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AVIATION WEATHER HAZARDS - THE ICING EVENT OF 18 DECEMBER 2002 AND THE TURBULENCE EVENT OF 23 DECEMBER 2002

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1. Introduction

A strong storm system moving through the upper Midwest on Wednesday, 18 December, 2002, produced a variety of wintery precipitation and the formation of a major hazard for aviation -- icing. Most of the Minneapolis Air Route Traffic Control Center (ZMP) airspace experienced the icing (ICG), which can be particularly dangerous to smaller aircraft (NTSB 1996), as these types of planes generally do not have anti-icing or de-icing equipment. ZMP airspace covers portions of nine states from the Plains to the Great Lakes (Fig. 1). Less than a week later, on 23 December 2002, another storm system produced a different aviation hazard - severe turbulence (TURB). This severity of turbulence can be very unnerving for the flying public, and in some situations can even cause serious injuries. This paper will detail the aviation hazards for these case studies and some techniques to improve forecasting of such hazards. These case studies can also be examined using the NWS Weather Event Simulator (WES).

Fig. 1. ZMP area of responsibility outlined in green shading (*courtesy FAA*).

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2. The icing event of 18 December 2002

A strong surface low (994 mb) tracked from the central Plains into northern Minnesota (Fig. 2). This storm caused snow and freezing rain to occur across parts of the Dakotas and northern Minnesota. Elsewhere across ZMP airspace, rain fell in Wisconsin with freezing rain in upper Michigan and northern lower Michigan. The precipitation pushed north during the day as the low and warm front moved north. Icing occurred north of the warm front as it lifted slowly north across ZMP airspace. Figure 3 shows the reports of moderate or greater icing between 1144 UTC 18 December 2002 and 0136 UTC 19 December 2002. The reports occurred in an area common for icing -- that of the Great Lakes and upper Midwest (Bernstein and Brown 1997).

