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Terminal Weather Information for Pilots (TWIP) Program Annual Report for 1995

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16. Abstract

The Federal Aviation Administration (FAA) is currently embarking on programs, such as the Terminal Doppler Weather Radar (TDWR) and Integrated Terminal Weather System (ITWS), that will significantly improve the aviation weather information in the terminal area. For example, TDWR data will be available at 47 airports across the United States that have high traffic and significant risk of wind shear. The TDWRs automatically report microburst, gust front and precipitation near the airport to air traffic control personnel on a 24-hour basis.

Given the great increase in the quantity and quality of terminal weather information, it is highly desirable to provide this information directly to pilots rather than relying on voice communications. Providing terminal weather information automatically via data link will enhance pilot awareness of weather hazards and lead to more efficient utilization of aircraft. It may also decrease air traffic controller workload and reduce radio frequency congestion.

This report describes work performed in 1995 to provide direct access to terminal weather information via an existing data link known as ACARS (Aircraft, Communications Addressing and Reporting System). More than 4000 aircraft operate in the United States with ACARS equipment. During 1995, five Lincoln-operated testbeds provided near real-time terminal weather information to pilots of ACARS-equipped aircraft in both text and character graphics formats. This effort follows earlier successful demonstrations during the summers of 1993 [1] and 1994 [2].

Section 2 of the report describes the TWIP message formats, Section 3 discusses the 1995 operational demonstration, and Section 4 presents the TWIP software design. Section 5 provides case analyses from the 1995 demonstration, Section 6 discusses future work, and Section 7 is the summary.

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ABSTRACT

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1. INTRODUCTION

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2. MESSAGE FORMATS

Terminal Weather Information for Pilots (TWIP) messages are generated in two formats: a text–only message and a character graphics map. These products were developed in consultation with a group of experienced airline pilots. The TWIP Text Message is compatible with typical ACARS cockpit displays, which are at least 20 characters wide by 10 lines high. The TWIP Character Graphics Depiction is compatible with cockpit printers that are at least 40 characters wide and which are available on some aircraft. Both products provide strategic information to pilots about terminal weather conditions, which can assist flight planning and improve situational awareness of potential weather hazards.

All TWIP messages are forwarded from the TWIP message generation processor, located at MIT Lincoln Laboratory, to a database maintained by ARINC. Messages are then relayed to aircrews by one of two protocols. Either pilots may request the most current TWIP text message or character graphics map from a particular site via an ACARS request, or certain TWIP text messages (Send/Cancel) may be forwarded automatically to participating aircraft. The choice of Request/Reply or automatic uplink is made individually by each participating airline and applies, fleetwide, to that airline.

2.1. Text Message

The TWIP Text Message consists of four sections: header, runway impact, storms and expected/previous. The header section provides the airport identification and the report time in UTC, plus a line identifying the message as terminal weather information.

The second section (identified by a leading asterisk (*)) is included if any runway or Area Noted for Attention (ARENA), which includes arrival and departure corridors associated with runways, is impacted by a microburst, gust front, heavy precipitation (NWS level 3 or above) or moderate precipitation (NWS level 2). For microburst or gust front impacts, the magnitude of the gain or loss is indicated on the next line. The start time of the impact is in the last line of the second section. When multiple hazards are present, only the most severe hazard is reported. In order of decreasing precedence, the reported hazard will be: microburst (30 knot or greater loss), wind shear with loss (less than 30 knots loss), wind shear with gain (gust front), heavy precipitation or moderate precipitation.

The third section (identified by a leading dash (–)) is included if there are any storms (level 2 or greater) within 15 nm of the airport. The first line of the section indicates the presence of one or more storms. The next lines list the three closest storms to the airport reference point (ARP). Storms are ordered by range and by intensity for multiple storms at the same range. The range of a storm is calculated as the minimum distance between any pixel within the storm and the ARP. Each storm is described in terms of range (in nautical miles), azimuthal extent, and intensity (moderate or heavy precipitation). The azimuthal extent is given in terms of starting and stopping compass octant (e.g., NE) in the clockwise sense; if the storm is less than 1 nm from the airport, then the azimuth is given as all quadrants (ALQDS).

The fourth section of the message (identified by a leading period (.)) is included if there is expected precipitation, previous wind shear or microburst, or no storms within 15 nm of the airport. If moderate or heavy precipitation is expected at the airport within 20 minutes, then the expected precipitation line is issued, followed by a line that includes the time the precipitation impact is expected to start. If more than one type of precipitation impact is expected, then only the most severe expected impact will be included. Also, the expected precipitation must be more severe than any current runway impact in order to be displayed.

If there was a previous microburst or wind shear runway impact which is now over, then the fourth section will note the previous impact (also indicated by a leading period) plus the beginning and ending time of that impact on the following line. Finally, if there are no storms within 15 nm of the airport or any runway impacts, then the fourth section will consist of a single line indicating ".NO STORMS WITHIN 15 NM".

Figure 1 provides examples of TWIP Text Messages. The left side of the figure shows the weather situation and the right side shows the corresponding text messages. The examples are of four messages for the Orlando airport (MCO) at ten–minute intervals starting at 1800Z (note: TWIP Text Messages are generated once per minute when weather is near the airport, although only every tenth message is shown here for convenience).

The first message at 1800Z shows a storm cell with moderate and heavy precipitation located to the east of the airport and moving west at 15 knots. The message indicates that moderate precipitation is expected to impact the airport in five minutes.

The second message at 1810Z shows that moderate precipitation is now impacting the airport and that the impact began at 1805Z. The message now indicates that heavy precipitation is expected to impact the airport at 1815Z. Also, a microburst with a 20–knot loss value is now present.

The third message at 1820Z shows that the microburst has intensified to a 30–knot loss value and is now impacting the airport. Although moderate and heavy precipitation impacts are present, the microburst impact is more severe and takes precedence.

The fourth message at 1830Z shows that the microburst has ceased to impact the runways, so heavy precipitation impact is now reported. The previous microburst impact is now reported, with the beginning and ending times on the following line.

The TWIP Text Message is generated once per minute whenever weather is near the airport. When there is no weather within 15 nm, the update rate is reduced to once every 10 minutes.

Two types of special TWIP text messages are generated in addition to the normal messages. A SEND message is generated when microburst, wind shear or heavy precipitation initially impacts the runways or when heavy precipitation is forecasted to impact the runways. The SEND message consists of a special SEND header plus the normal TWIP text message. The special header gives the type of SEND message (i.e., Microburst Alert, Windshear Alert, Heavy Precipitation or Heavy Precipitation Forecast, in order of precedence) and valid period (generally 20 minutes from the time issued). If more than one SEND condition is in effect, only the highest precedence SEND will be issued.

The SEND message remains in effect until it: 1) expires, 2) is superseded by another SEND, or 3) is cancelled. The SEND message expires following the end of the valid period. A SEND message can be superseded by another SEND message, such as a Microburst Alert following a Wind Shear Alert. However, a lower precedence SEND will not be issued until the higher precedence SEND expires (e.g., a Microburst Alert Send condition must expire or be cancelled before a lower–precedence SEND is issued).

A Cancel (CANC) message is issued whenever the SEND message condition ceases to be in effect for an adaptable time period (nominally five minutes), provided the message is not due to

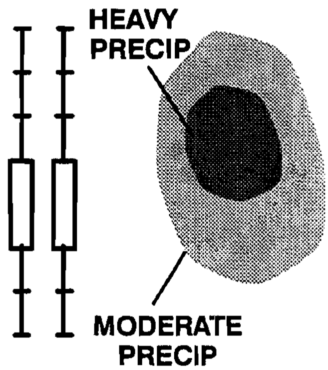
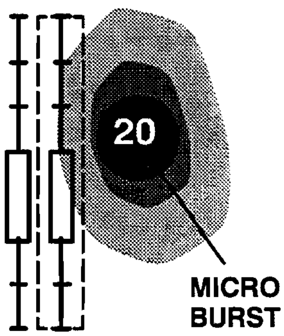
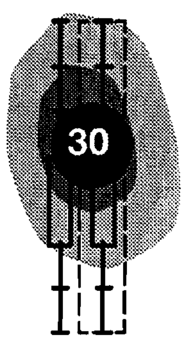
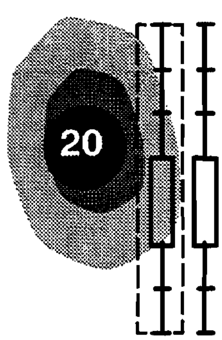
<table>
<tr><th>WEATHER SITUATION</th><th>TWIP TEXT MESSAGE</th></tr>
<tr><td>
</td><td>MCO 1800
TERMINAL WEATHER
–STORM(S)
3NM N–E MOD PRECIP
4NM NE HVY PRECIP
MOVG W AT 15KT
.EXPECTED MOD PRECIP
BEGIN 1805</td></tr>
<tr><td>
</td><td>MCO 1810
TERMINAL WEATHER
*MODERATE PRECIP
BEGAN 1805
–STORM(S)
ARPT ALQDS MOD PRECIP
1NM N–E HVY PRECIP
MOVG W AT 15KT
.EXPECTED HVY PRECIP
BEGIN 1815</td></tr>
<tr><td>
</td><td>MCO 1820
TERMINAL WEATHER
*MICROBURST ALERT
30KT LOSS
BEGAN 1815
–STORM(S)
ARPT ALQDS HVY PRECIP
ARPT ALQDS MOD PRECIP
MOVG W AT 15KT</td></tr>
<tr><td>
</td><td>MCO 1830
TERMINAL WEATHER
*HEAVY PRECIP
BEGAN 1825
–STORM(S)
ARPT ALQDS MOD PRECIP
1NM W–NW HVY PRECIP
MOVG W AT 15KT
.PREVIOUS MICROBURST
BEGAN 1815 END 1825</td></tr>
</table>

Figure 1. Examples of TWIP Text messages.

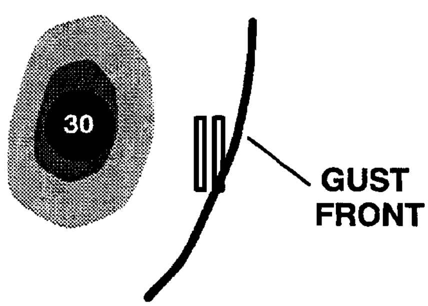
expire within another adaptable time period (also nominally five minutes). The CANC message is suppressed if a lower priority SEND message is issued following higher priority SEND message expiration.

2.2. Character Graphics Depiction

An example of the TWIP Character Graphics Depiction is shown in Figure 2. In this case there is a microburst–producing cell to the west of the airport. The moderate precipitation is indicated by a dash, "–", the heavy precipitation is indicated by a plus sign, "+", and the microburst is indicated by the letter "M". There is a gust front impacting the airport in this case, indicated by the "G"s. The runway location is indicated by the "X"s, except where the gust front impacts them as indicated by an asterisk (*). A scale is provided in nautical miles in the horizontal and vertical directions, plus a key to the symbols. Storm motion is also provided at the bottom of the character graphic depiction.

Because it is dependent on TDWR precipitation data that is refreshed every five minutes, the TWIP Character Graphics message is updated at five–minute intervals if there is weather (defined as moderate precipitation or greater) near the airport. If there is no weather within 15 nm of the airport, then the message is updated only every 10 minutes. In this case, the header section plus the phrase ".NO STORMS WITHIN 15 NM" is substituted for the empty map.

WEATHER SITUATION	TWIP CHARACTER GRAPHICS MAP




```
MCO 1830 MAP 15NM
TERMINAL WEATHER INFO
15     10      5    NORTH    5      10     15


10



              ----
5           --+++--          G
          ---++++---        G
          ---++MM+---    XX G
W         ---+++++---    XXG                  E
          ---+++---      X*
            ----         G
5                      GG
                       G


10



15     10      5      S      5      10     15
+=HVY -=MOD M=MB G=GF X=RWY *=RWY MB/GF
STORMS MVG SE AT 6KT
```

Figure 2. Example of TWIP Character Graphics Depiction.

3. OPERATIONAL DEMONSTRATION

TWIP was first demonstrated during the summer of 1993 at the ITWS testbed in Orlando, FL. A second demonstration was held during the summer of 1994 at ITWS testbeds in Orlando, FL and Memphis, TN. Each demonstration was conducted for approximately eight hours per day for a two–month period during the summer.

The TWIP demonstration for 1995 is illustrated in Figure 3. The number of participating sites was increased to include three ITWS testbed sites (Orlando (MCO), Memphis (MEM) and Dallas/Ft.Worth (DFW)) and two TDWR sites (Atlanta (ATL) and Washington National (DCA). Seven airlines participated in the demonstration: American, Delta, Federal Express, Northwest, United, UPS, and USAir. More than 2500 participating aircraft were equipped to receive the TWIP Text Messages and an additional 1300 aircraft also could receive the TWIP Character Graphics Depiction.

TWIP messages from ITWS and TDWR sites were relayed to ARINC via an X.25 packet switched connection. TWIP text and character graphics messages were stored in a database at ARINC headquarters in Annapolis, MD, from which messages were retrieved by Request/Reply. The automatic uplink protocols, utilizing SEND/CANCEL messages, were forwarded directly to the airlines via X.25; these messages were not archived by ARINC.

Aircrews from six airlines (American, Delta, Federal Express, United, UPS, and USAir) used Request/Reply protocols (adapted from on–board software to obtain another demonstration data link service, Digital Automatic Terminal Information Service (ATIS)). In contrast, Northwest aircrews received the special SEND/CANCEL TWIP messages via an automatic uplink protocol

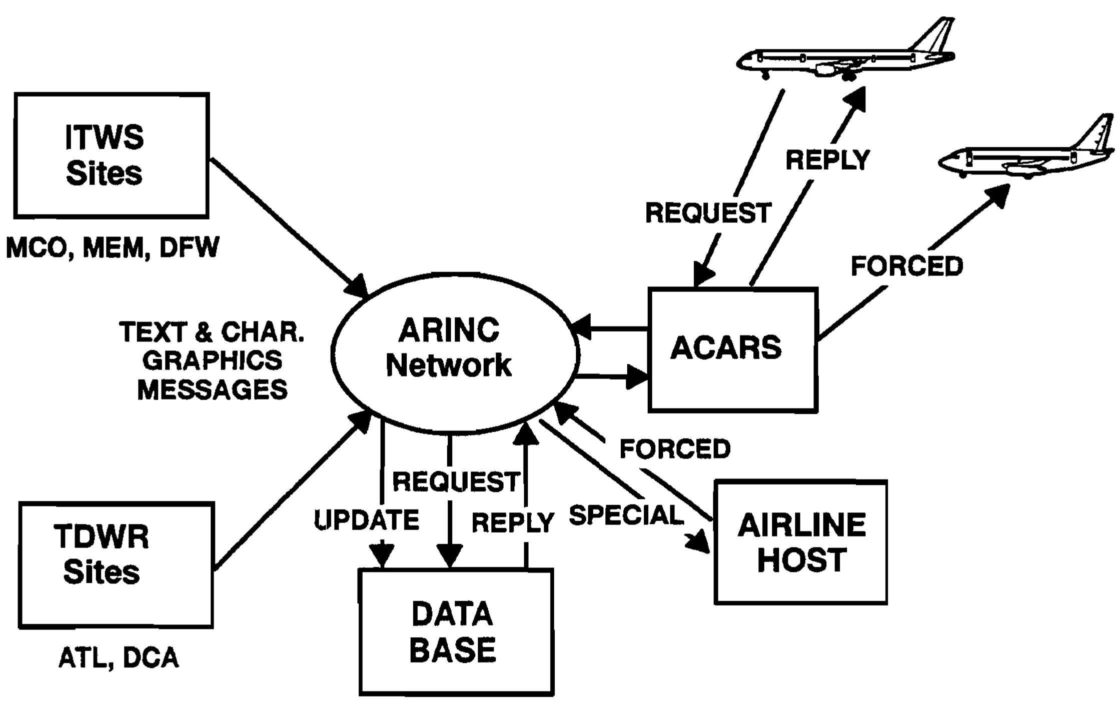


Figure 3. Terminal Weather Information for Pilots (TWIP) 1995 demonstrations at ITWS and TDWR sites.

whenever wind shear or heavy precipitation started or stopped at an airport and the aircraft was within 40 minutes of either landing or taxiing out for departure.

