Stockholm University

Department of Meteorology

Waves and Instabilities (MO7020)

# Synoptic Analysis of a Cyclone

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# 1 Introduction

Cyclones are large-scale low-pressure systems that are characterized by counterclockwise circulation in the Northern Hemisphere. Cyclones are associated with strong winds and heavy precipitation, and they can lead to storms and other severe weather conditions. Cyclones are therefore one of the most crucial elements in meteorology of the mid-latitudes, and understanding their development and dissipation is essential for weather forecasting, climate studies, and understanding atmospheric processes in the mid-latitudes. In this report, a detailed analysis of the synoptic situation for a cyclone in the northern Atlantic will be presented. The report will study the creation, life cycle, and dissipation of the cyclone, as well as the associated weather at a specific location in the northern Atlantic.

# 2 Theory Behind Cyclone Development

The simplest equation for describing atmospheric dynamics comes from the geostrophic balance, which is a balance between the pressure gradient force and the Coriolis force as

$$f, \hat{\mathbf{z}} \times \mathbf{u}_g = -\frac{1}{\rho}\nabla p \tag{1}$$

where $f$ is the Coriolis parameter, $\hat{\mathbf{z}}$ is the unit vector in the vertical direction, $\mathbf{u}_g$ is the geostrophic wind vector, $\rho$ is the air density, and $\nabla p$ is the horizontal pressure gradient. If one combines the geostrophic balance with the hydrostatic balance (and the ideal gas law), one obtains the thermal wind balance as

$$\frac{\partial \mathbf{u}_g}{\partial z} = -\frac{1}{f\rho}\hat{\mathbf{z}} \times \nabla p. \tag{2}$$

This equation shows that a strong temperature gradient will lead to a strong vertical shear in the geostrophic wind, which is associated with a strong upper-atmospheric jet in the mid-latitudes.

The geostrophic balance does, however, not take into account centrifugal forces, which are important for cyclones due to their rotating nature. Thus, a more accurate equation for describing the atmospheric dynamics of cyclones is the gradient wind balance, which describes the balance between the pressure gradient force, the Coriolis force, and the centrifugal force in a rotating fluid as

$$\frac{u^2}{r} + fu = \frac{1}{\rho}\frac{\partial p}{\partial r}. \tag{3}$$

Above, $u$ is the wind speed and $r$ is the radius of curvature of the flow. Using this relation and defining the total wind as

$$\mathbf{u} = \mathbf{u}_g + \mathbf{u}_a \text{ where } u_a \ll u_g, \tag{4}$$

where $u_g$ is the geostrophic wind and $u_a$ is the ageostrophic wind, one can derive the ageostrophic wind from the time-independent, non-viscous Navier–Stokes equation for spatially accelerating flow as follows:

$$\frac{D\mathbf{u}}{Dt} + f, \hat{\mathbf{z}} \times \mathbf{u} = \frac{1}{\rho}\nabla p \implies (\mathbf{u}_g \cdot \nabla)\mathbf{u}_g + f, \hat{\mathbf{z}} \times \mathbf{u}_a + \mathcal{O}(u_a^2) = 0 \tag{5}$$

$$\Rightarrow \quad \mathbf{u}_a = \frac{1}{f}, \hat{\mathbf{z}} \times [-(\mathbf{u}_g \cdot \nabla)\mathbf{u}_g] \implies \mathbf{u}_a \propto -\hat{\mathbf{z}} \times \nabla \left(\frac{u_g^2}{2}\right) \tag{6}$$

Since the geostrophic wind is related to the pressure gradient as $\mathbf{u}_g \propto \hat{\mathbf{z}} \times \nabla p$, one can see that an increase in the geostrophic wind will lead to an ageostrophic flow towards lower pressure. If the position itself is not a low-pressure center, this will lead to a horizontal divergence at this level.

Acceleration of the geostrophic wind can occur due to a strong thermal wind or a change in the circulation type. If one uses Equation 3 to look at the velocity needed for an anticyclone versus a cyclone, one can see that the velocity needed for an anticyclone is higher than the velocity needed for a cyclone (due to the Coriolis parameter). Thus, if the flow changes from an anticyclone to a cyclone, or from an upper-level trough to a ridge, it will lead to an acceleration of the geostrophic wind and thus an ageostrophic flow towards lower pressure.

