

LEADING EDGE ATMOSPHERICS, LLC

WEATHER ANALYSIS FOR EMB-145 ICING INCIDENTS - 2014

EMBRAER-145
NATURAL ICING INCIDENTS
2014
U.S.A.

INTRODUCTION

This report provides a summary of the weather conditions that were present during two EMB-145 flights that may have encountered icing over the central United States between February and April 2014. Information is provided about the flights that were made, and the location of the aircraft relative to important weather features. In the Flight Data and Tracks section, time-series charts and flight tracks show the aircraft location, altitude and ground-relative speed. In the Figures section, a series of figures is used to describe the meteorological environment within which the aircraft flew. Unless otherwise indicated, all heights are in feet above mean sea level (MSL), except for cloud base heights reported in METARs, which are given in feet above ground level (AGL). All times are in UTC.

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CASE 1: FEBRUARY 4-5, 2014

BASIC INFORMATION

Flights: There was one flight between Houston Intercontinental Airport (KIAH) and Memphis International Airport (KMEM) during the night of 4-5 February 2014. The aircraft departed KIAH at 0441 UTC and landed at KMEM at 0615 UTC. The event occurred just before landing at KMEM. It appears that the aircraft descended into a shallow layer of icing during final approach into KMEM and possibly during low-altitude holding to the south of KMEM, although that hold appeared to be just above cloud top (see Data Plots 1.1, 1.2). After a stepwise descent to 4,000 ft, then 3,000 ft, the aircraft was held at 1,900-2,000 feet to the south of KMEM for ~13 minutes (0601-0614 UTC) before final descent and landing at 0615 UTC.

RELEVANT WEATHER FEATURES

A weak area of low pressure was gradually lifting from Louisiana into Tennessee (Fig. 1.1). The low deepened slightly between 0000 and 0600 UTC and a cool front extended southward from it to the Gulf of Mexico. To the northwest, a strong area of high pressure was moving southward into Montana, pushing cold air into the central U.S. and a shallow layer of near-freezing air all the way to the western border of Tennessee by 0600 UTC.

Above the surface, deep moisture was present across western Tennessee and areas to the north at 0000 UTC, ahead of a low centered over Kansas, Missouri and Arkansas (Figs. 1.2, 1.3). At 850 mb and 925 mb (~5,000 ft and ~2,500 ft MSL), warm air was moving northeastward into Tennessee ahead of the low, while much cooler air was approaching from the northwest along the back side of the low.

By 0600, the deep upper-level moisture had moved east out of the Memphis area at 500 mb and 700 mb (~18,000 ft and ~10,000 ft; Fig. 1.4), leaving dry air in its wake at these levels. This feature extended down to 850 mb, while the 850 mb low moved into southern Indiana. Moisture did remain in place at very low levels, such as 925 mb, with temperatures very close to 0°C there (Fig. 1.5). Cooler air continued to advance toward Memphis from the northwest and temperatures were subfreezing across all of Missouri (close to Memphis) at this level. By 0900 UTC, the subfreezing air had advanced well into western Tennessee and northwestern Mississippi, including areas just to the south of Memphis (Fig. 1.6). Much warmer air was present around Houston at all levels and the freezing level was near 10,000 ft there (Figs. 1.5, 1.6).

A vertical cross section of the RUC model temperature and relative humidity fields from Houston to Memphis valid at 0600 UTC shows that a shallow layer of subfreezing, saturated air was present below ~500 m near Memphis (right side of the plot; Fig. 1.7). Above-freezing air was present between the two 0°C isotherms above Memphis, from ~500 m to ~2,000 m, then temperatures were cooler above 2,000 ft, where it became quite dry (yellow colors in the RH field indicate low RH). Vertical profiles of model temperature and relative humidity directly over Memphis show that slightly-subfreezing (0 to -2.5°C), essentially saturated air was expected in the layer from the surface up to ~700 m MSL (~1,630 ft; Fig. 1.8). A capping inversion was

indicated between ~500 m and ~1,600 m (near 850 mb), where temperatures increased to around +2.5°C. Very dry air was indicated above that level.

While this temperature structure can be indicative of the potential for “classical” freezing rain to develop via snow falling into warm air to form rain, then subsequently falling into low-altitude sub-freezing air to form freezing rain, this scenario is predicated on the formation of snow in the upper sub-freezing layer. As noted above, the air above the freezing level was quite dry (Figs. 1.7, 1.8), so it was extremely unlikely that snow would have been forming in the upper sub-freezing layer, so classical freezing rain was not being formed at this time. This is supported by observations of relatively warm cloud tops in satellite data.

A very similar structure was present in the balloon borne sounding taken at Little Rock, Arkansas (KLZK; Fig. 1.9), with a slightly subfreezing layer present between the surface and 925 mb (724 m MSL), an above-freezing layer between 925 mb and 700 mb (2973 m), and sub-freezing temperatures at all levels above 700 mb. Saturated conditions were only present from 787 mb (2029 m) to the surface and the coldest temperatures indicated where moisture was present were -2.9°C, which was located in the lower sub-freezing level at 954 mb (478 m). Such warm clouds are very unlikely to produce significant precipitation. To some extent, these clouds and a similar temperature/moisture structure were moving toward Memphis and northwestern Mississippi during the hours between 0000 and 0600 UTC (Fig. 1.10).

Infrared satellite imagery from 0415 and 0515 UTC (the two hours leading up to the event) indicated the presence of slightly subfreezing clouds moving from Arkansas (the state to the west of Memphis; KMEM) into western Tennessee and northwestern Mississippi with time (Figs. 1.11, 1.12). Cooler icing clouds were present further to the northwest in Missouri and northwestern Arkansas, while very warm (above-freezing) conditions were present just to the east of KMEM, while deeper, colder clouds were present across the eastern half of Tennessee.

By 0615 UTC, slightly sub-freezing clouds were clearly evident along the western edge of Tennessee, including KMEM, and extended into neighboring parts of Mississippi, including directly to south of KMEM, along the 90°W longitude line that essentially runs through Memphis (Fig. 1.13). It was in this area that the aircraft was placed in a racetrack holding pattern at altitudes as low as 1,900 ft (see Data Plots 1.1, 1.2). This level was likely just above the cloud tops, which were reported to be at 1,700 ft by a DC-10 just to the south of KMEM at 0458 UTC (see Relevant PIREPs below).

Infrared difference fields indicated that the clouds were very likely to have been liquid in phase. Drop sizes at cloud top appear to have been somewhat enhanced beyond “normal” drop sizes, but there is not a clear indication that they would have been SLD (see Fig. 1.14). The lack of SLD is supported by the lack of reports of drizzle or rain in METARs around the Memphis area (see Relevant METARs below), with only low overcast skies and mist reported (OVC004; BR with ½ mile visibility) reported at KMEM.

The KMEM weather station is a National Weather Service ASOS (Automated Surface Observing System). ASOS stations are designed to provide meteorological observations, including temperature, dew point, winds speed, present weather and other fields automatically, and this is done at many airports across the United States. At particularly important airports, the automated ASOS observations can be augmented with manually entered information from a Contract Weather Observer (CWO). One of the most important pieces of information that a CWO can add is a correction to the present weather, including current precipitation type. This is particularly important for this case, because a surface observation of drizzle (DZ) or freezing drizzle (FZDZ) would have provided a strong indication that SLD would have been present in the cloud layer over KMEM and the holding area to the south. Recent research has indicated that ASOSs are incapable of reporting DZ and FZDZ automatically, and when those conditions are actually occurring, they are often misreported as “mist” (BR). It turns out that “BR” was reported

at KMEM off and on between 0454 and 0654 UTC, and was continuously reported from 0654 to at least 0854 UTC (see Relevant METARs below). However, KMEM is a very busy Fed Ex hub and the station does have a CWO on site. Thus, if DZ or FZDZ was occurring, the “BR” in the KMEM METARs **should** have been corrected to reflect the presence of DZ or FZDZ. It was not, which indicates that either a) DZ and FZDZ were not falling at KMEM or b) the CWO was unable to see the precipitation (it can be difficult, especially at night) and/or did not report it. Both are possibilities, so it is not possible to rely heavily on the KMEM observations to determine whether or not SLD was present in the clouds above KMEM and nearby.

Given that satellite data signals were also inconclusive with regard to drop size, the primary remaining source to use when looking for SLD signals in the observations is NEXRAD radar imagery. When DZ or FZDZ are falling near a NEXRAD, a ring or disc of low radar reflectivity can show up in the radar echo pattern. However, this can only be seen if the radar is running in what is known as “clear air mode”, which allows the radar to display reflectivity values between -28 and +5 dBZ. Radar echoes from DZ and FZDZ mostly fall within this range. To see these values, the national radar mosaic data (e.g. Figs. 1.15, 1.16) may be useful, but it is best to look at the raw data from the individual radars. In this case, the closest radar was KNQA (Millington TN), which is located just to the north of Memphis and is at the same elevation as KMEM (86 m above MSL). Imagery from KNQA taken at 0607 UTC (Fig. 1.17) show that very little radar echo is evident to the south of KMEM, in the area where the aircraft was held and then made its final approach. Only a few small specks of reflectivity are present and these could easily be from noise. There is not clear indication of SLD to the south of KMEM in this image, nor the image from 0617 UTC (Fig. 1.18). In contrast, there are some hints of very low/light reflectivity to the north of KMEM which may indicate the presence of very light precipitation such as -DZ to the north of KMEM.

Overall, the Memphis radar data do not provide a clear indication of the presence of DZ or FZDZ in the holding and approach area. This, coupled with a lack of clear indications of the presence or absence SLD from satellite data and surface observations makes it difficult to say for sure whether the sub-freezing clouds encountered by the aircraft to the south of KMEM were comprised of cloud-sized supercooled water drops alone or a combination of cloud-sized droplets and SLD (FZDZ aloft).

In summary, it appears that the aircraft was put into a hold just above the top of a shallow layer of supercooled liquid water clouds to the south of Memphis, before descending into these clouds on final approach into KMEM at 0615 UTC.

As always, it is challenging to determine the liquid water content and median volumetric diameter of an environment. However, due to the relatively simplistic nature of the clouds in this case and their direct exposure to satellite view, it is possible to make a reasonable estimate. Cloud bases in the area of flight ranged from 300 to 500 ft AGL, which places them near 700 ft above sea level, when the elevation of the airports is taken into account (e.g. Memphis’ elevation is 282 ft). Cloud top height was indicated to be near 1,700 ft, according to a DC-10 pilot report noted earlier, so the cloud layer depth was on the order of 1,000 ft. Using a cloud base temperature of about -2°C (from the 200 m [700 ft; ~975 mb] level in Fig. 1.8), gives a cloud-base mixing ratio of ~3.38 g/kg. The temperature at cloud top appeared to be near -3°C at 520 m (~1,700 ft; ~950 mb) MSL, resulting in a cloud-top mixing ratio of ~3.22 g/kg. Because the RUC model vertical profile of temperature through this part of the atmosphere was essentially moist adiabatic (neutral relative to saturated cloud rising upward from cloud base), and no precipitation was falling from the clouds, it is reasonable to use the adiabatic assumption and the difference between the cloud-base and cloud-top mixing ratios to estimate the LWC at cloud top (Fig. 1.8). This difference is 0.16 g/kg, which converts to an LWC of ~0.2 gm⁻³ at cloud top after accounting for density. The LWC would have decreased linearly from ~0.2 to 0.0 gm⁻³ from

cloud top to cloud base. As for drop size, Fig. 1.12 indicates some variability on the local scale, but drop sizes that were likely to be on the order of 20-25 microns. This is only a rough approximation, but it is safe to say that there were no indications of SLD in satellite, radar and METAR data for the area around Memphis.

Overall, the conditions at cloud top are approximated to have been T near -3°C , with LWC of $\sim 0.2 \text{ gm}^{-3}$ and MVD on the order of 20-25 microns.

RELEVANT METARS

Memphis, Tennessee:

KMEM 050854Z 27005KT 6SM BR OVC008 01/M01 A3002 RMK AO2 SLP166 T00061006 51021 \$
KMEM 050817Z 27008KT 6SM BR OVC008 01/M01 A3001 RMK AO2 \$
KMEM 050754Z 26008KT 6SM BR OVC010 01/M01 A3000 RMK AO2 CIG 008V013 SLP160 T00061011 \$
KMEM 050735Z 27008KT 6SM BR BKN010 OVC013 01/M01 A2999 RMK AO2 CIG 006V012 \$
KMEM 050701Z 28012KT 1/2SM BR OVC006 01/M01 A2999 RMK AO2 SFC VIS 6 CIG 004V009\$
KMEM 050704Z 28011KT 6SM BR OVC006 01/M01 A2999 RMK AO2 CIG 004V009 \$
KMEM 050654Z 29012G19KT 1/2SM BR OVC004 01/M01 A2999 RMK AO2 SFC VIS 6 CIG 003V007 SLP156 T00061011 \$
KMEM 050554Z 28010KT 1/2SM OVC004 01/M01 A2995 RMK AO2 SFC VIS 8 SLP145 60010 T00061006 10017 20006
KMEM 050454Z 29007KT 1/2SM BR OVC004 01/M01 A2994 RMK AO2 SFC VIS 6 SLP140 T00061006 \$
KMEM 050354Z 29008KT 1/2SM OVC004 01/M01 A2992 RMK AO2 SFC VIS 7 SLP132 T00061006 \$
KMEM 050254Z 30006KT 1/2SM OVC004 01/00 A2992 RMK AO2 SFC VIS 8 SLP132 60010 T00060000 53022 \$

West Memphis, Tennessee:

KAWM 050853Z AUTO 26005KT 9SM OVC010 00/00 A3003 RMK AO2 CIG 006V012 SLP171 T00000000 51019
KAWM 050753Z AUTO VRB04KT 8SM OVC006 00/00 A3001 RMK AO2 SLP165 T00000000
KAWM 050653Z AUTO 28005KT 8SM BKN006 OVC015 00/00 A2999 RMK AO2 CIG 004V011 SLP160 T00000000
KAWM 050553Z AUTO 28005KT 9SM OVC004 00/00 A2997 RMK AO2 SLP152 60003 T00000000 10000 20000 400061017
KAWM 050453Z AUTO 30003KT 7SM OVC004 00/00 A2995 RMK AO2 SLP144 T00000000
KAWM 050353Z AUTO 30004KT 8SM OVC004 00/00 A2994 RMK AO2 SLP141 T00000000
KAWM 050253Z AUTO 29003KT 10SM OVC004 00/00 A2992 RMK AO2 SLP135 60003 T00000000 53017

Olive Branch, Mississippi:

KOLV 050855Z AUTO 27006KT 9SM OVC008 00/00 A3002 RMK A01 P000
KOLV 050835Z AUTO 25007KT 10SM OVC008 00/00 A3002 RMK A01 P000
KOLV 050815Z AUTO 27010G15KT 10SM OVC008 00/ A3001 RMK A01 P000
KOLV 050755Z AUTO 26007KT 8SM OVC008 00/ A3000 RMK A01 P000
KOLV 050735Z AUTO 28010G14KT 5SM OVC003 00/ A3000 RMK A01 P000
KOLV 050715Z AUTO 29013G16KT 3SM OVC003 00/ A3000 RMK A01 P000
KOLV 050655Z AUTO 27009G17KT 5SM OVC004 00/ A2999 RMK A01 P000
KOLV 050635Z AUTO 27006G18KT 6SM OVC003 00/ A2998 RMK A01 P000
KOLV 050615Z AUTO 27010G15KT 3SM OVC004 00/ A2997 RMK A01 P000
KOLV 050555Z AUTO 26007G15KT 6SM OVC004 00/ A2996 RMK A01 P000
KOLV 050535Z AUTO 28010G15KT 7SM OVC003 00/ A2994 RMK A01 P000
KOLV 050515Z AUTO 28009KT 3SM OVC002 00/ A2994 RMK A01 P000
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KOLV 050435Z AUTO 28009KT 2 1/2SM OVC002 00/ A2994 RMK A01 P000
KOLV 050415Z AUTO 28009KT 7SM OVC003 00/ A2992 RMK A01 P000
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KOLV 050335Z AUTO 28007KT 4SM OVC002 00/ A2991 RMK A01 P000
KOLV 050315Z AUTO 29007KT 4SM OVC002 00/ A2990 RMK A01 P000
KOLV 050255Z AUTO 28011KT 1 1/4SM OVC002 00/ A2991 RMK A01 P000

Tunica Municipal Airport, Mississippi:

KUTA 050855Z AUTO 26005KT 10SM BKN010 OVC041 00/00 A3006 RMK AO2
KUTA 050835Z AUTO 25004KT 10SM OVC010 00/00 A3006 RMK AO2
KUTA 050815Z AUTO 27004KT 10SM OVC010 00/00 A3005 RMK AO2
KUTA 050755Z AUTO 28007KT 10SM OVC010 00/00 A3004 RMK AO2
KUTA 050735Z AUTO 27007KT 10SM OVC008 00/00 A3003 RMK AO2
KUTA 050715Z AUTO 27012KT 10SM OVC008 00/00 A3004 RMK AO2
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KUTA 050635Z AUTO 28010G16KT 10SM OVC006 00/00 A3003 RMK AO2
KUTA 050615Z AUTO 28009KT 10SM OVC006 00/00 A3001 RMK AO2
KUTA 050555Z AUTO 27009KT 10SM OVC006 00/00 A3001 RMK AO2
KUTA 050535Z AUTO 27010KT 10SM OVC006 00/00 A3000 RMK AO2
KUTA 050515Z AUTO 27005KT 10SM OVC004 00/00 A2999 RMK AO2 LTG DSNT SE
KUTA 050455Z AUTO 29008KT 10SM OVC004 00/00 A2998 RMK AO2
KUTA 050435Z AUTO 29008KT 10SM OVC004 00/00 A2997 RMK AO2
KUTA 050415Z AUTO 28008KT 5SM BR OVC004 00/00 A2997 RMK AO2
KUTA 050355Z AUTO 28007KT 10SM OVC004 00/00 A2996 RMK AO2
KUTA 050335Z AUTO 29006KT 10SM OVC006 00/00 A2996 RMK AO2
KUTA 050315Z AUTO 31006KT 10SM OVC006 00/00 A2995 RMK AO2
KUTA 050255Z AUTO 31005KT 10SM OVC004 00/00 A2994 RMK AO2

Houston Intercontinental Airport, Texas

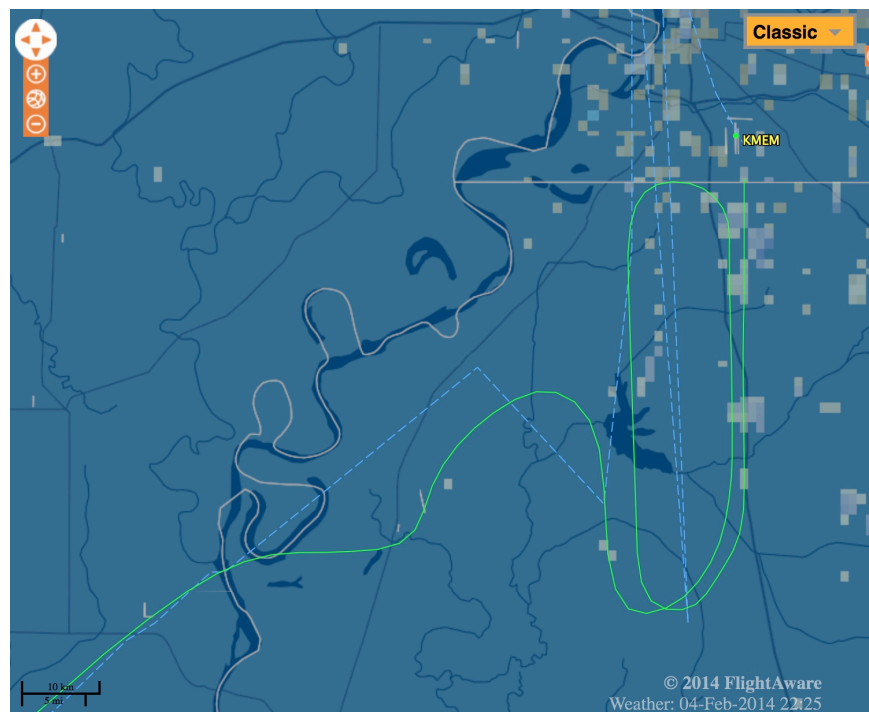
KIAH 050853Z 36005KT 10SM BCFG CLR 05/04 A3014 RMK AO2 SLP206 T00500044 53015
KIAH 050753Z 00000KT 10SM BCFG FEW002 04/04 A3012 RMK AO2 SLP201 T00440044
KIAH 050653Z 00000KT 10SM CLR 06/06 A3010 RMK AO2 SLP194 T00610056
KIAH 050553Z 36004KT 10SM CLR 06/06 A3009 RMK AO2 SLP191 T00610056 10106 20056 401110056 51023
KIAH 050453Z 08004KT 10SM CLR 07/06 A3007 RMK AO2 SLP184 T00720061
KIAH 050353Z 04003KT 10SM FEW015 07/06 A3005 RMK AO2 SLP176 T00720061
KIAH 050253Z 00000KT 10SM SCT016 BKN035 09/07 A3002 RMK AO2 SLP168 T00890072 53036
KIAH 050153Z 34006KT 10SM BKN016 OVC035 10/08 A2999 RMK AO2 SLP157 T01000078
KIAH 050137Z 34005KT 10SM BKN016 OVC035 11/08 A2998 RMK AO2
KIAH 050053Z 34005KT 10SM BKN014 OVC035 11/08 A2995 RMK AO2 SLP141 T01060078
KIAH 042353Z 34003KT 10SM BKN014 OVC035 11/08 A2992 RMK AO2 SLP132 60005 T01060078 10111 20083 53014

RELEVANT PIREPS

MEM UA /OV MEM 135050/TM 0230/FL280/TP MULTIPLE/TB MOD/RM ZME=
MEM UA /OV MEM180004 /TM 0458 /FLUNKN /TP DC10 /SK OVC004-TOP017=
BNA UA /OV BNA045025 /TM 0510 /FL220 /TP AT72 /TA M24 /IC LGT RIME=

DEQ UA /OV TXK360020 /TM 0347 /FL240 /TP C560 /TB CONS LGT CHOP /RM OVER LAST 100 MILES SW BOUND=
MSL UUA /OV MEM090115 /TM 0428 /FL300 /TP B752 /TB SEV=

FLIGHT DATA AND TRACKS



Data 1.1. Large-scale and zoomed Memphis area flight tracks.

FIGURES

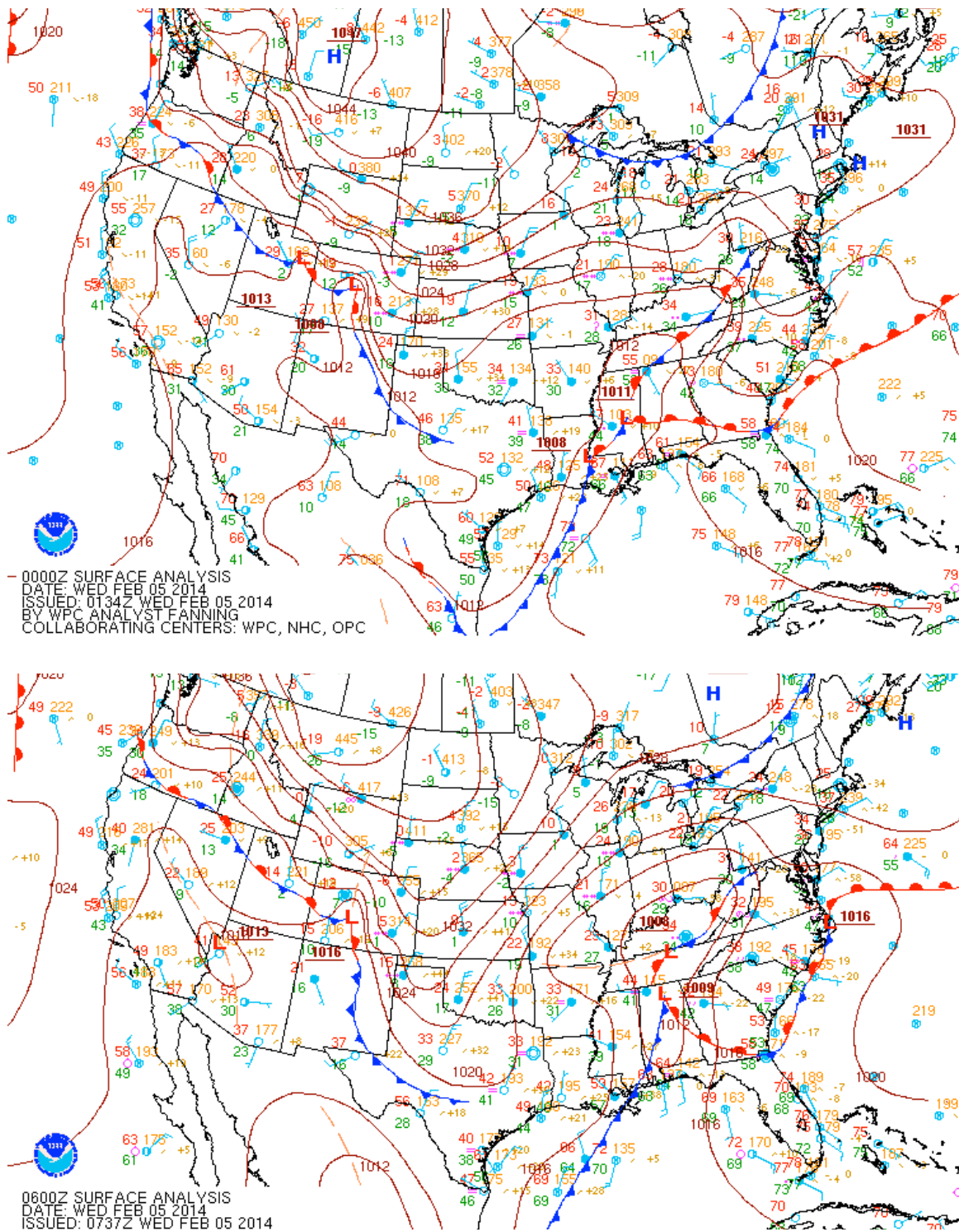
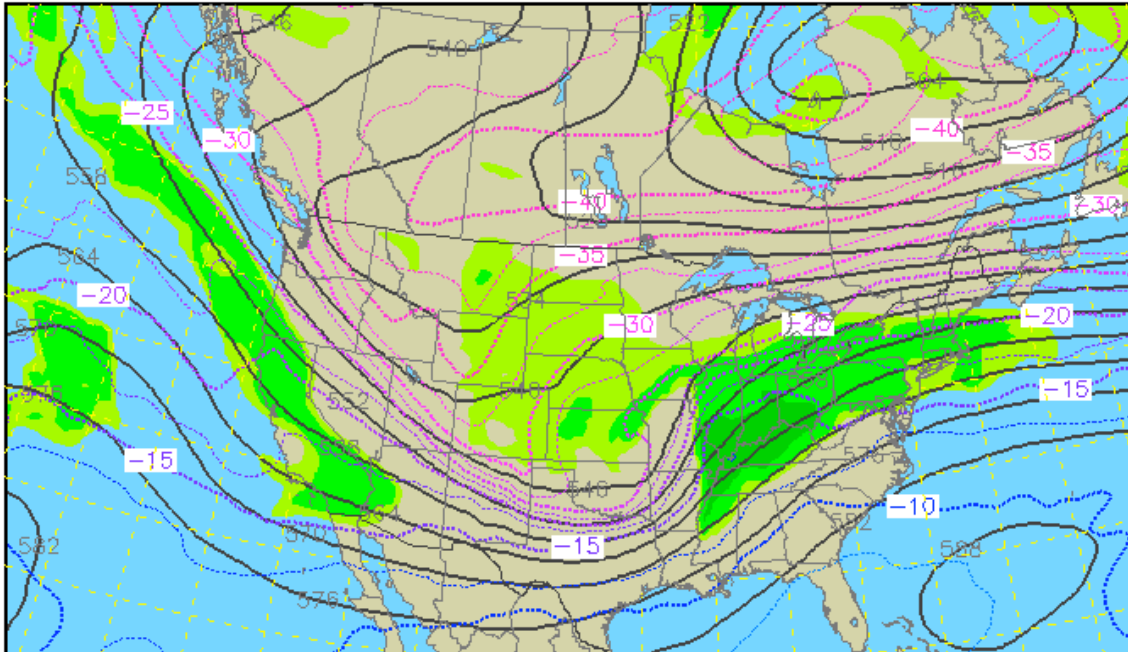


Fig. 1.1. Surface analysis for 0000 and 0600 UTC.