3.1. ITWS Testbeds

The TWIP products were generated in the ITWS testbeds as part of a demonstration of the ITWS Initial Operating Capability (IOC) products. The ITWS testbeds generated TWIP messages on an 18–hour per day, Monday–Friday schedule during July and August, plus limited coverage on weekends. Subsequently, the ITWS testbeds continued to generate TWIP messages on a weather–contingent basis.

3.2. TDWR–based Sites

The TWIP demonstrations during the summers of 1993 and 1994 operated for limited hours per day and for limited time periods. A key objective of the 1995 demonstration was to provide a 24–hour per day, seven–day–per–week TWIP demonstration for an extended period of time. In order to do this, it was necessary to adapt the existing TWIP software to operate from products generated by an operational TDWR.

A Sun workstation was configured as a TWIP Data Processor (TDP) to accept TDWR data, generate the TWIP messages and relay the messages to the ARINC database via the FAA's NADIN Packet Switched Network (PSN). The TDP accepts TDWR products from a serial port on the TDWR Display Function Unit (DFU) and is able to interface to the NADIN PSN via the Digital Multiplexing Network (DMN). (Note: because NADIN PSN certification had not been completed, the TWIP messages were sent directly to ARINC via an X.25 leased line connection). The TDP software design is discussed in detail in the next section.

The TDWR–based sites began operating on a limited basis during the summer of 1995. The Atlanta site began operating on a 24–hour basis in September, and the Washington National site began operating on a 24–hour basis in October.

3.3. Message Traffic

ARINC provided data on the message traffic for the five TWIP sites starting in July. For the ITWS sites, the average number of requests per month over the two–month demonstration period were as follows: Orlando (2450), Dallas/Ft.Worth (1465) and Memphis (515). For the two TDWR sites, the average message traffic for the September–December period was as follows: Washington National (2700) and Atlanta (700).

3.4. Weather Activity Summary for TDP Sites

Beginning with October, monthly statistical records were maintained to quantify the frequency and severity of weather events which impacted each 24–hour TWIP site; namely, ATL and DCA. The reported hours of weather activity were tallied along with the total number of days for which level 2 or greater precipitation and/or 15 knot or greater wind shear activity impacted the airport ARENAs. As a subset of this tally, numbers were generated which reflected the sum of wind shear or microburst alerts issued over a contiguous period of time. In conjunction, the magnitude and direction of the most substantial wind shear event recorded was included to highlight the day of maximal activity for that month. Table 1 summarizes the monthly weather statistics for each site for the October–December period (note: September was not included because of incomplete data).

Table 1
Monthly Weather Statistics

	Hours of Storm Activity	Number of Weather Impacts	Number of Wind Shear Impacts	Largest Wind Shear Event, Date of Event
ATL				
Oct	52.0 Hours	6 Events	6 Events	40 kt Gain 10/27
Nov	63.3 Hours	8 Events	2 Events	60 kt Loss 11/21
Dec	49.1 Hours	8 Events	3 Events	40 kt Loss 12/19
DCA				
Oct	64.9 Hours	9 Events	8 Events	55 kt Loss 10/27
Nov	63.2 Hours	11 Events	4 Events	55 kt Loss 11/12
Dec	29.3 Hours	4 Events	3 Events	40 kt Gain 12/01

4. TDP SOFTWARE DESIGN

4.1. Overview

A TWIP Data Processor is configured with software to decode and process TDWR data, to generate and format associated TWIP messages, to monitor messages for syntax and accuracy, and to relay messages to the remote database via a packet switched data network using the X.25 protocol. Figure 4 shows the main components of the TDP. This figure illustrates the final NADIN PSN configuration. However, since NADIN PSN was not available at the start time of the TWIP service, leased–lines were used in place of NADIN during 1995. NADIN PSN certification testing is expected in 1996. Section 4.2. describes the 1995 setup in more detail. The future NADIN PSN configuration is discussed in Section 4.3.

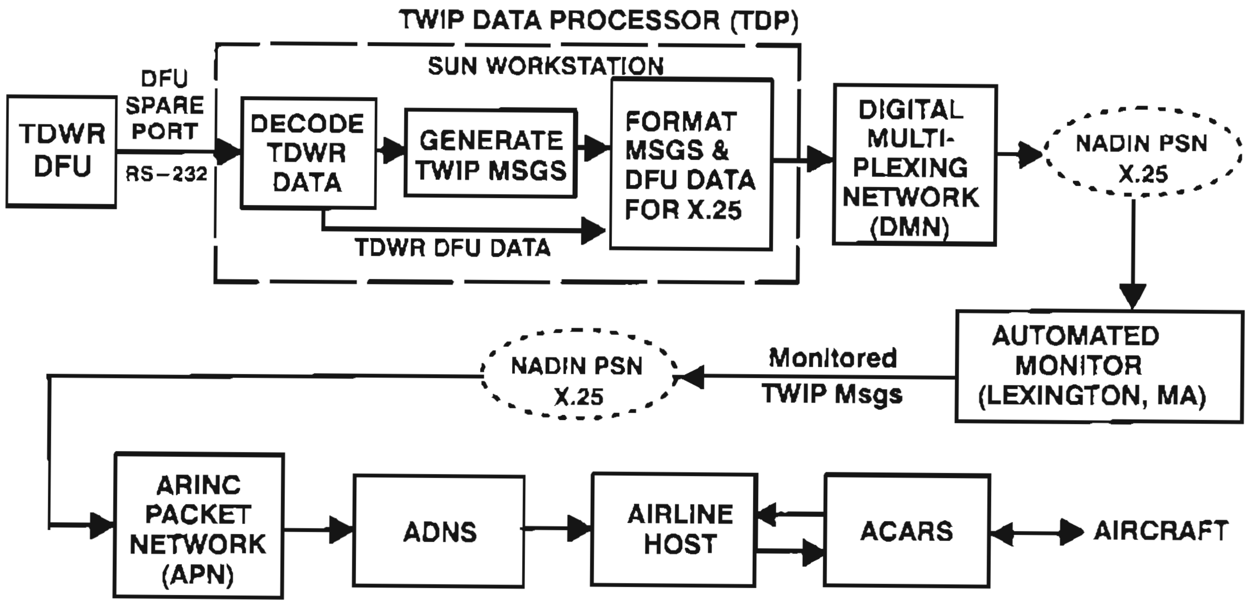


Figure 4. TWIP Data Processor (TDP) implementation. (Note: the NADIN PSN was not available for the 1995 demonstration, so the TWIP messages were sent directly to the ARINC Packet Network via leased line).

4.2. 1995 Leased Line Configuration

Figure 5 depicts the 1995 TWIP Data Processor (TDP) design. All of the message generation and automated message monitoring for TDWR sites are done locally at Lincoln Laboratory on a Sun workstation. This configuration requires the least time to develop and allowed the use of leased lines in place of NADIN, which was unavailable. A Sun workstation at the site reads the data from the TDWR DFU spare port and mirrors it back out on one of its own serial ports. This is done to adjust the port parameters for reading and decoding data. The data are then sent via modem over a leased line to another modem at Lincoln that is connected to the serial port of a second Sun workstation. This second workstation acts as a TDP. The data is then read serially by the DFU Data Decoding module as if it were connected to a real TDWR DFU spare port. After decoding, the data are fed via TCP/IP streams to the TWIP message generation modules which build the TWIP messages. The messages are then sent to the automated monitor which checks for formatting errors and compares the messages to the raw DFU data to ensure that they reflect the current weather scenario. If formatting

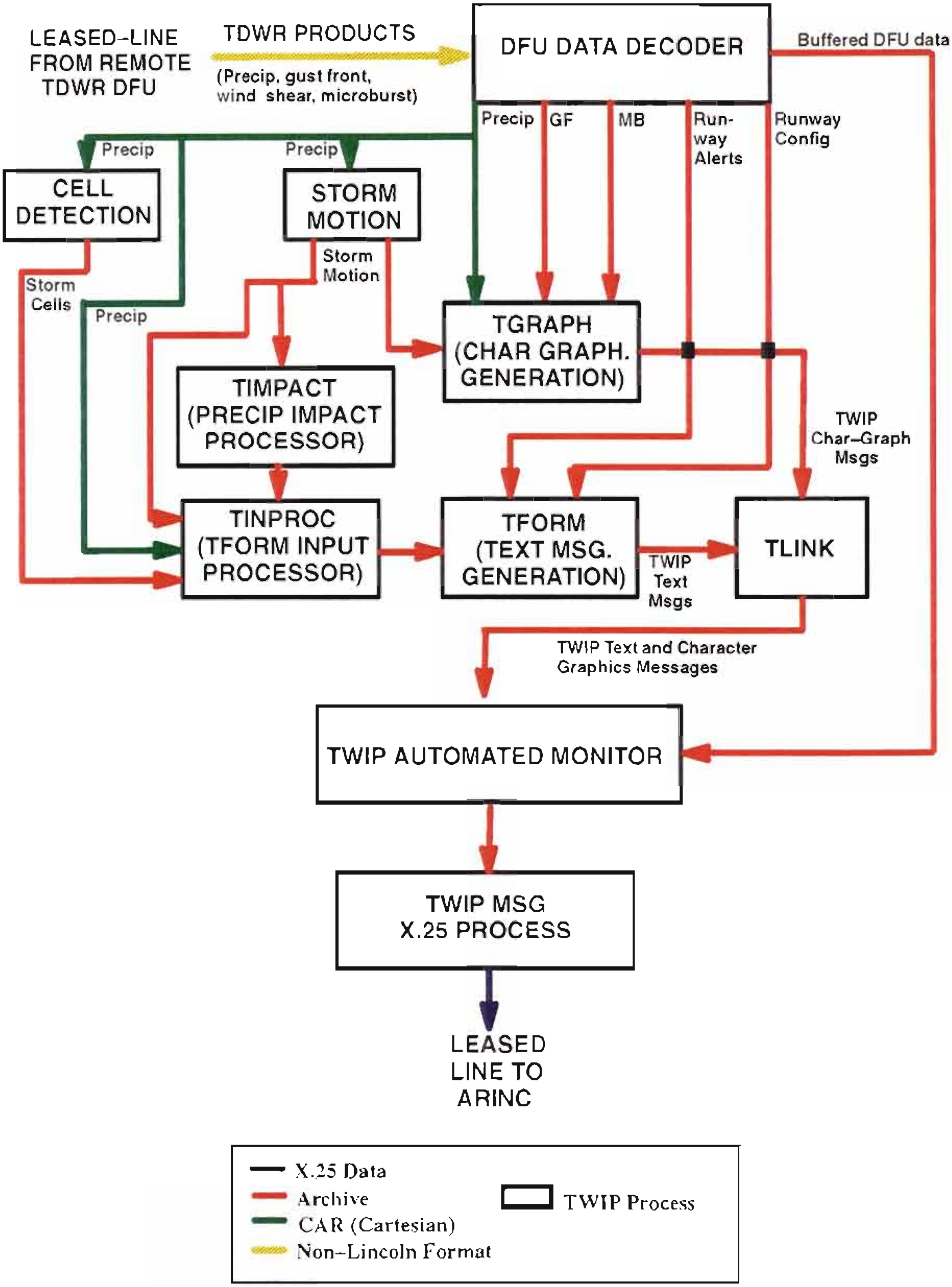


Figure 5. 1995 local TDP and Monitor software data flow (leased line configuration).

errors exist, or if the TWIP message does not accurately reflect the current weather situation, a "SYSTEM UNAVAILABLE" message is displayed and TWIP personnel are automatically notified. This is described in more detail in sections 4.7. and 4.8. Next, the monitored TWIP messages are sent via TCP/IP stream to the X.25 message send process. This process relays the messages over a leased–line to the ARINC database and to the Northwest Airlines host computers for uploading to aircraft. These processes are described in more detail starting in section 4.4.

4.3. Final NADIN PSN Configuration

Figure 6 depicts the expected final remote TDP configuration. Figure 7 shows the final local monitor configuration. Note that the actual TWIP message generation is expected to be done remotely at each site on a stand–alone Sun workstation. The messages are then sent over the NADIN PSN to Lincoln Laboratory to check their validity. The raw DFU product data is mirrored out of the decoder after filtering certain DFU records not used in the TWIP message generation. The filtered DFU data is also transmitted to Lincoln over the NADIN PSN by the dfu_x25_send process. The connections to the NADIN node from each remote site are made at each airport's Digital Multiplexing Network (DMN), typically located in the TRACON. Lincoln Laboratory is connected to the NADIN PSN via a leased line to the Nashua Enroute Center. Once the messages and the raw DFU product data arrive at Lincoln, the same Automated monitor module mentioned above checks the TWIP message format and content comparing it to the weather situation described by the DFU data. The checked messages are then sent back out to the NADIN PSN with parameter–configured destination addresses. Airline access to the TDWR DFU product data will be made available via the dfu_x25_send processes running at each remote site.

4.4. TDWR DFU Product Decoding

The TDWR DFU Decoder has two front–ends: a serial reader and a server–client (TCP/IP) reader. This enables the decoder to be run either at the remote site connected directly to the serial port of a DFU or at Lincoln. In the latter case, the decoder reads the DFU product data from an X.25 receiver process over a TCP/IP stream. The purpose of the decoder is to translate the incoming DFU weather product data into structures which can be read by the existing ITWS TWIP message generation software. This format frees the TWIP message generation software from a dependency on the source of the data. Next, the decoder determines the record length and record ID of the DFU product data and sends it on to the appropriate decoding routine. The decoder currently handles the following DFU product data: run–length encoded precipitation, graphical microburst shapes, graphical gust front shapes, runway alert text messages, runway configuration text messages, system status, and miscellaneous text messages (e.g., centerfield winds). Each decoding routine translates the DFU weather product data into a Lincoln–compatible format and sends each type of data out on a separate TCP/IP stream to the message generation software. The decoder may be configured to be compatible with different DFU build formats via a command–line option.

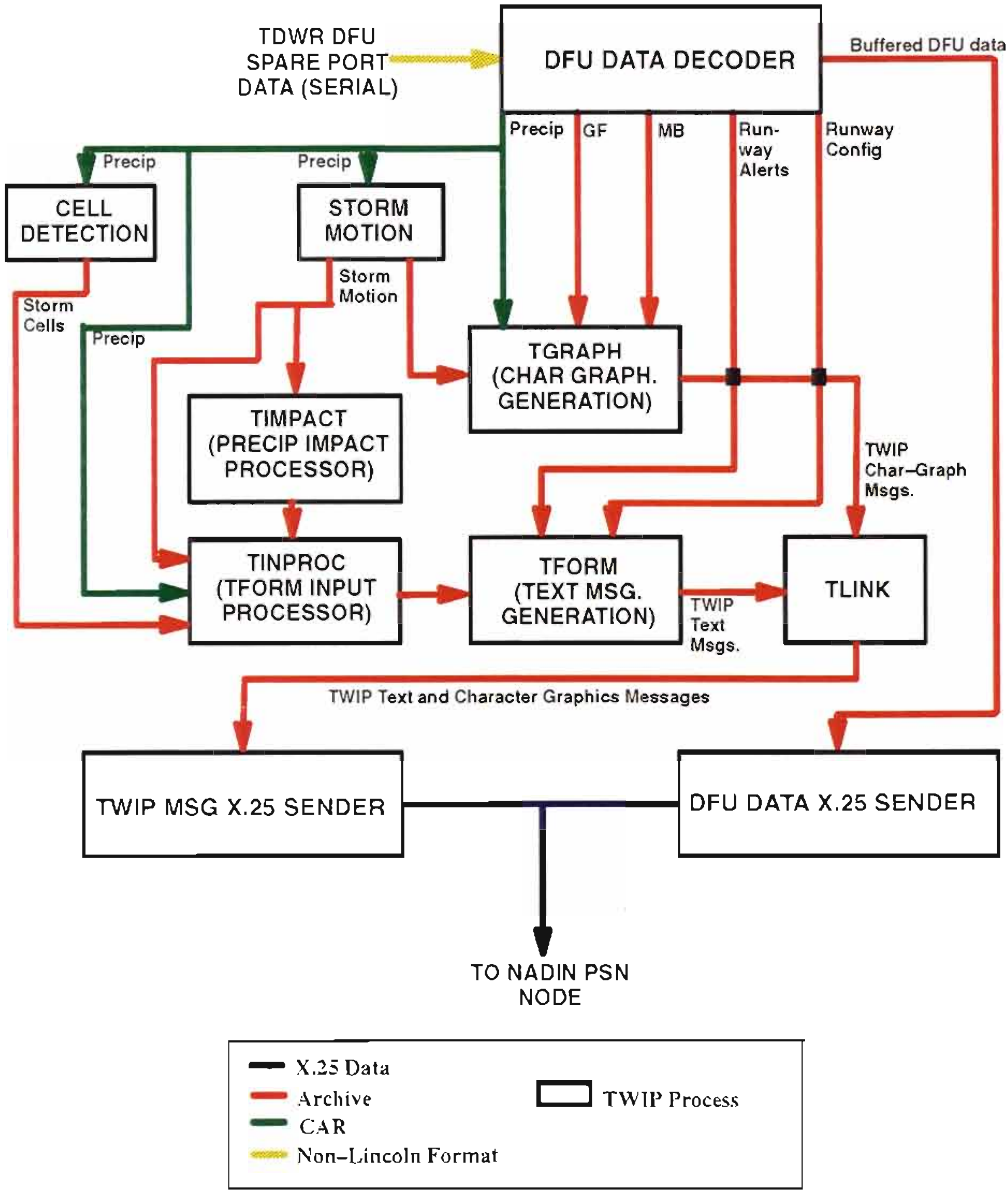


Figure 6. Expected remote TDP software data flow (NADIN PSN configuration).

