Atmospheric Rivers

Atmos 6250: Mountain Meteorology

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Major contributions from Dr. Jonathan Rutz

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 penetration into the interior western U.S.
  - Be able to forecast potentially high-impact AR events including comparisons with past events

Introduction

Key Moisture-Related Variables

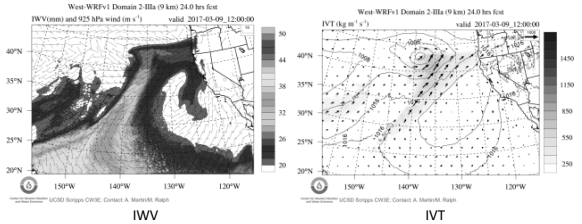
- Integrated water vapor (IWV) – the amount of water vapor in an atmospheric column expressed as the depth of water if that vapor were condensed
  - a.k.a. precipitable water or total precipitable water

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

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

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

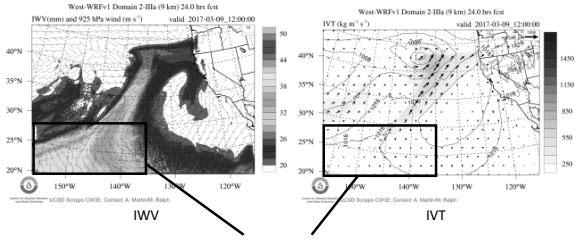
Key Moisture-Related Variables



IWV IVT

IWV & IVT are not equivalent

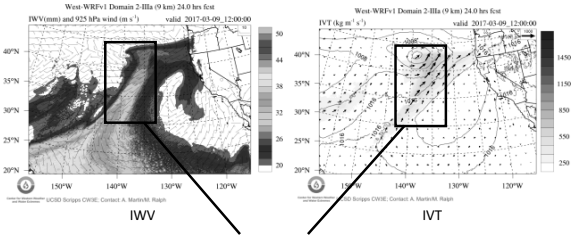
Key Moisture-Related Variables



IWV IVT

High IWV, Low IVT

Key Moisture-Related Variables

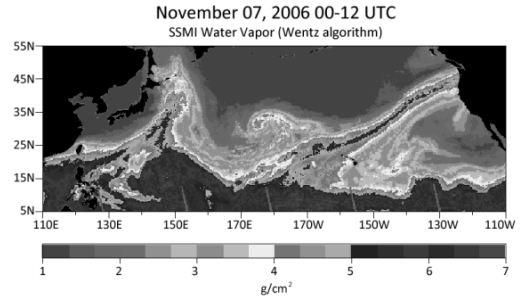


IWV decreases poleward, IVT increases

Atmospheric Rivers (ARs)

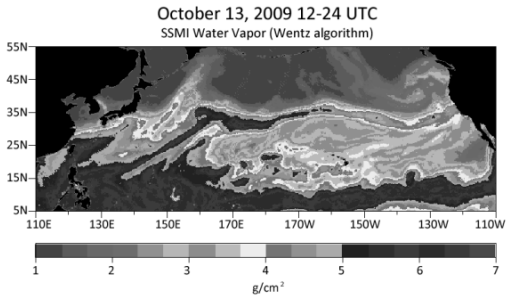
- Narrow corridors (i.e., filaments) of strong vertically integrated water vapor transport (Newell et al. 1992; Newell and Zhu 1994; Zhu and Newell 1998)
- Often found along the pre-cold-frontal LLJ and may contribute to the moisture-rich portion of the broader, ascending warm conveyor belt (Ralph et 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

Examples



https://www.esrl.noaa.gov/psd/atmrivers/events/

Examples



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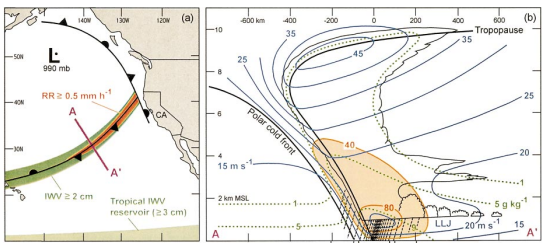
Importance of Pre-Frontal LLJ