500 mb Heights (dm) / Temperature (°C) / Humidity (%)

12-hour forecast valid 0000 UTC Wed 05 Feb 2014

NAM (WRF-NMM) (12z 04 Feb)



700 mb Heights (dm) / Temperature (°C) / Humidity (%)

12-hour forecast valid 0000 UTC Wed 05 Feb 2014

NAM (WRF-NMM) (12z 04 Feb)

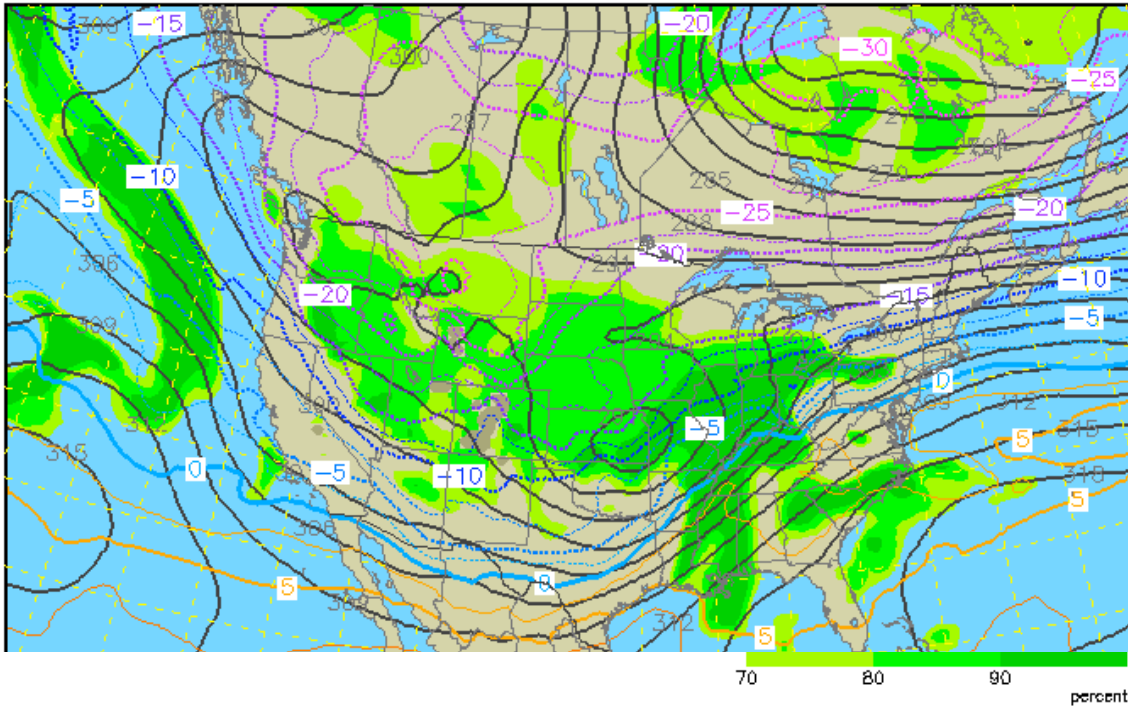
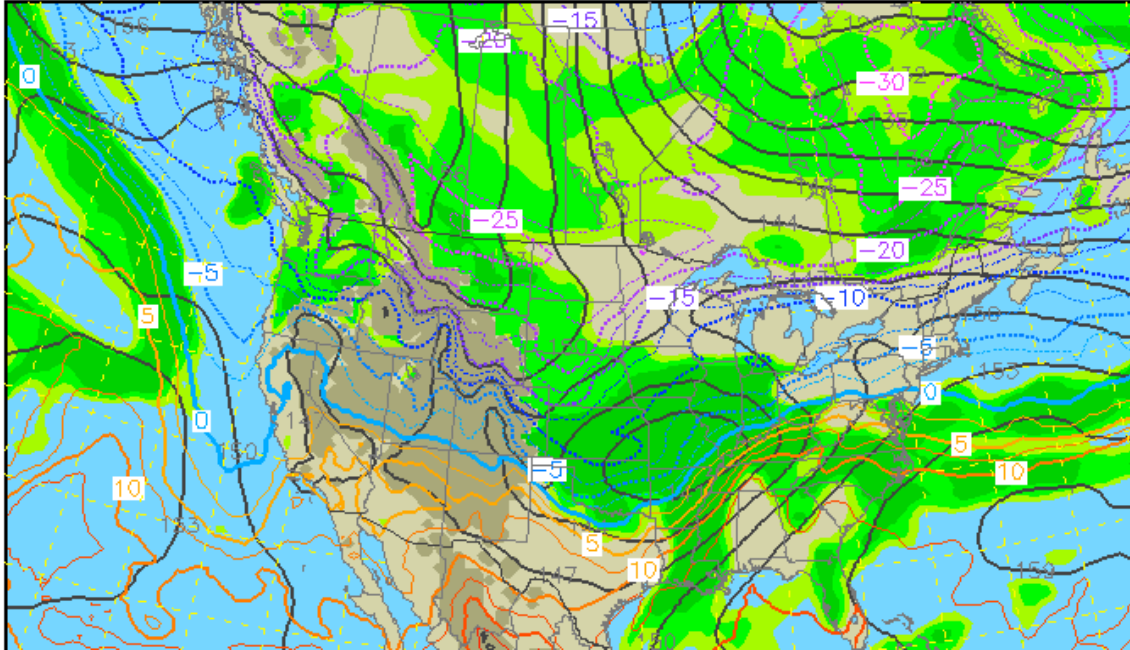


Fig. 1.2. NAM 12-hr forecast of T and RH for 500 and 700 mb valid at 0000 UTC.

850 mb Heights (dm) / Temperature (°C) / Humidity (%)

12-hour forecast valid 0000 UTC Wed 05 Feb 2014 NAM (WRF-NMM) (12z 04 Feb)



925 mb Heights (dm) / Temperature (°C) / Humidity (%)

12-hour forecast valid 0000 UTC Wed 05 Feb 2014 NAM (WRF-NMM) (12z 04 Feb)

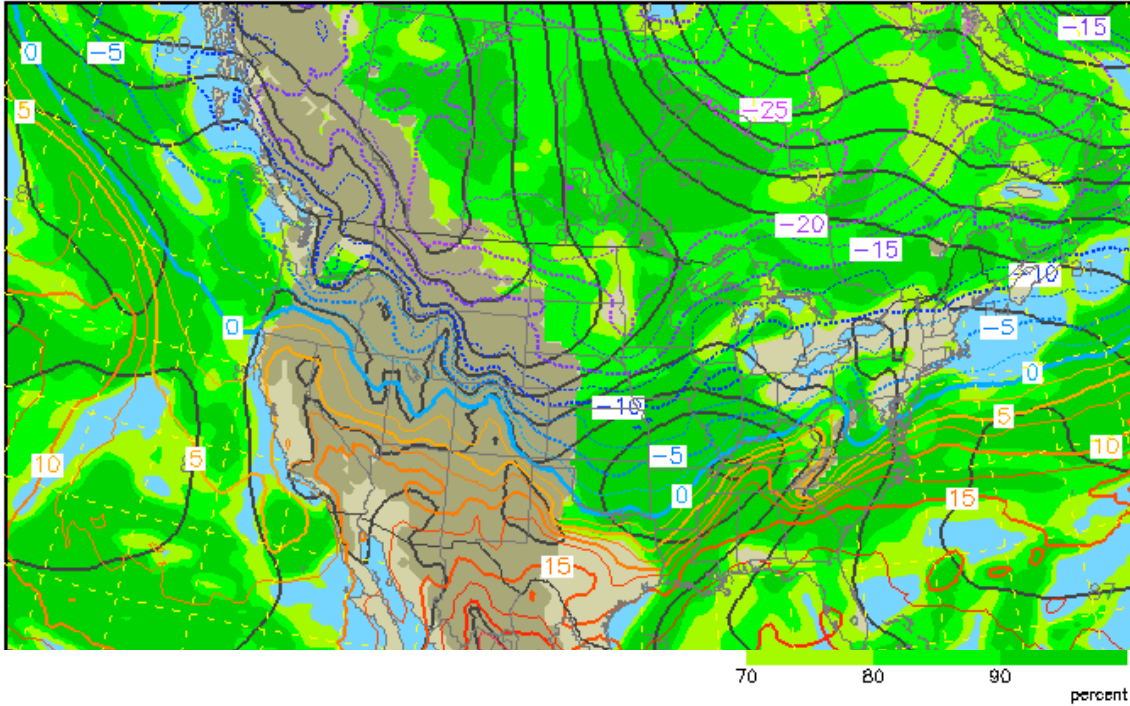
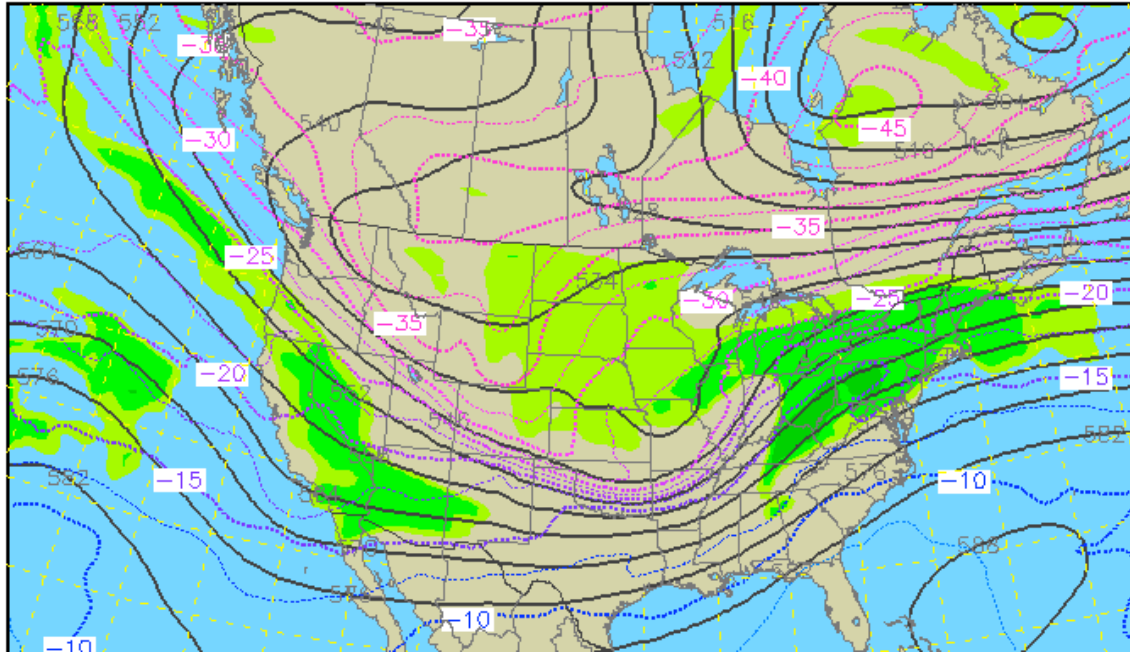


Fig. 1.3. NAM 12-br forecast of T and RH for 850 and 925 mb valid at 0000 UTC.

500 mb Heights (dm) / Temperature ($^{\circ}\text{C}$) / Humidity (%)

18-hour forecast valid 0600 UTC Wed 05 Feb 2014 NAM (WRF-NMM) (12z 04 Feb)



700 mb Heights (dm) / Temperature ($^{\circ}\text{C}$) / Humidity (%)

18-hour forecast valid 0600 UTC Wed 05 Feb 2014 NAM (WRF-NMM) (12z 04 Feb)

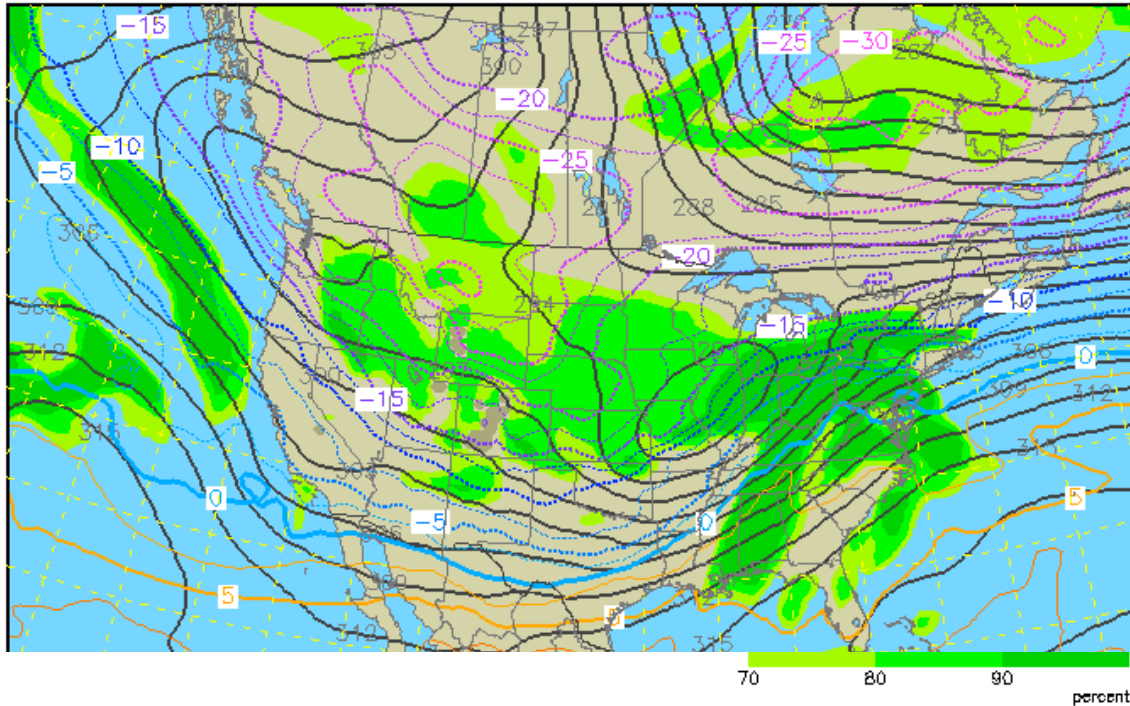
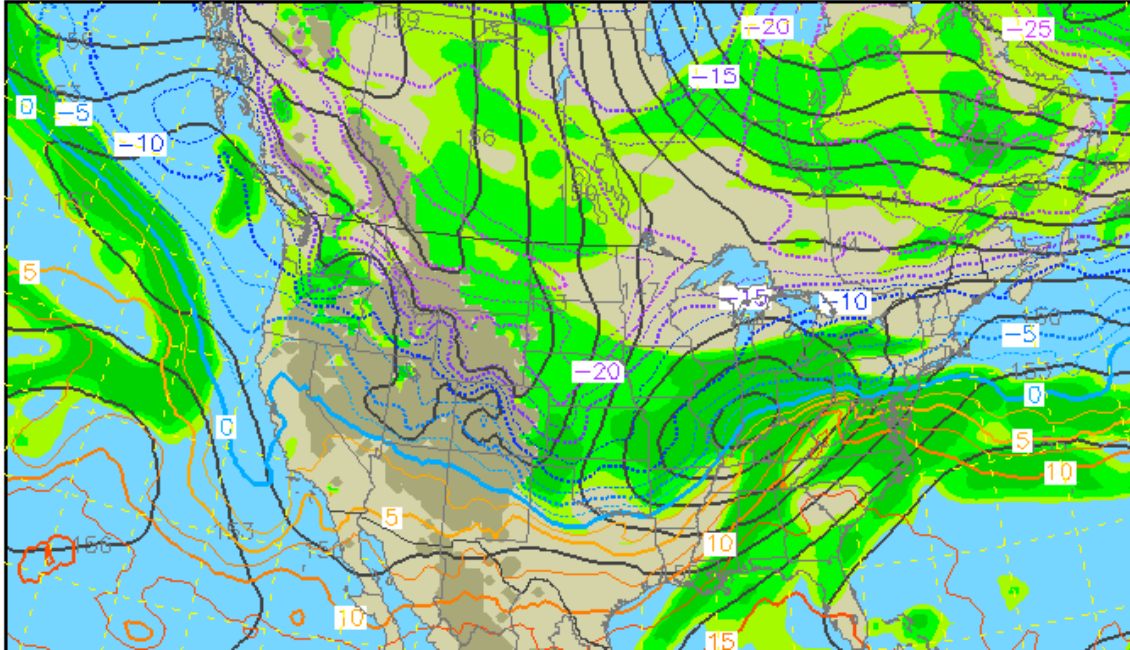


Fig. 1.4. NAM 18-br forecast of T and RH for 500 and 700 mb valid at 0600 UTC.

850 mb Heights (dm) / Temperature (°C) / Humidity (%)

18-hour forecast valid 0600 UTC Wed 05 Feb 2014

NAM (WRF-NMM) (12z 04 Feb)



925 mb Heights (dm) / Temperature (°C) / Humidity (%)

18-hour forecast valid 0600 UTC Wed 05 Feb 2014

NAM (WRF-NMM) (12z 04 Feb)

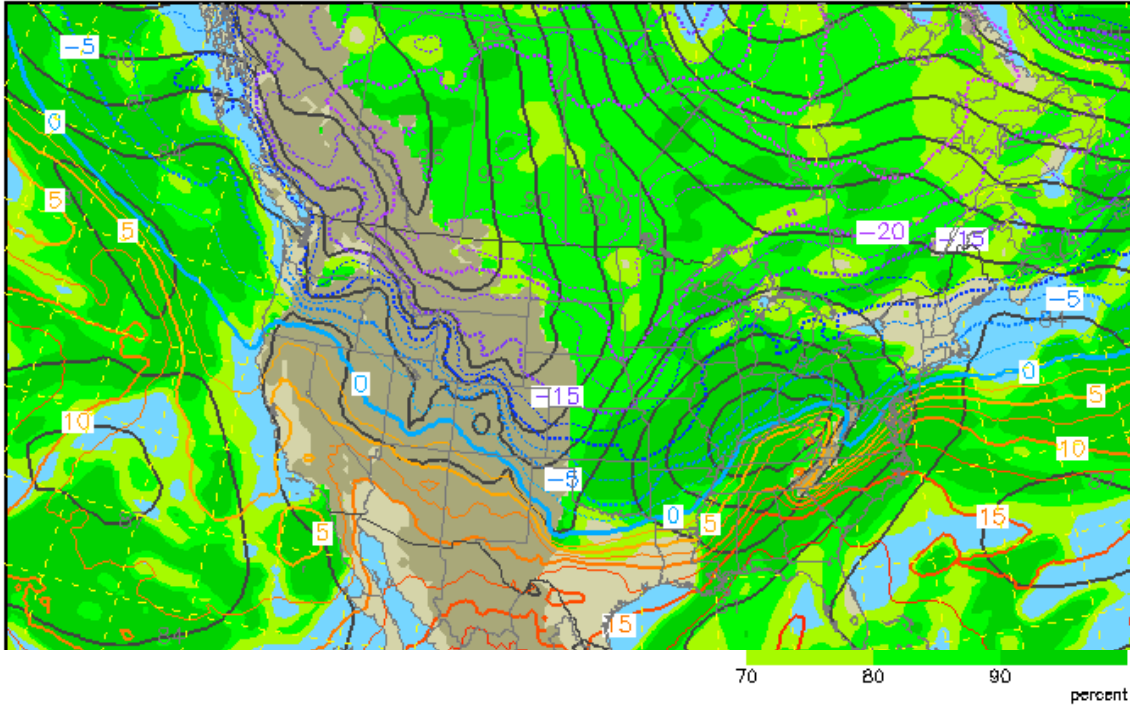


Fig. 1.5. NAM 18-br forecast of T and RH for 850 and 925 mb valid at 0600 UTC.

925 mb Heights (dm) / Temperature ($^{\circ}\text{C}$) / Humidity (%)

Analysis valid 0900 UTC Wed 05 Feb 2014

RAP (09z 05 Feb)

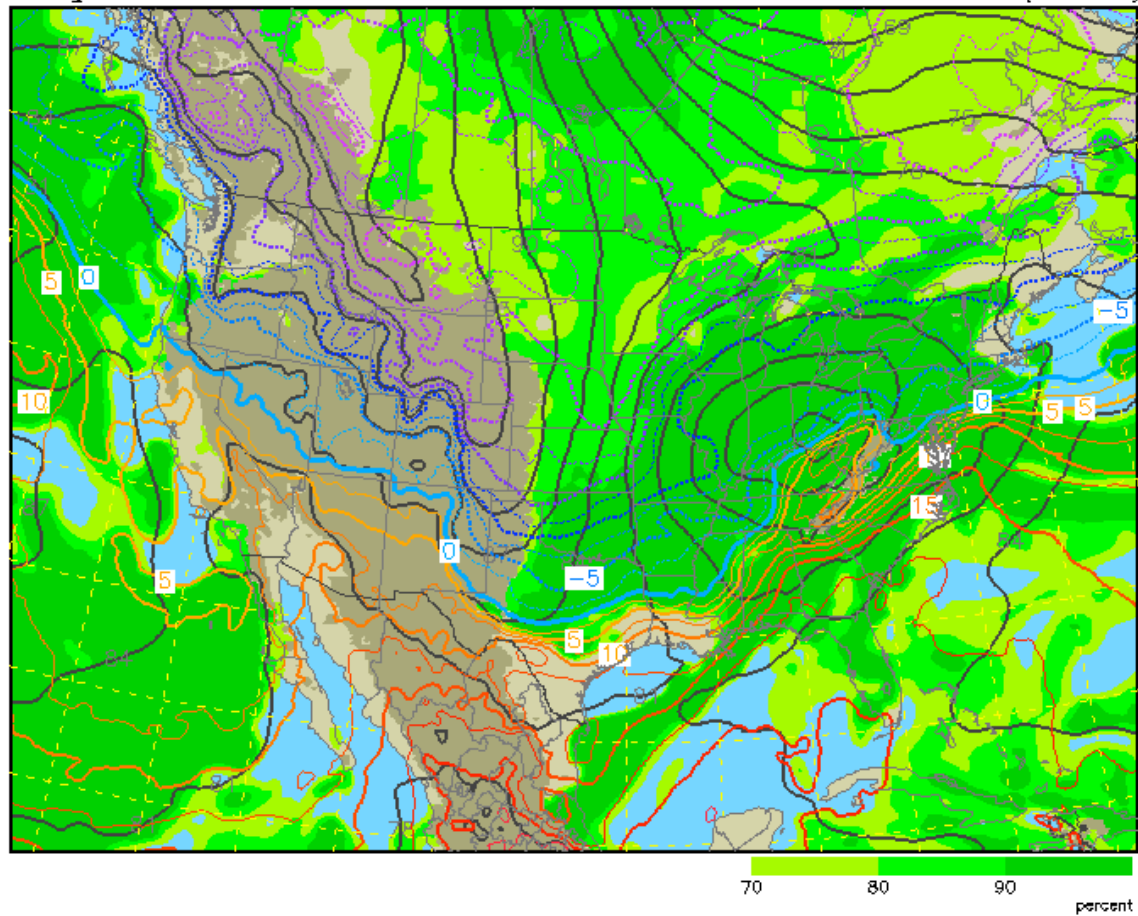


Fig. 1.6. RUC model 0-hr forecast of T and RH for 925 mb valid at 0900 UTC.

