NATIONAL WEATHER SERVICE

Integrating Research with Community Outreach to Improve Messaging and Forecast Methods for Mendenhall Glacier Dammed Lake Outburst Floods and Their Impacts to Downstream Residents in Juneau, Alaska

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American Meteorological Society 105th Annual Meeting
15th Conference on Transition of Research to Operations

Presenter:
Johnse Ostman, Alaska-Pacific River Forecast Center, Anchorage



Intro focus:

- monitoring and modeling and communication strategies developed between NWS, research, and community partners improved awareness and decision support services for folks impacted during the record August 2024 glacier lake outburst flood near Juneau, Alaska

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Gunalchéesh to the Tlingit people for their stewardship of Lingít Aaní since time immemorial and today. We at NWS acknowledge the traditional land of the Aak'w Kwáan people in Juneau, also known as Dzantik'i Héeni of which the Mendenhall occupies.

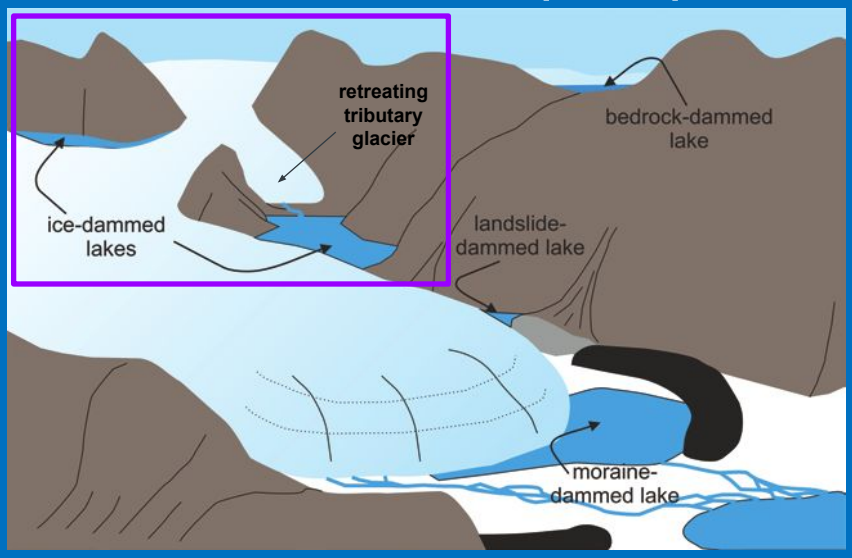
Acknowledgement of other NWS contributors, as well as many of our community and research partners, and the Alaska Native people and their traditional lands on which the Mendenhall resides.



Today the goal is to:

- First, define a Glacier Dammed Lakes (GDL) and Glacier Lake Outburst Floods (GLOF) & quickly explain how these occur;
- Identify the location of the Mendenhall Glacier, Lake, River, and Valley near Juneau, Alaska,
    - And talk about how this glacierized basin is unique
- Present how NWS and APRFC has:
    - historically FORECAST these GLOFs- *emphasis on Research partnership contributions*;
    - COMMUNICATED those forecasts for situational awareness pre- and during the events- *emphasis on Partner conversations to develop these communication strategies*;
    - some of the challenges BOTH in forecasting and communicating the potential flood impacts;
    - how NWS/APRFC ADAPTED these METHODS based on what each event has taught us & our PARTNER CONTRIBUTIONS & NEEDS,
- And finally, how did the forecast improve when a NEW record GLOF occurred in August 2024?!

Glacier Dammed Lakes (GDL)

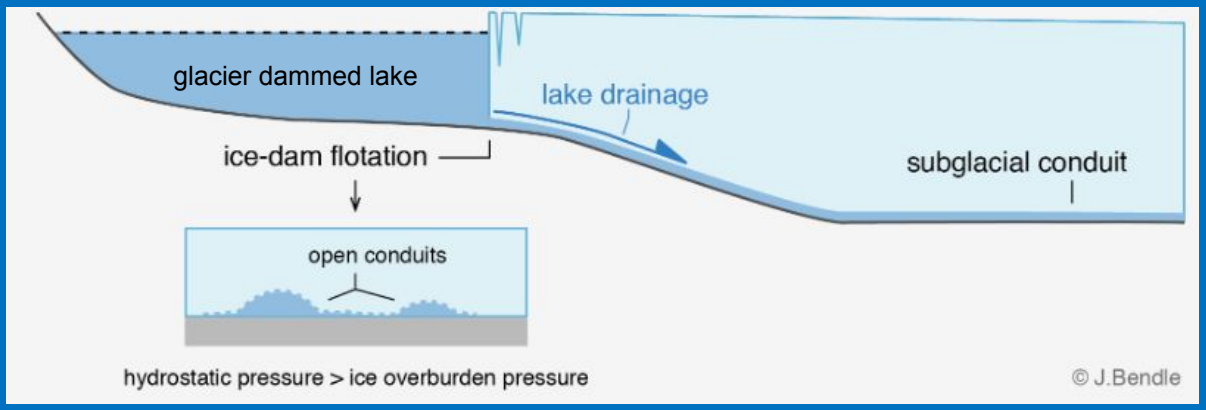


Bendle, 2025, https://www.antarcticglaciers.org/

Glacier dammed lakes form in many ways as shown in Jacob Bendle's cartoon here.

This talk focuses specifically on ice-dammed lakes formed when tributary glaciers to the mainstem glacier retreat (outlined in purple), leaving evacuated basins where snowmelt, glacier melt, and precipitation runoff can accumulate throughout the melt or runoff season.

Glacier Lake Outburst Flood (GLOF)



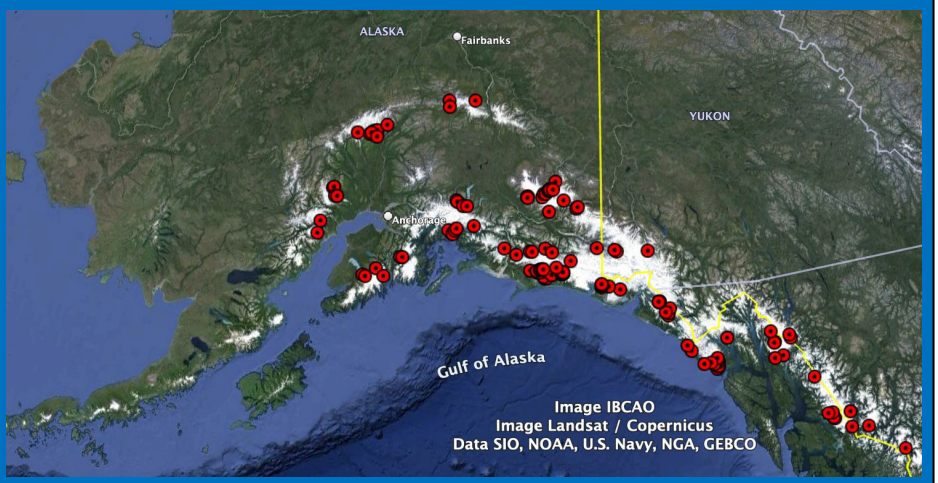
Bendle, 2025, https://www.antarcticglaciers.org/glacier-processes/glacial-lakes/glacial-lake-outburst-floods/

GDLs are really “just another lake” within a watershed until their capacity exceeds the basin volume- then we have GLACIER LAKE OUTBURST FLOODS, or these GLOFs.