Since the Navier–Stokes equation assumes incompressibility, the total mass flux is conserved, and the divergence of the total wind is zero. This means that any horizontal divergence in the geostrophic wind must be balanced by a vertical convergence. If this occurs at upper levels of the atmosphere, it will lead to a convergence at lower levels of the atmosphere. However, if the divergence is strong enough, it can lead to a surface low being created at the same location as the upper-level divergence if the convergence at lower levels is not sufficient. This is a common mechanism for cyclone development and will be used to explain the cyclone development in this report.

One can note that when the upper-level low and the lower-level low align vertically, the system is barotropic, and when they are tilted with respect to each other, the system is baroclinic. As derived, a baroclinic system will lead to the creation of cyclones; however, when the system reaches barotropicity, the cyclone will start to weaken. This is because there is no upper-level divergence to support the cyclone, and since the ageostrophic flow will be towards lower pressure, the cyclone will start to fill and weaken. Another way of dissipation can be that the cyclone is advected out of the jet stream, which will also lead to a lack of upper-level ageostrophic flow and thus divergence. These processes represent the final stage of the cyclone and will be used to explain the weakening of the cyclone in this report.

# 3 Methodology

To study the synoptic situation for a cyclone, a specific cyclone had to be chosen. This was done through the ECMWF (European Centre for Medium-Range Weather Forecasts) website. To analyze the development of the cyclone, the ECMWF control forecast data were used. The cyclone was viewed through a forecast of 10 days, with a base time of 3 February 2026 at 12 UTC. The specific cyclone was chosen by looking at the forecast of the 500–1000 hPa thickness and finding a strong low-pressure system that developed in the northern Atlantic, since this is a common location for cyclone development in the northern Atlantic. The cyclone was then analysed using two different approaches. The two tasks can be summarized as follows:

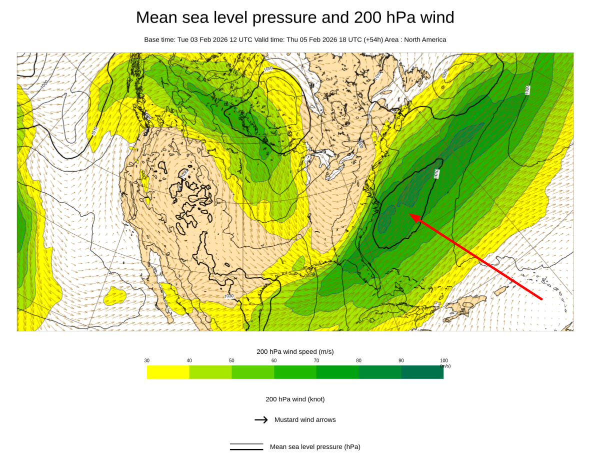
- Task 1: Follow and analyze the development of the cyclone and explain the creation and dissipation using the theory of cyclone development.
- Task 2: Analyze the weather associated with the cyclone at a specific location.

To analyze the cyclone in Task 1, a range of weather maps was used to explain the development and dissipation of the cyclone. In Task 2, the specific location for the weather analysis was chosen to be the point 50°N, 40°W, which is located in the middle of the northern Atlantic and thus is expected to be affected by the cyclone. To analyze the weather at this location, three different reanalysed soundings were used.

