An Analysis of Atmospheric Behaviors during the 18 May 2020 Heavy Rain Event / Edenville & Stanford Michigan Hydro Dam Failures in Central Lower Michigan.

MET 320WI Project Report

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Spring 2021

1. Event Overview

The month of May in central Michigan is, on average, the wettest month of the year. Specifically, the east-central Michigan town of Midland sees on average 3.10” of rainfall between May 1st and May 31st (Desert Research Institute/NCEI/RCC, 2021). May of 2020 in west-central Michigan, however, would be one for the record books after a nearly 3-day heavy rainfall event. 48hr rainfall storm reports from around the county of Midland, Michigan already exceeded the monthly average after said event between May the 17th - 19th. The Detroit / White Lake, Michigan National Weather Service notes a storm report from 1.5 NNE Midland of a rainfall total of 4.70”. (NWS DTX, 2020). However, other locations in northeast Michigan experienced far more incredible amounts of rainfall over the same 48hr period. The Gaylord National Weather Service office notes the following storm reports for 48hr rainfall: Au Gres - 8.10”, East Tawas – 7.97”, Sterling – 7.20”, West Branch – 5.47”. This historic rainfall resulted in historic flooding in the east-central region of Michigan’s lower peninsula. Said rainfall and flooding eventually led to a catastrophic dam failure in both Edenville and Stanford, Michigan, both on the Tittabawassee River (Figure 1). These dam failures resulted in a historic flash flooding incident along the Tittabawassee River in the towns of Stanford, Edenville and later Midland, Michigan where numerous houses and businesses were either completely destroyed or significantly damaged. Nearly 10,000+ residents were evacuated after flash flood emergencies warned of life-threatening flash flooding, (NWS DTX). According to the Detroit / White Lake, Michigan National Weather Service, the flooding observed between May 17th and 19th in east-central Michigan was on the order of a 200-year event, meaning any given year there is roughly a 0.05% chance of receiving rainfall nearing this capacity in this region, (NWS DTX 2020).

The aforementioned heaviest rainfall fell just north-northeast of the Stanford and Edenville dams (e.g. Au Gres – 8.10”), (Figure 2). This, combined with a gradual increase in elevation moving from the area of the dams to the area of heaviest rainfall made for a perfect situation for rapid flash flooding along the Tittabawassee River.

Synoptically, a stacked surface low and parent shortwave trough (Figure 3) where located across the southwestern Great Lakes region. An efficient blocking pattern was present over much of the CONUS at the time due to a stout ridge over eastern Canada while troughing existed further south around the southern Great lakes and Gulf of Mexico. Additionally, Tropical Storm Arthur can be noted tracking slowly north-northeastward along the Atlantic coast (Figure 4). This blocking pattern allowed for a very slow east-northeastward progression of the parent shortwave trough. Combined with the gradual progression, strong low-mid level southernly flow over the Ohio/Tennessee river valleys up through the lower Great lakes brought significant Gulf moisture into the region. A perfect set up for springtime heavy rainfall in Michigan. Specifically, the scope of this paper will remain focused on the events and analysis of May 18th, the day of the dam failures in Edenville and Stanford, Michigan.

2. Data Analysis

2a. Upper Air

Between the surface and to near 300 mb the shortwave trough over the southwestern Great Lakes was vertically stacked and heavily blocked, as briefly mentioned above. Marginal ridging over the central CONUS at 00 UTC May 18 also extended as far north as the southern Canadian prairies and even southern Hudson Bay, north of the cutoff shortwave trough, located in central-eastern Iowa at 00 UTC May 18 (Figure 4). This cut off shortwave with ridging to the north (while not overly strong) implies a pseudo rex-block-like pattern for the central and eastern CONUS, which will reside over the region for the duration of this event. This greatly mitigated forward progression of the trough until the stronger and larger trough coming onshore from the Pacific finally shunted it eastward. Additionally, T.S. Arthur is noted tracking north-northeastward along the Atlantic coast near North Carolina and Virginia at 00 UTC 18 May. This also aided in the lack of forward progression of the shortwave trough, (Figure 4). Another important note at 500 mb is the multiple waves within the parent 500 mb low. One such wave can be noted along the Mississippi river between AR/MO/TN/KY/IL at 18 UTC on the 500 mb analysis (Figure 4). These pieces of energy acted as additional sources of lift and mechanisms for a deepening of the shortwave trough. A response to this was an enhancement of flow along the trough's southern and eastern flanks, increasing return flow and even symmetric instability at lower levels (discussed in more detail later).

At the 850 mb surface, we find an elongated baroclinic zone extending from Iowa/Illinois/Wisconsin to the Gulf coast of Louisiana & Mississippi at 00z UTC 18 May. This baroclinic zone, strongest across the southwestern Great Lakes, advected rich Gulf moisture northward across the deep south, through the Tennessee & Ohio River Valleys and into the Great Lakes. This is noted by the stout 30-40kt south-southwest return flow / low level jet extending from the Great Lakes to the Gulf of Mexico (Figure 5). An elevated warm frontal zone is analyzed across the northern Lower peninsula of Michigan associated with the parent shortwave. This can be noted by localized backing of the 850 mb flow vectors and moisture flux along the backed flow. This likely was a major contributing factor to the prolonged widespread, steady rainfall across the region (Figure 5). Additionally at 850 mb, considerable warm air advection is observed via the Storm Prediction Center’s 18 UTC RAP mesoanalysis along the elevated warm frontal boundary axis in central and northern Michigan, directly near/along the axis of heaviest rainfall in the region (Figure 6). The aforementioned elevated warm frontal zone is also suggested by an area of deep frontogenesis extending from northern Lake Michigan eastward to southern Ontario (Figure 7). This is likely in response to the deepening pressure gradient between the shortwave trough over the southeastern Great Lakes and 850 mb ridging over Hudson Bay, as well a mid-level energy rotating around the trough, enhancing flow. As previously mentioned, a response to this was an increase in conditional symmetric instability across central and northern Michigan. This can be noted by the Storm Prediction Center’s 800-700 mb EPVg & Frontogenesis RAP Mesoanalysis plot from 06 UTC May 18 (Figure 8). Additional analyses during this period also point to potential Conditional Symmetric Instability (CSI). Analyzed further in later sections of this paper, we find on radiosonde analyses from APX (Gaylord, Michigan), that some vertical wind shear (speed shear) is present, as is a deep, moist & convectively stable, layer with high mean relative humidities. These atmospheric conditions are all characteristics that promote CSI (Moore & Funk). To continue analyzing how the environment supports CSI over the region, we find large-scale ascent is present due to the elevated warm frontal zone at 850 mb, according to Moore & Funk, large scale ascent releases CSI which in response allows slantwise accelerations (unstable parcels slanting upwards in motion) The release of CSI and increased slantwise accelerations result in “slanted, narrow, highly saturated and intense updrafts while downdrafts as generally weak or diffuse” (Moore & Funk) leading to lower reflectivity which will be discussed in later sections of this paper. Equivalent Potential Vorticity values between 800 mb and 700 mb in northern Michigan were near or below zero for much of the period, this also aided in the development of CSI. How CSI aided in the development and persistence of heavy rainfall will be discussed in later sections of this paper.

2b. Sounding Analysis

Soundings from APX (Gaylord, Michigan) and DTX (Detroit / White Lake, Michigan) are used to approximate the vertical characteristics of the atmosphere in regions of northern and central Michigan during this event. Here we will focus on 00 UTC 18 May, 12 UTC 18 May and 00z UTC 19 May soundings from said locations and examine the properties that may have aided in the production and persistence of heavy rain across the region.

2b – APX

Gaylord, Michigan, located approximately 90-95 miles north-northwest of the Stanford and Edvenville Dams shows a very indicative story that supports heavy rainfall. The most notable characteristic from APX (and DTX as we will examine later) was the northward advancing mid-level warm nose / warm air advection. This can be noted between roughly 600-500 mb at 00 UTC 18 May, (Figure 9). Throughout the period, (at 12 UTC 18 May and 00 UTC 19 May, Figures 10 & 11) this warm layer increases in temperature and moisture. Low and mid-level flow continues to back from southwest to southeast – near due east between 00 UTC 18 May and 00 UTC 19 May, in response to a deepening shortwave trough and enhancing baroclinic flow at the surface, 850 mb and 500 mb. Additionally at APX, the column is nearly completely saturated from the surface (at 12 UTC 18 May) up through about 450 mb, other than a shallow layer of slightly drier air between 850 mb and 650 mb. This can likely be attributed to the nose of a mid-level dry tongue advecting northeastward into the state as it wrapped around the shortwave trough, this will be examined in further detail in later sections of this paper. Throughout the period this 'drier' layer exists, however it's movement is interesting. At 00 UTC 18 May this dry layer can be found between 900 mb – 750 mb with saturation above and below this layer (Figure 9). By 12 UTC 18 May and later 00 UTC 19 May this dry layer ascends through the profile. The 12 UTC 18 May sounding from APX shows the dry layer has climbed to between 850 mb and 650 mb (Figure 10) and later at 00 UTC 19 May the layer is then between 800 mb and 700 mb and shrunken in both vertical depth and dewpoint depression (Figure 11). Upon aforementioned analyses, this may likely be caused by the mid-level nose of dry layer overriding the warm frontal boundary (gradual vertical lifting with northward advection), hence the gradual ascent of the dry layer.

Further analysis of these APX observed soundings also reveal the extent of CSI (Conditional Symmetric Instability) within the column which is present in all three APX radiosonde soundings. While CSI is not directly visible on a sounding, it can be inferred by other aspects of a sounding (plus additional upper air analyses) (Moore & Funk). Noted on the 12 UTC 18 May sounding from APX (Figure 10), we find the following characteristics that are related to the potential for CSI: the column is nearly or completely saturated between roughly the surface to around 400 mb, flow is unidirectional above 700 mb with some vertical wind shear present through the profile. Above ~ 625 mb the temperature slopes roughly parallel to the moist adiabat, and little to no convective instability through the profile & period. According to Moore & Funk, all of these characteristics can be implied as CSI being present at APX generally above the 650 mb surface.

2b – DTX

Detroit, Michigan is located to the southeast of the Edenville and Stanford Dams by roughly 110-120 miles. We will find a similar story for heavy rain on DTX soundings for 00 UTC 18 May, 12 UTC 18 May & 00 UTC 19 May. The aforementioned dry nose as previously noted on APX soundings is also present on early DTX soundings (Figure 12). Said dry nose is located between 900 mb and 700 mb and is quite dry, again this is likely attributed to the mid-level dry tongue wrapping around the base of the shortwave trough. With time, we notice the dry nose shrinking considerably. At 00 UTC 18 May the dewpoint depression at 750 mb is about 17 degrees Celsius while by 12 UTC 18 May, the same dewpoint depression at 750 mb is down to 5 degrees Celsius (Figure 13). We can assume based on previous analyses that the increase in moisture in that layer can be associated with backing mid-level winds, i.e. increasing Gulf moisture advection. Additionally, as noted on 850 mb analyses and water vapor satellite (discussed in more detail later), the dry tongue can be seen gradually propagating northward away from DTX. Warm air advection also increases with time at DTX. A stout low-level advection inversion strengthens as positive temperature flux increases during the period. However, while the inversion’s max temperature does increase (from ~ 5 degrees Celsius at 00 UTC 18 May to ~ 12 degrees Celsius at 00 UTC 19 May) (Figures 12 & 14), it does become shallower with time.

When examining the possibility for CSI at DTX, many of the same components / characteristics are present, (these characteristics were discussed in detail in the APX soundings section of this paper and should be referred to if necessary). One important note, however, about the DTX region (southern Lower Michigan), is we lose the effect of the warm frontal boundary (aloft) and overall large scale ascent is less (noted on 850 mb & 500 mb analyses), therefore this is interpreted that CSI is not as evident further across the south.

2c. Moisture Examination

The overall pattern for this event is considered to be on the better ways to pull Gulf moisture into the Great Lakes. Given the aforementioned pseudo-rex-block, combined with the elongated baroclinic zone extending to the Gulf of Mexico (GOM) made for an excellent conveyor belt of moisture.

At 850 mb, excellent return flow from the GOM is noted as the 850mb baroclinic zone gradually slides eastward and the shortwave energy as the base of the parent trough pivots east-northeastward (Figure 15). This influx of rich gulf moisture resulted in well above average precipitable water values (PWAT) across the entirety of the State of Michigan. 12 UTC – 18 UTC Storm Prediction Center RAP Mesoanalysis data suggests PWAT values anywhere between 1.10” – 1.4” across east-central Michigan, over the area of heaviest rainfall (Figure 16). APX soundings recorded PWAT values of 1.19” (30.34 mm as marked on the sounding). Based on the Storm Prediction Center’s Sounding Climatology for precipitable water on 12 UTC APX soundings, on average, PWAT values for 18 May are 0.58”, making the observed PWATs from 18 May 2020 well above the average (Figure 17).

Such strong return flow from the GOM between 17 May and 18 May allowed excessive moisture to pool along the warm frontal boundary in northern & central Michigan, hence the high PWAT values over the region. Additionally, the previously discussed strengthening pressure gradient over Michigan's Upper Peninsula, Lake Superior and southern Ontario, Canada also allowed for moisture to pool across the region. When combining these aspects for strong moisture advection, moisture pooling and they dynamics of the shortwave that lead to large scale lift and CSI, it is no surprise that heavy rainfall occurred across the region.

