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STORM SURGE ON LAKE BUTTE DES MORTS DURING THE 11 JUNE 2001 BOW ECHO EVENT

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1. INTRODUCTION

On 11 June 2001, a bow echo (derecho) moved southeast through central Wisconsin producing a large swath of strong straight-line winds. Winds exceeded 50 knots across a wide area, resulting in thousands of downed trees and damage to homes and businesses. The storm passed over several shallow lakes including Lake Butte des Morts near Oshkosh, WI creating a storm surge. This lake is oriented northwest-southeast directly in alignment with the crest of the bow echo. Strong winds lasted about thirty minutes creating a storm surge on the south end of the lake as high as .75m where many portable boat piers were destroyed. This paper presents a meteorological summary of this event along with the results of our damage survey at Lake Butte des Morts. To our knowledge, this is the first time a storm surge has been documented with a bow echo or derecho event.

2. METEOROLOGICAL OVERVIEW

The bow echo began as a complex of severe thunderstorms (some tornadic) across southern and central Minnesota during the mid-afternoon on 11 June 2001. The storms formed along and north of a warm front that extended eastward from a surface low over southern Minnesota and across Wisconsin (Fig. 1). A short-wave trough, moving across northern Minnesota, provided the synoptic-scale lift and destabilization over the genesis region. The short-wave trough acted in concert with low-level convergence associated with a 30 to 35 kt, 850 mb low-level jet over Iowa. The air mass south of the surface warm front in Iowa was very warm and moist with surface temperatures greater than 32 ºC (90 ºF) with surface dew points greater than 21ºC (70ºF). Despite boundary layer CAPES (Convective Available Potential Energies) of at least 3500 J kg^{-1}, the air mass south of the front over Iowa was strongly capped with 700 mb temperatures around 12 ºC.

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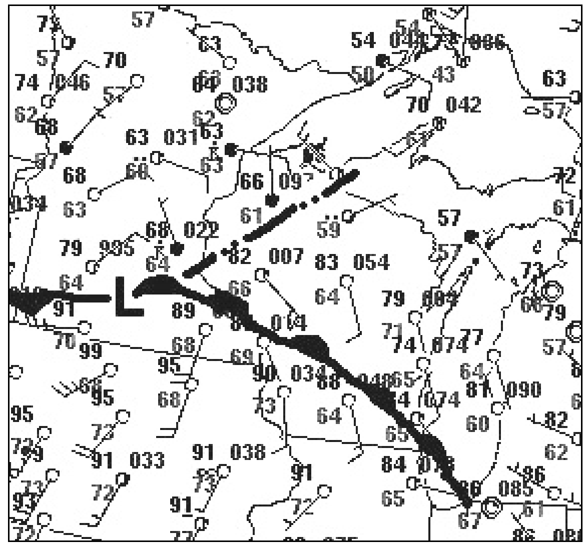

Figure 1. Surface weather map at 2300 UTC on 11 June 2001 for upper Midwest. Temperatures and dewpoints are in degrees F.

Farther north, thunderstorms were fed by a steady supply of very unstable air transported northward across the warm front and ahead of the short-wave trough over central Minnesota, where steep mid-level lapse rates of around 8 ºC km^{-1} were recorded. The mid-level instability was forecast to advect east into central and southern Wisconsin during the late evening.

Deep layer shear also was in place over the MCS (mesoscale convective system) where winds veered from 240 degrees at 30 knots at 850 mb, to about 270 degrees at 65 knots at 500 mb over central and southern Minnesota. Initial thunderstorms that developed over Minnesota during the mid- to late afternoon hours were supercellular, and spawned several tornadoes. These storms tapped the vorticity-rich boundary layer air just north of the surface warm front. The storms continued to move southeast into western and central Wisconsin by 0000 UTC (coordinated universal time) on 12 June and evolved into a large, damaging wind-producing bow echo that raced across east-central Wisconsin between 0000 and 0500 UTC on 12 June (Fig. 2).