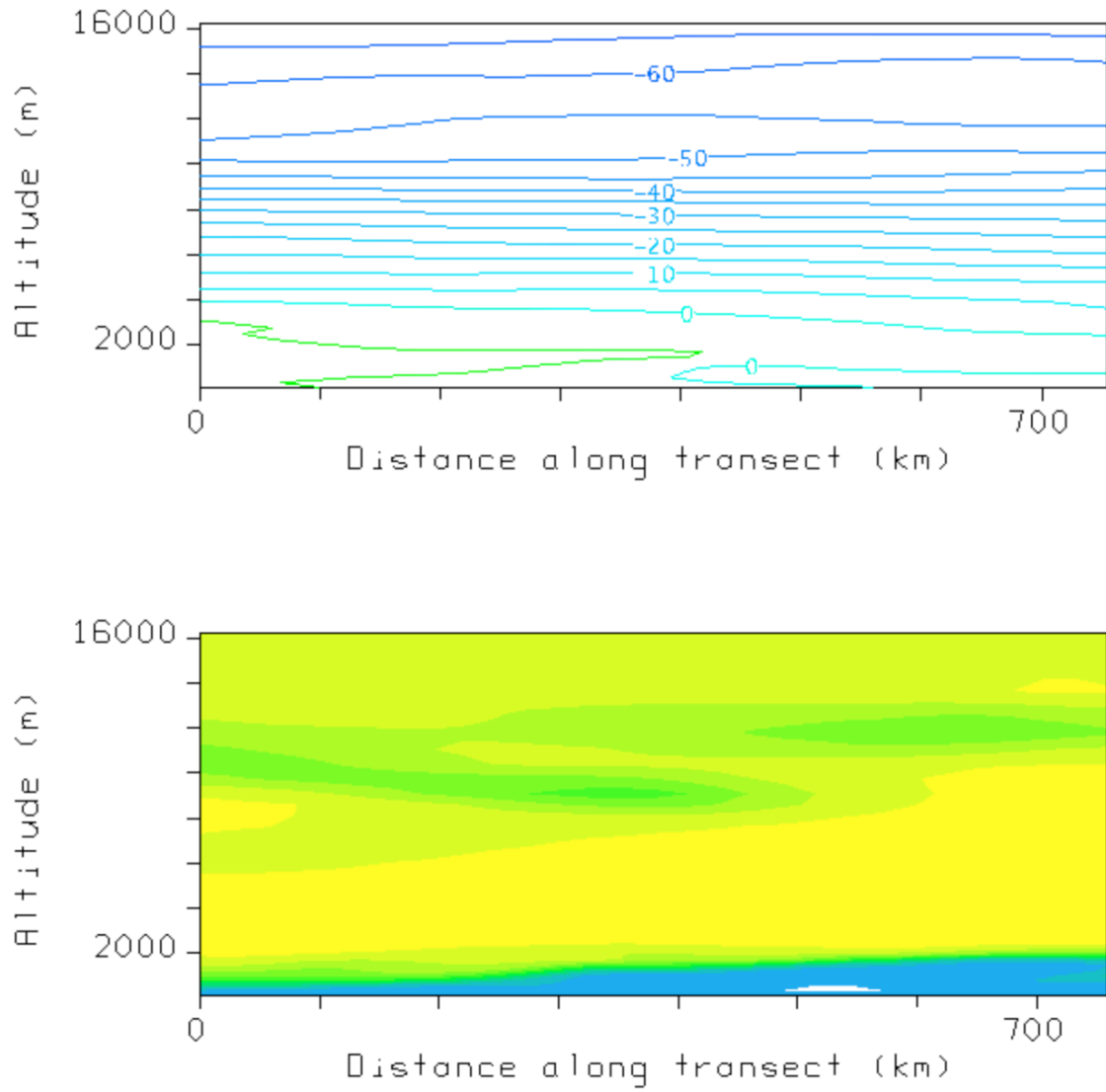


Fig. 1.7. RUC model vertical cross section of temperature (top) and relative humidity (bottom) from Houston (KLAH; left side) to Memphis (KMEM; right side) valid at 0600 UTC. Blue shades in the RH field indicate $RH > 80\%$. Heights on the y-axis are in meters above sea level. 700 mb is roughly equivalent to 3000 m MSL.

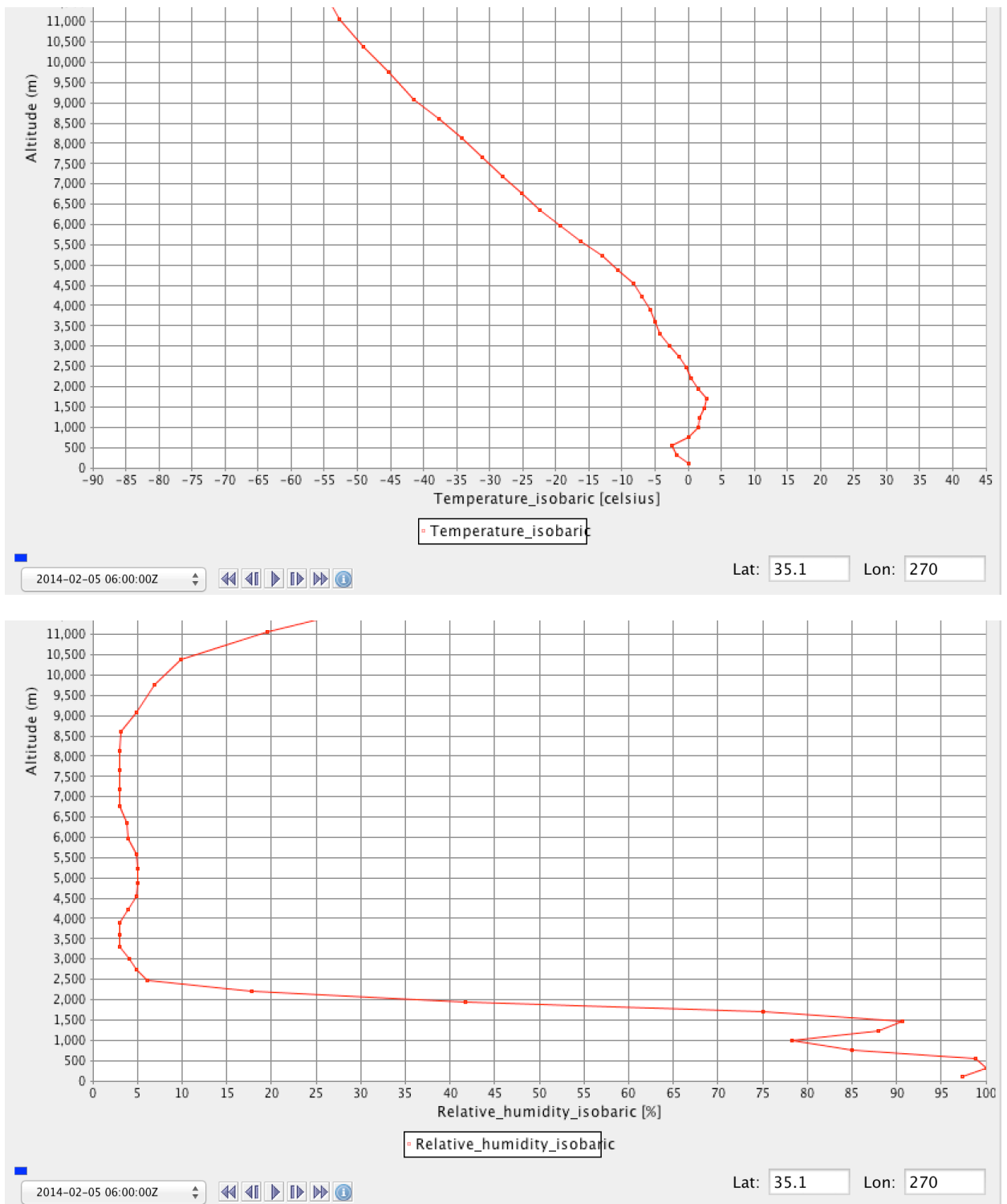


Fig. 1.8. Vertical profiles of RUC model vertical temperature (top) and relative humidity (bottom) valid over Memphis (KMEM; right side) at 0600 UTC.

72340 LZK Little Rock

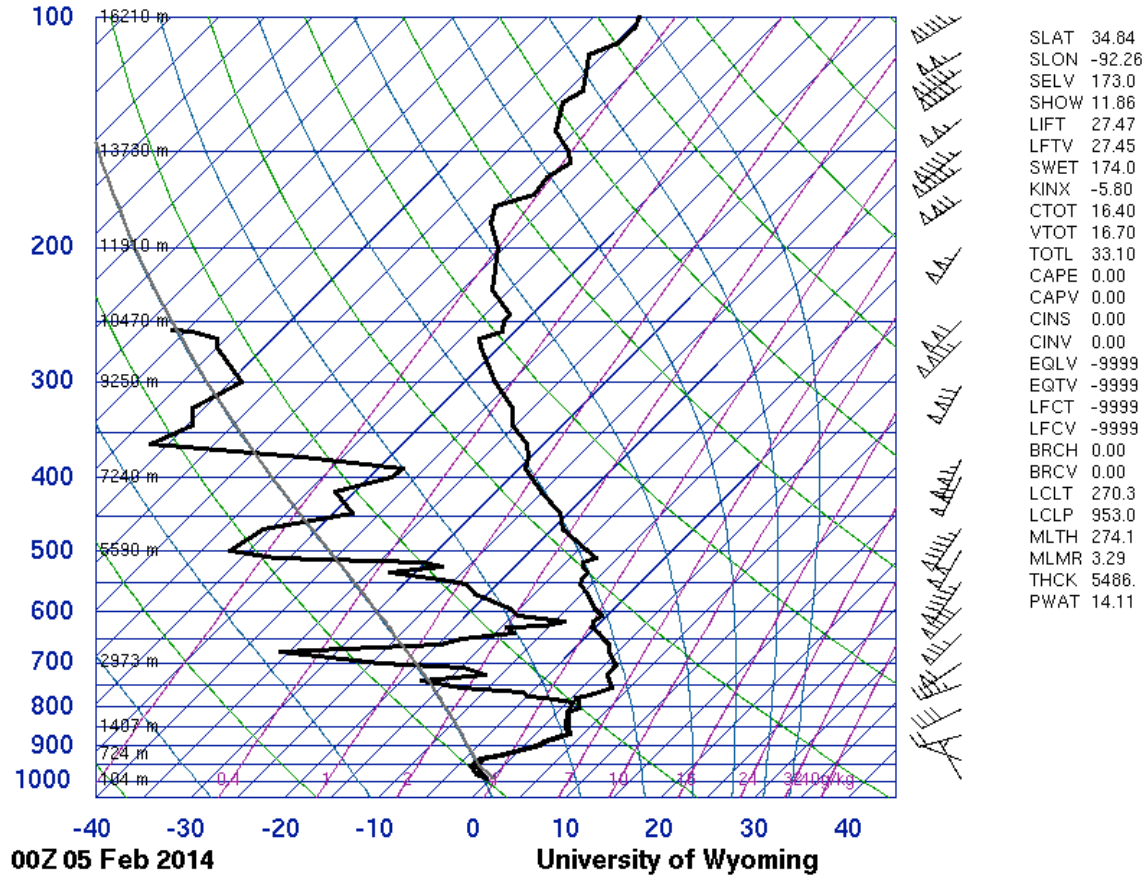


Fig. 1.9. Balloon-borne sounding taken at Little Rock, Arkansas (KLZK) at 0000 UTC and series of infrared satellite images from 0315 UTC to 0615 UTC.

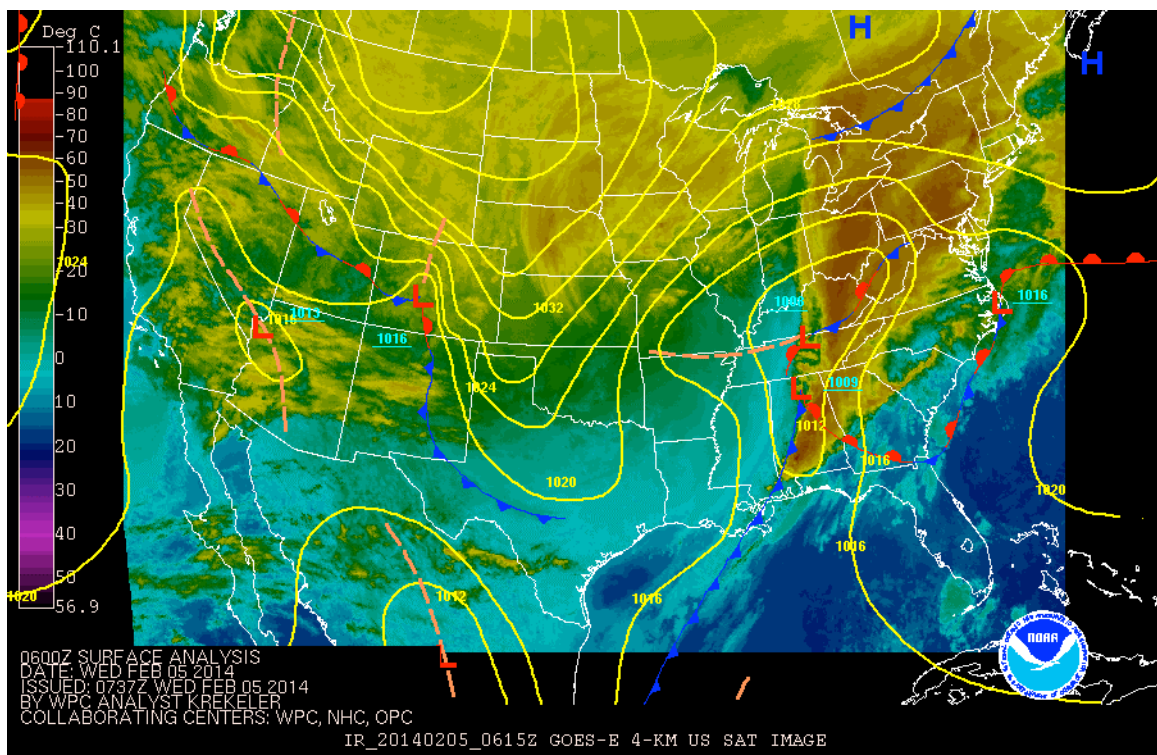
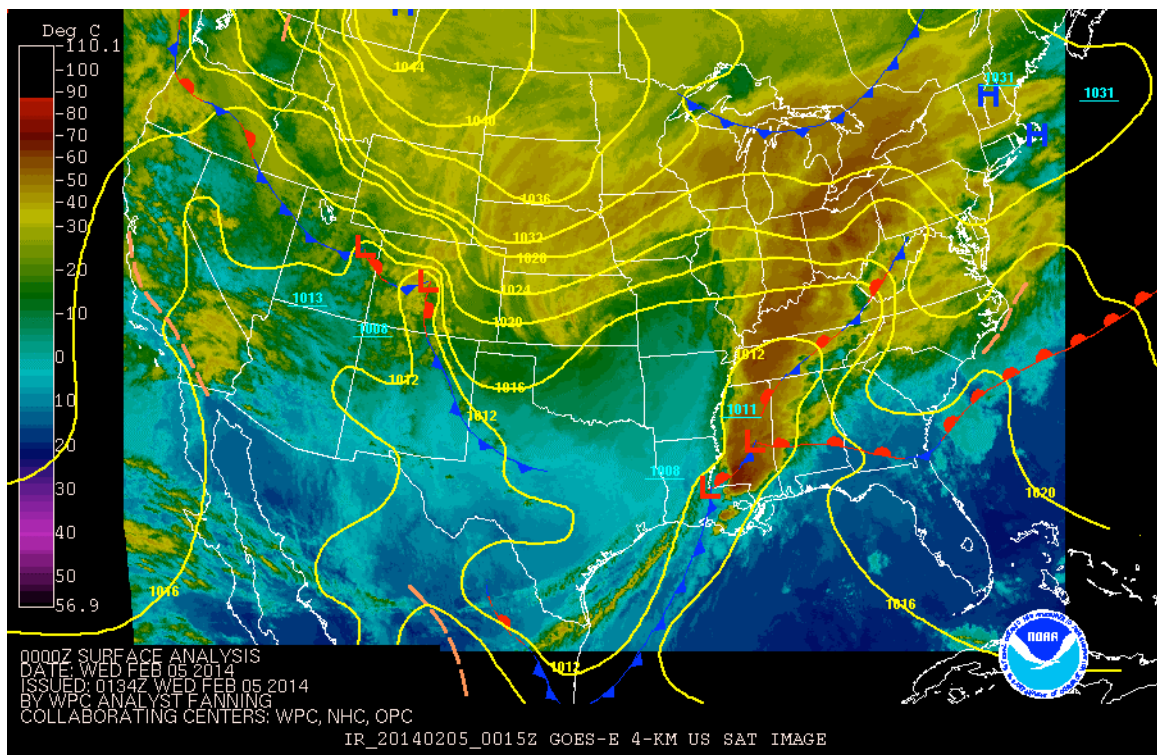


Fig. 1.10. NOAA surface pressure analysis with infrared satellite imagery overlaid for 0000 and 0600 UTC.

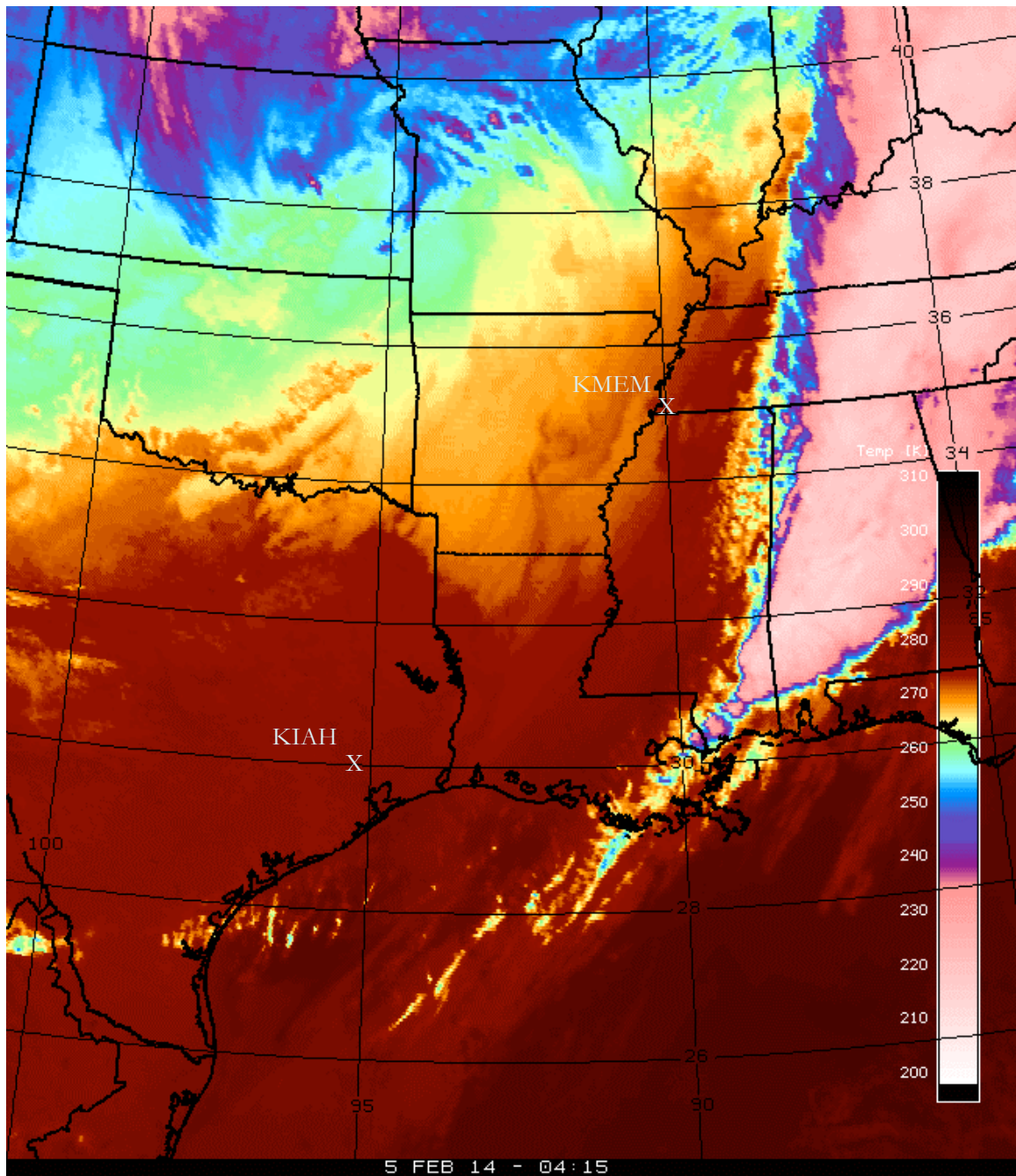


Fig. 1.11. Infrared satellite image for 0415 UTC. The approximate locations of Houston (KIAH) and Memphis (KMEM) are shown. Temperatures are in degrees Kelvin (degrees Celsius +273).

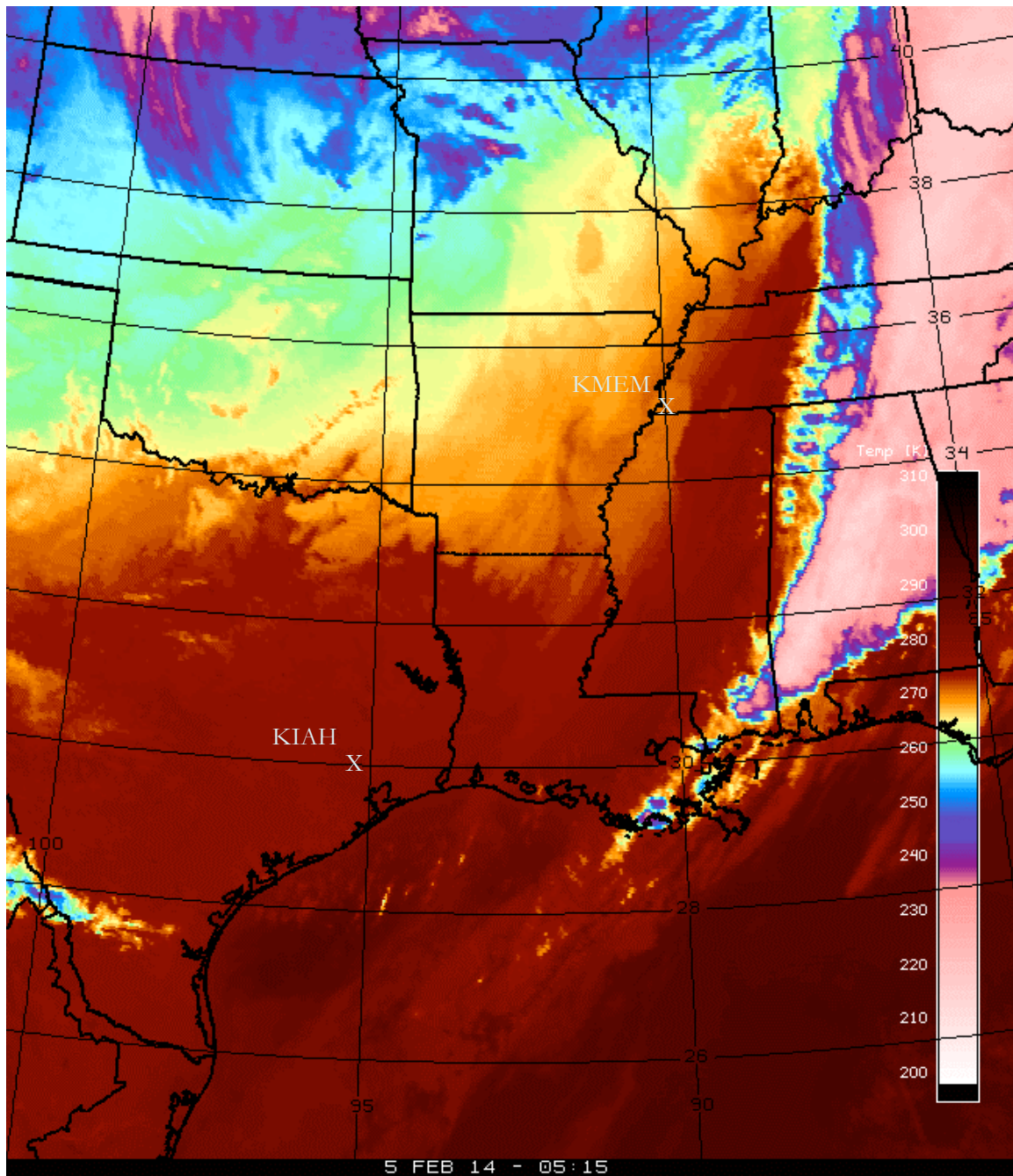


Fig. 1.12. Infrared satellite image for 0515 UTC. The approximate locations of Houston (KIAH) and Memphis (KMEM) are shown. Temperatures are in degrees Kelvin (degrees Celsius +273).

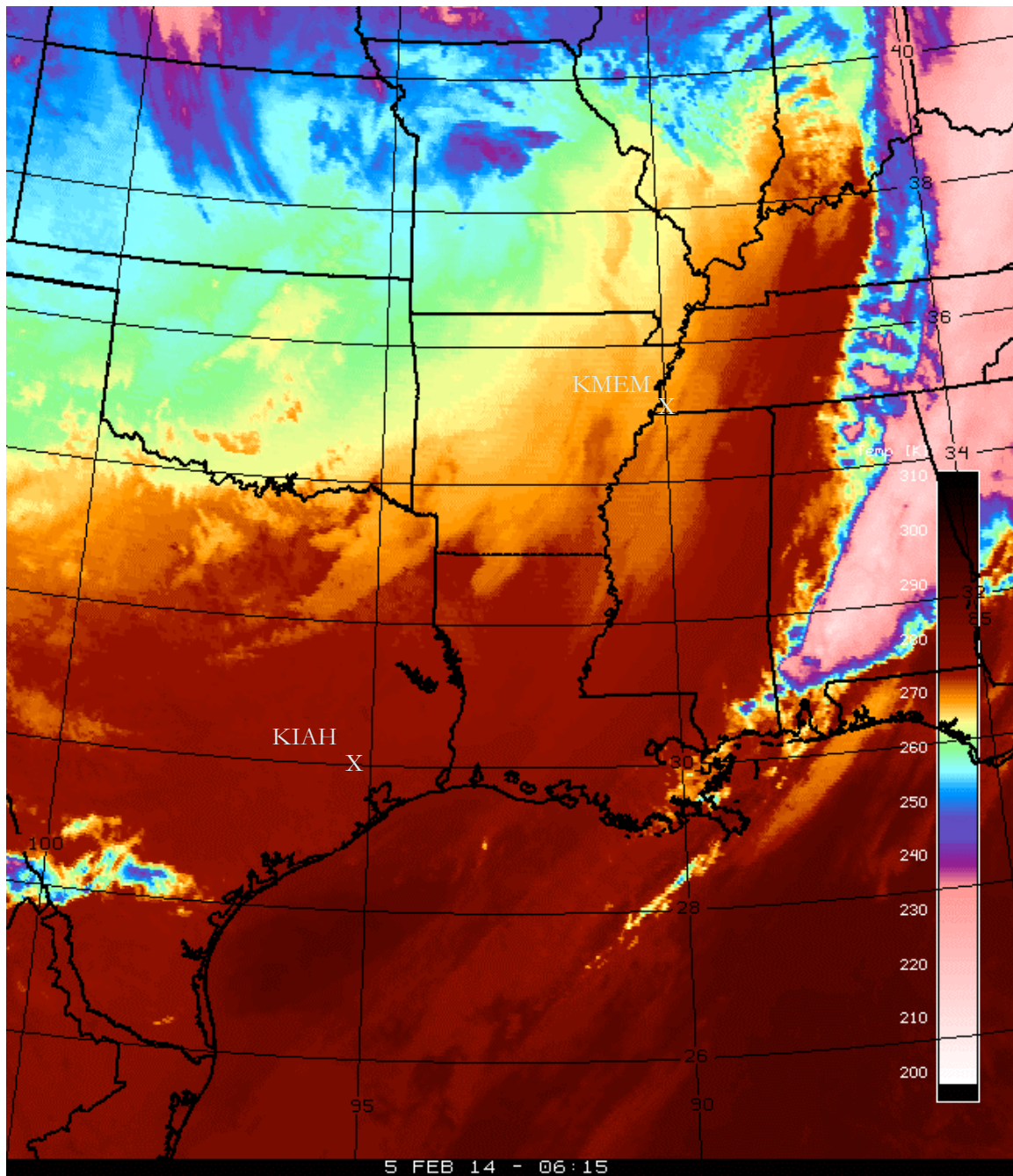


Fig. 1.13. Infrared satellite image for 0615 UTC. The approximate locations of Houston (KIAH) and Memphis (KMEM) are shown. Temperatures are in degrees Kelvin (degrees Celsius +273).

