THE FAA/M.I.T. LINCOLN LABORATORY
DOPPLER WEATHER RADAR PROGRAM [*]

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The Federal Aviation Administration (FAA)-sponsored Doppler weather radar program at M.I.T. Lincoln Laboratory focuses on providing real-time information on hazardous aviation weather to end users such as air traffic control (ATC) and pilots. Figure 1 summarizes the principal elements of the real-time system under development by the FAA to convey radar-derived weather information to the end users.

The existing Weather Surveillance Radar / Air Route Surveillance Radar (WSR/ ARSR) network which provides real-time reflectivity data via the Remote Radar Weather Display System (RRWDS) will be replaced by Next Generation Weather Radar (NEXRAD) in the latter half of this decade. At the Central Weather Processor (CWP), the data from various individual RRWDS and NEXRAD sites which are germane to a given Air Route Traffic Control Center (ARTCC) will be put together to provide various composite maps (e.g., low- and high-altitude hazardous weather regions) with a spatial resolution of approximately 4 km. The weather hazards of principal concern for initial NEXRAD deployment include:

- Heavy rain and hail
- Turbulence
- Low-altitude wind shear (microbursts, downbursts, gust fronts)
- Mesocyclones and tornadoes
- Short-term (10-30 min.) predictions of the locations of the above phenomena.

Preliminary estimates suggest that 9 to 40 NEXRAD sites will be used to generate the mosaic at each of the 20 ARTCC's in the United States.

In the near-term, the ASR-9 with a special weather channel will be a principal source of radar data for terminal controllers and control towers. When NEXRAD and the CWP are deployed, the CWP radar mosaic data will augment the ASR-9 data. However, reliable detection of short-lived wind shear phenomena will necessitate the use of a dedicated terminal Doppler weather radar (TDWR) at a number of major airports.
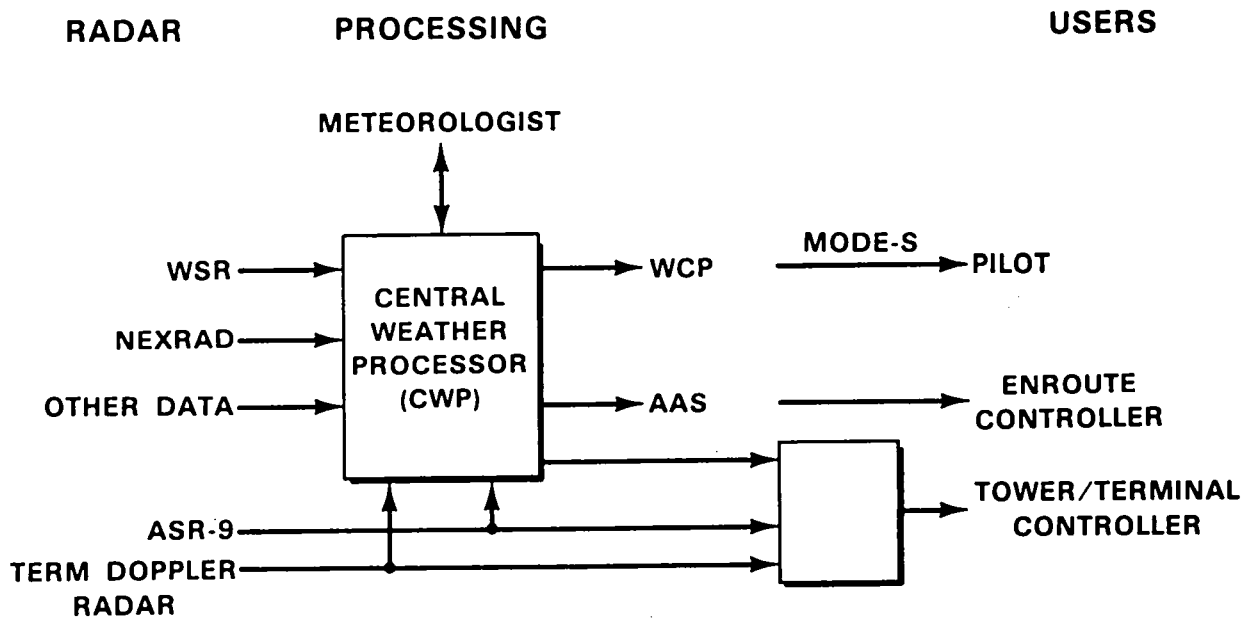

Figure 1. FAA Real-Time Radar-Derived Weather Information System.

