1 August 2006 – An Investigation of a Bow Echo along the Wasatch Front

Randy Graham and Chris Gibson

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Overview

- Environment review
- Review of terrain-induced discrete propagation
- Bow Echo interactions with complex terrain
  - Discrete Propagation
  - Modification of updraft interface
- Cold Pool evolution across the Salt Lake Valley

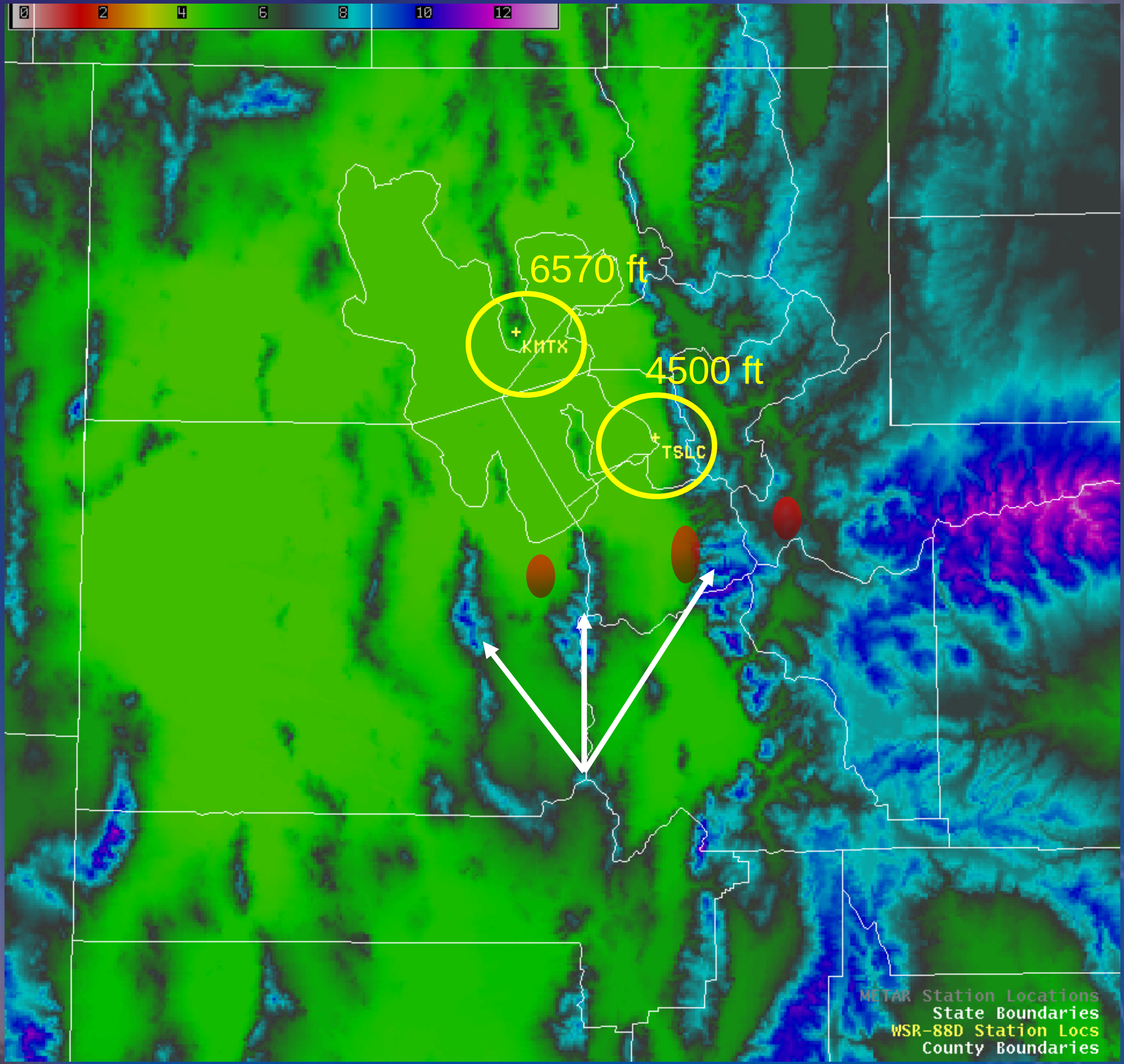
Photo NWS SLC

Event Summary

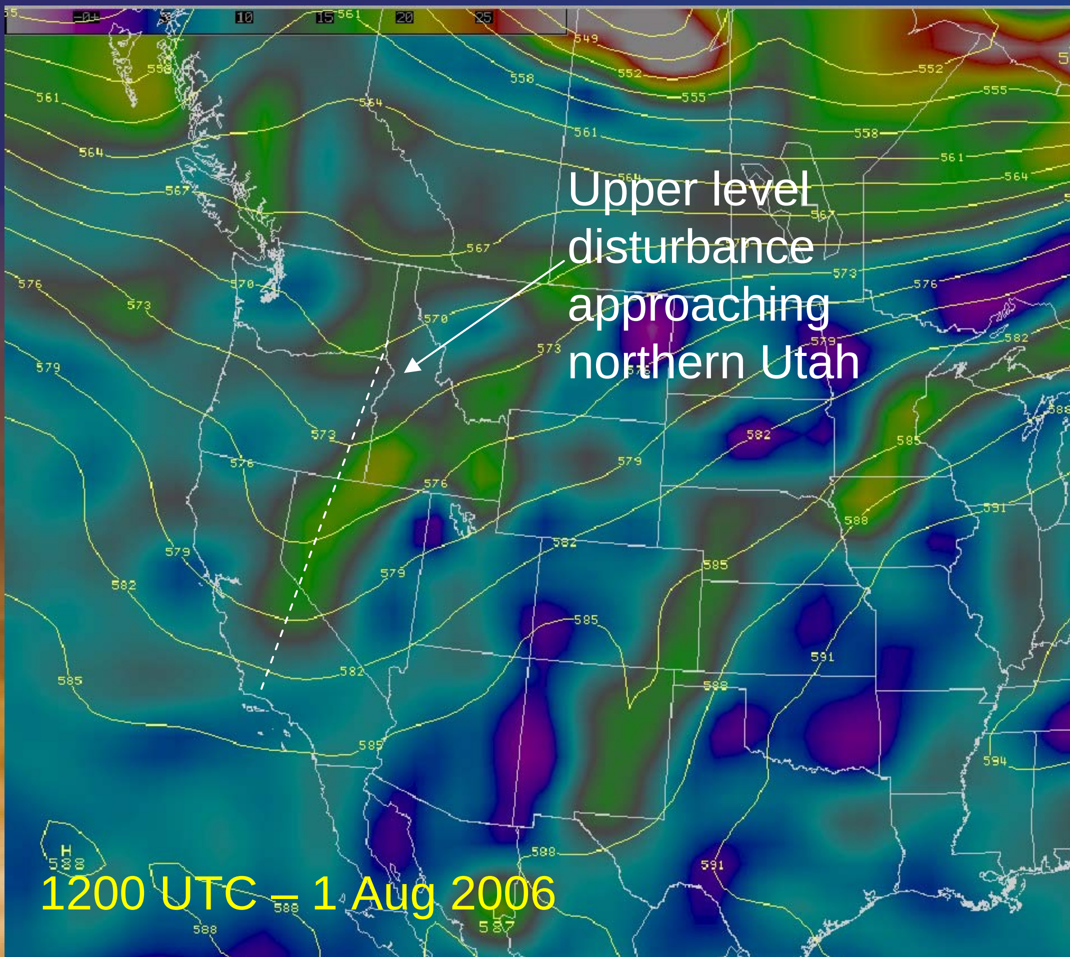
- One of the costliest events in the past 15 years with preliminary damage estimates in Utah County alone around $13 million
- Peak wind gusts were measured at 92 mph at the Provo Airport and estimated between 60 and 70 mph in East Millcreek of Salt Lake County
- Intense rainfall of one half to one inch in less than 30 minutes resulted in local street flooding
- Three-quarter inch diameter hail fell in Provo