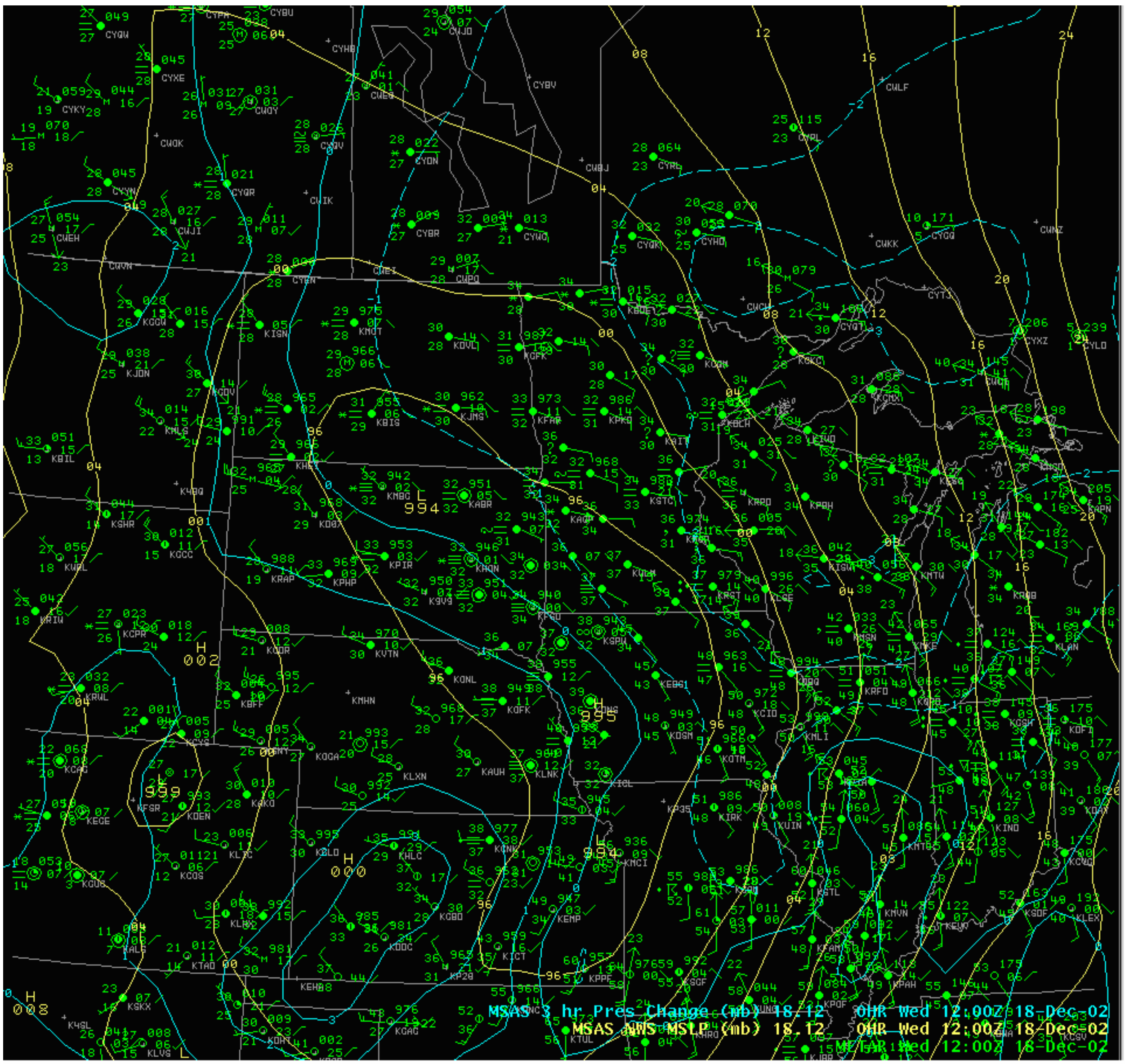

Fig. 2. Surface weather map 1200 UTC 18 December 2002.