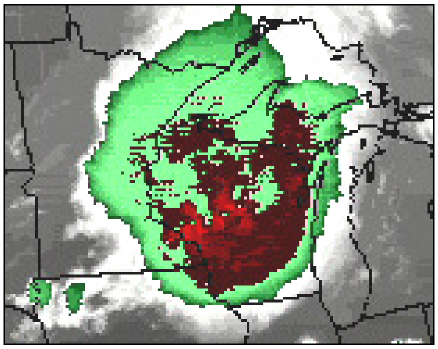

Figure 2. Large mesoscale convective system over Wisconsin on infrared satellite imagery at 0215 UTC on 12 June 2001.

The city of Oshkosh is just southeast of Lake Butte des Morts. As the bow echo passed Oshkosh, wind speeds of 33 to 61 knots were recorded from 0219 UTC until 0305 UTC, veering from west to north during the 46 minute time span. Refer to Table 1. Przbylinski (1995) as well as Johns and Hirt (1987) have studied similar bow echo events.

TIME (UTC)	WIND DIRECTION	WIND SPEED(kts)
0153	150 (SE)	12
0214	180 (S)	16 g 21
0220	270 (W)	29 g 39
0235	310 (NW)	38 g 49
0243	320 (NW)	45 g 57
0253	330 (NW)	34 g 57
0301	350 (N)	31 g 48
0353	360 (N)	12 g 23

Table 1. Selected surface wind conditions from Oshkosh, WI on 12 June 2001 during the bow echo event. Wind gusts are indicated after the letter "g".

3. RADAR ANALYSIS

Radar analysis of this event showed the classic evolution of the bow echo across central and southern Wisconsin. The formative stage occurred between 0000 and 0130 UTC on 12 June 2001 when a storm-scale mesocyclone, located on the northern flank of a bowing line segment, moved out of eastern Clark County and interacted with thunderstorm outflow generated by a supercell located further east in northern Wood County. As a result of this interaction, an intense vortex developed over northern Wood County. During the next 45 minutes, the vortex gradually strengthened and broadened in diameter as it moved east into Waushara County by 0130 UTC.

Between 0130 and 0330 UTC, the northern line end vortex continued to strengthen and organize as it moved eastward into Winnebago County, where Lake Butte des Morts is located. The first wave of severe winds occurred as the apex of the bowing line segment accelerated eastward between 0200 and 0230 UTC. The strongest winds were initially from the west-northwest. Then, as the comma-head of the bow echo complex moved into the eastern portion of Winnebago County, damaging winds shifted to the north. The northern portion of the bow echo eventually formed a clearly identifiable "eye" (Fig. 3). Strong winds blew across Lake Butte des Morts creating a storm surge along the southern shore.

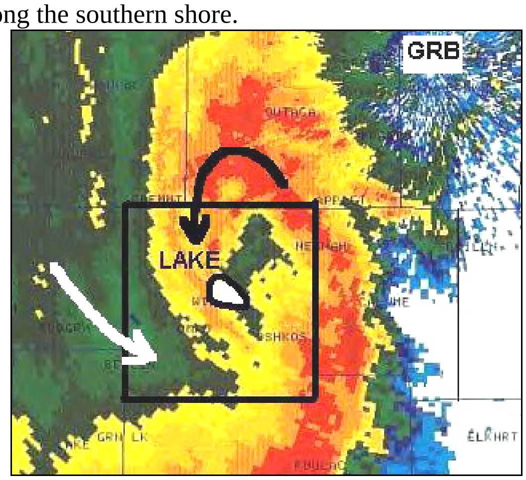

Figure 3. Radar reflectivity image from Green Bay at 0234 UTC on 12 June 2001 showing book end vortex and "eye" of the bow echo as it moved across Winnebago County. Approximate location of Lake Butte des Morts is outlined within Winnebago County.

4. DAMAGE SURVEY

A damage survey conducted after the storm revealed that a storm surge had occurred on several lakes in central Wisconsin. Lake Butte des Morts is one of the larger lakes in the region extending 11.3 km long and 4.8 km wide. The lake is oriented northwest-southeast and is quite shallow with a maximum depth of only three meters (Fig. 4).

