CW3E Event Summary: Helene Predecessor Rain Event

Center for Western Weather and Water Extremes
Scripps Institution of Oceanography
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Summary of the Predecessor Rain Event prior to Hurricane Helene (2024)

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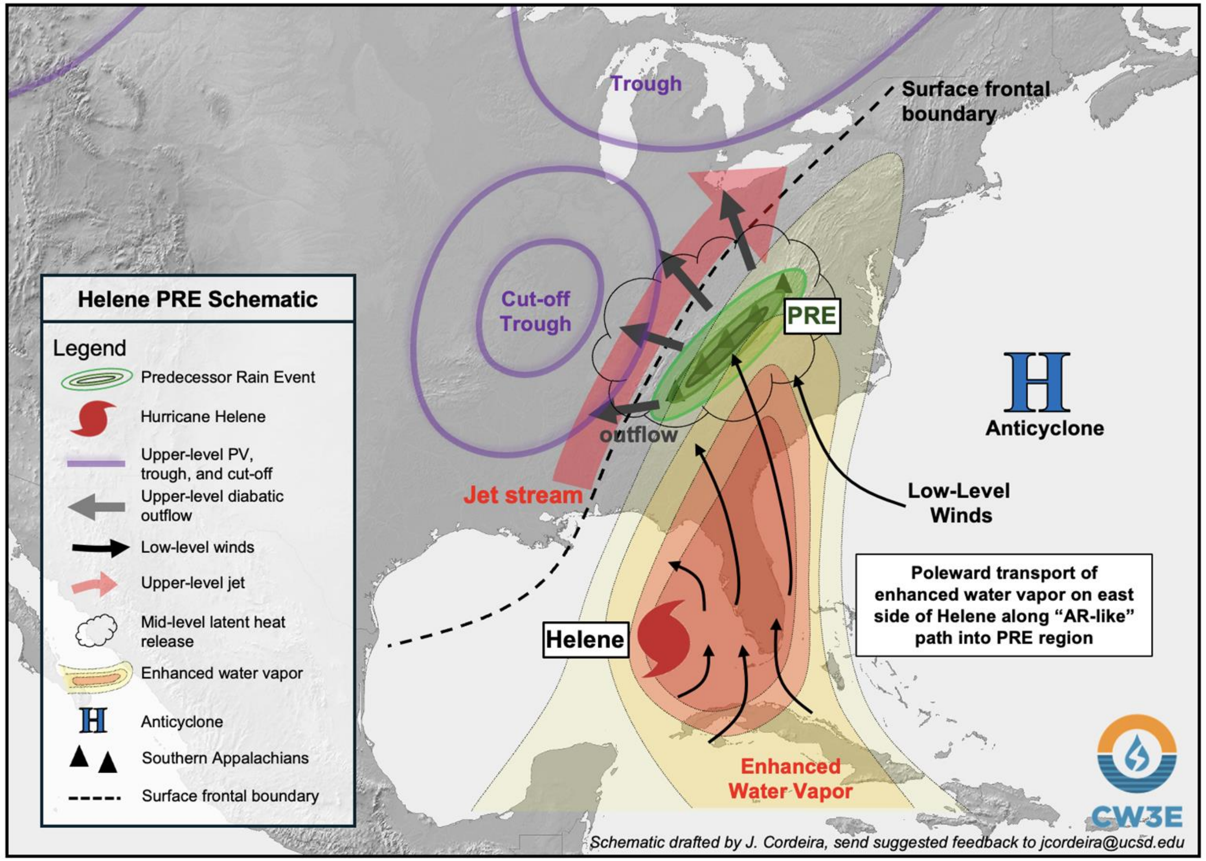

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Predecessor Rain Event contributes to extreme precipitation and catastrophic flooding in Southeast U.S.

- A heavy rainfall event occurred over the Southern Appalachians well in advance of Hurricane Helene on 26 & 27 September 2024. These events are referred to as **predecessor rain events (PREs).**

- PREs are "...coherent mesoscale (10s-100s km) regions of heavy rainfall, with rainfall rates ≥100 mm in 24 h, that can occur approximately 1000 km poleward of recurving tropical cyclones." as first defined in Cote (2007) and summarized by Galarneau et al. (2010).

- Rainfall totals from t**he combination of the PRE and Helene** exceeded 12 inches over a broad area of eastern Tennessee and western North Carolina, with totals exceeding 20 inches in some location where orographically enhanced precipitation brought significant rainfall to the high elevations of the Southern Appalachians. The antecedent PRE likely turned a moderate flood event into the observed catastrophic event.

- Sustained extreme rainfall was **caused by the atmospheric river (AR)-like poleward transport of enhanced water vapor on the east side of Helene prior to landfall**, the interaction of this moisture with terrain, and a favorable synoptic set-up (e.g., upstream cut-off trough, surface frontal boundary, upper-level jet, and western North Atlantic anticyclone).

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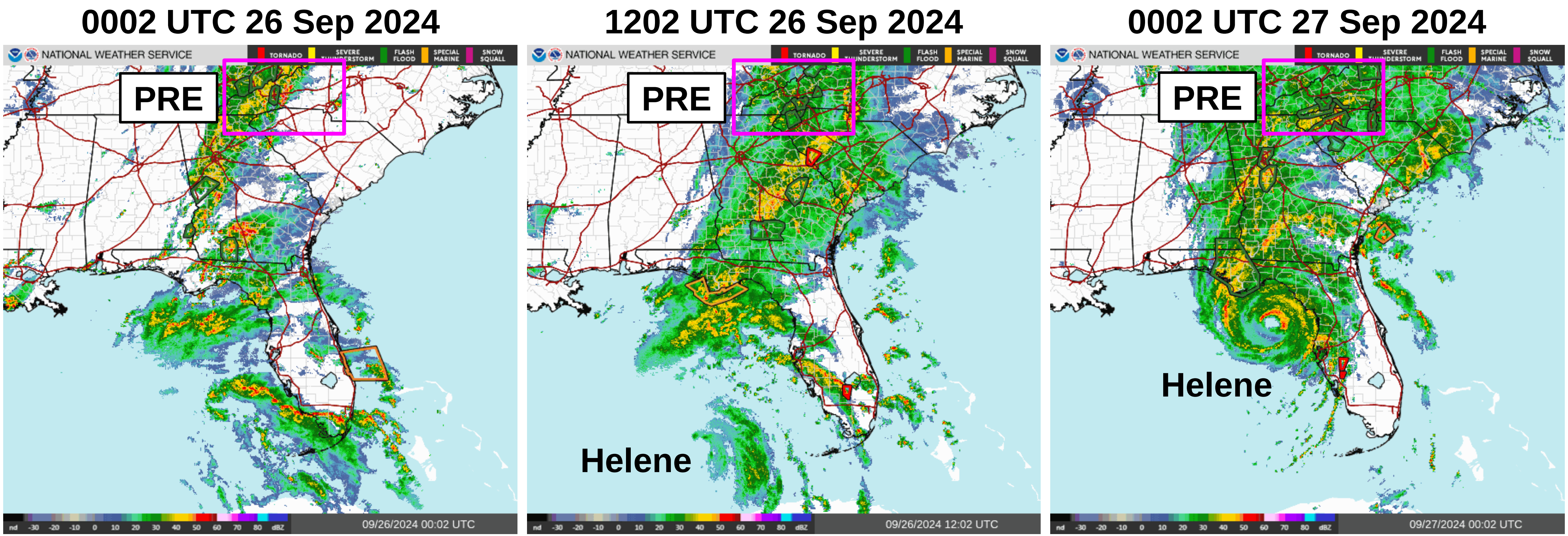