2d. Satellite Analysis

2d – Visible

Visible satellite imagery on 18 May 2020 displayed a beautiful low pressure system tracking across the southern Great Lakes. Classic Mid-Latitude Cyclone structure is noted. Additionally, disorganized Tropical Storm Arthur can be found off the coast of North Carolina / Virginia (Figure 20). Some important analyses from visible satellite imagery on 18 May 2020 are to follow. Strong return flow can be suggested (with previous analyses) by a vast stream of cumulus fields extending from the GOM up through the Great Lakes. Additionally, taller cloud structures are apparent through Kentucky, Indiana, and Ohio up into Michigan (based on more ice crystal-like appearances, suggesting taller, colder clouds). These are heavier rain showers, and even some thunderstorms in Indiana and Ohio. A second vast agitated cumulus field is noted on the southwest and south flanks of the low pressure system where the dry tongue (analyzed in previous sections of this paper) is likely providing marginal instability over the region. There is a clearing in the dry slot running nearly along the Mississippi River at 18 UTC 18 May up into far southwest Michigan. Across the north, the elevated warm frontal zone is quite easy to spot, given the mid-level stratus deck over Wisconsin and eastward over Lake Michigan, northern and central Michigan and into southern Ontario. These stratus clouds are in response to the upward slope of the elevated warm front. A closer look reveals potentially taller cumulus structure embedded within the stratus deck over central Michigan, (roughly along to just south of the Saginaw Bay region). This could be interpreted so some marginal elevated instability on the nose of the dry air intrusion. (confirmed by 18 UTC 18 May MUCAPE mesoanalysis).

2d – Infrared

GOES-16 Infrared Imagery notes much of the same story. However, we still see several important notes regarding cloud structures over the region. Infrared imagery relates to cloud temperature, so knowing this, we can interpret cloud properties. To the north, persistent high level cloud cover is noted from northern Indiana, up through Michigan and wrapping around the northern flank of the low pressure system into northern Wisconsin. This persistent ‘higher’ cloud deck is again evident of the elevated warm front boundary across northern lower Michigan, which can be interpreted as rather significant isentropic upglide, or large scale ascent over the region at 15 UTC 18 May (Figure 28). We can again note healthy moisture return from the GOM by analyzing cloud mass from the GOM to the Great Lakes. Several areas of convection can be found over the GOM, off the coast of North Carolina (due to T.S. Arthur) and up through Alabama and Indiana given isolated high cloud structures and anvil like formations.

2e. Radar Analysis

Throughout the period of heavy rainfall across central Michigan, radar returns from APX and DTX continued to show persistent rainfall, both light and heavy at times, near and north of the Edenville and Stanford Dams. On 18 May 2020, we can note high returns on APX’s WSR-88D 0.5 degree tilt base reflectivity scan at 0044 UTC, centered over east-central lower

Michigan (Figure 31). The highest of these returns can be found just west of U.S. interstate 75, from near Saginaw to near Gladwin, Michigan. This area includes Midland, Stanford and Edenville, Michigan where the most impact from the dam failures occurred. Some notes regarding the rainfall characteristics at 0044 UTC 18 May 2020, there is little evidence of any robust updrafts related to convection here. The most likely process driving this rainfall is related to isentropic upglide and CSI (discussed in detail in previous sections), as is likely the case for much of the event. Later into the period, shortly before 1900 UTC on 18 May 2020, while widespread heavy rainfall remains the case, there is a more cellular appearance to the rainfall that is moving through central and east central lower Michigan (Figure 32). This can be further confirmed by analysis of 0.5-degree tilt KDP (Specific Differential Phase) from APX during the same time (Figure 33). At 1459 UTC 18 May 2020 There are many very small areas of increased returns of KDP. Because KDP is the measurement of the change in ΦDP (Differential Phase Shift), this is indicative of small areas of increased rain drop size and/or rain drop concentration, which can be further interpreted as heavier rainfall over these areas. This is especially true over Reed City and Big Rapids, Michigan. This area of rainfall would eventually track east northeastward over the Edenville and Stanford dam areas (not shown here). In this case, ZDR (Differential Reflectivity) is not a major assistant to the analysis, however we can note a number of areas with ZDR values closer to 2-4dB, which is another indicator of larger rain drops (when used with additional analyses that support the same conclusion).

3. Discussion and Conclusions

Overall, we find that this event had a number of significant factors that contributed to the production of heavy rain. These factors and processes eventually lead to the failures of the

Edenville and Stanford Dams, in turn leading to the damage or destruction of numerous property and homes. The most notable feature of this event was the pseudo-rex-block that caused the slow progression of this system. Without said blocking, none of the other aforementioned factors would have been enough to produce as much rain, on their own. The slow progression of this low pressure system allowed for copious amounts of rich Gulf moisture to advect northward in to the Great Lakes. This northward stream of return moisture with the large area of isentropic upglide due to the elevated warm front draped across central and northern Michigan, would be a perfect scenario for a Great Lakes heavy rainfall event. Other factors look to have also played a role in locally heavier rainfall in central and east-central lower Michigan. Such factors include CSI which can be evaluated by interpretations of Storm Prediction Center Mesoanalysis data as well as observed soundings from APX (Gaylord, Michigan). Another localized factor was likely the development of marginal elevated MUCAPE (due to the dry air intrusion advecting northward into the area) during the afternoon. This is likely the reasoning behind the higher cloud tops on visible satellite imagery and the cellular appearance to APX's reflectivity around the same time, in the area. The major contributing factors to this event were as stated above, the blocking pattern and healthy Gulf moisture stream advecting into an area with isentropic upglide, however the two more localized contributions come from the CSI and MUCAPE across the localized area of central and northern lower Michigan. In a study of the applications of CSI in operational forecast settings, Wiesmuller and Zubrick study a heavy rainfall event that occurred 26 February 1993 in southern Maryland and northern Virginia. The production of heavy rainfall over the area was also related to frontogenic forcing/isentropic ascent and the presence of CSI (Wiesmuller and Zubrick 1998). Wiesmuller and Zubrick suggest using EVP and frontogenesis analyses, combined with convective instability analyses suggested that CSI was indeed present over the small area that received the heaviest rainfall. As stated in their study, localized banding of heavier rainfall persisted over the area for several hours. These locally heavier and ‘banded’ areas of the larger strato-form precipitation field were enhanced by CSI (Wiesmuller and Zubrick). On 18 May 2020, a very similar set up, both synoptically and locally was in place. We find that negative EVP and frontogenesis forcing are present, additionally no convective instability is present. Therefore when combining the set up, we find a very similar pattern. Radar returns on 18 May 2020 also showed similarities with localized areas of heavier rainfall and banding rainfall. There is no doubt that there were many factors that contributed to the heavy rainfall in Michigan’s lower peninsula on 18 May 2020, but a few stand out as excellent heavy rain producers, especially when paired together.

Figures

Figure 1: A view of the Edenville Dam Failure shortly after the initial breach occurred on May 19th between 21 UTC and 01 UTC. Image Courtesy Midland Daily News.

Figure 2: Major river map of Michigan with the region of highest 48hr rainfall accumulations highlighted. Locations of the Stanford and Edenville Dams are also plotted. Background map courtesy gisgeography.com.

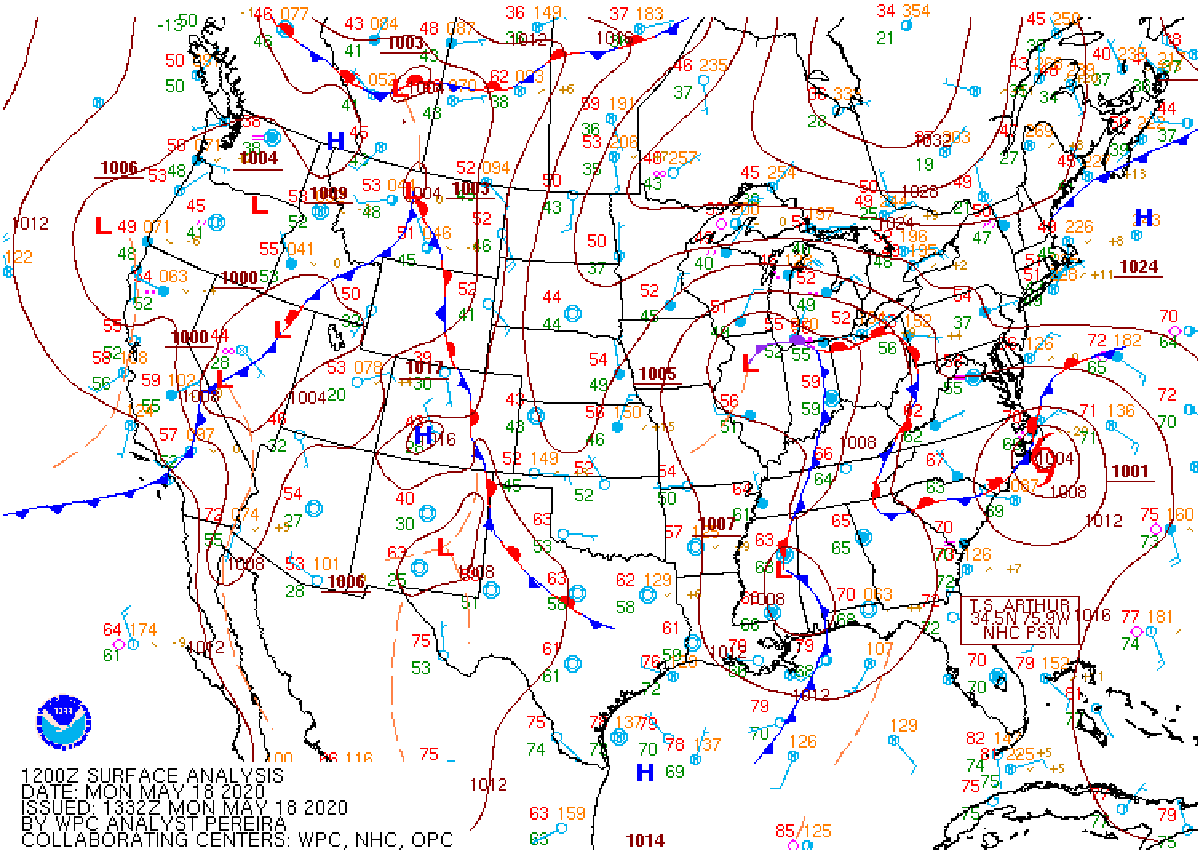

Figure 3: 18 May 2020 12 UTC WPC Surface Analysis. 12 UTC surface observations and 12z frontal analysis are plotted. Courtesy WPC / NOAA.

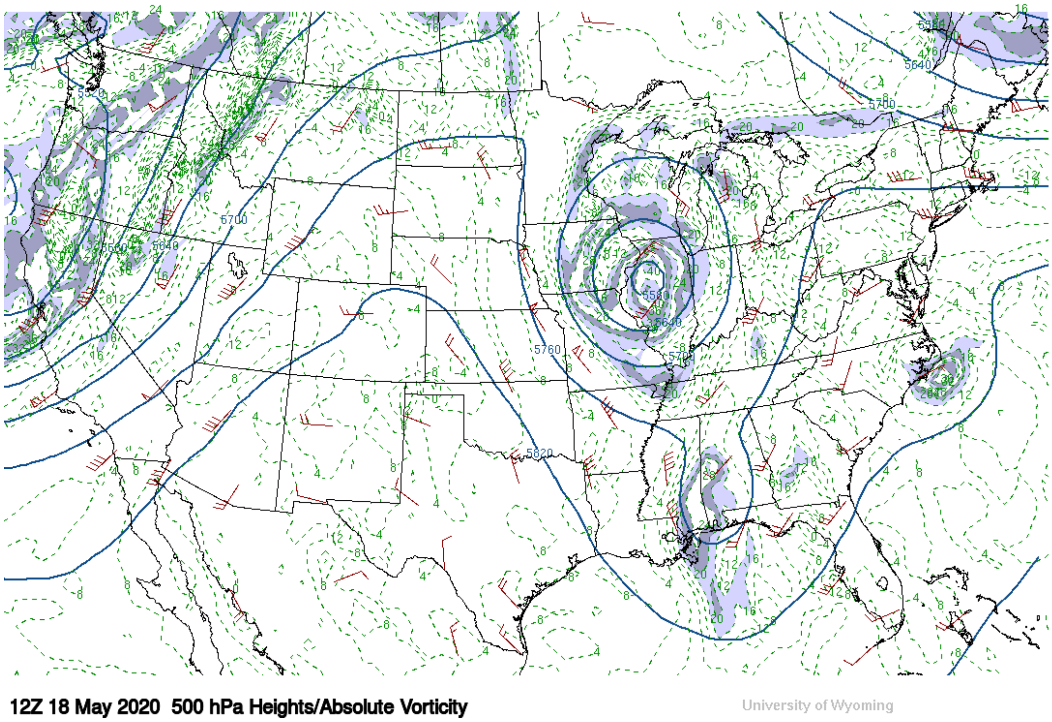

Figure 4: 18 May 2020 00 UTC 500mb Radiosonde Observations and RAP 500mb Analysis. Absolute Vorticity is plotted as color-filled contours. Courtesy University of Wyoming.