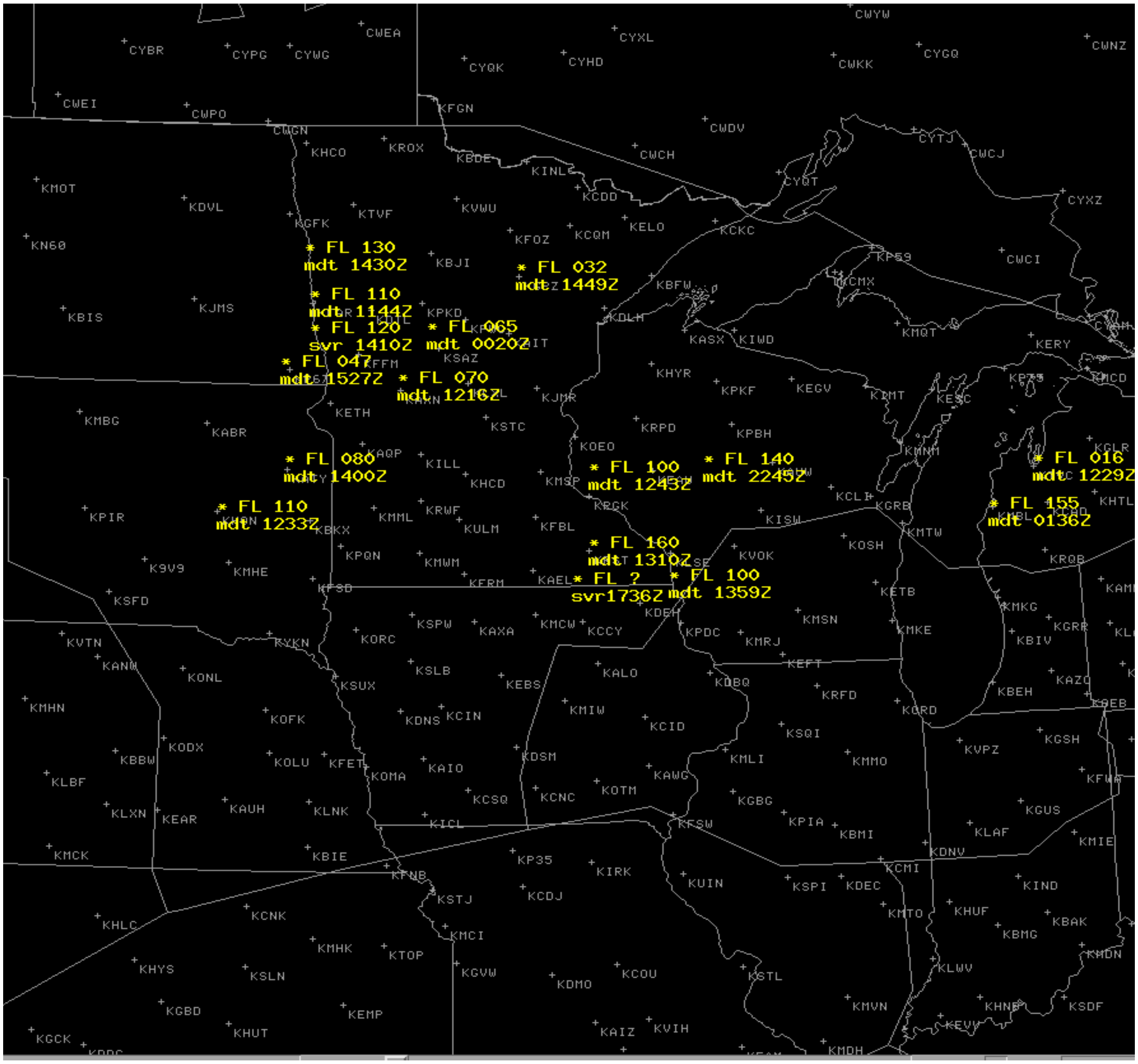

Fig. 3. Plan view of ZMP airspace with each plot of moderate or severe icing, FL, and time of occurrence in Z time on 18 December 2002.

Note the severe icing reported at flight level 12,000 feet (FL120) near Fargo, North Dakota at 1410 UTC on 18 December 2002. The Local Area Prediction model (LAPS) sounding for 1400 UTC (Figure 4) near Fargo illustrates conditions favorable for icing. First, the atmosphere was saturated. Second, temperatures at 12,000 feet were between 0° C and -15° C; these temperatures favor the presence of supercooled water droplets. The 1200 UTC Rapid Update Cycle (RUC) sounding (not shown) valid for 1400 UTC for the Fargo location was very similar to the observed LAPS sounding. The CWSU staff at ZMP has noted that icing reports often occur higher than what a sounding would support simply because the pilot may not see the ice until the airplane emerges from the cloud deck.

