

Aviation

Wave Clouds and Severe Turbulence

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ABSTRACT

Turbulence reports are related to wave clouds in visible satellite imagery which are provided to government and private users every 30 minutes through the Central Data Distribution Facility (CDDF) at Washington, DC. The clouds were in a zone of strong vertical wind shear associated with the polar jetstream.

1. INTRODUCTION

Satellite detection of wave clouds has been noted by Brandli and Taylor (2) in low clouds off the upper Texas coast. Waves in low clouds that formed downwind from higher terrain have been documented by Burroughs and Larson (3) and Ernst (4). Vizee et al (5) related early polar orbiting (image over the same area twice a day) cloud patterns to horizontal and vertical wind shear, wind speeds and frequency of turbulence at the level of the jetstream. They found a higher risk of severe or extreme turbulence when transverse bands (directional difference between orientation of cloud band and winds is greater than 80 degrees) were observed near the jet than when the bands were not present.

This note documents a case where several moderate and severe turbulence reports are related to wave clouds in a sequence of visible satellite images.

2. SATELLITE OBSERVATIONS

On 8 February 1980, the first visible satellite image (Figure 1a) revealed a narrow band of wave-like clouds over northern Missouri.

Coincidentally, a B727 pilot reported severe turbulence over Kirksville, Missouri (A) and another B727 pilot experienced light to moderate turbulence over Kansas City (B).

A mid-morning, 1-kilometer (1/2-mile) resolution (6) picture (Figure 2) showed better definition of the wave-cloud pattern over northeast Missouri. The clouds were not discernible in an 8-kilometer (4-mile) resolution image taken at the same time (Figure 3) because the coarse resolution in the infrared image and the lack of contrast with the clouds below. A sharp poleward edge (C)

to the thick, high clouds from southeast Kansas to central Illinois was near the polar jetstream (Figure 4a, b). These clouds were at the first enhancement level (7) (medium grey shade) which represents a temperature of -32C to -41C. The infrared image indicated the temperature of the wave clouds to be slightly warmer or -25C to -30C. This corresponds to a height range of 5-7 km (16,000 to 22,000 ft). When clouds are thin or scattered, the satellite radiometer senses a combination of cold radiation at cloud tops and warmer radiation from below which results in a derived temperature too warm so the calculated cloud heights are lower than observed cloud heights.

Subsequent imagery (Figure 1, b-g) showed the waves progressing eastnortheastward across Illinois and the southern tip of Lake Michigan into lower Michigan.

3. AIRCRAFT REPORTS

During the day, there were numerous aircraft reports of turbulence over northern Missouri, northern Indiana, Illinois, and lower Michigan (Table 1). All reports over this region were received via Service A and dedicated circuits at the National Severe Storms Forecast Center (NSSFC) at Kansas City between 1500 and 2200 GMT. Of course, there could have been other reports which were missed or not relayed. We were fortunate to have so many PIREPS because of the high density of jet travel over this area.

The primary high level jet routes between Kansas City and the Carleton, Michigan and the location identifiers for the pilot reports are indicated in Figure 5. Because the wave clouds were near flight level and moved at a speed of 60 knots along the jet routes, the intensity of the turbulence in and around the waves could be evaluated. Table 1 shows that the reports of severe turbulence tended to progress from west to east with the wave clouds. The light turbulence observations were either preceding, following, or south of the wave clouds. Pilots flying from Indianapolis to Chicago observed wave clouds resembling mountain waves.

4. DISCUSSION

Wind profiles at Topeka, Kansas (Figure 6,

a) and Flint, Michigan (Fig. 6, b) described a well-defined upper jet at around 9.2 km (30,000 ft). The profiles were strikingly similar, especially between 2.7 and 7.6 km (9,000 to 25,000 ft). Unusually large vertical wind shears of about 7 kt per thousand feet ($12 \times 10^{-3} \text{ s}^{-1}$) were measured at Topeka and 15 kt per thousand feet ($26 \times 10^{-3} \text{ s}^{-1}$) at Flint. The wind direction between 4 and 12 km (13,000 and 40,000 ft) did not vary more than 5 degrees from 265 degrees. The clouds were nearly perpendicular to the wind.