This real-time use of weather radar data differs from that by the National Weather Service (NWS) and USAF Air Weather Service (AWS) in several important respects:

1. The user uses data from the mosaic of many radars rather than a single radar alone and may not know which radars were actually used to produce the mosaic display for particular geographical area.

2. Automated hazard detection will be essential due to the large ARTCC geographical area and limited Center Weather Service Unit (CWSU) staffing.

3. The real-time data will be used by nonmeteorologists with a limited display capability for real-time weather avoidance. This usage requires rapid processing and communication of higher quality data as well as careful attention to product display simplification.

4. Short-term (i.e., 10-30 min.) prediction of hazardous regions is needed for en route flight path and airport runway usage planning so as to achieve sizable improvements in airport efficiency and reductions in aircraft fuel usage.

As a consequence of these considerations, the FAA has been carrying out a substantial R & D program for several years focused on the weather radar-derived products for real-time ATC use.

The three principal objectives of the FAA research program at M.I.T. Lincoln Laboratory are:

1. Determining the hardware and software (i.e., algorithms) for the TDWR

2. Validating and refining the algorithms for the key FAA NEXRAD and ASR-9 weather channel products

3. Assessment of the operational utility and meteorological validity of the CWP weather radar-derived products to be provided to real-time ATC users

A principal element of the FAA/Lincoln program is the measurement systems currently in operation near Memphis International Airport as shown in Figure 2. The S-band weather radar is intended to be functionally equivalent to a NEXRAD sensor. The key features of the S-band radar are as follows:

Figure 2. Memphis Weather Measurement Systems.

- A center-fed 8.5 m diameter parabolic reflector <u>antenna</u> which achieves the NEXRAD objective of a 1° BW and -25 dB first sidelobes with the sidelobes at least 40 dB down for angles greater than 10° from boresight

- The computer controlled <u>mount</u> with peak angular velocities of 30°/sec. in azimuth, 15°/sec. in elevation and peak accelerations of 15°/sec.² in both axes which can execute a variety of scan strategies

- A klystron transmitter with 1.1 mv' peak power for 0.8 μs pulses at rates up to 1200 pulses/sec. This klystron (from an ASR-8 system) has the spectral stability for 50 dB clutter suppression with polyphase modulation for range ambiguity resolution

- Use of a low-noise <u>receiver</u> to yield a sensitivity close to the NEXRAD objective of 0 dB SNR on a -8 dBz target at 50 km with an "instantaneous" AGC to yield a dynamic range of approximately 90 dB

- Finite impulse response clutter filtering and auto-correlation lag estimation by a fixed-point arithmetic Lincoln-designed <u>signal</u> <u>processor</u> designed to achieve a clutter suppression of 50 dB

- Execution of computationally intensive tasks such as conversion of auto-correlation values to weather estimates, data clean-up (e.g., clutter map editing, velocity de-aliasing, etc.), resampling to a Cartesian grid and feature extraction in a Lincoln-designed <u>data acquisition and analysis processor</u> which utilizes multiple processing elements to achieve a 50 million operations/sec. computation rate

- A Perkin Elmer Model 3252 <u>superminicomputer</u> for overall system control, higher order logic in automatic detection algorithms, and driving local and remote <u>color</u> <u>displays</u>

The supporting measurement systems for testing in Memphis include:

- A .25 MW, 5 cm, 1.5° band width pencil beam Doppler weather radar from The University of North Dakota (UND) to permit dual Doppler analyses

- Remote data from an existing FAA air route surveillance radar (ARSR-1) for aircraft location

- A 30-unit mesonet (with 1 minute measurement rate) interfaced to the Geostationary Operational Environmental Satellite (GOES)

- Data recorded from an operational 6-unit low-level wind shear alert system

(LLWSAS) at the Memphis airport

- An instrumented Cessna Citation II jet aircraft from UND

- An instrumented Convair 580 turbo-prop aircraft from the FAA Technical Center

Additionally, GOES satellite images and WSR-57 (RRWDS) data are also recorded to facilitate meteorological analysis of salient weather events.

