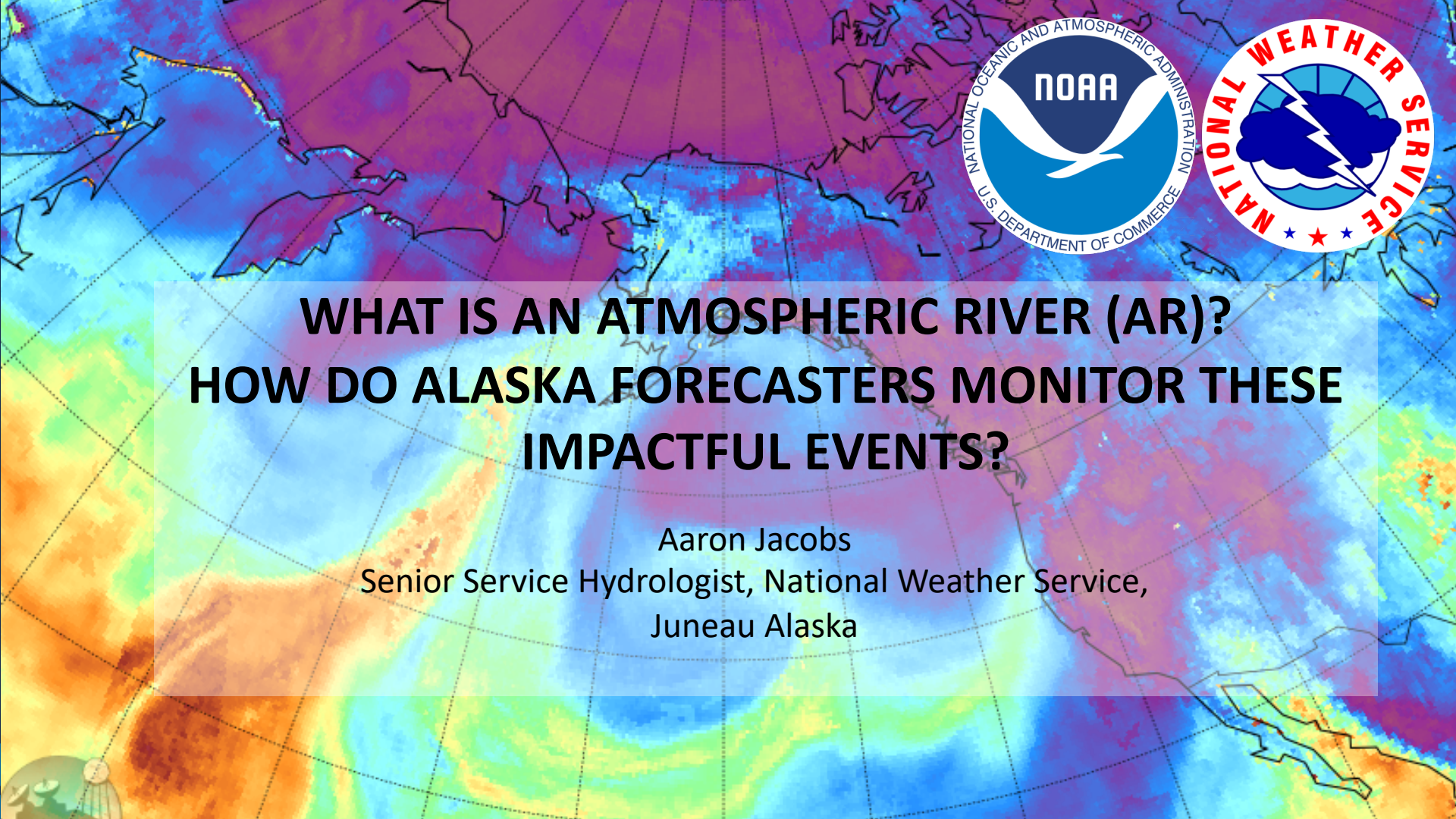


WHAT IS AN ATMOSPHERIC RIVER (AR)? HOW DO ALASKA FORECASTERS MONITOR THESE IMPACTFUL EVENTS?

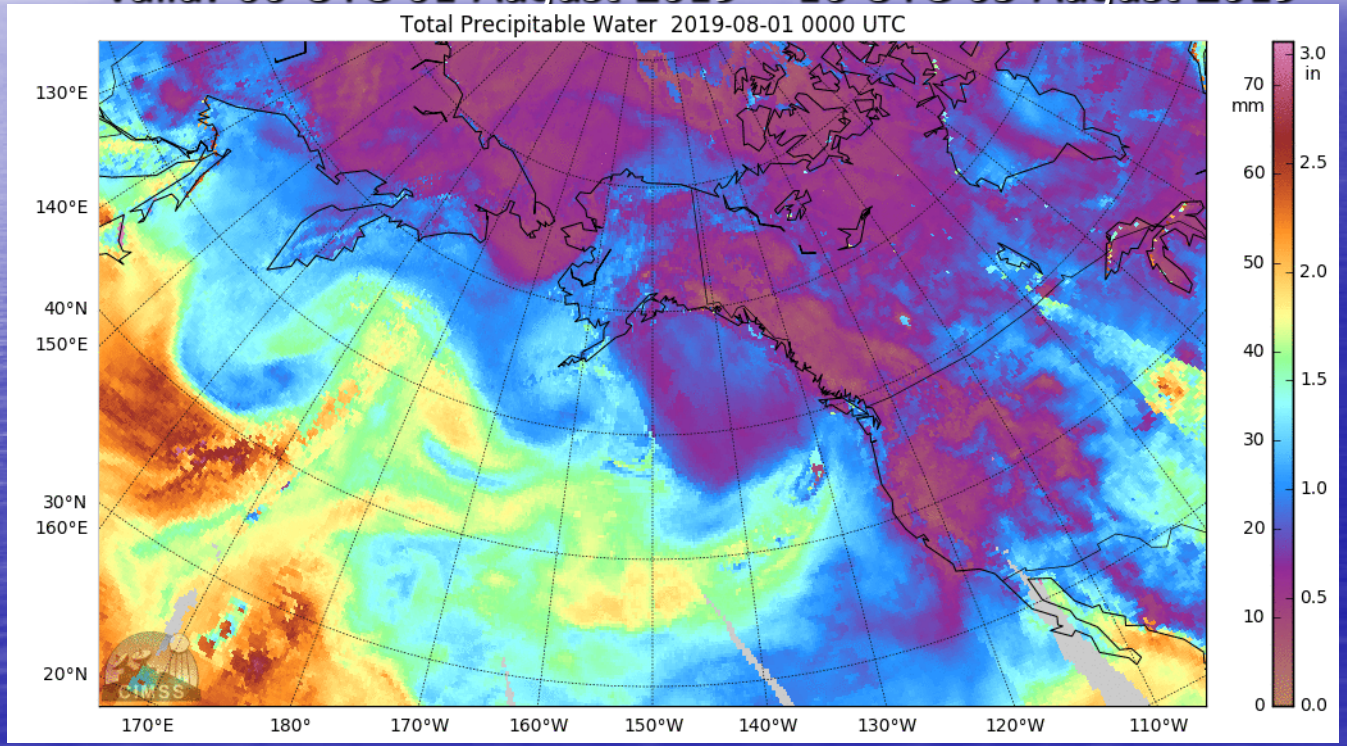
Aaron Jacobs
Senior Service Hydrologist, National Weather Service,
Juneau Alaska

Outline

- What is an atmospheric river (AR)?
- What are the conditions that lead to ARs?
- Impacts from ARs on Alaska Communities
- How are ARs, monitored, assessed and forecasted in Alaska?
- Ongoing AR research in Alaska

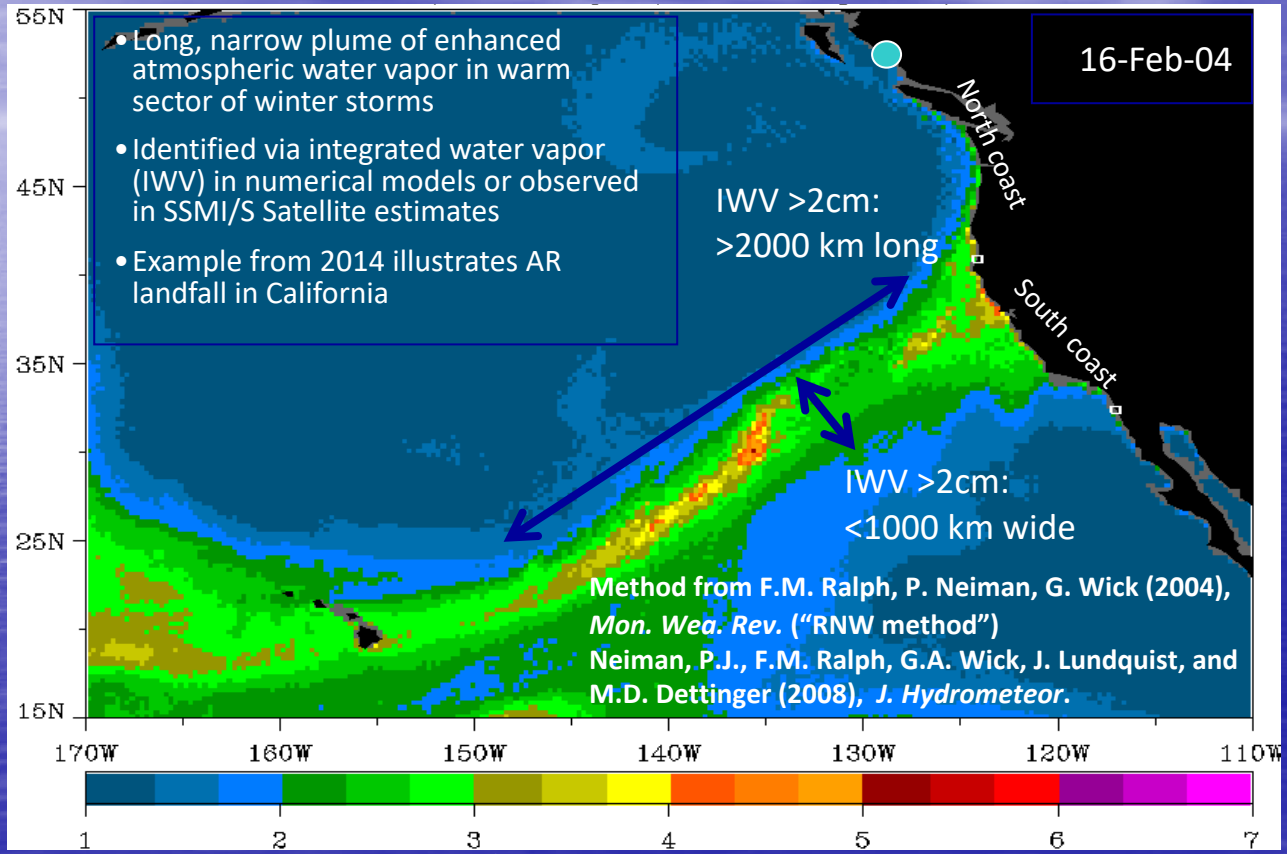
Atmospheric Rivers Over Alaska

- **SSMI/SSMIS/AMSR2-derived Integrated Water Vapor (IWV)**
  - Valid: 00 UTC 01 August 2019 – 16 UTC 05 August 2019