Image courtesy of KSL

Landmarks of Note

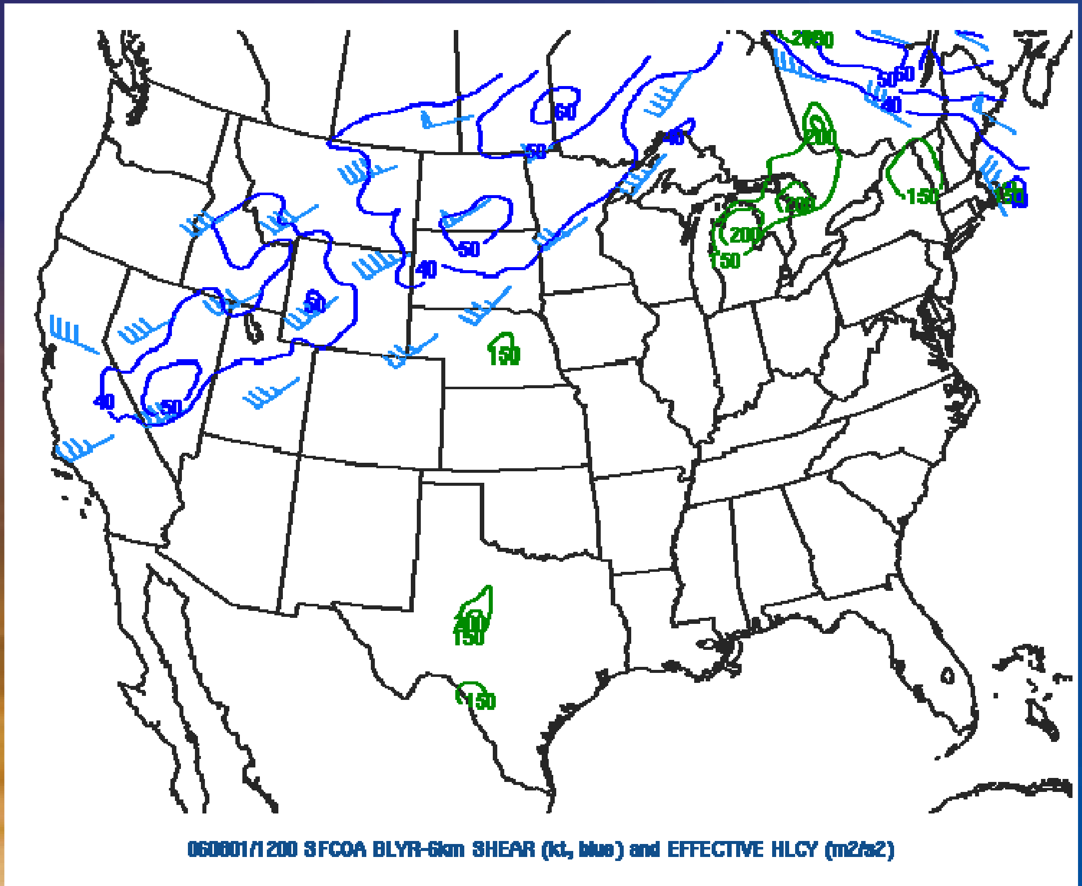


500 mb – 1200 UTC 1 Aug 2006



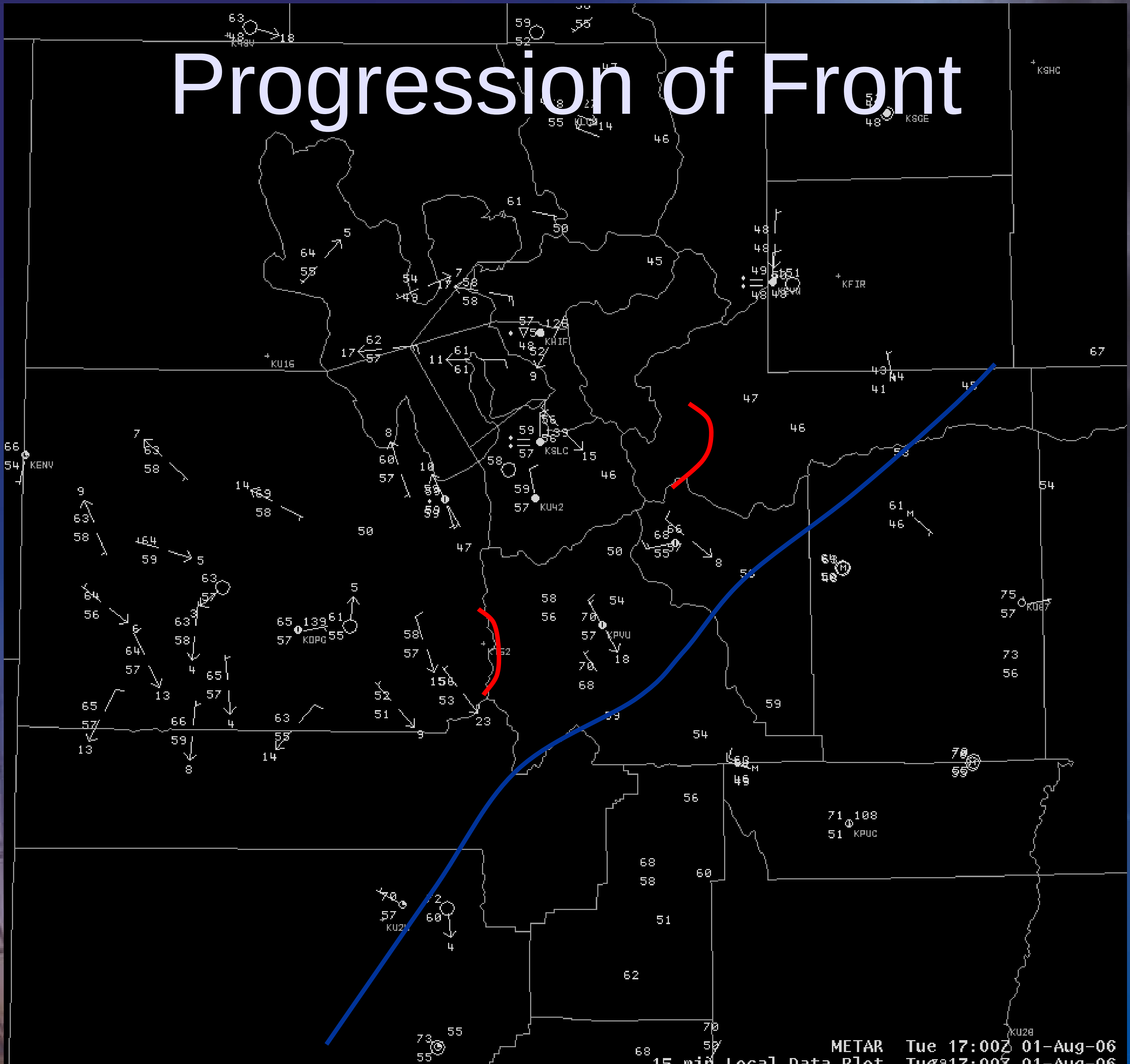
- Shortwave approaching northern Utah from the West
- Large scale lift ahead of wave
- Associated cold pool aloft helping to destabilize airmass

300 mb Jet and Deep Layer Shear



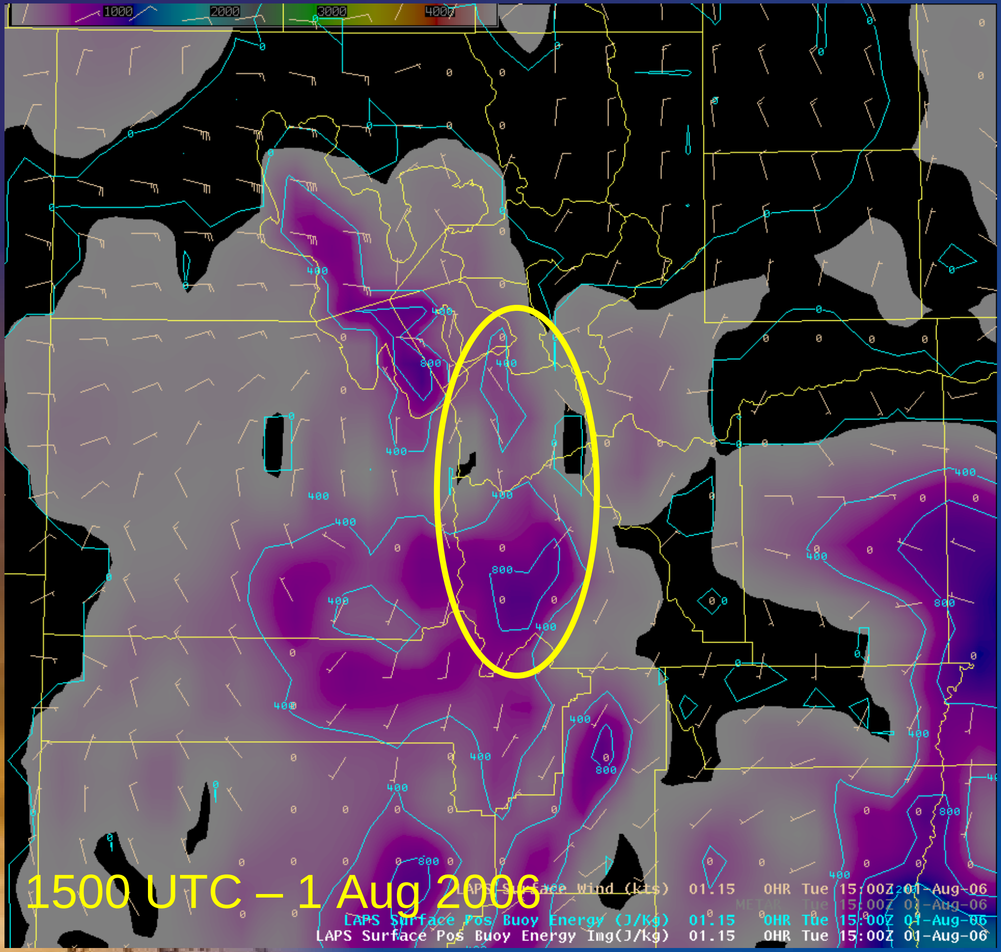
- Strong upper level jet over northern Utah
- Significant divergence in right entrance region
- Strong deep layer shear in place over northern Utah

Progression of Front



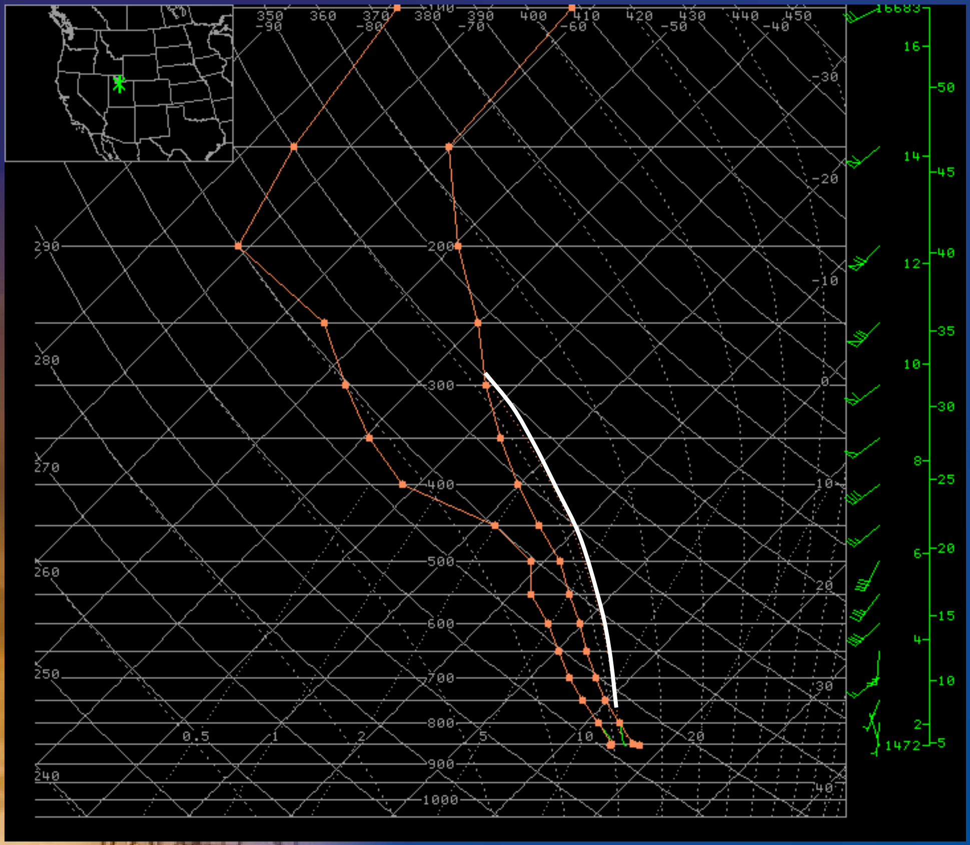
1100Z
1200Z
1300Z
1400Z
1500Z
1600Z
1700Z

