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DIAGNOSIS AND FORECAST OF A TROPOPAUSE FOLD ASSOCIATED WITH SEVERE TURBULENCE USING MAPS

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1. Inroduction

On 21 March 1993 at 0250 UTC, a Boeing 767 passenger jet enroute from Cincinnati, Ohio to Salt Lake City, Utah entered severe turbulence over northwest Colorado at a flight level of 41,000 feet (near 12.5 km MSL). An urgent pilot report indicated the turbulence forced the plane into an uncontrolled 30 degree bank. The pilot relayed to the FAA Air Route Traffic Control Center in Longmont, Colorado that this was the worst turbulence he had ever experienced.

At 0300 UTC, the Mesoscale Analysis and Prediction System (MAPS; Benjamin et al. 1991) analyzed a jet core between 250 and 300 mb. The 85 kt (43 m/s) core was oriented north to south from central Wyoming into northwest Colorado, on the west side of a progressive upper level trough. This jet was associated with a tropopause fold which reached 100 millibars lower than the mean tropopause level over the region. This particular synoptic environment is very frequently associated with moderate to severe clear air turbulence, especially in mountainous regions (Hopkins 1977).

Isobaric and cross section analyses, as used in the prototype AWIPS workstation at the National Weather Service Forecast Office (NWSFO) in Denver, will be employed to indicate the utility of the MAPS model in diagnosing the area associated with turbulence in this case. Specifically, wind and isotach analyses, potential vorticity, temperature and deformation fields will be used to evaluate the structure of the atmosphere in the vicinity of the turbulence report. In addition, the ability to forecast the pattern will be assessed using MAPS three- and six-hour forecasts of those parameters.

2. MAPS Analysis

2.1 200 mb

A 200 mb jet core of 65 kts (33 m/s) at 0300 UTC 21 March 1993 was located from Worland in central Wyoming (WRL) to just north of Craig, Colorado (CAG) (Figure 1).

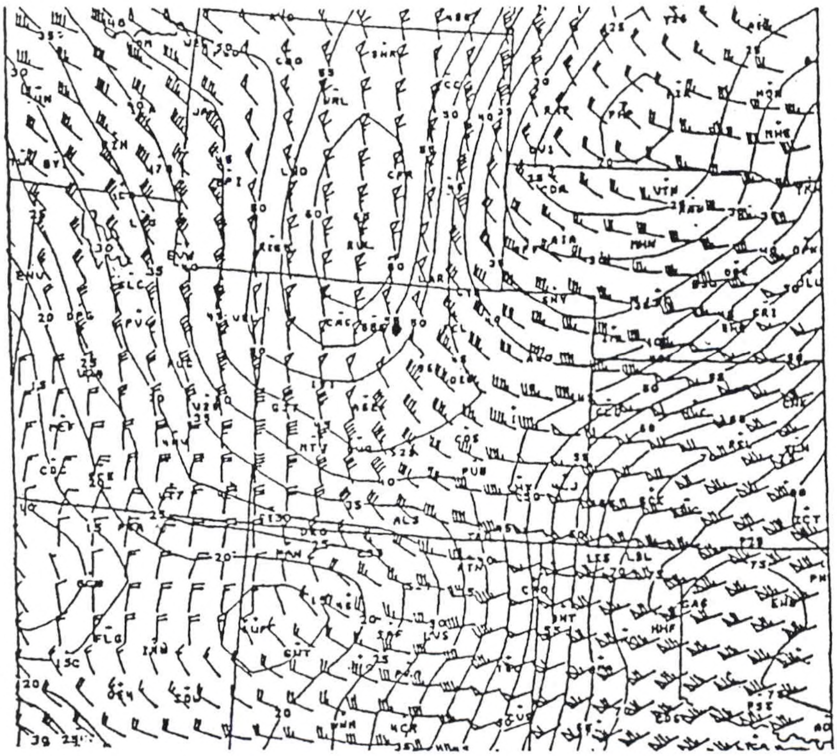

Figure 1. MAPS 200 mb (0300 UTC) analysis of winds (kts and isotachs). The dot on all figures is the estimated position of the jet when the turbulence occurred.

