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PRODUCTION OF A NATIONAL RADAR REFLECTIVITY MOSAIC AND AUTOMATED RADAR OBSERVATIONS FROM WSR-88D RADAR CODED MESSAGES

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Silver Spring, Md.
May 2002

U. S. DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / National Weather Service

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May 2002

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Table of Contents

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ABSTRACT

The methodology used for the automated production of a radar reflectivity mosaic and text-format radar observations for the conterminous United States is presented. The mosaic is defined as a polar stereographic grid of approximately 10-km resolution, with seven reflectivity levels ranging from < 5 dBZ to ≥ 55 dBZ. The textual radar observations contain a coded description of the precipitation echoes within individual radar umbrellas.

These products are based on Radar Coded Messages (RCM's) generated automatically twice per hour at Weather Surveillance Radar 1988 (Doppler)(WSR-88D) sites. The original RCM's receive no human quality control, and contain some echoes of nonhydrometeorological origin; the mosaicking algorithm compares the echoes to lightning, infrared satellite, and humidity observations to identify and remove echoes from birds, insects, ground clutter, anomalous propagation, or aircraft.

The Automated Radar Observations (AUTOROBS) generated by this algorithm are text descriptions of echoes within 230 km of each radar; the AUTOROB is essentially a reformatting of the information within the RCM in an historic coded format. The AUTOROB contains the azimuths and ranges of echo regions relative to the radar, their sizes and shapes, and echo types (i.e. convective or stratiform). The messages also contain the positions and intensities of echoes within the local portion of the national Manually-Digitized Radar (MDR) mosaic, a 40-km polar stereographic mosaic which has been produced by automated processes since the 1970's.

This memorandum describes the methods used to produce the reflectivity mosaic, identify and remove nonprecipitation echoes, and create the textual AUTOROBS. Some characteristics of the resulting mosaics are also presented.

1. INTRODUCTION

Weather surveillance radar is extensively used in short-range forecasting operations. It is often highly desirable to view the observations of several radars simultaneously, even for local forecasting operations, in order to monitor the development and movement of synoptic-scale systems or to get the best possible observations of small-scale features which are distant from the local radar.

The National Weather Service (NWS) implemented some radar mosaicking techniques as early as the 1960's. These mosaic operations were based on collection and compositing of manually-digitized information transmitted from individual radar sites as Radar Observations (ROBs) (Sadowski 1979; Departments of Commerce and Defense 1980). The ROBs included descriptions of echo regions, convective-scale phenomena (e.g. hook echoes, line-echo wave patterns), and echo movement. Nonprecipitation echoes due to ground clutter (GC), anomalous propagation (AP), or aerial targets such as aircraft, insect swarms or birds were eliminated by the operator based on other data and personal experience. A 40-km national Manually-Digitized Radar (MDR) mosaic was also created by compositing echo location and intensity data contained in the ROBs.

With the deployment of the WSR-88D network, the manually-produced ROB was replaced by the automatically-produced Radar Coded Message (RCM). The RCM contains information on echoes within the local portion of a national 10-km reflectivity grid, a description of convective echoes including maximimum reflectivity, echo tops and mesocyclone phenomena, and the local Velocity-Azimuth Display Wind Profile (OFCM 1991).

To preserve continuity in the dissemination of publicly-available products, it is necessary to transform the RCM's into the older ROB format through a purely automated process. These automated ROBs (AUTOROBs) contain echo descriptions in the same format as those in the original ROB's, and a local reflectivity grid remapped from the 10-km RCM projection to the older 40-km MDR projection.

The reflectivity data in RCMs generally feature some nonprecipitation echoes (NP echoes), mainly from migrating birds, insect swarms, and aircraft. In practice, most of these echo features can be reliably identified by the absence of other observations that confirm the existence of precipitation, particularly clouds as indicated by infrared satellite data, lightning strikes observed by radio detection networks, and upper-air humidity information. Many NP echo regions caused by birds and insects are also recognizable through their location relative to radar sites, their shape, and the statistical distribution of reflectivity levels with the region. The national mosaic and AUTOROB's are produced following the application of a quality-control (QC) algorithm that identifies and removes echo features that appear to be from sources other than precipitation.

The first software suite for the production of AUTOROBs and the national reflectivity mosaic was implemented within the NWS National Centers for Environmental Prediction (NCEP), at the Aviation Weather Center (Lewis and Mosher 1992; Cope 1993). This suite relied on communications systems and proprietary system software due to be eliminated with the introduction of the Advanced Weather Interactive Processing System (AWIPS). Accordingly, it was decided to rehost the software within NWS Telecommunications Gateway facility, on hardware that had been in use there for several years. This memorandum describes the implementation by the Meteorological Development Laboratory of the radar mosaic and AUTOROB production processes, and the resulting products.

The national reflectivity mosaic is operationally disseminated under WMO header HAXA00 KWBC; the AUTOROBs are disseminated under WMO headers SDUS4x KWBC, where x ranges from 1 to 6, indicating the geographic origin of the original radar data.

2. INPUT RADAR DATA

The RCM (OFCM 1991) contains a coded text description of the local portion of the national reflectivity mosaic grid, a coded description of convective storm cells within the local radar umbrella, and a Velocity-Azimuth Display (VAD) wind profile based on Doppler information. In the reflectivity grid portion of the RCM, lines of text contain the starting row and column position of runs of nonzero reflectivity levels (1-8) observed along rows within the grid. These reflectivities are derived from the Digital Hybrid Scan (DHS) reflectivity array, which is also used to derive precipitation accumulation estimates. The RCMs are produced twice per hour, roughly in the intervals 00:05-00:15 and 00:35-00:45, and are centrally collected on a file server at NWS headquarters.

The DHS incorporates quality control procedures that effectively reduce or eliminate GC, AP, and single-grid-box echoes sometimes referred to as 'shot noise' (Fulton et al. 1998). However, significant NP features sometimes remain in the RCM's, with AP appearing on occasion and returns from biological targets (birds and insects) being common from late winter through late autumn.

3. THE RADAR REFLECTIVITY MOSAIC

The mosaic is projected on a polar stereographic grid with the following characteristics:

Orientation: 105°W (255°E)
Reference latitude: 60°N
Mesh length at reference latitude: 11906.25 m
Extreme lower-left corner position: 119.036°W, 23.097°N
Extreme upper-right corner position: 58.025°W, 45.317°N
Number of rows: 360
Number of columns: 460

This grid is coaligned with the MDR grid and the Hydrologic Research and Applications Program (HRAP) grid, which have reference mesh lengths of 47625 m and 4762.5 m, respectively.

Note that our convention is that grid position (1,1) is at the lower-left corner of the lower-left box; thus continuous grid position values ≥ 1 and < 2 are within box 1, position values between 2 and 3 are within box 2, etc.

The reflectivity data within the grid describe the largest value observed within the box. The reflectivity values are coded as follows:

0: < 15 dBZ	4: 45-49 dBZ
1: 15-29 dBZ	5: 50-54 dBZ
2: 30-39 dBZ	6: ≥ 55 dBZ
3: 40-44 dBZ	7: No coverage or degraded coverage.

A value of 7 is placed in grid boxes that lack coverage from any radar, due to permanent gaps in network coverage, temporary gaps due to nonreporting radars, or subregions within radar umbrellas that are seriously occulted (blocked from the radar's view) by terrain features. Note that the RCM's themselves contain values of 7 and 8 to describe echoes beyond 230 km from the radar; these indicate echoes of indeterminate reflectivity level and no attempt has been made to include them in the mosaic or AUTOROB's.

