

Contributions of Atmospheric Rivers to Western United States Avalanche Fatalities

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Motivation

Loss of life and property

Disruption of transportation/commerce
(Highway 80 closure cost \$20k per minute)

CA pilot study

89% High Avalanche Danger days were “upside down storms”, of these, 100% were AR events

Ecological implications

Hypothesis: Atmospheric rivers will contribute to avalanche fatalities in a manner consistent with their regional climatological frequency

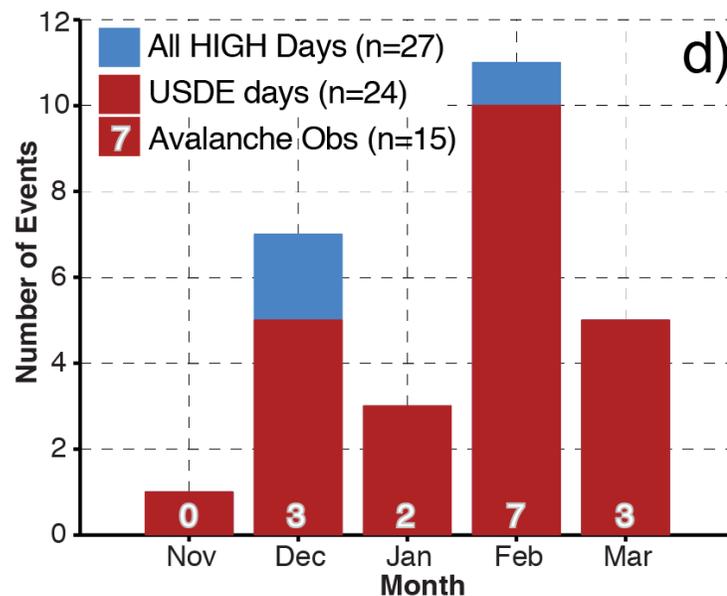
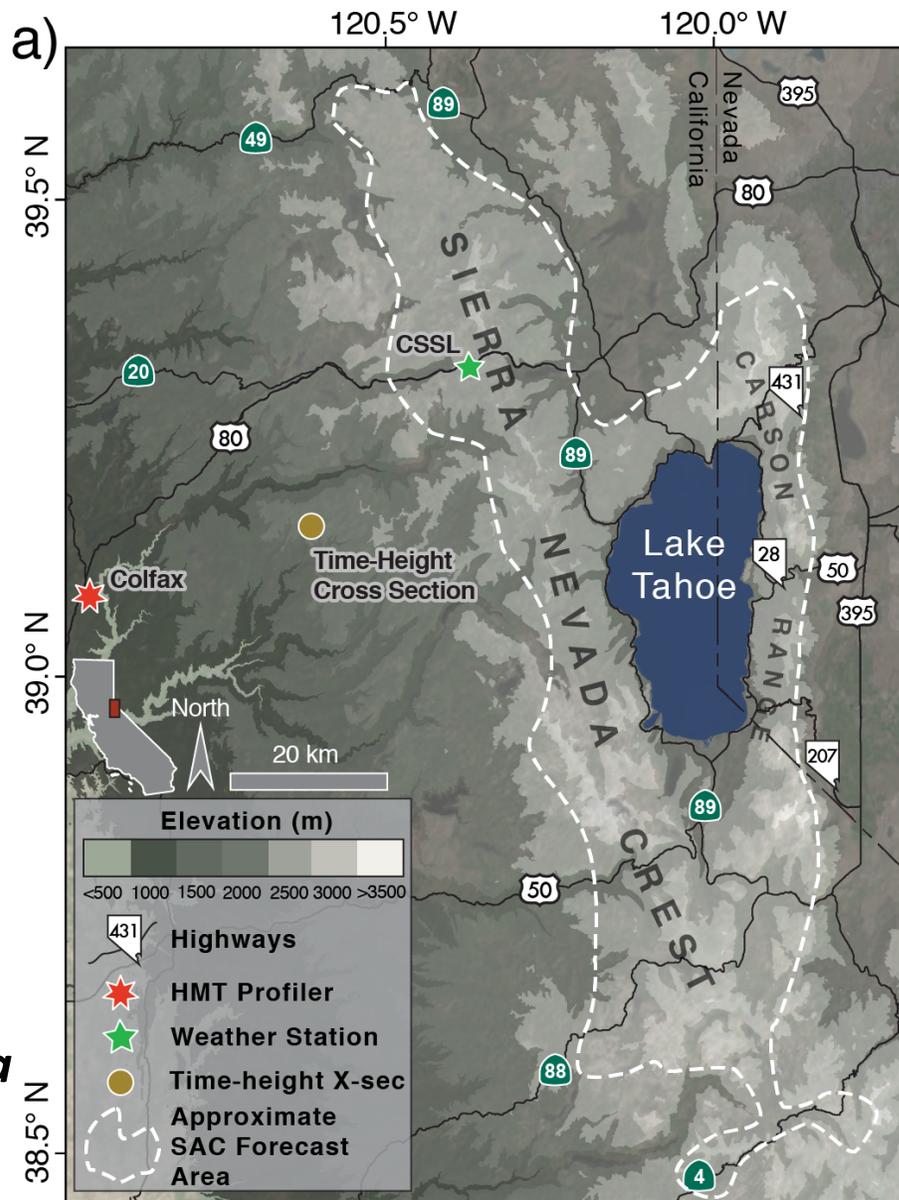