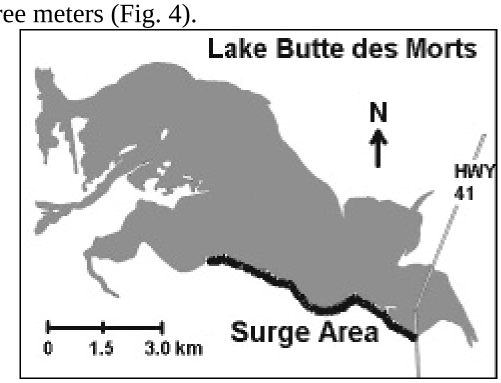

Figure 4. Map of Lake Butte des Morts (shaded area) showing surge area on south shoreline (dark line).

This lake is located just northwest of the city of Oshkosh. Numerous lake front homes had portable boat piers that extended into the lake. Many of these boat piers were destroyed during the storm (Figs. 5 and 6).

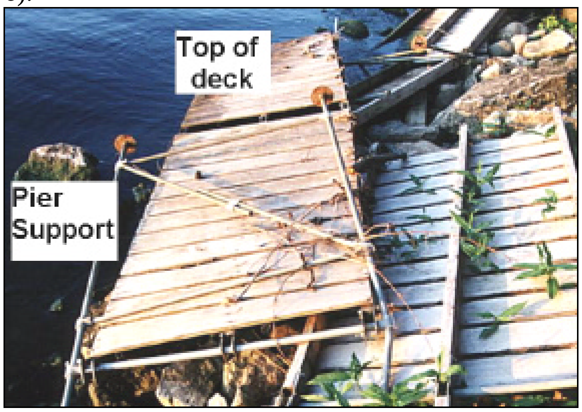

Figure 5. Boat pier debris on the shore of Lake Butte des Morts after the storm.

Figure 6. Pier area after storm. Large log (driftwood) deposited on step above the location of pier.

There were many types of boat piers on the lake. However, most boat piers were comprised of wooden plank decks secured to horizontal metal rails that spanned between pairs of metal posts. The metal posts and rails were aluminum or steel pipe. Metal couplings secured the rails to the posts. Some posts had pads that rested on the lake bottom whereas other posts had dowels or augers driven into the lake bottom. These boat piers were fairly lightweight and extended into water that was up to 1.5 m deep. Typically, wood decks had about .7 m clearance above the normal water level (Fig. 7).

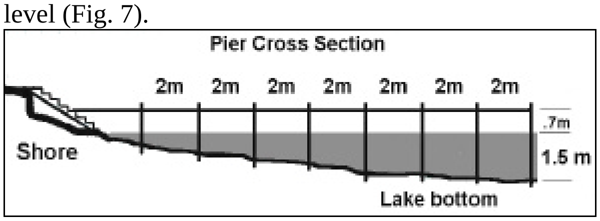

Figure 7. Typical cross section of a boat pier.

The boat piers were "portable" in that they were installed in the spring and removed during the fall as expanding ice on the lakes would destroy the piers during the winter.

Boat piers that were swept away during the storm were transported downwind as far as 45 m (Fig. 8). We also found evidence of scouring and erosion along the south and east shores on Lake Butte des Morts. Dirt and rocks had been removed along the shore and some property owners had filled the scoured areas with rock.

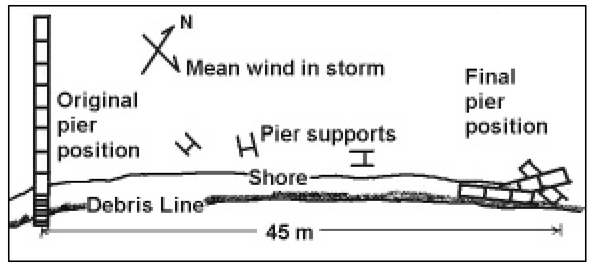

Figure 8. Original boat pier position and mapped debris field.

Examining the boat pier debris, we found a common failure mode. Tops of the metal couplings had broken where they had secured the rails to the posts (Fig. 9). This indicated that significant upward forces had lifted the rails and the attached wooden decks. Since wooden decks float in water, we surmise that the storm surge and wave action caused the wooden decks to float up and down lifting the posts off the lake bottom and slamming them back down. The couplings that secured the rails and wooden decks to the posts could not handle such impact loads and broke apart allowing the decks to float away. Interestingly, posts that rested on the lake bottom on pads remained undamaged whereas posts anchored into the lake bottom were bent.