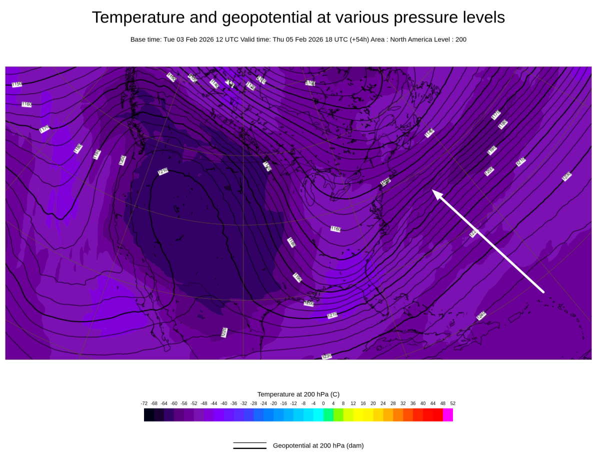
# 4 Analysis

## 4.1 The development of the cyclone

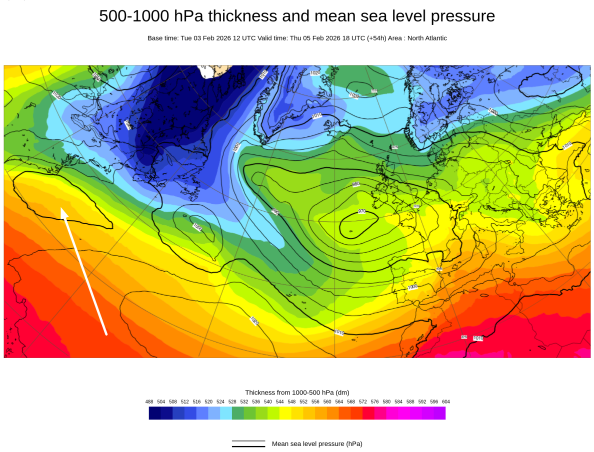
Below in Figure 1 are four important parameters that show the state of the atmosphere on 5 February 2026 at 18 UTC on the east coast of North America. If one follows the arrow in Figure 1c, one can see a region with a strong temperature gradient. Since a strong temperature gradient is associated with a strong thermal wind (as seen in Equation 2), one can expect a strong upper-atmospheric jet at this location. Thus, if one observes Figure 1a, one can, as expected, observe a strong upper-atmospheric jet. This jet follows the lines of fixed geopotential height, which can be seen in Figure 1b, showcasing a geostrophic flow. Furthermore, an acceleration of the upper-atmospheric jet is seen at the same location as the strong temperature gradient. Following the derivations made in Equation 6, one can see that an increase in the geostrophic velocity means an ageostrophic flow towards lower pressure, which can be seen to lie to the west of the jet. This results in divergence at the upper levels of the atmosphere, which can be seen in Figure 1d. This strong divergence makes this location favourable for the development of a cyclone, which can be seen in Figure 1b, where a surface low is seen developing at the same location as the strong divergence. Since the upper-level low and the newly created lower-level low are not located at the same coordinates, one can see a tilt in the pressure gradient. Thus, the cyclone will continue to develop and strengthen at this location. However, due to the presence of the westerly winds, the cyclone will move eastwards and thus enter a new phase of its life cycle.



