High Wind Event on 17 August 2002 Associated With a Large Amplitude Gravity Wave

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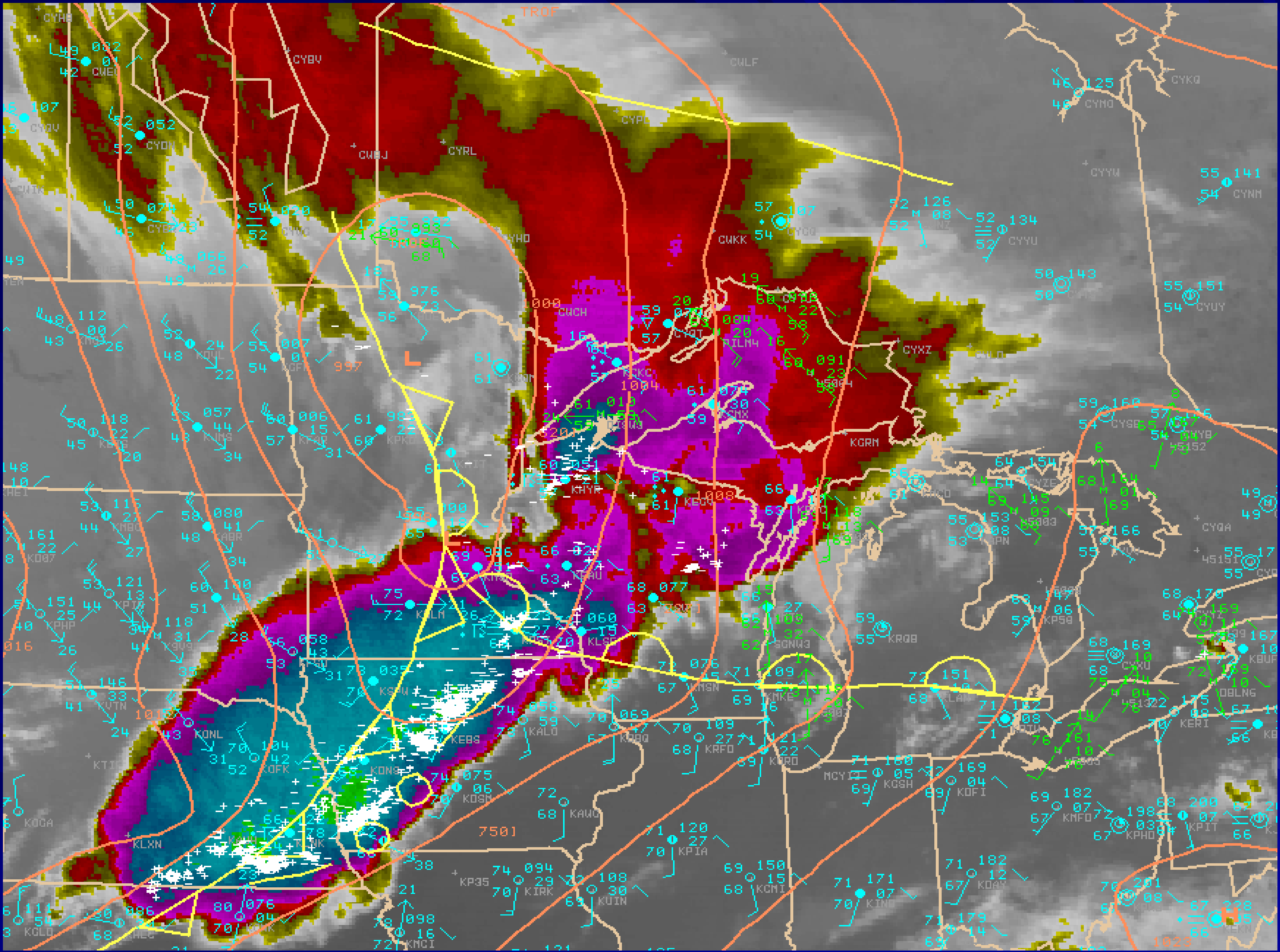
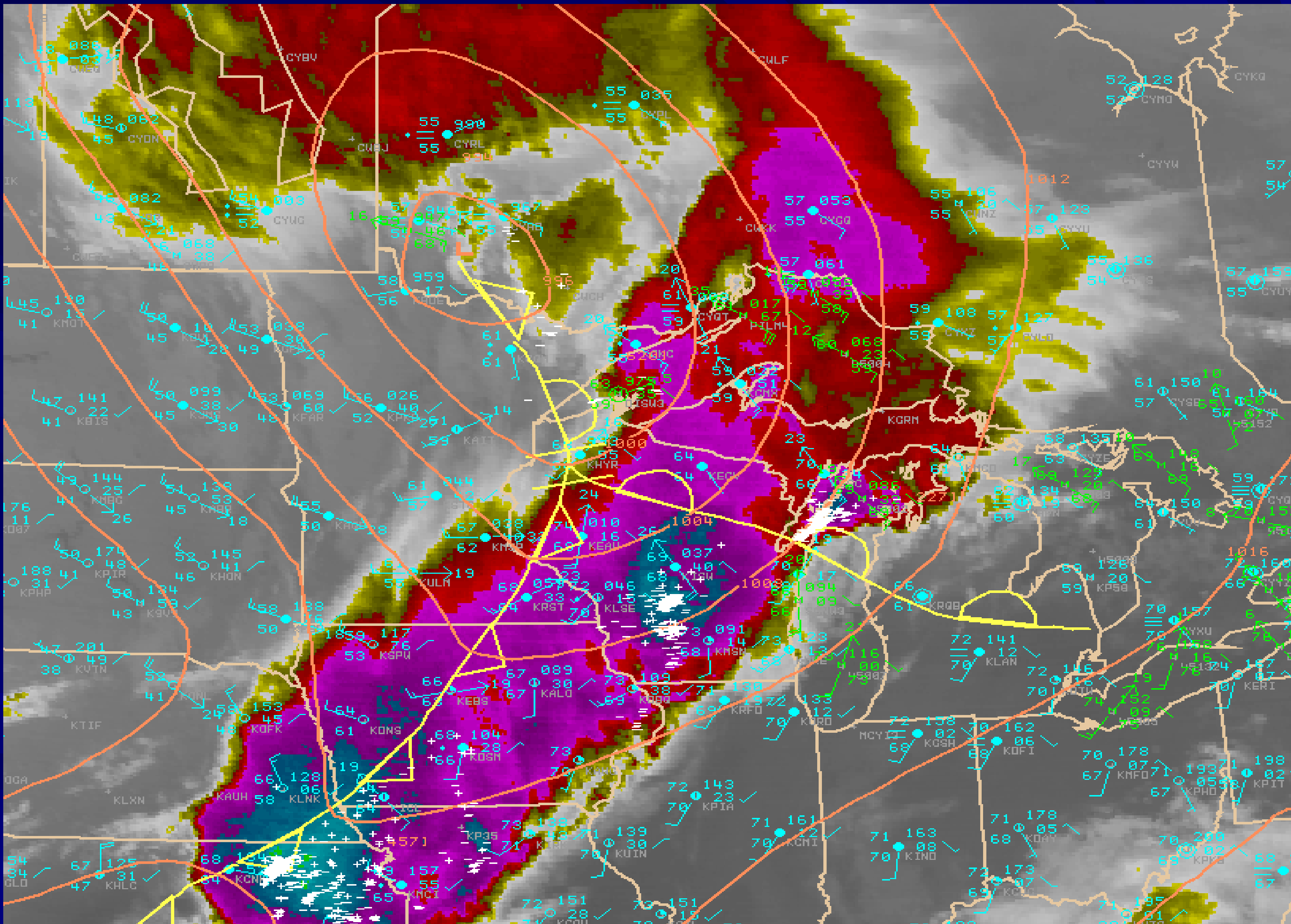
What will be covered

- Synoptic satellite and radar overview
- Event summary
- Review and application of gravity wave concepts to the case
- Forecast procedures

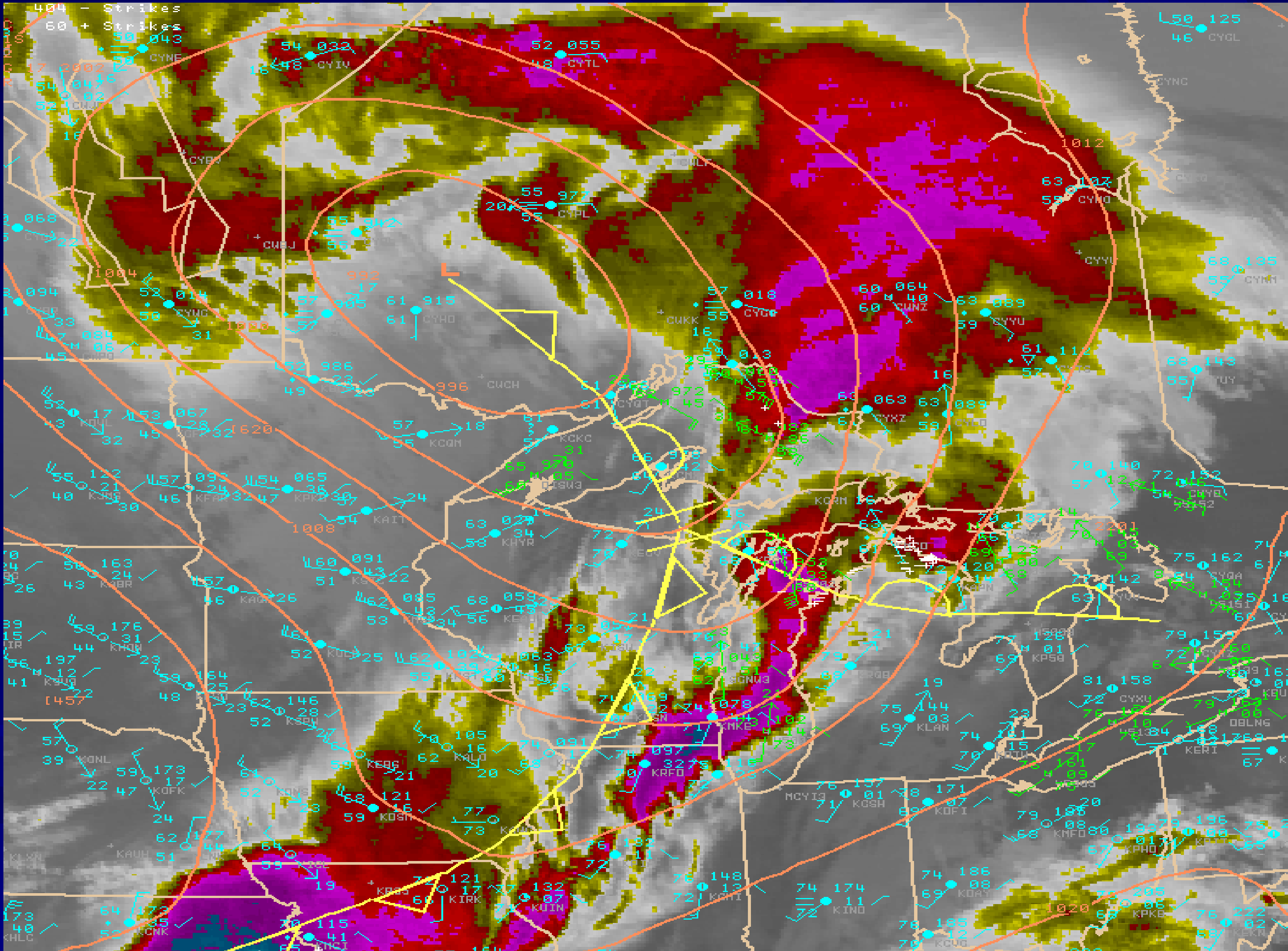
09Z (IR, HPC surface analysis)



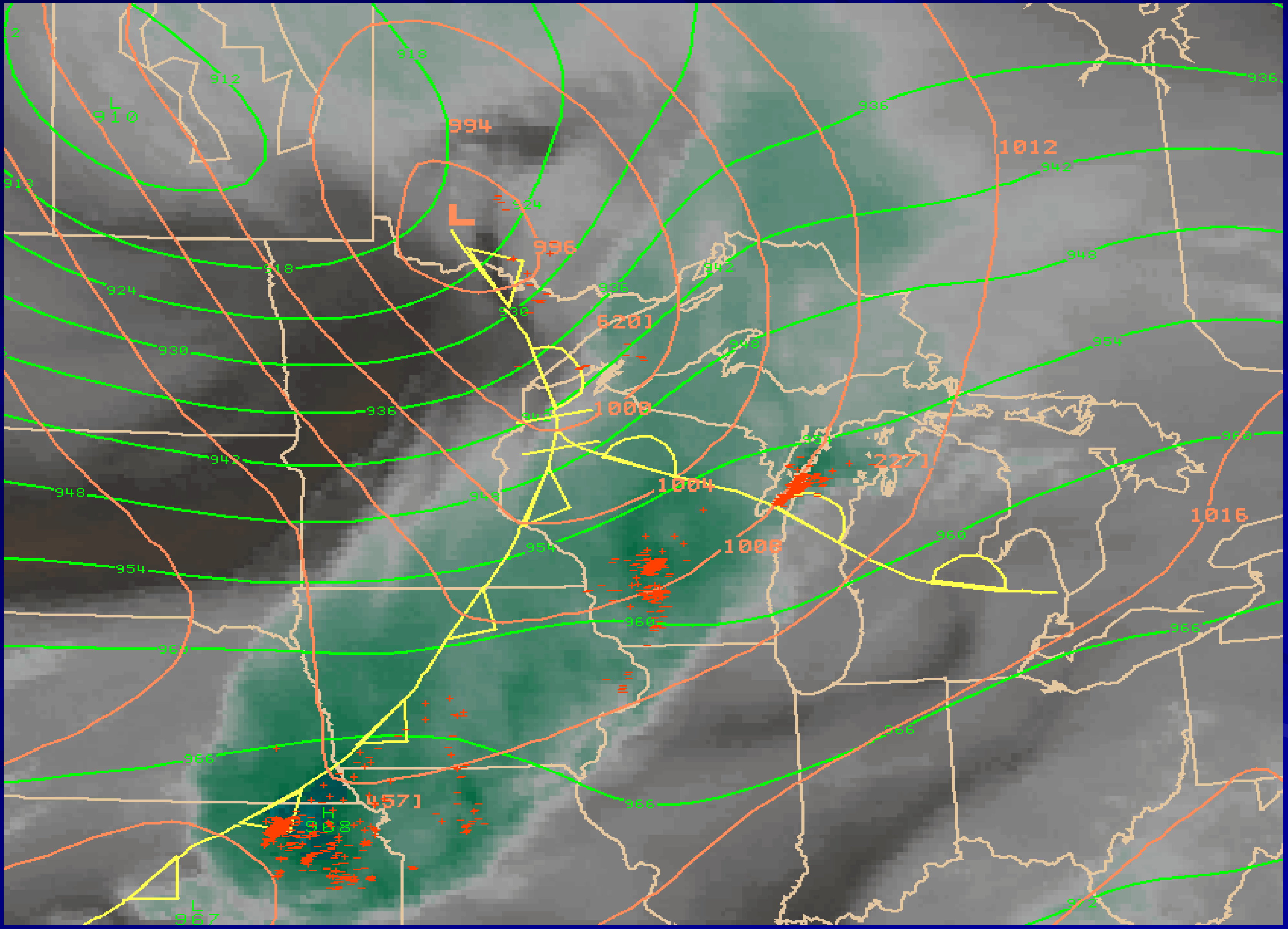
12Z (IR, HPC surface analysis)



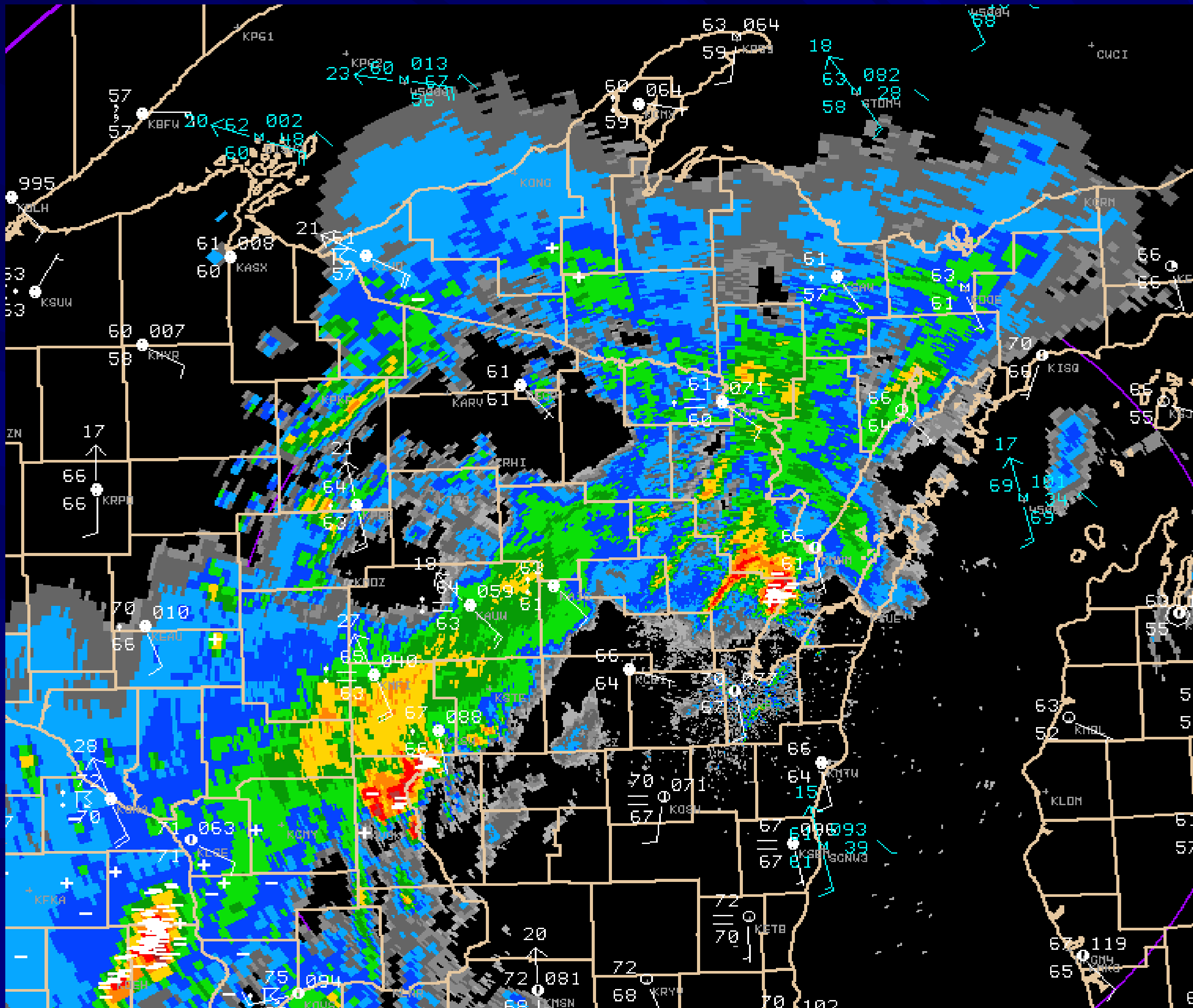
15Z (IR, HPC surface analysis)



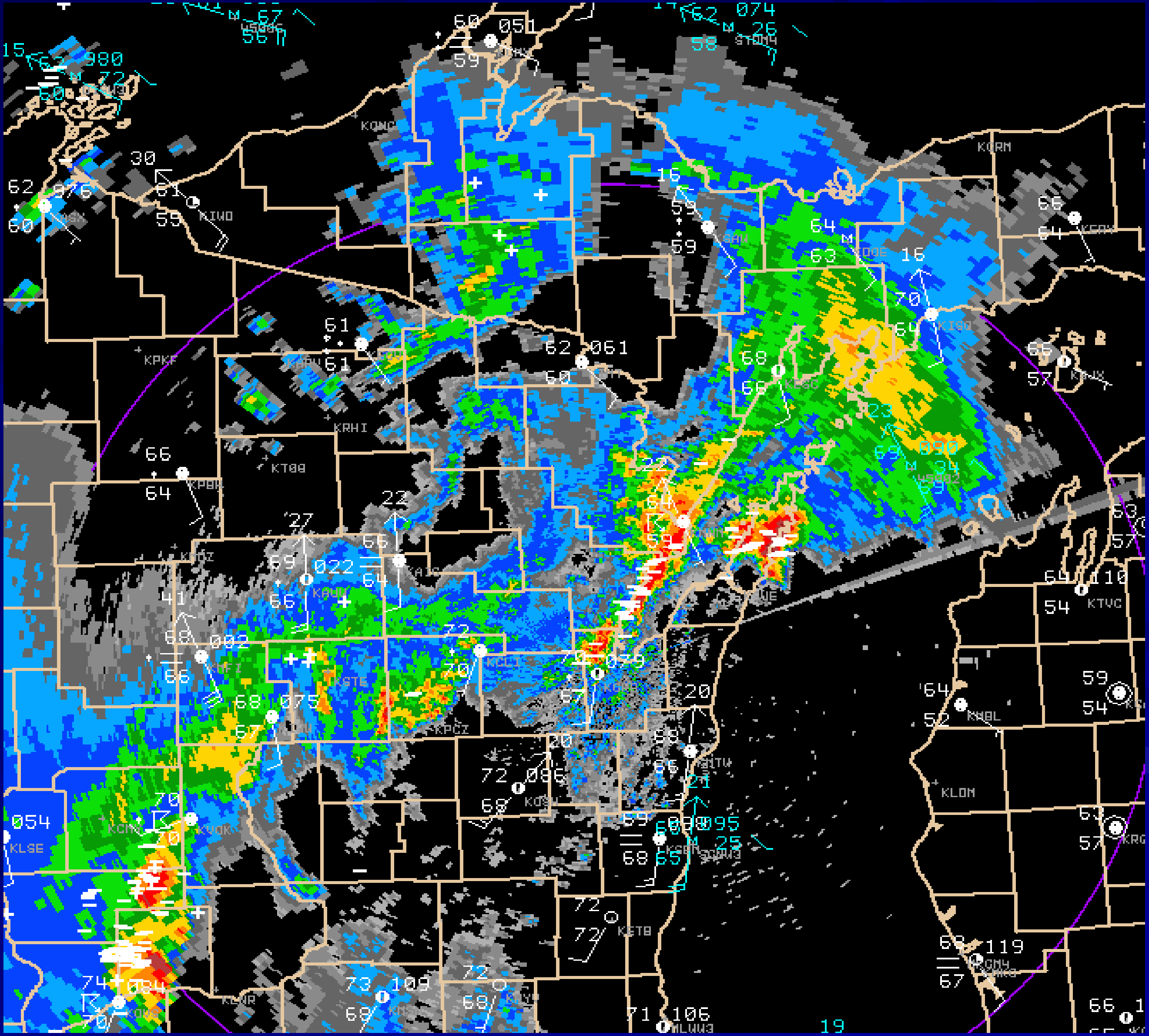
12Z (WV, 300 mb height, HPC surface analysis)