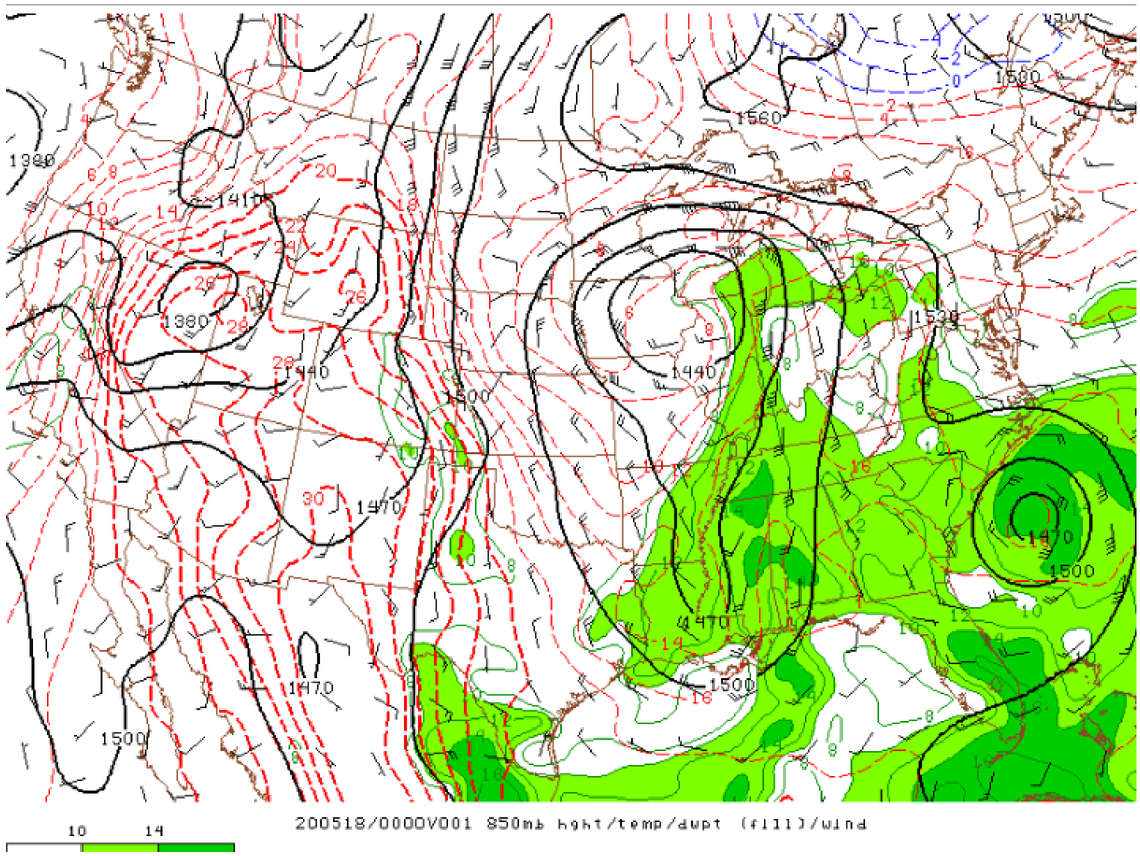

Figure 5: 18 May 2020 18 UTC RAP Mesoanalysis 850mb Height (dm), Temperature (degrees F), Dewpoint (degrees F) and Wind (kts). Courtesy SPC / NOAA.

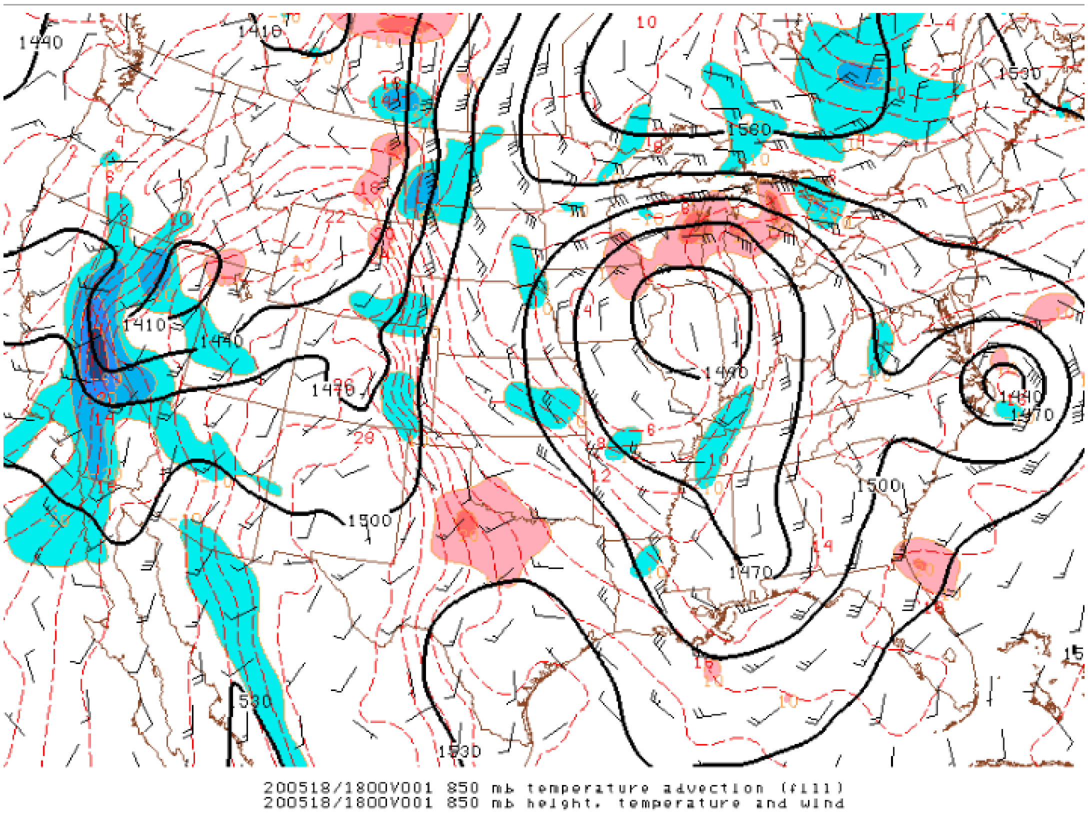

Figure 6: 18 May 2020 18 UTC RAP Mesoanalysis 850mb Height (dm), Temperature (degrees F), Wind (kts) & Temperature Advection as color filled contours. Courtesy SPC / NOAA.

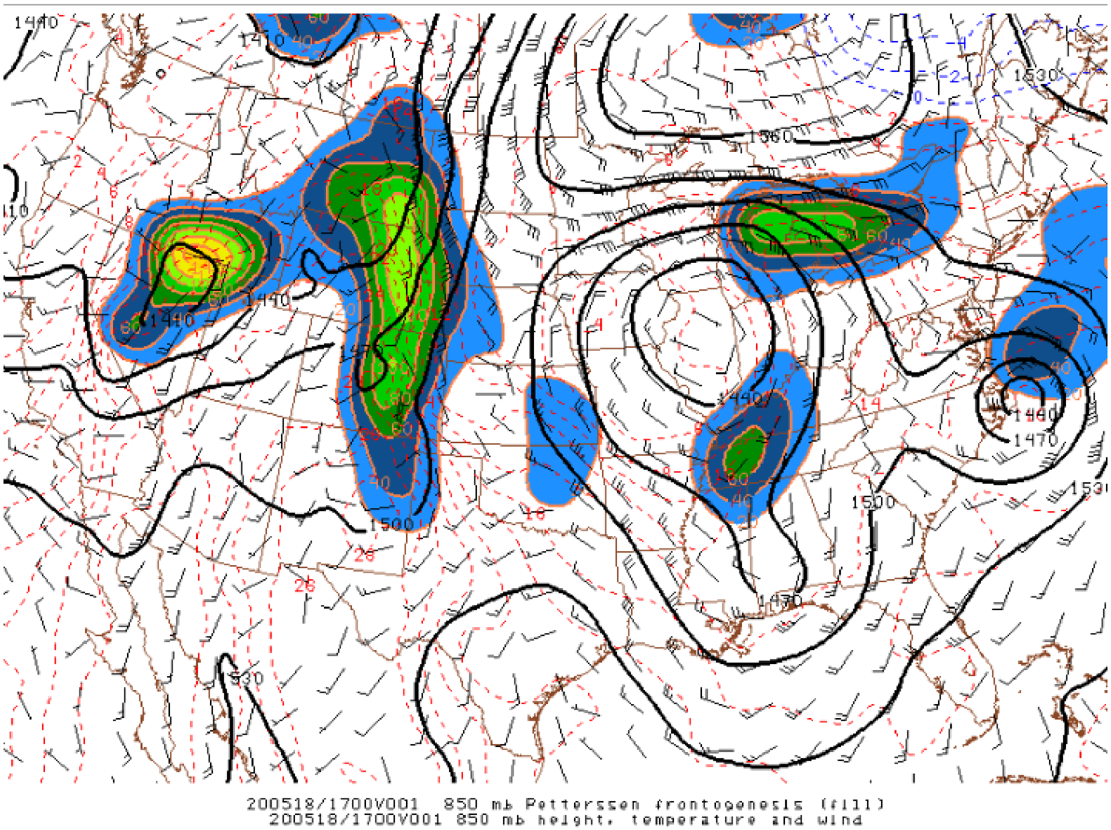

Figure 7: 18 May 2020 18 UTC RAP Mesoanalysis 850mb Height (dm), Temperature (degrees F), Wind (kts) & Petterssen Frontogenesis Analysis as color filled contours. Courtesy SPC / NOAA.

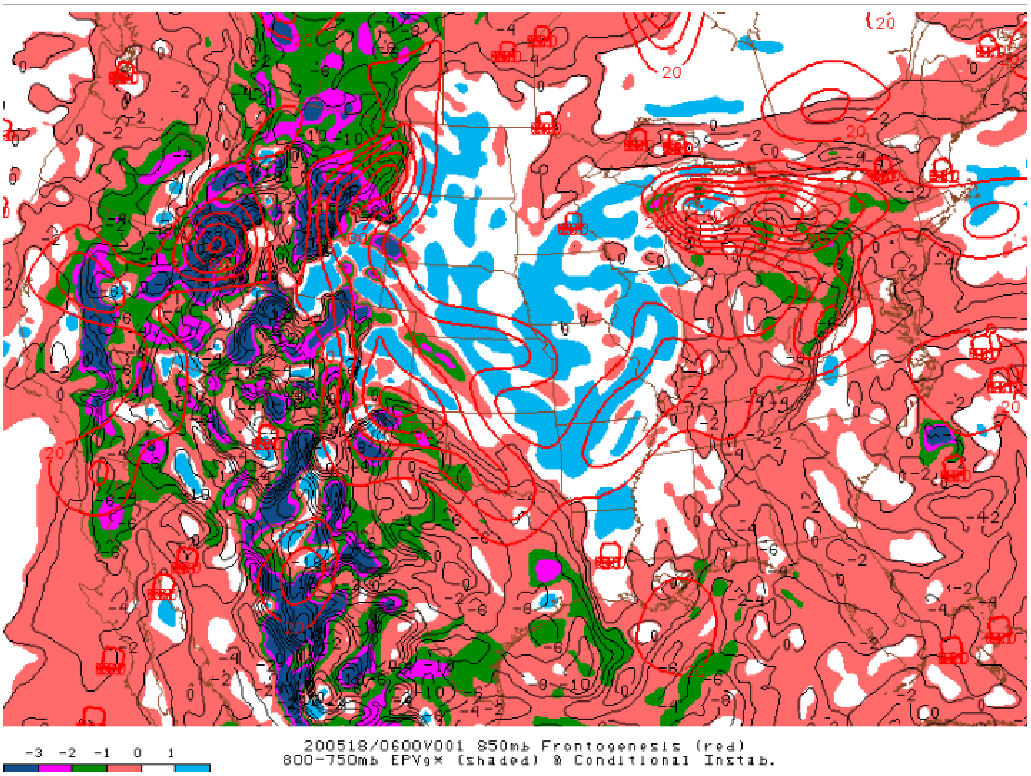

Figure 8: 18 May 2020 06 UTC RAP Mesoanalysis 850mb Frontogenesis (red contours), 800-700mb Equivalent Potential Vorticity (EPVg) (as color-filled contours) and conditional instability. Courtesy SPC / NOAA.