Surface-Based CAPE



- LAPS analysis indicates surface based parcels remain unstable behind front
- SBCAPE of 400-500 J/kg over Salt Lake County
- More unstable air to the south being lifted over the approaching front

1500 UTC LAPS Sounding – Salt Lake City



- LAPS profile modified for surface temperature and dewpoint ahead of bow echo
- ~600 J/kg SBCAPE in modified profile
- Strong speed shear in lowest 4km evident in profile

Previous Work – MCSs and Complex Terrain

- New convective cells are initiated by low-level updraft at the gust front (Fovell and Tan, Lin and Joyce)
- Discrete MCS propagation simulated across complex terrain (Chu and Lin; Chen and Lin; Frame and Markowski)
- Three moist flow convective regimes in complex terrain (Chu and Lin)
  - Upstream Propagating
  - Stationary
  - Downstream and Stationary
    - Hydraulic jump in lee slope
    - Mid level echo crosses over barrier

Image courtesy of KSL

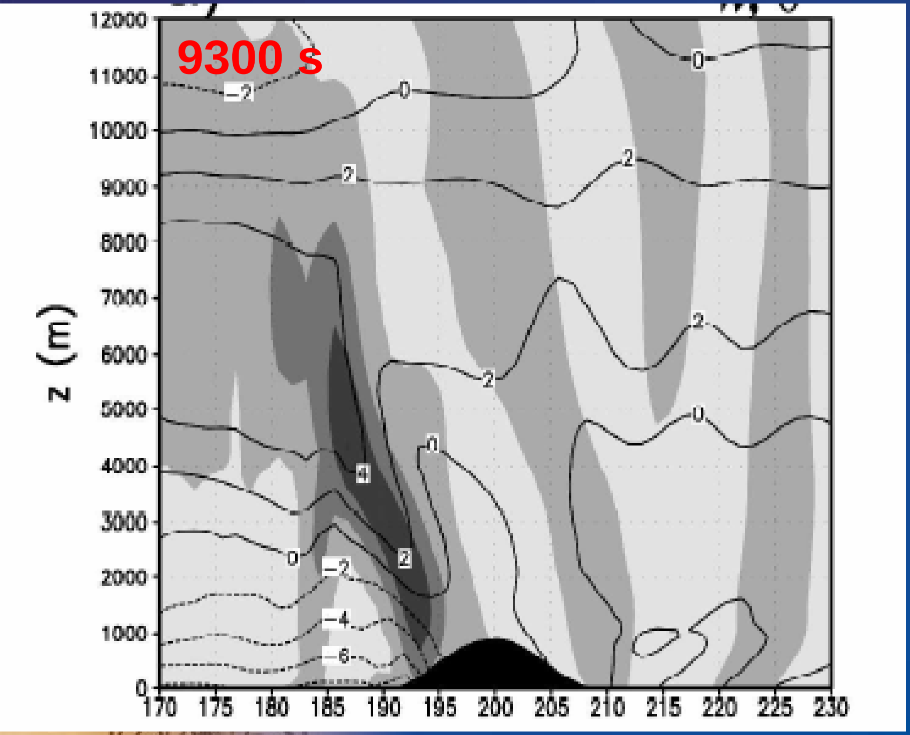
Frame and Markowski Simulation Details…

- Advance Regional Predication System (ARPS)
  - Horizontal grid spacing of 1.25 km
  - Vertical grid spacing of 150-500 m
- Squall line interacts with N-S ridge
  - Multiple simulations varied ridge width (10-40km) and height (300-1800m)
- Ridge archetype – 900m high; 20km wide
  - Results nearly the same for 1800 m ridge
  - Ridge height must be > 600m for discrete propagation

Image courtesy of KSL

MCS Approaching Obstacle…

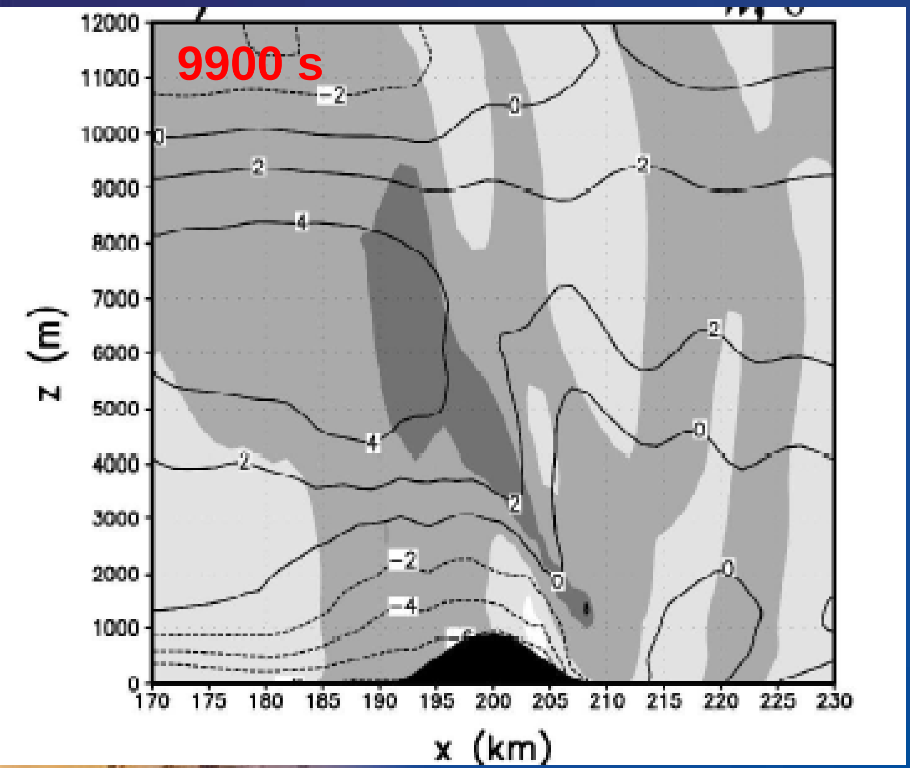
Frame and Markowski 2006



- -2° C isotherm denotes leading edge of cold pool
  - Shaded area is updraft
- As MCS approaches barrier it remains intact…similar to non-mountain MCS at this point
- Gust front updraft then weakens as it interacts with terrain inhibiting new cell development
- Heavy precipitation occurs on windward slope

Portion of Cold Pool Descends…

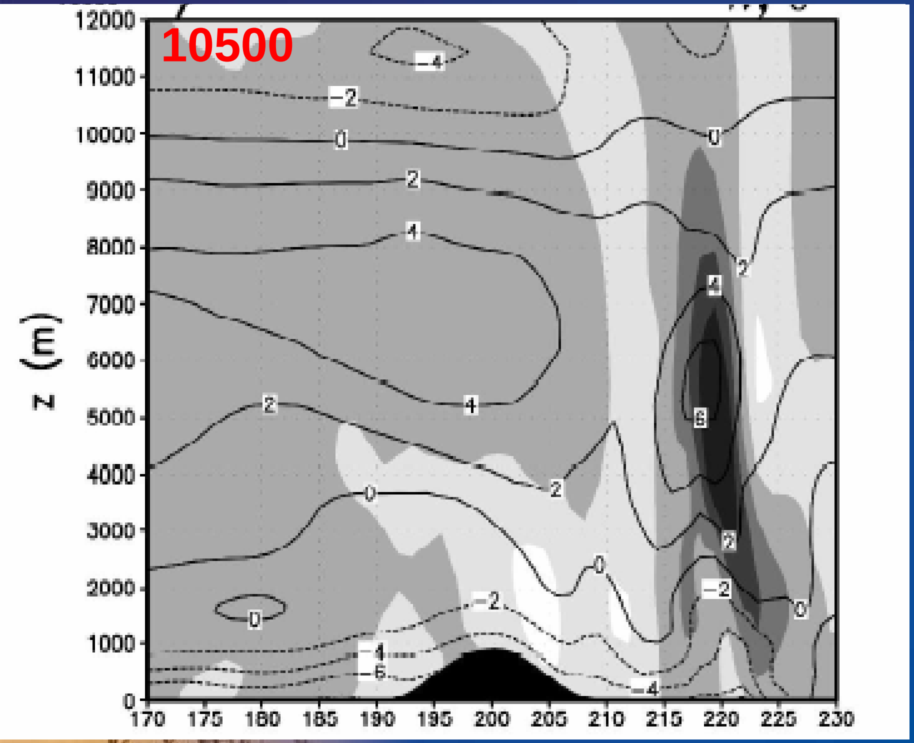
Frame and Markowski 2006



- Develops shallow supercritical flow during descent limiting new cells
- Cold pool becomes shallow (lowest several hundred meters blocked upwind)
  - Reduction in precipitation limits fresh cold air entering cold pool in the immediate lee
  - Adiabatic warming also limits cold pool in lee
  - Depth of cold pool and contrast across cold pool reduced
- Old updraft weakens dramatically

