

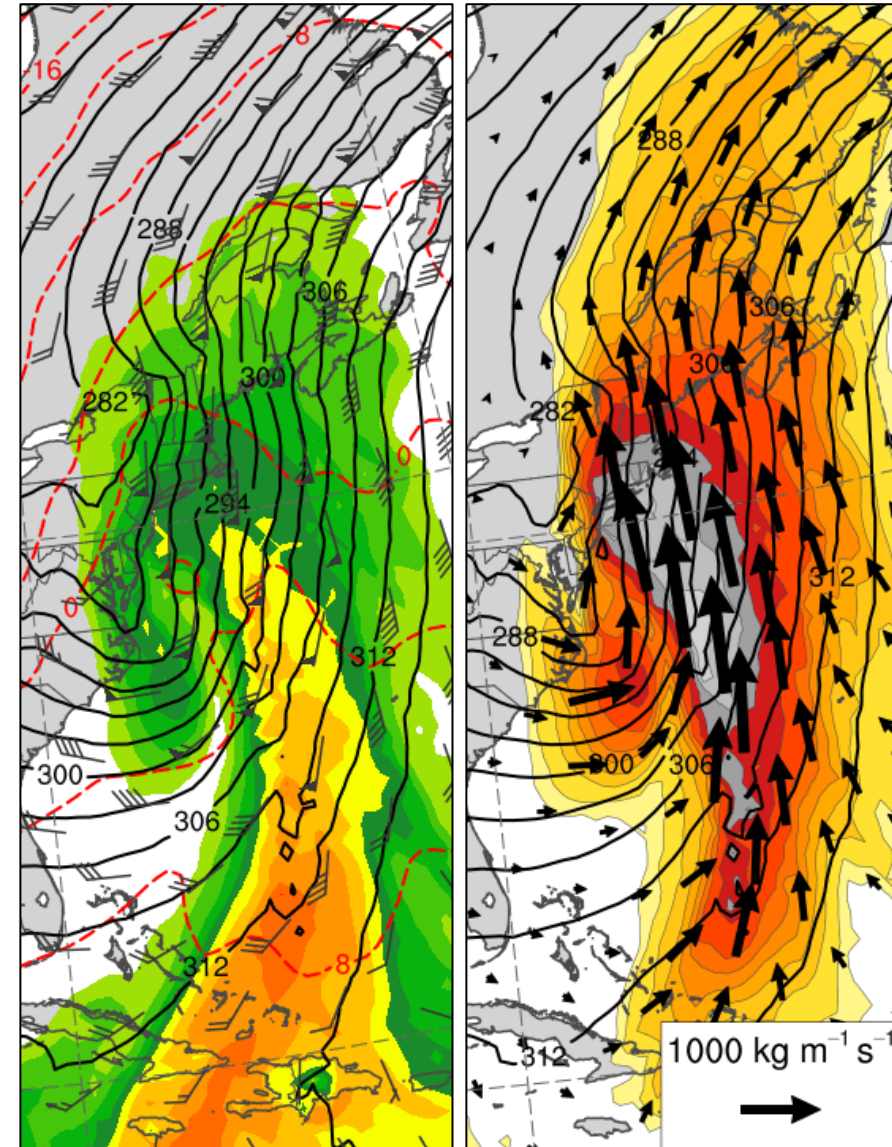


Summary of the 17–18 December 2023 East Coast Cyclone and Atmospheric River Event

With a focus on impacts in the Northeast U.S.

Jay Cordeira, PhD

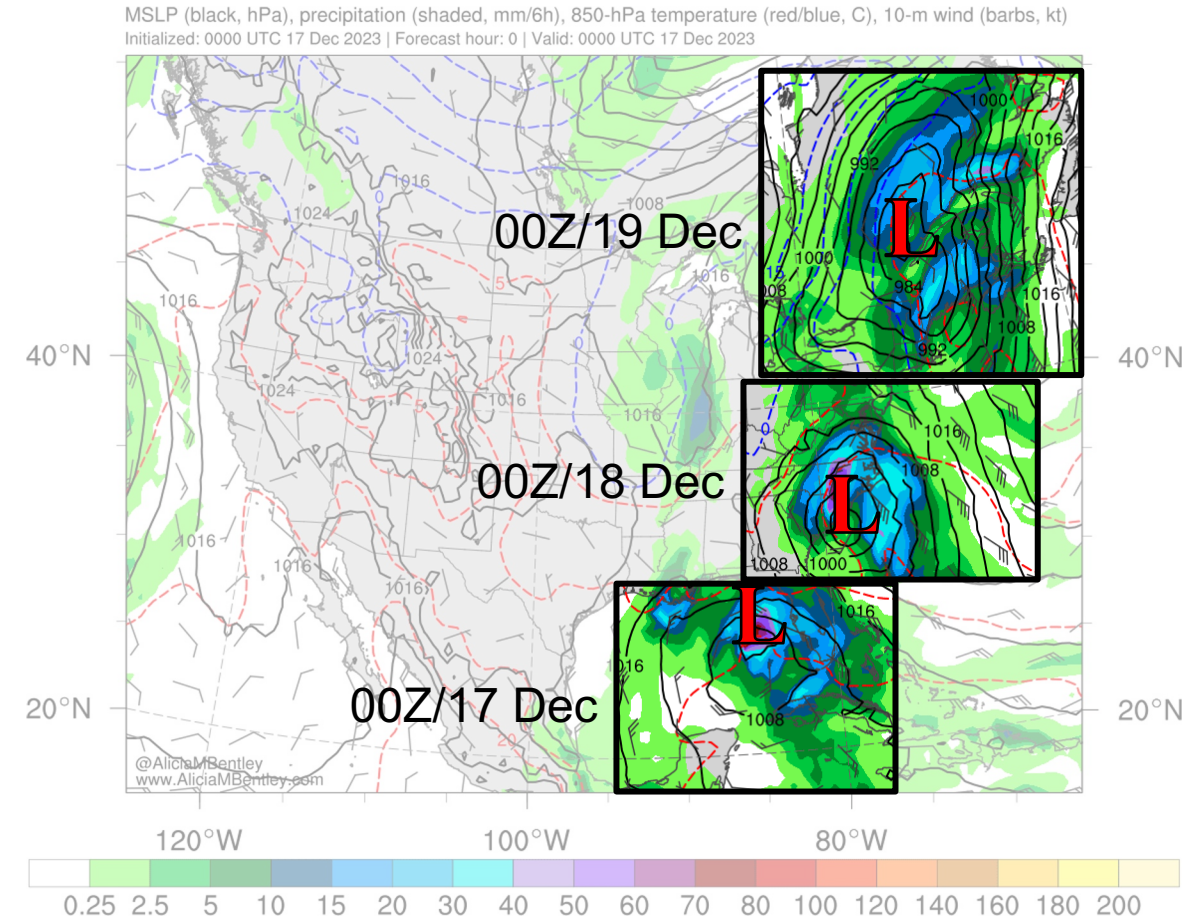
Center for Western Weather and Water Extremes
Scripps Institution of Oceanography
University of California San Diego





Summary

- A storm developed over the Gulf of Mexico on 17 December 2023 and tracked along the East Coast inland through New England on 18 December 2023
- The storm contained an exceptional atmospheric river that produced 3–12 inches of orographic enhanced rain and winds >50 mph along the coast
- Impacts included inland freshwater water flooding across Mid-Atlantic and Northeast regions and coastal surge-induced seawater flooding from South Carolina through Maine, and widespread power outages
- Flooding in northern New England was exacerbated by rain-on-snow and in southern New England by prior-week flooding



MSLP (hPa), precipitation, 850-hPa temperature, and 10-m winds with cropped snapshots at 00Z/17, 18, and 19 December 2023. Images adapted from Dr. Alicia Bentley



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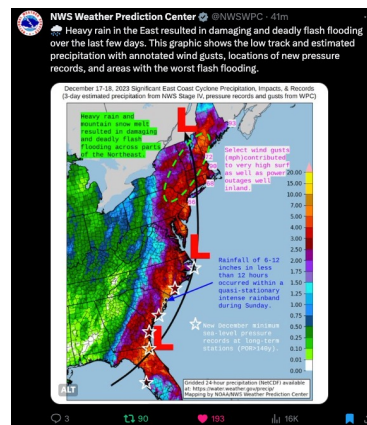
PRECIPITATION SCIENCE AND PREDICTION GROUP

Contact:
Jay Cordeira
jcordeira@ucsd.edu
<http://cw3e.ucsd.edu>

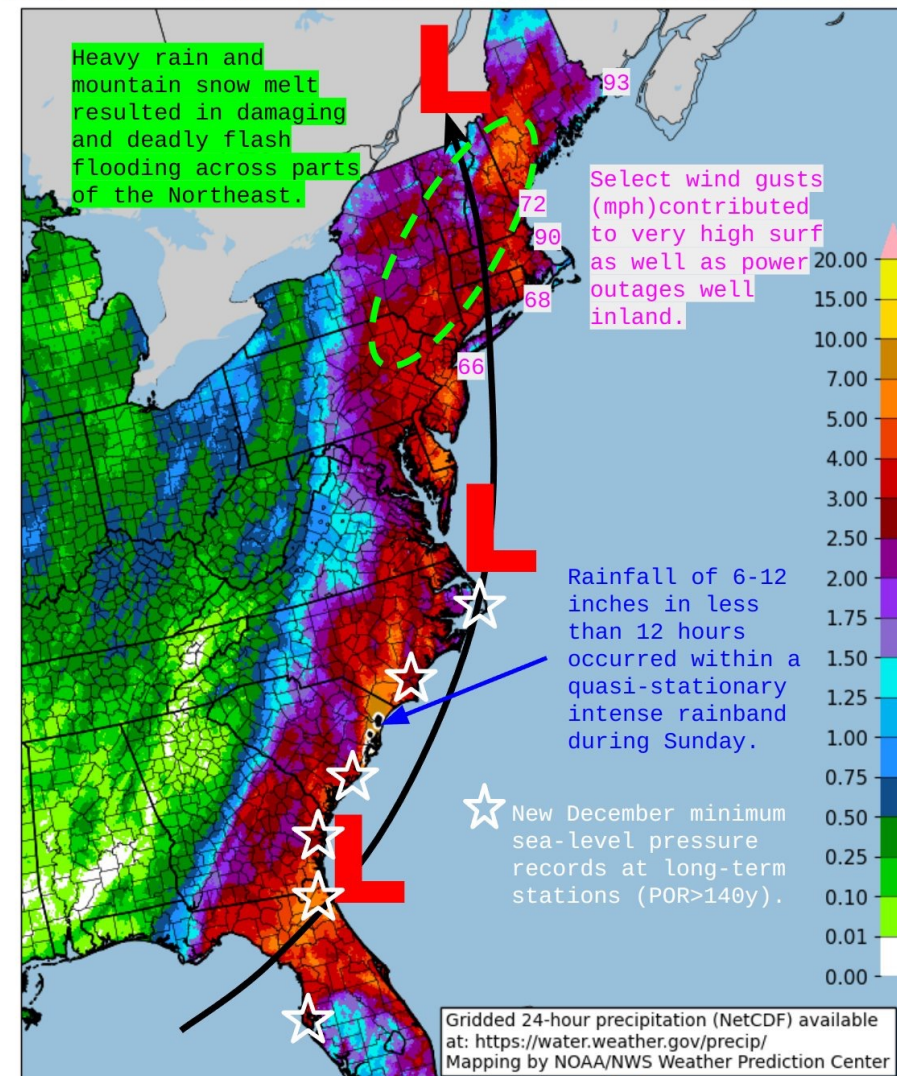
Summary

The NWS Weather Prediction Center offered the following event summary that was posted on X (Twitter) on 19 December 2023:

“Heavy rain in the East resulted in damaging and deadly flash flooding over the last few days. This graphic shows the low track and estimated precipitation with annotated wind gusts, locations of new pressure records, and areas with the worse flash flooding”



December 17-18, 2023 Significant East Coast Cyclone Precipitation, Impacts, & Records (3-day estimated precipitation from NWS Stage IV, pressure records and gusts from WPC)



Gridded 24-hour precipitation (NetCDF) available at: <https://water.weather.gov/precip/>
Mapping by NOAA/NWS Weather Prediction Center



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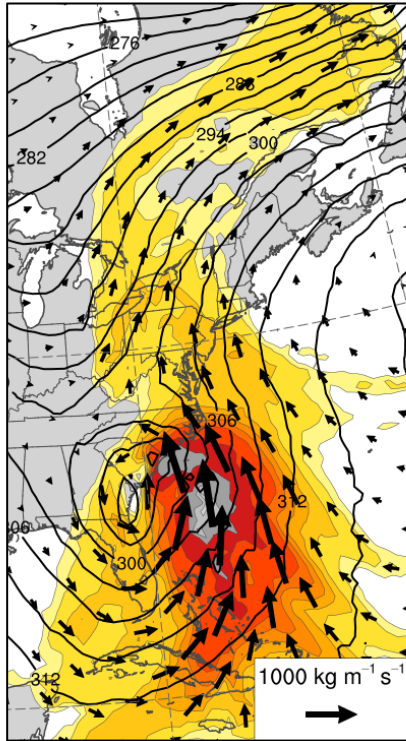
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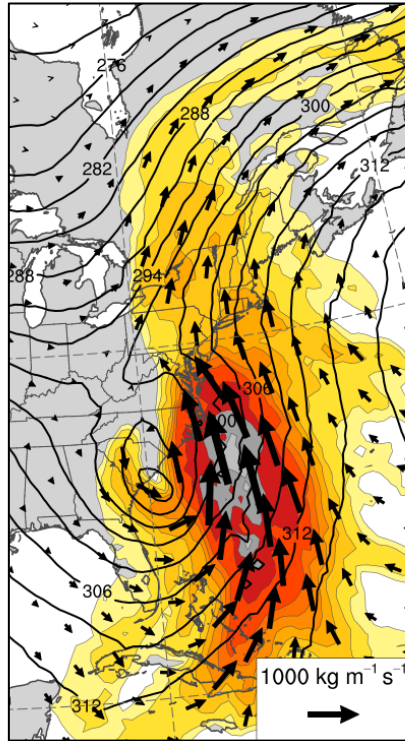
jcordeira@ucsd.edu

<http://cw3e.ucsd.edu>

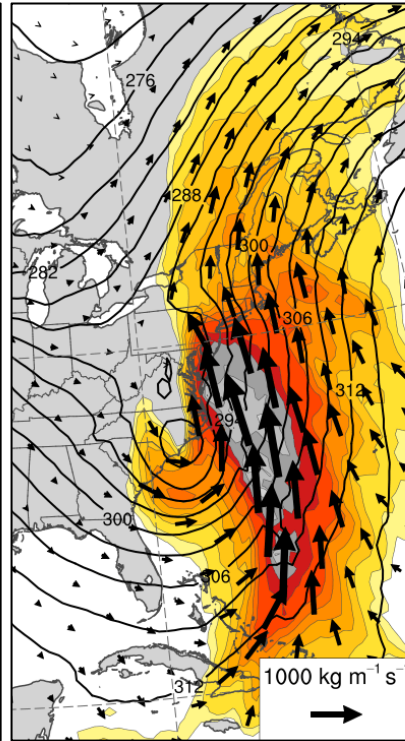
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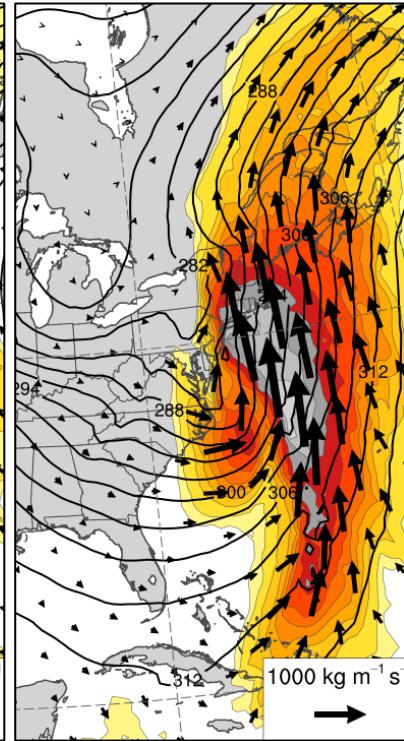
b. 0000 UTC 18 Dec 2023



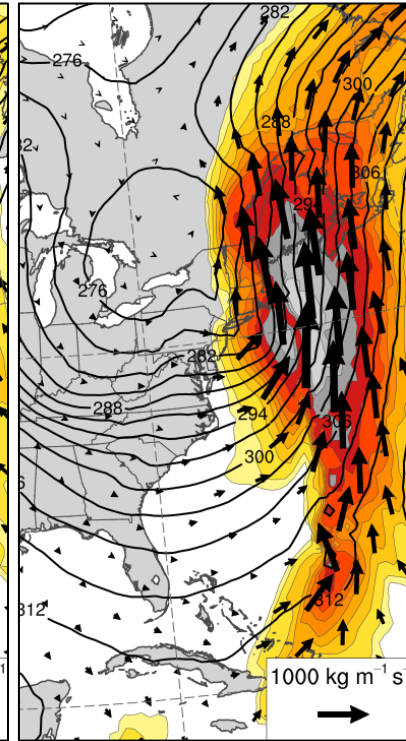
c. 0600 UTC 18 Dec 2023



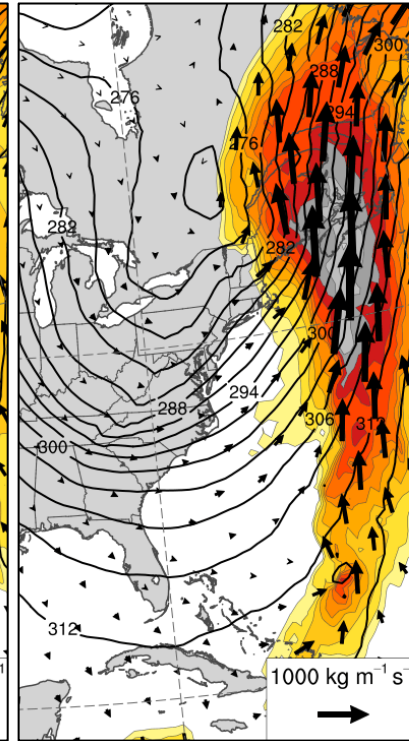
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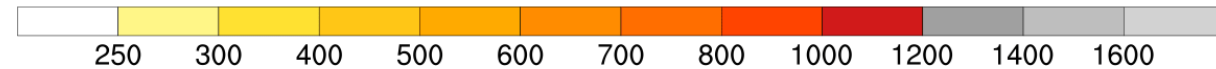
e. 1800 UTC 18 Dec 2023



f. 0000 UTC 19 Dec 2023



Select GFS Model Analyses of 700-hPa Geopotential Height, IVT magnitude, and IVT Direction (adapted from imagery provided by Dr. Alicia Bentley).



