Meteorological Conditions Associated with Extreme Precipitation & Differentiating between impactful and non-impactful Atmospheric River events

Aaron Jacobs, Senior Service Hydrologist/Meteorologist: WFO Juneau AK

Deanna Nash, Atmospheric Scientist: Center for Western Weather Water Extremes (CW3E)

Jon Rutz, Atmospheric Scientist: Center for Western Weather Water Extremes (CW3E)

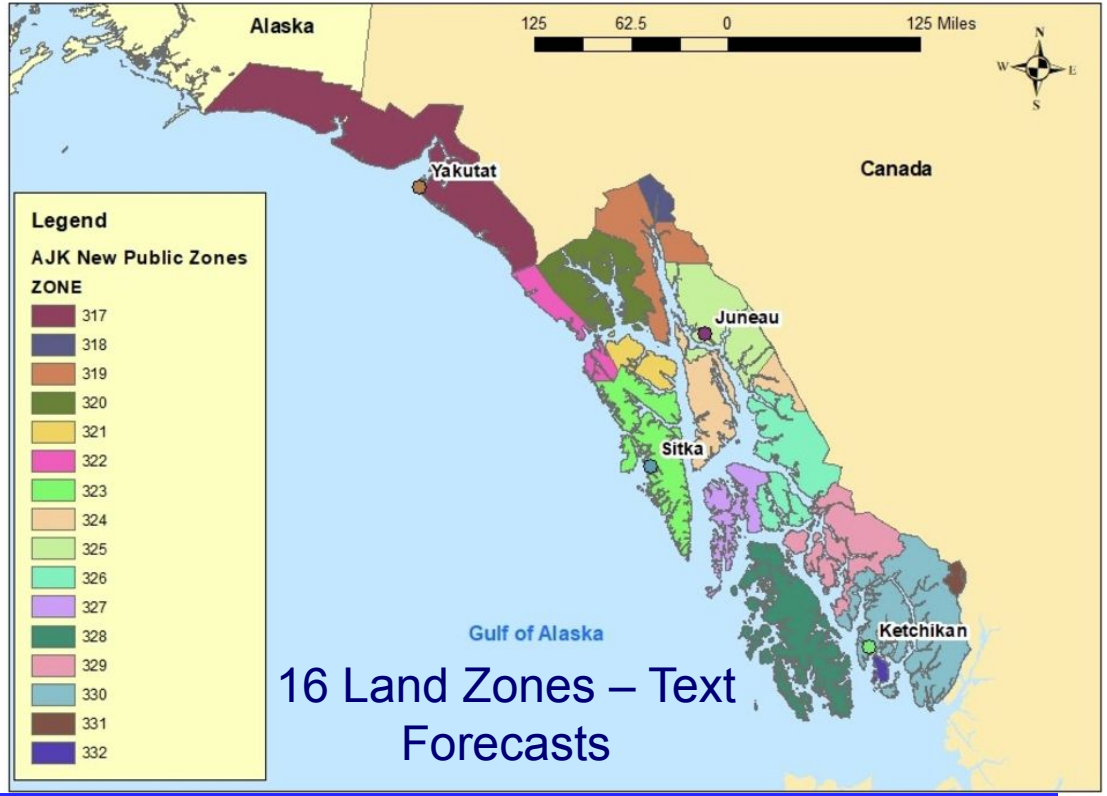
2025 WPC HMT Seminar Series for PEAR and WWE

Outline of Atmospheric Rivers in AK

- Overview of Southeast Alaska (SEAK)
- SEAK AR Climatology
- Tools to assess ARs in Alaska
- Impacts from ARs across SEAK
- How to assess an impactful AR to a non-impactful?

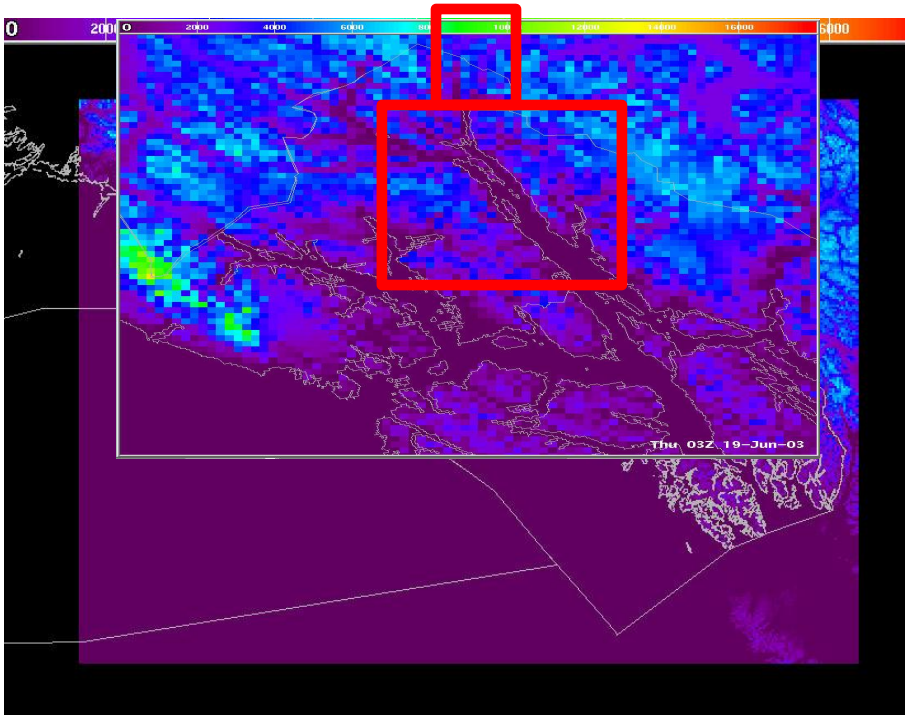
WFO Juneau Forecast Area

Area of Responsibility: 155,000 sq mi (3rd Largest in NWS)



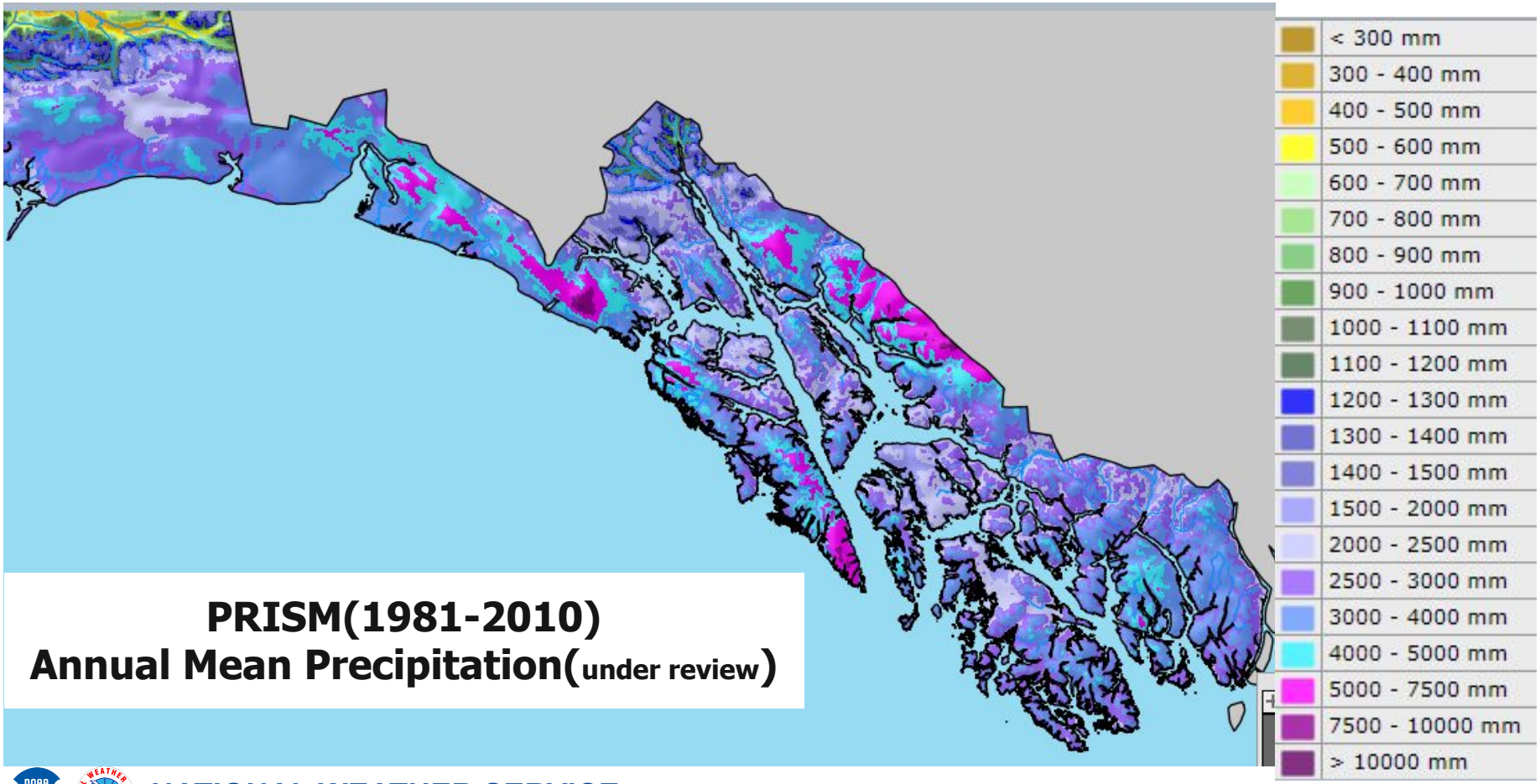
75 % of Forecast Area is covered by Water