Brandli and Lombardo (8) have presented an accurate method of determining wind direction and speed from satellite photographs of wave clouds that are not associated with terrain. They called these wave-shaped clouds "billows". The wind direction is perpendicular to the wave clouds and the altitude is determined by comparing the infrared temperature to a recent radiosonde observation. The wind speeds are calculated by the empirical relationship:

$$V = 18.4\lambda + 16.4$$

where λ is the wavelength of the waves in nautical miles. This is a measure of the distance between the centers of two successive waves. V is the speed of the wind in knots.

The wavelength in this case was 13 to 17 km (7 to 9 nm) which yields a wind speed of about 150 kt. Although greater than the observed speed of 125 kt at Flint, this estimate is within 20 percent of the observed wind.

5. SUMMARY

This case demonstrates the utility of 30-minute geostationary satellite imagery for detecting and monitoring mesoscale phenomena. The small area of waves which moved from northern Missouri to lower Michigan was

associated with moderate to severe turbulence. These clouds were in a zone of strong vertical wind shear below the polar jet-stream. Aviation forecasters should be alert to the fact that severe turbulence can be associated with clouds of this type. The waves in this case were in the mid- and upper troposphere and were not related to orography.

REFERENCES AND FOOTNOTES

1. Mr. Beckman received his B.S. degree in mathematics and a M.S. in meteorology, the latter from Texas A & M. He interned at the NSSF and spent 4 years in the USAF before taking his current assignment.
2. Brandli, H.W., Taylor, L.O., 1975: Invisible Billow Clouds. *Monthly Weather Review*, 103, 1140-1142.
3. Burroughs, L.D., Larson, R.N., 1979: Wave Clouds in the vicinity of Oahu Island, Hawaii. *Monthly Weather Review*, 107, 608-611.
4. Ernst, J.A., 1976: SMS-1 nighttime infrared imagery of low-level mountain waves, *Monthly Weather Review*, 104, 207-209.
5. Vizee, W., R.M. Endlich and S.M. Serebreny, 1967: Satellite-Viewed Jet Stream Clouds in Relation to the Observed Wind Field. *J. Appl. Meteor.*, 6, 929-935.
6. Resolutions are at the satellite (SMS-2) subpoint (near ON 75W).
7. Radiance measurements are converted to equivalent black body temperatures. Data in digital form are represented as different gray shades and displayed with various enhancement "curves".
8. Brandli, H.W., Lombardo, F.A., 1974: High Level Wave Clouds not associated with Terrain (billows). *Bull. Amer. Meteor. Soc.*, 55, 1472-1474.

TIME	LOCATION	FL	AIRCRAFT	TURB INTENSITY
1500	OVR MCI	250	B727	LGT-MDT
1522	OVR IRK	270	B727	SVR
1617	OVR MCI	370	N265	LGT
1700	OVR UIN	230	MU2	MDT
1815	OVR JOT	200	PAGE	LGT
1825	OVR IRK	370	MS 56	MDT
1913	OVR STL	DCRG	B727	LGT
2010	OVR SBN	270-330	Numerous	MDT-SVR
2025	IND-CHI	250	Numerous	MDT
2028	OVR SBN	220	AC6J	MDT-SVR
2114	OVR CAP	370	MISG	LGT
2126	OVR SBN	310	MISG	None
2151	OVR CRL	350	B727	SVR

Table 1. Locations, flight level, type of aircraft and intensity of turbulence between 1500 and 2200 GMT, 8 Feb. 1980 from northern Missouri to southern Michigan.

