is formed from all the "intermediate" correction factors (clustered about 0 and multiples of $2*V_{NY}$), and then parsed into sections separating these local clusters. Determining which section a gates' intermediate correction factor falls into thus determines the "true" (multiple of $2*V_{NY}$) correction to be applied. After the corrections are applied to all gates of the sub-region, the process then applies this full procedure on the next sub-region, continuing until all sub-regions are processed. Upon completing the processing of all sub-regions in the scan, a control environmental wind (sounding, VAD, etc.) is used to correct each sub-region (multiples of $2*V_{NY}$) to its final value. The method has been tested using sub-regions as small as 6 gates to as large as 7200 gates.

Some primary assumptions employed in this technique include (1) velocity jumps between gates are limited to $< V_{NY}$, and the environmental wind interpolated to the sub-region location is representative for that region. Thus, the method does not currently address multiple folds which admittedly should be limited to infrequent high shear regions. The system can currently process 7200 gates in 0.2 sec using 2 mb on a Sun Sparc II workstation. The method is somewhat similar to that of Ray et.al (1978), by simultaneously unravelling the velocity discontinuities over limited sub-regions, but waiting to unravel between sub-regions until final processing steps. A very important aspect of this approach is that it is not directional, thus if a dealiasing error occurs, it does not propagate into other sub-regions along radials or arcs. Results so far are quite promising.

6. Storm Tracking And Forecasting

The primary storm tracking method at NCAR is TITAN, an efficient method that has been employed in numerous studies. The method is a real-time storm identification, tracking, and forecasting system. It utilizes 3-D Cartesian-based information such as reflectivity, volume, and a geometric equivalent (ellipse) field. Geometric logic is used to identify and handle storm splits and mergers. The size and position parameters are forecast via use of a weighted linear history. Selection of Z and volume thresholds, such as 15-25 dBZ in snow and 30-40 dBZ in convective storms, allows the user to change the emphasis of the analyses from convective to more stratiform systems. Storm displacement between volume scans is done simultaneously for all storms via use of a distance-type cost function minimization approach. The distance-type parameters are related to both storm position and volume. The merging and splitting are identified through geometric overlap tests. The statistical forecasting model is a linear trend using double exponential smoothing.

Results indicate this automated method is roughly equivalent in skill to that of a human observer with POD, FAR, and CSI values ranging from .83-.63, .27-.62, .64-.31 for forecasts of 6 - 30 min, respectively. Analysis of the POD, CSI, and FAR distributions indicates the variability of these success measures (POD, etc.) is considerable, the wide scatter showing that some storms are tracked well, others quite poorly. An analysis of variability relative to storm type or class is not available for this report. Improvements under consideration include use of multiple thresholds, and more flexible geometric representation in place of the ellipsoidal form now used.

In related work, a preliminary study was performed to ascertain the rise times for convergence-initiated storms to develop from cumulus cloud/no cloud status. Radar detection of cumulus was considered positive when the reflectivity was within a range of -10 to -5 dBZ. Twelve cases, including stationary, moving, and colliding boundary line convergence were included in this study. The rise in reflectivity from 10 - 40 dBZ took between 8 - 16 min. The mean time required for development over this limited data set was about 12 min. Also noted was that the majority of thunderstorms were found associated with some sort of cloud feature at least 30 min prior to development. These results indicate that if clouds are not already present, then 30 min forecasts of 40 dBZ thunderstorm development is perhaps not prudent. Similarly, if a cloud already exists at time of expected line impact a 30 min forecast of 40 dBZ may lag actual storm development. This study will continue with testing over an increased variety of cloud/storm environments.

7. Polarimetric Studies

Some recent NCAR polarimetric research has focused upon detection of ice within storms, particularly hailstorms and winter snowstorms. The efforts associated with the hailstorm and snowstorm research in Colorado are not reported here. However, some results from observations within the stratiform region of an Mesoscale Convective Complex (MCC) and winter storm in Germany are noted. The investigations focus on use of polarimetry to deduce some macrophysical properties of ice, such as bulk density, and discrimination between oblate and prolate spheroid-type crystals. While standard radar measurements are related to the Ice Water Content (IWC) at standard weather radar frequencies, the wide variety of crystal shapes, sizes, densities, etc. do allow for simple size-mass relationships. Thus, there is large dispersion in IWC for a given measured Z_{HH} and large errors may arise in estimating water content. Using a model where shape is not related to size, and particles may be considered to fall into the two shape classes of oblate spheroid (plate-like) or prolate spheroid (needle-like), expressions for the polarimetric variables Z_{DR}, Z_{HH}, and K_{DP} are derived. The model shows that Z_{DR} is dependent upon bulk density and logarithm of axis ratio, Z_{HH} is dependent upon IWC and particle size distribution parameters. Meanwhile, K_{DP} is linearly related to IWC, wavelength (inversely), and weakly to density and axis ratio. These varying relationships offer the potential to develop methods for discrimination between shape types, and the IWC.

Observations were made with the NSSL S-band Cimarron radar and in-situ King Air aircraft, and the German C-band Poldirad radar. In agreement with previous observations, regions containing a high density of dendrites exhibited relatively low Z_{HH} (-5 - +10 dBZ) and high Z_{DR} (1 - 5 dB), while aggregate regions showed relatively high Z_{HH} (10 - 20 dBZ) and low Z_{DR} (-1 -+2 dB). Forming a Z_{HH} and Z_{DR} histogram plot showed some discrimination is possible between these two particle types.

8. Neural Network Clutter Techniques

NCAR is testing possible alternative methods for clutter removal with a focus on removing clutter contaminated weather signals. Classic techniques employ low SNR (noise) tests and low velocity tests (clutter) but are not totally reliable for those cases of moderate signal power and low-velocity weather. Clutter breakthrough is frequently noted even in the absence of weather. To remedy this situation such systems as TDWR employ a Clutter Residue Editing Map (CREM) that is designed to remove clutter signals that pass through the real-time clutter filtering within the Digital Signal Processor (DSP). However, this is often not completely successful. The NN approach is to interrogate the base data (after DSP) and distinguish clutter signal variability from weather signal variability. The approach is to characterize the "texture" of the signal, that is the variability in range of power, velocity, or spectrum width. The neural network approach is first trained on texture data from weather and clutter separately. Then, clutter, weather, and mixed clutter-weather data are used to determine if the model can discriminate between weather or clutter dominated signals in weather-clutter environments. The texture parameters used in this study were the RMS values of base data differences between range cells separated by specified lags (number of range gates).

Initial testing of the NN approach indicated that SNR and spectrum width showed good discrimination between weather and clutter, but velocity did not. The final parameters included in the test were mean SNR, mean velocity, and texture of SNR and spectrum width. The "training" set consisted of 300 samples drawn from the "test" set (1000 samples), with an additional set of 10,000 samples for testing on an unseen data set. The training set consisted of either clutter, or weather, signals. Testing the model against all three data sets yielded approximately 90% (94%), 89% (94%), and 92% (88%) correct identification of clutter (weather) for the training, test, and independent sets, respectively. Results were essentially identical for lags 1-3. Additionally, determining texture from 9-gate blocks was found superior to use of individual range gates.

9. Pulse Compression Techniques

Use of techniques to increase the speed of data acquisition, while still retaining data accuracy and high spatial and temporal resolution are being studied as part of the FAA Terminal Area Surveillance System (TASS) program to simultaneously detect, identify, and track aircraft and weather in airport terminal environments. NCAR is investigating the use of coded wide bandwidth waveforms that could be employed with electronically scanned radar systems. Pulse coding is routinely used in profiling radars, but not weather radars. These waveforms allow for higher spatial resolution and an increased number of independent samples. However, the difficulty is that there can be significant range-sidelobe contamination at typical weather radar wavelengths. The goal is to reduce this Integrated Sidelobe (ISL) by 40 dB.

NCAR has studied a number of coded waveform methods both analytically and with the 3 cm ELDORA testbed radar. The focus was the performance of these methods in clutter and high reflectivity gradient environments. For aircraft surveillance matched-filter designs appear superior, but for weather targets coded waveform and inverse filters (at least 5 times longer than transmitted waveform) are preferred. Unfortunately, with inverse filter designs the response is inversely related to velocity. Weather surveillance tests showed sidelobe leakage into radar measurements in regions of low weather signal. Results suggest that the Tangent Non-linear FM method with over-sampling may be superior to the Linear FM, PseudoNoise bi-phase, and Barker bi-phase code methods. These investigations are ongoing.

10. Data Integration, Display, And Management

The ZEB software developed by the NCAR Atmospheric Technology Division (ATD) is a suite of algorithms designed to integrate a wide variety of data sets to enhance data interpretation. Primarily, ZEB allows for the easy integration of diverse data sets, and provides for their display manipulation and overlay with other data. This system was developed on a SUN workstation running UNIX, stores and distributes data in a standard NetCDF (Network Common Data Format) format, and allows users to tie in user-developed software tailored to their data and requirements. Zeb is comprised of four classes of modules, including; (1) graphics and user interface, (2) data storage (storage, integration, and distribution), (3) ingest (usually specific to data), and (4) analysis (computations, remapping, etc.). The software is distributed to users on CD-ROM, and is in use in over 30 institutions.

Zeb has been employed in a wide range of experiments including CaPE, STORM-FEST, RAPS' 92, TOGA, and COARE and is also used as the real-time display for the ARM, ISS, and NEXUS systems. As an example of the diversity offered by Zeb, the following list includes existing datasets available from NCAR/RDP that have been developed over various field programs;

Satellite (McIDAS, GMS, SSMI)
Ground-based radar (NCAR)
Surface networks (PAM, SAO's or ASCII sfc data)
Soundings (CLASS, NWS or ASCII format, ISS)
Aircraft (FAA tracks, State fields, radar)
Lightning (LLP)
Profiler (ISS, NOAA, ASTER)
Radiometer
NOWRAD (WSR-57 mosaics)

Future work will include (1) interfacing to commercial databases, (2) providing for internet-wide data access capability, (3) configuration automation, and (4) editing and analysis features.

11. Bistatic Multiple Radar Techniques

NCAR continues to investigate the capability of multiple Doppler networks employing only one active Doppler transmitter system and remote bistatic non-transmitting, non-scanning receiver systems. With the entire system linked to a single timing source, multiple Doppler observations from a single illuminated pulse volume location within a storm can be obtained. These observations can be combined as with standard multiple-Doppler systems to retrieve the 2-D or 3-D windfield, and associated parameters such as divergence and vorticity.

The distinct advantages of this system are (1) the extremely low cost of a non-transmitting site (< 2% of a Doppler), and (2) that all systems are observing the "same" pulse volume simultaneously. The low cost means that it may be feasible to establish relatively inexpensive multiple Doppler sites wherever there is an existing Doppler radar (e.g. NEXRAD or TDWR). Obtaining samples simultaneously means that 2-D or 3-D winds are obtained in the transmitting Doppler radar scan planes without having to interpolate multiple Doppler observations to common data planes before combination. This reduces the spatial and temporal resolution problems often noted in traditional multiple-Doppler configurations. However, there are limitations to be overcome, including potentially reduced decreased sensitivity at the non-transmitting sites, contamination from transmitting radar sidelobe-high reflectivity regions, and azimuthal and elevational acquisition zones dependent upon the non-transmitting antenna selected.

To determine the feasibility of such a network, experiments were carried out in the Boulder, CO area, using a single bistatic receiver with the NCAR CP-2 radar during the summer of 1993, and two bistatic receivers with the NCAR CP-2 and MHR radars during the summer of 1994. The results of this test were extremely encouraging. In some cases the bistatic observations were considered superior in detail (e.g. low level surface divergence) to that obtained from the true multiple Doppler configuration. Differences in derived vector windfields between the bistatic and full Doppler configurations were about 1 - 2 m/s. Some contamination of bistatic-derived velocities in low SNR regions were noted. Also, some difficulty detecting high reflectivity field gradients was noted, although the latter capability was much improved in 1994 with new antenna systems.

H. NOAA NATIONAL SEVERE STORMS LABORATORY (PAR)

The National Severe Storms Laboratory (NSSL) continues to provide significant support to the NEXRAD program through ongoing test and evaluation of existing algorithms and refinement of NSSL algorithms that offer potential replacement.

Over the past year the NSSL Stormscale Research and Applications Division (SRAD) has continued to develop, enhance, test, and evaluate hardware, algorithms, and display systems for the purpose of enhancing the WSR-88D system. One important advancement this past year was the development and testing of a Warning Decision Support System (WDSS). This WDSS is the combination of a number of data algorithms developed at NSSL, the capability to ingest WSR-88D data in real-time into a workstation, and a novel display capability. The goal of the WDSS is to provide easy access to radar displays and algorithm output in such a manner that it allows meteorologists to make accurate and timely severe weather warnings.

The WDSS was tested for a six (6) week period in the Phoenix WSFO in conjunction with the Southwest Area Monsoon Project (SWAMP). Although the project continues to this date, feedback from NWS personnel has generally been very positive with an overwhelming number of suggestions for future "user friendliness" improvements. NWS users have been able to utilize the WDSS with minimal training, usually less than eight (8) hours per person.

SRAD continues to support FAA TDWR testing and evaluation of weather products through integration of TDWR alarms into the Low-Level Windshear Alert System (LLWAS). SRAD will also continue to enhance the hardware and software which form the WDSS throughout the next year. Below is a summary of each activity SRAD has supported during the past year.

Algorithm Enhancement And Development

1. Hail Detection Algorithm (HDA)

An evaluation of the accuracy of the Probability Of Severe Hail (POSH) parameter was completed. The fairly simple model used to generate the POSH values was developed using data from two Oklahoma storm days. The evaluation was done using reliability (of attributes) diagrams, which plot the forecast probability of hail versus the observed relative frequency. For the ten storms from the Southern Plains analyzed, thus far, the reliability of POSH is quite good. However, including storms from the Midwest and Florida (for a total of 25 cases), the reliability of POSH is noticeably poorer. Whether the cause of this poorer performance is genuinely meteorological in nature (i.e., the model for POSH developed on Oklahoma data is not appropriate for the Midwest and Florida), or is related to the quality of the ground-truth verification data, is yet to be determined (assuming that it is even possible to determine this one way or another).

In addition to the above mentioned work, four additional storm cases from Melbourne, FL WSR-88D radar were analyzed (3/6/92, 7/9/93, 7/10/93, and 8/9/93). All of these were "good" cases, in that there were at least five hail reports on each day. Performance evaluation produced some unexpected results. While the optimum warning threshold (i.e. highest CSI) for the 3/6/92 case fit well with the "Oklahoma" model (not unexpected), the three summertime cases were expected to have optimum warning thresholds significantly above those produced by the Oklahoma model. This turned out not to be the case. Two of the cases (7/10/93 and 8/9/93) had optimum thresholds matching the Oklahoma model, while the third case (7/9/93) had an optimum threshold below the Oklahoma model. Thus, simply raising the warning threshold to reduce false alarms during the summertime will also result in missed warnings for most of the severe hail that is reported. These findings also suggest that many of the declared false alarms (i.e. no corresponding hail report) may not be valid, and instead be due to inadequate ground-truth verification.

Performance evaluation and enhancement of the algorithm will continue with additional analysis of WSR-88D Archive II data for varied geographical and seasonal conditions. Work will also begin on enhancing the algorithm to detect the volumetric extent of hail within a storm.

2. Tornado Detection Algorithm (TDA)

During the past year, the NSSL TDA has undergone numerous changes. The algorithm now uses multiple shear (gate-to-gate velocity difference) thresholds to isolate the core circulations associated with tornadoes. Other enhancements include more stringent vertical association criteria. First, no more than one 2-D circulation may be missing between two vertically associated circulations. Second, the vertical association routine searches for the strongest 2-D circulation within 2.5 km of the previous vertically associated 2-D circulation feature. Also, the TDA produces trend output of various parameters. These parameters include the top, base, depth, low-altitude gate-to-gate velocity difference, the height and value of the maximum gate-to-gate velocity difference, and the maximum shear.

Numerous data sets from a wide variety of geographical sites have been obtained. Many of these data sets have been analyzed for the purpose of optimizing the current thresholds within the algorithm as well as to determine additional criteria for tornado detection and prediction. The sites included in the analysis are Norman, OK (KOUN), Houston, TX (KHGX), Melbourne, FL (KLMB), St. Louis, MO (KLSX), Sterling, VA (KLWX), Dodge City, KS (KDDC), Phoenix, AZ (KIWA), Amarillo, TX (KAMA), and Memphis, TN (KNQA). Approximately 28 tornadoes have been analyzed thus far.

3. Storm Cell Identification And Tracking (SCIT)

NSSL continues to evaluate the Storm Cell Identification and Tracking Algorithm. The primary difference is that instead of using a single reflectivity threshold (30 dBZ) for cell identifications, seven thresholds (60, 55, 50, 45, 40, 35, and 30 dBZ) are used. This approach allows the algorithm to identify distinct individual cells occurring in lines or clusters where the region of 30 dBZ for the storms is overlapping. The NSSL SCIT algorithm has been tested extensively on WSR-88D data from around the country. In a comparison of the identification performance of the SCIT algorithm with the WSR-88D Storm Series Algorithm, the NSSL SCIT algorithm has a Probability of Detection (POD) of 98% for storm cells of 30 dBZ or greater as opposed to a POD of 35% for the WSR-88D algorithm. The NSSL SCIT algorithm was delivered to the WSR-88D Operational Support facility in April, 1994, and is expected to be included in early 1996. A new enhancement, which is not part of the delivered OSF version, is the ability to display lightning data associated with each storm track.

4. Mesocyclone Detection Algorithm (MDA)

The NSSL Mesocyclone Detection Algorithm has gone through a major modification during FY-1994 in an attempt to improve detection performance and to provide information about circulations that are below typically defined mesocyclone strengths. The original design of the algorithm used strength thresholding at the first (radial) and second dimensions (area) before declaring a circulation a mesocyclone. The newer design uses much lower thresholds at the first and second dimension allowing many more circulation "features" to pass through the algorithm. Techniques have been developed to isolate the core areas of shear. This allows for a circulation to be classified as either a provisional mesocyclone or as a mesocyclone. Provisional mesocyclones can then be monitored by the algorithm prior to reaching the criteria for mesocyclones. The new design also classifies shallow circulations (notably those which occur along gust fronts) and mesocyclones associated with tornadoes. These modifications move the algorithm closer to a circulation detector (which classifies the circulation according to various characteristics) rather than simply a mesocyclone detector. Testing of the MDA on an expended data base has begun. The MDA was modified to include an additional circulation file (in conjunction with the Tornado Detection Algorithm) for use in a neural network test. The neural network is being tested on a number of tornadic (as indicated using ground verification) and non-tornadic circulations, using six (6) circulation attributes as predictors in a possible future rule base. Preliminary results are promising.

Future work will include continued evaluation of the new software on an expanded data base, including work using advanced image processing techniques to identify 2-D circulation features. The MDA will also be enhanced by adding an anti-cyclonic circulation detection technique, a 3-D storm convergence profile computation (which could be useful in determining the low-altitude convergence precursors to tornadic mesocyclones), the use of sounding data for depth criteria and helicity input, and the use of trends for mesocyclone classification. The output of test results from many cases to build mesocyclone climatologies, which can be used to determine which attributes are important for mesocyclone classification, will also be investigated.

5. Damaging Winds Algorithm (DWA)

NSSL recently began developing a Damaging Winds Algorithm to detect and short-term predict the occurrence of damaging winds from downburst-producing thunderstorms. The algorithm examines the velocity data to search for areas of mid-altitude convergence, storm-top divergence, and mid-altitude rotation - all of which have been shown to be precursors to downbursts. Together with the rate of change of the height of maximum reflectivity of a storm (if the maximum falls rapidly it is also a precursor), these parameters are used as input to an empirically-derived relationship to determine whether a given storm is capable of producing a downburst within the next 15 minutes. A prediction can be made for either a moderate (winds > 30 kn) or a severe (winds > 50 kn) downburst. If moderate or severe near-surface divergence is found to be associated with a storm, then a detection is declared. The DWA is being tested operationally for the first time at the Phoenix WSFO this summer. Initial results suggest that for the Phoenix environment, the DWA does a good job of detecting both moderate and severe downbursts, and shows good skill at predicting the occurrence of severe downbursts.

6. Gust Front Detection Algorithm (GFDA)

False detections of gust fronts are being studied at NSSL. The TDWR group is concerned specifically with gust front false alarms that are forecast to be within 10 km (6 nm) of airports. It was found that in most cases from the Oklahoma City site that false alarms from the algorithm do not occur within the 10 km circle, rather they tend to occur South of the radar, for example due to strong shears associated with the low-level jet (LLJ). It is often the case that false alarms are not extrapolated into the 10 km circle surrounding the airport, as the false alarms are usually static in nature within the LLJ.

To help these false alarms a Velocity-Azimuth Display (VAD) algorithm is used which employs Doppler radar data to estimate the vertical wind profile. This is then used to delineate high shear regions within the radar domain where the vertical wind shear is strong enough to cause GFDA false alarms. The building blocks of the GFDA (convergent features) are removed if they fall within these high shear regions, thus helping prevent LLJ contributions to radial convergence and GFDA false alarms.

A limited study of the GFDA's ability to quantify hazardous wind shear is being completed. The goal has been to test the sensitivity of the GFDA's estimate of an aircraft's gain in airspeed to the GFSA's adaptable parameters. Preliminary results indicate that because the GFDA is designed to locate gust fronts, rather than quantify them, the algorithm will need to be modified beyond simple adaptable parameter changes to capture specific shear hazard areas along a given gust front.

