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Atmospheric Rivers (ARs): Water Extremes that Shape Our Global Weather and Climate

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With collaboration / support from the
Center for Western Weather and Water Extremes (M. Ralph et al.)
CA Department of Water Resources (J. Jones)
NASA Energy and Water Cycle Research Program (J. Entin)

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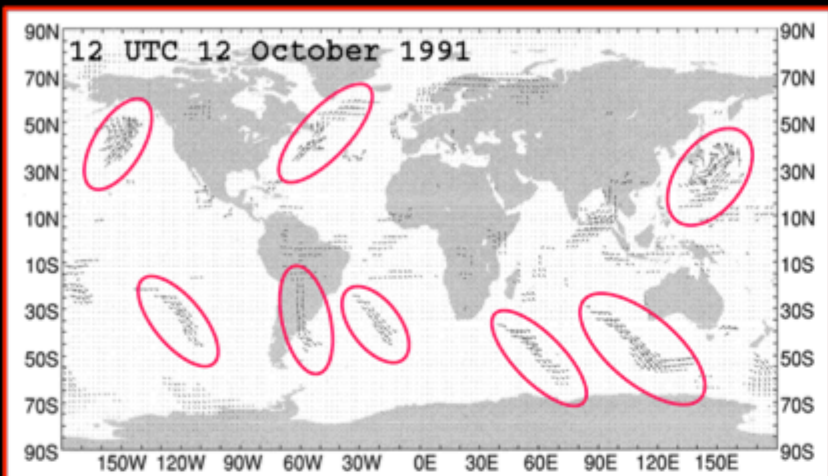
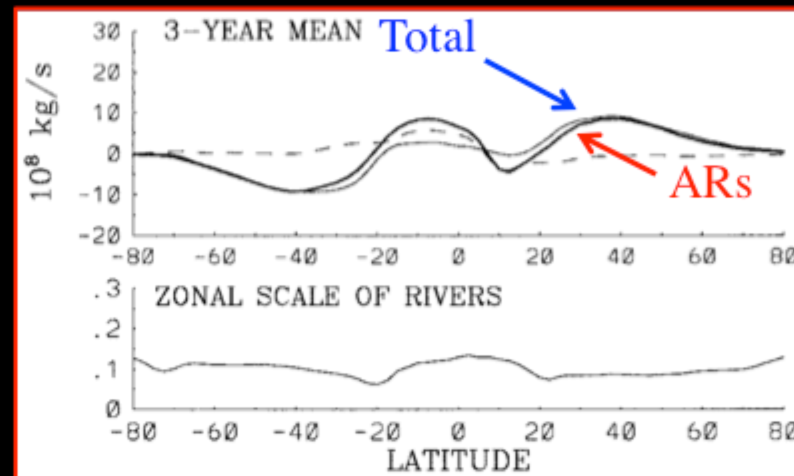
AR History: Poleward Moisture Transports

Influencing global Climate

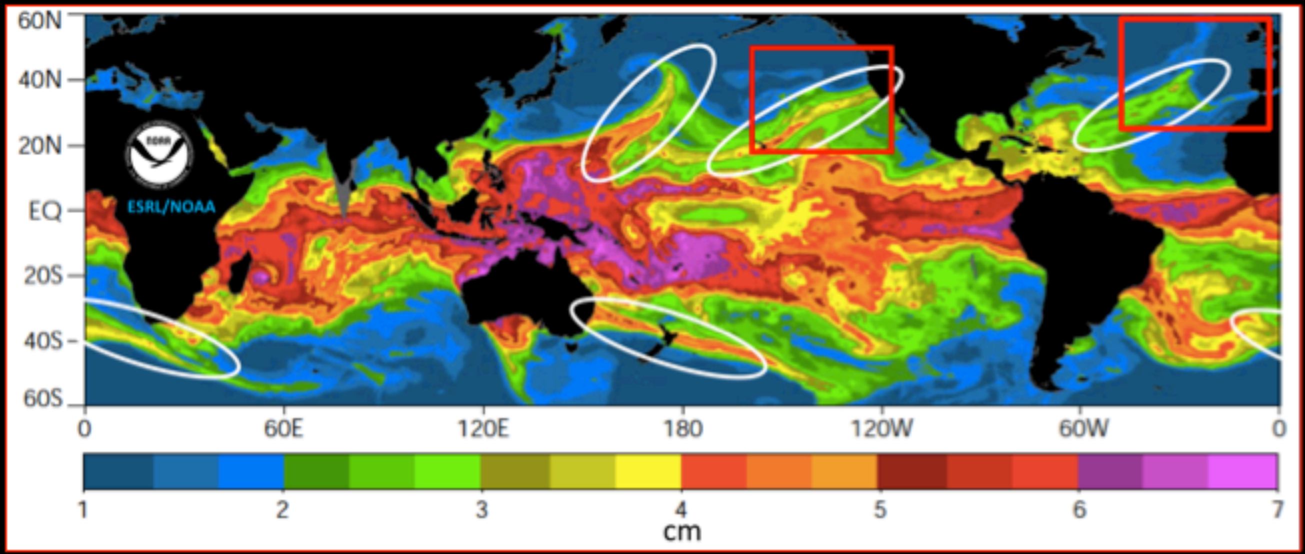
Filamentary structure is a common feature of atmospheric water vapor transport; the filaments may be termed "atmospheric rivers" because some carry as much water as the Amazon. Zhu & Newell, 1994