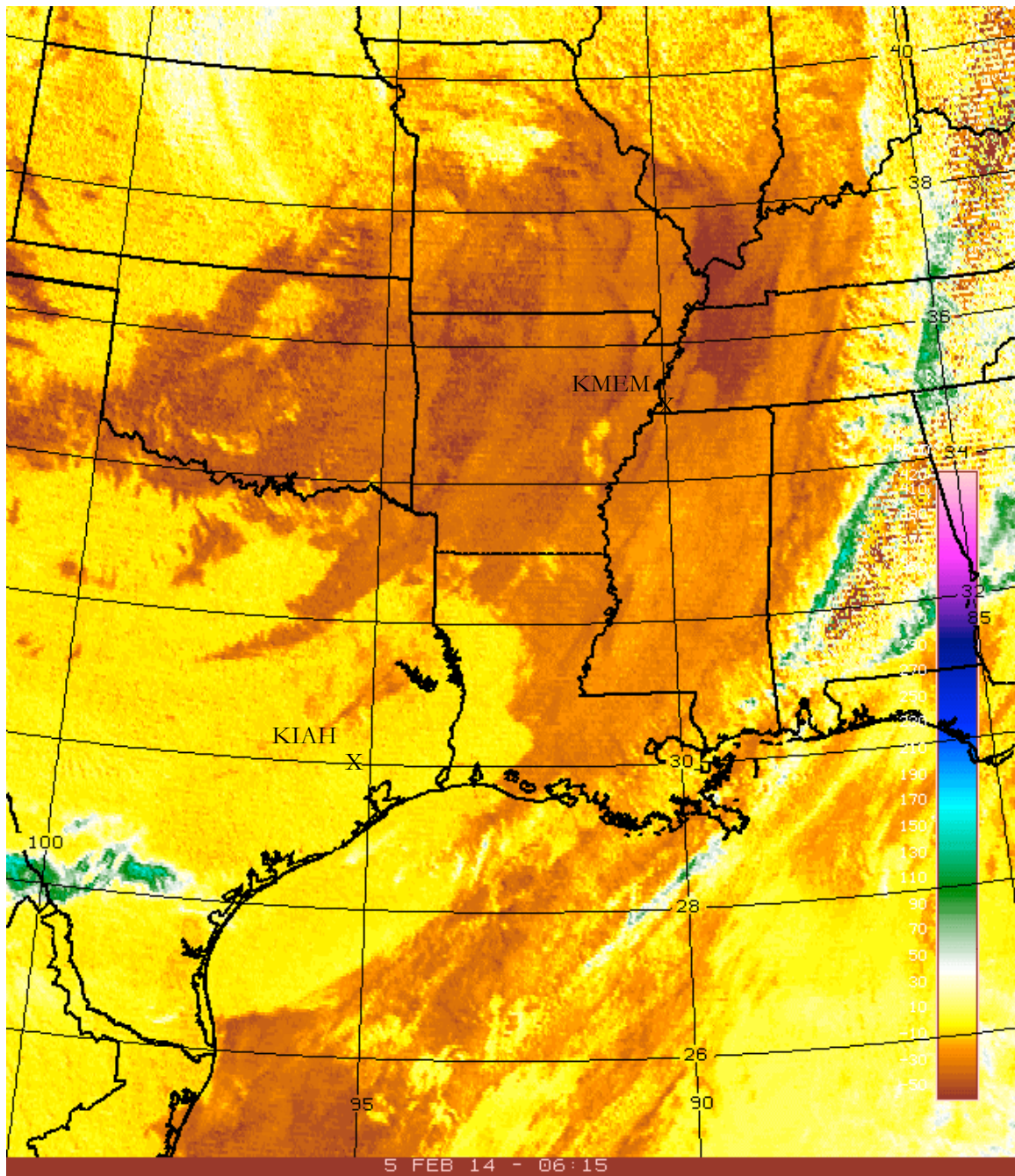


Fig. 1.14. Infrared difference field satellite image for 0615 UTC. The approximate locations of Houston (KIAH) and Memphis (KMEM) are shown.

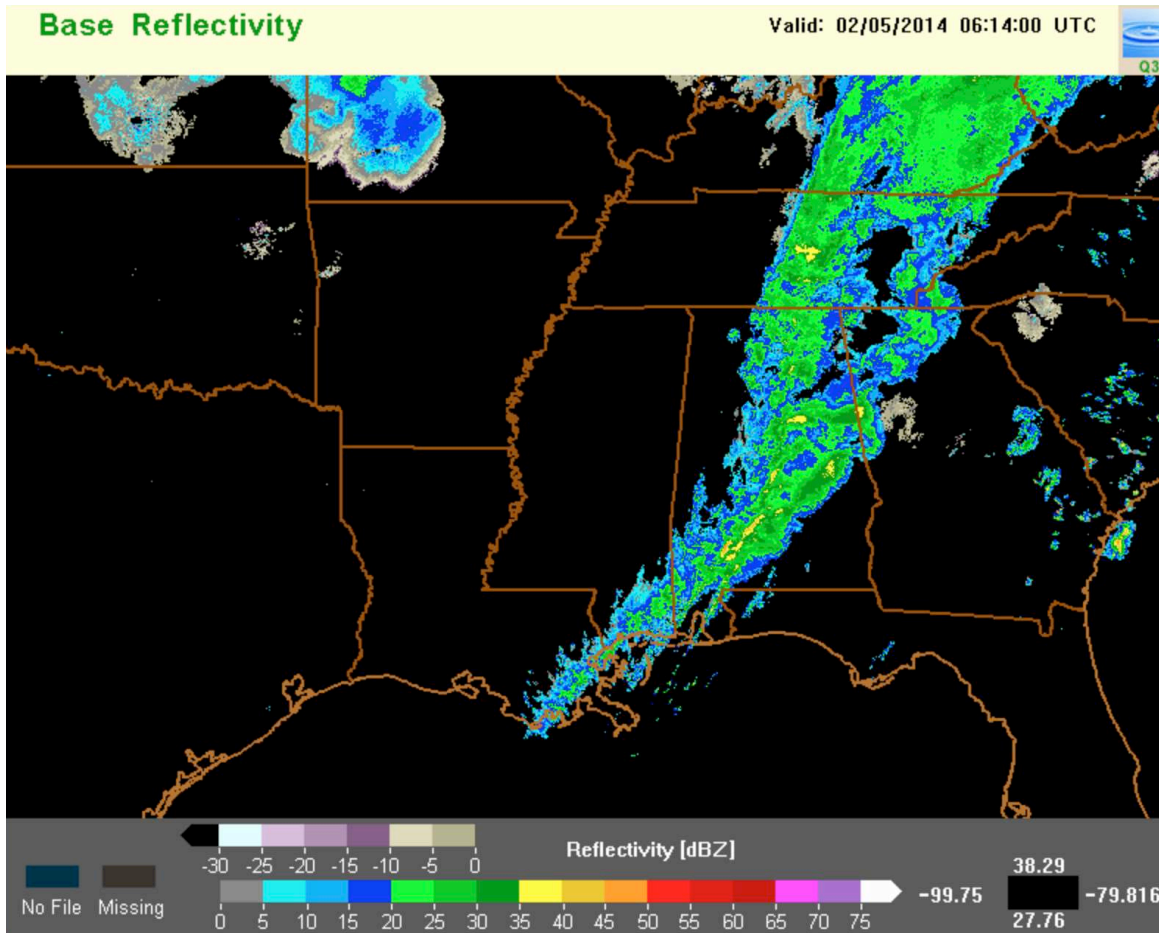


Fig. 1.15. Regional mosaic of low-tilt (0.5° elevation angle) radar reflectivity valid at 0614 UTC.

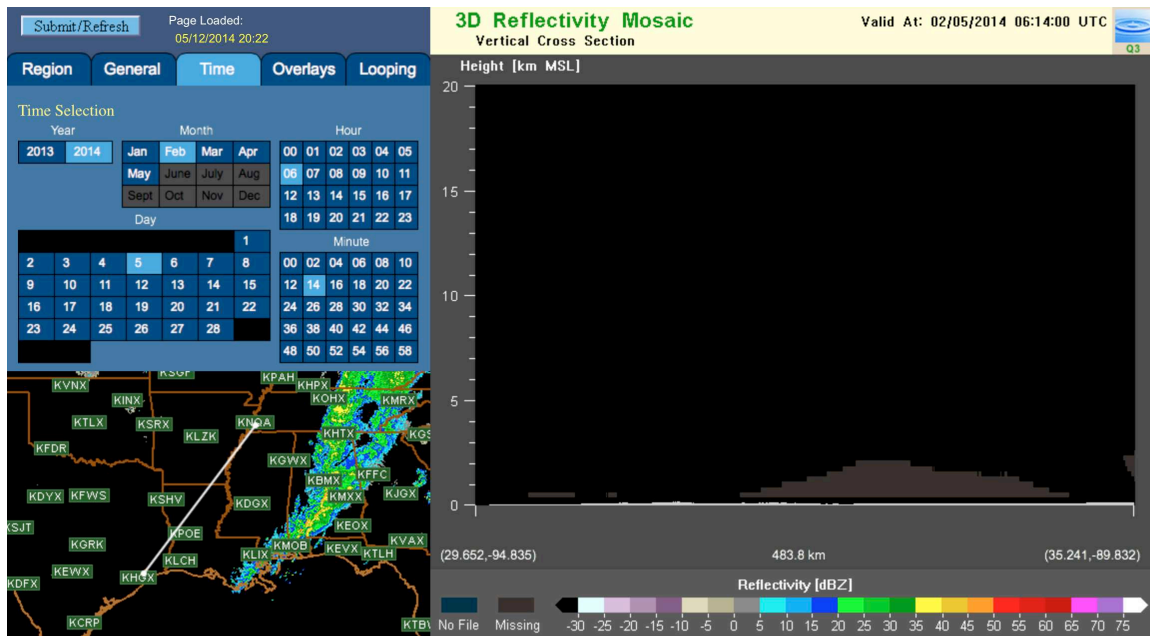


Fig. 1.16. Vertical cross section of radar reflectivity from Houston (KLAH; left side) to Memphis (KMEM; right side) valid at 0614 UTC. The dark grey area indicated at low levels between about 40% and 80% of the image indicates a lack of data due to the minimum elevation of the radar beams to the southwest of the KMQA (Memphis area) radar.

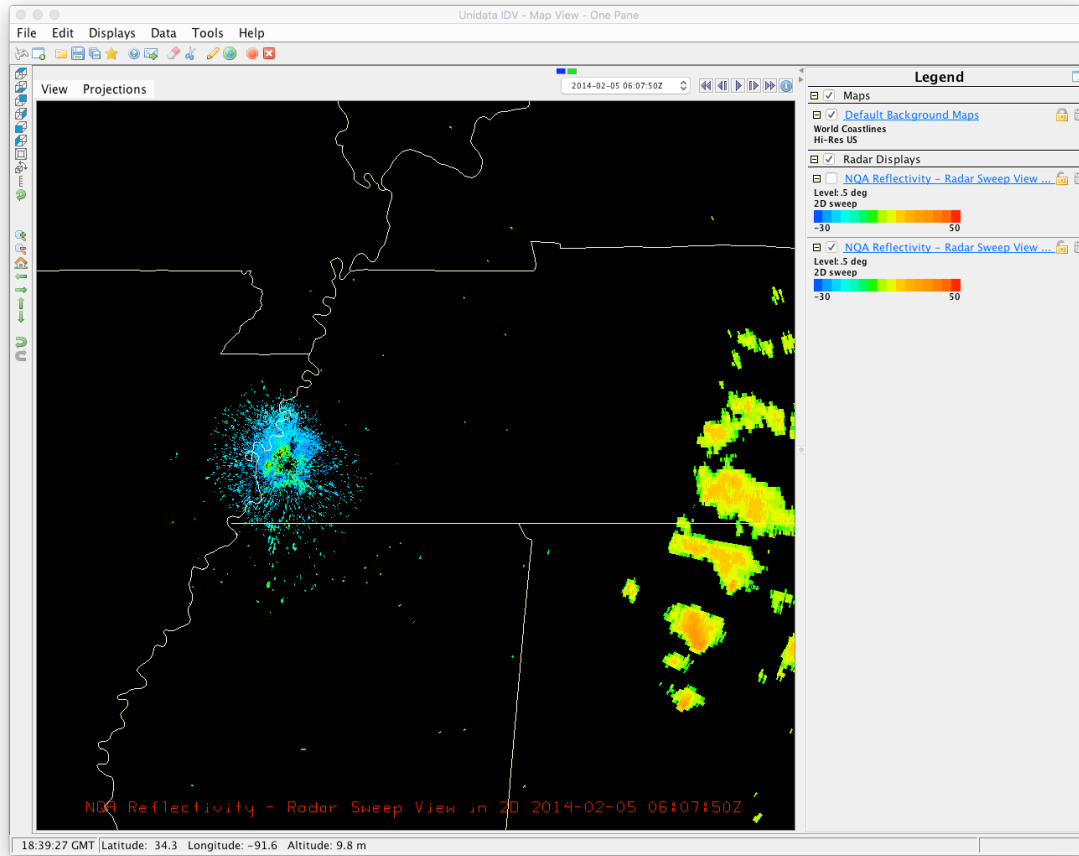


Fig. 1.17. NEXRAD radar reflectivity imagery from the lowest tilt (0.5° elevation angle) for 0607 UTC.

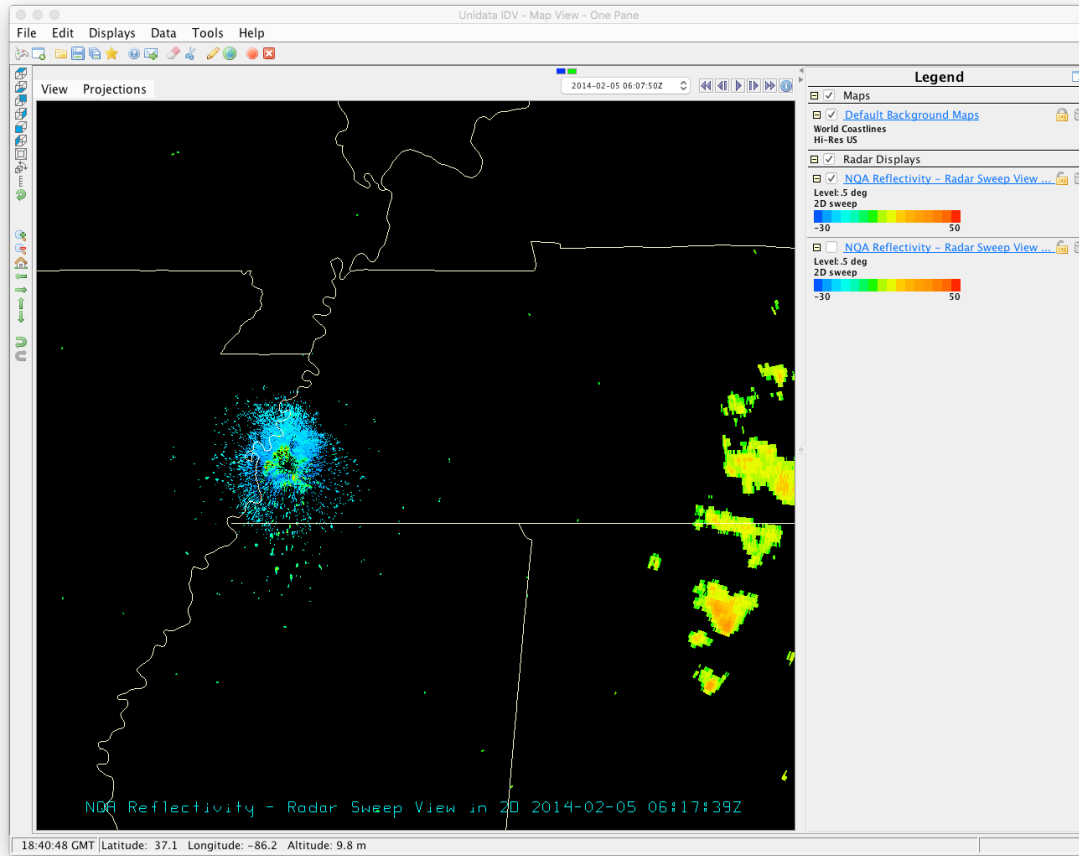


Fig. 1.18. NEXRAD radar reflectivity imagery from the lowest tilt (0.5° elevation angle) for 0617 UTC.

CASE 2: APRIL 7, 2014

BASIC INFORMATION

Flights: There was one flight between Chicago O'Hare Airport (KORD) and St. Louis Lambert Airport (KSTL) during the late morning of 7 April 2014. The aircraft departed KORD at 1612 UTC and landed at KSTL at 1658 UTC. The icing event was at approximately 1642 UTC and occurred as the aircraft turned from a heading of 200 to a heading of 225 as it began its initial descent on approach to KSTL.

RELEVANT WEATHER FEATURES

On this day, a weak area of low pressure was lifting northward from Tennessee into Kentucky and Indiana between 1200 and 1800 UTC (Fig. 2.1). A weak trough extended northwest from the low, across Illinois. This trough was weakly evident in upper-air charts, especially to the northwest of the upper low at 850 mb and 925 mb, along the Missouri-Illinois border (~5,000 ft and ~2,500 ft MSL; Fig. 2.2). Temperatures were above freezing at these levels. However, at 700 mb (~10,000 ft) they were sub-freezing in a swath of moisture that ran from southern Missouri across St. Louis to eastern Illinois, to the south of Chicago at 1200 UTC (Figs. 2.2, 2.3). Temperatures were as cool as -6°C at 700 mb (~10,000 ft), but unsaturated in the sounding taken just south of Chicago at KILX (Fig. 2.4). A saturated inversion layer was present near 11,000-13,000 ft (~670-620 mb) at about -10°C. This was capped by deep, ice-saturated conditions up to ~400 mb, where temperatures were near -30°C. Additional moisture was present above that level, as well.

By 1800 UTC, the 700 mb moisture laid along an axis from St. Louis northeastward to just south of Chicago, while a swath of moisture was present in this same area at 500 mb, and some patchy moisture was present to the northwest of Chicago, with a narrow dry swath in between (Figs. 2.5, 2.6). A piecewise, vertical cross-section of the 1600 UTC model analysis fields along the route (Figs. 2.7, 2.8) showed the swath of the best moisture around 1,500-3,500 m MSL (5,000-11,500 ft), where temperatures were between 0 and -5°C, then a gradual decrease in RH from 3,500 m upward to ~10,000 m (Fig. 2.7).

These same features were evident in a vertical profile of the model fields was made to the northeast of St. Louis, approximately where the aircraft changed course from direction 200 to direction 225 (see Fig. 2.9 and the green marker to the northeast of KSTL in Fig. 2.8). It showed the layer of ~100% relative humidity (RH) in the layer with temperatures between 0 and -5°C, the upper 1500 meters of which was essentially isothermal at -5°C. RH decreased to ~82% at 5,000 m (~16,400 ft), remained near this value from 5,000 m to 7,000 m (~23,000 ft; T in the -20 to -30°C range) and then fell off gradually with height. Bear in mind that this is a model analysis, not actual measurements of T and RH, so the profiles should only be considered as approximate. This is especially true for the RH profile and cloud layering that may be interpreted from it.

Satellite and radar imagery from 90 minutes before the event (1445 UTC) indicate the presence of deep, cold-topped, precipitating clouds around KSTL, then more showery, broken clouds over areas between KSTL and KORD, and weak, patchy clouds near KORD (Figs. 2.10-

2.13; see Relevant METARs below). These signatures persisted at 1545 UTC, with some significant breaks in the showers present to the east and northeast of St. Louis (Figs. 2.14-2.17).

Only weak, scattered clouds were present around KORD by 1615 UTC, with almost no clouds to its west and only very patchy clouds to its southwest (Figs. 2.18, 2.19; see Relevant METARs below). A few patches of somewhat stronger clouds were present to the south of KORD and the clouds became consistently more robust toward St. Louis (KSTL). It was in the latter area that the aircraft changed heading and began to descend as it approached KSTL from the east-northeast (see the black box in Fig. 2.18).

For the most part, the clouds to the east-northeast of St. Louis had cold tops and ice crystal signatures in infrared derivative fields (Figs. 2.19-2.21), but there was a noticeable, narrow swath of slightly warmer clouds (see the box in Fig. 2.19) with a somewhat more watery signature (see the box in Fig. 2.20) in the area of interest. Clouds in this area were still rather robust in visible satellite imagery (Fig. 2.18), though there were hints of localized weakening in the southwest-to-northeast oriented warm, watery looking swath. This hint of weakness may have not have been real, but instead may have been due to shadowing from higher clouds in the vicinity.

Radar data from 1614 UTC indicated more areas of relatively light precipitation in this area and that the apparent location of the icing incident was within a pronounced gap in the radar reflectivity above 4,000 m. Only weak precipitation existed beneath this gap (Figs. 2.22, 2.23). This was very close to the edge of some stronger showers to the northwest.

Icing flight program experience has shown that patches of localized icing sometimes exist in such reflectivity gaps as well as at the edges of and just outside of deeper, stronger showers, as long as the clouds still appear to be relatively robust in satellite imagery. These signatures tend to indicate that adequate lift remains present in the area (thus, the relatively robust clouds in satellite imagery), allowing for the production of supercooled liquid water, while depletion of said water is locally minimized by the lack of significant riming from snow falling through the clouds (as was evident in the relatively light echoes in the radar echo pattern in the area of interest). The snow falling through the clouds in nearby areas was reaching the ground as rain on this day, due to the presence of surface temperatures greater than +5°C in the area of showers (see Fig. 2.9). Overall, it is reasonable that some pockets of icing existed in and around the gaps in the rain showers on this day.

There were numerous PIREPs of icing made before 1400 UTC, with some light-to-moderate and moderate icing indicated between 13,000 and 16,000 ft there (Figs. 2.24, 2.25). As those clouds moved off to the east, there was still some patchy icing left behind. One report of light icing was made to the northwest of Chicago between 1400 and 1600 UTC (Fig. 2.26, 2.27) and another report of light icing was made at 10,000-11,000 feet to the south of Chicago (Fig. 2.27). Pilot reports of icing tend to be quite spotty and transient in the showery, patchy icing environment described above.

Although many of the clouds to the east-northeast of St. Louis appeared to be dominated by ice crystals, it appears that some patches and swaths of supercooled liquid water were likely to have existed between ~8,000 and perhaps 15,000 ft around the time of the event. The aircraft appears to have encountered one of these patches as it passed through the area of locally weak radar echoes during its initial descent into St. Louis.

For this case, it is MUCH more difficult to estimate the LWC and MVD because a) there are multiple cloud layers, 2) the upper-most, ice-laden layer shields the lower-altitude clouds encountered from satellite view, 3) the showery nature of the environment, and 4) the high altitude of the clouds encountered. In such environments, it is typical to encounter highly variable LWCs on the order of 0.1-0.3 gm⁻³, with a reasonably good chance of mixed phase (simultaneous presence of liquid water and ice crystals). The RUC model temperature profile of temperature (Fig. 2.9) indicates the presence of a fairly robust stable layer between 1,500 and

3,000 m beneath the clouds of interest. Such a structure is likely to have isolated the clouds encountered from boundary layer sources of CCN. The resulting environment will tend to be relatively “clean”, which tends to increase MVD. In addition, showers of precipitation may have cleaned the air as well, further increasing the potential for MVD enhancement. In contrast to that, these clouds did develop in the Central U.S., where there are abundant supplies of pollution and ground-based particles that can tend to depress MVDs. Overall, it is reasonable to expect MVDs on the order of 25-30 microns, but localized enhancement to MVDs on the order of 40 microns or greater is not out of the question. Conditions could change significantly with height, with LWCs tending to be maximized and temperatures tending to be minimized near cloud top, where the icing was likely first encountered during descent.

Although it is extremely difficult to generate a reasonable estimate of the conditions present within the clouds for this case, a rough guess at the conditions at cloud top is as follows: T near -15°C (from the aircraft trace), with LWC of $\sim 0.1\text{-}0.3\text{ gm}^{-3}$ and MVD on the order of 25-30 microns, with localized pockets of enhanced LWC and MVD possible, including a chance for $\text{MVD} > 40$ microns.