7. Velocity Dealiasing Algorithm (VDA)

Studies have continued to improve the WSR-88D VDA. In particular, an investigation into the output of the VDA data within circulation regions showed that almost half these areas had good data being removed by the algorithm. In some cases the data removal was so severe that circulation signatures were missed by the MDA and TDA. It was found that a filter applied to the data before it is dealiased greatly reduces the number of velocity data being removed. The same basic results can be obtained by not allowing the VDA to remove any points which it deems incorrect. Statistical studies have shown a marked improvement in the ability of the MDA and TDA to find valid circulations using the inserted, correctly dealiased data as opposed to the same data sets with removed velocity estimates. These studies also show a large improvement in the ability of the VDA to correctly dealias entire volumes of velocity data when compared to the same data which has been hand-edited.

Investigations into the VDA response to input sounding data were also conducted. It was found that the VDA is fairly insensitive to minor sounding errors. However, large errors in the input sounding can cause VDA output problems. These errors may be minimized through continuous VAD updates and downloading of the most recent upper air or model gridpoint data.

Ongoing pursuits include an adaptable parameter study for different Nyquist intervals in order to optimize a set of processing values. Scanning strategies will be tested using multiple pulse repetition frequencies (PRF) in order to provide WSR-88D data which is neither aliased in range nor velocity. Using previous findings a study to "build" data based on the wind profile, such as obtained from a sounding, will be conducted. These, and the above findings, will be integrated into a package which will be presented to the OSF early next year.

8. Precipitation Series Algorithm (PSA)

The WSR-88D PSA has been ported to the SUN UNIX workstation environment and integrated into the WDSS. The WSR-88D data being ingested by the workstation go through clutter removal using the CREM techniques discussed below before being passed to the PSA for processing. The PSA output can then be displayed on a grid of 1 km resolution using an enhanced color table. Precipitation amounts can be displayed for either one hour or storm total accumulations. This version of the PSA is being tested for the first time during the Phoenix WSFO project. Enhancements to the PSA within WDSS will continue to be addressed.

Radar Data Processing And Display

9. RISC-Based WSR-88D Data Ingest

The NSSL has developed a RISC-based workstation that provides users the ability to easily access a real-time WSR-88D Archive II data stream. An open system, currently a Sun SPARC 10/50 has been employed as a platform for a relatively low-cost and portable system that enables ease of radar data ingest. A modular and flexible design allows for a wide range of system configurations that meet varying experimental needs. The system acquires Archive II data via the User Port on the WSR-88D Radar Product Generator (RPG). A communication module handles all data requirements and data transfers between the RPG and the workstation. Included in the system are mechanisms that provide system control and configuration, system monitoring, and display of WSR-88D and workstation operational status information. Application software may be run on the workstation CPU or the data stream can be distributed over an Ethernet to other workstations for processing.

10. Editing Of WSR-88D Level II Data

The NSSL has implemented a Clutter Residue Editing Map (CREM) based upon work at LL. Generation of the CREM involves processing many volume scans of Level II data collected during quiescent weather, and assumed standard radar propagation conditions. The CREM represents consistent locations (in azimuth and range from the radar) of moderate to high reflectivity that pass through the WSR-88D clutter filtering process. These CREMs are used in our real-time system and tape playback modes to edit ground clutter contaminated radar measurement. The measurement is considered to be contaminated by clutter when the reflectivity of the gate is less than the value built into the map. The reflectivity, velocity, and spectrum width measurements are then edited to missing values. This then provides the NSSL algorithms a higher quality data stream for processing and eliminates clutter residue related problems.

11. Inventory Of WSR-88D Level II Data

During the 1994 calendar year, the NSSL chose the CODIAC database software (in cooperation with the OSF) to catalog and inventory the Level II data tapes, as well as other data sets held by the NSSL and the OSF. Furthermore, the NSSL and the OSF have been working together to determine those Level II data sets which are not currently held by either organization, but are vital to the development of current and future algorithms. To date, over 180 Level II tapes containing a variety of weather events have been added to the inventory. The NSSL is working to obtain additional

Level II data sets from the NCDC and maintain them within the CODIAC software.

12. Graphical User Interface Designs

A major accomplishment over this past year has been the improvement and enhancement of NSSL's Doppler radar display system. The Radar and Algorithm Display System (RADS) allows operational meteorologists easy access to information necessary to make timely warning decisions. It allows the user to view WSR-88D data with various algorithm output overlays. The system is also a very useful post-analysis and research tool.

One main area of improvement for RADS was the redesign of the user interface through the involvement of OSF human factors specialists. In addition to displaying algorithm output, RADS has been augmented with such features as one hour and storm total precipitation, along with mesonet and lightning overlays. Also included are the ability to watch the time trends of algorithm output for a storm (such as storm top height), a storm composite table which automatically keeps track of the most intense storms, and a point and click high resolution zoom. It is this system which is currently in Phoenix, AZ for real-time testing. During the course of the project, several improvements have been made to RADS as a result of suggestions by the NWS users. Enhancement work will continue to be done in RADS to increase functionality and utility for both real-time and post-analysis use.

A second radar display and statistical analysis package has been developed which allows perusal, hand editing, and evaluation of WSR-88D data. Level II data can be examined in post-analysis and each velocity measurement can be adjusted by Nyquist intervals to produce an output field the human deems to be correct. The other algorithm outputs, including the VDA can then be compared to this "thruthed" data set. In this manner statistical evaluation of the performance of the algorithms can be deduced.

Polarimetry Methods

13. Radar Polarimetric Techniques

NSSL continues its program into deriving practical applications of polarimetric variables in terms of rainfall rates, and general storm microphysical structure in general. The NSSL Cimarron s-band polarimetric radar routinely generates the standard 3 spectral moments as well as the polarimetric differential reflectivity Z_{DR}, the total differential phase PHI_{DP}, and the correlation coefficient between the copolar signals (RHO_{HV}), over 768 range gates. The specific differential propagation phase K_{DP} may subsequently be computed from PHI_{DP}. NSSL reports on a number of observational studies, including vertical incidence observations of a bright band, observations of MCS's, and general studies of precipitation and attenuation estimation. The bright band study demonstrates the utility of the RHO_{HV} and other parameters to clearly delineate the process from melting aggregates, to large raindrops, and breakup into smaller drops over a short vertical distance. Relative changes in RHO_{HV}, Z_{HH}, and V from near top to bottom of the bright band are 46 - 33 dBZ, .97 - .8, and +1 - -9 m/s. Measurements of RHO_{HV} continue with the prospect that this parameter may allow for better interpretation of precipitation type.

The MCS study continues to reveal the utility of polarimetric parameters to clarify microphysical states within complex storm systems. Here, differential reflectivity Z_{DR}, specific differential phase K_{DP}, and the correlation coefficient RHO_{HV} were employed. A high degree of correlation is found between heightened K_{DP} (GE 2 deg/km) and Z_{HH} (> 50 dBZ) in both horizontal and vertical planes. Scattergram plots indicate a good relationship between both increasing K_{DP} and Z_{HH}. Hail is assumed present upon conditions of Z_{DR} < 1 dB and Z_{HH} > 50 dBZ.

The observations suggest three distinct precipitation domains were detected; (1) a region exhibiting large Z_{DR} (3-4 dB) and small K_{DP} (< 1 deg/km) considered large raindrops, (2) high Z_{DR} (3-4 dB) and moderate K_{DP} (1 - 2.5 deg/km) considered large raindrops of which some possibly contain ice cores, and (3) Z_{DR} near 0 dB with K_{DP} high and RHO_{HV} is low (.75 - .85) assumed to consist of hail with and without rain.

The final reported efforts focus upon precipitation and attenuation measurements. Several estimators of rainrate and rain water content (for S-band) were compared via simulation with gamma drop size distributions. The various rainrate and content estimators employed Z_{HH}, Z_{HH} and Z_{VV}, K_{DP}, and K_{DP} and Z_{DR}, respectively. For simulations representing 10 - 200 mm/hr rainrates, the K_{DP}/Z_{DR} formulation exhibited standard error (1.1 - 3.1 mm/hr) 2-3 times less than the Z_H/Z_V estimator and 3-5 times less than the singular K_{DP} estimator. For water content the K_{DP}/Z_{DR} estimator remained superior with standard error (.16 - .22 g/m^3) at least 1.5 - 2 times better than the others over the range 1-5 g/m^3.

Finally, in a study of a squall line that appeared to produce significant attenuation (> 10 dB) for the Twin Lakes S-band WSR-88D measurements, polarimetric measurements were made with the Cimarron radar for verification. A method for correcting the bias in Z_{HH} using PHI_{DP} was empirically determined, and a similar relation was found for Z_{DR}. Estimation of attenuation via specific differential phase KDP was performed and appeared to account for significant attenuation for extended rain along the radial, such as when the squall line cellular structure is aligned along radar scanning directions. Results indicated that greater than 10 dB of attenuation for Z_{HH} and 3-4 dB for Z_{DR} was possible at a range of 120 km. Additional analysis suggested that as much as 3 dB of attenuation may occur at the radome during heavy rain events. These observations suggest that the WSR-88D measurements may routinely incur 4-5 dB attenuation if these various effects are not accounted for, with significant impact on the PPS algorithm outputs.

I. NOAA NWS REGIONAL OFFICE WSR-88D OPERATIONS

Included herein is a new entry for this review document. As more WSR-88D systems are deployed, operational forecasters are able to see real-time WSR-88D products and incorporate them into their short range forecasts. With seasoned knowledge of the nature of weather and storm related features, they are able to draw upon this experience and make comparisons with product outputs generated from the WSR-88D system. Through this comparative process, much of utility of the WSR-88D system will be obtained. Extremely useful will be the interpretation they offer to WSR-88D products, and insight into deficiencies of the system in their regional area. It is highly likely that programs undertaken at the NWS forecast centers will lead the difficult task of validating system performance on a regional/seasonal basis, and offer significant input to adaptation data parameters changes, and perhaps suggest additional changes that will provide for optimum system performance in their environment. While some centers have programs underway, others are in the state of definition. The NWS centers are very proactive, taking great interest in hands-on use and evaluation of the WSR-88D information, becoming familiar with the greater array of products and resolution of base data.

1. NOAA NWS - Southern Region W/SR3

Numerous items of interest are noted from the Southern region, falling into the three categories of operations, tuning, and algorithms. The following sections list some of the observations from initial use of the existing WSR-88D systems within this region.

During operations, a number of observations have been noted. It was noted that during passage of the remnants of Hurricane Andrew, 30 damaging wind events were reported across the region. Analysis indicated the majority of these damaging wind events were located within the NE quadrant of the storm (relative to storm motion), similar to past events. Such observations may lead to more precise forecasting of wind hazards warnings in such systems.

Another study found that use of a 4 panel presentation including PPI and RHI type scans were very useful in following the 3-D evolution of storms. In some cases, it may be more timely to employ the real-time base products rather than wait for the comprehensive products that are generated at the end of the volume scan. Other observations include cyclical behavior (30-40 min period) of the rotational velocity and VIL during a golfball-size producing thunderstorm where decreasing VIL was followed (within 5-10 min) by maximum in rotational velocity, and a mini-supercell marine storm that exhibited standard supercell characteristics but extended only to 30 kft in altitude.

A study correlating the storm maximum VIL along with 300 and 500 mb heights and temperatures suggested a nonlinear correlation that may be employed to discriminate between small hail/large hail days. This attempt to develop a VIL-of-the-day is similar to previously reported results. Additionally, development of a "checklist", a step by step procedure to be followed to maximize the ability to detect minimal tornadoes is an outgrowth of familiarization with the WSR-88D products.

The Melbourne Florida WSR-88D was detecting large chaff clouds that often were extensive in area and moderate in reflectivity (up to 40 dBZ). Twenty such occurrences have been noted. The source region is typically the Northern portion of the Gulf of Mexico and comes from military exercises, usually dropped from high altitudes. These chaff clouds are a concern for this site that is employed by NASA for observing/forecasting weather conditions for shuttle launches and landings, since the chaff clouds can obscure developing precipitation events and mask potential favorable convection areas in the boundary layer associated with convergence lines. The resultant procedure is for NASA to issue a warning of imminent activity to the armed forces, who would then be required to release chaff away from the Florida peninsular and from a height no greater than 15 kft. It is likely that other WSR-88D systems will also be affected by these chaff releases.

Other observations address the issue of tuning adaptation thresholds. Observations such as presented below will be crucial in developing adaptation data thresholds for algorithms. One example is drawn from observations of storms containing mesocyclones failing the 10 km height threshold, and others whose rotational velocity fell just below the 45 kn threshold, yet were found the source of confirmed tornadoes. One tornado occurred with no decernible mesocyclone, 3 others failed the 10 km height threshold, while 8 others failed the velocity thresholds for the range detected. Use of the base velocity data by the NWSO prompted the retention of a tornado warning for a system that was previously associated with a tornado, but was now failing to be declared due to threshold failure. This procedure was fortuitous since a tornado developed within 10 min.

Of considerable concern is the performance of the Precipitation Processing System of algorithms. Two important studies provide insight into disturbing potential inadequacies to be expected within these algorithms, and some deficiencies of the WSR-88D systems itself. Analyses were performed on the two data sets of 12-14 September 1993 and 12-13 December 1993. Both periods represented complex precipitation regimes, the September period one where an advancing cold front containing thunderstorms later interacted with the remnants of Hurricane Lidia and produced significant rain of up to 8 in accumulation. The December period included primarily convective rain to the Northwest and stratiform to the Southwest and resulted in 0.5 - 1.5 in rainfall accumulation. In both analyses the radar rainfall estimates were compared against raingauges. It should be noted that the PPS algorithms did not include the gauge adjustment capability.

During both periods the WSR-88D at Twin Lakes drastically erred in the accumulation estimates. During the September storm the WSR-88D generally produced estimates of only 50% of observed values, reaching to 75-100% (to the NW where max near 4 in) in limited areas, only 50% within the broad central region about the radar, and less than 33% of gauge reports over broad areas to the SE (max near 8 in).

During the December storm the Twin Lakes WSR-88D generated small areas of slight over-estimates (up to 120%) towards the NW, and overwhelmingly large areas of significant under-estimates (60 - 20%) from the NW towards the SE. By comparison, the Norman OK (KOUN) WSR-88D registered only moderate areas of over-estimates (up to 180%), with most areas remaining under-estimates registering 40-70% of gauge totals. Neither radar measured more than 20% of gauge totals for ranges greater than 90 km, even though the PPS range is about 125 nm. During both periods the NW sector was more convective in nature, while the SE section more stratiform.

Both analyses indicated the Twin Lakes system was generating abnormally low reflectivities, 3-6 DBZ when compared to the Frederick OK (KFDR) system, and 5-10 dBZ lower than the Norman OK (KOUN). This is significant, representing potentially more than a 100% difference in derived rainfall rates and accumulation between the two systems. It was noted that while gauge adjustment would have provided better results by adjusting the rainrates upwards overall, the gauge adjustment would have been a global change that would have most likely resulted in greater over-estimates in the NW regions and but smaller underestimates in the SE region. As a test, the September data were adjusted for a Z-R representing a more tropical regime, with new values closer to those observed by the gauge array. This indicates the convective WSR-88D Z-R relationship for convective rain will often lead to significant errors in different microphysical regimes.

Numerous sources of potential error were considered within the December data, however, the general pattern of primarily convective rainfall to the NW and lower-altitude stratiform to the SE indicate similarities in error sources. Analyses indicated that;

a. Bright band effects were partly responsible for the over-estimates in the NW area (Dec)

b. The radar beam overshooting the stratiform precipitation to the SE greatly attributed to enhancing under-estimation at large range.

c. The WSR-88D radars are not similarly calibrated

d. The PPS gauge adjustment, being a whole field adjustment would still result in large errors in derived rainfall rate and accumulation.

e. The use of a single Z-R relationship will lead to significant error where not representative over the whole field of view

While these "effects" are all expected, the magnitude of the errors reported here clearly indicate that significant changes may be required to provide reasonable rainfall and accumulation results. The following suggestions are made:

a. Develop a "global" calibration scheme to ensure all radars are similarly calibrated

b. Develop the capability to use a Z-R that varies regionally, climatically, with storm regime, or user selection

c. Sectorize the bias adjustment process to modify estimates according to the detected bias for that sector, rather than use one bias adjustment for the entire field.

2. **NOAA NWS - Western Region W/WR3x2** (PAR)

Forecasting significant weather in the mountainous terrain of the West differs slightly in comparison to the central and Eastern United States. Examples of these forecast problems include: dry microbursts (Wakimoto et al. 1993), non-supercell tornadoes (Wakimoto and Wilson, 1989), radar precipitation errors due to beam filling and invalid Z-R relationships (Zawadzki, 1984), fog and stratus along the West Coast (Mass and Albright, 1987; Golding, 1993), and winds associated with wildfires (Goens, 1990). The Western region WSR-88D Project was created to examine these and other weather radar issues unique to the West; hence, improving the operational utilization of the WSR-88Ds.

Two important aspects are associated with the WSR-88Ds in the West; (1) 0.0 - 0.5 scan strategies at mountaintop locations, and (2) beam blockage caused by the terrain. These circumstances can be directly dealt with through WSR-88D system changes, although the meteorological side-effects associated with these changes are largely unknown. Thus, the technology changes will directly influence the work accomplished through this project. Other organizations working on areas related to improving the WSR-88D in forecast operations are; (1) NSSL actively working on storm hazard phenomena, as well as the WDSS system designed to improve usability of single Doppler radar data in an operational setting, (2) HRL removing bright band effects and applying real-time gauge data to products, and (3) the OSF that has responsibility for overall WSR-88D program support.

These efforts indicate a significant amount of activity is occurring in topics related to the Western region WSR-88D Project. This project is designed to examine issues in cooperation with, or unrelated to efforts underway at these organizations. Contact with all these agencies has been established with the intent of forming good working relationships. Any proposed changes to the WSR-88D as a result of this work will be submitted directly to the OSF Applications Branch through the Change management process.

Project Objectives

The overall objective of this project is to improve the operational utilization of the WSR-88D by:

a. Determining and documenting the capabilities and limitations of the WSR-88D in complex terrain

b. Determining and documenting the effectiveness of the WSR-88D in the West

c. Optimizing algorithm adaptable parameters for the West

d. Developing and testing new algorithms when necessary

e. Ensuring the information associated with the above objectives is adequately transferred to field operations

Accomplishing these objectives requires:

a. An operating UNIX workstation containing the algorithm software, and appropriate data display capability

b. The identification of cases representing "typical" Western United States weather. These cases will be selected to examine the specific meteorological phenomena in question.

c. A thorough analysis of these cases using the workstation and, when appropriate, an analysis of associated "null" cases

d. The documentation of these analyses via AMS journal articles, conference preprints, and Western Region technical publications

e. The testing of proposed algorithm changes at Western Region field sites (with prior OSF approval), when appropriate

f. Field site visits by SSD personnel to give seminars on the results of this project

Steps b through f are repeated for each meteorological situation under scrutiny. Given the availability of Level II WSR-88D data, the highest priority objectives which are obtainable at this time involve examining the precipitation processing algorithm, and general microburst research.

Some of the mentioned requirements are being currently met including:

> SSD should have an HP 755 workstation by September 1994. Software has been requested from the OSF. This software will have to be ported from the IBM R6000 to the HP workstation. SSD will port portions of NSSL's Radar Analysis and Display Software (RADS) to the HP workstation. Contacts have been established with NSSL, OH, and OSF personnel. Case study data records are being evaluated for suitability as test cases.

The near term efforts will be directed towards (to be completed Dec 1994):

a. Establishing an operating HP workstation within SSD and porting NSSL's RADS software

b. Porting the OSF algorithmic software to the HP system

c. Linking the OSF algorithms into the RADS software

d. identifying and obtaining data for 10-35 precipitation and 5-15 downburst cases from the Boise and Phoenix radars to use as test cases.

J. NEXRAD OPERATIONAL SUPPORT FACILITY (AR)

The following sections discuss work the WSR-88D Operational Support Facility (OSF) has been involved with since August 1993.

1. Velocity Dealiasing

Algorithms Section staff completed a study comparing the performance of the WSR-88D velocity dealiasing algorithm with two other algorithms on 40 elevation scans from a variety of weather conditions. The first algorithm was a version of the WSR-88D that was modified by NSSL scientists for the Terminal Doppler Weather Radar (TDWR). It and the WSR-88D both rely primarily on radial continuity. The second dealiasing technique examined was a two-dimensional scheme developed by the Forecast Systems Laboratory (FSL). Section staff recommend retaining the current WSR-88D velocity dealiasing algorithm and modifying it.

Above 20 m/s Nyquist velocity all the algorithms performed at nearly the same level of 97 percent correct, or higher. The NSSL TDWR algorithm had a slight statistical edge in performance because both the WSR-88D algorithm and the FSL algorithm set large numbers of valid data bins to "missing." However, the WSR-88D algorithm had the best performance discounting the data it sets to "missing." Section staff also determined that the performance of the Mesocyclone and TVS algorithms could be compromised by the data bins that were set to missing. Below 20 m/s Nyquist velocity the NSSL TDWR algorithm was clearly superior to the other two. Because the NSSL TDWR closely resembles the WSR-88D dealiasing algorithm Section staff believe it is most cost effective to work to improve the WSR-88D algorithm by incorporating some of the methods of the NSSL TDWR. The FSL algorithm was rejected because it was considerably slower and larger than either of the other two algorithms and did not offer improved performance.