This isobaric surface was located within about 2000 feet (610 m) of the aircraft's flight level at the time of the turbulence report. The flight path of the aircraft took it across the tropopause, then through the exit region of the jet, where the turbulence occurred.

Figure 2 shows the local axes of dilatation of the deformation field overlaid on the isotherms. The orientation of these axes perpendicular to the isotherms over northwest and north central Colorado is indicative of frontolysis, which would be expected in the exit region of the jet streak. Indeed, Figure 3 depicts a substantial ageostrophic wind component, indicative of the secondary circulation about the jet exit region.

2.2 Cross Sectional View

The capability of the prototype AWIPS workstation plus the three-hour time resolution of the MAPS model permitted the construction of a cross section roughly along the flight path of the aircraft at the time of the turbulence report.

Figure 4, a cross section from Salt Lake City, Utah to Cincinnati Ohio, shows the Isentropic Potential Vorticity (IPV) and component of the wind into (solid lines) and out of (dashed lines) the plane of the cross section at 0300 UTC. Note the strong tropopause undulation which is present from just west of Cheyenne, Wyoming to around Grand Island, Nebraska. Also present is a smaller scale tropopause fold, located between Cheyenne and Salt Lake City. Further information on tropopause undulations and potential vorticity and their implications in forecasting can be found in Hirshberg and Fritsch (1991) and the references contained therein.

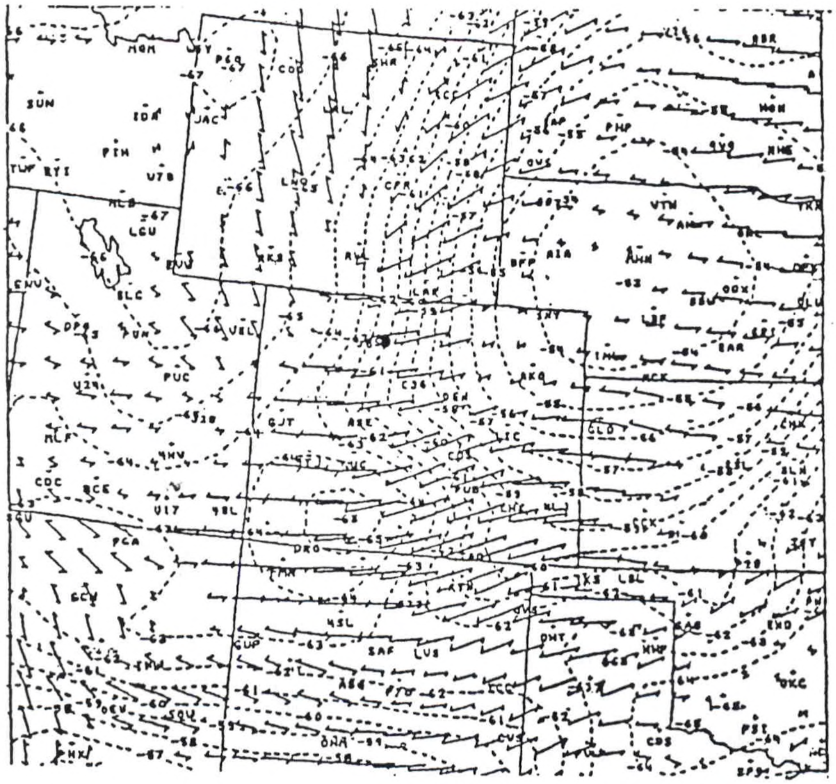

Figure 2. MAPS 200 mb (0300 UTC) analysis of isotherms (°C) and deformation vectors ($1*10^{-5}$s).

