# Understanding Atmospheric Rivers in a Future, Warmer Climate

Alexander Massa Millersville University, NESSI July 28, 2021





This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

#### Outline

- → **Background:** What is an atmospheric river (AR)?
- → **Motivation:** How will climate change impact atmospheric rivers?
- Plotting Atmospheric River Footprints: Using data from the Atmospheric River Tracking Method Intercomparison Project and NCAR Command Language (NCL) scripts to produce plots of ARs
- → Atmospheric River Detection Tools (ARDTs): Does the definition of an AR matter in order to understand ARs in a future climate?

#### → Summary and Future Work

#### What is an Atmospheric River?



Credit: NASA; December 2017

"A long, narrow, and transient corridor of strong horizontal water vapor transport that is typically associated with a low-level jet stream ahead of the cold front of an extratropical cyclone" (Glossary of Meteorology).

#### What is an Atmospheric River?

a. Drought [23 October 2015]

→ ARs provide around 30-50% of annual precipitation supply to areas along the West Coast (eg. Payne et al. and Dettinger)

c. Flood [15 February 2017]

b. Normal/full [23 June 2005]



d. Damage [27 February 2017]

→ ARs serve as 'drought busters'. Can also cause devastating environmental impacts (eg. Dettinger and Ralph et al.)



Oroville Dam



Credit: Fig. 1 from 'A Scale to Characterize the Strength and Impacts of Atmospheric Rivers.' Ralph et al. 2018

#### The Impacts of Climate Change

# AR Climate change trends found in the literature :

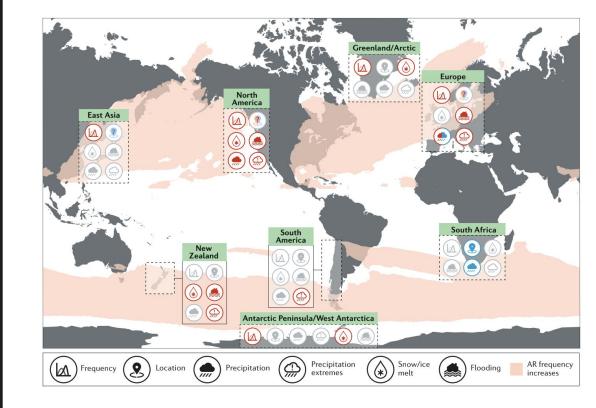
Regional summaries from NREE, Payne et al. 2020 based on all available literature.

Red icons = increases (Frequency poleward)

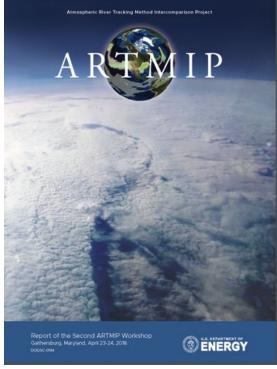
Blue icons = decreases (Frequency equatorward)

Pink shading based in Espinoza et al 2018 CMIP5 models with 1 algorithm.

Courtesy A. Payne



#### What is **ARTMIP**?



Picture credit: Jonathan Rutz Report credit: U.S. Department of Energy The goal of ARTMIP is to understand and quantify uncertainties in atmospheric river (AR) science based on choice of detection/tracking methodology.

https://www.cgd.ucar.edu/projects/artmip/

NCAR UCAR

#### The Data Behind ARTMIP?

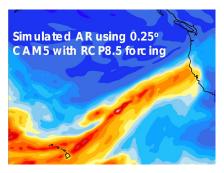
# Tier 1: MERRA v2 Reanalysis Data



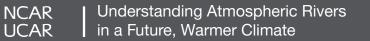
Source: https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/

# Tier 2:

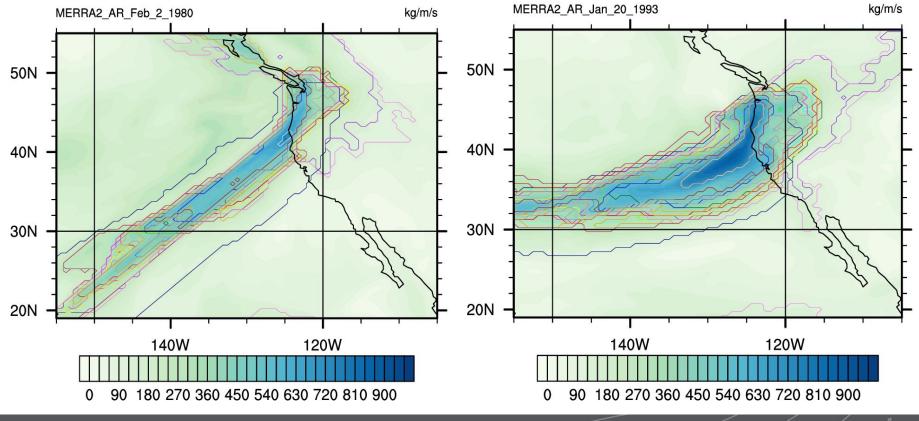
# Community Atmosphere Model (CAM5) Data [Historical & RCP8.5 Simulations]