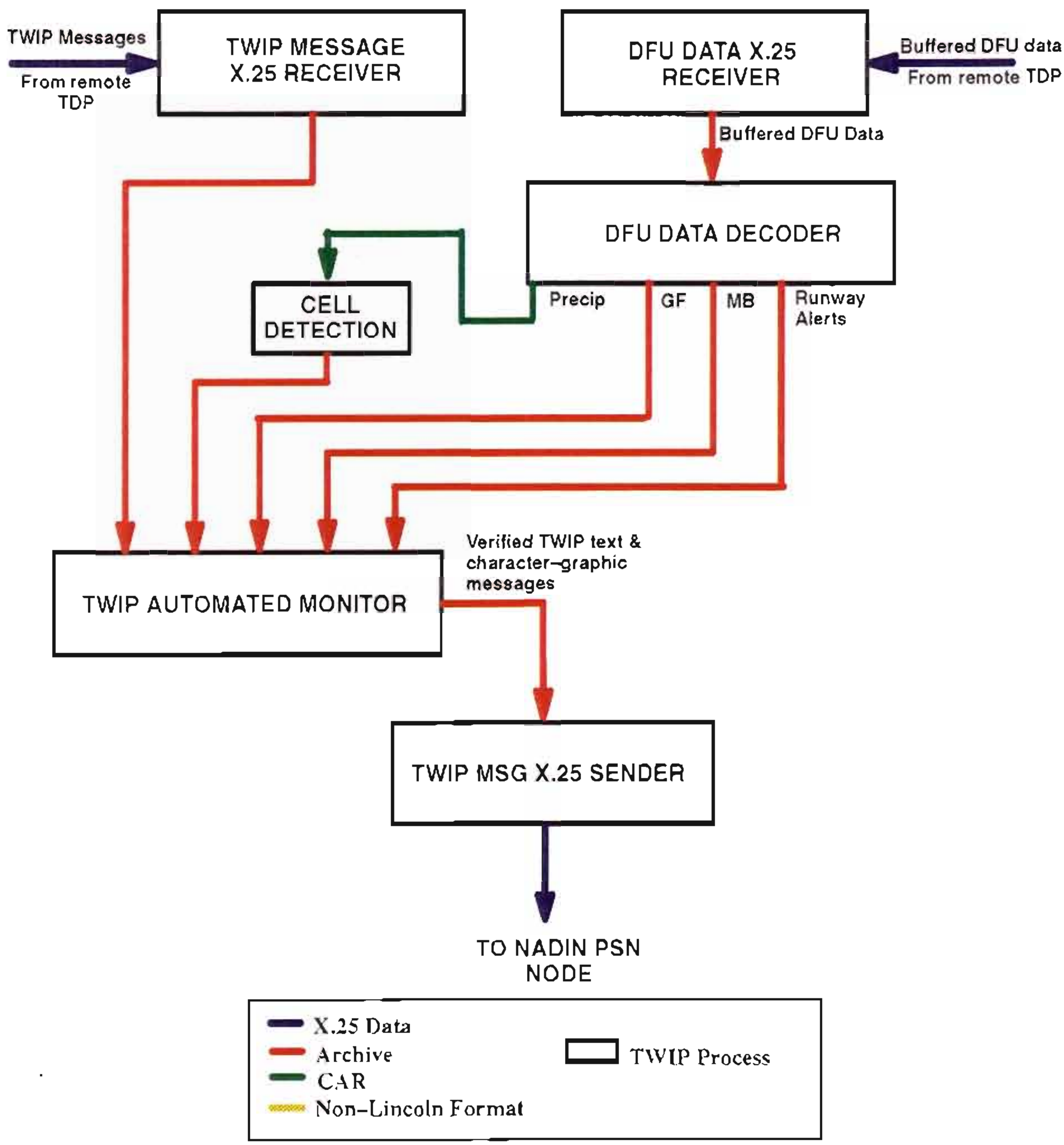


Figure 7. Expected TWIP Monitor data flow (NADIN PSN configuration).

4.5. TWIP Message Generation

There are seven modules responsible for generating the TWIP text and character character graphics messages (see Figure 5). These modules are as shown below, and a brief description of each module follows.

Module Name	Function
carcell	cell detection
xct	storm motion
timpact	precipitation
tinproc	twip input processor
tgraph	character graphics generator
tform	text message generator
tlink	message assembler

4.5.1. Cell Detection

Cell detection is performed on TDWR low resolution precipitation maps which are available every five minutes when precipitation is present within range of the TDWR. The detection is performed on two weather levels: level 2 which is considered "MODERATE" precipitation by pilots, and on levels 3 and above, considered "HEAVY" precipitation. The process starts by identifying rows of pixels, called "runs," which contain weather levels equal to or above threshold (for first pass, level 2). Next, vertically adjacent runs are combined to form two–dimensional "cells." Once a map has been scanned and level 2 cells have been identified, the level 2 and above cells are then scanned at the next higher weather level. This pass identifies the heavy cells. Contours are then formed around the heavy and moderate cells. Characteristics such as area–weighted x and y center and area are calculated for each cell. Cells below a parameter–defined area threshold are discarded. Upon completion, a set of heavy and moderate precipitation cells with x/y centers, areas, and contour points are passed to the TWIP Message Input Processor module. The locations of the three closest cells are noted in the cell information "–STORMS" section of the TWIP message associated with an airport.

4.5.2. Storm Motion

The ITWS grey–scale correlation tracker is used to estimate storm motion. This module compares time–sequenced precipitation maps and "moves" the latter map around until the greatest correlation with the first map is obtained. A motion estimate is determined from the amount of movement and the time difference between maps. Weather levels 2 and above are used in the correlation calculation. Note that growth and decay of storms can contribute to errors in the motion estimates. The storm motion vectors are passed to the character graphics generation module, the precipitation impact processor, and to the message input processor.

4.5.3. Precipitation Impact Processor

Timpact is the TWIP Precipitation Impact Processor. This module reads TDWR long–range, low–resolution precipitation available every five minutes from the DFU. It also reads in a set of

ARENA data which includes a reference latitude and longitude, typically that of the ARP. Each DFU precipitation map also contains a reference latitude/longitude, typically that of the TDWR radar from which the map was derived. The algorithm then scans each pixel in the precipitation map that falls within the ARENA points, checking the weather level of each pixel. The maximum and average level values of the pixels falling within each ARENA are calculated. If these values fall above parameter–defined thresholds, an impact is declared. Moderate impacts are declared for level 2 pixels. Heavy impacts result from level 3 pixels and above impacting an ARENA. In addition to reading precipitation, the Impact Processor also reads in storm motion vectors which are used in calculating expected precipitation impacts. The storm motion vectors are summed and averaged, resulting in a single motion estimate for the airport and vicinity. The ARENAs are then back–projected by the motion estimate amount in intervals of 3, 6, 9, 12, and 15 minutes. The impact calculations described above are performed for each time interval; the set of impacts and expected impacts are then sent onto the message input processor.

4.5.4. TWIP Message Input Processor

This module uses precipitation impacts, expected precipitation impacts, storm cells, and storm motion to perform the preliminary processing necessary to generate the TWIP text messages. For impacts, it sorts the impacts by time of onset and severity and transfers this list to the message generation module. For storm cells, the proximity and azimuthal extent of each cell are determined with respect to the ARP. The motion vectors from the storm motion module are summed and averaged to yield a single motion estimate for all storms at or near the airport.

4.5.5. Character Graphics Message Generator

The Character Graphics Message generation module receives microburst shapes, gust front shapes, and precipitation maps directly from the decoder, and storm motion vectors from the storm motion module. When weather is present at or near the airport, a set of microburst and gust front shapes will be available every minute. Each map is built and maintained separately. Thus, the following types of maps are generated: microburst, gust front, precipitation, and airport/reference marker maps. Upon receipt of a precipitation map, (about every five minutes in weather situations), each map is overlaid onto the output map. The priority is: runway/ARENA impact, runways and reference markers, microbursts, gust fronts, heavy precipitation, and moderate precipitation. Precipitation is grouped into moderate (level 2) and heavy (level 3 and above) and is denoted with the "–" and "+" characters, respectively. Refer to section 5.0 for examples of the TWIP character graphics messages.

4.5.6. Text Message Generator

The text message generator takes the weather inputs from the input processor, and runway alerts and configuration directly from the decoder. This information is used to build the following sections of the text message:

1. *ALERTS
2. –STORMS
3. .PREVIOUS/EXPECTED
4. STORM MOTION

The alerts are sorted by severity with the following priority: microburst loss, wind shear loss, and wind shear gain. The severity of each event is described in the "*ALERTS" section of the text message. The most severe event is displayed in the message. Precipitation impacts from the input processor are also described in the "*ALERTS" section if no wind shear conditions exist. Heavy impacts take precedence over moderate impacts. Again, only one impact is shown in the message. The "–STORMS" section is generated using data from the input processor. Only the three storms closest to the ARP will be reported. These are sorted by range and severity. Following the –STORMS section is the PREVIOUS/EXPECTED section. This section reports expected moderate or heavy precipitation impacts if such scenarios exist. It will also report PREVIOUS wind shear or microburst alerts. Finally, the storm motion vectors are summed and averaged, and a single motion estimate is included in the message. See section 5. for examples of the text message.

4.5.7. Message Assembler

The message assembler handles details such as appending X.25 and ARINC Data Network Service (ADNS) headers on the messages and determining whether to send a full character graphics map (in weather situations) or to substitute a "NO STORMS WITHIN 15NM" message for the character graphics map. It uses the output of the text message generator to determine this. The ADNS header is used by ARINC to determine where to forward the message after the X.25 header is unwrapped.

4.6. X.25 Interface

TWIP messages and DFU data are shipped and received by applications utilizing the 1984 version of the X.25 International Telephone and Telegraph Consultative Committee (CCITT) recommendation. This recommendation defines three layers of protocol: the packet layer, the frame layer, and the physical layer. The hardware interface and lowest level signalling conventions are defined at the physical layer. The X.25 specification for the frame layer allows either Link Access Procedures (LAP) or Link Access Procedures Balanced (LAPB) for data transfer between a Data Terminal Equipment (DTE) and a DCE (Data Circuit–terminating Equipment). The X.25 applications were developed on Sun platforms using Sun's SunNet X.25 software. To conform with most X.25 applications, the SunNet package uses LAPB. This is a subset of High–level Data Link Control (HDLC). The third layer, known as the packet layer, supports virtual circuits between DTEs, addressing of DTEs, and the mutiplexing of fully reliable end–to–end circuits. Packet Switched Networks usually support both Switched Virtual Circuits (SVCs) and Permanent Virtual Circuits (PVCs). The former are dynamically created and destroyed. An SVC is established when one DTE calls another and ends when one DTE breaks the circuit. Alternatively, PVCs are automatically created whenever the DTE establishes the link to the PSN. NADIN PSN supports only SVCs. The SunNet X.25 package allows the use of multiple SVCs. Thus, in the NADIN configuration, a single Sun workstation (i.e., a remote TDP) can establish three SVCs to send out character–based TWIP messages: binary TWIP messages and DFU data. The SunNet X.25 package allows applications to take advantage of all the major protocols and services described by the X.25 International Recommendation. It is also compliant with the National Institute of Standards and Technology (NIST). The hardware and software are supported by the FAA's NADIN PSN. Two types of applications were developed; one for sending TWIP messages and DFU data using the X.25 protocol and one for receiving each of the two types of data.

Messages are sent by a process called msgx25send. This module reads the TWIP messages (both character graphics maps and text messages) over a server/client (TCP/IP) stream, inserts them into a queue, and sends out each message using the X.25 protocol. The destination address, local address, packet size, and some other parameters are supplied on the command line. The destination address is the address of the PSN node to which the data will be sent. This is typically the ARINC database but can be any airline's host computer. An application running at the destination address handles the incoming TWIP messages. This process must already be active before an X.25 send process can be invoked. Once the messages have been received by the remote application, it is up to the database provider (ARINC, in this case) to relay the messages to aircrews.

A similar process called dfux25send forwards the DFU weather data. This process is used for two separate applications. First, the raw DFU data is sent from each remote field site to Lincoln. The data is then decoded at Lincoln and fed to both the automated monitor program to validate the TWIP messages and to a local TWIP analysis display. There are several examples of this display in section 5. Secondly, when the NADIN PSN is fully functioning, airlines should be able to obtain the TDWR DFU weather products directly from a NADIN node. It would then be the airline's responsibility to decode and use these graphical weather products. The dfux25send process buffers DFU records up to a parameter–defined quantity before shipping. This reduces the overhead of continually sending small DFU records. Thus, several DFU data records may be sent in a single X.25 buffer. In addition to buffering, a filtering capability was implemented to filter out those records not germane to the TWIP message, such as the high–resolution airport precipitation maps. This also reduces the necessary bandwidth and reduces traffic on NADIN PSN. Just as there are two applications to send TWIP data and DFU data, there are two such processes which receive these data. The TWIP message reader (msgx25recv) reads the TWIP messages as generated at each remote site. The message reader provides data in a server/client stream for the automated monitor to process. The DFU data reader reads a block of DFU data and sends it to the decoder for product decoding.

4.7. Automated Monitor

Automated monitoring is performed on all generated TWIP messages before they are sent to the ARINC database. The monitor reads the TWIP messages passed to it over a server/client stream by the msgx25recv module. It also reads gust front shapes, microburst shapes, and runway alerts directly from the data decoder running at Lincoln. Precipitation is processed by the monitor in the form of storm cells; a version of cell detection must run at Lincoln to support monitoring. Figure 5 illustrates the processes which send data to the monitor.