WFO Juneau Forecast Area Terrain



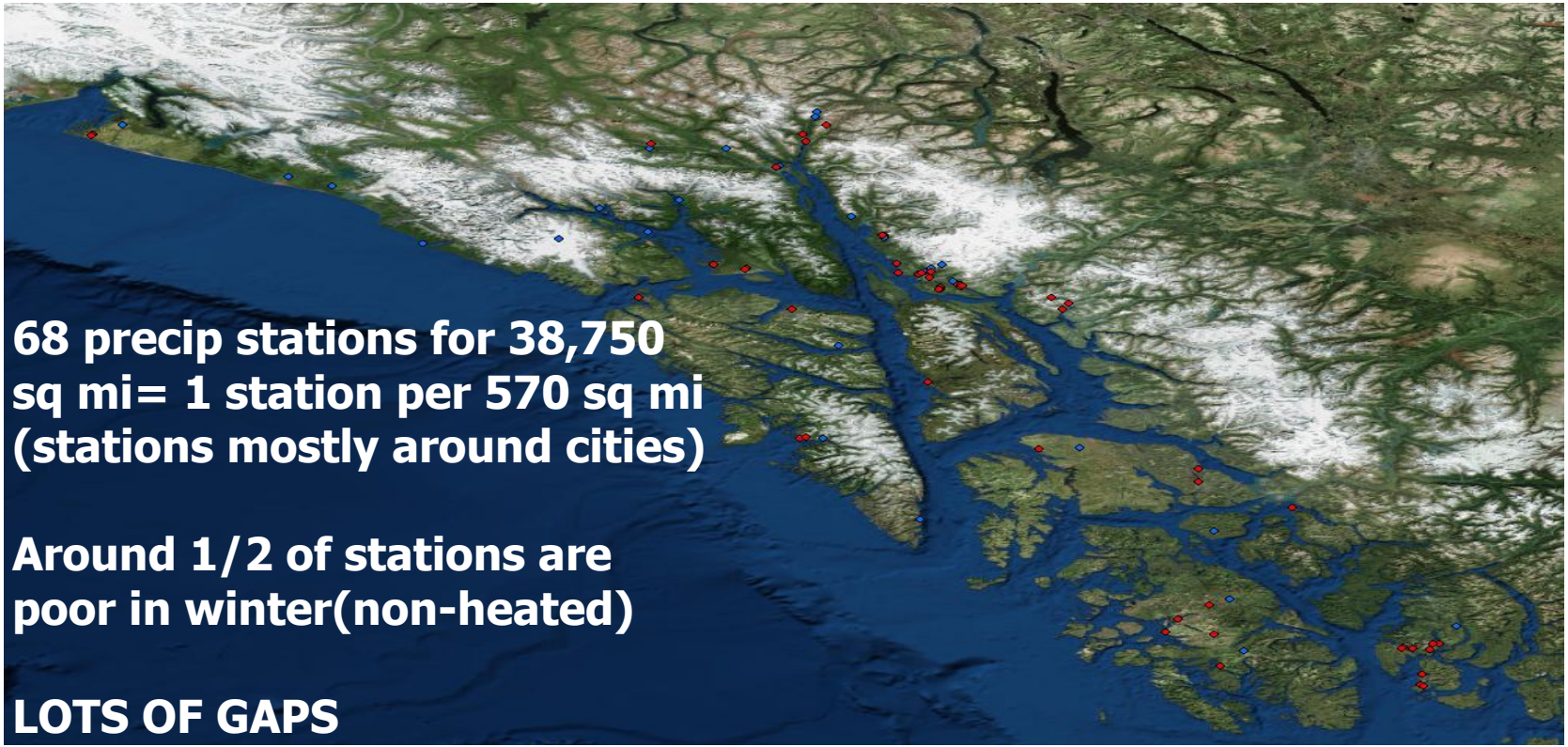
- Very steep terrain next to ocean. Area average=sea level to 3,000ft in 3 miles and in some cases sea level to 15,000ft in 8 miles

WFO Juneau Forecast Area

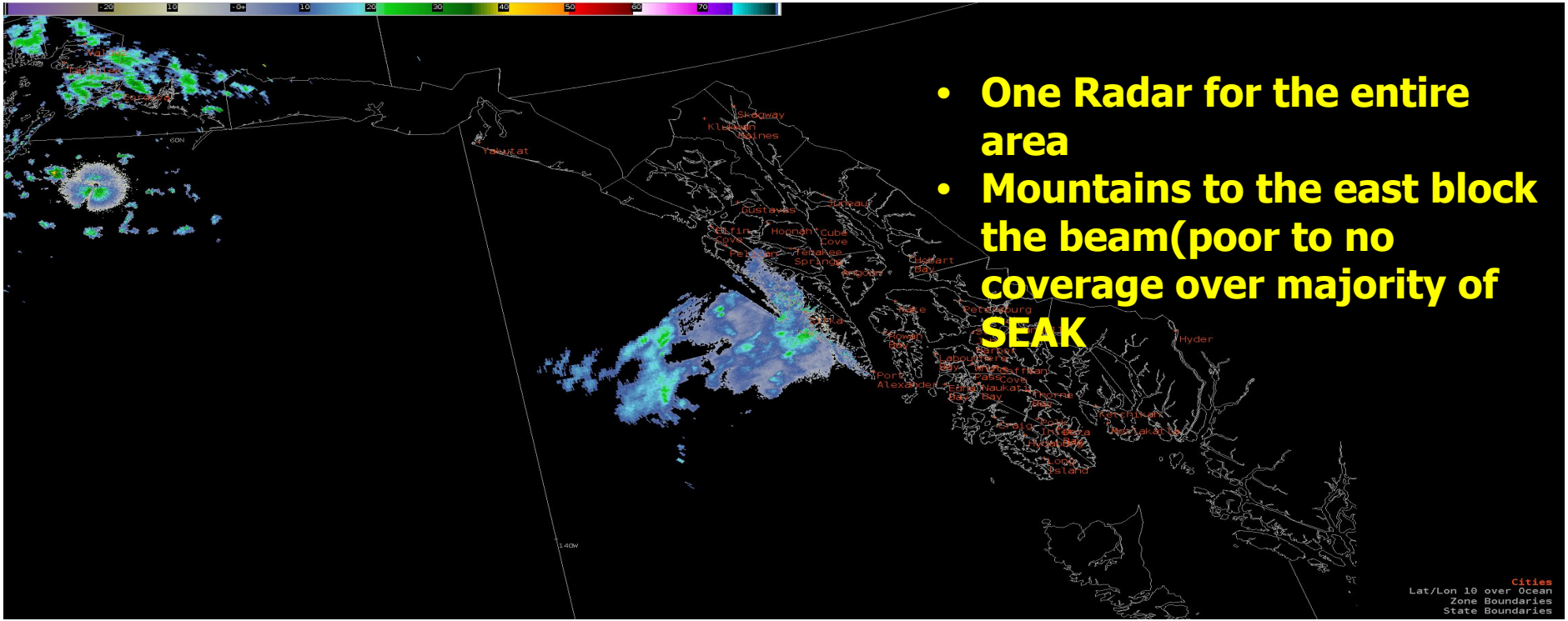


PRISM(1981-2010)
Annual Mean Precipitation(under review)

WFO Juneau Real-time Precip Gauge Network



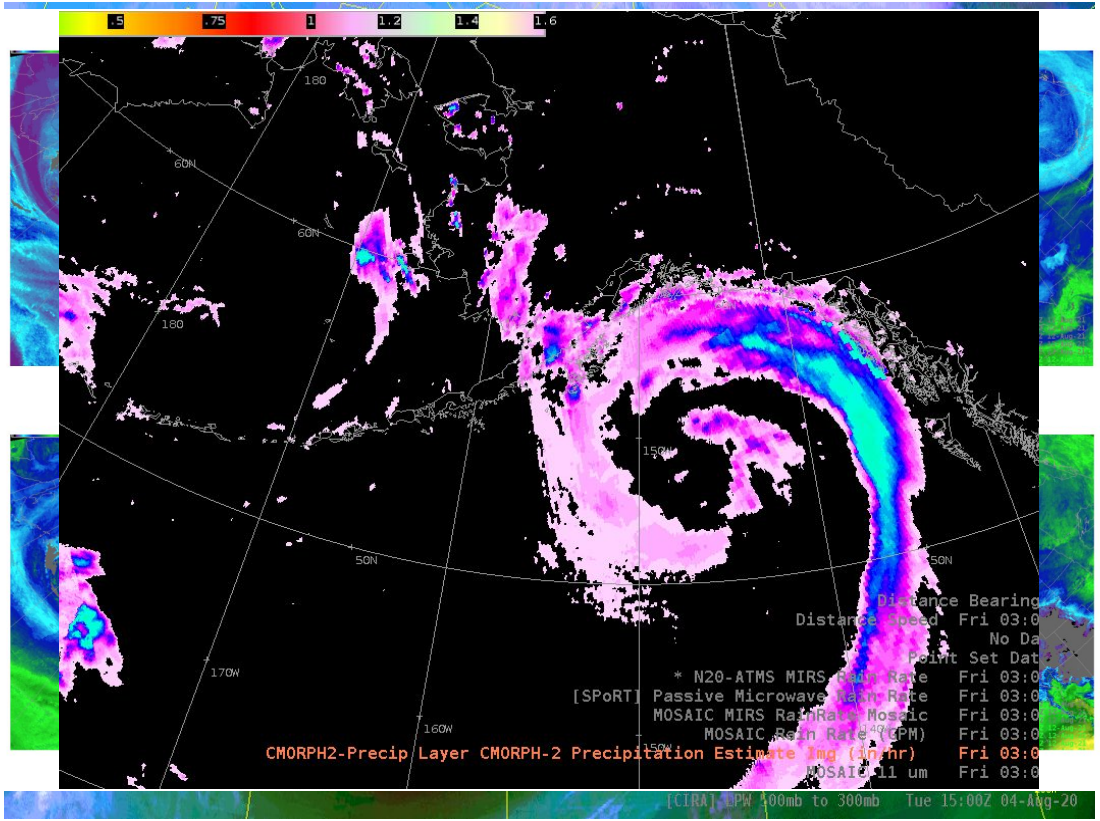
WFO Juneau Biorka Radar Coverage



- One Radar for the entire area
- Mountains to the east block the beam(poor to no coverage over majority of SEAK

How Does NWS Monitor Heavy/Extreme Rain Events

- Satellites:
  - Constellation of Satellites from US & international partners
    - Displaying moisture at different levels
    - Total moisture
    - Rain rate estimates



SEAK AR Climatology

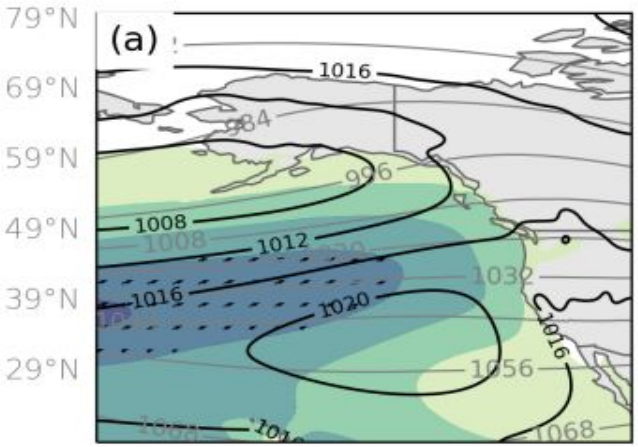
- Data: 1980-2019 ARs,Met elements (extreme precipitation, IVT…)
  - Precip: 4km dynamically downscaled from CFSv2 at a 1-hr temporal resolution

    Lader et al. (2020)
  - AR Detection: Tracking Atmospheric Rivers Globally as Elongated Targets(tARget) algorithm version 3 was used on 1.5º ERA5
    - Combine geometry & IVT intensity(>85 percentile)
    - Directional component(most move poleward)
  - For geopotential height, winds, temperature at multiple pressure levels, as well as mean sea level pressure and IVT used ERA5 0.25º at 1hr time steps