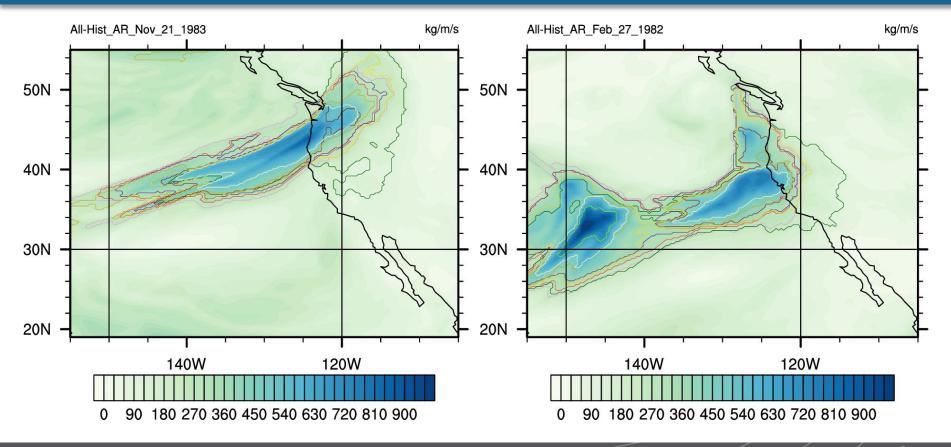
Source: https://www.cgd.ucar.edu/projects/artmip/experiment al-design.html



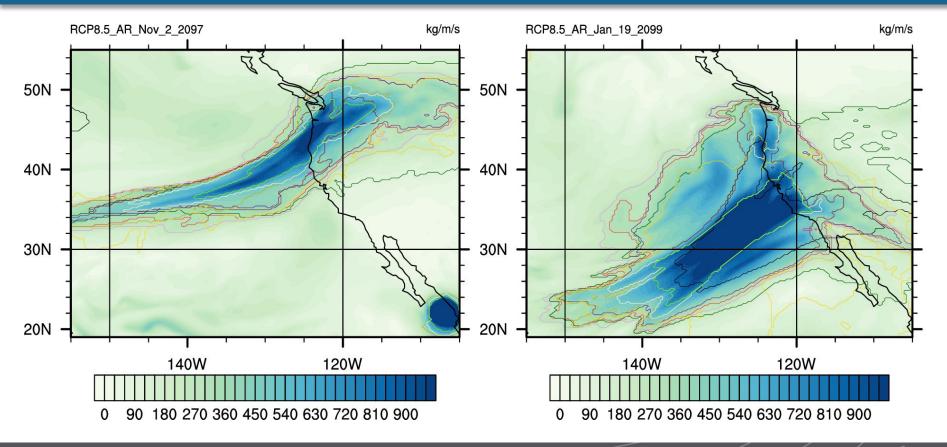
#### **Plotting Atmospheric River Footprints Using NCL Scripts**



#### **Plotting Atmospheric River Footprints Using NCL Scripts**



#### **Plotting Atmospheric River Footprints Using NCL Scripts**



#### **Does ARDT Definition Matter?**

→ Changes in future AR frequency, intensity, and size depends on the methods or algorithms being used

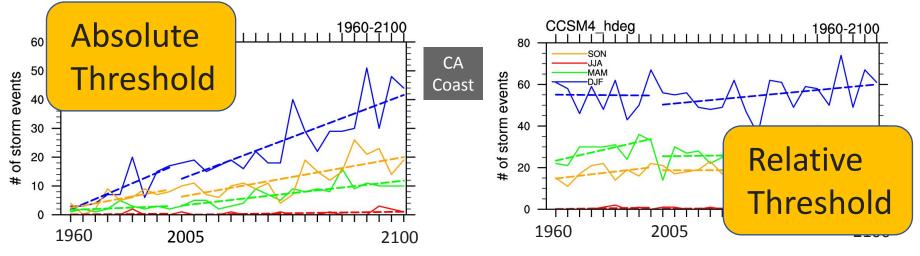


Image Courtesy of Shields and Kiehl 2016



- Plots provided are case studies
- Case studies are only moments in time, might not accurately represent all ARs of the future
- Further analysis of entire ARTMIP data sets is needed in order to paint an accurate picture of future ARs