The ability to achieve an adequate weather-to-clutter ratio at the low-elevation angles and short ranges associated with low-altitude wind shear detection has been an important issue for the TDWR. The NEXRAD technical requirements call for a 50 dB clutter suppression capability with at least 45 dB clutter suppression being demonstrated in the validation phase testing. Figure 3 shows 47 dB experimental clutter suppression by the test bed against clutter from a microwave tower with a coherent Doppler shifting repeater providing a synthetic weather signal. The suppression in this case is limited by spurious lines from the production line ASR-8 transmitter/receiver used in the test bed. We believe that a transmitter/receiver designed at the outset to achieving the NEXRAD-desired capability should have little difficulty meeting the NEXRAD technical requirements. Reference [1] describes many aspects of NEXRAD clutter suppression by the use of linear time invariant clutter filters.

Another important issue for the Memphis measurements is the extent to which the low-altitude wind shear phenomena of greatest concern, microbursts/downbursts, occur in a moist meteorological environment such as Memphis. These phenomena were found to be fairly frequent in the dry subcloud environment of Denver; however, there is currently considerable uncertainty regarding the frequency and (dynamic) generation mechanism for moist subcloud environment microbursts/downbursts. Figure 4 shows some very preliminary statistics on high-wind events observed on the 25 station mesonet which was operational in the May-November 1984 time period. These data have not been corrected for site obstruction effects; it is anticipated that more events and more sensors/events will be found in the final summary of the 1984 data.

Figure 5 shows preliminary results of analysis by Marilyn Wolfson of a microburst that induced a 30.2 m/sec. (68 mph) peak wind at mesonet station No. 25 at 1806 CST on 20 October 1984. This microburst was encountered at the end of Memphis runway 27. Before the onset of the microburst, the environmental wind was 7 to 9 m/sec. (16 to 20 mph) from the southerly direction. In two minutes, the wind reached its peak, followed by a decrease to below 15 m/sec. (34 mph) in the next two minutes. The duration of this microburst, defined as the period of

ILLUSTRATION OF 47-dB CLUTTER SUPPRESSION

**MOVING TARGET SIMULATOR
WITH
CLUTTER FILTER DISABLED**
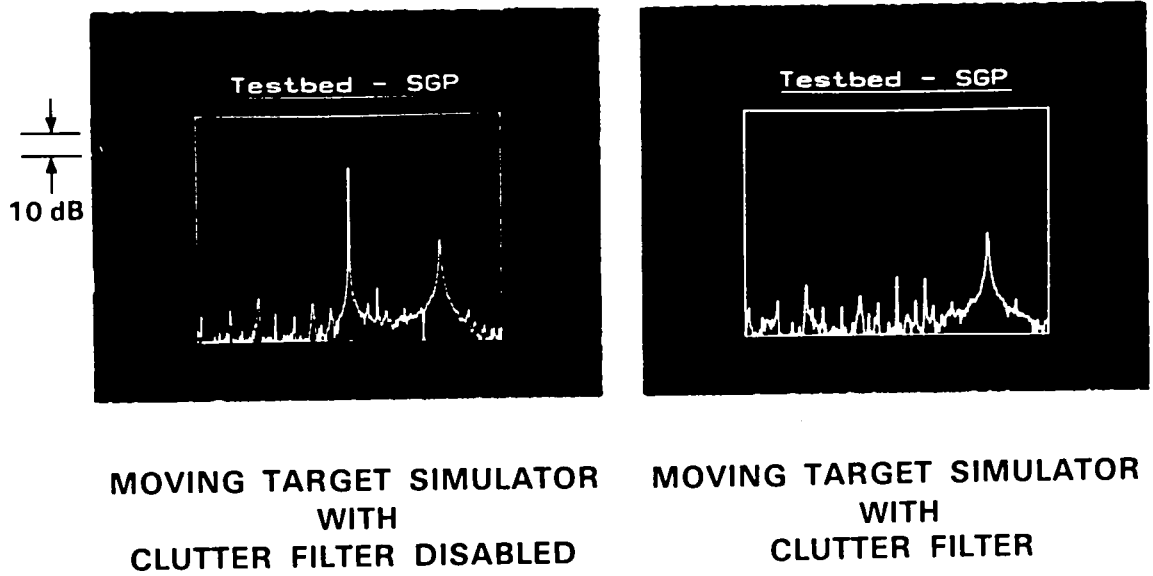
**MOVING TARGET SIMULATOR
WITH
CLUTTER FILTER**