GLOFs occur when accumulated runoff fills the GDL and the basin overtops the glacier dam and/or hydrostatic pressure exceeds the ice overburden pressure, which may form conduits for stored water to release along the glacier margins (edges), supra- (on), en- (within), or sub- (below) glacially.

Glacier Dammed Lakes (GDL)

- ~120 GDL in Alaska
- GDL monitoring uses remote sensing and pilot reports (PIREPs)
- Flood impacts typically range from minor to moderate



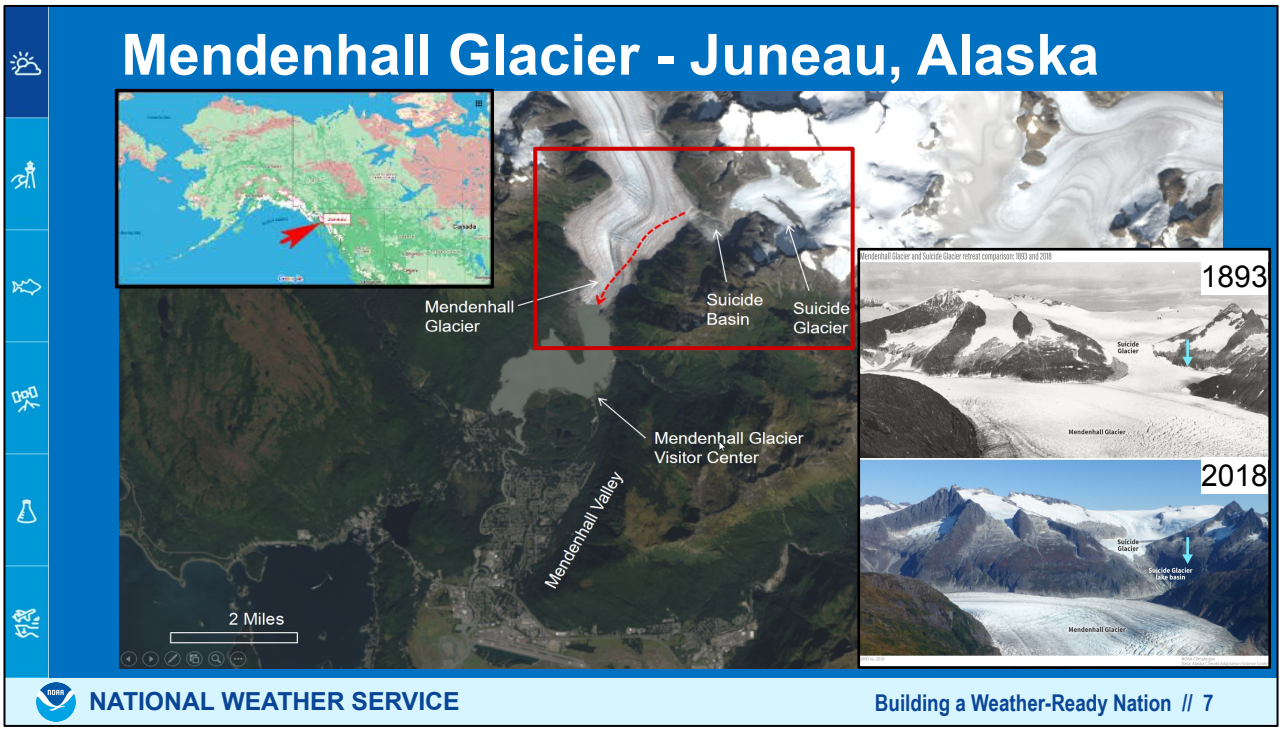
Brianna Rick et al, 2023

In Alaska we have identified more than 100 GDL, many of which release on a somewhat predictable cycle at 1-3 year frequency.

Because most of these GDL are in very remote locations, to MONITOR these GDL and forecast the resulting GLOFs we primarily use

- historical release frequency from downstream hydrographic observations,
- Sentinel-2 Visible Spectrum and Sentinel-1 Synthetic Aperture Radar (SAR) satellite imagery, and
- local pilot reports (PIREPs)

Literature review suggests that most developed GDL release nearly the full 100% of their volume every time, and that has been consistent with what we have seen in Alaska,
but until 2023 there was one known exception- the Mendenhall's Suicide Basin.



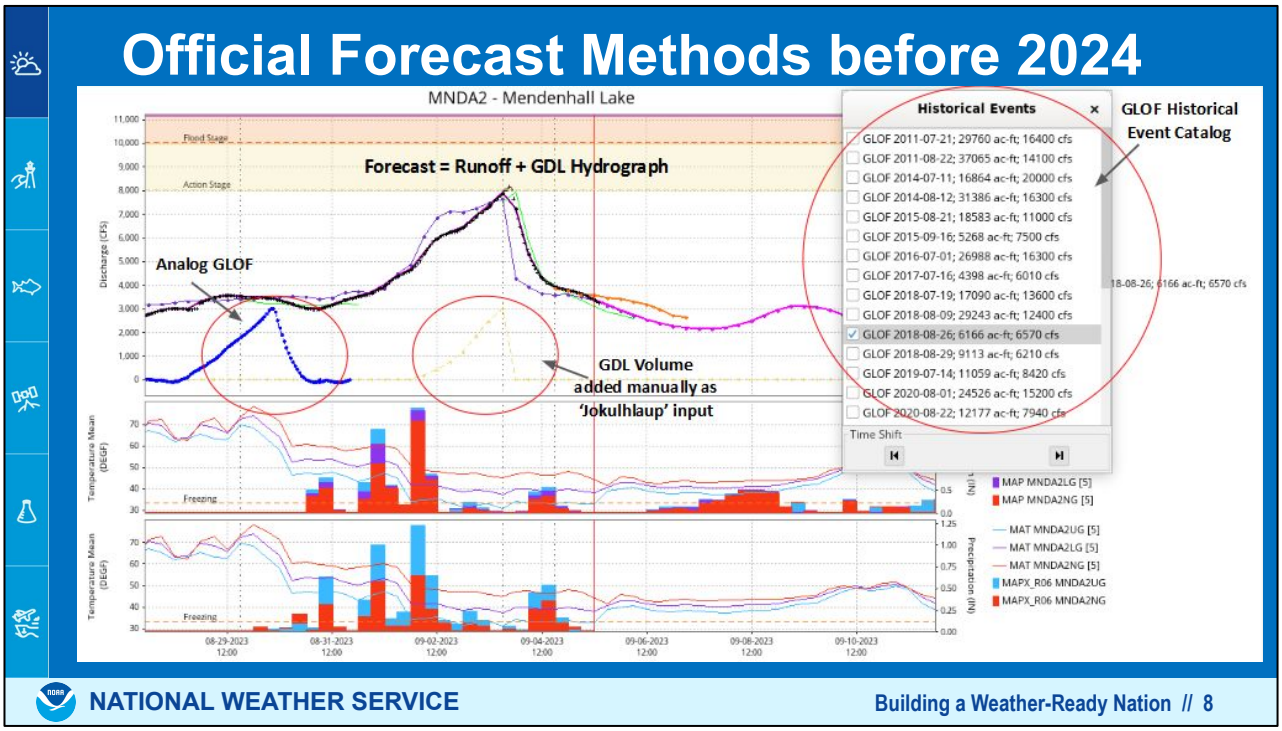
Juneau is Alaska's Capital City. It and the deglacierizied Mendenhall Valley are geographically located just downstream from the vast ~4000 sq km Juneau Icefield. Mendenhall Glacier is one of the rapidly retreating and deflating tributary glaciers flowing out of the Juneau Icefield, and a primary tourist attraction within Southeast Alaska's Tongass National Forest with almost 700,000 visitors annually.