RELEVANT METARS

St. Louis, Missouri:

KSTL 071651Z 32006KT 4SM -RA OVC036 08/06 A2972 RMK AO2 SLP065 P0014 T00830056
KSTL 071636Z 34006KT 3SM -RA BKN033 OVC044 08/05 A2972 RMK AO2 P0013
KSTL 071644Z 34006KT 4SM -RA BR BKN034 OVC044 08/06 A2972 RMK AO2 P0014
KSTL 071622Z 35008KT 3SM -RA BKN029 OVC039 08/05 A2972
KSTL 071622Z 35008KT 3SM -RA BKN029 OVC039 08/05 A2972 RMK AO2 P0011
KSTL 071551Z 34011KT 2 1/2SM RA OVC027 08/04 A2971 RMK AO2 SLP063 P0028 T00780044
KSTL 071451Z 32009KT 3SM RA OVC034 08/04 A2970 RMK AO2 SLP059 P0012 60013 T00780044 51001
KSTL 071414Z 35005KT 3SM -RA FEW017 OVC040 08/04 A2970 RMK AO2 P0002
KSTL 071400Z 32008KT 4SM -RA OVC040 08/04 A2970
KSTL 071400Z 32008KT 4SM -RA OVC040 08/04 A2970 RMK AO2 P0001
KSTL 071351Z 33008KT 5SM -RA BKN042 OVC060 08/03 A2970 RMK AO2 SLP058 P0001 T00830033
KSTL 071251Z 36009KT 10SM -RA BKN060 OVC075 10/02 A2970 RMK AO2 RAB50 SLP057 P0000 T01000017
KSTL 071151Z 02006KT 10SM OVC085 11/01 A2970 RMK AO2 RAE01 SLP055 P0000 60000 T01060011 10111 20094 58026

Springfield, Illinois:

KSPI 071652Z 36012KT 10SM OVC090 12/02 A2969 RMK AO2 SLP055 T01170017
KSPI 071552Z 02009KT 10SM OVC095 12/01 A2968 RMK AO2 SLP053 T01170011
KSPI 071452Z 01010KT 10SM BKN095 OVC110 10/02 A2969 RMK AO2 SLP053 T01000022 58024
KSPI 071352Z 01007KT 10SM BKN080 OVC095 08/02 A2973 RMK AO2 SLP069 T00830022
KSPI 071252Z 01006KT 10SM OVC100 07/02 A2974 RMK AO2 SLP072 T00720022
KSPI 071152Z 01005KT 10SM OVC090 07/02 A2976 RMK AO2 SLP078 T00670022 10072 20061 58009 \$

Bloomington, Illinois:

KBMI 071656Z 01012KT 10SM FEW095 09/01 A2968 RMK AO2 T00940011 SLP057
KBMI 071556Z 01012KT 10SM FEW100 08/02 A2968 RMK AO2 T00830016 SLP058
KBMI 071456Z 03011KT 10SM CLR 07/02 A2972 RMK AO2 56027 T00660016 SLP073
KBMI 071356Z 05010KT 10SM FEW100 04/01 A2975 RMK AO2 T00440011 SLP081
KBMI 071256Z 02010KT 10SM CLR 03/01 A2977 RMK AO2 T00330005 SLP088
KBMI 071156Z 05006KT 10SM CLR 03/00 A2981 RMK AO2 50005 T00270000 10033 20016 SLP100

Chicago NEXRAD, Illinois:

KLOT 071655Z AUTO 06014G19KT 10SM SCT110 12/M01 A2970 RMK AO2 T01241010 TSNO
KLOT 071635Z AUTO 06015G20KT 10SM SCT110 12/M02 A2972 RMK AO2 T01201017 TSNO
KLOT 071615Z AUTO 08015G19KT 10SM CLR 12/M01 A2972 RMK AO2 T01201012 TSNO
KLOT 071555Z AUTO 05016G21KT 10SM CLR 12/M01 A2972 RMK AO2 T01171006 TSNO
KLOT 071535Z AUTO 04015G19KT 10SM CLR 11/00 A2973 RMK AO2 T01141002 TSNO
KLOT 071515Z AUTO 03011KT 10SM CLR 11/00 A2975 RMK AO2 T01051002 TSNO
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KLOT 071435Z AUTO 04007KT 10SM CLR 08/01 A2976 RMK AO2 T00810007 TSNO
KLOT 071415Z AUTO 04008KT 10SM CLR 07/01 A2978 RMK AO2 T00700009 TSNO
KLOT 071355Z AUTO 06006KT 10SM CLR 07/01 A2979 RMK AO2 T00650005 TSNO

Chicago-O'Hare, Illinois:

KORD 071651Z 04013KT 10SM FEW150 BKN200 11/M02 A2971 RMK AO2 SLP064 T01111022 \$
KORD 071551Z 04009KT 10SM SCT150 BKN200 11/M02 A2974 RMK AO2 SLP072 T01111017 \$
KORD 071451Z 04005KT 10SM SCT150 OVC200 08/M01 A2977 RMK AO2 SLP083 T00831006 58026 \$
KORD 071351Z 04005KT 10SM FEW150 OVC180 07/M01 A2980 RMK AO2 SLP093 T00671006 \$
KORD 071251Z 03003KT 10SM SCT140 OVC250 04/M01 A2983 RMK AO2 SLP103 T00441011 \$
KORD 071151Z 01005KT 10SM OVC130 03/M02 A2985 RMK AO2 SLP110 T00331022 10044 20022 53003 \$

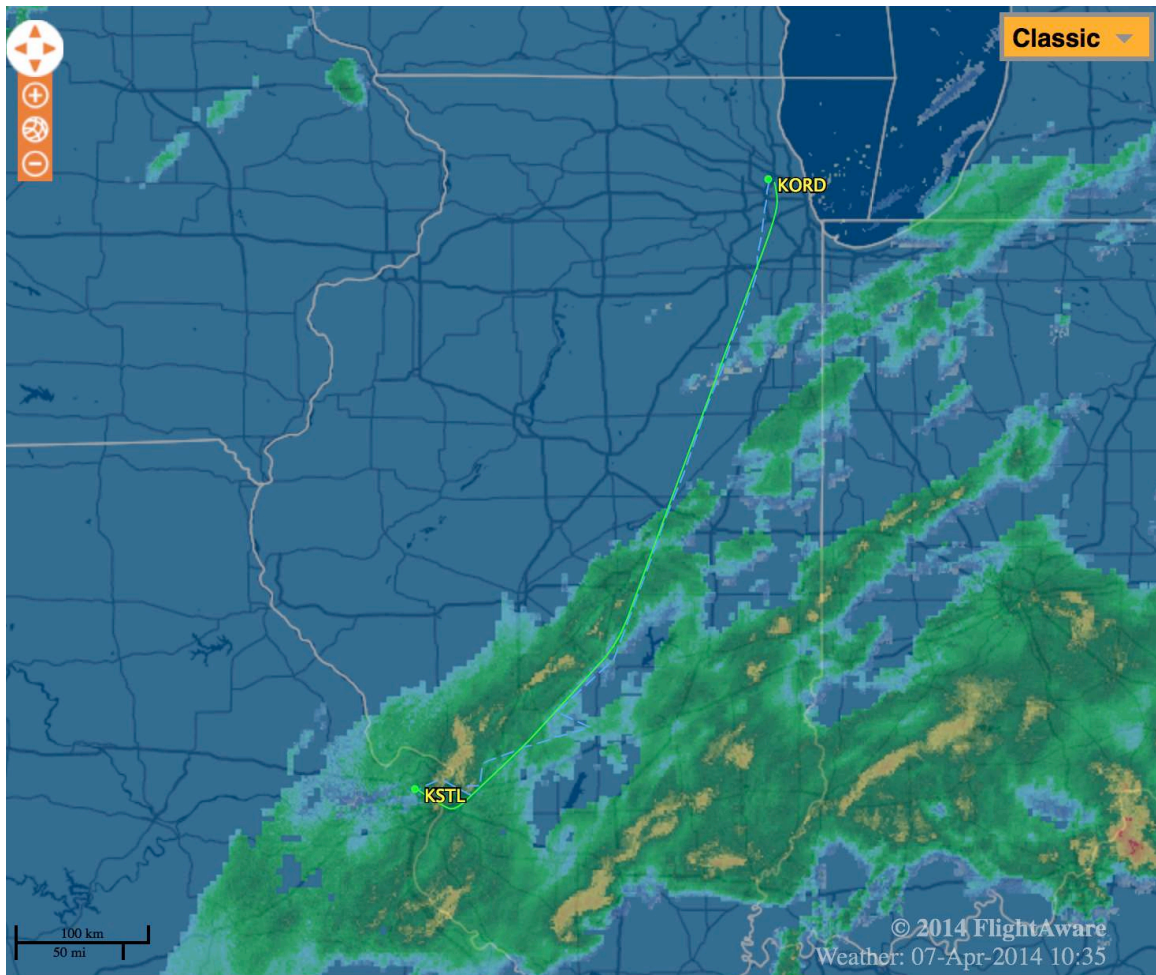
Chicago-Midway, Illinois:

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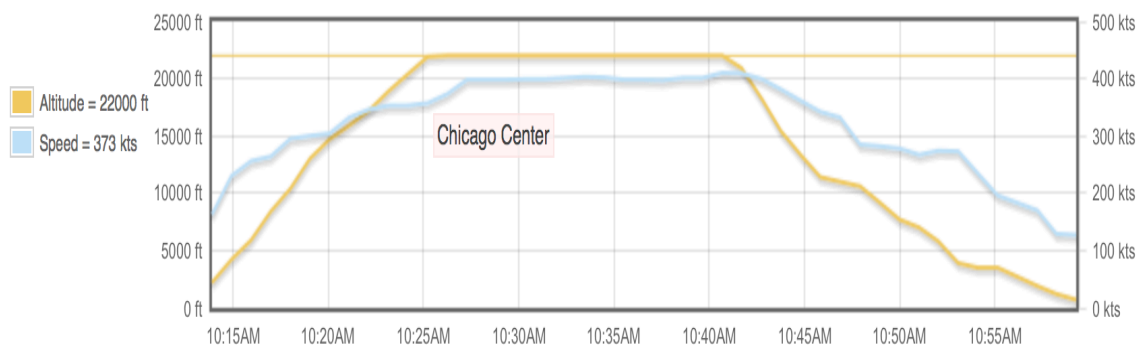
RELEVANT PIREPS

TIP UA /OV RBS090015 /TM 1257 /FL160 /TP C421 /TA M05 /IC MOD RIME=
PNT UA /OV PNT /TM 1326 /FLUNKN /TP E135 /TA M15 /IC LGT-MOD RIME 150-160=
IKK UA /OV IKK/TM 1627/FL100/TP C340/TA 00/IC LGT RIME 100-110=

FLIGHT DATA AND TRACKS



Data 1.1. Large-scale flight track.



Data 1.2. Time-history of altitude (yellow) and speed (blue).

FIGURES

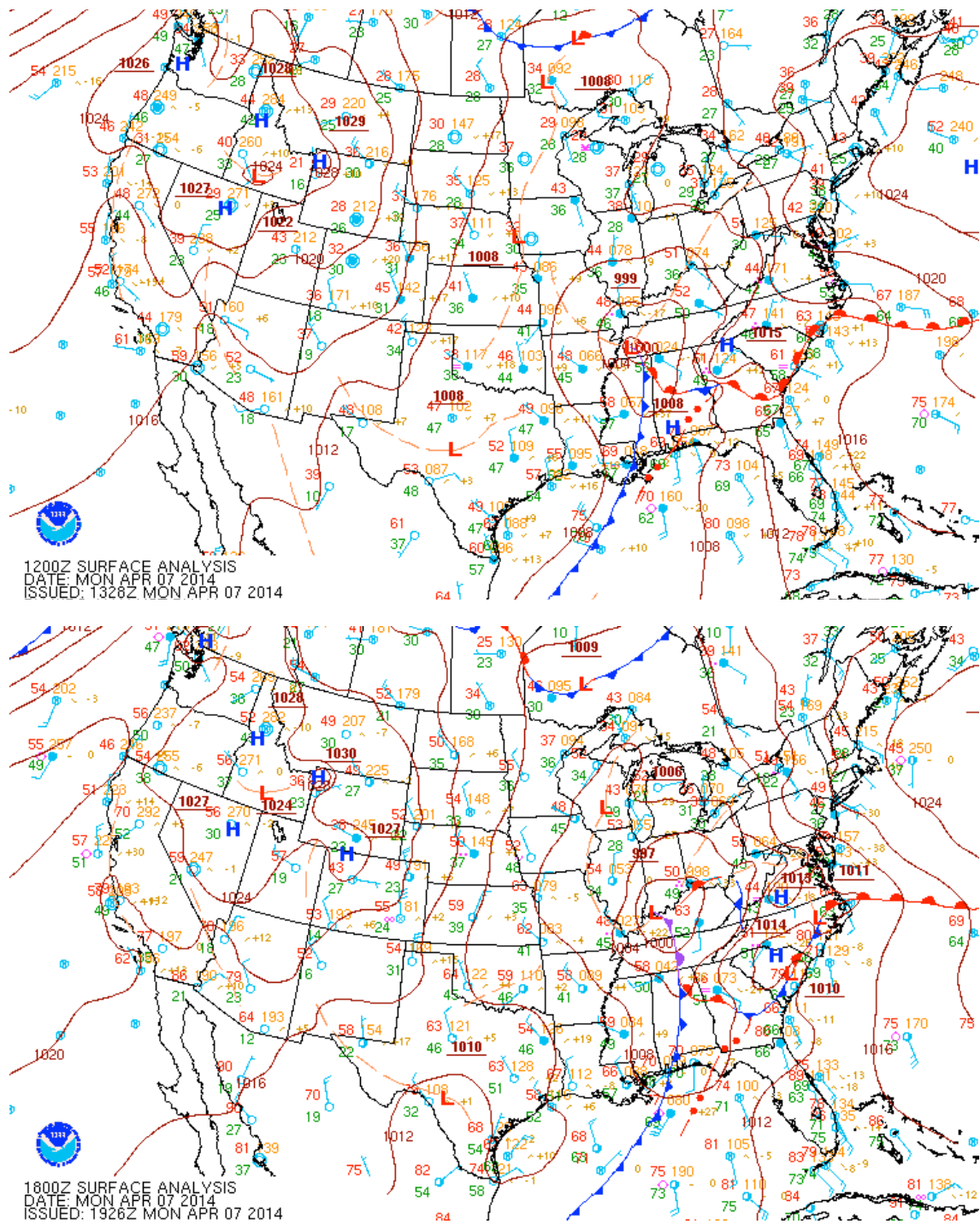
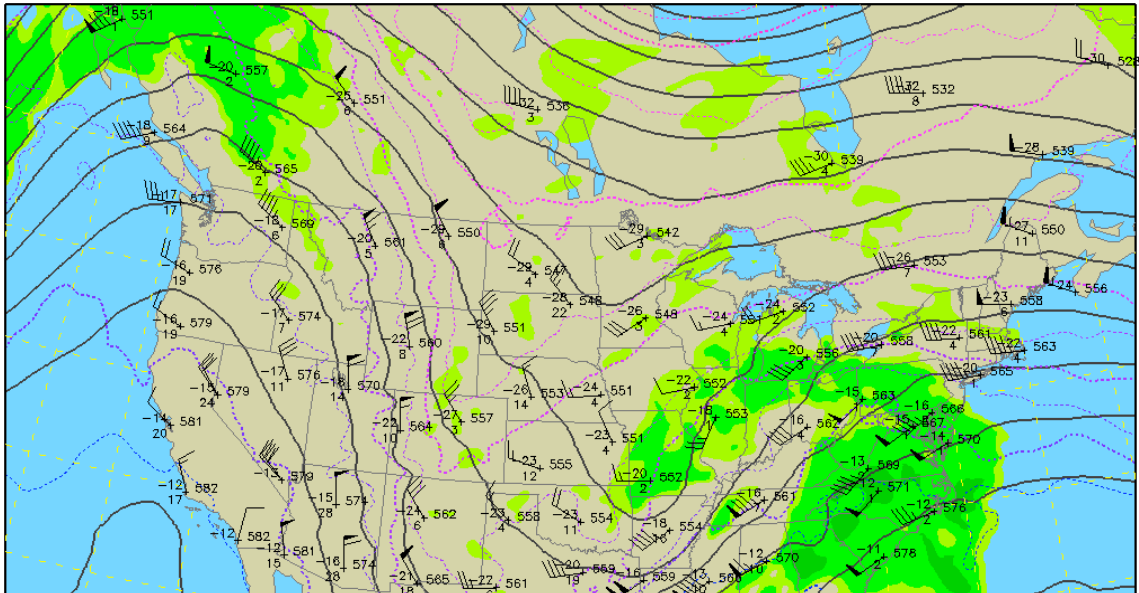


Fig. 2.1. Surface analysis for 1200 and 1800 UTC.

500 mb Heights (dm) / Temperature ($^{\circ}\text{C}$) / Humidity (%)

0-hour analysis valid 1200 UTC Mon 07 Apr 2014

RAP (12z 07 Apr)



700 mb Heights (dm) / Temperature ($^{\circ}\text{C}$) / Humidity (%)

0-hour analysis valid 1200 UTC Mon 07 Apr 2014

RAP (12z 07 Apr)

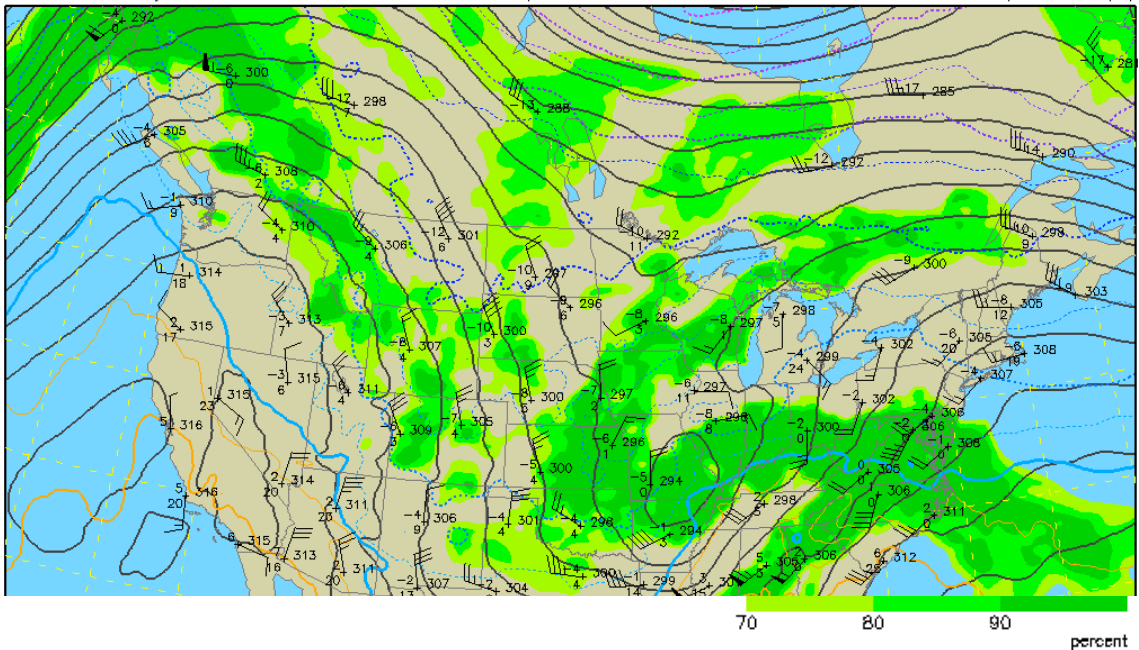
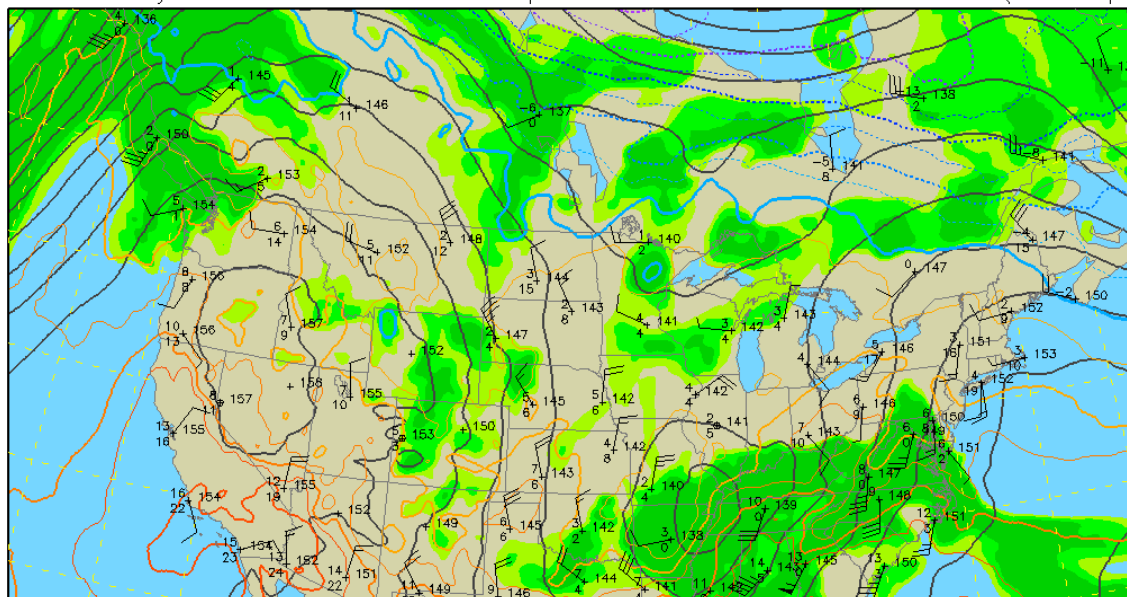


Fig. 2.2. NAM 12-hr forecast of T and RH for 500 and 700 mb valid at 1200 UTC.

850 mb Heights (dm) / Temperature ($^{\circ}\text{C}$) / Humidity (%)

0-hour analysis valid 1200 UTC Mon 07 Apr 2014

RAP (12z 07 Apr)



925 mb Heights (dm) / Temperature ($^{\circ}\text{C}$) / Humidity (%)

0-hour analysis valid 1200 UTC Mon 07 Apr 2014

RAP (12z 07 Apr)

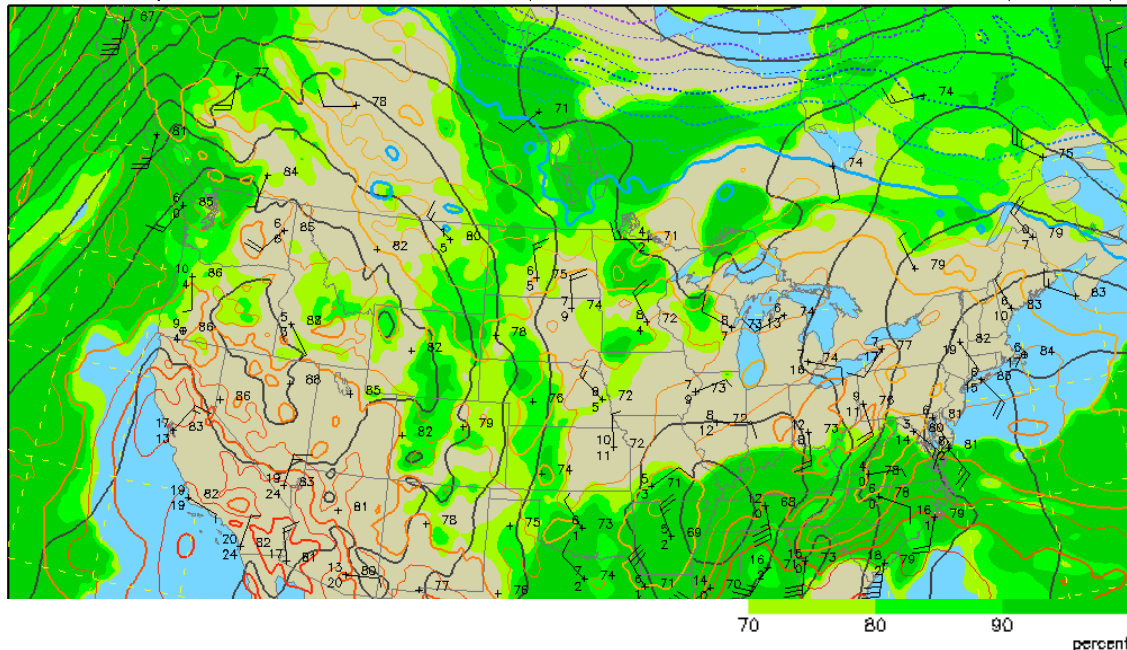
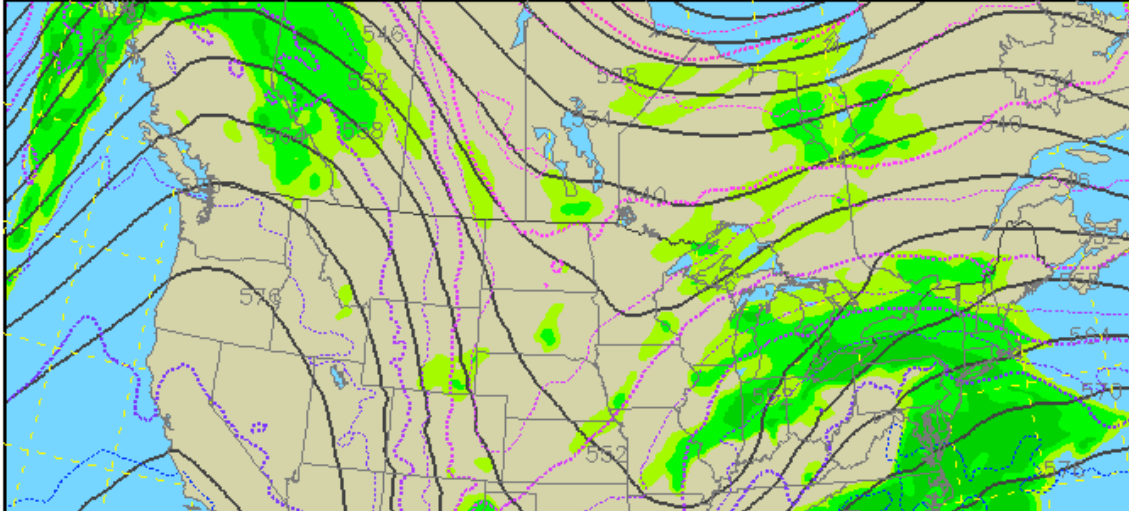


Fig. 2.3. NAM 12-hr forecast of T and RH for 850 and 925 mb valid at 1200 UTC.