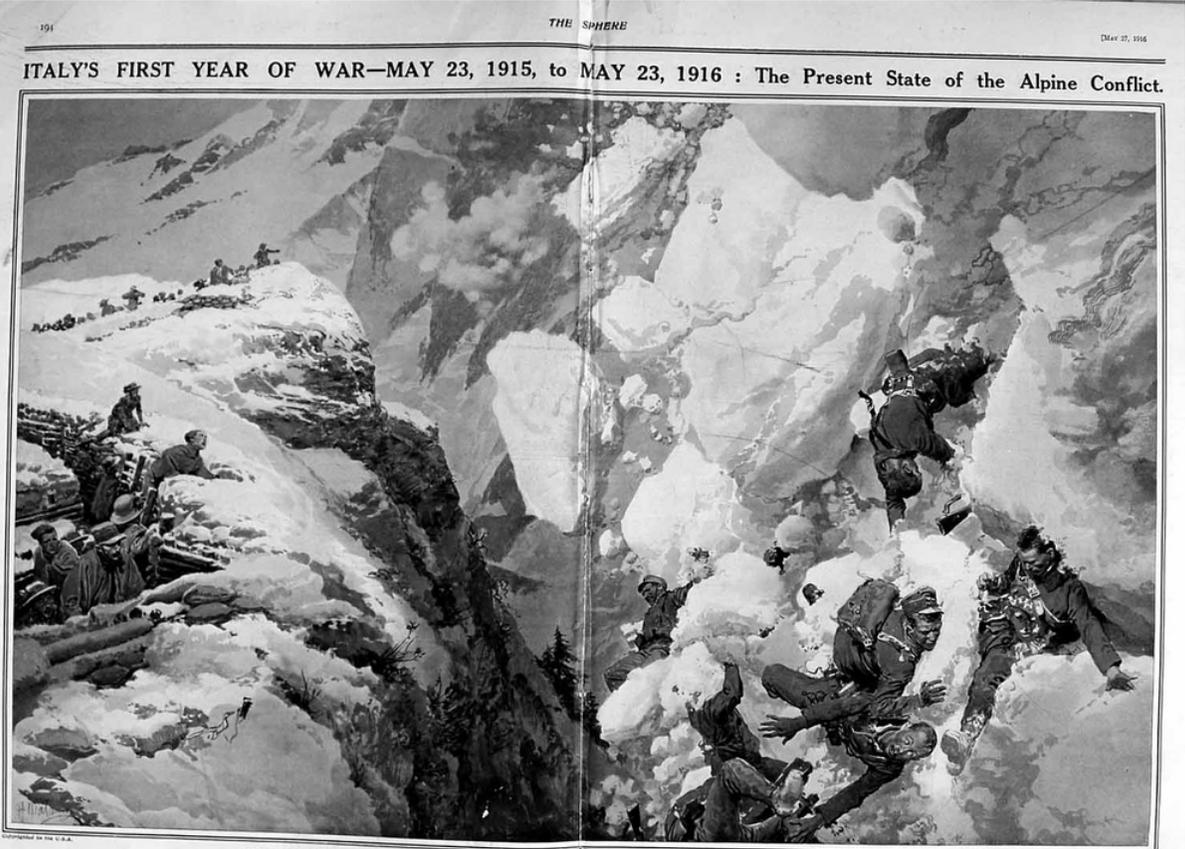
Fig 1. from Hatchett et al. (2016) *Proc. Int. Snow Sci. Work.*