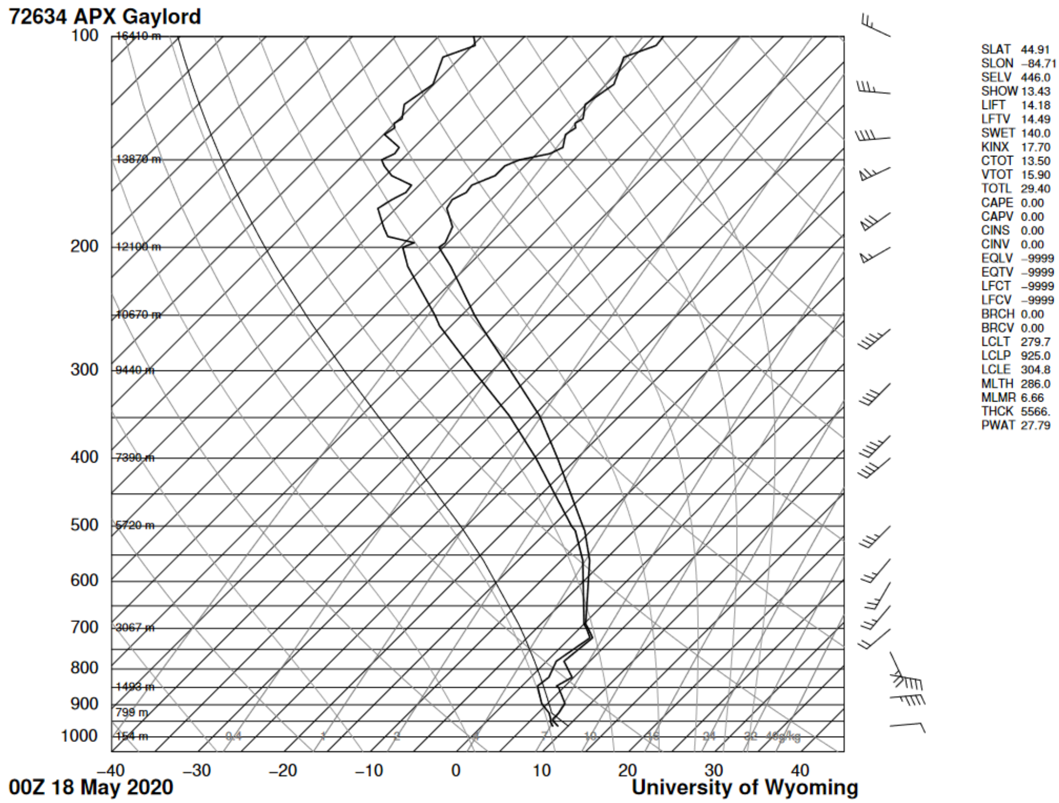

Figure 9: 18 May 2020 18 UTC Observed Radiosonde Sounding Analysis for APX (Gaylord Michigan) Right-hand line is Temperature, left-hand line is Dewpoint. Winds are noted as wind barbs to the right of the Skew-T. Courtesy University of Wyoming.

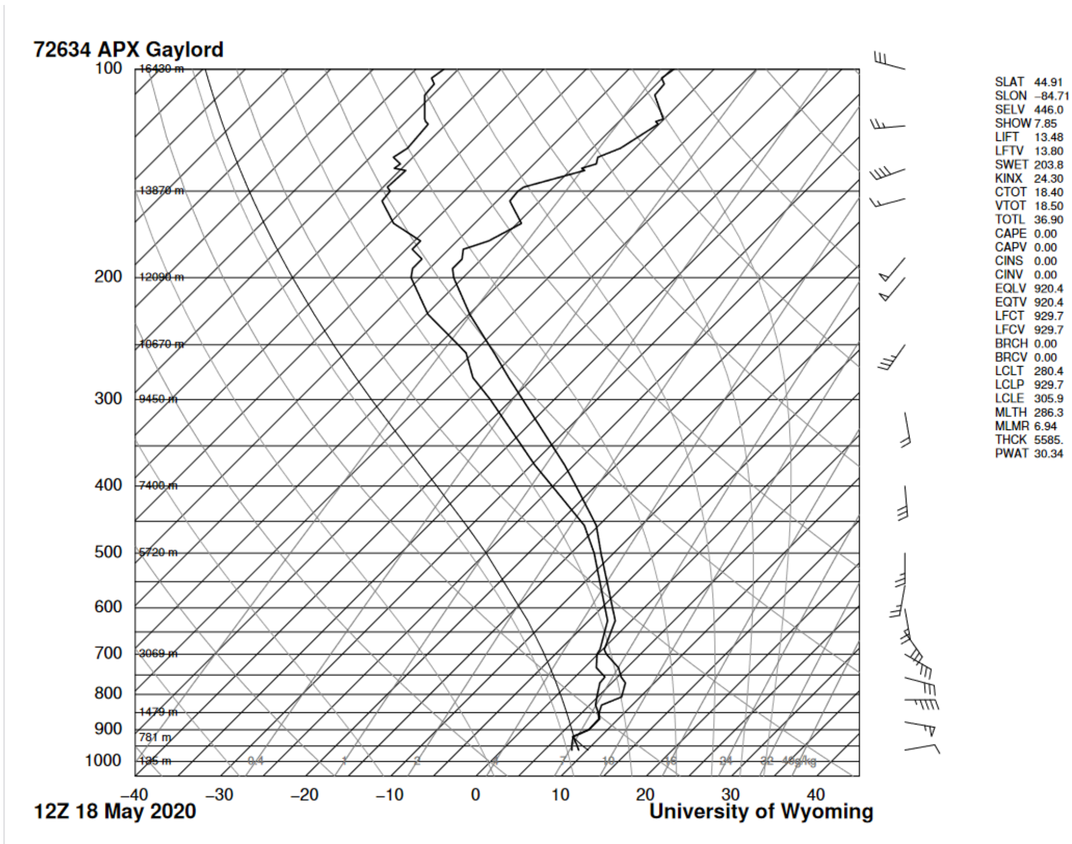

Figure 10: 18 May 2020 12 UTC Observed Radiosonde Sounding Analysis for APX (Gaylord Michigan) Right-hand line is Temperature, left-hand line is Dewpoint. Winds are noted as wind barbs to the right of the Skew-T. Courtesy University of Wyoming.

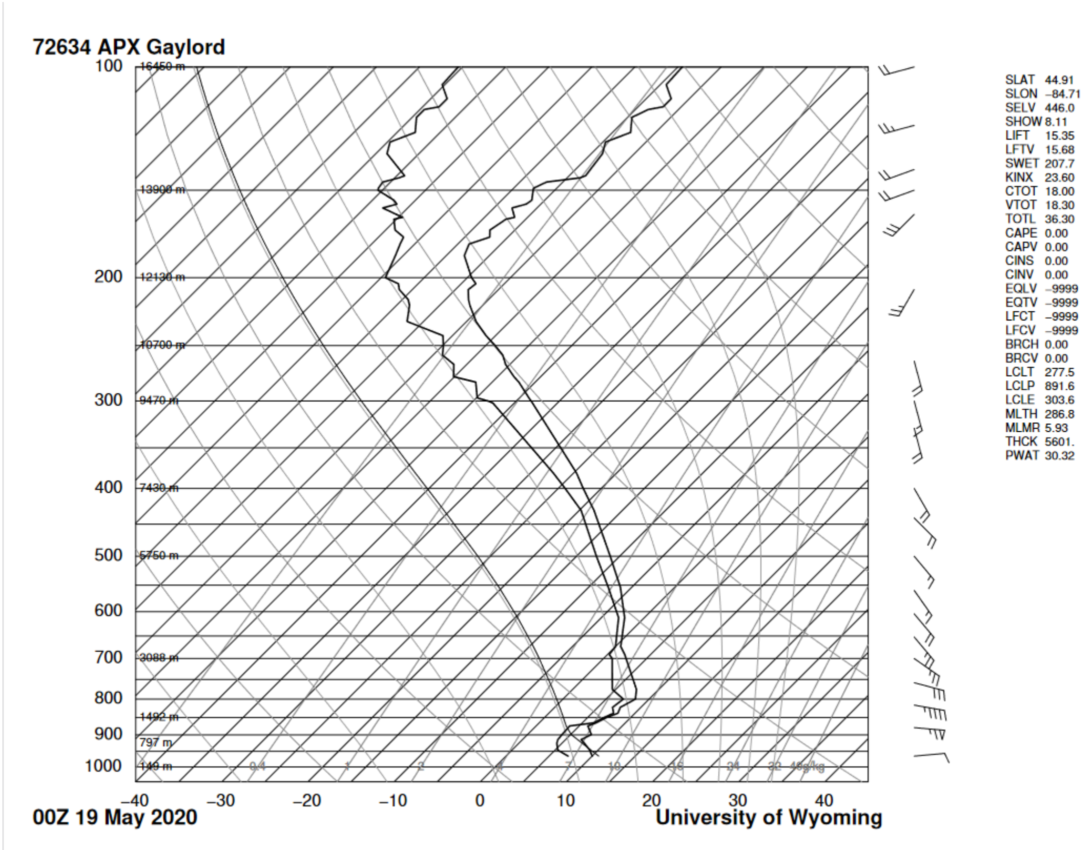

Figure 11: 19 May 2020 00 UTC Observed Radiosonde Sounding Analysis for APX (Gaylord Michigan) Right-hand line is Temperature, left-hand line is Dewpoint. Winds are noted as wind barbs to the right of the Skew-T. Courtesy University of Wyoming.

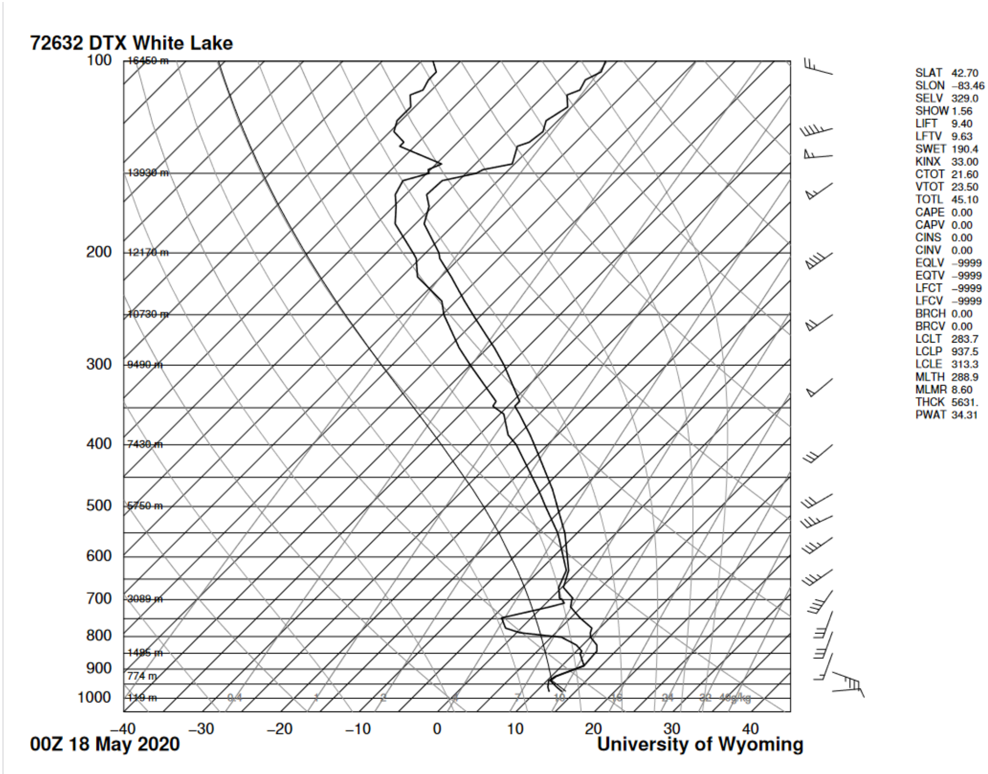

Figure 12: 18 May 2020 00 UTC Observed Radiosonde Sounding Analysis for DTX (Detroit, Michigan) Right-hand line is Temperature, left-hand line is Dewpoint. Winds are noted as wind barbs to the right of the Skew-T. Courtesy University of Wyoming.

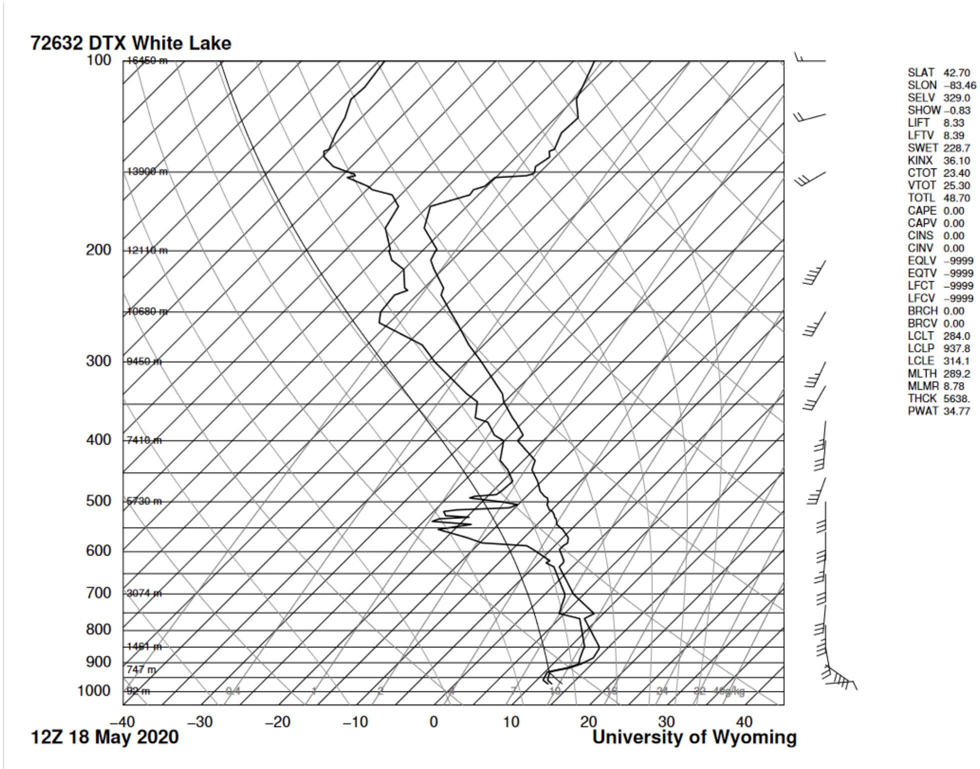

Figure 13: 18 May 2020 12 UTC Observed Radiosonde Sounding Analysis for DTX (Detroit, Michigan) Right-hand line is Temperature, left-hand line is Dewpoint. Winds are noted as wind barbs to the right of the Skew-T. Courtesy University of Wyoming.