10Z Reflectivity (0.5)



11Z Reflectivity (0.5)



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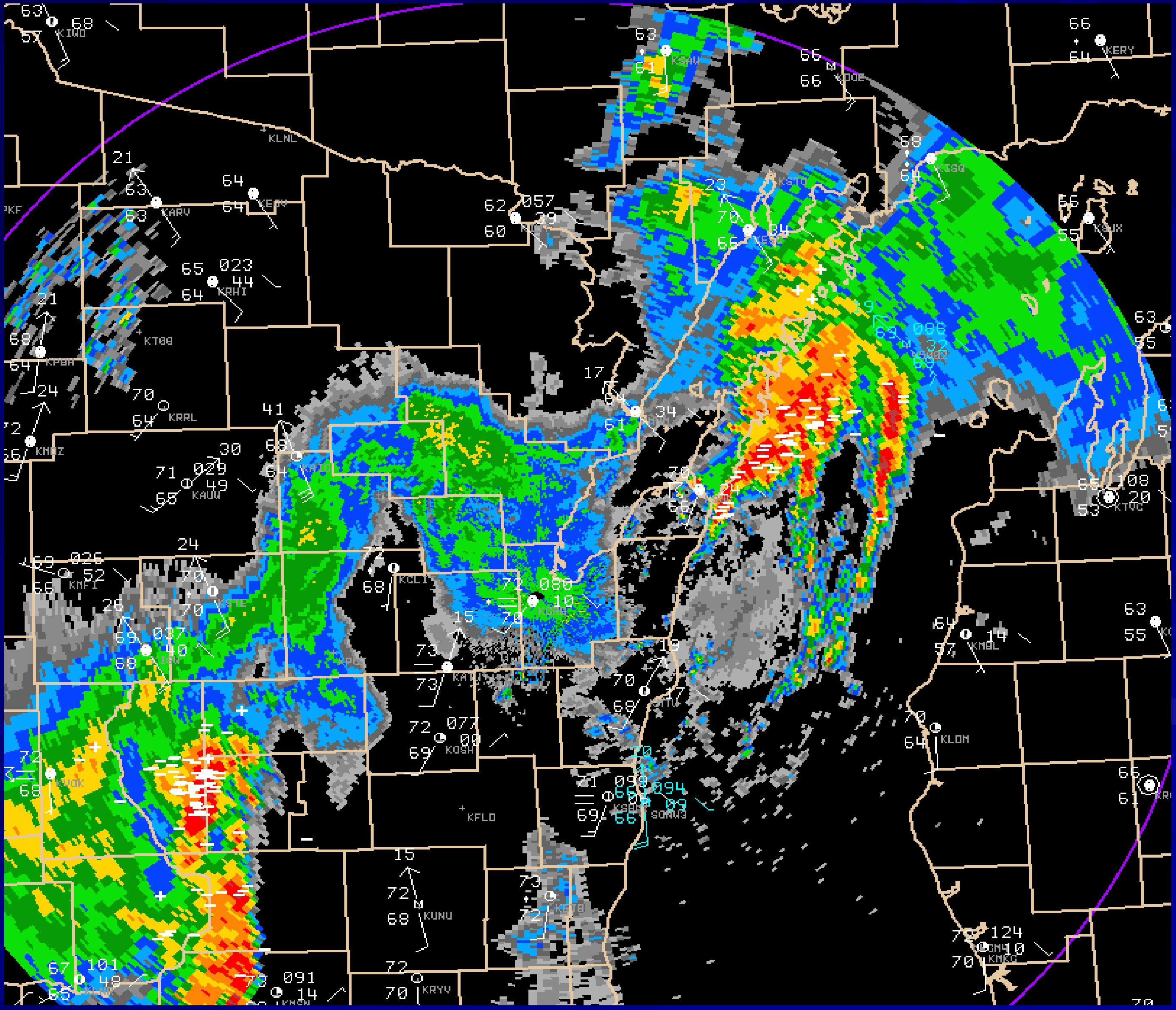

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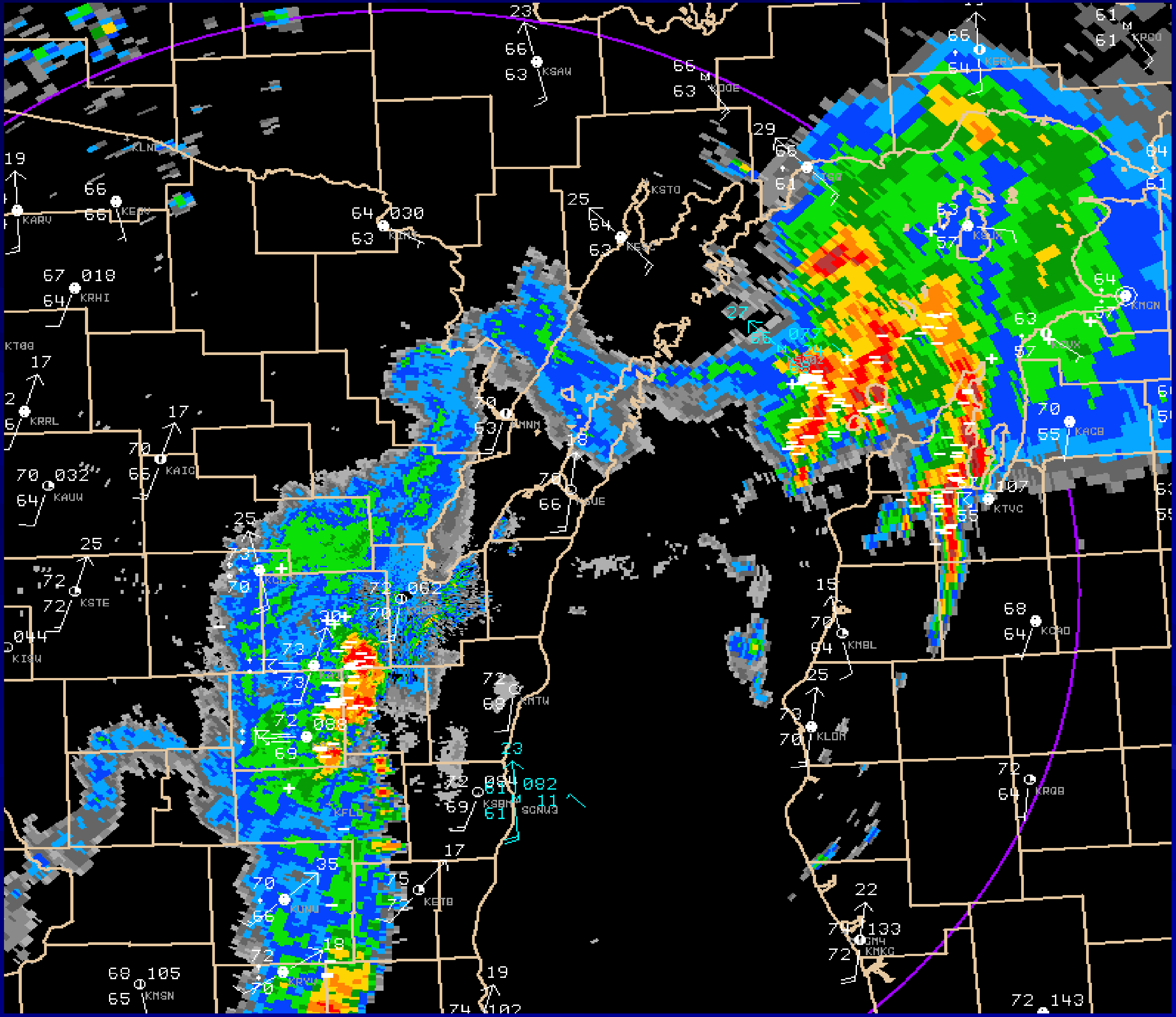
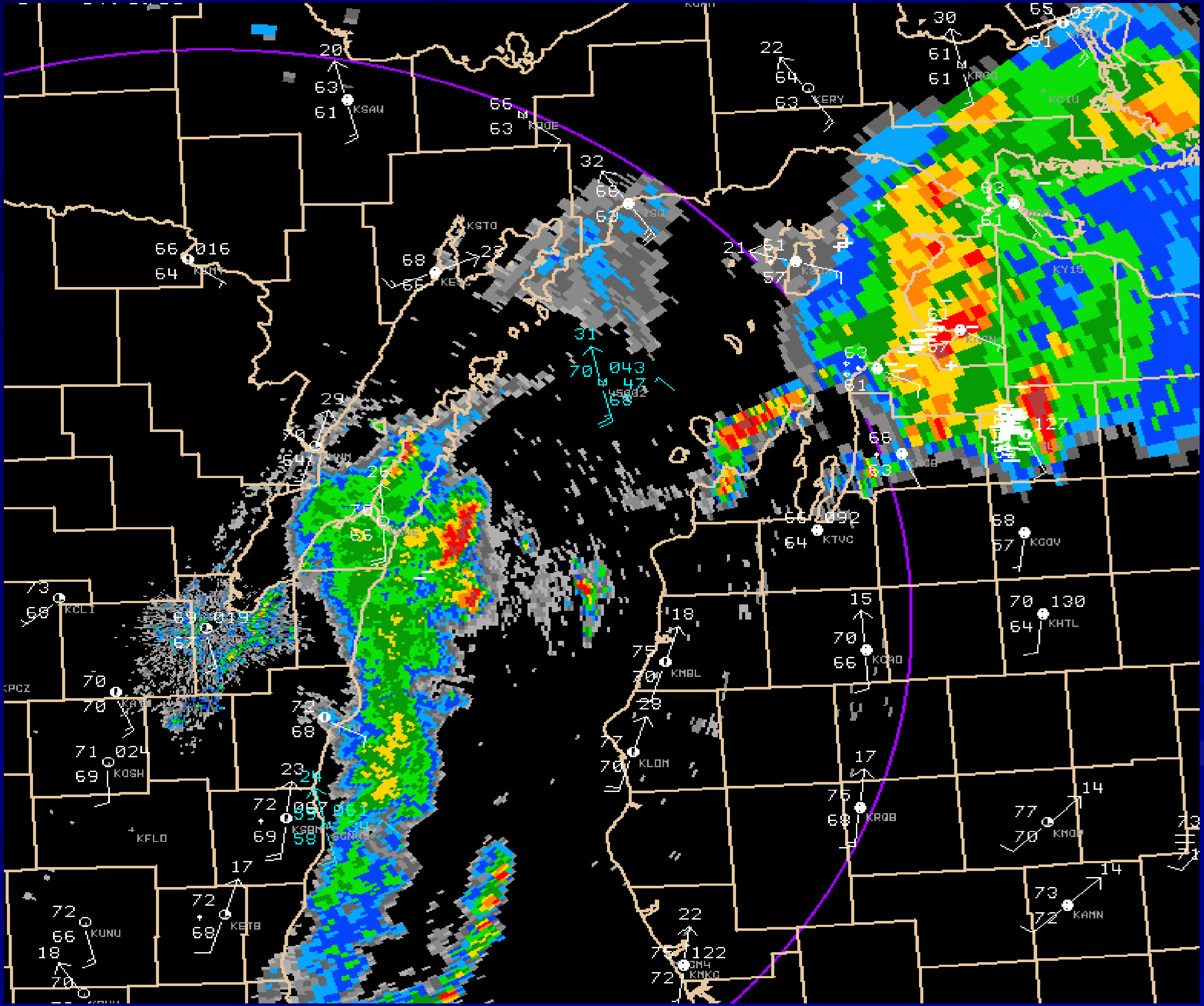


14Z Reflectivity (0.5)



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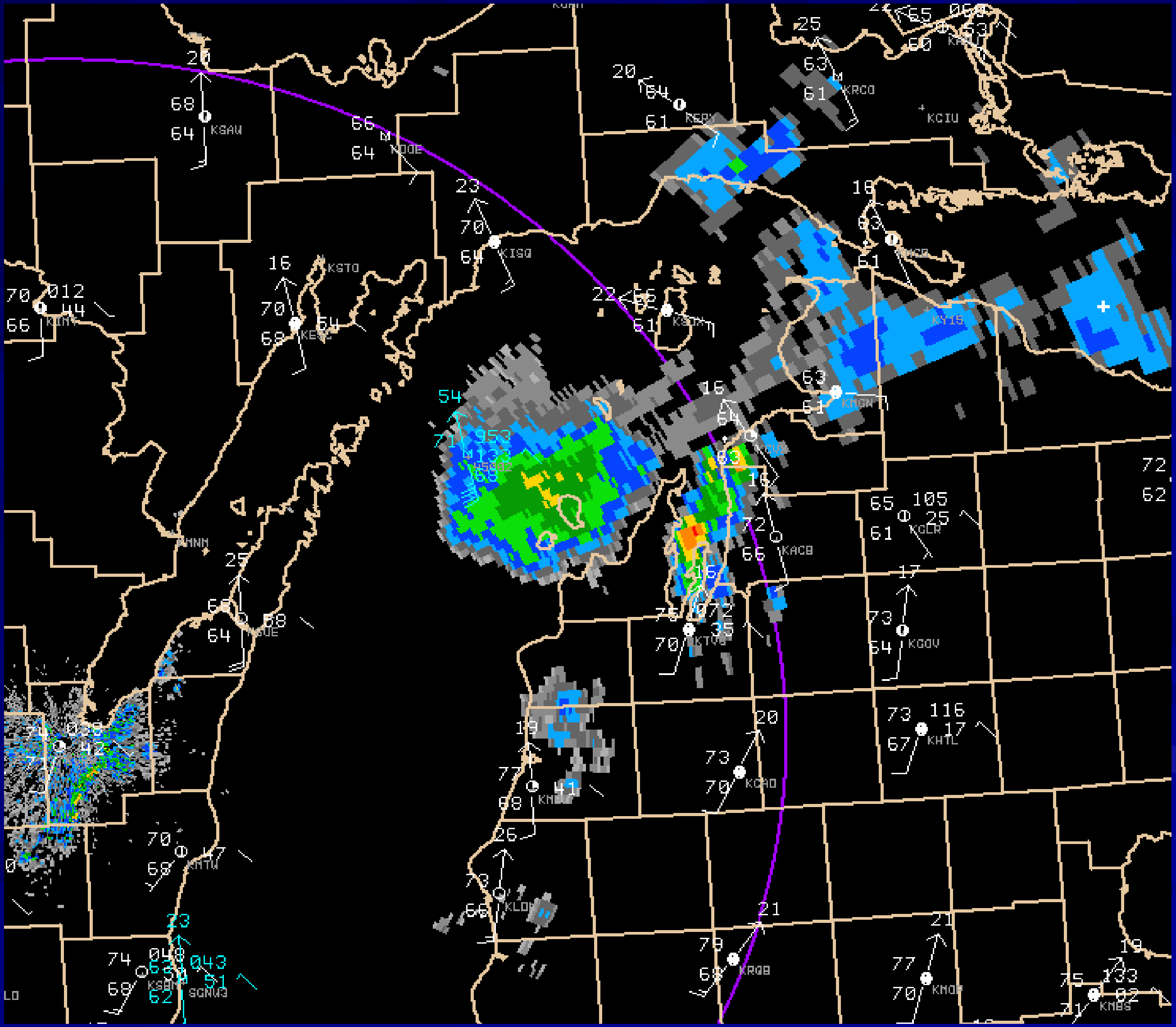
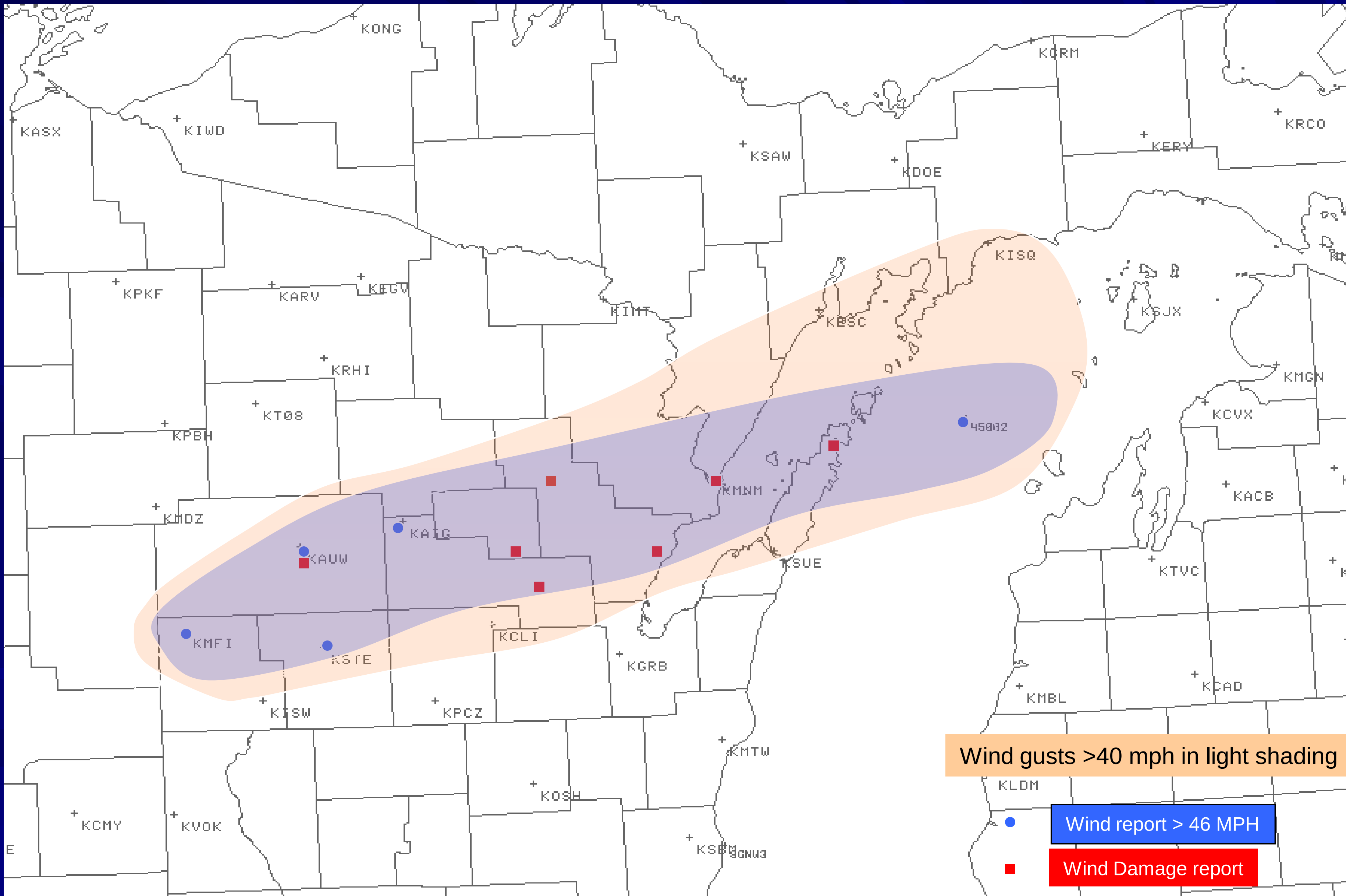


What Occurred?