Initiation of New Updrafts – Hydraulic Jump

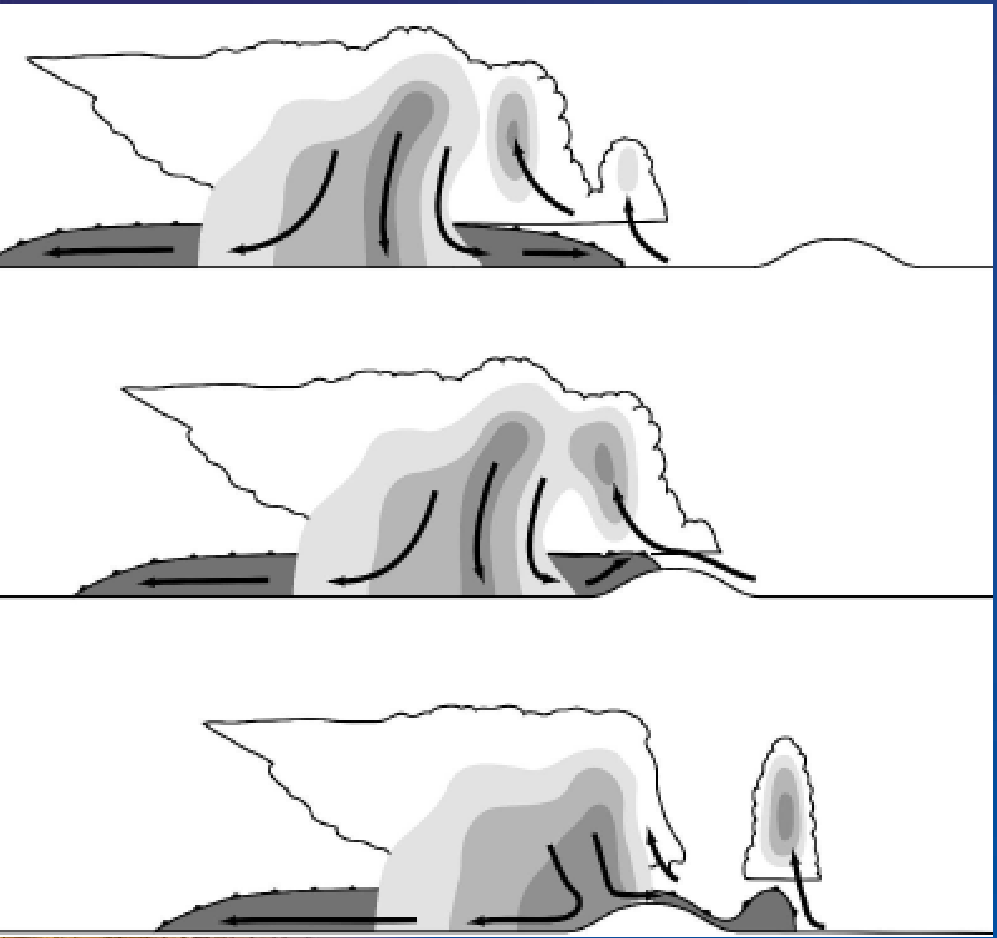
Frame and Markowski 2006



- Speed of gust front relatively constant …then decelerates at end of descent
- Leading edge becomes steep and deep with drop off just behind the nose as cold air begins to pool…flow again becomes subcritical
- Indication of the hydraulic jump…a sharp difference in the depth of a fluid.
- Steep leading edge induces intense new updrafts

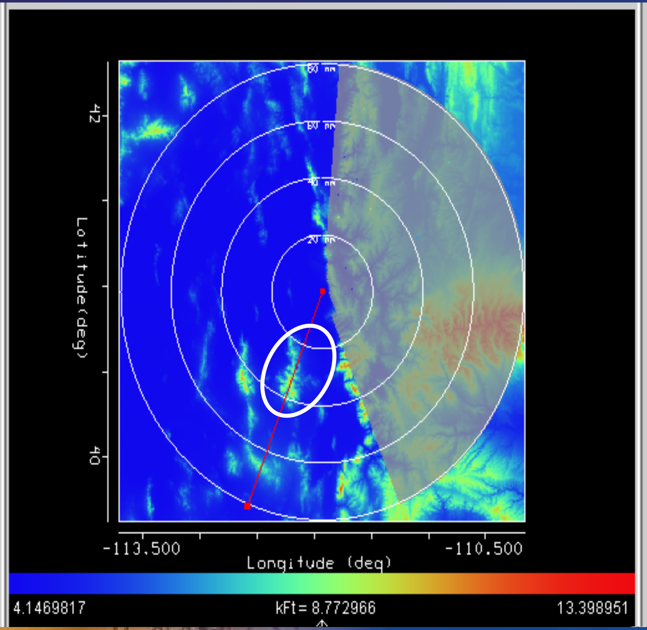
Conceptual Model – Impact of Terrain

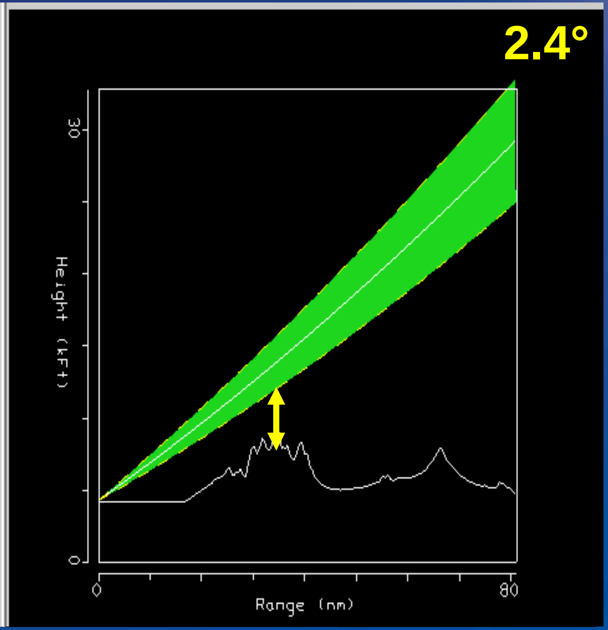
Frame and Markowski 2006



- Squall line and associated cold pool approach barrier…heavy precip on windward side
- Lower portion of cold pool does not ascend terrain
- Supercritical flow and adiabatic warming of cold pool in lee slope
- Cold pool decelerates at base of obstacle resulting in hydraulic jump initiating new convection

