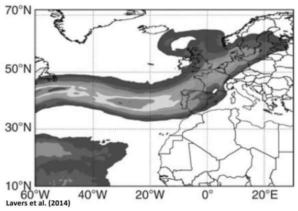
Atmospheric Rivers

VU2: Course Number 707813



Lavers et al. (2014)

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Learning Objectives

- After this class you should:
  - Be able to identify atmospheric rivers and their potential impacts using atmospheric analyses and numerical forecasts
  - Understand the processes that contribute to AR decay or maintenance during inland penetration and orographic interaction
  - Be able to forecast potentially high-impact AR events including comparisons with past events

Introduction

Key Moisture-Related Variables

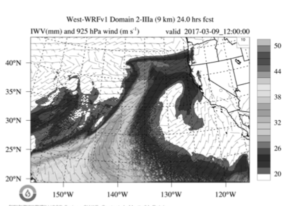
- Integrated water vapor (IWV) – the amount of water vapor in an atmospheric column expressed as the depth of water if that vapor were condensed
  - a.k.a. precipitable water or total precipitable water

$$\mathrm{IWV} = \frac{1}{g}\int_{p_{\mathrm{sfc}}}^{100\,\mathrm{hPa}} q\,dp,$$

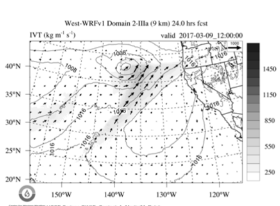
- Integrated water vapor transport (IVT) – the total amount of water vapor transport in an atmospheric column

$$\mathrm{IVT} = \frac{1}{g}\int_{p_{\mathrm{sfc}}}^{100\,\mathrm{hPa}} q\mathbf{V}\,dp,$$

Key Moisture-Related Variables



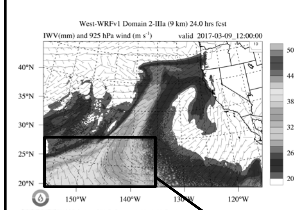
IWV



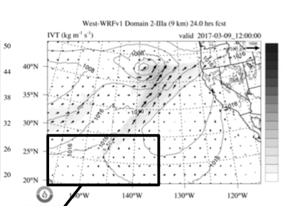
IVT

IWV & IVT are not equivalent

Key Moisture-Related Variables



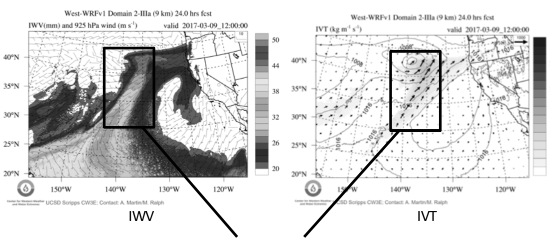
IWV



IVT

High IWV, Low IVT

Key Moisture-Related Variables



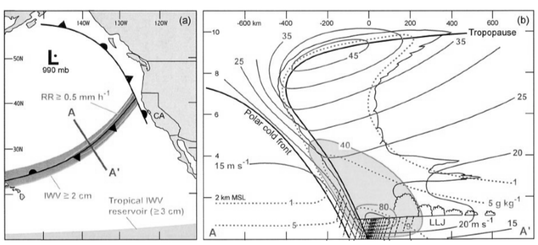
IWV IVT

IWV decreases poleward, IVT increases

Atmospheric Rivers (ARs)

- Narrow corridors (i.e., filaments) of strong vertically integrated water vapor transport (Newell et al. 1992; Newell and Zhu 1994; Zhu and Newell 1998)
- Often found along the pre-cold-frontal LLJ and may contribute to the moisture-rich portion of the broader, ascending warm conveyor belt (Ralph et al. 2004; Sodemann and Stohl 2013)
- Achieve their high water vapor content through transport from the tropics [i.e., tropical moisture exports (TMEs)] and/or moisture convergence (Knippertz et al. 2013; Cordeira et al. 2013)
- Associated with midlatitude hydrologic extremes