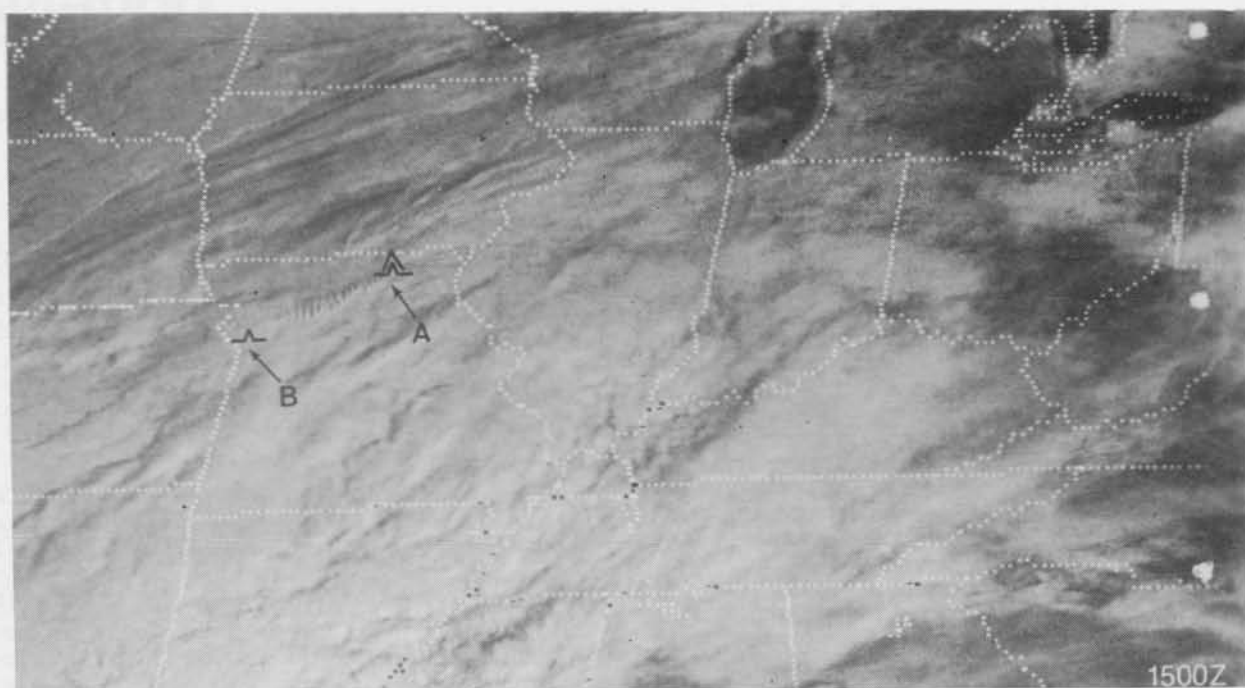


Figure 1.a

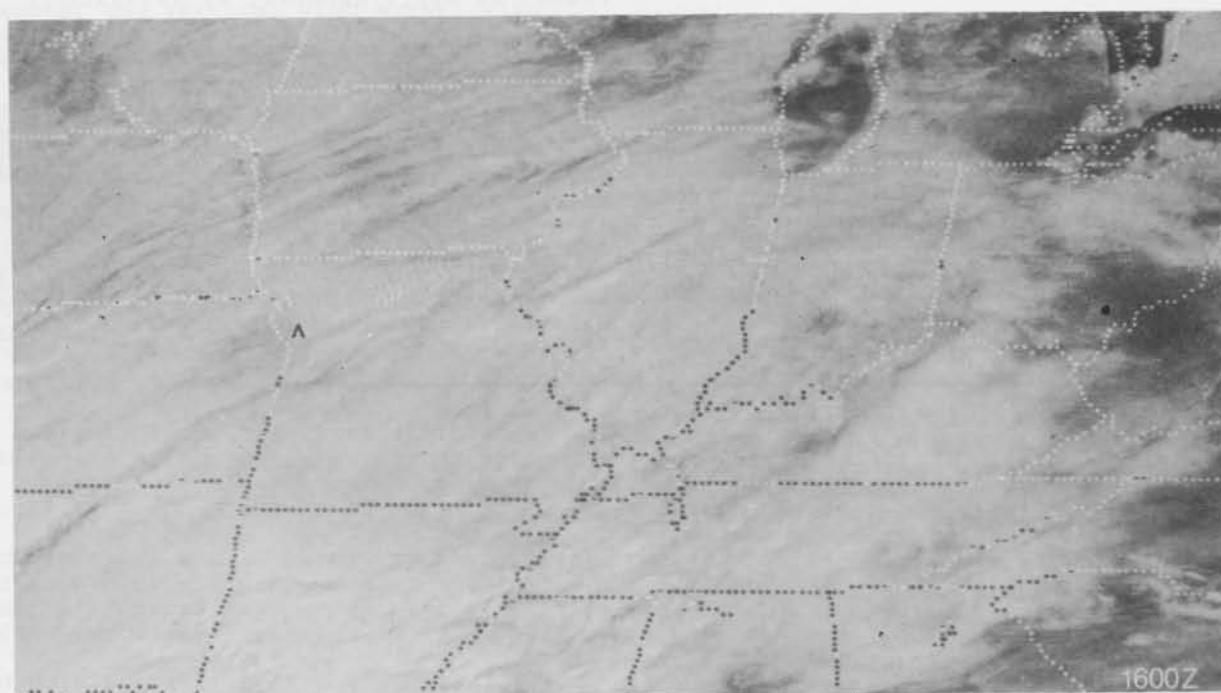


Figure 1.b

Figure 1. Hourly 2-km resolution visible imagery for 8 Feb. 1980. a) 1500 GMT b) 1600 GMT c) 1700 GMT d) 1800 GMT e) 1900 GMT f) 2000 GMT g) 2100 GMT. Turbulence symbols nearest observation time: light Λ , moderate Λ , and severe Λ .