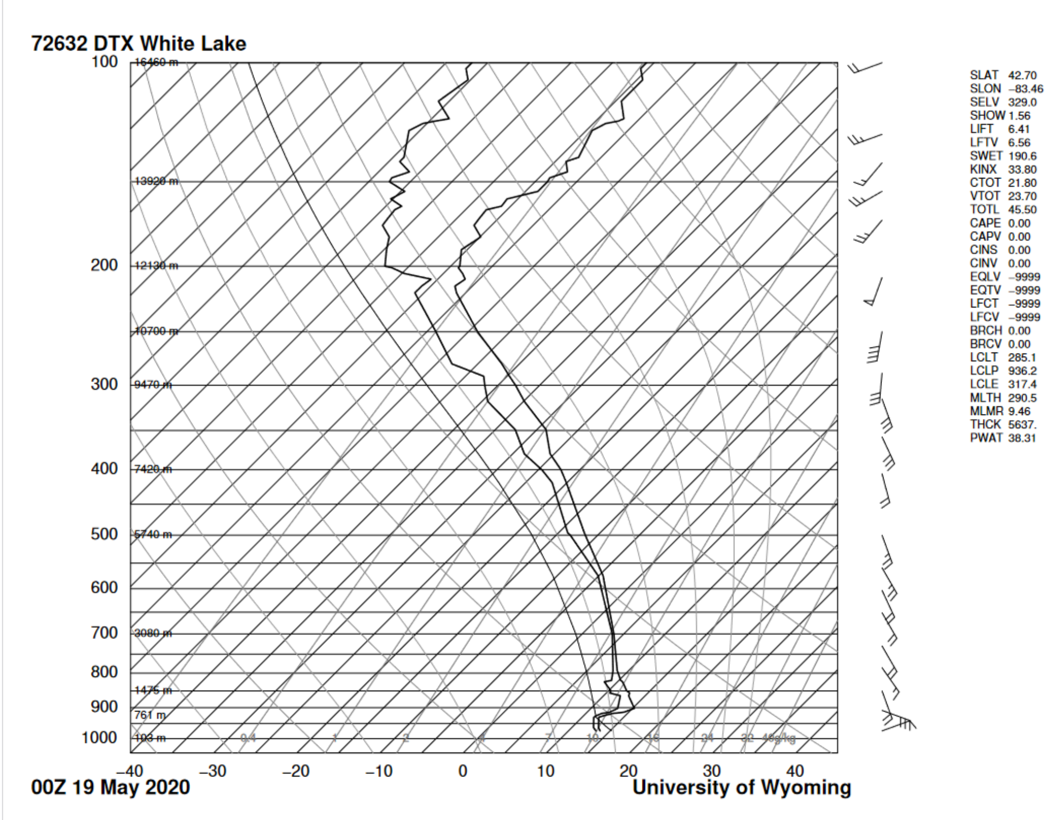

Figure 14: 19 May 2020 19 UTC Observed Radiosonde Sounding Analysis for DTX (Detroit, Michigan) Right-hand line is Temperature, left-hand line is Dewpoint. Winds are noted as wind barbs to the right of the Skew-T. Courtesy University of Wyoming.

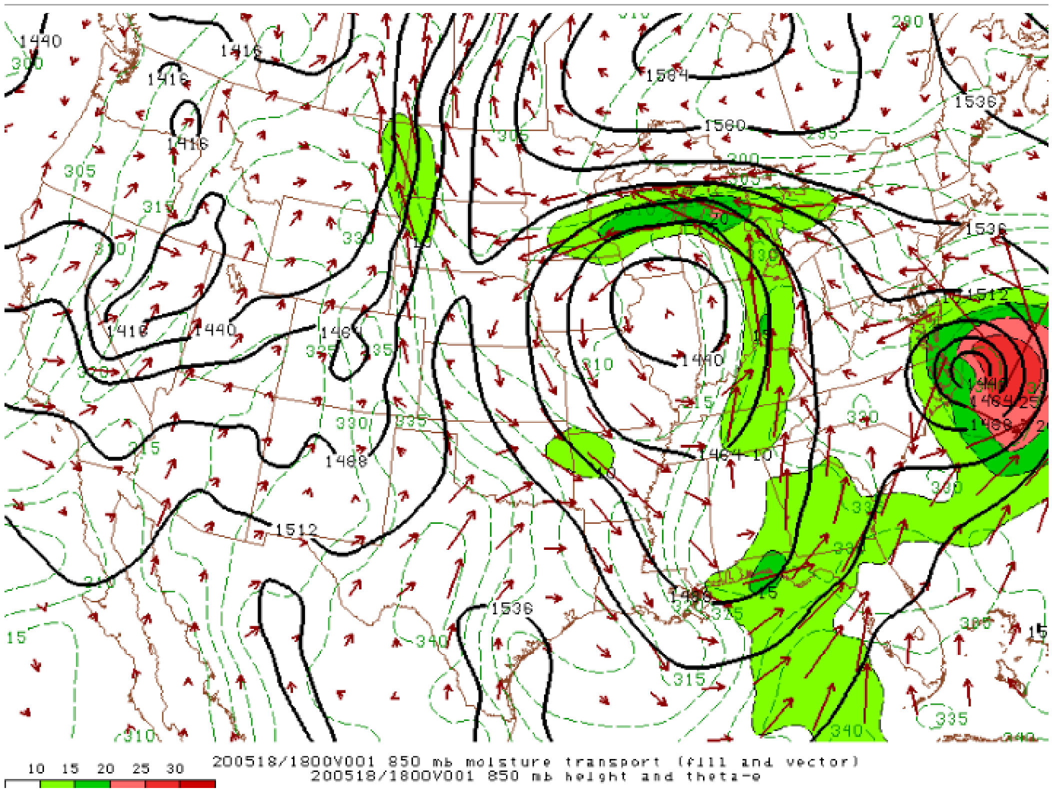

Figure 15: 18 May 2020 18 UTC RAP Mesoanalysis 850mb moisture transport (color-filled contours and vectors) with 850mb geopotential heights (solid contours) and theta-e (dashed contours). Courtesy SPC / NOAA.

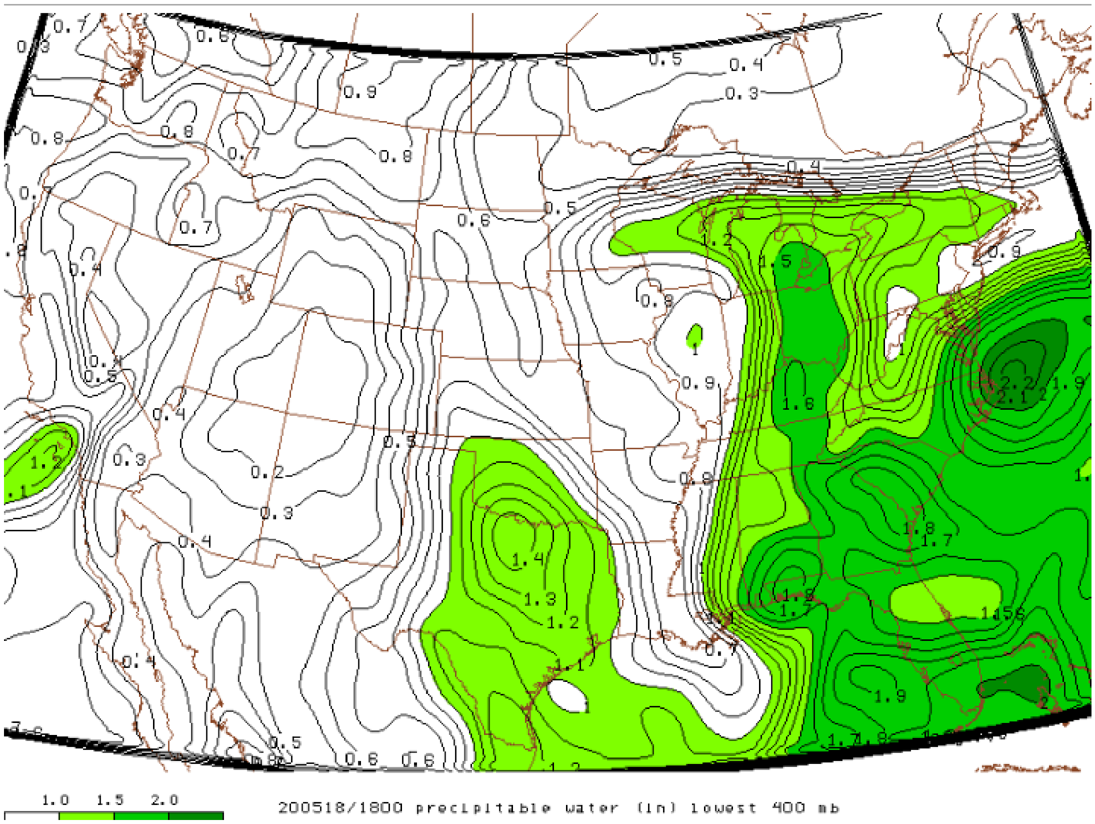

Figure 16: 18 May 2020 00 UTC RAP Mesoanalysis Lowest 400mb Precipitable Water (Contours & color filled contours for PWAT >1.0”). Courtesy SPC / NOAA.

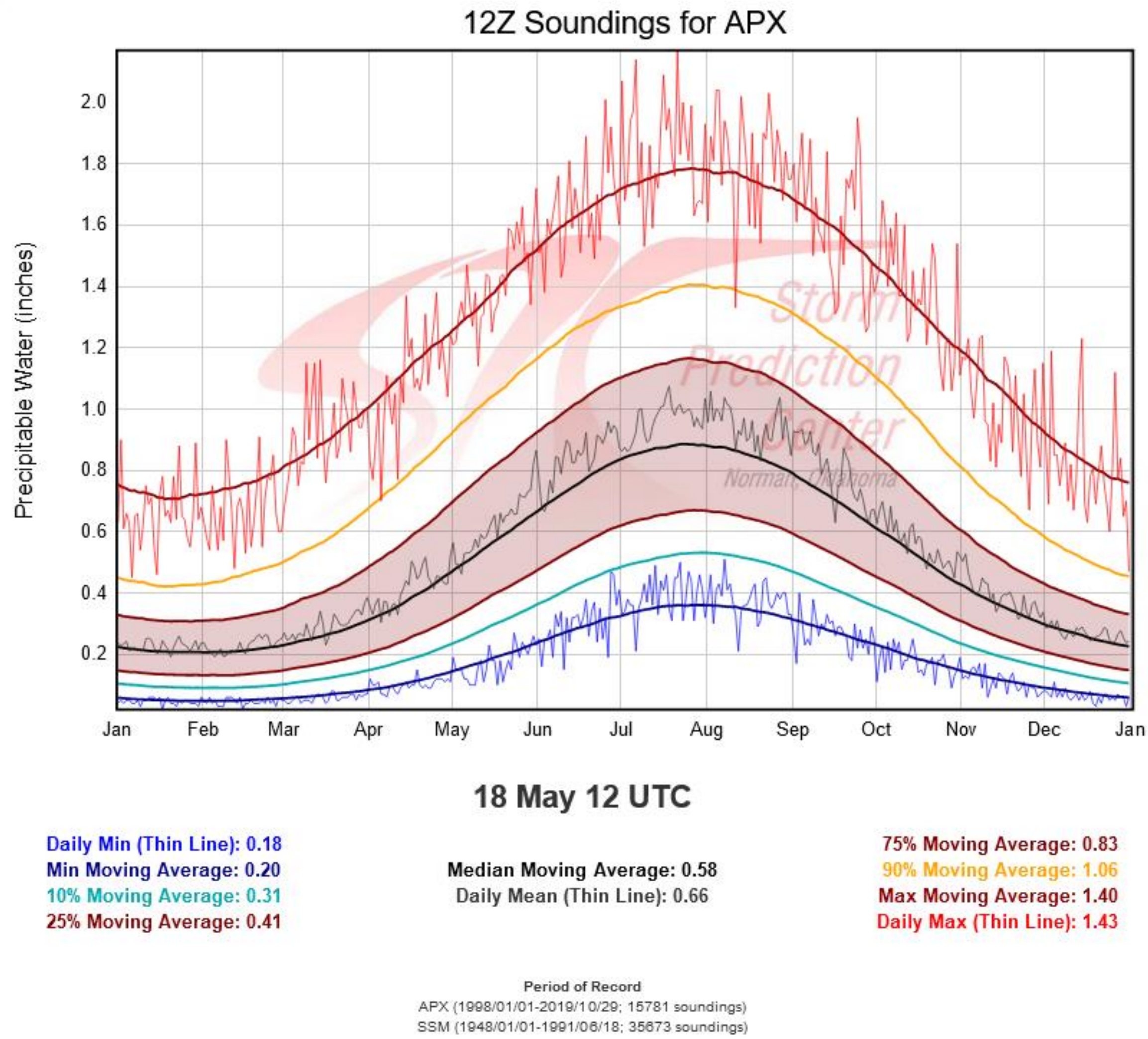

Figure 17: Precipitable water sounding climatology from 12 UTC APX soundings. Courtesy SPC / NOAA.