Section staff have begun to test adaptable parameters to reduce the number of data bins set to "missing" by the WSR-88D algorithm. The algorithm can be forced to not set any data to "missing" by adjusting just one parameter. The Critical Success Index for the 40 cases (when combined into one super case) then improves from about 82 percent to a little over 94 percent. Section staff tested the effects on the Mesocyclone and Tornadic Vortex Signature (TVS) algorithms of changing the adaptable parameter using Level 2 archive data from May 11, 1992--a day in which there were 22 documented tornadoes in Oklahoma. By modifying the velocity dealiasing adaptable parameter, the number of mesocyclones detected increased from 79 to 83 and the number of TVSs increased from 2 to 4 over a four-hour period. However, the velocity products over the same period showed an increase in the number of small, contiguous regions of incorrectly dealiased velocities (82 versus 51.)

When the algorithm is forced to not set any data to "missing," the Section staff found the number of bins which the algorithm incorrectly labeled as needing dealiasing increased. Currently, a study is being conducted on the location and nature of these false alarms, and possible adaptable parameter or algorithm changes to reduce the number of false alarms. Another study is focusing on where the algorithm sets the velocities to missing in order to determine if a value for the adaptable parameter exists at which crucial velocities are not set to missing. In the original study of the algorithms, the NSSL TDWR algorithm did not have as many false alarms or velocities set to missing as occurred for the WSR-88D. (David Zittel, Jessica Burkhart - Algorithms Section)

2. Mesocyclone Algorithm

a. False Alarm

Algorithms Section staff investigated the utility of mesocyclone depth, top, and base tests to reduce the number of false alarms triggered by the Mesocyclone algorithm. Based on six data sets, Level II and Level IV data, the OSF found that bases, tops, and depths of mesocyclones are weakly correlated with the type and severity of damage they caused (i.e. tornado vs. hail). However, Algorithms Section staff have discovered that a combination of mesocyclone depth <u>and</u> rotational velocity are highly correlated to damage produced by mesocyclones. Investigations are under way to verify these ideas on independent data sets. (Robert Lee - Algorithms Section)

b. Failures To Identify Valid Mesocyclone

A committee of experts composed of OSF and NSSL personnel, have been studying why the mesocyclone algorithm fails to identify damage-causing circulations in some Eastern and Central Region storms. Seventeen F0-F2 tornado cases from five different sites have been studied (three Level II data sets, five Level IV data sets). These storms have been classified as mini-supercells and bow echoes with comma heads or leading edge shear zones. Even though they are quite shallow (20-30 Kft tops) many of them exhibit velocity and reflectivity signatures that are similar to their larger cousins that occur in the great plains.

An adaptable parameter study revealed that by reducing the number of pattern vectors from 10 to 6 increased the overall performance (i.e., critical success index). However, the false alarm ratio also increased. (Robert Lee - Algorithms Section)

3. Combined Shear Algorithm

The Combined Shear (CS) algorithm is being modified to remove Echo Power thresholding. The intent was to threshold on signal-to-noise which is already being done at the RDA. Echo Power thresholding results in the algorithm throwing out a large percentage of usable data. The improved CS algorithm should show more information.

In conjunction with the thresholding change, many modules of the algorithm are also being modified to improve efficiency. The CS algorithm uses a very large amount of CPU resources, which could lead to Input Buffer loadshed problems. Thus far, a 15-25% reduction in CPU utilization has been achieved. (Steve Smith - Software Engineering Section)

4. VAD Wind Profile Performance Studies

Algorithms Section personnel have been collecting soundings and WSR-88D VAD Wind Profiles (VWP) from 12 sites, and wind profiler data from three sites. Ten stations (Amarillo, Denver, Dodge City, Ft. Worth, Norman, Stirling, Topeka, Little Rock, Jackson, and Pittsburgh) are collocated with soundings, and Houston and Palm Beach are from 60 to 110 miles distant. Little Rock has the best correlation thus far, and Stirling has the lowest.

A computer program has also been developed which analyzes the statistical differences between vertical wind profiles. These analyses will be performed on the above data and is expected to reveal why, at times, the VWP product fails to capture the winds as represented by nearby soundings and profilers. Section personnel have delivered the analysis program to the Houston National Weather Service Office and are seeking other offices which may be interested in this project. Houston personnel plan on releasing Pibals to compare vertical wind profiles of direction and speed to radar derived wind profiles.

In addition to categorizing and studying VWP-sounding comparisons, Section Personnel are studying the adaptable parameters of the VAD algorithm. The main parameter of interest, the VAD Range, determines which elevation angles are used to compute the VAD winds. Early study results from Stirling, VA suggest that reducing the VAD range (i.e., forcing VAD computations from higher elevation angles) increases compatibility between radar and rawinsonde observations. This study requires extra rawinsonde or Pibal releases to capture the environmental winds during anomalous radar VWP events, and Level II data to be recorded. (Robert Lee, Jim Ingram, Jerry Klazura - Algorithms Section)

5. Radar Vs. Precipitation Gauge Comparisons

The performance of the WSR-88D Storm Total Precipitation (STP) algorithm is being analyzed by comparing high-resolution, radar-estimated accumulation values with accumulation measurements from rain gauges. Comparisons performed are similar to the methods of the WSR-88D bias adjustment algorithm which will adjust the STP amounts in real time using rain gauge data. The gauge data are compared with radar estimates from nine surrounding 2 km X 1 deg "bins" with accumulation value resolutions of .01 inch, and the best match is computed. Comparisons are planned for various sites throughout the US. So far the process has been tested for three rain events in Oklahoma. The initial results show an excellent comparison for the June convective storm case, and fairly substantial radar under-estimates for the December and April widespread stratiform cases. (Jerry Klazura, Scott Kelly, Tim O'Bannon - Algorithms Section)

6. Algorithm Performance Survey

The Algorithms Section mailed approximately 76 survey forms to all National weather Service (NWS) forecast offices and Center Weather Service Units (CWSUs) that have been using the WSR-88D for six months or more. In a cooperative effort with the Air Force, Headquarters Air Weather Service also sent survey forms to 27 Department of Defense (DOD) sites. Survey form recipients were asked to subjectively rate 19 different algorithms and products (Good, Average, Poor, Don't Use) and to provide additional comments. The Algorithms Section has received survey forms from 27 DOD, 13 CWSU, and 61 NWS sites (a total of 157 individual responses). The algorithms rated highest (in order) by all 3 agencies (combined) are as follows: Vertically Integrated Liquid, VAD Wind Profile, One Hour Precipitation, Storm Total Precipitation, Three Hour Precipitation, Velocity Azimuth Display (VAD), and Layer Composite Reflectivity. Algorithms rated lowest were Echo Top Contour, Hail, Severe Weather Potential, and Combined Shear. Algorithms used the most (in order) were VAD Wind Profile, Storm Tracking, Vertically Integrated Liquid, Storm Total Precipitation, Mesocyclone, and One Hour Precipitation. Severe Weather Potential, Echo Top Contour, Layer Composite Turbulence, and Combined Shear were used least often. (Robert Lee, Jerry Klazura - Algorithms Section)

7. Problems Identified With Storm And Hail Algorithms

The following minor operational problems with the WSR-88D Storm Series and Hail algorithms have been reported by field sites, investigated by the Algorithms Section, and correction requests submitted:

a. Duplicate storm IDs have been assigned to different storms. When a new storm is identified by the Storm Series algorithms, a unique alphanumeric ID is assigned from a "circular file" to that storm throughout its life cycle. The circular file has 125 storm IDs. After the circular file is emptied, the last ID available is reassigned to each additional storm thus resulting in duplicate IDs. Because 125 new storms must be identified in less than 13 volume scans, this is a rare problem.

b. Haphazard storm tracks and forecasts have been reported just after Radar Data Acquisition (RDA) outages. When the RDA is down and the Radar Products Generator (RPG) remains up, the RPG retains the past storm positions. After the RDA starts operating again, the Storm Series algorithms attempt to correlate the current storm positions with the past positions. The larger the time difference between the current and past positions, the more likely the current storms will be incorrectly correlated. (The situation is more volatile when actual storm tracks are not consistent.) When a storm is incorrectly correlated, the erroneous track can have large jumps in speed and direction.

c. The Hail Alphanumeric Product lists attributes related to hail for each storm identified by the Storm Series algorithm. Due to coding errors, the radar ID and the last two lines on each page of the product (which correspond to the 9th and 10th (and 19th and 20th) storms if present) are not displayed in the product. (Mark Fresch- Algorithms Section)

8. Algorithm Development On Workstation

The Algorithms Section has ported several WSR-88D meteorological algorithms to an IBM RS/6000 graphics workstation. Currently, the ported algorithms include the Precipitation Detection Function, the Precipitation Processing System (PPS), the Velocity Dealiasing algorithm, the Mesocyclone/Tornadic Vortex Signature algorithms, the Vertically Integrated Liquid algorithm, and the Echo Tops algorithm. In addition, the Algorithms Section has developed graphics modules using Advanced Visual Systems (AVS_{TM}) software to display PPS products, Base Velocity, Base Reflectivity, and Base Spectrum Width products. Section personnel are currently developing three-dimensional displays of WSR-88D data using (AVS_{TM}). (Tim O'Bannon, Travis Smith - Algorithms Section)

9. WSR-88D Level II Archive Of Storm Phenomena

Significant progress continued to be made in collecting, archiving, and distributing Level II data during 1994.

Data Collection. In June 1994, the NEXRAD agencies signed the Level II Data Collection Plan which establishes the policy for Level II data collection, recorder supply and repair, names the National Climatic Data Center (NCDC) as the Level II Archive Center, and requires the OSF to provide the required technical documentation. In the summer of 1994, the Air Force and NWS committed funds to equip all Air Force and NWS WSR-88D Systems with Level II recorders. The deployment of recorders, approximately 25 per month, is scheduled to begin in January 1995.

Data Archiving. Earth System Data Information Management (ESDIM) Program support of the NCDC and the Radar Data Archive Service Center (off-site Level II tape backup storage facility) operations continued in FY94. By August 1994, approximately 2500 Level II tapes were in the NCDC. The OSF has submitted a budget proposal to ESDIM to continue this support for FY95. The NWS Office of Systems Operation has included basic archiving of Level II data as a budget item for FY96 and beyond. The NWS Office of Meteorology has included value-added user services for the Level II archive to their budget for FY96 and beyond.

Data Distribution. The NCDC began producing copies of Level II tapes in the fall of 1993. By the summer of 1994, the NCDC had filled approximately 150 requests for Level II data and shipped over 450 tapes. The NCDC also was distributing copies of software developed by the National Severe Storms Laboratory to read and display Level II data on a UNIX workstation. The NSSL, OSF, and NCDC are planning another Level II Data User Conference, ESDIM supported, that will be held in the spring of 1995 in Asheville. (Lt Col Tim Crum - Applications Branch)

10. Data Quality Assessment

The Forecast Systems Laboratory (FSL) in collaboration with the National Center for Atmospheric Research (NCAR) are working with the OSF under a Memorandum of Understanding in this area. Also, the OSF has activated a Calibration Action team. Work includes development and testing of a network-wide calibration scheme, identification of an approach to treat sea clutter, development and testing of an anomalous propagation mitigation scheme, and development of a clutter filter bias error correction scheme.

The OSF has developed a new method for receiver calibration which will be released to the field in November. This calibration technique uses external, traceable calibration test equipment in conjunction with the on-line calibration software to verify the WSR-88D built-in calibration routines.

The OSF/FSL is investigating systematic bias errors obtained using the Unisys-provided suncheck code. After correcting boresite errors in the solar antenna gain check, typical bias errors were 3 dB with standard deviations of 0.2 dB. Initial indications were that an incorrect calculation of excess noise ratio of internal noise source was a dominant source of error. FSL is analyzing the code to determine all error sources

Another area of OSF work is in the reduction of the effects of anomalous propagation, using a "clutter recognizer". FSL is analyzing data sets for filter bias verification. The basic scheme will use a postprocessing algorithm to select filtered or non-filtered outputs while a target recognizer will choose whether to select filtered or non-filtered. The decision will be based upon spatial characteristics of echo. A bias error correction would then be applied for the filtered weather returns. It is anticipated that this technique will be evaluated in FY-95. (Ed Berkowitz - Director's Office)

11. Human Factors Studies

HFG Involvement with OSF Engineering Projects.

The OSF Human Factors Group (HFG) has worked with the Engineering Branch on several projects. The work primarily involved the application of well established human factors principles to layout, labeling, and menu structure to increase usability and accommodate user expectations.

a. Rotational Velocity Functionality At PUP

The Human Factors Group met with representatives from the OSF Engineering and Training Branches. The HFG subsequently provided refinements to the initial implementation plans which ensured a higher degree of usability for the forecasters.

b. STATUS of PRECIPITATION UCP Menus

The Engineering Branch requested HFG review of new UCP menus associated with the "Status of Precipitation". Work was done by the HFG to refine the menu layouts, format, labeling, and information content to attain a greater degree of usability for the forecasters. Recommendations and examples were returned to the Engineering Branch in June, 1994.

c. Range Blanking PDR/CDR Meeting (6/14/94)

Informal recommendations were made at the meeting to maintain consistency in the UCP password format. Also, it was mentioned that the Spot Blanking notice to the primary users was insufficient. A preliminary recommendation was to place a thin red strip across the top of products bearing spot blanking.

d. UCP Editable Precipitation Products Levels

Work similar to the above was accomplished. Issues involved with the design of the specific UCP menus were recommended.

e. UCP Help Screens

Several pages of additions and revisions to UCP Help Menus were passed to the HFG for review and recommendations. This task is currently being undertaken. Major, short-term revisions to these proposed menus from the HFG are not expected. These menus contradict fundamental principles and practices of human factors since they repress ease-of-use by the primary user of the UCP. Long-term plans to improve and enhance this aspect of the UCP are underway through the HFG.

f. HFG Projects with NSSL

The majority of involvement with NSSL projects resulted from OSF funding provided by a Memorandum of Understanding (MOU) applicable to the 1994 calendar year. Prior to 1994, collaboration with NSSL was dedicated to iterations of the WVS software and documentation. Improvements to the Radar Analysis and Display System (RADS) were accomplished through substantial interaction between NSSL and the OSF Human Factors Group. As a multidisciplinary team, dramatic changes to the RADS human-computer interface (HCI) were made prior to operational testing at the Phoenix, AZ Weather Forecast Office (WFO). The HFG has been involved with substantial applications of the human factors engineering methodology through this project.

Project activities included prototyping, testing (including usability metrics), training, analysis, documentation, collaboration with other human factors specialists, and evaluations of lessons learned. The experimental analysis and evaluation of the HCI have continued after the Phoenix test has ended.

g. WVS

The HFG worked with NSSL to refine the Earth System Data and Information Management (ESDIM) Program and the WSR-88D Visualization System (WVS) Documentation. ESDIM and WVS are being distributed with Level II data from the National Climatic Data Center (NCDC).

h. RADS Redesign Team

Numerous meetings convened to attack specific RADS interface concepts. Piecewise implementation occurred as the redesign team formulated and agreed to changes. Prototypes of possible interface designs were created and presented to the team by the HFG. Discussions regarding specific topics of the new RADS interface were often fortified by the HFG knowledge of established human factors principles.

i. RADS Experiment

RADS was operationally tested during the summer of 1994 at the Phoenix WFO. The purposes of the experiment as they pertained to the HFG were to 1) apply established human factors usability testing in order to establish quantifiable techniques, and, 2) incorporate findings toward the benefit of the WSR-88D program. The experiment required substantial preparation. Training of participant and gathering of other baseline information were to be accomplished. Equipment set-up and testing procedures were established. The human factors methodology involved the use of audio and video data collection and techniques for evaluating. In the context of a Video Analysis Method (VAM), a taxonomy has been tentatively formulated to provide an ordering and classification scheme toward empirical analysis of the RADS HCI. A Human Factors professor, Dr. Schlegel, and a student preparing his Masters thesis on the analysis of the RADS experiment have greatly enhanced and benefitted the HFG efforts. (John Jarboe, Randy Steadham - Applications Branch)

K. OKLAHOMA UNIVERSITY

Center for Analysis and Prediction of Storms (CAPS) (AR)

1. Wind Retrieval Methods

Some of the efforts underway at the University of Oklahoma include utilization of Doppler radar for use in data assimilation models. While not representing a WSR-88D algorithmic technique, the use of WSR-88D Doppler data to drive a kinematic and thermodynamic analysis of the environment offers much potential in understanding the surrounding environment. Such techniques may some day reside in workstations that are available for the forecaster in more fully analyzing the WSR-88D product data, and ancillary analyses that assist in understanding and forecasting. In addition, reconstruction of environmental variables may potentially be useful in tuning WSR-88D algorithmic adaptation parameters.

Mesoscale data assimilation is being attacked on several fronts at CAPS. One of the key scientific challenges in storm-scale weather prediction is the problem of estimating, dynamical, thermodynamical, and microphysical variables from limited and/or indirectly observed data using various constraints. Much of the efforts at CAPS has focused on deriving the full wind vector field from single-Doppler radar data. Substantial progress has been made in this direction with so-called "advective retrievals", that is retrievals that work with scalar conservation equations (e.g. for radar reflectivity). Among these retrievals are the diagnostic procedures of Gal-Chen and Zhang (1993) and Shapiro (1993), 1994) and the simple-adjoint procedures of Xu et al. (1993, 1994a,b). Substantial progress has also been made in full-model adjoint retrievals of wind and thermodynamic variables (e.g. Sun et al. 1991) and in the forward assimilation of single-Doppler data into a numerical model (Liou et al. 1991). These retrieval/assimilation techniques may have important implications for hazard warning and nowcasting as well as for the initialization of numerical weather prediction models. Although these schemes have been tested primarily with research radar data (e.g. Phoenix II) and TDWR data, one of the intended CAPS applications is to utilize radar data from the WSR-88D systems.

L. US AIR FORCE PHILLIPS LABORATORY (AR)

The Phillips Laboratory (PL) group is currently focused upon mesocyclone detection, with a new effort characterizing the storm structure via analysis of weak echo regions now underway. Sadly, the polarimetric efforts at PL have been curtailed. Due to funding difficulties the powerful PL polarimetric radar, and primary scientist J. Metcalf, have been assigned other duties.

1. Mesocyclone Detection

Phillips Laboratory (PL) is interested in mesocyclone quantification as a means to assess the associated tornado and hail threat. In quantifying the mesocyclone it is important that the procedure followed yields accurate results. Because single-Doppler data provides a limited perspective, it is standard practice to interpret the mesocyclone velocity couplet as a circular flow. In fact, the current operational criteria for mesocyclone detection that are incorporated into every mesocyclone detection algorithm are based on the assumption that mesocyclone flows are circular. The degree to which mesocyclone flows depart from the simple circular model is not well understood.

PL's mesocyclone modelling effort evolved out of the concern that the current model used to interpret single-Doppler mesocyclone data may not be sufficiently accurate. Single Doppler mesocyclone observations are generally not well simulated by the circular model. An example of this is seen in Desrochers (1992). It is also apparent from multiple-Doppler derived vorticity fields that the mesocyclone vorticity structure is far more complex than is provided by the circular model (e.g. Brandes, 1984).

The objective of PL's mesocyclone modelling effort is to examine the effects of shape and velocity distribution on mesocyclone appearance by single-Doppler radar. The shape of the model mesocyclone flow can vary from a circle to an ellipse of the appropriate eccentricity, to fit the shape of the observed mesocyclone. In the circular model, the velocity variation across the core region is constrained to be linear and vertical vorticity is uniform. In the new model, velocity can vary as a sinusoid across the core region, and therefore, vorticity is not necessarily uniformly distributed and a better simulation of the single-Doppler mesocyclone is achieved. The model allows asymmetric flows, where the flow is enhanced towards one side of the mesocyclone, to simulate the horseshoe-shaped vorticity field that is sometimes observed at low levels of the mesocyclone. The impact of orientation of the flow relative to the radar on the single-Doppler appearance is simulated by the model. Range effects are simulated as well. Vorticity and divergence fields are generated separately in the model. Processing in this manner reveals the separate contributions to the single-Doppler mesocyclone appearance.

The primary contribution of the modelling effort to date has been to add to the understanding of the interpretation of the single-Doppler radar data. During fiscal year 1995 the thrust of mesocyclone modelling work will be to automate the analysis technique. One of the primary goals of the effort is to achieve more realistic estimates of mesocyclone kinematics through application of a more realistic model. It is hoped that improved kinematic estimates will lead to improved warnings for severe weather.

M. NOAA TECHNIQUES DEVELOPMENT LABORATORY

The Techniques Development Laboratory continues development of probabilistic forecast methods. Methods and information gleaned from their recent efforts in forecasting radar reflectivity fields are being applied to the areas of severe local storms and rainfall. Additional work has also continued in RADAP II data archiving.

1. Short Range Reflectivity Forecasting

While research is underway in methods for forecasting severe weather and rainfall, results are not available for this report. However, some further details of the extrapolative-statistical forecasting of radar reflectivity fields using Oklahoma RADAP II data are available. This method generates 30 and 60 minute forecasts of zero-tilt reflectivity (ZTR). The process includes estimation of a Storm Motion Vector to extrapolate fields of ZTR, VIL and echo tops, and use of a set a probabilistic relationships between the new "forecast ZTR" and these extrapolated fields. Either an estimate of the ZTR at that point, or the probability of exceeding a ZTR threshold, may be generated. This method does not specifically forecast area evolution, other than via carrying the most recent field shape forward in time to the next forecast period. The Storm Motion Vector is estimated by a binary matching process of the observed current field with the previous ZTR field (on a 4 x 4 km grid). To minimize erratic estimates, a 30 min time separation is typically used.