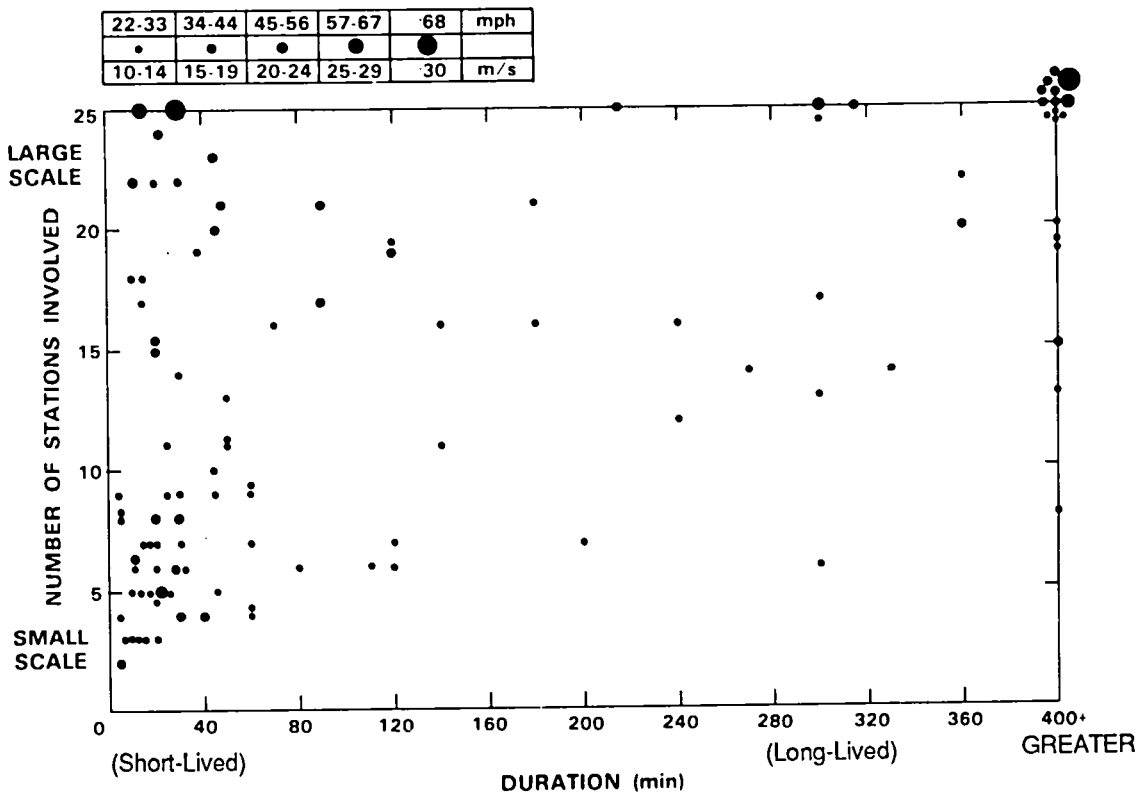Figure 3. Illustration of 47-dB Clutter Suppression.