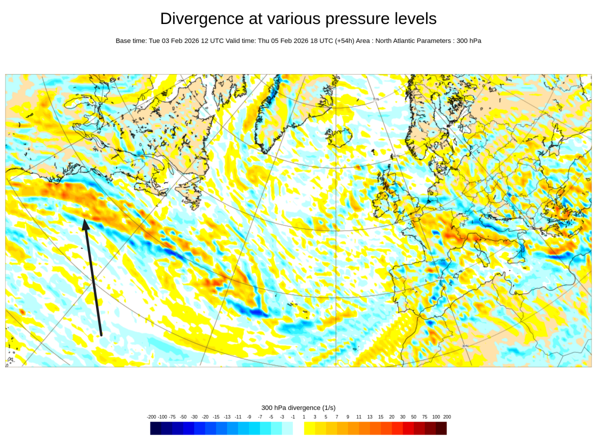

**(a)** The upper atmospheric jet at 200 hPa over North America.




**(b)** The 200 hPa geopotential height over North America.



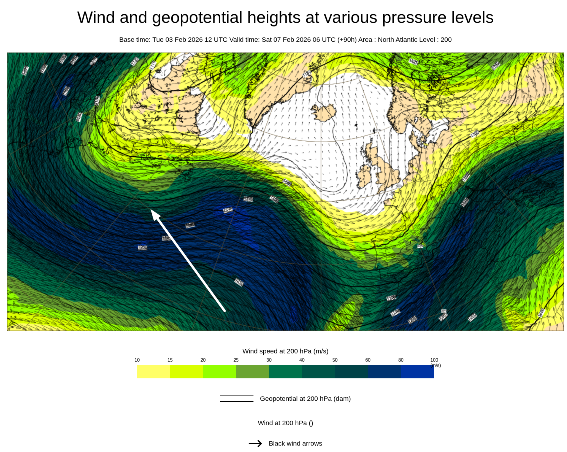

**(c)** The 500–1000 hPa thickness over the northern Atlantic, which indicates the temperature of the airmass.



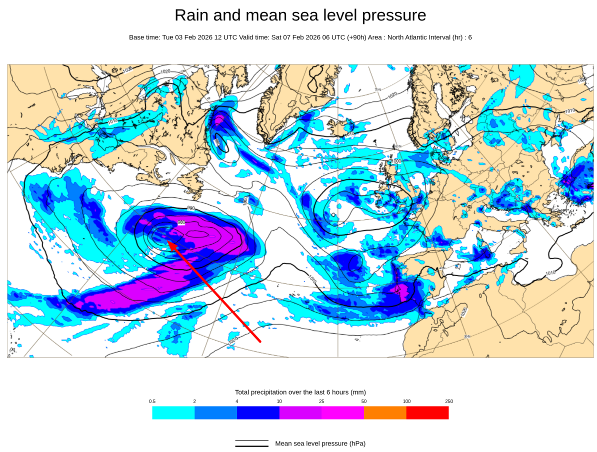

**(d)** The 300 hPa divergence over the northern Atlantic.

**Figure 1:** These figures show the upper atmospheric jet, the 500–1000 hPa thickness, and the 300 hPa divergence over the northern Atlantic on 5-february-2026 at 18UTC. The arrows indicate the position of the developing cyclone near the offshore waters of Atlantic Canada

In Figure 2, one can see the state of the atmosphere 36 hours after the initial development of the cyclone. The cyclone has moved eastwards and is now located in the middle of the northern Atlantic. Furthermore, the upper-atmospheric jet has also moved eastwards, but at a different speed than the cyclone. Thus, the upper-level low and the lower-level low are now more aligned than before, which means that the system is more barotropic. This indicates that the cyclone has nearly reached its peak and will soon start to weaken. In Figure 2b, one can see that the cyclone is now associated with strong precipitation. Since the cyclone showed strong divergence at upper levels of the atmosphere during its development, it is expected that the cyclone will be associated with a strong updraft, which will lead to condensation and thus precipitation.



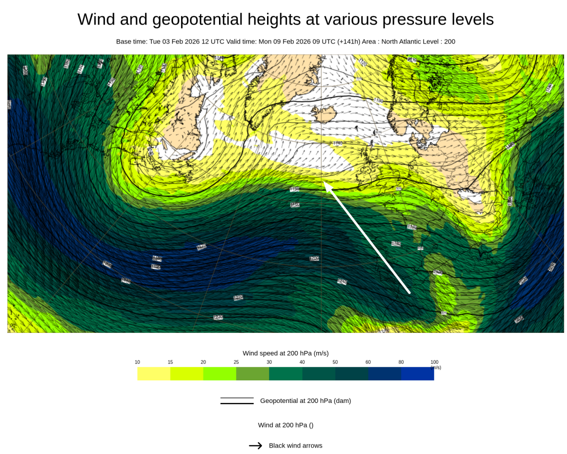

**(a)** The upper atmospheric jet and geopotential height at 200 hPa over the northern Atlantic.



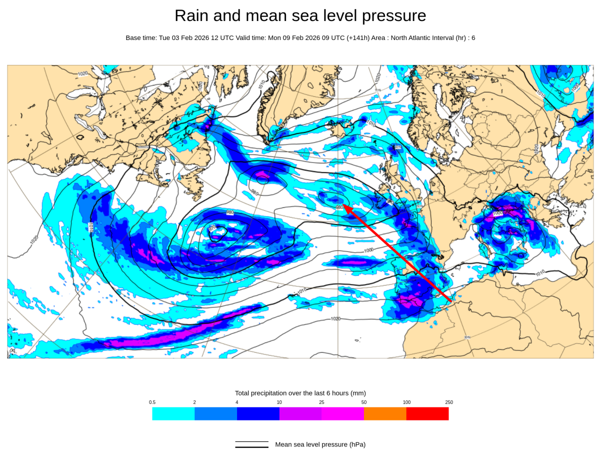

**(b)** The surface pressure and precipitation over the northern Atlantic.

**Figure 2:** These figures show the upper atmospheric jet and geopotential height at 200 hPa, and the surface pressure and precipitation over the northern Atlantic on 6-february-2026 at 18UTC. The arrows indicate the position of the cyclone.

The dissipation of the cyclone can be seen in Figure 3, 89 hours after the initial development of the cyclone. The cyclone has now moved further eastwards and is located close to the European coast. In Figure 3a one can see that the cyclone has deviated north from the upper atmospheric jet. This means that the upper level divergence from the jet is no longer supporting the cyclone, and thus the cyclone has severely weakened. The resulting dominant agesostrophic flow is now towards the low altitude low pressure center. This means that the cyclone is now filling up. This can be seen in Figure 3b where the cyclone is no longer associated with a deep low pressure, and the heavy precipitation has also disappeared.