Cities evaluated for the NSF Kutí project(the Tlingit (indigenous peoples of Southeast Alaska word for weather)

SEAK AR Climatology

"Composite" ARs over Southeast Alaska



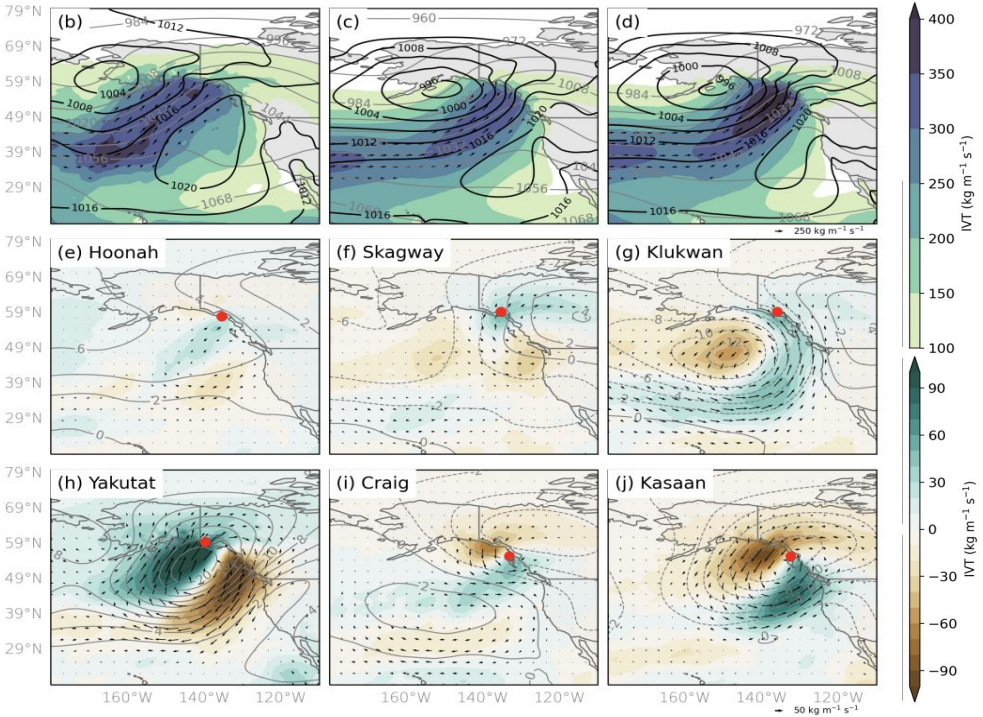
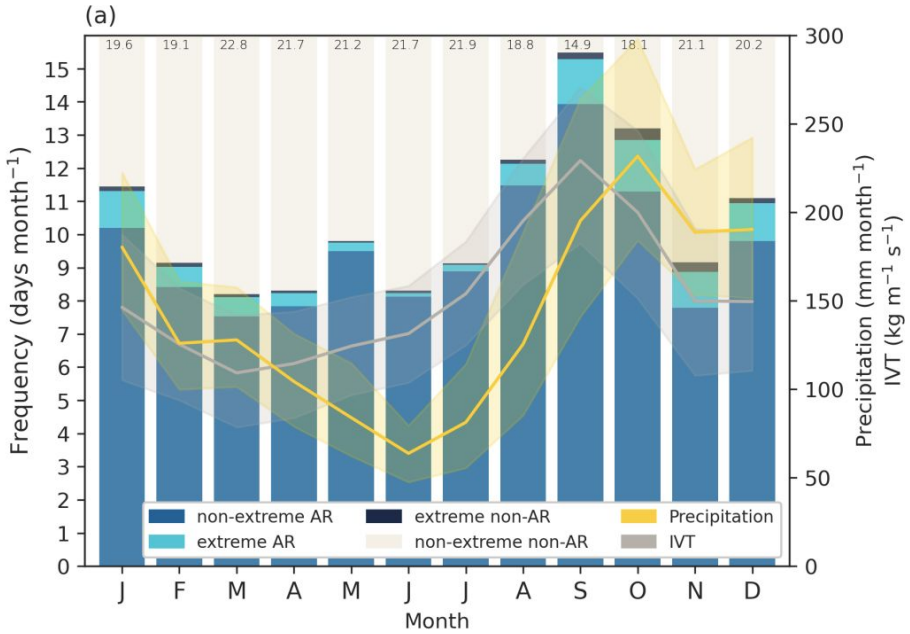


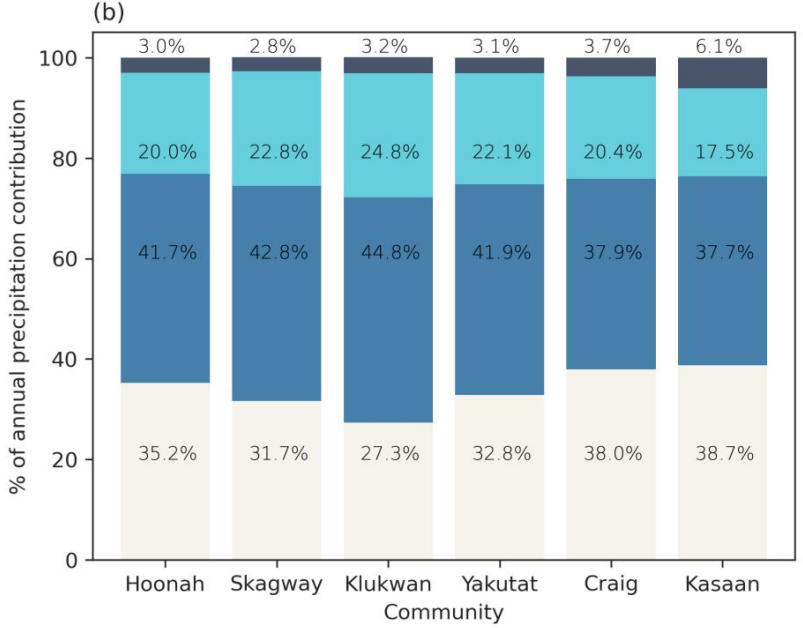
Figure 4. (a) Average daily composites of ERA5 IVT (shaded and vectors; kg m^{-1} s^{-1}), 250 hPa geopotential height (gray contours; dam), and MSLP (black contours, hPa) for all days between 1980 and 2019. (b) Same as (a), but for all AR days in Southeast Alaska that are > 95th percentile IVT and < 5th percentile precipitation (n=56). (c) Same as (a) but for all AR days in Southeast Alaska that are > 95th percentile precipitation (n=1266). (d) Same as (a) but for all AR days in Southeast Alaska that are > 95th percentile for both IVT and precipitation (n=566). (e) Composite differences of ERA5 IVT (shaded and vectors; kg m^{-1} s^{-1}) and 250 hPa geopotential height (contours; dam) for Hoonah during extreme Atmospheric River days and the average for all communities during extreme AR days (e.g., Community AR IVT - Average AR IVT). The red dot indicates the location of Hoonah. (f-j) Same as (e) but for (f) Skagway, (g) Klukwan, (h) Yakutat, (i) Craig and (j) Kasaan.

Provided by: Nash, Rutz, and Jacobs, 2024

SEAK AR Climatology

Average monthly frequency of AR days in Southeast AK



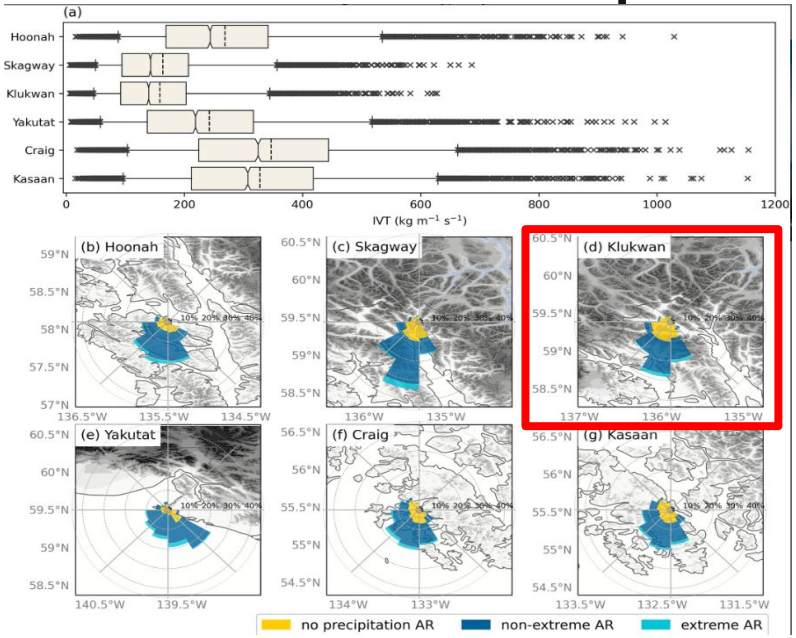


About six atmospheric river days per year are the source of up to 91% of Southeast Alaska's extreme rain and snow days.

Provided by: Nash, Rutz, and Jacobs, 2024

SEAK AR Climatology

Some communities are more likely to see extreme precipitation when the atmospheric river is a certain direction



(a) Distribution of daily maximum ERA5 IVT (kg m^{-1} s^{-1}) for all AR days between 1 January 1980 and 31 December 2019 when precipitation was >2.5 mm day^{-1} for each community (note that the sample size of AR days for each community ranges from 4,610 to 4,691). The box extends from lower to upper quartiles of the data, with a black solid line at the median and a black dotted line at the mean. The whiskers show the range of the data from the fifth percentile to the 95th percentile. (b) Topographical map of Hoonah using USGS GMT elevation data (shaded, m) where higher elevations are darker shades. Wind rose diagrams for IVT direction from ERA5 data for all days when an AR was present in Southeast Alaska is overlaid, centered on the grid cell nearest Hoonah. The total length of each bar indicates the frequency (%) of events with IVT in that particular direction. The length of colored areas within the bar indicates the frequency (%) of events with precipitation <2.5 mm day^{-1} (yellow), <95th percentile precipitation (blue), and >95th percentile precipitation (aqua) that also occurred in that direction (c)–(h) Same as (b) but for (c) Skagway, (d) Klukwan, (e) Yakutat, (f) Craig and (g) Kasaan.