Importance of Pre-Frontal LLJ

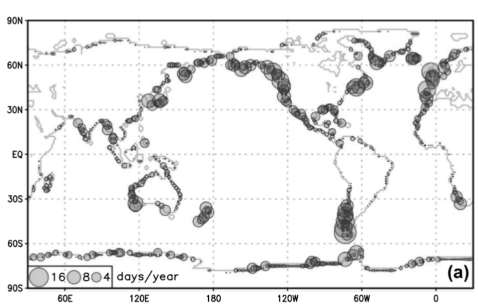


Ralph et al. (2004)

Identification

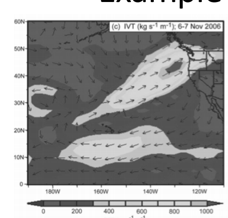
- Satellite based (Ralph et al. 2004)
  - IWV readily available; IVT not readily available
  - Use IWV as an IVT proxy (OK, but not great)
  - ARs identified as contiguous regions of IWV ≥ 20 mm that are ≥ 2000 km in length and ≤ 1000 km in width
- Analysis or NWP based
  - IVT magnitude
    - e.g., contiguous regions of IVT ≥ 250 kg m^{-1} s^{-1} ≥ 2000 km long (Rutz and Steenburgh 2012; Rutz et al. 2014)
  - Percentile IVT approaches
    - e.g., seasonally varying 85th percentile IVT (Guan and Waliser 2015)

Global Landfall Distribution



Guan and Waliser 2015

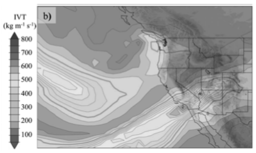
Example AR Events



Mt. Rainier: 6–7 Nov 2006
450 mm in 36 h
Park evacuated
Damage led to 5-month closure

Neiman et al. (2008), NPS, https://www.nps.gov/mora/learn/management/upload/2006%20Flood%2012_17_09.pdf

Example AR Events



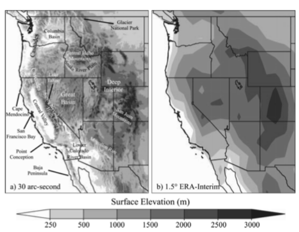
December 2010
Inland penetrating AR
232 cm snow @ Mammoth Mt, CA
191 cm snow @ Sundance, UT

Mammoth Mountain, Bill Nalli, Rutz et al. (2014), Steenburgh (2014)

Characteristics of ARs over Western U.S.

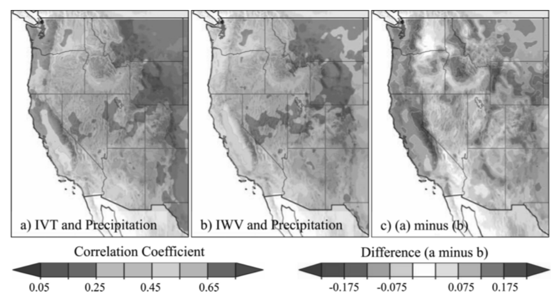
AR Characteristics: Western U.S.

- Reanlayis data:
  - ERA-Interim
  - Cool-season (Nov-Apr)
  - Nov 1988–Apr 2011
- AR definition:
  - ≥ 2000-km in length
  - IVT ≥ 250 kg m^{-1} s^{-1}
- Precip:
  - NOAA/CPC unified daily precip analysis (0.25º)
  - SNOTEL gauge



Rutz et al. (2014)

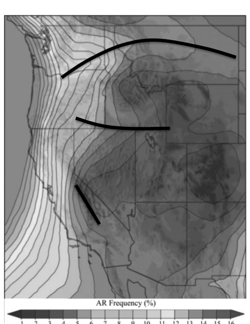
Importance of IVT

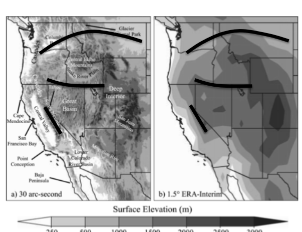


Better correlation with precipitation

Rutz et al. (2014)