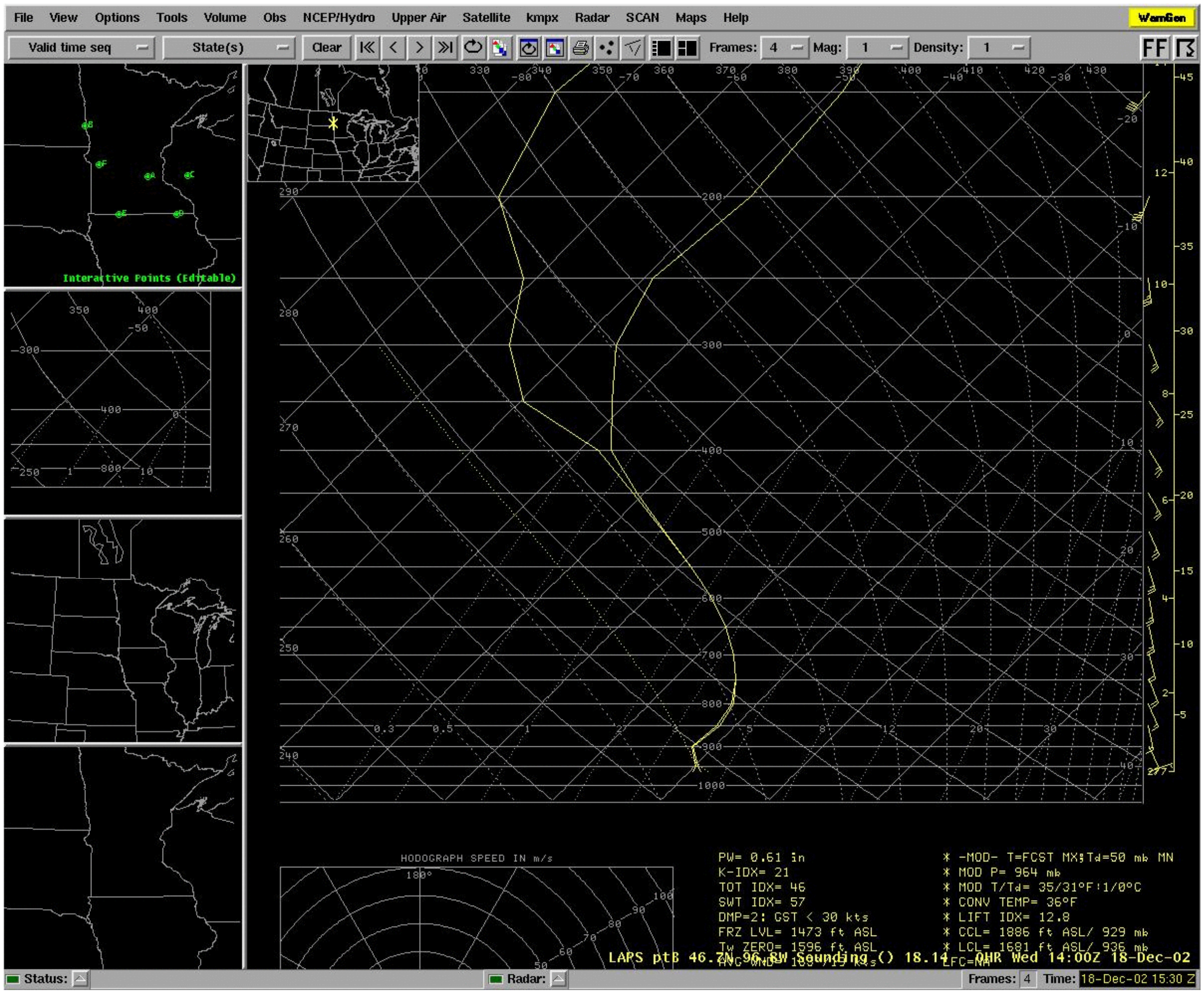

Fig. 4. LAPS sounding for Fargo, North Dakota valid 1400 UTC, 18 Dec 2002.

Operationally, ZMP makes extensive use of the North American Mesoscale Model (NAM) cross-sections available in the Advanced Weather Information Processing System (AWIPS) to forecast icing events. To set up cross-sections for forecasting icing using AWIPS, in D2D, first select **tools**, then **baselines** to position the desired cross-section. Next, click on **volume browser**, select **cross section**, source **NAM**, fields **temperature, rel humidity, wind, omega**, planes specify **line A-J** (as chosen in baselines), select **load**, then make RH an image. The COMET icing module (COMET 1998) states that icing occurs where the relative humidity is at least 70 percent and the temperatures are between 0° C and -15° C. ZMP experience has been that moderate or greater icing occurs with these *additional* conditions:

1. relative humidity at least 90 percent.
2. wind shear (to enhance turbulent mixing, particularly at cloud top).
3. upward vertical motion to enhance drop size.

Figure 5 depicts an ETA[1] forecast cross-section for 1800 UTC 18 December 2002. The cross section was the part of the basis for the Meteorological Impact Statement issued by a ZMP meteorologist at 1759 UTC:

FAUS KZMP 181759
ZMP MIS 02 VALID 181800-190300
...FOR ATC PLANNING PURPOSES ONLY...
ZMP AREA N OF A LN FM 55N RAP TO ANW TO 55E MBS.
LGT TO MOD...CHC SEV...RIME/MXD ICGICIP BLO 160.
SEE SIGMET QUEBEC FOR SEV ICG.
ZMP AREA E OF A LN FM 50W YQT TO 55S DSM.
LGT TO MOD TURB BLW 080...WITH OCNL LLWS.

[1] The ETA model became the NAM in January 2005.