90% of extreme ARs in Klukwan feature

south-southwesterly or **south-southeasterly** IVT

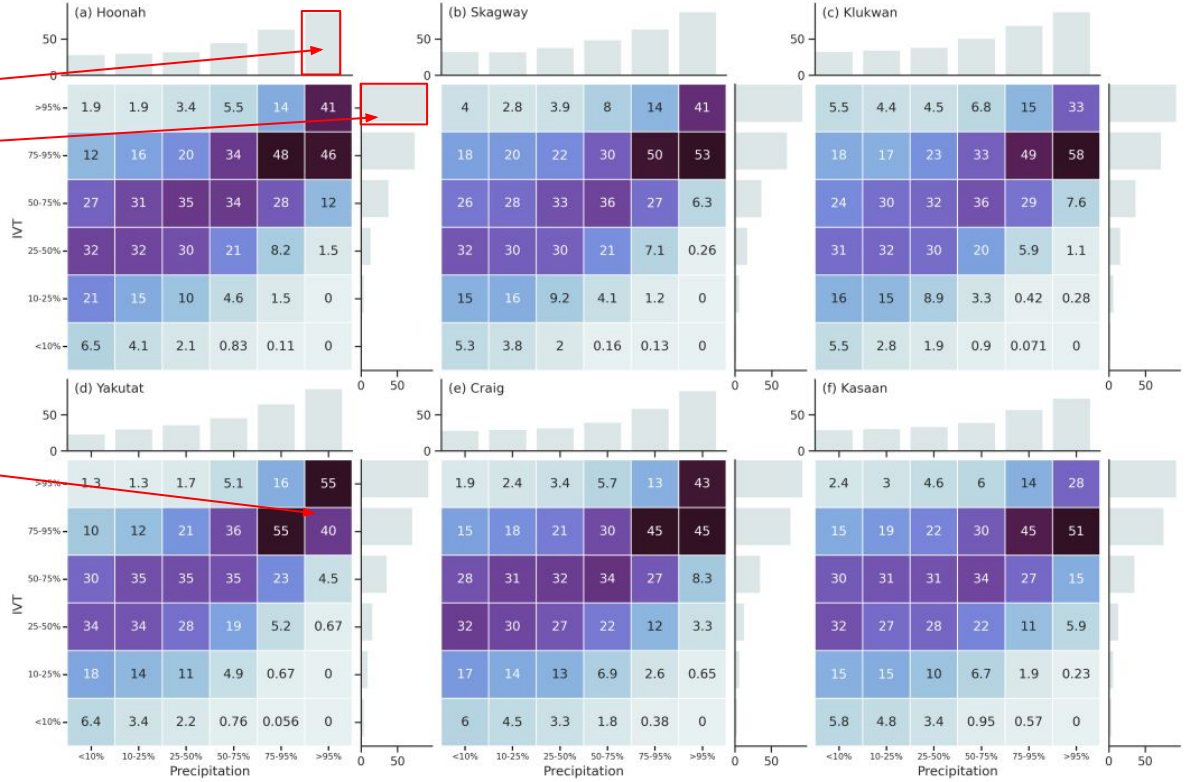
Provided by: Nash, Rutz, and Jacobs, 2024

SEAK AR Climatology

In Southeast AK, 80%–96% of days with extreme precipitation have >75th percentile moisture transport.

In Hoonah, 80-90% of days with > 95th percentile precip were also AR days. Nearly 100% of days with > 95th percentile IVT were AR days.

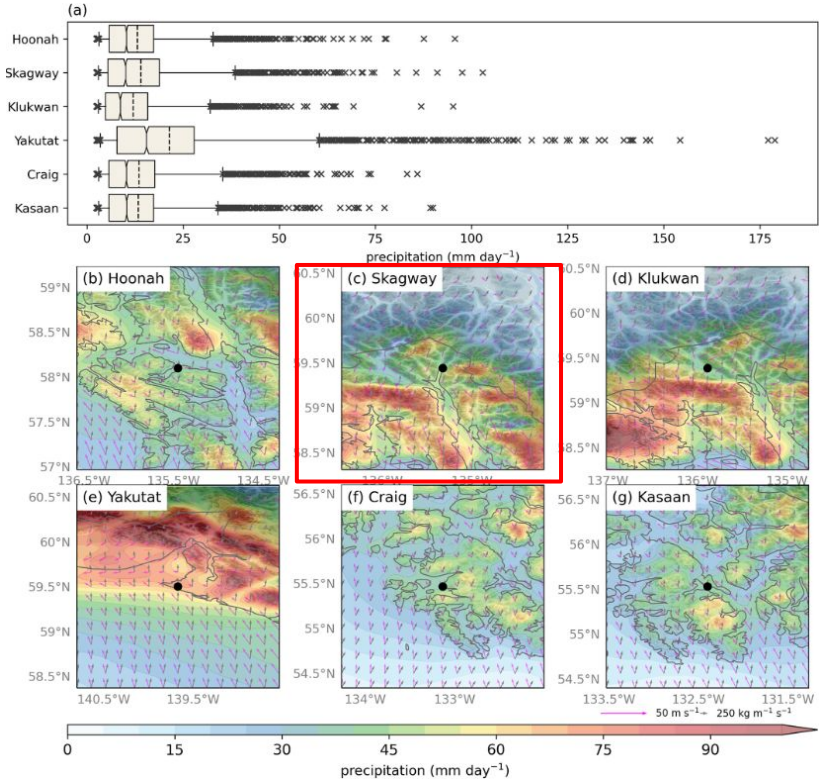
In Yakutat, 55% of days with > 95th percentile precip were also > 95th percentile IVT. In other words, the top 5% IVT days explain 55% of the precip.



bs, 2024

SEAK AR Climatology

Some communities are more likely to see extreme precipitation when the atmospheric river is a certain direction to induce increase orographic effects



(a) Distribution of daily WRF precipitation for all AR days between 1 January 1980 and 31 December 2019 when precipitation was >2.5 mm day^{-1} for each community (note that the sample size of AR days for each community ranges from 3,155 to 3,618). The box extends from lower to upper quartiles of the data, with a black solid line at the median and a black dotted line at the mean. The whiskers show the range of the data from the fifth percentile to the 95th percentile. (b) Average daily composites of WRF precipitation (shaded, mm day^{-1}), ERA5 IVT (gray vectors, kg m^{-1} s^{-1}), and WRF 1000 hPa winds (pink vectors, m s^{-1}) for Hoonah during extreme AR days. The location of Hoonah is shown by the black point. USGS GMT elevation data (gray shaded, m) is shown where higher elevations are darker shades (c)–(h) Same as (b) but for (c) Skagway, (d) Klukwan, (e) Yakutat, (f) Craig and (g) Kasaan.

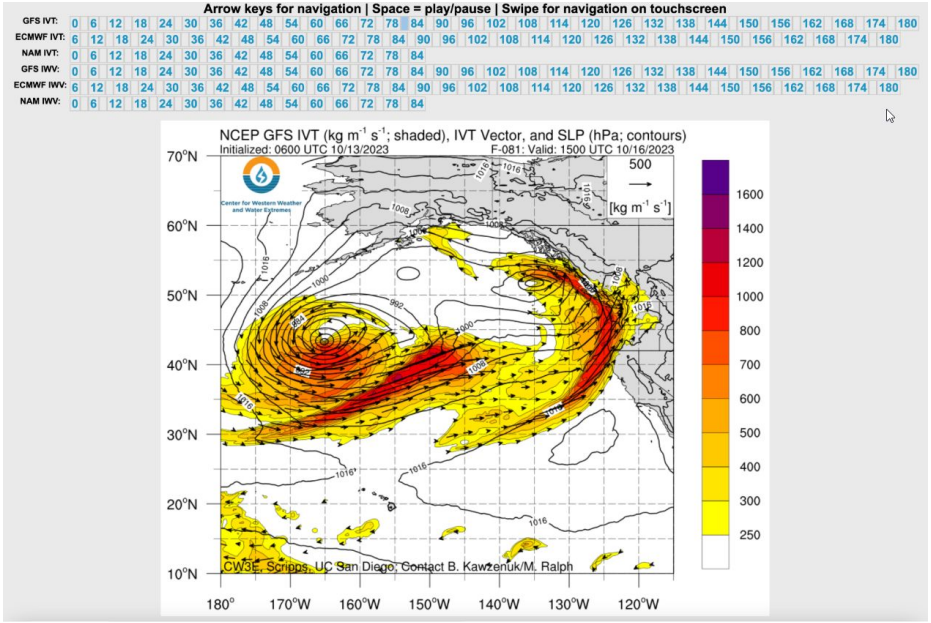
Most ARs IVT is from the SW but LLJ is from the SSE to maximize the moisture transport through the complex terrain and then orographic effects to produce extreme precipitation.

Provided by: Nash, Rutz, and Jacobs, 2024

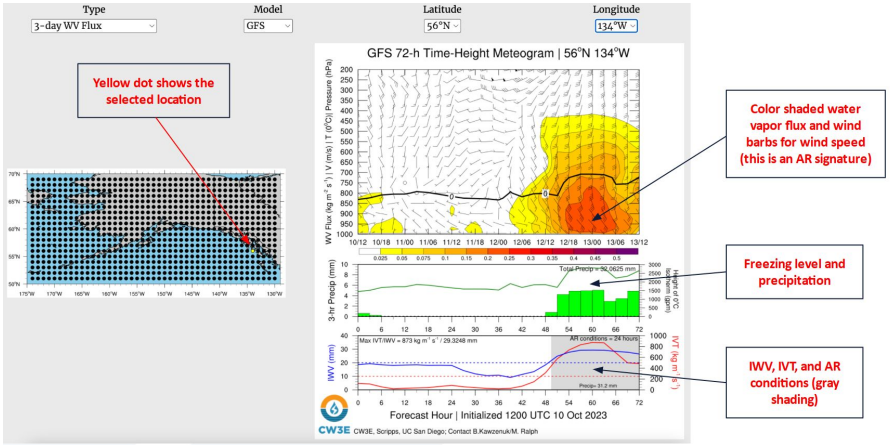
Tools to assess ARs in Alaska

Data Access: https://cw3e.ucsd.edu/alaska/

Plan-View IVT:



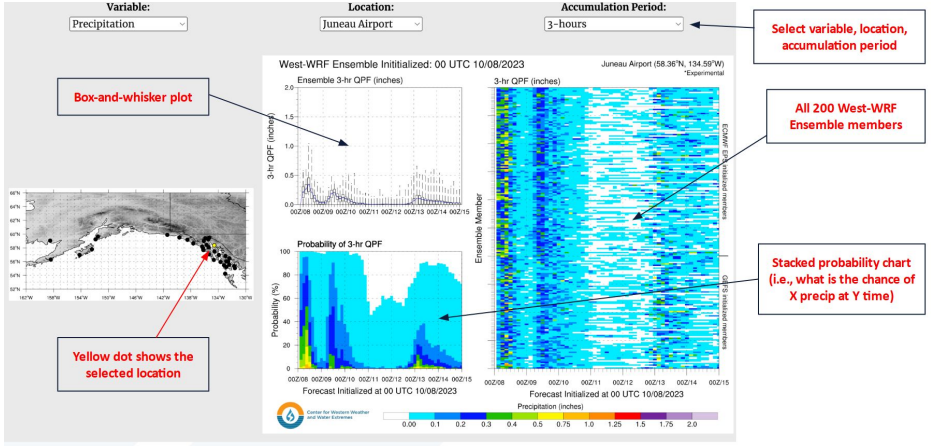
Time-Height Meteograms:



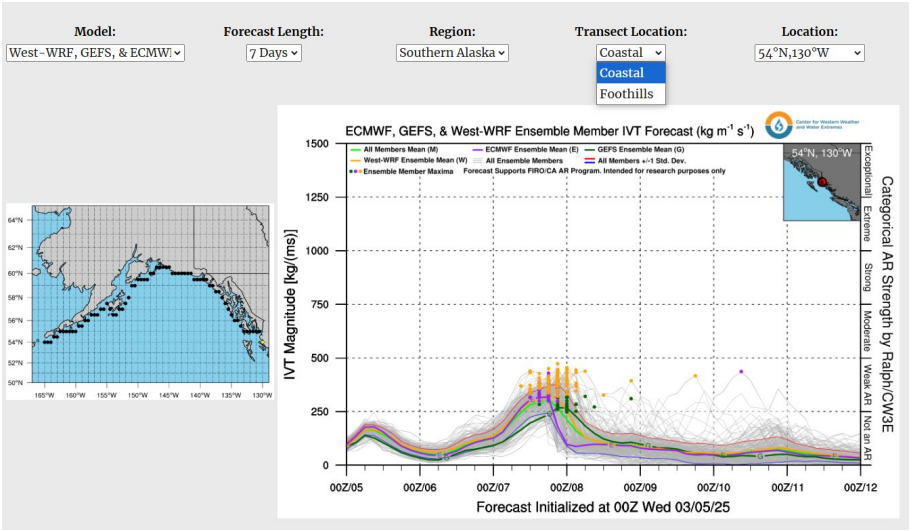
Tools to assess ARs in Alaska

Data Access: https://cw3e.ucsd.edu/alaska/

West-WRF Ensemble:



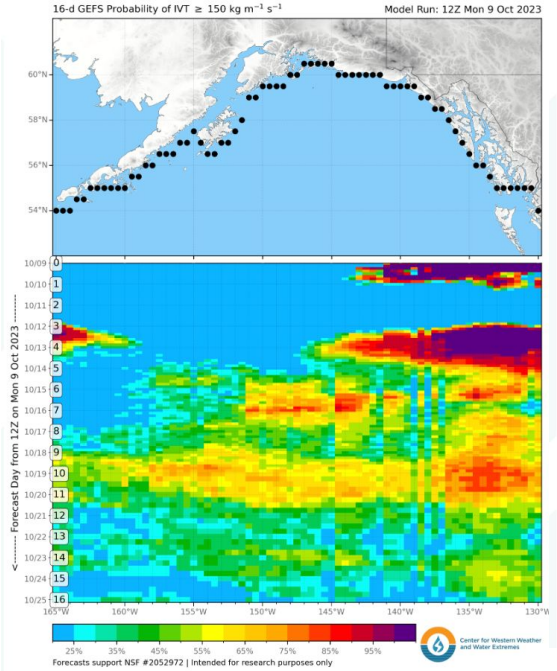
IVT Magnitude Plume:

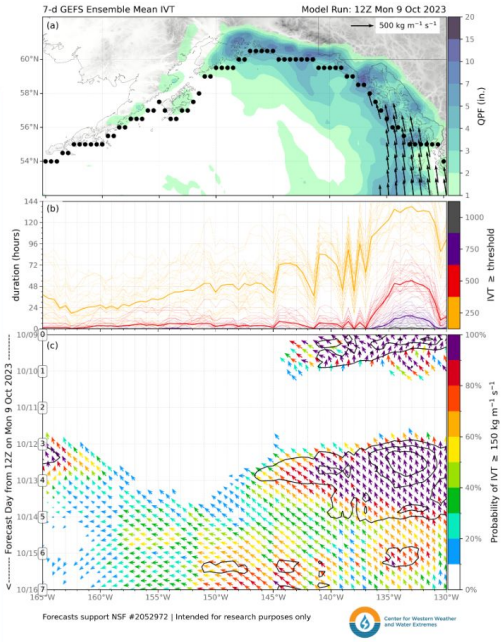


Tools to assess ARs in Alaska

Data Access: https://cw3e.ucsd.edu/alaska/

AR Landfall Tool





IVT Magnitude Plume:

- Points at every longitude (0.5°) along southern coast of Alaska(coastal,inalnd,foothills)
- Plot reads from top to bottom
- Includes forecasts from West-WRF, GEFS, ECMWF, and ECMWF minus GEFS

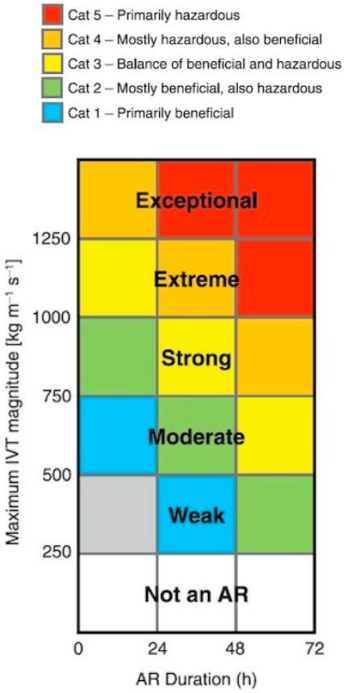
What is the AR Scale?

A categorical ranking system that broadly characterizes ARs strength and intensity, at one point, based on two variables:

- Maximum IVT during an AR Event: the maximum IVT that occurs at any time during the AR event (can be observed via radiosonde/dropsonde or taken from model/reanalysis data)
- Duration of the AR Event: the duration of AR event or in other words, the duration of AR conditions (IVT ≥ 250 kg m^{-1} s^{-1})

The ranking is determined by first noting the maximum IVT and then adjusting based on duration. If the duration is ≤ 24 hours, the storm is "demoted" one rank. If the duration is ≥ 48 hours, the storm is "promoted" one rank. If the duration is > 24 hours and < 48 hours, no further change is made. If an AR1 event is demoted due to a low duration, it is no longer considered an AR.

Center for Western Weather and Water Extremes

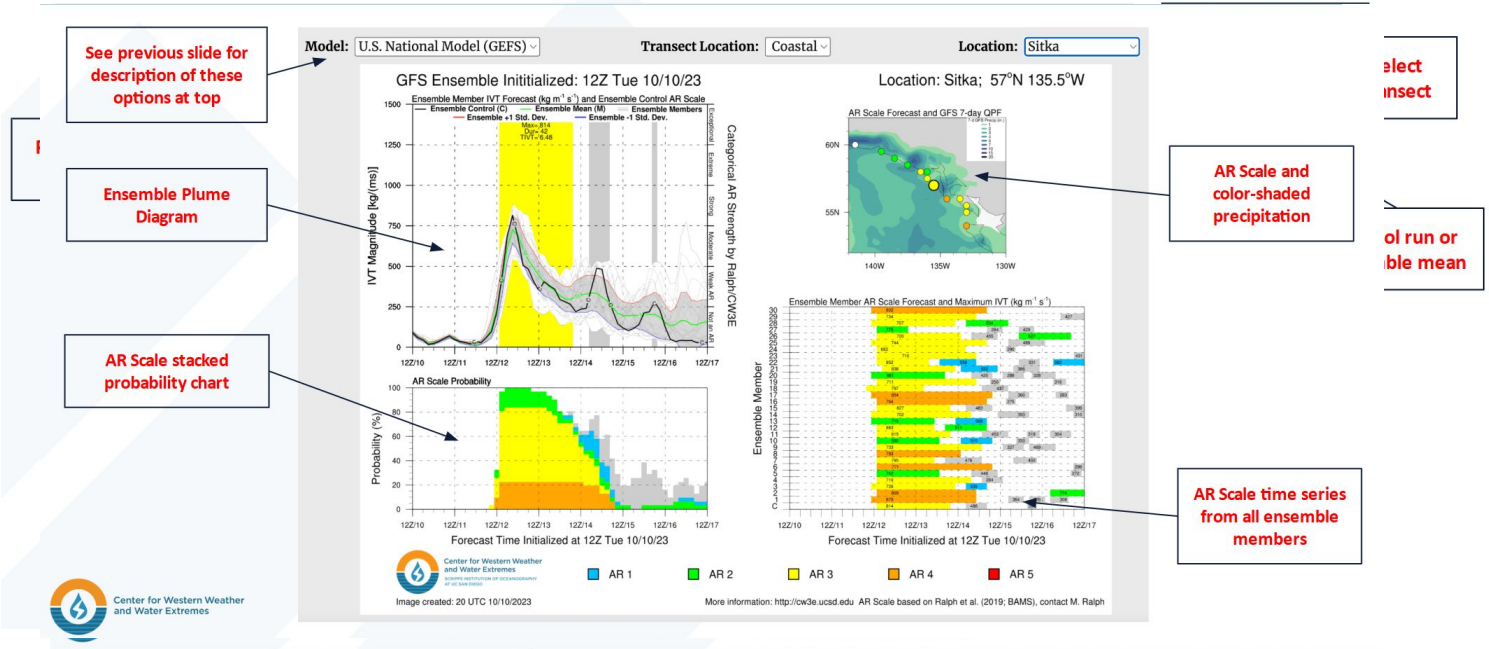


Ralph et al. (2019)

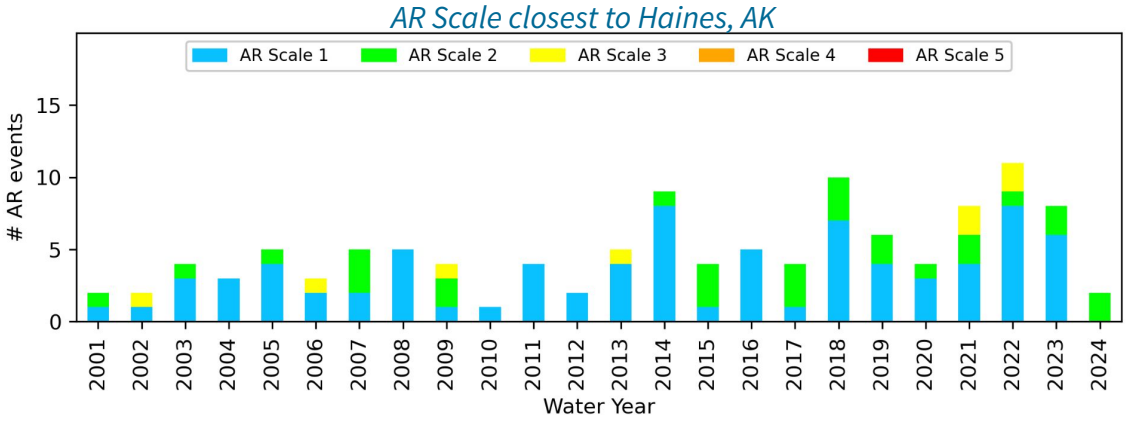
Tools to assess ARs in Alaska

AR Scale Forecast Tools:

- Data Access: https://cw3e.ucsd.edu/alaska/



Most AR events in Southeast Alaska are classified as AR Scale 1 or 2, with very few AR Scale 3, 4, or 5 events.