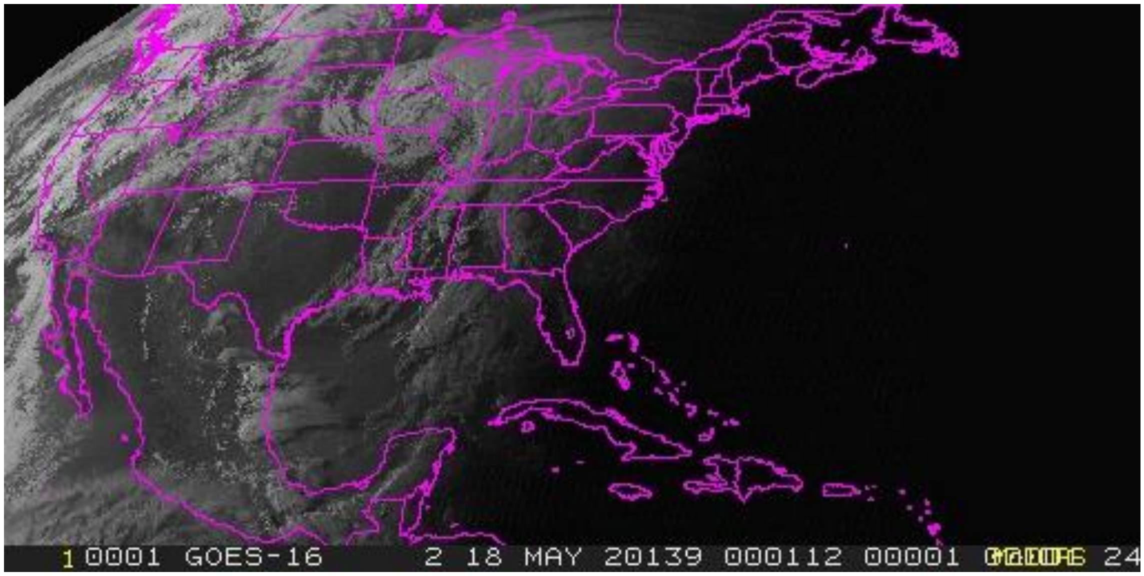

Figure 18: 18 May 2020 0001 UTC GOES-16 CONUS Visible Satellite. Courtesy NOAA / NCAR.

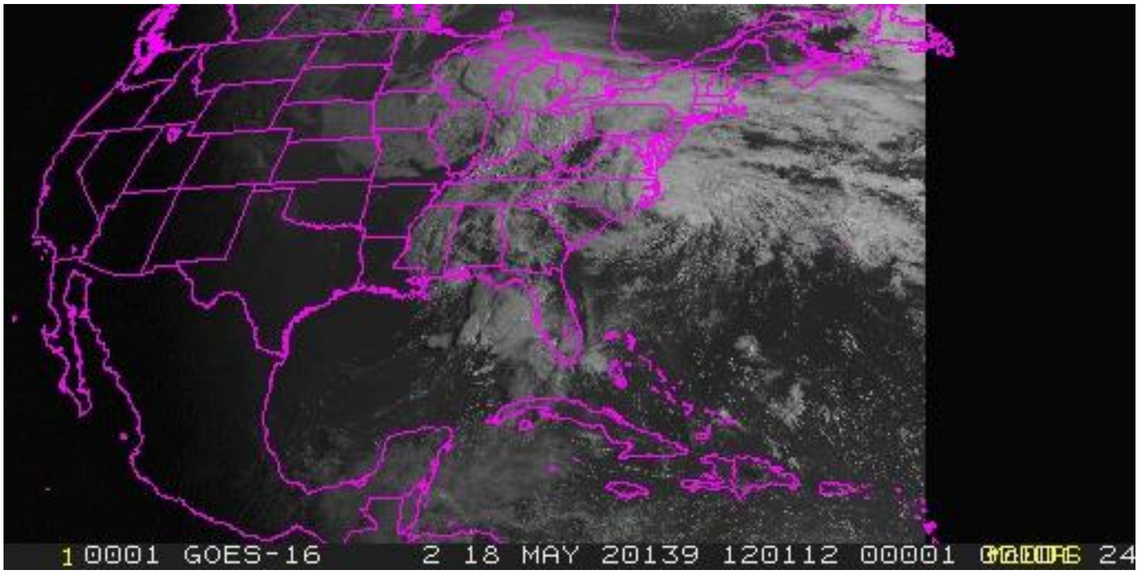

Figure 19: 18 May 2020 1201 UTC GOES-16 CONUS Visible Satellite. Courtesy NOAA / NCAR

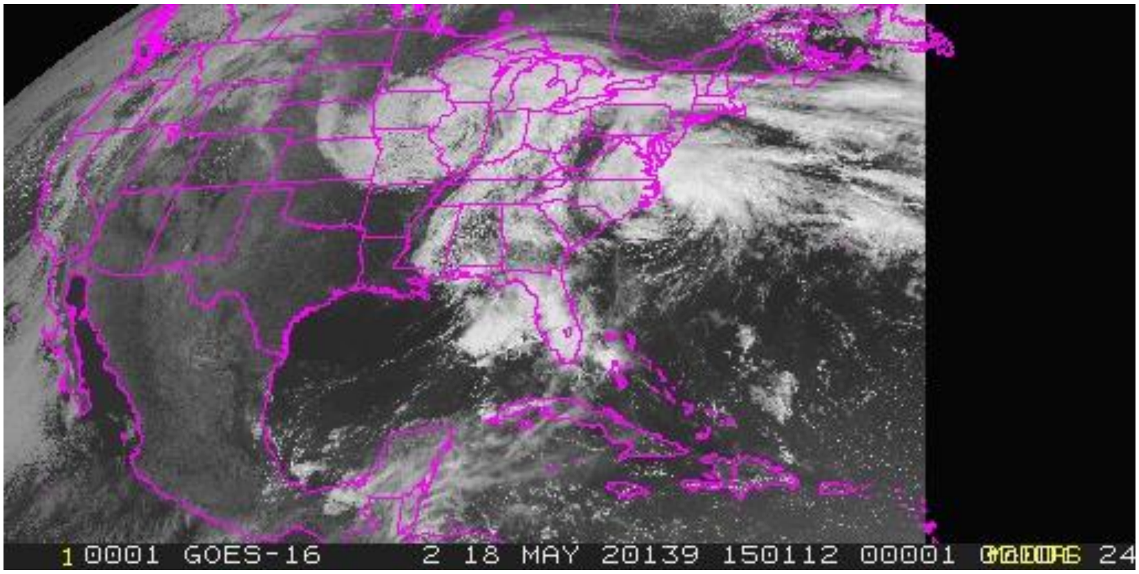

Figure 20: 18 May 2020 1501 UTC GOES-16 CONUS Visible Satellite. Courtesy NOAA / NCAR.

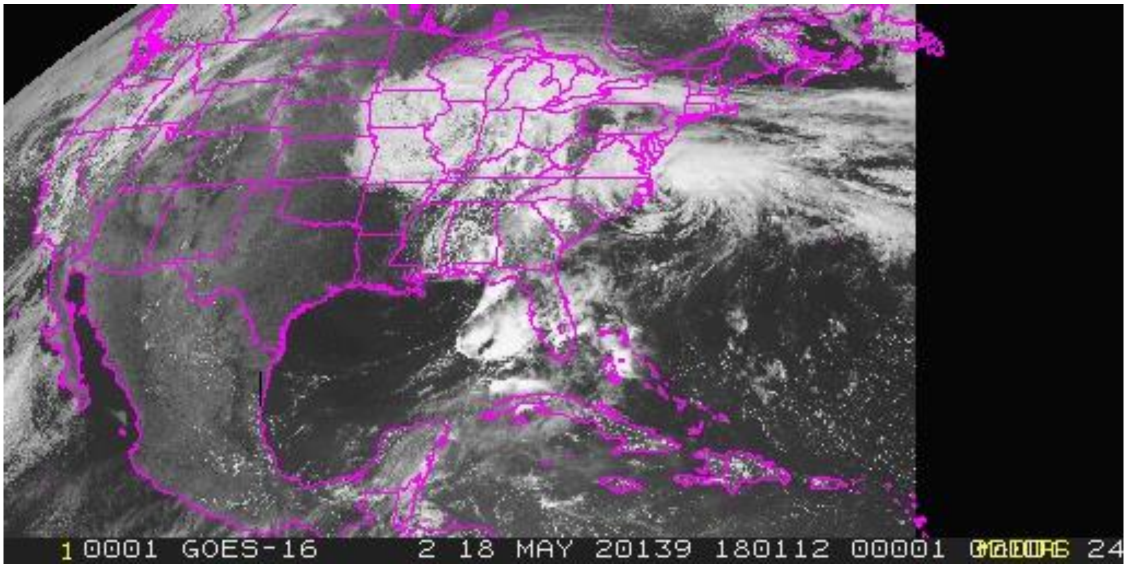

Figure 21: 18 May 2020 1801 UTC GOES-16 CONUS Visible Satellite. Courtesy NOAA / NCAR.

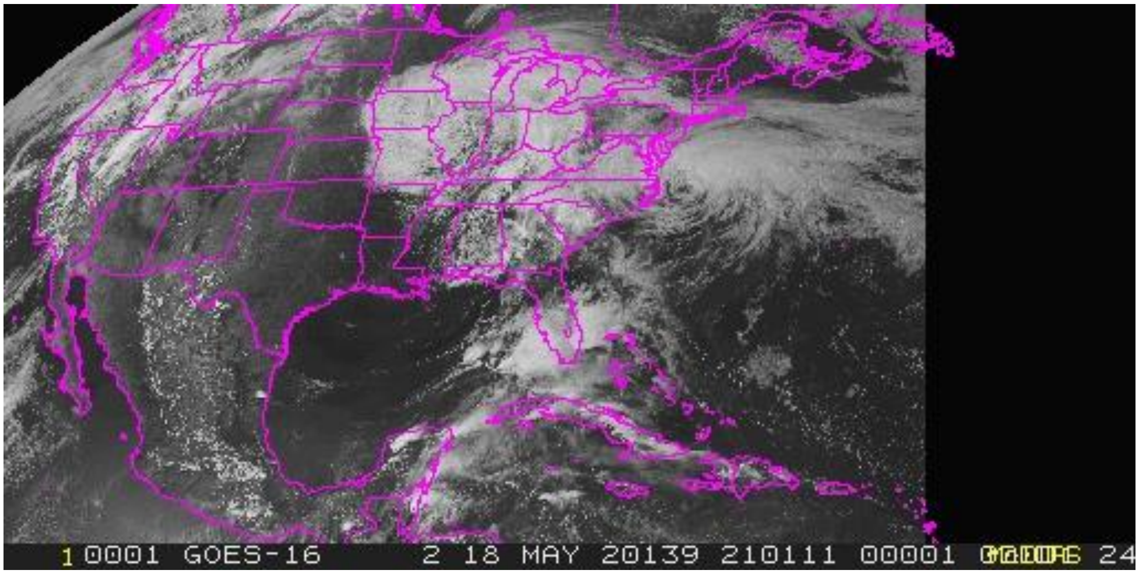

Figure 22: 18 May 2020 2101 UTC GOES-16 CONUS Visible Satellite. Courtesy NOAA / NCAR.