The storm contained an “Exceptional AR5” Event

- The atmospheric river contained integrated vapor transport magnitudes >1600 kg/ms in its core that extended from south-southeast to north-northwest into New England.
- Atmospheric river conditions (IVT mag. >250 kg/ms) persisted for >24 hours, making this an **exceptional AR5 event according to the Ralph et al. (2019) AR scale**.
- Atmospheric rivers along the East Coast are not rare (e.g., Kaminski et al. 2023*); however, storms of this magnitude and orientation are climatologically abnormal.
- Several recent and historic flooding events in New England are associated with similar “climatologically abnormal” atmospheric rivers (e.g., October 2017, March 1936).

*<https://journals.ametsoc.org/view/journals/apme/62/1/JAMC-D-21-0253.1.xml>



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Jay Cordeira

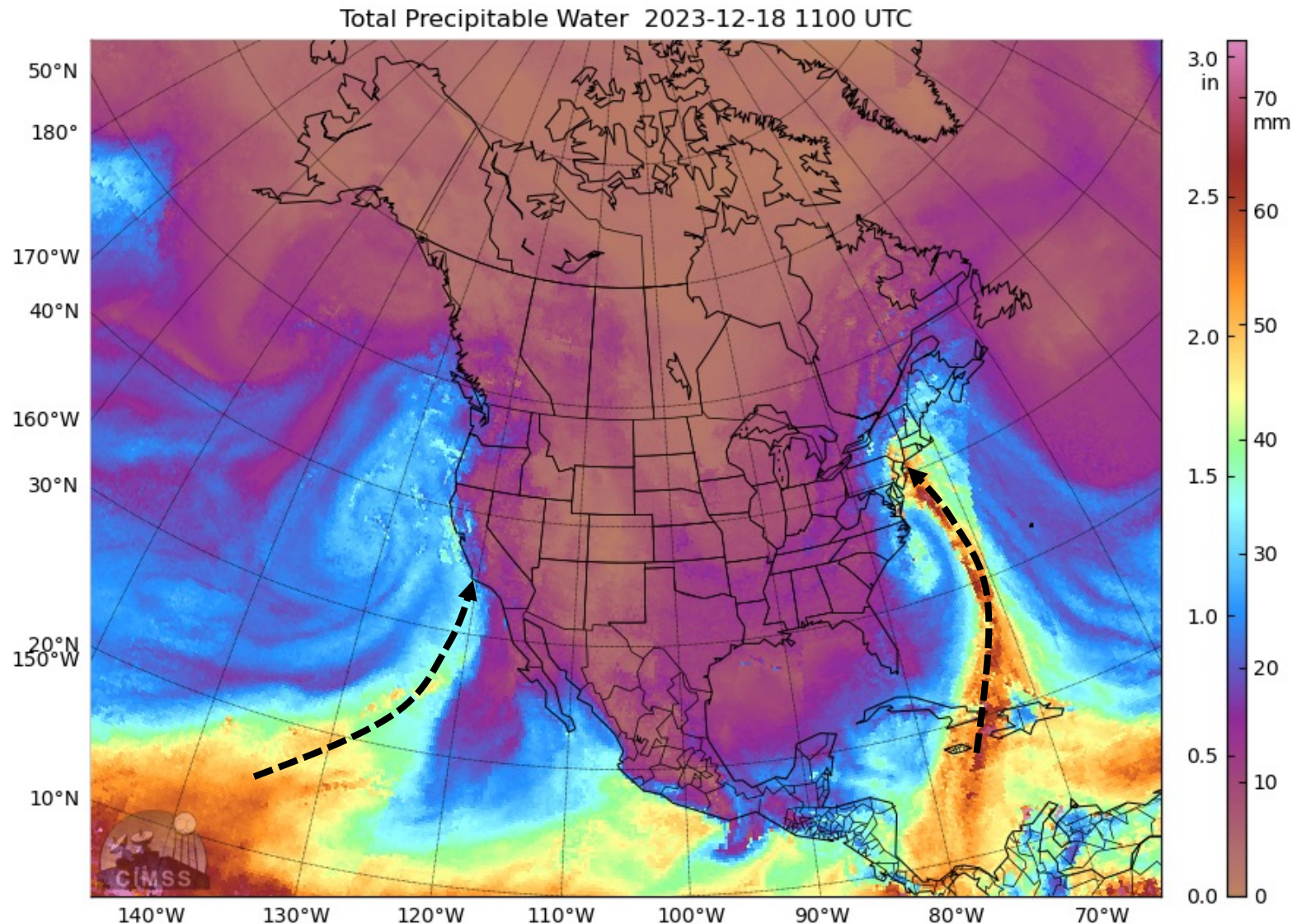
jcordeira@ucsd.edu

<http://cw3e.ucsd.edu>

Satellite-derived integrated water vapor identified two landfalling atmospheric rivers in the U.S. on the morning of 18 December 2023.

A weak atmospheric river made landfall in California associated with a cut-off cyclone while the strong atmospheric river made landfall in the Mid-Atlantic and Northeast.

The storm along the East Coast contained satellite-derived integrated water vapor values >50–60 mm.



Satellite-derived integrated water vapor courtesy SSEC at the University of Wisconsin



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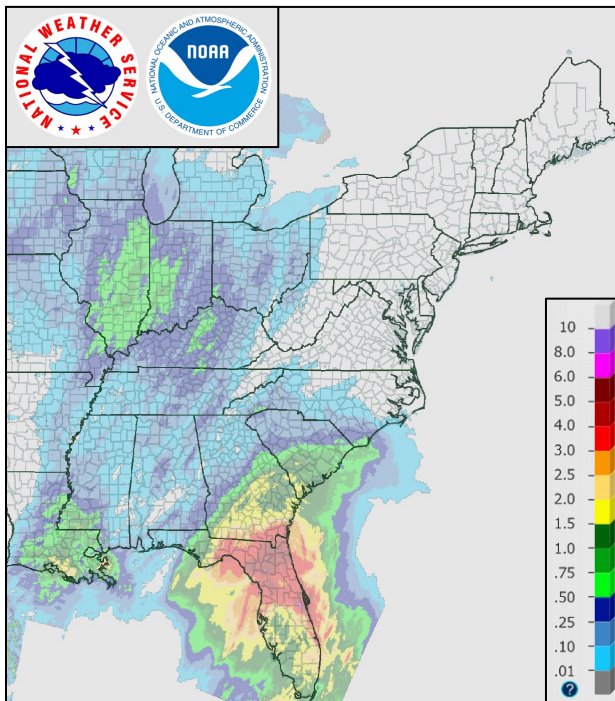
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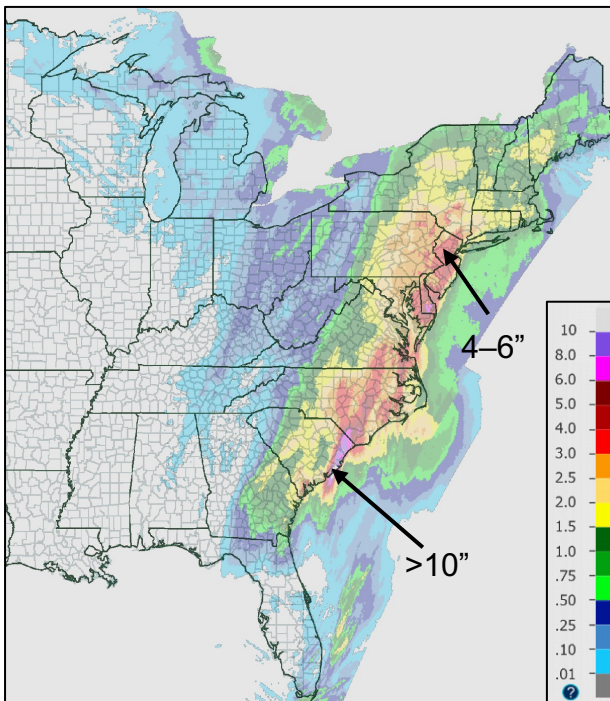
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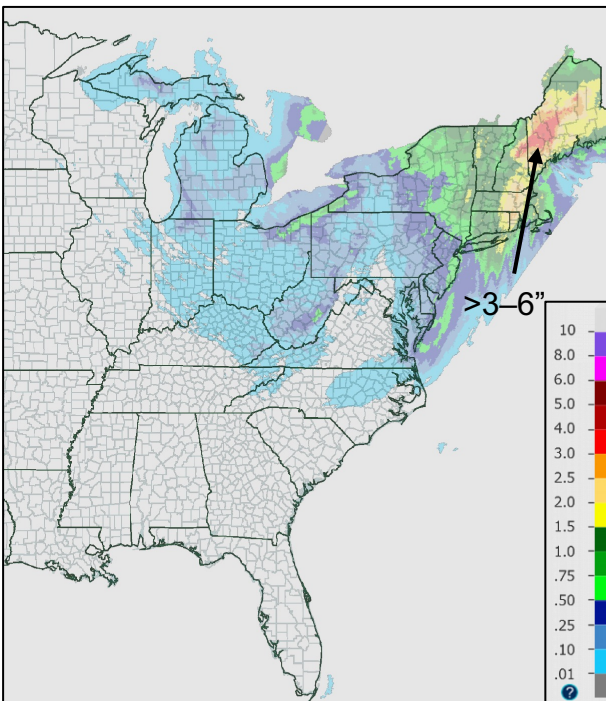
a. 1-day QPE ending 1200 UTC 17 Dec 2023



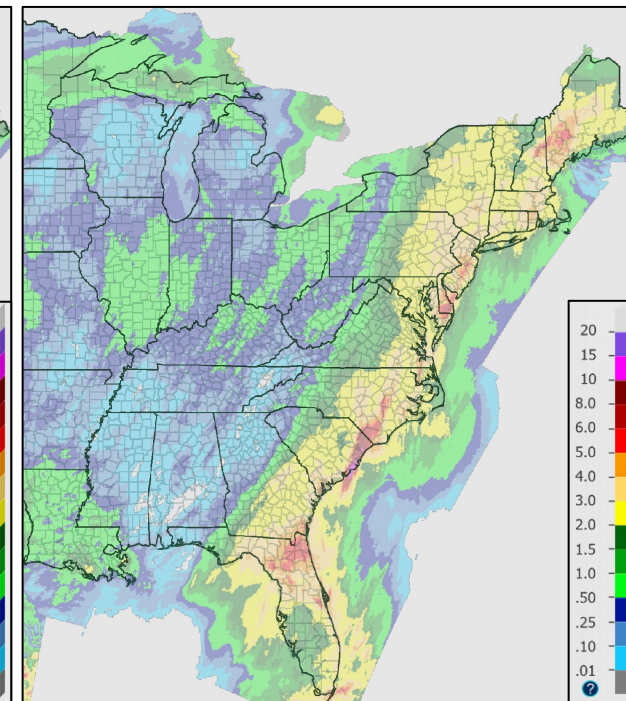
b. 1-day QPE ending 1200 UTC 18 Dec 2023



c. 1-day QPE ending 1200 UTC 19 Dec 2023



d. 7-day QPE ending 1200 UTC 19 Dec 2023



Precipitation totals for 24-hour periods ending at (a) 1200 UTC 17 Dec 2023, (b) 1200 UTC 18 Dec 2023, (c) 1200 UTC 19 Dec 2023, and for (d) the 7-day period ending at 1200 UTC 19 Dec 2023. Imagery adapted from the NOAA/National Weather Service from <https://water.weather.gov>. Note that colorbars differ between panels (a – c) and (d).

The storm produced a footprint of >3–5” rain from Florida through Maine

- Daily rainfall totals exceeded 3–5” in every East Coast state from Florida through Maine on 17, 18, and 19 December 2023.
- The largest daily rainfall total fell in coastal South Carolina where >12” fell in the 24-hour period ending at 1200 UTC 18 December 2023 (source: CoCoRaHS).
- Storm total rainfall amounts exceeded 6” in Florida, South Carolina, North Carolina, Maryland, Connecticut, New Hampshire, and Maine.