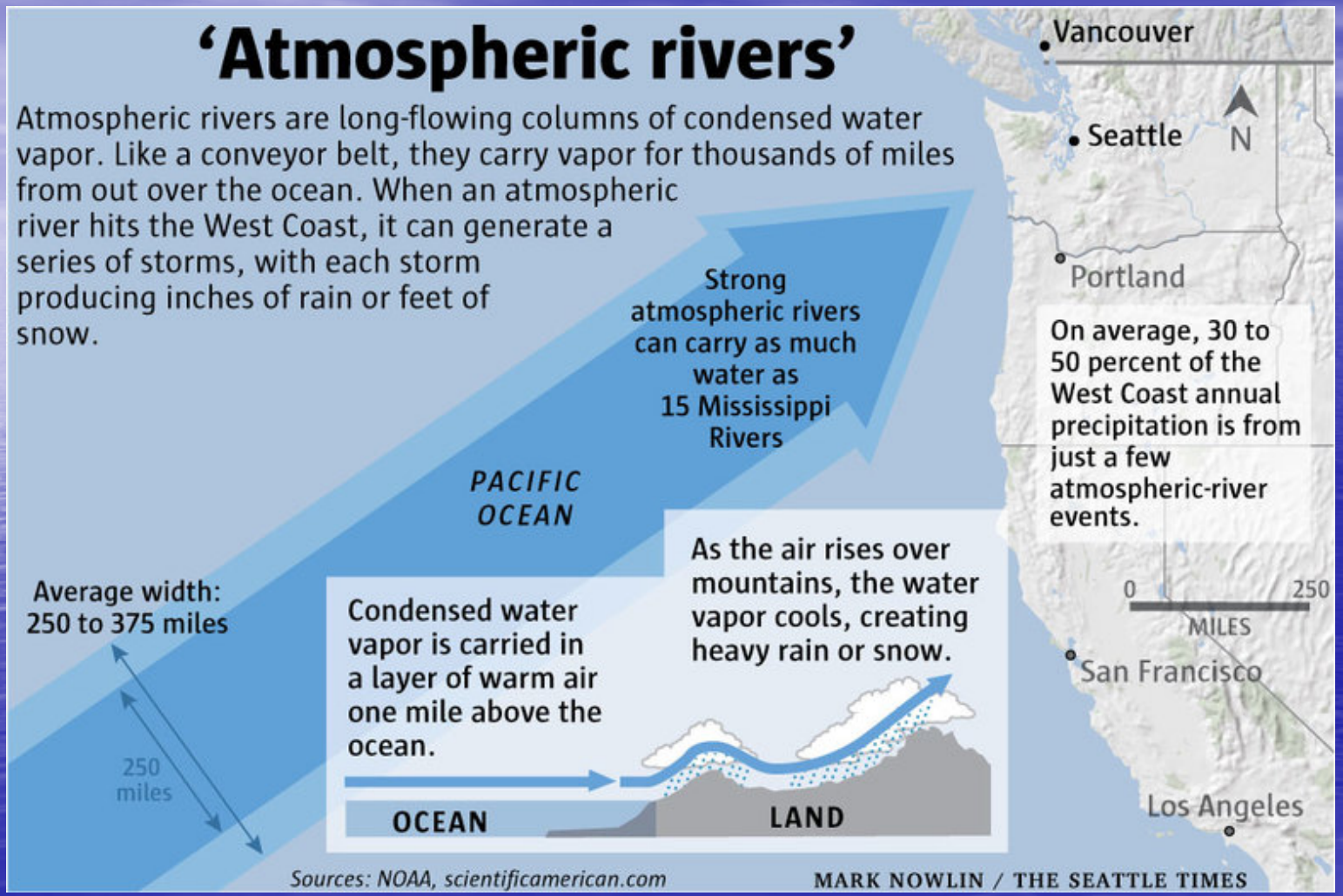
Provided by: B. Kawzenuk & C. Hecht

First Multi-year Catalog of AR Events Created Used RNW 2004 Method & Satellite IWV Data



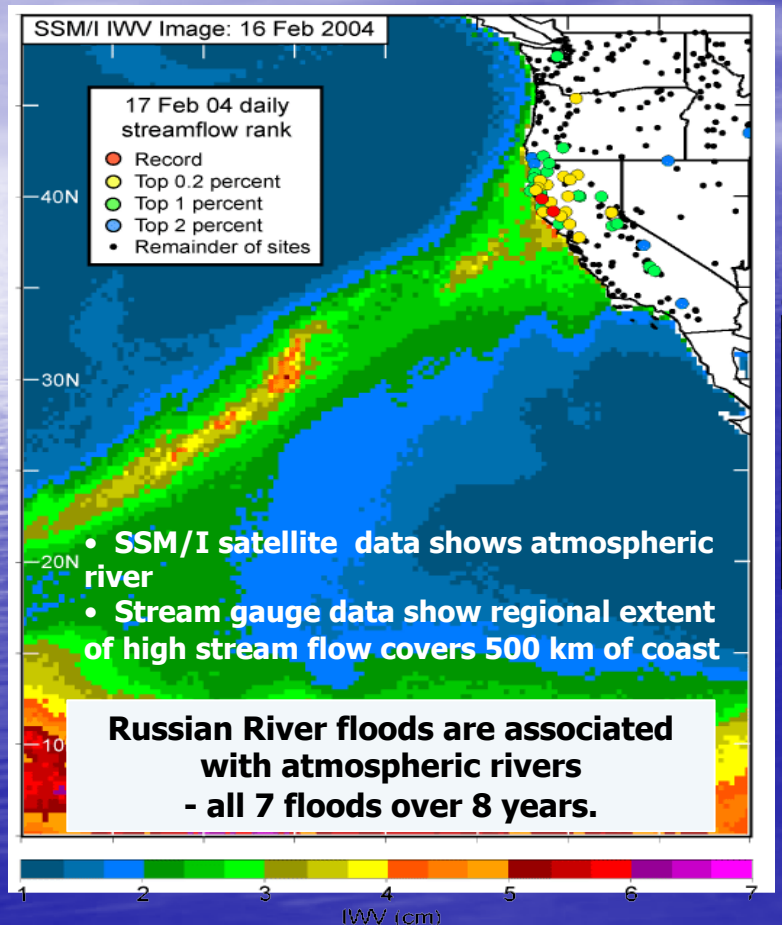
‘Atmospheric rivers’

Atmospheric rivers are long-flowing columns of condensed water vapor. Like a conveyor belt, they carry vapor for thousands of miles from out over the ocean. When an atmospheric river hits the West Coast, it can generate a series of storms, with each storm producing inches of rain or feet of snow.