For grid boxes covered by multiple radars, the highest observed reflectivity is placed in the final composite. While it is sometimes considered desirable to assign the reflectivity observed by the closest radar to the box, the strategy we chose is the simplest to apply operationally, and insures continuous spatial coverage when some radars are temporarily out of commission, or when radar units are moved or installed. The 'highest observed reflectivity' method may sometimes introduce features such as elevated hail cores into the composite while the 'nearest radar' approach would not; however such features are of concern mainly when the aim is to produce rainfall estimates from the data. The primary purpose of this composite is to provide a synoptic overview, with an emphasis on identifying the location and approximate intensity of rainfall (National Weather Service 1992). It is not intended for rainfall estimation, since the input reflectivity field has insufficient spatial and temporal resolution for such a purpose.

Sample reflectivity composites appear in Fig. 1 (national view) and Fig. 2 (regional view). The composites are produced twice per hour, and are available at about 00:05 (for RCMs from 00:45) and 00:35 (for RCMs from 00:15).

4. QUALITY CONTROL OF THE REFLECTIVITY FIELD

A. Nonprecipitation echoes in radar coded messages

The presence of NP targets in RCM reflectivity makes some quality control (QC) necessary prior to dissemination of the mosaic and AUTOROBs. Comparison of unedited and manually-edited mosaics suggests that almost 50% of the echo area is due to NP targets at night during the spring and autumn bird migration seasons, about 20-30% are NP during daytime hours between late spring and early autumn, and about 15% are NP during winter.

Efforts at automatically detecting and removing NP echoes from radar products have generally been focused on high-reflectivity features such as terrain, GC, and AP (see, for example, Fulton et al. 1998; Grecu and Krajewski 2000), which have serious effects on rainfall estimates. The QC algorithms applied to the RCM reflectivity appear to have been very successful at removing such echoes.

The remaining NP echoes in the RCM, while generally < 30 dBZ, have a major impact on the visual representation of the overall echo field. In order to eliminate birds, insects, aircraft, and other NP echoes from the composite and the AUTOROBs, RCM grid boxes with nonzero echo levels are flagged for deletion if other data indicate little potential for precipitation, if the local echo texture and reflectivity spectrum suggest biological rather than precipitation targets, or if there is a lack of spatial continuity in the echo field. Thus three mosaic-editing processes are used to remove NP echoes: a bird/insect check, a cloud/humidity check, and a shot-noise filter. A fourth check identifies surface reports of precipitation, lightning observations, and radar echo characteristics that tend to confirm precipitation. This final check locally overrides the results of the first three, by reinserting any echoes that are within five grid spaces of the confirming feature. The various editing checks are described below.

Bird/insect check

The periods late winter through spring and late summer through early autumn are known to be prime bird migratory seasons. At night, migrating birds generally fly high enough to be detected by the WSR-88D, and echoes from birds are often observed (Gauthreaux and Belser, 1998). In these cases, RCM's show a circular or annular return pattern symmetric about the radar site. The size of this pattern can vary depending on the birds' flight altitude, their volumetric concentration, radar beam elevation angle, and radio propagation conditions. During the nighttime and early morning hours (primarily from 0200 to 1200 UTC), the unedited mosaic often contains many circular reflectivity patterns from birds.

The characteristic bird feature contains almost entirely level 1 (15-29 dBZ) echoes, with a geometric centroid near the radar Using these criteria, the radar mosaic is analyzed for returns of this nature. When such features are observed near contributing radars at night during migration seasons, they are removed from the final mosaic.

At times, bird echo patterns can overlap several radar umbrellas, thus escaping the above mentioned check. The overlapping patterns occur primarily in the southern plains during peak bird migration seasons (April and September). These appear as very large areas of level-1 echoes; such areas can be differentiated from precipitation because precipitation almost invariably features some echoes of 30 dBZ and higher. Therefore a second texture check is applied during those months and during the peak diurnal flight period (0200-1000 UTC). This texture check deletes any 5x5-box (50x50 km) consisting entirely of level-1 echoes, provided that snow is not indicated ($T_{850} \geq 3°C$).

Insect returns are observed chiefly during the summer months, and can appear during daytime given certain radio propagation conditions. Like bird returns, they tend to be centered near or over a radar and appear on the mosaic as circular or elliptical echoes of less than 30 dBZ. The bird return check also effectively removes insect returns.

While many biological echoes would be eliminated by the cloud check described below, such echoes often occur under dense, cold cloud shields near precipitation areas. Because their characteristic shape is used to recognize them automatically, and because applying cloud-detection editing could alter that shape, the bird check is applied before the cloud/humidity check.

Cloud/humidity check

While the bird/insect check helps eliminate most large NP features from the mosaic, some biological and other echoes generally remain. Many NP features can be recognized when they occur in the absence of precipitating clouds. A method of using satellite and model data was developed to identify such conditions. This editing method is based upon the statistical probability of a return being deleted by a human analyst, given only the mean relative humidity, static stability, and infrared cloud-top temperature in the atmospheric column where the echo was observed.

The cloud editing procedure developed by Lewis and Mosher (1992) utilized a comparison between the satellite temperature and the estimated cloud-condensation level temperature, followed by a check based on the lifted index and the surface-500 mb mean relative humidity. Later these tests were augmented by reference to a commercially-produced radar mosaic (Lewis and Mosher, personal communication). Our intent was to develop a method that did not require both satellite and upper-air data, and which produced acceptable results without reference to externally-processed radar data.

To develop the new method, an extensive set of unedited mosaic images created between April 1999 and March 2000 was manually edited. A statistical database was constructed, containing for each grid box the editing results (0 for retention, 1 for deletion), the mean relative humidity (RH), K index, 850-500 mb lifted index, the infrared (IR) satellite temperature, and the original reflectivity level itself. The probability that an echo in a grid box would be deleted was positively correlated with IR temperature and lifted index, and negatively correlated with mean RH, K index, and reflectivity level (in practice most echoes of 40 dBZ and higher were retained by the analyst). Upper-air information was derived from forecasts of the Aviation run of NCEP's Global Spectral Model (Kalnay et al. 1990). Satellite IR data were obtained from the 11-μ channel of GOES-East and GOES-West.

The atmospheric variables were then applied as statistical predictors of the editing result. Since the statistical predictand was a 0/1 binary value, forward-selection linear screening regression yielded equations giving the probability that an echo would be deleted. Examination of the data showed that in winter and spring the mean RH was the best discriminator between precipitation and nonprecitation echoes, while in summer and early autumn seasons the satellite cloud-top temperature was the best discriminator. Therefore, separate equations were derived for the winter, spring, and summer season. As noted above, there is considerable diurnal variation in the prevalence of biological echoes; therefore separate equations were also derived for the daytime and nighttime hours. A complete listing of the various data sample properties and equations appears in the Appendix. In practice, an echo is deleted from a grid box only if the deletion probability is 70% or higher; this yields good agreement between the manual and automated methods.

Shot noise filter

After the bird check and cloud editing, some small echo features, generally due to aircraft flying in the vicinity of cold clouds, can remain. These generally appear as isolated 1-box echoes. Therefore, a final shot-noise check is done on the mosaic. When a reflectivity value is present, the surrounding 5x5 grid box region is checked for nonzero reflectivity values, and if there are none, that reflectivity point is deleted.

Features confirming precipitation

We consider that surface reports of precipitation, cloud-to-ground lightning, and echoes detected by multiple radars confirm precipitation. Detection by multiple radars indicates that an echo feature has fairly deep vertical extent. However, during migration seasons many bird echoes are detected by two radars. Therefore during the spring, summer, and autumn, echoes observed by three or more radars confirm precipitation, while during the winter detection by two or more radars is considered necessary. The results of the other editing procedures are ignored within a radius of five grid boxes of a confirming precipitation feature.

B. Editing results

There are still certain spurious features which can remain in the mosaic despite the checks outlined above. Anomalous propagation sometimes appears in areas with cold clouds. Radar calibration patterns, which are transmitted from sites while an artificial radio signal is fed into the antenna's receiver horn, can also appear in the final mosaic when cold clouds cover part of the radar umbrella. These patterns are plainly recognizable in the mosaic as concentric rings of level-3 or higher echoes; they are more difficult to distinguish when described in a textual Radar Observation, as described below. We have adopted a convention whereby suspicious RCM's featuring echo coverage over almost their full 460-km coverage radius are excluded from further analysis.