As a measure of skill, both 18 and 40 dBZ field thresholds were tested against persistence (non-extrapolated) fields for comparison. Surprisingly, the POD, FAR, and CSI for both 30 min (12 km grid box) and 60 min (20 km grid box) forecasts were found nearly identical for the 18 dBZ extrapolated and persistence fields at about 70%, 25%, 57%, (57%, 40%, 40%, (60 min)), respectively. This result indicates that both methods generated (e.g. for 30 min) about 40% as many misses (did not forecast presence) as hits, and about 35% as many false alarms (no true presence where forecast), as correct forecasts of ZTR presence. The 40 dBZ ZTR field results showed greater separation (about 10%) between extrapolation and persistence results, however with a POD, FAR, CSI of only about 35%, 65%, 22%, respectively.

The mean reflectivity error in forecasts was found near 10 dBZ, indicating specific spatial forecasts of ZTR was not warranted. However, the percentage of 12 km grid regions in which 40 dBZ echoes occurred was nearly linearly related to forecasts of ZTR, VIL, and tops (at the forecast location). Linear relationships were developed between these variables to yield the probability of exceeding 40 dBZ 30 and 60 min later. Thus, forecasts for the "potential" of rainfall were developed. Peak CSI (about .43) for both times occurs a near a threshold probability of 35 %. While a better forecast tool, the utility of these forecasts is not completely understood. Because of the well behaved probabilistic relationships between these precipitation and storm related variables, efforts are underway to apply these techniques to parameters such as rainfall accumulation that are spatially and temporally less variable than ZTR.

2. Data Archiving Of RADAP II

A revised RADAP II User's Guide was recently issued (April 1994) to provide detailed information on RADAP II data acquired between 3 March 1985 to 30 September 1992. While these data represent quantized reflectivities from non-Doppler systems (WSR-57 & WSR-74S), they have been successfully employed in a number of studies relating storm precipitation characteristics to severe weather phenomena. The steps include 0 - 15 for reflectivity ranges of 18.5 - 57.0 dBZ (warm season) and 18 - 45 dBZ (cold season). These data include some quality control (range normalization, atmospheric attenuation, hybrid scan to minimize ground clutter, and point target removal checks. The data are two degree beamwidth (180 radials/full PPI) and cover the range interval 10 - 126 nm. Data are supplied on 9-track magnetic tape media and may be requested from the National Climatic Data Center.

N. UNIVERSITY OF NORTH DAKOTA

1. Freezing Rain

The University of North Dakota (UND) efforts have previously focused on freezing rain detection. After quite successful characterization of the unique Doppler velocity and reflectivity factor signatures within 5 freezing rain events, UND is waiting support to develop a proposed algorithm (Prater and Borho, 1992) based on these signatures.

2. Microburst Studies

In the area of hazardous wind detection, UND issued a final report in comparison of the UND and LL C-band radars simultaneously observing microbursts. Results indicated minimal differences in location (1 km average), time of detection (average 23 sec), differential wind velocity (average 0.01 m/s) and reflectivity factor (average 1 dBZ). The microbursts had a slight preference to rotate cyclonically (55%) rather than anticyclonically (45%) in the Orlando Florida domain, considerably different from the NIMROD results near Chicago that found about 90% rotated cyclonically. These comparisons are similar to those made by UND when the LL radar was S-band, indicating the WSR-88D system capability (using appropriate algorithms) to detect microbursts should be comparable to that of the TDWR.

O. **UNISYS** (PAR)

1. Tropical Algorithms

UNISYS, in cooperation with Florida State University, has successfully demonstrated the tropical forecasting algorithms on simulated and real data sets. They have also been demonstrated to the National Hurricane Center in Miami using real hurricane data. They have not been employed with WSR-88D data to data due to the lack of adequate WSR-88D data. This Tropical Algorithm package includes:

Storm Identification/Location (REFLEYE)
Velocity Eye Location and Storm Strength (INTNSVORT)
Eye Tracking and Forecast Position (STORMTRACK)
Typhoons/Hurricane Storm Surge Forecast (STORMSURGE)

UNISYS is prepared to discuss a joint development program for completion and testing of these algorithms on a WSR-88D system.

UNISYS, through its Independent Research and Development Program, has also sponsored development of an approach to Improved Velocity Dealiasing for WSR-88D systems. Extensive simulation testing has demonstrated significant improvement in reduction of range ambiguities. UNISYS is interested in establishing a joint program with the U.S. Government to continue this development and prove its advantages in a field test using a WSR-88D system.

APPENDIX A: LIST OF ACRONYMS

AGFA	Advanced Gust Front Algorithm
AGL	Above Ground Level
AMS	American Meteorological Society
AR	As Received
AP	Anomalous Propagation
ARTCC	Air Route Traffic Control Center
ASR-9	Air Surveillance Radar–9th generation
ATI	Area-Time Integral
AWIPS	Automated Weather Information Processing System
CHILL	U. of Chicago and Illinois State Water Survey Doppler Radar
CLADA	Convergence Line Automated Detection Algorithm
CM	Center of Mass
CSI	Critical Success Index
CSU	Colorado State University
DAAC	Distributed Active Archive Center (NCDC)
DemVal	Demonstration/Validation
DFAD	Digital Feature Analysis Data
DSD	Drop Size Distribution
DSP	Digital Signal Processor
ECP	Engineering Change Proposal
ERKE	Excess Rotational Kinetic Energy
ESDIM	Earth System Data and Information Management
ESR	Environmental Shear Regions
FAA	Federal Aviation Administration
FAR	False Alarm Ratio
FFP	Flash Flood Potential (WSR-88D)
FSL	NOAA Forecast Systems Laboratory (NOAA/ERL/FSL)
FSS	Flight Service Station
FTL	Functional Template Correlation
GFA	Gust Front Algorithm
GP	US Air Force Phillips Laboratory Geophysics Directorate (formerly the Air Force Geophysics Laboratory (AFGL)
GSD	Geographical Situation Display
HDA	Hail Detection Algorithm (NSSL)
HDP	Hourly Digital Precipitation (WSR-88D)
HRL	NOAA Hydrologic Research Lab (NOAA/OH/HRL)
ITWS	Integrated Terminal Weather System
LAPS	Local Analysis and Prediction System
LL	Lincoln Laboratory
MCS	Mesoscale Convective System
MDA	Mesocyclone Detection Algorithm
MHR	Mile High Radar

MIGFA	Machine Intelligent Gust Front Algorithm
MIT	Massachusetts Institute of Technology
MSFC	NASA Marshall Space Flight Center (NASA/MSFC)
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCDC	National Climatic Data Center
NEXRAD	NEXt Generation Weather RADar
NIDs	NEXRAD Information Dissemination Service
NOAA	National Oceanic and Atmospheric Administration
NSSL	NOAA National Severe Storms Lab (NOAA/ERL/NSSL)
NWS	NOAA National Weather Service (NOAA/NWS)
OSF	NEXRAD Operational Support facility
PAR	Partially As Received
PL	Phillips Laboratory (PL/GPAP Prediction Branch)
POD	Probability of Detection
PPI	Plan Position Indicator
PPS	Precipitation Processing System
PRF	Pulse Repetition Frequency
PRI	Pulse Repetition Interval
PRT	Pulse Repetition Time
PVF	Potential Vortex Fit
RAP	NCAR Research Applications Program (NCAR/RAP)
RCV	Rankine-Combined Vortex
RDP	NCAR Atmospheric Technology Division Research Data Program (NCAR/ATD/RDP)
RFC	River Forecast Center
RSF	NCAR Atmospheric Technology Div. Remote Sensing Facility (NCAR/ATD/RSF)
SCIT	Storm Cell Information and Tracking
SHI	Severe hail Index
SNR	Signal to Noise Ratio
STP	Storm Total Precipitation (WSR-88D)
STX	Hughes-STX Corp.
TAC	Technical Advisory Committee
TDA	Tornado Detection Algorithm (NSSL)
TDL	NOAA Techniques Development Lab (NOAA/NWS/TDL)
TDWR	Terminal Doppler Weather Program
T-LAPS	Terminal-LAPS
TN	Technical Need
TRMM	Tropical Rainfall Measuring Mission
TVS	Tornado Vortex Signature
VAD	Velocity Azimuth Display
VIL	Vertically Integrated Liquid Water
VPR	Vertical Profile of Reflectivity
VVP	Volume Velocity Processing
WARP	Weather and Radar Processor
WFO	NWS Weather Forecast Office

WIA	Weather Impacted Airspace
WSP	Wind Shear Processor
WBZ	Wet Bulb Zero
WSR-88D	Weather Surveillance Radar - 1988 Doppler (NEXRAD)
ZTR	Zero Tilt Reflectivity

APPENDIX B: TABLE OF GROUPS/INDIVIDUALS SURVEYED

The following table lists all groups that were contacted via mail and/or fax and/or phone. The groups that responded with material to be used within this review are indicated by entries in the Topics column.

Org	Individual	Tel #	Address	Topic
CSU	V.N. Bringi S. Rutledge P. Kennedy	(303) 491-5595 FAX 491-2249 (303) 491-6248	Colorado State U. Dept. Atmos. Sci. Fort Collins, CO 80523	Storm Structure Polarimetry
FSL	J. McGinley Matt Kelsch	(303) 497-6161 (303) 497 6719	NOAA/FSL/LAP Dept. of Commerce 325 Broadway Boulder, CO 80303-3328	Rainfall Estimation Workstations
FSU	P. Ray	(904) 644-1894	Florida State U. Dept. of Meteor. 404 Love Bldg. Talahassee, FL 32306	Tropical Cyclones Wind Retrieval
HRL	R. Fulton	(303) 713-0640 FAX 713-0963	NOAA/Off. of Hydrology/HRL 1325 E-W highway W/OH3 Silver Spring, MD 20910	Precip Algorithms Bright Band Flash Flood Prediction
HSTX	F.I. Harris	(617) 377-7208 (Phillips) FAX 377-8892 (617) 863-0677 (Lexington)	Phillips Laboratory PL/GPAB Hanscom AFB, MA 01731	Mesocyclone Detection WER Detection
LL	J. Evans	(617) 981-7433	Air Traf. Surv. Group MIT/Lincoln Lab Lexington, MA 02173-0073	Storm Tracking AP & Clutter Gridded Winds GF & MB Wind Shift Signal Processing
MSFC	S. Goodman	(205) 544-1683 FAX 544-5760	NASA/MSFC ES42 Huntsville, AL 35812	Data Fusion Precip Algorithms

Org	Individual	Tel #	Address	Topic
NCAR	J. Wilson M. Cornelius	(303) 497-8818 FAX 497-2044	ATD/Rem. Sen. Fac. NCAR P.O. Box 3000 Boulder, CO 80307-3000	Storm Tracking Initiation Clutter Snow Hail Turbulence Wind Retrieval Velocity Dealiasing Bistatic Radar Workstations Pulse Compression Polarimetry
NCAR	F. Pratte R. Rasmussen	(303) 497-2021 (303) 497-8430	NCAR P.O. Box 3000 Boulder, CO 80307-3000	(combined with above)
NSSL	D. Zrnic M. Eilts (Wea. Haz. Avia.) M. Jain	(405) 366-0403 (405) 366-0450 (405) 366-0491 FAX 366-0472	NOAA/NSSL Dept. of Commerce 1313 Halley Circle Norman, OK 73069	Mesocyclone & Tornado Detection Velocity Dealiasing
NWS W/AR 4	G. Hufford	(907) 271-3508 FAX 271-3711	NWS, W/AR4 Rm 517 222 W. 7th Ave. Anchorage AK 99513-7575	
NWS W/CR 3	R. Livingston	(816) 426-5672 FAX 426-3270	NWS, W/CR3 Rm 1836 601 East 1th St. Kansas City, MO 64106-2897	
NWS W/ER 3	G. Carter P. Stokols	(516) 244-0133 FAX 244-0167	NWS, W/ER3 630 Johnson Ave Bohemia, NY 11716-2626	
NWS W/PR 1	J. Partain	(808) 541-1671 FAX 541-1678	NWS, W/PR1 P.O. Box 50027 Honolulu, HI 96850-0001	
NWS W/SR 3	D. Smith	(817) 334-2671 FAX 334-3475	NWS, W/SR3 Rm 10A26 819 Taylor St. Ft. Worth, TX 76102-6171	Operations

Org	Individual	Tel #	Address	Topic
NWS W/WR 3	K. Mielke	(801) 524-5131 FAX 524-5246	NWS, W/WR3 Rm 1210 125 S. State St. Salt Lake City, UT 84111	Operations
OSF	LtCol T. Crum (Applications) P.G. Klazura	(405) 366-6530 (ext. 252) (ext. 267) FAX 366-6555	NOAA/NEXRAD/OSF Dept. of Commerce 1200 Westheimer Dr. Norman, OK 73069	Velocity Dealiasing Mesocyclone Algorithm Combined Shear VAD Analyses Radar/gauge Comparison Archiving Human Factor Algorithm Perform'ce
OU	W. Beasley	(405) 325-6561 FAX 325-7689	Univ. Oklahoma Dept. Meteor. Sarkey's Energy Center Rm 1310 100 East Boyd Norman, OK 73019-0628	Wind Retrieval
PL	P. Desrochers	(617) 377-2948 FAX 377-8892	Phillips Laboratory PL/GPAB Hanscom AFB, MA 01731	Mesocyclone Detection WER Detection
TDL	D. Kitzmiller	(303) 713-1781 FAX 713-0003	NOAA/NWS/TDL W-OSD23 1325 E-W highway Silver Spring, MD 20910	Reflectivity Forecasting Severe Weather Potential
TX A&M	M. Biggerstaff	(409) 847-9090 FAX 862-4466	Texas A & M College of Geosciences & Maritime Studies Dept. of Meteor. Eller O & M Bldg RM 1204 College Station, TX 77843-3150	

Org	Individual	Tel #	Address	Topic
UND	R. Rinehart	(701) 777-2183 FAX 777-2940	Univ. N. Dakota Cen. Aerospace Sciences Dept. Atmos. Sci. P.O. Box 9006 Grand Forks, ND 58202-9006	Freezing Rain
UNISYS	R. Benzinger L. Lemon	(516) 574-3783 (816) 373-9990 FAX 574-3318	Business Development (MS 3R116) Systems Development 365 Lakeville Rd Great Neck, New York, NY 11020-1696	Tropical Cyclones Dealiasing

APPENDIX C: BIBLIOGRAPHY

APPENDIX C: BIBLIOGRAPHY

The bibliography was derived from both extensive manual and electronic searches. The manual search was implemented to enable the development of the NEXRAD-relevance rating and summary. The rating ranges from L (Low), to M (Moderate), and to H (High). Typically, a rating of Low indicates non-NEXRAD work of general scientific interest only. A rating of M indicates the research results may potentially affect current or future forms of NEXRAD applications, or the information may promote greater understanding of the environment within which NEXRAD operates. A rating of H indicates direct current NEXRAD applicability. The rating is shown as "[#]" along with the brief summary "italics" below the citation.

A designation of [-] indicates that the article was not reviewed. This year an effort was initiated to include references mentioned by respondees, as a point of interest. These were almost exclusively published outside the review period for this report, and thus have not [-] been reviewed.

The author is solely responsible for the rating and gist given each article. The following is a list of journals that were reviewed.

Atmospheric Environment
Boundary Layer Meteorology
Bulletin of the American Meteorological Society
Bulletin of the World Meteorological Organization
IEE Proceedings - Radar, Sonar, And Navigation
IEE Proceedings - Science, Measurement, And Technology
IEE Proceedings - Vision, Image, And Signal Processing
IEEE Signal Processing Letters
IEEE Signal Processing Magazine
IEEE Transactions On Antennas And Propagation
IEEE Transactions on Geoscience and Remote Sensing
IEEE Transactions on Image Processing
IEEE Transactions on Neural Networks
IEEE Transactions on Pattern Analysis and Machine Intelligence
IEEE Transactions on Signal Processing
International Journal of Remote Sensing
Journal of Applied Meteorology
Journal of Atmospheric and Oceanic Technology
Journal of the Atmospheric Sciences
Journal of Climate
Journal of Geophysical Research
Journal of the Meteorological Society of Japan

Meteorology and Atmospheric Physics
Monthly Weather Review
Pattern Recognition
Pattern Recognition Letters
Quarterly Journal of the Royal Meteorological Society
Radio Science
Russian Meteorology and Hydrology
Signal Processing
Tellus
The Meteorological Magazine
Theoretical And Applied Climatology
Weather and Forecasting

M.T. Abuelma'atti, "Simple Methods For Calculating Fourier Coefficients Of Experimentally Obtained Waveforms", IEE Proceedings of Science, Measurement, And Technology, **141**, 1994, pp177-178
[L, Alternate expressions for calculating Fourier coefficients.]

Angevine, W.M., Doviak, R.J., and Z. Soibjrm, "Remote Sensing Of Vertical Velocity Variance And Surface Heat Flux In A Convective Boundary Layer", Journal Of Applied Meteorology, **33**, 1994, pp977-983
[L, Boundary layer characteristics from profiler observations. Shows variance reaches maximum (2.5 m^2/s^2) at roughly .3 times boundary layer depth.]

A.H. Auer Jr., "Hail Recognition Through The Combined Use Of Radar Reflectivity And Cloud Top Temperatures", Monthly Weather Review, **122**, 1994, pp2218-2221
[H, Very interesting. Method combines cloud top temperature derived from satellite IR data and low level (below melting level) scan radar reflectivity to discriminate between hail, and no hail or heavy rain within New Zealand storms. Satellite data within 30 min of radar observations, and cloud top may be taken from other sources (e.g. radar 15 dBZ altitude and sounding). Striking discrimination seen in nomogram of T_B versus Z_{HH} delineating the hail, heavy rain regions. Observations also provide some size discrimination. POD, FAR, and CSI changed from 56 to 91%, 22 to 12%, and 48 to 81% when hail forecast derived from T_B and Z_{HH} rather than Z_{HH} alone. Techniques not applied to rapidly growing or dissipating storms. Similar but more successful than earlier US techniques?]

R.L. Bankert, "Cloud Classification Of AVHRR Imagery In Maritime Regions Using A Probabilistic Neural Network", Journal Of Applied Meteorology, **33**, 1994, pp909-918
[L, Interesting from standpoint of automated technique that classifies cloud types (classifications) over sub-regions of field of view (16X16 pixels), as determined from sub-region characteristics of spectra, texture, and physical parameters. Quite successful (90% success). Use of texture as in clutter detection or image classification.]

Bateman, M.G., Rust, W.D., and T.S. Marshall, "A Balloon-Borne Instrument For Measuring The Charge And Size Of Precipitation Particles Inside Thunderstorms", Journal Of Atmospheric And Oceanic Technology, **11**, February 1994, Part 2, pp161-169
[L, Measures 1 particle at a time, with examples of charge, size, and fallspeed measurements taken inside thunderstorms.]

Baumgartner, M.F., and G. Apfl, "Towards An Interpolated Geographic Analysis System With Remote Sensing, GIS, And Consecutive Modelling For Snow Cover Modelling", International Journal Of Remote Sensing, **15**, 1994, pp1507-1518
[L, Integrates satellite, climate, hydrologic, topographic, etc. data with off-the-shelf components. Designed with emphasis on determining/tracking snow cover.]

Behar, E., and Bom Son Lee, "Full-Wave Solutions For Rough-Surface Bistatic Radar Cross Sections: Comparisons With Small Perturbation, Physical Optics, Numerical, And Experimental Results", Radio Science, **29**, 1994, pp407-429
[L, Interesting only for use of non-approximated theory that works over full range of small-perturbation thru physical optic solutions (surface features << to >> wavelength). Verifies that irregular surface can be approximated by 2-D joint Gaussian function of surface heights and slopes (i.e. surface hgts and slopes are uncorrelated).]

Belon, A., and I. Zadwadzki, "Forecasting Of Hourly Accumulation Of Precipitation By Optimal Extrapolation Of Radar Maps", 26'th International Conference On Radar Meteorology, 1993, Paper 24.8
[Previously reviewed]

M. Berman, "Automated Smoothing Of Image And Other Regularly Spaced Data", IEEE Transactions On Pattern Analysis And Machine Intelligence, **16**, 1994, pp460-468
[L, Uses new technique of minimum noise fraction (MNF) that finds noise by maximizing SNR. Seems very time consuming.]

Biggerstaff, M.I., and R.A. Houze Jr., "Kinematics And Microphysics Of The Transition Zone Of The 10-11 June 1985 Squall Line", Journal Of The Atmospheric Sciences, **50**, 1993, pp3091-3110
[L, Transition (sometimes called precipitation free) zone that lies between leading convective line and trailing mesoscale region identified as containing mean subsidence and lowered Z. Study finds zone contains an upper and lower negative vertical velocity regime. Upper zone driven by interaction of updraft with stable air, possibly generating gravity waves, and may result from rearward drift of downdrafts associated with dissipating and old Z cells. Lower zone driven by negative buoyancy (max -W at melting level) from melting and evaporation of precipitation ejected to this region from lower rear portion of convective line. Thus the three squall line zones of convective leading edge, transition, and trailing mesoscale are characterized by updraft (& minor downdraft with older cells), subsidence (2 downdraft zones), and an upper ascent and lower descent zones separated by bright band, respectively. Upper downdraft appears to play little role in Z minimum. Lower downdraft removes moisture from air, not allowing small ice crystals to grow and inhibiting aggregation, and is responsible for minimum Z in this zone.]