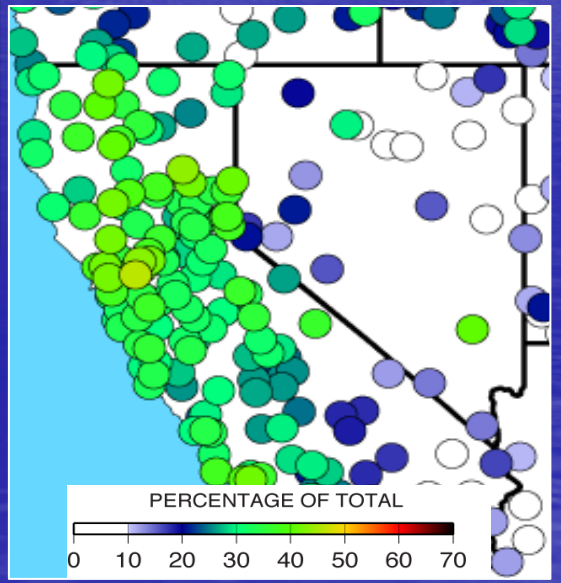
Sources: NOAA, scientificamerican.com

MARK NOWLIN / THE SEATTLE TIMES



Flooding on California's Russian River: Role of atmospheric rivers

ARs can CAUSE FLOODS and PROVIDE WATER SUPPLY

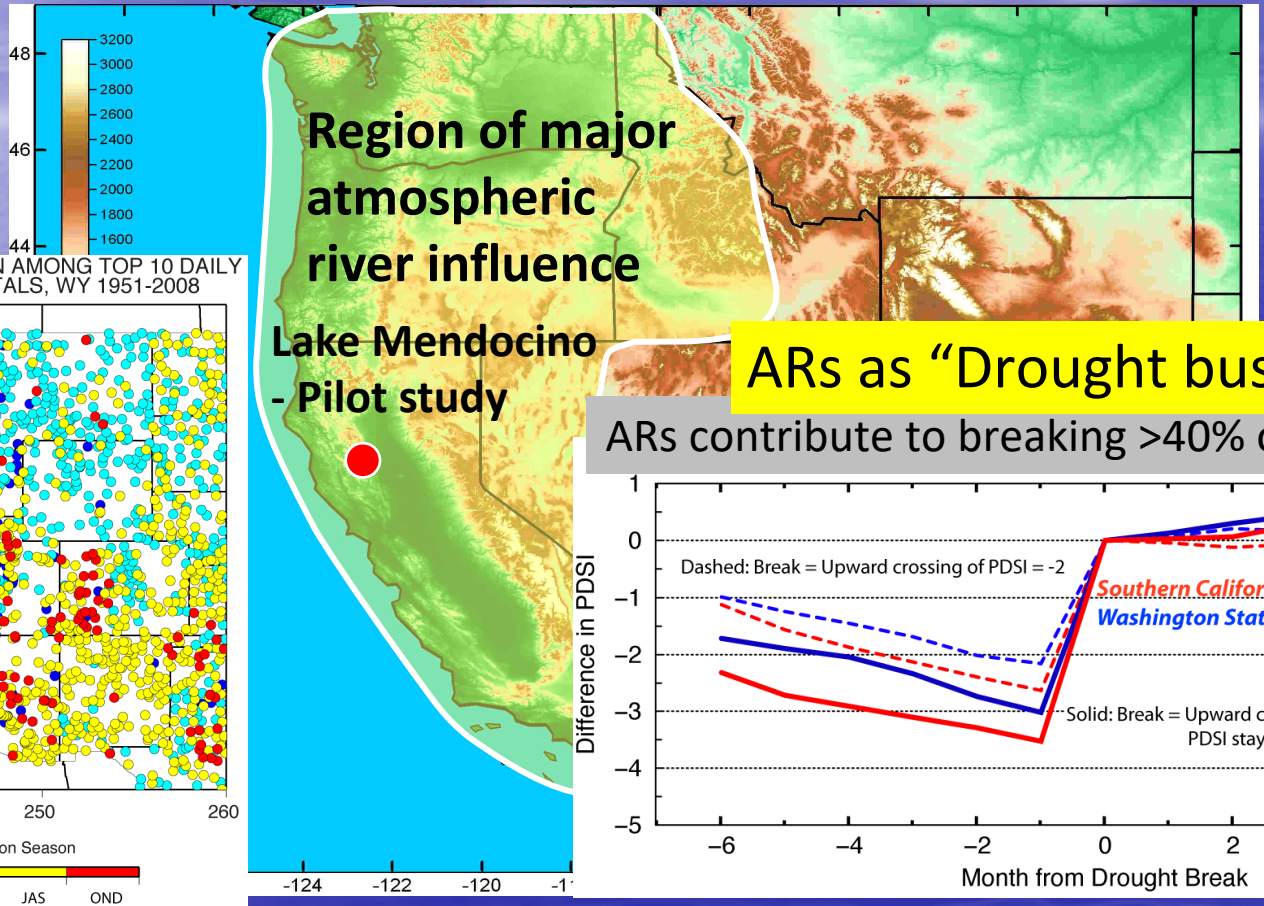


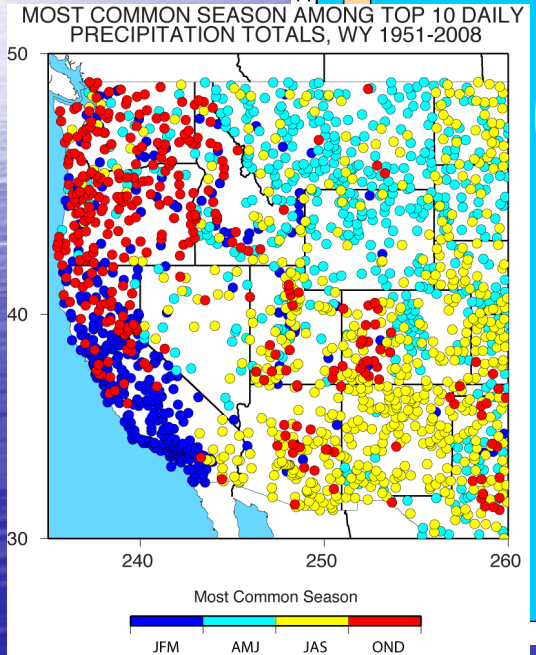
Rivers, Floods and the Water Resources of California

Mike Dettinger, M. Ralph, , T. Das, P. Neiman, D. Cayan

(Water, 2011)

Region for which atmospheric river events are a dominant cause of extreme precipitation, flooding and contribute to water supply in the Western U.S. (Ralph et al. 2014)

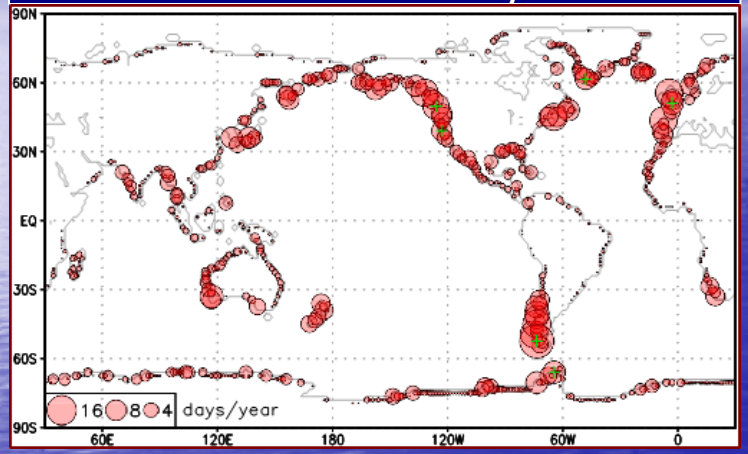




ARs as "Drought busters"

ARs contribute to breaking >40% of CA droughts

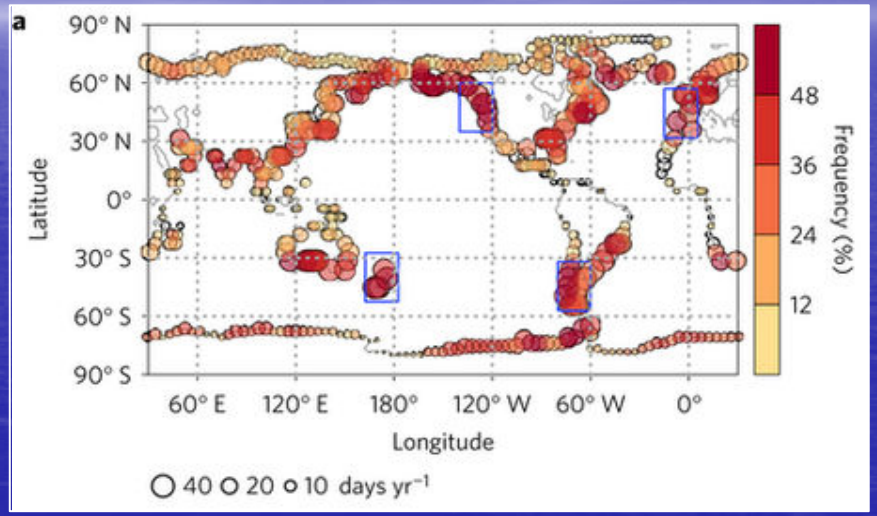
Where do Atmospheric Rivers Make Landfall Globally?



Locations (dots), and frequencies (dot sizes) of landfalling atmospheric rivers

Guan and Waliser, 2015 (JGR)

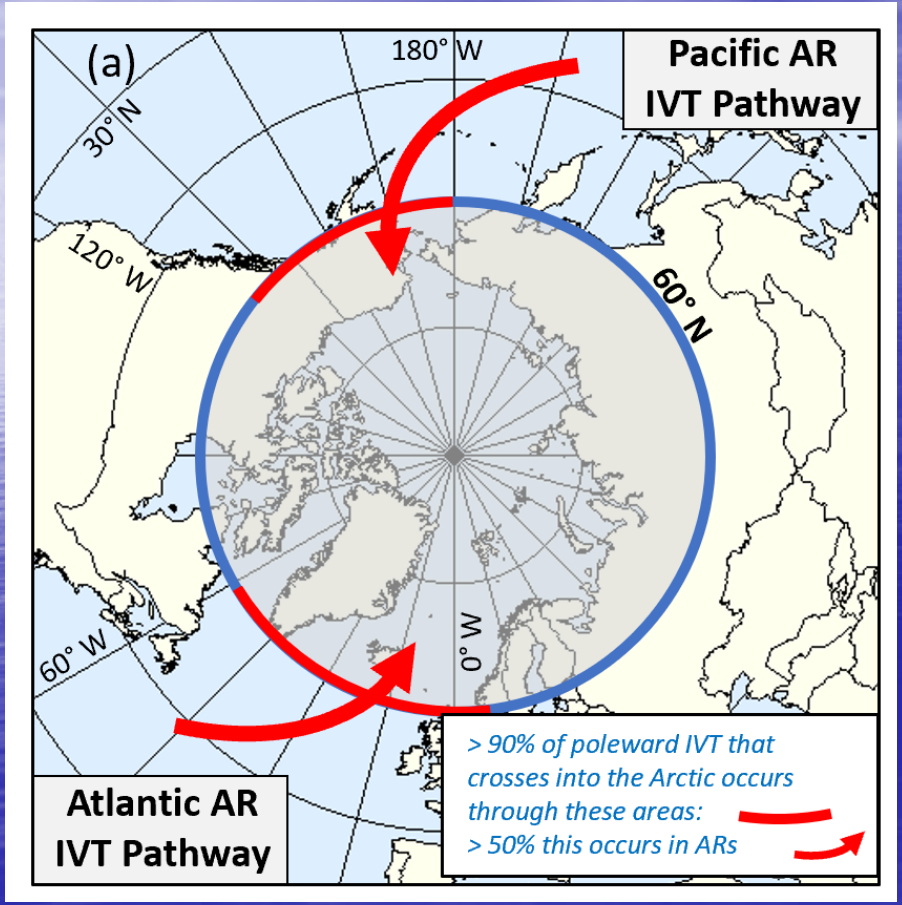
Relationship Between Coastal Extreme Surface Winds and AR Landfall?



Percentage of coastal extreme surface winds events that are associated with landfalling atmospheric rivers (color fill), and frequency of occurrence (dot size).

Waliser and Guan, 2017 (Nat. Geoscience)

Emerging Topic: Impacts of ARs on Polar Regions



The Role of Atmospheric Rivers in Extratropical and Polar Hydroclimate,
JGR- Atmos 2018
Deanna Nash, D Waliser, B. Guan, H. Ye and F.M. Ralph

Dropsonde Observations of Total Integrated Water Vapor Transport within North Pacific Atmospheric Rivers

F.M. Ralph, S. Iacobellus, P.J. Neiman, J. Cordeira, J.R. Spackman, D. Waliser, G. Wick, A.B. White, C. Fairal, *J. Hydrometeorology (2017)*

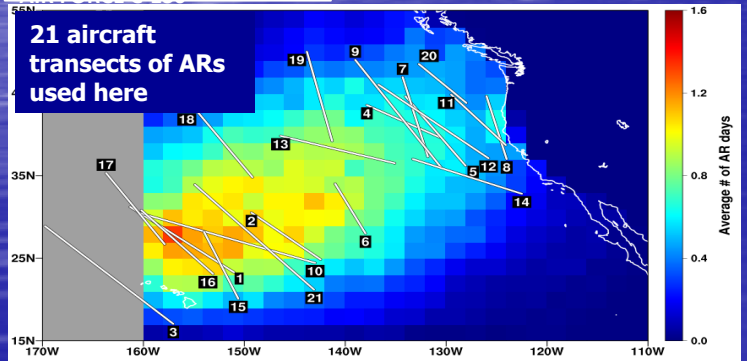
Method/Data: Uses 21 AR cases observed in 2005 - 2016 with full dropsonde transects. AR edges best defined by using IVT = 250 kg m^{-1} s^{-1}

Conclusions*:

- Average width: 850 km
- 75% of water vapor transport occurs below 3 km MSL; < 1% occurs above 8 km MSL
- Average max IVT: ~800 kg m^{-1} s^{-1}

KEY FINDING

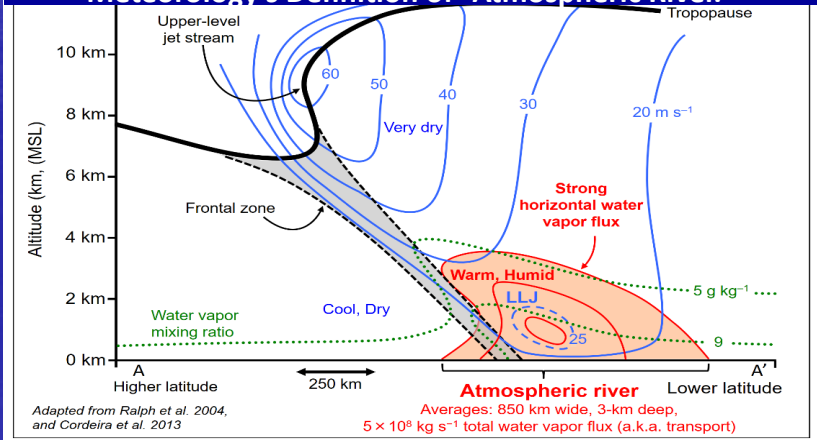
An average AR* transports 4.7 ± 2.0 x 10^8 kg s^{-1} of water vapor; equivalent to 2.6 times the average discharge of liquid water by the Amazon River