A comparison of manual editing results and the full suite of automated editing checks was made based on the dataset described above. Within this dependent sample of cases, the results agreed in about 90% of cases in the winter, and in 80-85% of cases during the remainder of the year. The most common error was retention of NP echoes, a bias we favor as being the more conservative alternative. In practice, few large spurious features appear in edited mosaics, and major precipitation features are rarely altered.

It should be noted that the procedures outlined above would probably be less successful if applied to reflectivity data that had not already undergone the QC checks built into the Digital Hybrid Scan procedure. Features such as GC and AP have image characteristics substantially different from those produced by birds or aircraft, and could be difficult to identify when they occur under humid, cloudy conditions.

Unedited and edited mosaics appear in Figs. 3-4. This springtime case featured extensive bird echoes over much of the southern Plains region, as well as several large areas of precipitation. The automated editing checks were able to identify NP features even when they were in close proximity to precipitation, as occurred over Texas.

5. INDICATIONS OF MISSING RADAR COVERAGE

Although most places in the United States are within 230 km of one or more WSR-88D's, there are coverage gaps over sparsely-populated portions of the Great Basin and the Southwest. Also, some places within 230 km of only one radar are essentially uncovered because of beam blockage by terrain features. In addition to such permanent coverage gaps, temporary gaps appear in the vicinity of nonfunctioning or nonreporting radars. We have adopted a convention of indicating these gaps as an aid in interpreting the movement and evolution of precipitation patterns in areas of degraded radar coverage.

The effects of terrain blockage on radar coverage in the western United States is illustrated in Fig. 5, which shows the relative frequency of echoes ≥ 15 dBZ during the period 1 October - 31 December 1997 and 1 September - 31 October 1998. Occulted areas appear as clear wedges near the boundaries of individual umbrellas, mostly near the national borders (note particularly the umbrellas surrounding El Paso, Texas; Tuscon, Arizona; and Portland, Oregon). In occulted areas, only a few echoes are ever detected. Because this climatology was derived from RCM mosaics, most occulted areas within the interior of the country are covered by neighboring radars. Occultation gaps generally appear only at some distance from the radar, because at close ranges reflectivity from the second or third antenna elevations is used to approximate the value at the lowest angle when the lowest beam is blocked. These higher angles often overshoot precipitation at greater ranges.

To account for the effects of beam blockage by terrain, we obtained occultation maps for each site from the NWS Radar Operations Center. The maps indicate the percentage of the radar beam that is blocked by terrain as a function of azimuth and range for the each of the lowest four antenna elevation angles. These four scans are used to construct the DHS reflectivity product, from which precipitation accumulation and the RCM reflectivity are derived.

By comparing these maps to the echo climatology we developed a convention for determining blockage in the RCM grid. A box is considered blocked with respect to a radar if either condition (a) or (b) apply:

(a) the box is centered more than 100 km from the radar and more than 50% of the azimuth/range bins over the box are more than 55% occulted at the lowest antenna elevation;
(b) more than 33% of the azimuth/range bins over the box are more than 55% occulted at both the first and second antenna elevation angles.

These conventions yield good agreement with the echo climatologies described above. The blockage pattern surrounding each radar is applied to the local section of the mosaic when the radar's observations are incorporated. If the reflectivity level for a box is zero and the occultation map indicates that the box is blocked, a missing indicator is stored there. The indicator is cleared if another radar's observations cover the box.

Mosaic grid boxes left uncovered for any reason are described by a reflectivity code of 7. Note that this is different from the convention within RCM's, where 7 and 8 describe echoes beyond 230 km from the reporting radar.

In practice, a file containing the portion of the national RCM grid covered by each radar has been created. When individual RCM's are composited, this file is used to determine which subsection of the national grid is effectively covered by the local radar. Occulted areas within the local umbrella remain uncovered in the national grid unless another radar is present to complete the coverage.

In Fig. 1, coverage gaps beyond 230 km from any radar exist over extreme northeastern Arizona and northwestern New Mexico; gaps due to occultation are evident to the west of Portland, Oregon, and south of Tuscon, Arizona; a temporary coverage gap due to nonreporting radars appears over Maine, New Hampshire, and Vermont.

6. SUMMARY OF GEOGRAPHIC COMPOSITING ALGORITHM

The procedures for compositing and applying quality control (QC) to the RCM-based mosaic can be summarized as follows:

a. Initialize entire array of grid boxes to 'missing' indicators (a value of 7);

b. For each available RCM:

   i. Decode; if correct current time is indicated then read the local umbrella coverage map from a table and apply zero values to grid boxes that have not been covered by radars found earlier; leave occulted grid boxes within the local umbrella flagged as missing.

   ii. Apply nonzero reflectivity values from the RCM to the national grid, whenever these values are higher than the previous estimate

c. Apply QC procedures: first bird/insect checks (depending on season and time of day), then cloud/humidity check, finally shot-noise check; reintroduce any echoes in the immediate vicinity of precipitation-confirming features, if such echoes were deleted.

The quality-controlled mosaic is encoded in Gridded Binary (GRIB) format (Dey 1996; WMO 1988) and disseminated under WMO identifier HAXA00 KWBC. A color graphic version is available in real time through the National Weather Service's World Wide Web page.

7. AUTOMATED RADAR OBSERVATIONS

The Automated Radar Observation (AUTOROB) is a text description of radar echoes within the coverage umbrella of a single radar. Radar echo features described include the echo shape (either 'area', 'cell', or 'line'), the maximum reflectivity level, the percentage of echo coverage within the area, movement of echo centroids, and the maximum echo top height. The reflectivity pattern within the local portion of the national 40-km MDR grid is also coded as part of the message.

Historically, this textual information was produced in real time by technicians who interpreted Plan-Position Indicator and Range-Height Indicator displays and manually transmitted text codes to indicate the location, intensity, shape characteristics, and movement of the echoes. Data from these Radar Observations (ROB's) were centrally mosaicked and plotted on facsimile charts. To supply users with data in this historical format, both reflectivity field and storm cell information from the RCM's are analyzed to reproduce the contents of the manual ROB in the AUTOROB.

An example of an AUTOROB appears in Fig. 6. The first two lines are the WMO message header and message source information. The first non-header line shows the station identifier JAX (Jacksonville, Florida), nominal observation time (1835 UTC), and the largest precipitation feature, in this case an area of thunderstorms. Succeeding lines indicate the location of an intense thunderstorm cell and the presence of a large band of lighter rain showers covering a substantial portion of the radar umbrella.

After consultation with the Office of Operational Systems, the nominal observation time has been specified as 35 minutes after the hour, as it has historically been specified in ROB products. Both automatic and manual observations on which the ROB is based have generally been taken before 00:30. However, many users expect the time characters to include at '35' and it was decided to retain that convention.

The notation "AUTO" indicates that the observation was generated by an automated process rather than manually. For several years during the deployment of the WSR-88D network, the NWS simultaneously disseminated both AUTOROBS from WSR-88D sites and manual ROBS from WSR-57 and WSR-74 sites.

The "^" symbol indicates the beginning of the digital reflectivity portion of the message, which describes the location and intensity of echoes in the subsection of the national MDR grid surrounding the KJAX radar site. A complete description of the codes for the shape, size, intensity, and movement of echo areas, and conventions for coding of the MDR portion of the AUTOROB message, are presented in National Weather Service (1980).

The MDL version of the AUTOROB procedure is largely a rehosted version of the procedures outlined by Cope (1993). However, a new convention has been adopted by which the content of the AUTOROB is derived solely from the data contained in the source site's own RCM, rather than from reflectivity patterns in the national mosaic.[1] The national mosaic is used as a QC mask to determine which grid boxes contained precipitation, but the reflectivity levels shown in the AUTOROBs are taken from the local RCM. Also, areas of precipitation that did not appear in the local RCM are not introduced into the AUTOROB from the national mosaic. This insures consistency between the AUTOROB and the local Plan Position Indicator display in situations where other radars detect precipitation from shallow clouds near the boundaries of the local umbrella, while the same precipitation is below the minimum 15-dBZ threshold when viewed by the local radar.