Figure 1.c



Figure 1.d

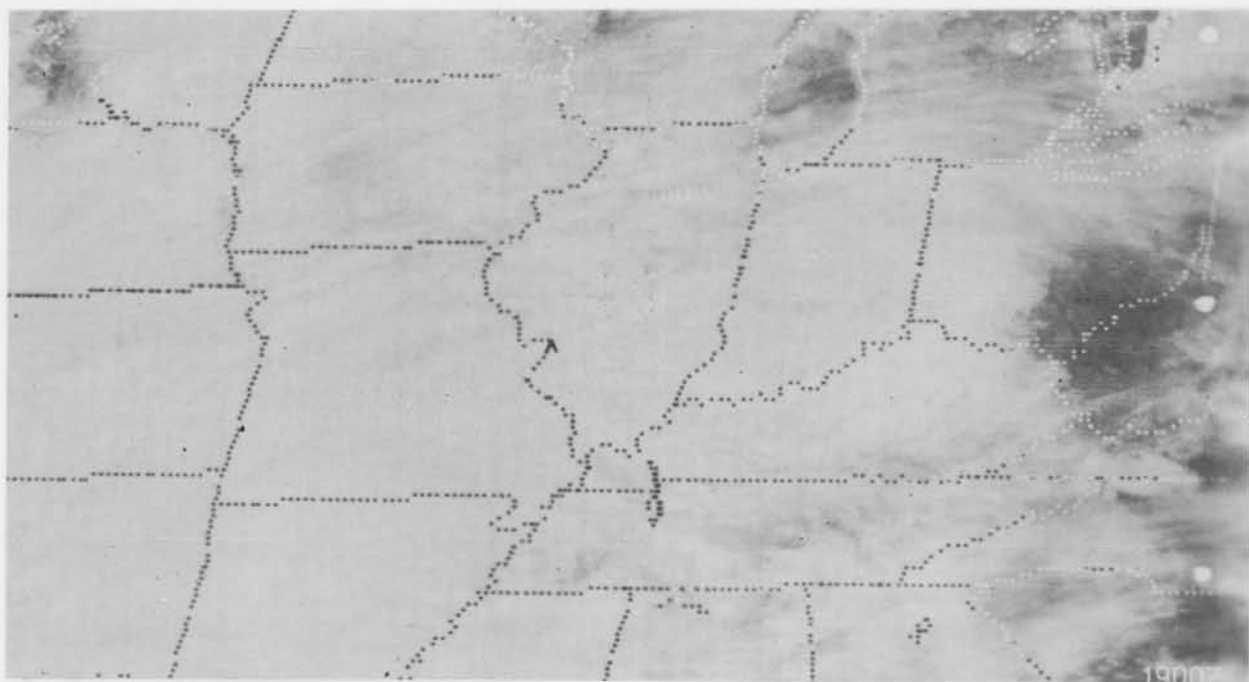


Figure 1.e

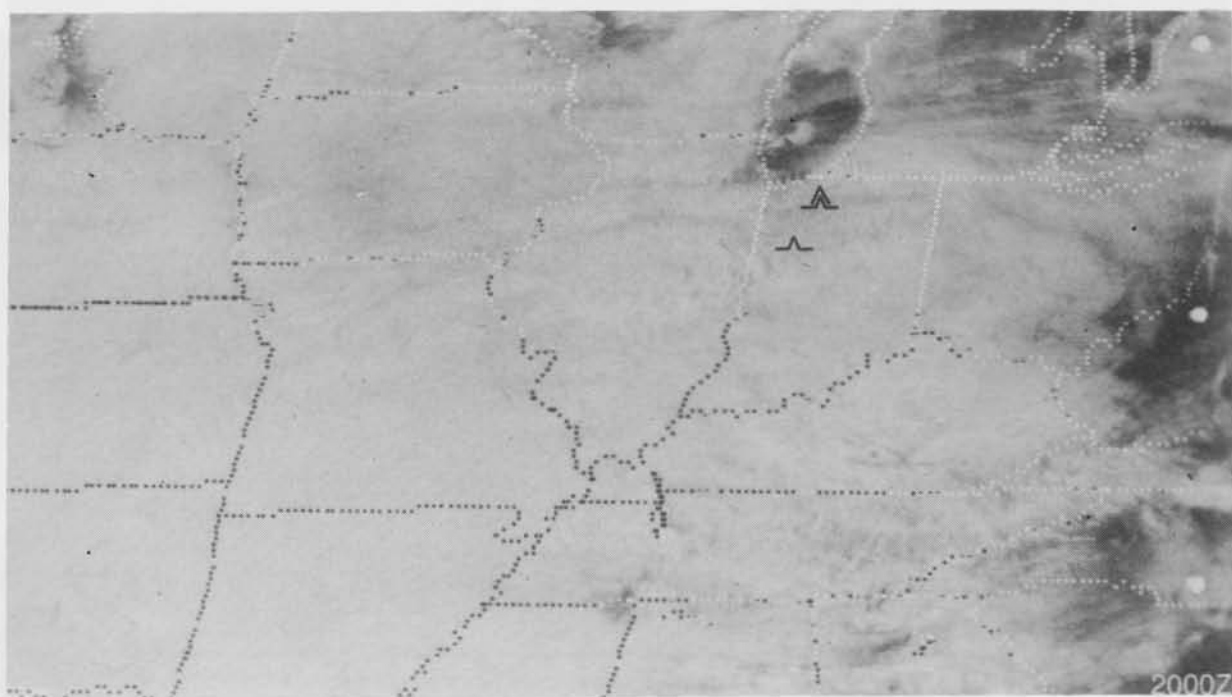


Figure 1.f



Figure 1.g



Figure 2. One-km visible image at 1630 GMT, 8 Feb.