Looking up towards the top of the Beach Road Landslide in Haines, AK (E. Stevens)

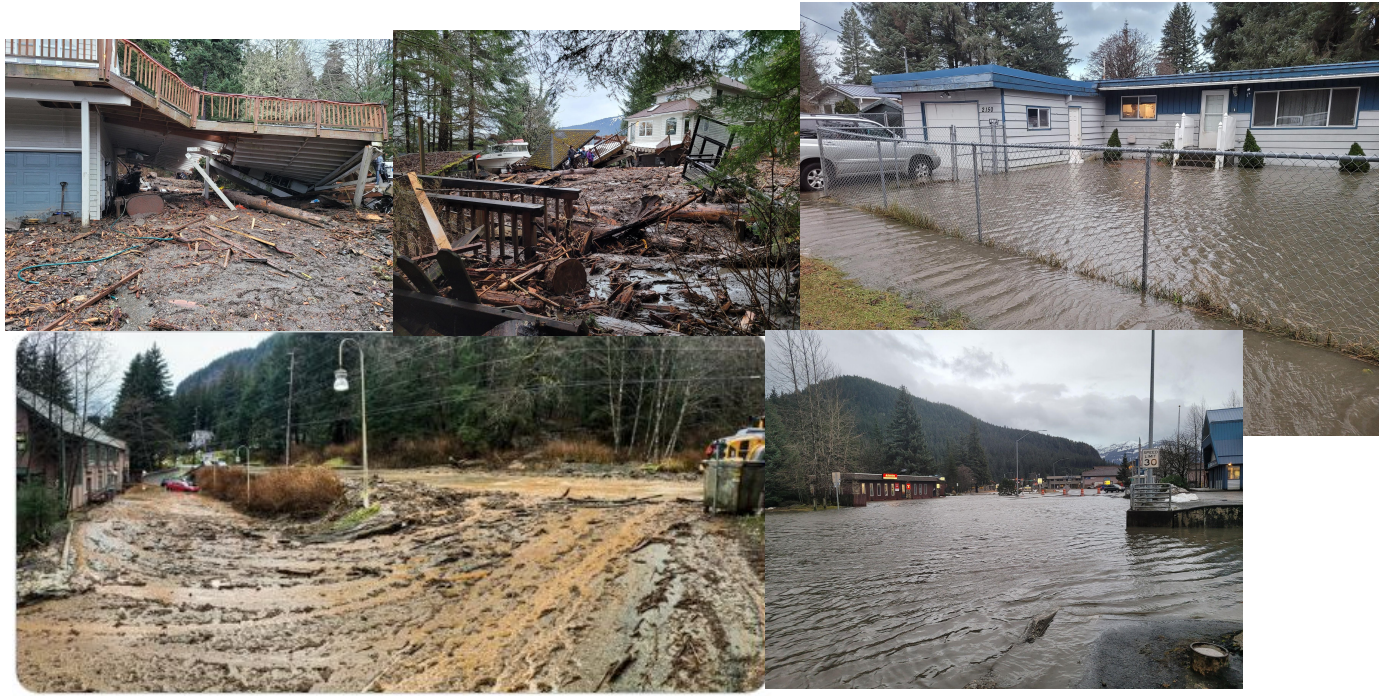
Flooding & Debris Flow – Haines AK

01-02 Dec 2020

3 ft of water in parts of downtown Haines
Homes damaged/destroyed in multiple mudslides (2 fatalities)

Flooding & Debris Flow – Juneau AK

01-02 Dec 2020



Landslide Wrangell Nov 2023

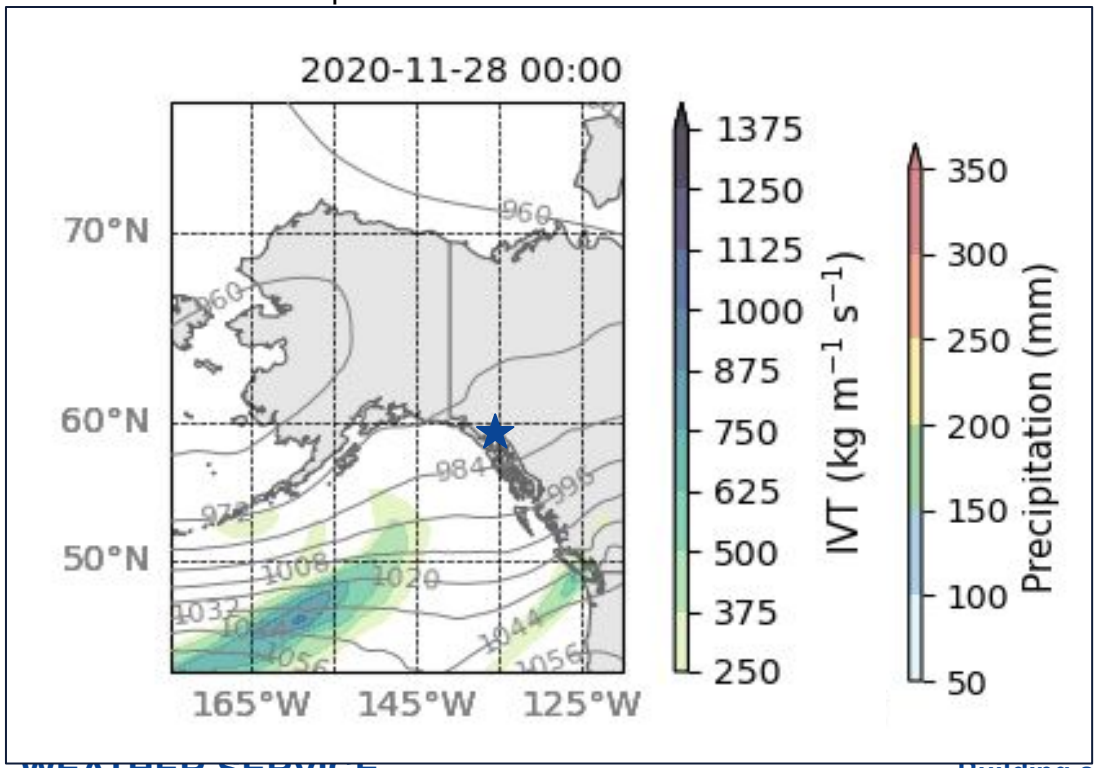
What are the key characteristics that indicate an impactful vs. non-impactful atmospheric river?

Example of two ARs in December 2020 that resulted in devastating impacts across Southeast Alaska

Increase in water vapor strength

Duration of atmospheric river

Multiple atmospheric rivers in a row



ratio of rain to snow

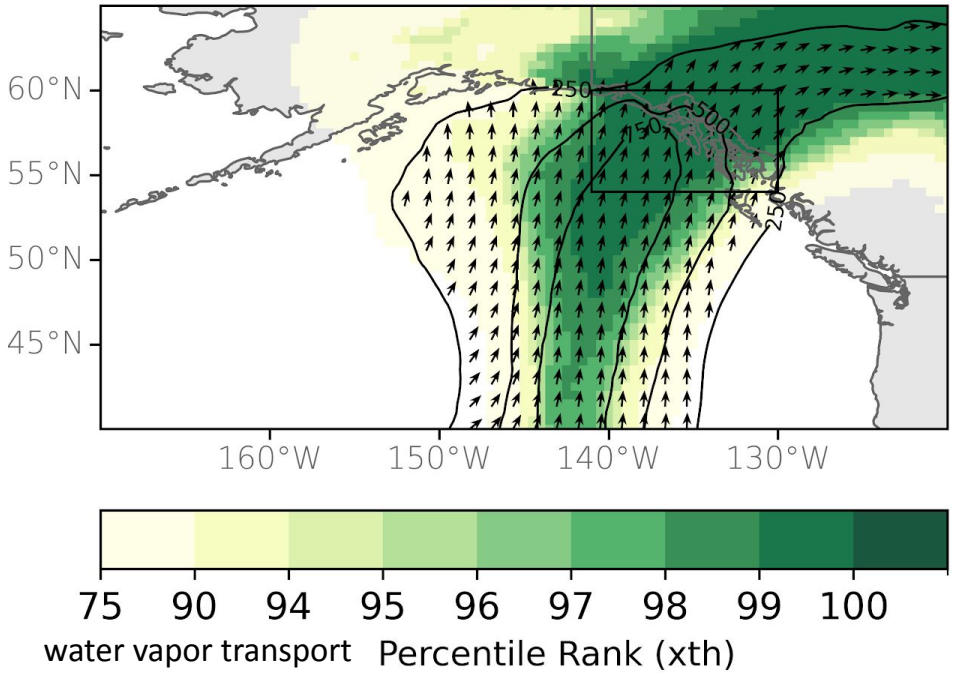
Direction of water vapor transport

strong **low level winds**

Model climate places important forecast elements in the context of reforecasts with the same lead time and at similar times of year.

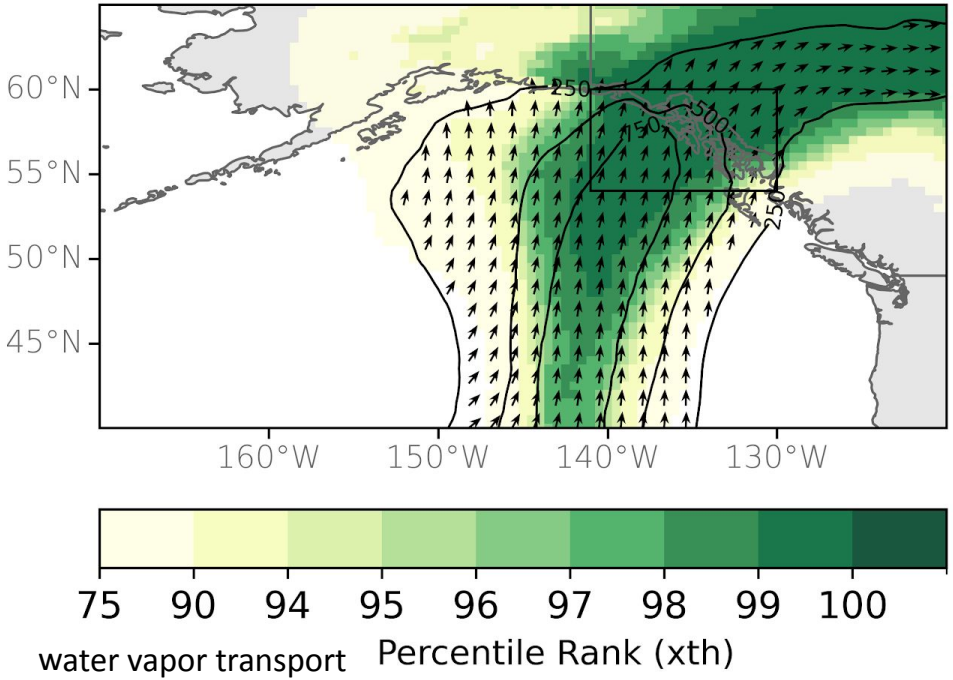
Mclimate relative to GEFS reforecast 4 month period (2000-2019) centered on the week of the forecast

Initialized: 00Z 28 Nov 2020 | F-96 | Valid: 00Z 02 Dec 2020



A maximum water vapor transport rank for a long duration and multiple events in a row indicates potential for impacts.