Two levels of checking are performed on each message. First, the syntax of each message is put through a rigorous set of checks to verify that all of the necessary components exist in each message. Next, the message is compared with the actual weather as described by the raw DFU data. Major discrepancies between weather scenarios depicted by the DFU data and the TWIP message will cause a "SYSTEM UNAVAILABLE" message to be displayed instead of the faulty message. To ensure consistency, the weather checking section of the monitor is broken down into two parts: alerts/impacts, and terminal weather. To check the alerts/impacts section, a C++ object was designed to describe the alert type, intensity, time, etc. Instances of this object are created from reading the DFU runway alerts stream and from reading the *ALERTS section of the TWIP text message. If an alert exists in the DFU data but a corresponding alert does not exist in the current TWIP message or has not existed in the last "n" (parameter–defined) TWIP messages, a potentially serious error condition exists and an "UNAVAILABLE" message will be substituted. The same is true for false alerts in a TWIP message. If the message indicates some type of wind shear alert but the DFU data does not verify the condition, the "UNAVAILABLE" message is substituted. The storm cells are read in by the monitor to determine if the TWIP precipitation impacts (found in the *ALERTS section if there are no current wind shear alerts) being reported match the actual precipitation fields. The storm cell stream is also used to verify the "–STORMS" section of the message. There are several types of problems which the monitor can identify. These are shown in Table 2. If the problem is severe enough to warrant substituting a "SYSTEM UNAVAILABLE" message, TWIP personnel are beeped with an error code indicating the condition that caused the error. If the system is producing "SYSTEM UNAVAILABLE" messages for any reason, i.e., if the TDWR is in a maintenance mode, the monitor will issue the beep to notify TWIP personnel. Table 2 shows the beeper codes and their causes. Each code has a single–digit prefix indicating which site is experiencing problems. A code of 1160, for instance, would indicate that the DCA TDWR was running a playback and that a "SYSTEM UNAVAILABLE" message was issued. The Beeper Manager is discussed in more detail in the next section.

Table 2
TWIP Monitor Beeper Codes

Beeper Code	Reason
100	low / high character count in TWIP message
101	no final line feed in message
102	no EXT character at end of message
103	low carriage return count in message
105	low linefeed count in message
105	CR / LF counts don't match
106	no QU priority (ADNS) line in message
107	no dot "." before ADNS destination address
108	invalid number of characters in ADNS destination address
109	bad ADNS timestamp
110	no stx character at beginning of message
111	no TIS format tag (ADNS address specific)
112	no AD preamble (Arrival/Departure)
113	invalid airport identifier in message
114	no ADNS line in message
115	invalid A&D airport
116	no A&D tag in message
117	format specific problems
118	no "TERMINAL WX INFO" in message
121	no GAIN/LOSS token in a valid alert section
122	bad GAIN/LOSS token in the alert section
123	other bad ALERT
124	SYSTEM UNAVAILABLE
125	PRECIP UNAVAILABLE
126	storm trigger "–", but no "STORM(S)"
127	invalid storm bearing
128	other bad storm syntax
129	excess / insufficient storms reported
135	TLINK TWIP stream is dead
150	alert in TWIP message, not in DFU
151	alert in DFU, not in TWIP message
160	>24 hour old data. TDWR site running a playback?
501	2nd failure of the ARINC X.25 sending process
502	3rd failure of the ARINC X.25 sending process
503	4th failure of the ARINC X.25 sending process
(Site prefix codes: ATL: 0xxx; DCA: 1xxx; ORD: 2xxx; BOS: 3xxx; CLT: 4xxx; DEN: 5xxx)	

4.8. Beeper Manager

To support 24–hour–per–day, seven–day–per–week operation, it was necessary to alert Lincoln Laboratory TWIP personnel in the event of problems such as those described in Table 2. TWIP personnel at Lincoln carry beepers and can remotely dial in to the system to find and correct, if possible, problems with the TWIP messages for each site. The beeper manager is driven by a finite state machine with three modes of operation: vigilant, alarmed, and reminder. The process starts out in vigilant mode. When the monitor has detected an error, it determines the code as shown in Table 2 and sends the code to the beeper_manager over a datagram socket. If two such errors are received by the manager within 30 minutes, it goes into alarm mode and immediately dials the TWIP beeper numbers and sends the appropriate error code. The manager then goes into reminder mode. In reminder mode, the manager waits for two hours, and if the condition still exists (i.e., it is still receiving the error code from the monitor), a beep is reissued. If the condition clears for 30 minutes, the manager goes back into vigilant mode. The error codes assist TWIP personnel diagnose the problem.

4.9. Summary of Expected FY96 Tasks

Certification testing to allow Lincoln access to NADIN PSN will be carried out with the FAA Technical Center and completed in spring 1996. The software described above has been running on a 24–hour–per–day, seven–day–per–week basis for sites at DCA and ATL using the leased–line configuration since September 1995. This software is flexible enough to run without modification in the final NADIN PSN configuration. The Boston TDWR will become the first site to become operational through the NADIN PSN in summer, 1996. Chicago, Charlotte and Denver sites are expected to come on line in 1996. In addition, the TWIP message generation code is being rewritten to simplify software maintenance.

5. CASE STUDIES

The utility of the TWIP messages generated by the ITWS testbeds was evaluated in previous reports [1],[2]. In order to determine the utility of the TWIP messages generated from TDWR data, studies were carried out on cases collected over the 1995 season. These studies had three objectives. The first was to demonstrate enhanced situational awareness provided by the TDWR–based TWIP messages over Surface Observations. The second was to demonstrate correct performance of the TDP message generation software. The third was to identify any performance issues relating to the TWIP message generation or the TDWR products.

5.1. Enhanced Situational Awareness

Figure 8, Figure 9, Figure 10, and Figure 11 provide a sequence of snapshots of an August 19th storm at Atlanta. These pictures are representative of how the TWIP Text Messages and the TWIP Character Graphics Depictions portray an isolated convective storm in comparison with Surface Observations provided by the Automated Surface Observing System (ASOS).

By 22:43Z (Figure 8) the cells, which first appeared on the northern edge of the precipitation field, had tracked southward, maturing along the way. Note that the cell locations, their storm motion and direction, and the expected precipitation impact time are clearly depicted in both of the TWIP messages, whereas the ASOS offers no indication of storms in the vicinity. Also notice the increased situational awareness created by the heavy precipitation forecast (HVF SEND 2243 2303). The message alerts pilots to the expected impact of the impending storm which is to occur between 22:43Z and 23:03Z.

At 22:52Z (Figure 9) notice that the ASOS message, nearly an hour old, did not reflect the heavy precipitation impacting the airport. Also observe that this impact created a new TWIP SEND message (HVY SEND 2252 2312), alerting pilots to the presence of the heavy precipitation. One algorithmic problem arose during this time, however. The first expected heavy precipitation forecast issued at 22:43Z was for 23:02Z, but notice that the impact occurred at 22:52Z. The expected precipitation algorithm, which relies on using storm motion estimates and storm contouring to create theoretical storm tracks into the airport, was misled by the spatial growth of the storm. In effect, the storm outgrew its level 3 and above contours which the expected precipitation algorithm was using to estimate the storm's time of impact. However, some recognition should be given to the 22:47Z message (not shown) which decremented the impact time to 22:56Z due to a new cell contouring which accounted for the growth up until that time. In this case, the growth seemingly had little effect on the storm motion estimates, but this is not always the case. In some events, such storm growth not only affects the speed but also the direction. Such problems could be alleviated by including a storm growth and decay prediction algorithm which could account for the continual metamorphosis of a storm.

By 22:58Z (Figure 10) the storm has begun to produce microburst–strength shears at the airport, causing the TWIP Character Graphics Depiction to show microburst impacts while forcing the TWIP Text Message to alert its users of the presence of a 40–kt loss induced by a microburst. But note that the four–minute–old ASOS message neither gave warning of the microburst strength impacts nor correctly assessed the magnitude of the precipitation at the airport, which ASOS labeled as light rain. Note, also, that ASOS lacks the capability to provide storm motion estimates.

It was not until 23:02Z (Figure 11) that another ASOS report was issued indicating the presence of winds gusting to 25 knots and heavy rain, but by this time the cell was almost centered over the

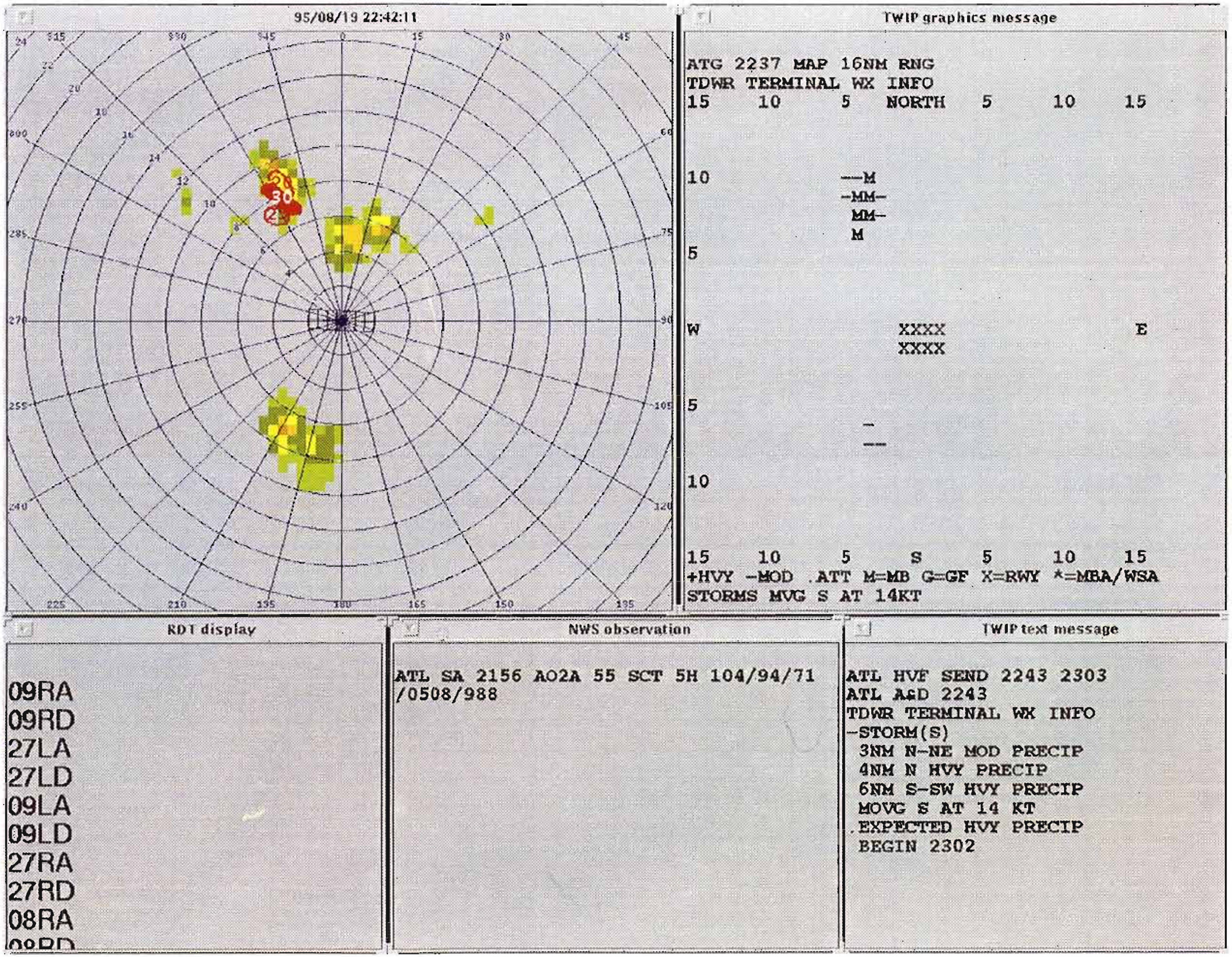


Figure 8. ASOS (timeliness)/G&D and its effect on storm motion (August 19th storm at ATL).

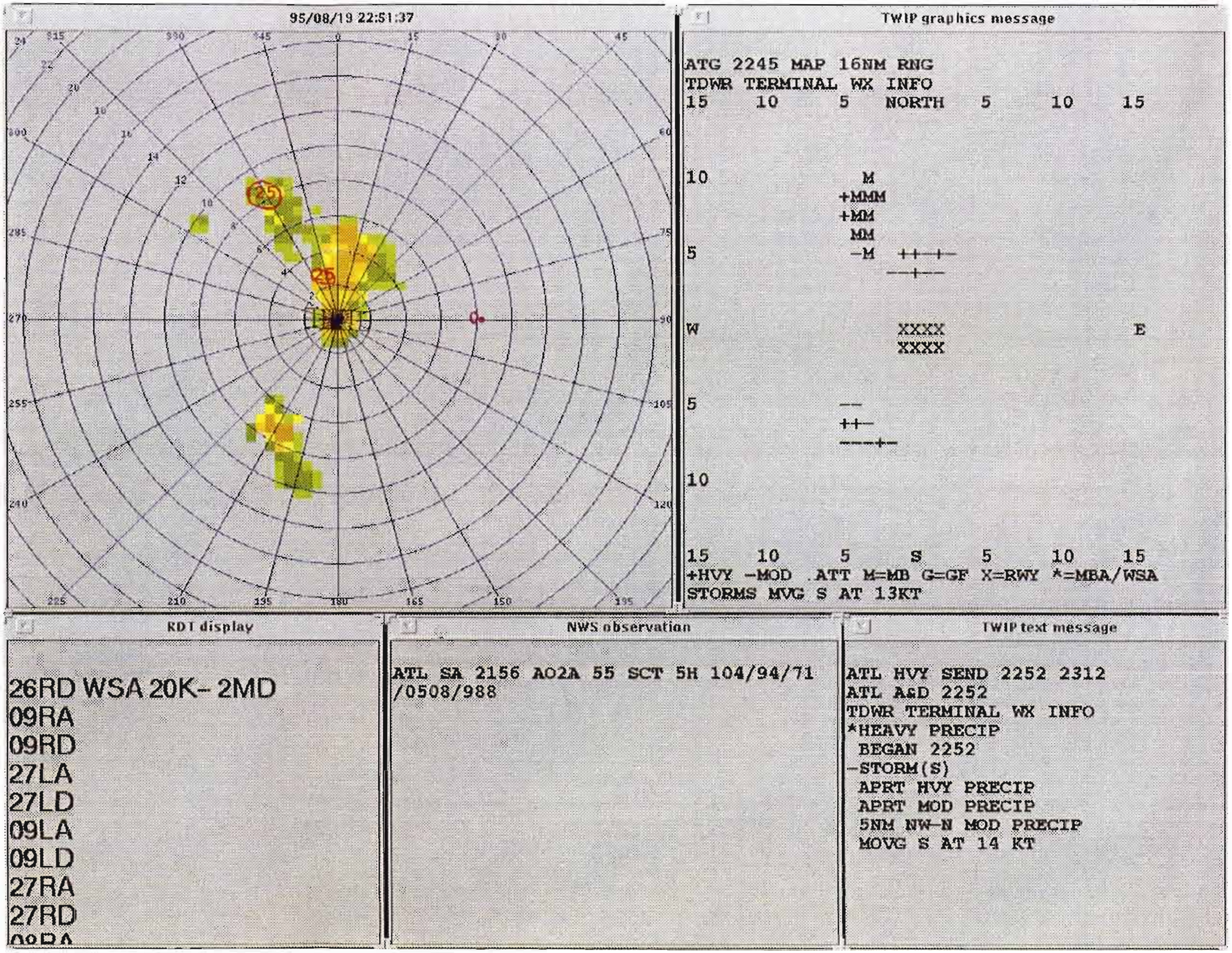


Figure 9. August 19th storm at ATL (cont'd.).