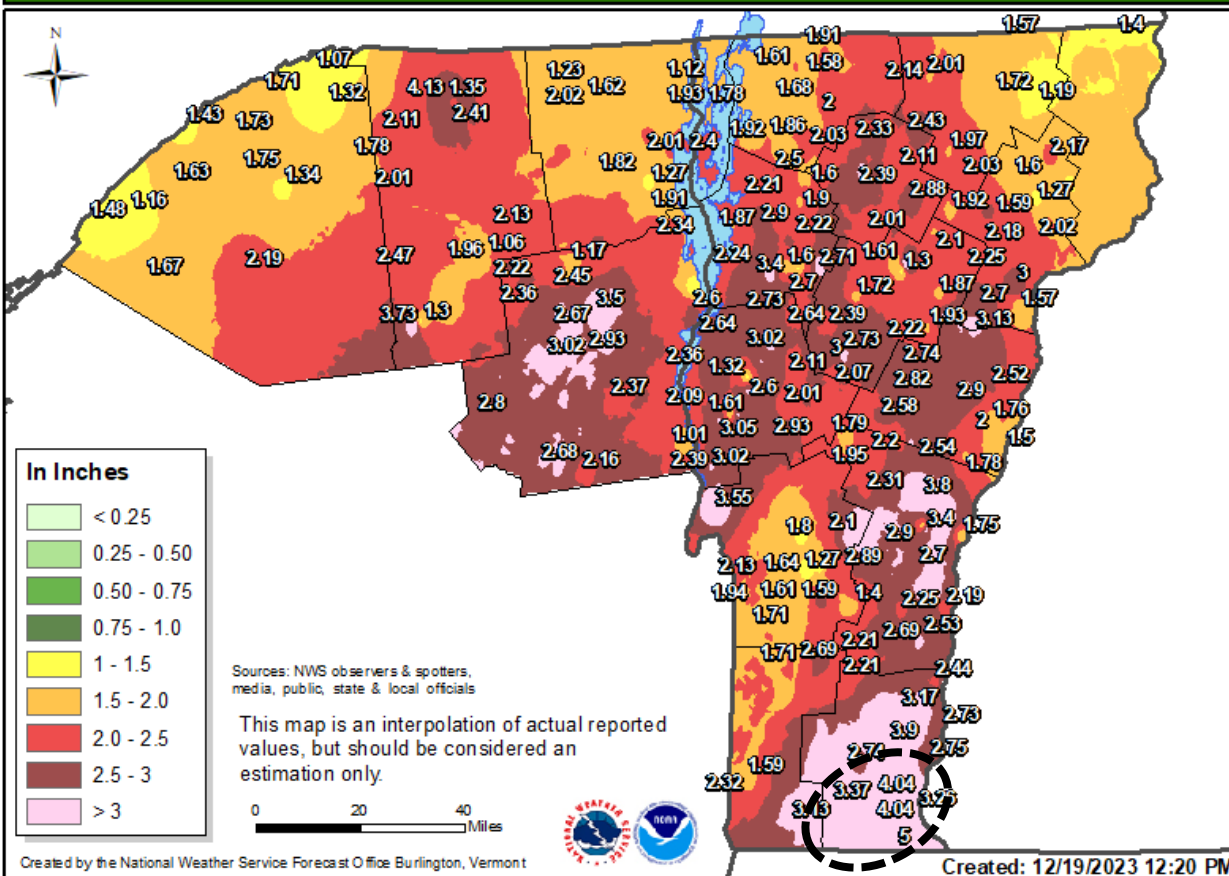
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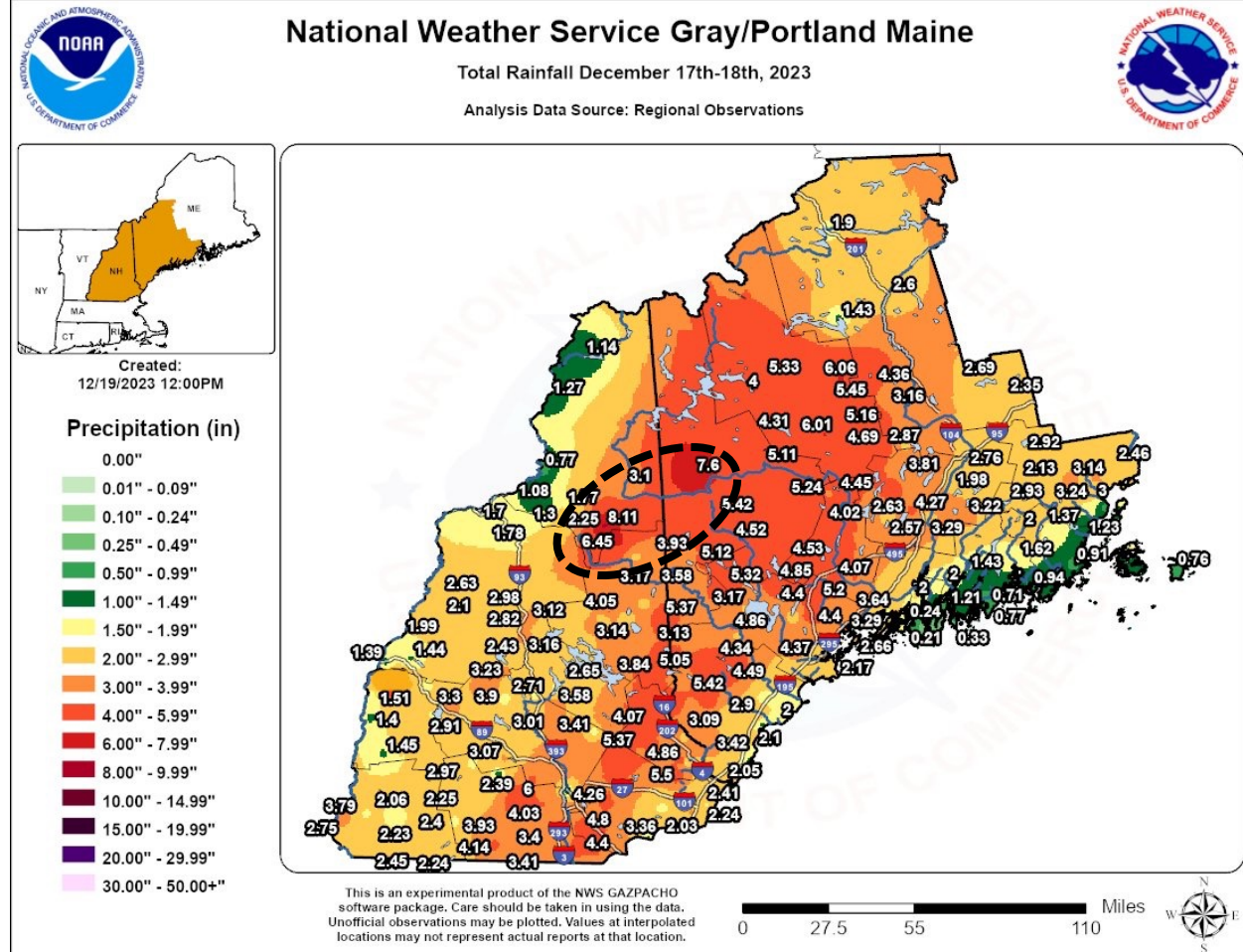
Contact:
Jay Cordeira
jcordeira@ucsd.edu
<http://cw3e.ucsd.edu>

North Country Storm Total Rainfall Ending December 19, 2023



National Weather Service Gray/Portland Maine

Total Rainfall December 17th-18th, 2023
Analysis Data Source: Regional Observations



The highest rainfall totals in the Burlington, VT County Warning Area exceeded 4" in southern Green Mountains, whereas totals exceeded 6–8" in the Gray, ME County Warning Area in the White Mountains. The highest total of 8.11" was recorded at ~4000' at Hermit Lake near Tuckerman Ravine. Rainfall maxima occurred on the upwind southern/eastern slopes of regional topography.



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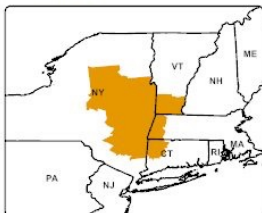
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Jay Cordeira
jcordeira@ucsd.edu
http://cw3e.ucsd.edu



National Weather Service Albany New York

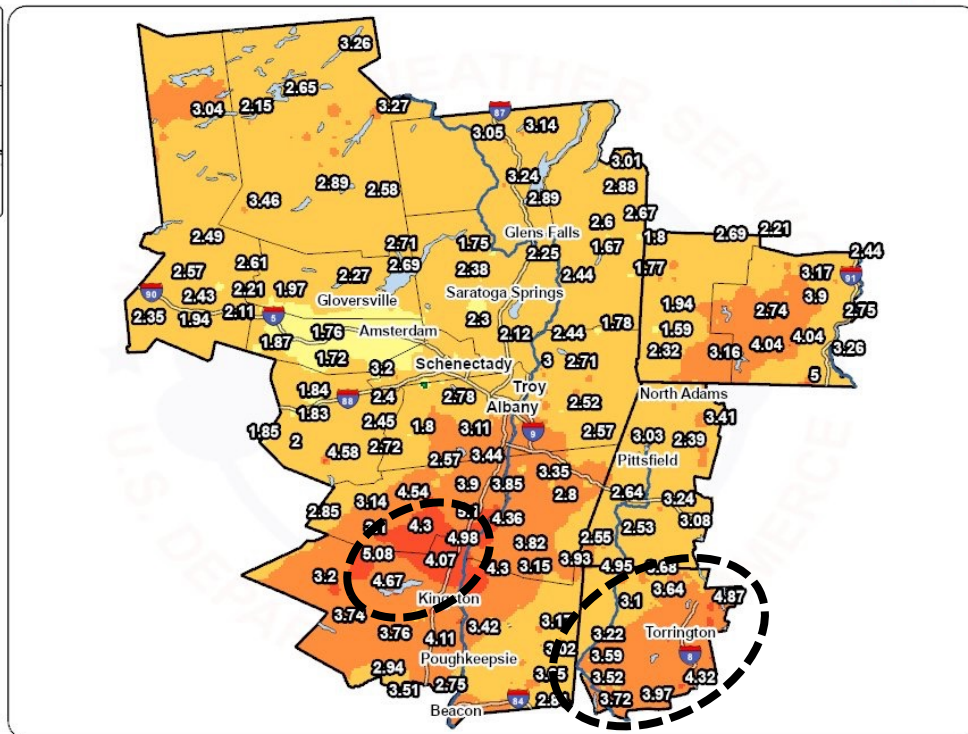
December 17-18, 2023 Heavy Rain Event

Analysis Data Source: NCEP Stage IV and Regional Observations (Values Estimated at Locations)

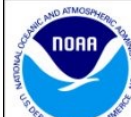


Created:
12/19/2023 12:26PM

Precipitation (in)



This is an experimental product of the NWS GAZPACHO software package. Care should be taken in using the data. Unofficial observations may be plotted. Values at interpolated locations may not represent actual reports at that location.



National Weather Service New York, NY

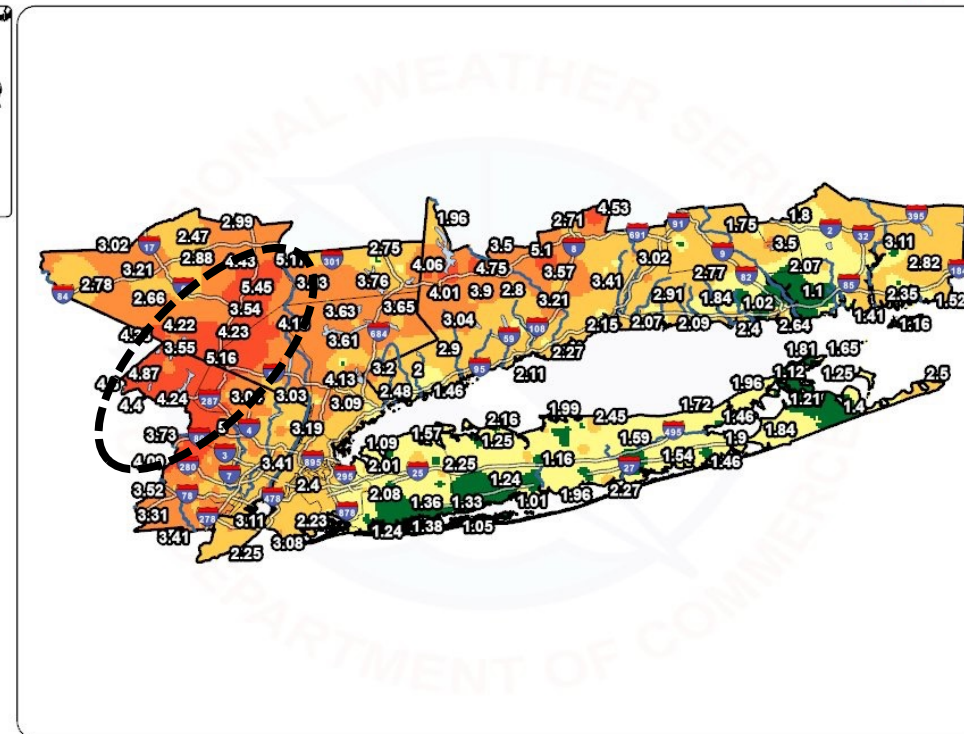
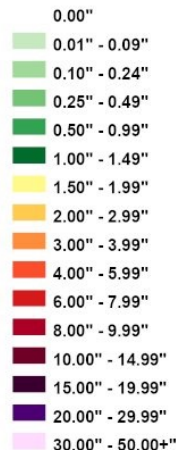
Rainfall Analysis 12/17/2023 07:00AM to 12/18/2023 01:00PM EST

Analysis Data Source: Regional Observations



Created:
12/18/2023 05:20PM

Precipitation (in)



This is an experimental product of the NWS GAZPACHO software package. Care should be taken in using the data. Unofficial observations may be plotted. Values at interpolated locations may not represent actual reports at that location.



The highest rainfall totals in the Albany, NY County Warning Area exceeded 4–5" in the Catskills with localized maxima of 3–4" across the Litchfield Hills in northwest Connecticut. Totals exceeded 4–5" in the New York, NY County Warning Area across the Piedmont Plateau in northern New Jersey and southern Catskills in New York.

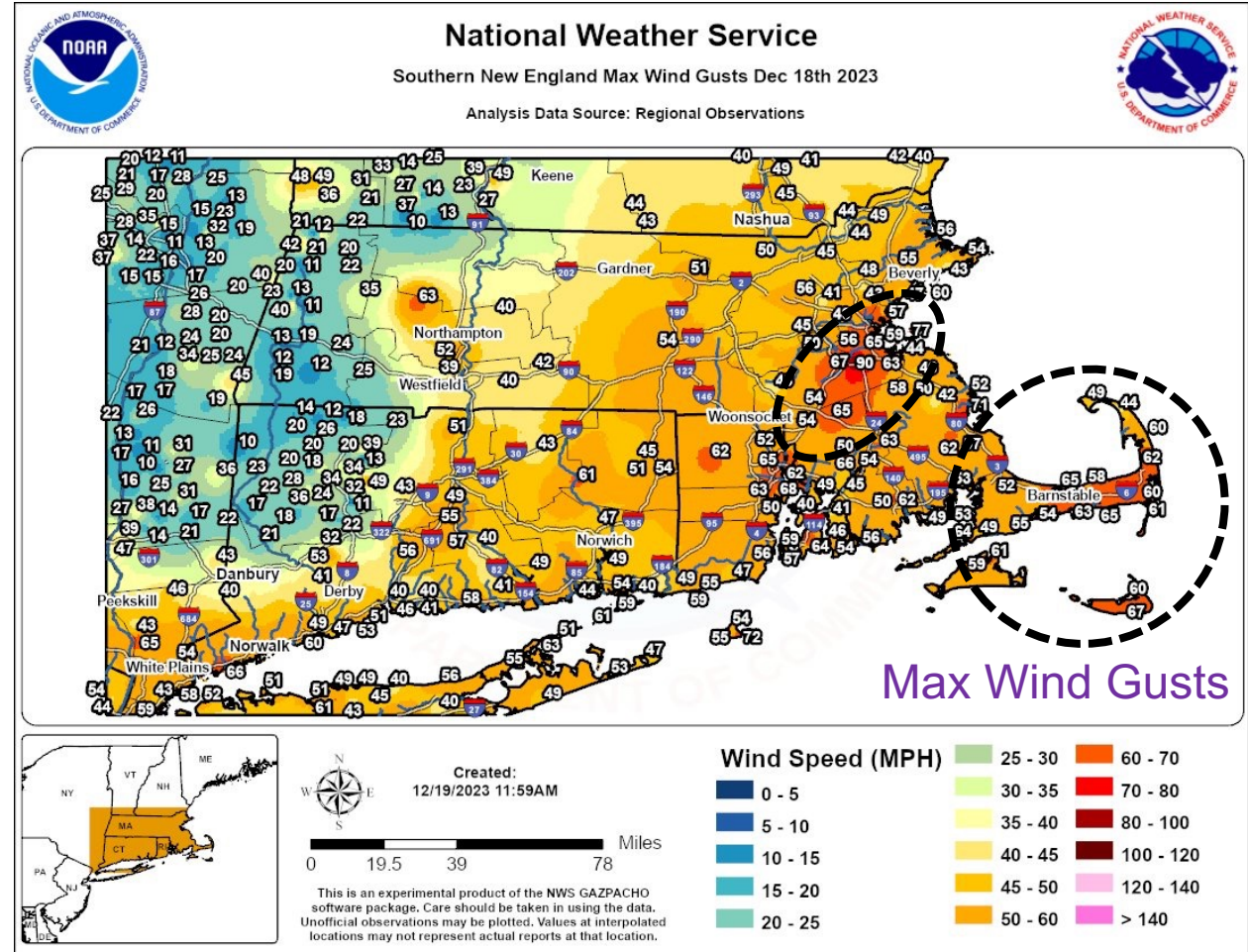
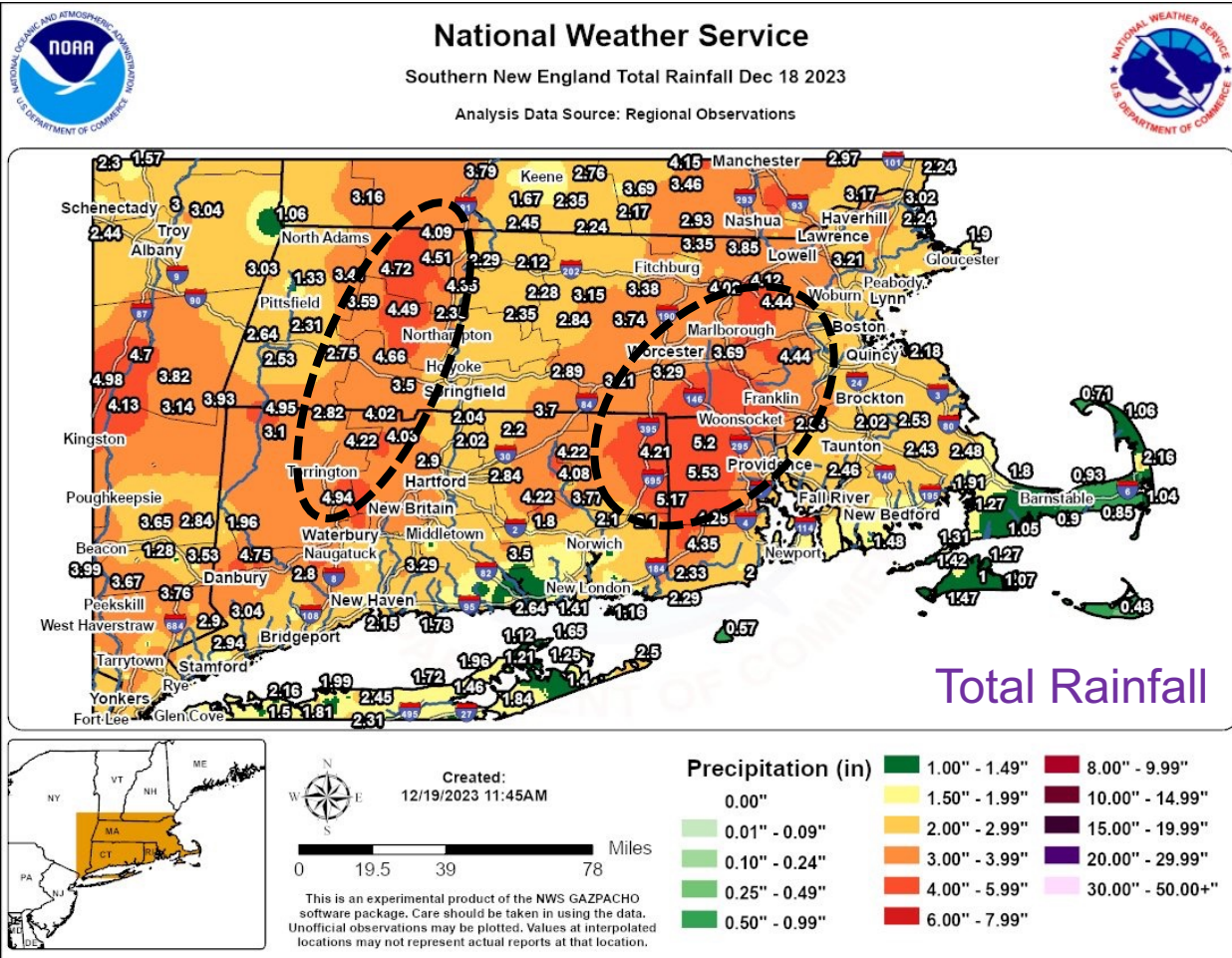