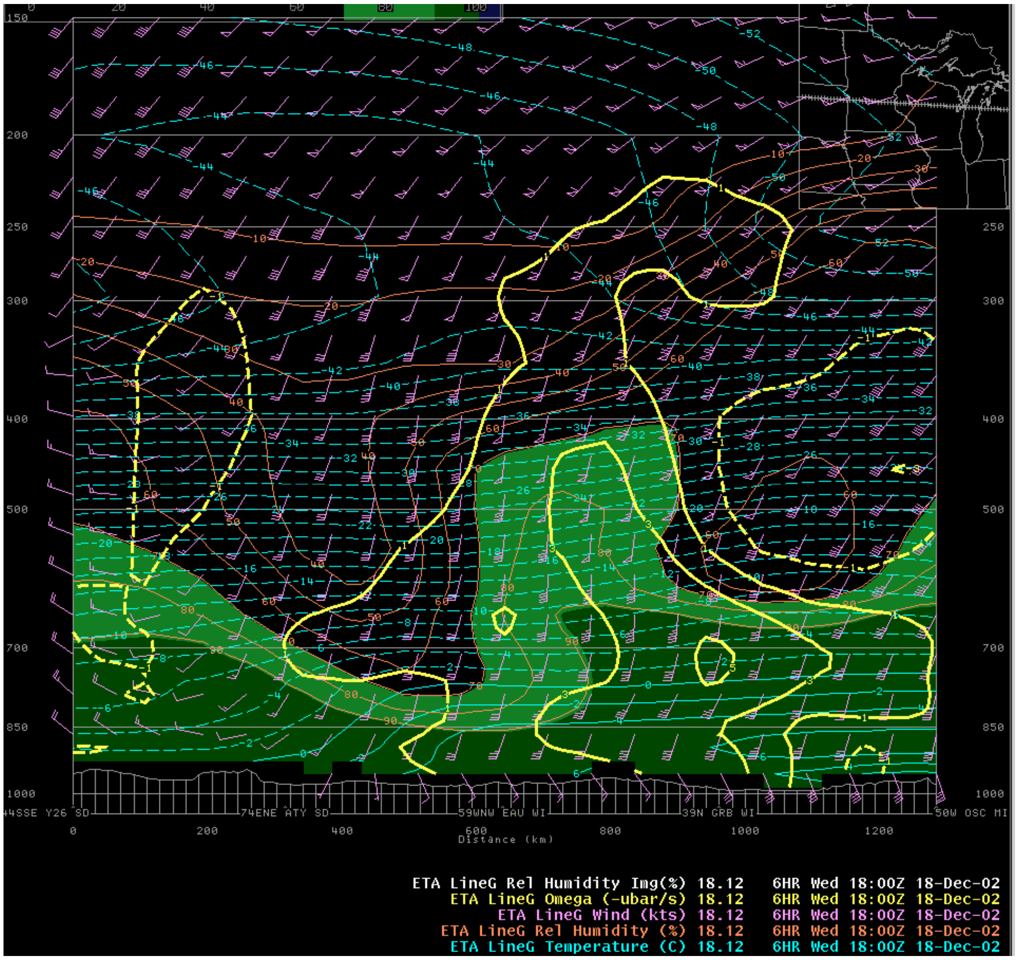

Fig. 5. Forecast Icing Cross-section (ABR-APN) for 1800 UTC 18 Dec 2002

3. The turbulence event of 23 December 2002

An intense upper-level low pressure system was located east of James Bay Canada, while another strong upper-level low was in the southern Rockies. The 12-hour 250-mb forecast from the 1200 UTC 23 Dec 2002 Eta model is depicted in Figure 6. The strong horizontal speed shear produced moderate to severe turbulence between 17,000 feet and 39,000 feet across Nebraska, southern Minnesota, Iowa, Wisconsin, and lower Michigan. The turbulence also affected much of the eastern United States, but was not included in this study. This case was unusual in having so many reports of moderate to severe turbulence over a large part of the country. Moderate to severe turbulence reports are plotted in Figure 7.