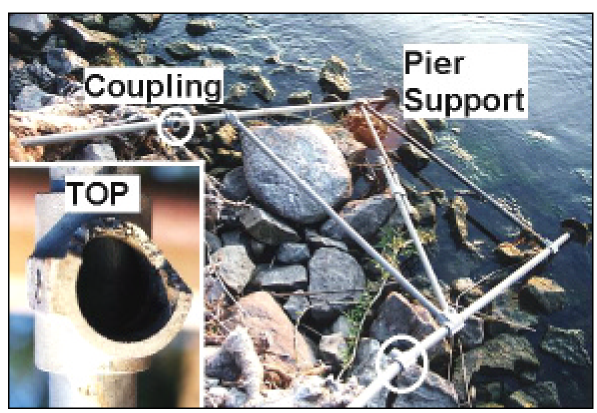

Figure 9. Boat piers failed when the tops of the metal couplings (circled) broke on pier supports allowing the rails and wooden deck to float away. Inset photograph shows close-up view of broken top on coupling.

Water lines found in boat houses at the edge of the lake were .75 m higher than the normal water level. These water lines looked like bathtub rings and indicated the maximum height of the still water levels during the storm (Fig. 10). Such water lines are common in hurricanes and floods, but this is the first time a storm surge has been documented with a bow echo storm of relatively short duration on a shallow lake. Many objects within the boat houses, such as refrigerators and freezers, had floated. We also found lake debris inside the boat houses where the doors had been pushed open. In addition, lines of debris on the shoreline were slightly higher in elevation than the still water lines, indicating wave action had occurred during the storm. Fletcher et al. (1992) documented similar water lines caused by Hurricane Iniki's storm surge on the Island of Kauai.

The depth of water controls the maximum wave height. According to FEMA (1989), waves crest at 55% the depth of the water. Thus, waves at the end of the boat piers could have reached .55 m high. Waves also generate large forces. A water wave traveling ten feet per second can exert pressures up to 200 pounds per square foot against barriers. As a result, the boat piers broke apart in the wave action.

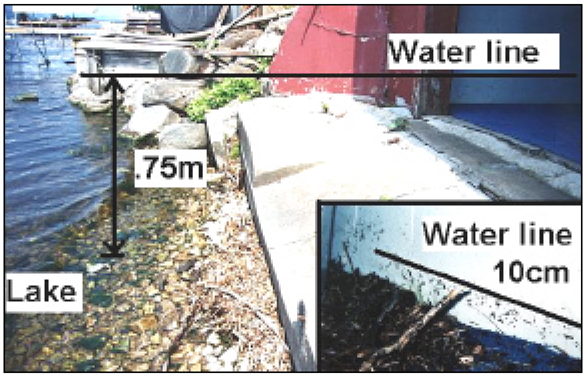

Figure 10. Water line was 10 cm above the floor in this boathouse, or .75 m above the normal water level on the south side of the lake.

5. SUMMARY

A bow echo moved southeast through central Wisconsin during the evening of 11 June 2001 producing a large swath of strong straight-lined winds. Wind gusts of 33 to 61 knots occurred over a 46 minute period at Oshkosh, WI, downing trees and power lines as well as damaging homes and businesses. The crest of the bow echo and "eye" traveled down the long dimension of Lake Butte des Morts near the city of Oshkosh, WI creating a storm surge that rose as high as .75 m (30 in). This lake is prone to storm surges as it is a large body of water that is shallow in depth. Strong winds blew across the long dimension of the lake and had sufficient fetch to pile up water on the opposite end of the lake. This effect is analogous to blowing air across a dinner plate that is full of water causing the water to pile up at the opposite end of the plate.

In addition, waves up to .55 m high were superimposed on the storm surge resulting in the destruction of numerous boat piers. Boat piers were displaced downwind and washed up on shore. This was the first time we have observed a storm surge associated with a bow echo event. It is also the first time to our knowledge that a storm surge has been documented with a bow echo and represents yet another hazard associated with such storms. Even shallow lakes can turn violent quickly.

Water lines were found in boat houses resembling those observed with hurricane storm surges and floods. Debris lines also were found along the south and east lakeshore. Portions of the shoreline were visibly scoured and eroded.

6. ACKNOWLEDGEMENTS

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