- Non thunderstorm high winds exceeding 46 mph from central Wisconsin and southern Upper Michigan into northern Lake Michigan occurred between 10z and 16z 17 August 2002
- Numerous reports of trees, branches and power lines down from northeast Wisconsin into far south Upper Michigan

High Wind Reports



Notable gravity wave events producing high winds

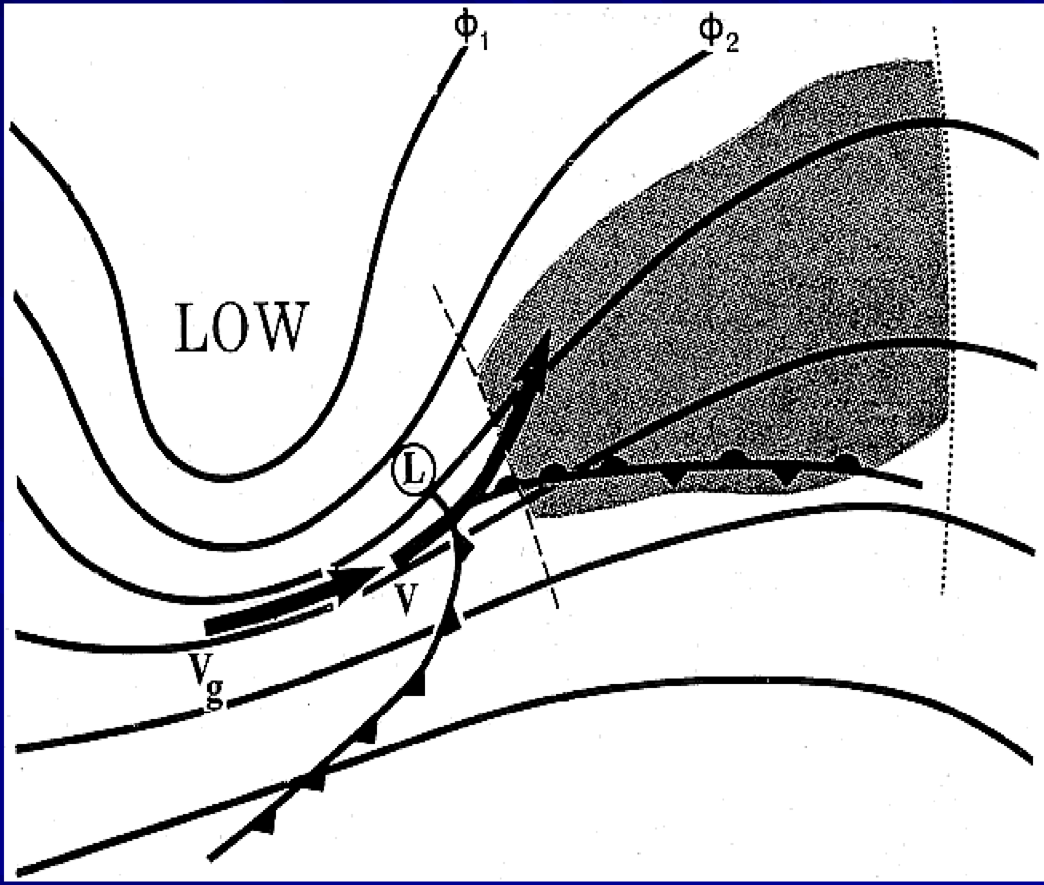
- 15 December 1987 Midwest Cyclone (Schneider, 1987)
  - Period of more intense blizzard conditions as wave where pressure perturbation up to 10 mb occurred
- 27 February 1984 southeast CONUS (Bosart and Seimon, 1988)
  - 65-70 mph winds with 3-14 mb pressure perturbation
- 28 April 1996 Mid Mississippi Valley (Gaffin, 1999)
  - 60 mph winds easterly winds in the wake of an MCS

Gravity Wave Review

- Gravity waves result from the action of the restoring force of gravity acting upon air parcels that are displaced vertically in a statically stable atmosphere (e.g., Holton, 1992)
- Caused by a wide range of phenomena
  - Topography - lee waves
  - Convection
  - Vertical shear instability
  - Geostrophic adjustment

synoptic pattern favoring geostrophic adjustment process

- Gravity waves are generated near the axis of inflection in the 300-mb height field and decay upon approaching the ridge axis
- Southern boundary of wave region is defined by the location of a surface stationary or warm front. An upper-level jet streak (**V**) must be propagating toward the inflection axis, and away from the geostrophic wind maximum (**V***g*), located at the base of the trough, for gravity waves to be generated by geostrophic adjustment processes, according to the conceptual model of Uccellini and Koch (1987) ,



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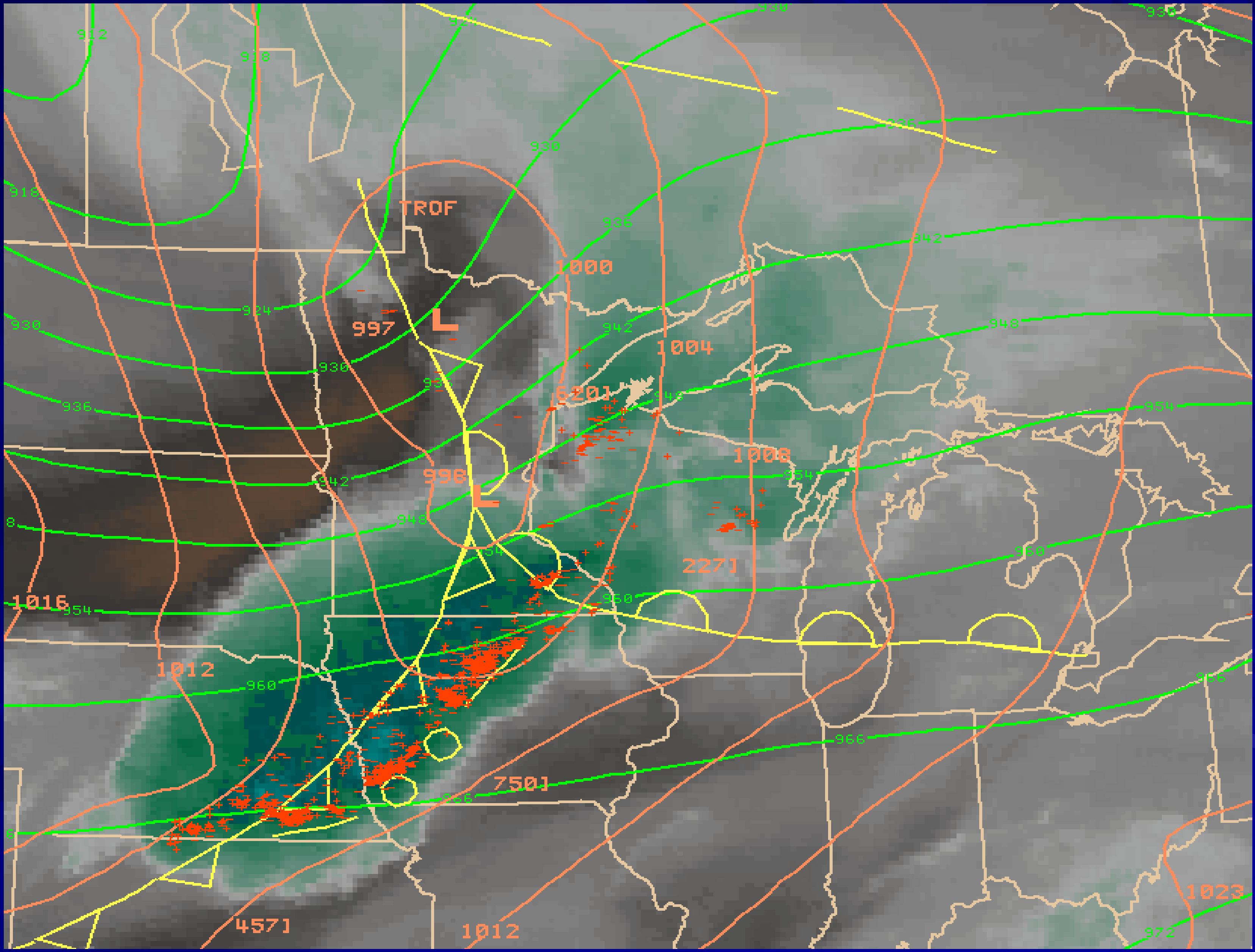

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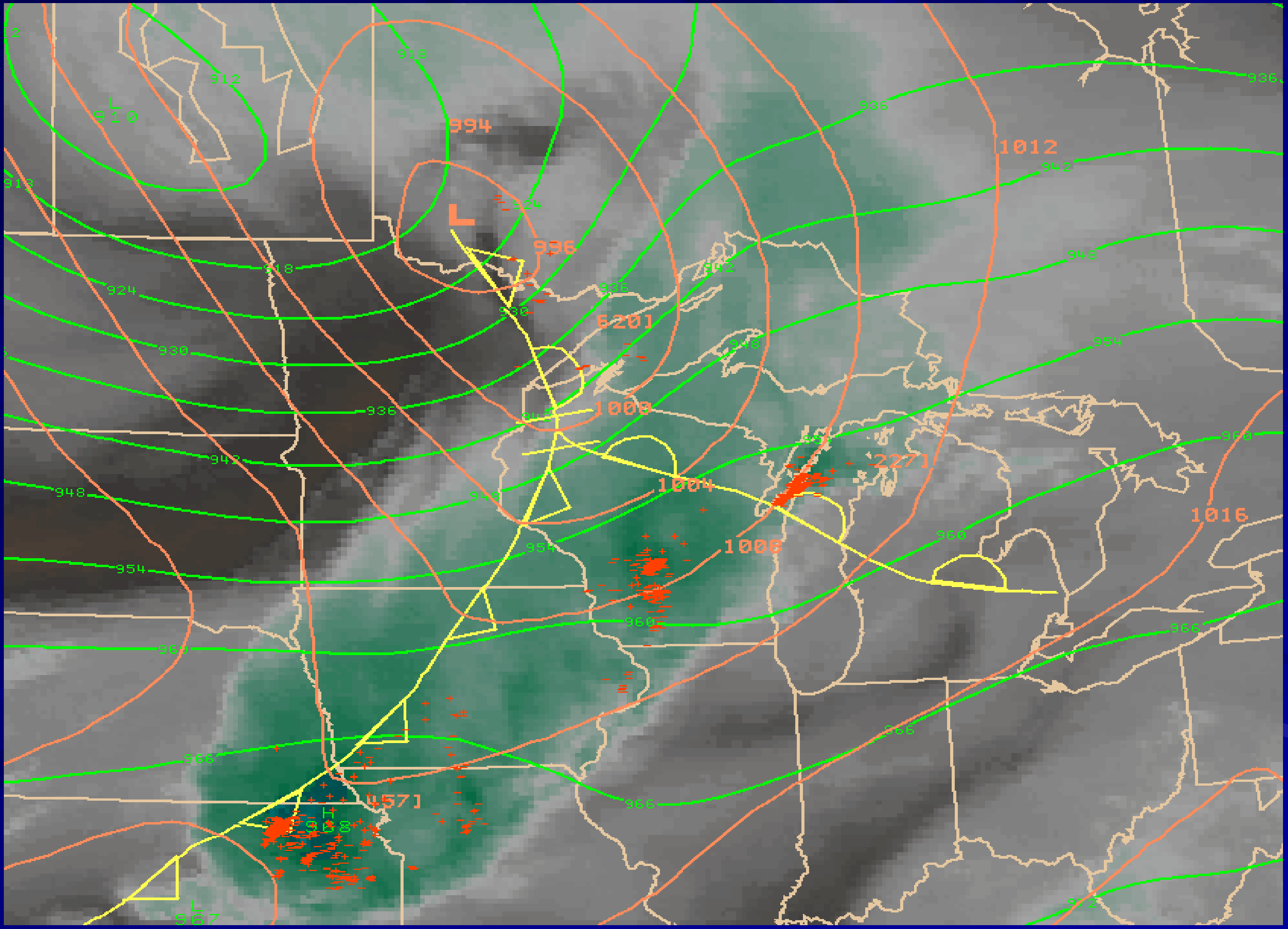
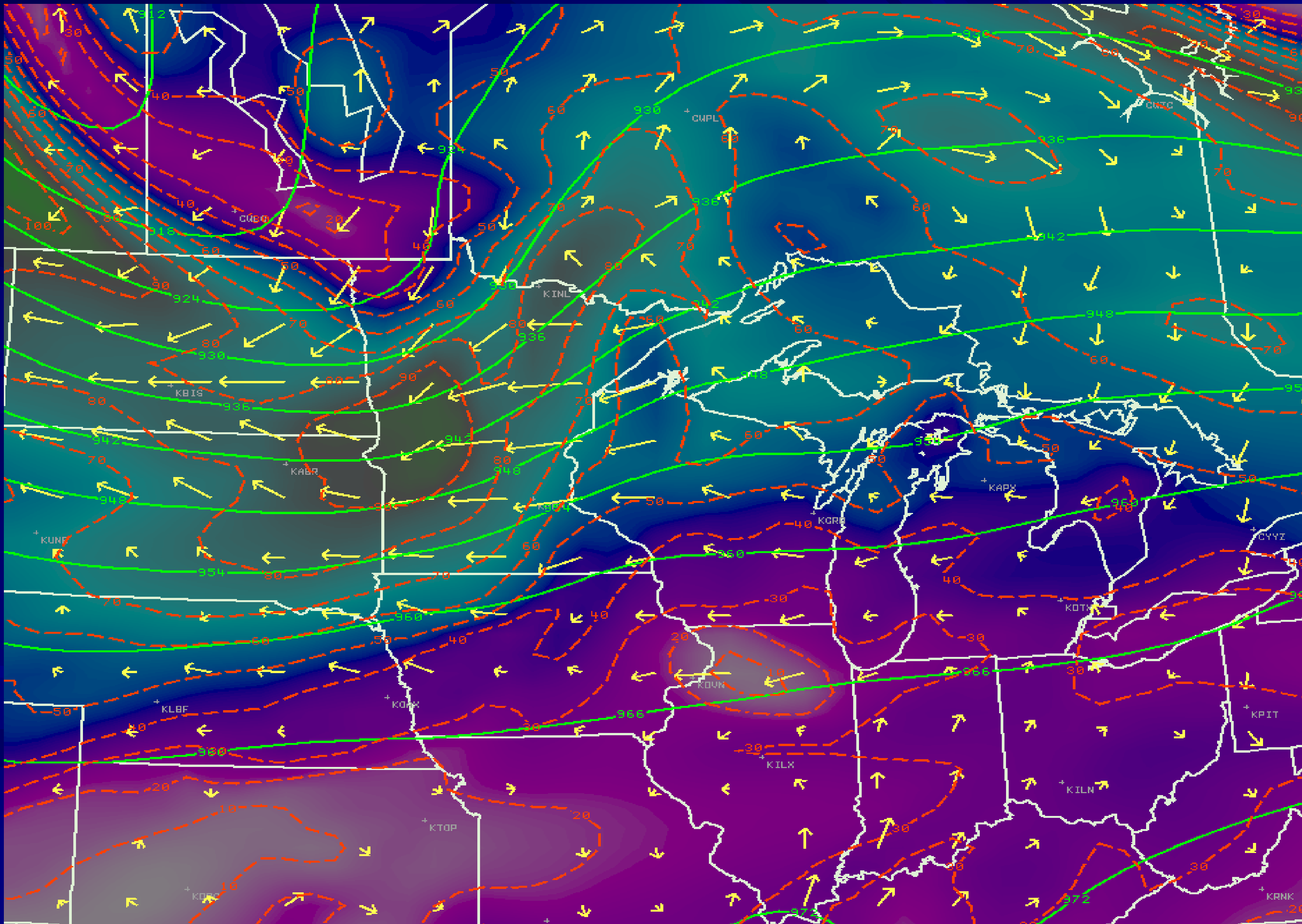


Lagrangian Rossby Number

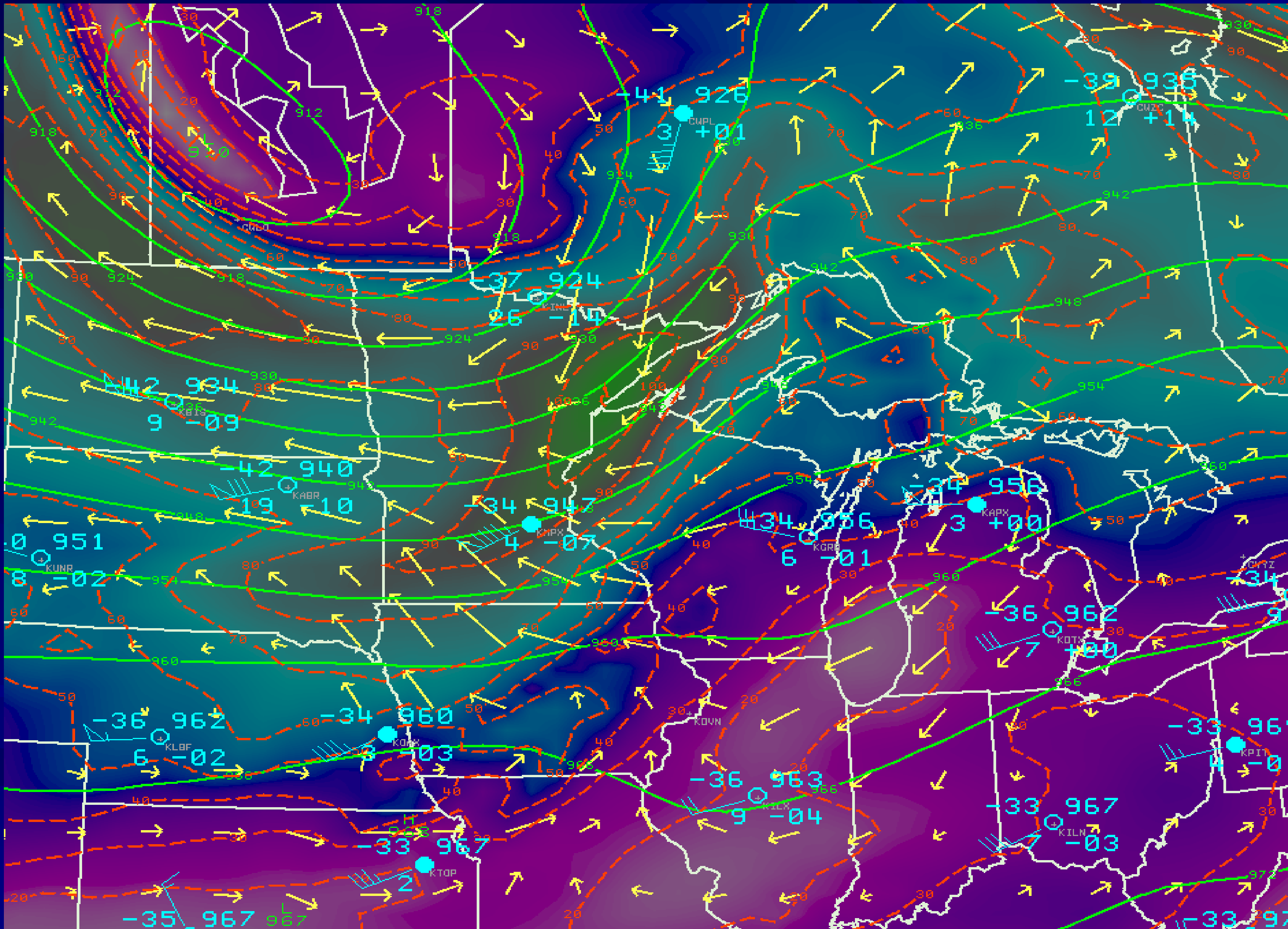
$$Ro_L \cong \frac{\left|\mathbf{V}_{\overrightarrow{ag}}\right|}{\left|\mathbf{V}\right|}$$

- Examine component of ageostrophic wind that is directed across height contours
- High RoL (greater than 0.5) with flow from anticyclonic side of the jet to lower heights in the exit of the geostrophic jet – would indicate “imbalance”
- Secondary wind circulation will be insufficient to restore mass-wind balance. Restoring process, known as the geostrophic adjustment process can generate gravity waves

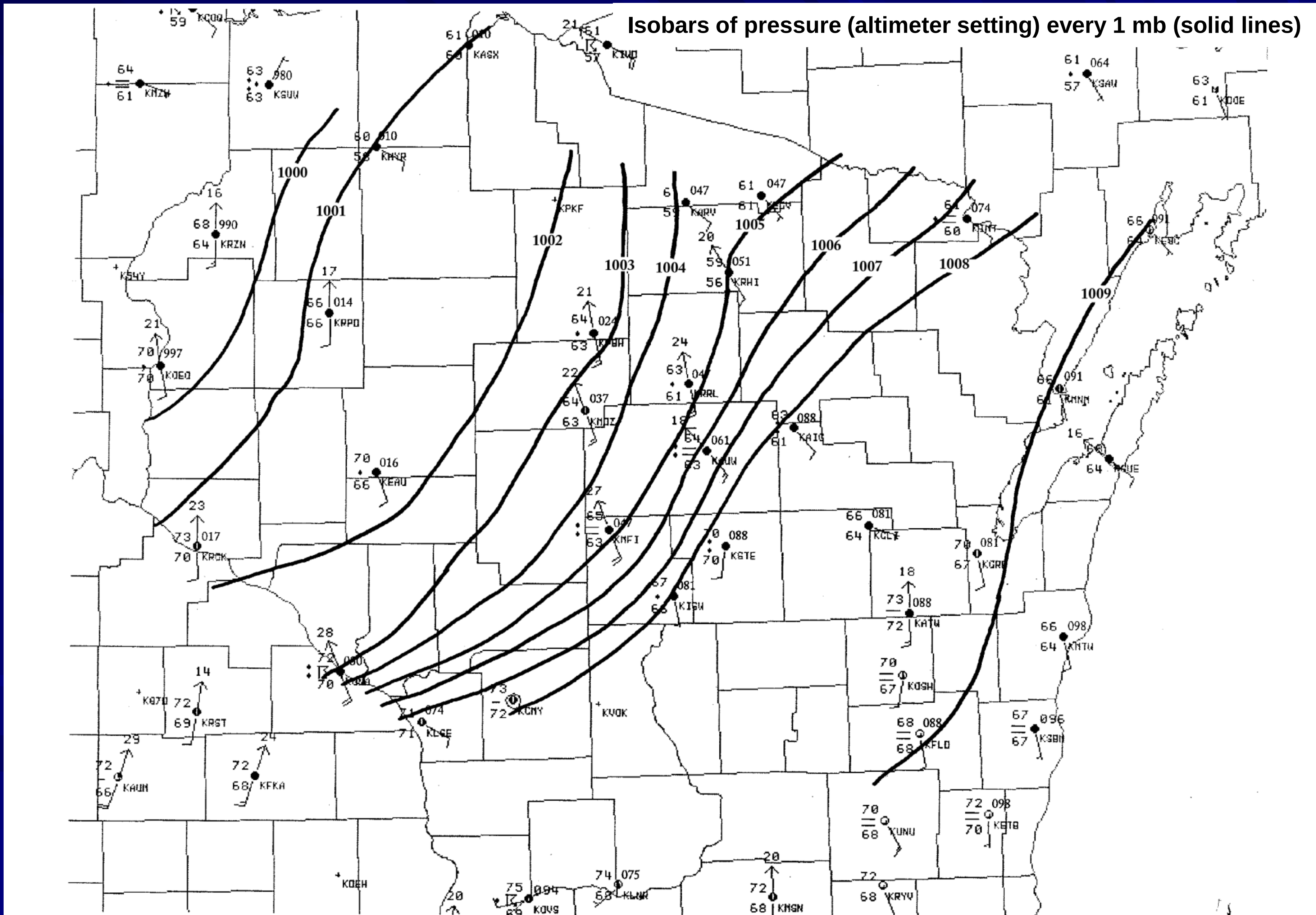
09z 300 mb (Eta 3 hr forecast Height, Windspeed, Ageostrophic wind arrows)