#### Conclusions

 ARs play an important role in transporting large amounts of water vapor to regions across the globe

- In the future, ARs will have the ability to potentially transport more water vapor as a result of changes in the Clausius Clapeyron relationship
- Changes in future AR frequency, intensity, and size depends on the method or algorithm being used

- Utilize entire ARTMIP datasets to better identify future changes in ARs
- Move away from case studies, and begin to analyze the differences between historical climatological data and projected future climatological data associated with ARs

#### Acknowledgements

A Special Thank You to....

**Christine Shields** 

Jerry Cyccone

AJ Lauer and Virginia Do

Maria Molina

NCAR

Everyone on the NESSI and SIParCS Team



# **Extra Slides**

# What I Learned This Summer

- ★ Developed an understanding of and appreciation for ARs and climate change
- $\star$  Learned these tools
  - NCL
  - Unix Commands
  - C Shell
  - Ncview
  - HPC
- ★ Learned the basics of data management, proposal writing, giving a scientific presentation, and much much more!

# **Breaking Down ARDT Parameters**

Parameter Type	Computation Type	Geometry Requirements	Threshold Requirements	Temporal Requirements	Regions (Examples)
Parameters Choices	Condition If conditions are met, then AR exists for each time instance at each grid point. This counts time slices at a specific grid point. Tracking Lagrangian approach: if conditions are met, AR object is defined and followed across time and space.	Length Width Shape Axis or Orientation	Absolute Value is explicitly defined. Relative Value is computed based on anomaly or statistic. No thresholds (object only)	Time slice Consecutive time slices can be counted to compute AR duration, but it is not required to identify an AR. Time stitching Coherent AR object is followed through time as a part of the algorithm.	Global North Pacific Landfalling North Atlantic Landfalling Southeast U.S. South America Polar

Credit: Figure 1 from 'Atmospheric River Tracking Method Intercomparison Project (ARTMIP): project goals and experimental design' Shields et al. 2018

# **Categorizing ARs**

TABLE 2. (top) An AR intensity scale based on maximum instantaneous IVT magnitude and duration of AR conditions (i.e.,  $IVT > 250 \text{ kg m}^{-1} \text{ s}^{-1}$ ), and (bottom) a subjective assessment of the potential for beneficial or hazardous impacts.