500 mb Heights (dm) / Temperature (°C) / Humidity (%)

03-hour forecast valid 1800 UTC Mon 07 Apr 2014

RAP (15z 07 Apr)



700 mb Heights (dm) / Temperature (°C) / Humidity (%)

03-hour forecast valid 1800 UTC Mon 07 Apr 2014

RAP (15z 07 Apr)

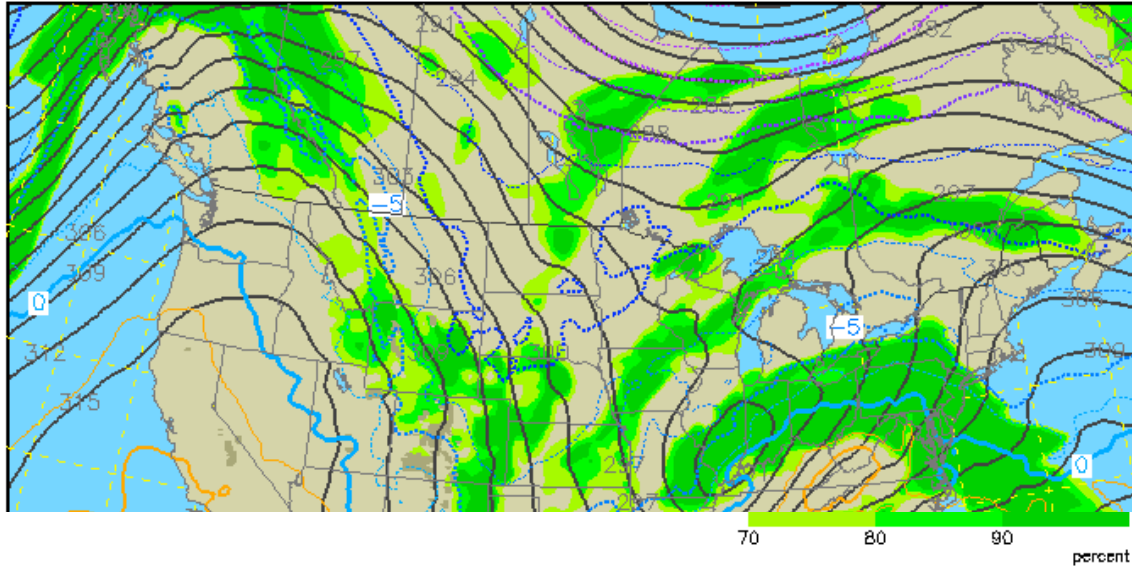
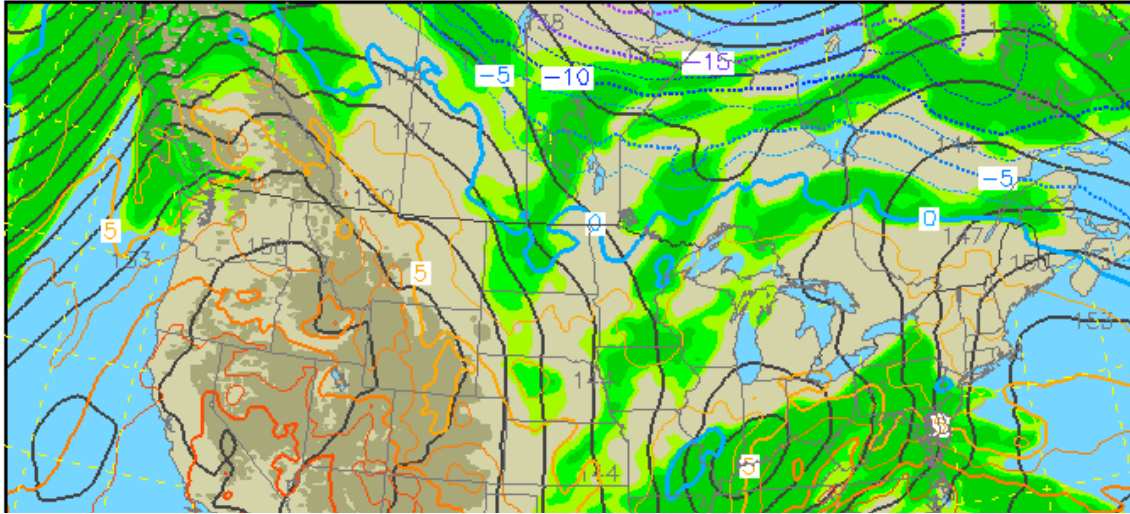


Fig. 2.5. NAM 6-hr forecast of T and RH for 500 and 700 mb valid at 1800 UTC.

850 mb Heights (dm) / Temperature (°C) / Humidity (%)

03-hour forecast valid 1800 UTC Mon 07 Apr 2014

RAP (15z 07 Apr)



925 mb Heights (dm) / Temperature (°C) / Humidity (%)

03-hour forecast valid 1800 UTC Mon 07 Apr 2014

RAP (15z 07 Apr)

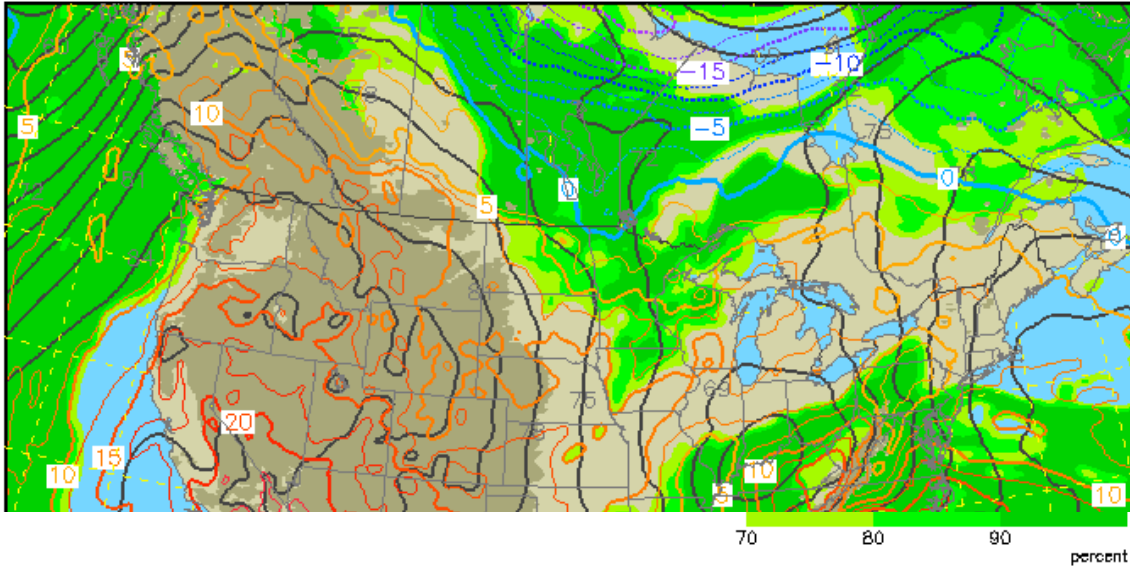


Fig. 2.6. NAM 3-br forecast of T and RH for 850 and 925 mb valid at 1800 UTC.

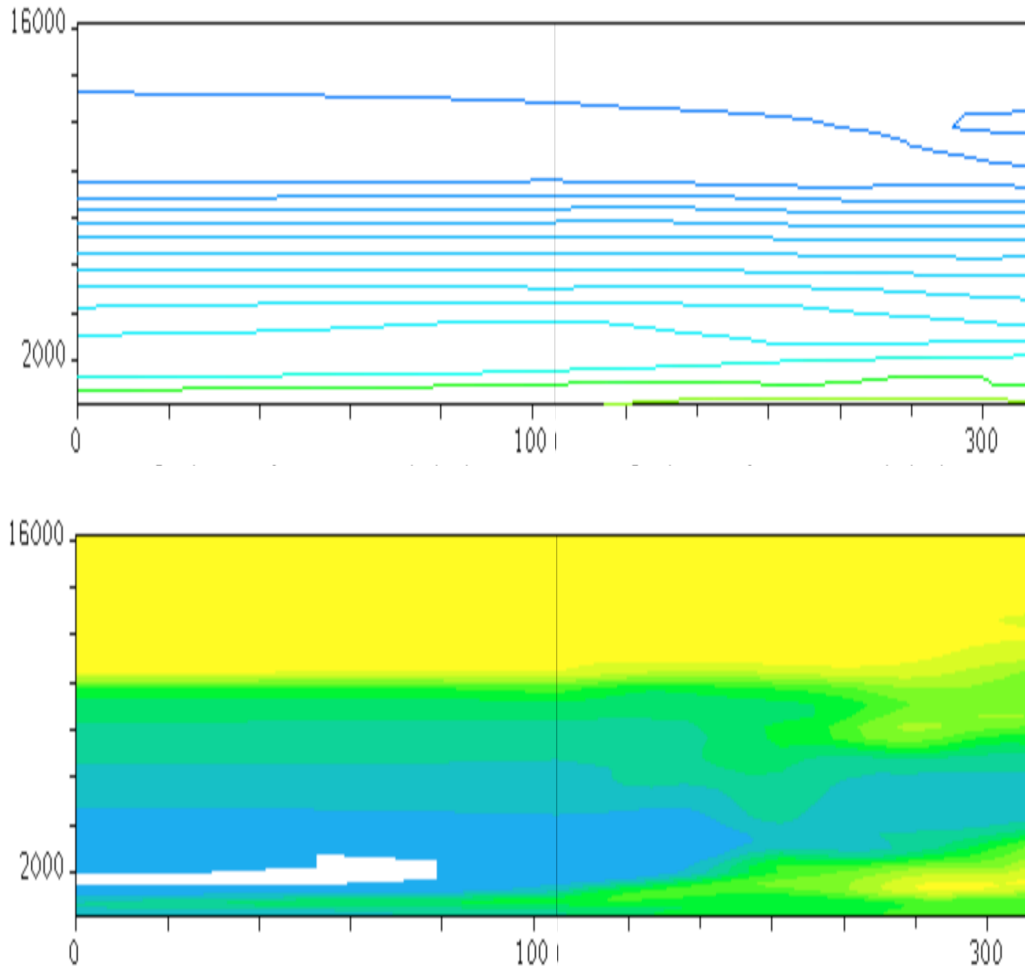


Fig. 2.7. Piecewise RUC model vertical cross section of temperature (top) and relative humidity (bottom) along the approximate route between St. Louis (KSTL; left side) and Chicago O'Hare (KORD; right side) valid at 1600 UTC. The vertical line in the middle of the chart is the approximate location of the icing event. Blue shades in the RH field indicate $RH > 80\%$. Heights on the y-axis are in meters above sea level. 700 mb is roughly equivalent to 3000 m MSL.

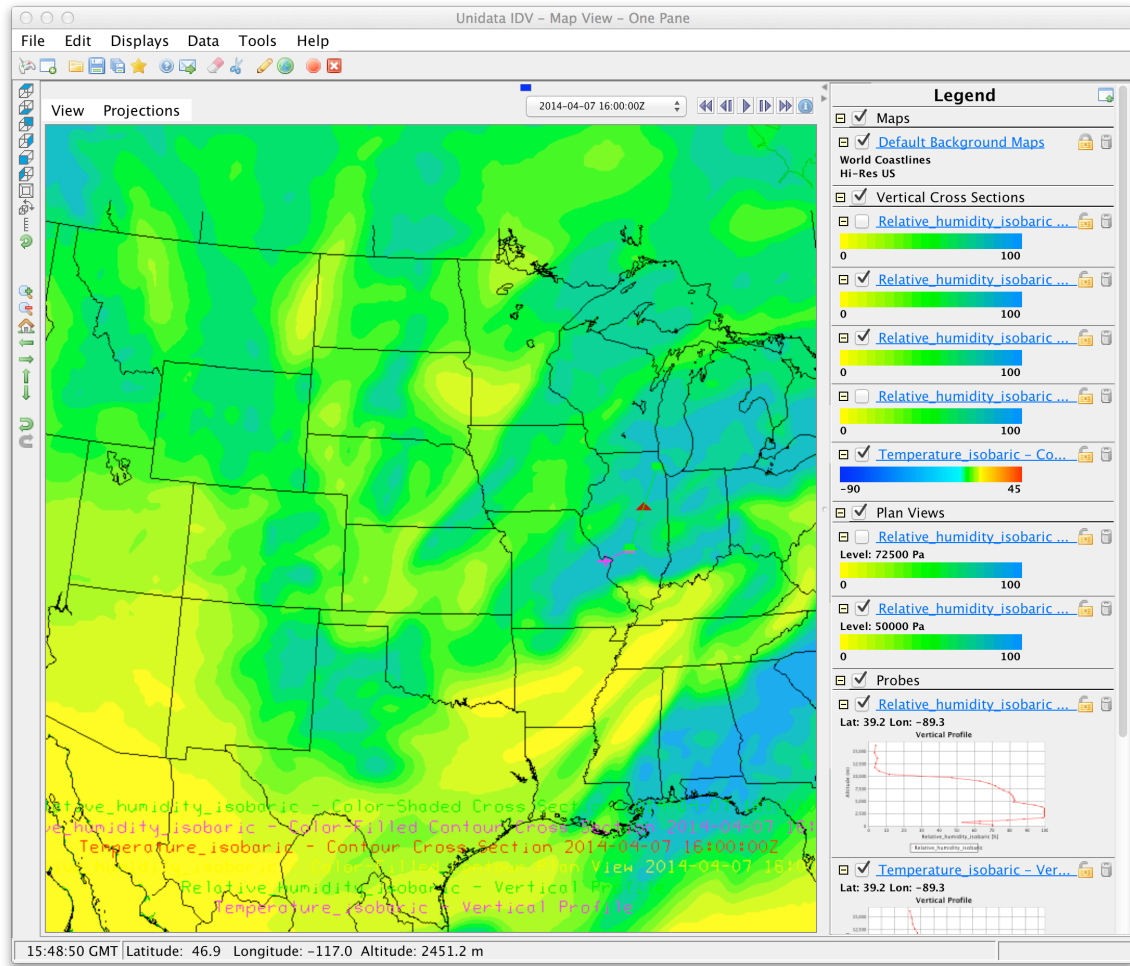


Fig. 2.8. RUC model RH valid at 550 mb (~16,000 ft), showing the approximate route from Chicago O'Hare (KORD; upper right) to St. Louis (KSTL; lower left) valid at 1600 UTC. The route is in two segments, along a green line and along a magenta line. Blue shades in the RH field indicate RH>80%. A green marker along the magenta line to the northeast of KSTL shows the location of the vertical profiles in Fig. 2.9.

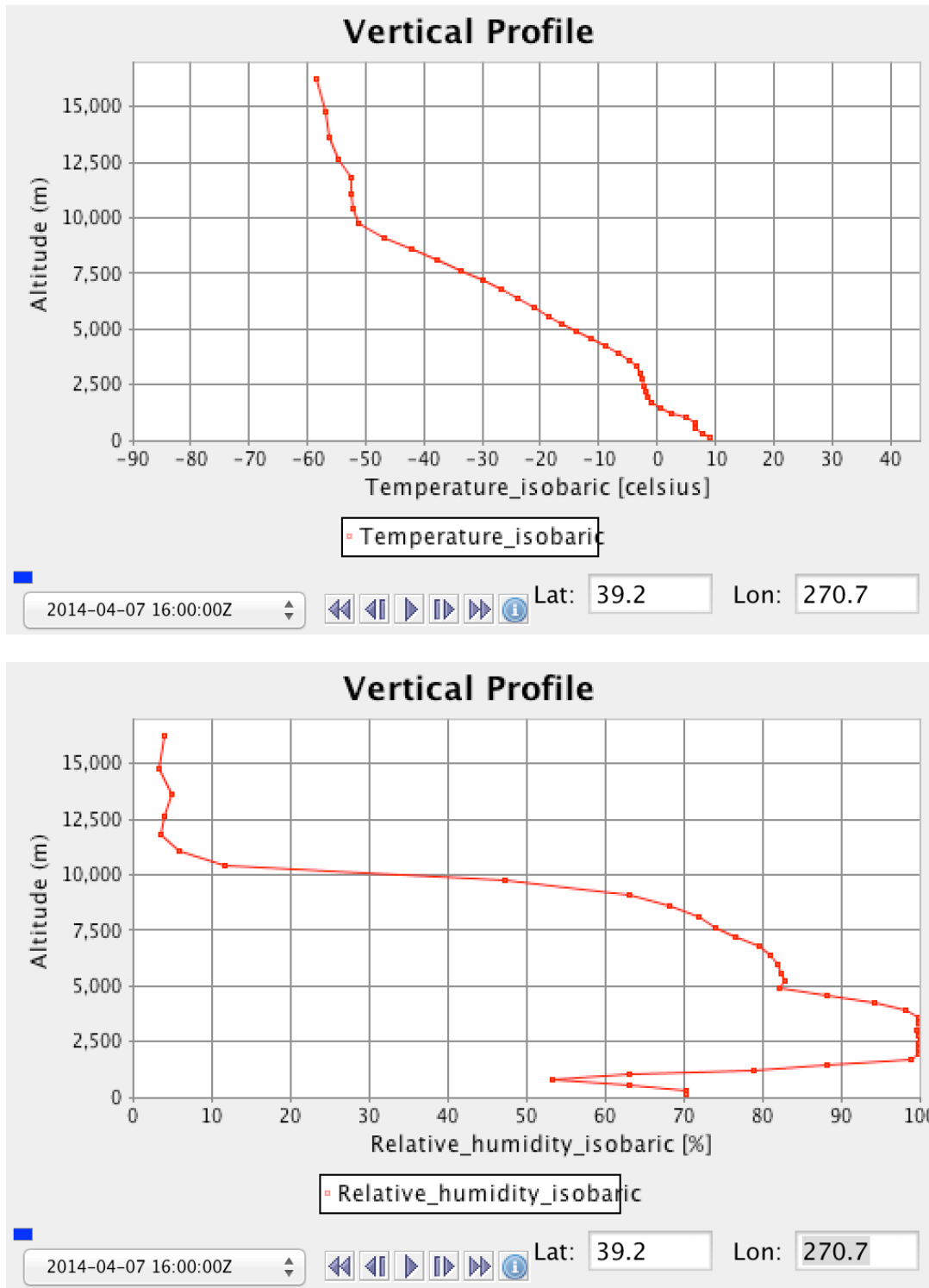


Fig. 2.9. Vertical profiles of RUC model vertical temperature (top) and relative humidity (bottom) valid to the northeast of St. Louis (KSTL); green marker on the magenta line in Fig. 2.8) at 1600 UTC.

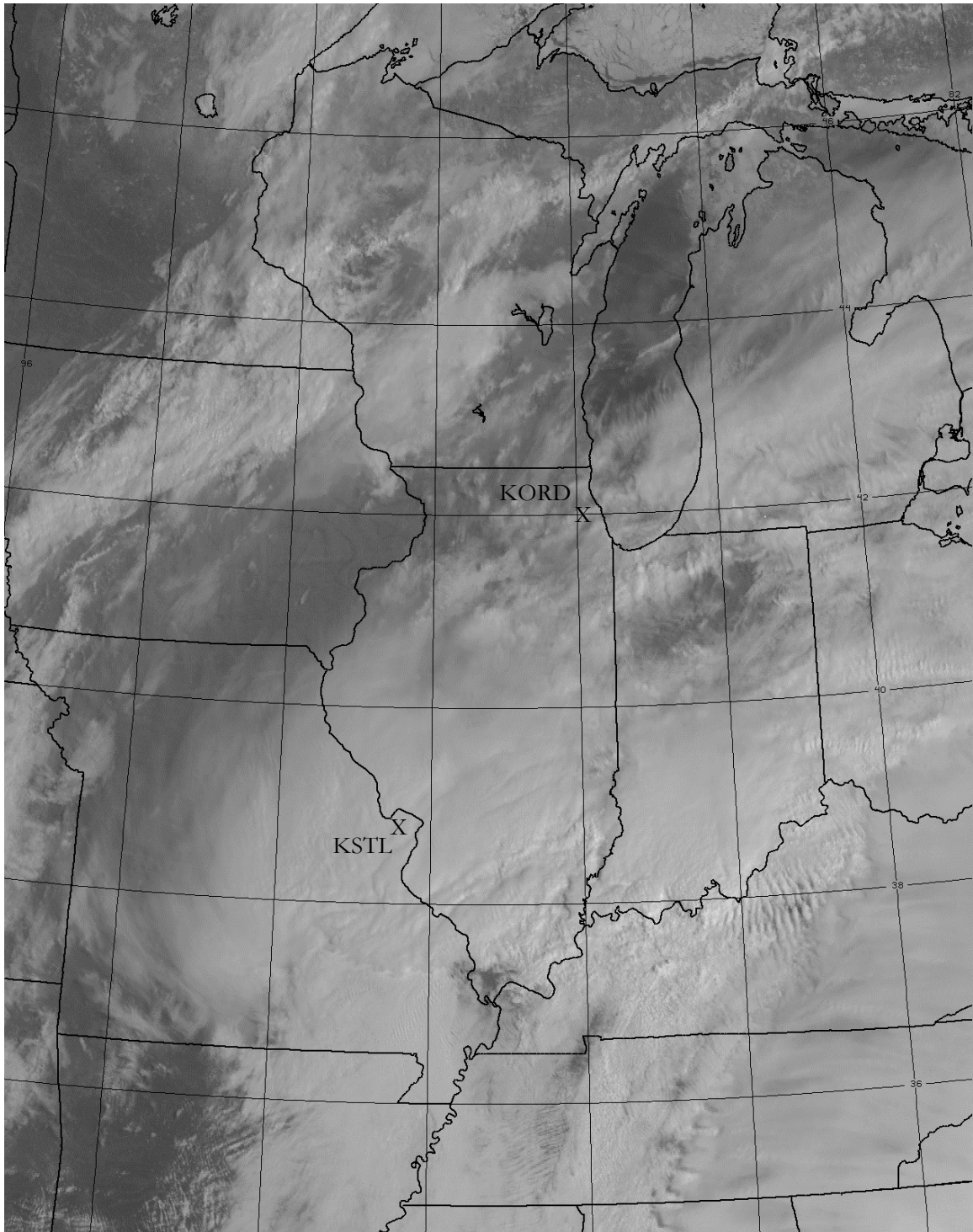


Fig. 2.10. High-resolution, visible satellite image for 1445 UTC. The approximate locations of St. Louis (KSTL) and Chicago O'Hare (KORD) are shown.

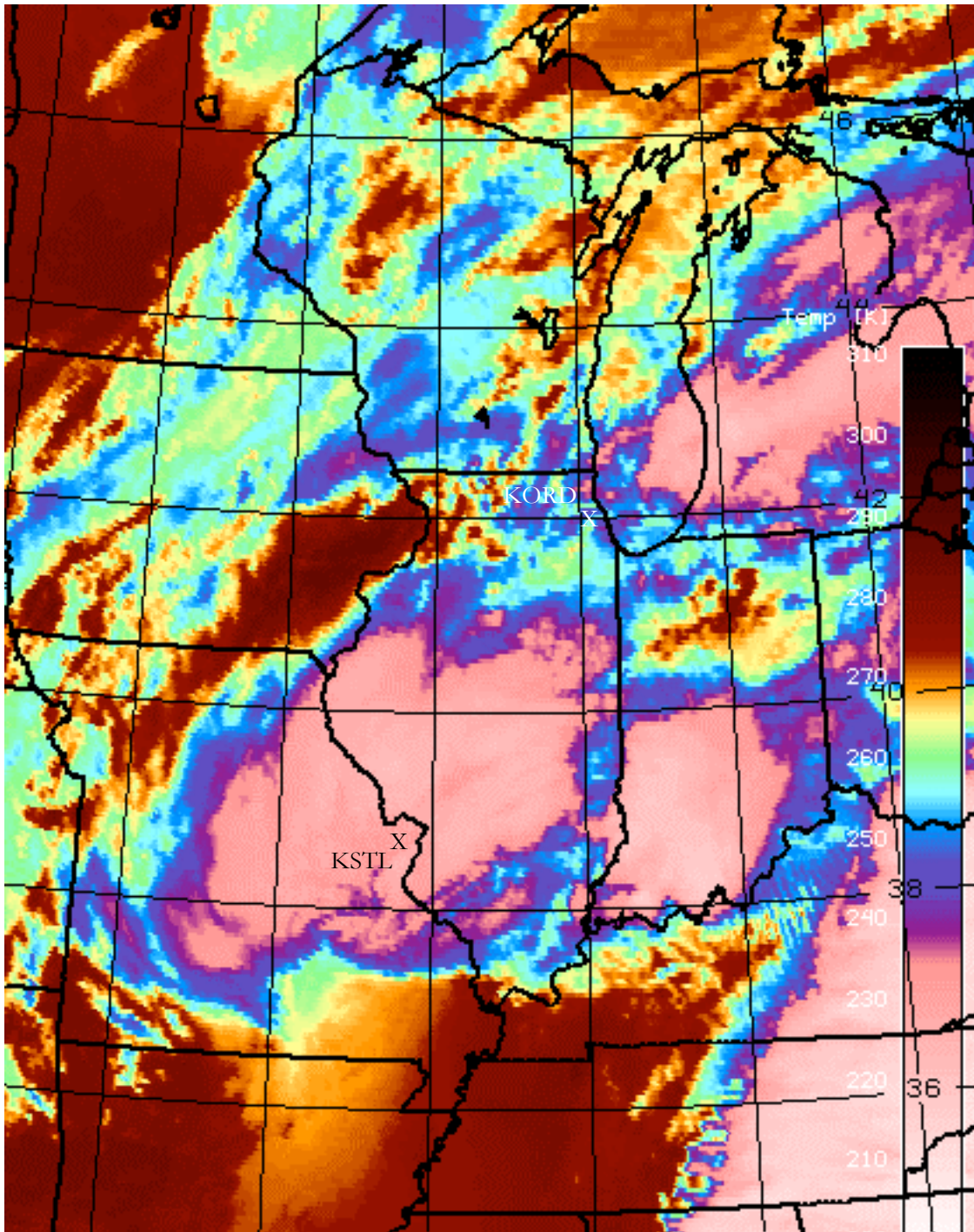


Fig. 2.11. Infrared satellite image for 1445 UTC. The approximate locations of St. Louis (KSTL) and Chicago O'Hare (KORD) are shown. Temperatures are in degrees Kelvin (degrees Celsius +273).

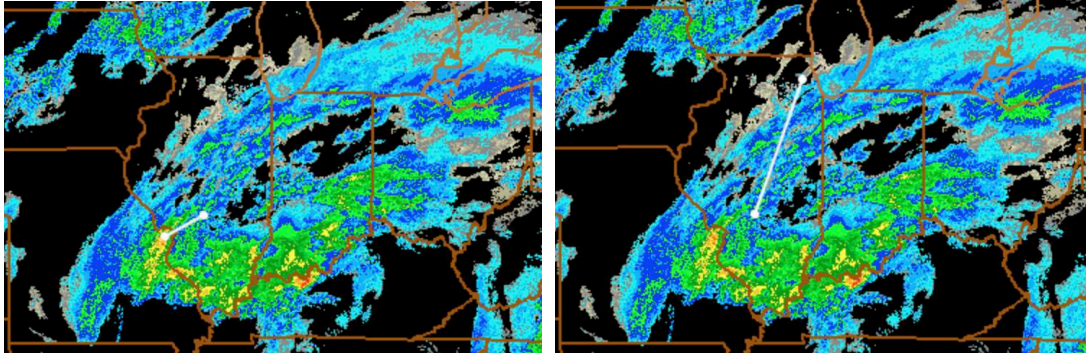


Fig. 2.12. Regional mosaic of low-tilt (0.5° elevation angle) radar reflectivity valid at 1444 UTC, with the two segments of the vertical cross section shown.