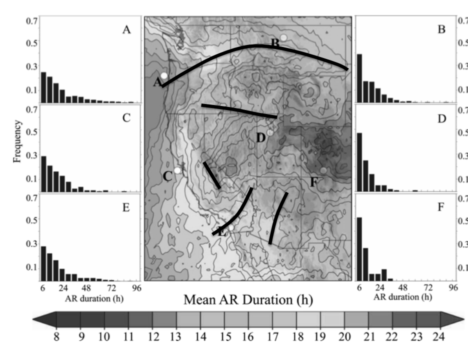
AR Frequency





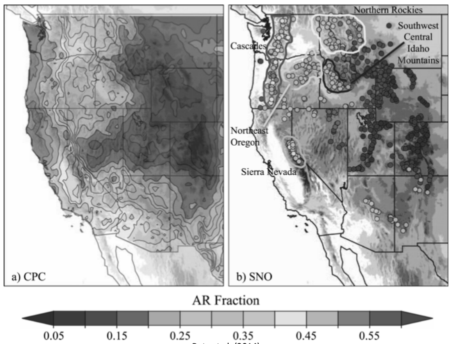
Rutz et al. (2014)

AR Duration



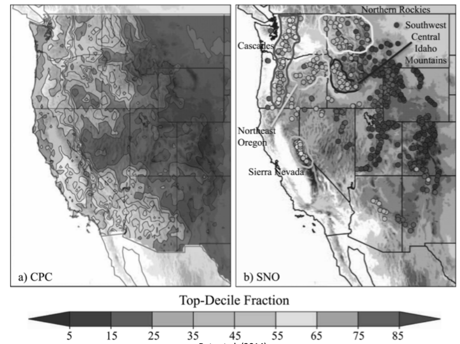
Rutz et al. (2014)

Fraction of Cool-Season Precip



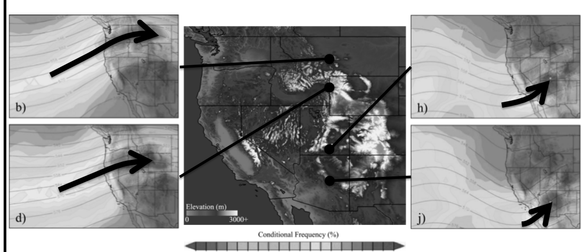
Rutz et al. (2014)

Top Decile 24-h Events



Rutz et al. (2014)

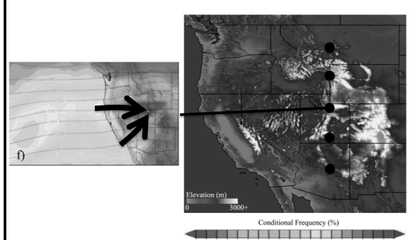
AR Pathways/Sierra Influences



Composite 500-mb height and conditional AR frequencies

Rutz et al. (2014)

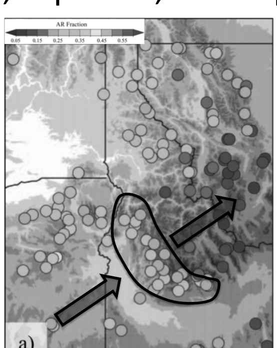
AR Pathways/Sierra Influences



Composite 500-mb height and conditional AR frequencies

Rutz et al. (2014)

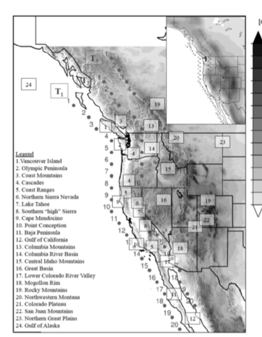
Aspect, Exposure, WV Depletion



Rutz et al. (2014)