Elementary image processing is used to categorize RCM reflectivity levels into 'echo families'. An echo family is a geographically connected area of echoes. An RCM gridpoint echo is considered to be associated with another echo if the two are separated by 4 RCM grid boxes or less. The echo family type (isolated storm cell, line, or area) is determined based on its shape. The maximum reflectivity level, the percentage areal coverage by echoes of that intensity, and echo velocity information contained in the RCM are stored for output in the AUTOROB. Some echo areas with only light or scattered precipitation are excluded from the AUTOROB, such as small areas with echoes no more intense that level 3, or areas with less than 5% echo coverage.

An AUTOROB message is generated for every WSR-88D site within the conterminous United States. If a site within the list of all radars has not reported a current RCM, a 'PPINA' (Plane Position Indicator Not Available) message is

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[1]This decision was ratified by the Committee on Analysis and Forecast Techniques Implementation in June 2000.

generated for that site. If no precipitation or only light precipitation covering a small fraction of the umbrella is indicated, a 'PPINE' (Plan Position Indicator No Echoes) message is generated for the site.

The AUTOROB indicates snow rather than rain ("S" rather than "R") for echo areas in which most MDR grid boxes are believed to have an 850-mb temperature ≤ 273 K and a surface temperature ≤ 277 K, following a convention adopted by Cope (1993). These temperature indications are based on forecasts of the Eta model. We are experimenting with a new procedure in which rain/snow differentiation is based on operational Model Output Statistics probability of snow guidance.

Note that the AUTOROB contains no explicit information on areas of missing coverage within the radar umbrella, as the 10-km digital reflectivity mosaic does. Only areas with precipitation are mentioned; no distinction is made between areas with reflectivity < 15 dBZ and areas which are shielded from the radar by terrain.

The AUTOROBS are operationally disseminated in text format under WMO headers SDUS4*x* KWBC, where *x* is an integer ranging from 1 to 6; the *x* is an indicator of the geographic region of the originating radar. Dissemination is once per hour at approximately 00:40.

The AUTOROB generation procedure for any one site can be summarized as follows:

If no RCM or an RCM with noncurrent data are reported, generate a PPINA message;

If little or no precipitation is indicated within the local portion of the national grid, after quality-control, then generate a PPINE message;

If precipitation is indicated in the local portion of the RCM mosaic:

Identify echo families;

For each echo family:

Determine fractional echo coverage within the family's area;

Identify convective cells contained in the RCM and remove those in areas flagged as nonprecipitation by the mosaic QC algorithms;

Determine motion of echo areas as the mean of the motions of storm cells within them;

Associate the area or the storm cell containing the RCM's maximum echo top with that top's magnitude, azimuth, and range;

Check the surface and 850-mb temperatures for rain/snow criteria, and rename the precipitation characteristic to "snow" if conditions are sufficiently cold;

Write out the location, coverage, velocity, and characteristics of all echo families and convective cells;

Based on the reflectivity pattern in the RCM grid, determine the reflectivity pattern within the local portion of the MDR grid;

Relocate the MDR grid to the local radar-centered coordinate system and write out strings describing nonzero reflectivity values.

8. GENERATION OF THE NCEP FACSIMILE RADAR SUMMARY CHART

Information from both the AUTOROBs and the radar mosaic is contained in a facsimile chart generated by NCEP (Fig. 7). The reflectivity field is displayed in contoured form, with contour intervals set at reflectivity levels 1, 3, and 5. Information on the precipitation area and convective cell movement and echo tops is plotted in text format. The content of the chart is fully described by Sadowski (1979).

A schematic diagram (Fig. 8) illustrates the general flow of data for the complete product generation process; RCM's from individual radar sites are collected and composited into a national mosaic; the content of the mosaic is compared to cloud indications determined from satellite and humidity data and nonprecipitation echoes removed; ROBs and the digital mosaic are created; the Radar Summary Chart is generated from the mosaic and ROBs.

9. FUTURE WORK

Efforts are now underway to create higher-resolution mosaics of reflectivity, vertically-integrated liquid (VIL), rainfall, and other WSR-88D products. These mosaics will feature 16 intensity levels and can be generated at 2- and 4-km resolution several times per hour.

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REFERENCES

Cope, A., 1993: Identification of precipitation systems from a composite digital data base. *Preprints Ninth Conference on Interactive Information Processing Systems for Meteorology, Oceanography, and Hydrology*, Anaheim, Amer. Meteor. Soc., 187-190.

Cummins, K. L., M. J. Murphy, E. A. Bardo, W. L. Hiscox, R. B. Pyle, and A. E. Pifer, 1998: A combined TOA/MDF technology upgrade of the U. S. National Lightning Detection Network, *J. Geophys. Res.*, **103**, 9035-9044.

Department of Commerce and Department of Defense, 1980: *Federal Meteorological Handbook* 7, Weather radar observations: Part A, National weather radar network observing and reporting procedures. [Copies of relevant portions available from Meteorological Development Laboratory, W/OST2, National Weather Service, 1325 East West Highway, Silver Spring, Maryland, 20910.]

Dey, C. H., 1996: GRIB, Edition 1, the WMO format for the storage of weather production information and the exchange of weather product messages in gridded binary form. *NCEP Office Note* 388, National Centers for Environmental Prediction, National Weather Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, 5 sections and appendix.

Fulton, R. A., and J. P Breidenbach, D.-J. Seo, D. A. Miller, and T. O'Bannon, 1998 : The WSR-88D rainfall algorithm. *Wea. Forecasting*, 13, 337-395.

Gauthreaux, S. A. Jr., and B. G. Belser, 1998: Displays of bird movements on the WSR-88D: Patterns and quantification. *Wea. Forecasting*, 13, 453-464.

Grecu, M., and W. F Krajewski, 2000: An efficient methodology for detection of anomalous propagation echoes in radar reflectivity data using neural networks. *J. Atmos. Oceanic Technol.*, 17, 121-129.

Kalnay, E., M. Kanamitsu, and W.E. Baker, 1990: Global numerical weather prediction at the National Meteorological Center. *Bull. Amer. Meteor. Soc.*, 71, 1410-1428.

Lewis, J., and F. Mosher 1992: National editing of the WSR-88D Radar Coded Message. *Preprints Eighth Conference on Interactive Information Processing Systems for Meteorology, Oceanography, and Hydrology*, Atlanta, Amer. Meteor. Soc., 18-21.

National Weather Service, 1980: National Weather Service radar code users's guide. National Oceanic and Atmospheric Administration, U. S. Department of Commerce, 179 pp. [Copies of relevant portions available from Meteorological Development Laboratory, W/OST2, National Weather Service, 1325 East West Highway, Silver Spring, Maryland, 20910.]

_____, 1992: *Integrated User Language Functional and Performance Requirements*. National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Appendices B, D, E, and F, Tables B.4.1, D.4.1, E.4.1, and F.4.1.

Office of the Federal Coordinator for Meteorology (OFCM) 1991: *Federal Meteorological Handbook 11*, Doppler radar meteorological observations: Part C, WSR-88D products and algorithms. OFCM, NOAA, U.S. Department of Commerce.

Sadowski, A. F., 1979: The radar guidance program. *NWS Technical Procedures Bulletin* No. 253, National Oceanic and Atmospheric Administration, U. S. Department of Commerce, 14 pp. [Available from Office of Climate, Water, and Weather Services, W/OS, National Weather Service, 1325 East West Highway, Silver Spring, Maryland, 20910.]

WMO, 1988: *Manual on Codes*, Vol. 1, Part B - Binary Codes. WMO No. 306, World Meteorological Organization, Geneva.