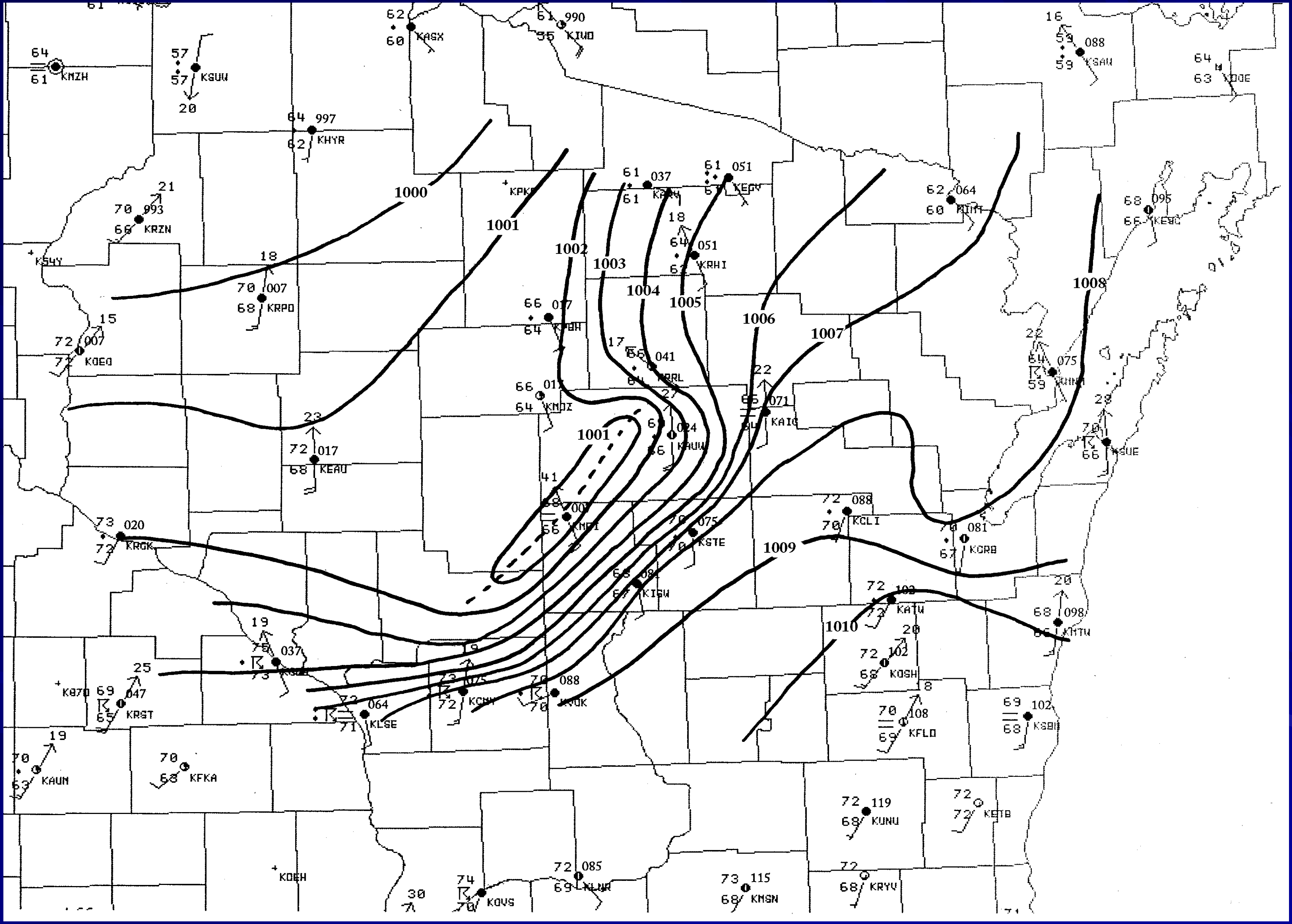
12z 300 mb (Eta 00 hr Height, Windspeed, Ageostrophic wind arrows)



10Z partial subjective surface analysis



11Z partial subjective surface analysis



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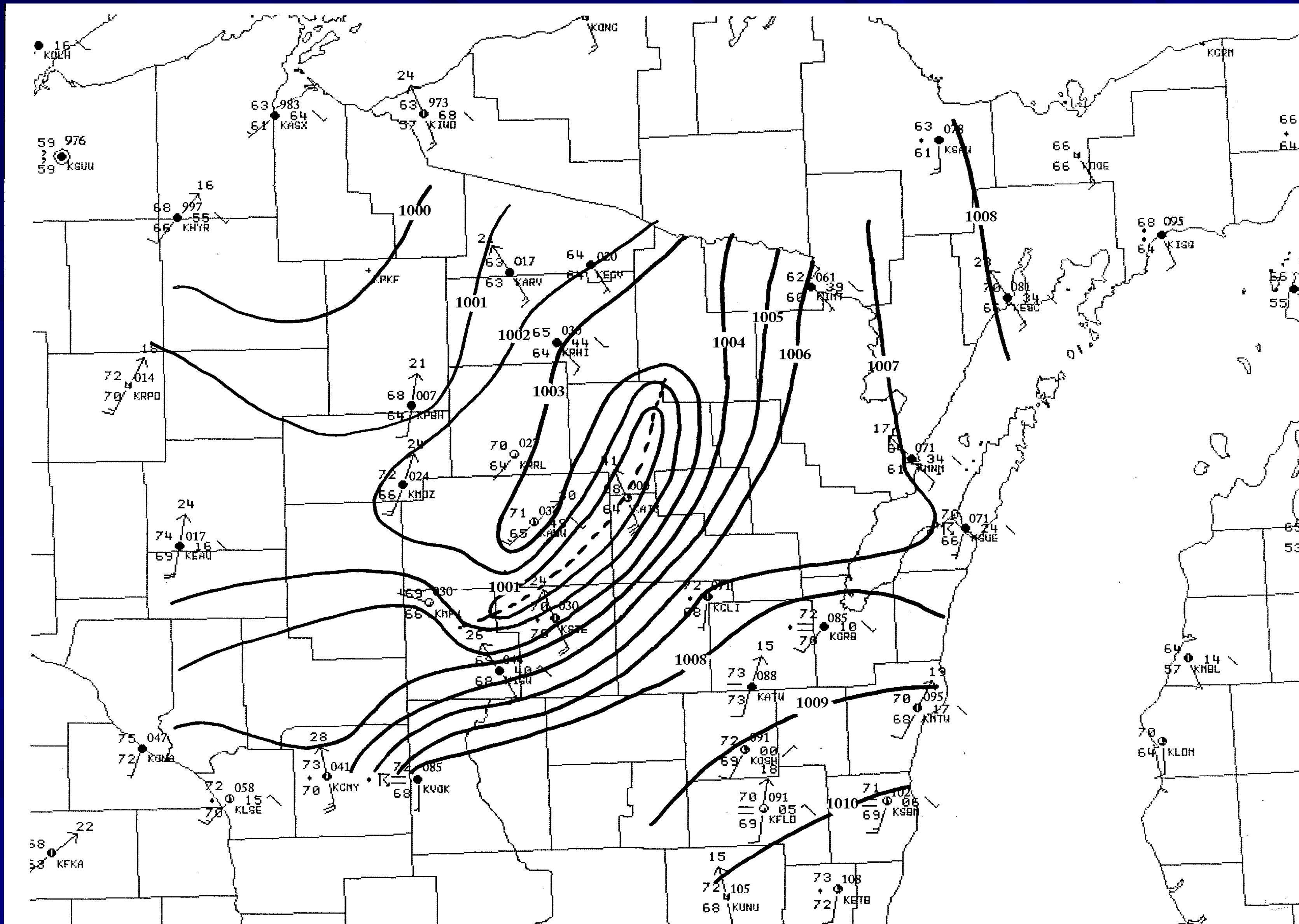

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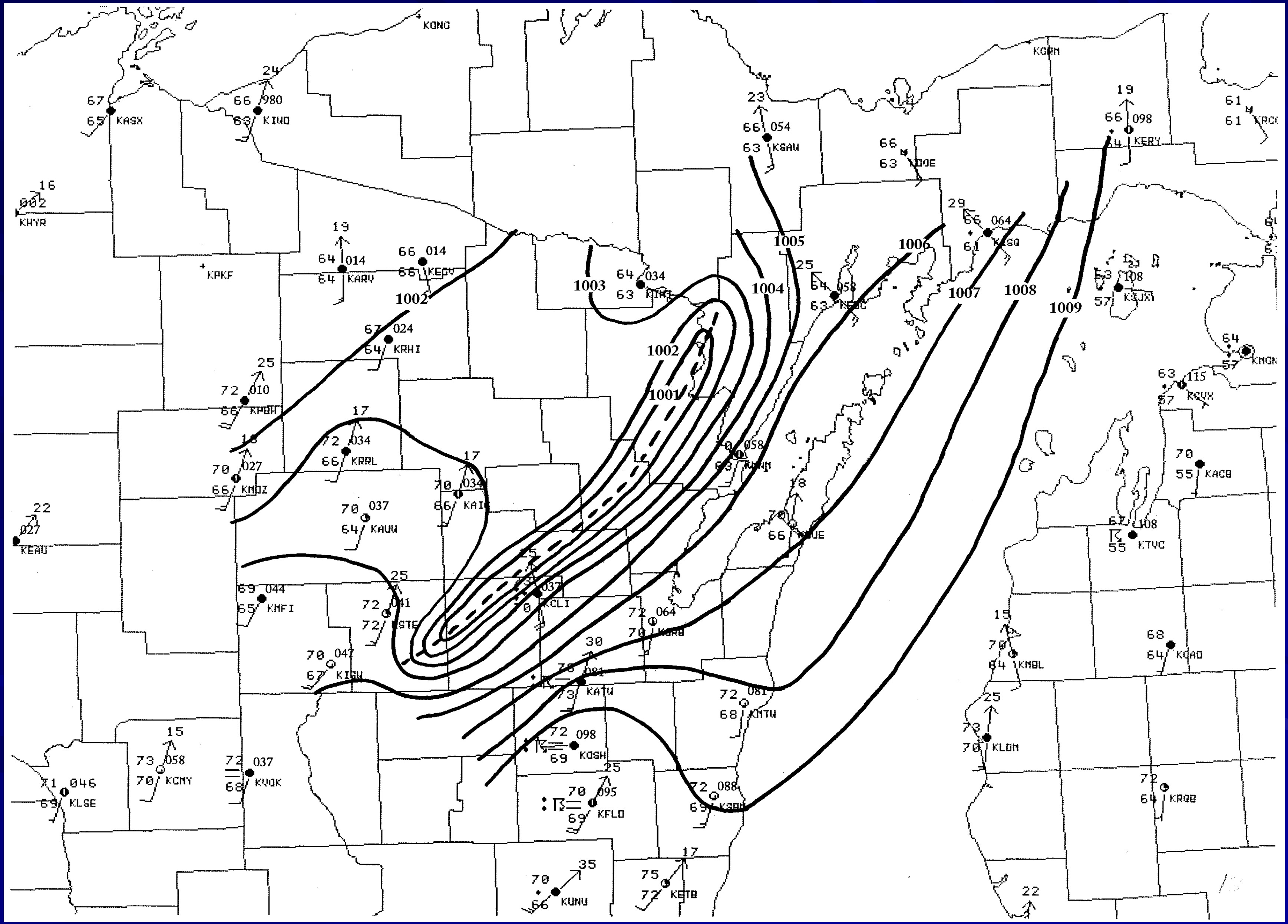

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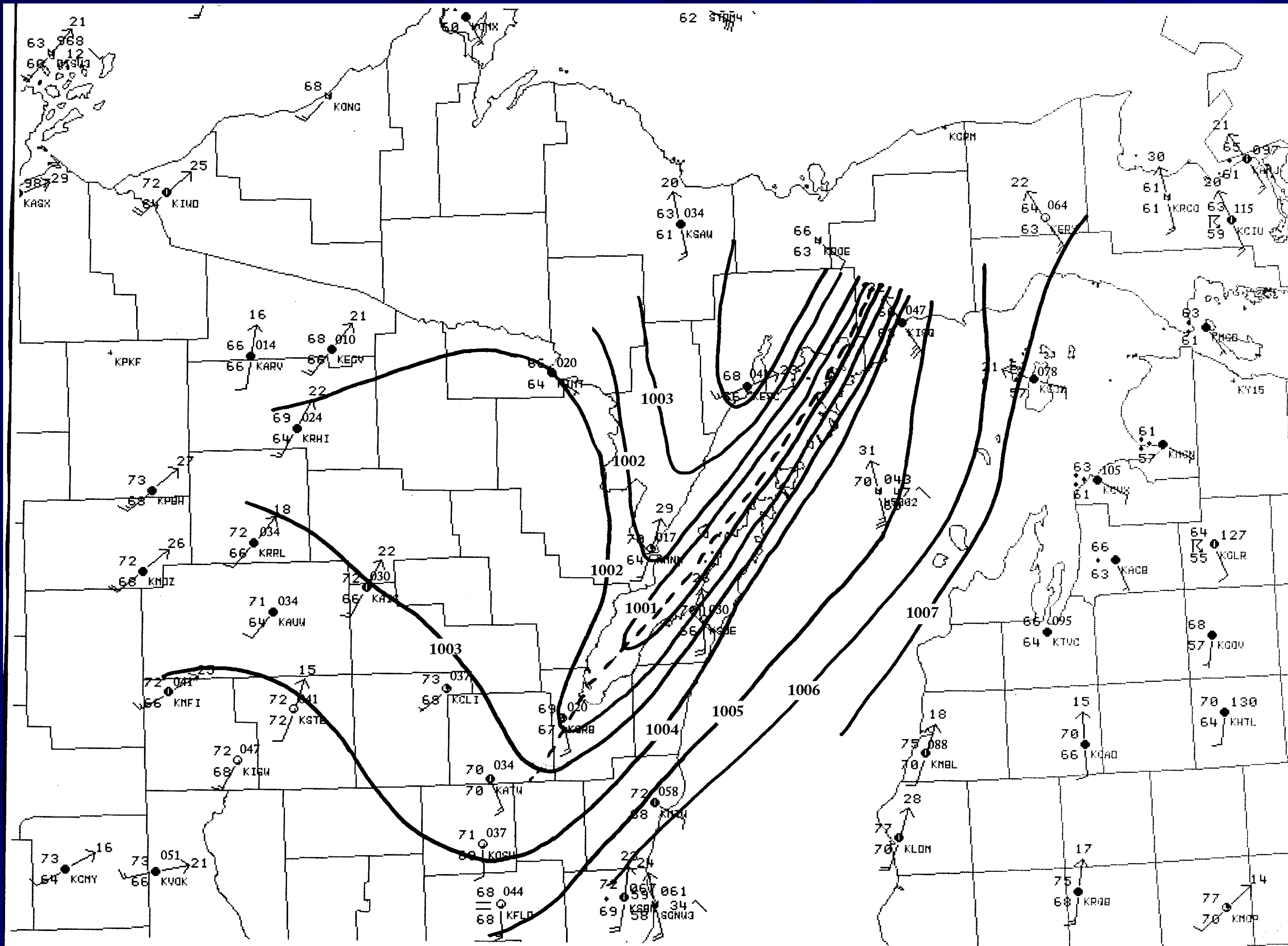

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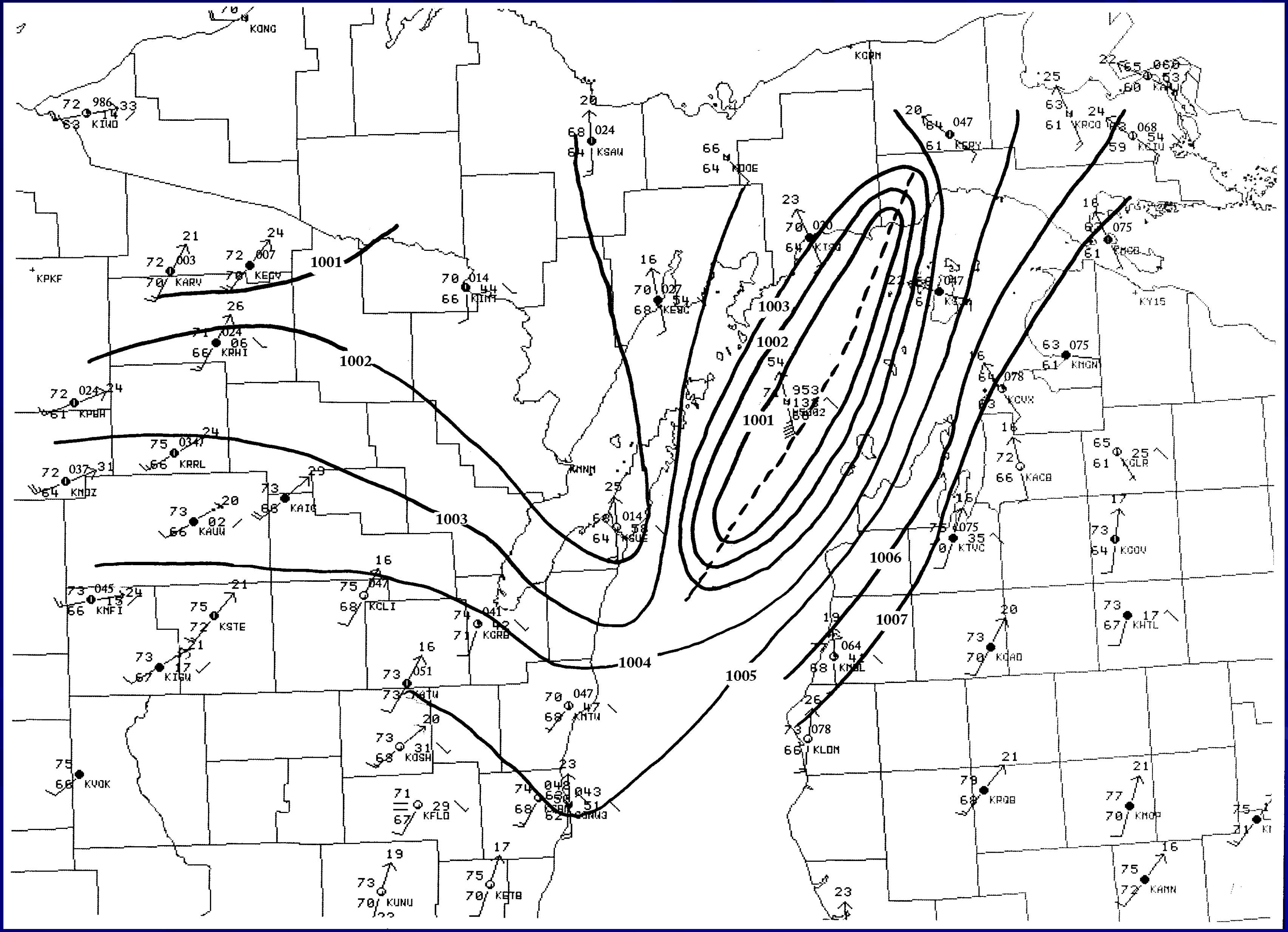
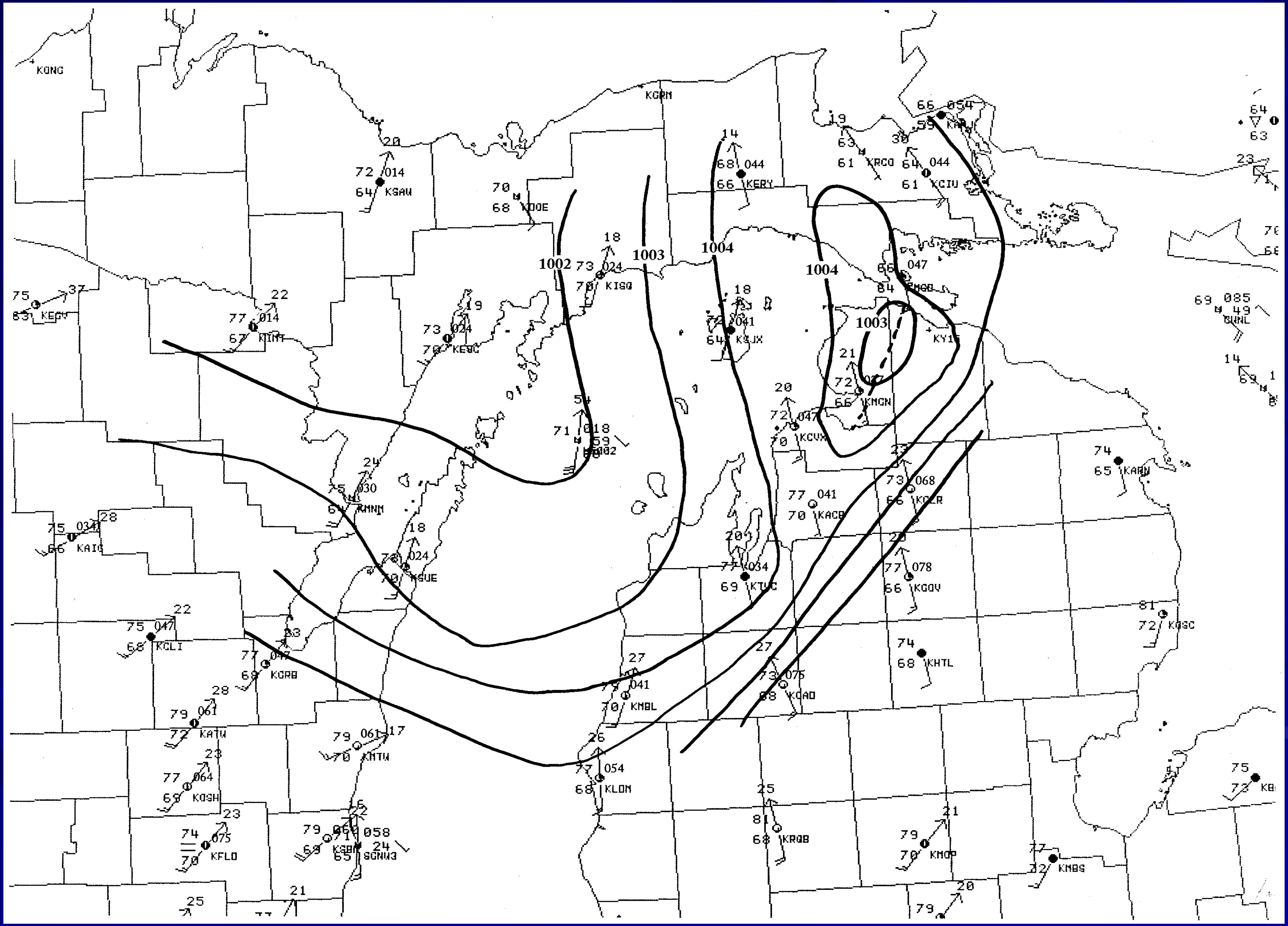
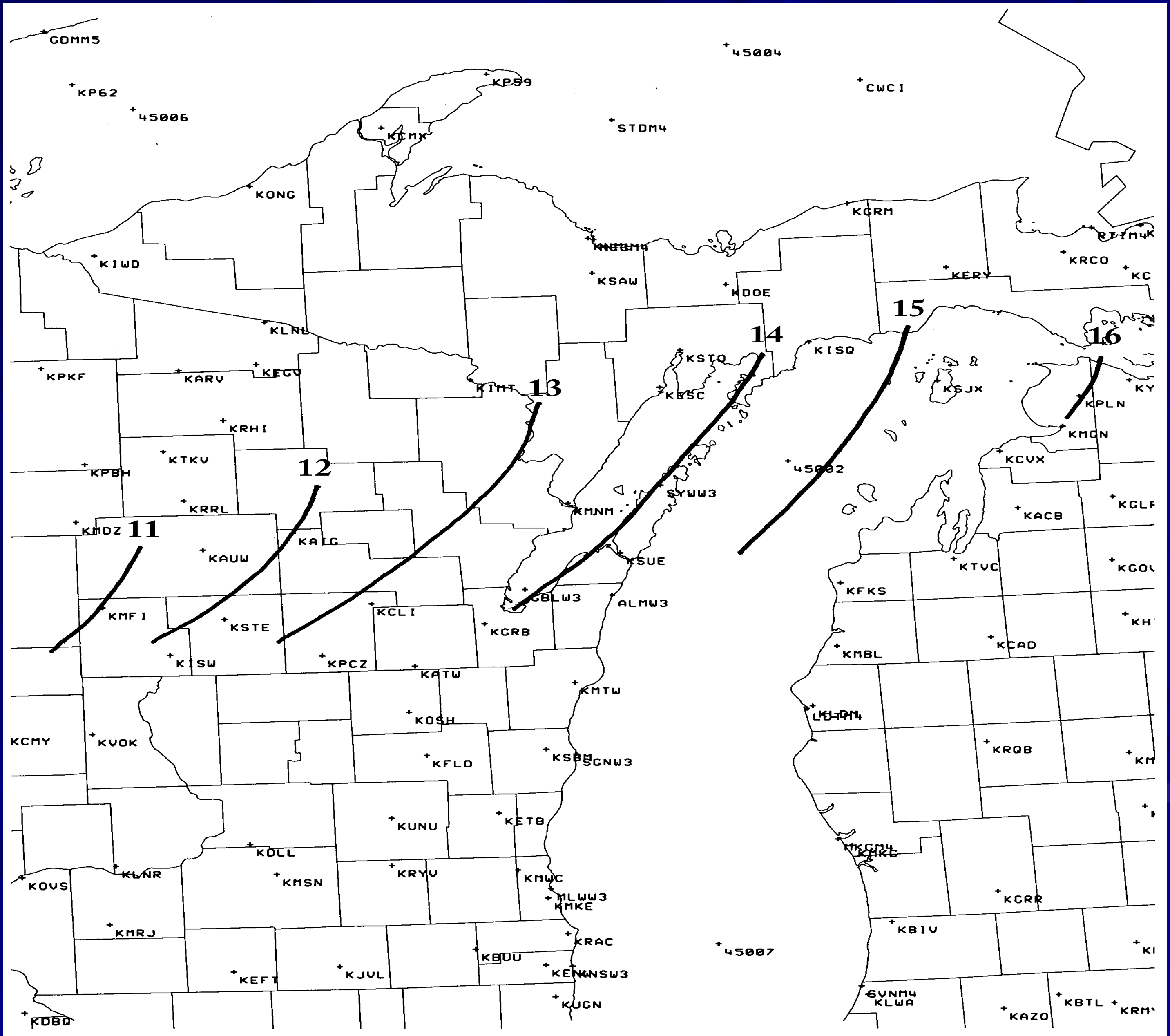