Bluestein, H.B., Hrebenach, S.D., Chang, C.-F., and E.A. Brandes, "Synthetic Dual-Doppler Analysis Of Mesoscale Convective Systems", Monthly Weather Review, **122**, 1994, pp2105-2124
[M, Interesting technique to be applied to single Doppler radar. Radar makes volume scan, then after storm advected performs another volume scan, and assuming stationarity of storm, two scans assumed simultaneous from two different viewing locations. Despite obvious concerns about stationarity, demonstrated to produce reasonable flow characteristics in MCS.]

Bohne, A. R., Harris, F. I., Sadoski, P. A., and D. Egerton, "Short-Term Forecasting of Cloud and Precipitation", AFGL-TR-88-

0032, January 1988
[Previously reviewed]

E.A. Brandes, "Vertical Vorticity Generation And Mesocyclone Sustenance In Tornadic Thunderstorms", Monthly Weather Review, **112**, 1984, pp2253-2269
[-]

Brown, R.A., and R.J. Meitin, "Evolution And Morphology Of Two Splitting Thunderstorms With Dominant Left-Moving Members", Monthly Weather Review, **122**, 1994, pp2052-2067
[L, Preferential GF movement results in preferential new development along left flank of storms. Both storms cycle through 10 updrafts about 11 min apart each.]

Brown, R.A., and V.T. Wood, "On The Interpretation Of Single-Doppler Velocity Patterns Within Severe Thunderstorms", Weather And Forecasting, **6**, 1991, pp32-48
[Previously reviewed]

Browning, K.A., and R. Reynolds, "Diagnostic Study Of A Narrow Cold-Frontal Rainband And Severe Winds Associated With A Stratospheric Intrusion", Quarterly Journal Of The Royal Meteorological Society, **120**, Part B, 1994, pp235-258
[L, Stratospheric air intrusion produces near surface wind gusts of > 70 kn. Two wind surges, (1) associated near cold frontal rainband, and (2) about 200 km behind front, detected by tracking descending potential vorticity signature. Radar obs suggested standard narrow-band convection but further investigation showed frontal passage characterized by (1) katafront (low level winds away from cold front) rather than anafront, (2) veering with time was gradual rather than typical sudden change, (3) windspeed increased rather than decreased, and (4) line convection was oriented about 30 - 40 deg from front line rather than typical 20 deg. This suggests that radar obs may be able to detect this non-standard event.]

Bruintjes, R.T., Clark, T.L., and W.D. Hall, "Interactions Between Topographic Airflow And Cloud/Precipitation Development During The Passage Of A Winter Storm In Arizona", Journal Of The Atmospheric Sciences, **51**, 1994, pp48-66
[L, Model and in-situ measurements on 10-100km scales identify existence of forced gravity waves that result in ice/precipitation generation downwind of frontal zone.]

Beuchler, D.E., and S.J. Goodman, "Radar Characteristics Of Cloud To Ground Lightning Producing Storms In Florida", Preprint, 25'th Conference On Radar Meteorology, American Meteorological Society, 1991, pp897-900
[Previously reviewed]

J.B. Burl, "A Reduced Order Extended Kalman Filter For Sequential Image Containing Moving Object", IEEE Transactions On Image Processing, **2**, 1993, pp

[L, Reduces Noise, increasing SNR of image and then can do velocity estimation. Appears to work for isolated objects, but not well in low SNR.]

Byrd, G., DeSouza, R., Fingerhut, W., and C. Murphy, "Integrating Technology Into The Meteorology Classroom: Summary Of The 1993 Northeast Regional Unidata Workshop", Bulletin Of The American Meteorological Society, **75**, 1994, pp1677-1683
[L, UCAR-based activity, sponsored by NSF. DOS PC workstation can be used to run McIDAS, GEMPAK, and WXP programs at high schools and universities.]

N.L. Byzova, "Characteristics Of Coherent Structures In The Atmospheric Boundary Layer", Atmospheric And Oceanic Physics, **29**, 1993, pp23-32
[L, 300 m meteorological tower used to observe turbulence. Intensity found high in updrafts and retarded flow regions. Observations made during neutral to unstable stratification from surface to 1 km.]

Canianx, G., Redelsperger, J.-L., and J.-P. Lafore, " ", Journal Of The Atmospheric Sciences, **51**, 1994, pp
[L, Interesting numerical model of mesoscale region of MCS systems. Model identifies level of zero vertical motion located with and just below 0 deg isotherm.]

Challeror, P.G., and P.J.T. Carter, "On The Accuracy Of Monthly Means", Journal Of Atmospheric And Oceanic Technology, **11**, 1994, pp1425-1430
[L, Uses statistics of data samples to deduce accuracy bounds of data for short & long-range trended data. Potential application to NEXRAD climatologies to be developed.]

Chan, J.C.L. and W.-K. Kay, "Performance Of The United Kingdom Meteorological Office Global Model In Predicting The Movement Of Tropical Cyclones", Weather And Forecasting, **8**, 1993, pp326-336
[L, Results are similar to Peng et. al. where persistence proved best for well behaved storms, but for erratically moving storms model forecast tracks were more accurate.]

Chandrasekar, V., and R.J. Keeler, "Antenna Pattern Analysis And Measurements For Multiparameter Radars", Journal Of Atmospheric And Oceanic Technology, **10**, 1993, pp674-688
[L, Techniques shown for bias in Z_{DR} and cross correlation ratio. Velocity measurements unaffected by pattern mismatch. CP-2 adjustments resulted in more uniform patterns and error reduction.]

Chang, W., Bosworth, B., and G.C. Carter, "Empirical Results Of Using Back Propagation Neural Networks To Separate Single Echoes From Multiple Echoes", IEEE Transactions On Neural Networks, **4**, 1993, pp993-995
[L, Interesting, showing how failures can occur when applying NN on actual data that is different (here in terms of SNR) from training data set. Good references on

image processing.]

Chelton, D.B., and M.G. Schlax, "The Resolution Capability Of An Irregularly Sampled Data Set: With Application To Geosat Altimeter Data", Journal Of Atmospheric And Oceanic Technology, **11**, April 1994, Part 2, pp534-550
[L, Interesting in development of method for determining filter equations and transform functions.]

Chilson, P.B., Ulbrich, C.W., Larsen, M.F., Perillot, P., and J.F. Keener, "Observations Of A Tropical Thunderstorm Using A Vertically Pointing Dual-Frequency, Collinear Beam Doppler Radar", Journal Of Atmospheric And Oceanic Technology, **10**, 1993, pp
[L, UHF and VHF observations. Detect precipitation spectra and wind spectra. Show examples of how using Z to estimate fallspeed and vertical wind speeds often in significant error (when using Rogers method). Turbulence broadening shown to often be source of error if not accounted for.]

E.S. Chornoboy, "Clutter Filter Design For Multiple-PRT Signals", Preprints: 26th International Conference On Radar Meteorology, 1993, pp235-237
[Previously reviewed.]

Chornoboy, E.S., and M.E. Weber, "Variable-PRI Processing For Meteorological Doppler Radars", IEEE National Radar Conference, 1994, pp85-90
[L, Description of nonuniform sampling and generalized periodgram analysis to achieve unambiguous velocity. Explains concept of non-uniform sampling reflecting incomplete sampling from much higher sample rate. Discusses aspects of dealiasing and clutter rejection.]

Chornoboy, E.S., and A. Matlin, "Extrapolating Storm Location Using The Integrated Terminal Weather System (ITWS) Storm Motion Algorithm", Lexington, MA, MIT Lincoln Laboratory, DOT/FAA/RD-94/2, ATC-208, 29 March 1994
[H, Very nice description of algorithm. Explains, and provides numerous examples of processing methodology. Display options, use of partial-correlation consensus motion averaging, and philosophy of appraoch described.]

Chou, J., Weger, R.C., Ligtenbers, J.M., Kuo, K.-S., Welch, R.M., and P. Breeden, "Segmentation Of Polar Scenes Using Multi-Spectral Texture Measures And Morphological Filtering", International Journal Of Remote Sensing, **15**, March 1994, pp
[M, Very nice if you are interested in texture. Discusses classification methods opening/closing, segmentation, divide-and-conquer, Mahalanobis classifiers, vector texture measures, etc. Means, variance, and angular second moment usually used for discrimination and classification. Notes how different operators may provide focus on different aspects of same problem! Interesting again for clutter and image processing.]

Cohen, L.D., and I. Cohen, Finite-Elements Methods For Active Contour Models And Balloons For 2-D And 3-D Images", IEEE Transactions On Pattern Analysis And Machine Intelligence, **15**, 1993, pp1131-1147
[L, Very complex, but concept of tracking 2-D slices and getting 3-D volume interesting. Paper points out how it is easier to visualize structure and change via 3-D model than 2-D model.]

S.A. Cohn, "Investigation Of The Wavelength Dependence Of Radar Backscatter From Atmospheric Turbulence", Journal Of Atmospheric And Oceanic Technology, **11**, April 1994, Part 1, pp225-238
[L, Bragg scattering expected to follow radar lambda$^{-1/3}$ dependence. Observations suggest this is reasonably accurate in the mean, but significant scatter about this is observed during normal observation. Dispersion reflects non-isotropic turbulence, layers, etc. are often present.]

Cole, R.E., and F. Wesley Wilson, "ITWS Gridded Winds Product," Submitted to the Sixth Conference on Aviation Weather Systems, Dallas, TX, 1995.
[Not available]

Conway, J.W., and D.S Zrnic, "A Study Of Embryo Production And Hail Growth Using Dual-Doppler And Multiparameter Radars", Monthly Weather Review, **121**, 1993, pp2511-2528
[M, Dual-Doppler derived particle trajectories combined with multiparameter measurements to detect and track hail, and hail embryo paths. Find column of heightened differential reflectivity Z_{DR} that extends up to 2 km above freezing level. Column contains drops (median dia 2.8 mm), wet and frozen particles and are located adjacent but NW of weak reflectivity notch. Suggests passage (once or recirculated) through column crucial to hailstone growth and that growth in updraft too quick to form hail. Column has weaker updraft in which embryos can linger and grow. Suggests this column derived from melting of frozen particles, not as water collision and coalescence as in other storms.]

Cotton, W.R., Thompson, G., and P.W. Mielke Jr., "Real-Time Mesoscale Prediction On Workstations", Bulletin Of The American Meteorological Society, **75**, 1994, pp349-362
[L, Using RAMS numerical model on high-power RISC workstation to make winter forecasts over CO. Nice example of things to come, especially with advancing technology.]

Courtier, P., Derber, J., Errico, R., Louis, J.-F., and T. Vukicevic, "Important Literature On The Use Of Adjoint, Variational Methods, And The Kalman Filter In Meteorology", Tellus, **45A**, 1993, pp342-357
[M, Interesting as a reference source for general methods as well as variational data assimilation excluding adjoints or Kalman filters, and variational data assimilation using adjoints, Kalman filters, sensitivity analysis, instability, parameter estimation.]

Dalandier, F., Sidi, C., Crochet, M., and J. Vernin, "Direct

Evidence of "Sheets" In The Atmospheric Temperature Field", Journal Of The Atmospheric Sciences, **51**, 1994, pp237-247
[L, High resolution balloon measurements locate horizontal sheets of + temperature gradient, implying regions for ducting and reflection for radars and profilers. Good reference list for reflection/refraction of profiler and radar measurements.]

Davies-Jones, "The Onset Of Rotation In Thunderstorms", 13'th Conference On Severe Local Storms, American Meteorological Society, 1990, pp
[H, Thought I would include this foundation paper on use of helicity in forecasting thunderstorm potential. Use of helicity in conjunction with hodographs.]

Davis, C.A., and M.L. Weisman, "Balanced Dynamics Of Mesoscale Vortices Produced In Simulated Convective Systems", Journal Of The Atmospheric Sciences, **51**, July 1994, pp
[L, Discussion of Mesoscale Convective Vortex (MCV) often found associated with MCS's. Surface cold pool supplies initial ascent, then vortex develops in trailing mesoscale region. Employs Houze model of AMS Bulletin 1989.]

J.A. Deller Jr. "Tom, Dick, And Mary Discover The DFT", IEEE Signal Processing Magazine, **11**, April 1994, pp36-51
[H, A "must" for those who want to visualize the DFT operation, and for understanding the pitfalls if you do not understand assumptions inherent with DFT use.]

P.R. Desrochers, "A Modelling Study Of The Mesocyclone", PL-TR-92-2330, **ERP #1113**, Dec 1992, 43pp
[H, Very interesting description, in good detail, of the elliptical mesocyclone model. Examples of circulation, velocity, vorticity provided in ample detail.]

Dixon, M., and G. Wiener, "TITAN: Thunderstorm Identification, Tracking, Analysis, And Nowcasting - A Radar-Based Methodology", Journal Of Atmospheric And Oceanic Technology, **10**, 1993, pp785-797
[H, Nice presentation on methodology of geometric tracking using ellipsoids. A real-time system. Requires clutter removal and SNR thresholding on data input to system. Future enhancements includes multiple thresholds and more detailed shape representation. Examples show for 30 min forecast, based on at least 15 min history, that POD, FAR, and CSI remain quite variable, with potential noticeable decrease in variability only after 1.5 - 2 hrs of tracking.]

Efstratiadis, S.N., and A.K. Katsaggelos, "An Adaptive Regularized Recursive Displacement Estimation Algorithm", IEEE Transactions On Image Processing, **2**, July 1993, pp
[M, Produces high definition 2-D motion vector fields. Uses subsets of data, error minimization, and elliptical trial forecast direction domains. Minimizes error within each subregion to determine best location.]

Erickson, M.C., Dullavalle, J.P. and J.S. Jensenius Jr.,

"Comments On Snow Versus Rain: Looking Beyond The Magic Numbers", Weather And Forecasting, **8**, 1993, pp542-544
[L, Discussion of forecasting precipitation type using NGM model outputs with post analyses of 100-850mb, 850-500mb thickness, 850 mb temp and wet bulb temperatures.]

Evans, J.L., Ryan, B.F., and J.L. McGregor, "A Numerical Exploration Of The Sensitivity Of Tropical Cyclone Rainfall Intensity To Sea Surface Temperature", Journal Of Climate, **7**, 1994, pp616-623
[L, This modelling study finds positive correlation of rising rainfall with increasing temperature. Authors suggest caution with results, though, since rising temperature also implies destabilization of atmosphere, ...i.e. difficult to interpret actual reason for increased rainfall.]

Fabry, F., Zawadzki, I., and S. Cohn, "The Influence Of Stratiform Precipitation On Shallow Convective Rain: A Case Study", Monthly Weather Review, **121**, 1993, pp3312-3325
[L, Simple study showing effects of precipitation from upper level rainband passing over a lower convective region. First weak drizzle from aloft seeds convective growth, later heavier precipitation from aloft scavenges convective cloud droplets and destroys convection.]

Fraedrich, K., and C. Larner, "Scaling Regimes Of Composite Rainfall Time Series", Tellus, **45A**, August 1993, pp
[L, Uses power spectrum approach to scale rainfall regimes according to frequency. Power spectral form P(F) = a f^{-b} form for climatology (00 to 3 yrs, b=0), plateau (3 yrs to 1 month, b=0), transition (1 month to 3 days, no scaling), frontal (3 days to hrs, b=.5), and storms (hrs to min, b=1). Primarily of interest for fractal type analysis.]

H. P. Frank, "Boundary Layer Structure In Two Fronts Passing A Tower", Meteorology And Atmospheric Physics, **53**, 1994, pp95-110
[L, Investigation of ana- and katafront events locating turbulence regime at narrow section of frontal surface. Katafront shows a deeper turbulent zone and greater winds behind front.]

Franklin, J.L., Lord, S.J, Fever, S.E., and F.D. Marks Jr., "The Kinematic Structure Of Hurricane Gloria, (1985) Determined From Nested Analyses Of Dropwindsonde And Doppler Radar Data", Monthly Weather Review, **121**, 1993, pp2433-2451
[L, Center unusually baratropic. Radius of maximum wind (RMW) nearly vertical below 500 mb. Strongest tangential winds above bdy layer near 550 mb where RMW a minimum. Asymmetric reflectivity structure. Direction and speed comparable to mean wind at both 56km and 667 km from eye at 700 mb.]

R. Frehlich, "Cramer-Rao Bound For Gaussian Random Processes And Applications To Radar Processing", IEEE Transactions On Geoscience And Remote Sensing, **31**, 1993, pp1123-1131
[L, New estimates of accuracy of mean frequency estimators shows previous results good for moderate and greater SNR, but low spectral width and high SNR data can

be improved by a factor of 2 in estimator accuracy.]

Frehlich, R.G., and M.J. Yadlowsky, "Performance Of Mean Frequency Estimators For Doppler Radar And Lidar", Journal Of Atmospheric And Oceanic Technology, **11**, 1994, pp1217-1230
[L, Nice review of methods and performance evaluation (using PDF) of estimates.]

Fujiki, N.M., Geldart, D.J.W., and P. Chylek, "Effect Of Air Bubbles In Radar Backscattering By Hailstones", Journal Of Applied Meteorology, **33**, 1994, pp304-308
[L, Interesting, showing Mie region peaks and maximum values of peaks shifted as air volume increases. Air must be trapped near surface, as little to no effect if air within central ice core! Modifications not large and perhaps not identifiable in standard radar observations of water coated and mushy hail, but perhaps detectable in a controlled experiment.]

T. Gal-Chen, "A Method For The Initialization Of The Analastic Equations: Implications For Matching Models With Observations", Monthly Weather Review, **122**, 1978, pp1204-1217
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Gal-Chen, T., and J. Zhang, "On The Optimal Use Of Reflectivities And Single-Doppler Radar Velocities To Deduce 3-D Motions", Preprints, 26'th International Conference On Radar Meteorology, Norman, OK, American Meteorology Society, 1993, pp414-416
[Previously reviewed]

Galelberg, C.R., and N.K. Gamage, "Structure-Preserving Wavelet Decompositions Of Intermittent Turbulence", Atmospheric Environment, **70**, 1994, pp217-246
[L, Description of use of wavelets to locate patches of turbulence. Use of sinsusoids to identify non-isotropic long wavelength and isotropic short wavelength.]

Gamache, J.F., Houze, Jr., R.A., and F.D. Marks Jr., "Dual-Aircraft Investigation Of The Inner Core Of Hurricane Norbert. Part III: Water Budget", Journal Of The Atmospheric Sciences, **50**, 1993, pp3221-3243
[L, Water budget estimation using Doppler radar as 1 data source identifies asymmetric positioning of water products. Moisture inflow enters at storm front (advancing side), condensation occurring on side to the left of inflow, and precipitation found primarily on back-left side.]

Gamage, N. and W. Blumen, "Comparative Analysis Of Low-Level Cold Fronts: Wavelet, Fourier, And Empirical Orthogonal Functions", Monthly Weather Review, **121**, 1993, pp2867-2878
[M, Presented here to provide focus on this exciting new approach to 1-D data analysis, to detect features that are "localized" within the data set. Shows how Fourier analysis inappropriate because it expects periodic occurrences of basis harmonic functions and smears out feature. EOF is better than F method, but not

as good as W analysis where basis functions can be chosen that "mimic" structure of feature in data. W analysis provides information on position and scales of feature that have a structure similar to basis function. Example uses "tanh" to locate position, inner and outer scales of frontal temp gradient structure. Some interpretation guidelines are; (1) location of large coefficients locates position, (2) max of coefficients in a region gives scale, (3) coefficients at maximum proportional to % variance explained by wavelet at that location, (4) if several dilations at given location these identify inner (low max) and outer (high max) scales, of the structure respectively. This could be powerful tool to locate localized turbulence and dominant scales, etc.]

Ghno, H., Suzuki, O., Nikusawa, H., Yoshizaki, M., Hasegawa, N., Tanaka, Y., Muramatsu, Y., and Y. Ogura, "Okayama Downburts on 27 June 1991: Downburst Identifications And Environmental Conditions", Journal Of The Meteorological Society Of Japan, **72**, 1994, pp197-222
[L, Standard MB conditions found, including; (1) dry adiabatic lapse rate layer (1100 m deep) below LCL, (2) an elevated dry layer, and (3) large difference (> 20 deg) in potential temp between surface and minimum aloft (typical PT curve is parabolic-like curvature with a min aloft). Good references and descriptions (e.g. macroburst/microburst diameters are >/< 4 km, divergent velocity > 10 m/s and initial separation of max vel centers < 4 km, CINDE exp found 60-70% of thunderstorm days had mb's, JAWS found ave mb life cycle = 13 min, max low-level Z of precip core varied 15-65 dBZ and max radial vel diff = 24 m/s at 3.1 km separation, at 81 m agl.)]

Given, T., and P.S. Ray, "Response Of A Two-Dimensional Dual-Doppler Radar Wind Synthesis", Journal Of Atmospheric And Oceanic Technology, **11**, April 1994, Part 1, pp239-255
[L, Interesting. Evaluates sources of error due to interpolation functions, pulse volume size, etc. Finds Cressman filter with influence radius 1.85 - 2.25 times maximum data spacing best for interpolation.]

Gluhovsky, A., and E. Agee, "A Definitive Approach To Turbulence Statistical Studies In Planetary Boundary Layers", Journal Of The Atmospheric Sciences, **51**, 1994, pp1682-1689
[M, Very nice approach on how to use data for moment, power, variance, skewness, kurtosis, etc. to determine when data length is long enough to ensure a particular % degree of confidence in estimates. Techniques could possibly be applied to radar VAD data etc.]