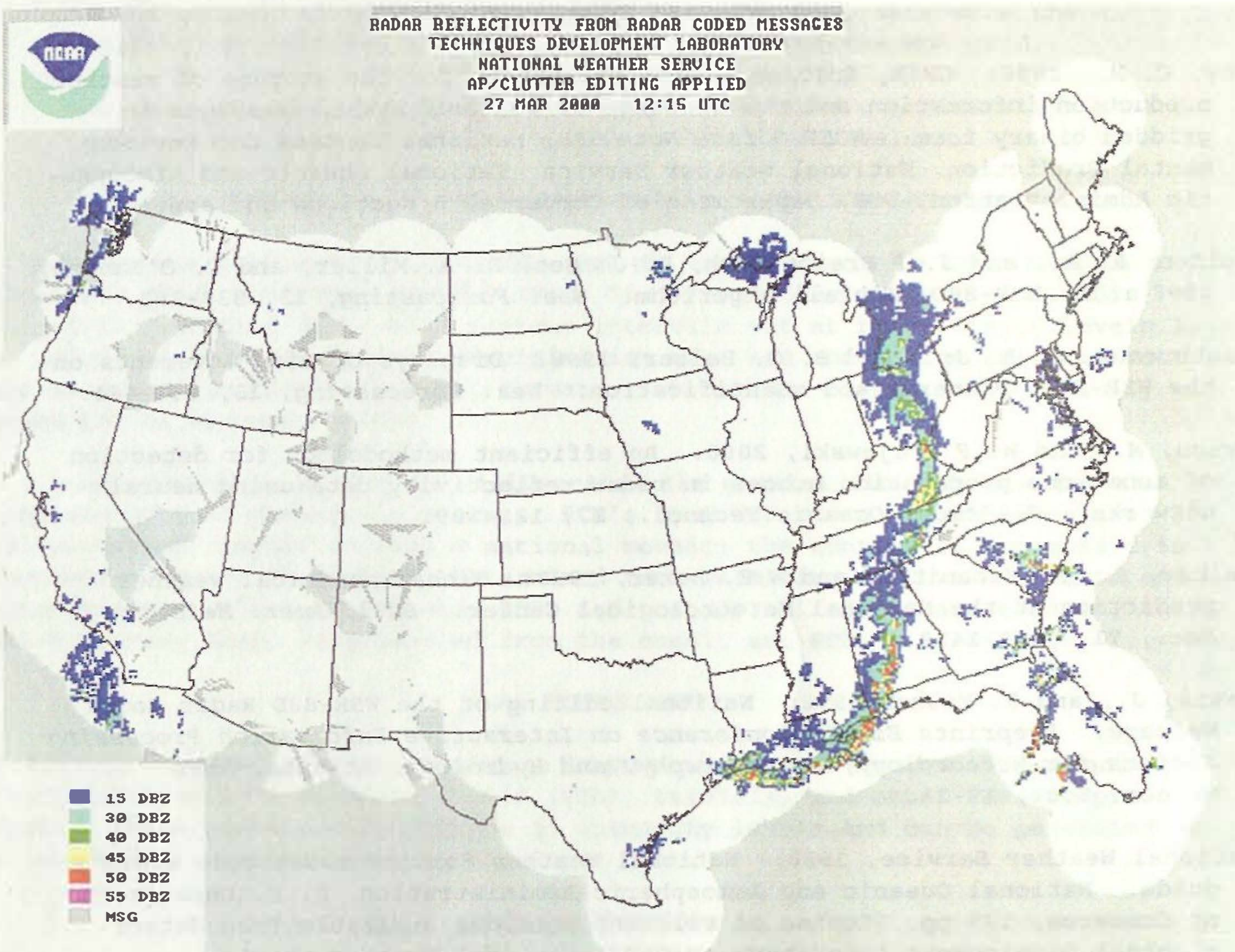

Figure 1. National 10-km radar composite from Radar Coded Messages, for 1215 UTC, 27 March 2000. Blank areas indicate reflectivity < 15 dBZ, light gray indicates areas beyond 230 km from the nearest radar, or areas blocked from the radar network by terrain. Precipitation reflectivity levels are indicated in the legend.

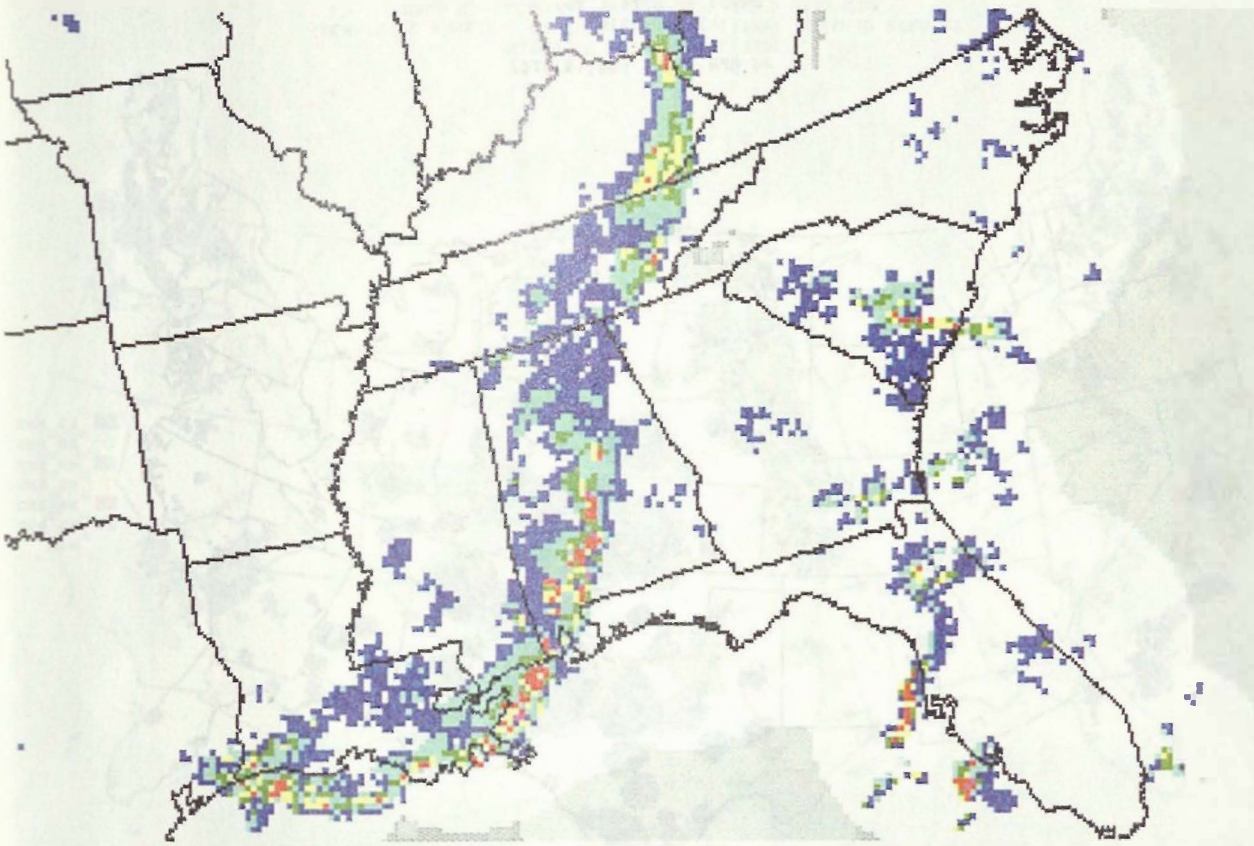

Figure 2. As in Fig. 1, except a subsection covering the southeastern United States.