16Z partial subjective surface analysis



Isochrones (hours, UTC)



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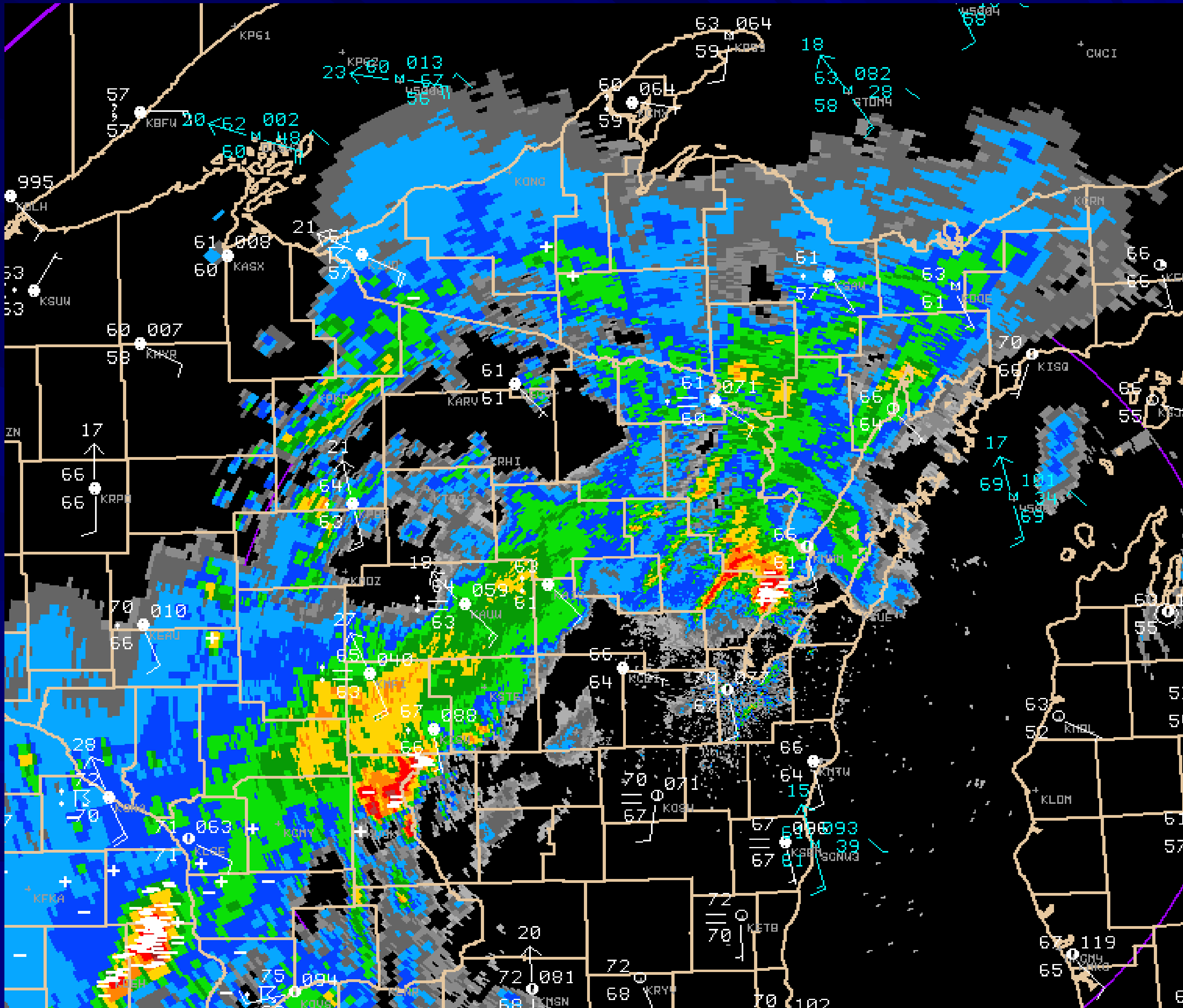

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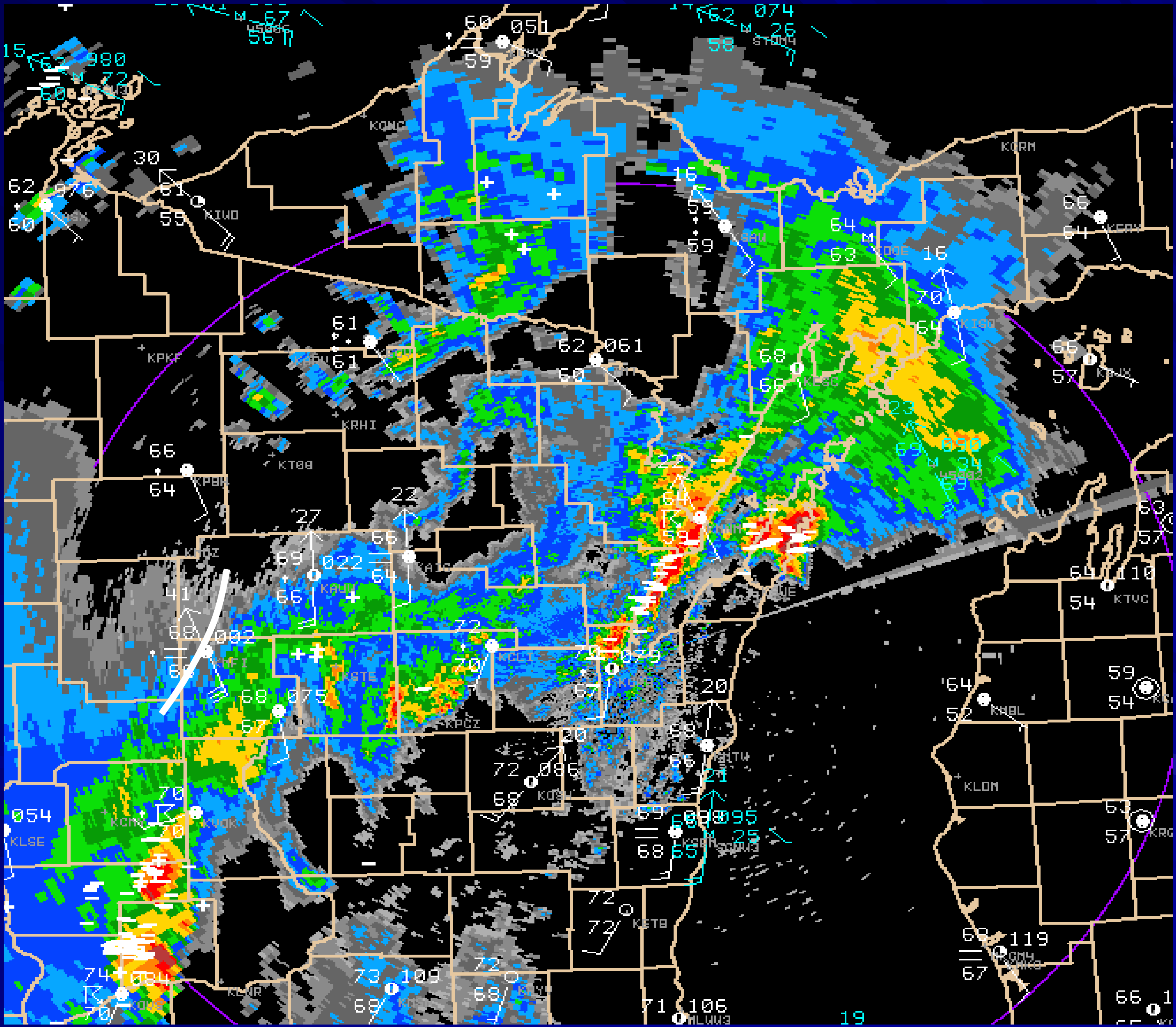

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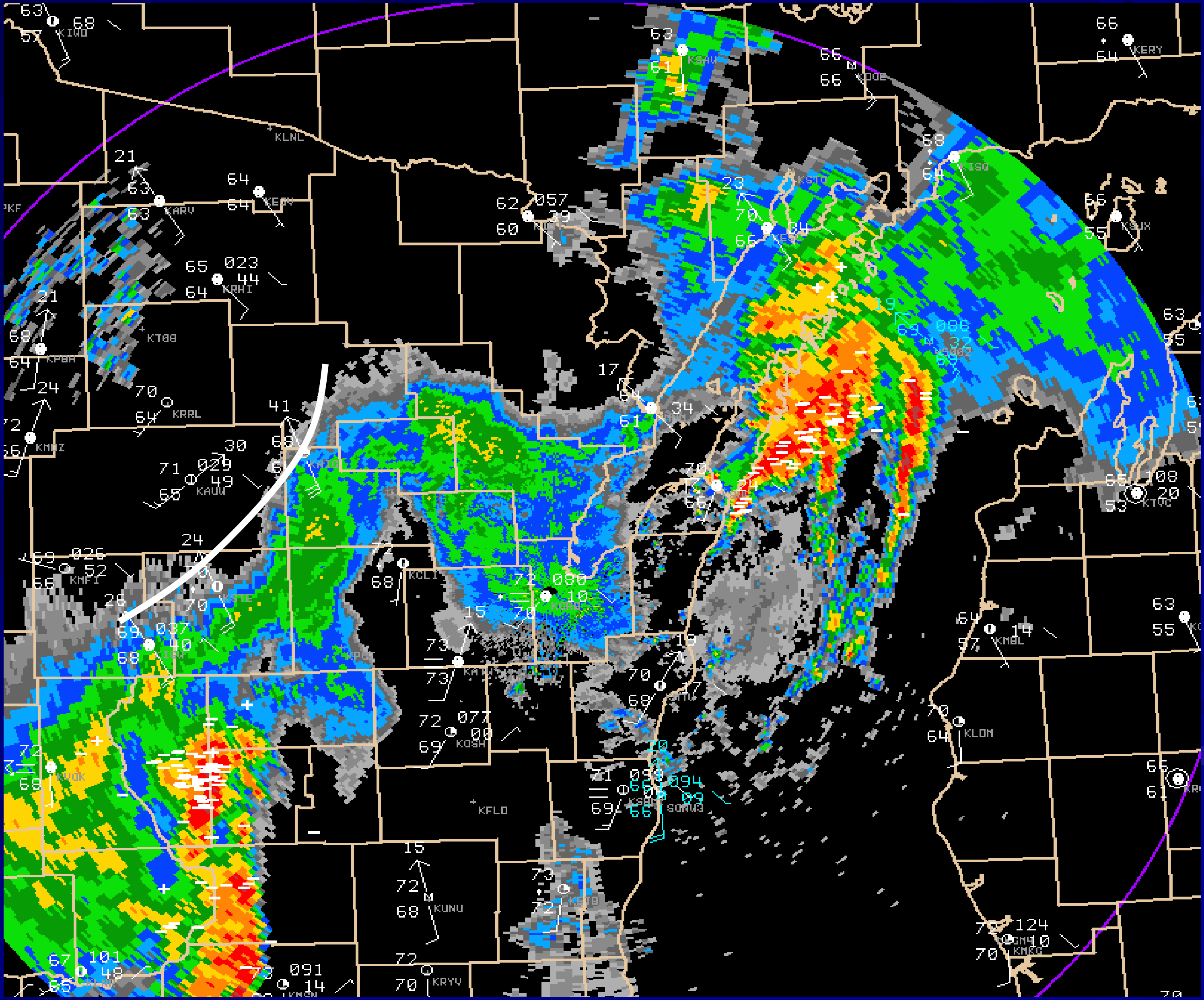

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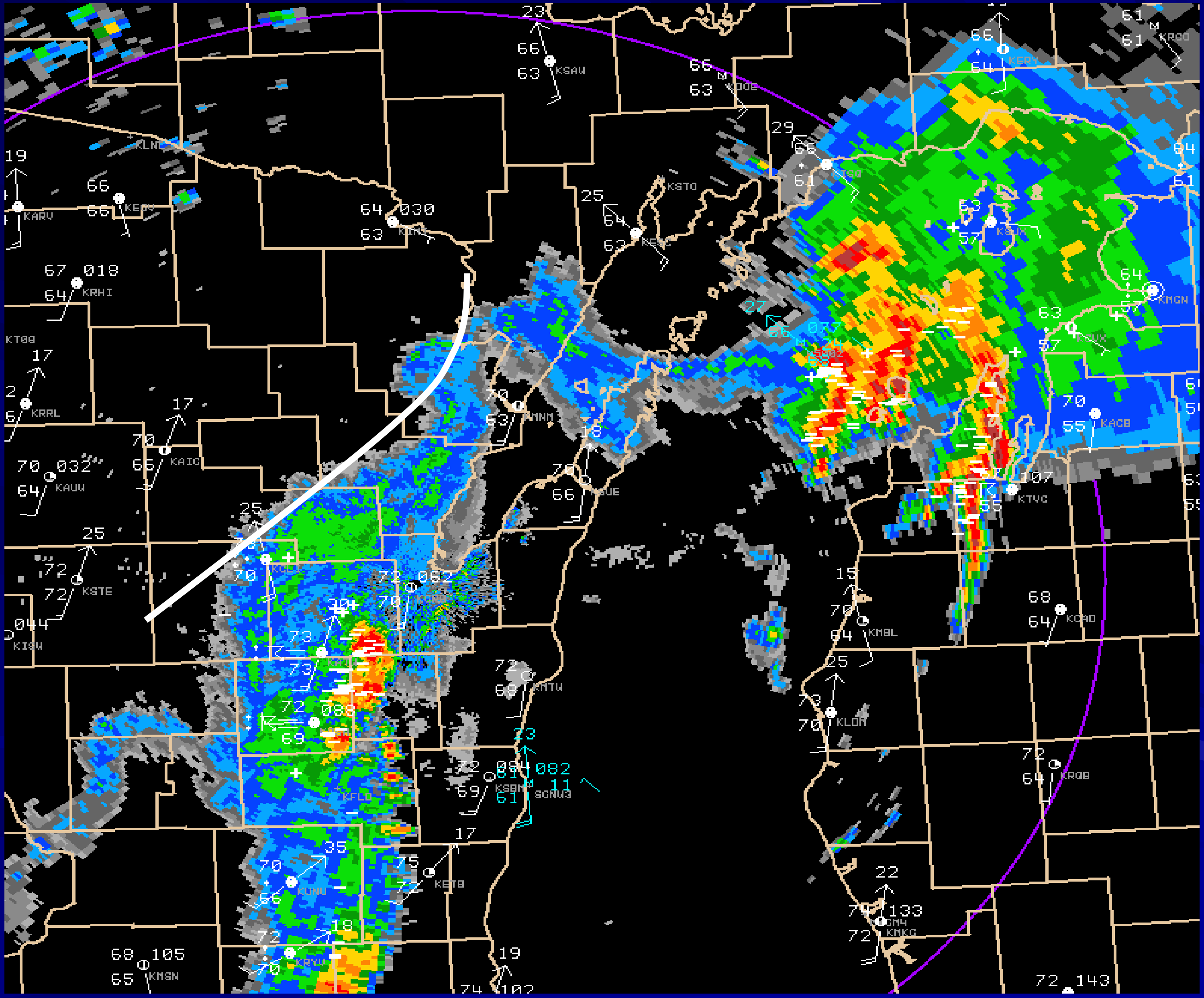

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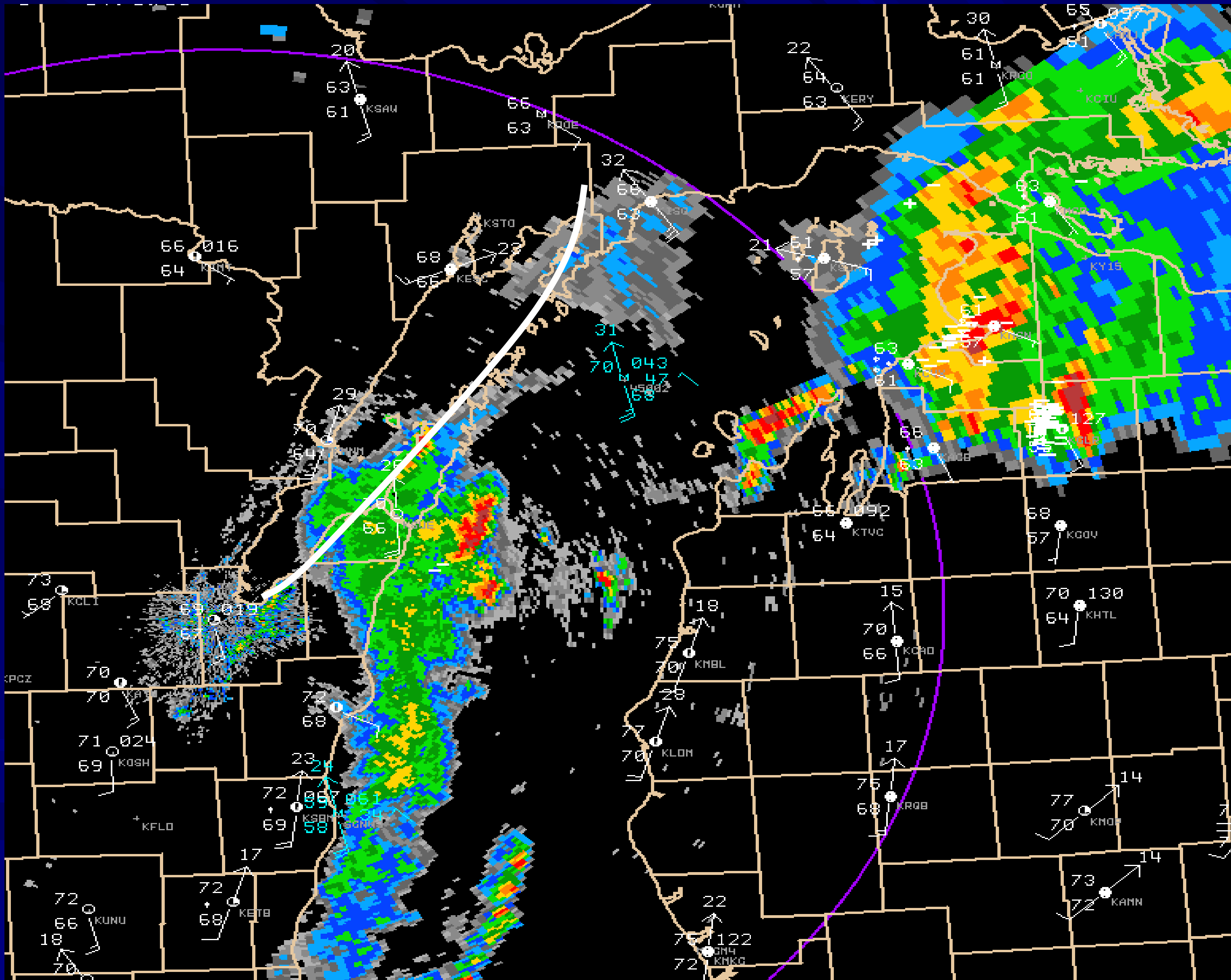

