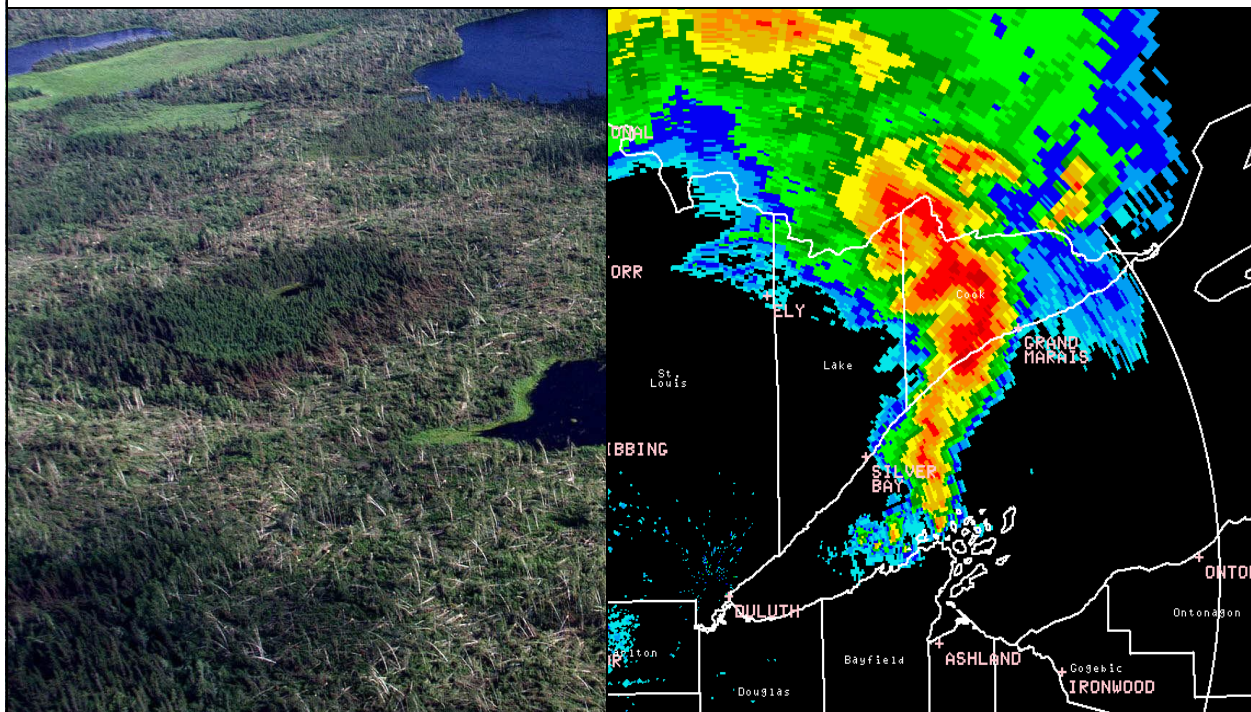


# BOUNDARY WATERS WINDSTORM THE BLOWDOWN OF JULY 4TH, 1999

by  
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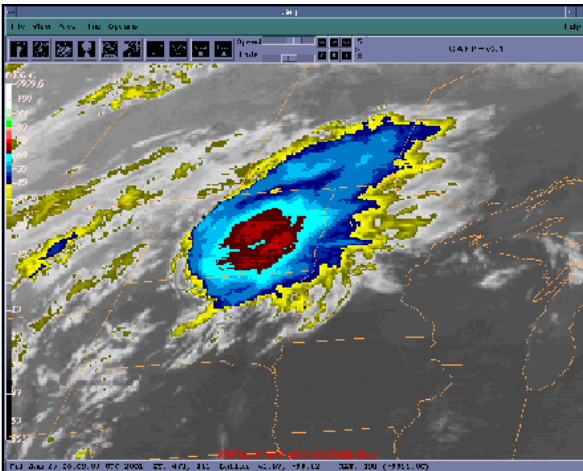


## Abstract

A mesoscale convective system (MCS) originating over the western plains evolved into a bow echo approximately 40 miles west of Fargo, ND shortly after 7:00 a.m. CDT, July 4th, 1999. The bow echo continued northeast through the Boundary Waters Canoe Area Wilderness (BWCAW) of northeastern Minnesota during the remainder of the morning, before passing into southwest Ontario in the early afternoon. The synoptic environment featured warm temperatures at 700 mb which formed a cap, trapping low level moisture over areas along and just south of the storm path. Lift and cooling at the 500 mb level resulted in de-stabilization along the northern edge of the 700 mb cap on the morning of July 4th. Outflow from the MCS intensified into a bow echo when it moved into the low level moisture. Once formed, a convectively induced rear-inflow jet (RIJ) developed, intensifying the storm and accelerating it to speeds in excess of 55 mph. After passing Ely, Minnesota, the storm accelerated significantly as rapidly intensifying convective elements merged with the northern end of the storm. At this stage of the storms development, two deep rear-inflow notches (RINs) were observed with the Duluth WSR-88D Doppler Radar which corresponded with the vast swath of destruction of the underlying forest cover in the BWCAW. As a result of this storm, the BWCAW will remain under heightened fire danger for years to come.

## Introduction

During the evening of July 3rd, 1999, thunderstorms over southeastern Montana and western South Dakota merged into a mesoscale convective system (MCS), which then drifted east-northeast across the Dakotas through the night (Fig. 1). The system slowly weakened early in the morning of July 4th as it moved into eastern North Dakota. About 7:00 a.m. CDT, the storm abruptly changed its character, intensifying into an intense squall line about 30 to 40 miles west of Fargo, ND. Within 15 to 20 minutes, the storm struck Fargo. Trees and power-lines were brought down, many roofs in both residential and commercial areas were destroyed. At the Hector Airport, where a hangar was demolished, winds of 91 mph were recorded. Total damage costs exceeded 30 million dollars.