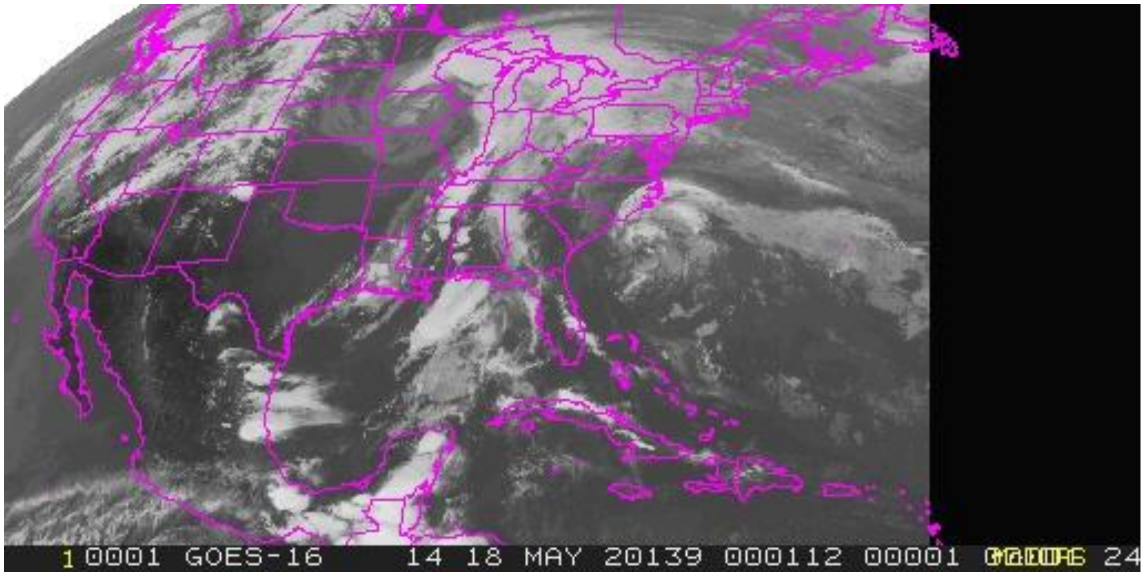

Figure 23: 18 May 2020 0001 UTC GOES-16 CONUS Infrared Satellite. Ch 14 Courtesy NOAA / NCAR.

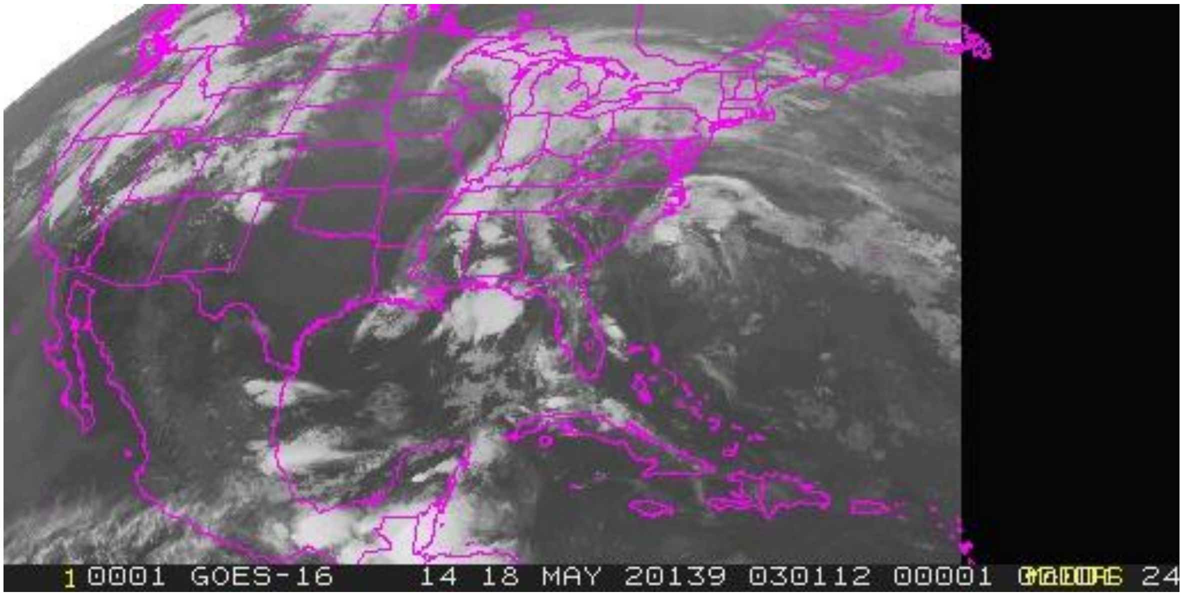

Figure 24: 18 May 2020 0301 UTC GOES-16 CONUS Infrared Satellite. Ch 14 Courtesy NOAA / NCAR.

Figure 25: 18 May 2020 0601 UTC GOES-16 CONUS Infrared Satellite. Ch 14 Courtesy NOAA / NCAR.

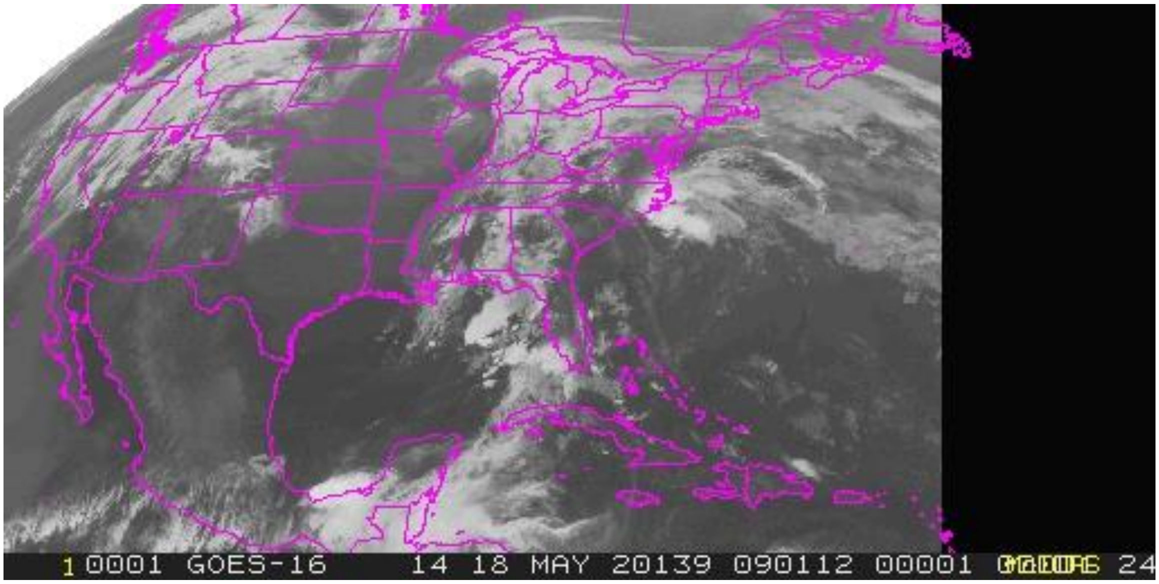

Figure 26: 18 May 2020 0901 UTC GOES-16 CONUS Infrared Satellite. Ch 14 Courtesy NOAA / NCAR.

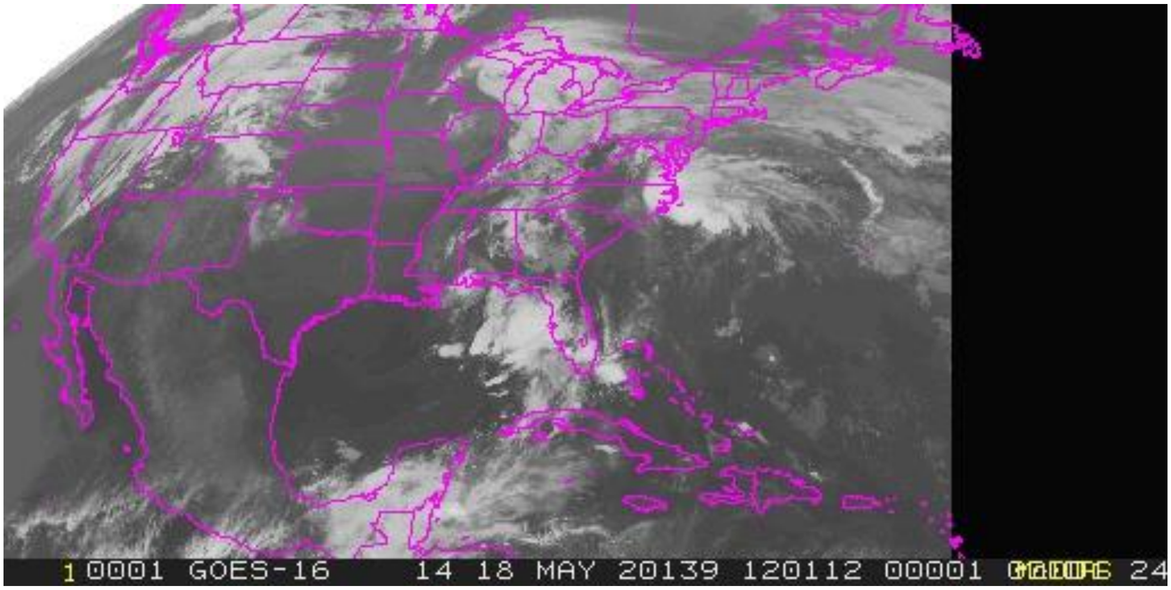

Figure 27: 18 May 2020 1201 UTC GOES-16 CONUS Infrared Satellite. Ch 14 Courtesy NOAA / NCAR.

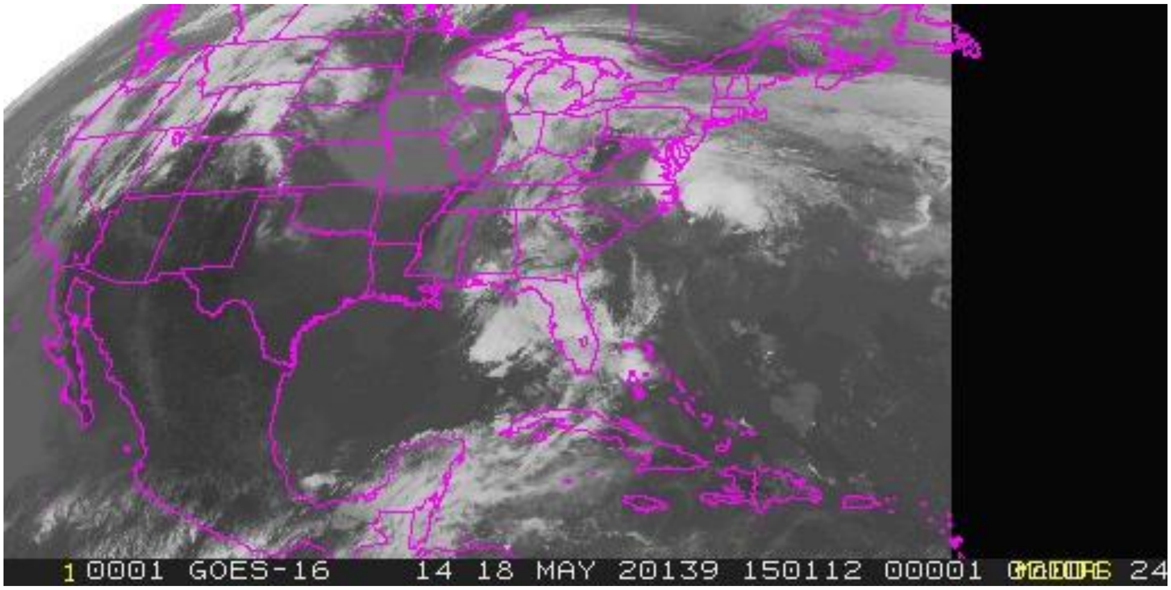

Figure 28: 18 May 2020 1501 UTC GOES-16 CONUS Infrared Satellite. Ch 14 Courtesy NOAA / NCAR.

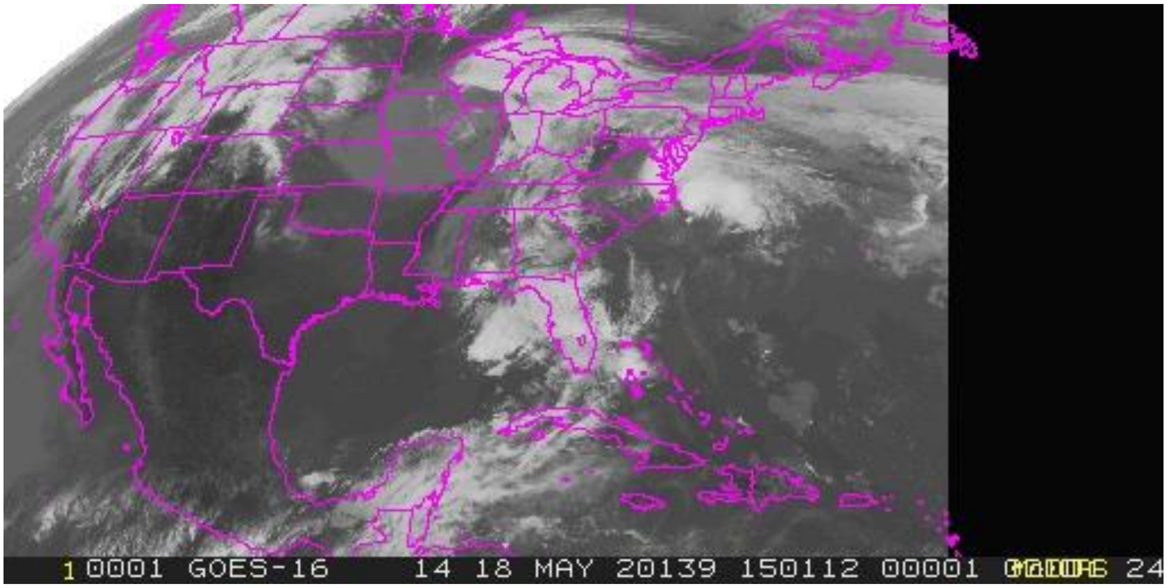

Figure 29: 18 May 2020 1801 UTC GOES-16 CONUS Infrared Satellite. Ch 14 Courtesy NOAA / NCAR.