Suicide Glacier, in an E corner of the lower Mendenhall, is a tributary ice arm that retreated out of a bedrock cirque during the past few decades, creating the "Suicide Basin" GDL, and fills annually with glacier and snow meltwater and precipitation runoff, as well as calved ice from the Mendenhall Glacier.

Beginning in 2011, Suicide Basin

- ANNUALLY has released SOME of the accumulated runoff volume;
- MOST years multiple releases have occurred throughout the summer months.
- TOTAL of 46 independent releases since 2011.

Before 2023, the Mendenhall GLOF were unique in that Suicide Basin never released its full volume before the glacial conduit plugged or other mechanism halted the release of dammed water.



APRFC mission is to provide official deterministic forecasts for nearly 100 rivers in Alaska. The Mendenhall River is one of those and resembles a typical glacial river in a northern temperate rainforest except for during glacier lake outburst floods.

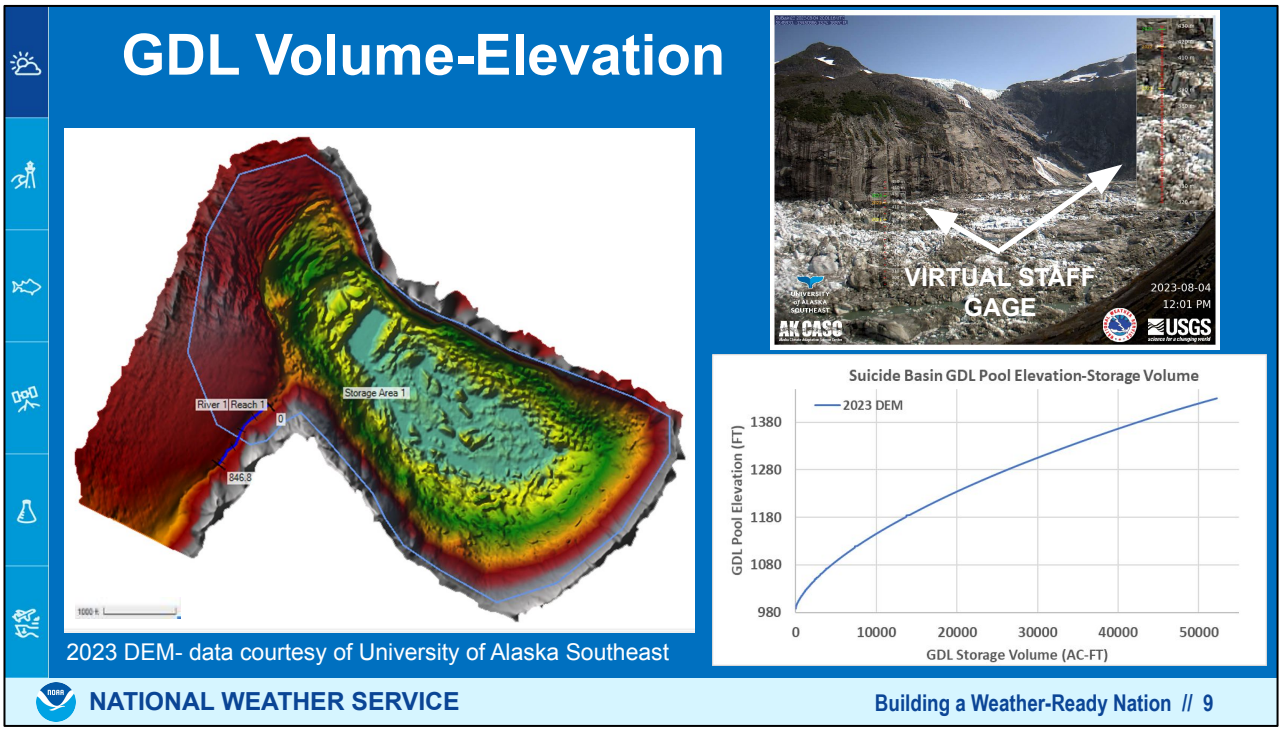
Prior to 2023, within the Community Hydrologic Prediction Service (CHPS) model, APRFC used a catalog of historical GLOF event releases as ANALOG EVENTS to add a 'Jokulhlaup' input to the precipitation-runoff driven flow hydrograph.

How we selected which ANALOG curve and forecast these GLOF was … Subjective

- At ONSET, had to ESTIMATE TIME SINCE RELEASE BEGAN
- LIMITED in that we **could not forecast a LARGER event than we had previously observed**
- USED **slope of the hydrograph rising limb**,
- USED an estimate of basin volume relative to past years from
    - remote sensed products- Satellite Imagery and USGS in-situ basin camera, and other methods