*Fig. 1. Infrared satellite image from 1015 UTC (5:15 a.m. CDT), July 4, 1999.*

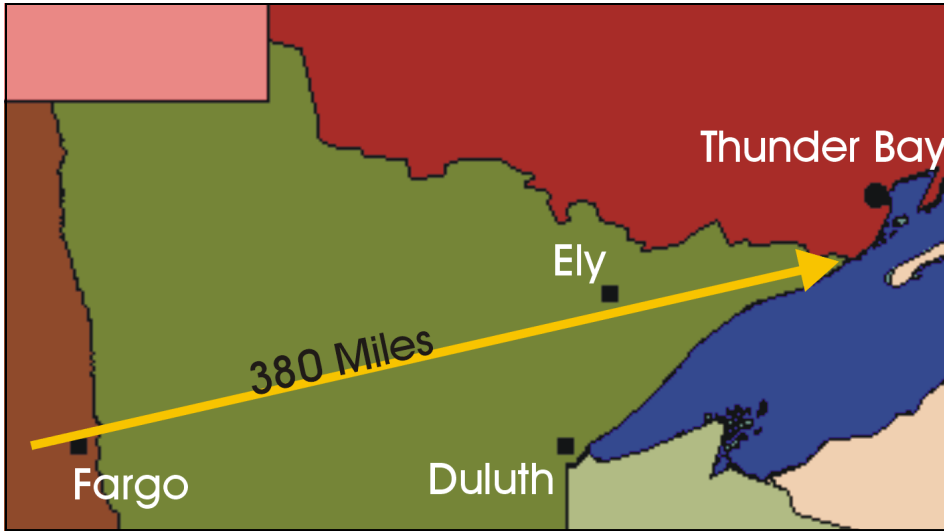


Fig. 2. Track of the July 4, 1999 Derecho across northern Minnesota.

The bow echo seemed to divide its energy just after 8:00 a.m. CDT in extreme western Minnesota, near Detroit Lakes. The southern portion produced one or two small tornadoes and resulted in numerous reports of winds over 60 mph, hail up to an inch in diameter, and widespread, minor damage. This part of the storm reached the north shore of Lake Superior, just north of Duluth, about noon CDT (Fig. 2). The stronger northern portion reached Bemidji about 9:30 a.m., resulting in a report of 75 mph winds and one inch hail nearby. Winds of 81 mph were reported at the Chisolm-Hibbing Airport as the storm passed through about 11:30 a.m. CDT.

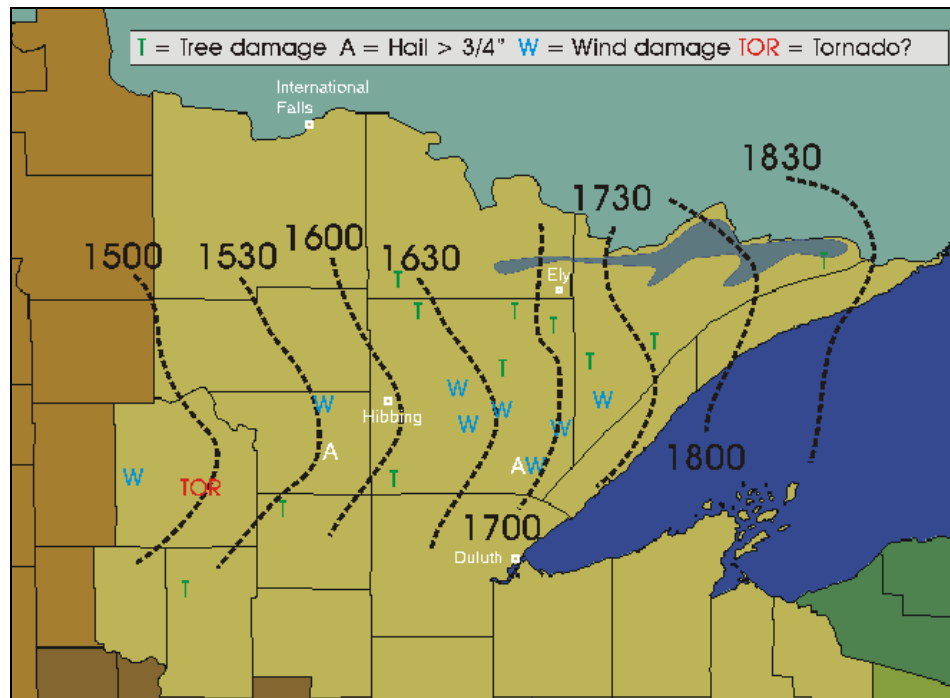
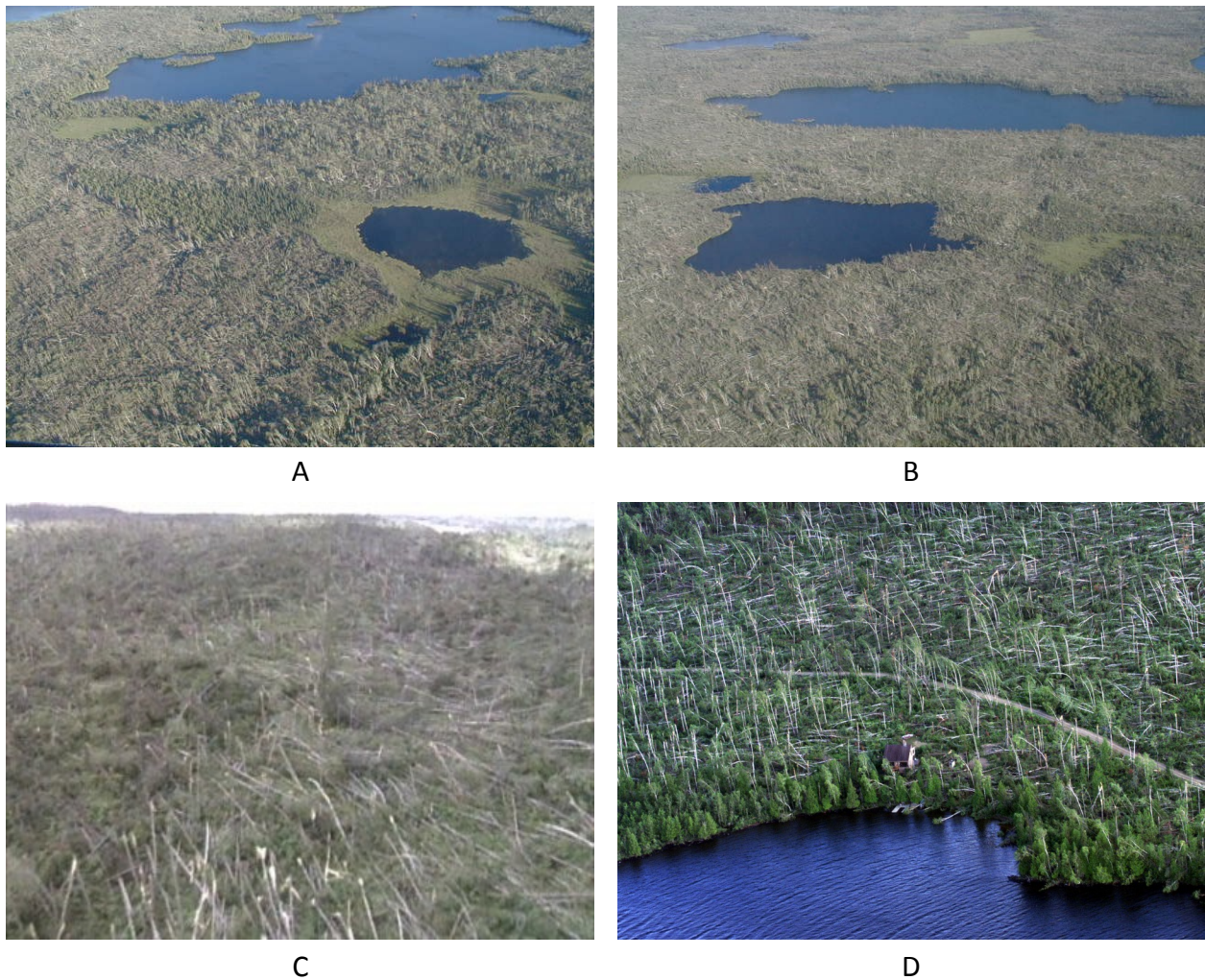