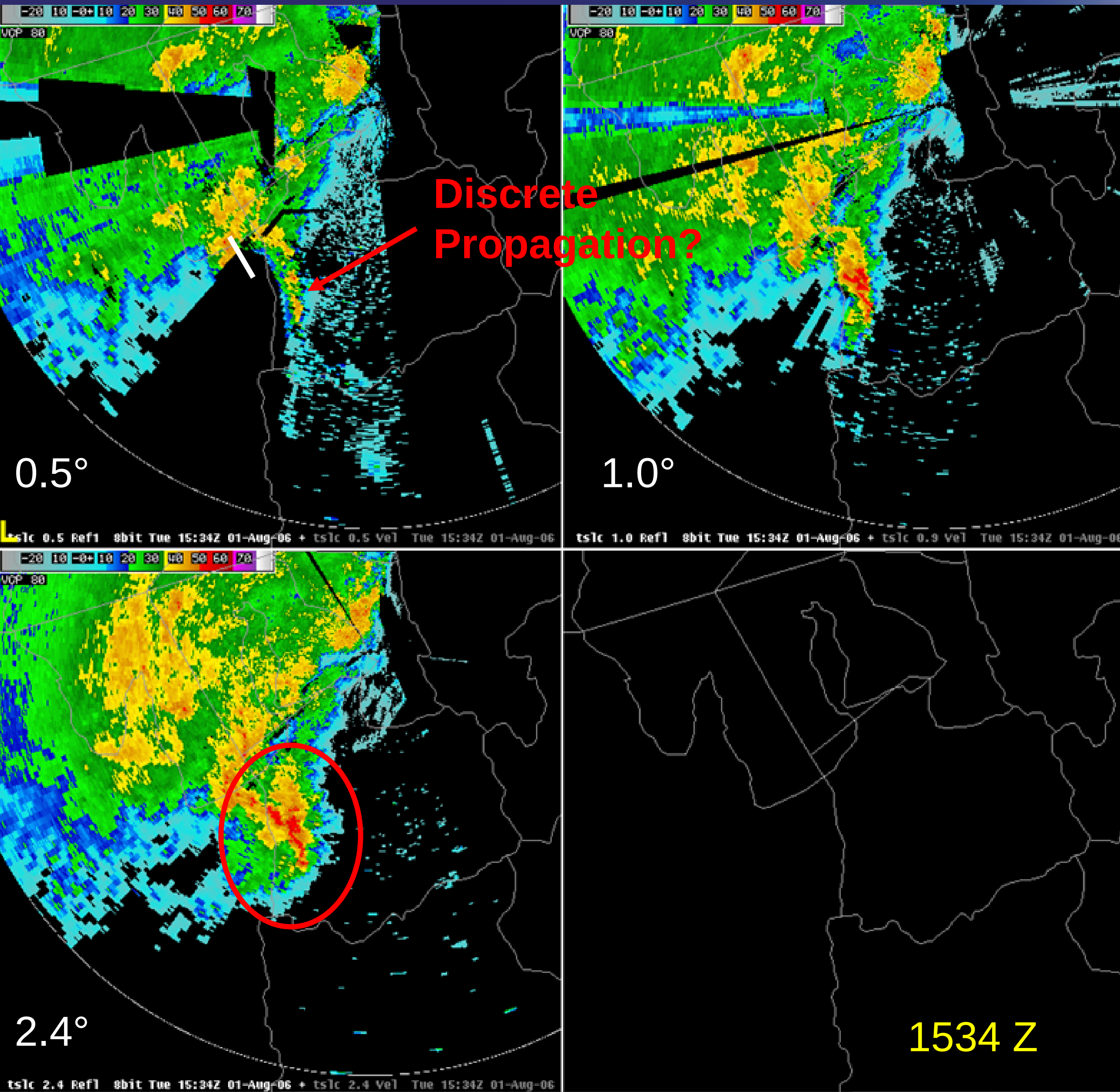
Beam Blockage – TSLC TDWR





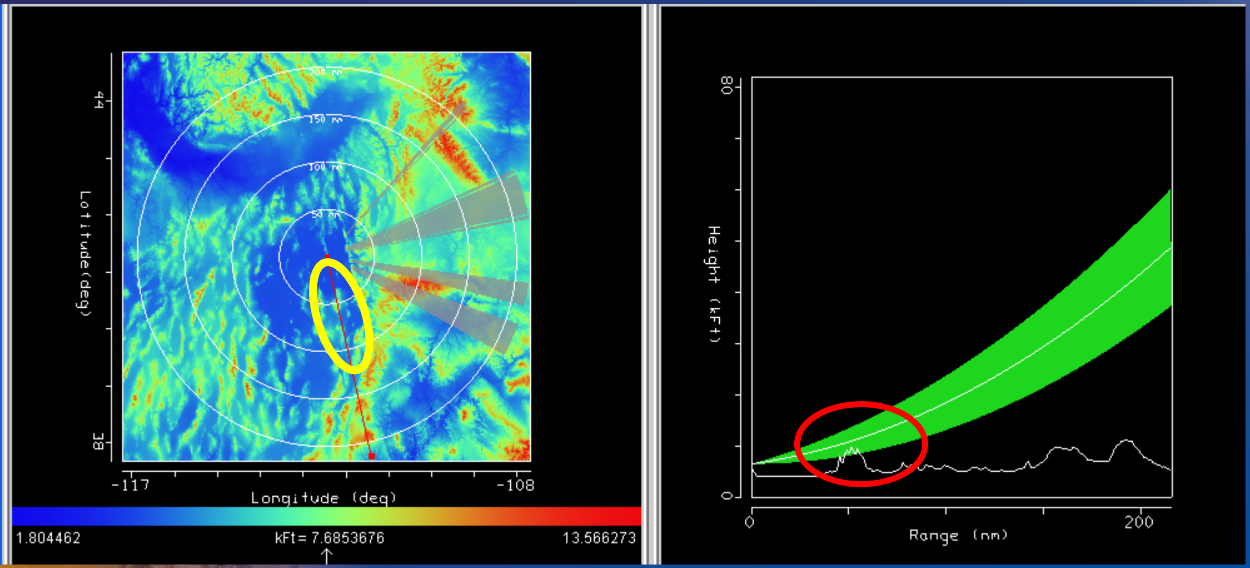
- 0.5° from the TDWR is totally blocked southwest of the Oquirrhs
- The 2.4° slice suffers no blockage across the Oquirrhs

TDWR – Lee Slope Updraft Initiation



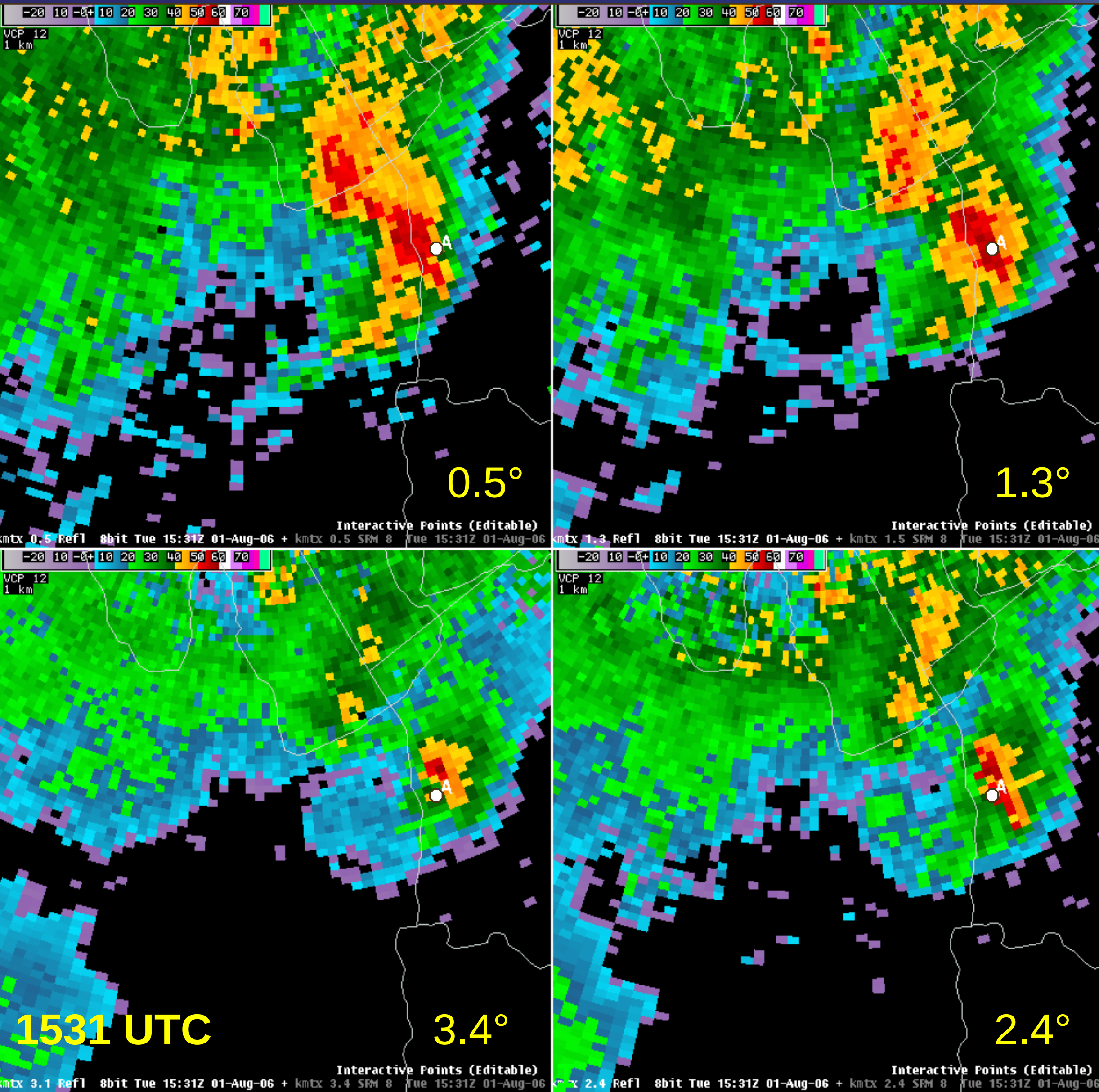
- Well defined linear segment with forward tilt with height
- Initiation of new updrafts evident in lee of Oquirrhs
- Mid-level returns appear to cross unimpeded…with some loss in linearity
- System becomes aligned with Oquirrhs

Beam Blockage – KMTX WSR-88D



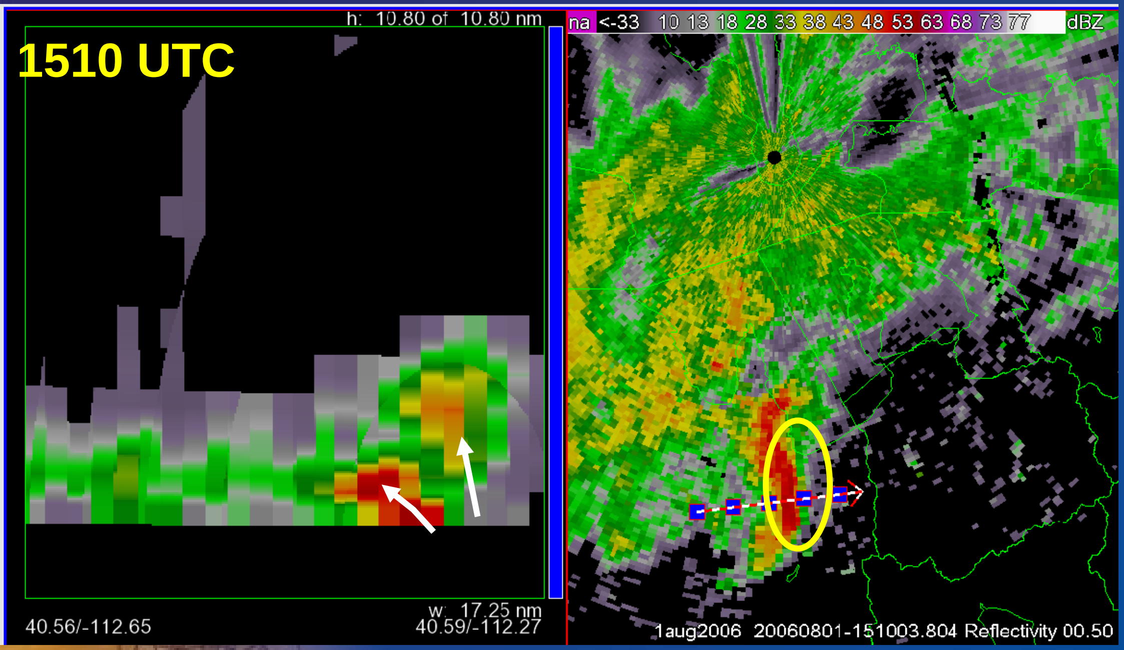
- Less than 30% blockage at 0.5°
- Several dBZ potentially added downstream of barrier for precipitation algorithm
- No modification of reflectivity return by radar software