Figure 4. Temporal and Spatial Scales vs. Intensity of Mesonet
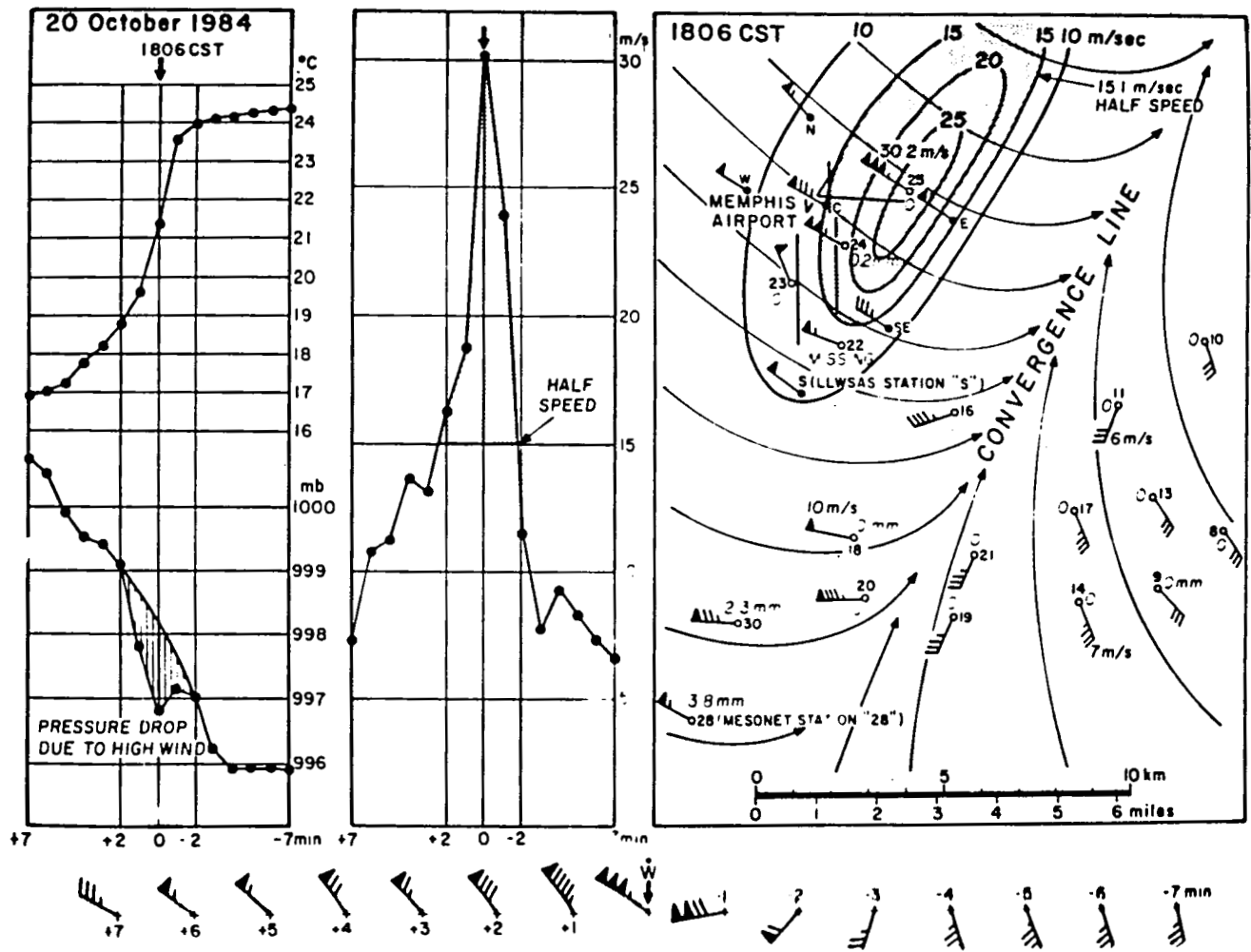Wind Events, 1984.

Figure 5. Microburst at Memphis International Airport.

one-half of the peak windspeed, was four minutes.

A detailed analysis of the mesonet data revealed that the microburst was located just behind a gust front which swept across the Memphis area. Consequently, the area of the microburst, after its dissipation, was replaced by the cold air pushing behind the gust front. Both temperature and pressure changes were characterized by those of a gust front except for a significant pressure drop during the microburst winds.

This microburst was accompanied by a very strong wind shear at low altitude. A hypothetical aircraft penetrating the storm from southeast to northwest would experience a 20 m/sec. (39 kts) increase in headwind, followed by a 15 m/sec. (29 kn) loss of headwind within approximately 3 km (10,000 ft.).

Typical results from one of the correlation tracker/reflectivity map extrapolation algorithms developed at Lincoln for use in NEXRAD are shown in Figure 6. The algorithm determines the velocity vectors associated with various cells by cross-correlating the data from different measurement times and then predicts the reflectivity map at a future time by moving appropriate features of the current map according to the estimated velocity vectors. A Lincoln report [2] describes this and several other tracking techniques, as well as the capability of this extrapolation technique to provide useful 10- to 30-minute predictions.