Fig. 3. Summary of squall line position on the morning of July 4, 1999. Times in UTC. Gray area depicts most intense damage areas across the BWCAW.



The first large swath of intense forest destruction occurred while the storm was still west and northwest of Ely, MN about noon, CDT. This first swath was approximately five miles wide and 25 miles long (Fig. 3). There was a second damage swath in the Boundary Waters Canoe Area Wilderness (BWCAW). This began after the northern part of the storm passed east of Ely and accelerated into a well-defined bow-shaped echo, about 1230 p.m. CDT (1730 UTC). Moving through a wilderness area, no wind speeds were measured. However, 478,000 acres of forest, in a swath 12 miles by 30 miles, was leveled and completely destroyed. Access to the area was blocked by tree trunks, many stripped of their bark, blown into drifts 15 to 20 feet high. Twenty people were injured, and had to be air-lifted to hospitals.



*Fig. 4(a) - (d). Various photos of the devastation across the BWCAW.*

Intense forest destruction occurred for several miles on either side of this second swath of total destruction, and continued another 30 or 40 miles to the east, along the international border. Within the United States, a third swath of intense forest destruction, about 15 miles wide, angled southeastward from the second damage swath. This third area was about 30 or 40 miles long.

After traveling north of the international border, the storm continued to lengthen its path of destruction, crossing central Ontario and the northern edge of Lake Superior later Sunday afternoon and Sunday evening. The storm crossed southern Quebec late that night, and re-entered the United States, leaving a swath of heavy damage across extreme northern New York and northern New England during the early morning of Monday, July 5th. Several Canadian cities had been struck. Deaths and widespread urban damage were reported.

The storm then moved off the Maine coast just before midmorning, Monday, then followed the perimeter of a large, hot coastal high through the western Atlantic Ocean. The storm then moved onshore just north of Myrtle Beach, SC late in the morning of Tuesday, July 6th, then spent the remainder of the day leaving a path of severe wind damage as it moved west-southwest through South Carolina, Georgia, Alabama and Mississippi before crossing the Mississippi Delta on its way into the central Gulf of Mexico. The final storm track totaled about 6000 nm in length. Follow this link for a discussion of the Mesoscale Vorticity Center responsible for maintaining this system.

This article will confine itself to the segment of the storm path that crosses the Boundary Waters Canoe Area Wilderness.

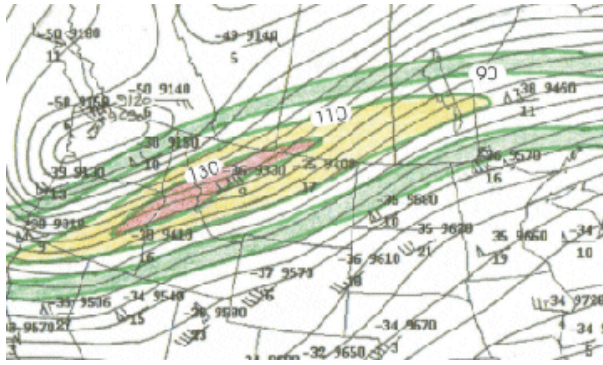
## **The Pre-Storm Environment**

Aloft, a pool of unseasonably cold air and low pressure over Washington and Oregon extended east-northeastward into Saskatchewan. A strong 300 mb jet axis remained along the southern edge of this pool, and extended into northern Ontario. Jet maxima, on the order of 130 knots or more, were moving along the jet axis (Fig. 5a).

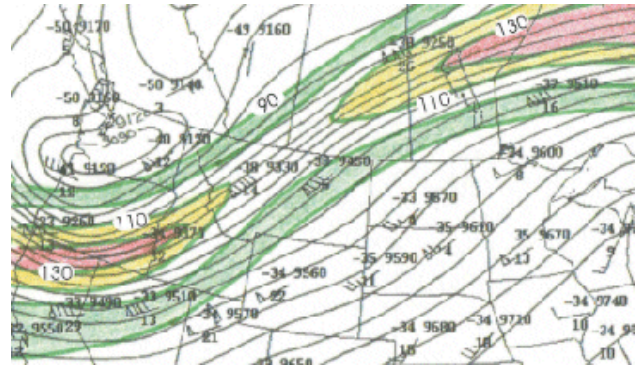
At 500 mb, an extremely tight temperature gradient had developed over eastern Montana at 04/00Z (Fig. 5c). A negatively tilted shortwave over western Montana and Wyoming, was moving northeastward. At 300 mb, also at 04/00Z, the right-rear quadrant of an intensifying jet maximum was creating local lifting along the tight temperature gradient (Fig. 5a and b). Downward motion was occurring either side of the lifted area. So a smooth, tight temperature pattern, at 04/00Z (Fig. 5c), abruptly buckled, with a strong axis of minimum temperatures, at 500 mb, moving into northwestern Minnesota early Sunday morning (04/12Z) (Fig. 5d).

The newly formed 500 mb temperature pattern was nearly 180 degrees out of phase with the advancing short wave, now over the central Dakotas, at 12Z on the 4th (Fig. 5d). As the atmosphere tried to adjust during the day, the short wave deepened, accelerated, and its negative tilt increased. The shot of cold air, at the 500 mb level, reached the location where large amounts of low level moisture had pooled, immediately east of a low level temperature ridge at the northern edge of the 700 mb cap. The approaching cold air aloft resulted in a dramatic destabilization of the atmosphere at the point where the bow-echo formed just west of Fargo, North Dakota. The cold pocket aloft moved along the edge of moisture and the edge of the 700 mb cap, subsequently releasing large amounts of energy.