Georges, T.M., Harlan, J.A., Neryen, L.R., and R.G. Peer, "Tracking Hurricane Claudette With The US Air Force Over-The Horizon Radar", Journal Of Atmospheric And Oceanic Technology, **10**, 1993, pp444-451
[L, Very interesting application of OTH radar to detect hurricanes, and even determine surface layer wind speeds. Need lots of money to run OTH though.]

D. Goens, "Meteorological Factors Contributing To The Canyon Creek Fire Blowup", Western Region Technical Memorandum, NWS WR-208, 1990, pp21

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B. W. Golding, "A Study Of The Influence Of Terrain On Fog Development, Monthly Weather Review, **121**, 1993, pp2259-2541
[-]

Gorgucci, E., Scarchilli, G., and V. Chandrasekar, "A Robust Estimator Of Rainfall Rate Using Differential Reflectivity", Journal Of Atmospheric And Oceanic Technology, **11**, April 1994, Part 2, pp586-592
[M, New method of combining Z_{HH} and Z_{DR} data that remains stable when Z_{DR} becomes small and erratic. Found to perform better at "all" rainfall rates than previous Z_{HH}-Z_{DR} formalisms. Error dependent upon spectrum width and V/H cross correlation, but not factors that affect Z_{DR}.]

E.E. Gossard, "Measurement Of Cloud Droplet Size Spectra By Doppler Radar", Journal Of Atmospheric And Oceanic Technology, **11**, 94, pp712-726
[L, Very interesting approach to determine distribution of "small" particles. Used at profiler frequencies and requires assumptions on drop size spectra and turbulence broadening spectrum parameters.]

P.T. Gough, "A Fast Spectral Estimation Algorithm Based On The FFT", IEEE Transactions On Signal Processing, **42**, 1994, pp1317-1322
[L, Use of iterative FFT passes allows frequency discrimination between frequency locations of 1-pass FFT. Simple and easy to use.]

Granvillle, V., Krivanek, M., and J.-P. Rasson, "Simulated Annealing! A Proof Of Convergence", IEEE Transactions On Pattern Analysis And Machine Intelligence, **16**, 1994, pp652-656
[L, Mathematical proof of convergence properties... a bit dry.]

Hamill, T.M., and T. Nekhorn, "A Short-Term Forecast Scheme Using Cross Correlations", Weather And Forecasting, **8**, 1993, pp401-411
[M, Techniques use (1) matching of pixels (15X15) of current time with previous time and maximum correlation coefficient for entire box area, (2) 2-pass Cressman in (x,y) to fill-in gaps and smooth vector displacements, (3) semi-Langrangian scheme to correct previous trajectory in areas of curved flow to get more accurate current advection vector, and (4) forecast by moving pixels according to most recent advection vectors in bilinear method. A simple but effective method that employs TREC-type concepts. Has some problems handling clutter, boundary of image, etc. but interesting.]

M.T. Hanna, "Windows With Rapidly Decaying Sidelobes And Steerable Sidelobes, IEEE Transactions On Signal Processing, **42**, 1994, pp2037-2044
[L, Interesting from viewpoint of window = sum of cosine terms and expressions for estimating sidelobe decay and minima locations adjustable.]

T. Hayashi, "An Analysis Of Wind Velocity Fluctuations In The Atmospheric Boundary Layer Using Orthogonal Wavelet Transforms", Atmospheric Environment, **70**, 1994, pp 307-326
[L, Wavelet spectra similar to Fourier spectra, but smoother. Vertical momentum transport shown contained in non-isotropic large eddies, whereas smaller scales are isotropic.]

Hermes, L.G., Witt, A., Smith, S.D., Klingle-Wislon, D., Meinis, D., Stumpf, G.J., and M.D. Eilts, "The Gust Front Detection And Wind-Shift Algorithms For The Terminal Doppler Weather Radar Systems", Journal Of Atmospheric And Oceanic Technology, **10**, 1993, pp693-709
[H, Description of algorithms and shortcomings. Discusses potential problems with vertical association (some now corrected). Forecasts based upon centroid motion may be affected by gust front evolution, and polynomial fit may not always be representative of largest hazard at that frontal section. Test results from three sites show Kansas City forecasts more variable (greater error) than Denver and Orlando. Denver had greatest range of forecast displacements (km), but distribution was highly centered about .5 - 1.0 km (10 min), Orlando forecasts highly limited to < 2 km (10 min) and < 3 km (20 min), while Kansas City forecast displacements were well distributed up to 5 km (10 min) and 7-8 km (20 min). Further improvements are thin line detection, different vertical association, better GF representation. and improved forecast methods. Some sources of error were range aliasing, velocity dealiasing failures, and false detections due to vertical shear.]

Hodanish, S., and W.M. Gray, "An Observational Analysis Of Tropical Cyclone Recurvature", Monthly Weather Review, **121**, 1993, pp2665-689
[M, Simple rules developed for forecasting recurvature of cyclone tracks after analysis of 21 yrs of synoptic data. Critical factor for curving from standard 260-320 degree track is development of zonal flow at 300-200 mb in West to N quadrants (Q) within 6-8 deg radius of cyclone center. Rules are (1) remain on NW course for at least 36 hrs if zonal winds in mid-troposphere (300mb) at 8 deg radius to N, NW, or W of cyclone center are from East and zonal winds at upper-trop (200mb) are from East or West (< 5 m/s), (2) sharp recurve within 12 hr if mid & upper trop winds within 8 deg N & NW shift from East to Westerly (from W to E), (3) gradual recurve within 12 hr if 8 deg wind at NW Q shift from East to weak Westerly, (4) will recurve sharply when 6 deg radius winds at W, NW, & N Q shift from East to Westerly, (5) begin gradual recurve when 6 deg radius winds at W, NW Q shift from East to Westerly, (6) left recurvature when winds within 6-8 deg radius in W Q shift from East to Westerly and N Q shift from Northerly (S to N) to Westerly. Could be useful if additional data input to hurricane tracking routines.]

Hoffman, R.R., Detweiler, M., Conway, J.A., and K. Lipton, "Some Considerations In Using Color In Meteorological Displays", Weather And Forecasting, **8**, 1993, pp 505-518
[M, Suggests color coding of displays "can" be extremely useful for finding features of interest. However, color can also "lose" such features. Suggests standardization of color usage, determination of color-related problems, and provide guidance from other research. Extensive set of references.]

A.W. Hogan, "Objective Estimates Of Airborne Snow Particles", Journal Of Atmospheric And Oceanic Technology, **11**, April 1994, Part 2, pp432-444
[M, Interesting from viewpoint of statistics of area/mass ratios, cross-section area/mass ratio statistics, as functions of median equivalent diameter, and the changes in mass as functions of light rime coat. These are plate-like crystal observations, but may aid in modelling data for interpretation.]

Howell, J. F., and L. Maant, "An Adaptive Multiresolution Data Filter: Applications To Turbulence And Climatic Time Series", Journal Of The Atmospheric Sciences, **51**, 1994, pp2165-2177
[L, Interesting use of multiple passes with length/weight varying window filters, followed by reconstruction to remove noise and focus on desired scales. Can retain well shape of time series and gradients. Can possibly be a VAD prefilter if desired and concept could be transferred to 2-D spatial data.]

F.A. Huff, "Record Breaking Microstorm System Supports New Rainfall Frequency Estimates In Illinois", Bulletin Of The American Meteorological Society, **75**, 1994, pp1223-1226
[L, 6.3 in of rain fell within 3 hr period, breaking 104 yr record and causing major flood damage. Not expected according to 1 in a 100 yr event data. Shows 85% of 100 yr events associated with small to medium scale storm systems. Suggest regional means replace point measurements in such record methodology.]

"Special Issue On Wavelets And Signal Processing", IEEE Transactions On Signal Processing, **41**, Dec 1993
[L, Only for those strong of heart. Includes topics on filters, image reconstruction, etc.]

"Special Issue: Scaling In Remote Sensing", International Journal Of Remote Sensing, 15, Aug 1994,
[M, Interesting- numerous papers dealing with scaling and texture of observations. Shows how discrimination is done with different texture measures (e.g. paper by J.P Rundant et. al.) as a function of scale, or via function of viewing beam dimensions. Potentially useful in clutter detection and image processing.]

A.R. Jameson, "The Meteorological Parameterization Of Specific Attenuation In Rain Viewed At Nadir", Journal Of Applied Meteorology, **33**, 1994, pp1026-1033
[L, Parameterization of specific attenuation in terms of polynomials for 9 - 35 GHz for use in rainfall estimation.]

A.R. Jameson, "Measuring Rainwater Content By Radar Using Propagation Differential Phase Shift", Journal Of Atmospheric And Oceanic Technology, **11**, April 1994, Part 1, pp299-310
[L, Method depends on estimates of "mass weighted mean axis ratio" of raindrops, that can be derived from Z_{DR}. Minimum error about 18 - 35% and is dependent upon R. Suggests this method still better than traditional Z-R or A-R approaches. Should be compared to Z_{HH}, Z_{DR} methods.]

A.R. Jameson, "An Alternative Approach To Estimating Rainfall Rate By Radar Using Propagation Differential Phaseshift", Journal Of Atmospheric And Oceanic Technology, **11**, Februrary 1994, Part 2, pp122-131
[L, Suggests use of 3 and 13 GHz together with DPS measurements for estimating rainwater content.]

Jameson, A.R., and I.J. Caylor, "A New Approach To Estimating Rainwater Content By Radar Using Propagation Differential Phaseshift", Journal Of Atmospheric And Oceanic Technology, **11**, April 1994, Part 1, pp311-322
[L, Further demonstration at 3 GHz of method showing superiority over traditional method. Should be compared with Z_{HH} Z_{DR} methods.],

K.A. Jangbluth, "Barron County, Wisconsin, Multiple Tornadoes and Hailstones Of 11 Sept. 1990", Weather And Forecasting, **8**, 1993, pp 440-452
[M, Nighttime quasi-stationary thunderstorm cluster with 4 tornadoes and 7 cm hail occurred over 2.25 hr period. No appreciable movement of parent mesocyclones and storms produced over 3 of rain. Though very slow moving, storm-relative helicity sufficient for supercell development. WSR-57 reflectivity difficult to interpret, yet deviation to right of mean wind, severe weather, wind shear increasing with veering show classic environment for supercell. Suggests hodograph analysis should include "what-if scenario" for SR helicity allowing forecasters to forecast which storm movements will generate mesocyclone development.]

E.R.Jayaratne, "Conditional Instability And Lightning Incidence In Gaboron, Botswana", Meteorology And Atmospheric Physics, **52**, 1993, pp169-176
[L, During convective seasons, monthly lightning activity total increases (decreases) by at least an order of magnitude for a 2 degree rise (drop) in wet bulb temperature, a reflection of greater convective potential. Not applicable for monsoonal events (different CAPE than continental storm environments) nor convection during wintertime periods. Also interesting for further support for + cloud-ground to originate from lower + charge center between 0 deg C and sign reversal region, possibly from charging dry graupel, and not originating from + charge center at storm top.]

E.R. Jayaratne, "The Heat Balance Of A Riming Graupel Pellet And The Charge Separation During Ice-Ice Collision", Journal Of The Atmospheric Sciences, **50**, 1993, pp3185-3193
[L, Finds old theory of rimed graupel negatively (positively) charging when evaporating (growing by vapor diffusion) may be inadequate. Finds localized vapor pressure and surface structure at contact points may be influential. Suggests + charge acquired by "surface" that is (1) growing "faster", or (2) evaporating "slower", or (3) growing when other particle is evaporating. Small ice generally assumed growing by vapor deposition, larger (graupel) by riming. LWC/Cloud-temp curve for sign reversal found linear, not curved as by Takahashi (1978).]

Jing, Z., and G. Wiener, "Two-Dimensional Dealiasing Of Doppler

Velocities", Journal Of Atmospheric And Oceanic Technology, **10**, 1993, pp798-808
[H, Somewhat similar to old P. Ray approach. Seems quite accurate, and nicely "localizes" dealiasing failures when they occur. Still some potential problems for isolated storms. See appendix for details.]

Johns, R.H., and C.A. Doswell III, "Severe Local Storms Forecasting", Weather And Forecasting, **7**, 1992, pp88-612
[H, Included here as excellent reference on calculation of storm relative helicity from sounding data and radar reflectivity. Used 0-3 km layer to compare with other studies, even though 80% contribution to S-R helicity from 0-2 km layer. Both (+/-) S-R helicity summed over layer with zero storm motion used, yielding 265 m^2/s^2 value lower than previous reports for threshold. Suggests that warm front boundary nearby could have produced an "effective non-zero" relative velocity for S-R helicity calculation. Another example of non-moving S-R helicity capable of supercell status.]

Johnson, D.H., and P.W. Shami, "The Signal Processing Information Data Base", IEEE Signal Processing Magazine, **10**, Oct 1994, pp36-41
[M, Shows how to access statistical databases (software and data) via internet. Save valuable time.]

Jones, R., and I. Svalbe, "Morphological Filtering As Template Matching", IEEE Transactions On Pattern Analysis And Machine Intelligence, **16**, 1994, pp438-444
[L, Open/close operations with series of 3X3 template filters. Very fast, shows examples removing noise.]

H. Kanehisa, "Density Currents In Jet Shear Flows", Journal Of The Meteorological Society Of Japan, **71**, 1993, pp633-636
[L, Analysis of cold pool density current interaction with environmental shear for maintaining convection. Finds that depth and propagation speed of current increases (decreases) when magnitude of uniform shear environment increases (decreases). But also finds that only the "low-level" shear (e.g. shear over lower half depth of current) influences behavior of the current.]

Kitzmiller, D.H., and J.P. Breidenbach, "Probabilistic Nowcasts Of Large Hail Based On Volumetric Reflectivity And Storm Environment Characteristics", Preprints, 26th Conference On Radar Meteorology, 1993, American Meteorological Society, Paper 5.8
[Previously reviewed]

Kotroni, V., Lemaitre, Y., and M. Petitdidier, "Dynamics Of A Low-Level Jet Observed During The FRONTS 87 Experiment", Quarterly Journal Of The Royal Meteorological Society, **120**, 1994, pp 277-305
[L, Interaction of Western boundary of low-level jet (100 km wide) with approaching cold front generates low-level preferential shear, acceleration, and precipitation development.]

Keren, D., Cooper, D., and J. Subrahmahia, "Describing Complicated Objects By Implicit Polynomials", IEEE Transactions On Pattern Analysis And Machine Intelligence, **16**, 1994, pp38-53
[L, Interesting. Shows very complex shapes (e.g. reflectivity contours) are very well described by 4'th order polynomials. Could be useful for tracking and forecasting.]

B.A. Klimowski, "Initiation And Development Of Rear Inflow Within The 28-29 June 1989 North Dakota Mesoconvective System", Monthly Weather Review, **122**, 1994, pp765-779
[L, High Plains storm. Rear inflow initiated at rear of high reflectivity cells of squall line, within 20 min of initial system formation. Expanded with time rearward, increased in intensity, and descended to near surface behind Northern sector of squall line. Strong convection was primary forcing function. Another favored region was also at rear of trailing stratiform region.]

P. Kraniauskas, "A Plain Mans Guide To The FFT", IEEE Signal Processing Magazine, **11**, April 1994, pp24-35
[H, Another "must" for those who wish to visualize how the FFT operates.]

Krishnamurthy, S., Iyengar, S.S., Holyer, R.J., and U. Lybanon-, "Histogram-Based Morphological Edge Detection", IEEE Transactions On Geoscience And Remote Sensing, **32**, 1994, pp759-769
[L, Very nice method that uses histogram distribution to locate edges, particularly in weak gradient regions. Very good isolation of complex edges. Locating GF and line features?]

M. Kurz, "Severe Thunderstorms Over Western Germany - A Case Study Of The Weather Situation On 20 August 1992", The Meteorological Magazine, **172**, 1993, pp177-188
[L, Interesting example of MCS caused by instability release from large scale ascent, not from frontal forcing or frontogenesis. Use of two 12 hr forecast parameters, KO and Q-factor, to forecast areas favorable for convective development. KO = .5(Oe500 +Oe700) - .5(Oe850 + Oe950) tells if potential instability available (-). Q = (-delVg/Delx(gradp.O - delVg/dely(gradp.O) (on 510 pa surface) gives rate of change of O within a geostrophic current. Areas favorable for large scale ascent (convection) forecast when KO =-# and Q indicates convergence.]

Laine, A., and J. Fan, "Texture Classification By Wavelet Packet Analysis", IEEE Transactions On Pattern Analysis And Machine Intelligence, **15**, November 1993, pp
[L, Interesting, shows how wavelet analysis can determine subtle characteristics of terrain texture, that can later be used in classification (e.g. signal from clutter!).]

Landberg, L., and S.J. Watson, "Short-Term Prediction Of Local Wind Conditions", Atmospheric Environment, **70**, 1994, pp171-196
[L, Interesting, combines NWP forecast output with a physical/statistical local model to "tune" NWP to provide 36 hr forecast of wind direction and speed.]

Lea, S.M., and M. Lybanon, "Automated Boundary Delineation In Infrared Ocean Images", IEEE Transactions On Geoscience And Remote Sensing, **31**, 1993, pp1256-1260
[L, Simple technique detects features by interactive "opening and closing" routine (similar to expansion and dilation). Extremely fast thresholding technique to look for features near some expected thresholds.]

Lee, W.-C., Marks Jr., F.D., and R.E. Carbone, "Velocity Track Display- A Technique To Extract Real-Time Tropical Cyclone Circulations Using A Single Airborne Doppler radar", Journal Of Atmospheric And Oceanic Technology, **11**, April 1994, Part 2, pp337-356
[L, Variation of VAD technique to airborne data. Appears to develop consistent observations.]

P. W. Leftwich, Jr. "On The Use Of Helicity In Operational Assessment Of Severe Storm Potential", 16'th Conference On Severe Local Storms, 1990
[M, Discusses use of helicity in operational forecasting.]

Lenschow, D.H., Mann, J., and L. Kristensen, "How Long Is Long Enough When Measuring Fluxes And Other Turbulence Statistics", Journal Of Atmospheric And Oceanic Technology, **11**, 1994, pp661-673
[L, Results indicate that continuous sampling (e.g. 1-D data) not required, but that instantaneous samples taken T sec apart, where T reflects a spatial passage of no larger than the integral scale length returns results with random and systematic error within 8% of that derived from continuous data. This should be able to be transformed into 2-D spatial sampling application.]

Lhermitte, R.M., and P. Krehbiel, "Doppler And Radio Observations Of Thunderstorms", IEEE Transactions On Geoscience Electronics, **17**, 1979, pp162-171
[-]

Li, L.W., Yeo, T.S., Kooi, P.S., and M.S. Leung, "Comment On Raindrop Size Distribution Model", IEEE Transactions On Antennas And Propagation, **42**, 1994, pp1360
[L, New distribution parameters for use in Singapore N0=0.03a7832 cm^{-4}, alpha=2.72 mm^{-1}, beta=0.19774]

Lin. Y., and P.S. Ray, "Initialization Of A Modelled Convective Storm Using Doppler Radar-Derived Fields", Monthly Weather Review, **121**, 1993, pp2757-2775
[L, Multiple Doppler derived winds and rainwater, with thermodynamically retrieved temp and pressure (Gal-Chen). Method uses a "fill-in" technique for transition region between radar measured storm winds and adjacent clear air storm environment. If environment flow is significantly perturbed, method can introduce considerable error.]

Liou, Y.C., Gal-Chen, T., and D.K. Lilly, "Retrievals Of Wind, Temperature, And Pressure From Single-Doppler Radar And A Numerical Model", Preprints, 25'th International Conference On Radar Meteorology, 1991, Paris France, American Meteorological Society 1991, pp151-154
[Previously reviewed]

Liu, L., Bringi, V.N., Chandrasekar, V., Mueller, E.A., and A. Murukotore, "Analysis Of The Copolar Correlation Coefficient Between Horizontal And Vertical Polarizations", Journal Of Atmospheric And Oceanic Technology, **11**, August 1994, Part 1, pp950-963
[M, Interesting from standpoint of optimizing antenna pattern performance. Done to assure minimal biases in cross correlation coefficient RHO_{HV}*. Need bias < .01, (.001) for hail (rainfall estimation). Range of* RHO_{HV} *is typically 0.8 - 1.0 normally. Find .001 not readily achievable even after hardware and processing alterations, but potentially if "simultaneous" sampling is done. Processing should use "sample-based" method for Gaussian spectra, and FFT method for non-Gaussian spectra.]*

Locatelli, J.D., Martin, J.E., and P.V. Hobbs, "A Wide Cold-Frontal Rainband And Its Relationship To Frontal Topography", Quarterly Journal Of The Royal Meteorological Society, **120**, Part B, 1994, pp 259-276
[M, Interesting investigation and very nice analysis shows that steering level (wind velocity same as cores) of precipitation cores along cold front is contained within a thin layer on the frontal surface. Vertical velocity and reflectivity (about 35 dBZ) found maximized where slope of this "surface" is greatest. Heirarchy of development seen with steepest slopes (cores), next-steepest slopes (sub-bands (contain high cores)), and smaller sloped regions associated with widespread precipitation. Interesting use of motion of precipitation cores to "map" the frontal surface!]