**(a)** The upper atmospheric jet and geopotential height at 200 hPa over the northern Atlantic.

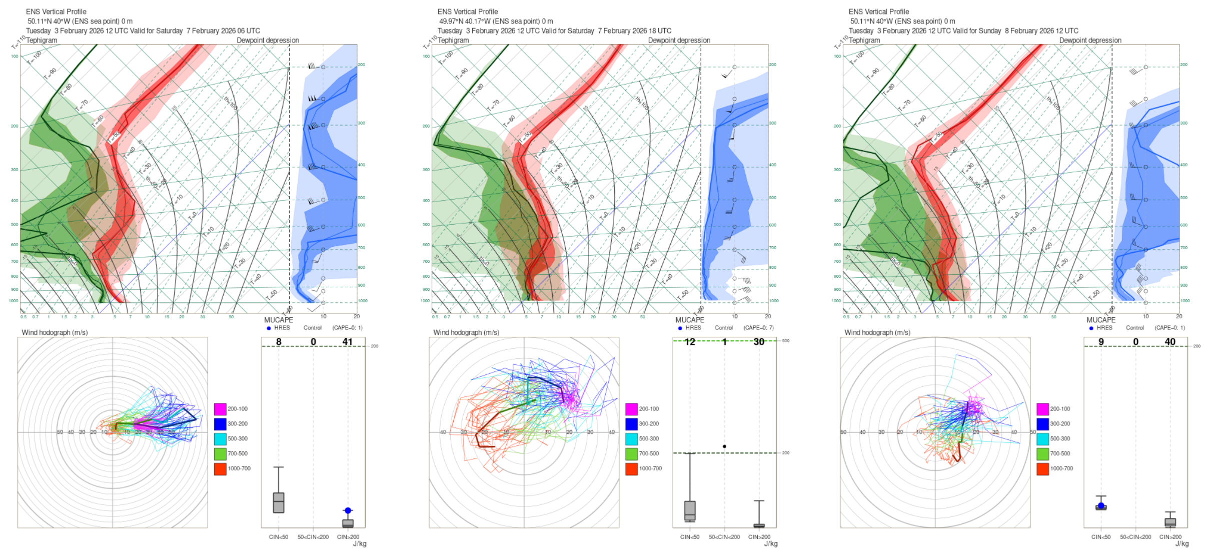



**(b)** The surface pressure and precipitation over the northern Atlantic.

**Figure 3:** These figures show the upper atmospheric jet and geopotential height at 200 hPa, and the surface pressure and precipitation over the northern Atlantic on 9-february-2026 at 18UTC. The arrows indicate the position of the cyclone.

### 4.2 The weather of the cyclone

The weather associated with the cyclone at the location 50°N, 40°W can be seen in the tephigram Figure 4. The initial vertical structure of the atmosphere can be seen in Figure 4a, where a dry atmosphere with predominantly easterly winds is observed. In Figure 4b, when the cyclone is passing over the location, a strong increase in the moisture content of the atmosphere is observed. This is expected due to the strong updrafts associated with the cyclone. Thus, at this location one can expect a lot of cloud cover together with significant precipitation. The wind is much more variable with height, although higher altitudes show more north-easterly winds. This shift in wind direction is expected due to the cyclonic circulation around the low-pressure center. Furthermore, the large wind shear observed indicates a large temperature gradient and thus a frontal passage. Finally, in Figure 4c, when the cyclone has passed the location, the moisture content of the atmosphere has decreased to a drier profile than before the cyclone. Thus, one can expect the location to have clear skies. Furthermore, an inversion can be observed at around 700 hPa, which may explain the very dry conditions. If one observes this inversion together with the change in temperature profile between Figure 4a and Figure 4c, one can suggest that the cyclone has advected a new air mass to the location, and thus a front has passed the location.




**(a)** The sounding before the passing of the cyclone on 7-february-2026 at 06UTC.

**(b)** The sounding before the passing of the cyclone on 7-february-2026 at 18UTC.

**(c)** The sounding before the passing of the cyclone on 8-february-2026 at 12UTC.

**Figure 4:** These figures show the soundings at the location 50°N, 40°W before the passing of the cyclone on 7-february-2026 at 06UTC, when the cyclone passes over the location on 7-february-2026 at 18UTC and when the cyclone has passed the location on 8-february-2026 at 12UTC.