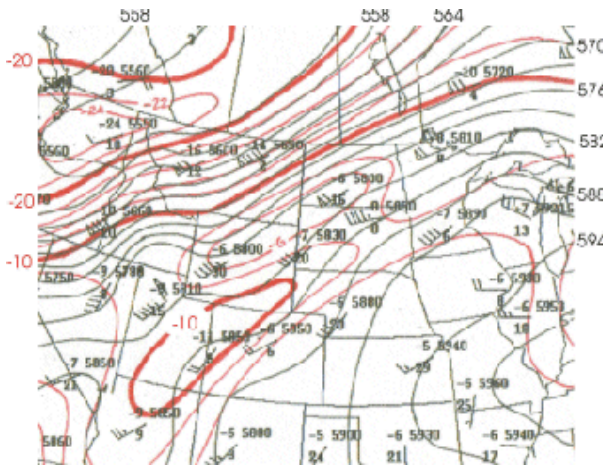




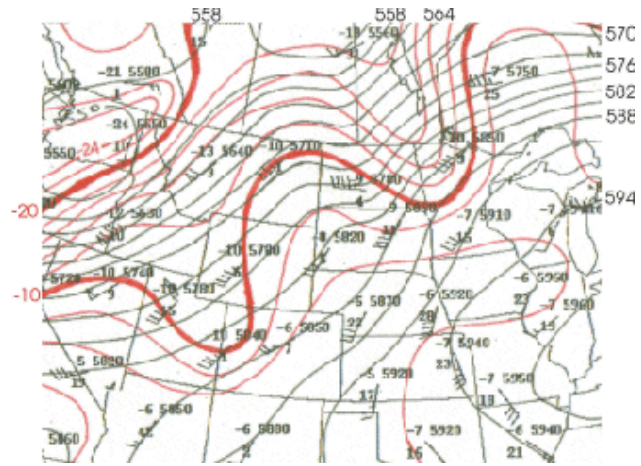
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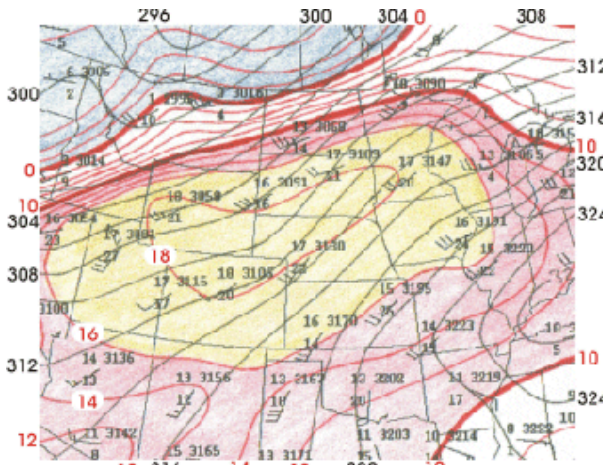


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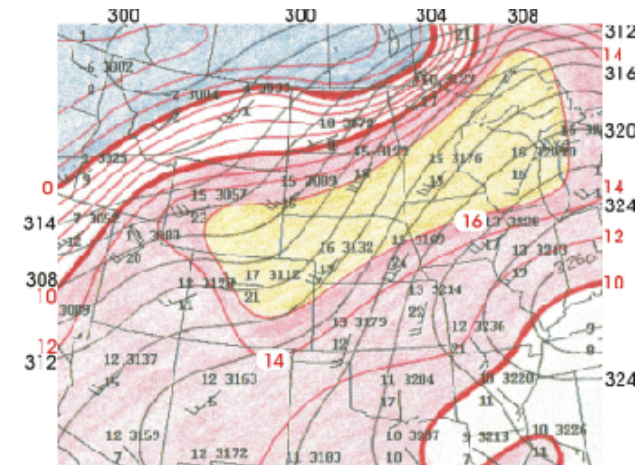


D

Fig. 5. (a) 300 mb height (in decameters) and isotachs (in knots, colored) for 00Z, July 4, 1999. (b) Same as b, except for 12Z, July 4, 1999. (c) 500 mb height (in decameters, black) and isotherms (in degrees celsius, red) for 00Z, July 4, 1999. (d) Same as c, except for 12Z, July 4, 1999.



A



B

Fig. 6. 700 mb heights (in decameters, black) and temperature (in celsius, shaded) for (a) 00Z, July 4, 1999, (b) 12Z, July 4, 1999.



Perhaps the most important feature July 4th, was a large area of unusually warm temperatures at 700 mb, apparent from Saturday evening (04/00Z) into Sunday morning (04/12Z) of July 4th (Figs. 6a and b). Note the 700 mb, 10°C isotherm in Figure 6a where readings exceeded 10°C from the western Gulf northward into the vicinity of International Falls. By 1200 UTC (7:00 a.m. CDT) on the 4th, the 700 mb temperature gradient was very strong, ranging from 16°C at Hibbing MN to 6°C at Winnipeg and -4°C at The Pas, both in southern Manitoba (Fig. 6b). A fast-moving, negatively-tilted 500 mb shortwave trough (discussed above) over the central Dakotas (Fig. 5d) was about to force the sharp northwest edge of the 700 mb cap slightly southward.