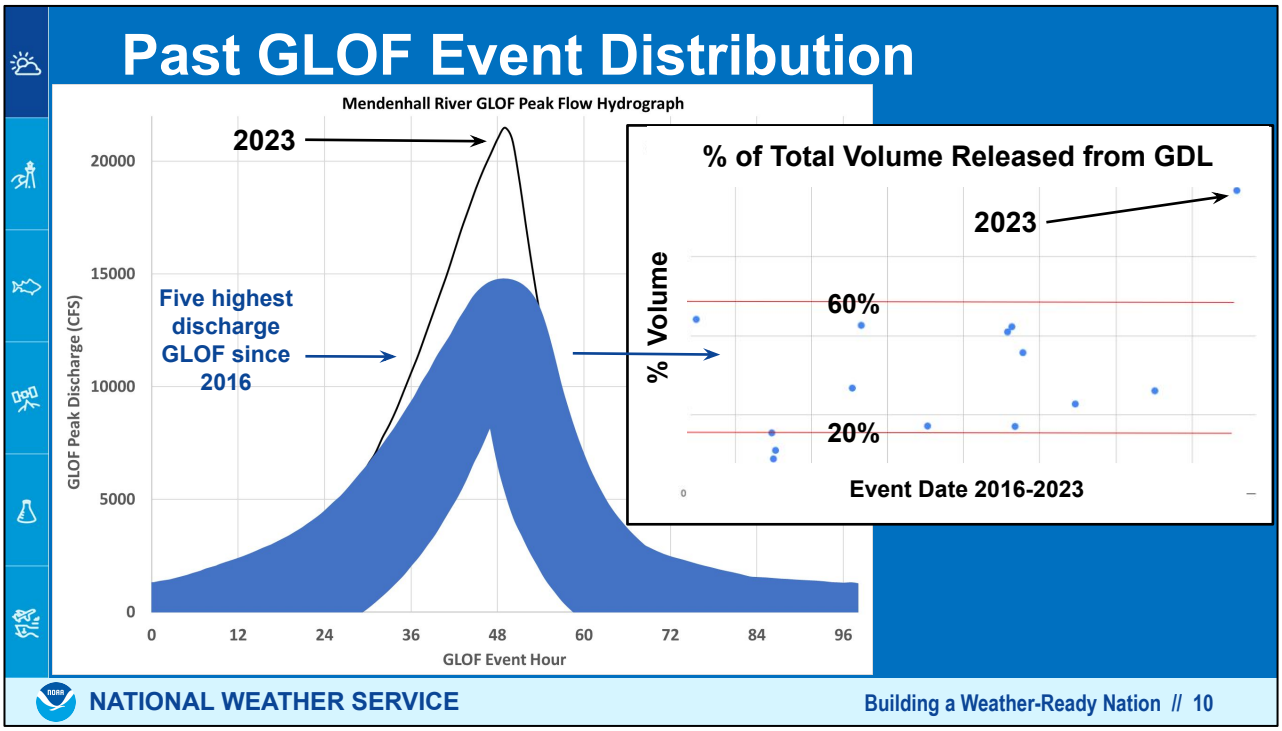
And we **COULD NOT PROVIDE pre-GLOF event situational awareness** of impacts to our partners.

Most GLOF forecasts verified throughout and after the releases, as we "CHASED" the GLOF hydrograph throughout the event



Unknown until after the event, the August 2023 “then” record GLOF was the first “full” release of the GDL volume.
Finally!

- NWS research partners at UAS and USGS could build a new Digital Elevation Model (DEM) (left image)
  - from LiDAR of a **“nearly” empty GDL**
  - And **using DEM differencing to account for the melange of icebergs captured within the DEM**
- From this new DEM, APRFC produced a **new Storage-Elevation curve**
  - (shown here in the lower right chart with GDL pool elevation on the y-axis, and storage volume in AC-FT on the x-axis).
- And NWS could use for example, the since-2016 USGS remote camera with **imposed “virtual” staff gage** (upper right image; developed by UAS and NWS Juneau)
  - APRFC used this to
    - estimate pool elevation, and
    - compute an accurate estimate of maximum GDL volume, ie DEFINE THE **PRE-RELEASE STORAGE**



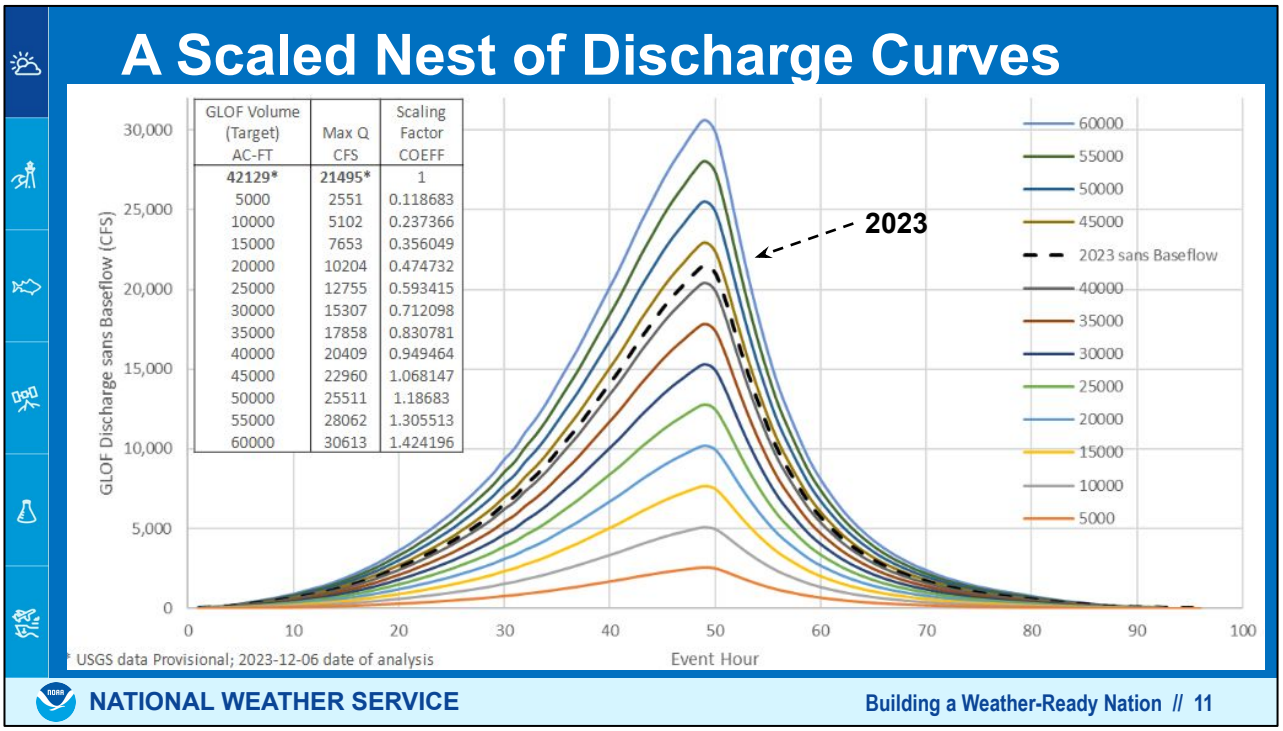
ALSO after the 2023 “then” record flood we also reviewed all GLOF over that 2011-2023 period, **and noticed that if you**

- deliberately s**hifted the downstream Mendenhall River EVENT peaks** WITH BASEFLOW REMOVED to **align on a 48-hour crest timeframe**
- each of the GLOF is essentially **a SCALED representation** of the others- the only difference is volume of water released.

Interestingly with the new “empty basin” DEM, revealed these **5 HIGHEST, and 10 out of 14** GLOF between 2016 and 2023, released ONLY approximately **20-60% of the 2023-computed total GDL basin volume**- these are events that have a PRE-RELEASE POOL ELEVATION & are plotted in the *second figure as dots between the red lines*.