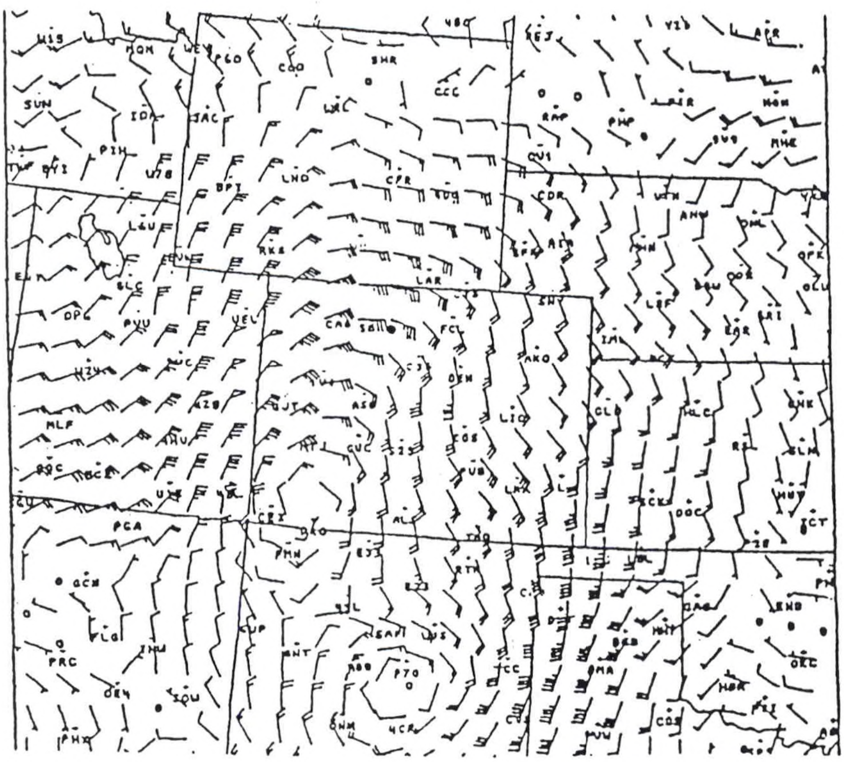

Figure 3. MAPS 200 mb (0300 UTC) analysis of ageostrophic wind component (kts).

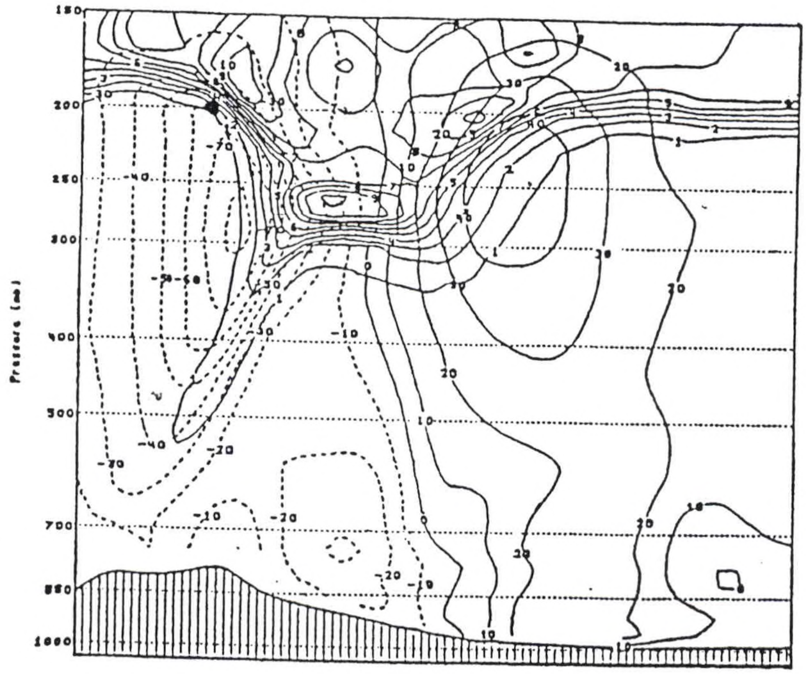

Figure 4. MAPS 200 mb (0300 UTC) cross section, from Salt Lake City, UT to Cincinnati, OH, of isentropic potential vorticity ($1*10^{-5}$s) and component of wind out of (dashed line) into (solid line) the plane of the cross section.