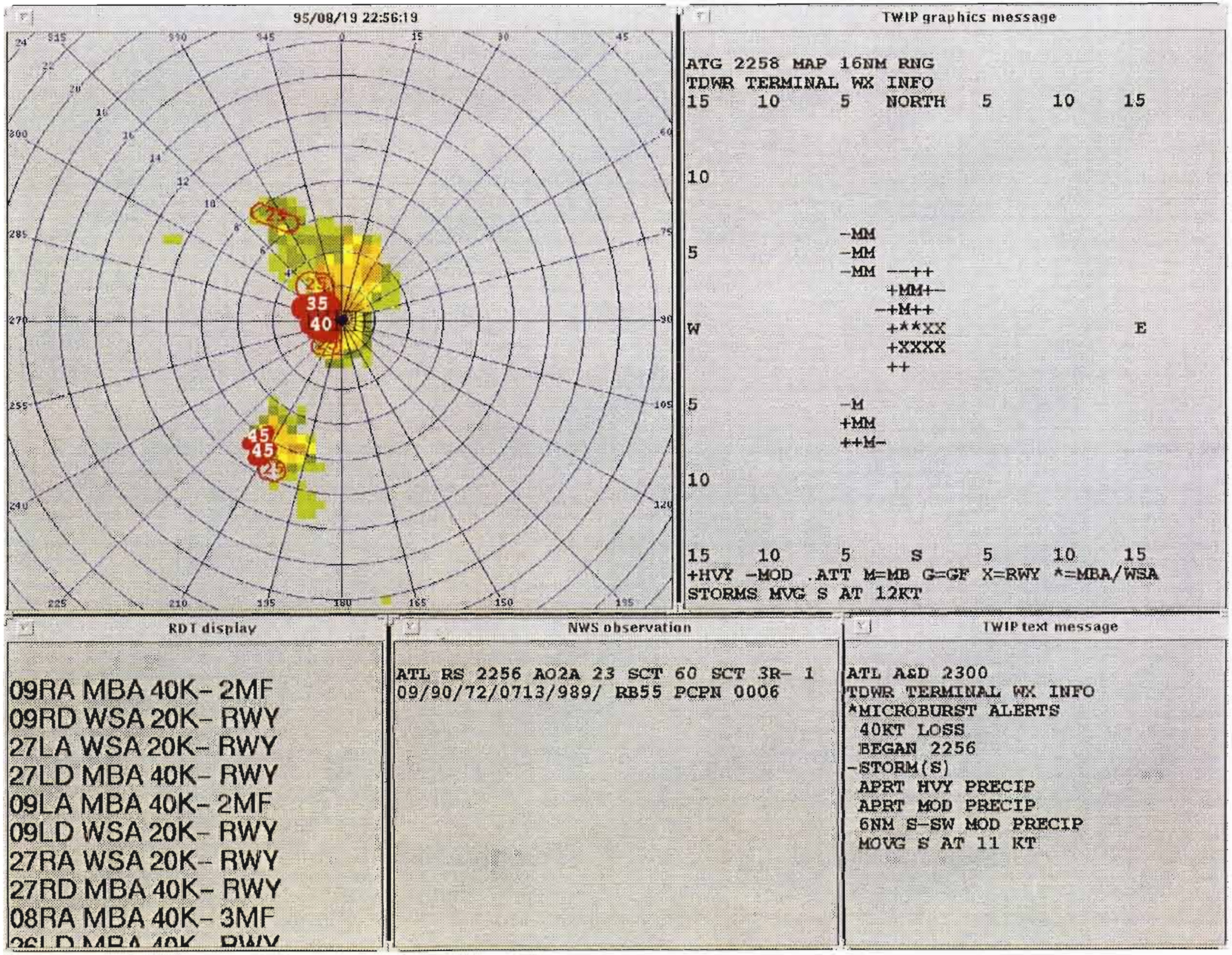


Figure 10. August 19th storm at ATL (cont'd.).

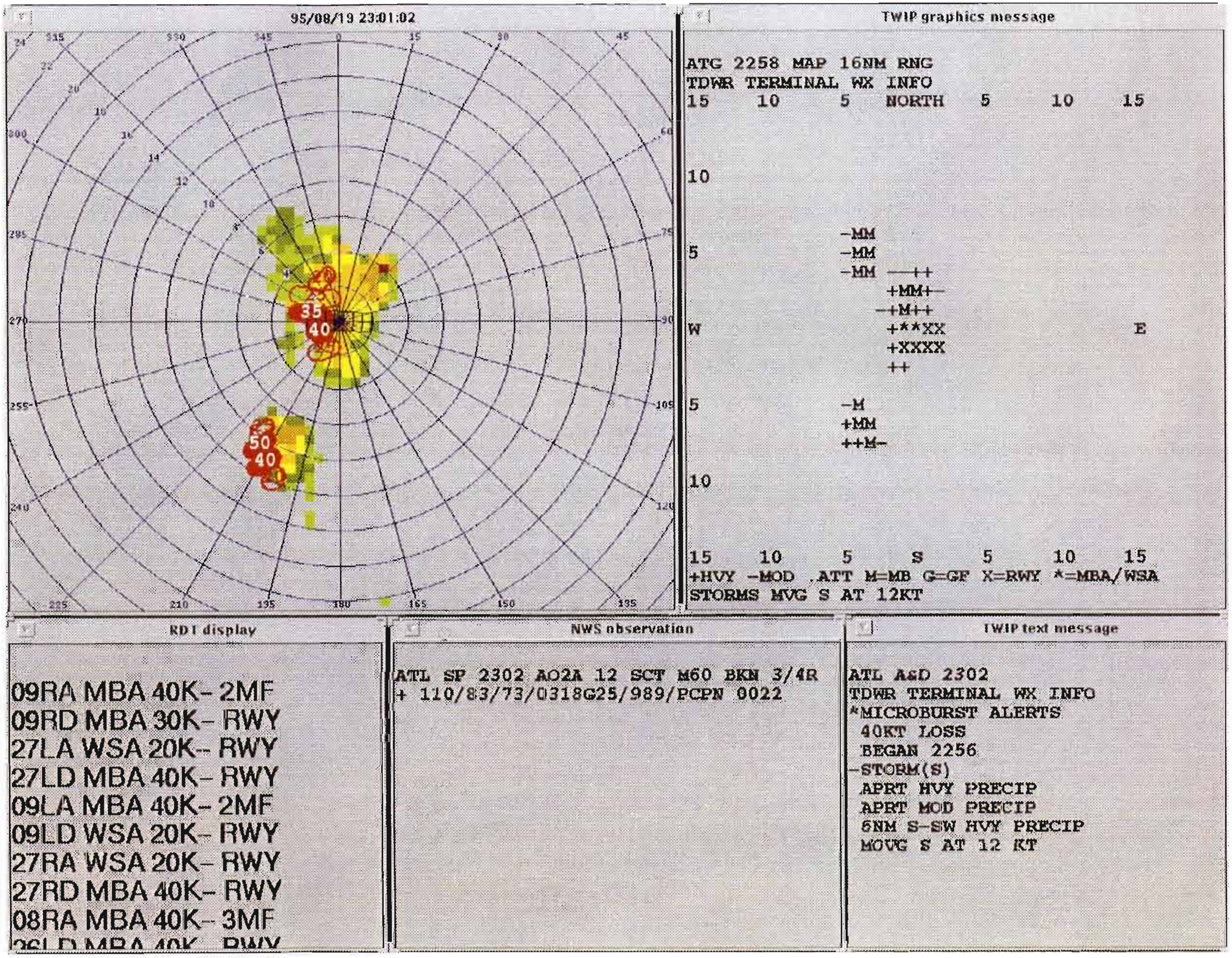


Figure 11. August 19th storm at ATL (cont'd.).

airport. This ASOS message not only lagged approximately five minutes behind TWIP's issuance of a microburst alert but it also underestimated the magnitude of the wind shear.

5.2. Performance Issues

After reviewing all of the 1995 cases, many instances of anomalous behavior were observed in the TWIP system which could be linked to the products generated by the TDWR. Although most of the problems were directly attributed to deficiencies in the present suite of software used by the TDWR, some of the inadequacies were due to either shortcomings in the TWIP or ITWS algorithms.

5.2.1. Microburst and Gust Front Detection

It was noted that TDWRs would occasionally declare a wind shear event when in reality no precipitation echo existed to support such an event. For instance, in an October 31st storm (Figure 12) at ATL two overlapping microburst shapes, 35 and 50 knots, were displayed over no supporting precipitation echoes. This particular inadequacy could be alleviated by incorporating a Vertically Integrated Liquid (VIL) test into the TDWR microburst detection algorithm. Such a test would suppress clear air wind shear alerts by recognizing the lack of VIL associated with these events.

It was also observed that oversized microburst shapes were issued occasionally by a TDWR. For example, in an October 6th storm at DCA (Figure 13) a large 40–knot microburst shape was generated over the southern end of the ARENAs. This particular shape measured roughly 6 nm in length and should have been divided into smaller shapes.

Gust fronts are also a source of difficulty for the TDWR microburst algorithm. In some cases the algorithm detects the divergence behind a gust front as a row of microburst shapes. Such an event occurred in an October 27th storm at DCA. The microburst detection algorithm was actually first in detecting the developing line divergence at 21:52Z (Figure 14) and subsequently it began issuing microburst shapes along the divergence. The gust front detection algorithm later began identifying the gust front (Figure 15), but in the mean time another developing gust front nearer to the airport was again detected first by the microburst detection algorithm. Later the event peaked (Figure 16) with four gust front detections, two of which had microburst shapes running nearly the entire extent of the detections. One hypothesis is that these gust fronts were actually caused by gravity waves originating from a cell west of the airport. By the time the last gust front reached the edge of the runways (Figure 17) all of the others had dissipated, along with the host of microburst and wind shear shapes trailing behind the fronts. However, at this juncture another gust front algorithm problem arose.

After the gust front touched upon the edge of the runways as stated above, the detection disappeared for roughly twenty minutes, although the microburst shapes continued to be detected. Not until the gust front had passed over the airport and traveled approximately ten nautical miles to the east–southeast did the detection reappear (Figure 18). In all of the gust front cases analyzed this sort of occurrence is fairly common, but the extent of the disappearance can vary widely. In some cases the gust front will disappear completely, as did all of the other gust fronts associated with the October 27th case. In other cases the gust front edge will vary in length over time rather than disappear totally.

5.2.2. Storm Motion

As shown before in the August 19th storm at ATL, the growth and decay of storms can cause significant errors in the storm motion estimates generated by the ITWS Storm Motion Algorithm.

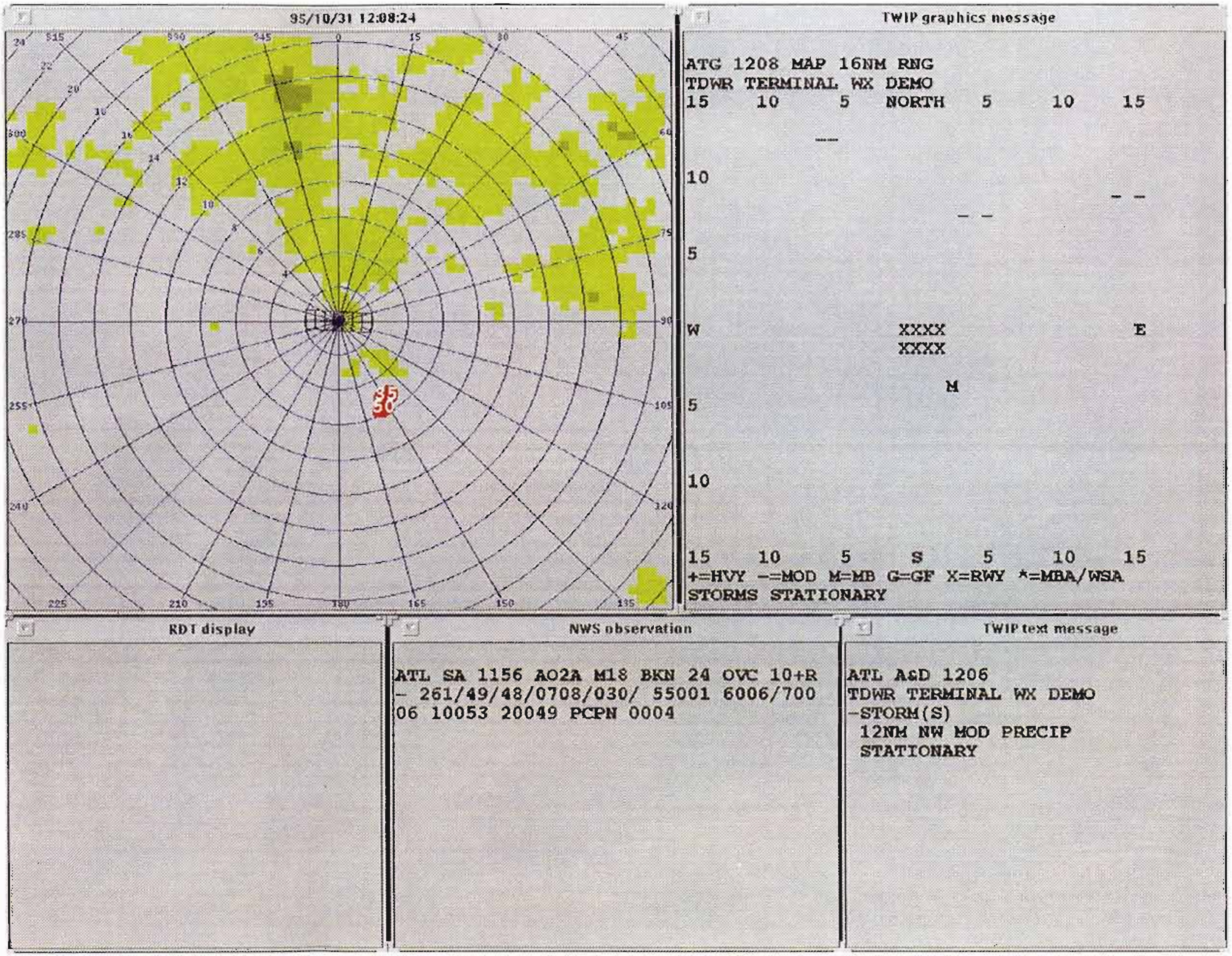


Figure 12. False MB shape (October 31st storm at ATL). Note: the range rings in all of the following figures are in 2 nm increments.

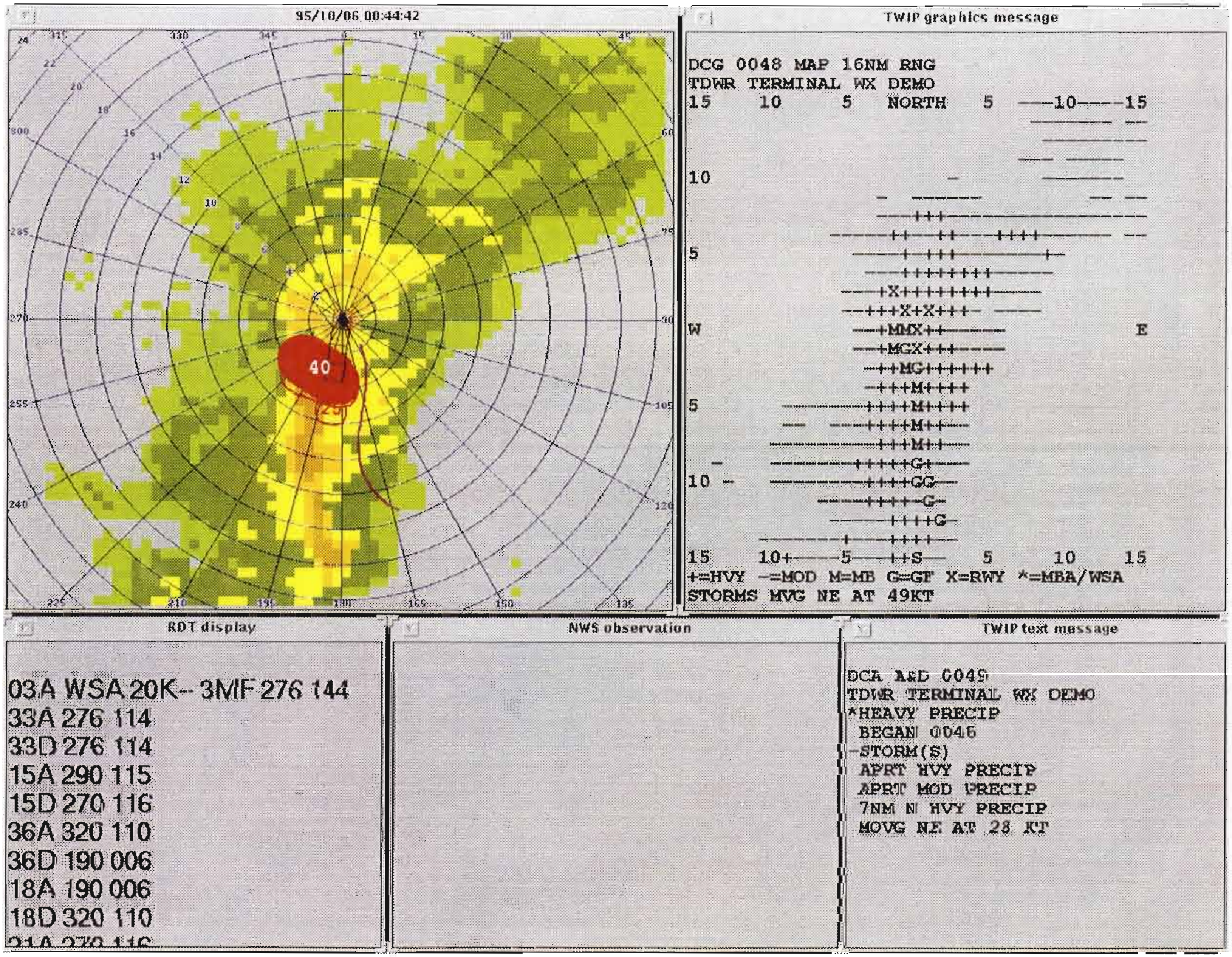


Figure 13. Large MB shape (October 6th storm at DCA).