This was significant because the **distribution suggested we may be able to assign a somewhat historical likelihood of volume expected to release** given the events of the past

- **this DISTRIBUTION is important for communication of potential event probabilities within historical context, BUT FIRST WE NEED a way to forecast the GLOF i.e., a CURVE …**



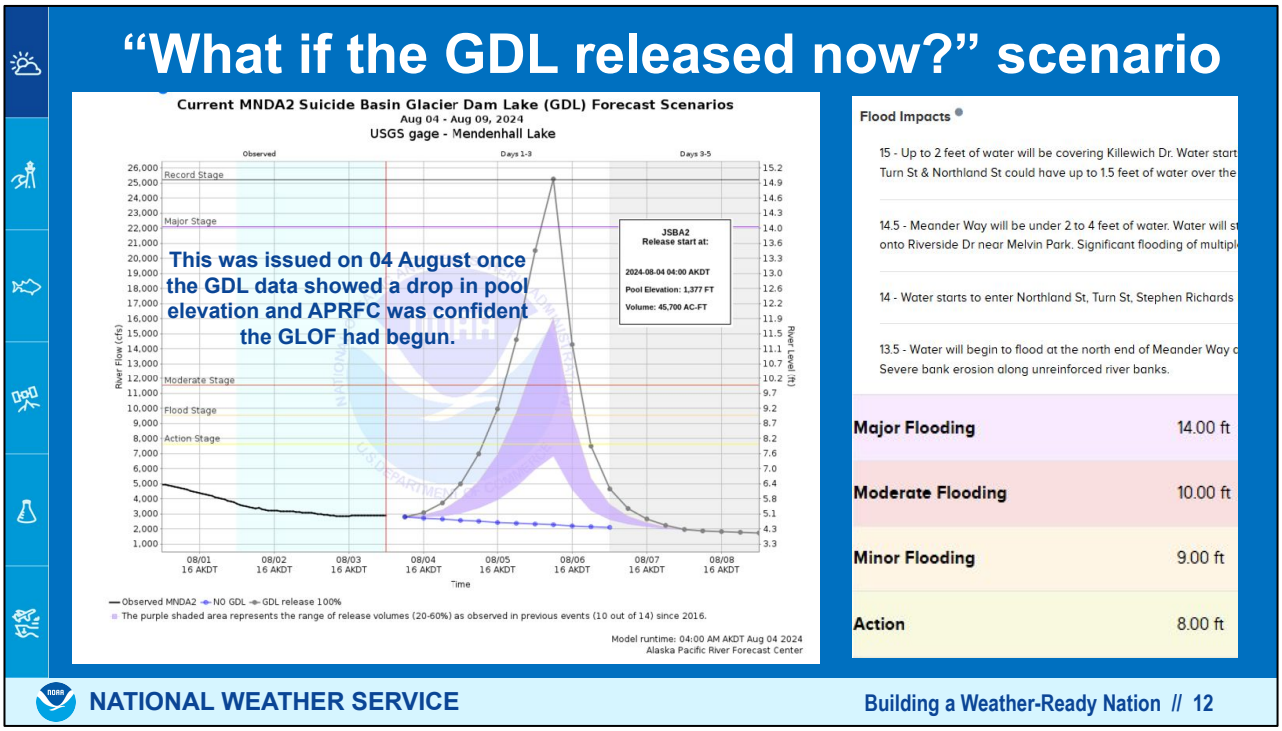
USING the then record 5 Aug 2023 GLOF as the base curve model and scaling factor coefficients, we produced a **nest of curves scaled by event volume** (in AC-FT), both below and above the 2023 GLOF, and centered on a 48-hour event crest.

This allowed us to produce more accurate OFFICIAL FORECASTS for a GLOF events,

- BY CHOOSING the curve closest to the estimated volume stored in the GDL, and then
- ADDING THAT CURVE as ANALOG to the current precipitation-runoff forecast hydrograph in the CHPS model.

To ensure we had a GDL POOL ELEVATION TO COMPUTE THE VOLUME …

- in spring 2024, our partners at UAS and USGS IMPROVED MONITORING at Suicide Basin
    - SURVEYING TO CONFIRM GAGE DATUM OF PRIMARY REMOTE SATELLITE CAMERA
    - ADDED a bank-mounted laser sensor referenced to gage datum THAT TRANSMITTED AT NEAR REAL-TIME FREQUENCY
    - ADDED a second REMOTE SATELLITE camera



Predicting when a GDL release is going to occur is <u>nearly impossible</u>- the glacial systems are too dynamic- but SINCE WE KNOW:

- the GDL pool elevation,
- the glacier dam elevation, and
- have a historical catalog of GLOFs,

We should be able to produce a "what if the GDL released now" scenario with every official forecast.

(Thankfully) all historical GLOF have occurred at relatively low baseflow in the downstream river. This method allows us to impose a GLOF on any precipitation-runoff scenario, including for example, Atmospheric River-induced flood flows.

Therefore, NWS designed a strategy to generate these hydrographs daily with the official forecast once the MAX GLOF curve exceeded Flood stage, and shared them among partners for situational awareness USING:.

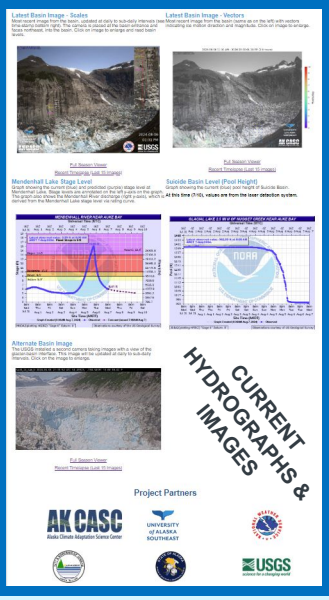
- the current downstream USGS river gage MNDA2 observations
- the daily official forecast produced from CHPS model-**INCLUDES ALL PRECIP & MELT RUNOFF**
- The most appropriate scaled event curve based on that days current GDL max volume,
- The defined flood stages for river gage MNDA2 (horizontal lines mid-plot above) and each level's associated impacts,
- The 20-60% envelope of historically most "likely" release based on 10 (of 14)

- GLOFs since 2016 (purple shaded area between official forecast sans GLOF (blue) and maximum (full pool) release forecast (black)

Following the Aug 2024 GLOF, we removed the ‘probabilistic’ shaded area from hydrographs with the assumption that the distribution (and glacier mechanics) likely changed in 2023 and was no longer relative.