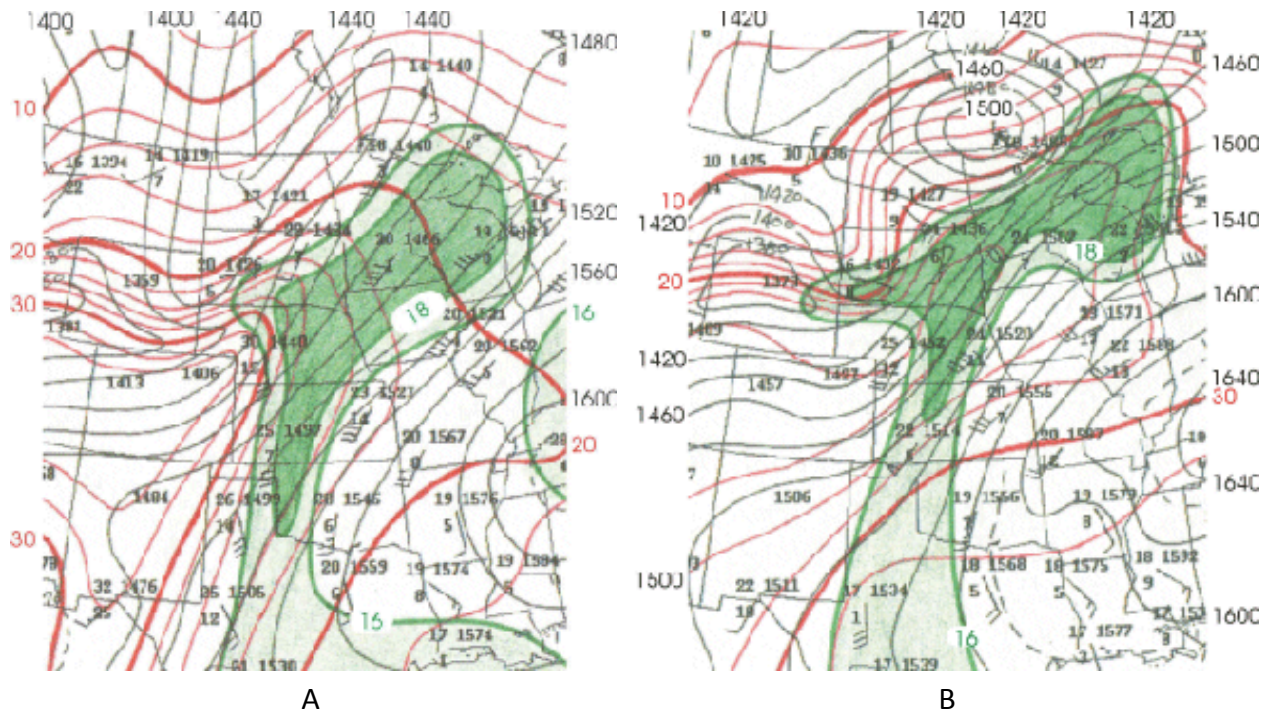


Fig. 7. 850 mb heights (in decameters, black), temperature (in celsius, red) and dewpoint (in celsius, shaded green) for (a) 00Z, July 4, 1999, (b) 12Z, July 4, 1999.

A bit lower in the atmosphere on Saturday evening, a 40 knot, 850 mb jet from the western Gulf extended northward into southern Minnesota, and northwestern Wisconsin (Fig. 7a). This jet caused large amounts of tropical moisture to under-run the 700 mb cap and pool near its northern edge. At 12Z, the 850 mb jet had subsided southward, with a track across eastern Nebraska and Iowa, but it left plenty of moisture in place, near and just south of the storm track (Fig. 7b). An additional important moisture source was evapo-transpiration from the forest canopy and undergrowth. The two months leading up to July 4th, 1999 comprised a period of above normal temperatures and near-record rainfall, saturating the ground and stimulating rapid growth of vegetative cover. Large amounts of moisture were being moved from the ground through unusually lush plant tissues and into the atmosphere, supplementing the moisture contribution from the Gulf of Mexico near and just south of the storm path. The strong 700 mb cap kept this canopy-provided moisture from being "drawn-off" into other convection.

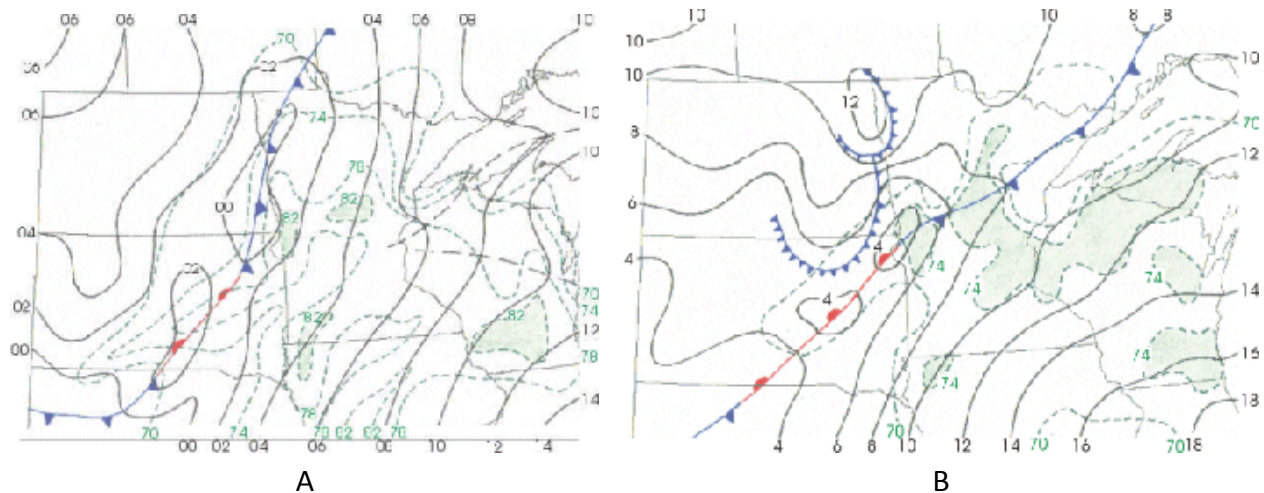


Fig. 8. Surface pressure (in mb, black), dewpoint temperature (in fahrenheit, dashed-green) and fronts for (a) 00Z, July 4, 1999 and (b) 12Z, July 4, 1999.

At the surface, a cold front near Warroad, Minnesota, extended through Fargo, North Dakota into the Aberdeen, South Dakota area on the evening of July 3rd (Fig. 8a). The front moved to a position from Ely, Minnesota southwestward through the Iron Range to near Aberdeen SD at 700 a.m. CDT the morning of July 4th (Fig. 8b). The combined result of advection and evapo-transpiration resulted in a pool of excessive low-level moisture. Surface dew-points were in the 25°C to 26°C range with 850 mb dew points were in the 19°C to 20°C range from east-central Minnesota across northwestern Wisconsin by Sunday morning, July 4th (04/12z) (Figs. 7b and 8b). Moisture pooling was north of a weak surface trough that extended from extreme northeast South Dakota through Cambridge, Minnesota, Eau Claire, Wisconsin to the Madison, Wisconsin. There is no data to indicate whether or not the strong 850 mb jet max over eastern Nebraska worked its way northward into north-central Minnesota late Sunday morning; a sharp 90° to 135° backing of 850 mb winds over western Minnesota and the extreme eastern Dakotas that morning indicates a likelihood that it had.

The approaching area of thunderstorms, over the Dakotas, was maintaining a strengthening surface meso-high along the international border. This high was clearly reflected at the 850 mb level, with a center just northwest of the Northwest Angle of Minnesota (Fig. 7a). The high was approaching a slow-moving surface trough, extending from Aberdeen, SD northeastward to the International Falls, MN area during the early morning hours of Sunday, July 4th.

To sum up the low level situation, a capping inversion had an abrupt northern edge near the area of concern (Fig. 9). The cap had trapped low-level moisture just south of its edge. The western edge of low level moisture was just east of a low-level temperature ridge. A bubble high, fed by thunderstorms to its south, was moving eastward toward the area where the moisture gradient was near the northern edge of the cap.