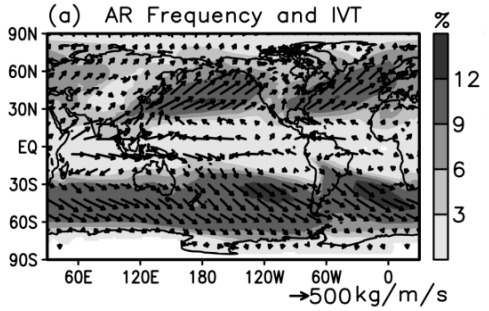


Ralph et al. (2004)

Identification

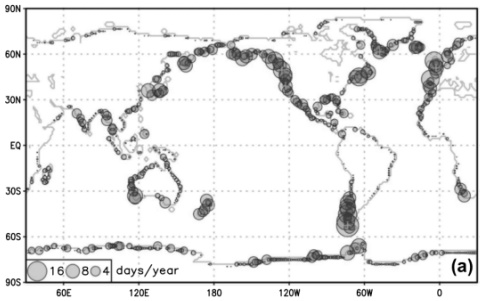
- Satellite based (Ralph et al. 2004)
  - IWV readily available; IVT not readily available
  - Use IWV as an IVT proxy (OK, but not great)
  - ARs identified as contiguous regions of IWV ≥ 20 mm that are ≥ 2000 km in length and ≤ 1000 km in width
- Analysis or NWP based
  - IVT magnitude
    - e.g., 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 Frequency/Mean AR IVT



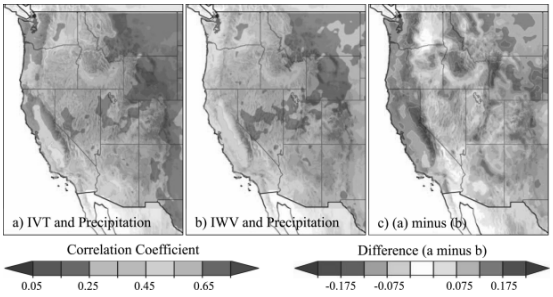
Guan and Waliser 2015

Global Landfall Distribution



Guan and Waliser 2015

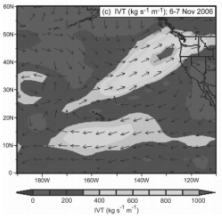
Importance of IVT



Better correlation with precipitation

Rutz et al. (2014)

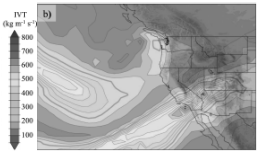
Western US Events



Mt. Rainier: 6–7 Nov 2006
450 mm (17.7 in) 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 (91 in) snow @ Mammoth Mt, CA
191 cm (75 in) snow @ Sundance, UT

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

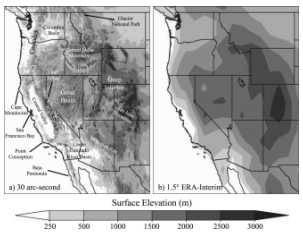
Characteristics of ARs over Western U.S.

Discussion

- Where and why do you think atmospheric rivers are most common
  - Along the US west coast?
  - In the western US interior?
- What processes favor AR decay during penetration into the western US?
- What processes might contribute to AR maintenance or intensification?

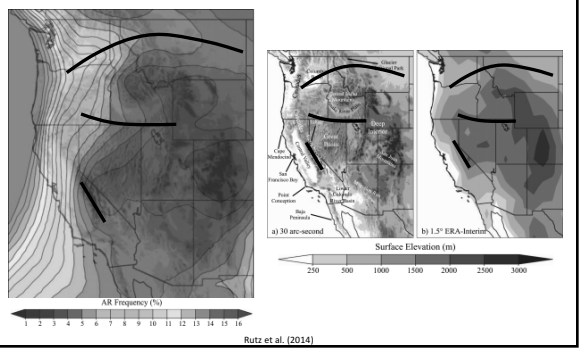
AR Characteristics: Western U.S.