## 5 Discussion

The creation of the cyclone was in this report explained by the strong temperature gradient located on the offshore waters of Atlantic Canada. This large temperature gradient at this location is, broadly speaking, a result of cold air coming from the polar region and warm air coming from the equator meeting. However, that this occurs at this specific location may be explained by the presence of the Labrador Current and the Gulf Stream meeting at this location. The Labrador Current brings cold polar water from the Arctic Ocean down along the coast of Canada, while the Gulf Stream brings warm water from the Gulf of Mexico. Since the temperature of the ocean has a large impact on the temperature of the air mass above, a collision of the two ocean currents will lead to a strong temperature gradient in the air masses above. This strong temperature gradient will then lead to a strong thermal wind, accelerating the geostrophic wind and thus creating the ideal conditions needed for cyclone development, as explained previously.

However, the accelerating geostrophic wind may also be explained by the upper-atmospheric change from a ridge to a trough, which will also lead to an acceleration of the geostrophic wind, as explained earlier.

This cyclic change from ridge to trough is a common feature of the upper-atmospheric flow in the mid-latitudes, and it is a result of planetary Rossby waves. The large-scale meander pattern of the Rossby waves is a result of the conservation of potential vorticity in a rotating fluid and is often used to explain the large-scale weather patterns in the mid-latitudes. Since the northwestern Atlantic region is located to the right of the North American mainland, and large mountain ranges like the Rocky Mountains, the Rossby waves are forced to move northwards at this location, leading to a trough to ridge transition in this area. Since ridges have a larger geostrophic wind speed than troughs, this transition will lead to an acceleration of the geostrophic wind and thus to an ideal location for cyclonic development.

Both of these mechanisms may thus explain the acceleration of the geostrophic wind needed for cyclone development at this location, and it is likely that both mechanisms played a role in creating a strong upper-level divergence and thus the development of the cyclone studied in this report. Thus, when a small low-pressure perturbation is formed in this area, it will be amplified by the strong upper-level divergence. This small perturbation could be a result of mid-altitude heating or the strong upper-level divergence itself. Since the upper-level divergence is strong enough to create a surface low, it is likely that the initial low-pressure perturbation was created by the upper-level divergence itself.

Another interesting aspect of this cyclone is the fact that the passing of the cyclone created a dry, cloud-free area in the middle of the northern Atlantic. This is likely a result of the well-known quasi-geostrophic omega equation. The omega equation is a diagnostic tool used in meteorology to understand the vertical motion of air in the atmosphere. This diagnostic equation relates temperature advection to the vertical movement of air. Since subsidence could be seen after the passing of the cyclone, one can thus conclude that this was a result of cold air advection. Furthermore, since the cyclone is related to anticlockwise circulation, the cyclone would drag cold air from the north to the western side of the cyclone. Thus, the subsidence and clear skies after the cyclone are a reasonable result and align well with the theory.

# 6 Conclusion

To summarize the results of this report, the development of the cyclone was explained by the presence of a strong temperature gradient located on the offshore waters of Atlantic Canada. The strong temperature gradient led to a strong atmospheric jet at upper levels of the atmosphere, which accelerated the geostrophic wind together with the change from a ridge to a trough, and thus created a large divergence. This strong divergence created ideal conditions for cyclone development, and thus a surface low was created and amplified at this location. The cyclone then moved eastward by the westerly winds and reached its peak in the middle of the northern Atlantic. Afterwards, the cyclone moved further eastwards and was advected out of the jet stream, which led to a lack of upper-level divergence and a more barotropic state was created. This led to ageostrophic flow towards the low-pressure center, and thus the cyclone started to fill and later dissipated. The weather associated with the cyclone at the location 50°N, 40°W was explained by the strong updrafts associated with the cyclone, which led to a strong increase in moisture content and thus a large amount of precipitation. After the cyclone passed the location, the moisture content decreased to a drier profile than before the cyclone, which was explained by cold air advection from the north. This lab report thus presented a detailed analysis of the development and dissipation of a cyclone in the northern Atlantic. The results of this report align well with the theory of cyclone development and can thus be used as a case study to understand the synoptic situation for cyclones in the mid-latitudes.