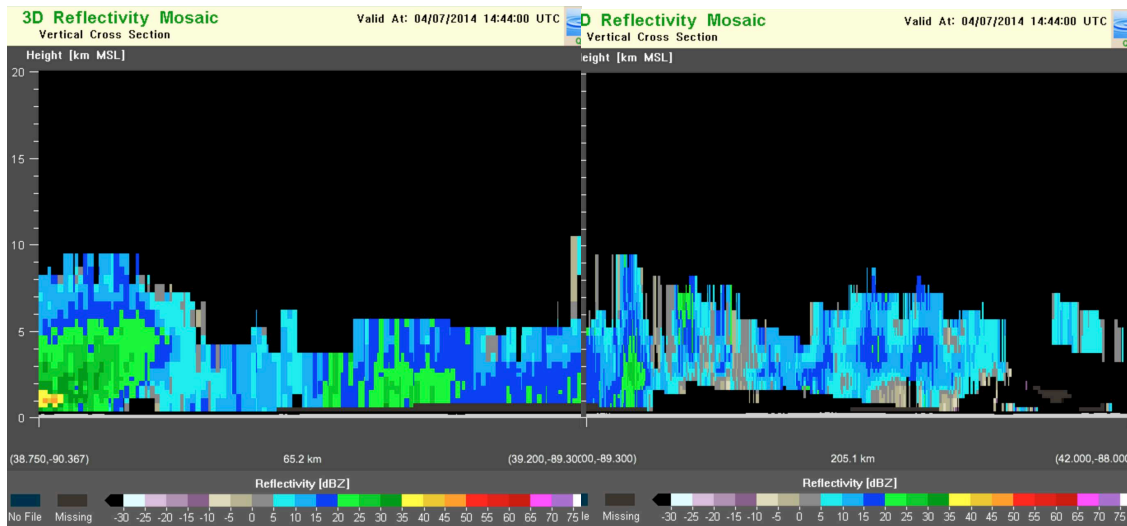


Fig. 2.13. Piecewise, vertical cross section of radar reflectivity from St. Louis (KSTL; left side) to Chicago (KORD; right side) valid at 1444 UTC. The vertical, dashed line in the middle of the chart is the approximate location of the icing event. The black area indicated beneath the echoes in the middle of the chart indicate a lack of data due to the minimum elevation of the radar beams to the southwest of the KLOT (Chicago area) radar.

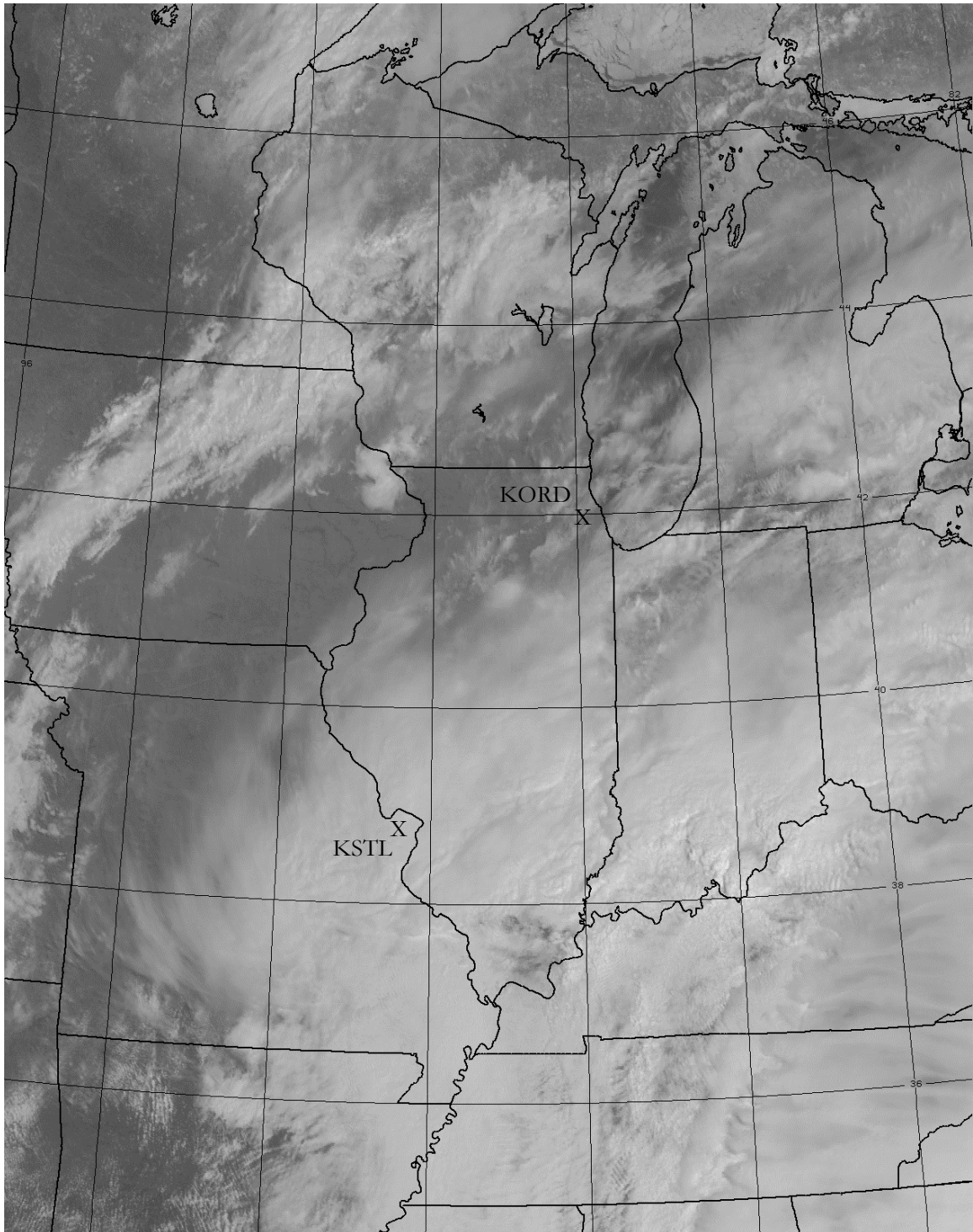


Fig. 2.14. High-resolution, visible satellite image for 1545 UTC. The approximate locations of St. Louis (KSTL) and Chicago O'Hare (KORD) are shown.

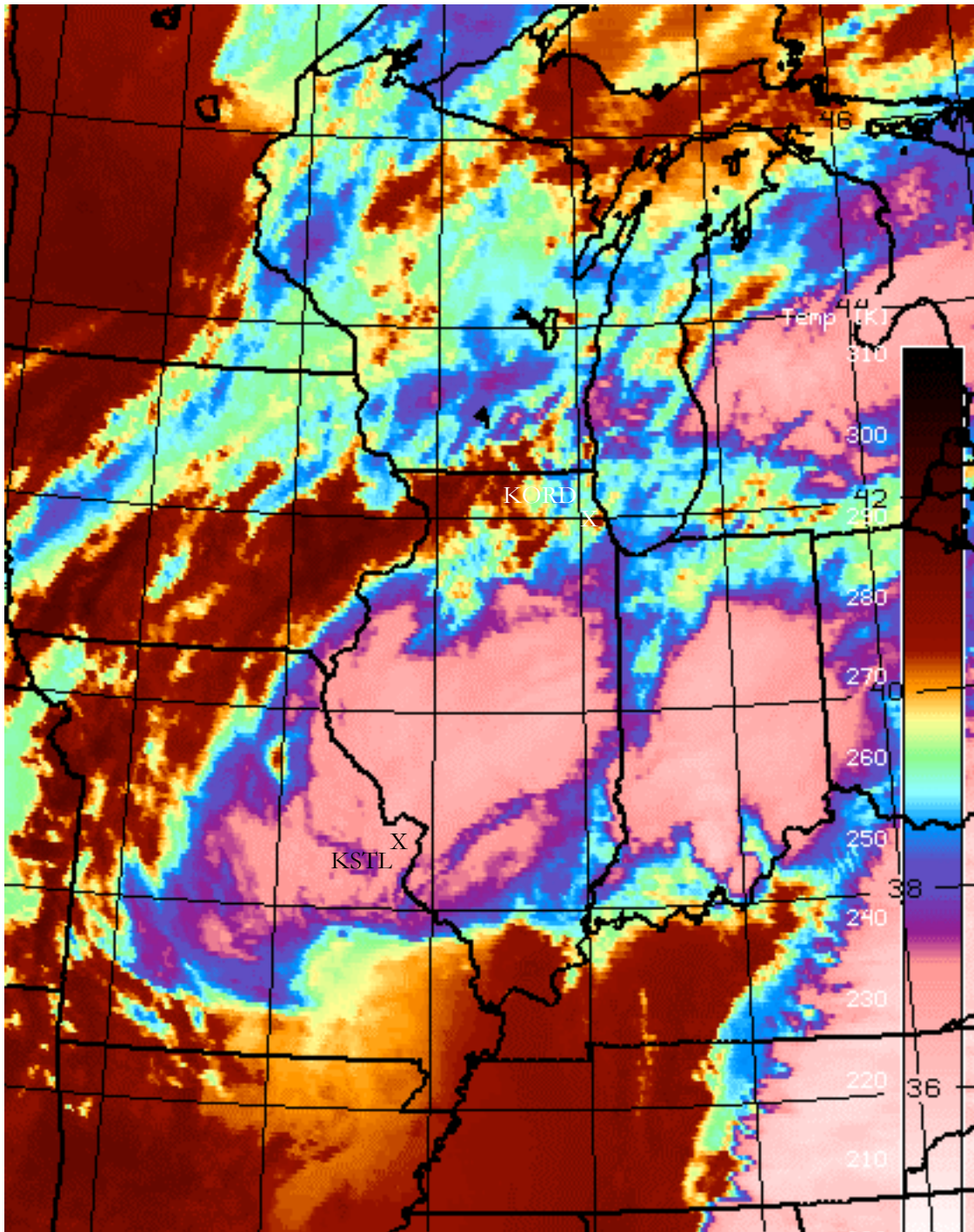


Fig. 2.15. Infrared satellite image for 1545 UTC. The approximate locations of St. Louis (KSTL) and Chicago O'Hare (KORD) are shown. Temperatures are in degrees Kelvin (degrees Celsius +273).

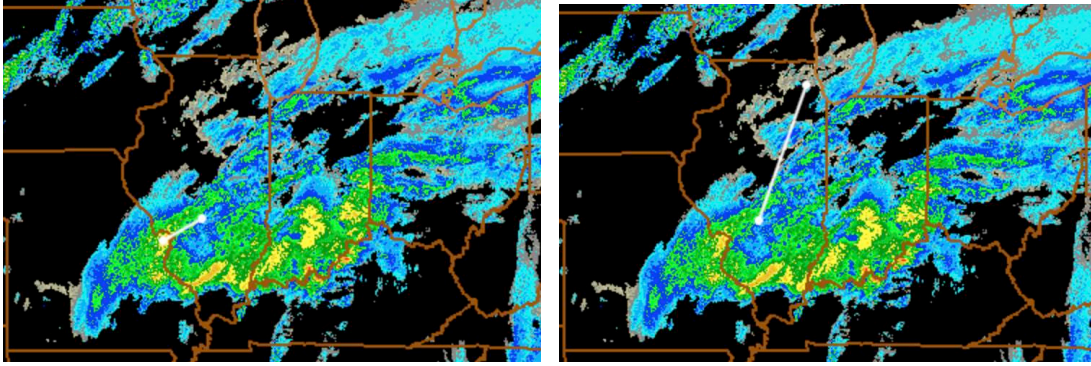


Fig. 2.16. Regional mosaic of low-tilt (0.5° elevation angle) radar reflectivity valid at 1544 UTC, with the two segments of the vertical cross section shown.

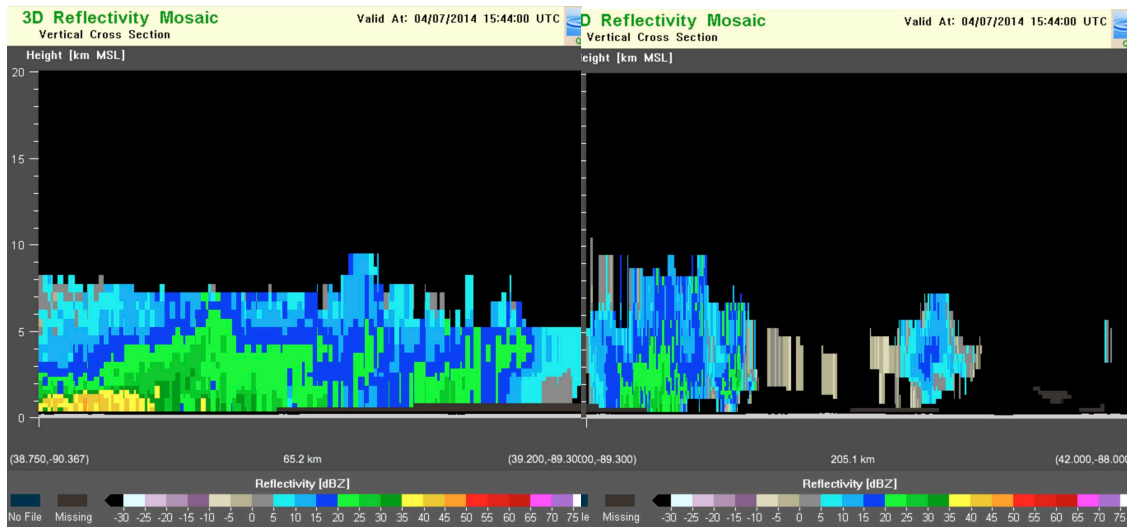


Fig. 2.17. Piecewise, vertical cross section of radar reflectivity from St. Louis (KSTL; left side) to Chicago (KORD; right side) valid at 1544 UTC. The vertical, dashed line in the middle of the chart is the approximate location of the icing event. The black area indicated beneath the echoes in the middle of the chart indicate a lack of data due to the minimum elevation of the radar beams to the southwest of the KLOT (Chicago area) radar.

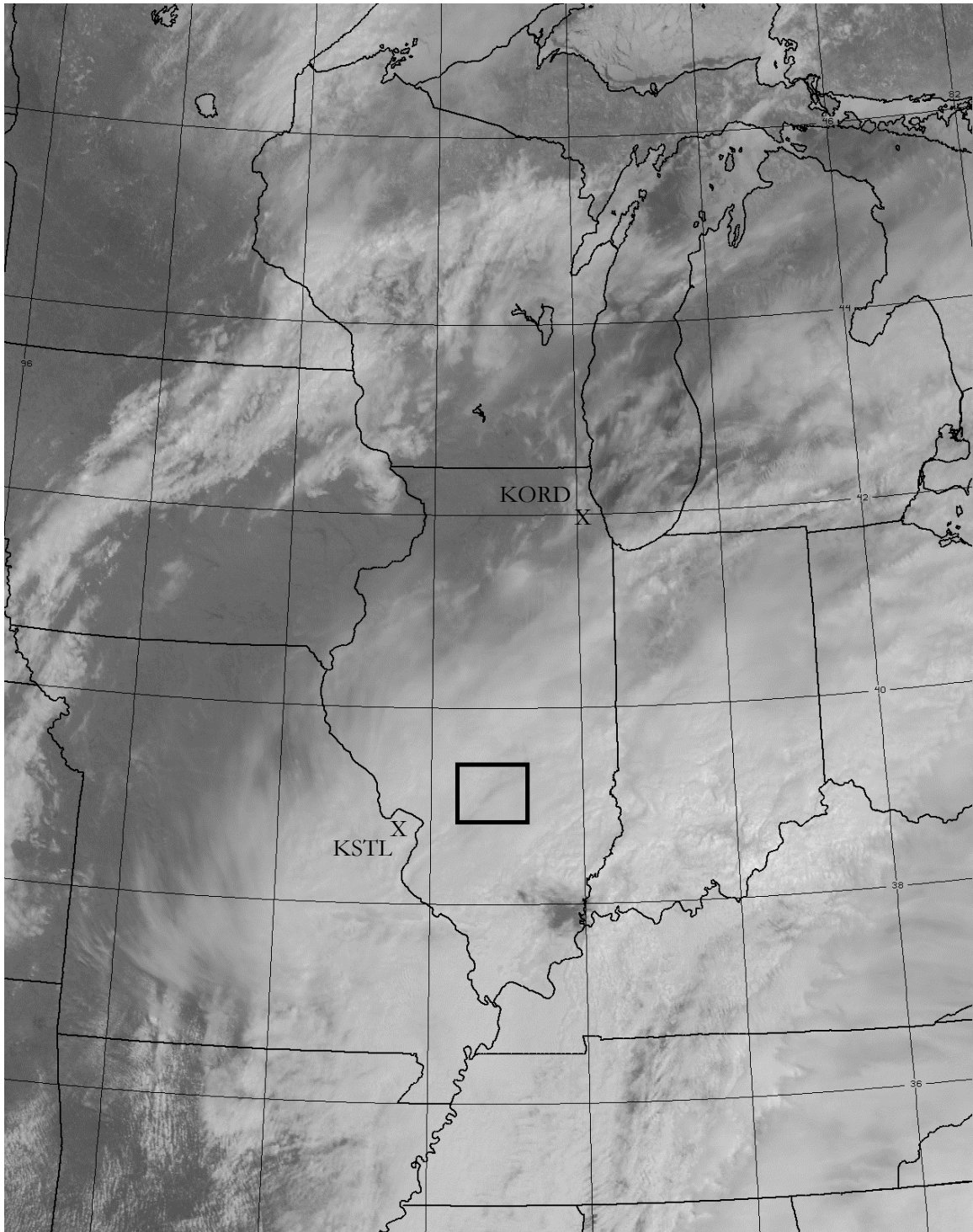


Fig. 2.18. High-resolution, visible satellite image for 1615 UTC. The approximate locations of St. Louis (KSTL) and Chicago O'Hare (KORD) are shown. The black box encapsulates the approximate location of the icing event.

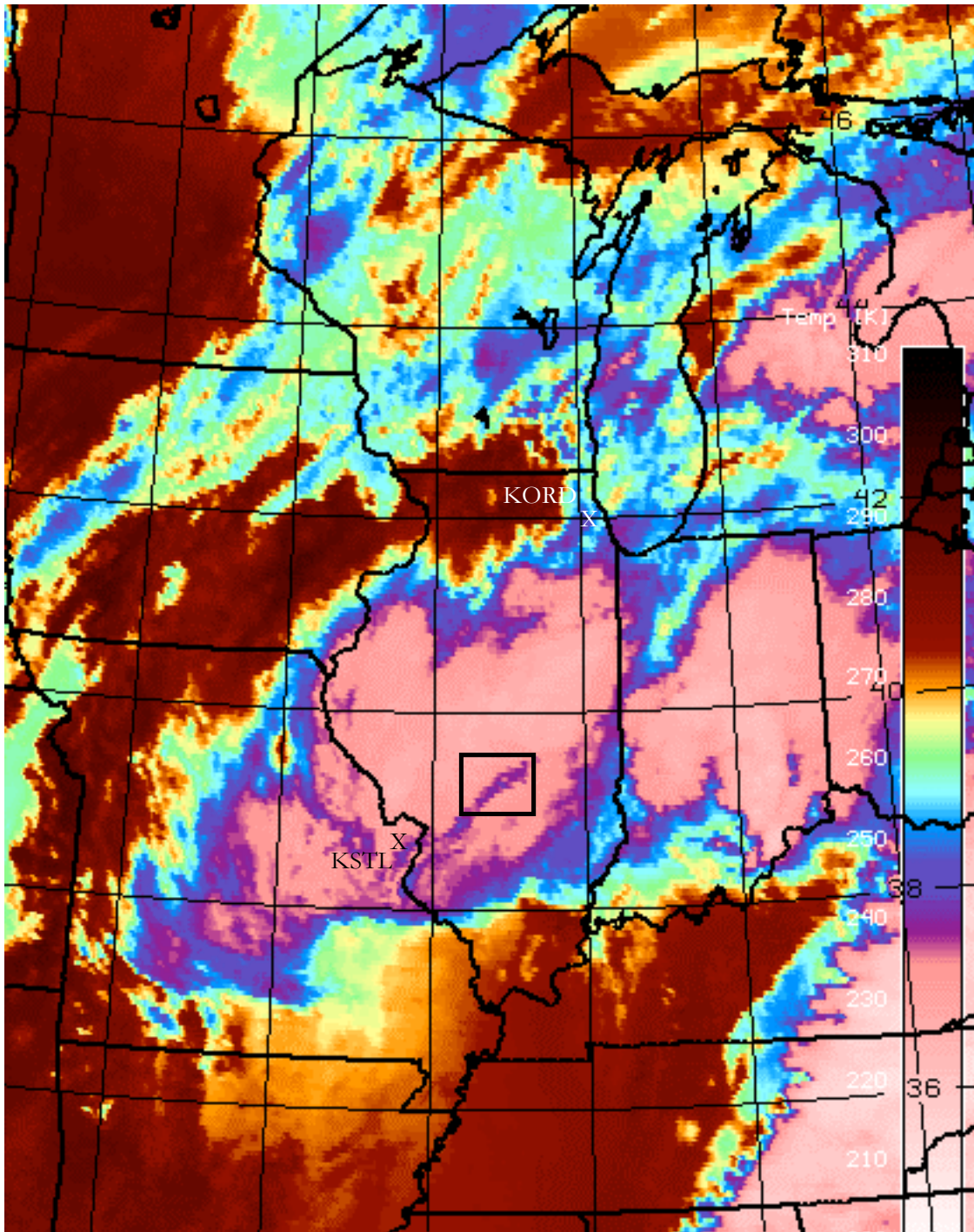


Fig. 2.19. Infrared satellite image for 1615 UTC. The approximate locations of St. Louis (KSTL) and Chicago O'Hare (KORD) are shown. Temperatures are in degrees Kelvin (degrees Celsius +273). The black box encapsulates the approximate location of the icing event.

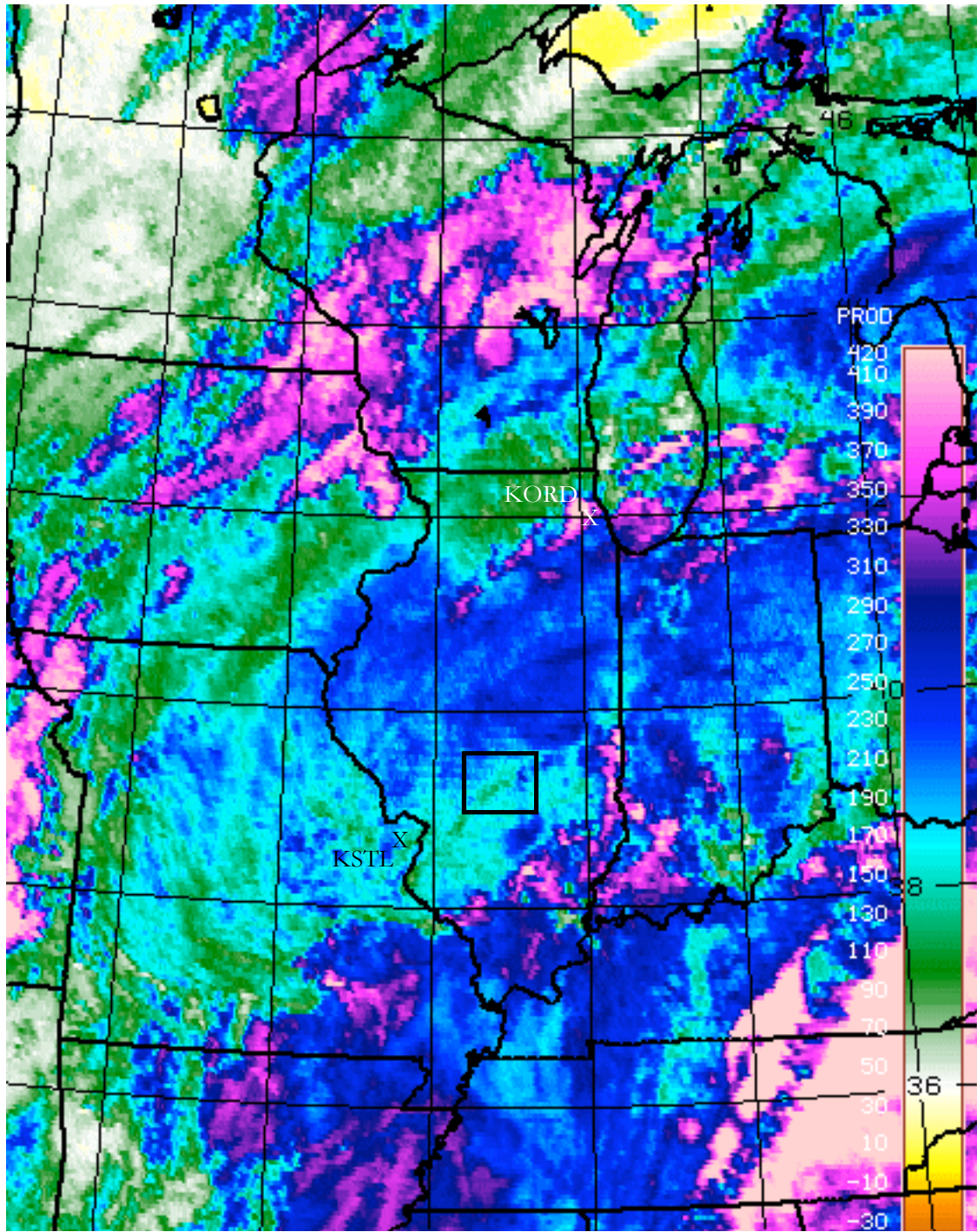


Fig. 2.20. Infrared channel difference image for 1615 UTC. The approximate locations of St. Louis (KSTL) and Chicago O'Hare (KORD) are shown. Temperatures are in degrees Kelvin (degrees Celsius +273). The black box encapsulates the approximate location of the icing event.