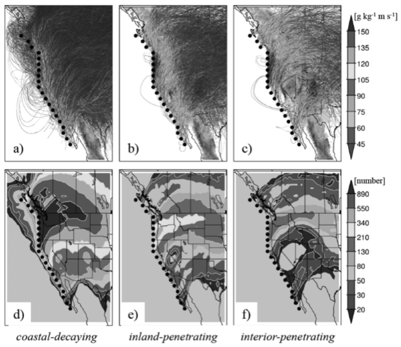
Lagrangian Perspective

- Launch 950-hPa trajectory from T_1 when AR is present
- <u>Coastally Decaying</u>: Reaches T_2, but not in an AR
- <u>Inland Penetrating</u>: Reaches T_2 in an AR
- <u>Interior Penetrating</u>: Reaches T_2 in an AR



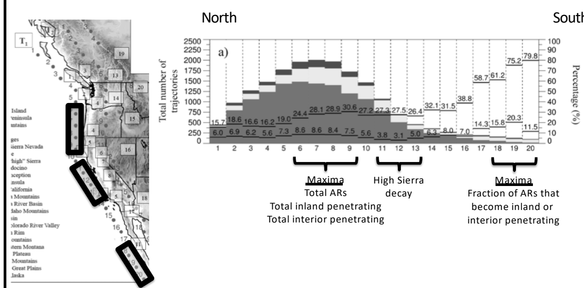
Rutz et al. (2015)

Overview



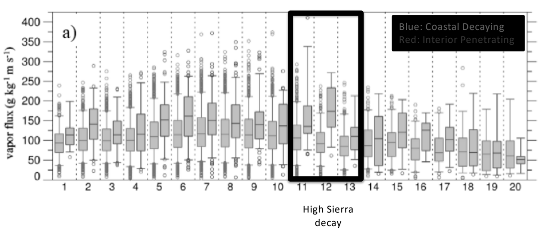
Rutz et al. (2015)

Overview



Rutz et al. (2015)

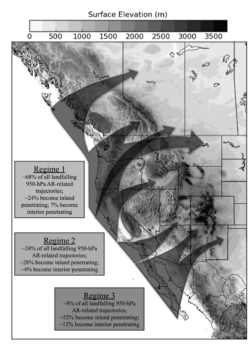
Characteristics @ Initiation



The best way to get an interior penetrating AR is to start with a "big" AR at the coast

Rutz et al. (2015)

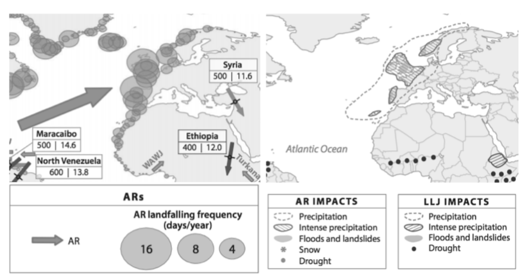
Summary



Rutz et al. (2015)

Characteristics of ARs over Europe

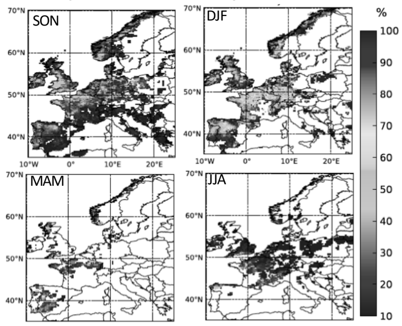
Landfall Frequency and Impacts



*Study overlooks impacts in Alps

Gimeno et al. (2016)

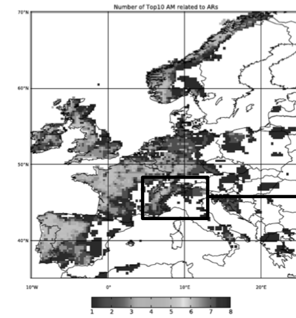
Impact on Major Events



Percentage of annual daily maximum events (1979-2011) associated with ARs

Lavers and Villarini (2013)