Slope of Updraft Interface



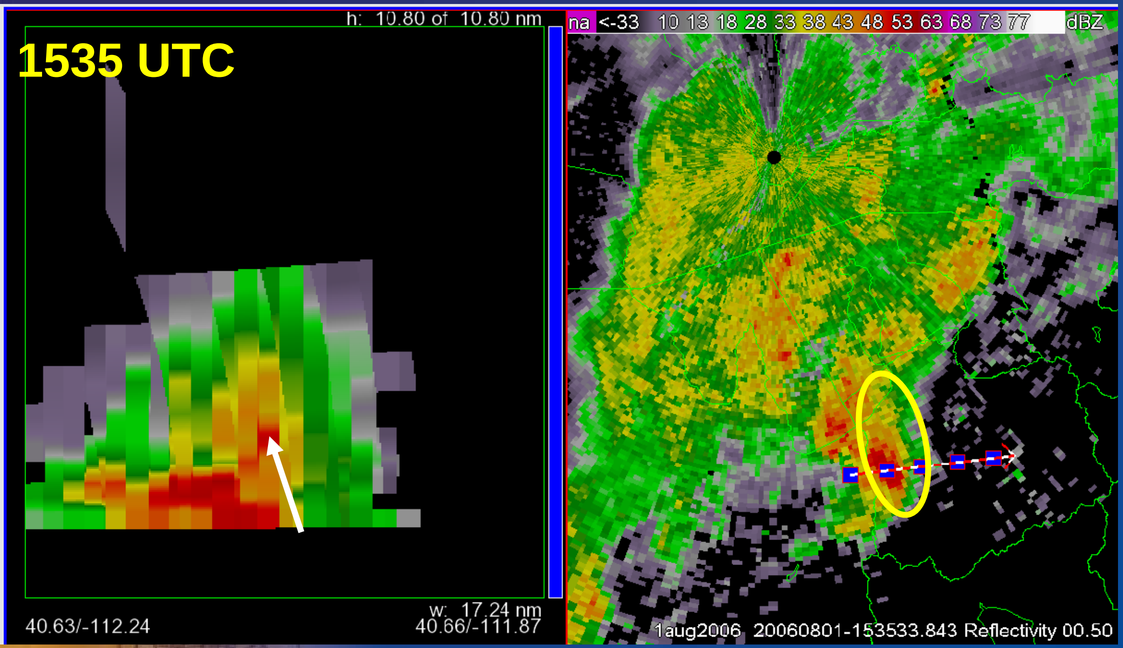
- Note new updraft development ahead of tight low level Ref gradient
- As line intensifies in lee slope note that updraft interface over the gust front is nearly vertical

Slope of Updraft Interface



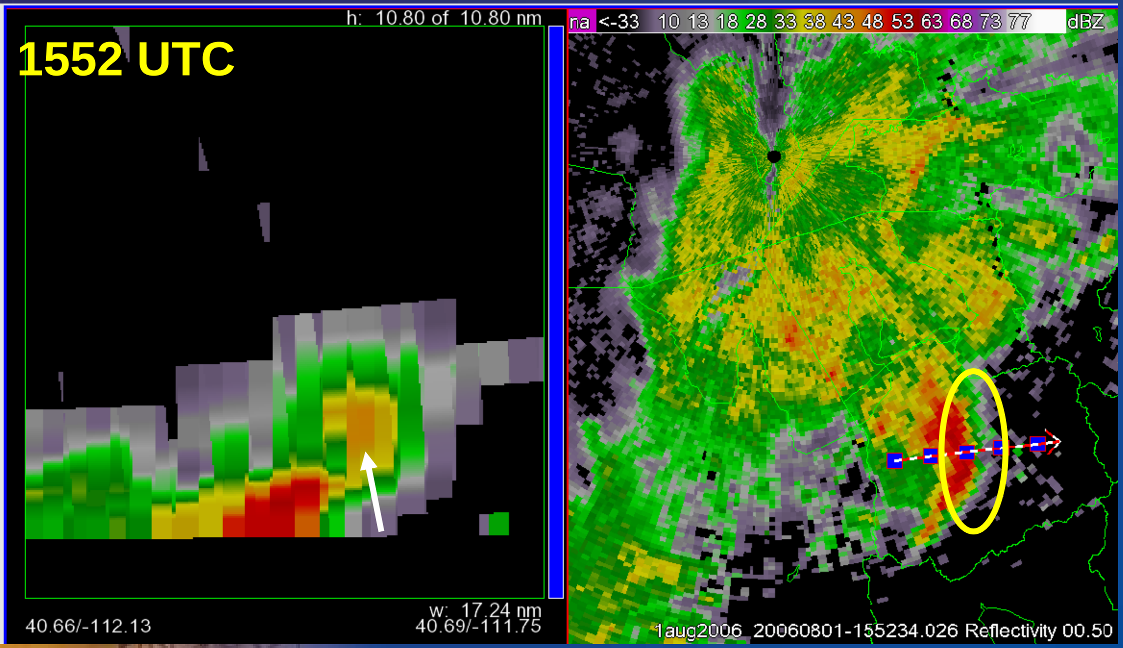
- Well formed bow echo across Tooele Valley with tight low level ref gradient
- Front-to-rear flow implied in upshear tilted echo region
- Note new cell forming along Gust Front Updraft (GFU)

Re-Generation of Gust Front Updraft



- As line crosses the Oquirrhs the tight low level reflectivity gradient weakens
- Note vertical nature of updraft interface as front-to-rear flow has not yet re-established itself