*Represent averages for the Northeast Pacific Ocean in the January-March season

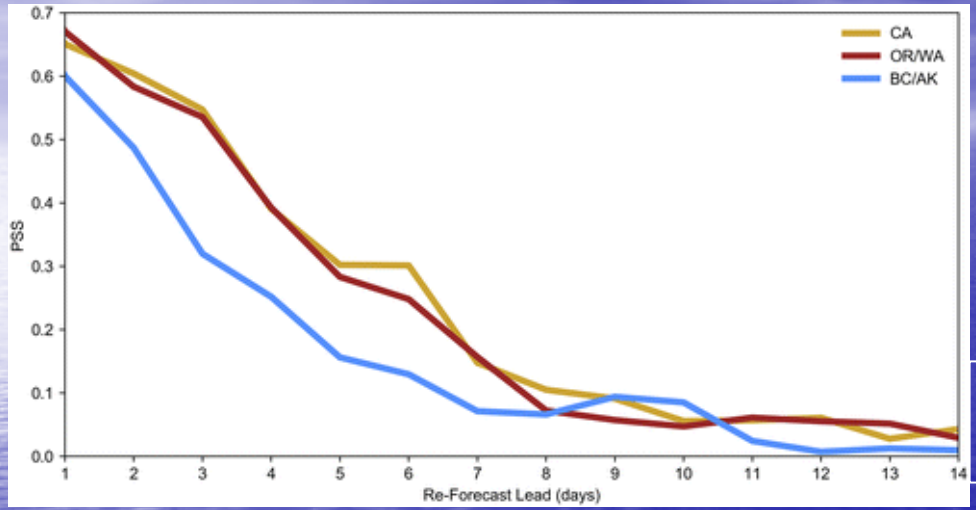
Background image denotes weekly AR frequency during cool seasons (Nov -Feb).

Synthesis from 21 observed ARs; Used in the Glossary of Meteorology's Definition of "Atmospheric River."



Forecasting Challenges in Alaska & British Columbia

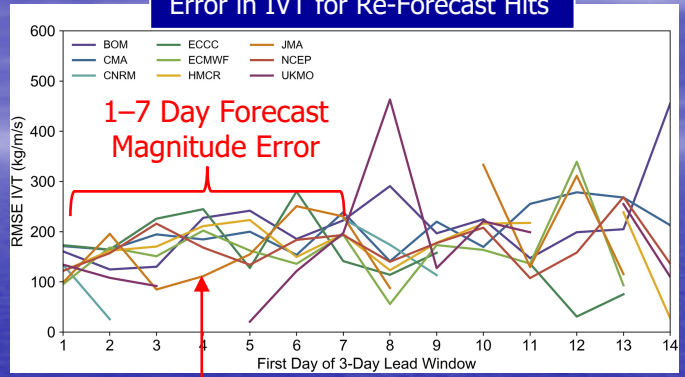
Model-averaged Peirce skill score (PSS)



Forecast Models tend to perform worse over British Colombia and Alaska compared to the rest of the U.S. West Coast when forecasting atmospheric rivers out to 8-day lead times

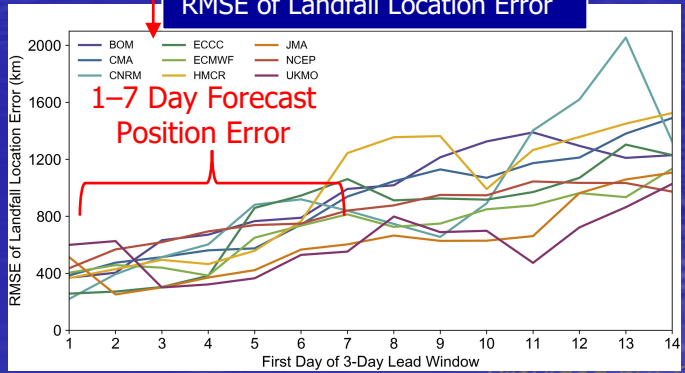
Beyond 8-day lead times, forecast models perform comparably for all Western North American locations

Error in IVT for Re-Forecast Hits



Forecast models tend to mis-forecast IVT magnitudes by 100 to 250 kg m^{-1} s^{-1} AR landfall location by 200–1000 km out to 7-day lead times over British Colombia and Alaska

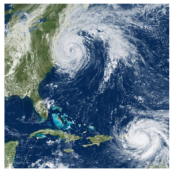
RMSE of Landfall Location Error



Analysis and graphics from Nardi et al. 2018

Provided by: C. Hecht

Atmospheric Rivers Highlighted in the U.S. Fourth National Climate Assessment, released on 3 November 2017



9 Extreme Storms

KEY FINDINGS

5. The frequency and severity of landfalling "atmospheric rivers" on the U.S. West Coast (narrow streams of moisture that account for 30%–40% of the typical snowpack and annual precipitation in the region and are associated with severe flooding events) will increase as a result of increasing evaporation and resulting higher atmospheric water vapor that occurs with increasing temperature. (*Medium confidence*)

1. Tropical Cyclones (Hurricanes and Typhoons)
2. Severe Convective Storms (Thunderstorms)
3. Winter storms
4. **Atmospheric Rivers (NEW in 4th Assessment)**

Image Credit

Front Cover: Atmospheric rivers are relatively long, narrow regions in the atmosphere – like rivers in the sky – that transport most of the water vapor outside of the tropics. When an atmospheric river makes landfall, extreme precipitation and flooding can often result. The cover features a natural-color image of conditions over the northeastern Pacific on 20 February 2017, helping California and the American West emerge from a 5-year drought in stunning fashion. Some parts of California received nearly twice as much rain in a single deluge as normally falls in the preceding 5 months (October–February). The visualization was generated by Jesse Allen (NASA Earth Observatory) using data from the Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi National Polar-orbiting Partnership (NPP) satellite

Impacts from ARs on Alaska Communities

Heavy rain producing: damaging flooding

Heavy rain producing: debris flows

Heavy snowfall producing: dangerous driving/traveling conditions, increased avalanche potential

Heavy rain producing: beneficial effects

Impacts from ARs on Alaska Communities:

Heavy Rainfall-Debris flows/Record High Streamflows

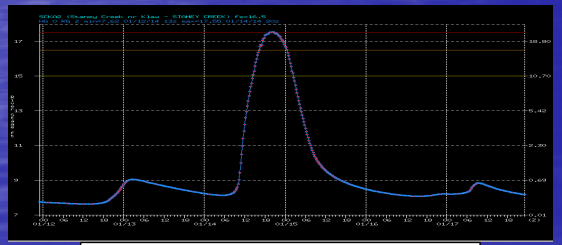
January 14, 2014, Sitka and Prince of Wales Island (POW)

Debris flows resulted from:

- Very moist antecedent soil conditions – nearly continuous rainfall over previous month (17"-37"), with record daily rainfall amounts on Jan 14 of 2.5"-3.5"
- Strong wind gusts (greater than 45 mph) which helped to generate widespread mudslides along steep and deforested terrain on POW

Flooding and impacts:

- Highest ever stage and flow ever recorded on Staney Creek, 17.55 ft
- Numerous roads were flooded and impassable, along with debris flows over roadways isolated several communities disrupting transportation
- Debris flows also caused loss of power and damaged structures
- Storm water drainage pumps became clogged with debris



Staney Creek river gauge showing record crest of 17.55 feet, moderate flood stage is 17.5 feet (source: USGS/NWS)

Home in the Hollis area caught in landslide, along with some flooding, courtesy of state troopers.

Landslide on the Klawock-Hollis Highway, courtesy of state troopers,

Impacts from ARs on Alaska Communities:

Heavy Rainfall/Flooding

December 10-14 2013, Ketchikan

- 5 days of heavy precipitation (wettest 5 day period since 1902) ranging from 13 to 23 inches, with one day totals from 3 to 5 inches
- Spillways on many area dams released water uncontrollably into Ketchikan Creek and produced flooding -- Area dams rose 7 to 14 ft with at least 2 ft over spillway

Flooding of home on Ketchikan Creek, courtesy of Ketchikan Public Utility.

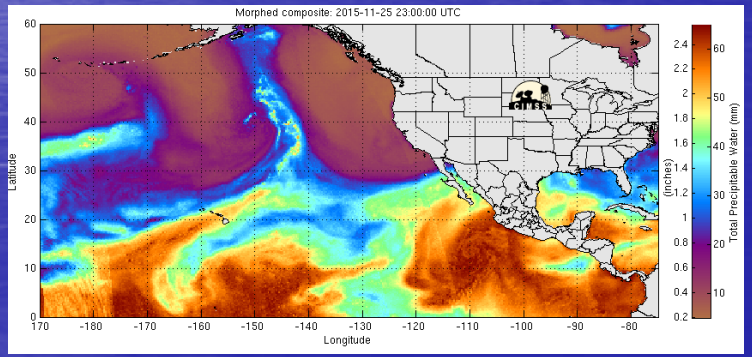
Flooding of home on Ketchikan Creek, courtesy of Ketchikan Public Utility.