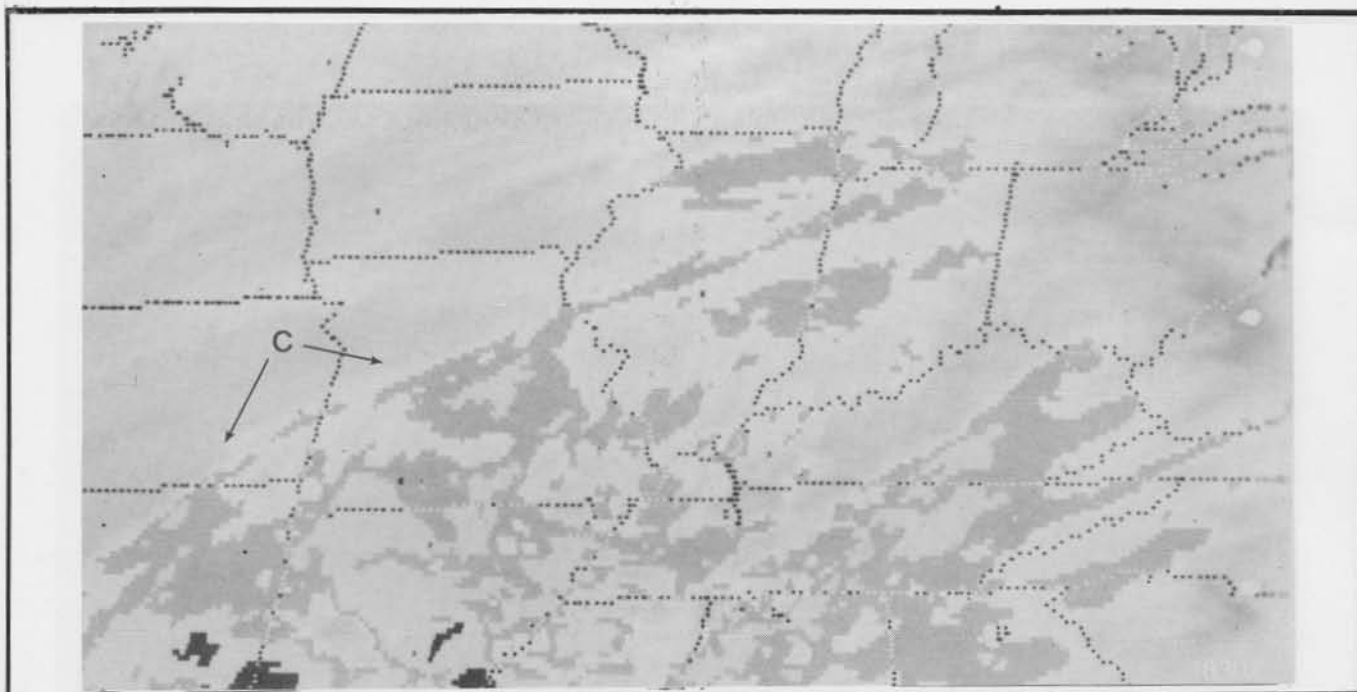