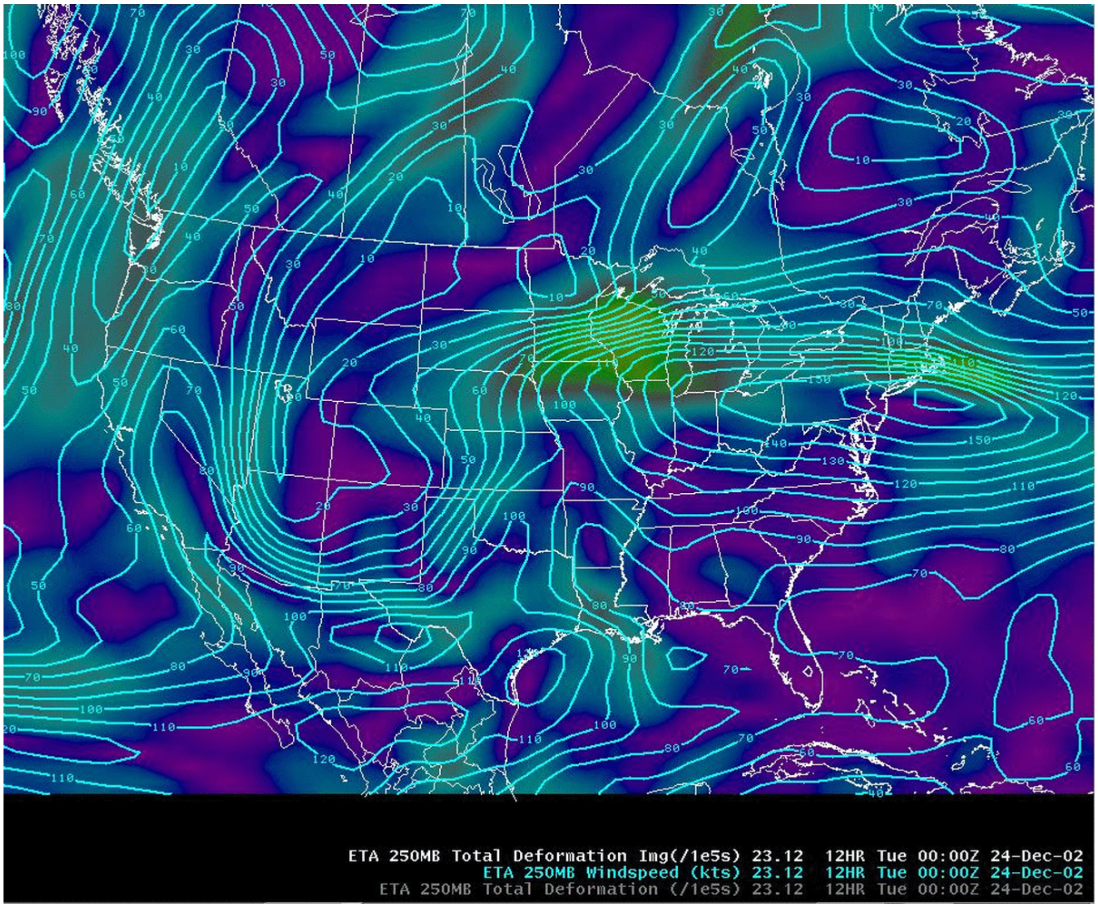

Fig. 6. 250-mb total deformation (image) and 250-mb isotachs (solid blue lines) valid at 0000 UTC 24 Dec 2004, based on the 1200 UTC 23 Dec 2002 Eta forecast.