Impacts from ARs on Alaska Communities:

Heavy Snowfall

November 20-25, 2015, Susitna Valley

- Antecedent cold airmass kept precipitation as snow in the northern Susitna Valley
- 2 day snow totals exceeded 40 inches and 5 day totals exceed 60 inches
- The Parks Highway is closed due to dangerous driving conditions and avalanche mitigation work
- Alaska Railroad train is caught in an avalanche. Crew is rescued, but railroad remains closed for 2.5 days



Left: *Alaska Railroad train covered in snow from avalanche. Photo courtesy of Alaska Railroad*

Middle: *Total Precipitable Water in November 2015 showing atmospheric river impacting southern Alaska. Image courtesy of CIMMS*

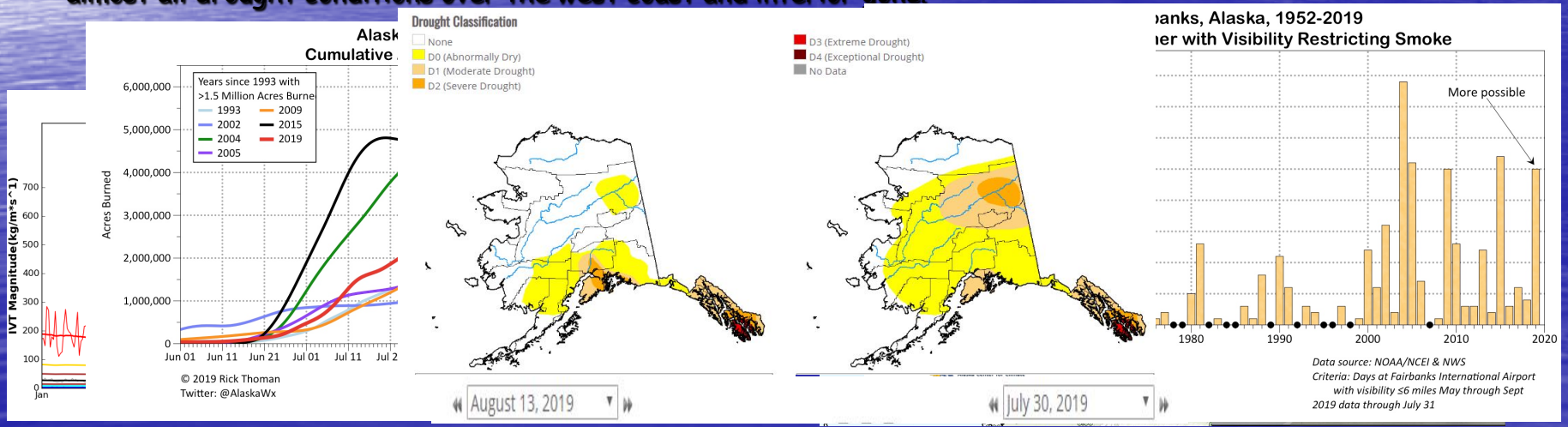
Right: *Heavy equipment works to dig out buried train cars and clear the tracks during a multi-day closure after an avalanche. Photo courtesy of Alaska Railroad*

Impacts from ARs on Alaska Communities:

Heavy Rainfall/Beneficial

August 1st-3rd, 2019, West Coast and Interior of Alaska

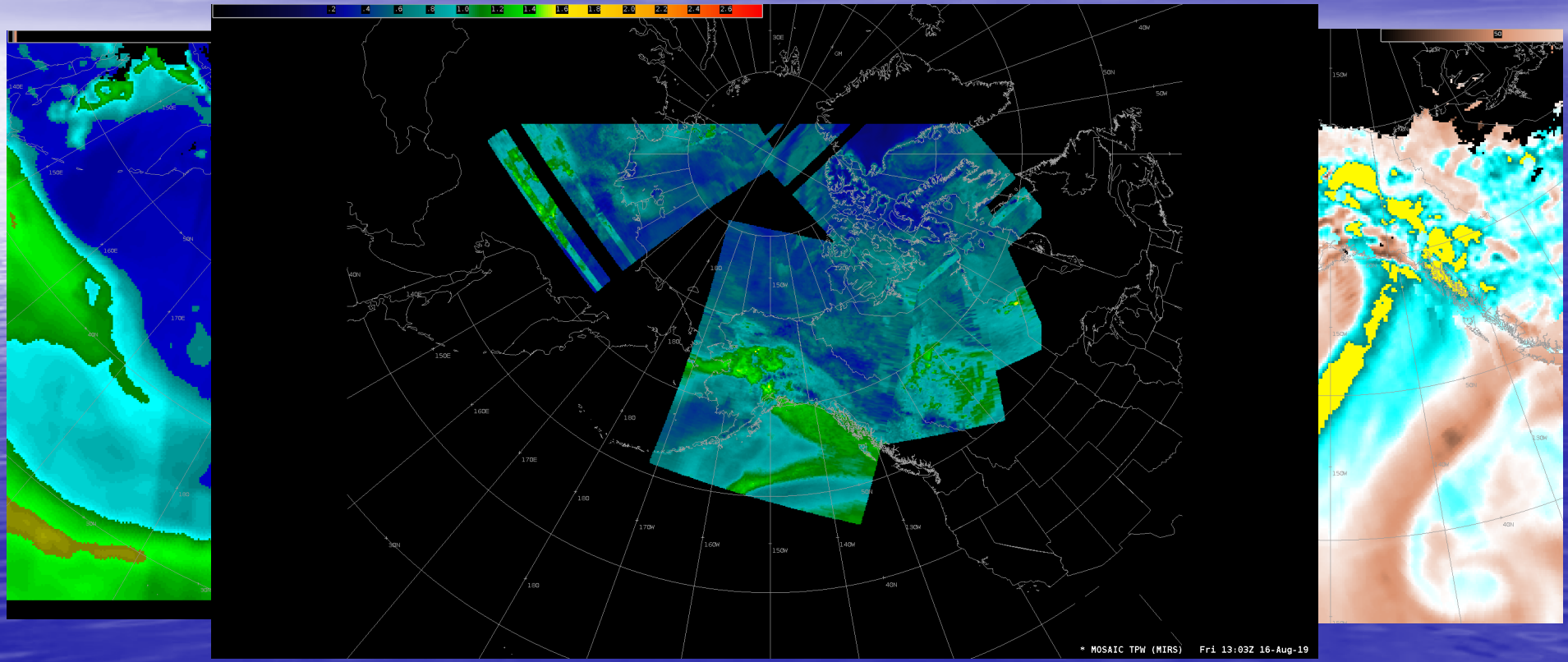
- All time 24hr rainfall record of 2.47" at Nome AK going back 110years , 48hr rainfall from 1-4"
- Record IVT value at Fairbanks(758 kg m^{-1} s^{-1}), ranked 2nd at McGrath(870kg m^{-1} s^{-1}) & Bethel (1116 m^{-1} s^{-1}) 1948-2018 climatology
- As of July 1st 503K acres burned, 2.36M acres burned by July 31st, 120,700ac since Aug 1st about 6% of what burned in July, most of that was from the Southcentral area most fires in the interior put out.
- 5th most days with visibilities <6miles at Fairbanks airport(25), most days 39 2004.
- July30 widespread D0(abnormally dry) with areas of D1(moderate) and D2(severe) drought conditions, by August 13th almost all drought conditions over the west coast and interior gone.



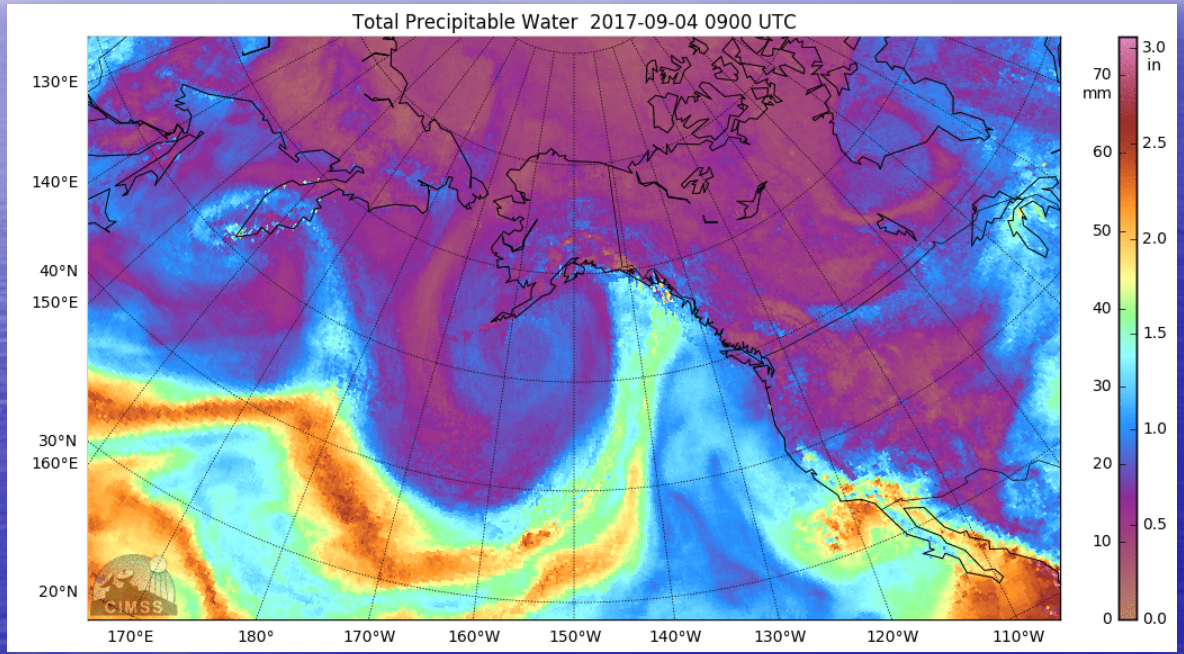
How are ARs: monitored, assessed and forecasted in Alaska?

- Remote Sensing: Blended TPW/% of normal, MIMIC PW, Advected Layer PW, Snowfall Rate, Rain rates(MiRS,GPM), IMERG(QPE estimates)
- Weather balloon radio sounding IVT/PW climatology
- Numerical Weather Prediction
  - Automated Atmospheric River Detection (ARDT-IVT)
  - GEFS(ensemble mean IVT) compared to GFS
  - Ensemble IVT probability plots
  - IVT/IWV values from GFS and NAM
  - IVT Meteograms from GFS
  - IVT Cross Sections from GFS

Remote Sensing:
Blended TPW/% of normal/MiRS TPW



Remote Sensing: MIMIC PW



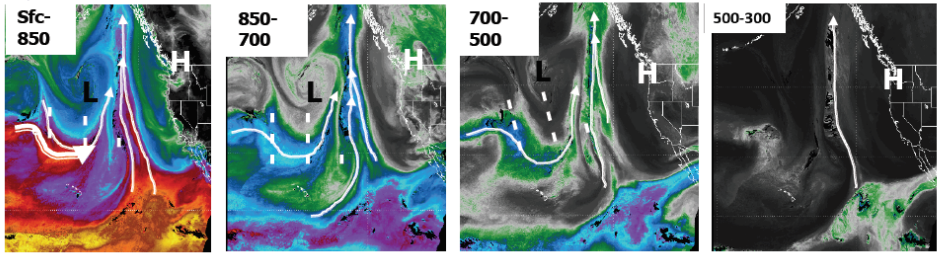
Remote Sensing: Advected Layer PW

NOAA Satellites and Information
National Environmental Satellite, Data, and Information Service

Sheldon Kusselson/Aaron Jacobs

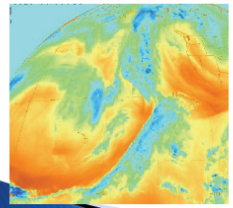
"Atmospheric Rivers" of High Concentrated Moisture into Alaska at 4 layers For Excessive Valdez Snowfall – 6 December 2017

CIRA/Colorado State University Advected Layered Precipitable Water (ALPW) for 00 UTC 7 December 2017

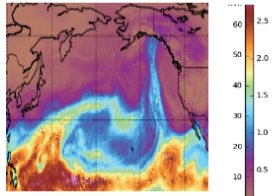


Thompson Pass (just outside Valdez, AK)
Snow
1.7" in 10 minutes
5" in 30 minutes
10" in one hour
15" in 1.5 hours
40" in 12 hours