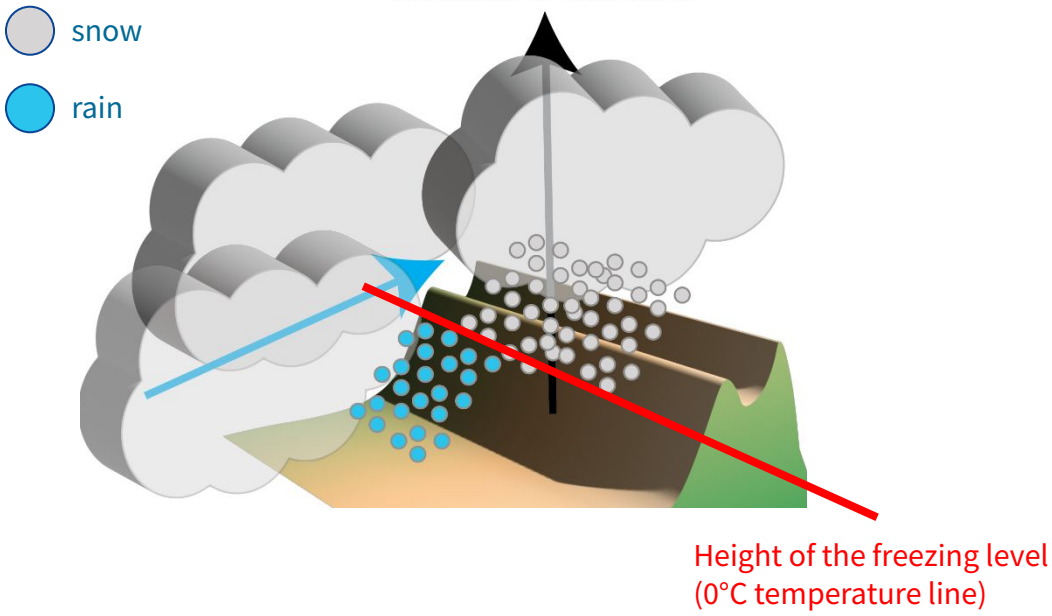
Initialized: 00Z 28 Nov 2020 | F-96 | Valid: 00Z 02 Dec 2020



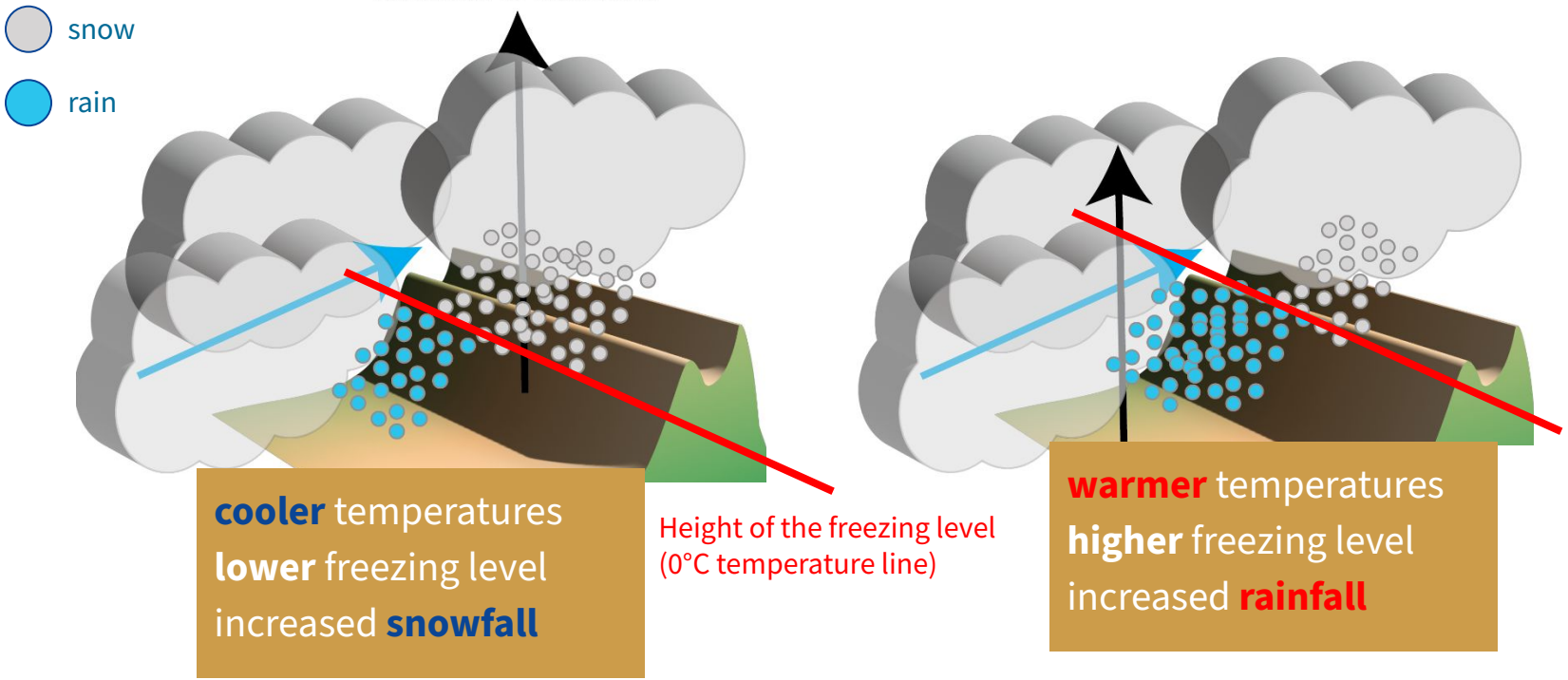
What is the maximum percentile rank for each forecast lead time within Southeast Alaska?

Date	Hour	
	06Z 6	75
Sat 28	12Z 12	98
	18Z 18	99
	00Z 24	97
Sun 29	06Z 30	97
	12Z 36	97
	18Z 42	95
	00Z 48	93
Mon 30	06Z 54	75
	12Z 60	0
	18Z 66	0
	00Z 72	97
Tue 01	06Z 78	99
	12Z 84	99
	18Z 90	99
	00Z 96	99
Wed 02	06Z 102	99
	12Z 108	99
	18Z 114	99
	00Z 120	99
Thu 03	06Z 126	98
	12Z 132	97
	18Z 138	95

When moisture within atmospheric rivers encounters topography and is lifted, it typically results in precipitation.

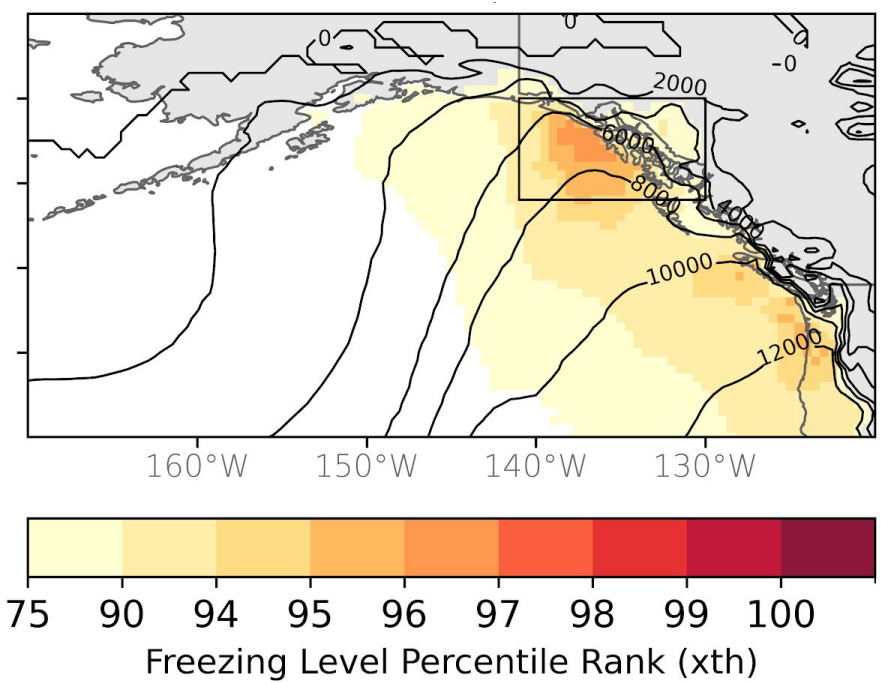


Increases in temperature lower the height of the freezing level, which decreases snow and increases rainfall.



A higher model climate freezing level rank indicates potential for a higher fraction of rain to snow.