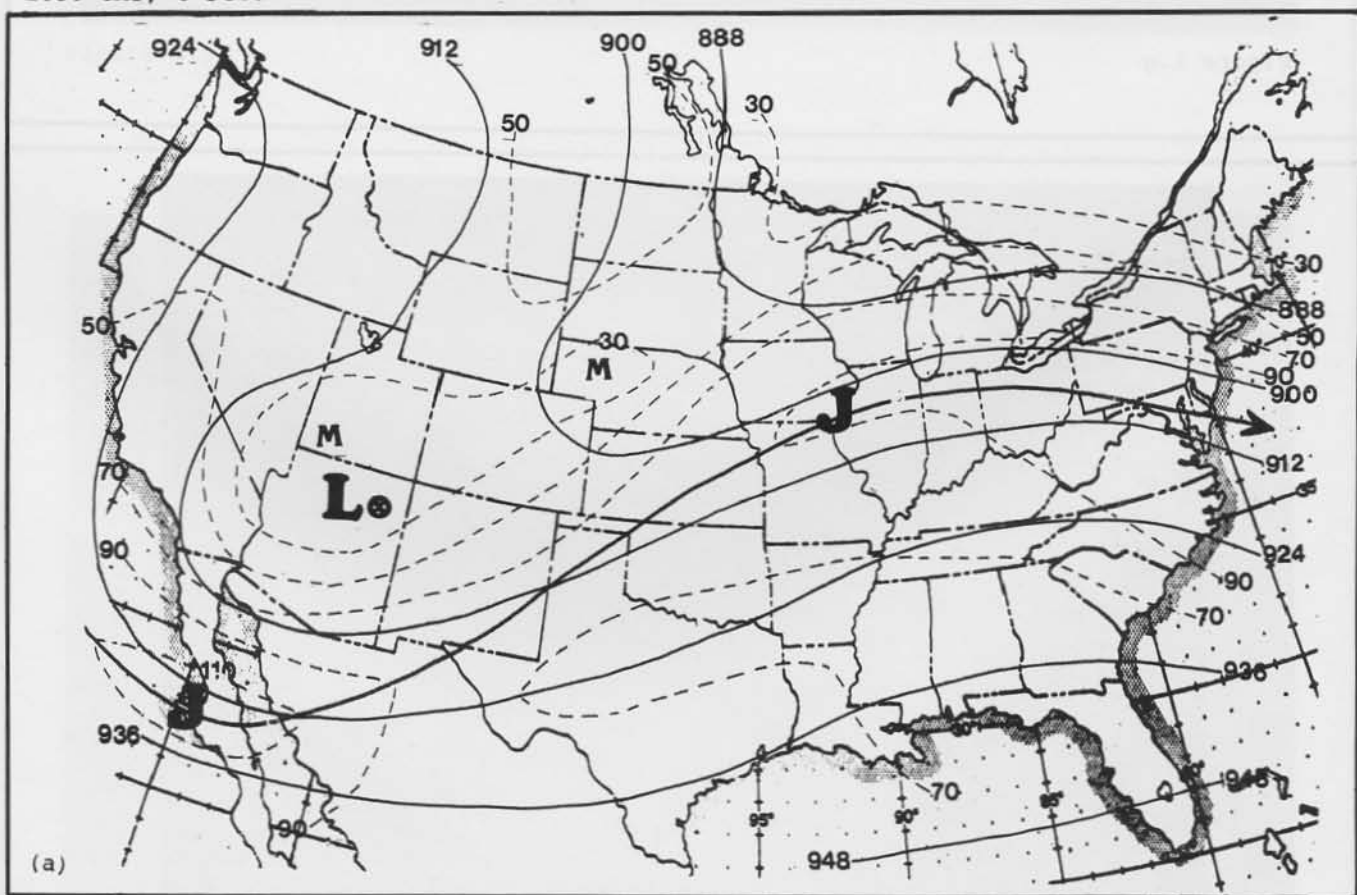