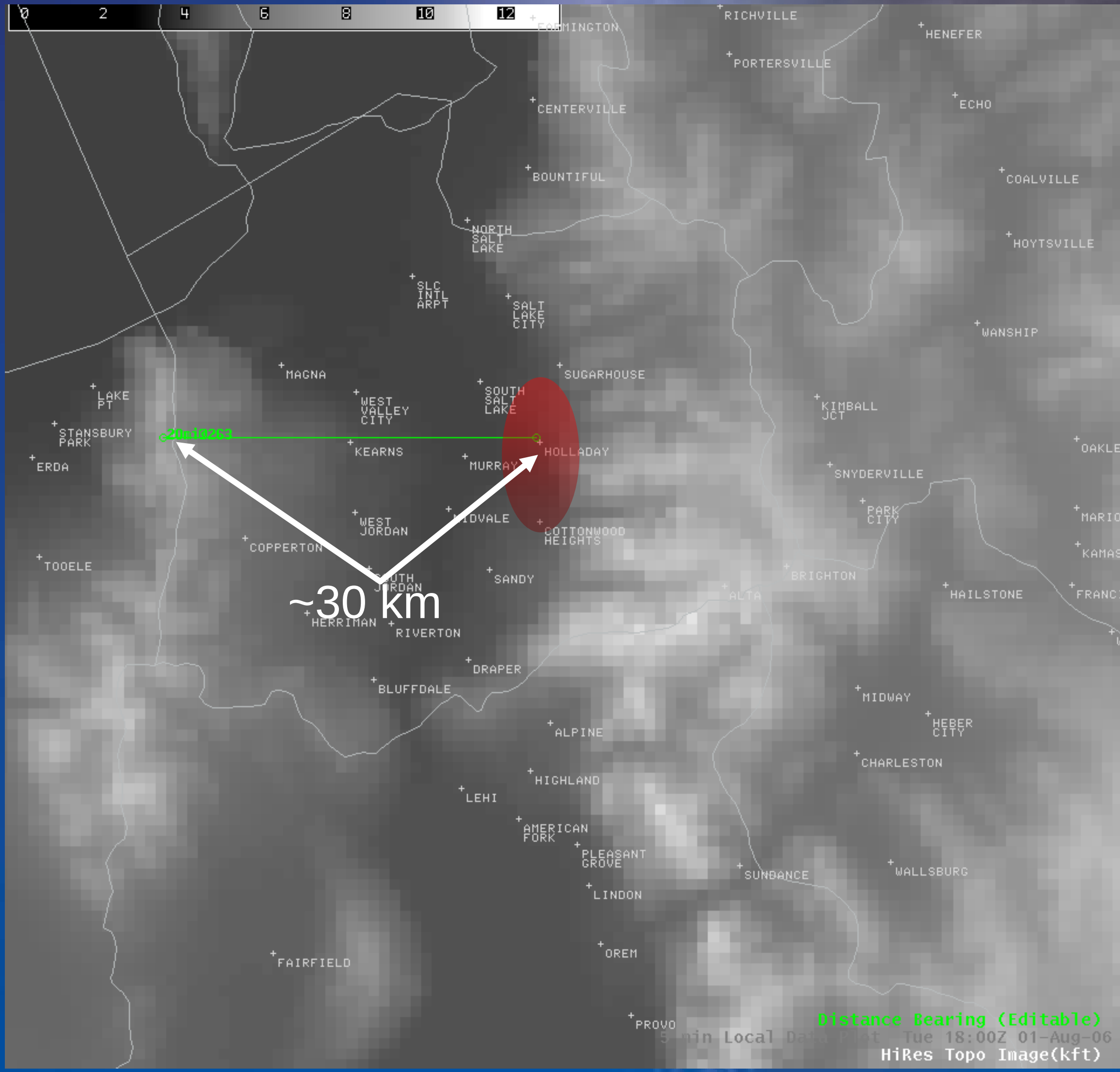
Gust Front Updraft Evolution



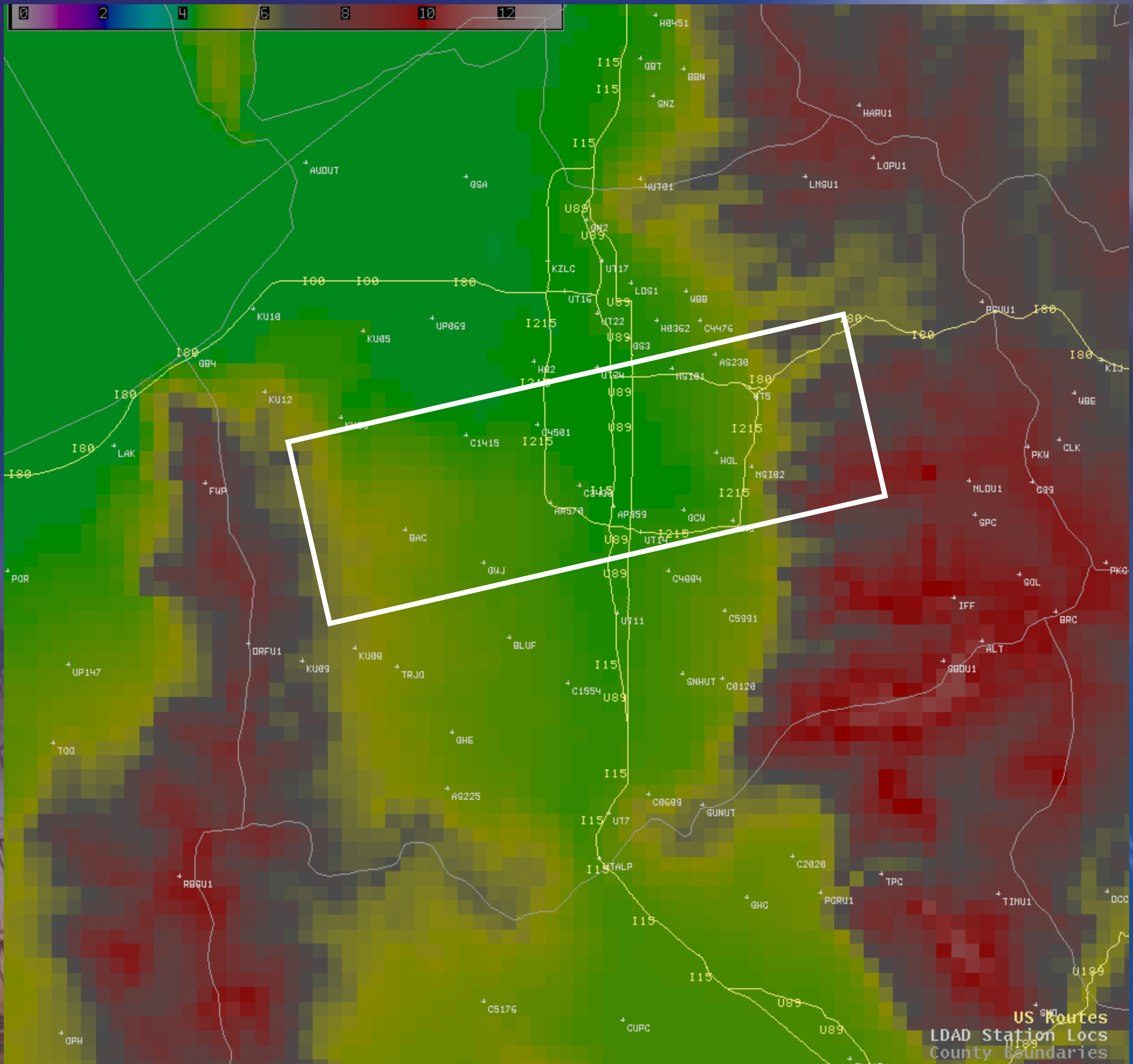
- By central Salt Lake County tight low level ref gradient has re-established itself
- Note new echo development above Gust Front Updraft

Wind Distribution in the Lee of Terrain

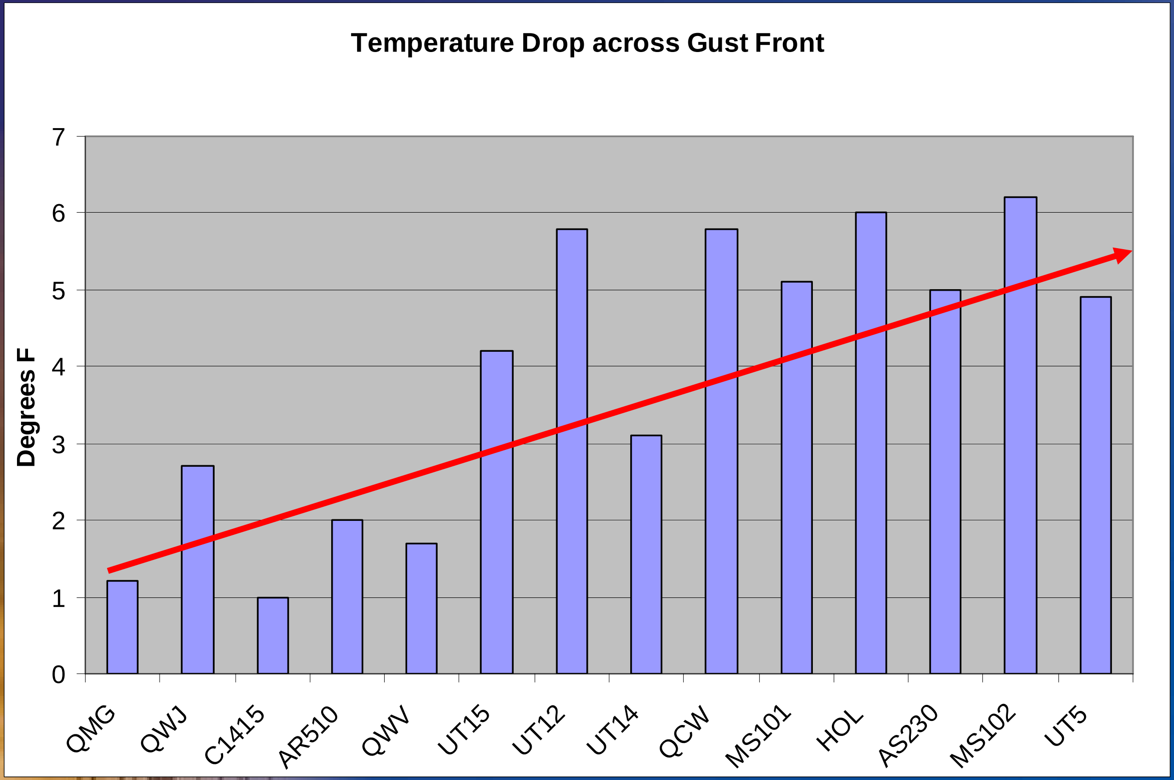
- Damaging wind potential is greater in terrain simulation
- Greater coverage of significant convection in lee of terrain
- Negative buoyancy during descent contributes to wind potential.
- Damaging winds initiate 15-20 km downstream of barrier



Cold Pool Evolution

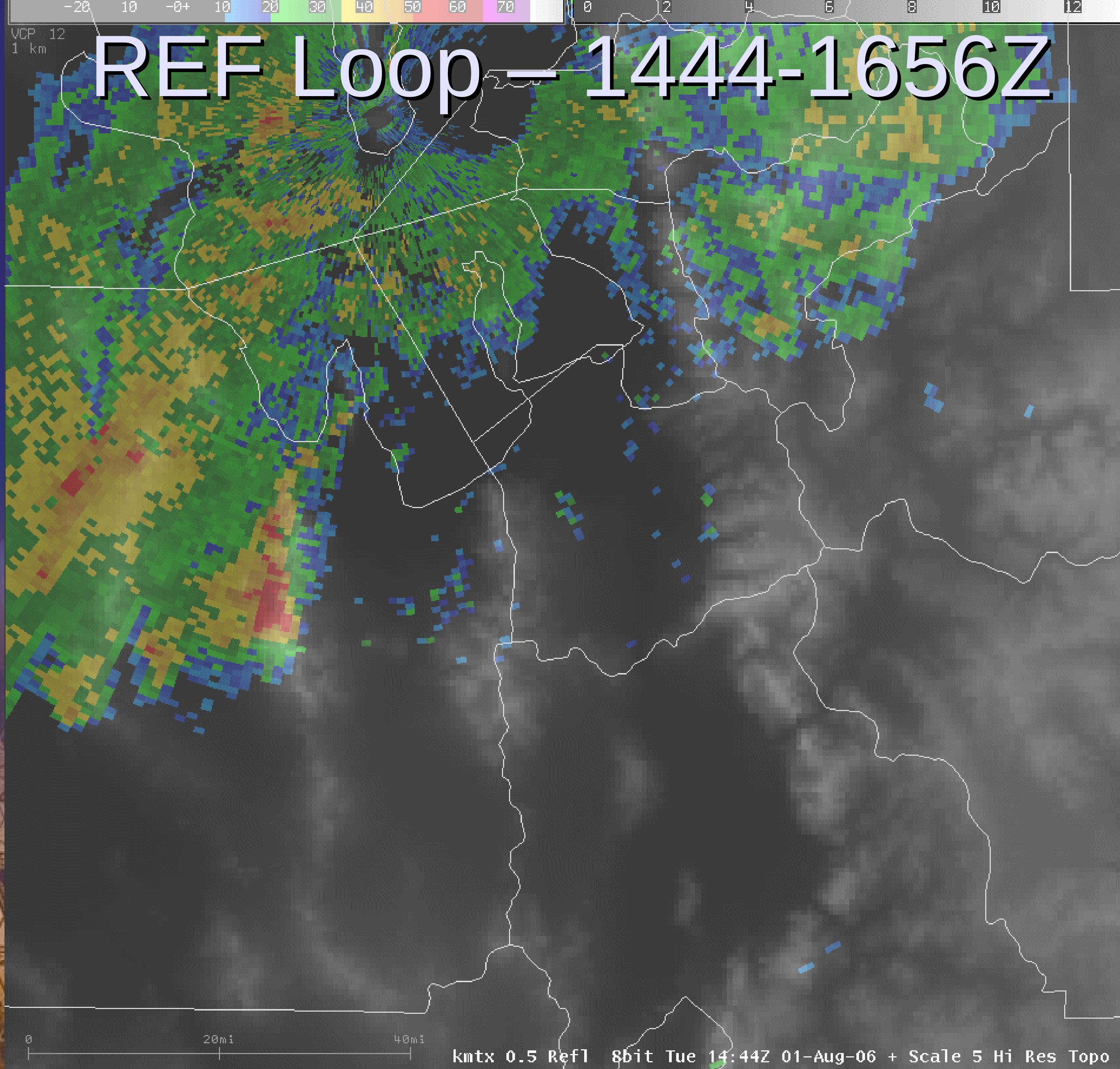


Temperature Change across Gust Front



- Examination of temperature change across gust front
- 14 sensors directly impacted by cold pool across the Salt Lake Valley
- Temperature drop of 1-3° F across the west side of the valley increases to 4-7° F across the east side of the valley