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Contact:
Jay Cordeira
jcordeira@ucsd.edu
http://cw3e.ucsd.edu



The highest rainfall totals in the Boston, MA County Warning Area were >4" focused along the east slope of the Berkshires and east slope of the relatively elevated Worcester Hills extending into Rhode Island. The strongest winds were recorded over eastern Massachusetts with maximum wind gusts >50–60 mph in Narragansett and Buzzards Bay, Cape Cod and the Islands. The highest wind gust of 90 mph was recorded on the top of Blue Hill (635 feet ASL).

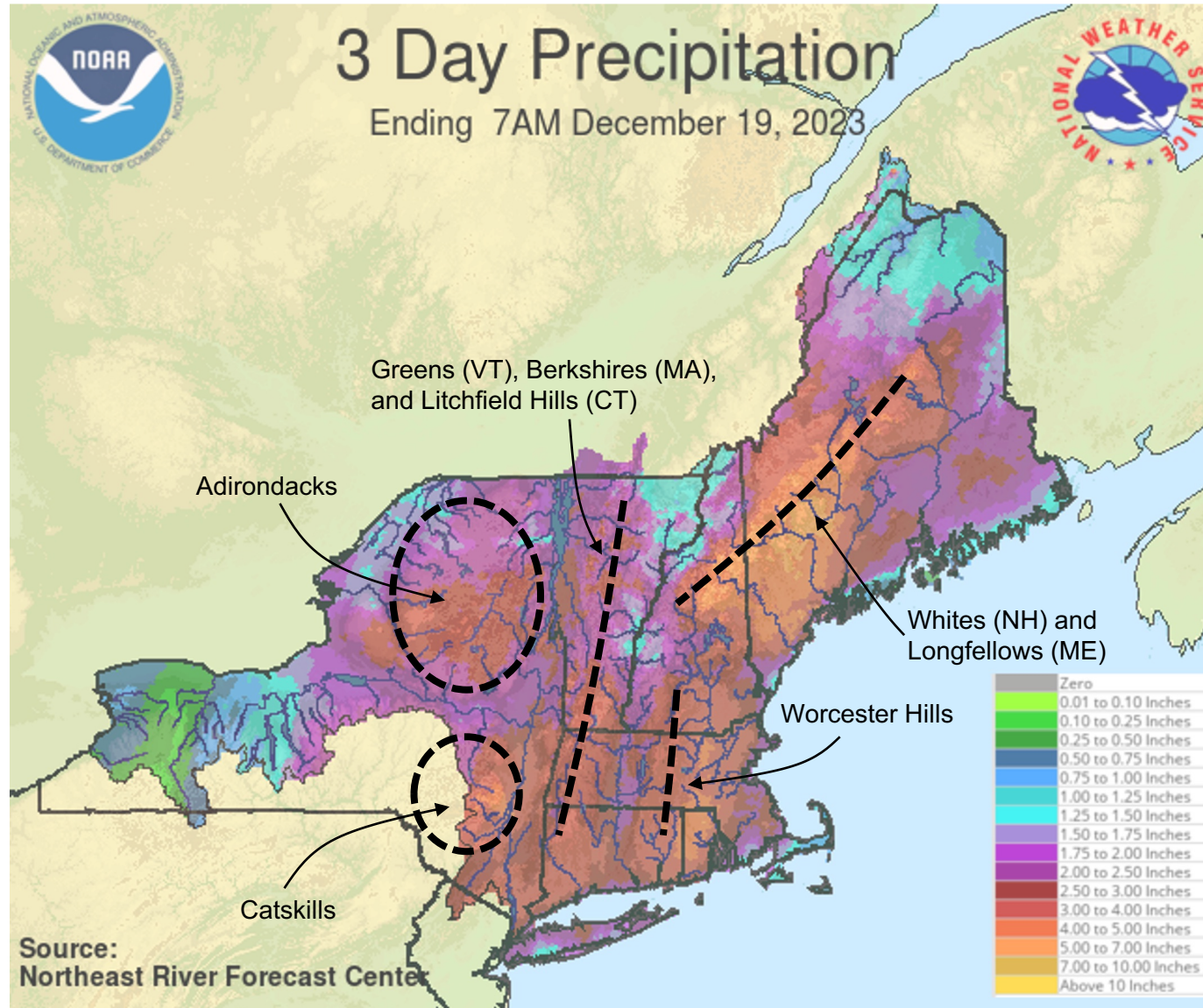
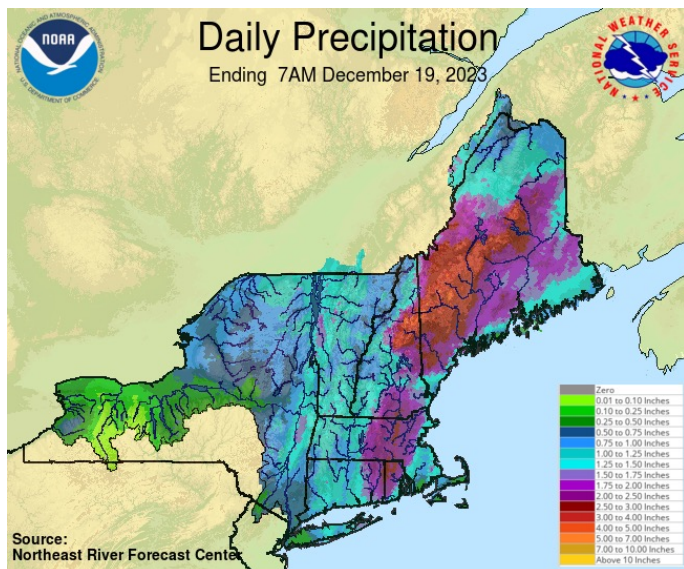
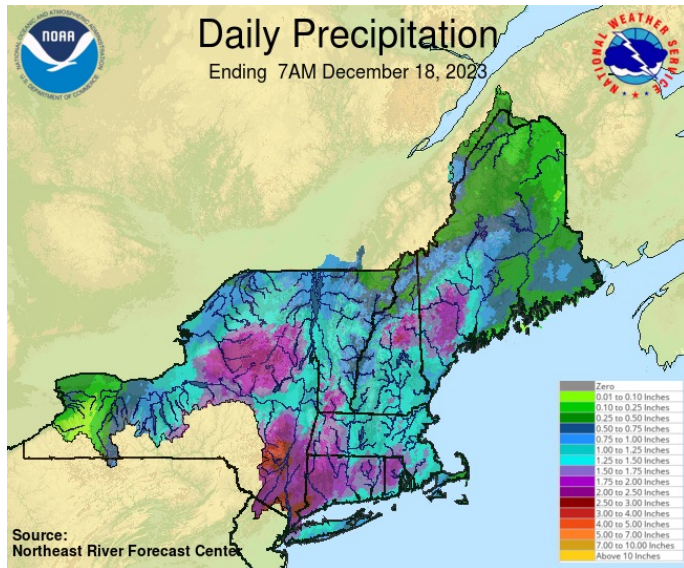


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Contact:
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jcordeira@ucsd.edu
http://cw3e.ucsd.edu



These images, provided by the Northeast River Forecast Center, illustrate the distribution of extreme rainfall over New England for the period 18–19 December 2023.

The highest totals are focused on the southern and eastern sides of all the region's topographic barriers, consistent with the strong southerly and south-southeasterly flow along the landfalling atmospheric river and orographic-enhancement of rainfall.

Note that many of the lowest rainfall totals fell in the northern slopes of many of the topographic barriers where downslope winds likely suppressed precipitation.



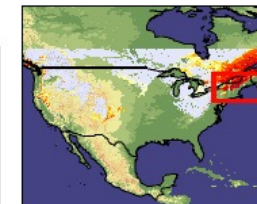
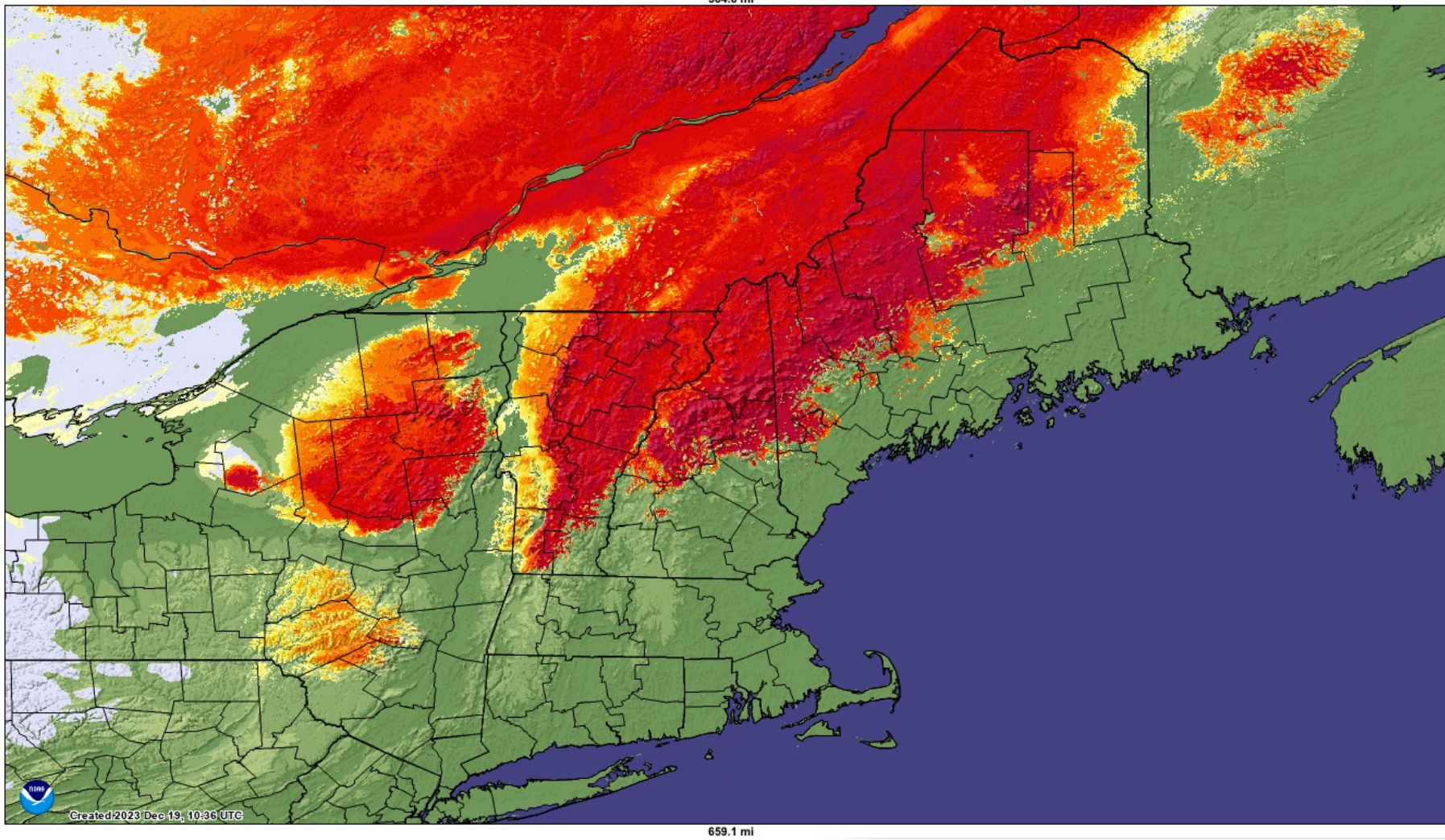
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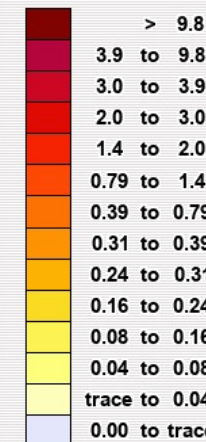
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Contact:
Jay Cordeira
jcordeira@ucsd.edu
http://cw3e.ucsd.edu

Total Modeled Snow Melt during 48h preceding 2023 December 19, 5:00 UTC
584.8 mi

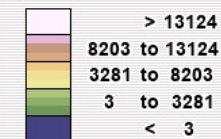


Inches of water equivalent



Not Estimated

Elevation in feet



Snowpack temperatures increased to near freezing with warm temperatures persisting for several days prior to the storm's arrival.

The ripe snowpack was susceptible to rapid ablation as the atmospheric river brought warm, humid airmass and strong winds to the region.

The dewpoint temperature on Mt. Washington, NH (6288' ASL) increased to 41F on 18 December and was above 32F for 22 hours.

Rain-on-snow exacerbated snow melt across northern New England with snow-water equivalent losses of ~1-3".

Total modeled snow melt during the 48-hour period ending at 0500 UTC (1AM ETS) Tuesday 19 Dec. Analysis provided by NWS NOHRSC



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PRECIPITATION SCIENCE AND PREDICTION GROUP

Contact:
Jay Cordeira
jcordeira@ucsd.edu
http://cw3e.ucsd.edu

Widespread Moderate to Major Flooding

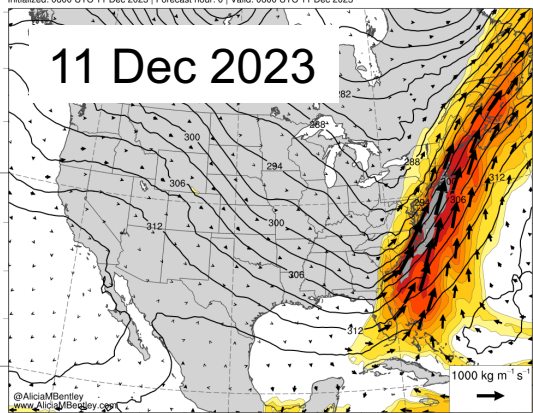
The ground across the Northeast was either snow-covered, mostly frozen, or mostly saturated due to prior-month cold temperatures in late November and prior-week heavy rainfall in New England on 11 December, coincidentally also from an atmospheric river.

Heavy rainfall, combined with favorable antecedent ground conditions and a ripe snowpack, resulted in significant riverine flooding across New England.

In some locations, e.g., the White Mountains of New Hampshire extending into Western Maine, received ~7–8" of rain that combined with ~2–3" of melted snow-water equivalent, to yield >10" of "forcing" for streamflow flooding.