Historical Motivation White Friday Avalanche

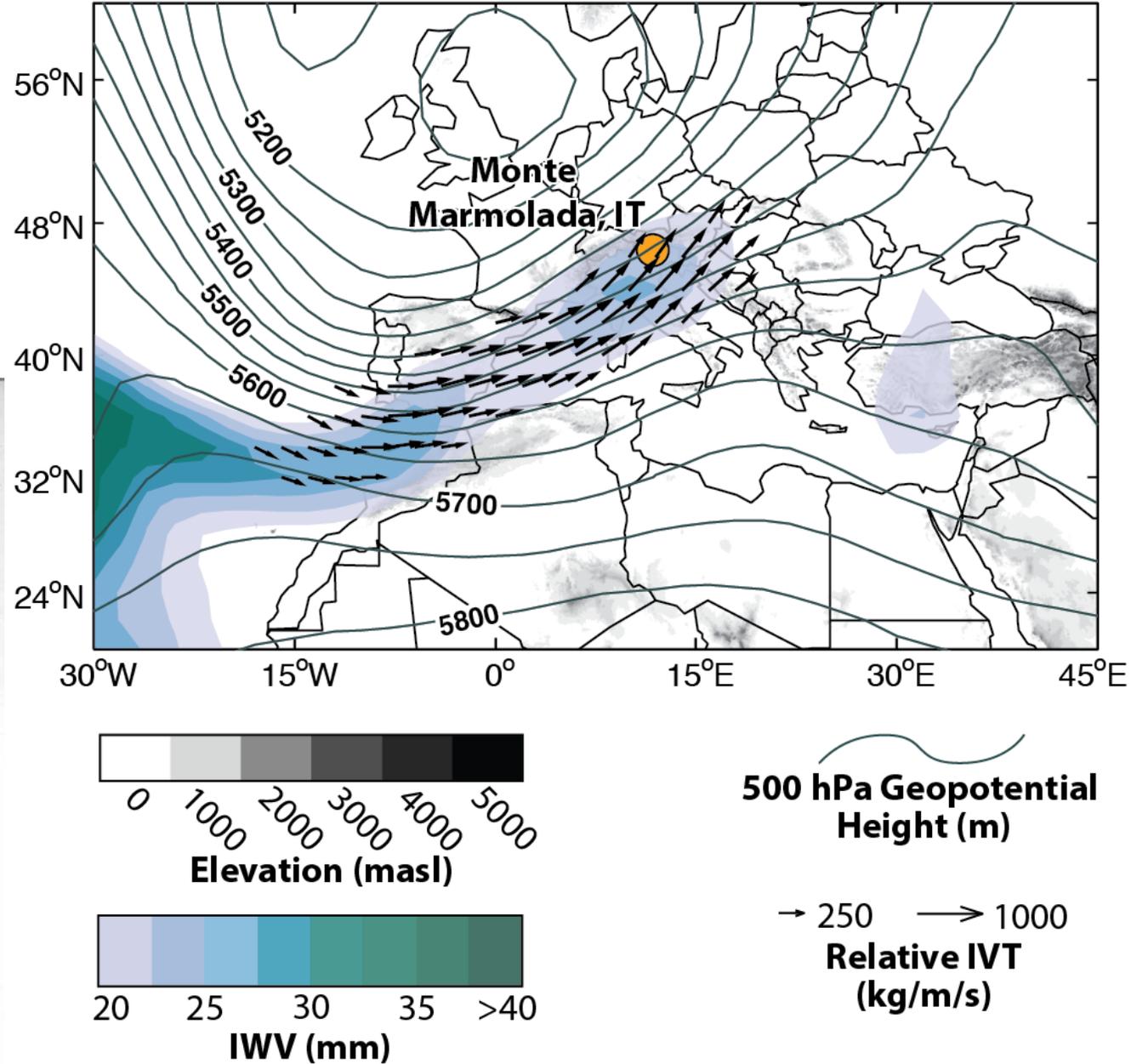
10,000 killed in WWI

20th Century Reanalysis

(Compo et al. 2011 *Quat. J. Roy. Met. Soc.*)



a) 12 December 1916



Data

Avalanche Statistics For Conterminous Western United States

Archived avalanche fatalities from Colorado Avalanche Information Center and U.S. Avalanche Accident Reports (state, date, number, *possibly* more information)

Existing Research

Snow Climates (Mock and Birkeland 2000 *Bull. Am. Met. Soc.*)

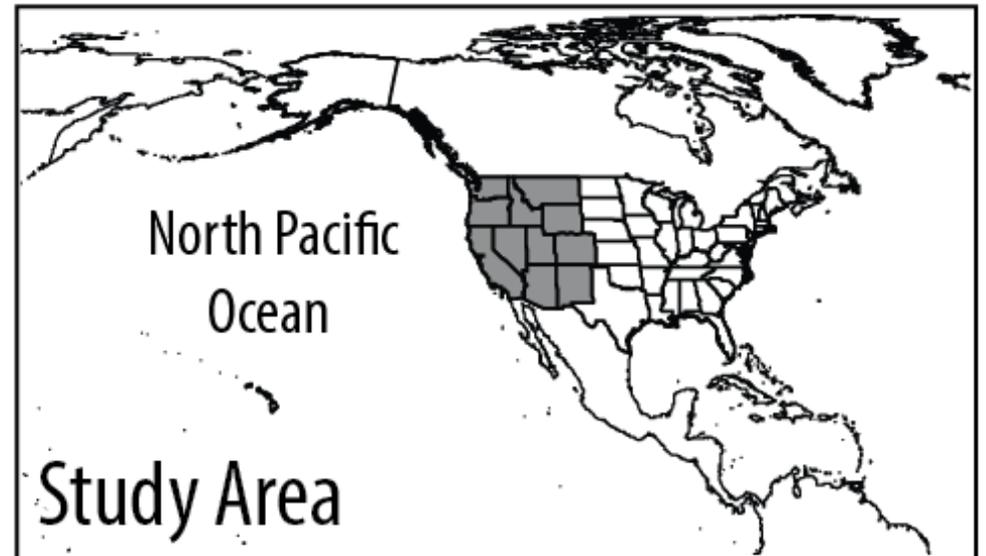
AR catalog and derived fractions of cool season precipitation (Rutz et al. 2014 *Mon. Wea. Rev.*)

Reanalysis Products

North American Regional Reanalysis
(Mesinger et al. 2006 *Bull. Am. Met. Soc.*)

Weather Stations

792 SNOTEL stations



Methods

Use archived reports to estimate location of incident, remove incidents un-related to snowfall