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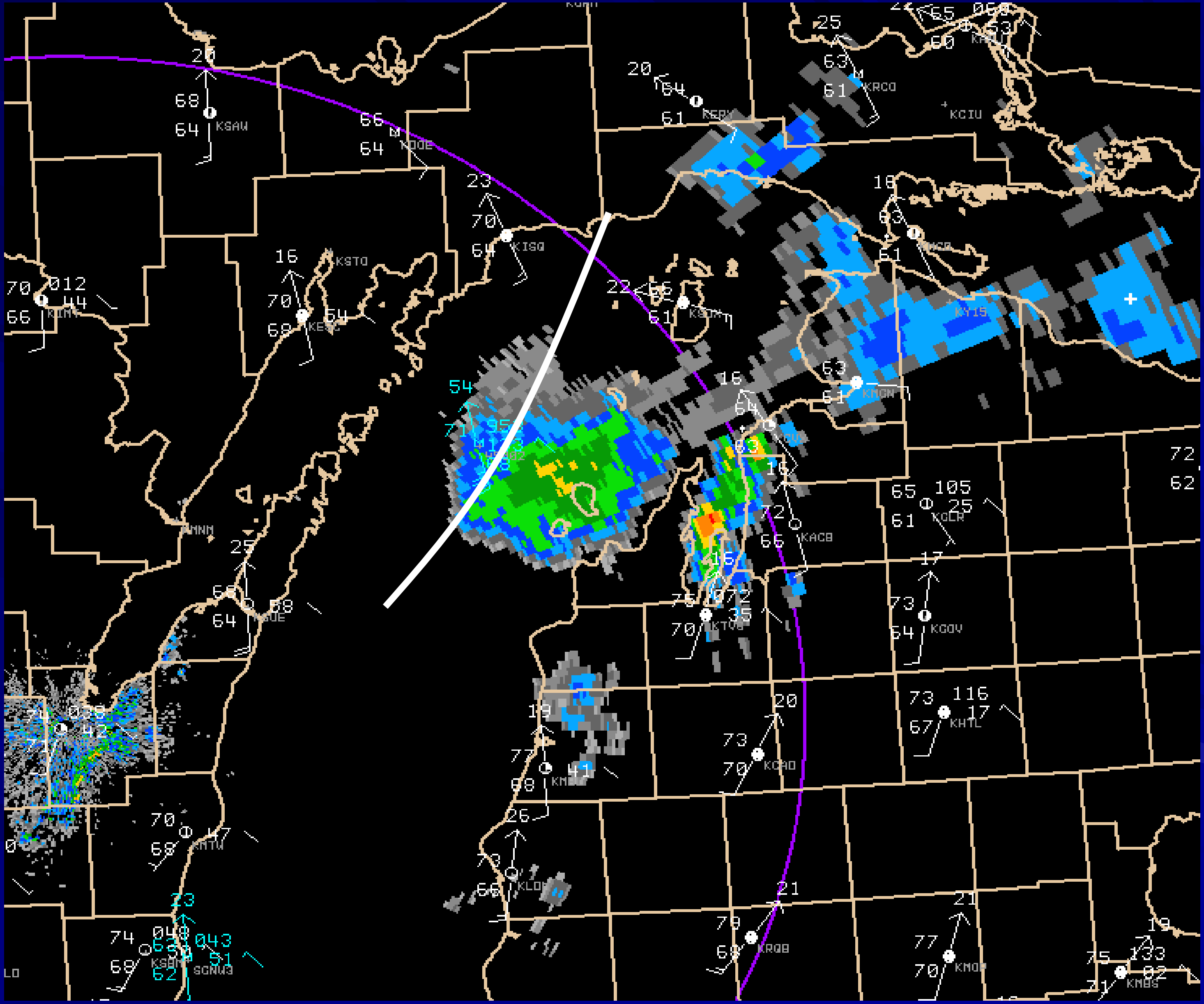
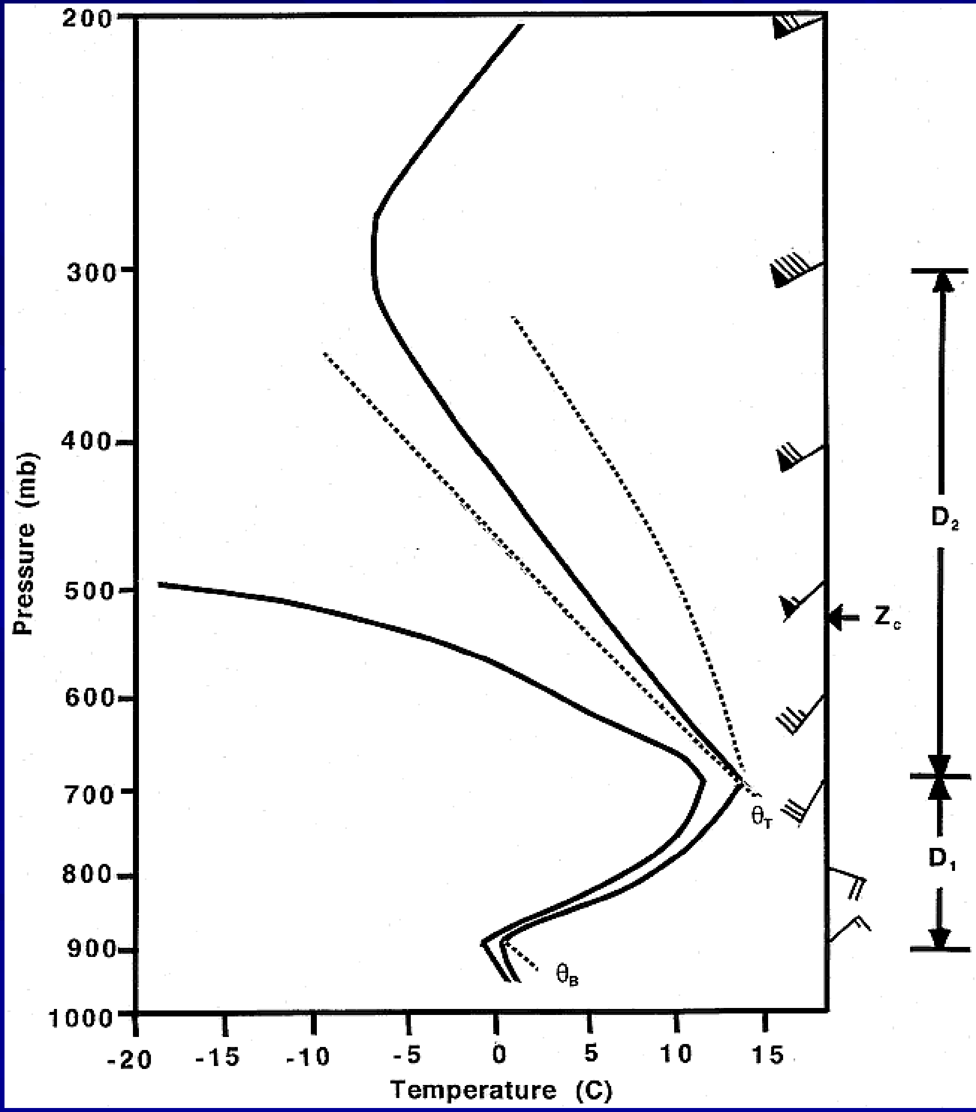


Idealized sounding for wave ducting

Lindzen and Tung (1976)

- Layer 1 is characterized by strong static stability (*N*1), has depth D1, and is the duct layer needed to maintain gravity waves with intrinsic speed **C***d*
- Layer 2 is a conditionally unstable "reflecting layer" of depth *D*2, in which the vertical propagation of wave energy is impeded, so that wave energy is maintained in the duct layer beneath it.
- The critical level for a wave propagation vector **C** = 225°, 25 m s−1 is denoted by *Zc* and must be present only within the reflecting layer for an efficient wave duct.



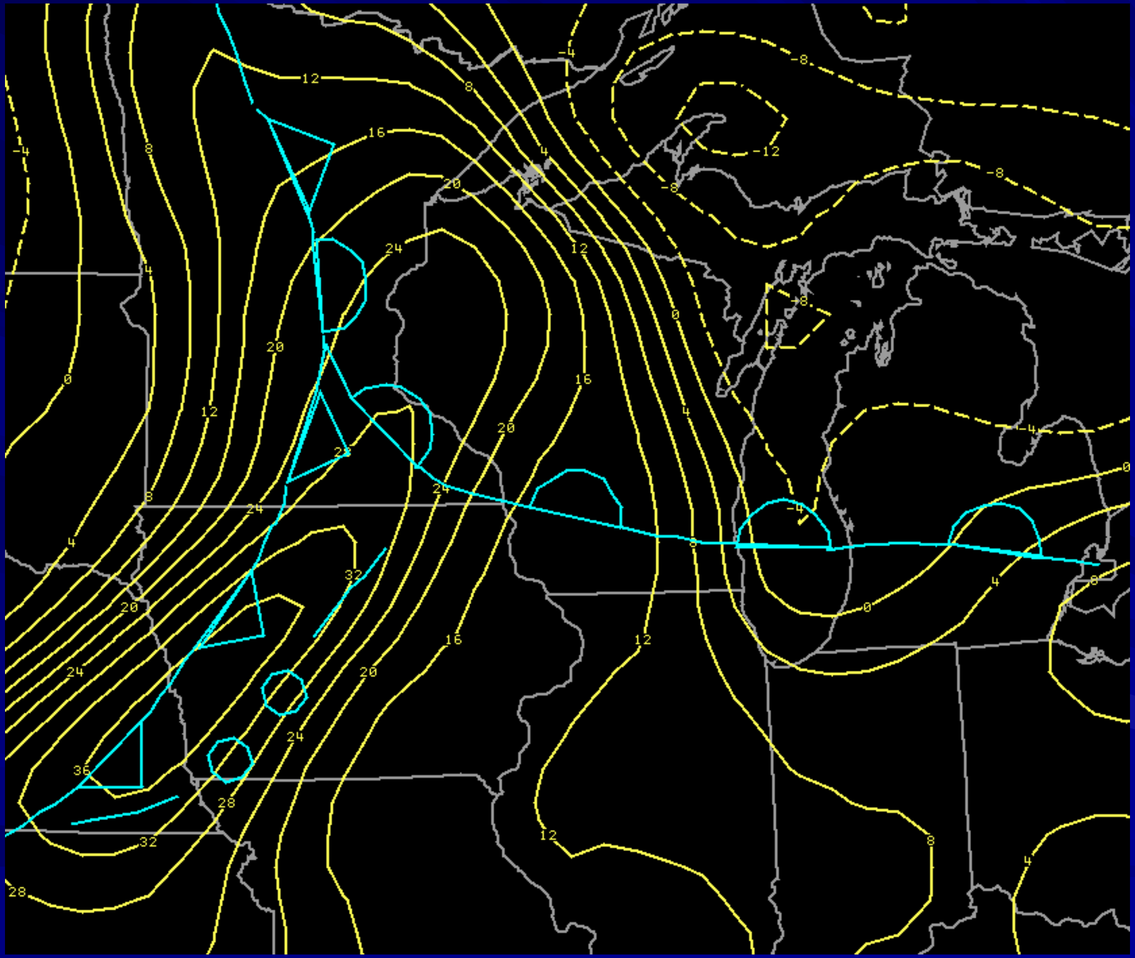
Duct Function

$$DF = \Theta(800) - \Theta(950) + \Theta_e(800) - \Theta_e(400)$$

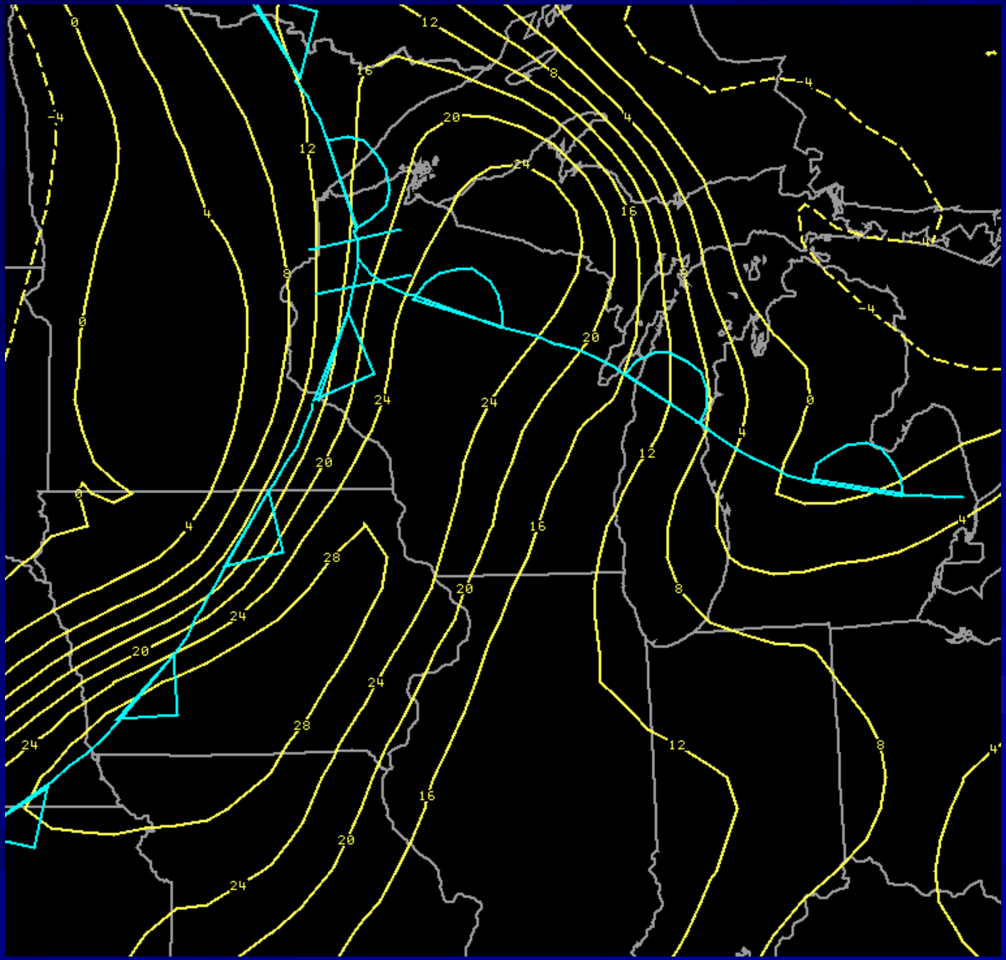
A B

- Parameter that includes contributions from
  - A Low level stable layer
  - B Conditionally unstable layer

09z RUC 00 hr Forecast Duct Function



09z RUC 03 hr Forecast Duct Function Valid 12z



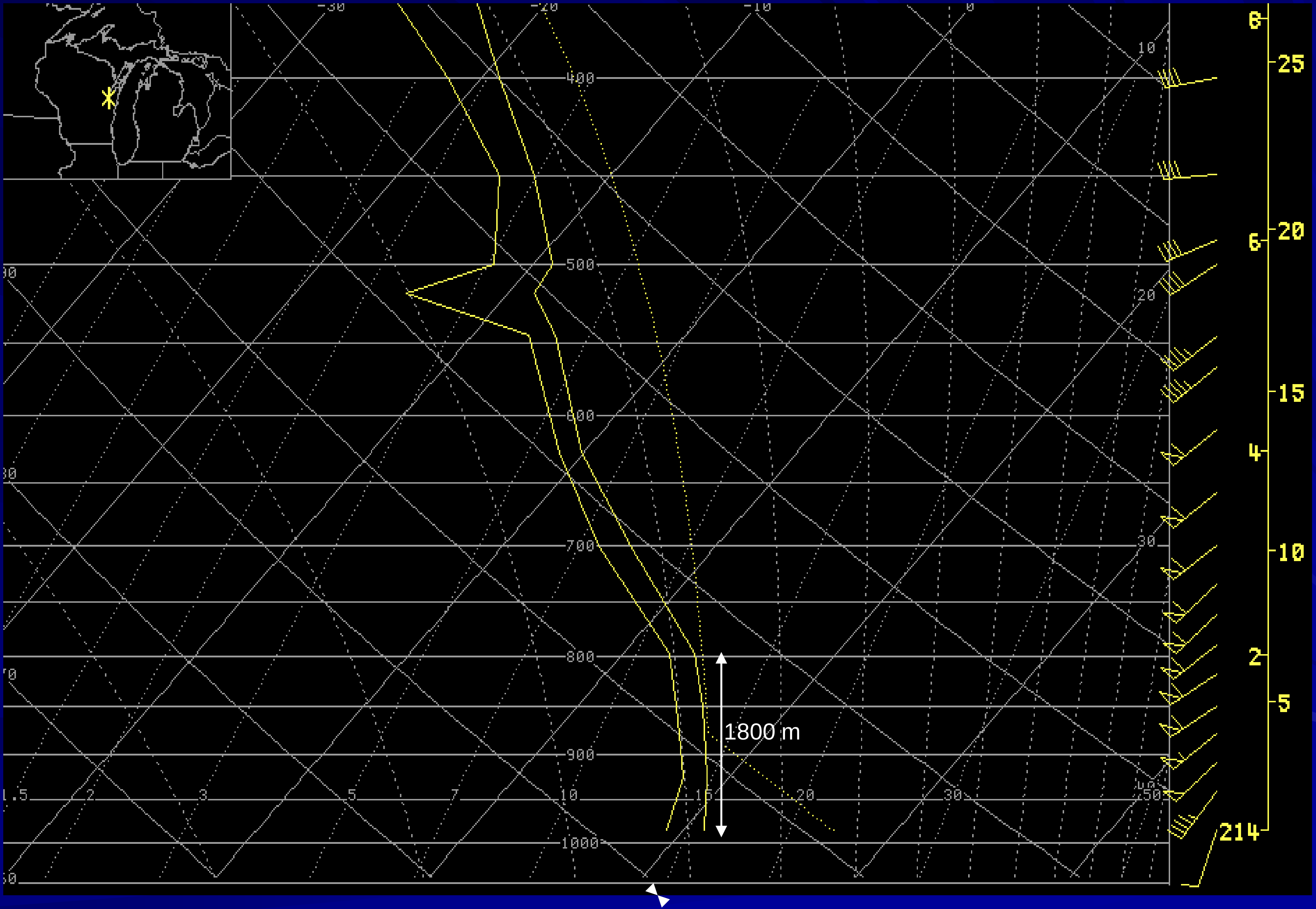
Calculation of required duct thickness

Lindzen and Tung (1976)

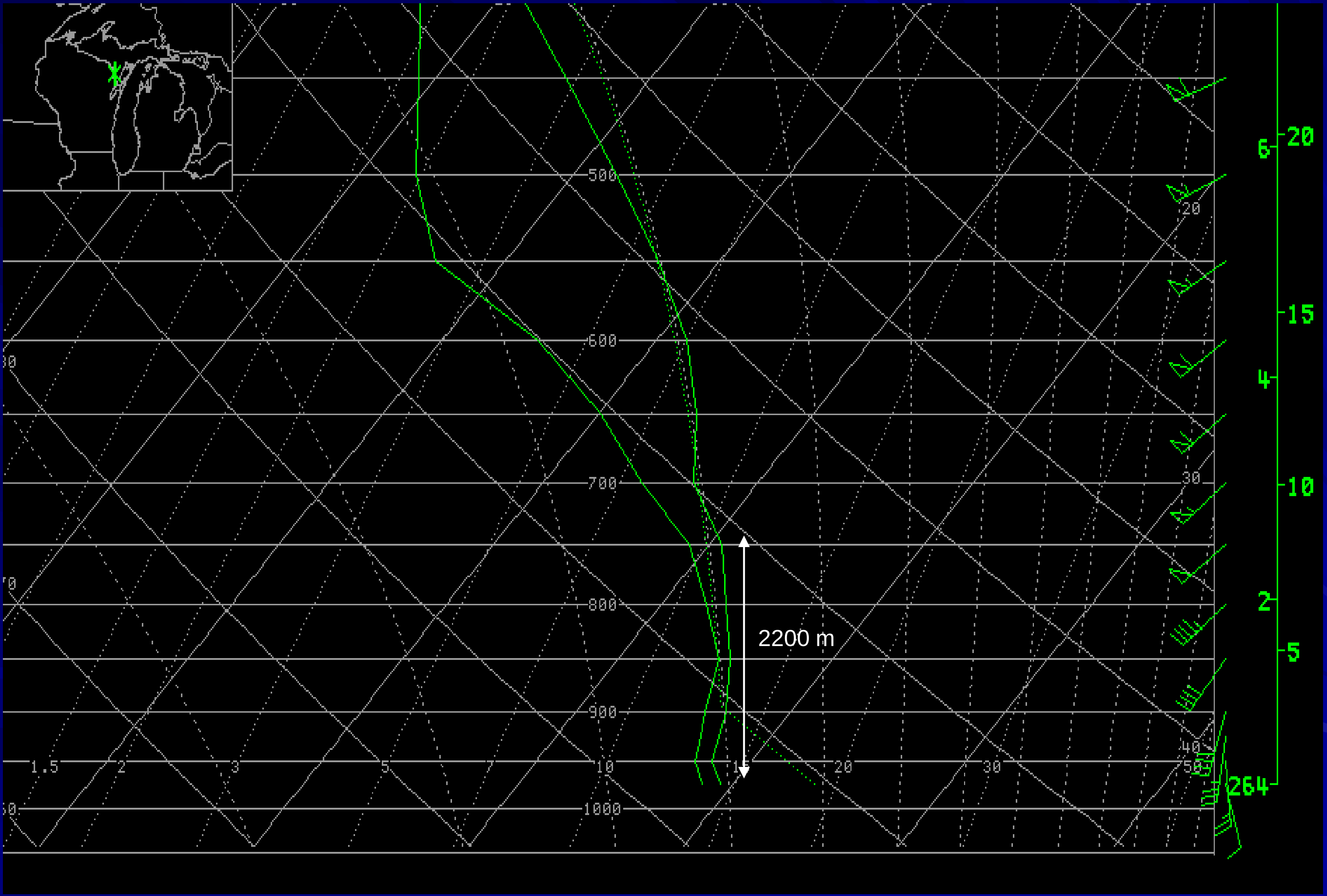
$$D_1 > \frac{\pi}{2}\frac{C^*}{N_1} = \frac{\pi}{2}\frac{\left(C - \overline{U}\right)}{N_1}$$