Assessment of the utility and validity of the weather products to be supplied to ATC users is an important element of the FAA/Lincoln program. Figure 7 shows a block diagram of the testbed system emphasizing the various display options which will be utilized in the next few years.

Information on aircraft position are obtained from the common digitizer (CD) output of a FAA ARSR for use in tracking the instrumented aircraft and providing position reports for ATC aircraft/weather displays. Figure 8 shows a strawman display format for weather and aircraft data developed by MITRE Corporation researchers in McLean, Virginia. Work is currently under way at Lincoln Laboratory to develop weather image coding techniques which could be used to transmit images to aircraft over the Mode-S data link. We hope to carry out real-time testing of the capability as a part of the Mode-S data link flight test program which will commence this year.

In summary, the FAA is actively engaged in the engineering application of Doppler weather radar research work to achieve an order of magnitude improvement in detection of hazardous aviation weather and provision of the results to principal ATC users. A principal focus for this work is the test bed radar and supporting sensors which will be used for measurements in key meteorological regimes over
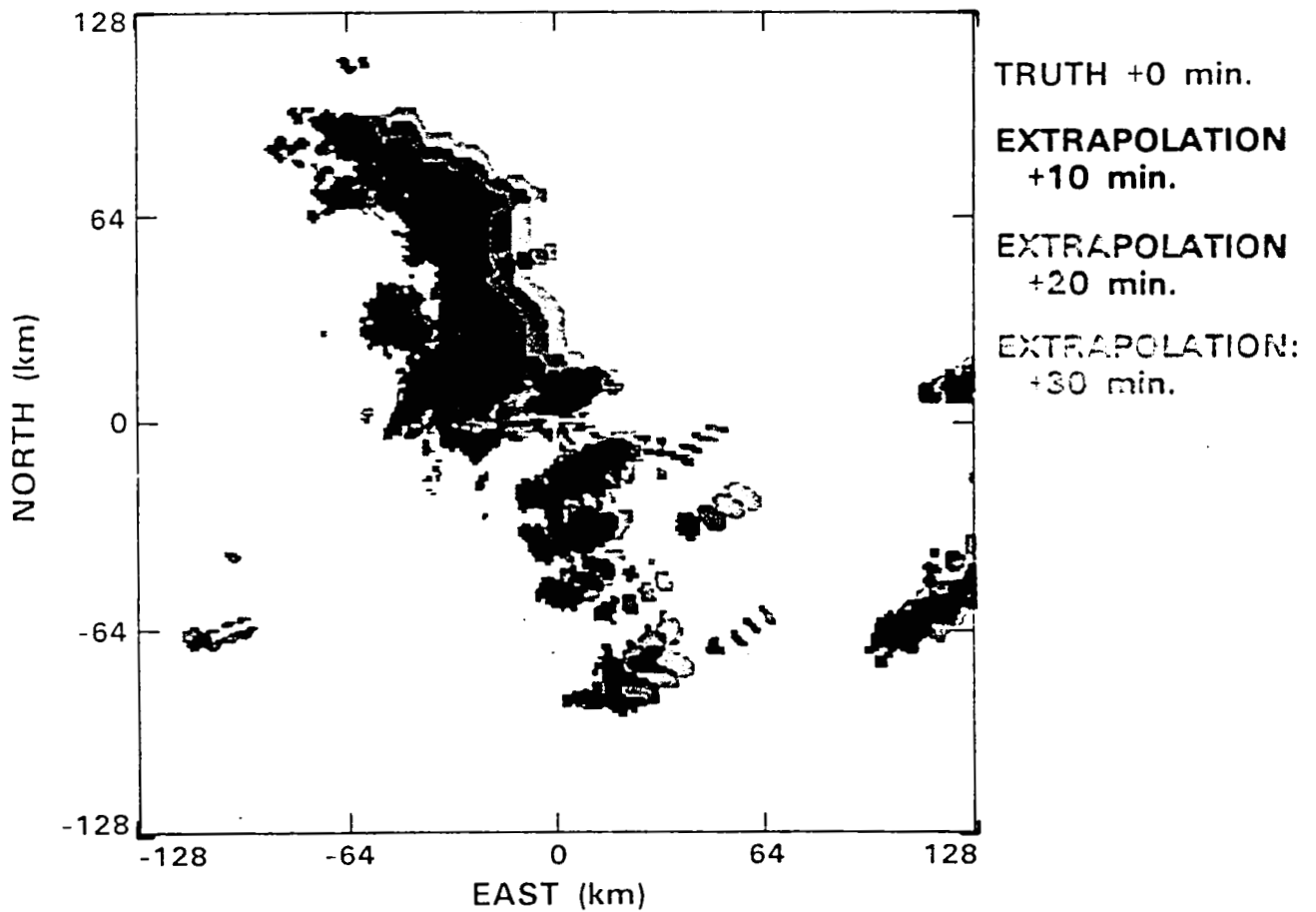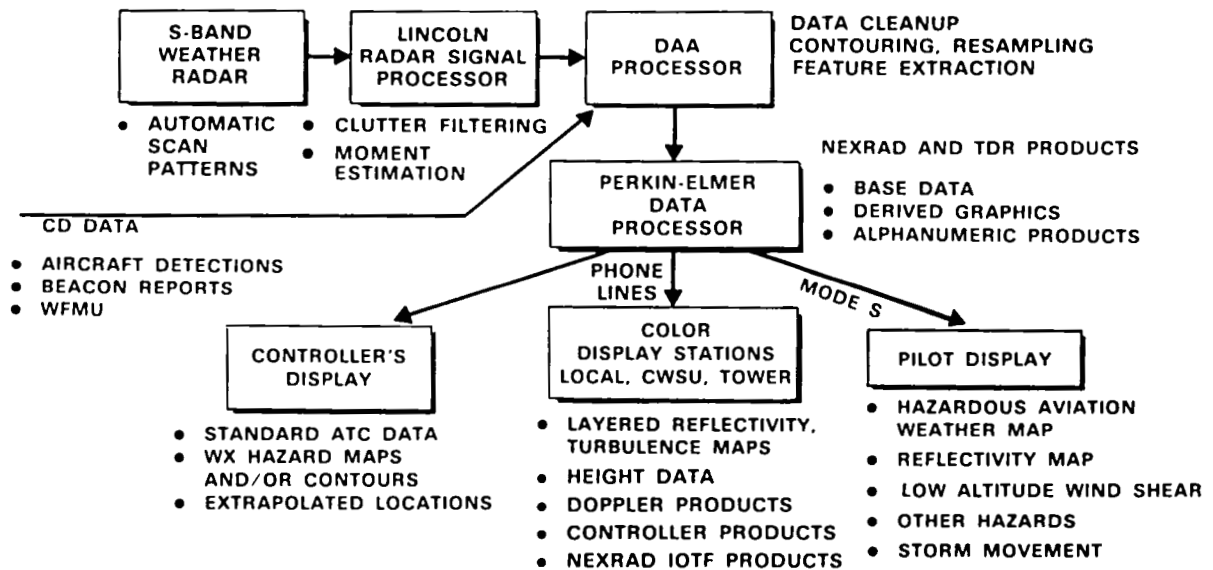
TRUTH +0 min.