The component of wind out of the cross section (north to south) associated with the jet is in excess of 80 kts (40 m/s) between 250 and 300 mb on the west side of the undulation. It is in the vicinity of this tropopause undulation, while at the exit region of the jet, that the turbulence occurred. Reports from other aircraft at similar flight levels, but further to the southeast and away from the jet and tropopause undulation, indicated no turbulence.

3.0 MAPS Forecast

Three-hour forecasts based on 0000 UTC data and six-hour forecasts based on 2100 UTC data were available to assess the MAPS model's ability to forecast the meteorological phenomena associated with the turbulence.

3.1 200 mb

Both the three- and six-hour forecasts identified the magnitude of the jet core within 5 knots (3 m/s) of the 0300 UTC 200 mb analysis. The six-hour forecast was about 60 km too far west (one model grid point) and slightly weak on the core maximum speed, but the three-hour forecast was stronger on the core maximum speed and very close on the placement of the jet core (Figure 5a and 5b).

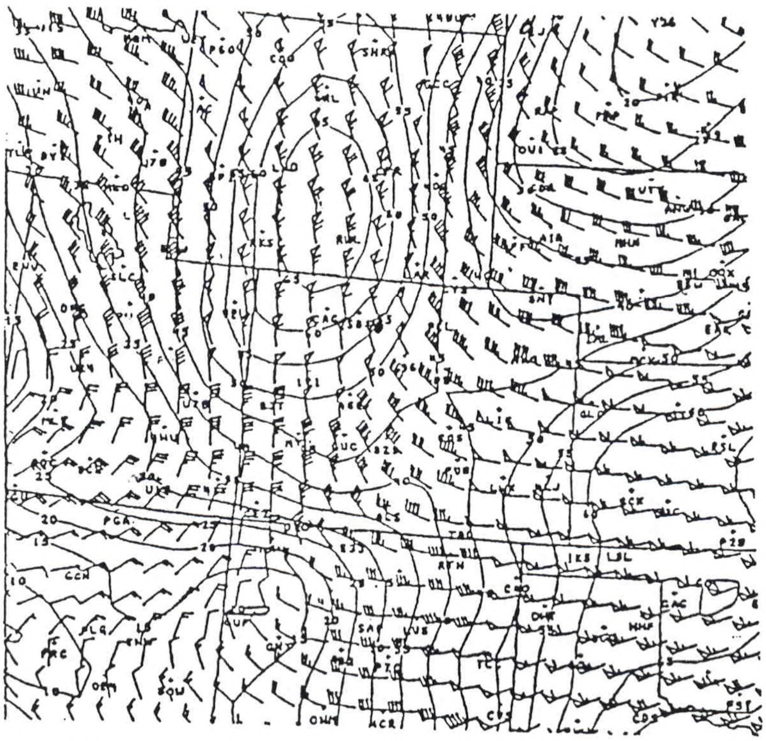

Figure 5a. MAPS 3-hour forecast 200 mb (valid 0300 UTC) winds (kts) and isotachs.