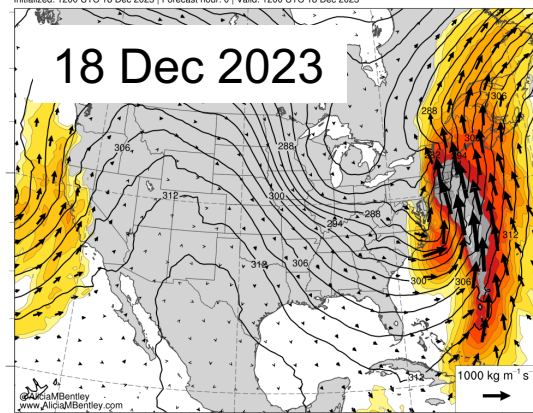
700-hPa geo. height (black, dam), Integrated water vapor transport [IVT] (shaded, kg/m/s) (vectors, kg/m/s)
Initialized: 0600 UTC 11 Dec 2023 | Forecast hour: 0 | Valid: 0600 UTC 11 Dec 2023

11 Dec 2023



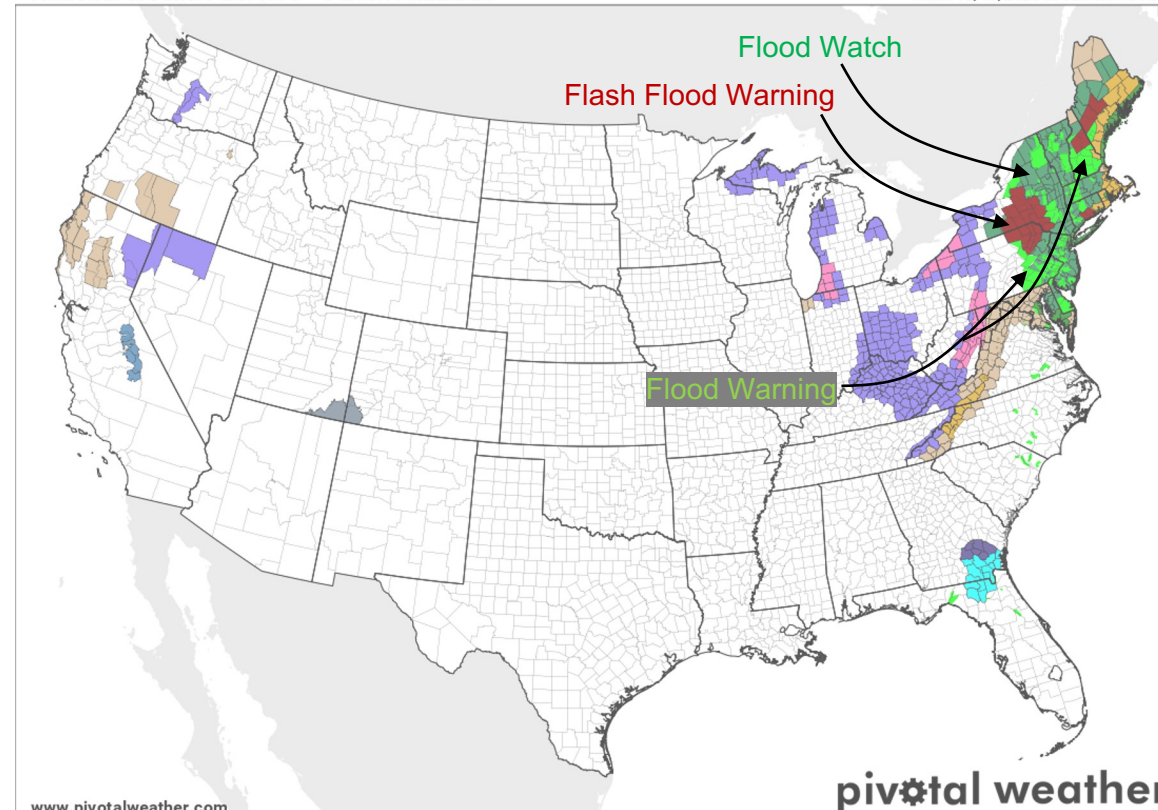
700-hPa geo. height (black, dam), Integrated water vapor transport [IVT] (shaded, kg/m/s) (vectors, kg/m/s)
Initialized: 1200 UTC 18 Dec 2023 | Forecast hour: 0 | Valid: 1200 UTC 18 Dec 2023

18 Dec 2023



National Weather Service - Current Hazards

Valid: 12/18/2023 at 16:38:06 UTC



www.pivotalweather.com

pivotal weather

Convective/Tropical	Flooding	Winter	Non-Precipitation
<ul style="list-style-type: none"> Tomado Warning Tomado Watch Severe Thunderstorm Warning Severe Thunderstorm Watch Hurricane Warning Hurricane Watch Tropical Storm Warning Tropical Storm Watch 	<ul style="list-style-type: none"> Flash Flood Warning Flash Flood Watch Flood Watch Flood Warning Coastal Flood Warning Coastal Flood Watch 	<ul style="list-style-type: none"> Blizzard Warning Blizzard Watch Ice Storm Warning Winter Storm Warning Winter Storm Watch Winter Weather Advisory Freeze Warning Freeze Watch 	<ul style="list-style-type: none"> Red Flag Warning Excessive Heat Warning Excessive Heat Watch Heat Advisory Dense Fog Advisory High Wind Warning High Wind Watch Wind Advisory

Select GFS Model Analyses of 700-hPa Geopotential Height, IVT magnitude, and IVT Direction (adapted from imagery provided by Dr. Alicia Bentley).

National Weather Service watches, warnings, and advisories that were active at 1638 UTC (11:38AM EST) on 18 December 2023 courtesy Pivotal Weather.



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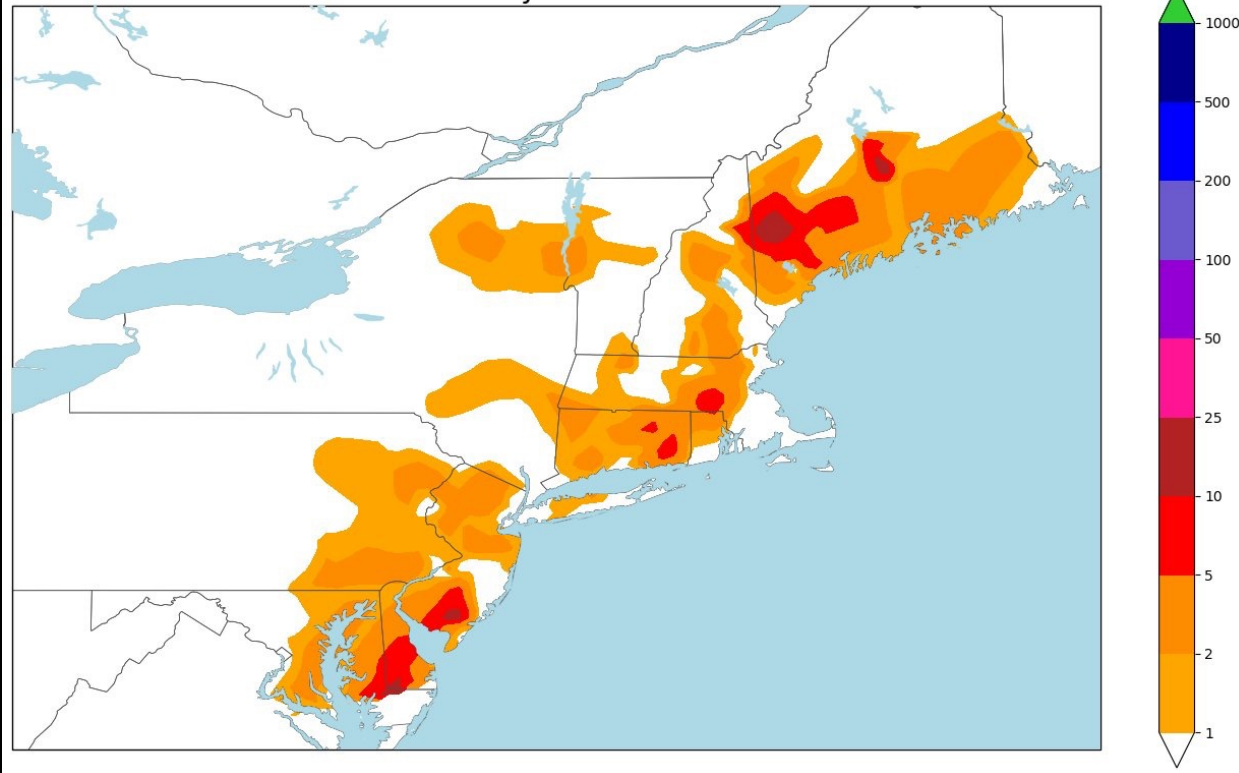
Contact:

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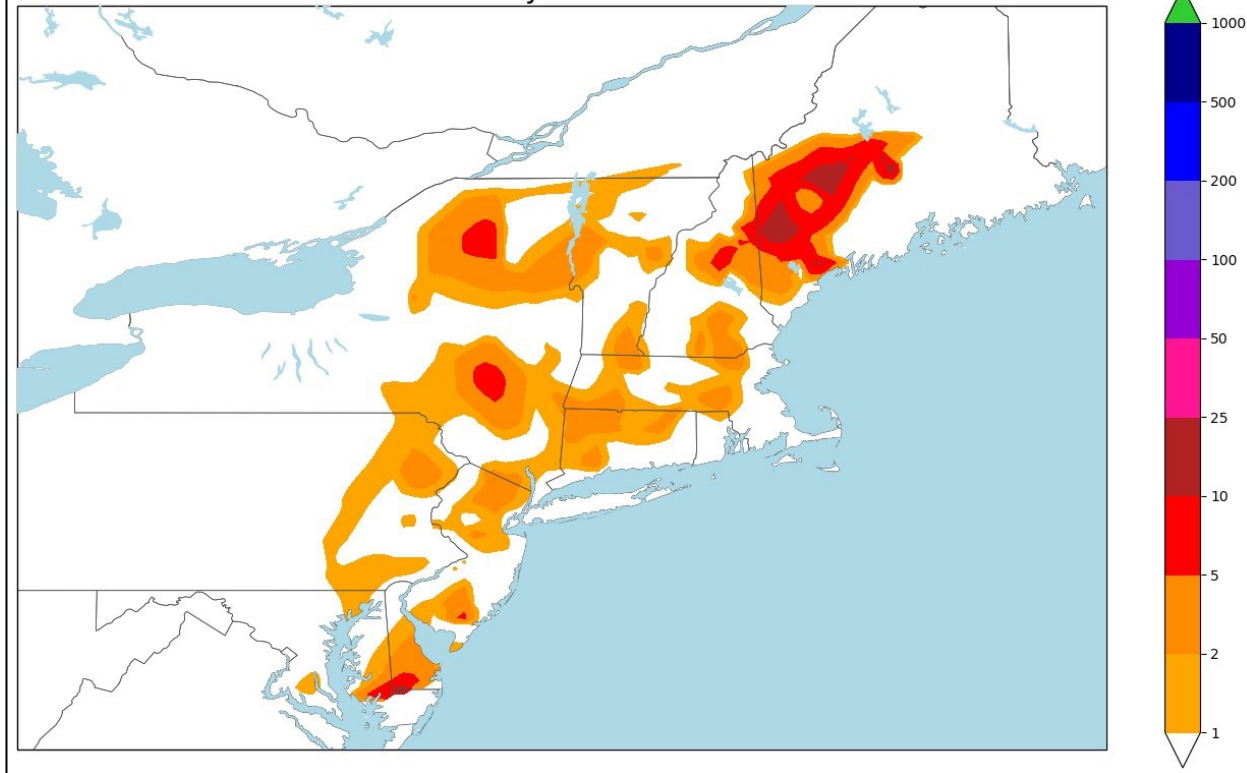
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December Storm Series 2023 10-day ARIs and Record Crests

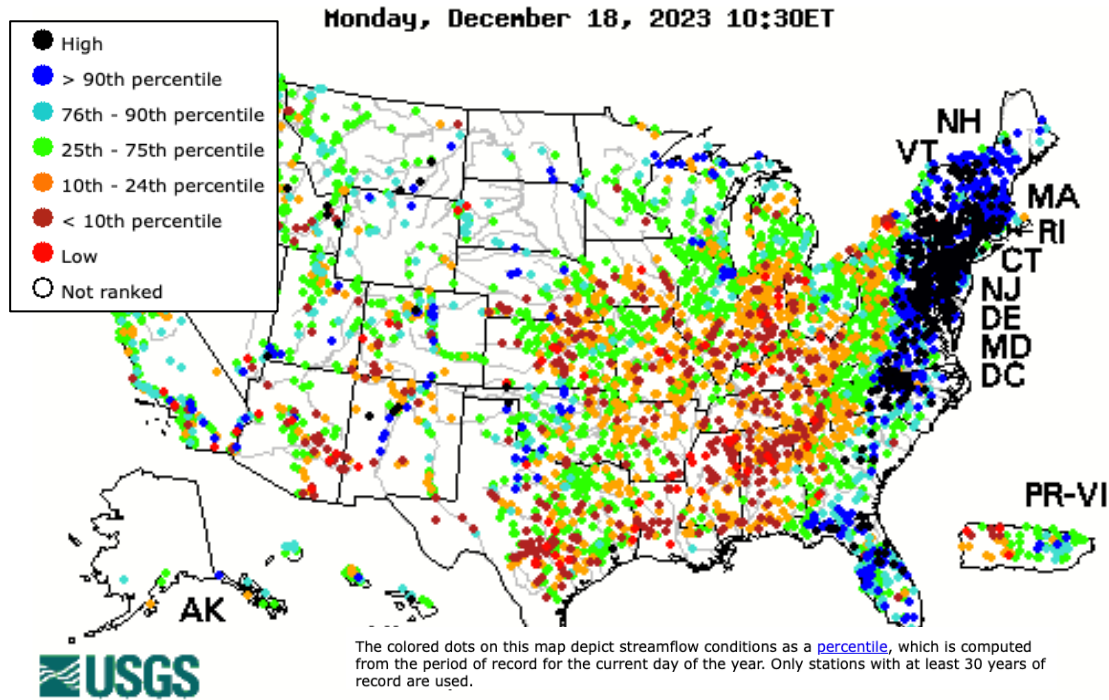


Second December Storm 2023 2-day ARIs and Record Crests

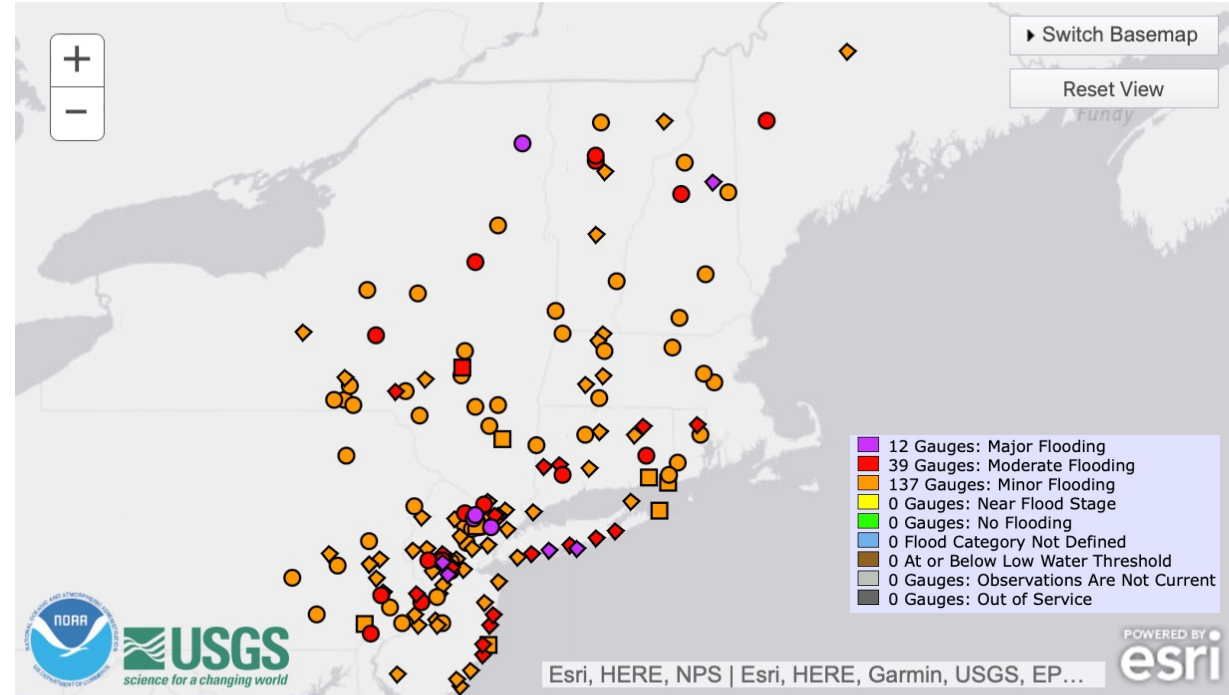


(left) 10-day and (right) 2-day rainfall totals summarized by their “annual recurrence interval” (ARI). The 10-day period includes 9–18 December 2023 and the 2-day period includes 17–18 December 2023. Images are obtained from X/Twitter and created by Jacob Feuerstein; used with permission.