00 UTC 7 December 2017



GOES-15 Water Vapor



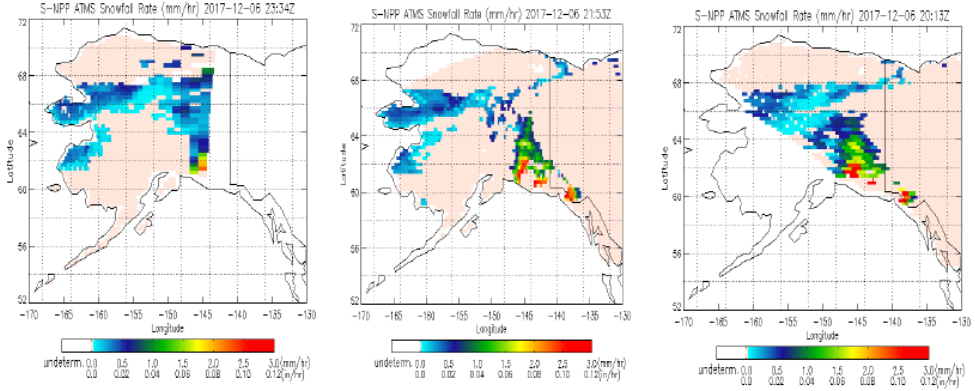
CIMSS MIMIC TPW2.0

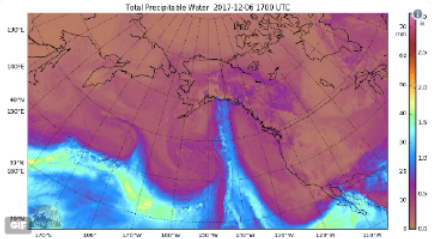
Snowplows clearing Richardson Highway near Thompson Pass, Ak. (Alaska Dept of Transp & Pub Facilities)

Analysis Prepared by Sheldon Kusse

Remote Sensing: Snowfall Rate Product

NOAA/NESDIS Snowfall Rate Product





NWS APRFC
@NWSAPRFC

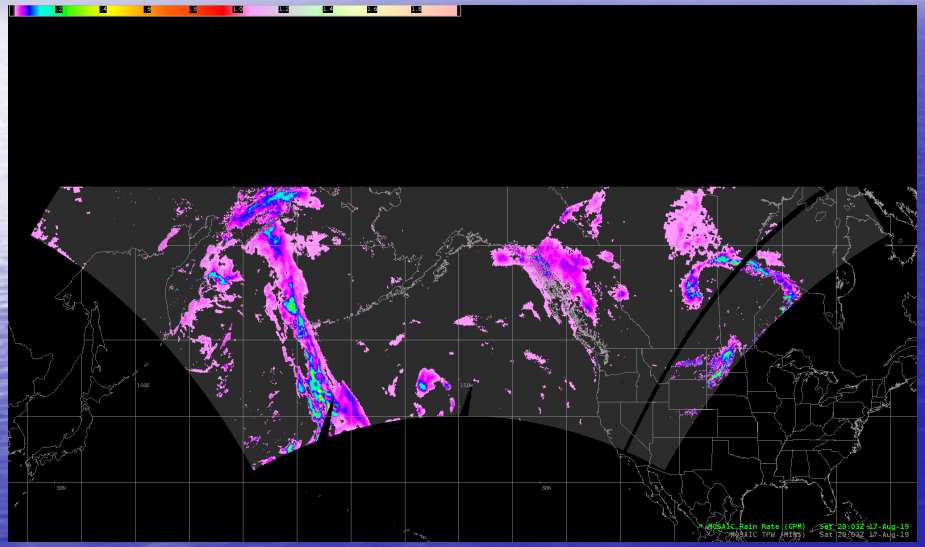
What is hitting the North Gulf Coast is what we like to call a "snow AR" or an atmospheric river that is producing snow instead of rain. Over the last 3 days, nearly 6 feet of snow has been recorded at Thompson Pass near Valdez, Alaska.

NWS APRFC
@NWSAPRFC

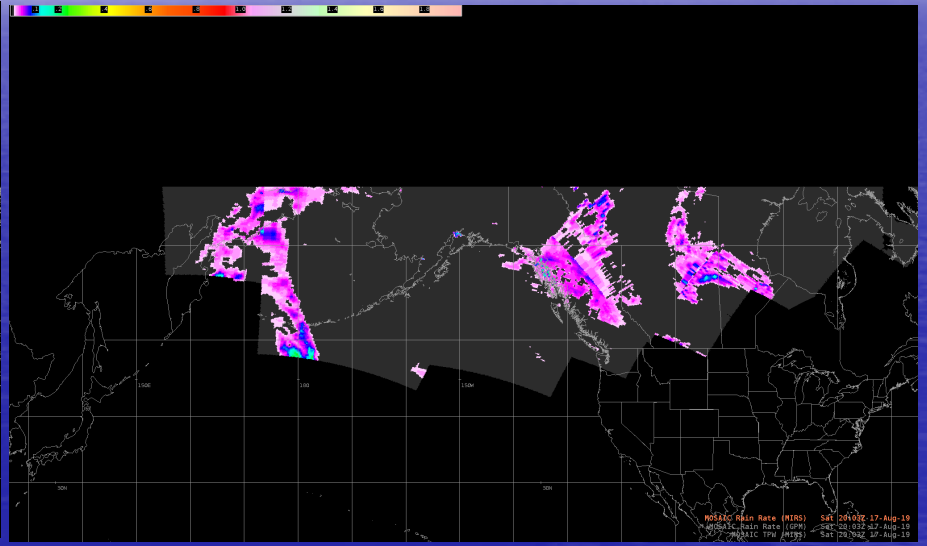
Snow update from Thompson Pass near Valdez, #Alaska - in the last three days the #NRCS SNOTEL site at Nicks Valley at 4280ft has now picked up 83" of snow over the last 3 days as of 1pm and now totals 126".

7:20 PM - Dec 6, 2017

Remote Sensing:
Rain rates(MiRS,GPM)



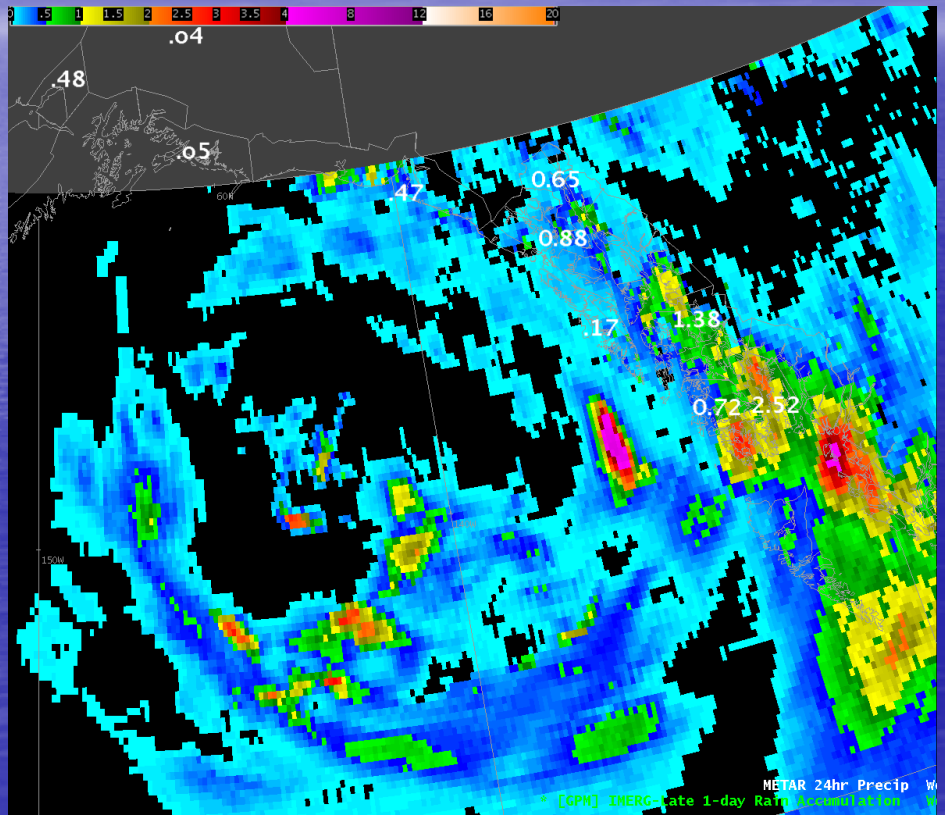
GPM Rain Rate Mosaic
(Global Precipitation Mission(NASA))



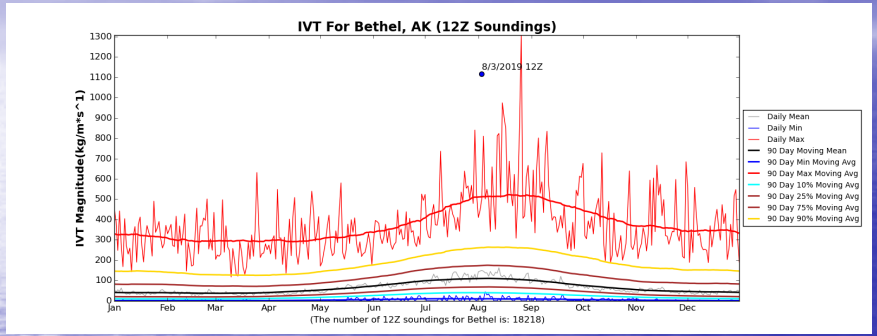
MiRS Rain Rate Mosaic
(Microwave Integrated Retrieval System(NOAA))

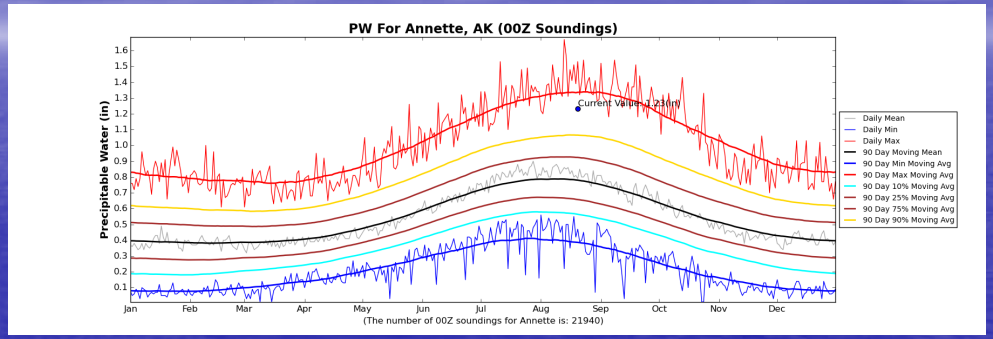
Remote Sensing:
1,3,6,12,24hr NASA IMERG (Rainfall estimates)