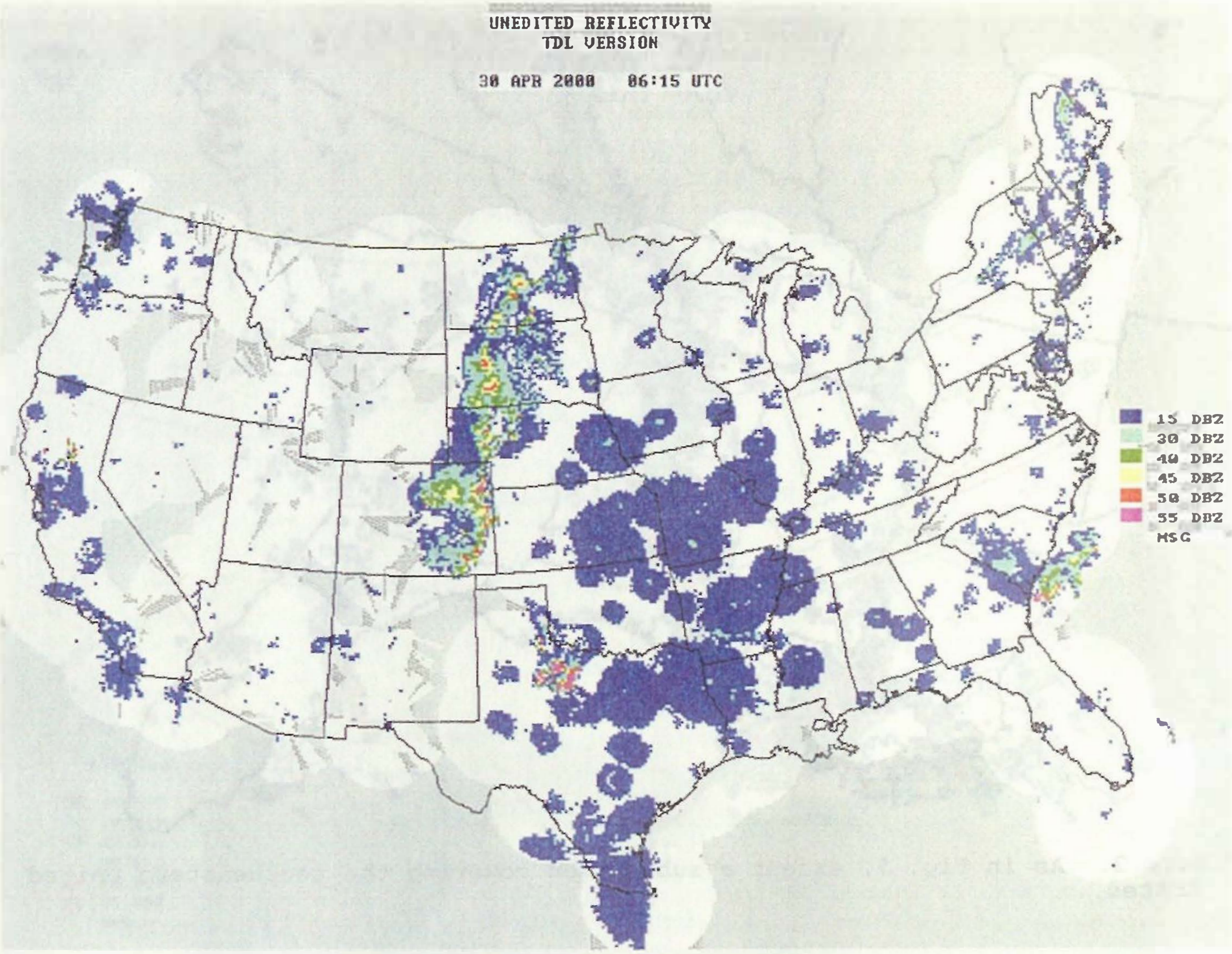

Figure 3. Unedited reflectivity mosaic, 0615 UTC, 30 April 2000. There are extensive echo regions from migrating birds (large areas of 15-dBZ echoes extending from Texas and Louisiana north to Nebraska and Iowa), and shot-noise features elsewhere.

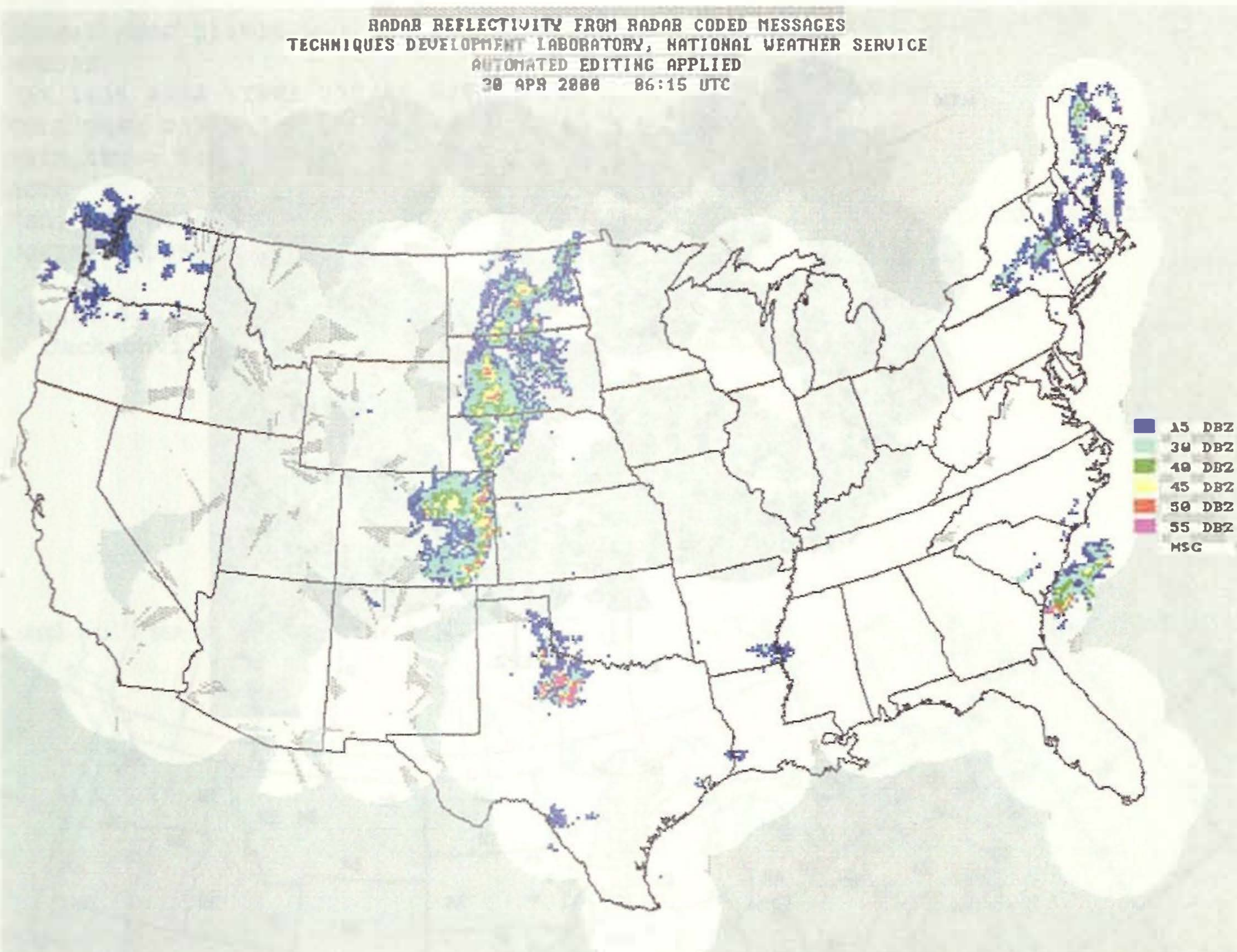

Figure 4. As in Fig. 3, after automated edit procedure was applied.