V. F. Lopcheva, "The Character Of Deep Convection During Development Of Strong Squalls And The Locations Of The Area Of Their Origin From satellite And Radar Data", Russian Meteorology And Hydrology, **7**, 1993, pp46-52
[L, Discussion of Russian methods for forecasting MCC events. MCC (quasi-circular in shape and develop mainly at night) convection potential uses echo top hgt, log(Zmax), air temp at echo top hgt, and difference in altitude of echo top hgt and troposphere. Data suggests strong squall lines only form when positive development of MCC during previous night was observed.]

Lvettgen, M.R., Karl, W.C., and A.S. Willsky, "Efficient Multiscale Regularization With Applications To The Computation Of Optical Flow", IEEE Transactions On Image Processing, **3**, 1994, pp41-64
[M, Produces dense 2-D field of motion vectors; can produce separate flow fields on different spatial scales. A TREC-like methodology.]

Maria, M. and J. Kaplan, "A Statistical Hurricane Intensity

Prediction Scheme (SHIPS) For The Atlantic Basin", Weather And Forecasting, **9**, 1994, pp209-220
[L, Intensity (current and max possible), vertical wind shear, persistence, and flux convergence of eddy angular momentum used to decrease original forecast intensity by 10 - 15 %.]

Martin, J. D., and W. M. Gray, "Tropical Cyclone Observation And Forecasting With And Without Aircraft Reconnaissance", Weather And Forecasting, **8**, 1993, pp519-532
[L, Study of tropical storm center position and intensity via aircraft does not generally improve "forecasts of movement" over that from satellite data alone. Only in cases of storm re-curvature was improvement seen (in <12 hr forecasts). Interesting since satellite-aircraft center fixes may be as much as 110 km different! Satellite storm intensity often in error. Mean sat/aircraft position differences was 56 km, with 15% cases > 100km.]

Martinelli, G., and R. Perfetti, "Least Squares Spectrum Estimation Through A Neural Network-Inverse Prediction Structure", IEE Proceedings On Vision, Image, And Signal Processing, **141**, Feb 1994, pp68-70
[L, NN approach to "mean" frequency estimation in presence of simulated sinusoids and white noise. Implementation in hardware suffers from device connections, otherwise quite accurate.]

Martner, B.E., Snider, J.B., Zamura, R.J., Byrd, G.P., Niziol, T.A., and P.I. Joe, "A Remote Sensing View Of A Freezing Rain Storm", Monthly Weather Review, **121**, 1993, pp2562-577
[H, Nice Depiction. Demonstrates proposed NEXRAD freezing rain algorithm of Borho and Prater. Deep layer of warm moist air overrunning shallow layer of subfreezing flow ahead of surface warm front. Includes (1) melting layer, (2) well defined directional shear layer associated with frontal zone below bright band, and (3) surface temperature < 0 deg C.]

Mass, C.F., and M.D. Albright, "Coastal Southerlies And Alongshore Surges Of The West Coast Of North America: Evidence Of Mesoscale Topographically Trapped Response To Synoptic Forcing", Monthly Weather Review, **115**, 1987, pp1707-1738
[-]

Meneghini, R., and H. Kumagai, "Characteristics Of The Vertical Profile Of Dual-Frequency, Dual Polarization Radar Data In Stratiform Rain", Journal Of Atmospheric And Oceanic Technology, **11**, 1994, pp701-711
[L, Good references. Somewhat disappointing results suggests that even these capabilities do not lead to much better resolution of types, sizes, etc. of particles in the melting layer.]

Meyers, S.D., Kelley, B.G., and J.J. Obrien, "An Introduction To Wavelet Analysis In Oceanography And Meteorology: With Applications To The Dispersions Of Yanai Waves", Monthly Weather

Review, **121**, 1993, pp2858-2866
[L, Further discussions on wavelet analysis (see Gamage et. al.). Shows how 1-D data expanded into 2-D analysis space and yields measure of local activity of a particular scale. Better discussion of interpretation of results and data preconditioning.]

Misumf, R., Divjak, M., Tanahashi, S., and T. Takeda, "A Numerical Study On The Formation Of Organized Convective Storms: Part I, Formation Patterns Of Long-Lasting Cells", Journal Of The Meteorological Society Of Japan, **72**, 1994, pp235-253
[M, Initial conditions are small random thermals. Final convective cells classified as (1) short-lived with down-shear tilting updraft, (2) similar to (1) but forced by other cells and long-lived, and (3) long-lived with upshear tilted updraft, developing surface cold pool and becomes self-maintained. Type (3) occurs when (1) updraft root moves with outflow diverging from one short-lived storm, or (2) boundaries forming from successive short-lived storms, or (3) moves with outflow from pre-existing type 3 storm.]

Morrissey, M.L., Krajewski, W.F., and M.J. McPharen, "Estimating Rainfall In The Tropics Using The Fractional Time Raining", Journal Of Applied Meteorology, **33**, 1994, pp387-393
[L, Used in tropical areas where consistency of rainfall events greatest. Fraction of Time that Rain (FTR) occurs based on observations that total accumulation proportional to time raining. Time periods used are of order of 1 month, that is, long enough to average out variabilities. Is actually related to ATI method in concept, and again supports global versus DSD type methods for rainfall estimation.]

Nanoyanan, R.M., Doerr, P.W., and D.C. Rundquist, "Power Spectrum Of Wind Influenced Vegetation Backscatter At X-Band", IEE Proceedings On Radar, Sonar, And Navigation, **141**, April 1994, pp125-130
[L, Only that treetrunks and limbs produce a low frequency signal (sway), and leaves a high frequency signal (flutter).]

G.D. Nastrom, and R.E. VanZandt, "Mean Vertical Motions Seen By Radar Wind Profilers", Journal Of Applied Meteorology, **33**, 1994, pp984-995
[L, Upper tropospheric characteristics via profiler show upper troposphere mean vertical motion is 3 - 5 cm/s downward, near zero at tropopause, and + motion above.]

R.C. Nelson, "Finding Line Segments By Stick Growing", IEEE Transactions On Pattern Analysis And Machine Intelligence, **16**, 1994, pp519-523
[L, Very unusual method that tries to overcome problems of Hough and other more complex techniques. Allows growth of "sticks" and selects intersections via use of local gradients, etc.]

Nieweglowski, J., Gabbouj, M., and Y. Neuvo, "Weighted Medians-Positive Boolean Function Inversion Algorithms", Signal

Processing, **34**, 1993, pp149-162
[L, Interesting advancement from use of simple median filters to weighted median filters.]

Neuman, and Pelisser, "Analysis Of Atlantic Cyclone Forecast Errors", Monthly Weather Review, **109**, 1981, pp1248-1266
[L, Description of the Climatology and Persistence forecast method (CLIPER)]

Nikias, C.L., and J.M. Mendal, "Signal Processing With Higher-Order Spectra", IEEE Signal Processing Magazine, **10**, July 1993. pp10-37
[L, Observations and discussions of higher order spectra (multiple lags), power spectrum, bispectrum, etc. and discusses how these can further characterize Gaussian signals.]

Niino, H., Suzuki, O., Nirasawa, H., Fujitani, T., Ohno, H., Takayaba, I., and W. Kinoshita, "Tornadoes in Chibu Prefecture On 11 Dec 1990", Monthly Weather Review, **121**, 1993, pp3001-3018
[M, Two storms developed supercell characteristics except for constant storm motion to NW. Parent mesocyclone spawned a child meso-circulation on parent edge that was associated with tornado. Vertical vorticity (1-5 km alt) suddenly increased markedly to 3 x 10^{-2} s^{-1} *20 min prior to tornado. Second storm mesocyclone cycled twice through weak-strong phases, and surface locations of meso and tornado were 5 km apart.]*

Ohno, H., and O. Suzuki, "Small-Scale High Wind Cores Enhancing Low-Level Wind Shear: Doppler Radar Observation Of Opposing Wind Adjacent To The Sea Breeze Frontal Zone On 20 September 1989", Meteorology And Atmospheric Physics, **52**, 1993, pp147-152
[L, Very strong Low Level Wind Shear (LLWS) detected during events when environmental wind opposes sea breeze event. C Band radar in clear air detecting small cores (.5 - 1km) of enhanced shear located about 1 km away from advancing frontal surface. Periodic placement suggests gravity wave interaction. Regions are hazardous to aircraft. Gust front events may generate similar shear zones.]

Onural, L., Alp, M.B., and M.I. Gurelli, "Gibbs Raather Review, **109**, 1981, pp1248-1266
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Onural, L., Alp, M.B., and M.I. Gurelli, "Gibbs Random Field Model Based Weight Selection For The 2-D Adaptive Weighted Median Filter", IEEE Transactions On Pattern Analysis And Machine Intelligence, **16**, 1994, pp831-837
[M, Interesting, very powerful for removing "texture" clutter, and preserving lines in the image. A complex filter uses large influence domain to set filter coefficients for smaller-operating filter over "its" small domain. Once again, clutter or image processing applications?]

Papasatoris, A.D., and P.A. Watson, "A Rigorous Explanation For The Resonances Observed In The Scattering From Spherical Ice Particles", IEEE Transactions On Antennas And Propagation, **42**, 1994, pp1350-1354
[L, Cross section peaks in backscatter cross-section are reflecting oscillations of free and bound charges, synchronizing with applied field, leading to excitation of a secondary field.]

Pazmany, A.L., McIntosh, R.E., Kelly, R.D., and G. Vali, "An Airborne 35GHz Dual-Polarized Radar For Cloud Studies", IEEE Transactions On Geoscience And Remote Sensing, **32**, 1994, pp731-739
[L, Description of system, parameters involved, and some results from observations of melting layer. A 3mm wavelength system clearly depicts clouds, wisps, etc.]

M. A. Pedder, "Interpolation And Filtering Of Spatial Observations Using Successive Corrections And Gaussian Filters", Monthly Weather Review, **121**, 1993, pp2889-2902
[M, Method of Bratseth using fixed weighted matrix to irregularly spaced data with varying local varying means. Used for interpolation, filtering, and scale selection. It uses only "one" influence scale for "all" operations, not changing between iterations as does the Barnes and Maddox methods. Simpler and often superior to B & M methods, but not as robust as spline interpolation.]

Peles, S., and B. Friedlander, "The Achievable Accuracy In

Estimating The Instantaneous Phase And Frequency Of A Constant Amplitude Signal", IEEE Transactions On Signal Processing, **41**, June 1993, pp
[L, assumes phase and frequency can be represented by polynomials, allows prediction of accuracy given SNR and polynomial degree.]

Peng, M. S., Jeng, B.-F., and C.-P. Chang, "Comparison Of Forecast Movements Of Typhoons Made Between The Tapei Central Weather Bureau Limited Area Numerical Model, The OTCM (One-way Interactive Tropical Cyclone Model) and Climatology and Persistence (CLIPER)", Weather And Forecasting, **8**, 1993, pp309-325
[L, For non-erratic typhoons CLIPER was best, but for erratically moving typhoons the numerical models were better with errors of 415 km (392km) for 1989 (1990) seasons for 48 hr track forecast.]

Petersen, W.A., Rutledge, S.A, Buccippio, D.J., and E.R. Williams, "The Electrification Of Tropical Oceanic Clouds Observed During TOGO-COARE", Preprints, 17'th Conference On Severe Local Storms, American Meteorological Society, 1993, pp798-802
[-]

Prater, E. T., and A. A. Borho, "Doppler Radar Wind And Reflectivity Signatures With Overrunning And Freezing Rain Episodes", Journal of Applied Meteorology, **31**, 1993, pp1350-1358
[Previously reviewed; the foundation of the potential feezing rain algorithm.]

Qiu, C.-J., and Q. Xu, "A Spectral Simple-Adjoint Method For Retrieving Low-Altitude Winds From Single Doppler Radar", Journal Of Atmospheric And Oceanic Technology, **11**, August 1994, Part 1, pp927-936
[L, New approach uses data on coarser grid than previous method that used interpolated data onto data collection grid. Using low frequency spectral components (mean wind from large scale), removes data noise and perturbation components that may change rapidly with scans. Phoenix II data, where time-mean windfield was indeed smooth, shows good results from this faster, higher temporal resolution technique. Thus, if time-mean windfields contain grid scale perturbations that must be tracked, use previous method and gain better spatial resolution, if not use new method and gain better temporal resolution.]

Rasmussen, R. M., Crook, A., and C. Kessinger, "Snow-Band Formation And Evolution During The 15 November 1987 Aircraft Incident At Denver Airport", Weather And Forecasting, **8**, 1993, pp453-480
[M, Generation of snow bands along advancing cold front producing heavy snow and dilution of de-icing fluid on aircraft wings, leading to re-buildup of iced wings and subsequent crash. Good description and use of Doppler radar and soundings, with some topographic effects noted.]

Rasmussen, E.N., and S.A. Rutledge, "Evolution Of Quasi-Two-Dimensional Squall Line. Part I: Kinematic And Reflectivity Structure", Journal Of The Atmospheric Sciences, **50**, 1993, pp2584-2606
[L, Main emphasis is that for these well organized storms, evolutionary nature is similar even though time scales may vary significantly. Nature characterized by - horizontal vorticity sheet (Hv = delu/delz - delw/delx) located between the ascending and descending flows. Sheet tilts more to horizontal as storm transitions from intensifying (most vertical) to mature and dissipating (most horizontal) stages.]

Rauber, R.M., Ramamurthy, M.K., and A. Tokay, "Synoptic And Mesoscale Structure Of A Severe Freezing Rain Event; The St. Valentines Day Ice Storm", Weather And Forecasting, **9**, 1994, pp183-208
[M, Forecast of surface warming in error leading to unexpected freezing rain event. Suggests that rain arriving as convective bands, advecting upward and northward over warm frontal surface was keeping surface air at 0 deg C, thus hindering sublimation and melting of heavy ice coat on ground. Uses SCaPE, frontogenetical function, etc. in analysis. Suggests WSR-88D may be useful in detailing 2-D flow (and equations used in analysis) to identify such storms.]

Ray, P. S., and C. Ziegler, 1977, "Dealiasing First Moment Doppler Estimates", Journal of Applied Meteorology, **16**, 1977, pp563-564
[M, One of the parent 2-D dealiasing techniques.]

Reynolds, R.W., and T.M. Smith, "Improved Global Sea Surface Temperature Analyses Using Optimum Interpolation", Journal Of Climate, **7**, 1994, pp929-948
[L, Interesting because it returns to older techniques of interpolation with residual error minimalization, followed by classification of error types (correlated, uncorrelated, etc.).]

Roberti, L., and G. Perona, "Ground Clutter Removal And Data Coding In Radar Meteorological Maps", IEEE Transactions On Geoscience And Remote Sensing, **31**, 1993, pp1260-1264
[H, Very fast, simple technique for removing speckled type clutter, but not for continuous clutter regions. May lose mini-thunderstorms if not careful. A real-time technique that relies on variations of reflectivity among nearest neighbors and small area to perimeter ratio.]

Rosenfeld, D., D.B. Wolff, and E. Amitai, "The Window Probability Matching Method For Rainfall Measurements With radar", Journal Of Applied Meteorology, **33**, 1994, pp687-693
[H, Method advances previous Probability Matching Method (PMM) by matching Ze, R only over a window above the gauge. Window only large enough to account for spatial timing and geometrical errors (account for advection, fallspeeds, etc.), but small enough to represent that point. Uses a 3km radial length by 3 azimuths wide area. Time for integration is 9 min (3 3 min periods combined). All windows over same range intervals combined in determining Z-R relationships (uses

3 range stratifications). Note that data must still be classified as function of storm type. Data requirements are that full dynamic range of rainfall intensities for a given storm type are observed (preferably numerous times) over network (suggested min of 600 mm accumulation over network required per range interval per storm type). Find that Z-R relationship is non-linear (log-log plot), and thus better representation than traditional power law (straight line on log-log plot). Non-linearity in agreement with earlier findings of probability methods. The Z-R relation is applied to whole field for given storm type and range interval.]

Rosenfeld, D., Wolff, D. B., and D. Atlas, "General Probability-Matched Relations Between Radar Reflectivity And Rain Rate", Journal of Applied Meteorology, **32**, January 1993, pp50-72
[Previously reviewed]

Roy, D.P., and O. Dikshit, "Investigation Of Image Resampling Effects Upon The Textural Information Content Of A High Spatial Resolution Remotely Sensed Image", International Journal Of Remote Sensing, **15**, 1994, pp113-1140
[M, Another interesting paper showing (simply) the effects of different "beam" sizes. Use five parameters termed inertia, mean, entropy, energy, and inverse difference moment. Energy/entropy both very pixel/beam size dependent.]

Ryzhkov, A.V., and D.S. Zrnic, "Precipitation Observed In Oklahoma Mesoscale Convective Systems With Polarimetric Radar", Journal Of Applied Meteorology, **33**, 1994, pp455-464
[L, included in NSSL appendix]

Sahr, J.D., and E.R., Grannan, "Simulated Annealing Searches For Long Binary Phase Codes With Application To Radar Remote Sensing", Radio Science, **28**, 1993, pp1053-1055
[M, Technique using Metropolis algorithm searches for pulse compression codes via a "simulated annealing" (near energy minimization) process. States that checking aperiodic codes difficult due to large number of combinations. Energy is sum of squares of unwanted sibelobes. Example of search for auto and cross-correlation minimization. Although such codes generally used for incoherent scatter measurements, suggests that method may provide potential for developing codes to remove velocity-range problem when sent at Nyquist rates.]

Scialom, G., and Y. Lemaitre, "QVAD: A Method To Obtain Quadratic Winds From Conical Scans By A Doppler Weather Radar Network", Journal Of Atmospheric And Oceanic Technology, **11**, August 1994, Part1, pp909-926
[M, Wind assumed quadratic in form, thus enabling greater detail in derived windfield to be obtained. Somewhat complicated with each radars' data solved independently, then mutual solution obtained in areas scanned by both or neither. May have application for NEXRAD with two radars scanning simultaneously or one radar employing advected data and stationarity assumptions. Compare to Bluestein method.]

A. Shapiro, "A Single-Doppler Velocity Retrieval In The

Convective Planetary Boundary Layer", Preprints, 26'th International Conference on Radar Meteorology, Norman, OK, American Meteorological Society, 1993, pp441-443
[Previously reviewed]

A. Shapiro, A Single_Doppler retrieval Of Winds In A Phoenix II Microburst", Preprints, Tenth Conference On Numerical Weather Prediction, Portland, OR, American Meteorological Society, 1994, pp469-471
[-]

Shchukin, G.G., Galperin, S.M., Stusenko, V.N., Bahnikov, V.I., Frolov, V.I., and I.I. Tarabukin, "Complex Radiophysical Cumulonimbus Study", Preprints, 26'th Conference On Radar Meteorology, American Meteorology Society, 1993, pp685-686
[Previously reviewed]

Sheppard, B.E., and P.I. Joe, "Comparison Of Raindrop Size Distribution Measurements By A Joss-Waldvogel Disdrometer, A PMS 2DG Spectrometer, And A POSS Doppler Radar", Journal Of Atmospheric And Oceanic Technology, **11**, August 1994, Part 1, pp874-887
[L, Comparison between impact (JWD), optical (2DG), and Doppler power spectrum (POSS) methods. In general DSD's averaged over 1 min in agreement and are seen to be multimodal, but long term average tends to MP distribution (data only extends to rates < 16 mm/hr)). POSS over-estimates small drop numbers, while JWD and 2DG under-estimate large drop numbers. Standard errors against tipping bucket are in range 17 - 24 % as measured by "daily" catches. Perhaps expect greater errors over shorter time periods, particularly when DSD is for very heavy rain (lots large drops) or very light rain (lots small drops).]

Shimizu, K., Short, D.A., and B. Kedem, "Single And Double Threshold Methods For Estimating The Variance Of Area Rain Rate", Journal Of The Meteorological Society Of Japan, **71**, pp673-683
[M, Develops quadratic relationship between rain rate variance and probability that rain rate exceeds a fixed threshold level. Suggests that single and double threshold methods for quadratic estimation of rain rate variance, with optimal thresholds identified. Results show single (31 mm/hr empirical, 42.4, 24.8, and 27.4 mm/hr for lognormal, gamma, and Gaussian distributions) as effective as double for estimating linear area-average rain rate first and second moments. Good references.]

Sicony, S.M., Kahl, J.D.W., and N.A. Zaitseva, "Differences Between Radiosonde And Dropsonde Temperature Profiles Over The Artic Ocean", Journal Of Atmospheric And Oceanic Technology, **11**, 1994, pp1400-1408
[M, Interesting, showing both devices introduce lag in measurements and thus error with height. For example, for a true temperature profile shaped like a ">" radiosonde (dropsonde) places maximum above (below) true height, and under-estimates (over-estimates) temperature below max, while over-estimating (under-estimating) temperature above.]

Signal Processing, **32**, 1993
[L, Of interest only because the entire issue is dedicated to image processing methodologies. The introduction attempts to bring the whole suite of image processing into a common language of steps of (1) Observation (data acquisition and thresholding), (2) Transformation (edge extraction (detection and linking)), (3) Matching/prediction (current & old), (4), Updating (forecast), and (5) Image flow Model /Prediction (forecast model (i.e. Kalman)).]

Sikora, T.D., and G.S. Young, "Observations And Applications Of The Horizontal Perturbation Windfield Within Convective Structures Of The Marine Atmospheric Surface Layer", Atmospheric Environment, **68**, 1994, pp419-426
[M, Shows "patchiness" of turbulence. Wavelength of maximum energy between .03 - 2.0 km, and varies considerably with environment. Longer eddies observed in convective environments.]