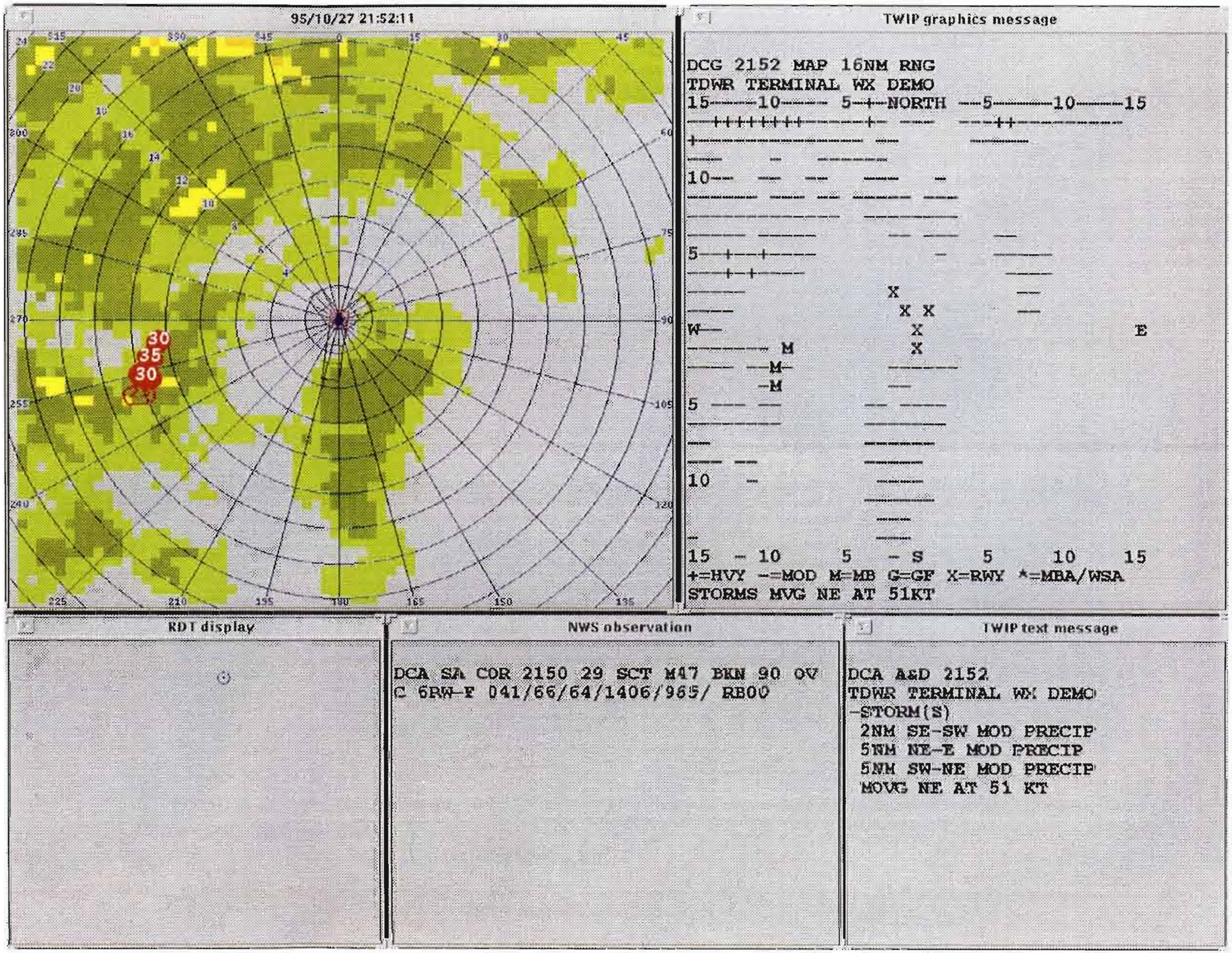


Figure 14. MB behind GF/GF disappearing (October 27th storm at DCA).

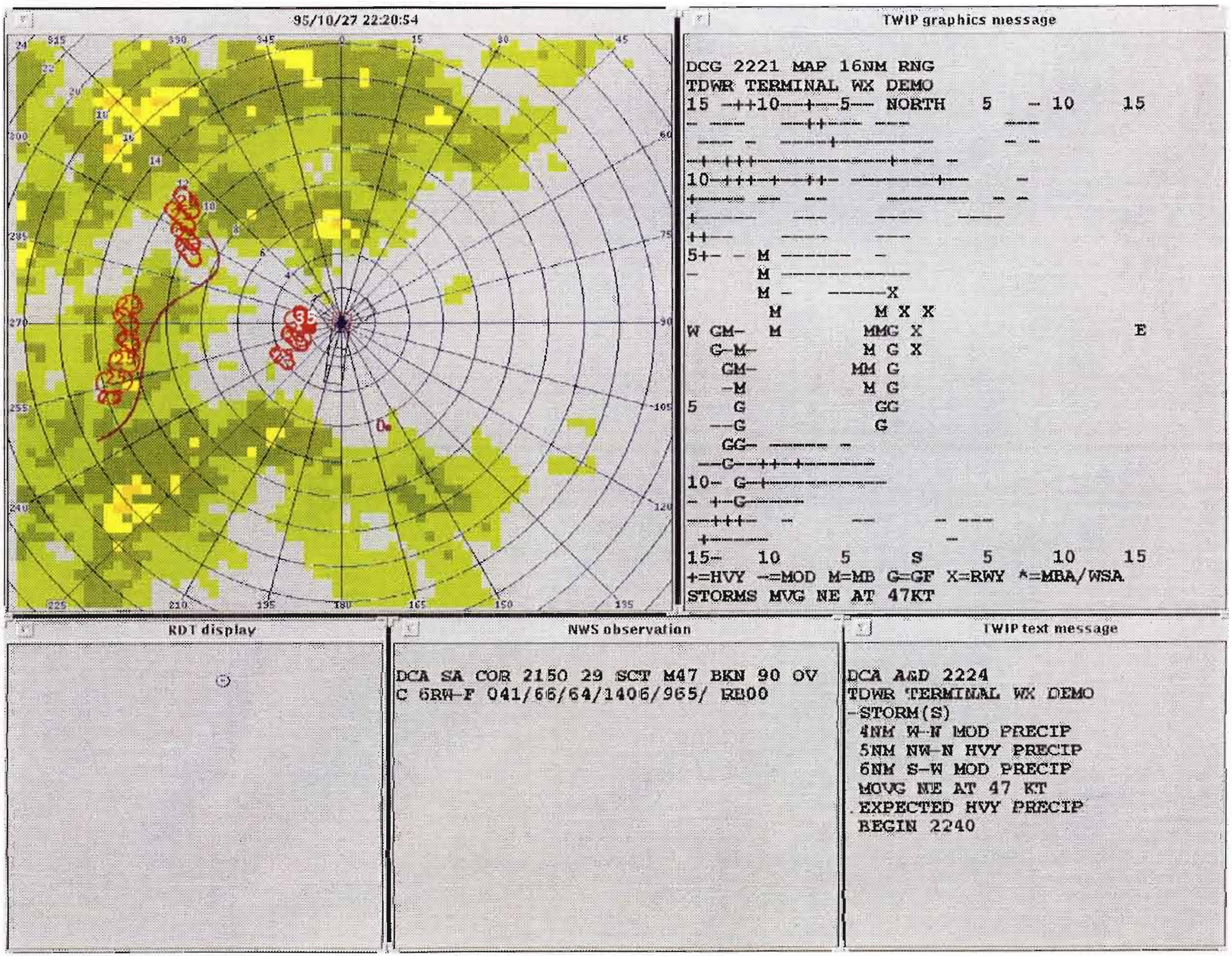


Figure 15. October 27th storm at DCA (cont'd.). Divergence behind a gust front triggering microburst detections.

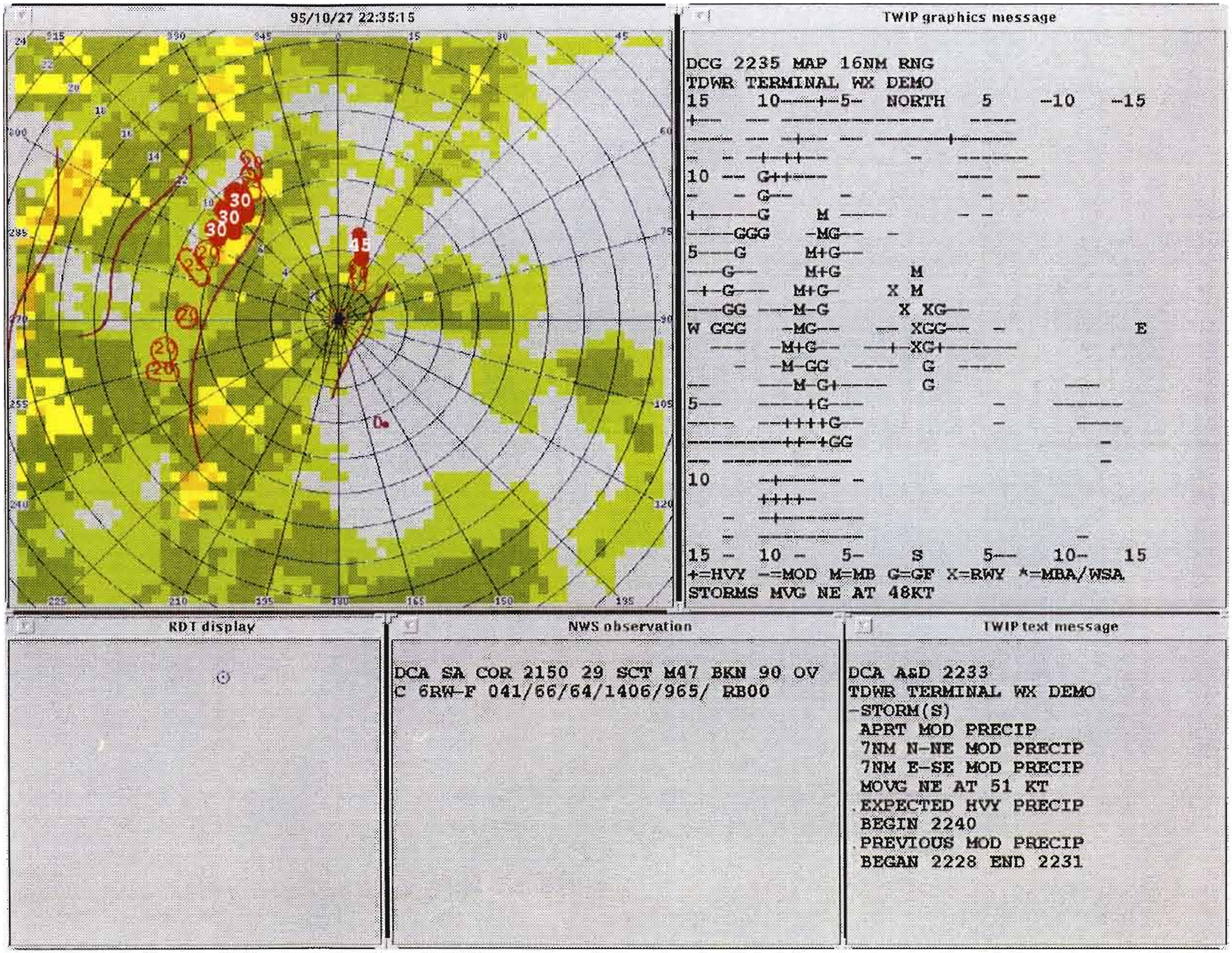


Figure 16. October 27th storm at DCA (cont'd.). Four gust front detections. Note microburst shapes behind the 2nd front caused by divergence behind the front.

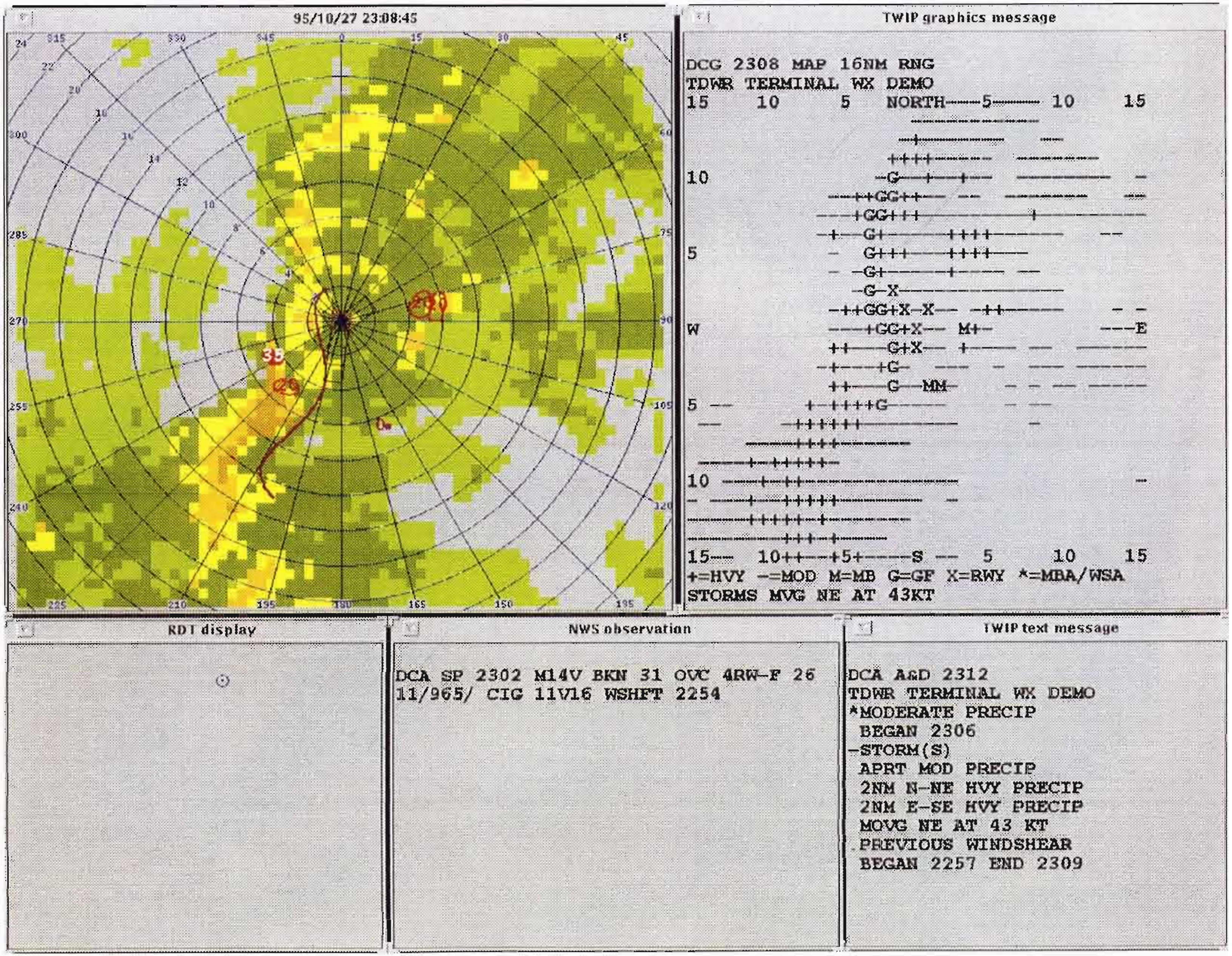


Figure 17. October 27th storm at DCA (cont'd.). Single gust front approaching the airport.