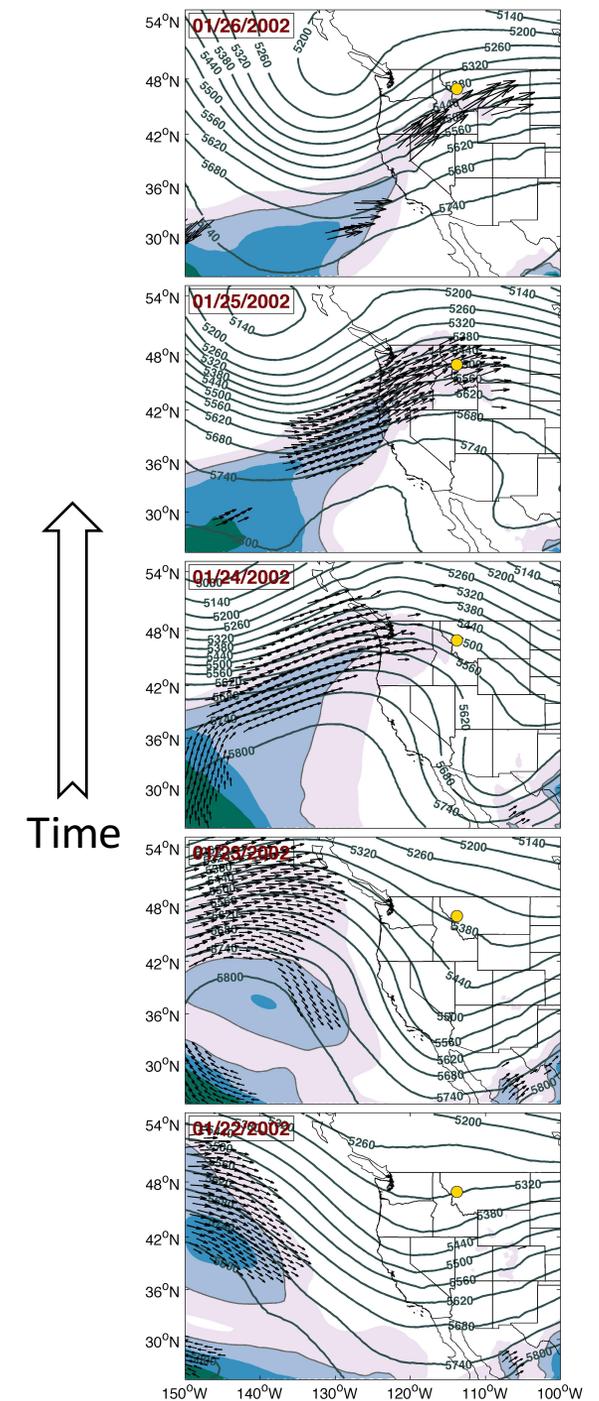
Calculate IVT, IWV for six-day window (-4, +1 day)

Identify if $IVT > 250 \text{ Kg m}^{-1} \text{ s}^{-1}$, check against Rutz et al. (2014) 6hrly

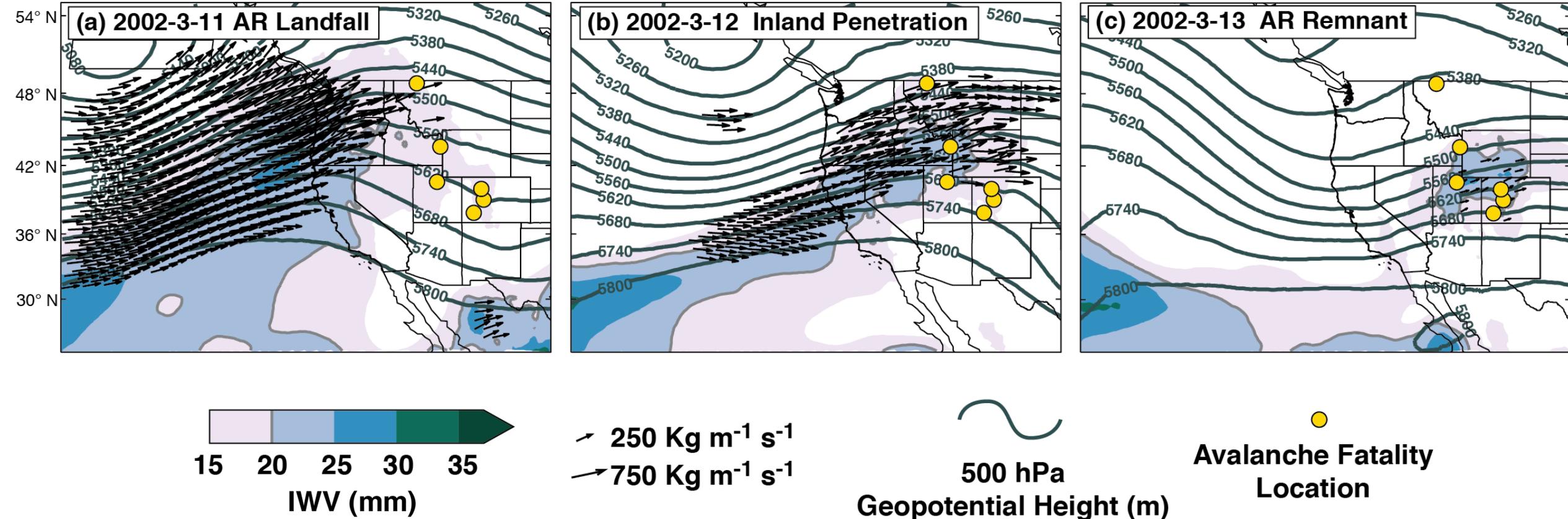
Find SNOTEL within 0.5° of incident, calculate:

Change in snow water equivalent (ΔSWE ; mm)

Maximum precipitation percentile based on non-zero cool season days in POR (1981-2014)