Near real time data access & visualization





https://www.weather.gov/ajk/suicideBasin

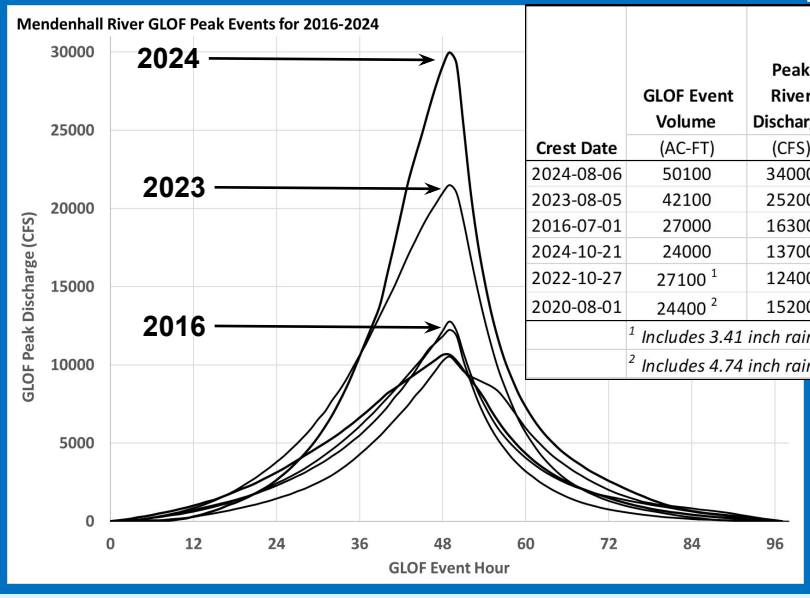


VIRTUAL STAFF GAGE

IN PREPARATION FOR THE 2024 GLOF …

- NWS Juneau Forecast Office expanded their Suicide Basin Monitoring and Current Conditions web page
- **… so all associated data and information would be easy to find, interpret, and share for situational awareness**

2016-2024 Peak GLOF Comparison



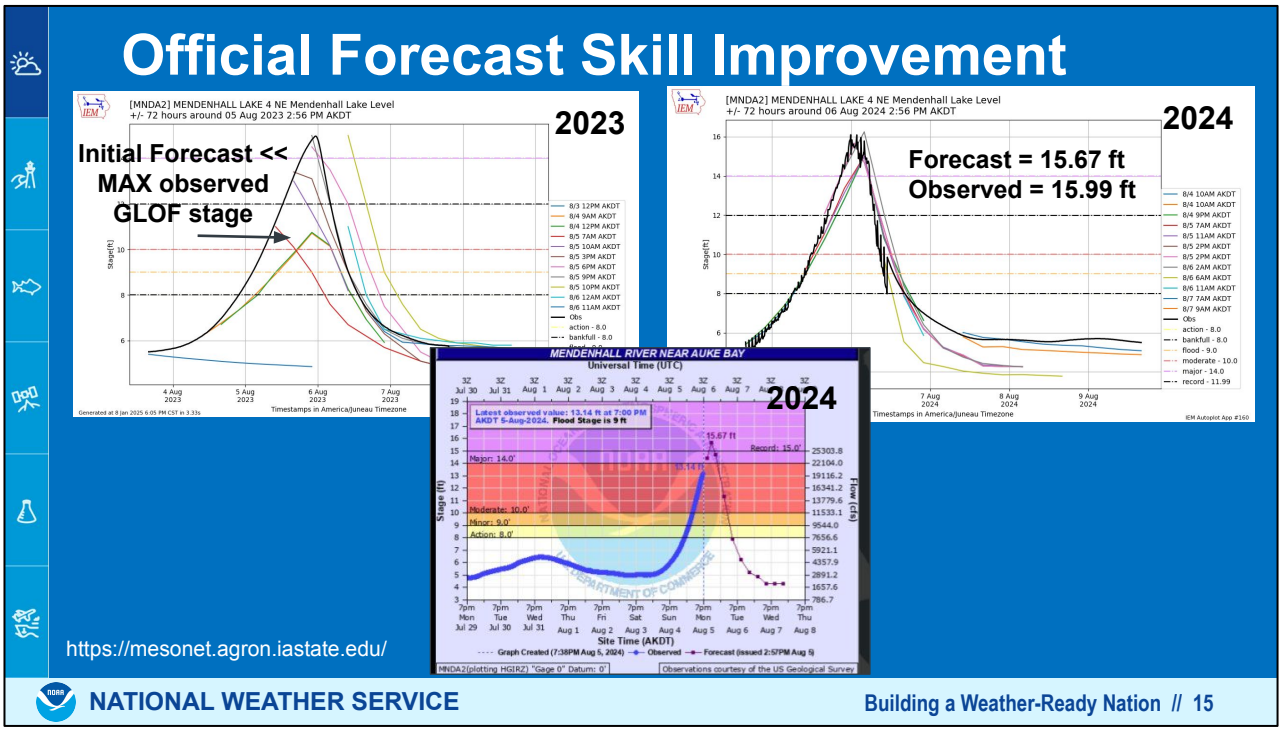
Crest Date	GLOF Event Volume (AC-FT)	Peak River Discharge (CFS)	River Discharge Increase (CFS)	Peak River Stage (FT)	GDL Level Start (FT A.S.L.)	GDL Level End (FT A.S.L.)	GDL Volume Released (%)
2024-08-06	50100	34000	31310	15.99	1371	900	**95**
2023-08-05	42100	25200	21610	14.97	1387	< 950	**96**
2016-07-01	27000	16300	13060	11.99	1446	NA	55
2024-10-21	24000	13700	11960	10.77	1245	< 950	63
2022-10-27	27100 [1]	12400	10240	8.11	NA	NA	ND
2020-08-01	24400 [2]	15200	11510	11.55	1407	1302	51

[1] *Includes 3.41 inch rainfall over previous 5 days*

[2] *Includes 4.74 inch rainfall through GLOF duration*

So how did 2024 compare to 2023?

- MNDA2 (DOWNSTREAM RIVER GAGE): 1 ft higher stage than 2023 RECORD stage & 9000 CFS higher Q (30% more discharge than 2023!)
-
- JSBA2 (GDL): RELEASED 8000 AC-FT MORE WATER THAN IN 2023 even with THE EVER-DEFLATING, and an approximately **12 ft lower glacier dam** elevation
-
- > Six times as many homes impacted (>300 homes impacted vs ~50 in 2023)
-
- BUT … Community awareness, preparation, and messaging was vastly IMPROVED … and so was the event river forecast …



Despite the unprecedented magnitude of the August 2024 GLOF, we saw vast improvement in forecast skill throughout the event. WHY? …

- We had an accurate volume estimation of GDL volume = we knew an approximate MAX volume in the GDL meant we knew which curve to choose from the scaled set of curves …
- Which meant we knew what the MAX or "worse case" scenario was A**ND we could forecast that compared with 2023 when the highest flood stage we could use as ANALOG was 11.99 ft**
- RATHER THAN **CHASE THE ASCENDING LIMB** OF THE EVENT HYDROGRAPH THROUGH THE GLOF as is clear in the 2023 forecast curves

As you can see in the 2024 hydrograph, the "shape" of ANALOG curve at the peak is not as steep as the observed data & is attributed to:

- FORECAST IS A SCALED MODEL OF THE 2023 EVENT & ANYTHING ABOVE THE 2023 OBSERVED DISCHARGE IS EXTRAPOLATION on a **6-hour time interval**
- USGS OBS DATA WERE CHANGING MID-EVENT AS GAGE HEIGHT CORRECTIONS AND RATING SHIFTS WERE APPLIED FROM SITE VISIT DATA

2024: Sawtooth behavior in Mesonet 2024 observed data (compared to 2023 smooth obs curve) are due to mid-event revisions by USGS.