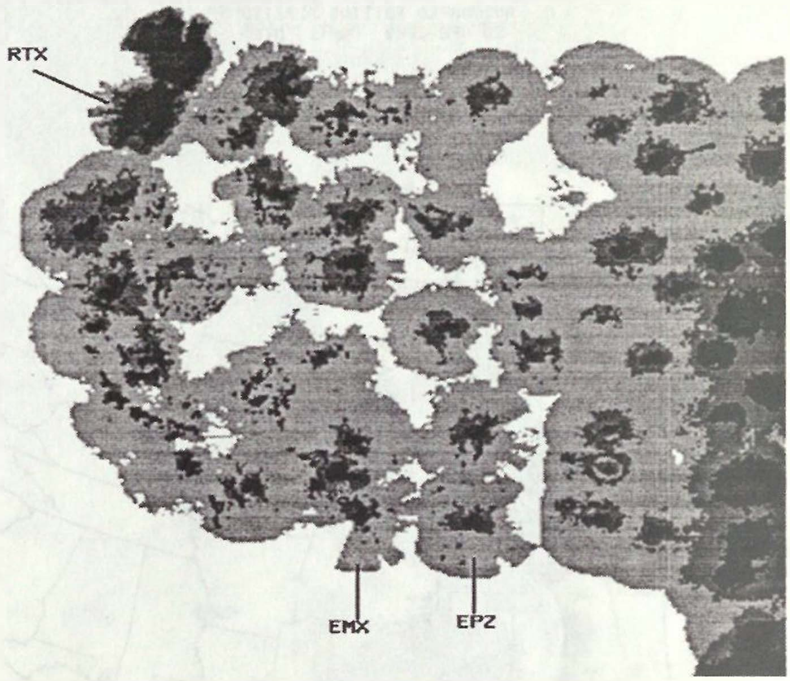

Figure 5. Relative frequencies of radar echoes > 15 dBZ, from unedited RCM mosaics. The period covered is 1 October - 31 December 1997 and 1 September - 31 October 1998. Blank indicates < 1%, gray shades indicate 1-5%, 6-10%, and > 10% from lightest to darkest. Effects of terrain occultation are clearly evident near Portland, Oregon (RTX), Tuscon, Arizona (EMX), and El Paso, Texas (EPZ).

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SDUS42 KWBC 211814
ROBJAX
JAX 1835 AREA 5TRWX 232/88 225/72 11W MT 370 230/109  C2536
CELL TRWX 237/117 D3
AREA 4RW++ 54/117 226/127 161W  C2536
AUTO
^GO2 HM2 HO344 IM223432 JK12 JN21143 KJ1 KM222134 LK32221 MK21122 NJ23322
OJ43432 PJ3554 QI254=
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Figure 6. Sample of an Automated Radar Observation (AUTOROB) for Jacksonville, Florida at 1814 UTC, 21 January 2002.

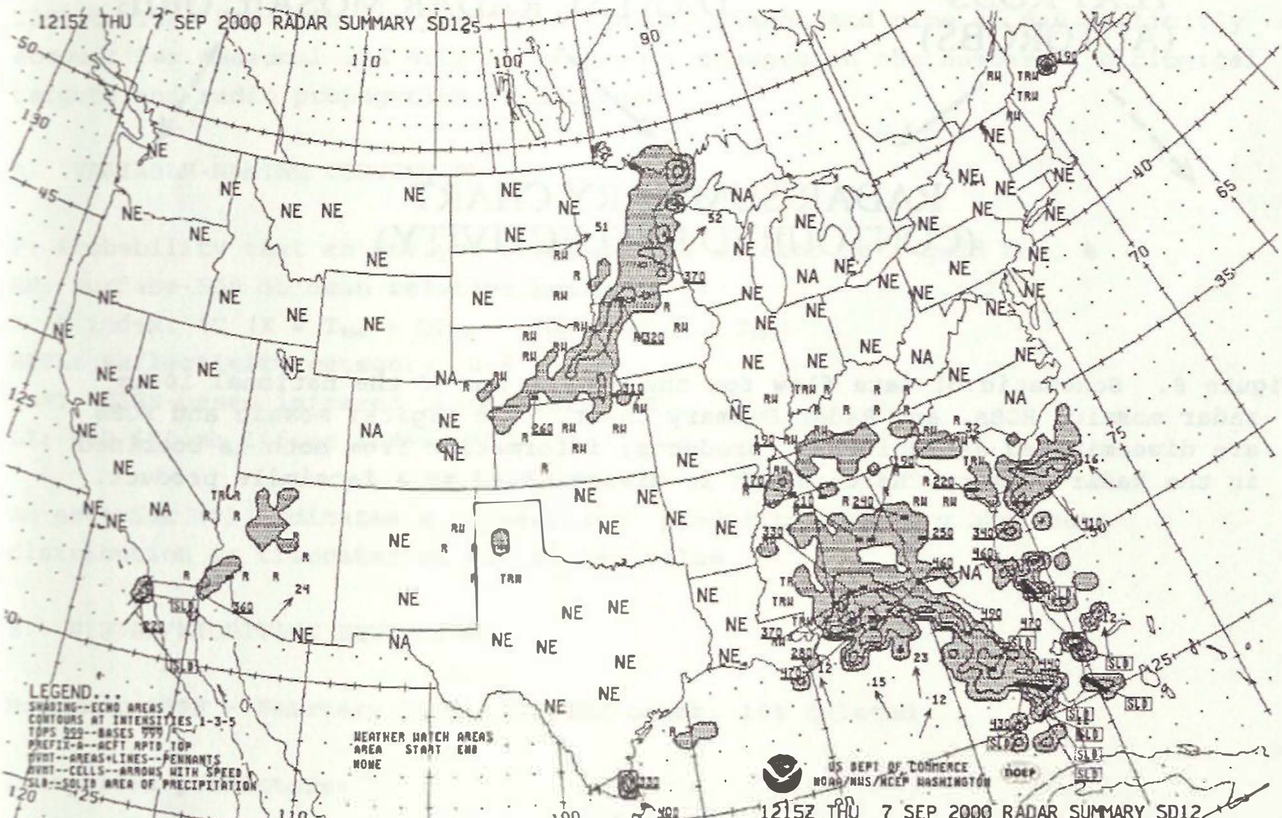

Figure 7. NCEP Radar Summary Chart created from the digital reflectivity mosaic and ROBs. Reflectivity contours are set at levels 1, 3, and 5. Information on echo tops, echo movement, and precipitation characteristics is derived from ROBs. "NE" indicates no precipitation echoes within the individual radar umbrella, "NA" indicates a nonreporting site.