Combined, the two “atmospheric river” storms produced 10-day precipitation totals in the Mid-Atlantic and Northeast that contained annual recurrence intervals (ARIs) of ~1–10 years with maxima >10 years over localized portions of the Delmar Peninsula, southern New Jersey, and inland Maine. The 17–18 December 2023 storm produced similar 2-day precipitation total ARIs. Note that a 10-year ARI suggests that an event has a ~10% chance of occurring in any given year. Note also that New England has experience *several 10-year ARI events in 2023*.



USGS Daily Streamflow as percentage of daily values for 18 December. Image valid at 10:30 AM EST on 18 December 2023.



NOAA/USGS analysis (<http://water.weather.gov>) of stream gauges at or above flood stage at 2:14PM EST on 18 December 2023. Note that several of these gauges in VT, NH, and ME had yet to crest.

At one point, almost all stream gauges on the East Coast contained >90% or their highest (100%) streamflow in their climatological record for 18 December. These streamflow values translated to 137 gauges in minor flood, 39 gauges in moderate flood, as 12 gauges in major flood at 2:14PM EST on 18 December. Note that several additional gauges in Vermont, New Hampshire, and Maine had yet to crest as major floods at that time.



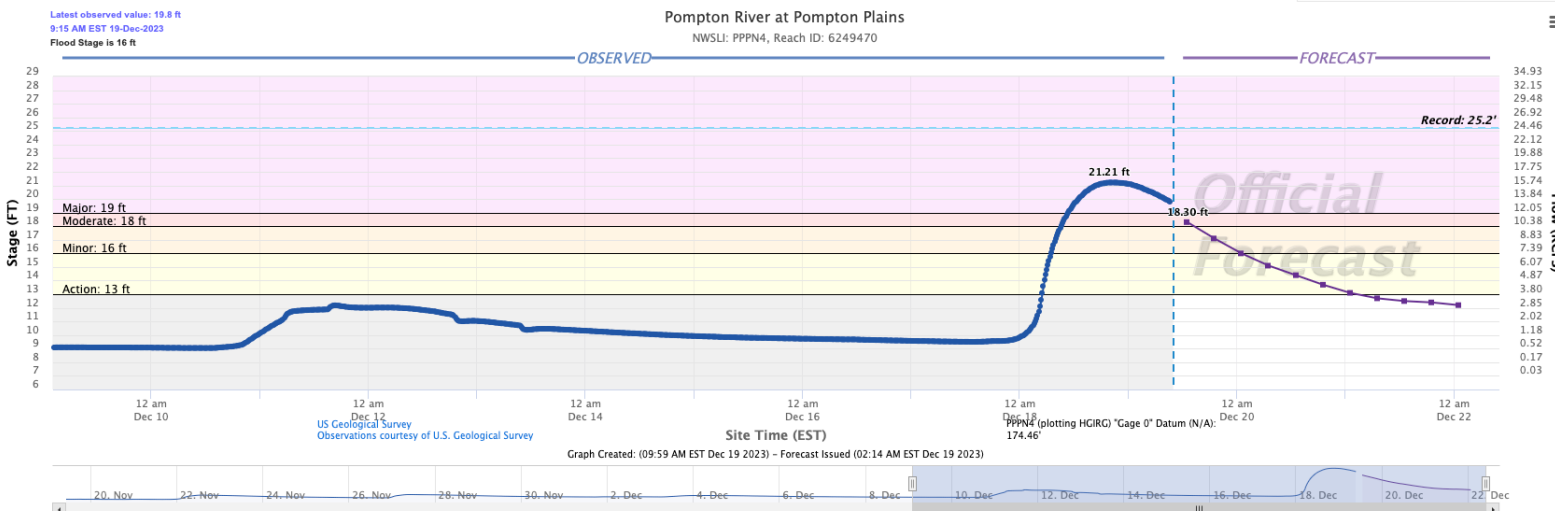
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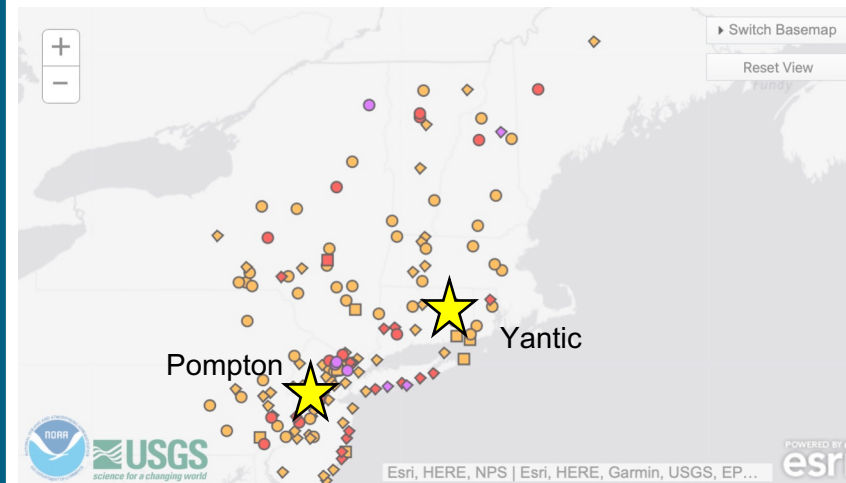
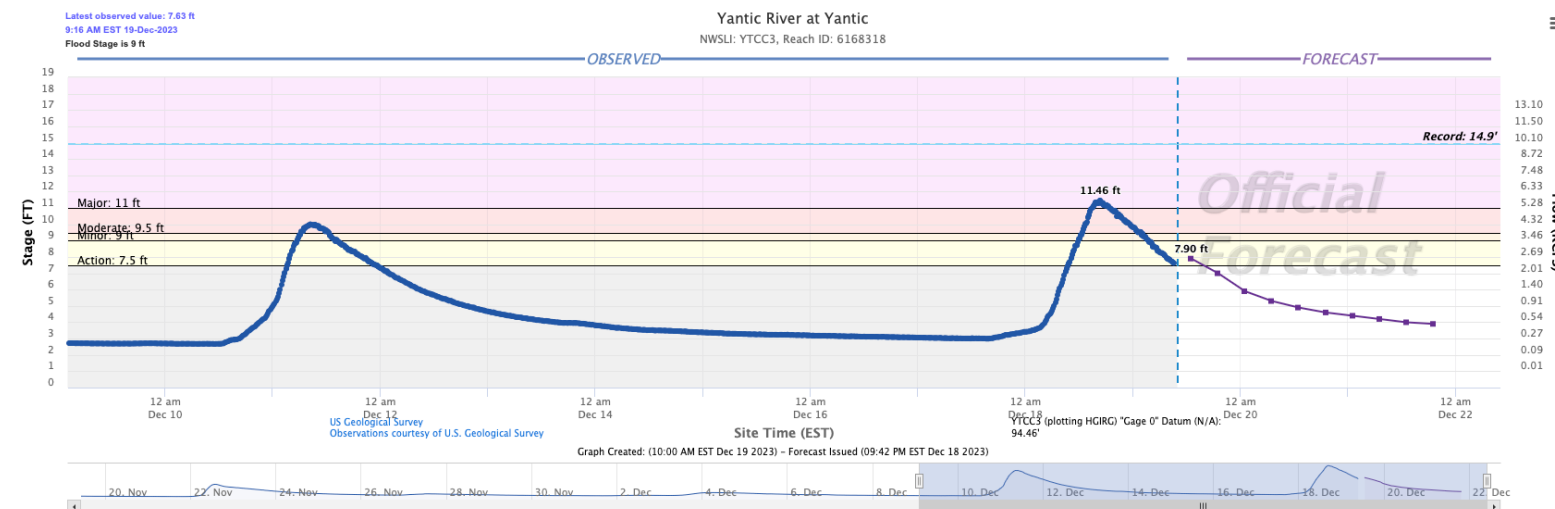
Contact:
Jay Cordeira
jcordeira@ucsd.edu
http://cw3e.ucsd.edu

Upstream gauge unavailable



Images NWS/Data USGS

Upstream gauge unavailable



Many rivers crested above major flood stage, including several in New Jersey (e.g., Pompton River at Pompton Plains) and Connecticut (e.g., Yantic River at Yantic).

Note that in both stream gauge stage graphics, enhanced streamflow due to the prior storm on 11 December is visible, notably producing moderate flooding in Connecticut.

Yantic crest at 11.46' was 10th all time and the highest river level since Sep 2018. It is the highest December crest on record.

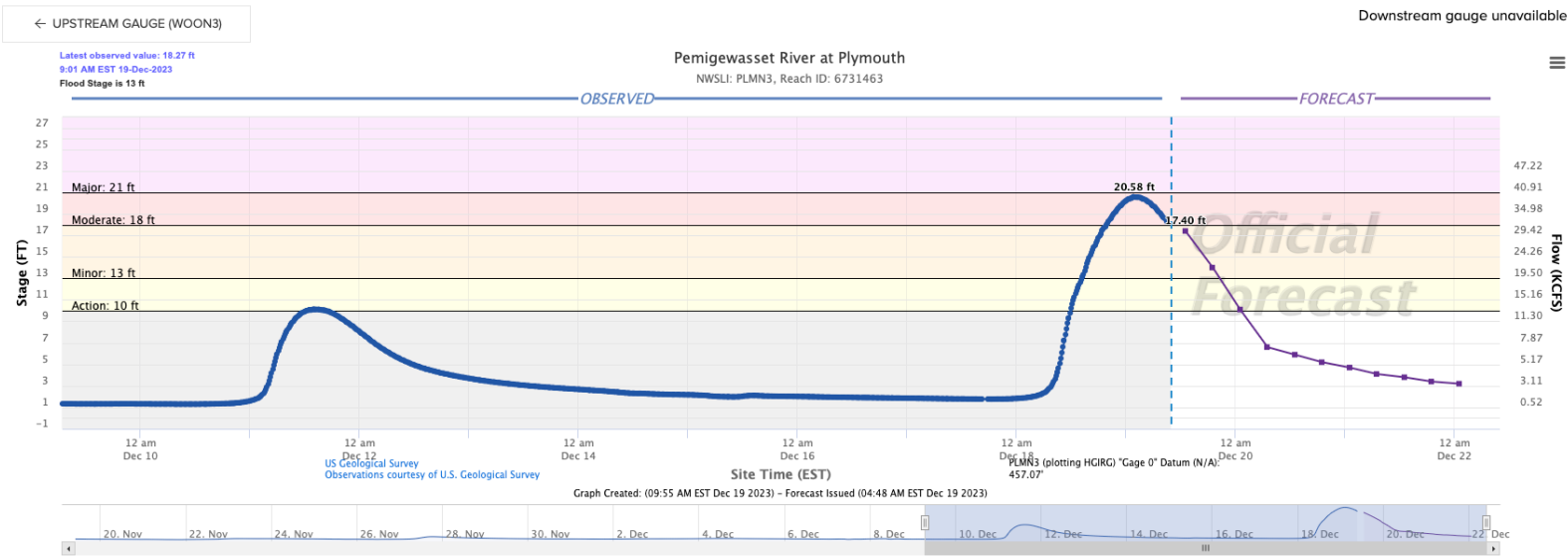
Pompton crest at 21.21' was 8th all time and the highest river level since Hurricane Irene (2011). It is the highest December crest on record.



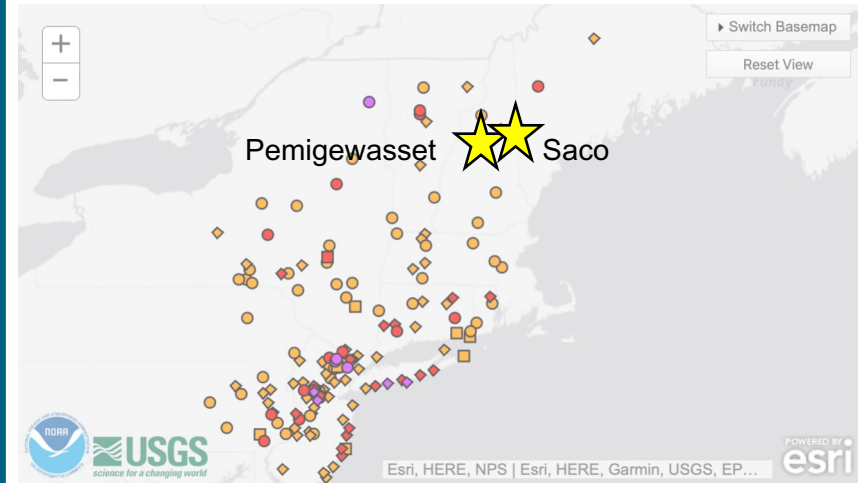
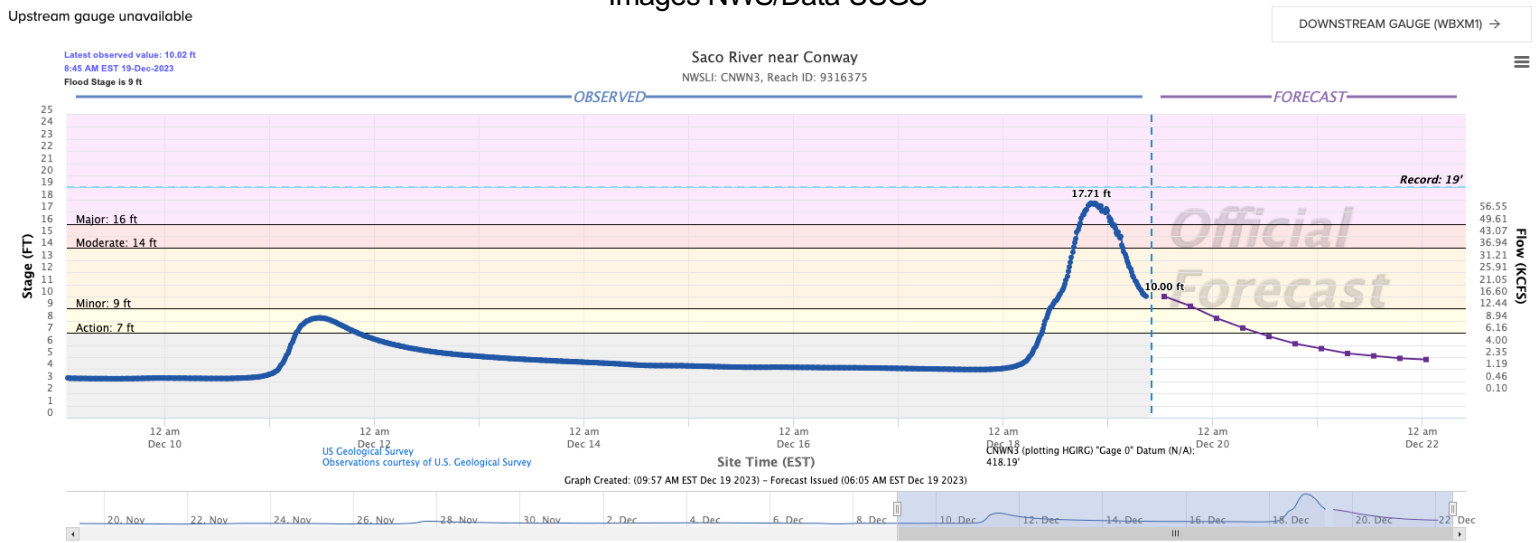
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jcordeira@ucsd.edu
http://cw3e.ucsd.edu



Images NWS/Data USGS



Many rivers crested above major flood stage, including several in New Hampshire (e.g., the Pemigewasset at Plymouth and the Saco at Conway).

Note that in both stream gauge stage graphics, enhanced streamflow due to the prior storm on 11 December is visible, notably producing “action stage” near-minor flooding.

Pemigewasset crest at 20.58’ was 10th all time and the highest river level since Hurricane Irene (2011). It was the 2nd highest December level behind Dec 1973 (20.61’).

Saco crest at 17.71’ was 2nd all time, higher than Hurricane Irene (2011, 17.23’) and second only to March 1979.