REF Loop – 1444-1656Z



Summary

- Evolution of radar reflectivity shows cycling of Bow Echo organization and strength as it interacts with complex terrain
- Appearance of discrete propagation in lee of Oquirrhs as indicated by TDWR data
- Change in slope of updraft interface consistent with hydraulic jump theory
- Distribution of wind damage in Salt Lake and Tooele valleys reasonably consistent with Frame and Markowski (2006) model simulations
- Clear trend in strengthening of cold pool from west to east across Salt Lake Valley

Future Work

- Examine additional bow echoes which cross complex terrain
  - Cold pool evolution
  - Discrete propagation

- Assess potential MCS predictability and wind damage potential
  - Environment assessment

References

- Chen, S.-H., Y.-L Lin, 2005: Effects of Moist Froude Number and CAPE on a Conditionally Unstable Flow over a Mesoscale Mountain Ridge. *J. Atmos. Sci.*, **62**, 331–350.
- Chu C.-M., and Y.-L. Lin, 2000: Effects of orography on the generation and propagation of mesoscale convective systems in a two-dimensional conditionally unstable flow. *J. Atmos. Sci.*, **57**, 3817–3837.
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- Frame, J., and P. Markowski, 2006: The interaction of simulated squall lines with idealized mountain ridges. *Mon. Wea. Rev.*, **134**, 1919–1941.
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Rear Inflow Jet Development

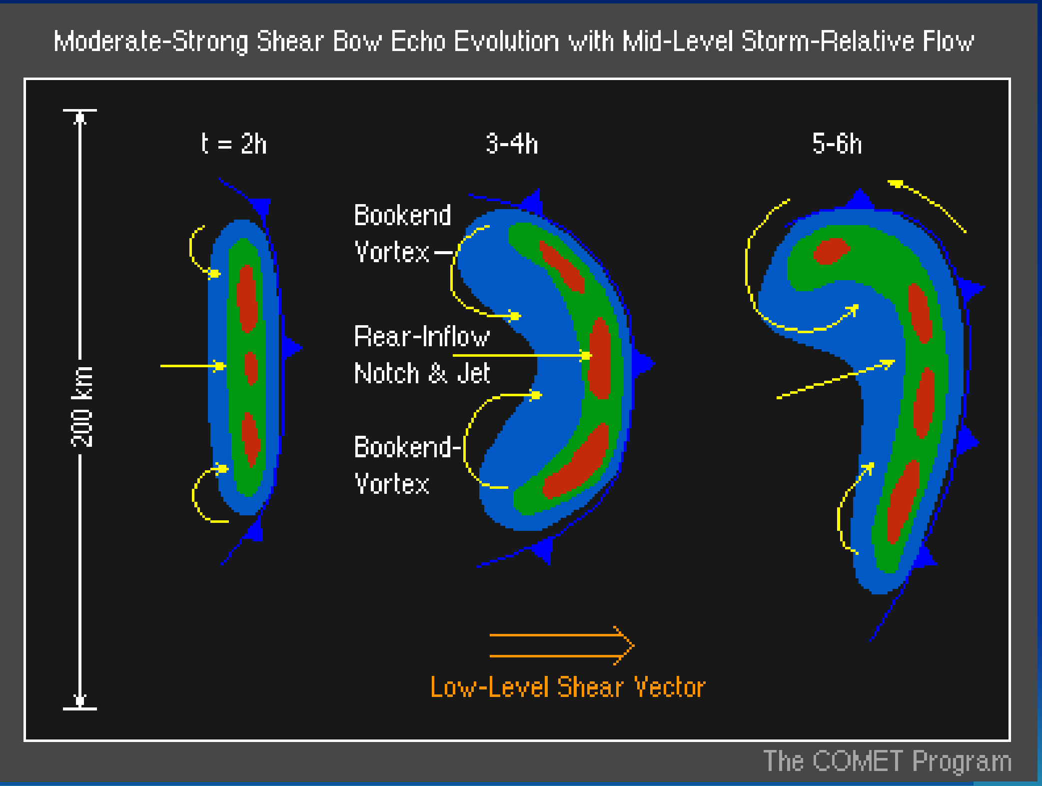
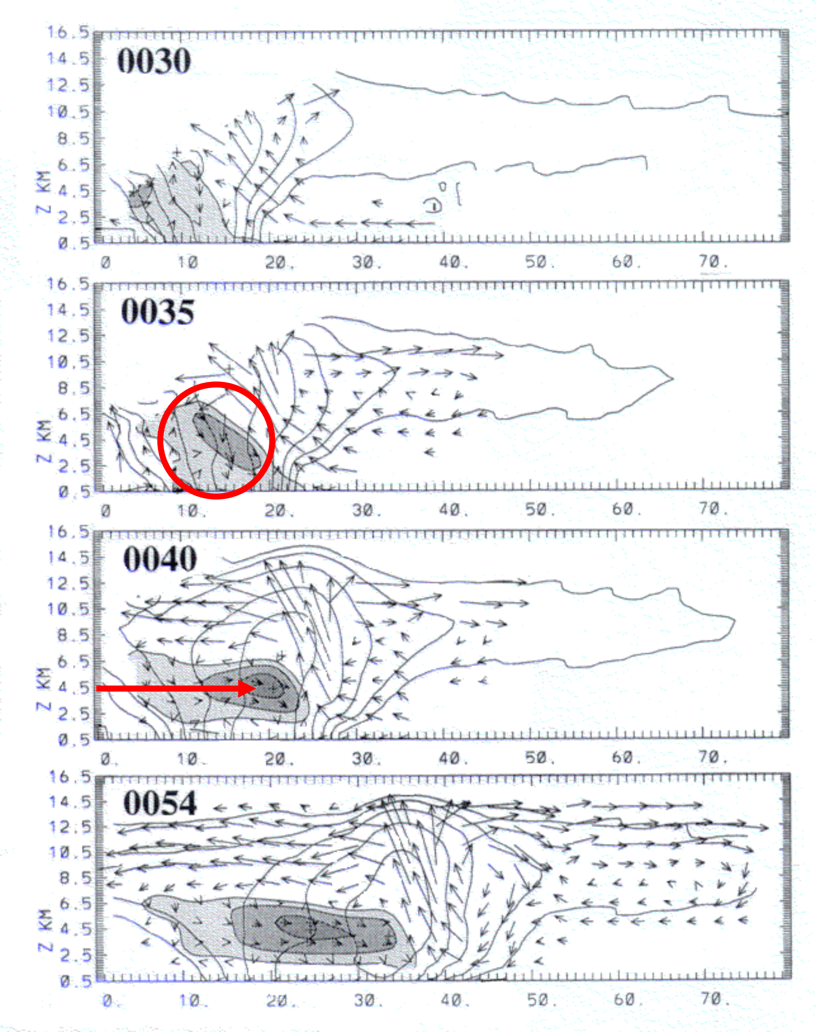


Image from COMET

- Front-to-rear flow begins to spread warm air aloft over developing cold pool
- This 'conveyor' of warm air over the surface cold pool produces an area of lower pressure at the mid levels
- Flow responds by diverging at the surface and converging in the mid levels.
- This is the initiation of the rear inflow jet
  - Bookend vortex development also plays a role in enhancing RIJ

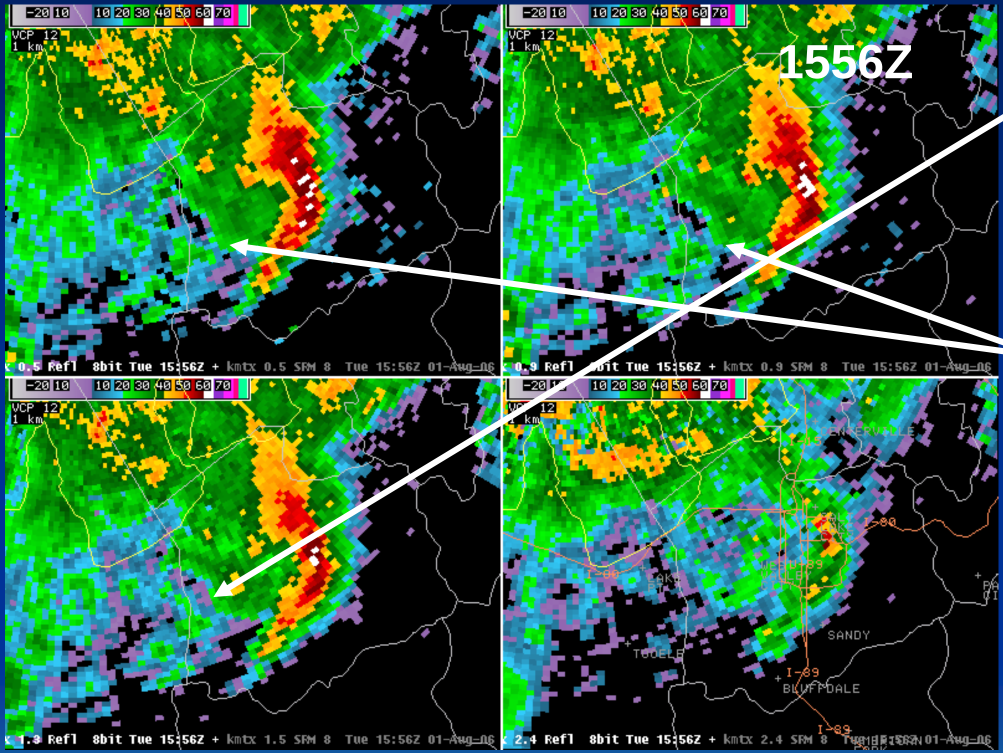
RIJ Initiation



(Klimowski 1994).

- RIJ develops near the backside of the intense convection and spreads rearward
  - Mid level jet does NOT 'punch' into the backside of the convection
- Builds back over cold pool with time
- Initiation of rear inflow begins entrainment of low theta-E air to produce damaging winds

1 August 2006 – RIJ Development



- Note evacuation of echo aloft
- ‘Donut hole’ in high reflectivity develops downward with time
- Can anticipate development of weak echo channel and location of most damaging winds

Mid-Altitude Radial Convergence Signature