- 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



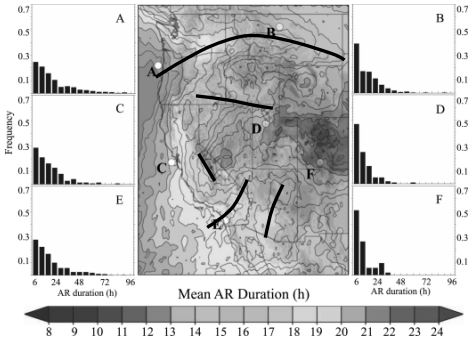
Rutz et al. (2014)

AR Frequency



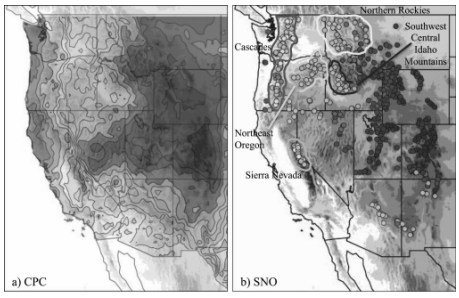
Rutz et al. (2014)

AR Duration



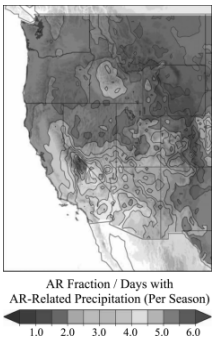
Rutz et al. (2014)

Fraction of Cool-Season Precip



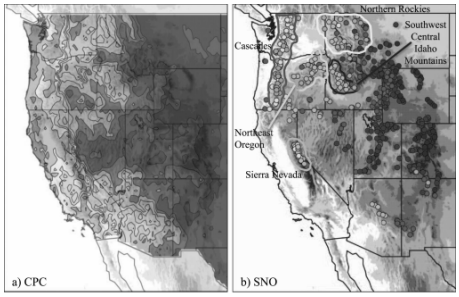
Rutz et al. (2014)

Significance of Infrequent ARs



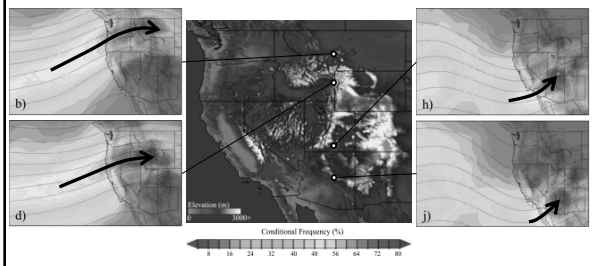
Rutz et al. (2014)

Top Decile 24-h Events



Rutz et al. (2014)

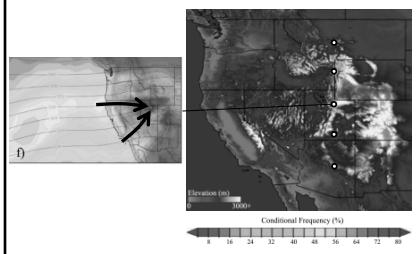
AR Pathways/Sierra Influences



Composite 500-mb height and conditional AR frequencies

Rutz et al. (2014)

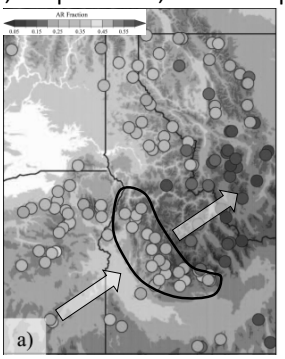
AR Pathways/Sierra Influences



Composite 500-mb height and conditional AR frequencies

Rutz et al. (2014)

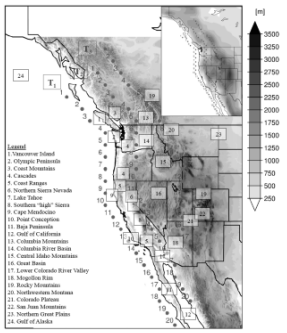
Aspect, Exposure, WV Depletion



Rutz et al. (2014)