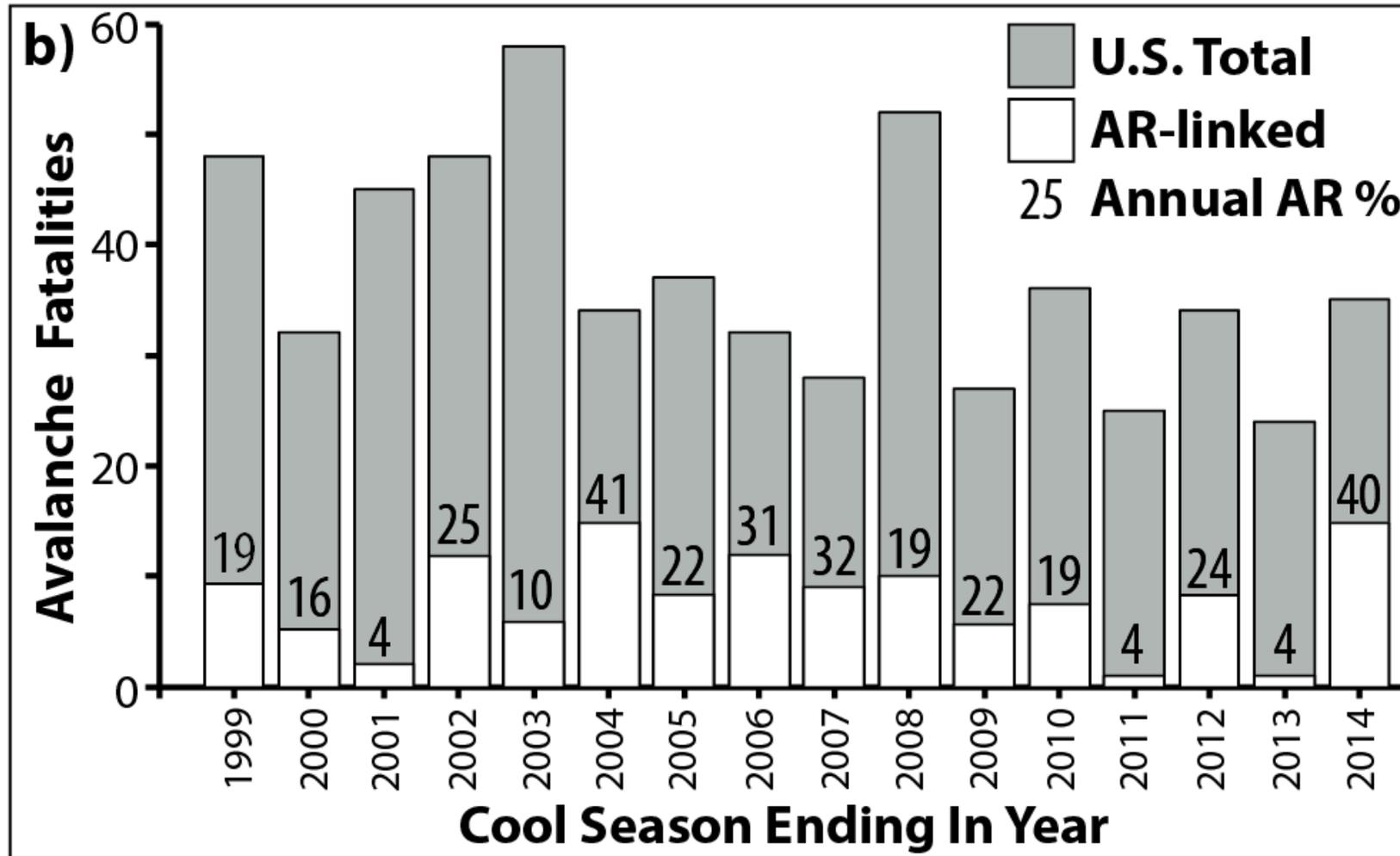


Multi-state Example: 11-13 March 2002

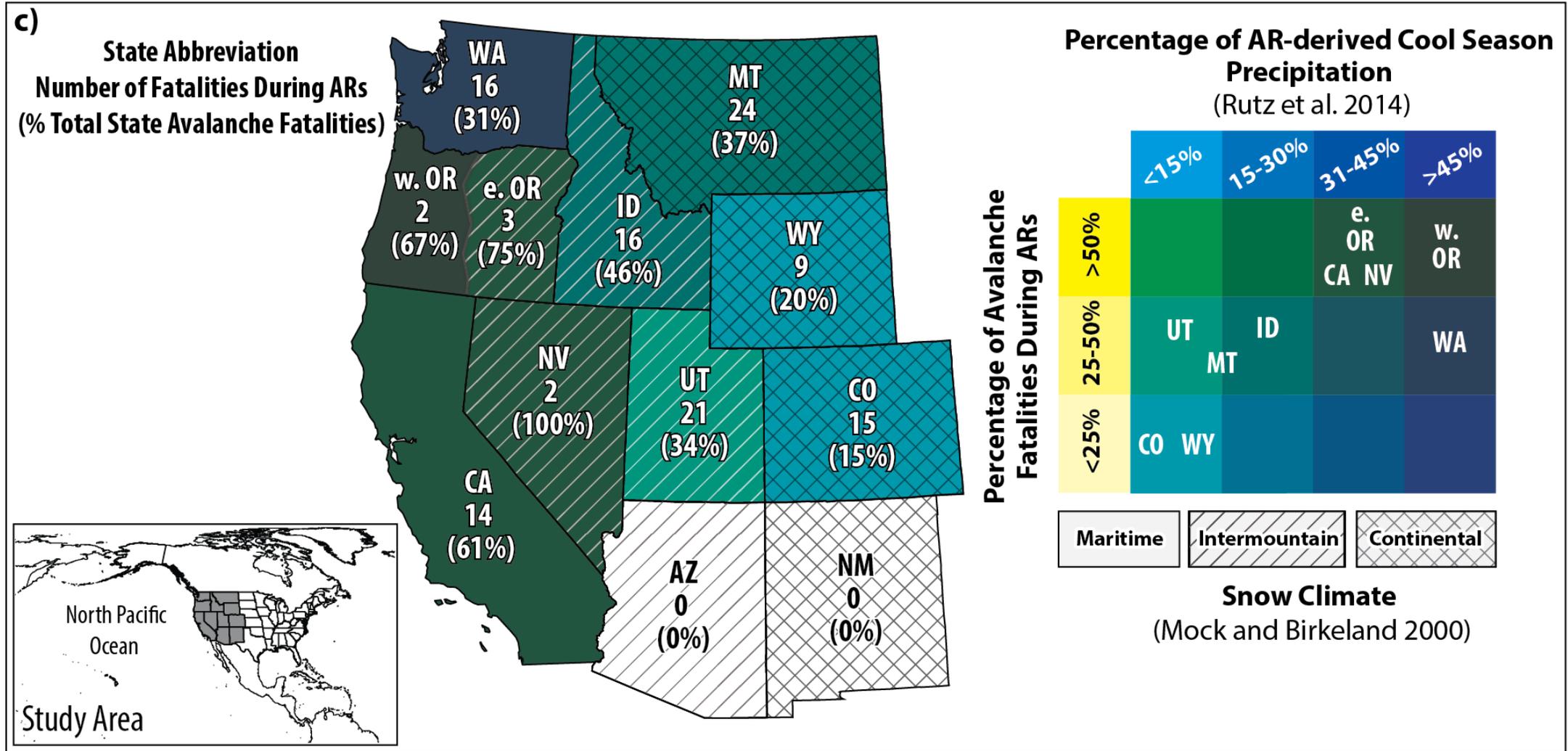


Results: Counting

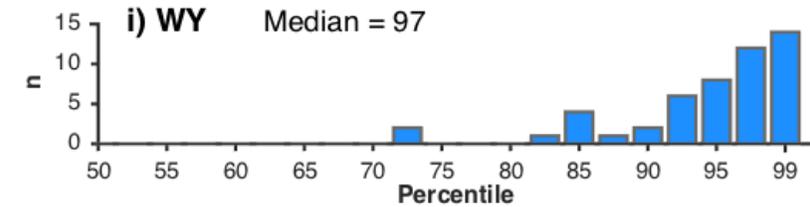
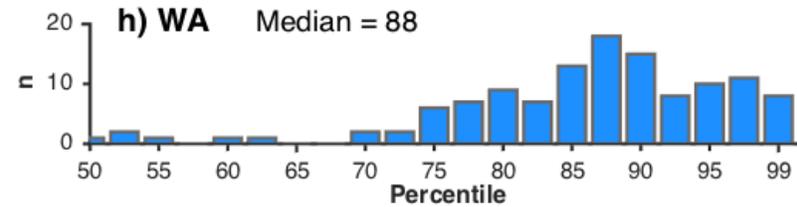
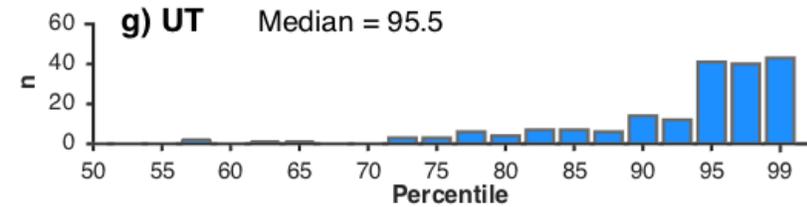