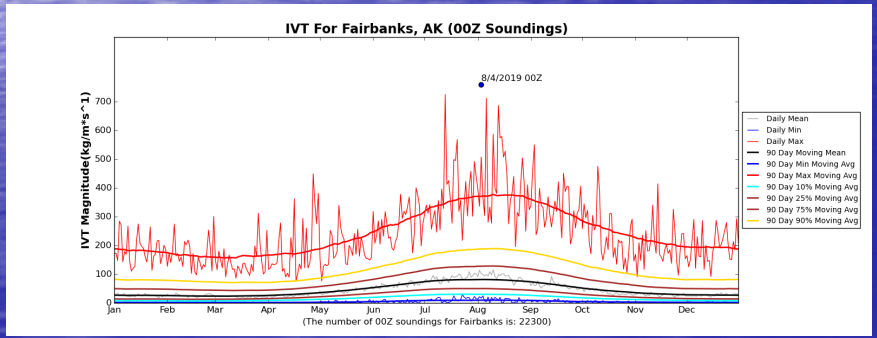
- Post event analysis (due to latency of products)
- Improve R2O

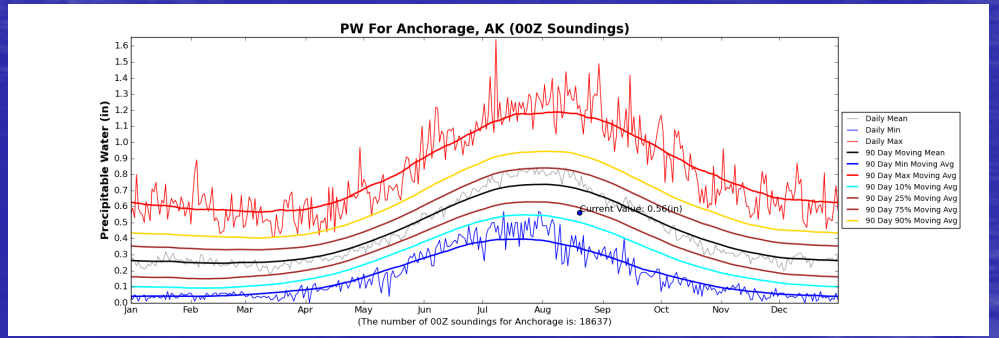


Weather balloon sounding IVT/PW 1948-2018 climatology for Alaska Locations



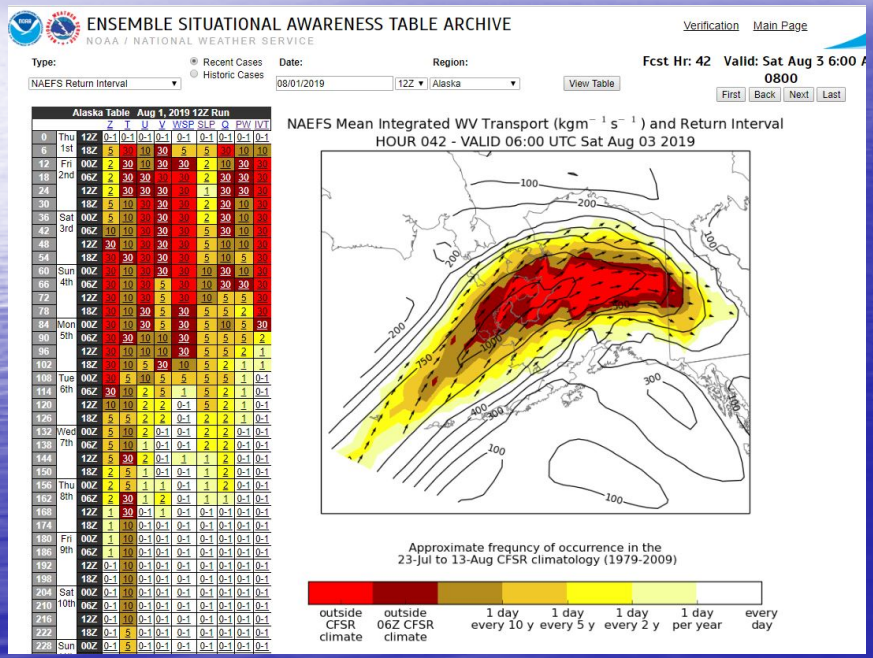


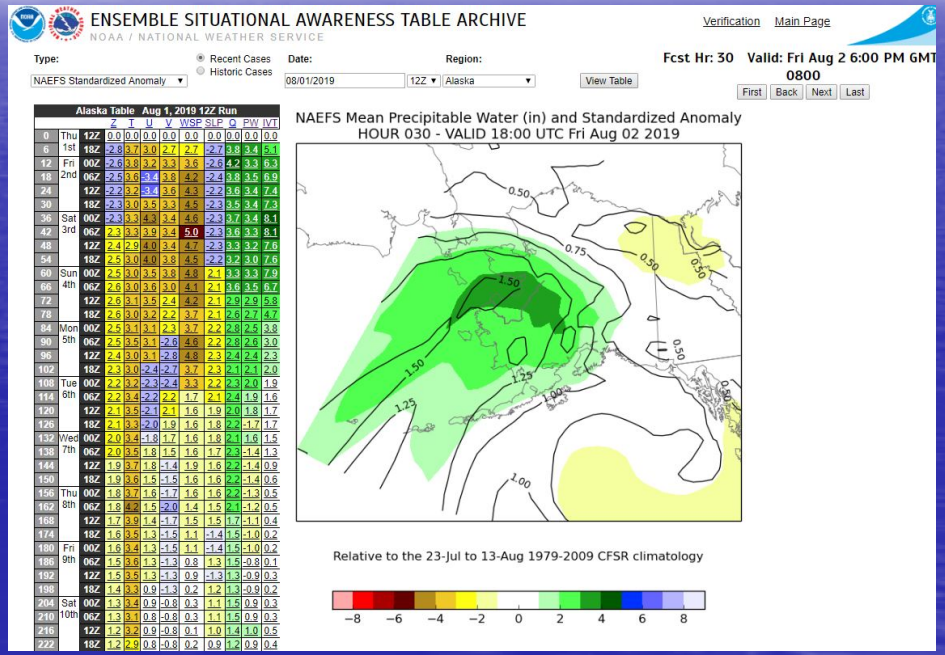




Provides great situational awareness in a historical/climate context

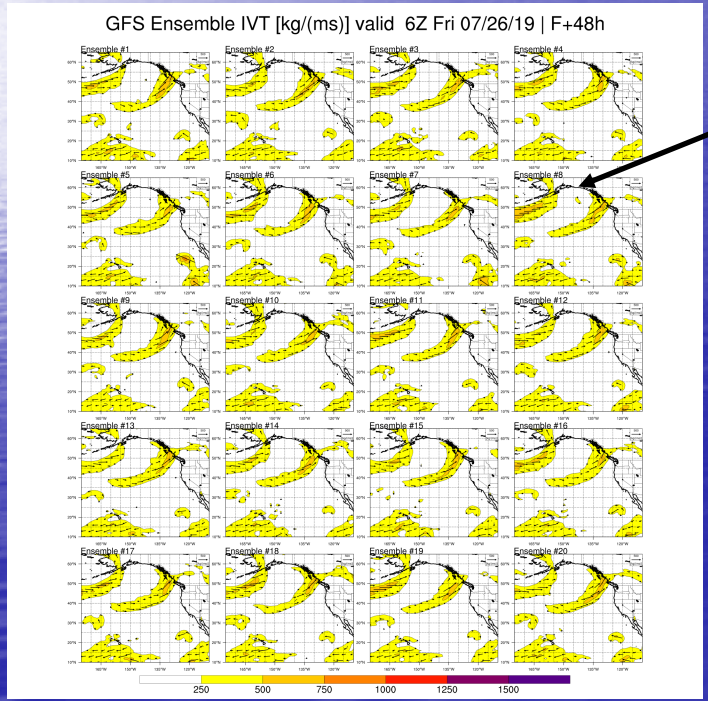
Numerical Weather Prediction: NAEFS Ensemble SA Table





Numerical Weather Prediction: NCEP GEFS Atmospheric River Forecasts

NCEP GEFS IVT Thumbnails 48-hour Forecast

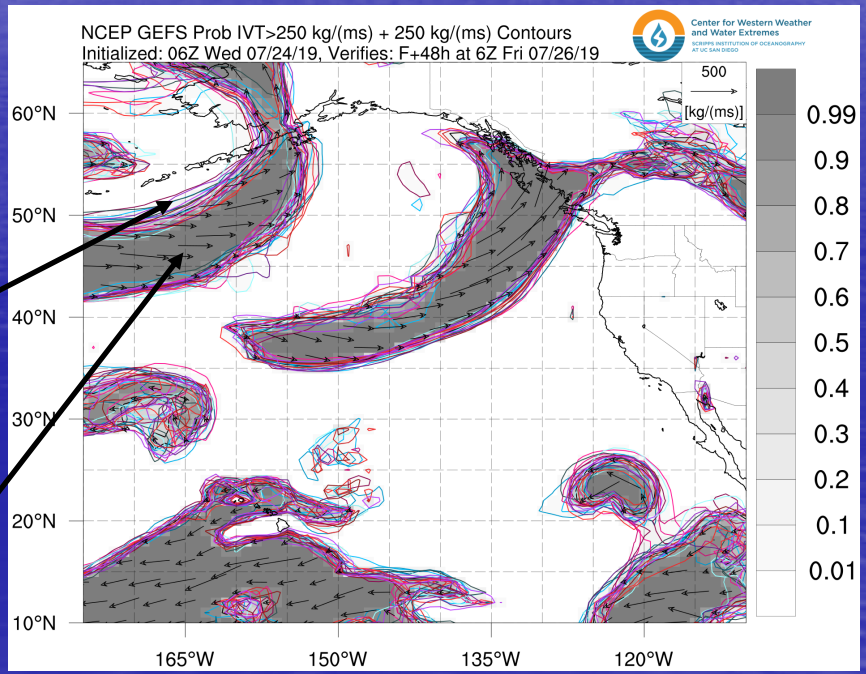


IVT from the 20 ensembles members of the GEFS

IVT = 250 kg m^{-1} s^{-1} contours from all ensemble members (contours)

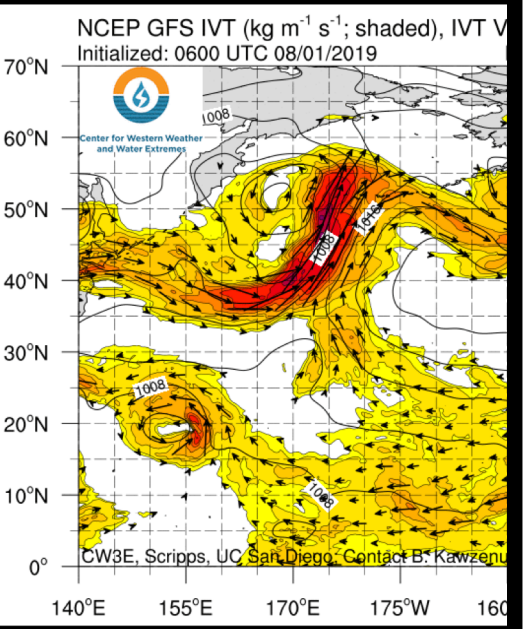
Probability of IVT >250 kg m^{-1} s^{-1} (shading)