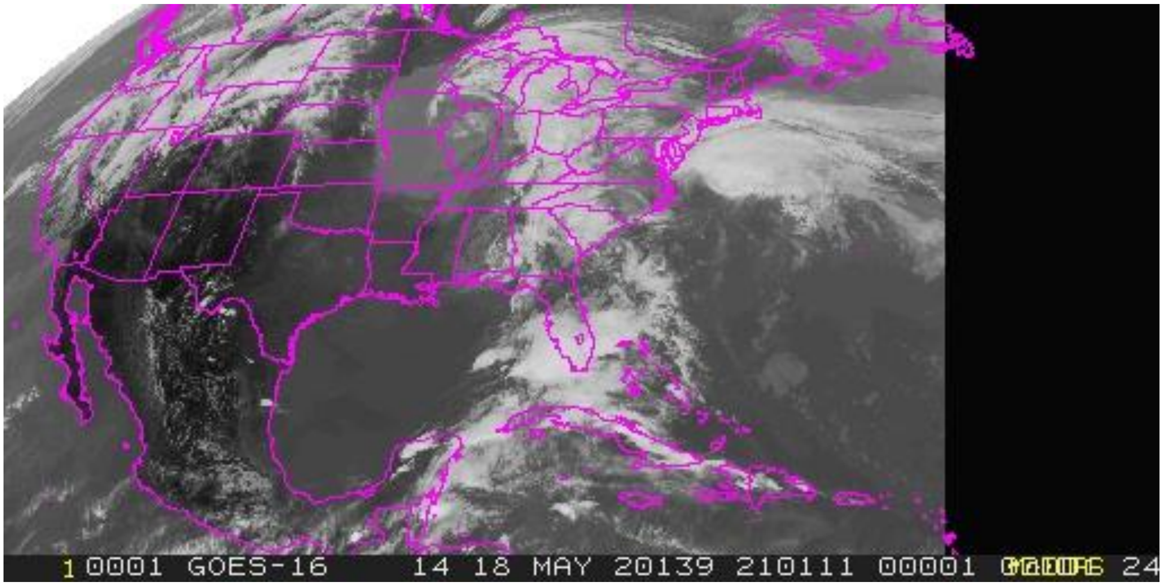

Figure 30: 18 May 2020 2101 UTC GOES-16 CONUS Infrared Satellite. Ch 14 Courtesy NOAA / NCAR.

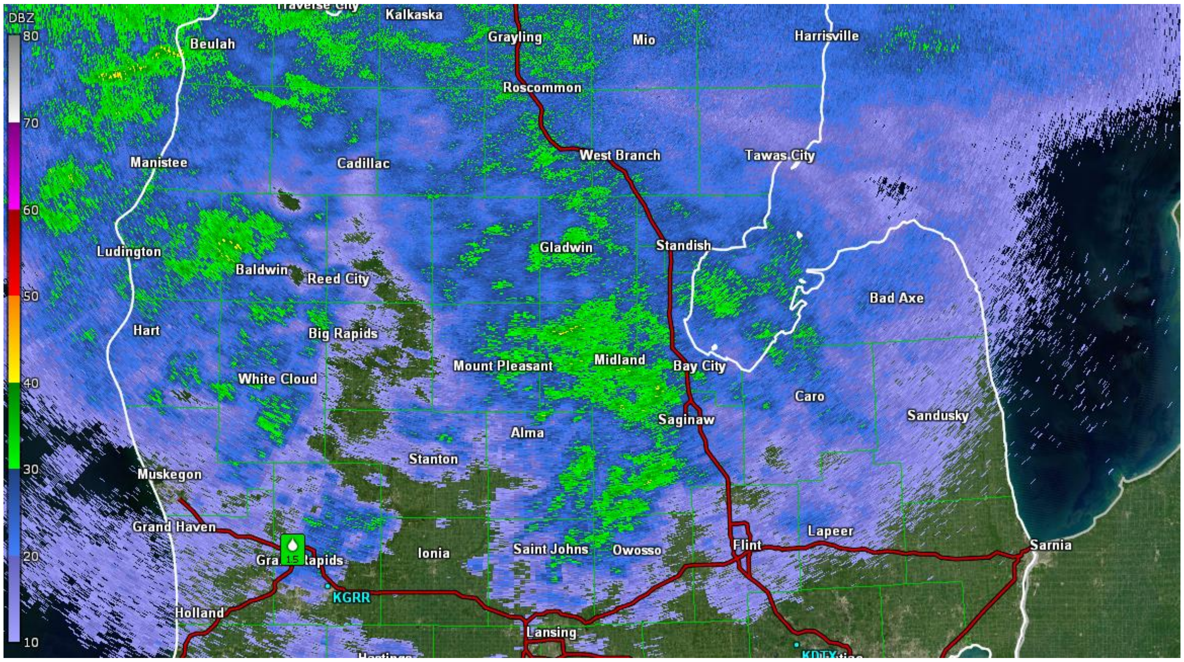

Figure 31: 18 May 2020 0004 UTC APX 0.5 degree tilt base reflectivity centered over Michigan’s central Lower Peninsula.

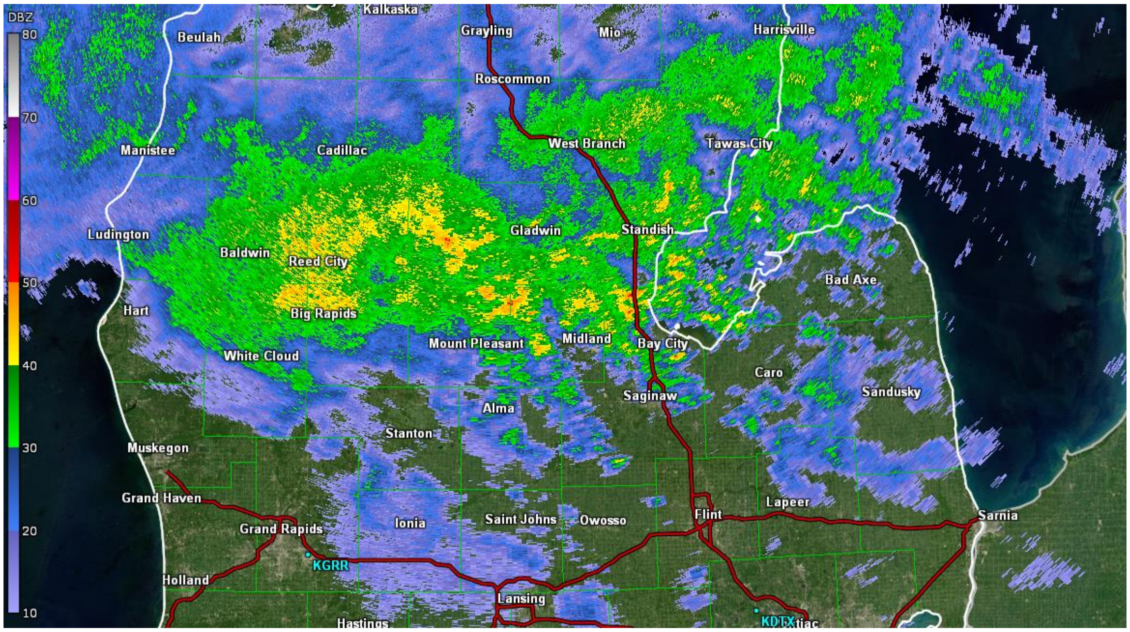

Figure 32: 18 May 2020 1459 UTC APX 0.5 degree tilt base reflectivity centered over Michigan’s central Lower Peninsula.

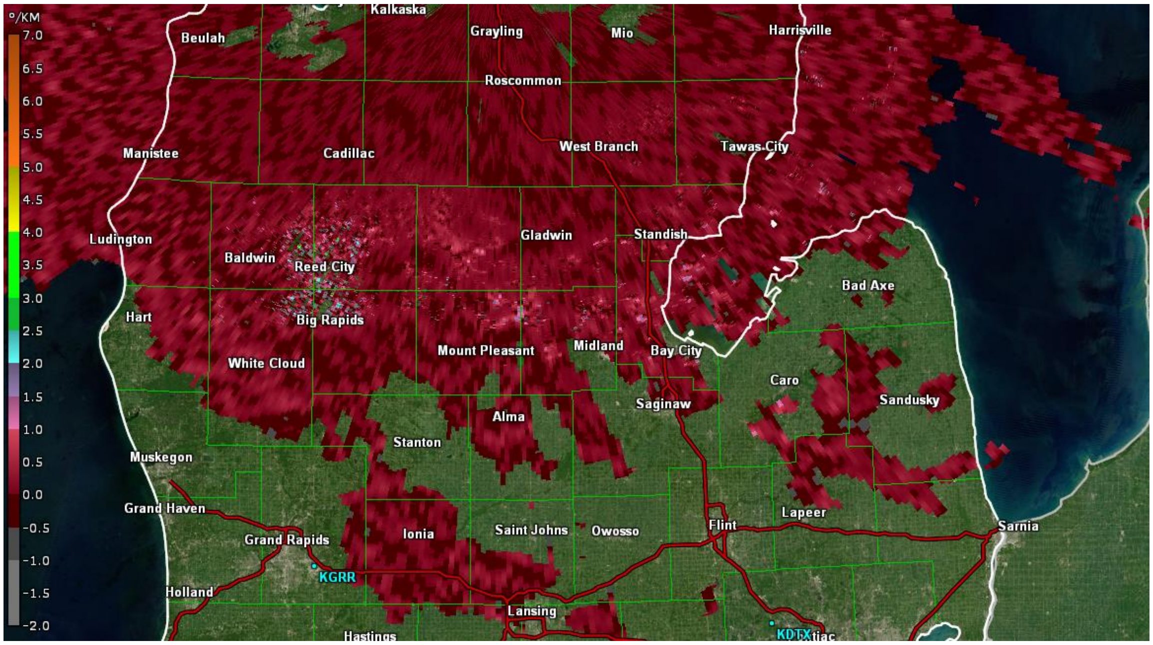

Figure 33: 18 May 2020 1459 UTC APX 0.5 degree tilt specific differential phase centered over Michigan's central Lower Peninsula.

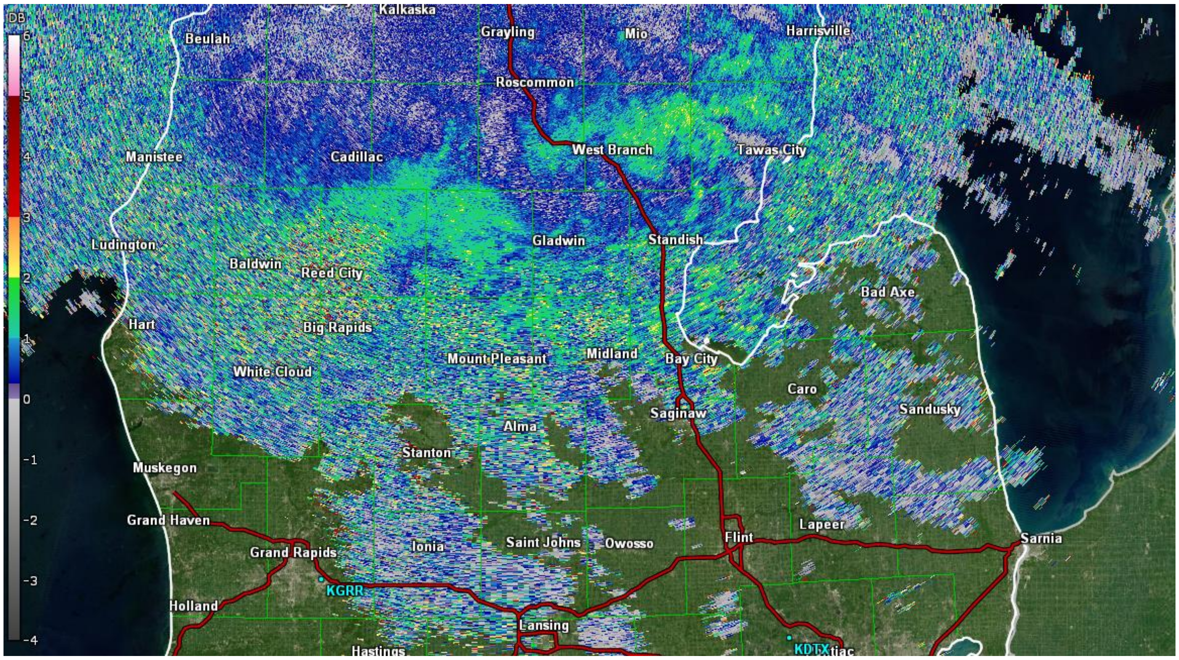

Figure 34: 18 May 2020 1459 UTC APX 0.5 degree tilt differential reflectivity centered over Michigan’s central Lower Peninsula.

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