Cyclone Pathways and Intensification of Extreme Atmospheric Rivers In the Northeast U.S.

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I. Introduction

An atmospheric river (AR) is a narrow channel of intense water vapor transport that occurs in conjunction with an extratropical cyclone (ETC). AR intensity is defined by vertically integrated water vapor transport (IVT), a water vapor flux dependent on atmospheric moisture content and horizontal wind speed (AMS 2022). Average maximum IVT values for an AR in the northeast U.S. range between 750-999 kg $m^{-1}s^{-1}$ (Kaminski et al. 2023) and winter IVT values above 425.8 kg m^{-1} s^{-1} are considered extreme. The water vapor contained within northeast ARs originates from the Gulf of Mexico, the Atlantic Ocean, and the Caribbean Sea. IVT values are highest to the east of a cold front when a strong pressure gradient is created between the ETC and a high-pressure system off the eastern U.S coast (Henny et al. 2023). Henny et al. (2023) also showed that ETCs associated with a Northeast AR follow a variety of storm tracks (Fig. 1), which can alter the IVT associated with an AR. The goal of this study is to understand the role of the high-pressure system over the Atlantic Ocean in AR intensification for various cyclone pathways through a case study of several Northeast ARs that occurred during the winter of 2023-2024.

II. Methodology

Archived GFS analyses were obtained from the University of Albany - Alicia M. Bentley webpage. Records were selected in 12-hour intervals from the formation of the 500-hPa trough associated with the AR until the AR dissipated or exited the map domain. Selected analyses included: mean sea level pressure, 925-hPa wind speed anomalies, 850-hPa temperature anomalies, 700-hPa IVT, 500-hPa geopotential height & relative vorticity, and 250-hPa wind speed.

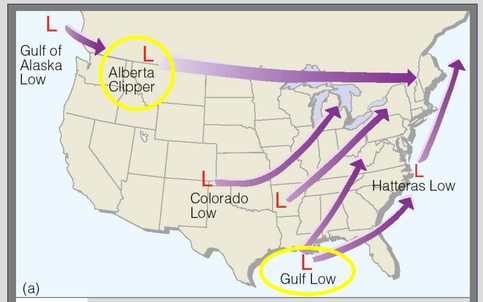


Fig. 1 Various pathways of ETCs *(University of Illinois)*

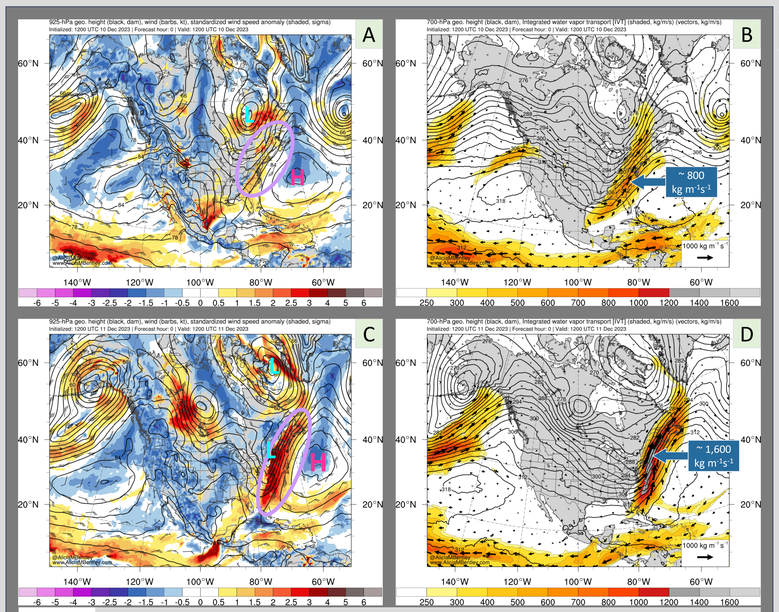


Fig. 2 925-hPa wind speed anomalies (a) (c) and 700-hPa IVT (b) (d) 24 hours before (12/10/23 at 1200 UTC) and at the time of peak IVT intensity (12/11/23 at 1200 UTC), respectively

III. Alberta Clipper – December 11th, 2023

Cyclogenesis occurs on 12/06 over Alberta, Canada

1200 UTC 10 December 2023

- Low over Quebec, Canada
  - Far from moisture sources
- High-pressure system over the Atlantic Ocean
  - Weak gradient between ETC
  - Weak low-level winds (< 2 σ; Fig. 2a)
- IVT values **< 800 kg $m^{-1}s^{-1}$** (Fig. 2b)
  - "Average" maximum IVT for a Northeast AR

+ 24 hours – 1200 UTC 11 December 2023

- Atlantic high-pressure remains stationary and strengthens
- Primary low has moved northeast
- A secondary low forms on the trailing cold front of the initial ETC
  - Creates strong gradient with Atlantic ridge
  - Strong low-level winds (> 3 σ; Fig. 2c)
- IVT values **> 1,600 kg $m^{-1}s^{-1}$** (Fig. 2d)
  - "Extreme" IVT for winter Northeast ARs
  - Moisture transport from southern sources