Summary

- GLOF forecasting requires physically-based models based on measurable parameters
- Post-2023 GLOF used expertises of NWS, APRFC, our Research (USGS, UAS, AK DGGS) and Community (CBJ, AK DOT&PF, Tlingit and Haida, USFS) partners to improve both before and during an event:
  - Data monitoring
  - Near real-time data access and visualization
  - Impact assessment accuracy
  - Communication
  - Official river forecast
- Next Steps
  - Develop probabilistic messaging for:
    - Timing, risk, and impact
  - Update flood inundation extents and impacts



Photo courtesy Jamie Pierce/USGS

Questions?

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Thank You!

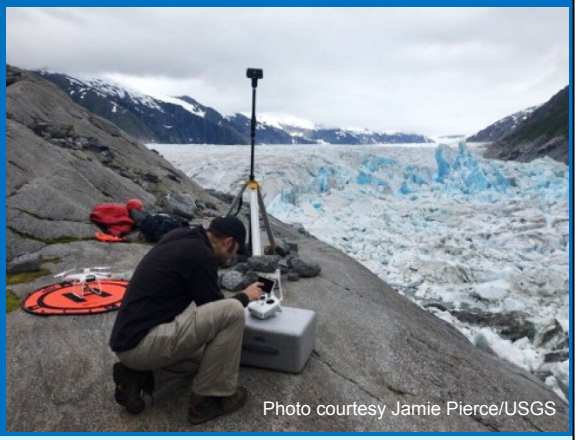


Photo courtesy Jamie Pierce/USGS

Extra slides

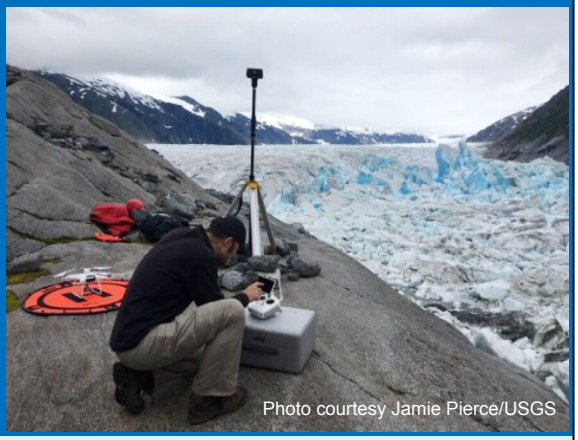
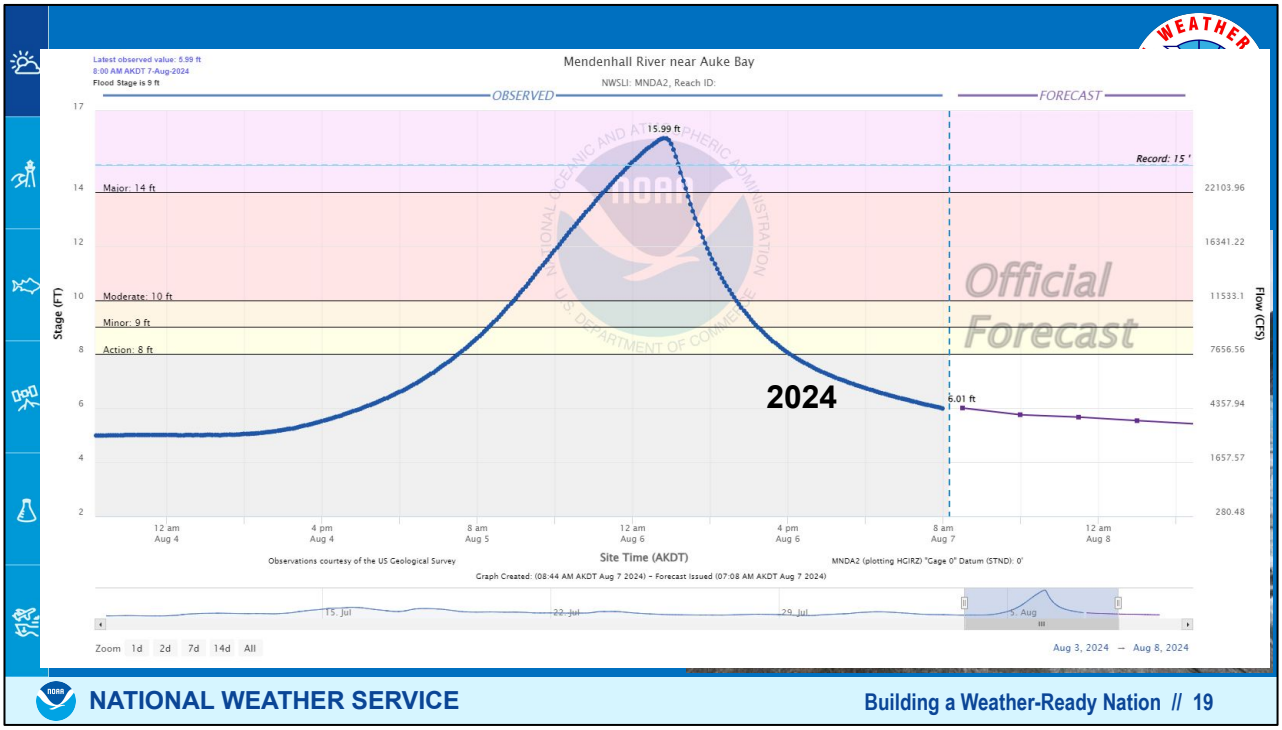
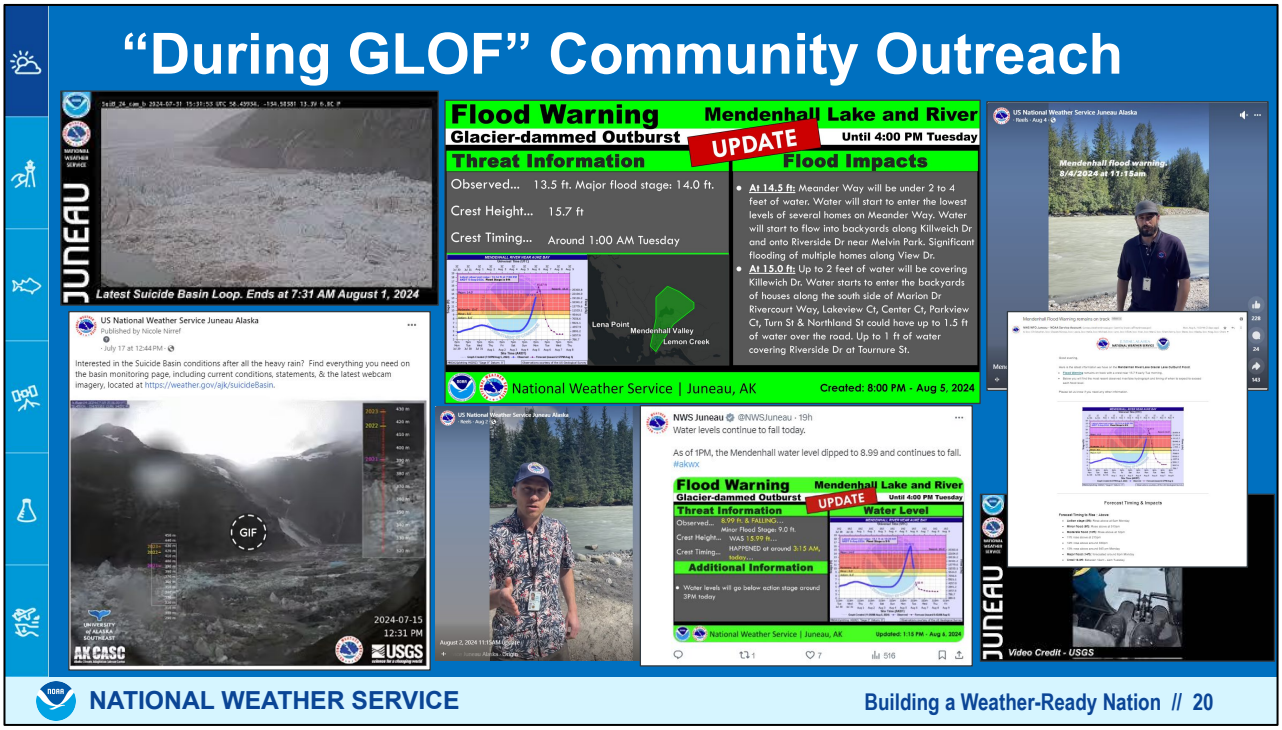