- D_1 Thickness of the stable layer
- N_1 Brunt Vaisala frequency of stable layer
- C^* Mean flow-relative velocity
- C wave propagation velocity
- U Component of stable layer mean wind in direction of C

12Z GRB Sounding



13Z 00 hour RUC Sounding



Calculation of Brunt-Vaisala Frequency N

$$N^2 = \frac{g}{\bar{\theta}} \frac{d\bar{\theta}}{dz}$$

- Parameters
  - dz = 2000 m
  - Mean theta = 301 k
  - d theta = 11 k
- N = 0.0139 s^{-1}

$N^2 = \frac{g}{\bar{\theta}} \frac{d\bar{\theta}}{dz}$

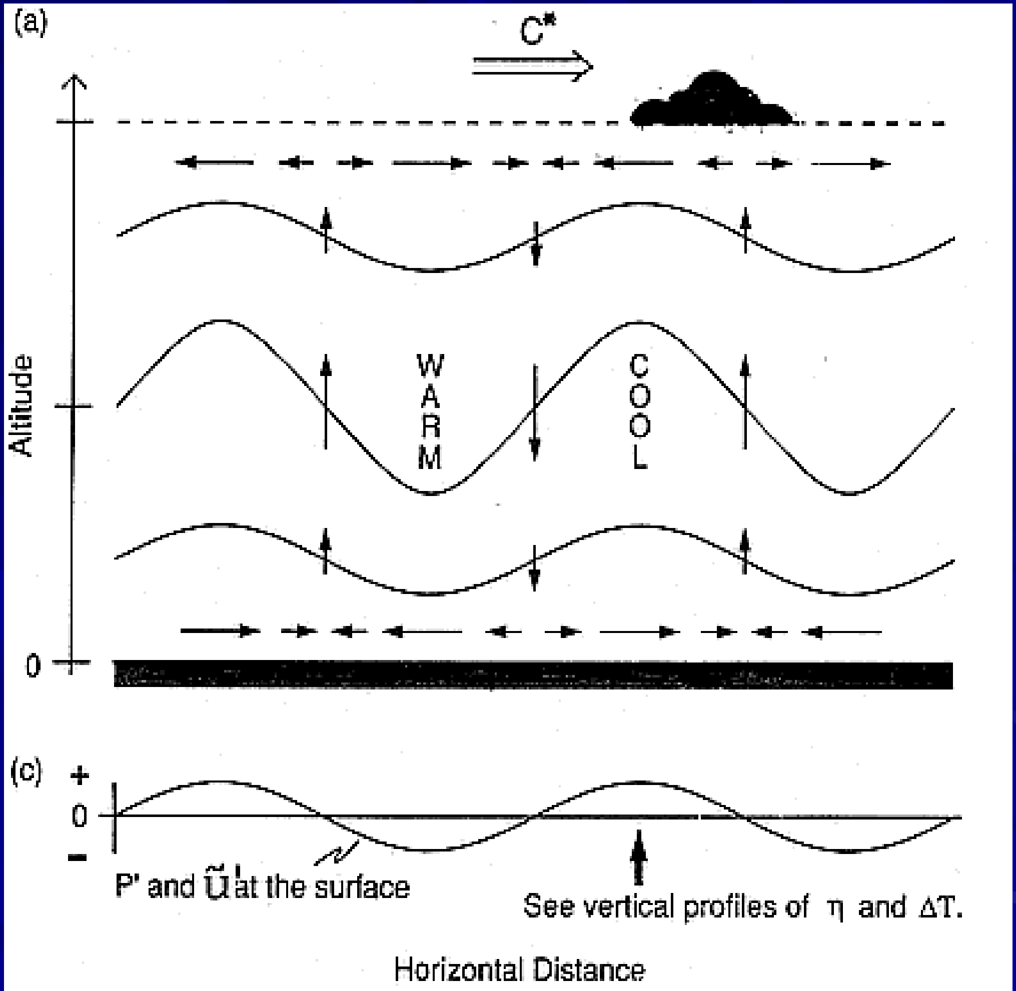
Calculation of required duct thickness

$$D_1 > \frac{\pi}{2} \frac{C^*}{N_1} = \frac{\pi}{2} \frac{\left(C - \overline{U}\right)}{N_1}$$

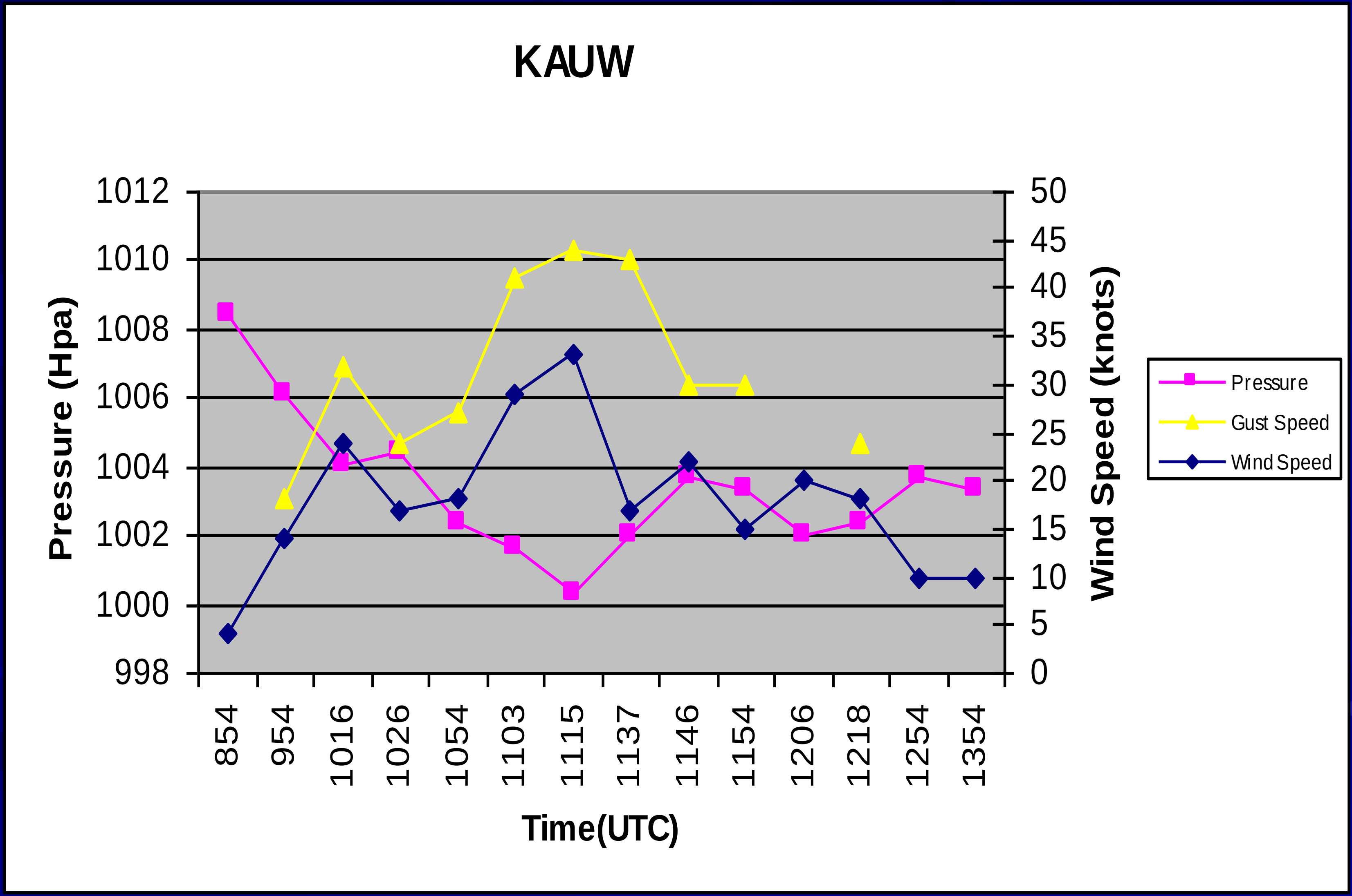
- Parameters
  - C (wave propagation vector) = 255 @ 27 ms^{-1}
  - Mean stable layer wind = 200 @ 21 ms^{-1}
  - U = 12 ms^{-1} (component of stable layer mean wind in direction of C)
- Required duct thickness (D_1) = 1800m

Schematic depiction of a ducted mesoscale gravity wave

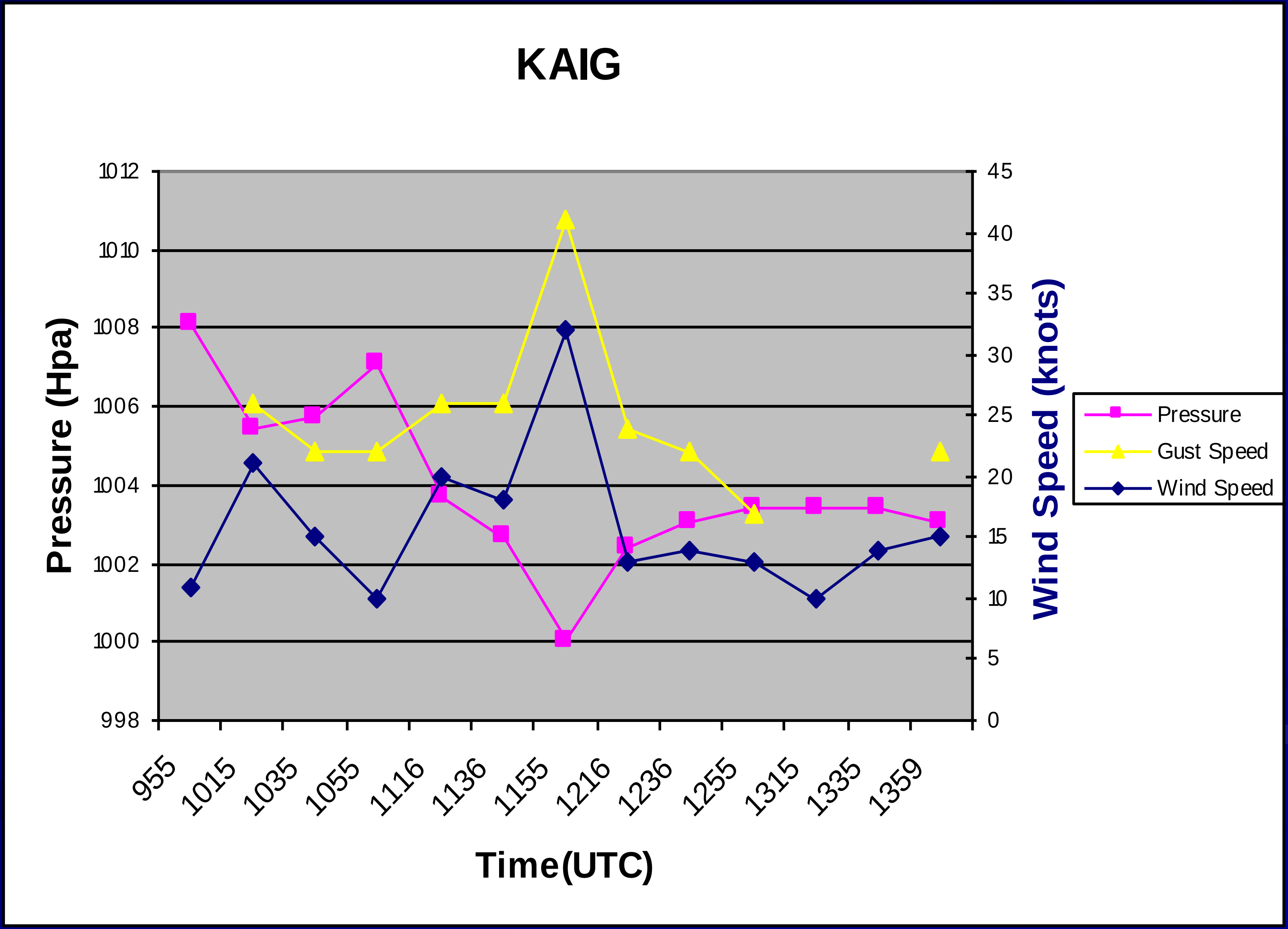
- Vertical cross section in the direction of wave propagation, showing wave-induced horizontal and vertical wind motions, streamlines or isentropes (solid lines), and the critical level (dashed), for a wave that is propagating with intrinsic (mean flow-relative) phase speed **C*** faster than the winds in the duct layer.
- Wave-induced surface pressure perturbations (*p*′) and wind perturbations in the direction of wave propagation (u′) drawn for the same wave segment shown in (a). Cloud depicts location of rainband axis relative to gravity wave system for a simple nontilted wave structure