National Weather Service radar reflectivity with overlaid watches, warnings, and advisories prior to the landfall of Hurricane Helene on 26-27 September 2024. The images were obtained from an archive at https://bmcnoldy.earth.miami.edu/tropics/radar/

A region of heavy precipitation occurred over southern Appalachians far in advance of Hurricane Helene on 26 and 27 September 2024, that is representative of what is known as a **predecessor rain event.**

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What is a predecessor rain event?

Definition: "PREs are coherent mesoscale regions of heavy rainfall, with rainfall rates ≥100 mm in 24 h, that can occur approximately 1000 km poleward of recurving tropical cyclones." - First defined by Cote (2007) and summarized in Galarneau et al. (2010).

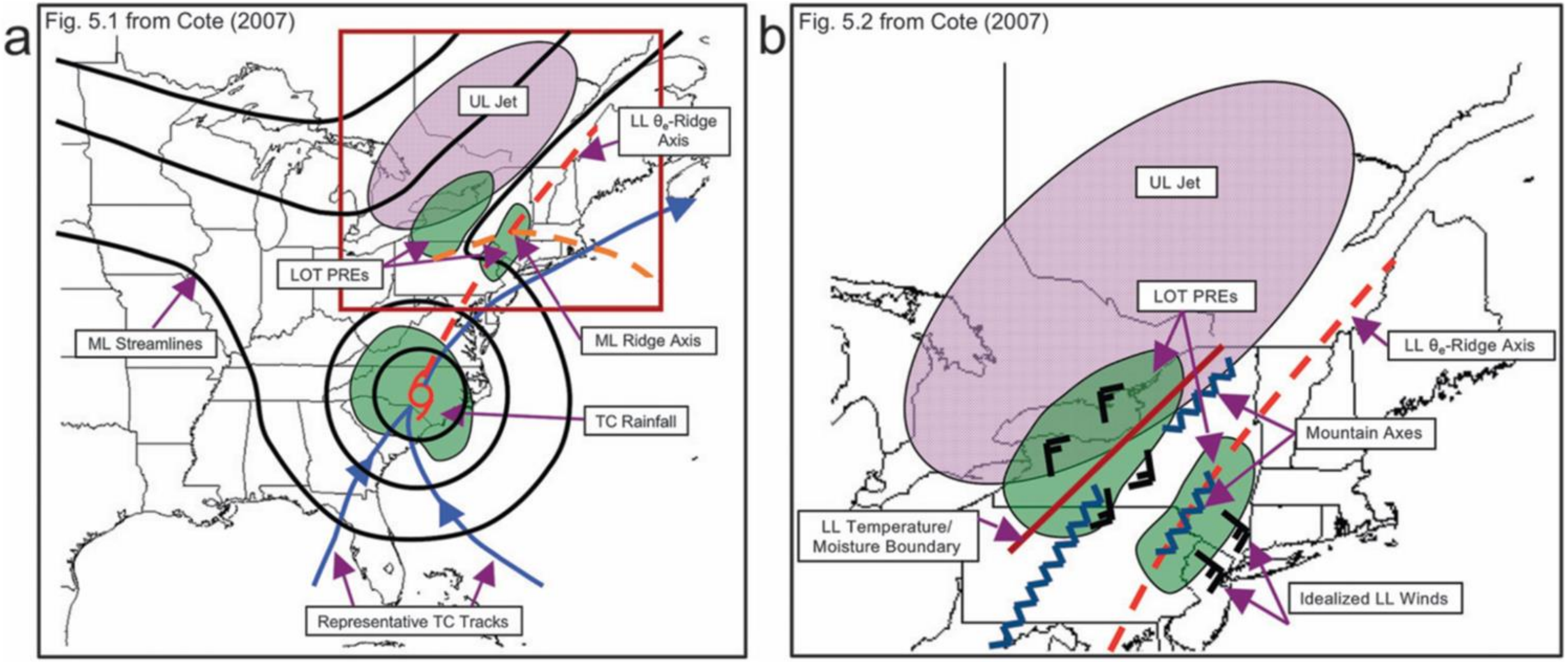

FIG. 24 from Galarneau et al. (2010): (a) Conceptual model of the synoptic-scale environment associated with LOT and AC PREs in advance of TCs, revised and updated from Bosart and Carr (1978). Position of TC is given by the tropical storm symbol. Representative TC tracks are marked with solid blue arrows. Low-level (LL) features are representative of the 925-hPa level, midlevel (ML) features are representative of the 700-hPa level, and upper-level (UL) features are representative of the 200-hPa level. (b) Boxed region from (a) indicating the area of the mesoscale and physiographic conceptual model. [Reproduced from Figs. 5.1 and 5.2 in Cote (2007).]