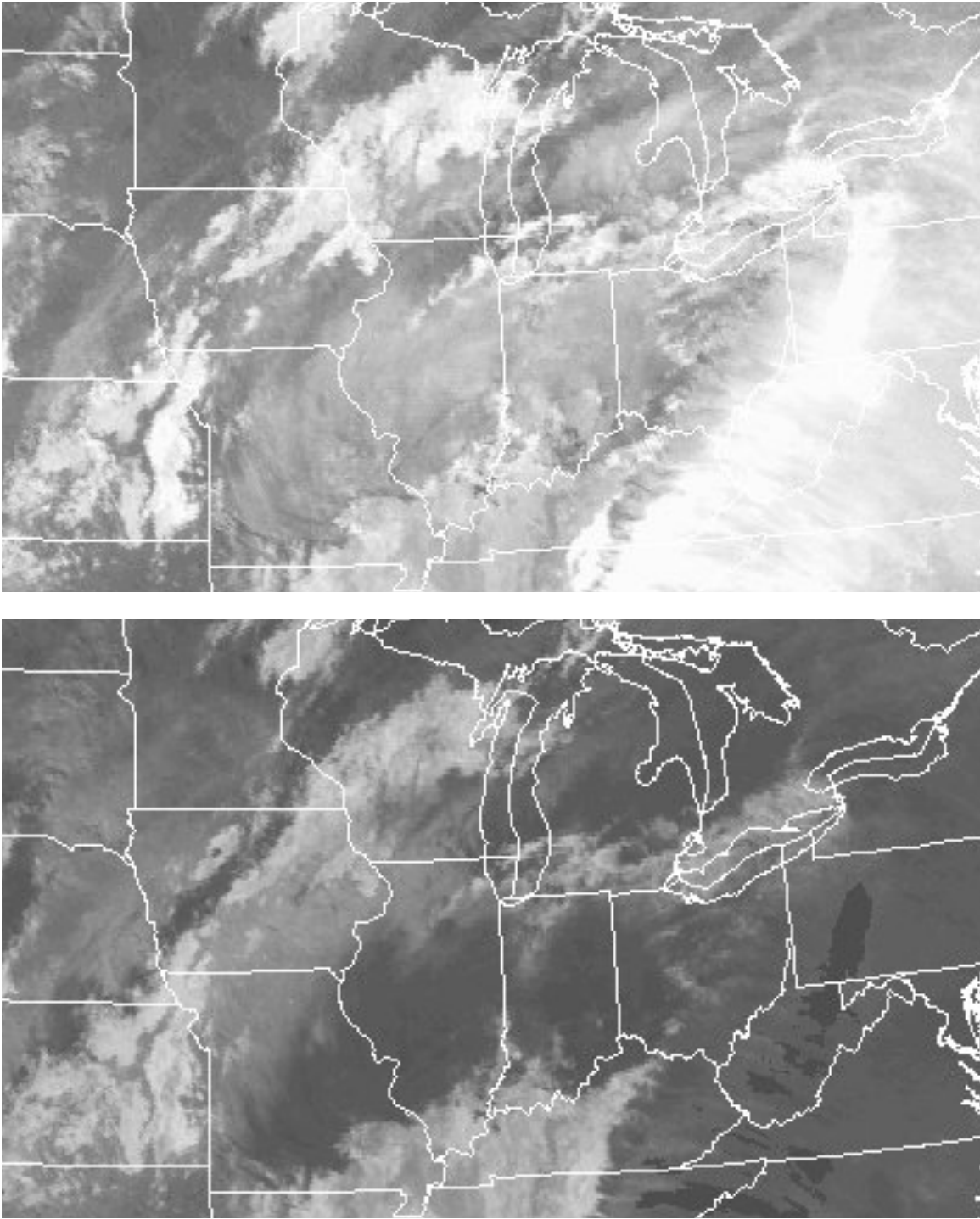


Fig. 2.21. Alternative infrared channel difference image and shortwave reflectance images for 1615 UTC.

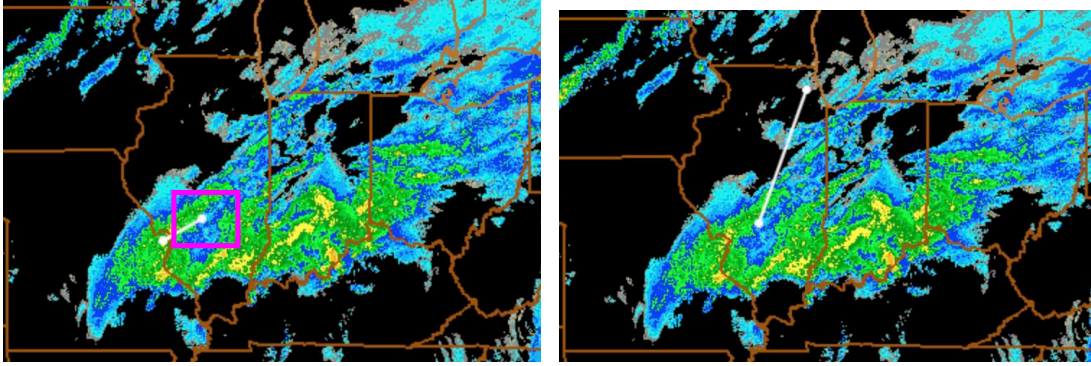


Fig. 2.22. Regional mosaic of low-tilt (0.5° elevation angle) radar reflectivity valid at 1614 UTC, with the two segments of the vertical cross section shown. The magenta box encapsulates the approximate location of the icing event.

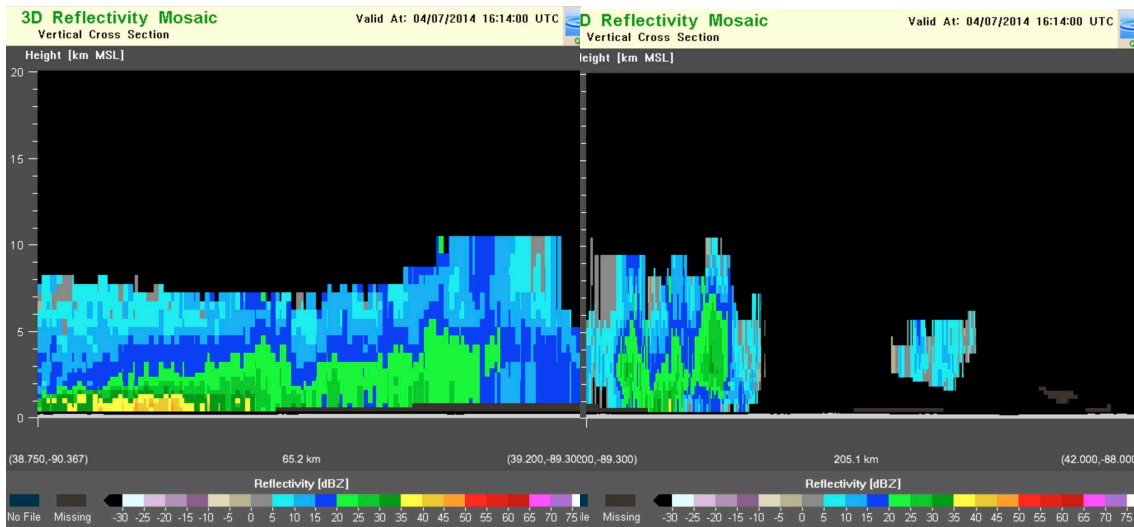


Fig. 2.23. Piecewise, vertical cross section of radar reflectivity from St. Louis (KSTL; left side) to Chicago (KORD; right side) valid at 1614 UTC. The vertical, dashed line in the middle of the chart is the approximate location of the icing event. The black area indicated beneath the echoes in the middle of the chart indicate a lack of data due to the minimum elevation of the radar beams to the southwest of the KLOT (Chicago area) radar.

Pilot Reports (PIREPs) of Icing
1124z - 1241z 04/07/14

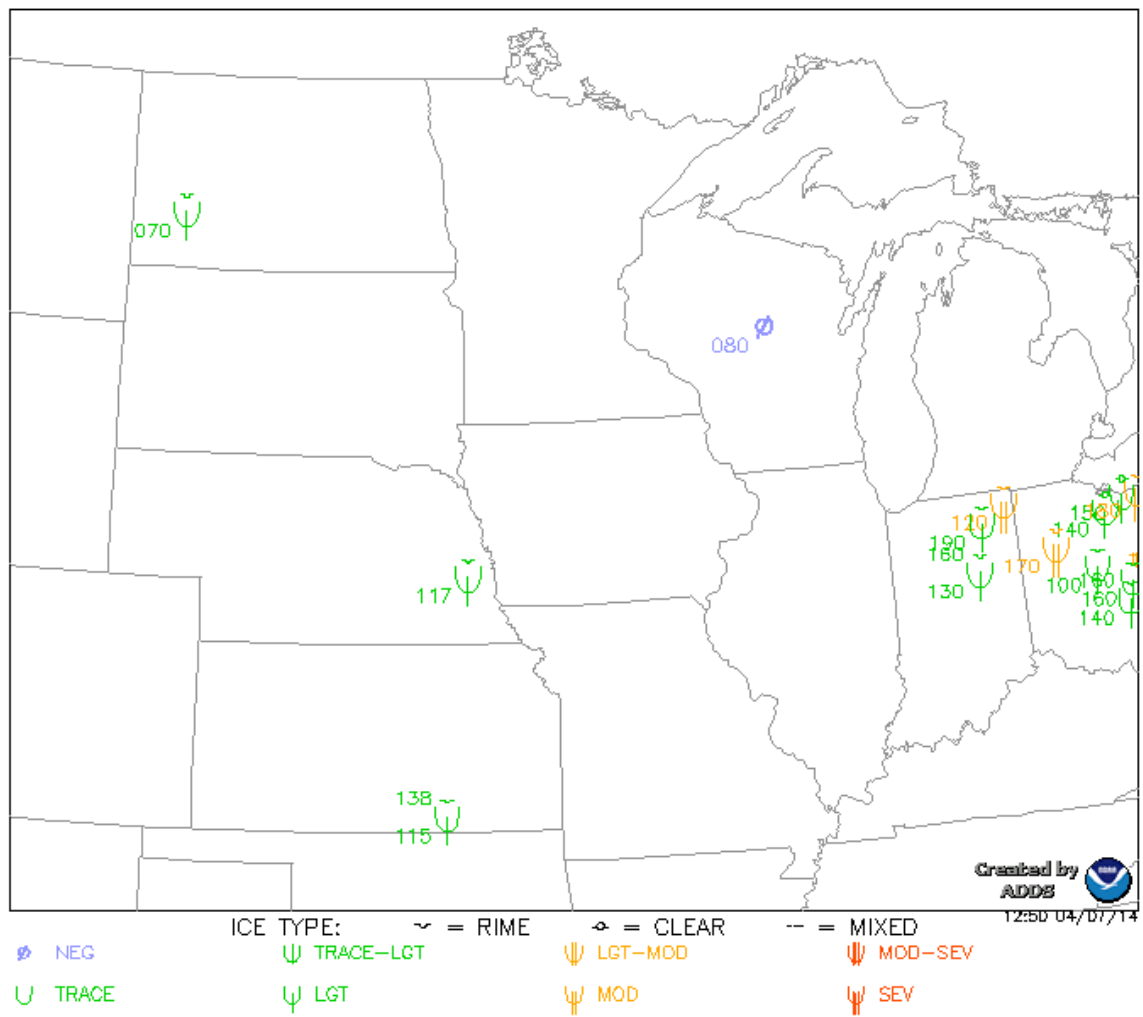


Fig. 2.24. Pilot reports of icing for 1100-1300 UTC.

Pilot Reports (PIREPs) of Icing
1219z - 1340z 04/07/14

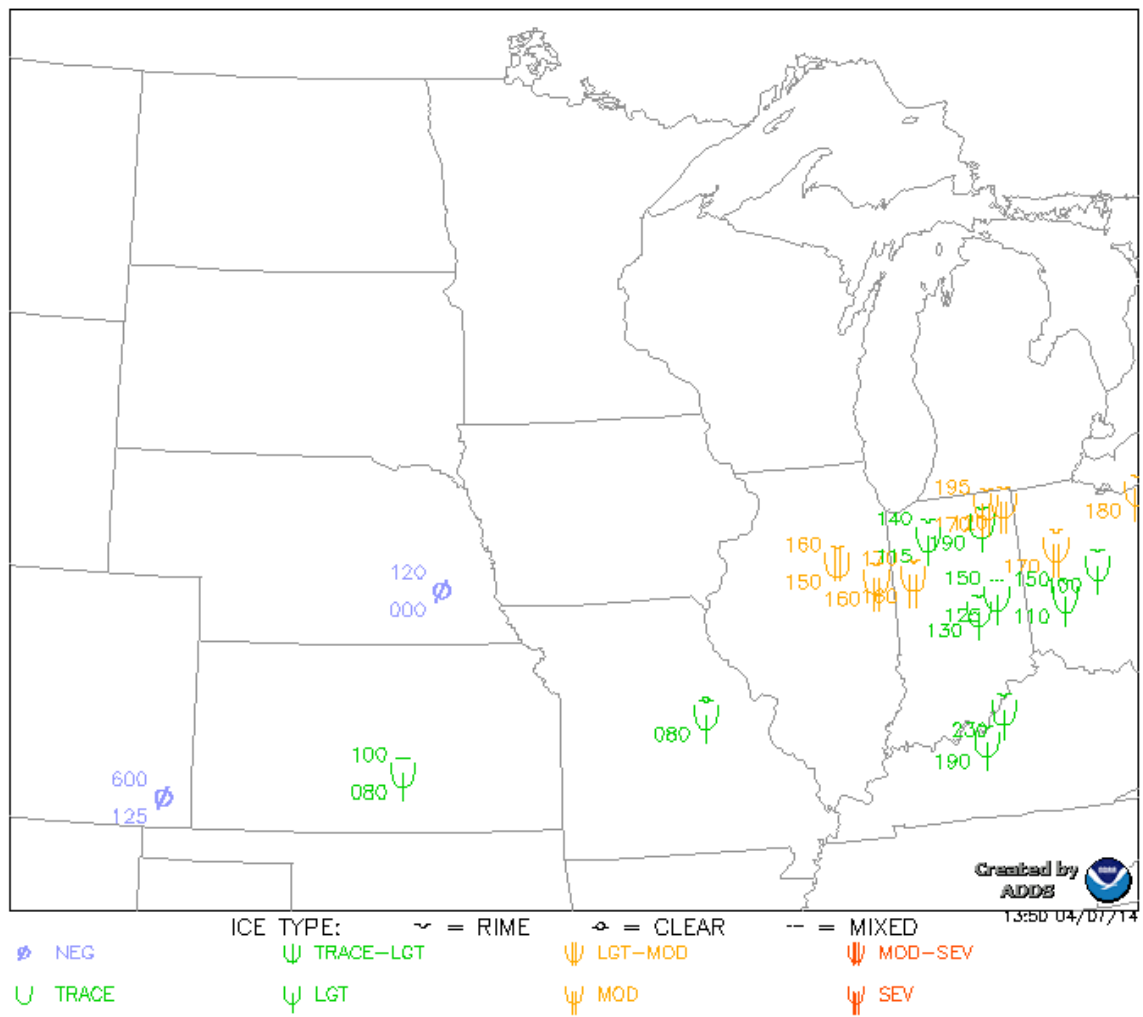


Fig. 2.25. Pilot reports of icing for 1200-1400 UTC.

Pilot Reports (PIREPs) of Icing
1320z - 1440z 04/07/14

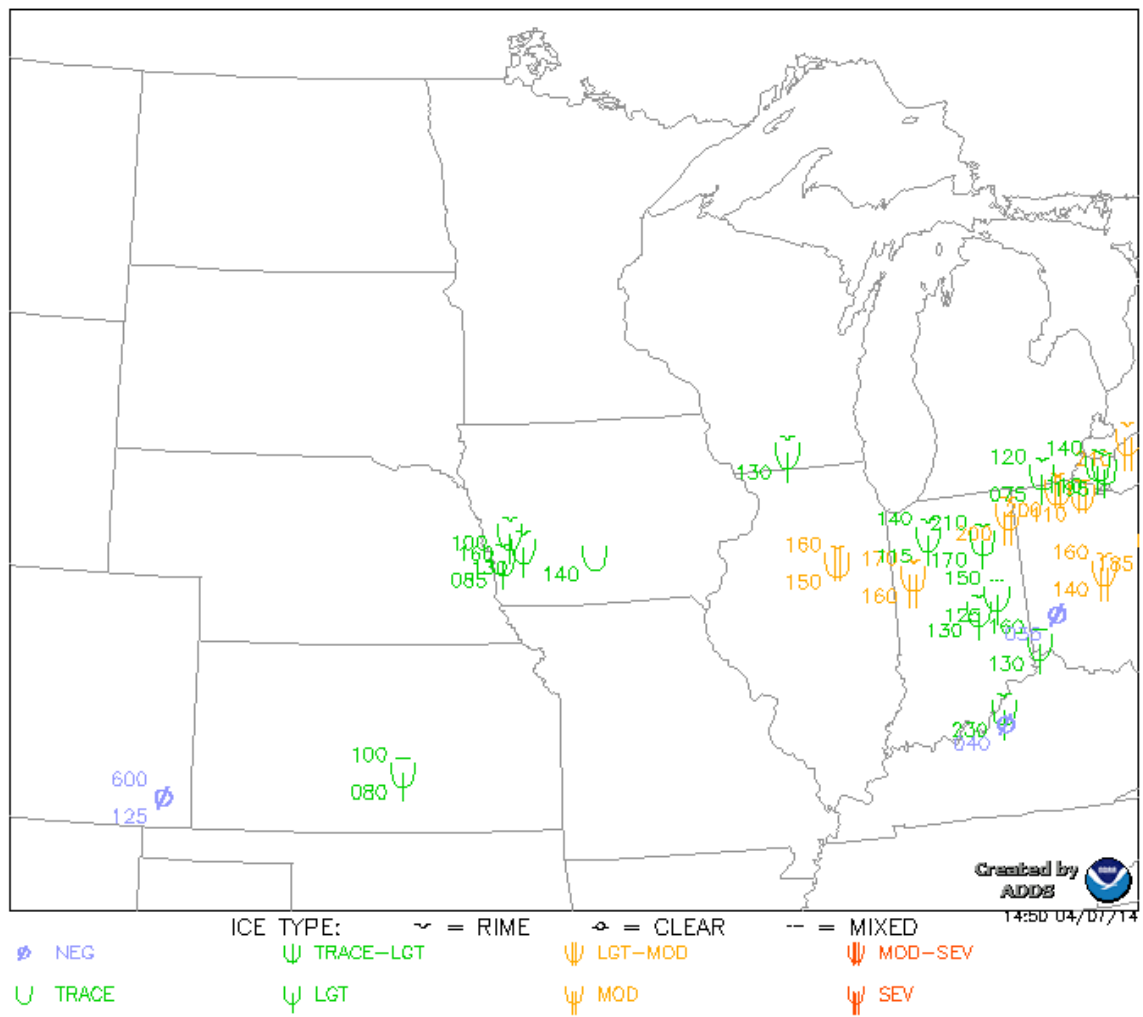


Fig. 2.26. Pilot reports of icing for 1300-1500 UTC.

Pilot Reports (PIREPs) of Icing
1419z – 1527z 04/07/14

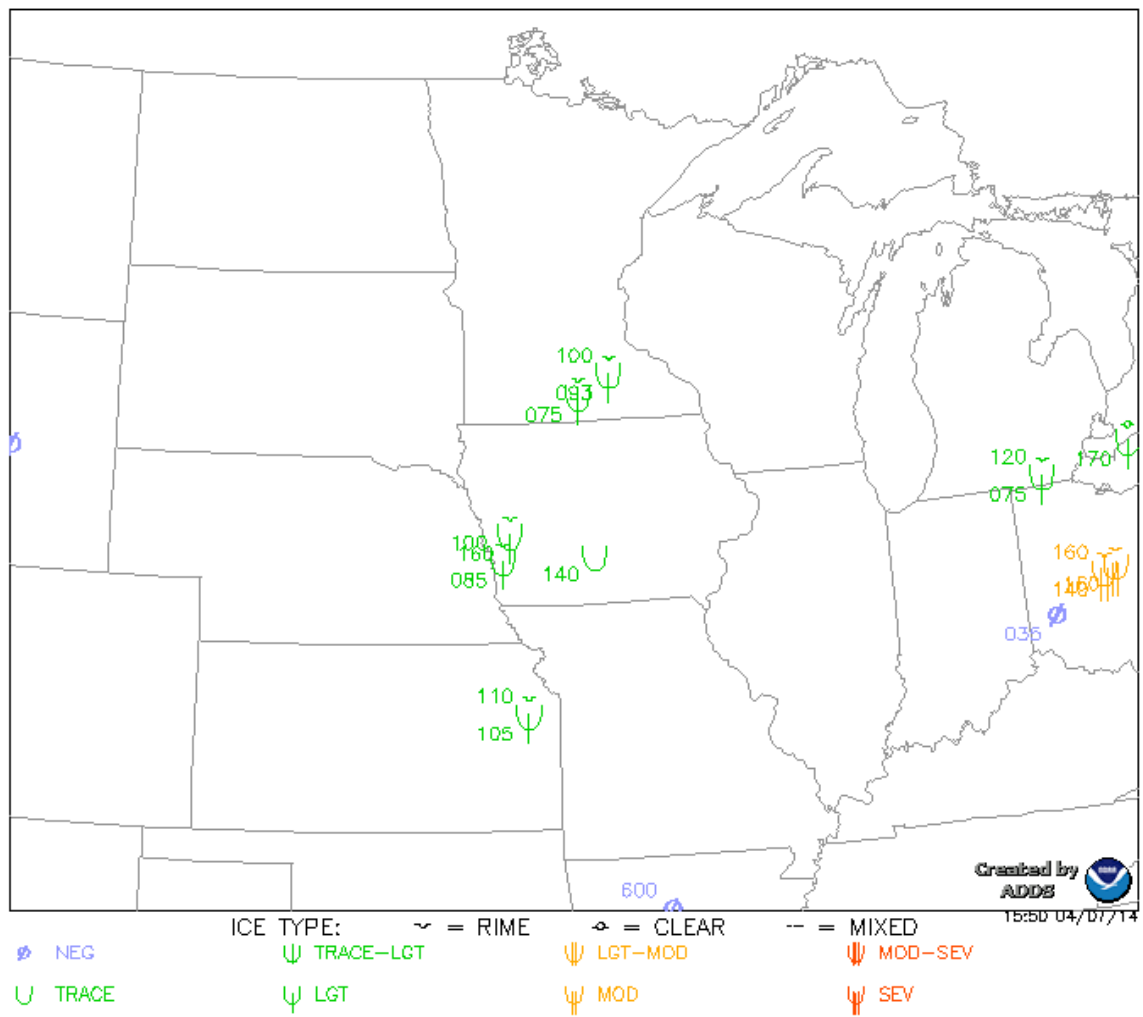


Fig. 2.27. Pilot reports of icing for 1400-1600 UTC.

Pilot Reports (PIREPs) of Icing
1527z - 1636z 04/07/14

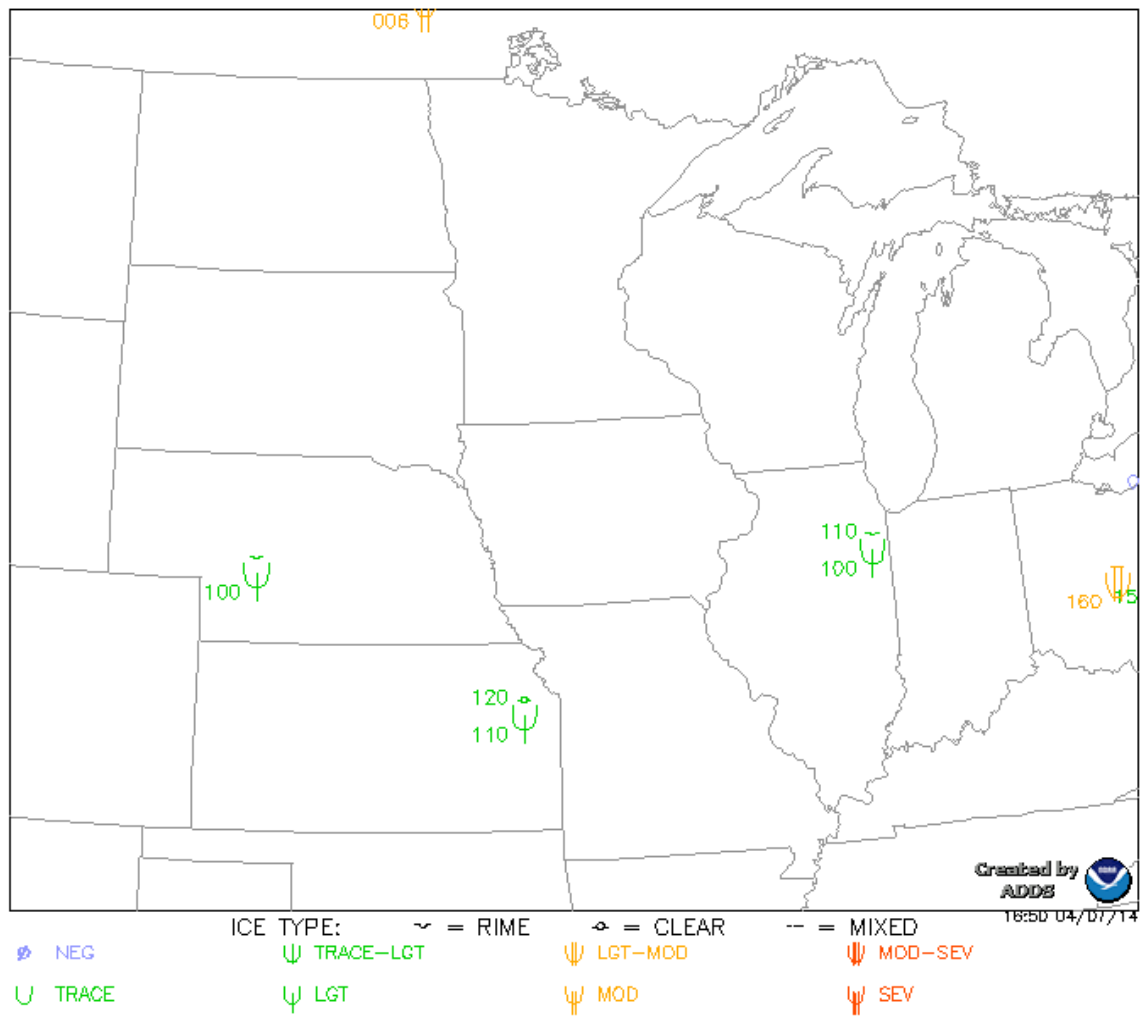


Fig. 2.28. Pilot reports of icing for 1500-1700 UTC.