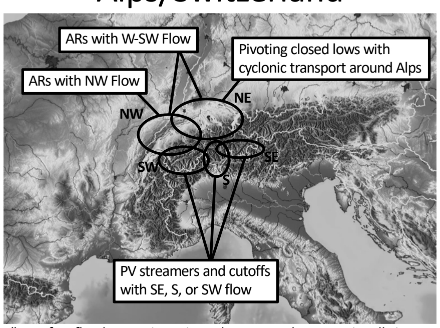
Top 10 AMs Produced by ARs



Note decline from western to eastern Alps

Lavers and Villarini (2013)

Alps/Switzerland

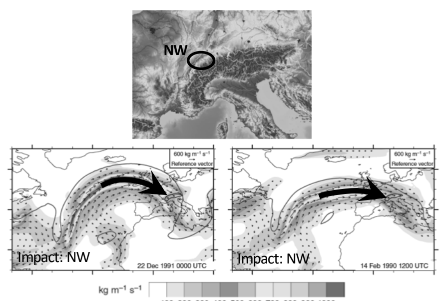


"Ten of 14 flood events investigated correspond to exceptionally intense IVT perpendicular to orography"

Froidevaux and Martius (2016)

ARs with NW flow

NW

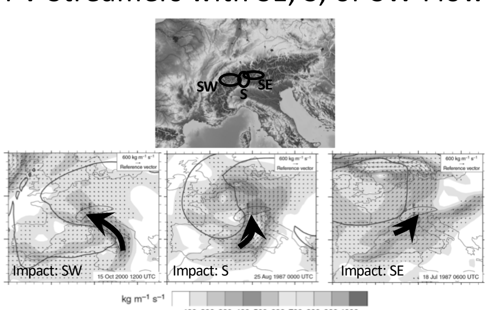


Anticyclonically curving AR with large IVT directed toward Alps with flooding in NW Switzerland

Froidevaux and Martius (2016)

PV Streamers with SE, S, or SW Flow

NW

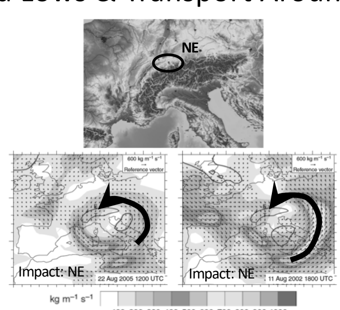


IVT directed toward barrier and following pathways that minimize orographic interaction and water vapor depletion from precipitation

Froidevaux and Martius (2016)

Closed Lows & Transport Around Alps

NW

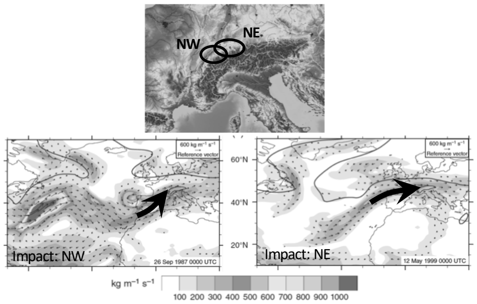


Closed lows with cyclonic moisture transport around Alps and IVT impinging on north slopes

Froidevaux and Martius (2016)

ARs W to SW flow

NW



IVT quasi-parallel to Alpine chain with flooding in northern Switzerland

Froidevaux and Martius (2016)

Discussion

What synoptic patterns contribute to heavy precipitation over the Austrian Alps?

Group Activity

- Evaluate the characteristics of a future AR event along the west coast of North America or Europe over the next 10 days
  - What is the range of potential intensities and landfall locations?
  - How unusual are the lowest and highest intensities relative to past events?
  - How long might the event persist at a specific location?
  - What sort of forecast, watch, or warning action does the event warrant at the present time?

References

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