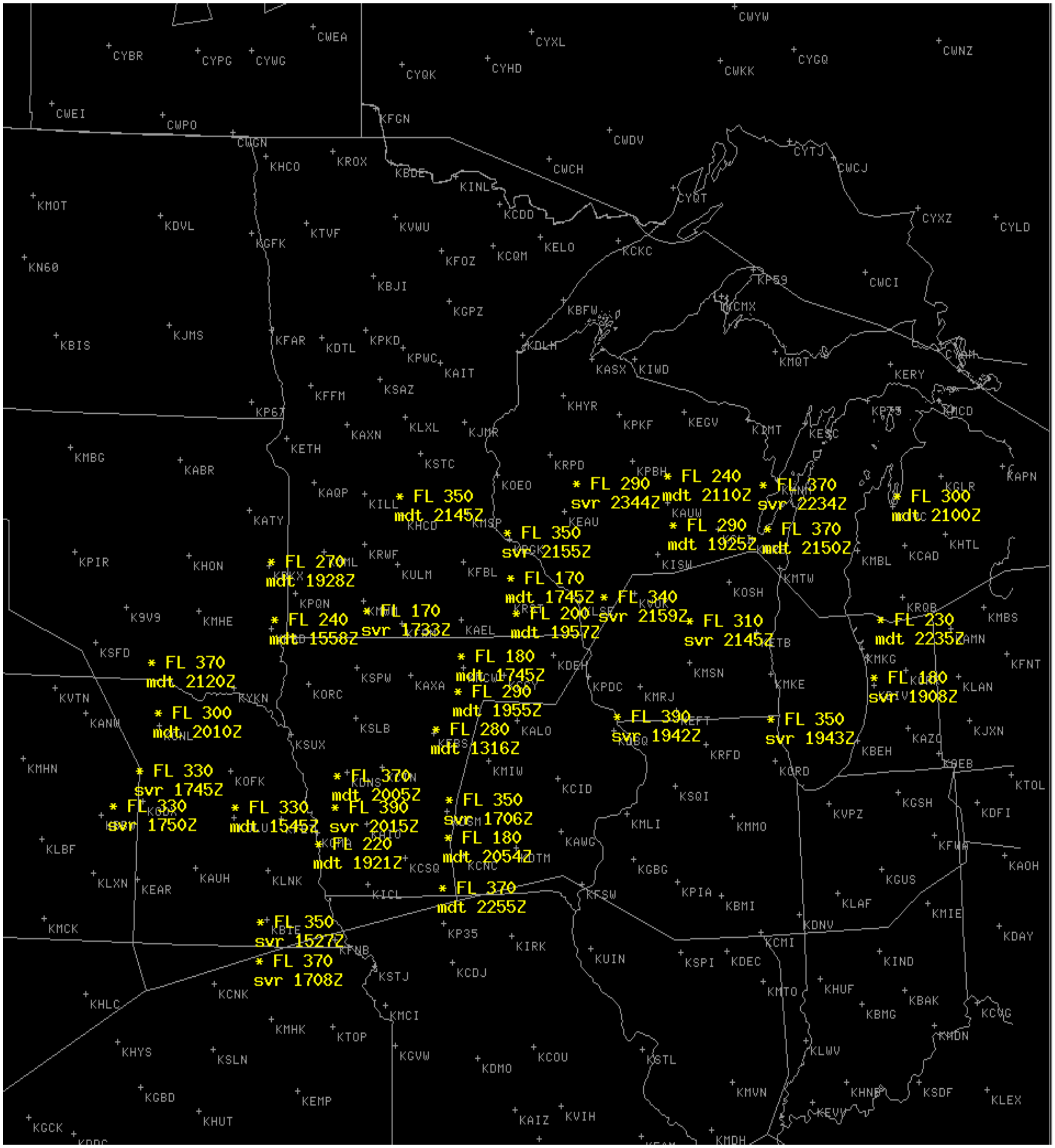

Fig. 7. Plan view of ZMP airspace with each plot of moderate or severe turbulence, FL, and time of occurrence in Z time for 23 December 2002.

One of the quickest ways to find turbulence forecasting is at the Aviation Weather Center (AWC) homepage[2] using two different techniques. The first one is the Ellrod Index which takes into account horizontal deformation and vertical wind shear using numerical model forecast winds aloft (Ellrod and Knapp 1992). The second method is the Graphical Turbulence Guidance (GTG) which utilizes eleven different operationally used and tested turbulence forecasting tools. Some of the tools this guidance uses include the Richardson Number, shear, divergence and temperature gradient. At the CWSU, both of these techniques are routinely used and are quite accurate, but unfortunately, neither was archived for use in this paper.

Although not used in real-time during this turbulence event, there is a proxy for the Ellrod Index in AWIPS. The 2004 version of the Petterssen 2-D frontogenesis in AWIPS includes only the deformation term; in other words, the tilting, diabatic, and convergence terms from the Petterssen 3-D frontogenesis equation (Bluestein 1993) are neglected.

This allows the first Ellrod Index (TI1) to be rewritten as:

$$\mathbf{TI1} = \boldsymbol{F}\mathbf{(2g/fT)}$$

where F is the Petterssen 2-D frontogenesis, g is the gravitational constant, f is the Coriolis parameter, and T is the temperature in degrees Kelvin.

Therefore TI1 is related to Petterssen 2-D frontogenesis **without the convergence term**, which is available in AWIPS. Keep in mind that Petterssen 2-D frontogenesis in AWIPS, and by extension its relationship to TI1, neglects the tilting term (which may be very important in the middle and upper troposphere) and diabatic terms.

The second form of the Ellrod index, TI2, includes a convergence term. Although not quantitatively available in AWIPS, forecasters can subjectively include the convergence term by looking for areas where **both** Petterssen 2-D frontogenesis is occurring and convergence is present. Remember, that again tilting terms and diabatic effects are neglected. Note in Figure 8, the report of moderate to severe turbulence in Wisconsin occurred where Petterssen 2-D frontogenesis was positive and wind convergence was occurring.

Figure 8 also displays the total deformation in the 250-300 mb layer. Although the moderate to severe turbulence occurred where the total deformation was large, the reader is cautioned that the correlation between total deformation and clear air turbulence is poor (Dutton 1980).