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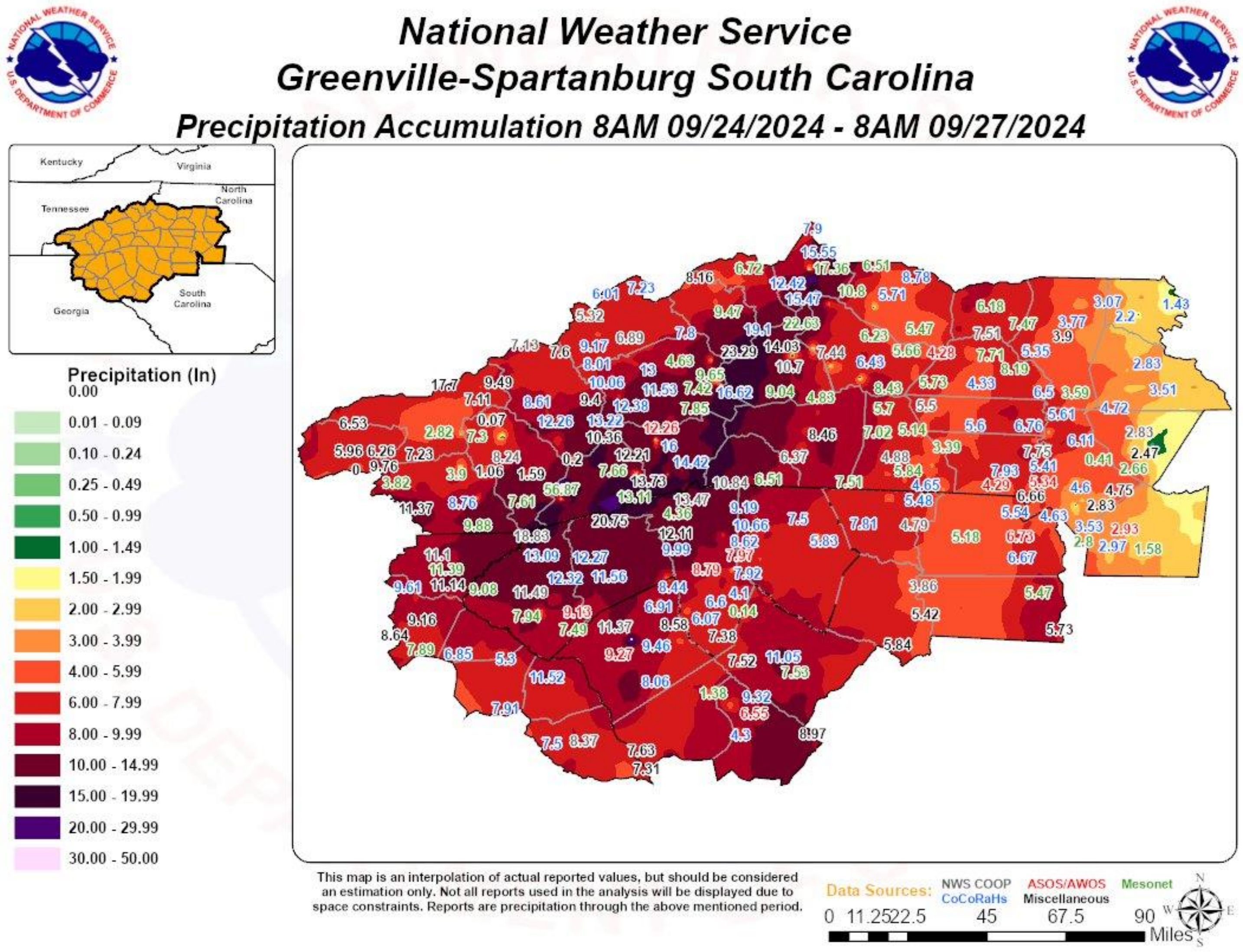

Image courtesy NWS GSP: https://x.com/NWSGSP/status/1839701767552147752/photo/1

Precipitation Totals

- Storm total precipitation, inclusive of the predecessor rain event and the remnants of Hurricane Helene over western North Carolina and eastern Tennessee exceeded 12 inches, with localized observations exceed 20 inches.
- Locations in the Southern Appalachians at elevations that spanned 2000 to 6000+ feet received the most precipitation where terrain led to orographic enhancement.

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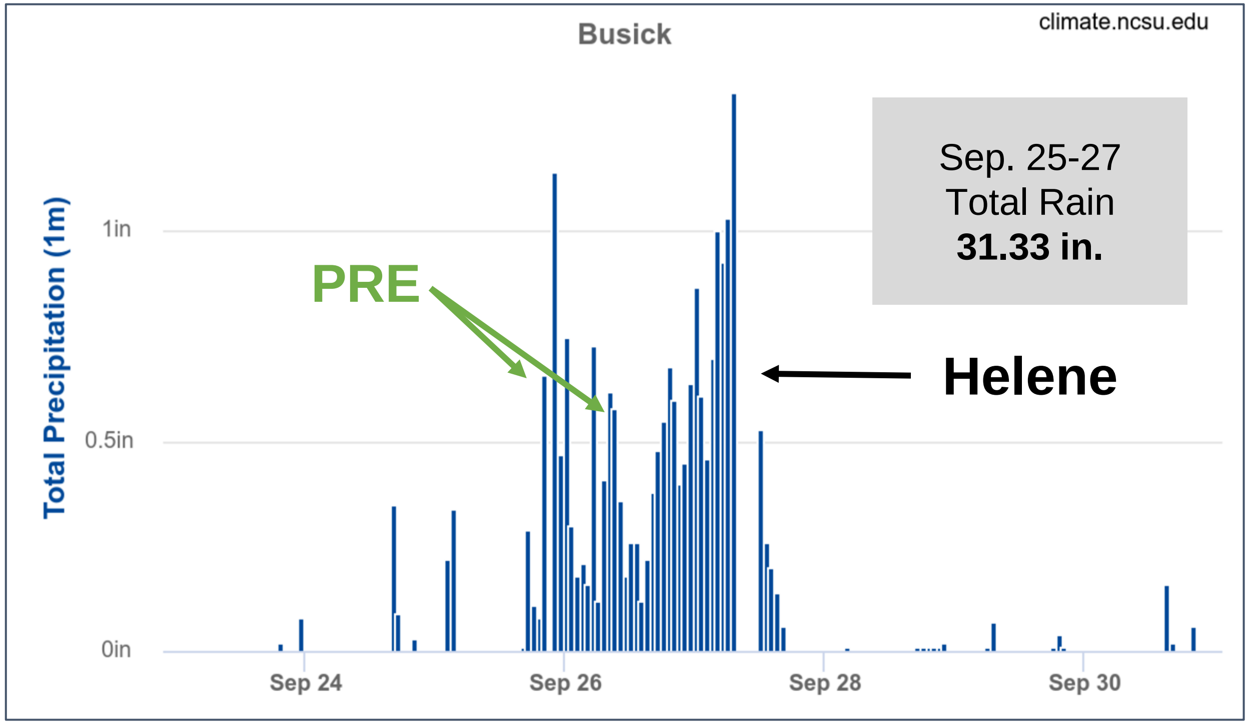