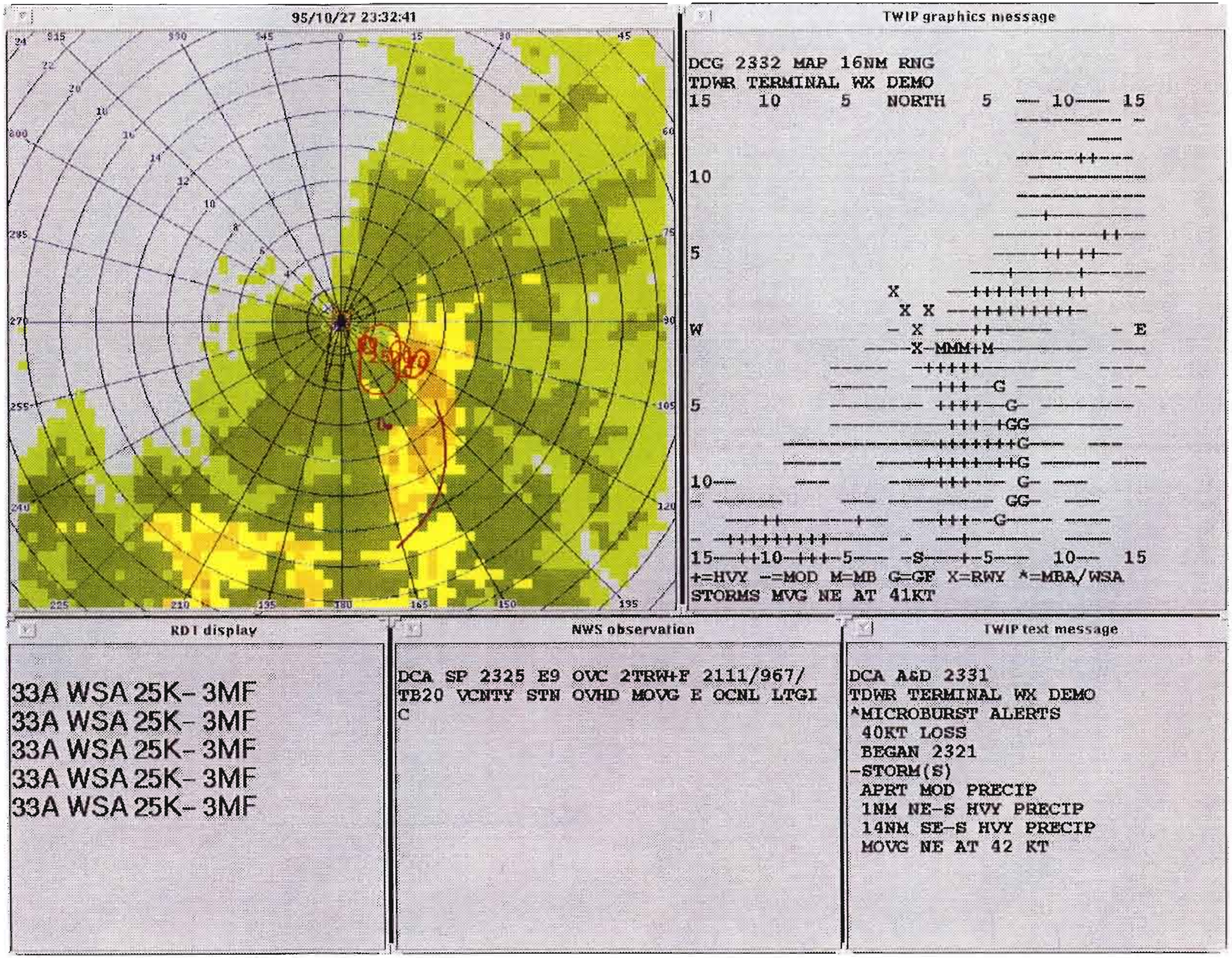


Figure 18. October 27th storm at DCA (cont'd.); reappearance of the gust front. Disappearance was possibly due to the alignment of the front relative to (perpendicular to) the radar beam. Note: the radar is located approximately 4.5 km east of and 10.5 km south of the airport.

However, there exist other problems which are involved with tracking the cells that can also affect the output of the algorithm. The current algorithm tracks storm cells of level 2 or greater intensity, but under certain circumstances this methodology proves to be inadequate. This mainly occurs when a large-scale stratiform event saturates the precipitation field with level 2 echoes. In such a situation the Storm Motion Algorithm uses only the contours of the small higher echo cells embedded within the larger area of level 2 precipitation. If the motion of these cells is radically different in speed and direction than the motion of the storm's envelope, an erroneous storm motion estimate is generated. Arguably this is not a severe problem most of the time for two reasons. First, in a saturated precipitation field, the information provided by a storm motion estimate does not offer any tactical information because all of the quadrants in the terminal area are affected by weather. Second, the original storm motion estimate given to the frontal edge of the storm is allowed to influence the future estimates produced by the Storm Motion Algorithm. This built in 'persistence' within the algorithm thereby gives the future estimates a certain amount of credence since any erroneous estimates will, in effect, be averaged in with the previous ones. However, over time the storm motion estimate will slowly degrade at a rate that depends on the quality of the input data. An example of storm envelope motion versus the motion of the embedded cells is graphically depicted in a November 3rd case at ATL.

On this particular day a defined line of precipitation swept through the Atlanta terminal area from the west, bringing a brief period of moderate precipitation to the airport. When the ITWS Storm Motion Algorithm, along with the TWIP software suite, was played back using the level three tracker (Figure 19, Figure 20, and Figure 21), a radically different storm motion estimate was generated when compared with the motion estimate produced by the level two tracker (Figure 22, Figure 23, and Figure 24). Again, for each case, storm motion vectors for individual cells were overlayed onto their respective cells to clarify which components comprised the final storm motion estimate. In the level 2 case, one can easily see that the motion of the storm was correctly depicted by the motion of the fairly dominant level 2 cells which defined the envelope of the storm. However, notice that in the level 3 case the envelope of the storm is not given the correct motion estimate. Instead, the embedded level 3 cells within the line and their apparent northeast movement forced the Storm Motion Algorithm to provide the motion of the storm moving northeast. As the level three cells dissipated (Figure 24) the Storm Motion Algorithm no longer had any cells to track, causing the storm motion estimate to incorrectly indicate that the storms were stationery.

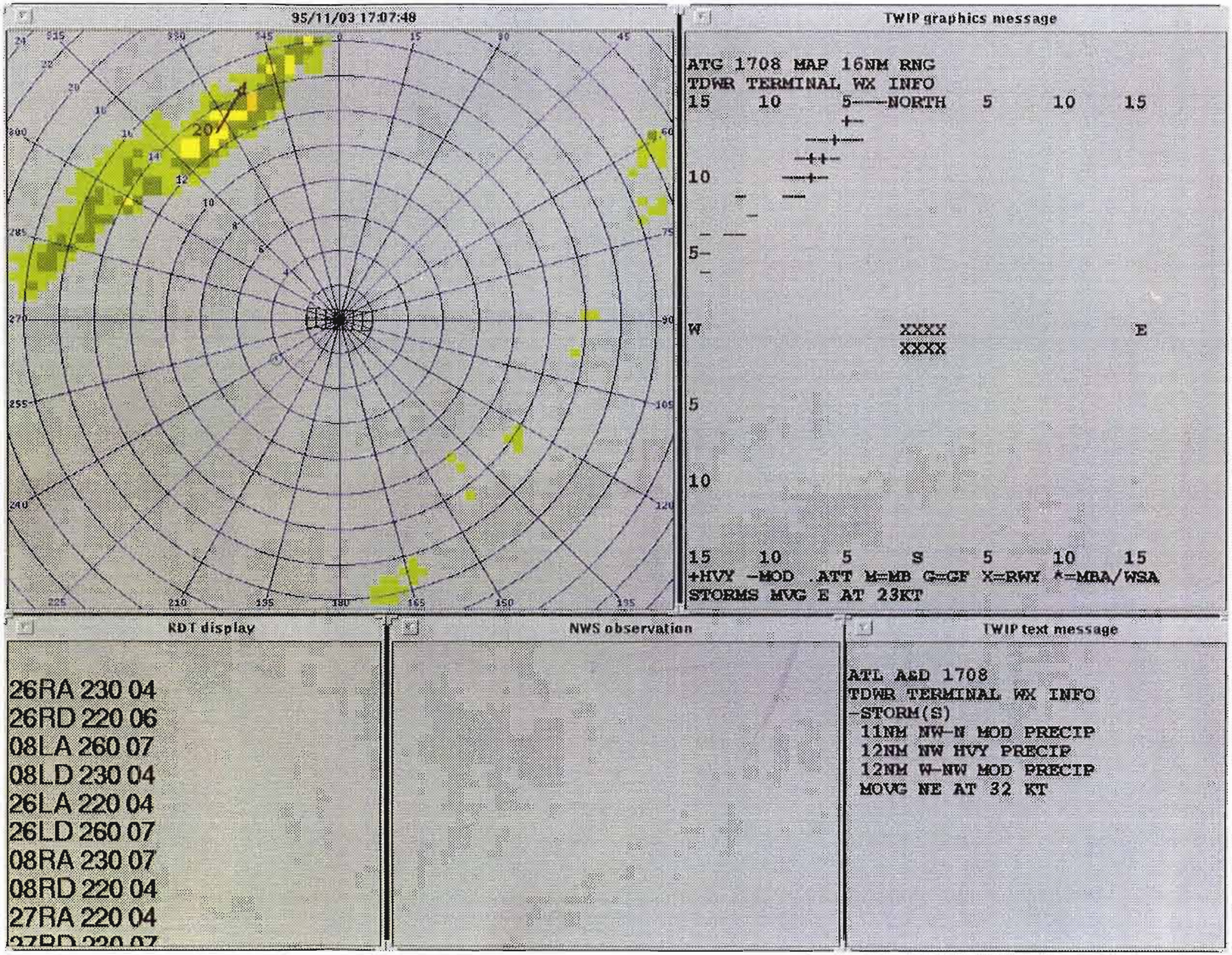


Figure 19. Level 3 Storm Motion Case, 1 of 3.

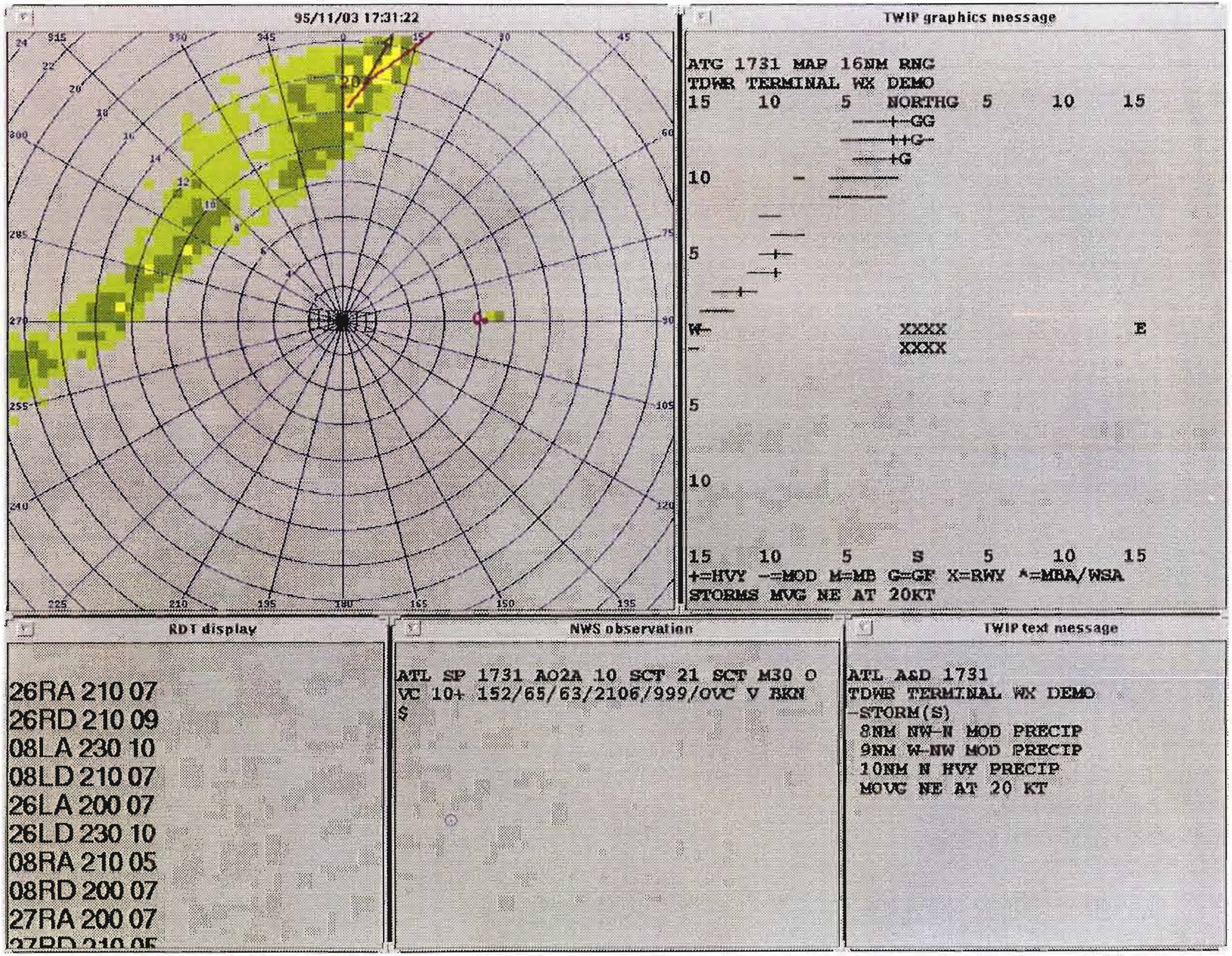


Figure 20. Level 3 Storm Motion Case, 2 of 3.

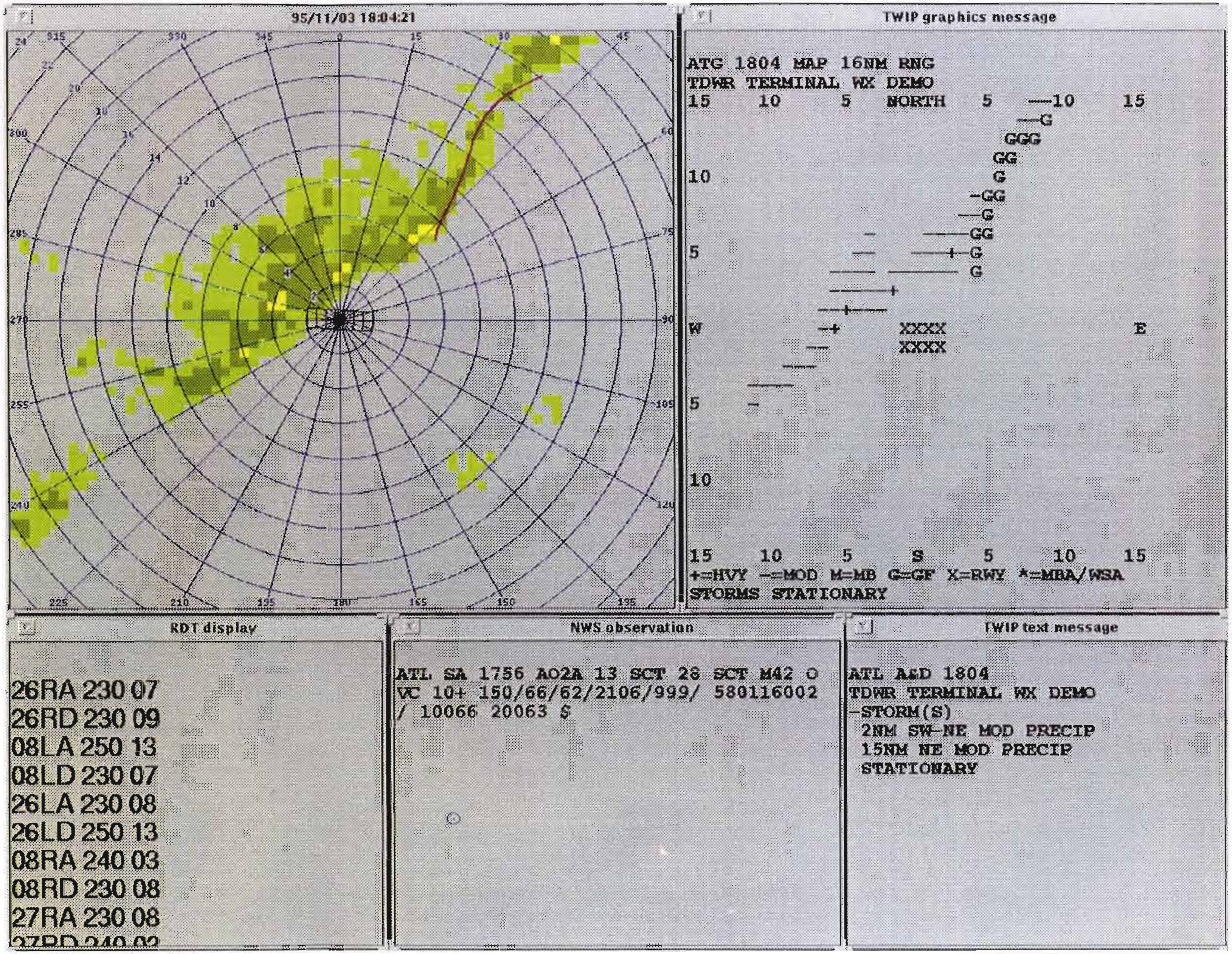


Figure 21. Level 3 Storm Motion Case, 3 of 3.