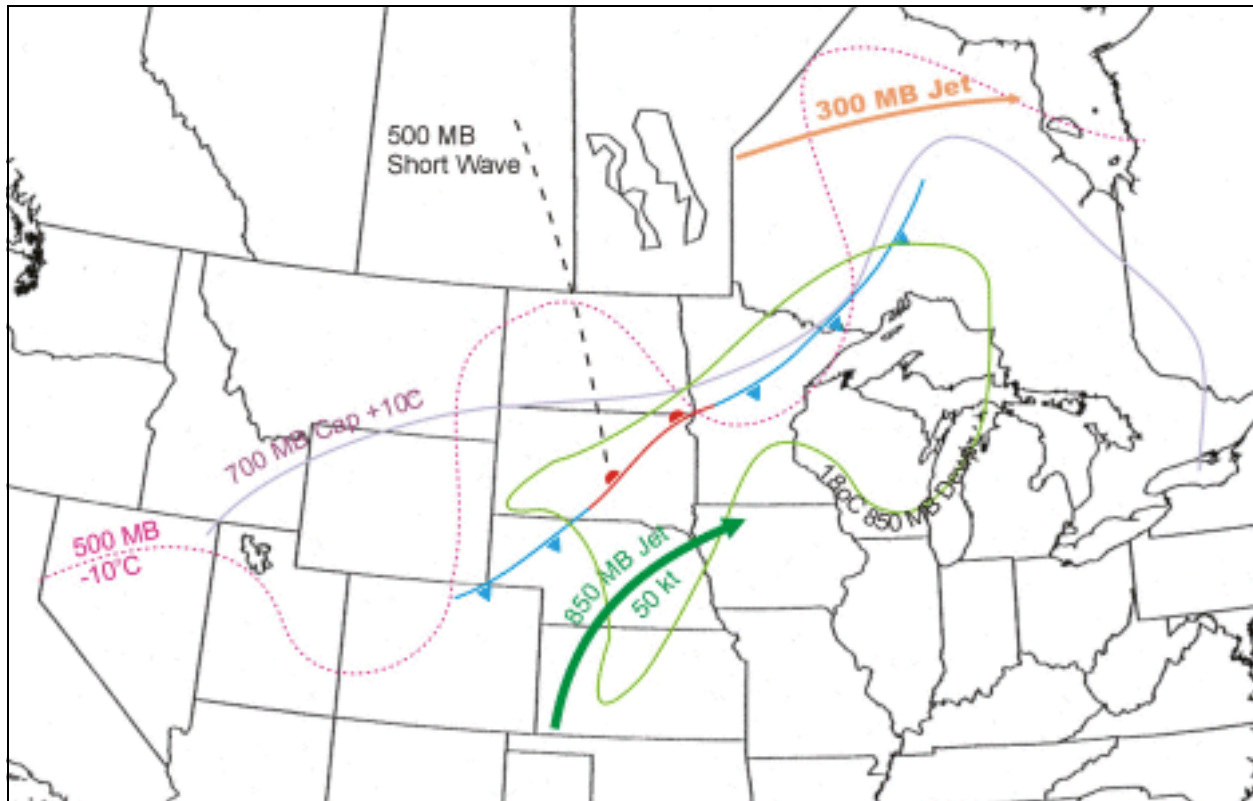


Fig. 9. A composite of the 12Z UTC, July 4, 1999 synoptic setting featuring positioning of the 300 mb jet, 500 mb short wave trough and  $-10^{\circ}\text{C}$  isotherm, 700 mb  $+10^{\circ}\text{C}$  isotherm, 850 mb jet and  $18^{\circ}\text{C}$  isodrosotherm.

## Storm Development

A derecho is defined by Johns and Hirt (1987) and Fujita and Wakimoto (1981) as a storm that has a damage path of at least 250 nm in length, with at least three reports of hurricane force winds, each separated by at least 40 nm, and with no more than three hours between successive wind damage events. Derechos are uncommon in the upper Great Lakes (Fig. 10), but a few have been quite intense. For example, another Independence Day derecho struck northwest Wisconsin in 1977 causing extensive damage (Fig. 11).

The Boundary Waters storm, with a path of about 6000 nm and its entire land-path associated with significant wind damage, clearly qualifies as a derecho. There have been other transcontinental derechos, with paths of well over 1000 nm, but this is the first recorded case of one spending more than a day over open ocean before returning to a distant shore, to resume its damage path.

As Johns (1987) pointed out, "The lifetime of the convective system that spawns a derecho is usually considerably longer than the period of time when damaging winds are occurring. In almost all cases, the associated convective complex develops at least three hours before

derecho initiation. In the majority of cases, the thunder storm complex develops more than six hours before initiation. This storm, with its beginnings southwest of the Black Hills of South Dakota, fit the latter description.

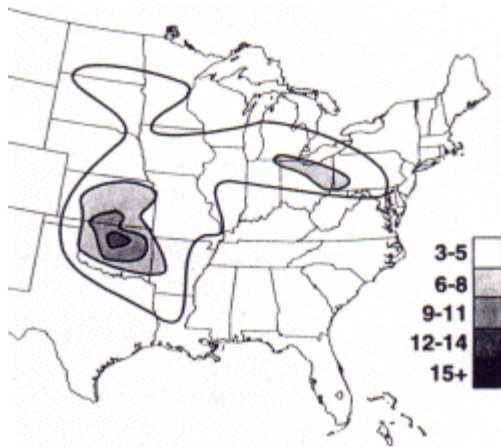


Fig. 10. Total number of derechos occurring during the entire year, 1986-1995, from Bentley et al., 1998.

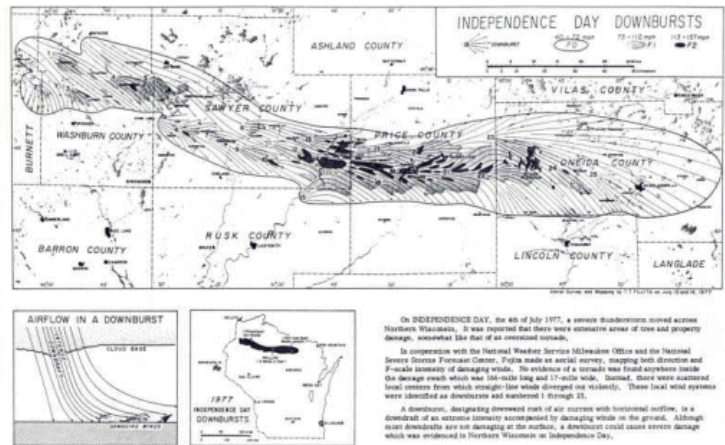


Fig. 11. Detailed map produced from aerial surveys of damage resulting from the Independence Day storm of 1977, from Fujita, 1985.