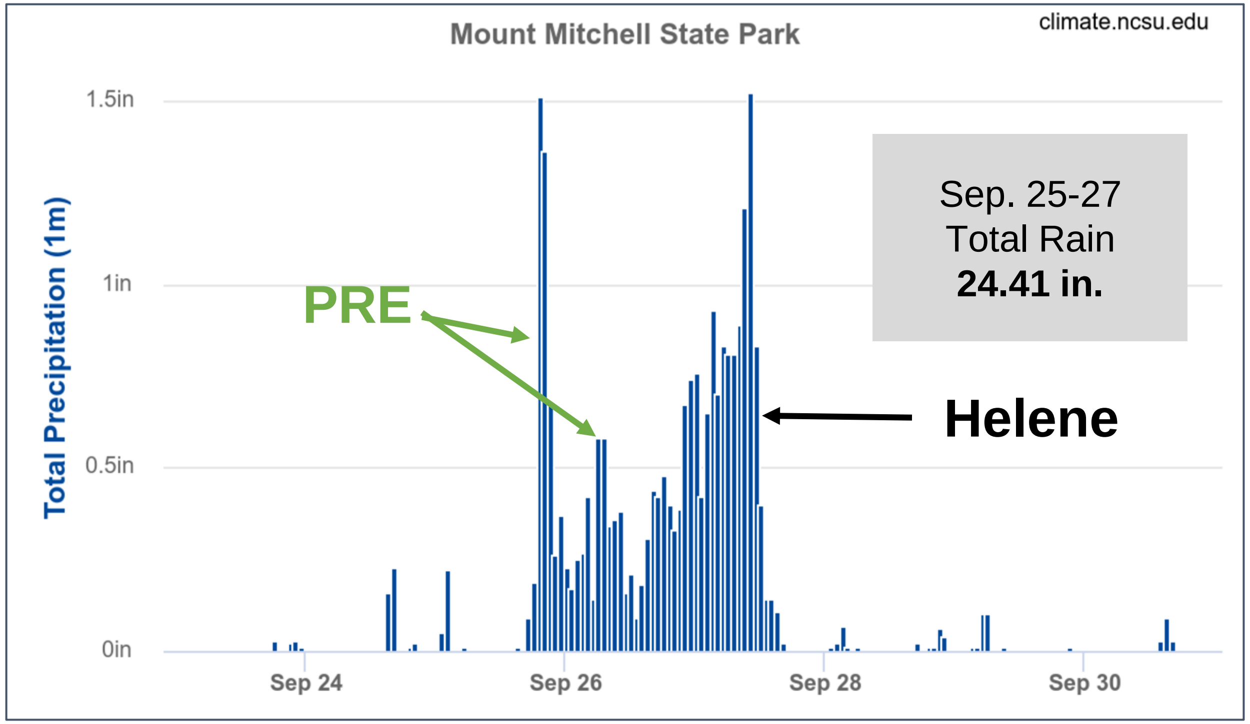

Hourly rainfall observations at the Busick RAWS (BSKN7) and Mount Mitchell State Park ECONet (MITC) weather stations between 24 Sep - 30 Sep 2024. Accessed via the North Carolina State Climate Office (https://products.climate.ncsu.edu/cardinal/scout/)

Examples of precipitation:

- Storm-total precipitation at Busick: 31.33” & at Mount Mitchell State Park: 24.41”
- Hourly rainfall observations from two stations located to the northeast of Asheville, NC illustrate the dual-peak maximum in precipitation associated with both the PRE and passage of Hurricane Helene.

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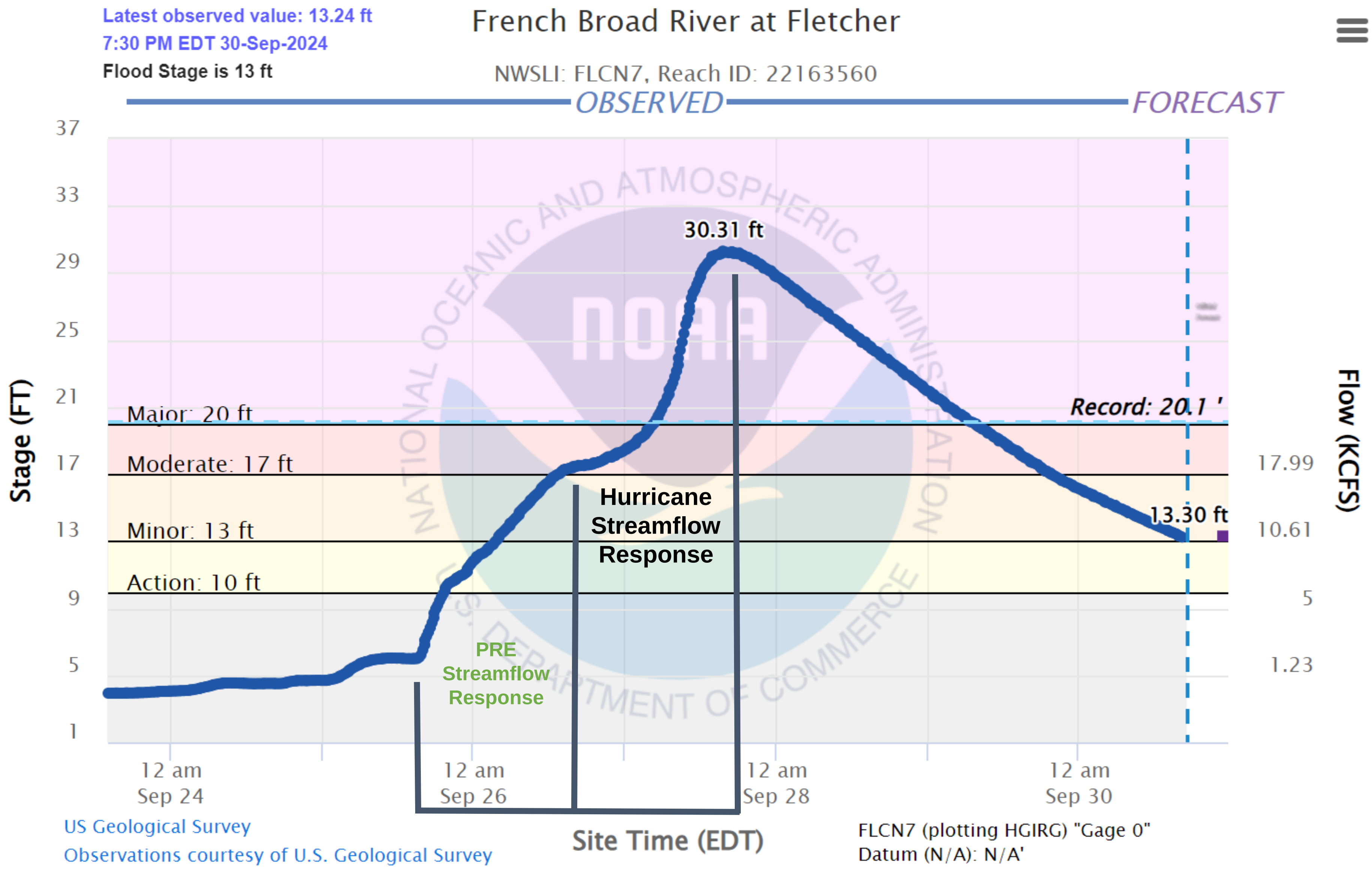