Initialized: 00Z 28 Nov 2020 | F-96 | Valid: 00Z 02 Dec 2020



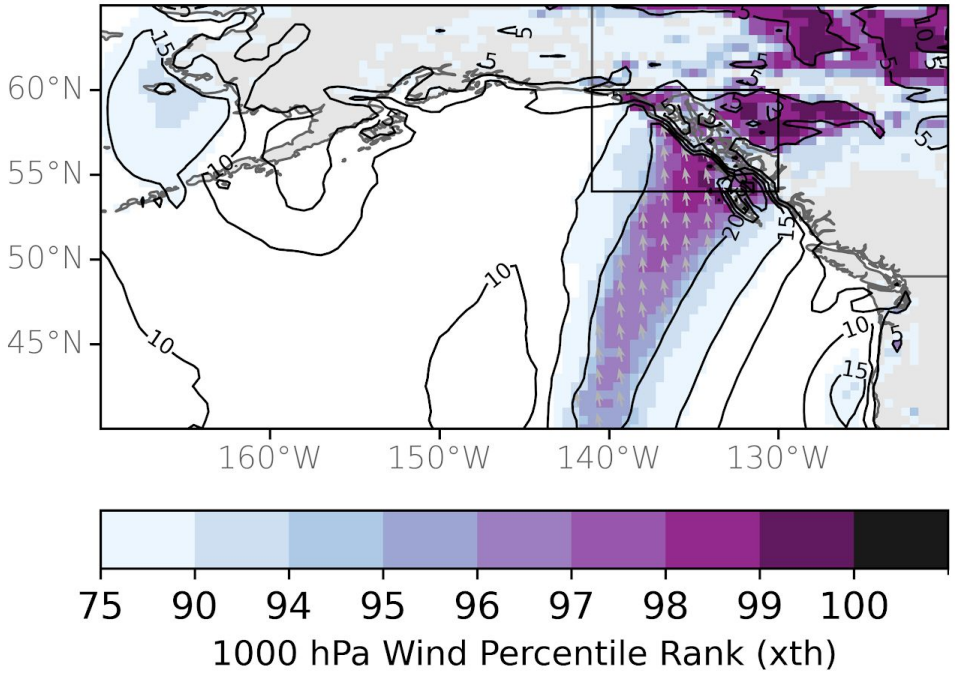
Date	Hour			
	06Z	6	75	0
Sat 28	12Z	12	98	0
	18Z	18	99	0
	00Z	24	97	0
Sun 29	06Z	30	97	0
	12Z	36	97	0
	18Z	42	95	0
	00Z	48	93	0
Mon 30	06Z	54	75	0
	12Z	60	0	0
	18Z	66	0	0
	00Z	72	97	0
Tue 01	06Z	78	99	95
	12Z	84	99	96
	18Z	90	99	96
	00Z	96	99	96
Wed 02	06Z	102	99	96
	12Z	108	99	97
	18Z	114	99	97
	00Z	120	99	96
Thu 03	06Z	126	98	93
	12Z	132	97	91
	18Z	138	95	75

cool storm

warm storm

A higher model climate low-level wind rank indicates potential for more wind-related impacts.

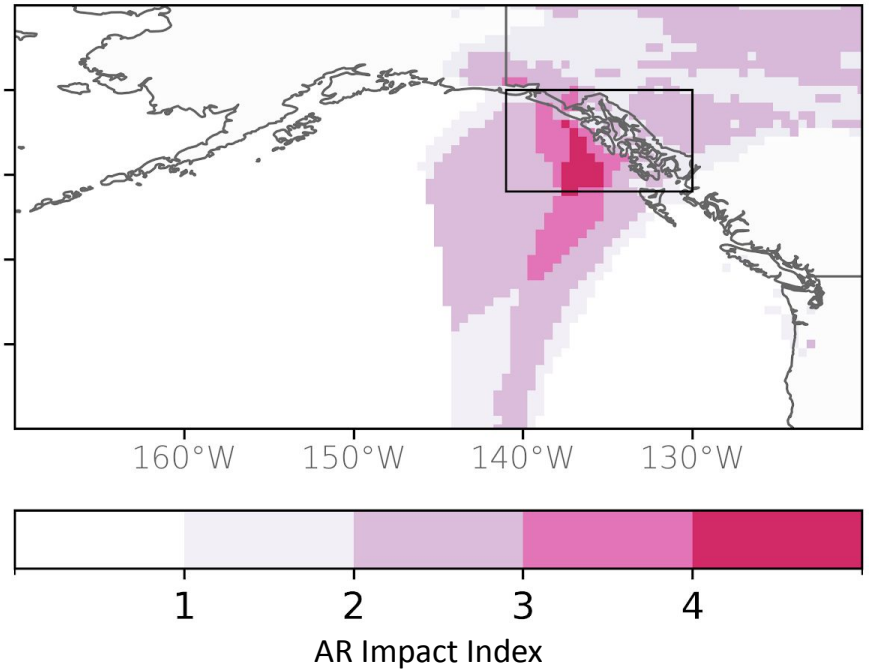
Initialized: 00Z 28 Nov 2020 | F-96 | Valid: 00Z 02 Dec 2020



Date	Hour			
Sat 28	06Z	6	75	0	95
	12Z	12	98	0	99
	18Z	18	99	0	99
Sun 29	00Z	24	97	0	99
	06Z	30	97	0	99
	12Z	36	97	0	99
	18Z	42	95	0	98
Mon 30	00Z	48	93	0	92
	06Z	54	75	0	75
	12Z	60	0	0	98
	18Z	66	0	0	94
Tue 01	00Z	72	97	0	97
	06Z	78	99	95	99
	12Z	84	99	96	99
	18Z	90	99	96	99
Wed 02	00Z	96	99	96	99
	06Z	102	99	96	99
	12Z	108	99	97	99
	18Z	114	99	97	99
Thu 03	00Z	120	99	96	98
	06Z	126	98	93	96
	12Z	132	97	91	92
	18Z	138	95	75	90

A percentile-based forecasting tool for IVT, freezing level, and low-level wind can greatly improve situational awareness prior to impactful rain and snow events in Southeast Alaska.

Initialized: 00Z 28 Nov 2020 | F-96 | Valid: 00Z 02 Dec 2020



View the Atmospheric River Impact Tool

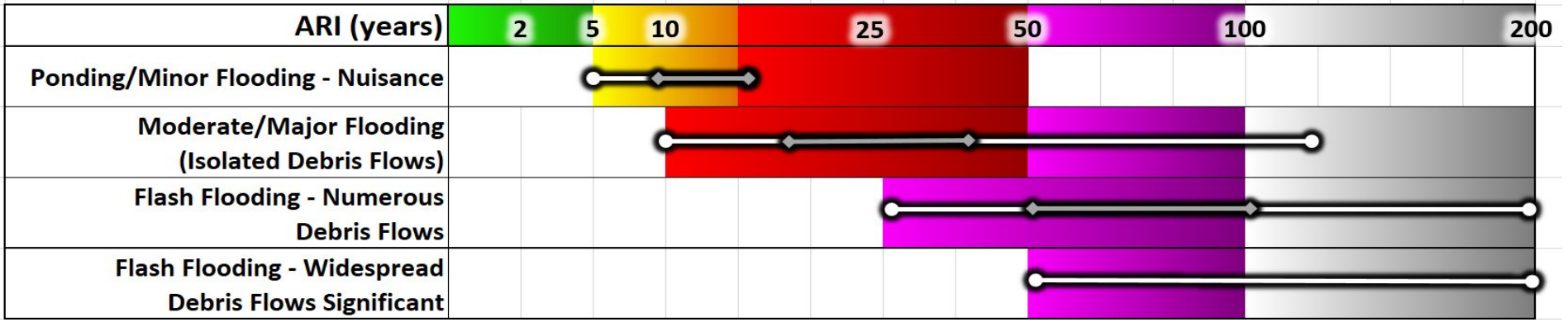
peer-reviewed paper

Learn more about our findings

non-technical summary

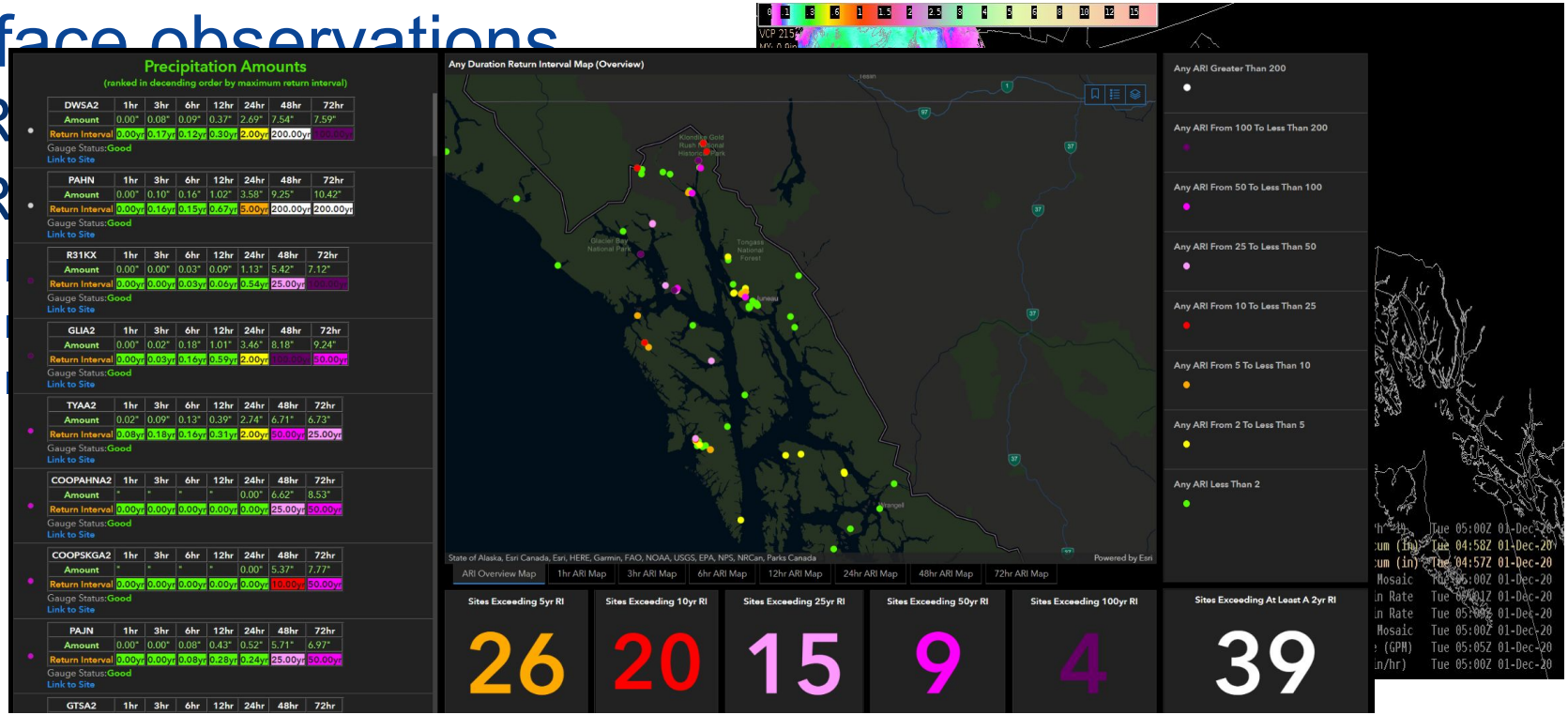
Precipitation ARI Thresholds for Increased Risk of Landslides from Case Studies

- Precipitation ARI information was compiled from previous landslide events over the past 20 years.
- From those case studies ARI thresholds, along with ranges of onset of impacts have been developed and adjusted with more data. (table below)
- Precipitation return periods >25 years correlates to significantly increased landslide potential with >50 year return intervals becoming more likely.
- Increased situational awareness tools using ARIs for NWS Juneau forecasters looking into the future (forecast model output) along with current conditions (realtime rain gauges).



How Does NWS Monitor Heavy/Extreme Rain Events

- Surface observations
  - R
  - R



Questions??

Aaron Jacobs, Senior Service Hydrologist/Meteorologist
aaron.jacobs@noaa.gov