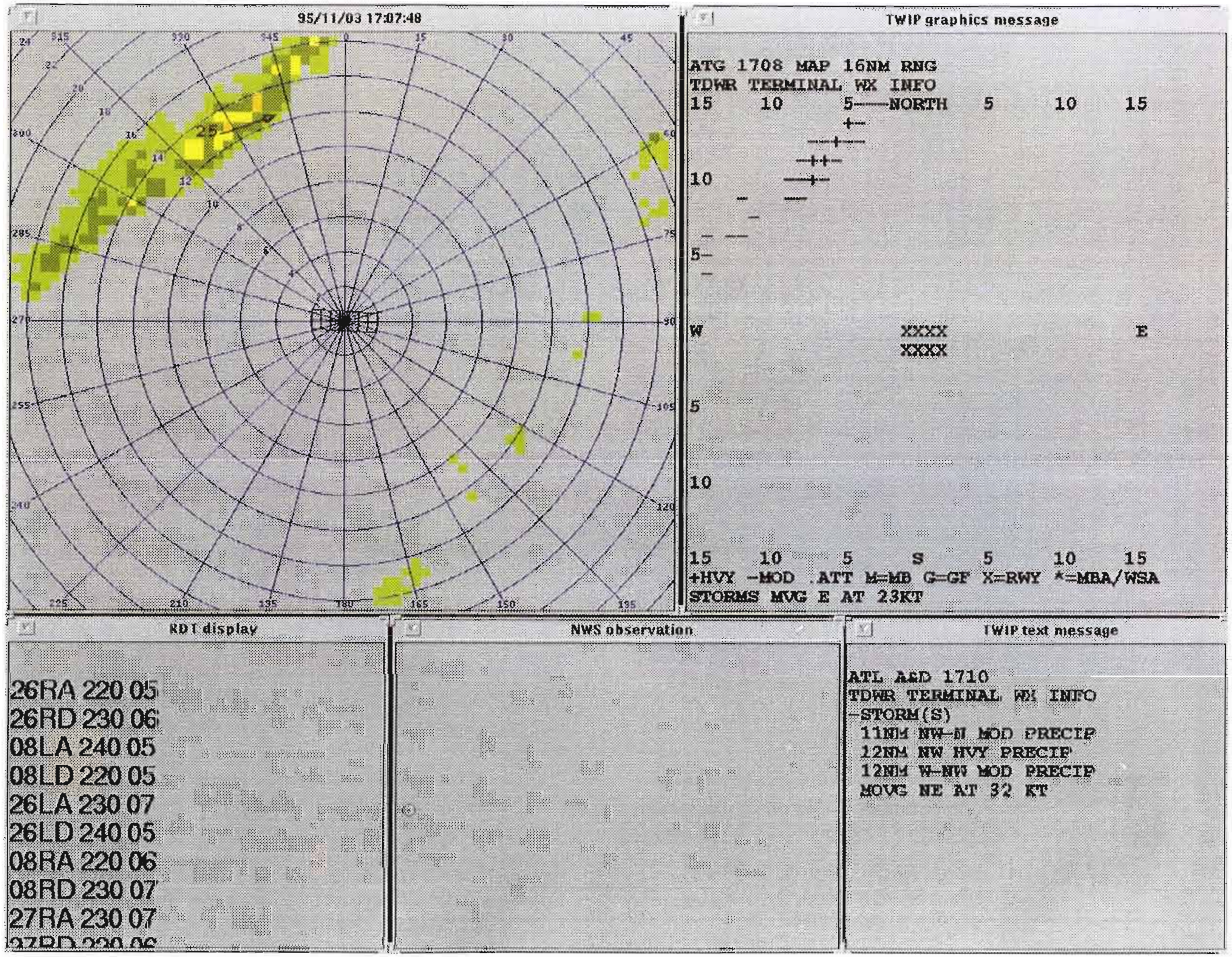


Figure 22. Level 2 Storm Motion Case, 1 of 3.

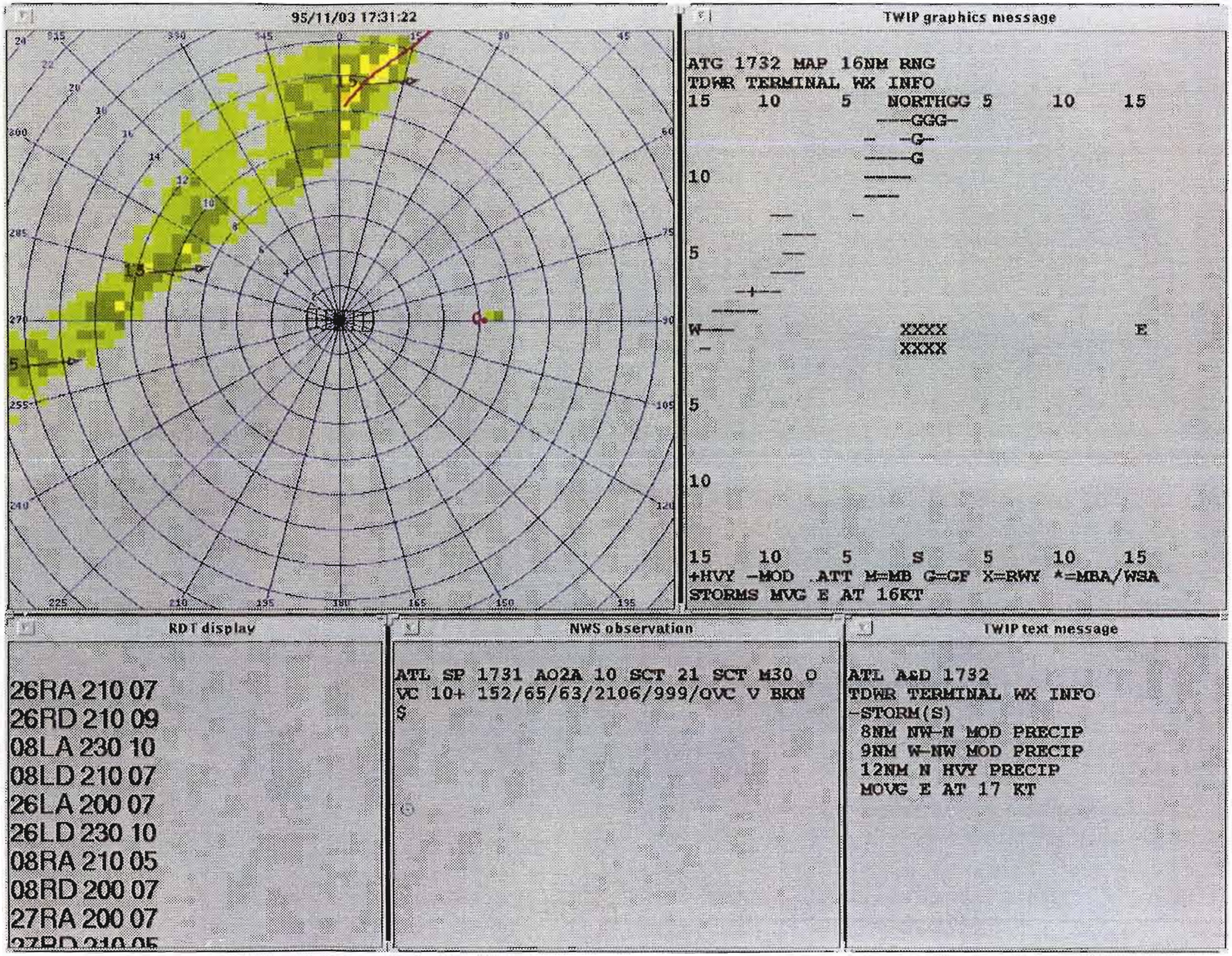


Figure 23. Level 2 Storm Motion Case, 2 of 3.

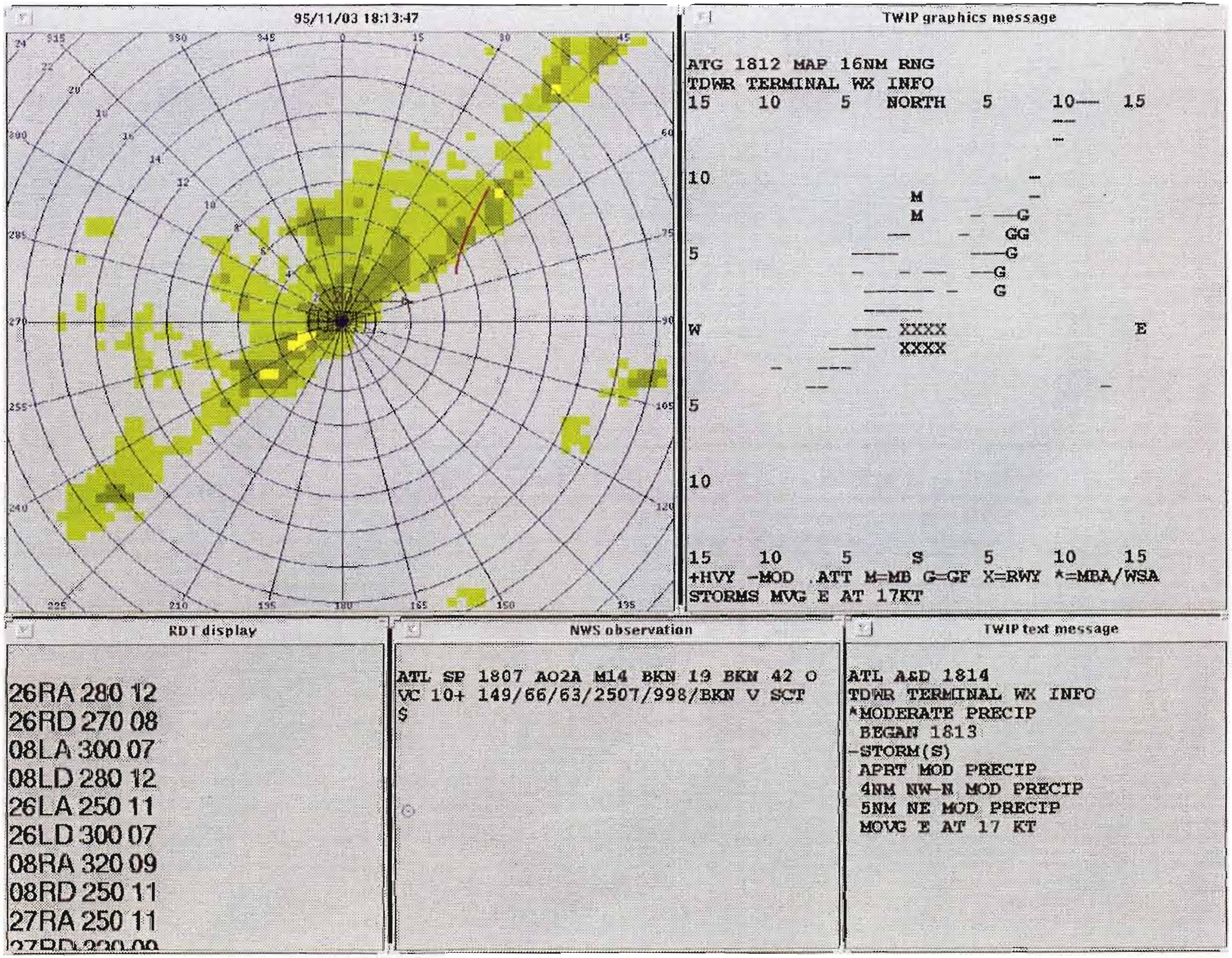


Figure 24. Level 2 Storm Motion Case, 3 of 3.

6. FUTURE WORK

Work is in progress to add TWIP as an upgrade to the operational TDWRs. Under this approach the TDWRs will generate TWIP products, and provide TWIP and TDWR products to users via NADIN PSN. The TDWR RPG software will be modified to include the Storm Motion capability, and the TDWR DFU will be modified to perform the TWIP message generation and NADIN PSN interface. It is planned to begin deploying the TWIP retrofit to the operational TDWRs in the spring 1997 time frame.

7. SUMMARY

This report has described work in providing terminal weather information to pilots in the form of text and character graphics messages. The advantage of this approach is that it utilizes new weather sensors currently being deployed by the FAA and employs existing aircraft data link and display capabilities.

The TWIP concept has been successfully demonstrated over the past three years in cooperation with major airlines at several sites. Pilot surveys and message traffic analysis show that pilots rated the TWIP service positively and made use of the demonstration service. A comparison of TWIP messages with currently available weather information shows that TWIP provides more timely and accurate information about terminal weather hazards.

GLOSSARY

ACARS	Aircraft Communications Addressing and Reporting System
ADNS	ARINC Data Network Service
ALQDS	All Quadrants
ARENA	Area Noted for Attention
ARINC	Aeronautical Radio, Inc.
ARP	Airport Reference Point
ASOS	Automated Surface Observing System
ATIS	Automatic Terminal Information Service
ATL	Atlanta
CAR	Cartesian
CCITT	International Telegraph and Telephone Consultative Committee
DCA	Washington National Airport
DCE	Data Circuit Terminating Equipment
DFU	Display Function Unit
DFW	Dallas/Ft. Worth International Airport
DMN	Digital Multiplexing Network
DTE	Data Terminal Equipment
FAA	Federal Aviation Administration
GMT	Greenwich Mean Time
HDLC	High–level Data Link Control
IOC	Initial Operating Capability
ITWS	Integrated Terminal Weather System
LAP	Link Access Procedures
LAPB	Link Access Procedures Balanced
MEM	Memphis International Airport
MCO	Orlando International Airport
NIST	National Institute of Standards and Technology
PSN	Packet Switched Network
PSDN	Packed Switched Data Network
PVC	Permanent Virtual Circuits
SVC	Switched Virtual Circuits
TCP/IP	Transmission Control Protocol/Interprocess Communication
TDP	TWIP Data Processor
TDWR	Terminal Doppler Weather Radar
TWIP	Terminal Weather Information for Pilots
VIL	Vertically Integrated Liquid Water

REFERENCES

[1] Campbell, S.D, "Terminal Weather Message Demonstration at Orlando, FL, Summer 1993," Lexington, MA, M.I.T. Lincoln Laboratory Project Report ATC–210, March, 1994.

[2] Campbell, S.D., "Terminal Weather Information for Pilots (TWIP) Test Report for 1994, Memphis and Orlando Demonstrations," Lexington, MA, M.I.T. Lincoln Laboratory Report ATC–227, April, 1995.