Figure 3. Eight-km resolution infrared image with M_b enhancement curve at 1630 GMT, 8 Feb.



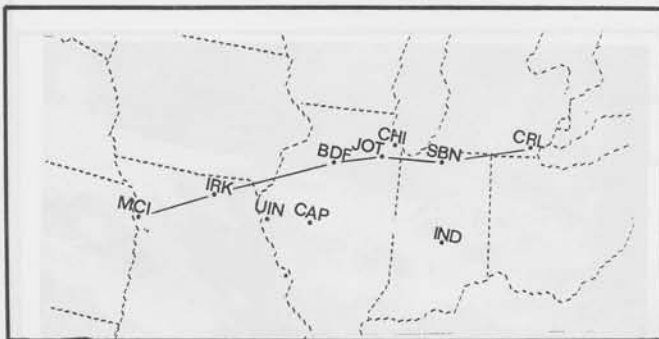
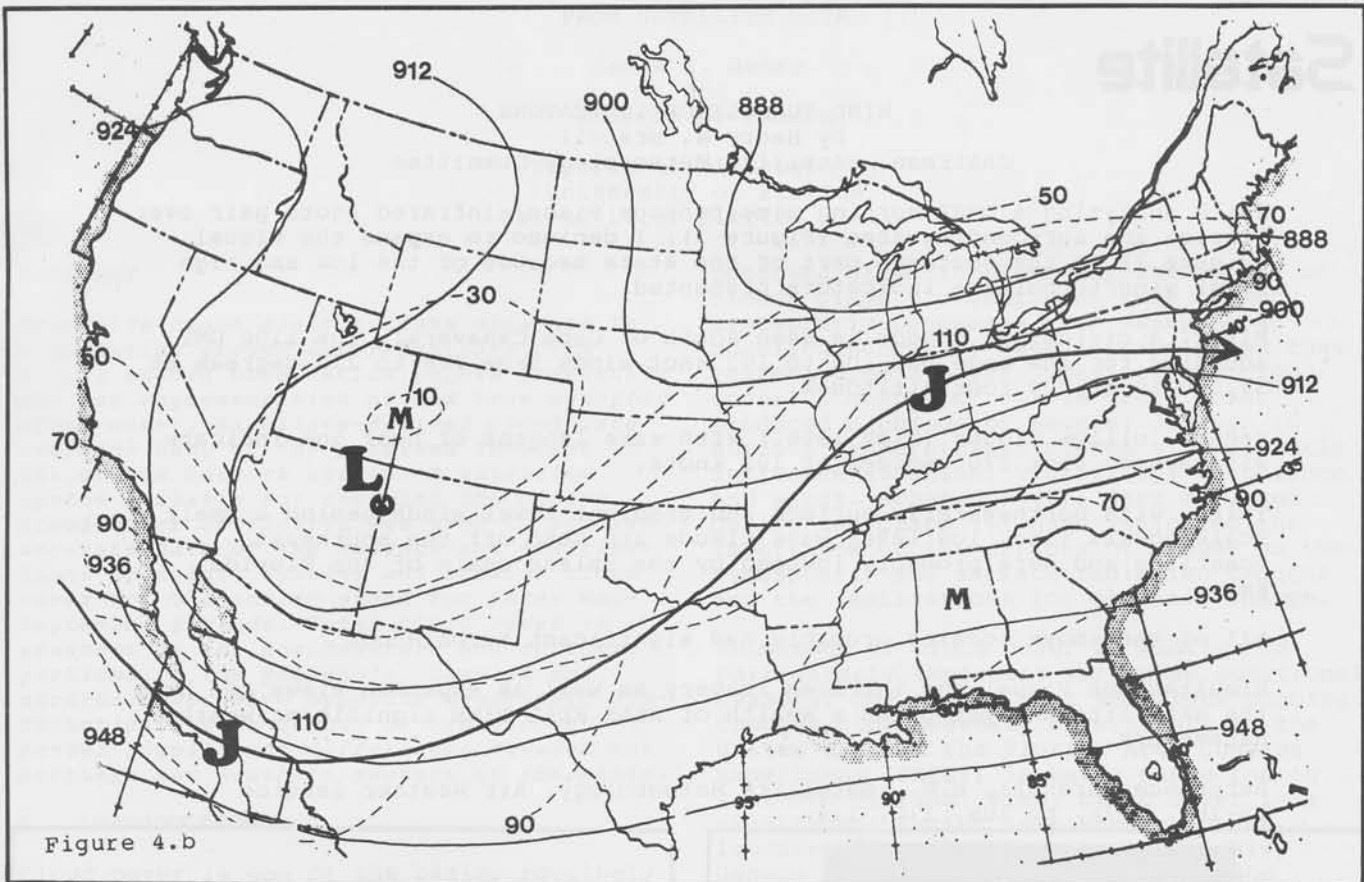