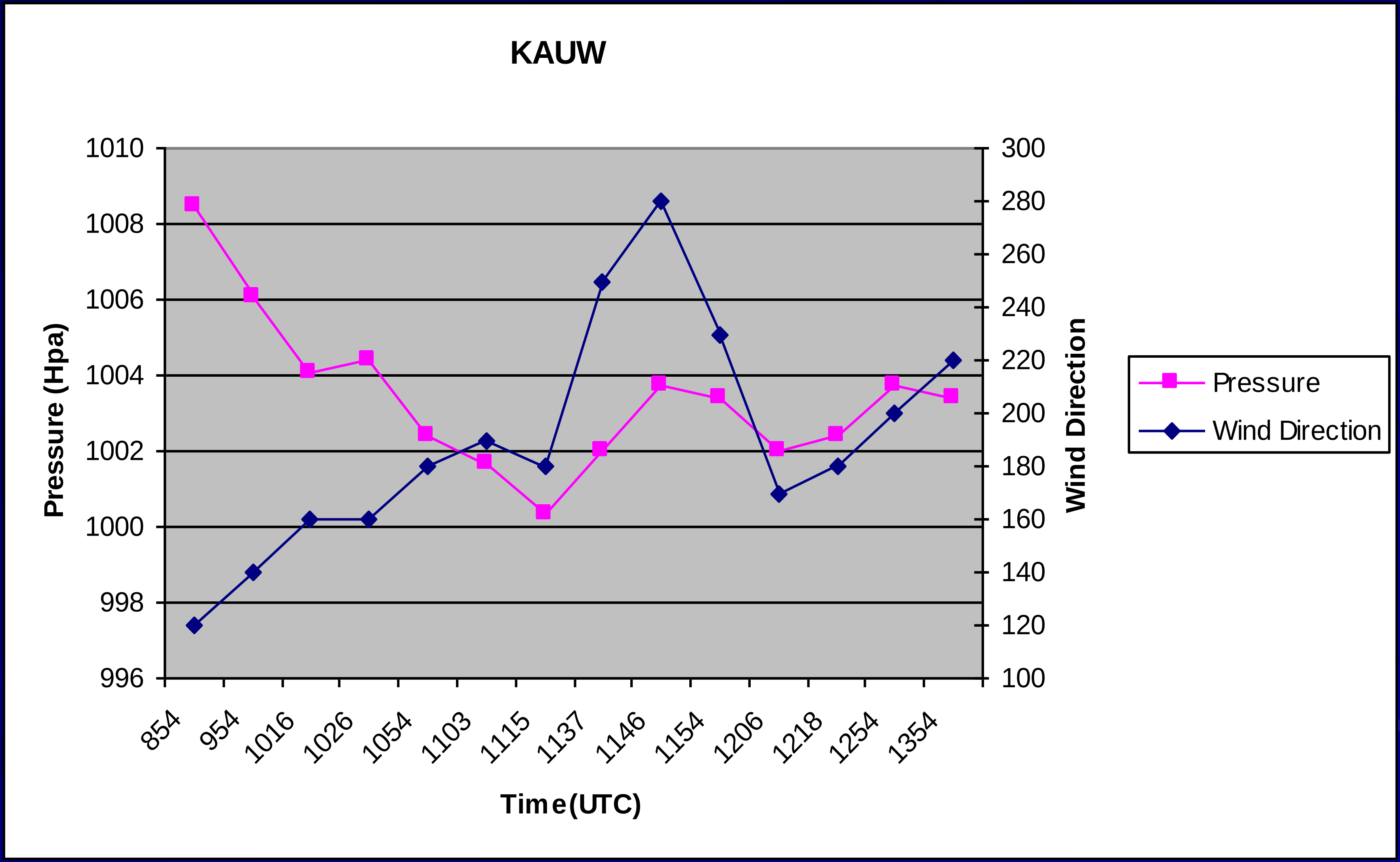
KAUW pressure, wind and gust speed



KAIG pressure wind and gust speed



Pressure and wind direction



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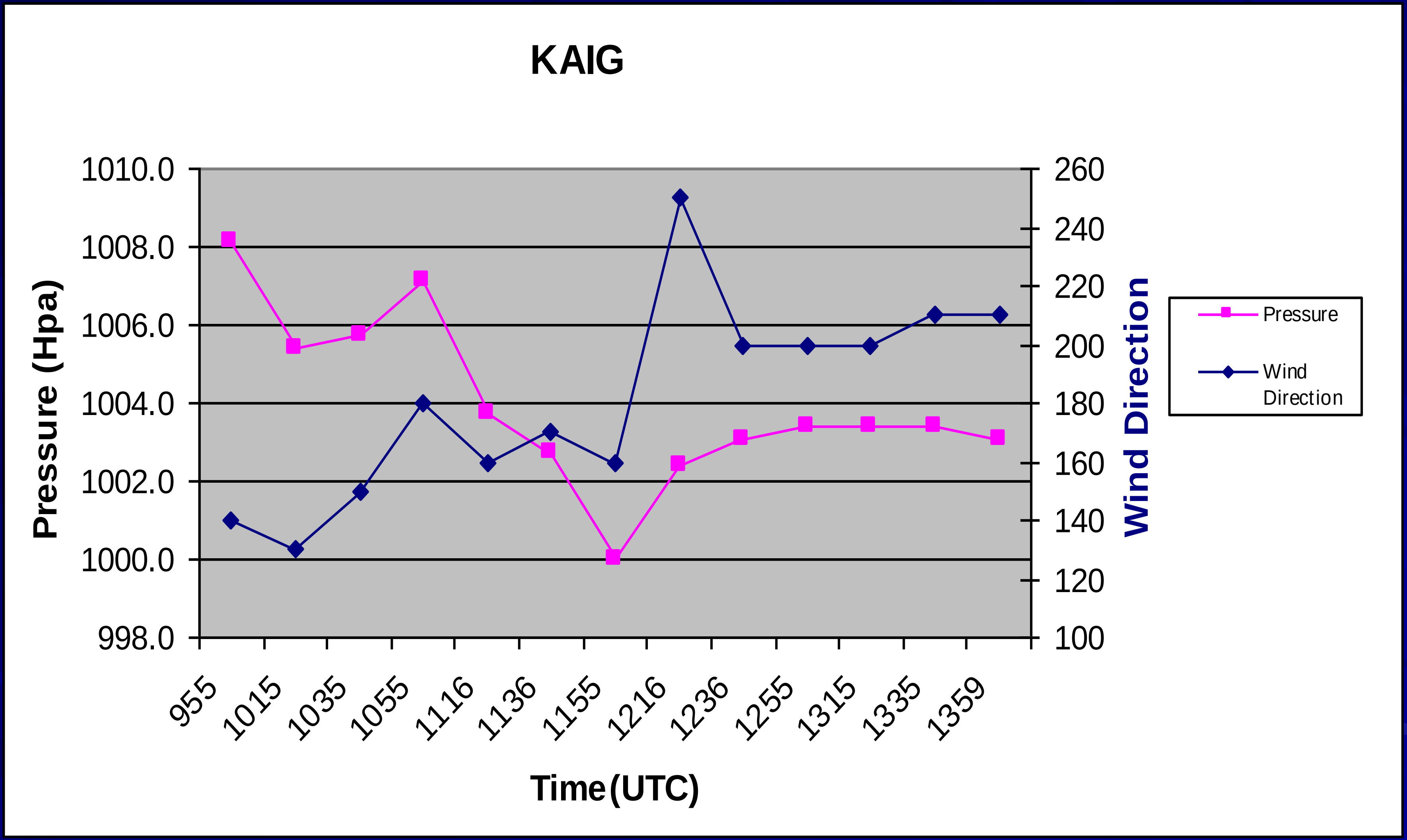
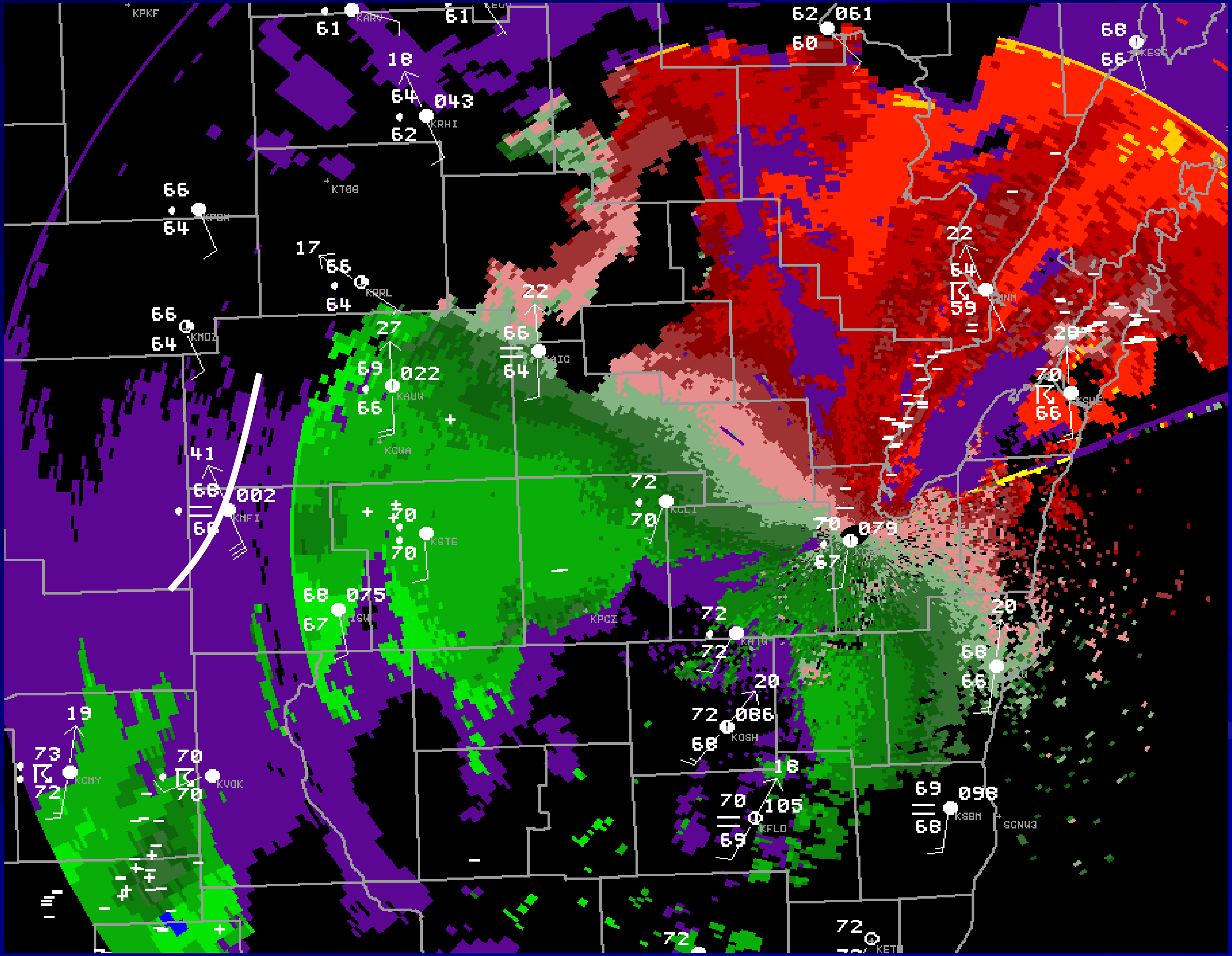
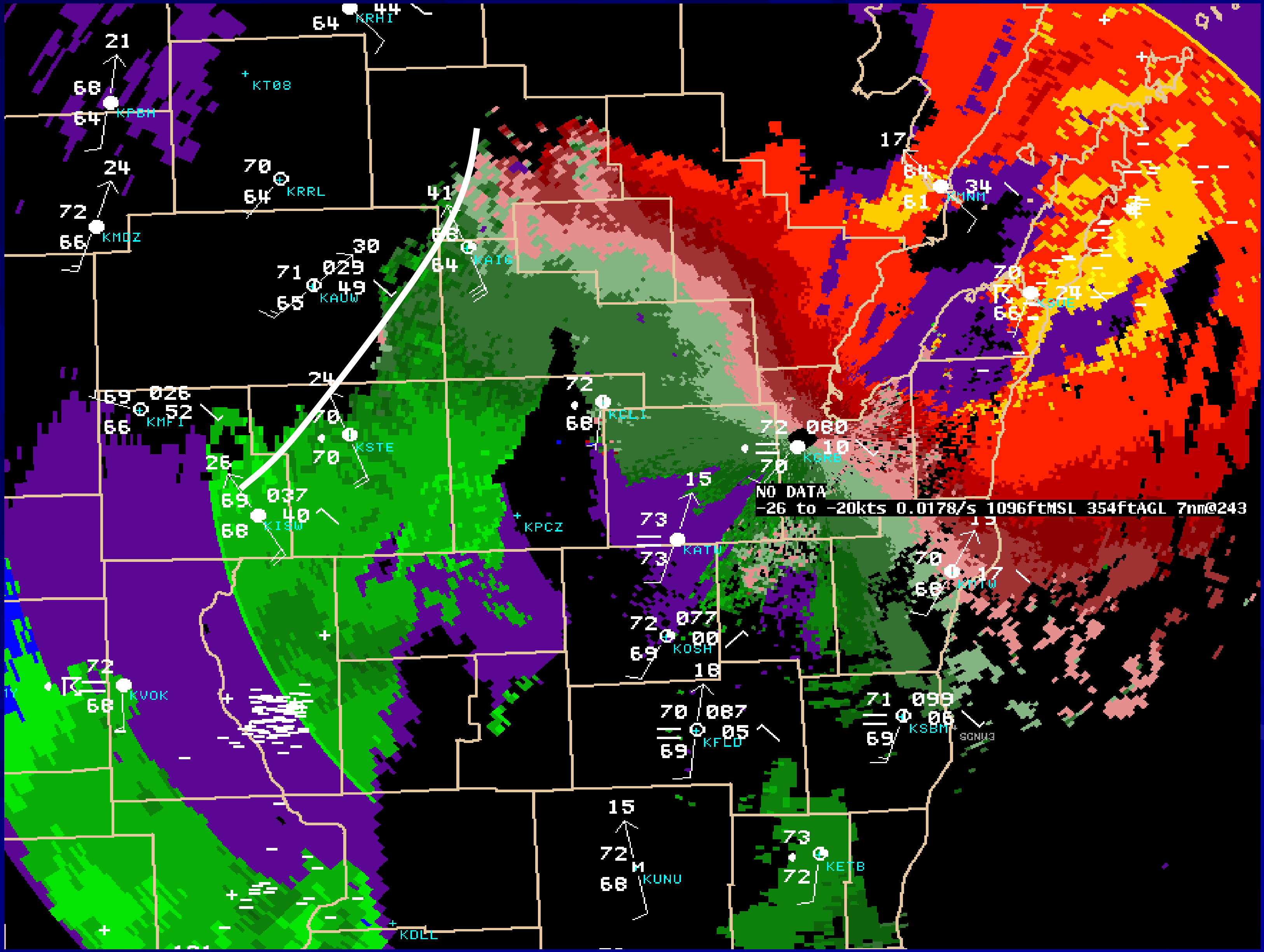


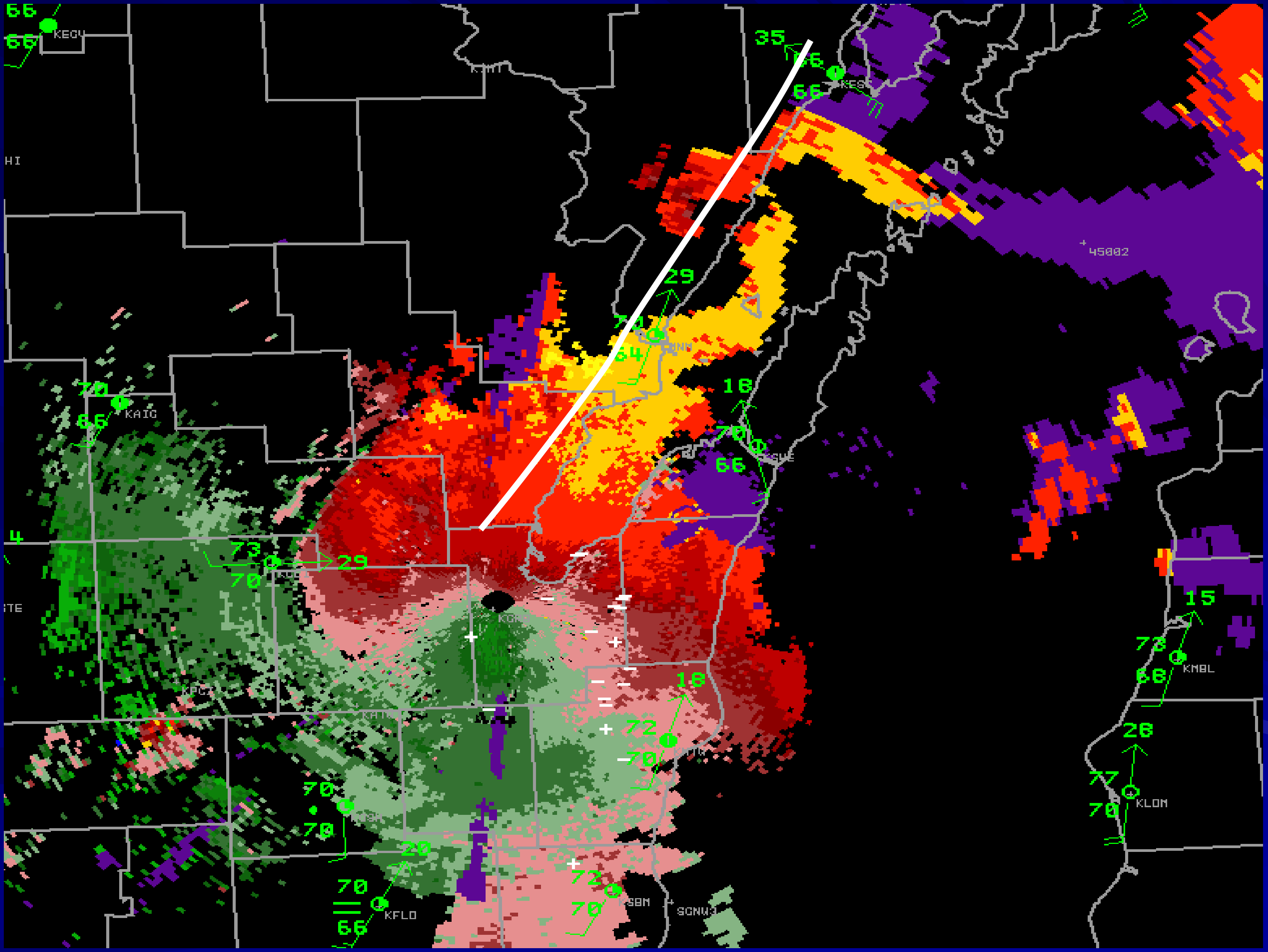
1102Z Base Velocity (0.5)



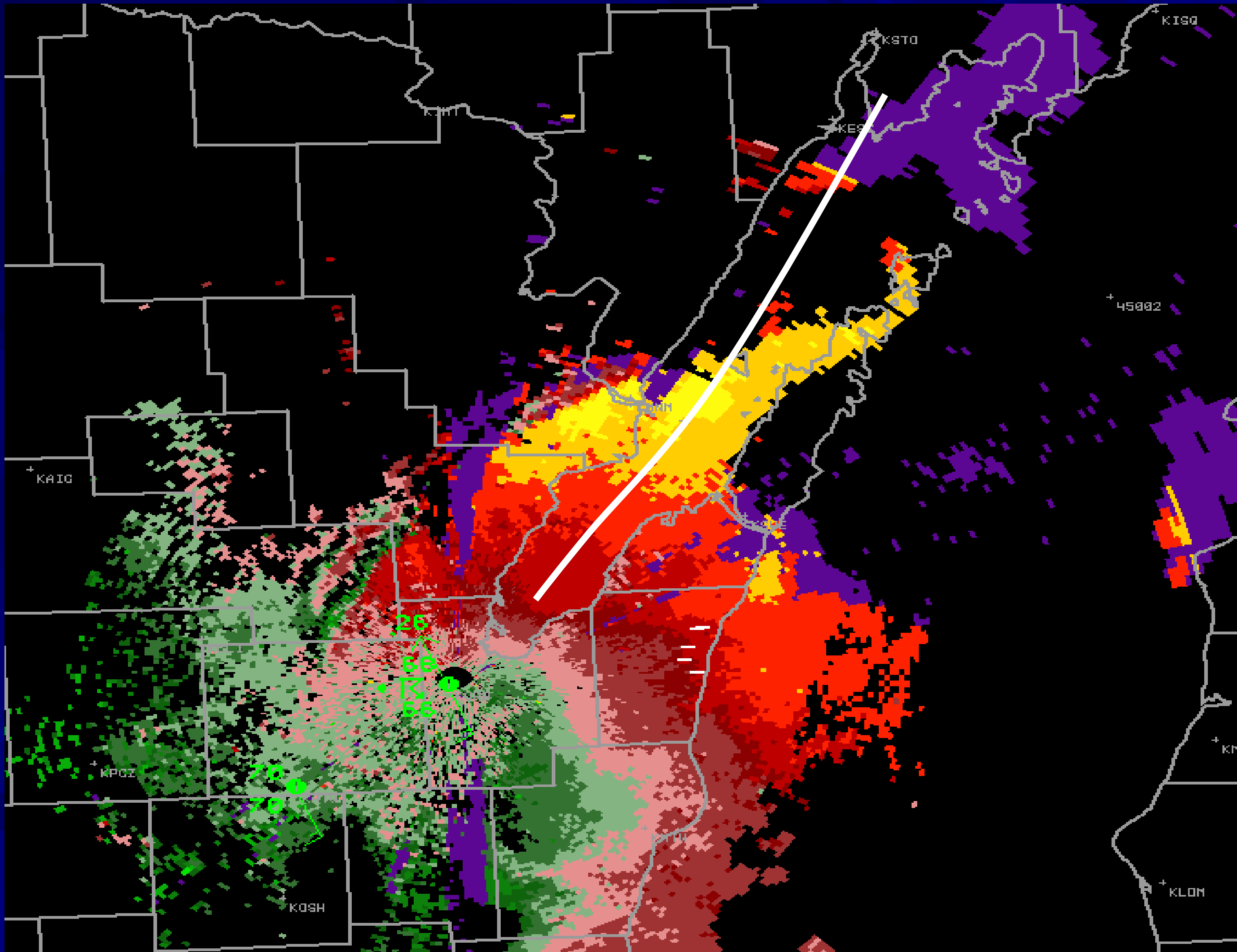
1149Z Base Velocity (0.5)



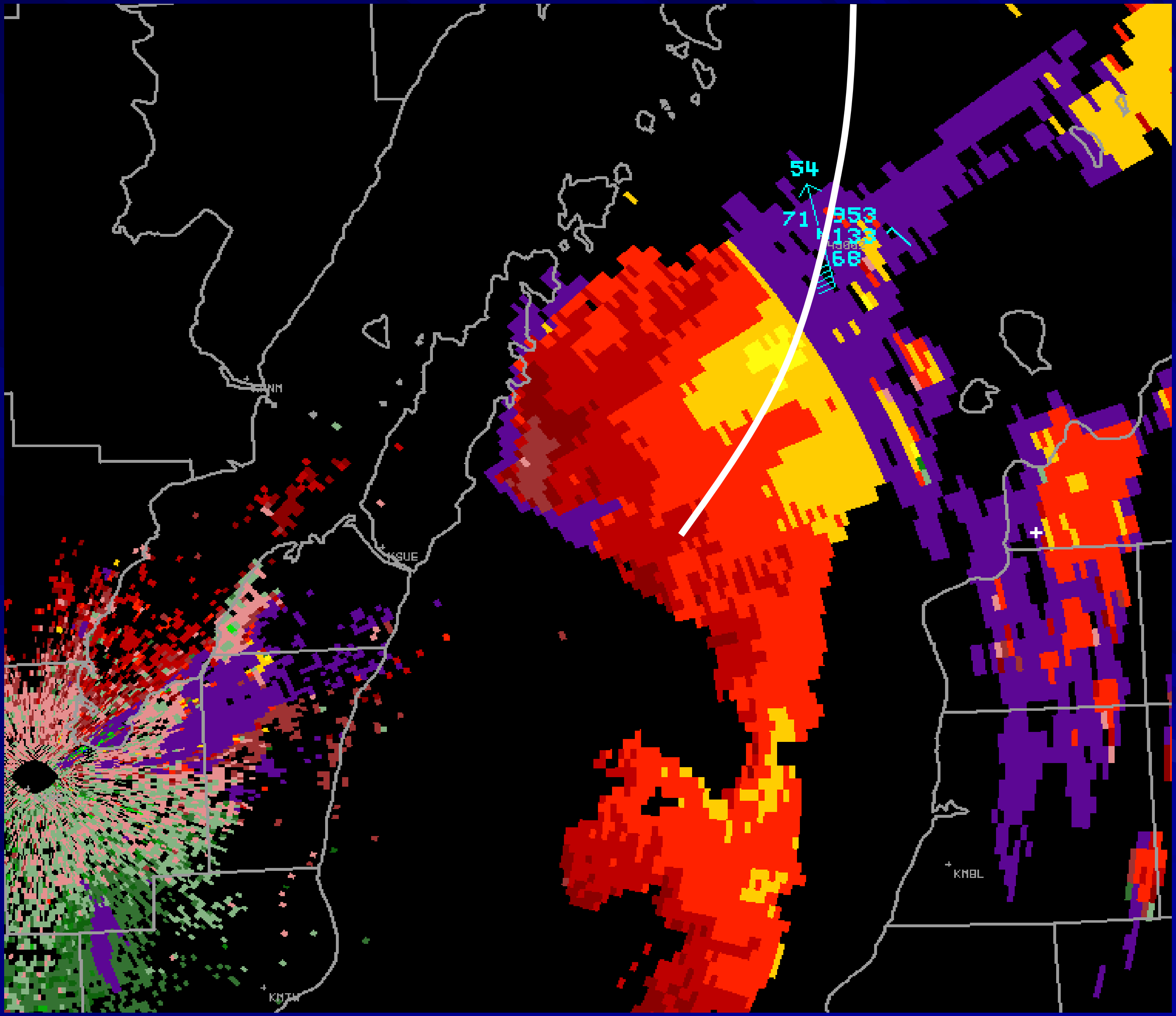
1328Z Base Velocity (0.5)



1345Z Base Velocity (0.5)



1438Z Base Velocity (0.5)



Summary

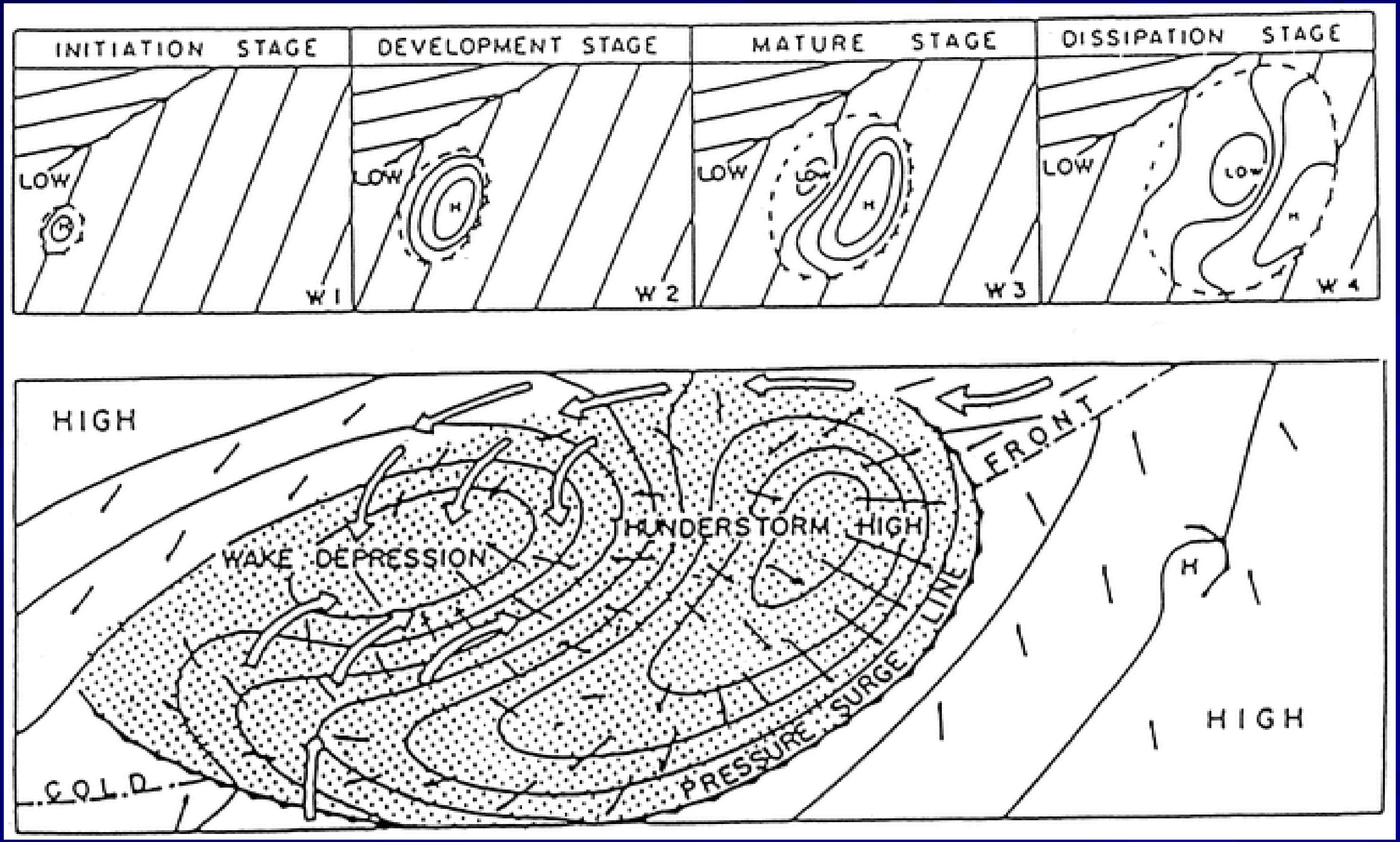
- Non thunderstorm high winds were associated with a large amplitude gravity wave
- The gravity wave was likely generated by geostrophic adjustment
- The gravity wave likely helped to mix strong 950-850 mb winds toward the surface to produce damaging surface wind gusts.

Forecast Procdures

- Identify synoptic pattern favorable for the generation of gravity waves
  - – Unbalanced flow possible?
- Duct available to sustain the gravity wave?
- Significant pressure-wind perturbation observed?
  - – 5-minute ASOS information, bandpass filter
- Estimate propagation of the wave by using mean wind of the conditionally unstable layer
- Forecast wind impacts and effects on precipitation and convection

References

Wake Low schematic



- Isobar patterns for four stages of squall mesosystems [(top), from Fujita (1963)]. The W designates warm-sector-type system.
- Schematic of surface pressure field in a squall line thunderstorm [(bottom), from Fujita (1955)]. Small arrows indicate surface wind, large arrows relative flow into the wake. Stippling indicates extent of precipitation-cooled air.

Wake Low schematic

- Schematic cross section through a wake low and (b) plan view of surface pressure and wind fields and precipitation distribution during squall line mature phase.
- Winds in (a) are system relative with the dashed line denoting the zero relative wind. Arrows indicate streamlines, not trajectories, with those in (b) representing actual winds. Note that horizontal scales differ in the two schematics (from [Johnson and Hamilton 1988]).