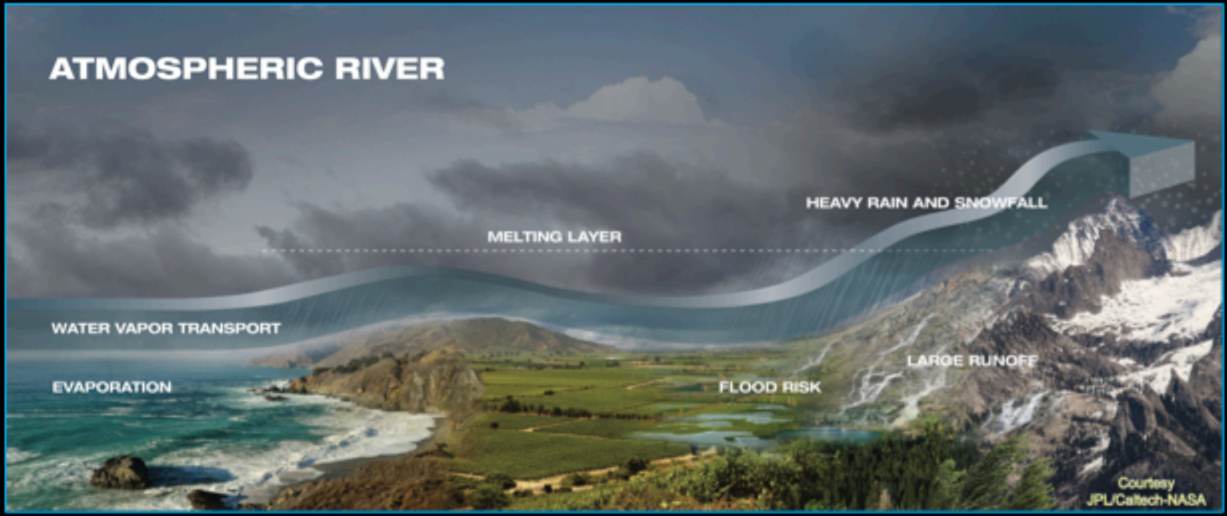
Over 90% of poleward moisture transport at midlatitudes is by ARs that take up only ~10% of the zonal circumference; Zhu and Newell (1998)

Atmospheric Rivers



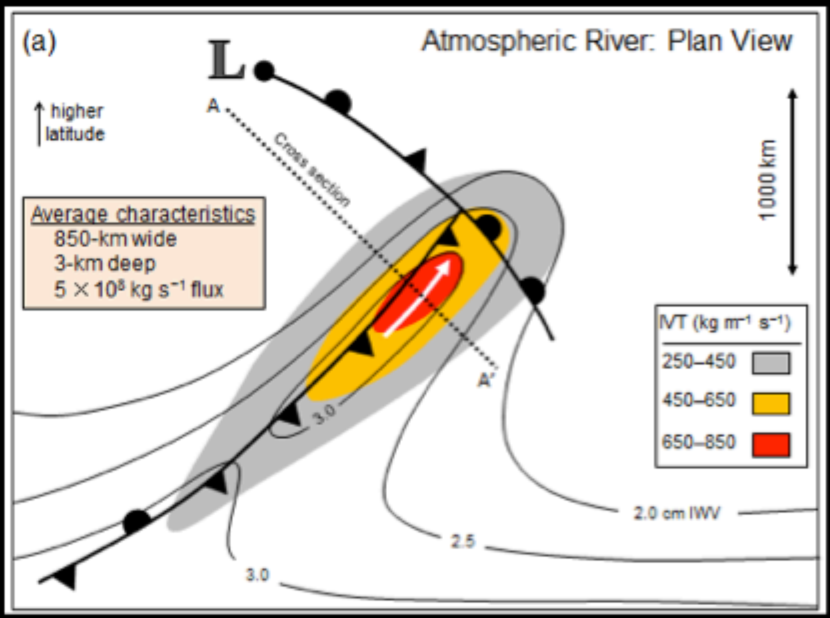
Most AR studies to date have been regionally focused on western N. America and western Europe.