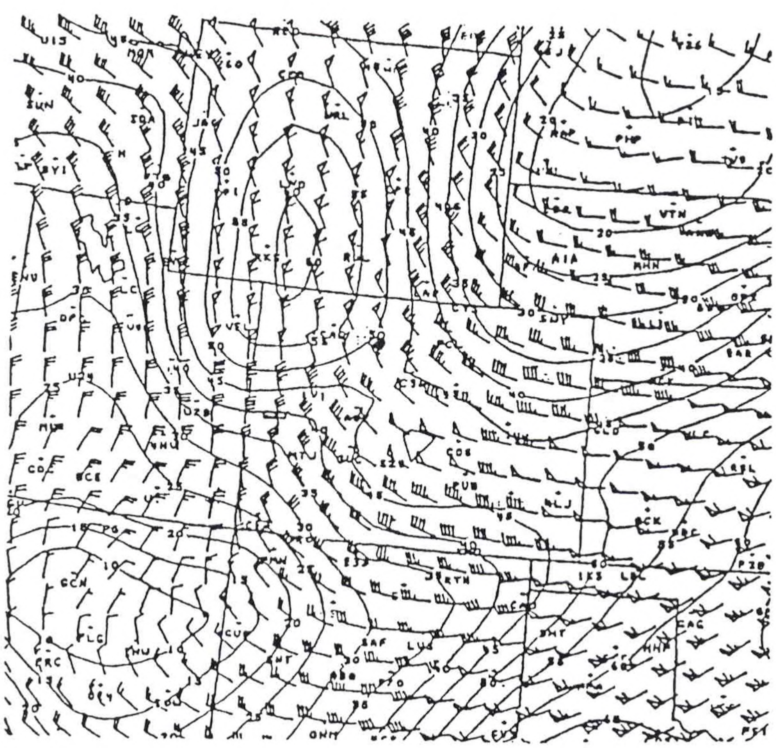

Figure 5b. Same as 5a except 6-hour forecast.

The area of frontolysis based on the thermal gradient and deformation field was also well forecast, though a bit farther west on the six-hour forecast than three-hour forecast (Figure 6a and 6b), paralleling the placement of the jet. The ageostrophic wind component (not shown) was not well forecast at six hours though by the three-hour forecast the character of the secondary circulation about the jet exit region was becoming clearer.

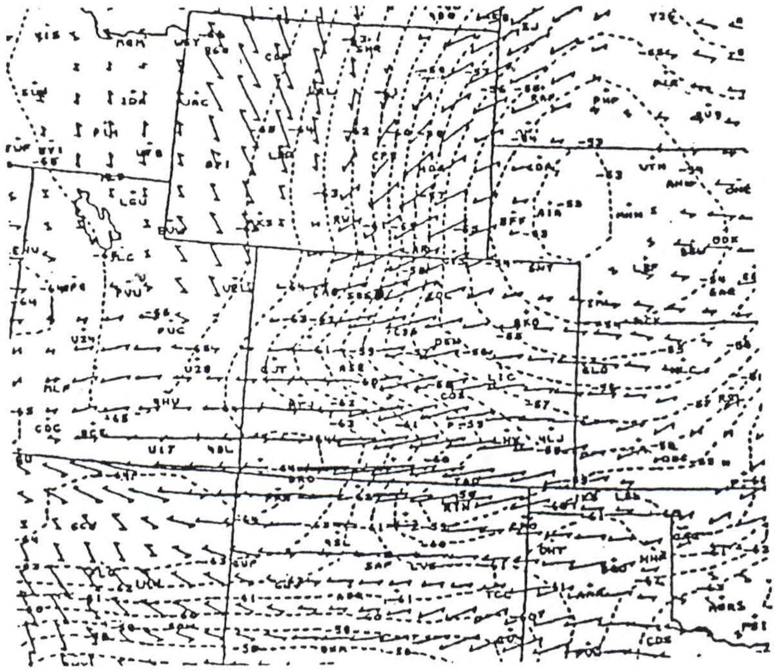

Figure 6a. MAPS 3-hour forecast 200 mb (valid 0300 UTC) isotherms (°C) and deformation vectors ($1*10^{-5}$s).

Figure 6b. Same as 6a except 6-hour forecast.

3.2 Cross Sectional View

Three- and six-hour forecast cross sections along the flight path (from Salt Lake City to Akron, Colorado in these examples) both indicated the tropopause fold, undulation and jet core (Figure 7a and 7b). The six-hour forecast was again a bit weak on the core maximum speed and not as strong with the undulation as the three-hour forecast. Nonetheless, it did indicate these features six hours before the event occurred.