USGS stream gauge along the French Broad River near Fletcher, NC recorded a peak gauge height of 30.31 ft on 9/27, **exceeding the record flood at the same location by more than 10 feet.**

PRE would have produced moderate flooding on its own; however, the added precipitation from Helene then led to record (catastrophic) flooding thereafter.

Image courtesy NOAA with USGS data.

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Significant flooding along US 70 near Silver Creek (upper left), widespread flooding and damage surveyed via aircraft (upper right), and severe washout of Interstate 40 near the North Carolina/Tennessee border

Upper Left:
https://x.com/NCDOT/status/1840391740009660893
Upper Right:
https://x.com/NCNationalGuard/status/1840456181787005399
Lower Left:
https://x.com/NCDOT/status/1840092022717157657

View of US 74 from I-40 during flooding 27 Sep. VS A normal view from a similar location, accessed via Google Street View.

https://x.com/NCDOT_Asheville/status/1839672315254059441

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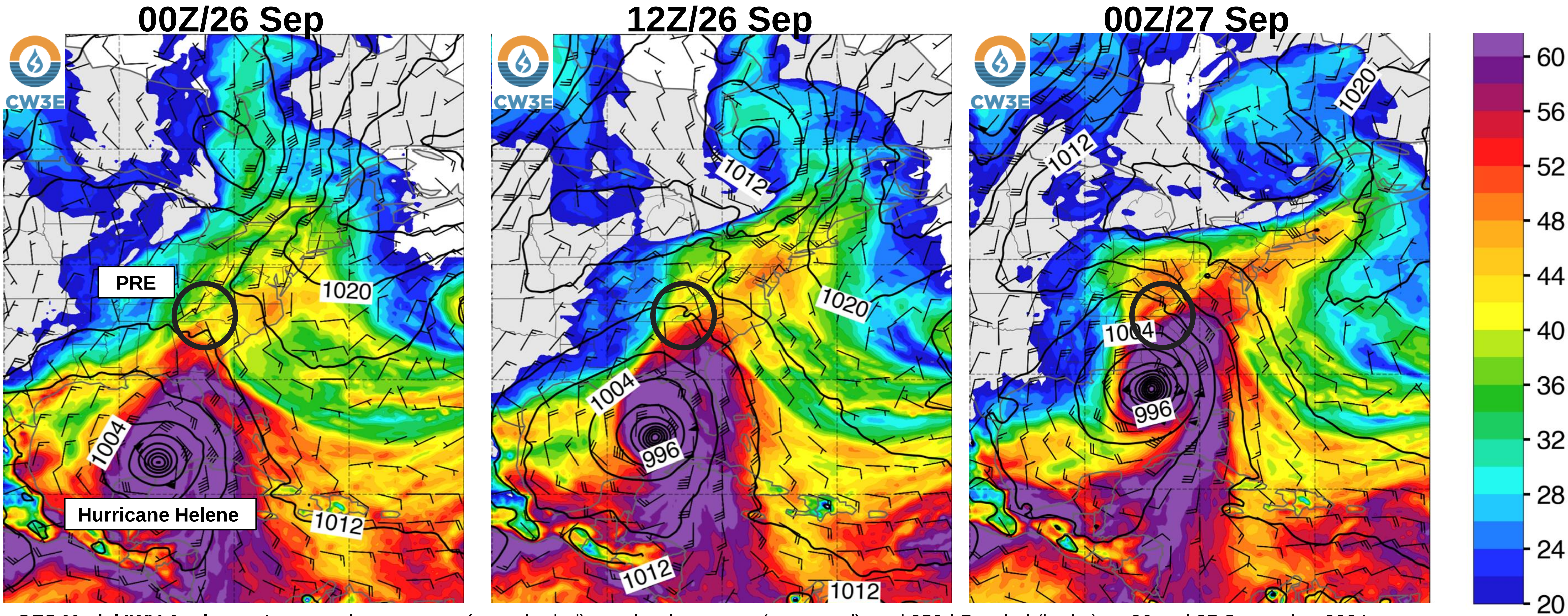

GFS Model IWV Analyses: Integrated water vapor (mm; shaded), sea level pressure (contoured), and 850-hPa wind (barbs) on 26 and 27 September 2024.

The PRE region is ahead of Helene and connected to hurricane through integrated water vapor (IWV; **shown above**) and water vapor transport (IVT). The enhanced IWV is transported poleward by the low-level winds out ahead of Helene and into the Southern Appalachians on 26 and 27 September 2024. There is inferred orographic ascent of this moisture by terrain, along with other factors not shown (an upstream trough and surface frontal boundary).