Center for Western Weather and Water Extremes

SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UNIVERSITY OF CALIFORNIA SAN DIEGO

PRECIPITATION SCIENCE AND PREDICTION GROUP

Contact:
Jay Cordeira
jcordeira@ucsd.edu
<http://cw3e.ucsd.edu>



Many images and videos on social media captured the impacts due to heavy rain and freshwater flooding over New England. The four chosen on this page include:

- *Flooding of Rt. 175A in Holderness, NH by the Pemigewasset River near Plymouth State University.*
- *A closure of Rt. 2 near St. Johnsbury, VT due to a mudslide.*
- *Damage to the road leading to Sugarloaf ski area in Carrabassett Valley, Maine.*
- *Major flooding at Jackson Falls in Jackson, NH near the foothills of Mt. Washington.*



Coastal Storm Surge

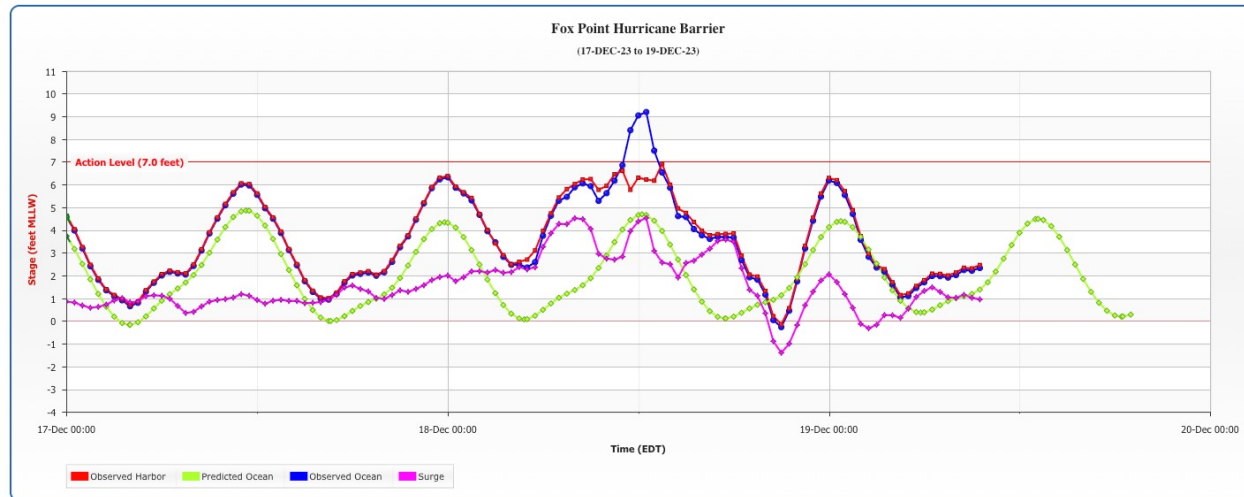
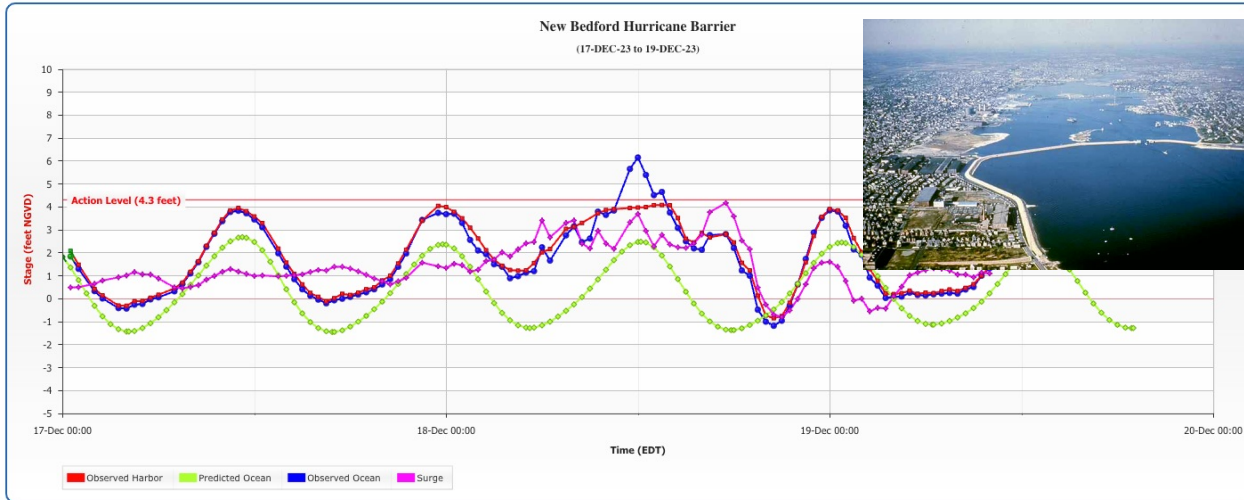
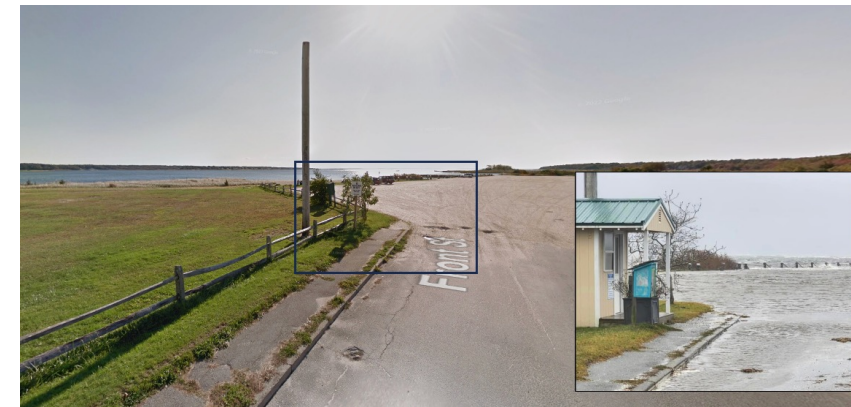
The coastal-to-inland track and rapid intensification of the parent cyclone, combined with strong southerly winds, produced a storm surge along the South Coast of New England.

Both the Narragansett River in Providence, RI and the Acushnet River in New Bedford, MA are protected by “Hurricane Barriers” designed to mitigate storm surge into their respective harbors. The barriers were closed on 18 December.

The ocean height in Buzzard’s Bay outside of the New Bedford Hurricane Barrier reached ~6.5 feet, but was kept at 4 feet in the harbor, coincident with a storm surge of 3–4 feet.

The ocean height in Narragansett Bay outside of the Fox Point Hurricane Barrier reached >9 feet, but was kept below 7 feet in the harbor, coincident with a storm surge of 4–5 feet.

Photograph with Google “Street-view” comparison to highlight storm surge flooding into Buzzard’s Bay in Marion, MA. Source social media/Cathy Cordeira →



Tidal and ocean measurements in New Bedford, MA and Providence, RI courtesy the U.S. Army Corps of Engineers. Compare the levels of the blue (ocean height) and red (harbor height) lines with the pink line (storm surge). Inset image courtesy USACE.



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NWS Boston
@NWSBoston

[12 pm] Unfortunately #PowerOutages continue to climb, 261k customers without power in Massachusetts. Winds will subside this afternoon, good news for crews restoring power. #MAwx

Massachusetts Power Outages
261090 customers without power as of 12/18/2023 11:50:12 AM

Customers Without Power

- 0% - 100% of customers without power
- 1-10% of customers without power
- 10%-25% of customers without power
- 25%-50% of customers without power
- 50%-75% of customers without power
- 75%-100% of customers without power

Zoom Map to a Town:
Select a Town

Filter By Utility:
Select a Utility

12:01 PM · Dec 18, 2023 · 36K Views

Christian Bridges
@ChristianWGME

Waking up to one of the largest power outages in Maine history this morning after yesterday's historic storm. Quiet and fairly mild weather today should help with restoration. Hang in there Maine 😞😞

PowerOutage.us

Maine

Customers Tracked: 852,082
Customers Out: 432,303
Last Updated: 2023-12-19 03:22:08 AM

Outage Scale: 0% 10% 30% 60% 100%

3:34 AM · Dec 19, 2023 · 1,935 Views

Central Maine Power
@cmpco

Now that the storm has cleared and the sun has risen, we are working to gain access to areas hardest hit, survey and assess damage, and can begin to make repairs. Because of dangerous conditions and blocked roads, our crews can now start accessing certain areas.

8:59 AM · Dec 19, 2023 from Maine, USA · 6,610 Views

- Many posts on social media captured the **impacts due to strong winds on the power grid**. The three chosen above include:
- A spatial representation of town-by-town power outages posted by the National Weather Service office for Boston, MA on 18 December 2023.
 - A post by WGME meteorologist in Maine highlighting >400,000 customers without power on 19 December 2023.
 - A post by Central Maine Power highlighting some of the damage and repair needs for the state.



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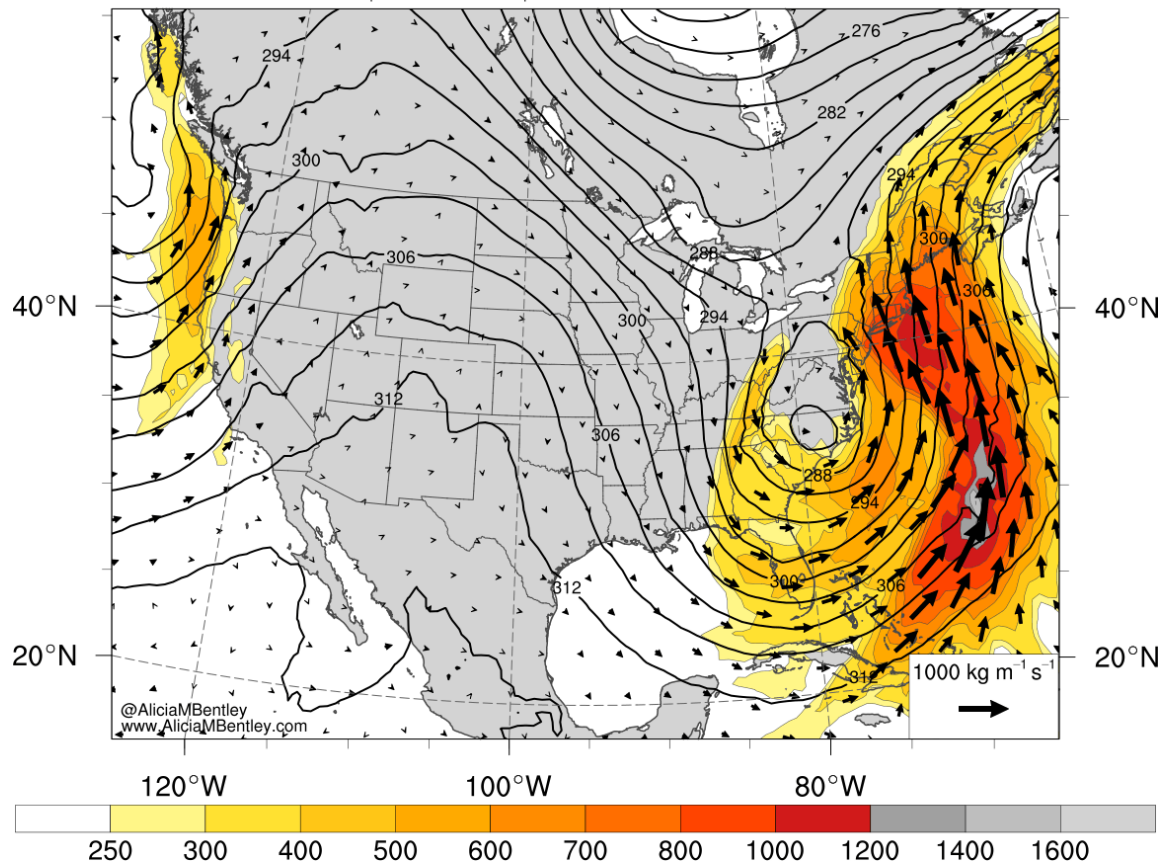
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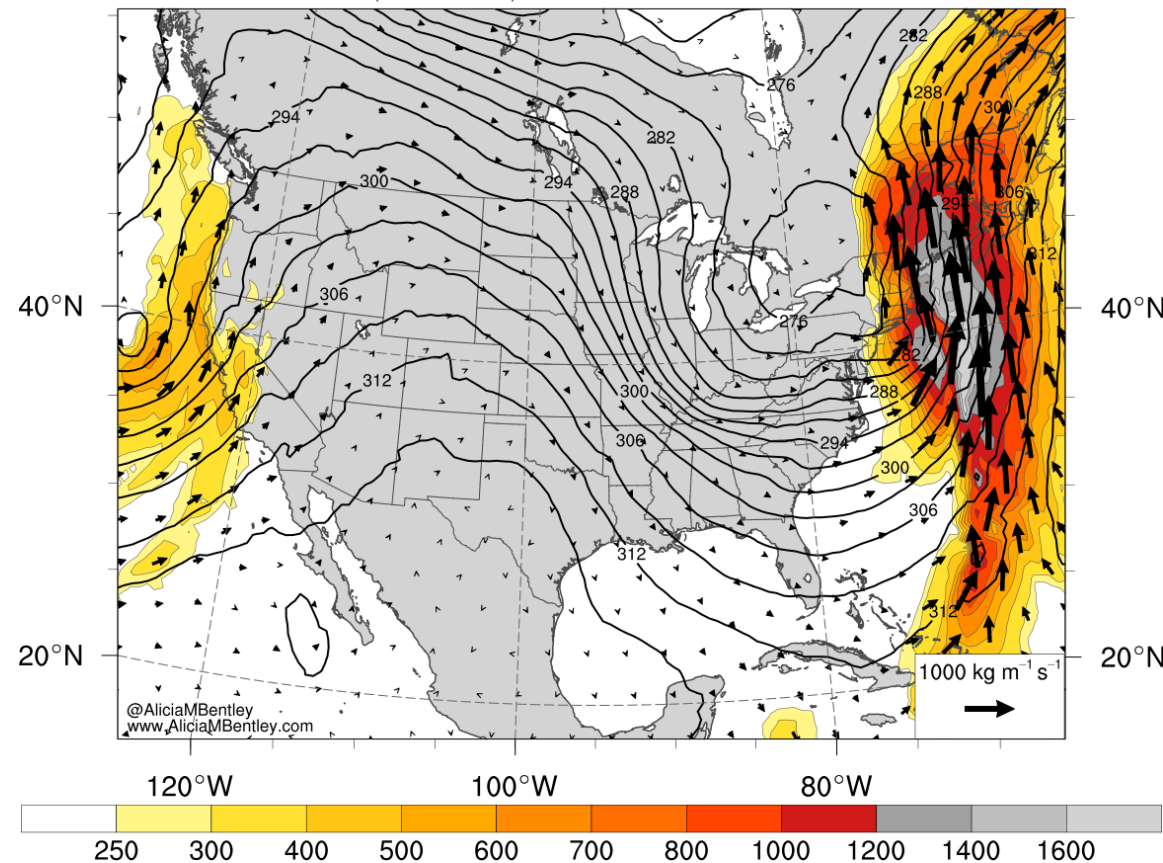
174-h forecast made 11 Dec and valid for 18 Dec 2023

700-hPa geo. height (black, dam), Integrated water vapor transport [IVT] (shaded, kg/m/s) (vectors, kg/m/s)
Initialized: 1200 UTC 11 Dec 2023 | Forecast hour: 174 | Valid: 1800 UTC 18 Dec 2023



Verifying analysis at 1800 UTC 18 Dec 2023

700-hPa geo. height (black, dam), Integrated water vapor transport [IVT] (shaded, kg/m/s) (vectors, kg/m/s)
Initialized: 1800 UTC 18 Dec 2023 | Forecast hour: 0 | Valid: 1800 UTC 18 Dec 2023



Select GFS Model Forecast and Analysis of 700-hPa Geopotential Height, IVT magnitude, and IVT Direction (adapted adapted from imagery provided by Dr. Alicia Bentley).

Global models provided reasonable long-range guidance of a potentially impactful event along the East Coast; however, the exact track and intensity were uncertain. Note that the prior event on 11 December was **not well forecast** by the models which may have decreased overall forecast confidence in the days leading up to this event over New England.