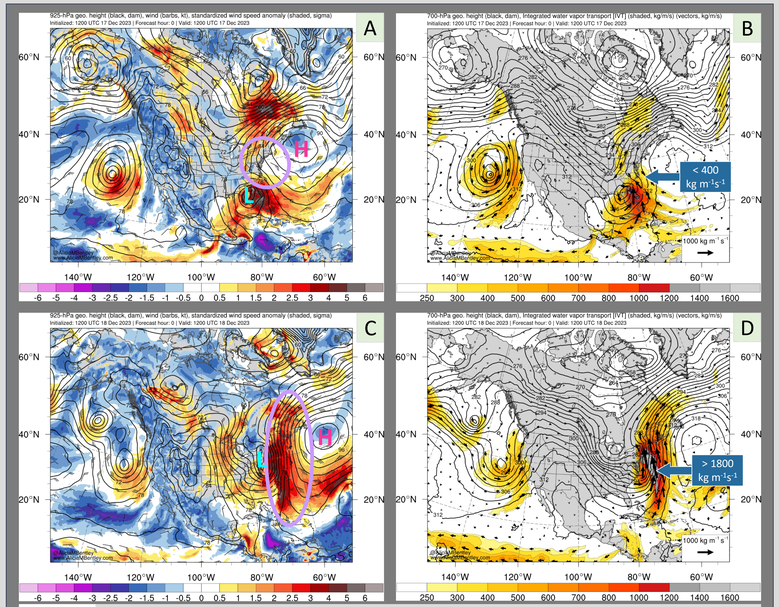


Fig. 3 925-hPa wind speed anomalies (a) (c) and 700-hPa IVT (b) (d) 24 hours before (12/17/23 at 1200 UTC) and at the time of peak IVT intensity (12/18/23 at 1200 UTC), respectively

IV. Gulf Low– December 18th, 2023

Cyclogenesis occurs on 12/17 over Gulf of Mexico

1200 UTC 17 December 2023

- Low over Florida
  - Limited moisture transport to Northeast
- High-pressure system over the Atlantic
  - Strong gradient restricted to the south
- Weak wind anomalies in the northeast (< 2.5 σ; Fig. 3a)
- Strong IVT values restricted to the south
  - **< 400 kg $m^{-1}s^{-1}$** in the northeast (Fig. 3b)

+ 24 hours – 1200 UTC 18 December 2023

- Atlantic high-pressure remains stationary
- Low moves over the mid-Atlantic
  - Generates a strong gradient over the northeast
- Strong wind anomalies in the northeast (> 4 σ; Fig. 3c)
- Northeast IVT > **1800 kg $m^{-1}s^{-1}$** (Fig. 3d)
  - "Extreme" for winter Northeast ARs
  - Moisture transported from Gulf of Mexico

V. Gulf Low – January 6th, 2024

Cyclogenesis occurs on 01/05 over Gulf of Mexico

1200 UTC 6 January 2024

- Low over the mid-Atlantic states
- High-pressure system over the Atlantic to the northeast of the low
  - Strong gradient restricted to the south
- Negative wind anomalies in the northeast (up to -2 σ; Fig. 4a)
- Strong IVT values restricted to the south
  - **< 500 kg $m^{-1}s^{-1}$** in the northeast (Fig. 4b)

+ 24 hours – 1200 UTC 7 January 2024

- Low moves directly over the northeast
- Atlantic high-pressure moves east
  - Decreases the gradient over the northeast
- Negative wind anomalies remain in the northeast (-2 σ; Fig. 4c)
- Northeast IVT **< 250 kg $m^{-1}s^{-1}$** (Fig. 4d)
  - AR moves over the Atlantic Ocean with IVT **~800 kg $m^{-1}s^{-1}$**

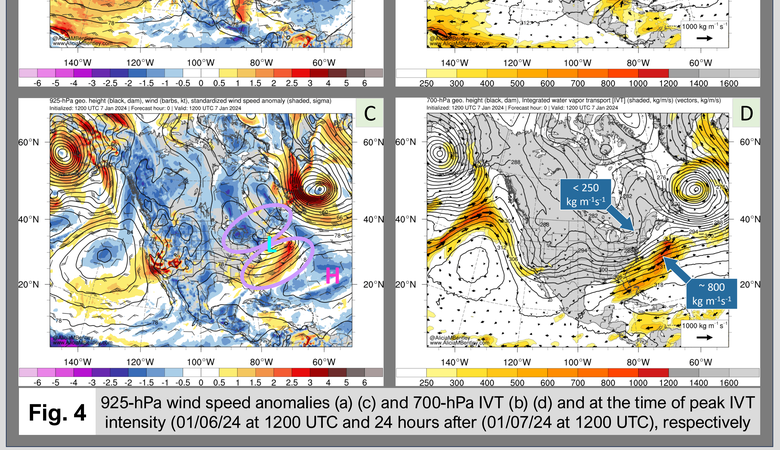


Fig. 4 925-hPa wind speed anomalies (a) (c) and 700-hPa IVT (b) (d) and at the time of peak IVT intensity (01/06/24 at 1200 UTC and 24 hours after (01/07/24 at 1200 UTC), respectively

VI. Conclusion

This study examined three ARs that occurred in the northeast U.S. to evaluate how different ETC pathways impact AR intensification. A stationary high-pressure system over the Atlantic Ocean has a critical role in creating a strong pressure gradient over the northeast. This increases wind speeds and transports moisture from the Gulf of Mexico, resulting in enhanced values of IVT. Without this mechanism, Alberta Clipper ETCs, as seen on December 11th, 2023, would not tap into enough moisture to achieve high IVT values because they originate far from moisture sources. Alternatively, the Gulf Low, such as the AR on December 18th, 2023 originates in a moisture-rich area, but the enhanced wind speed and the trajectory of the cyclone transport water vapor specifically to the northeast region. When the Atlantic high-pressure system does not remain stationary, as seen on 6 January 6 2024, the IVT values in the Northeast do not reach extreme values because the intensity of the pressure gradient is not maintained over this region.

References:

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