EXTRAPOLATION +10 min.

EXTRAPOLATION +20 min.

EXTRAPOLATION: +30 min.

Figure 6.   New England Squall Line Extrapolation.

Figure 7.   Eventual Configuration for Display of ATC Weather Products at Testbed.

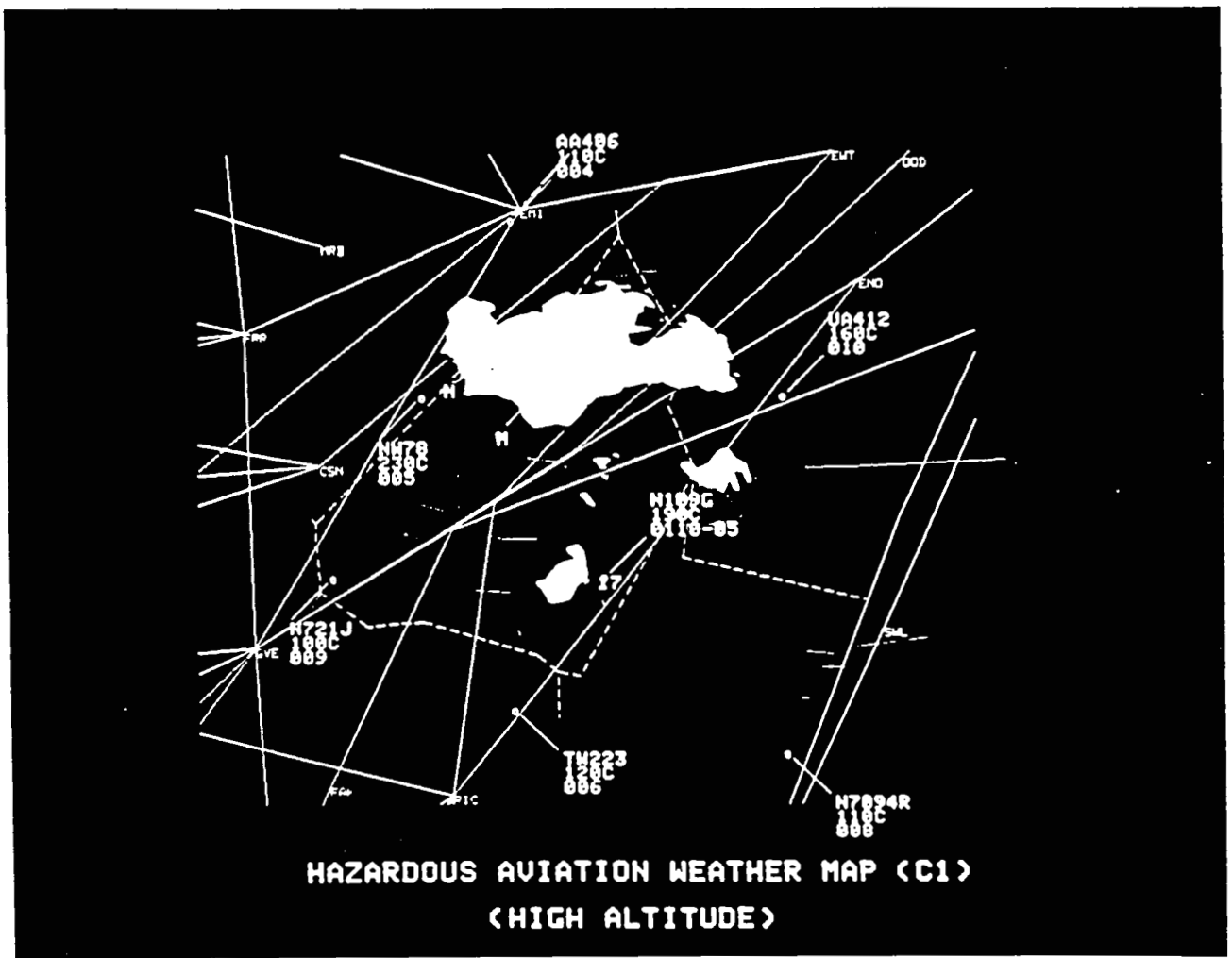HAZARDOUS AVIATION WEATHER MAP (C1)
(HIGH ALTITUDE)

.Figure 8.   Example of ATC Weather Display.

the next few years to refine and validate the product generation algorithms and displays.

The transportable test bed radar is largely due to the concerted efforts of W. Drury, M. Merritt, P. La Follette, A. Dockrey, W. Rataj and F. Groezinger. M. Merritt provided the clutter suppression results in Figure 3 while M. Wolfson accomplished the 20 October 1984 microburst analysis. The mesonet data summary in Figure 4 is due to B. Forman, J. DiStefano and M. Wolfson while M. Goldburg provided the correlation tracker results shown in Figure 6.

References

1. Evans, J. E.: "Ground Clutter Cancellation for the NEXRAD System," Project Report ATC-122, Lincoln Laboratory, M.I.T., 19 October 1983.

2. Brasunas, J. C.: "A Comparison of Storm Tracking and Extrapolation Algorithms," Project Report ATC-124, Lincoln Laboratory, M.I.T., 31 July 1984.