Photo courtesy Jamie Pierce/USGS



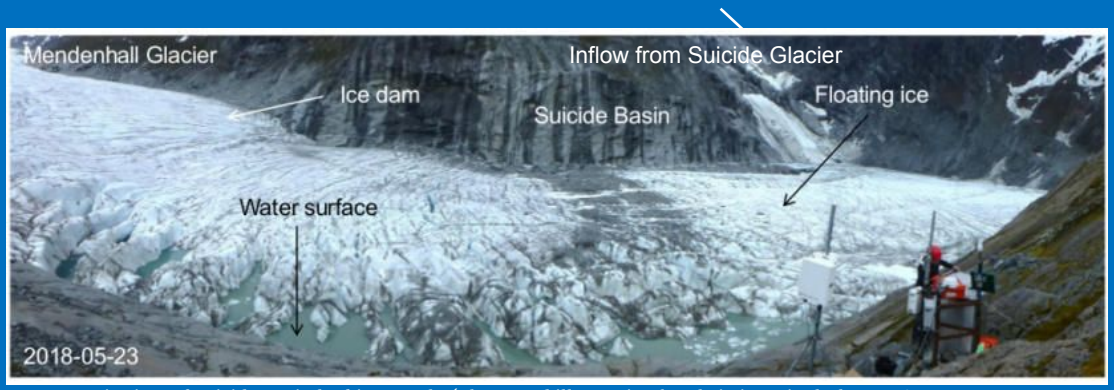
2024 event hydrograph NWPS



All of these tools, garnered from partner conversations and research, improved the pre- and during GLOF Decision Support Services (DSS).

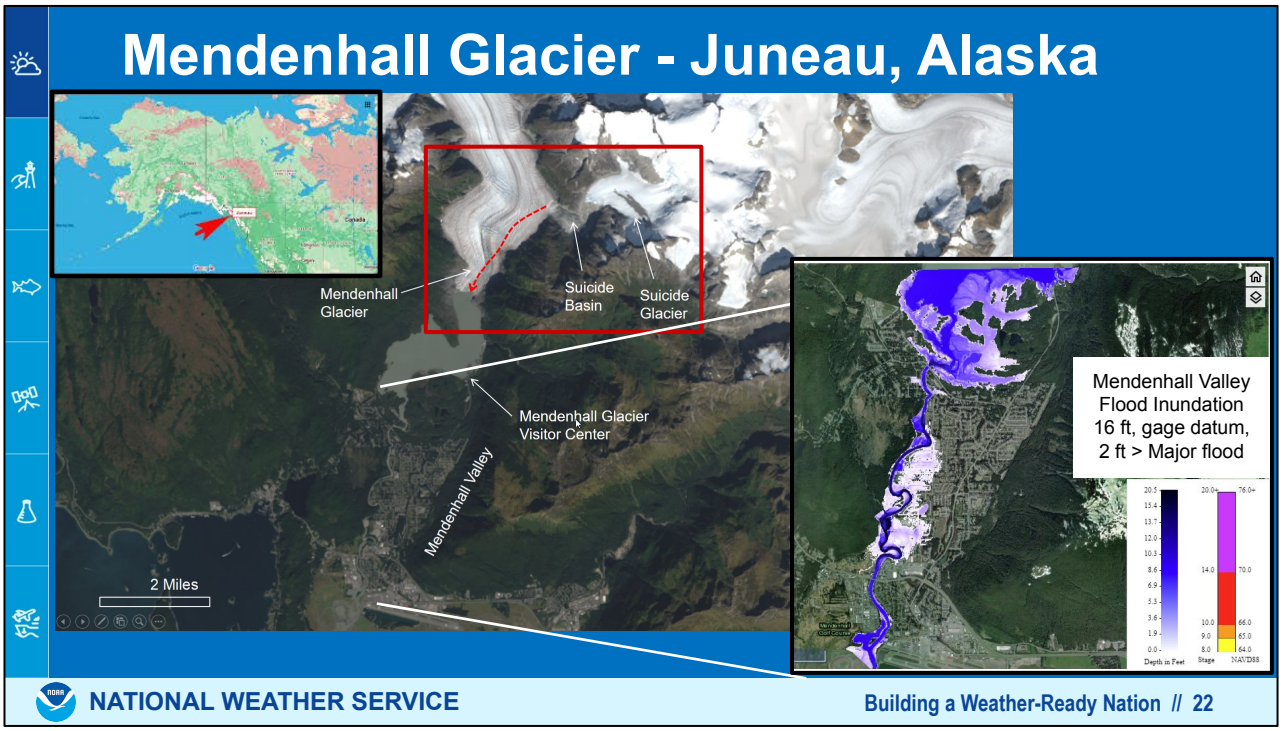
NWS was able to present accurate and timely updates, on-site reports, and partner-contributed videos to the public to improve overall public awareness.

Mendenhall Glacier - Suicide Glacier



Panoramic view of Suicide Basin looking north. (Photo and illustration by Christian Kienholz, UAS/USGS

Suicide Basin schematic



Duplicate slide but INCLUDES FIM- REMOVED FROM EARLIER ITERATION OF SLIDE DECK

The figure in the lower right corner shows the flood inundation of the Mendenhall Valley downstream of Mendenhall Lake at a stage 2 ft greater than Major flood level, and approximately that of the August 2024 outburst flood, a river or inundation level that was never considered plausible in the past.