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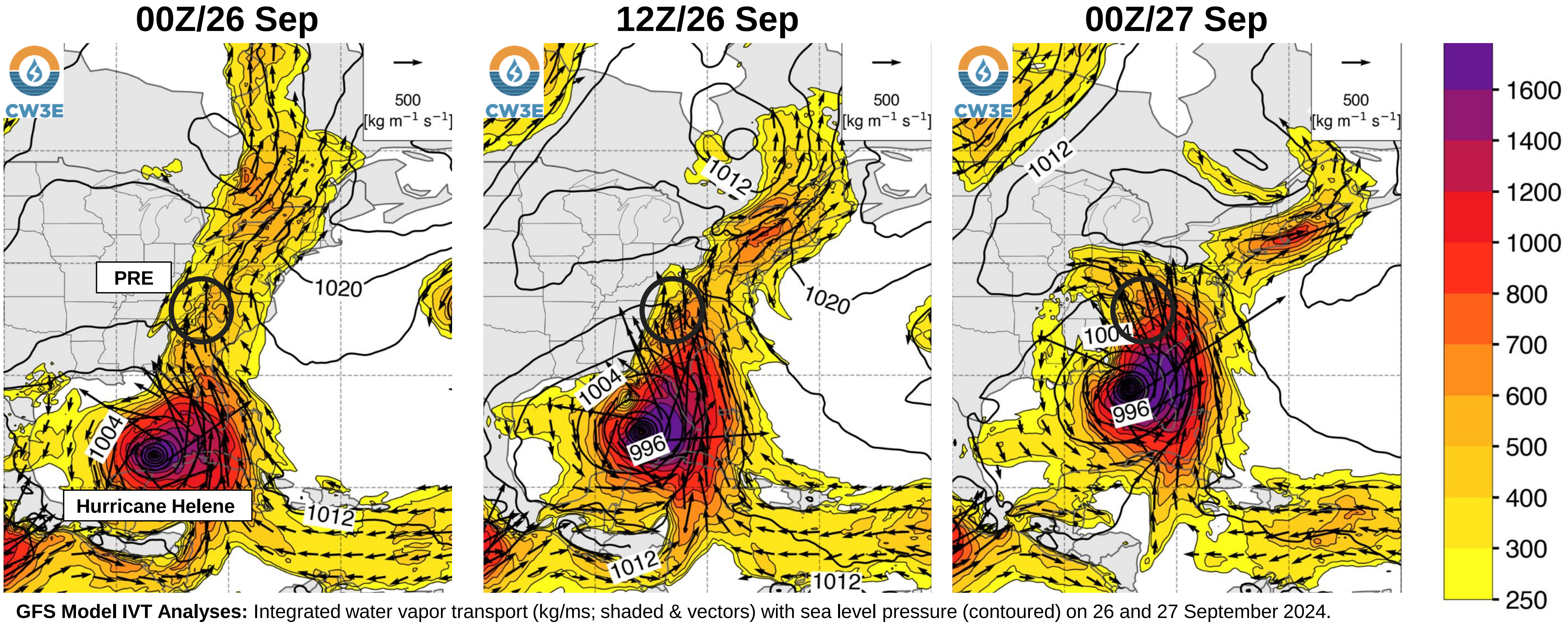

GFS Model IVT Analyses: Integrated water vapor transport (kg/ms; shaded & vectors) with sea level pressure (contoured) on 26 and 27 September 2024.

The PRE region is ahead of Helene and connected to hurricane through integrated water vapor (IWV) and water vapor transport (IVT; **shown above**). The enhanced IWV is transported poleward by the low-level winds out ahead of Helene and into the Southern Appalachians on 26 and 27 September 2024. There is inferred orographic ascent of this moisture by terrain, along with other factors not shown (an upstream trough and surface frontal boundary).

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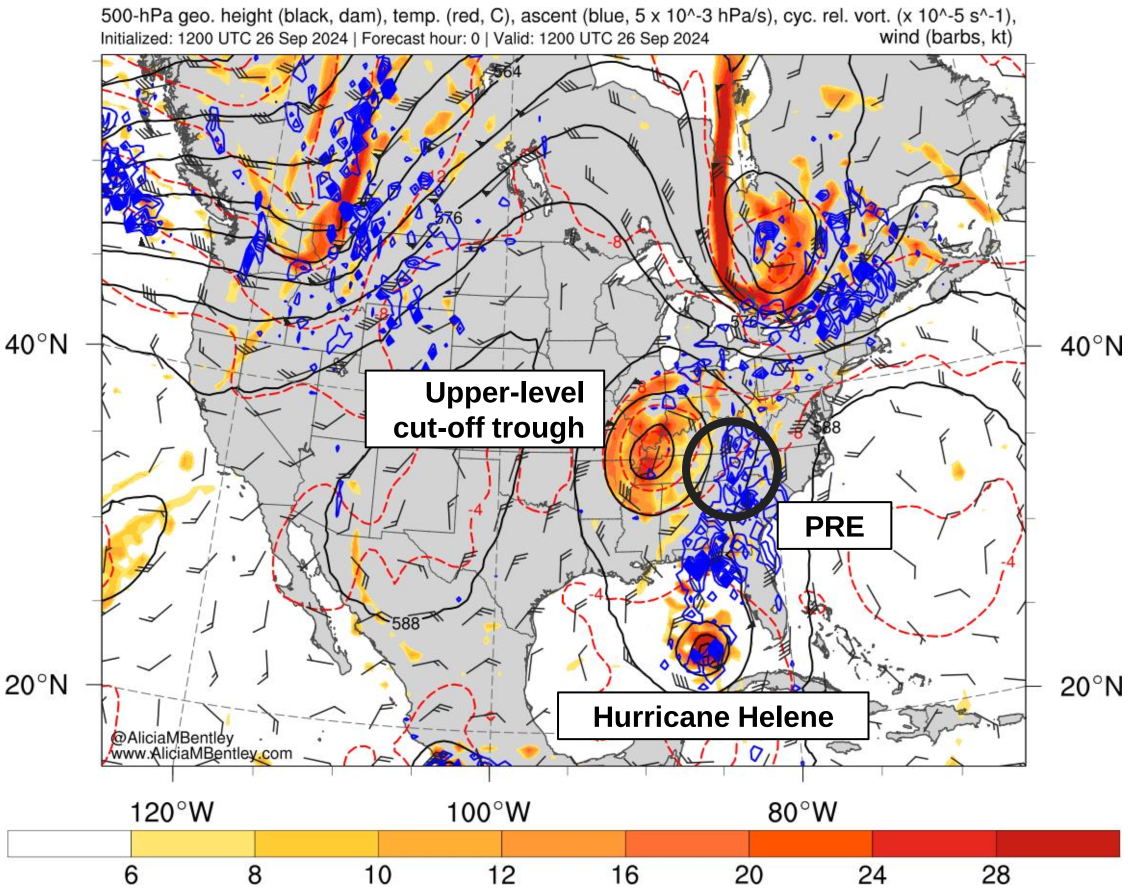