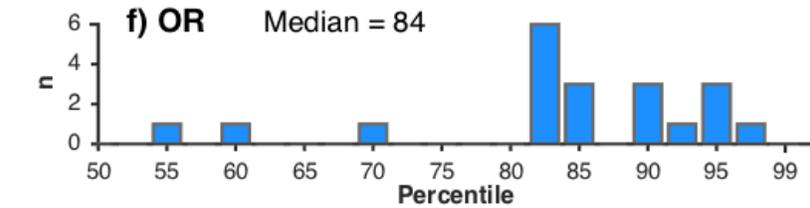
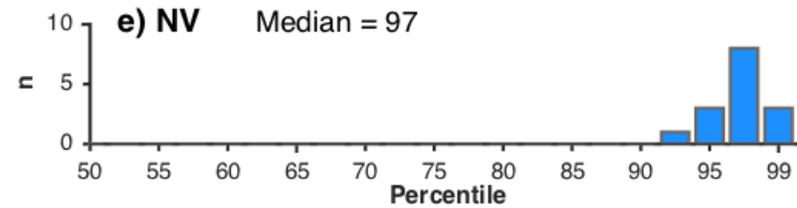
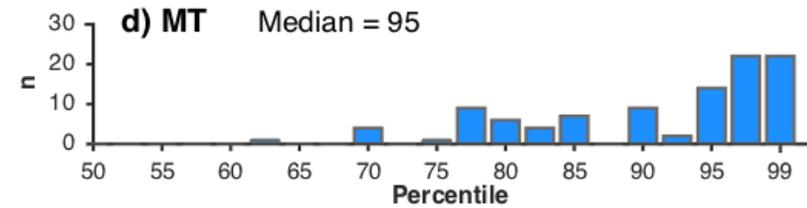
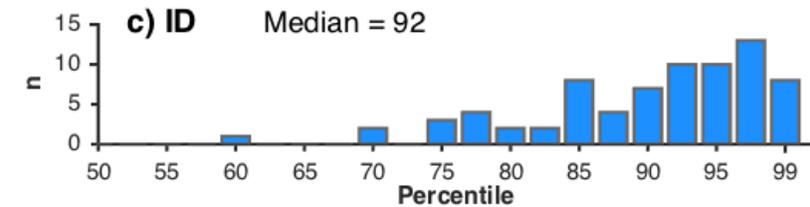
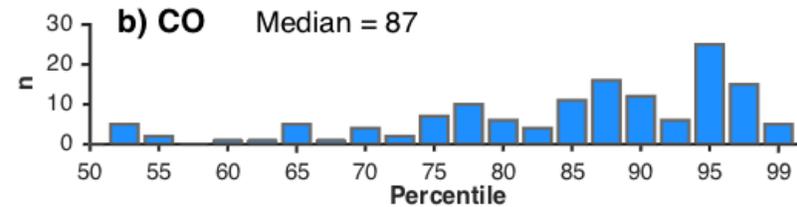
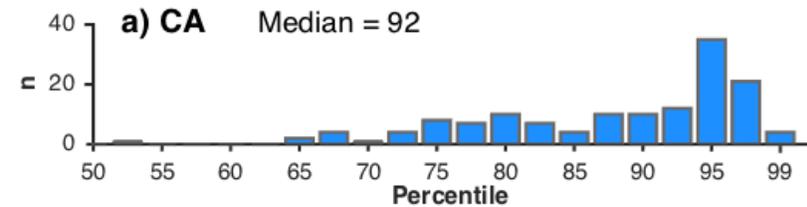
104 unique events, 122 fatalities (avg. 8 year⁻¹)