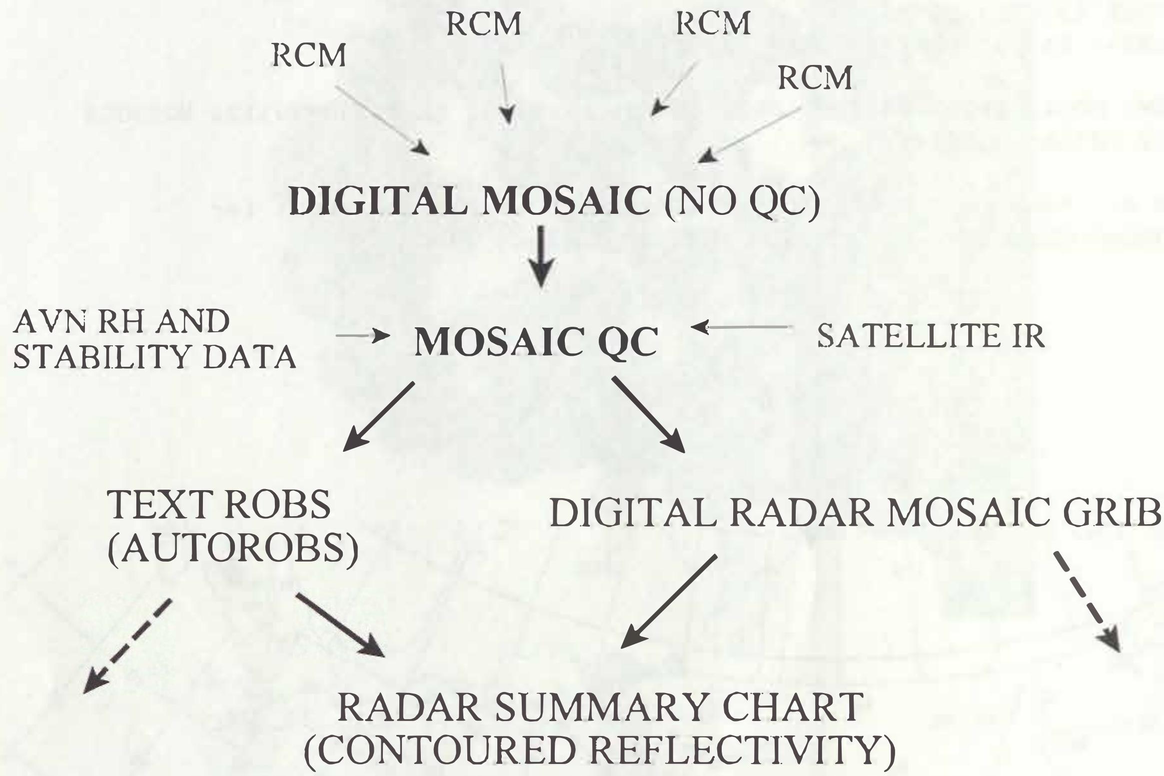

Figure 8. Schematic of data flow for the generation of the national 10-km radar mosaic, ROBs, and Radar Summary Chart. The digital mosaic and ROBs are disseminated as individual products; information from both is combined in the Radar Summary Chart, which is disseminated as a facsimile product.

APPENDIX. EQUATIONS FOR PROBABILITY OF NONPRECIPITATION ECHOES

The equations below yield the probability that a radar echo would be judged as nonprecipitation by an analyst, as a function of satellite-derived infrared cloud temperature, mean relative humidity, K and lifted indices, and the reflectivity level itself. The equations are based on results of manual editing of radar images from the period July 1999 - April 2000. Alternate equations excluding either satellite or upper-air data are also given, for use in situations when these data are operationally unavailable. Upper-air data have been taken from forecasts of the Aviation run of NCEP's Global Spectral Model. Satellite data are from GOES.

The 'summer' season refers to the period June to September, 'spring' from March through May, and 'winter' from November through February. 'Nighttime' equations are applied from 0000 to 1300 UTC, 'daytime' equations 1200 to 2300 UTC. These categorizations by season and time of day implicitly account for seasonal and diurnal frequency changes in the number of biological targets and radio propagation conditions.

A. VARIABLE-NAMING CONVENTION

P: Probability that an analyst would delete an echo in a grid box, %
RH: Surface-500 mb mean relative humidity, %
K: K index, °C ($K = T_{850} + DP_{850} - T_{700} + DP_{700} - T_{500}$)
REFL: Reflectivity category, 0-6
TSAT: GOES-based infrared temperature, °C
LI: 850-500 mb lifted index, °C

An asterisk (*) indicates a 'linearized' predictor, usually one whose distribution is truncated at the stated value.

B. WINTER/NIGHTTIME EQUATIONS

November 1999 - February 2000; 222,822 cases, 18% deleted

Linearized predictors:

RH* = RH, RH* ≤ 80%
REFL* = REFL, REFL* ≤ 2
TSAT* = TSAT, TSAT* ≥ -22 °C
K* = K, K* ≤ 28 °C

$$P = 141.131-(2.635\ RH^*)+(1.011\ TSAT^*)+(.866\ RH)+(.507\ K^*)+(.724\ LI)-(3.757 REFL^*)$$

For missing satellite data:

$$P = 152.788-(2.759\ RH^*)+(.713\ RH)+(.404\ K^*)-(4.354\ REFL^*)$$

For missing upper-air data:

$$P = 66.622+(2.291\ TSAT^*)-(9.805\ REFL^*)$$

C. WINTER/DAYTIME EQUATIONS

November 1999 - February 2000; 222,848 cases, 17% deleted

Linearized predictors:

$RH^* = RH$, $RH^* \le 80\%$
$REFL^* = REFL$, $REFL^* \le 2$
$TSAT^* = TSAT$, $TSAT^* \ge -22$ °C
$K^* = K$, $K^* \le 28$ °C

$$P = 114.587-(1.458\ RH^*)+(.622^*\ TSAT^*)-(3.416\ REFL^*)+(.214\ RH)$$

For missing satellite data:

$$P = 127.791-(1.584\ RH^*)+(.174\ K^*)-(3.843\ REFL^*)$$

For missing upper-air data:

$$P = 53.038+(1.771\ TSAT^*)-(7.957\ REFL^*)$$

D. SPRING/NIGHTTIME EQUATIONS

March - May 2000; 839,778 cases, 51% deleted

Linearized predictors:

$RH^* = RH$, $RH^* \le 80\%$
$REFL^* = REFL$, $REFL^* \le 2$
$TSAT^* = TSAT$, $TSAT^* \ge -15$ °C

$$P = 154.338 - (1.100\ RH) + (0.799\ TSAT) - (0.645\ TSAT^*) - (17.300\ REFL^*) - (0.674\ LI)$$

For missing satellite data:

$$P = 167.911 - (1.380\ RH) - (24.327\ REFL^*) - (0.615\ LI)$$

For missing upper-air data:

$$P = 100.165 + (1.399\ TSAT) - (1.068\ TSAT^*) - (24.616\ REFL^*)$$

E. SPRING/DAYTIME EQUATIONS

March - May, 2000; 828,053 cases, 24% deleted

Linearized predictors:

$RH^* = RH,\ RH^* \le 80\%$
$REFL^* = REFL,\ REFL^* \le 2$
$TSAT^* = TSAT,\ TSAT^* \ge -22\ °C$

$$P = 113.580 + (0.493\ TSAT) - (0.879\ RH^*) - (8.098\ REFL^*) + (0.496\ TSAT^*)$$

For missing satellite data:

$$P = 123.910 - (0.998\ RH^*) - (13.307\ REFL^*) - (0.255\ RH)$$

For missing upper-air data:

$$P = 68.20 + (0.621\ TSAT) + (0.883\ TSAT^*) - (10.478)\ REFL^*)$$

F. SUMMER/NIGHTTIME EQUATIONS

June - September 1999; 366,536 cases, 34% deleted

Linearized predictors:

$RH^* = RH,\ RH^* \le 71\%$
$REFL^* = REFL,\ REFL^* \le 2$
$TSAT^* = TSAT,\ TSAT^* \ge -15\ °C$
$K^* = K,\ K^* \le 33\ °C$

$$P = 101.705+(2.099\ TSAT^*)-(.157\ RH^*)-(11.387\ REFL^*)-(.479\ K^*)-(.318RH)$$

For missing satellite data:

$$P = 140.709-(.78\ RH)-(21.098\ REFL^*)+(1.18\ LI)-(.55\ RH^*)$$

For missing upper-air data:

$$P = 66.486+(2.521\ TSAT^*)-(14.884\ REFL^*)$$

G. SUMMER/DAYTIME EQUATIONS

June - September 1999; 489,921 cases, 23% deleted

Linearized predictors:

RH* = RH, RH* ≤ 71%
REFL* = REFL, REFL* ≤ 2
TSAT* = TSAT, TSAT* ≥ -15 °C
K* = K, K* ≤ 33 °C

$$P = 76.245+(1.849\ TSAT^*)-(.773\ K^*)-(11.031\ REFL^*)-(.173\ RH)-(.174\ TSAT)$$

For missing satellite data:

$$P = 116.002-(.417\ RH^*)-(17.169\ REFL^*)-(.576\ K^*)+(1.378\ LI)-(.478\ RH)$$

For missing upper-air data:

$$P = 48.266+(2.116\ TSAT^*)-(13.335\ REFL^*)-(.161\ TSAT)$$