Figure 5. Location of stations in pilot reports. Solid line depicts main jet routes between Kansas City and Detroit.

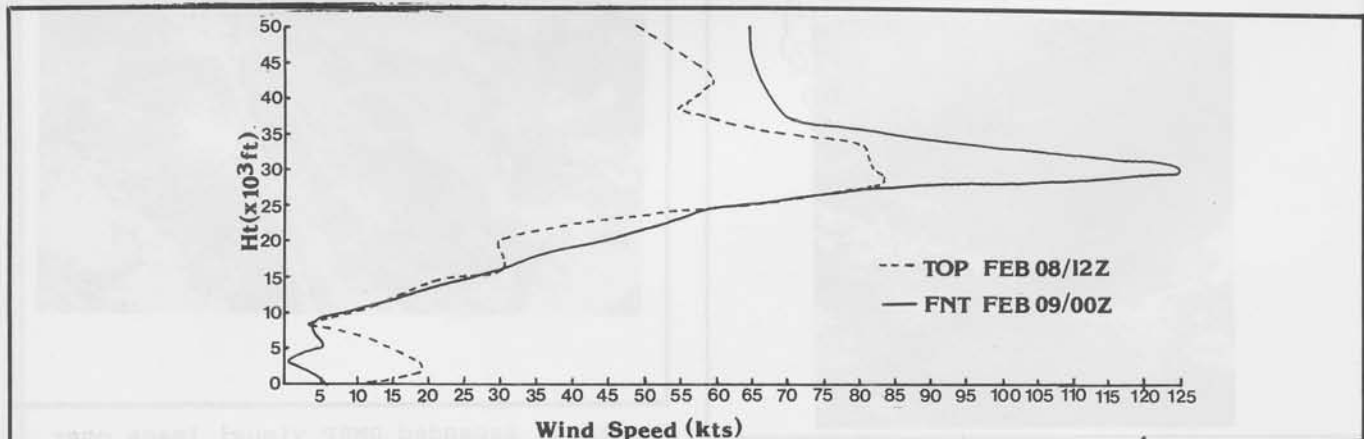


Figure 6. Wind speed profiles for Topeka, Kansas at 1200 GMT, 8 Feb and Flint, Michigan at 0000 GMT, 9 Feb.