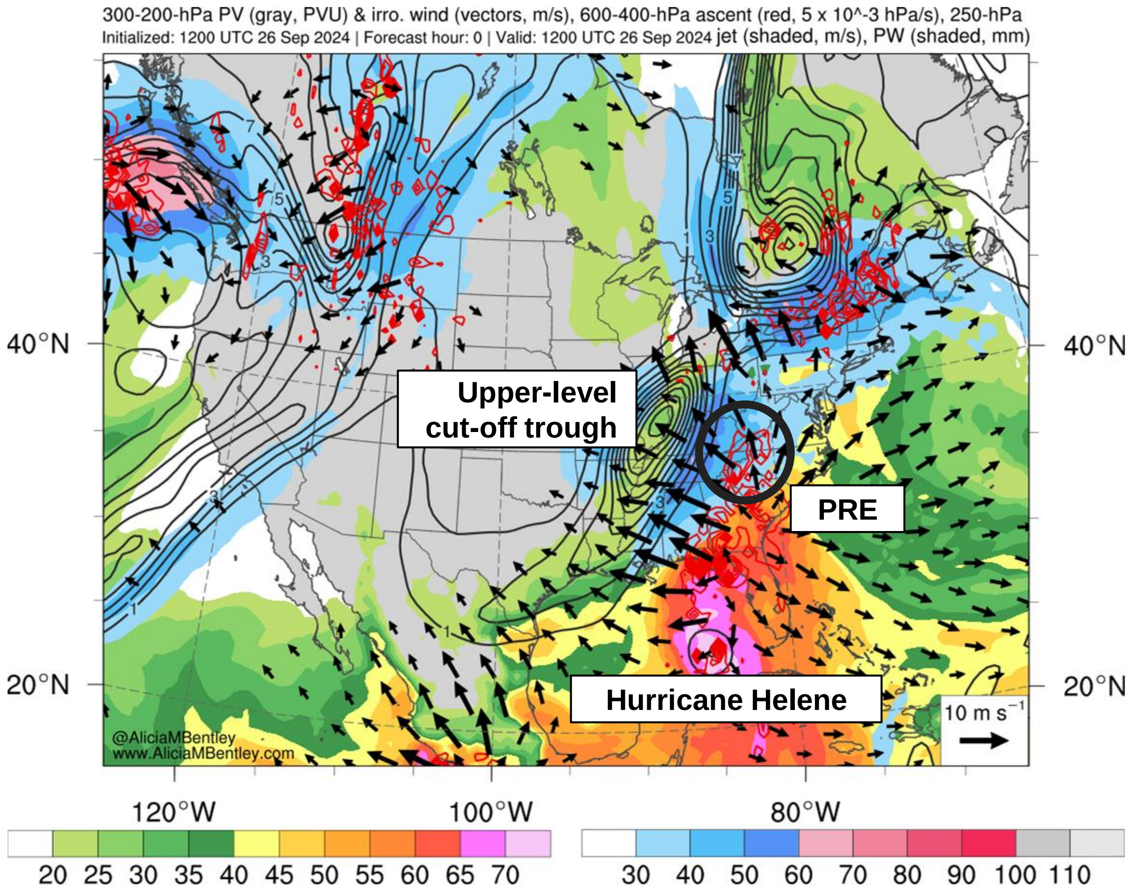

1200 UTC 26 September 2024: Left: 500-hPa geo. heights, relative vorticity, ascent, and wind. Right: 300-200-hPa potential vorticity, irrotational wind, 600-400-hPa ascent, 250-hPa winds, and integrated water vapor. Imagery adapted from www.AliciaBentley.com.

PREs are often very dynamic regions in the atmosphere featuring robust processes. In this case, an upstream cut-off trough provided additional synoptic-scale forcing ascent over the Southern Appalachians. The deep moist ascent of the precipitation with the PRE also produced diabatic outflow that reinforced gradients in upper-level PV that sustained favorable jet dynamics, producing a positive feedback loop for extreme precipitation.

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Predecessor Rain Events and Atmospheric Rivers