The derecho phase of this storm appeared to begin at the point where under-running moisture reached the sharp edge of a strong cap and where the air was also beginning to be abruptly destabilized by upward motion and rapid cooling at mid-levels. Soon after formation, this derecho accelerated to a speed that exceeded the wind speed of any level between the surface and 300 mb. Prevailing winds, at the 300 mb level, at INL, were about 50 knots, and showing a slow weakening trend. Prevailing winds at lower levels, reported at INL, were less. Simulations (Weisman, 1992 and 1993) indicate that winds near and behind the gust front are strongest just above the ground behind the gust front, then curl upward and back. Surface winds, or winds just off the surface, are thus apt to be well in excess, perhaps as much as double the gust front speed. Furthermore, simulations indicate that extremely powerful surface winds might persist for a significant amount of time behind a large-scale gust front.

There are a number of factors that would drive a derecho to such high rates of speed. A convectively-induced rear-inflow jet (RIJ) develops near the top of the cold outflow, then slams into the nearly vertical updraft, pushing it, and the storm rapidly forward (Johns and Hirt, 1987, and Przybylinski, 1995, Weisman, 1992 and 1993) as depicted in Figure 12. Some of the high-momentum air, from the convectively induced jet, reaches the surface near the gust front. The jet, within the cold outflow air, forms for the following reasons:

1. A significant density difference exists between cold, dry outflow air and warm, very humid air that the outflow is displacing,
2. The down draft is being accelerated into a layer of low pressure. Because



warm wet updraft air is light, an area of low pressure exists at its base, or its interface with dense outflow air. This low-pressure base slopes down toward the front of the outflow. The cold, dense outflow, beneath, is therefore being accelerated forward and downward into this sloping low-pressure layer,

3. Horizontal vorticity is generated in the inflowing warm air by friction with the ground. This spin, at the base of the warm updraft, further accelerates the rear inflow jet downward and forward, toward the surface gust front,

4. Precipitation loading and evaporation loads, cools and increases the density of and downward acceleration of the outflow air, and

5. A cyclonic circulation north of the bow echo and an opposing anticyclonic circulation narrows and focuses the rear inflow jet.



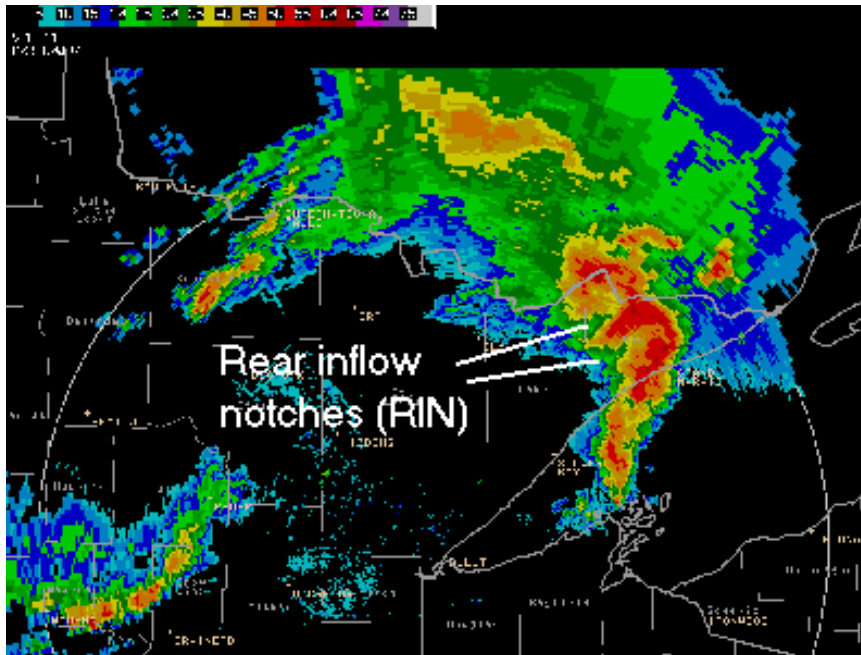
*Fig. 12. Idealized bow echo in its mature phase. Cold pool circulation is balanced by the ambient vertical shear and the rear-inflow jet. The yellow pipe depicts the updraft, while the dark blue pipe depicts the rear-inflow jet. The shaded area denotes the cold pool and the thin, circular arrow represent the significant areas of horizontal vorticity. From COMET, 1999, modified from Weisman, 1993.*

From radar imagery, the derecho developed, in eastern North Dakota as a "Type-1" bow-echo, from a descriptive 1985, Przybylinski study of 23 bow-echo cases. The storm then split, soon after entering western Minnesota, retaining its "Type-1" characteristics. As the storm passed Ely, Minnesota and accelerated, it evolved into an extremely dangerous type-2" bow-echo.

A "Type-1" bow echo exists as two or three bowing line segments, each individual segment up to 65 nm in length. A weak micro-circulation may exist at the pole-ward end of each segment. A strong low-level reflectivity gradient exists along the leading edge and signifies the location of updraft centers. Maximum echo tops are over, or in the case of more powerful systems, down-wind of the strong low-level reflectivity gradient. Numerous fairly small rear-inflow

notches, each 7 to 10 nm in width, occur along the trailing edge of each bowing segment.

A "Type-2" bow echo is a short, solid bowing convective line segment, 50 to 65 nm in length. A band of scattered to broken convective elements, associated with warm advection, extends downwind from the northern end of the bow echo. Each convective element develops 35 to 50 nm downwind from the approaching bow echo, and rapidly intensifies as the bow echo approaches them. Prior to a merger, strong upwind gradients develop in the convective element. Mergers, in more than half the cases studied, resulted in several violent and intense (F-3 to F-5) tornadoes forming at the time of the merger.



*Fig. 14. Base reflectivity image from 1817 UTC, July 4, 1999. Note the two prominent rear-inflow notches (RIN) over the eastern part of the Arrowhead.*

Radar imagery clearly showed prominent dry V-notches (Fig. 14) pointing into the stratiform return behind the gust front and toward the gust front. V-notches are due to evaporation within rapidly descending air, and establish the existence of convectively-derived rear-inflow jets behind the bow-echo outflow boundary. In this storm, a rear-inflow jet accelerated the storm from 55 to 60 knots to about 80 knots after the storm passed Ely, Minnesota. Such movement would suggest the potential for low level wind speeds approaching 100 knots in the wilderness blow-down area.