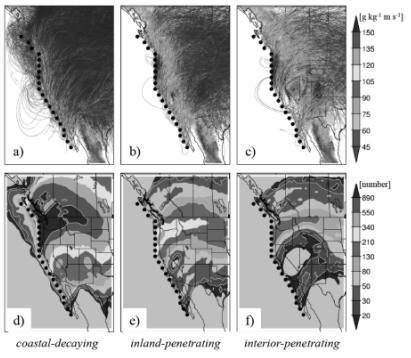
Lagrangian Perspective

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



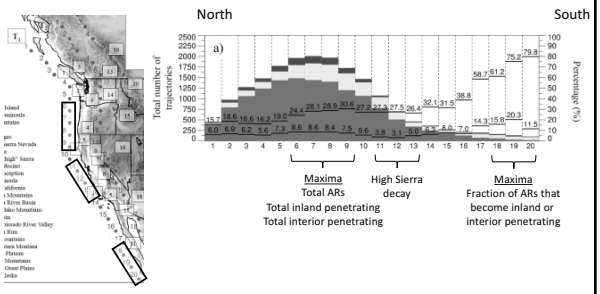
Rutz et al. (2015)

Overview



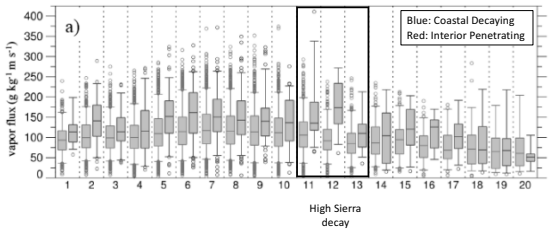
Rutz et al. (2015)

Overview



Rutz et al. (2015)

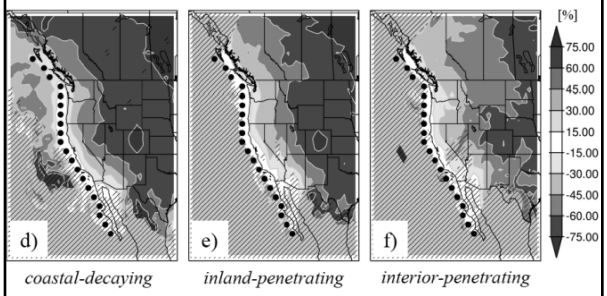
Characteristics @ Initiation



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

Rutz et al. (2015)

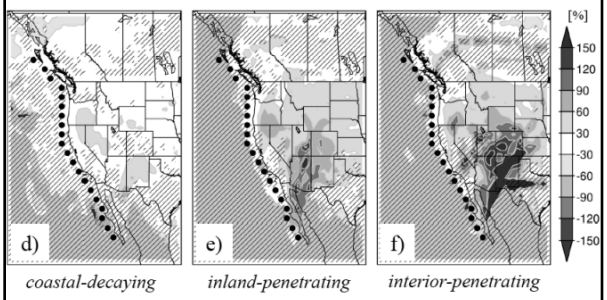
Drying Ratio



Total Change in q (~"drying ratio")

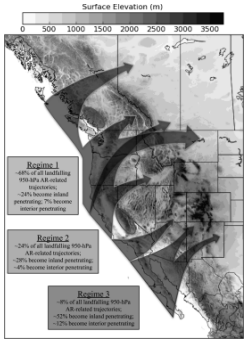
Rutz et al. (2015)

Integrated Momentum Change



Rutz et al. (2015)

Summary



Rutz et al. (2015)

AR Prediction

Useful Web Sites

- Atmospheric River Portal, Center for Western Weather and Water Extremes
  - http://mead.ucsd.edu/
    - Many many products – good for IVT identification, intensity, structure, probability, etc.
- NWS/WR Ensemble graphics
  - http://ssd.wrh.noaa.gov/naefs/
    - GEFS IVT
- NWS Situational Awareness Table
  - http://ssd.wrh.noaa.gov/satable/
  - IVT standardized anomalies and return periods

Real-Time Examples & Exploration

Group Activity

- Evaluate the characteristics of a future AR event along the west coast of North America 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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