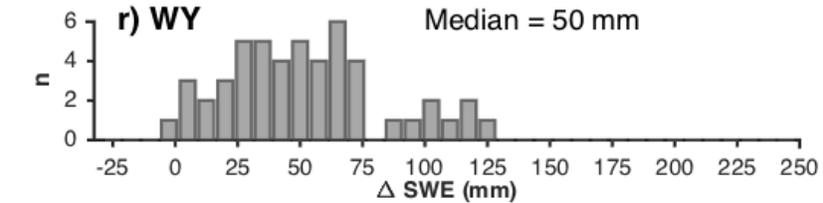
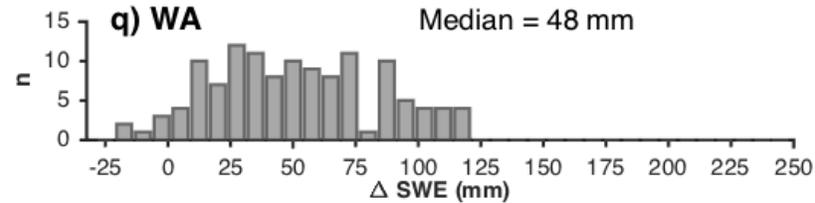
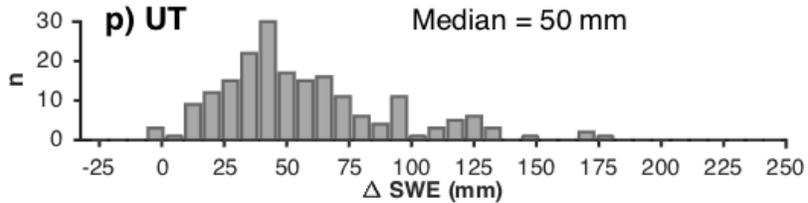
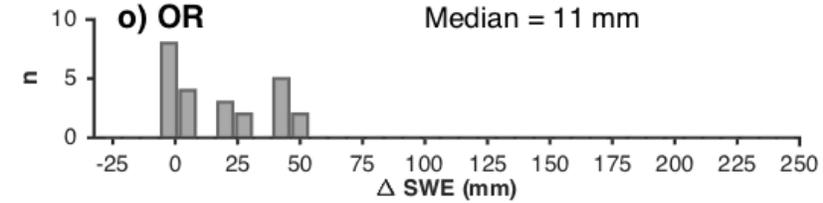
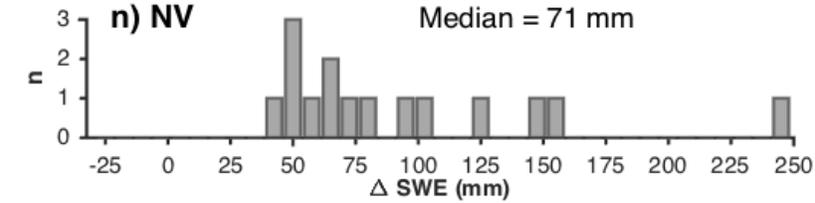
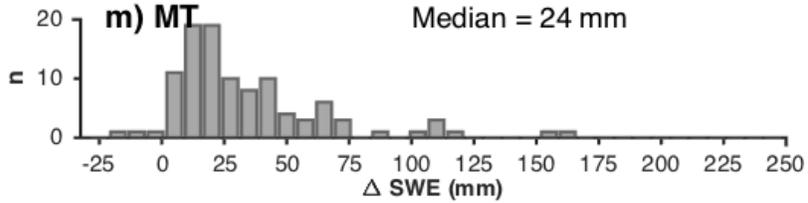
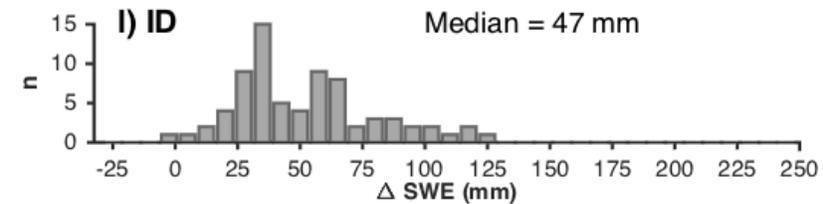
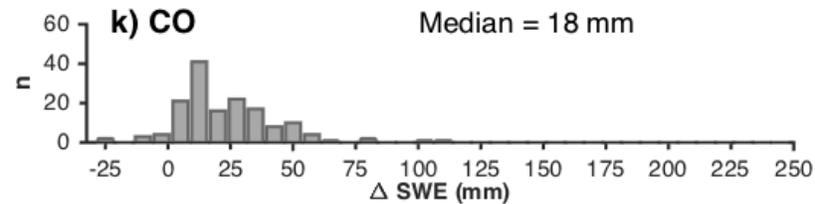
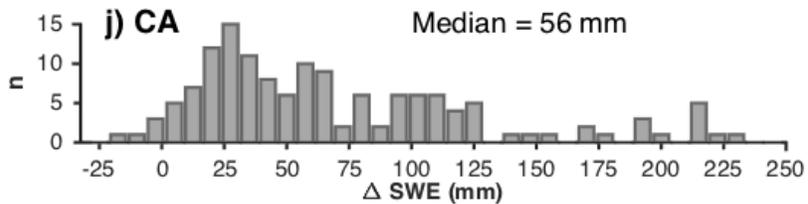
Results: Inland decrease in AR-related fraction of avalanche fatalities