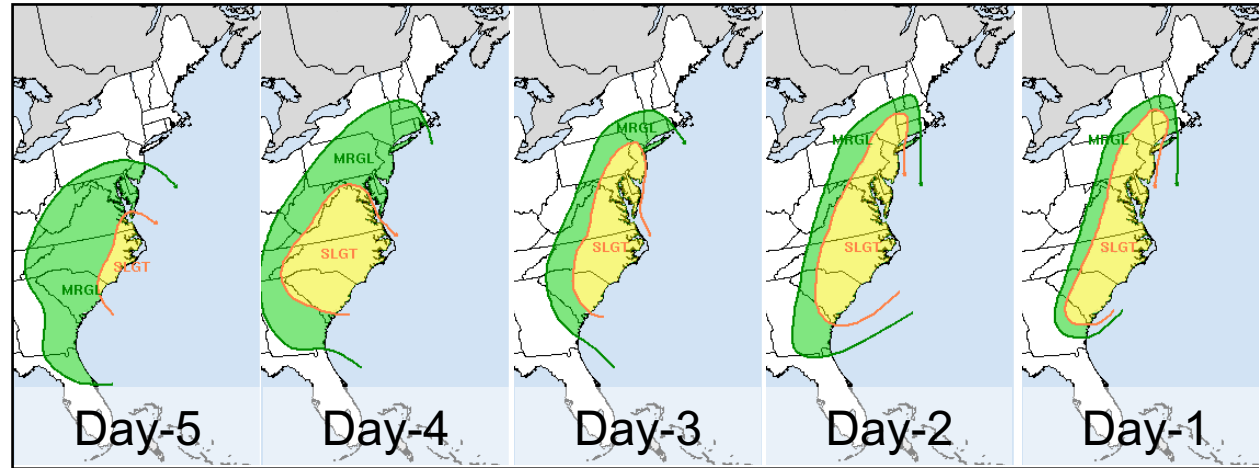
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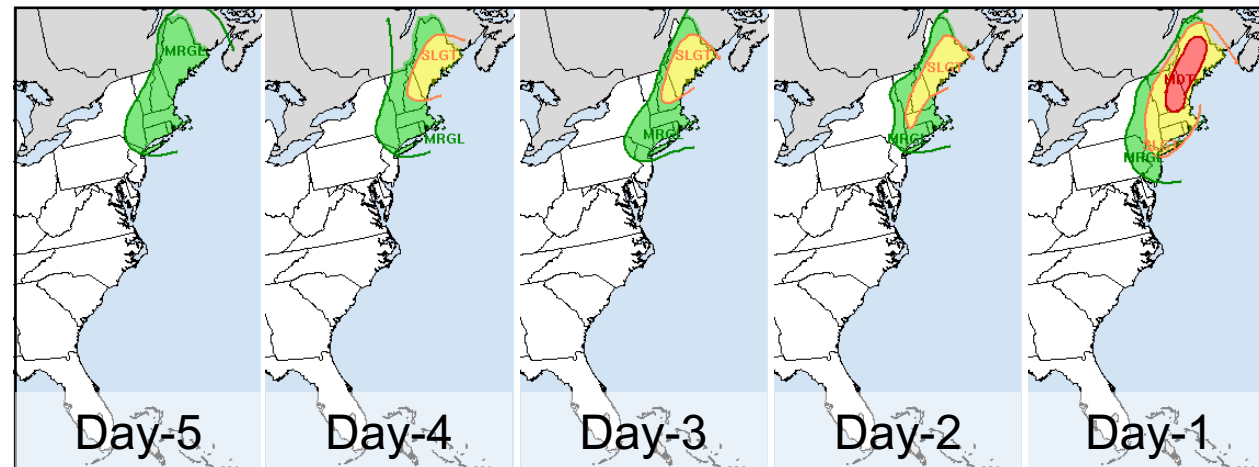
PRECIPITATION SCIENCE AND PREDICTION GROUP

Contact:
Jay Cordeira
jcordeira@ucsd.edu
<http://cw3e.ucsd.edu>

a. NWS WPC Excessive Rainfall Outlooks Valid 24-h ending 1200 UTC 18 Dec 2023



b. NWS WPC Excessive Rainfall Outlooks Valid 24-h ending 1200 UTC 19 Dec 2023



Excessive Rainfall Outlooks

The NWS Weather Prediction Center issued at least a marginal or slight risk for flash flooding in their excessive rainfall outlooks at leads times >5 days for all locations along the U.S. East Coast for the 24-hour periods ending at 1200 UTC 18 December 2023 and 1200 UTC 19 December 2023.

A Day-1 Moderate Risk for excessive rainfall was issued for New England at 1622 UTC on 18 December 2023 for the period from 1600 UTC 18 December 2023 through 1200 UTC 19 December 2023.

NWS Weather Prediction Center Excessive Rainfall Outlook: Risk of rainfall exceeding flash flood guidance within 25 miles of a point. Key: **MDT: At least 40%**, **SLGT: At least 15%**, **MRGL: At least 5%**



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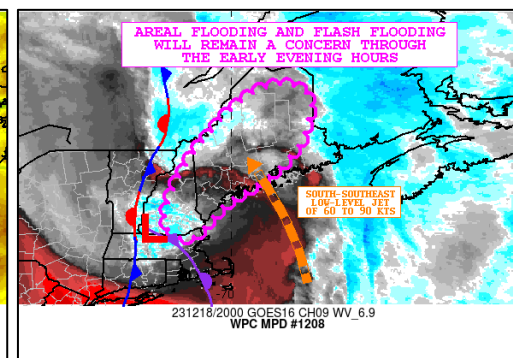
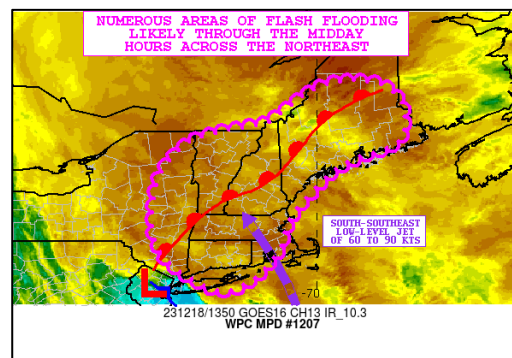
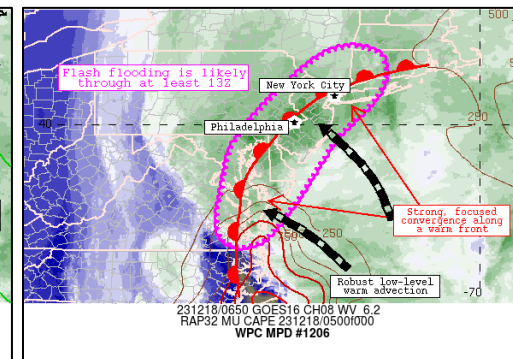
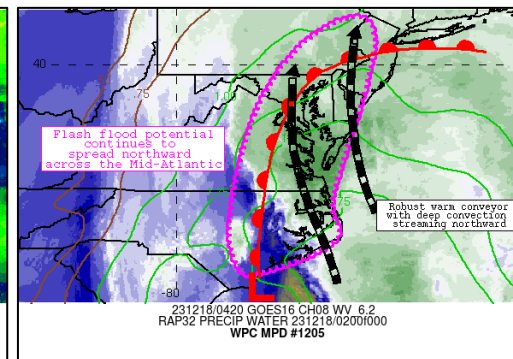
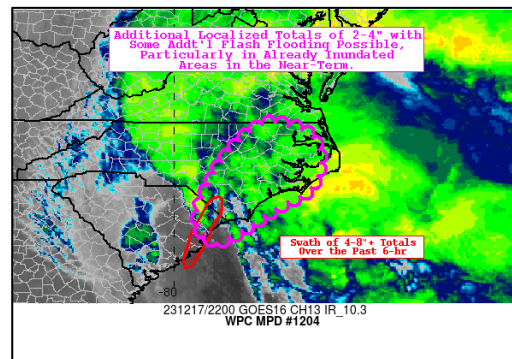
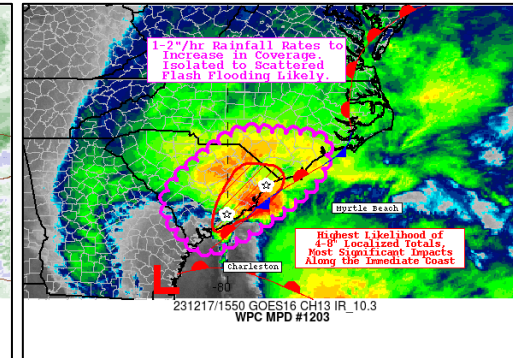
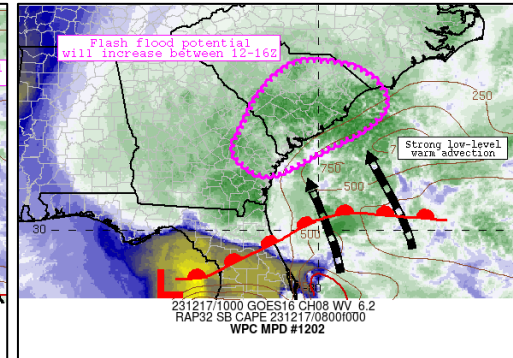
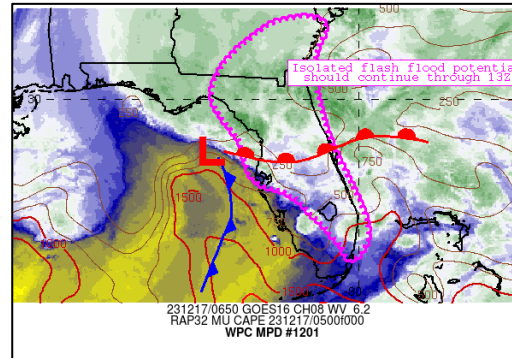
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Mesoscale Precipitation Discussion

The NWS Weather Prediction Center issued 8 mesoscale precipitation discussion (MPD) products on 17 and 18 December 2023.

Note that MPDs are issued as “short term guidance during heavy rain events leading to a threat of flash flooding to the National Weather Service (NWS) Weather Forecast Offices (WFOs), River Forecast Centers (RFCs), the media, emergency managers and interested partners”





Center for Western Weather and Water Extremes

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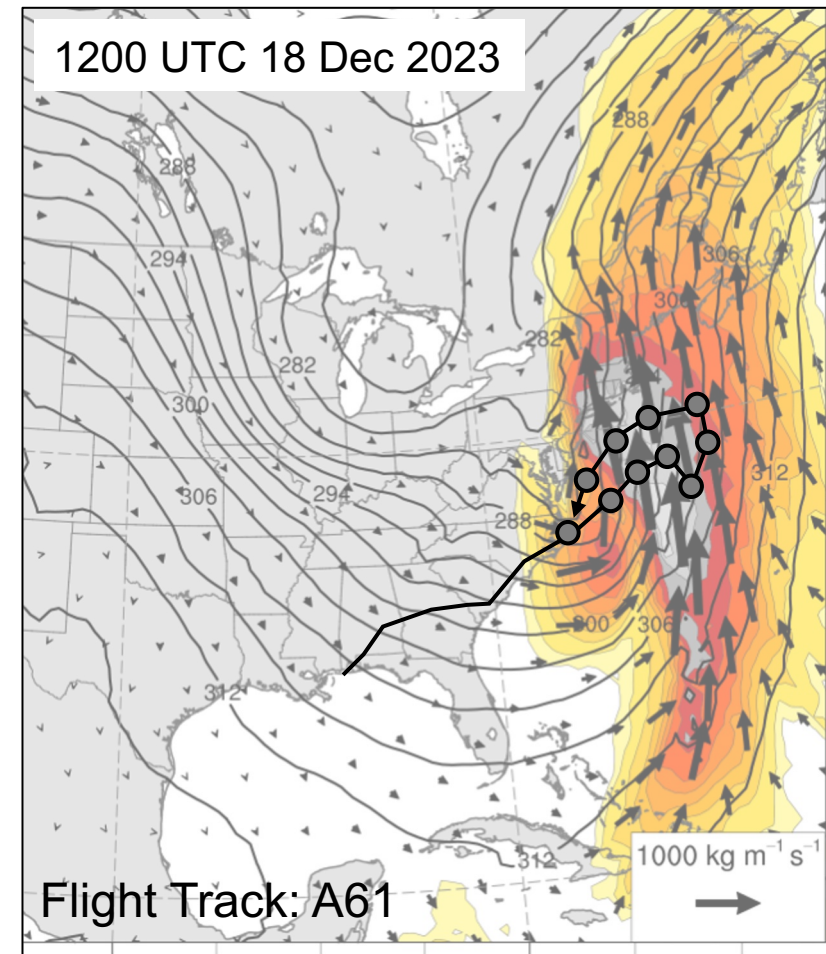
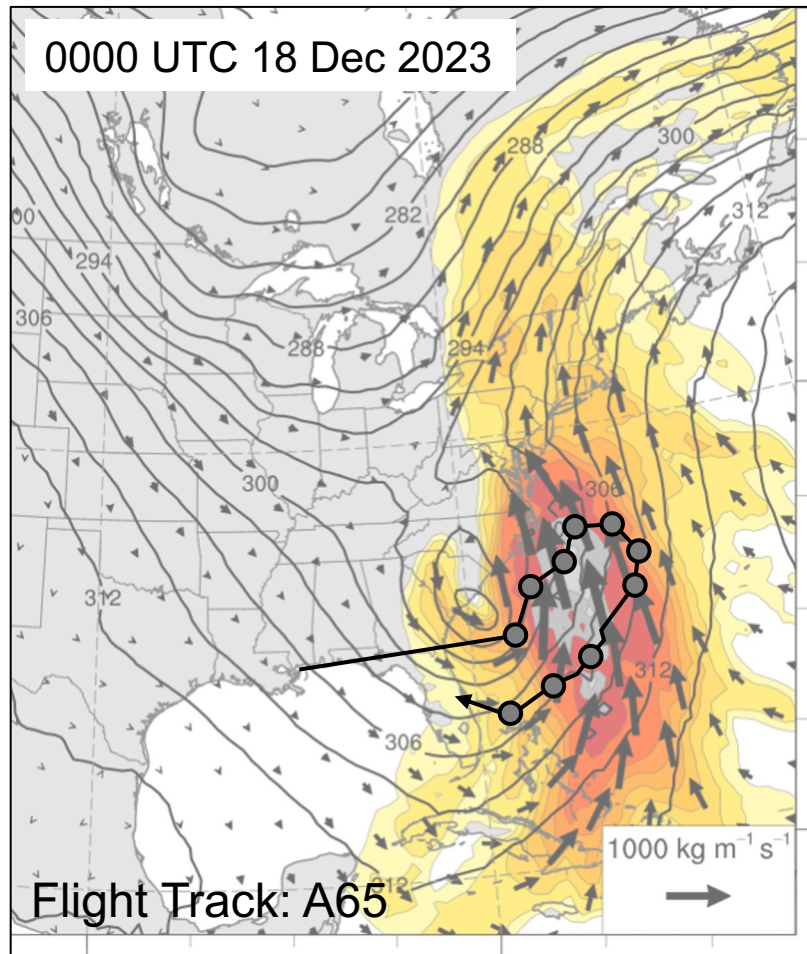
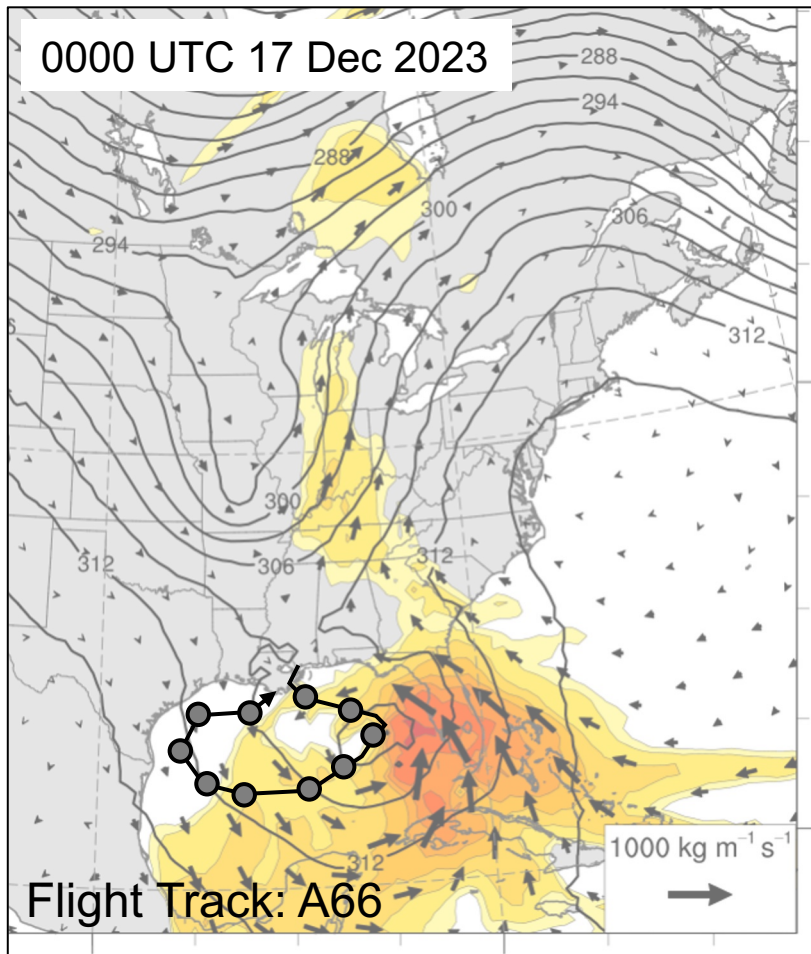
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Contact:

Jay Cordeira

jcordeira@ucsd.edu

<http://cw3e.ucsd.edu>



As part of the NOAA National Winter Season Operations Plan and Winter Storm Reconnaissance, the Air Force 53rd Weather Reconnaissance Squadron was tasked by the NOAA SDM, in collaboration with the NWS Weather Prediction Center, to provide enhanced observations for model data assimilation at 0000 UTC 17 December 2023, 0000 UTC 18 December 2023, and 1200 UTC 18 December 2023. The approximate tracks and drop locations of these data are shown above overlaid atop GFS analyses of IVT magnitude, direction, and 700-hPa geopotential heights.