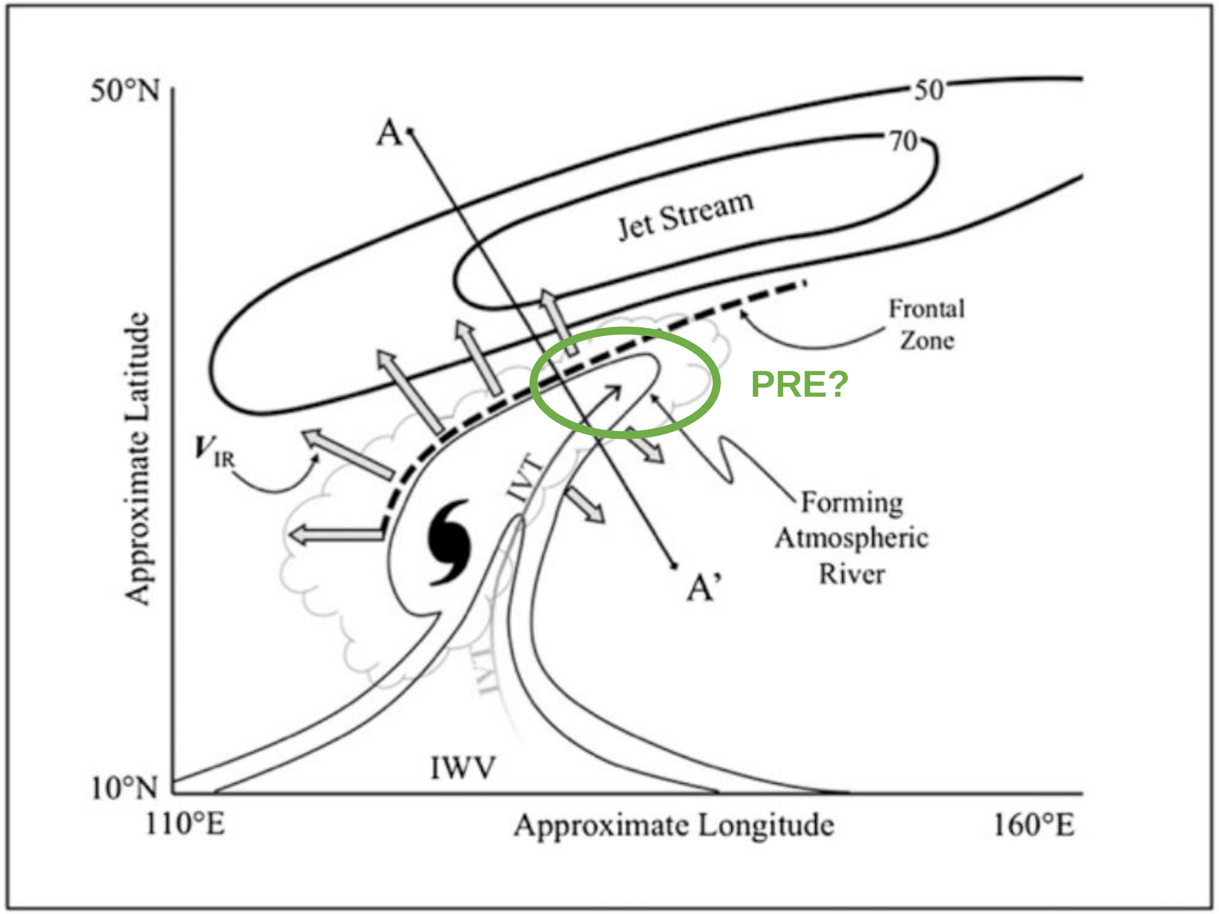

Fig. 11 from Cordeira et al. (2013) highlighting a schematic of enhanced poleward water vapor transport and IVT on the east side of a tropical cyclone, jet stream interaction, and the formation of an atmospheric river. Green oval and text added for emphasis.

Cordeira et al. (2013) discussed the similarities between PREs and ARs. They hypothesized that the poleward transport of water vapor on the east side of the tropical cyclone may take the form of an AR.

The physical processes that transport the water vapor away from the tropical cyclone in PREs often differ from those with ARs. For example, ARs derive their origin from the low-level jet in baroclinic (front-containing) environments, whereas PREs typically originate from water vapor advancing poleward by the TC's circulation in combination with broader synoptic-scale circulations (i.e., the confluent deformation field created by the TC and a downstream anticyclone).

An appropriate phrasing may be "AR-like" to describe the sometimes long-narrow transport of water vapor poleward of a TC that may lead to a PRE.

While not all PREs form in association with ARs (or vice versa), they represent an important mechanism associated with the poleward transport of tropical moisture into midlatitudes during extreme precipitation events.

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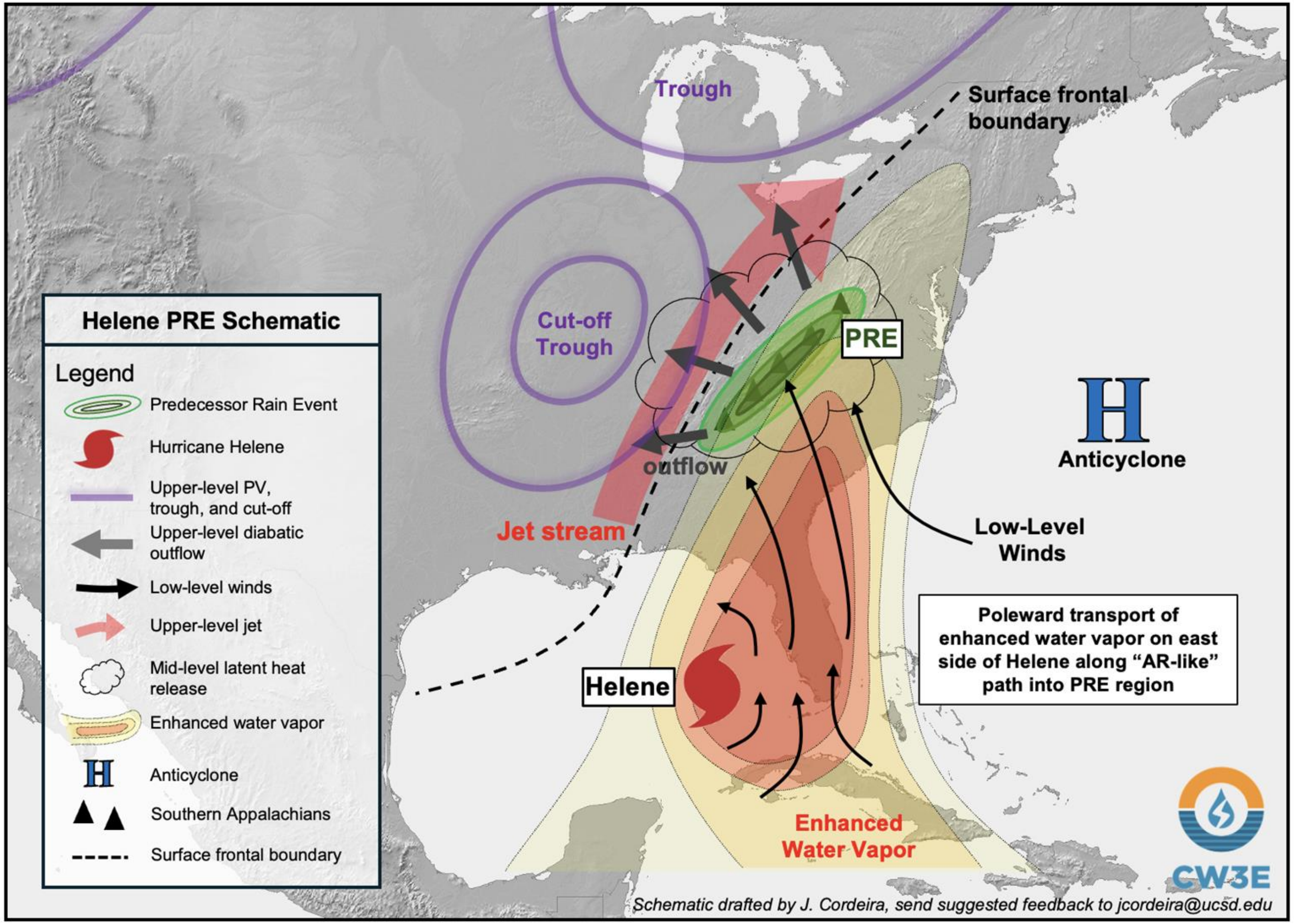

A schematic interpretation of the meteorological ingredients leading to extreme precipitation and catastrophic flooding over the Southern Appalachians with a predecessor rain event ("PRE") and Hurricane Helene are shown at left.

These ingredients include the "AR-like" poleward transport of enhanced water vapor on the east side of Helene prior to landfall, the interaction of this moisture with terrain, and a favorable synoptic set-up (e.g., upstream cut-off trough, surface frontal boundary, upper-level jet, and western North Atlantic anticyclone).

Schematic drafted by J. Cordeira and feedback is always welcome to improve the quality of the analysis. Contact: jcordeira@ucsd.edu