The tornado-prone portion of the July 4th storm confined itself to Canadian territory. Mergers visible from the DLH radar suggest a "Type-2" pattern and that most of an outbreak of violent tornadoes occurred over sparsely populated and wilderness areas in Canadian territory. A photograph of a large funnel cloud approaching the Thunder Bay, Ontario area (Fig. 15), along with Duluth WSR-88D reflectivity imagery, further suggest a "Type-2" pattern. Storm damage in the BWCAW Wilderness, of Minnesota, was confined to intense straight-line winds. Canadian radar had been "knocked-out" by lightning damage hours before this storm struck the area.



## To Summarize, the July 4, 1999 Derecho:

- Had a very long path, as a progressive derecho (Johns and Hirt, 1987): To be classified as a derecho, a damage path must be at least 250 nm in length. This storm had a wind-damage path, only interrupted by ocean-travel, of about 6000 nm.
- Resulted in serious wind damage over a long path. Recorded wind speeds, very rare along a sparsely-populated wilderness path, were as high as 91 mph near the beginning of the storm. Damage was well in excess of F-1 along much of its path.
- Moved very rapidly; it was traveling at 55 to 60 knots when it entered northeastern Minnesota, and accelerated to near 80 knots or more after passing Ely, Minnesota. At no time, while in northeastern Minnesota, did the prevailing wind, at any level, equal or exceed storm speed. The storm traveled about 6000 nm in only 2 days.
- A parent MCS system existed more than six hours before the bow echo phase of the storm began, in eastern South Dakota.
- The bow-echo phase of the storm began just after 1100 UTC (5:00 a.m. CDT), a time window when very few derechos develop or remain in existence. The storm then maintained itself, round the clock, for 2 days, persisting throughout all time-periods.
- The storm evolved from an MCS over eastern North Dakota, about 700 a.m. CDT, into a Type-1 Bow Echo. The storm then evolved, after passing Ely, Minnesota, into an extremely dangerous Type-2 Bow Echo. The tornadic portion of this configuration appeared to remain north of the Canadian border during the afternoon of July 4th, 1999.



*Fig. 15 Funnel Cloud in Westfort area of Thunder Bay, Ontario around 1830 UTC (1230 p.m. CDT), July 4, 1999. Courtesy of the Chronicle-Journal of Thunder Bay, Ontario.*

## Storm Implications

There are three implications that come to mind, with this storm. The first is the disruptive effects of the storm, across northeastern Minnesota. Transportation was blocked in many

areas along the storm path. Survivors injured by debris and falling trees, had to be located and lifted out by helicopter over a period of a week (Fig. 16a and b). The remainder of the summer was spent opening up main roads, mainly along the Gunflint Trail.



Fig. 16. (a) Canoeists and (b) campers in the BWCAW shortly after the July 4, 1999 derecho passed through.

The second is insufficient communication into wilderness areas. While the National Weather Service at Duluth issued a number of warnings with significant lead-times along the entire storm path, there was not an effective means to get this warning to campers, hikers and fisherman. This wilderness area was, at the time, beyond the reach of NWR transmitters. As a result of this storm, three NWR transmitters were installed (Fig. 17). One at Ely, another near Gunflint Lake and another in Bogus Lake.

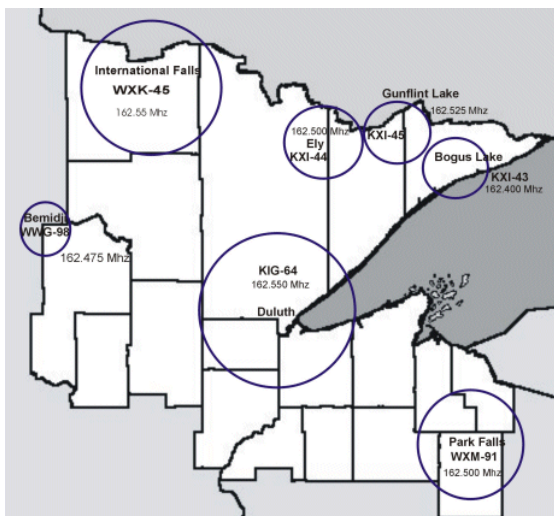
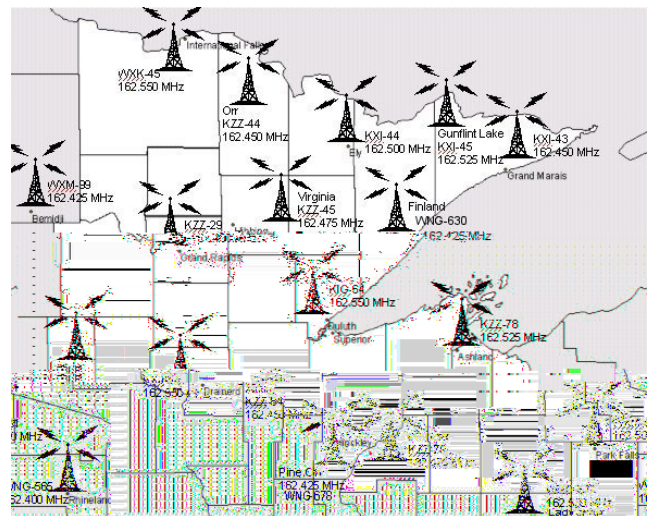


Fig. 17. NOAA Weather Radio Coverage in northeastern Minnesota and northwestern Wisconsin.



NOAA Weather Radio Coverage in northeastern Minnesota and northwestern Wisconsin as of 2005.



The third implication is fire danger in and near forested areas destroyed by the storm. There were 665,000 acres of forest destroyed, with dead fuel load averaging 60 tons per acre. Worse are reports that very little of the fuel is in contact with the ground, and that most of it is not packed, and is exposed to the air (Fig. 18). The idea of logging the area is fraught with political considerations and economic practicality. With such a fuel situation, an intense wildfire is possible. And, given the right conditions, such a fire could spread beyond the damage area. Since people plan to return to the damage area, for various reasons including recreation, the problem of communication in wilderness areas might need to be addressed anew.



*Fig. 18. Photo of several trees downed by the July 4, 1999 derecho. Note that the trees were in many cases broken off well above the ground. As a result, very little of the dead tree is in contact with the earth's surface which allows the timber to dry more readily.*

## **Conclusion**

Derechos are very severe convective windstorms with long damage paths. These storms arise from conditions that are somewhat rare in the upper Midwest and adjacent areas during the warm season. Warnings for and studies of such storms require multi-office and sometimes international cooperation.

The scope of this paper is only limited to a very minor segment of the storm path of the July 4th, 1999 derecho. This paper is not expected to stand by itself, in any form, but serve as a non-technical treatment of a very local and limited interest, and possibly contribute an idea or two to broader and more comprehensive studies dealing with this particular storm.

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