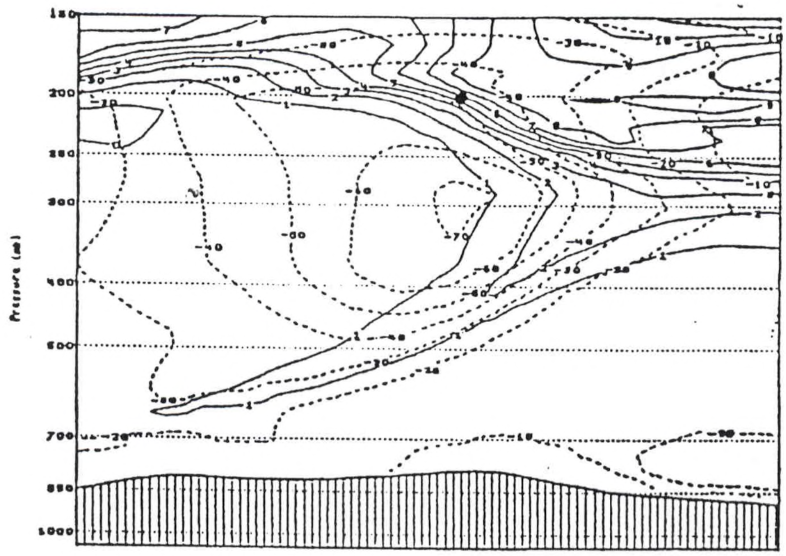

Figure 7a. MAPS 3-hour forecast 200 mb (valid 0300 UTC) cross section, from Salt Lake City, UT to Akron, CO of isentropic potential vorticity ($1*10^{-5}$s) and component of wind out of (dashed line) the plane of the cross section.

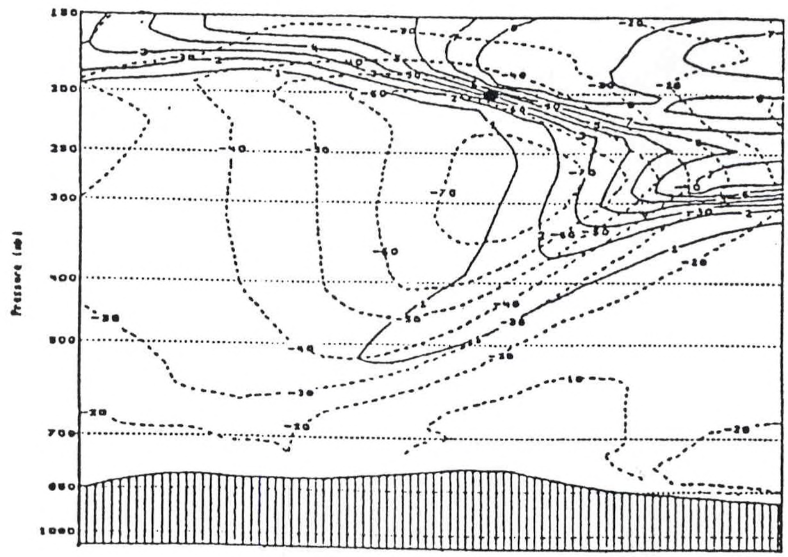

Figure 7b. Same as 7a except 6-hour forecast.

4. Summary

A modest jet and associated tropopause fold dropping across the central Rockies during the evening of 21 March 1993 were associated with a report of severe turbulence by a large passenger jet aircraft. By means of pressure level and cross section analyses, at the time and location of the event, it has been shown that the turbulence likely occurred as the aircraft was exiting from the stratosphere into the troposphere across a tropopause undulation and strong shear area of a jet streak.

Three- and six-hour forecasts from the MAPS model indicated these meteorological phenomena (jet and tropopause undulation) were indeed forecastable in both time and space at least six hours in advance. This paper indicates the utility of the MAPS model in diagnosing and forecasting meteorological conditions frequently associated with significant turbulence, in both the time and space resolutions necessary to aid aviation forecasting.

5. Acknowledgements

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6. References

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