[2]Aviation Weather Center website: http://aviationweather.gov/exp

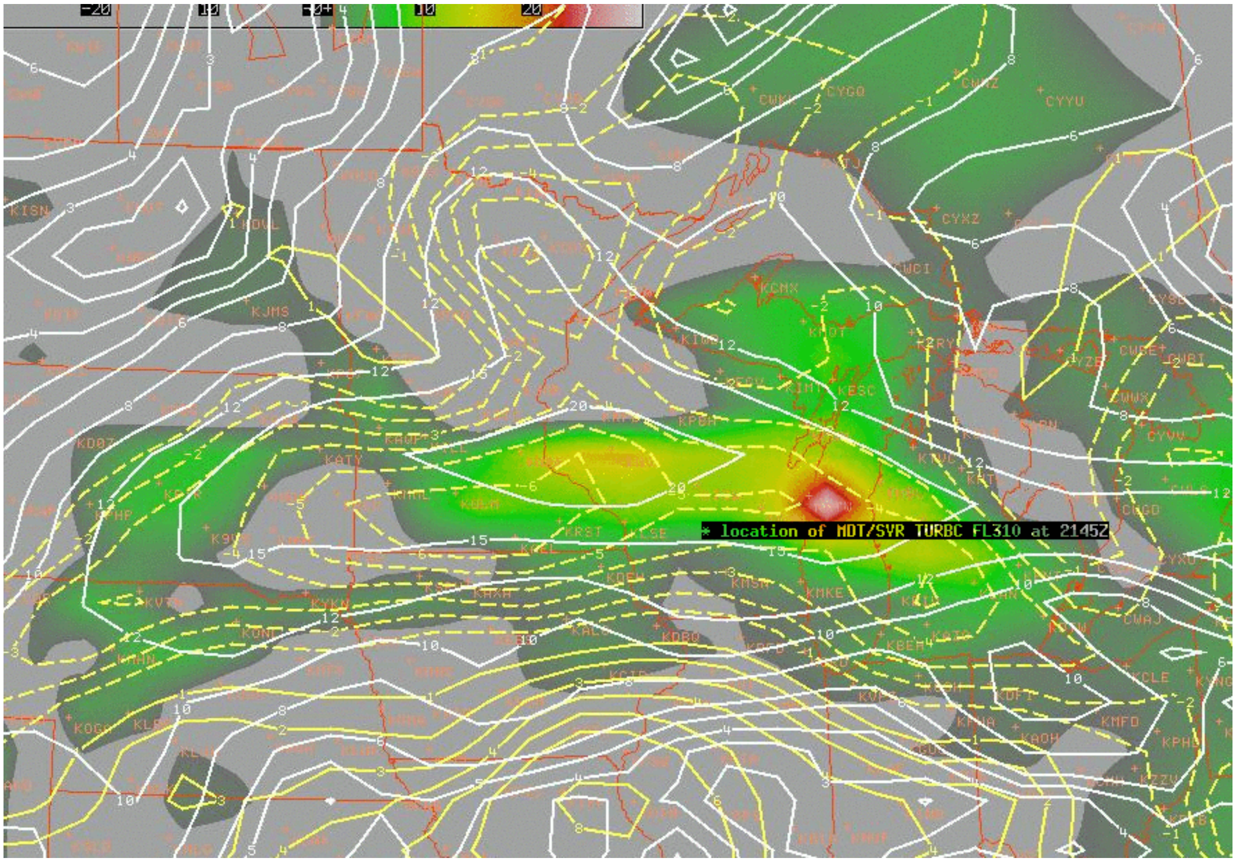

Fig. 8. RUC 2100 UTC 23 Dec 2002 analysis. Image is 250-300 mb Petterssen 2-D frontogenesis. White lines represent 250-300 mb total deformation. Yellow lines represent 250-300 mb wind divergence (dashed yellow are negative divergence or convergence).

4. Summary

Winter storms can be both challenging and dangerous to the aviation community with the threat of ICG and TURB, as evident by these two case studies: 18 and 23 December 2002. At the CWSU, the mission is to lessen the danger of flying during adverse weather conditions by accurately forecasting these events and incorporating new technology into those forecasts.

5. Acknowledgments

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6. Abbreviations

CWSU= Center Weather Service Unit
FAA= Federal Aviation Administration
ICG= Icing
TURB= Turbulence
ZMP= Minneapolis Air Route Traffic Control Center

7. References

Bernstein, B., and B. Brown, 1997: A Climatology of Supercooled Large Drop Conditions Based Upon Surface Observations and Pilot Reports of Icing. *Preprints, 7th Conf. on Aviation, Range and Aerospace Meteorology*, Long Beach, CA, AMS (Boston), 82-87.

Bluestein, H., 1993: *Synoptic-Dynamic Meteorology in Midlatitudes Volume II Observations and Theory of Weather Systems*, Oxford University Press, New York.

Cooperative Program for Operational Meteorology, Education and Training, 1998: Forecasting Aviation Icing: Icing Type and Severity. University Corporation for Atmospheric Research, COMET module.

Dutton, M. J. O., 1980: Probability Forecasts of Clear-air Turbulence Based on Numerical Model Output. *Meteorol. Mag.,* **109**, 293-310.

Ellrod, G., and D. Knapp, 1992: An Objective Clear-Air Turbulence Forecasting Technique: Verification and Operational Use; *Weather and Forecasting,* **7**, 150-165.

NTSB Report Number AAR-96-01, 1996: In-flight Icing Encounter and Loss of Control, Simmons Airlines, Roselawn, Indiana, October 31, 1994; Safety Board Report, **1**. 340 pp.