M. R. Sinclair, "A Diagnostic Study Of The Extratropical Precipitation Resulting From Tropical Cyclone Bola", Monthly Weather Review, **121**, 1993, pp2690-2707
[L, Interesting for large orographic influence on rainfall.]

R. B. Smith, "A Hurricane Beta-Drift Law", Journal Of The Atmospheric Sciences, **50**, 1993, pp3213-3215
[L, Scaling analysis used to re-derive simple relation for drift speed and direction of hurricanes after initial development. Assuming Coriolis force of form F = beta x Lat + F0, Vdrift=,72 $B^{-.54}$ and Odrift=308 (deg) - 9.6(deg) X LOG10(B) where B=Rm^2 x beta/Vm where Rm is range (from center) to max velocity Vm. Another potentially useful add-on to hurricane tracking algorithm?]

Stensrud, D.J., and J.M. Fritsch, "Mesoscale Convective Systems In Weakly Forced Large-Scale Environments, Part 1, Observations", Monthly Weather Review, **121**, 1993, pp3326-3344
[L, Large scale flow generating weak buoyant energy not utilized until weak inversion eroded away from slow ascent. Two MCS's move "upstream" of environmental flow. Analysis suggests that density current generating favorable new convection location most likely, and columnar blocking also possible. Ducted gravity waves' speed too great and environment does not support ducting layer. It is not totally clear, however, that this is not simply an exaggerated example of strong "motion to the right" of the mean environmental wind.]

J. Sun, "Fitting A Cartesian Prediction Model To Radial Velocity Data From Single Doppler Radar", Journal Of Atmospheric And Oceanic Technology, **11**, February 1994, Part 2, pp200-204
[L, Utilizes actual radial velocities in spherical geometric acquisition space into retrieval method, showing good results.]

Sun, J., Biggerstaff, M.I., Fovall, R.G., and R.A. Houze, Jr., "Warm Upper-Level Downdrafts Associated With A Squall Line", Monthly Weather Review, **121**, 1993, pp2919-2927
[L, Upper level (4-9.5 km alt) downdrafts that lie adjacent ahead and behind of main convective updrafts are found positively buoyant and contribute negatively

to vertical heat flux. Buoyancy comparable to that in convective updraft when measured against the mean environmental flow, not adjacent parcels. Lower level downdrafts (< 4km alt) are negatively buoyant and generate + heat flux.]

Sun. J.D., Flicker, W., and D.K. Lilly, "Recovery Of Three-Dimensional Wind And Temperature Fields From Simulated Single-Doppler Radar Data", Journal Of The Atmospheric Sciences, **48**, 1991, pp876-890
[-]

Sun, T., Gabbouj, M., and Y. Neuvo, "Center Weighted Median Filters: Some Properties And Their Applications To Image Processing", Signal Processing, **35**, 1994, pp213-230
[L, Further discussions on weighted median filters, and another class of "center-weighted" median filters.]

Suzuki, O., Ohno, H., Kusunoki, K., and K. Nakai, "Image Processing System To Deal With Doppler Radar Data - A Supporting Tool For Developing The Mesoscale Disturbance Detection Algorithms, 26'th International Conference On Radar Meteorology, 1993, Paper 1.12
[Previously reviewed]

J. E. Tillman et al., "Turbulence On Mars", Journal Of The Atmospheric Sciences, **51**, 1994, pp1709-1722
[L, Interesting for its use of statistical methods in estimating turbulence properties.]

Troxel, S., and R. L. Delanoy, "Machine Intelligent Approach To Automated Gust Front Detection For Doppler Weather Radars" SPIE Proceedings–Sensing, Imaging, and Vision for Control and Guidance for Aerospace Vehicles, **2220**, Orlando, FL, April 4-5, 1994, pp182-192
[M, Very nice presentation on the MIGFA methodology. Explanantion of the Functional Template Correlation (FTC) as a "scoring function", relating to the potential that feature of interest exists in data field. Interesting graphical example of GF data thru processing chain.]

M. Tucenyan, "Moment-Based Texture Segmentation", Pattern Recognition Letters, **15**, 1994, pp659-668
[L, Interesting by giving examples of filters, and physically interpreting their actions. This reference provided to highlight the innumerable discussions (texture, edge detection, classification, neural networks, transforms, etc.) that can be found in this and the "Pattern Recognition" journals.]

Turner, B.J., and M.Y. Leclerc, "Conditional Sampling Of Coherent Structures Of Atmospheric Turbulence Using The Wavelet Transform", Journal Of Atmospheric And Oceanic Technology, **11**, February 1994, Part 2, pp205-209
[L, Nice example on use of wavelets to isolate "local patches" of turbulence and

obtain characteristics of these regions. Strengthens concept of estimating turbulence over regions (i.e. patches) in lieu of older concepts of averaging turbulence measurements everywhere (e.g. over entire boundary layer, etc.)]

M. Unser, "Fast Gabor-Like Windowed Fourier And Continuous Wavelet Transforms, <u>IEEE Signal Processing Letters</u>, **1**, May 1994, pp76-79
[L, Efficient methods for speeding up these methods using optimum sampling windows generated by COSINE sums.]

Uppala, S.V., and J.D. Sahr, "Spectrum Estimates Of Moderately Overspread Radar Targets Using Aperiodic Transmitter Coding", <u>Radio Science</u>, **29**, 1994, pp611-623
[M, Aperiodic pulse transmission method potentially useful to weather radar in removing range-frequency ambiguities. Demonstrates that DFT approach can, if done with care, be applied to aperiodic sample train to retrieve good estimates (as compared to true spectrum) of spectral properties. Basically technique under-samples out-of-range data. Applicability and similarity to old NSSL multiPRF schemes should be considered.]

Vivekanandan, J. Raghavan, R., and V.N. Bringi, "Polarimetric Radar Modelling Of Mixtures Of Precipitation Particles", <u>IEEE Transactions On Geoscience And Remote Sensing</u>, **31**, September 1993, pp
[M, Beautiful demonstration of polarimetry via simulation of various polarimetric parameters from 2-D cloud model. Delineations of growth regimes, rain, graupel/hail domains easily seen. Evolution of microphysics is observed in terms of polarimetric variables. Snow hard to isolate and elevation angle corrections not required for < 20 deg.]

Wakimoto, R.M., and N.T. Atkins, "Observations Of The Sea Breeze Front During CaPE. Part 1-Single Doppler, Satellite, and Cloud Photogrammetry", <u>Monthly Weather Review</u>, **122**, 1994, pp1092-1114
[M, Evolution and propagation of sea breeze front, including interaction with other structures (cloud streets, etc.). Development of preferential cloud/storm initiation locations. Usual very thorough RM analysis, always a pleasure to read.]

Wakimoto, R., Kessinger C., and D. Kingsmill, "Kinematic, Thermodynamic, And Visual Structure Of Low-Reflectivity Microbursts", <u>Monthly Weather Review</u>, **122**, 1993, pp72-92
[Previously reviewed]

Wakimoto, R. M., and J. K. Lew, "Observations Of A Florida Waterspout During CaPE", <u>Weather And Forecasting</u>, **8**, 1993, pp412-423
[M, Example of case difficult for WSR-88D. Developed from small cumulus during land growth stage and dissipated when rain shower from descending precipitation core reached ground. Pronounced rotational couplet not seen below 1 km altitude even though storm only 15 km away. Largest Doppler shear > 2 x 10^{-3} sec^{-1} observed during waterspout dissipation, but no recognizable couplet. Vortex

dimensions about 79 - 175 m at cloud base with largest shear of 5 x 10^{-3} sec^{-1} observed 4-5 min after formation.]

Wakimoto, R., and J. Wilson, "Nonsupercell Tornadoes", Monthly Weather Review, **117**, 1989, pp1113-1140
[-]

Wamazi, N.M., Penafiel, P., and C.M. Fan, "Non-uniform Image Motion Estimation Using Kalman Filtering", IEEE Transactions On Image Processing, **3**, 1993, pp678-687
[M, Very interesting technique uses small subregions and Kalman filtering to determine track. Separate technique based on likelihood ratio test used to identify moving pixels from noisy data.]

B. Wang, "Climate Regimes Of Tropical Convection And Rainfall", Journal Of Climatology, **7**, 1994, pp1109-1118
[L, Interesting from standpoint of image analysis of climate data to show rainfall distributions varying with time. Concept of use here is development of radar parameter climatologies.]

Wang, T., and C.-L. Wang, "On The Optimum Design Of The Block Adaptive FIR Digital Filter", IEEE Transactions On Signal Processing, **41**, June 1993, pp
[L, Correction terms, not filter coefficients are optimized with each block. Offers fast convergence and built using LMS concept.]

Y. Wang, "Active Mesh - A Feature Seeking And Tracking Image Sequence Representation Scheme", IEEE Transdactions On Image Processing, **3**, 1994, pp610-624
[L, Interesting, uses irregular shaped nodes that are matched, image by image. Allows for spatial evolution, but quite complex in implementation.]

Watanabe, A., Fukao, S., Yamanaka, M.P., Sumi, A., and H. Uyeda, " A Rotor Circulation Near The Baiu Front Observed By The MU Radar", Journal Of The Meteorological Society Of Japan, **72**, 1994, pp91-105
[L, Precipitation and cloud weak in downdraft but extends to 9km near back of circulation. Rotor located between two cloud bands.]

Weaver, J.F., Purdom, J.F.W., and E.J. Szuke, "Some Mesoscale Aspects Of The 6 June 1990 Limon Colorado, Tornado Case", Weather And Forecasting, **9**, 1994, pp45-66
[M, While severe weather forecast for Eastern half of state, storms remained highly localized. Study finds localization due to mesoscale phenomena with thunderstorm outflow from Kansas and Nebraska, along with sharp moisture gradient both combining to focus areas favorable for development, including generation of capped stable air mass due to low level outflow (moving westerly) from overnight Kansas and Nebraska thunderstorms, and air mass over Rocky mountains too dry to support general deep convection. Finds storms moving easterly from Denver weekend when meeting stable air, but interaction between current and developing storms were responsible for generation of conditions supporting tornado

development. Outflows and interactions documented by satellite and radar data and used to explore failure of numerical models in predicting localization effects. Interesting for forecast operations.]

H.E. Westcott, "Merging Of Convective Clouds,: Cloud Initiation, Bridging, And Subsequent Growth", Monthly Weather Review, **122**, 1994, pp780-790
[M, Shows merging primarily a result of horizontal expansion of individual storms. Noted that percentages of mergers was 65% between a young echo and parent storm, 25% between young echoes, and 10% between echoes from two different systems. May be useful as a discriminant for merging in standard tracking and forecasting algorithms.]

L.G. Weiss, "Wavelets And Wideband Processing", IEEE Signal Processing Magazine, **11**, January 1994, pp13-32
[M, Discusses sampling-ambiguity functions from narrow-wideband - wavelet applications.]

Wilson, J.W., and C.K. Mueller, "Nowcasts Of Thunderstorm Initiation And Evolution", Weather Forecasting, **8**, 1993, pp113-131
[Previously reviewed; decsription of process]

Wilson, J.W., Weckwerth, T.M., Vivekanandan, J., Wakimoto, R.M., and R.W. Russell, "Boundary-Layer-Clear-Air Echoes: Origin Of Echoes And Accuracy Of Derived Winds", Journal of Atmospheric And Oceanic Technology, **11**, 1994, pp1184-1206
[H, Very nice. Use of X, C, S band and polarimetric (Z_{DR}) measurements to show boundary layer return from insects (modelled as prolate spheroids), and convergence lines are locations of increased density of insects. Above boundary layer Bragg scatter (at least at 10 cm) dominates. Observations suggest insects remain good wind tracers, at least during these "non-migratory" periods. Exceptions could be expected for migrating periods when mean vector motion may occur, and in updrafts (especially near tops) when bugs reorient to fall back down to warmer regions. Reflectivity range about -10 to + 10 dBZ, and Z_{DR} about 5 to 10 dB.]

V.T. Wood, "A Technique For Detecting A Tropical Cyclone Center Using A Doppler Radar", Journal Of Atmospheric And Oceanic Technology, **11**, 1994, pp1207-1216
[M, Uses Doppler velocity shear "pattern vectors", modelled into an expected envelope region. The envelope region is a function of storm size and distance from radar. Reasonable results but at least half of storm should be observable.]

Wu, C.-G., and K. A. Emanuel, "On Hurricane Outflow Structure", Journal Of The Atmospheric Sciences, **51**, 1994, pp1995-2003
[L, Simple numerical model/analysis of potential vorticity show interaction of cyclone baroclinic vortex with background environmental wind shear can lead to cyclone drift to the left of the shear vector (N. Hem.) and to a strong deformation of the outflow resulting in a jet-like outflow structure. Results not quite similar when environment PV "gradient" exists.]

Xu, M., and T. Gal-Chen, "A Study Of The Convective Boundary Layer Dynamics Using Single Doppler Radar Measurements", Journal Of The Atmospheric Sciences, **50**, 1993, pp3641-3662
[M, Truly a fine study. Ku band (.87cm) observations within 5.4 km range of radar taken in a VAD mode. To achieve reasonable ensemble (statistically stable) results, analysis extends VAD method by forming estimates at numerous altitudes, each altitude an average of data from multi-radial VAD circles, and multiple volume scans. Mean wind and mean turbulent properties estimated. VAD analysis of second moment also performed to estimate sub-pulse volume transport. Error estimates generated. Technique less computationally intensive than VVP and allows some investigation of dominant perturbation scales by observing properties as function of circle radius (e.g. data here show stability only at larger circle radii). Should consider applicability to WSR-88D.]

Xu, Q., Qiu, C.-J., and J. Xyu, "Adjoint-Method Retrievals Of Low-Altitude Wind Fields From Single-Doppler Reflectivity Measured During Phoenix II", Journal Of Atmospheric And Oceanic Technology, **11**, April 1994, Part 1, pp275-288
[L, Improved reflectivity advection used for clear air. Multiple time-level data increases accuracy of retrieval, with judicious setting of cost function weights and filter helpful.]

Xu, Q., Qiu, C.-J., and J. Xyu, "Adjoint-Method Retrievals Of Low-Altitude Wind Fields From Single-Doppler Wind Data", Journal Of Atmospheric And Oceanic Technology, **11**, April 1994, Part 2, pp579-585
[L, Uses wind as tracer rather than reflectivity. Radial momentum employed, and pressure gradient, vertical advection, and other terms treated as unknown sources. Has application where reflectivity not well conserved, but expected problematic when time-mean residual terms are correlated with advection term (not seen in Phoenix II data so far ?).]

XU, Q., Qiu, C.J., YU, J.X., and H.D. Gu, "Adjoint-Method Retrievals Of Low-Altitude Wind Fields From Single-Doppler Reflectivity Measured During Phoenix II", Journal Of Atmospheric And Oceanic Technology, **11**, 1994a, pp275-288
[-]

XU, Q., Qiu, C.J., YU, J.X., and H.D. Gu, "Adjoint-Method Retrievals Of Low-Altitude Wind Fields From Single-Doppler Wind Data", Journal Of Atmospheric And Oceanic Technology, **11**, 1994b, pp579-585
[-]

XU, Q., Qiu, C.J., YU, J.X., Gu, H.D., and M. Wolfson, "Adjoint-Method Retrievals Of Microburst Winds From Tdwr Data", Preprints, 26'th International Conference On Radar Meteorology, Norman, OK, 1993, American Meteorological Society, pp433-434
[Previously reviewed]

Yeh, T.-C., and R.L. Elsberry, Interaction Of Typhoons With The Taiwan Orography. Part I: Upstream Track Deflections", Monthly Weather Review, **121**, 1993, pp3193-3212
[L, Deflection direction opposite to that expected from blocking viewpoint. "Approach" towards Northern Taiwan results in deflection to South, whereas "approach" towards middle or South Taiwan results in deflection to North.]

Yeh, T.-C., and R.L. Elsberry, Interaction Of Typhoons With The Taiwan Orography. Part II: Continuous And Discontinuous Tracks", Monthly Weather Review, **121**, 1993, pp3213-3233
[L, Numerical model simulations for vortices that "hit" land show modification of cyclone flow structure. Vortices "hitting" Norther end of island move around barrier. Those "hitting" middle or Southern end often result in terminated tracks.]

Yoshizaki, M., and H. Seko, " A Retrieval Of Thermodynamic And Microphysical Variables By Using Wind Data In Simulated Multi-Cellular Convective Storms", Journal Of The Meteorological Society Of Japan, **72**, 1994, pp31-42
[L, New retrieval technique that includes time varying precipitation processes. Extends beyond the Poisson method of Gal-Chen and scalar eq. energy minimization of Ziegler. Some success, but currently seems too sensitive to Doppler radar measurement inaccuracies.]

Zahrai, A., and D.S. Zrnic, "The 10 CM Wavelength Polarimetric Weather Radar At NOAA's National Severe Storms Laboratory", Journal Of Atmospheric And Oceanic Technology, **10**, 1993, pp649-662
[L, Nice system description]

I. Zawadzki, "Factors Affecting The Precision Of Radar Measurements Of Rain", Preprints, 22'nd Conference On Radar Meteorology, American Meteorology Society, Zurich, Switzerland, pp251-256
[-]

Zawadski, I., Monteiro, E., and F. Fabry, "The Development Of Drop Size Distributions In Light Rain", Journal Of The Atmospheric Sciences, **51**, 1994, pp1100-1113
[L, Demonstrate that M-P distribution results from ice-ice interaction processes, and not from rain processes of nucleation and condensation with coalescence and breakup. That is, warm rain should not result in M-P distribution.]

S.F. Zevin, "Steps Toward An Integrated Approach To Hydrometeorological Forecasting Services", Bulletin Of The American Meteorological Society, **75**, 1994, pp1267-1276
[L, Good references. NWS provides flash flood forecasts to 3000 of 20000 flood prone areas in U.S. Floods that form in < 24 hrs and flash floods (< 6 hr) still a significant challenge. Maintenance of major raingauge networks a major problem.]

Zhang, J., Modestino, J.W., and D.A. Largon, "Maximum-Likelihood Parameter Estimation For Unsupervised Stochastic Model-Based Image Segmentation", IEEE Transactions On Image Processing, **3**, 1994, pp404-420
[L, Unsupervised segmentation in terms of color intensity, again seems complex.]

Ziegler. C. L., and D. R. MacGorman, "Observed Lightning Morphology Relative To Modeled Space Charge And Electric Field Distributions In A Tornadic Storm", Journal Of The Atmospheric Sciences, **51**, 1994, pp838-851
[L, Interesting study of Binger storm finds peak intra-cloud (IC) activity near mesocyclone occurred during max storm intensity. Peak -cloud to ground (-CG) followed IC peak by 15-20 min. Non-inductive charging exceeds inductive and parallels reflectivity growth in 7-9 km altitude layer and responsible for much of electrification of updraft and mesocyclone region. Suggests that great updraft strength elevated the - charge center up above normal altitude resulting in reduced -CG and increased IC activity. When updraft later decreases - charge center lowers in altitude resulting in increased -CG observed later! Model suggests that discharging is followed by induced charging that does not change net volume charge, but that can generate layers of different charge if a separation (such as sedimentation) mechanism is present. This seems one plausible reason for greater number of IC activity.]

Zrnic, D.S., Balakrishnan, N., Ryzhkov, A.V., and S.L. Durden, " ", IEEE Transactions On Geoscience And Remote Sensing, **32**, 1994, pp740-748
[L, Correlation coefficient between horizontal and vertically polarized (RHO_{HV}) is large at bright band, particularly with wet aggregates. Shows min RHO_{HV} just below max reflectivity as in previous work, and establishes bottom of BB. Prolates with axis ratio near 3, or distorted spheres with surface roughness of 15%, could produce observed low RHO_{HV} of 0.8.]

Zrnic, D.S., Raghavan, R., and V. Chandrasekar, "Observations Of Copolar Correlation Coefficient Through Bright Band At Vertical Incidence", Journal Of Applied Meteorology, **33**, 1994, pp45-52
[L, Included in NSSL appendix]

APPENDIX D: TAC TECHNICAL NEEDS SUMMARY

APPENDIX E: SUPPLEMENTAL REPORTS/PAPERS FOR CSU

APPENDIX F: SUPPLEMENTAL REPORTS/PAPERS FOR FSL

APPENDIX G: SUPPLEMENTAL REPORTS/PAPERS FOR NOAA/HRL

APPENDIX H: SUPPLEMENTAL REPORTS/PAPERS FOR HUGHES STX

APPENDIX I: SUPPLEMENTAL REPORTS/PAPERS FOR MIT/LL

APPENDIX J: SUPPLEMENTAL REPORTS/PAPERS FOR NASA/MSFC

(no reports provided)

APPENDIX K: SUPPLEMENTAL REPORTS/PAPERS FOR NCAR

APPENDIX L: SUPPLEMENTAL REPORTS/PAPERS FOR NSSL

APPENDIX M: SUPPLEMENTAL REPORTS/PAPERS FOR NWS

APPENDIX N: SUPPLEMENTAL REPORTS/PAPERS FOR OSF

(no reports provided)

APPENDIX O: SUPPLEMENTAL REPORTS/PAPERS FOR OU

(no reports provided)

APPENDIX P: SUPPLEMENTAL REPORTS/PAPERS FOR PL/GPAP

APPENDIX Q: SUPPLEMENTAL REPORTS/PAPERS FOR TDL

APPENDIX R: SUPPLEMENTAL REPORTS/PAPERS FOR UND

APPENDIX S: SUPPLEMENTAL REPORTS/PAPERS FOR UNISYS

(no reports provided)