Results: High daily precipitation totals



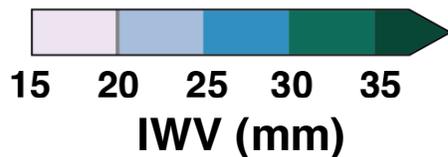
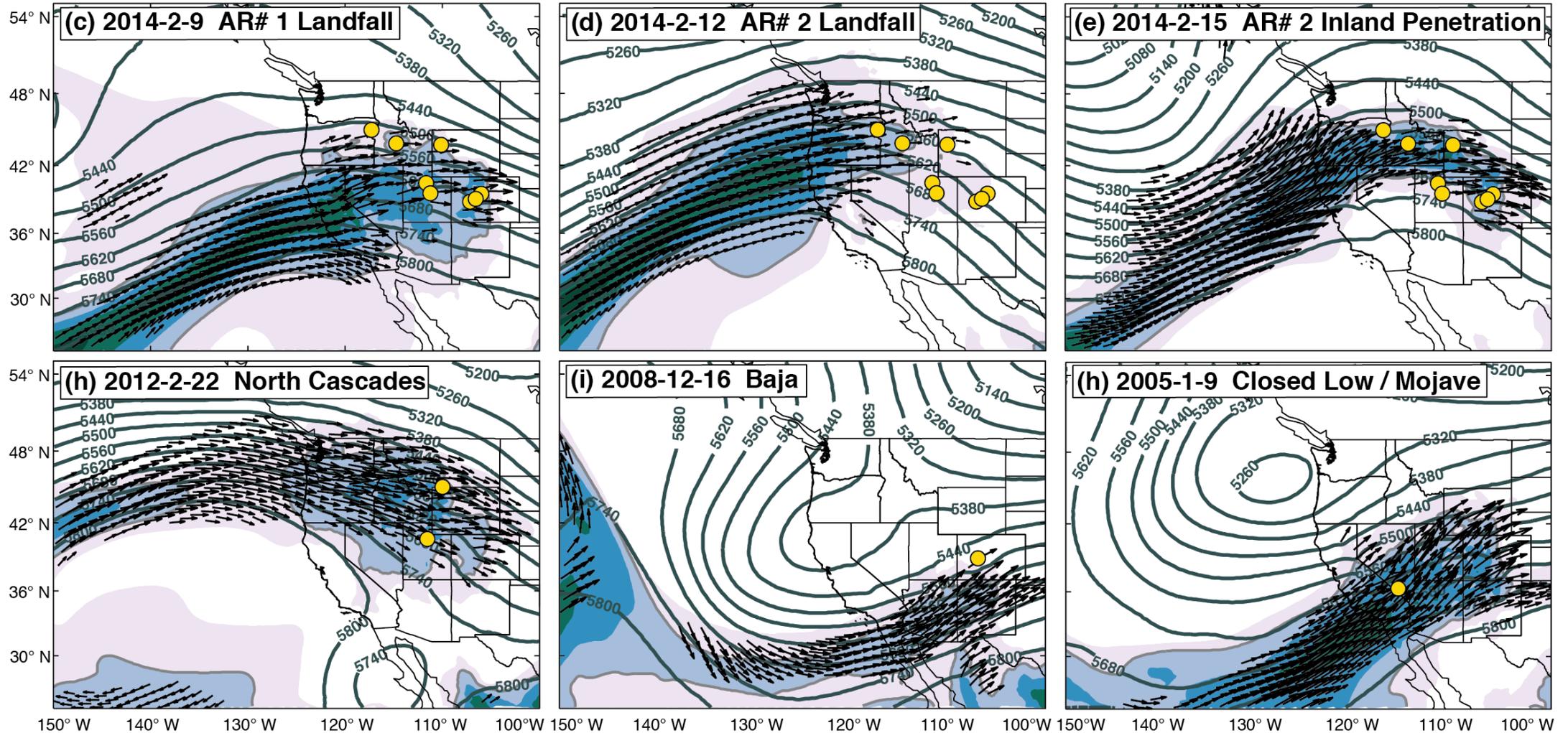
Results: High daily precipitation totals drive large changes in SWE → snowpack loading → failure



Threshold loading for avalanches: 30 cm

Atwater (1954) *Sci. Amer.*, Bair (2013) *Cold Reg. Sci. Tech.*

Consideration: Preferential Pathways of Inland Transport



↘ 250 $\text{Kg m}^{-1} \text{s}^{-1}$
→ 750 $\text{Kg m}^{-1} \text{s}^{-1}$

500 hPa
Geopotential Height (m)

●
Avalanche Fatality
Location

Conclusions

31% of western US avalanche fatalities occurred during AR events between 1998-2014

Regional contributions of ARs to avalanche fatalities are consistent with climatological AR-fractions and snow climates

Heavy to extreme precipitation leads to snowpack loading

→ often exceeds 30 cm threshold for avalanche activity

→ coincidence with upside down storms

Using preferential pathways and IVT may improve forecasts for increases in avalanche hazard

Future work must incorporate role of human decision making, include AR science in avalanche education



Thanks!

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Photo courtesy Josh Hejl