Max IVT (kg m <sup>-1</sup> s <sup>-1</sup> ) Outrator S24 AR conditional   \leq 250 Not an AR Not an AR   \leq 250-500 Weak AR AR Cat 1 AR Cat 2   \leq 500-750 AR Cat 1 AR Cat 2 AR Cat 3   \leq 500-750 AR Cat 2 AR Cat 3 AR Cat 4   \leq 500-750 AR Cat 2 AR Cat 3 AR Cat 4   \leq 500-750 AR Cat 3 AR Cat 3 AR Cat 4   \leq 500-750 AR Cat 3 AR Cat 3 AR Cat 4   \leq 500-750 AR Cat 4 AR Cat 3 AR Cat 4   \leq 500-750 AR Cat 3 AR Cat 4 AR Cat 5   \leq 51,000-1,250 AR Cat 4 AR Cat 5 AR Cat 5   \leq 51,000-1,250 AR Cat 4 AR Cat 5 AR Cat 5   \leq 64 AR Cat 4 AR Cat 5 AR Cat 5   \leq 64 Mosty beneficial-waterodous-watero						
≤250Not an ARNot an ARNot an AR≥250-500Weak ARAR Cat IAR Cat 2≥500-750AR Cat IAR Cat 2AR Cat 3≥750-1,000AR Cat 2AR Cat 3AR Cat 4≥1,000-1,250AR Cat 3AR Cat 4AR Cat 5≥1,250AR Cat 4AR Cat 5AR Cat 5AR cat 9AR Cat 4AR Cat 5AR Cat 5AR cat 1Primarily beneficial vs hazardousImproveAR Cat 2Mostly beneficial and hazardousAR Cat 4AR Cat 3AR Cat 4AR Cat 5AR Cat 4AR Cat 5AR Cat 5	Max IVT	Duration of AR conditions (h)				
≥250-500Weak ARAR Cat IAR Cat 2≥500-750AR Cat IAR Cat 2AR Cat 3≥750-1,000AR Cat 2AR Cat 3AR Cat 4≥1,000-1,250AR Cat 3AR Cat 4AR Cat 5≥1,250AR Cat 4AR Cat 5AR Cat 5AR category scaleAssessment of beneficial vs hazardousImpactsAR Cat 1Primarily beneficial.VVAR Cat 2Mostly beneficial.VVAR Cat 3Balance of beneficial and hazardousAR Cat 4AR Cat 4Mostly hazardous.V	(kg m <sup>-1</sup> s <sup>-1</sup> )	≤24	≥24–48	≥48		
≥500-750AR Cat IAR Cat 2AR Cat 3≥750-1,000AR Cat 2AR Cat 3AR Cat 4≥1,000-1,250AR Cat 3AR Cat 4AR Cat 5≥1,250AR Cat 4AR Cat 5AR Cat 5AR category scaleAssessment of beneficial vs hazardousImage: Cat 1AR Cat 1Primarily beneficial, but also hazardousImage: Cat 1AR Cat 2Mostly beneficial and hazardousImage: Cat 1AR Cat 3Balance of beneficial and hazardousImage: Cat 1AR Cat 4Mostly hazardous, but also beneficialImage: Cat 1	≤250	Not an AR	Not an AR	Not an AR		
≥750–1,000AR Cat 2AR Cat 3AR Cat 4≥1,000–1,250AR Cat 3AR Cat 4AR Cat 5≥1,250AR Cat 4AR Cat 5AR Cat 5AR category scaleAssessment of beneficial vs hazardousImpactsAR Cat 1Primarily beneficial, but also hazardousImpact 1AR Cat 2Mostly beneficial and hazardousImpact 1AR Cat 3Balance of beneficial and hazardousImpact 1AR Cat 4Mostly hazardous, but also beneficialImpact 1	≥250–500	Weak AR	AR Cat I	AR Cat 2		
≥1,000-1,250AR Cat 3AR Cat 4AR Cat 5≥1,250AR Cat 4AR Cat 5AR Cat 5AR category scaleAssessment of beneficial vs hazardous impactsAR Cat 1Primarily beneficial, but also hazardousAR Cat 2Mostly beneficial and hazardousAR Cat 3Balance of beneficial and hazardousAR Cat 4Mostly hazardous, but also beneficial	≥500–750	AR Cat I	AR Cat 2	AR Cat 3		
≥1,250AR Cat 4AR Cat 5AR Cat 5AR category scaleAssessment of beneficial vs hazardous impactsAR Cat 1Primarily beneficial.Impact 1AR Cat 2Mostly beneficial.Impact 1AR Cat 3Balance of beneficial and hazardousAR Cat 4Mostly hazardous.	≥750–1,000	AR Cat 2	AR Cat 3	AR Cat 4		
AR category scaleAssessment of beneficial vs hazardous impactsAR Cat 1Primarily beneficialAR Cat 2Mostly beneficial, but also hazardousAR Cat 3Balance of beneficial and hazardousAR Cat 4Mostly hazardous, but also beneficial	≥1,000−1,250	AR Cat 3	AR Cat 4	AR Cat 5		
AR Cat IPrimarily beneficialAR Cat 2Mostly beneficial, but also hazardousAR Cat 3Balance of beneficial and hazardousAR Cat 4Mostly hazardous, but also beneficial	≥1,250	AR Cat 4	AR Cat 5	AR Cat 5		
AR Cat 2Mostly beneficial, but also hazardousAR Cat 3Balance of beneficial and hazardousAR Cat 4Mostly hazardous, but also beneficial	AR category scale	Assessment of beneficial vs hazardous impacts				
AR Cat 3Balance of beneficial and hazardousAR Cat 4Mostly hazardous, but also beneficial	AR Cat I	Primarily beneficial				
AR Cat 4 Mostly hazardous, but also beneficial	AR Cat 2	Mostly beneficial, but also hazardous				
	AR Cat 3	Balance of beneficial and hazardous				
AR Cat 5 Primarily hazardous	AR Cat 4	Mostly hazardous, but also beneficial				
	AR Cat 5					

Credit: Table 2 from 'A Scale to Characterize the Strength and Impacts of Atmospheric Rivers.' Ralph et al. 2018



#### Definitions

- → Atmospheric River (AR) "A long, narrow, and transient corridor of strong horizontal water vapor transport that is typically associated with a low-level jet stream ahead of the cold front of an extratropical cyclone" (Glossary of Meteorology).
- Climate Change changes in atmospheric characteristics that deviate from climatological norms
- Atmospheric River Detection Tool (ARDT) Methods used to identify and track atmospheric rivers