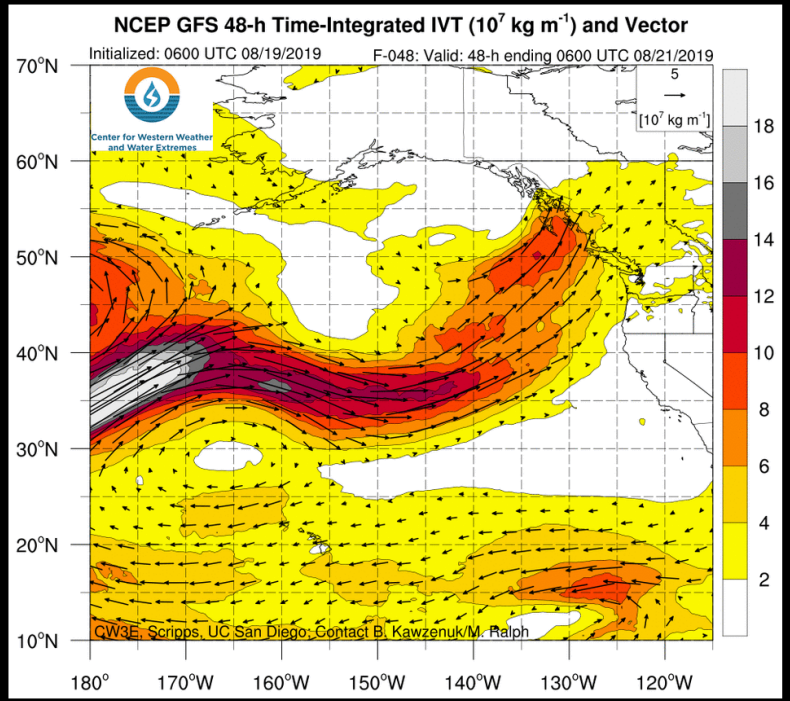
NCEP GEFS IVT Ensemble Probability 48-hour Forecast IVT>250kg/m

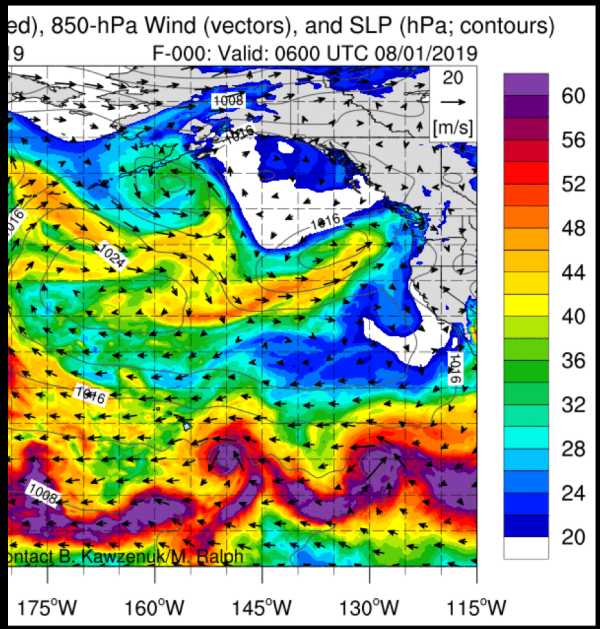


Provided by: B. Kawzenuk

Numerical Weather Prediction: NCEP GFS Atmospheric River Forecasts



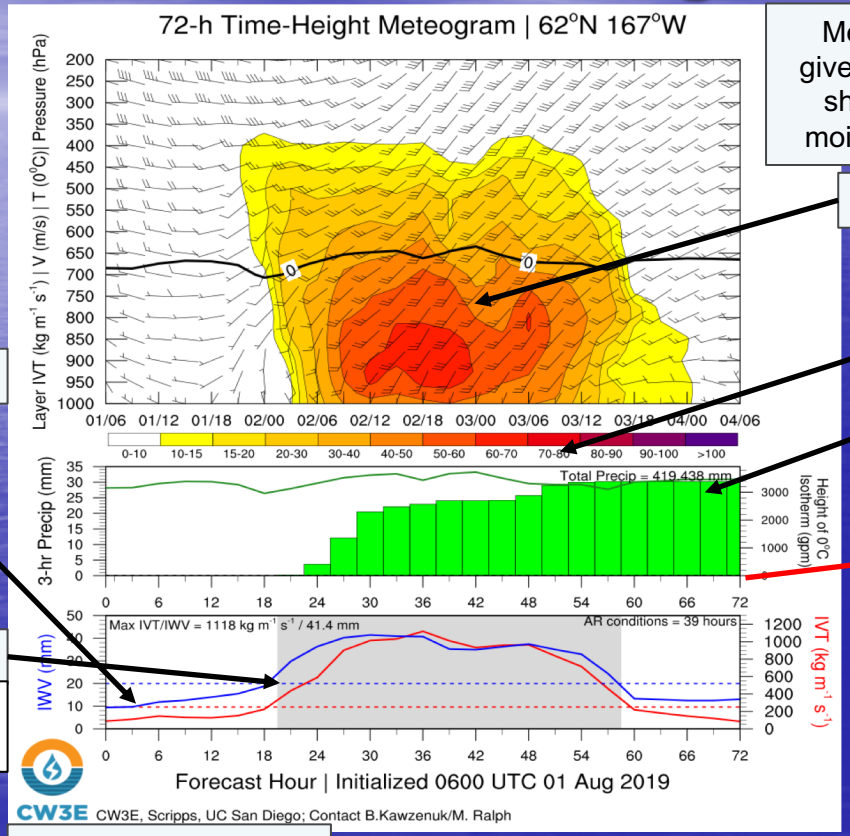




Provided by: B. Kawzenuk & C. Hecht

Numerical Weather Prediction: NCEP GFS Meteogram Forecasts

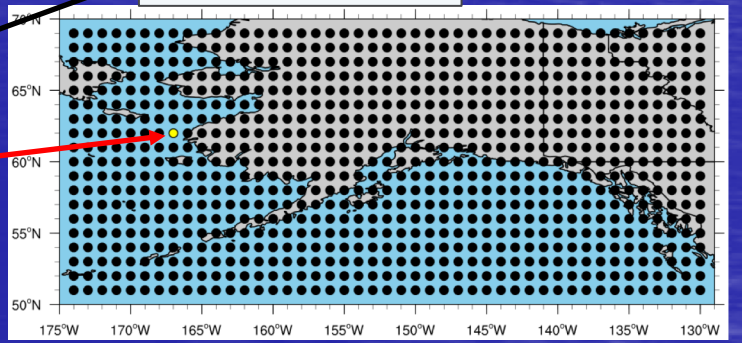
Meteograms illustrate the forecasted conditions over a given location for the 3 or 7-day forecast period. The plots show forecasts of the vertical distribution of winds and moisture, freezing level, precipitation, and AR conditions.



Vertical distribution of IVT and winds

Freezing level

3-hour precipitation



Meteograms available at all above locations

Increasing height

IWV and IVT

AR conditions

(IVT >250 kg m-1s-1 and IWV >20 mm)

Increasing lead time

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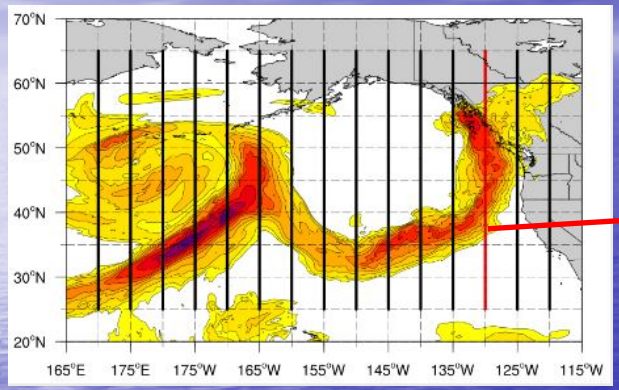
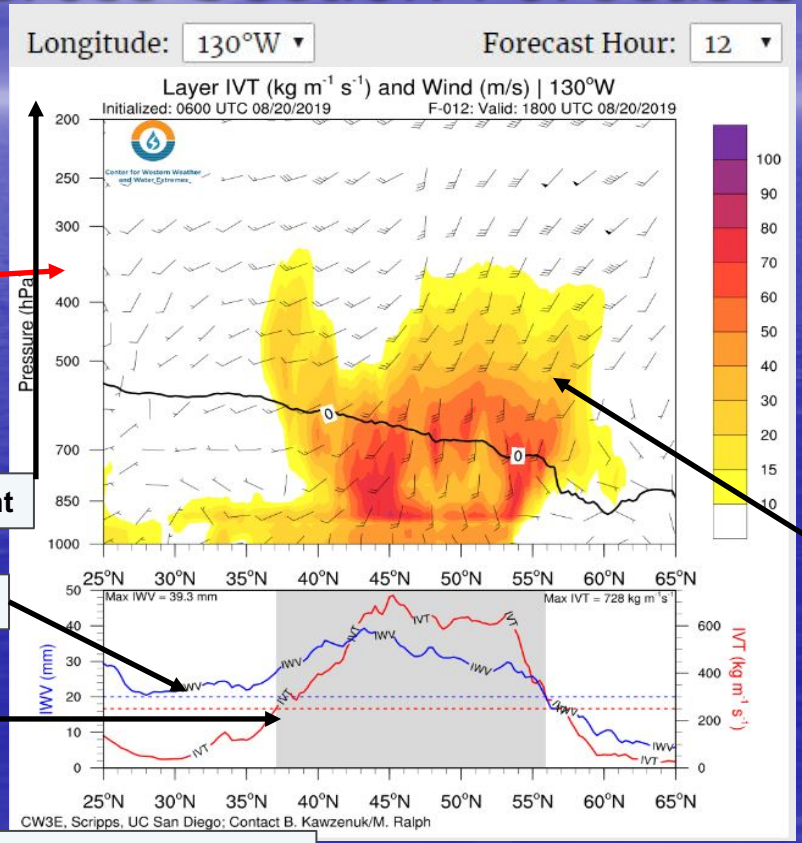
Numerical Weather Prediction: NCEP GFS Cross Section Forecasts





Cross sections illustrate the forecasted conditions along a longitudinal line from 25-65°N for the given forecast time from the GFS model. The plots show forecasts of the vertical distribution of winds and moisture, freezing level, AR conditions and MAX IVT.

Increasing height

IWV and IVT

AR conditions
(IVT >250 kg m-1s-1 and IWV >20 mm)

Vertical distribution of IVT and winds

Increasing latitude

Provided by: B. Kawzenuk & C. Hecht

Ongoing AR research in Alaska

- Derive a regional and seasonal classification scheme: non-AR, weak AR, moderate AR and Strong AR (NWS)
- Station climatology of specific fields Integrated water transport (IVT), Precipitable water values (IWV), time integrated IWV with statistics (mean and standard deviation) from precipitation data and/or impact base analysis (NWS)
- Flood/Streamflow trends to AR events (USGS/USDA FS)
- Promote remote sensing capabilities to produce a near real-time IVT data-set for better spatial detection of impactful IVT values (NWS)

THANK YOU

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