Account for ~40% of California's annual water supply in a few storms
Account for most flooding events on U.S. West coast



AR Definition

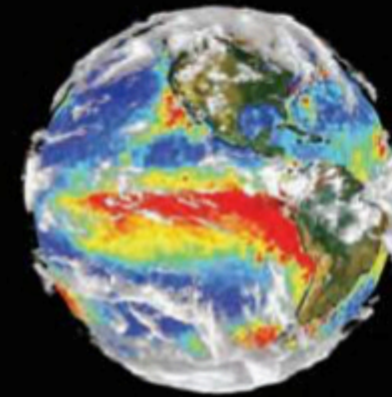
AMS Glossary of Meteorology



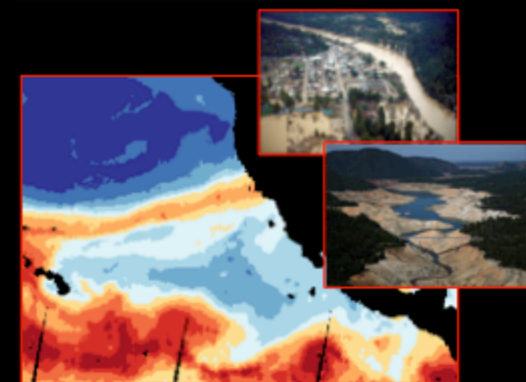
***Glossary of Meteorology*, AMS (2017):**
<u>A long, narrow, and transient corridor of strong horizontal water vapor transport</u> that is typically associated with a low-level jet stream ahead of the cold front of an extratropical cyclone. The water vapor in atmospheric rivers is supplied by <u>tropical and/or extratropical moisture sources</u>. Atmospheric rivers frequently lead to <u>heavy precipitation</u> where they are forced upward—for example, by mountains or by ascent in the warm conveyor belt. Horizontal water vapor transport in the midlatitudes occurs primarily in atmospheric rivers and is focused in the lower troposphere.

ARs – the workhorses of horizontal moisture transport

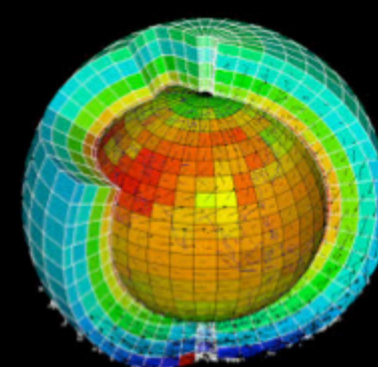
Outline



I. AR Detection
- *Global Algorithm*
- *Global AR Characteristics*



II. AR Impacts
- *Wind and Precipitation Extremes*
- *Hydrology Extremes*
- *Polar hydroclimate*



III. AR Simulations & Predictions
- *Climate change projections*
- *Model evaluation and process-improvement*

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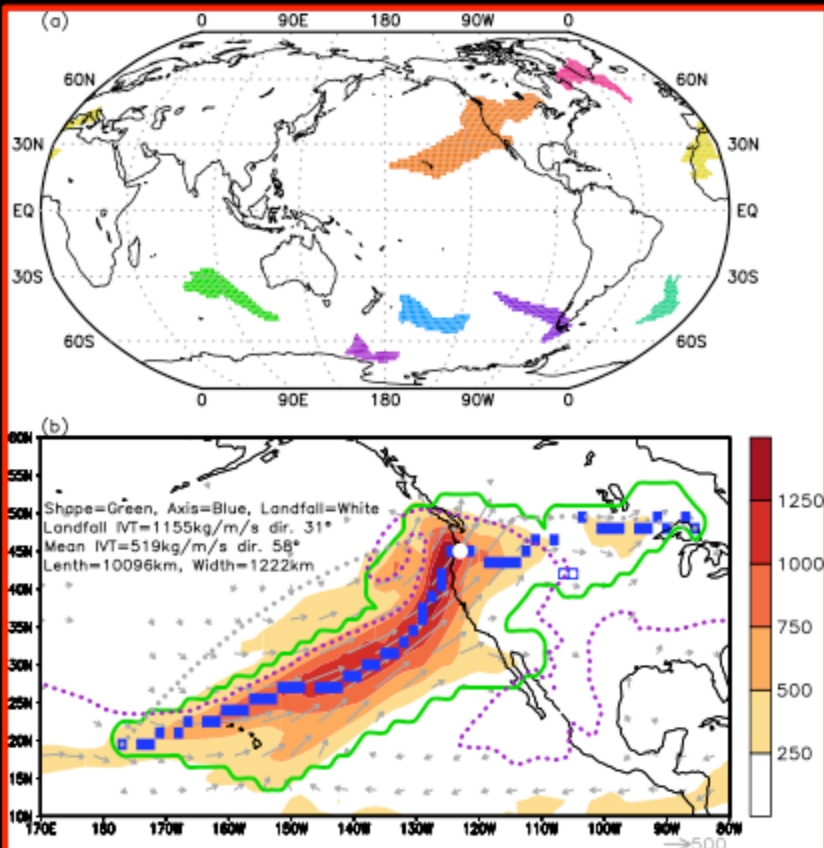
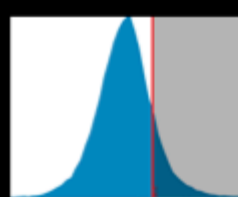
Global AR Detection Algorithm



- Based on Integrated Vapor Transport (IVT) fields and a number of common AR criteria (e.g. Ralph et al. 2004).
- Developed for global studies and for observations/reanalysis and models.
- Applied to:
  - ERA-I, MERRA-2, CFSR, NCEP/NCAR
- Code and databases available at:
  - https://ucla.box.com/ARcatalog
- Databases include AR Date, $IVT_{x,y}$, Shape, Axis, Landfall Location, etc.

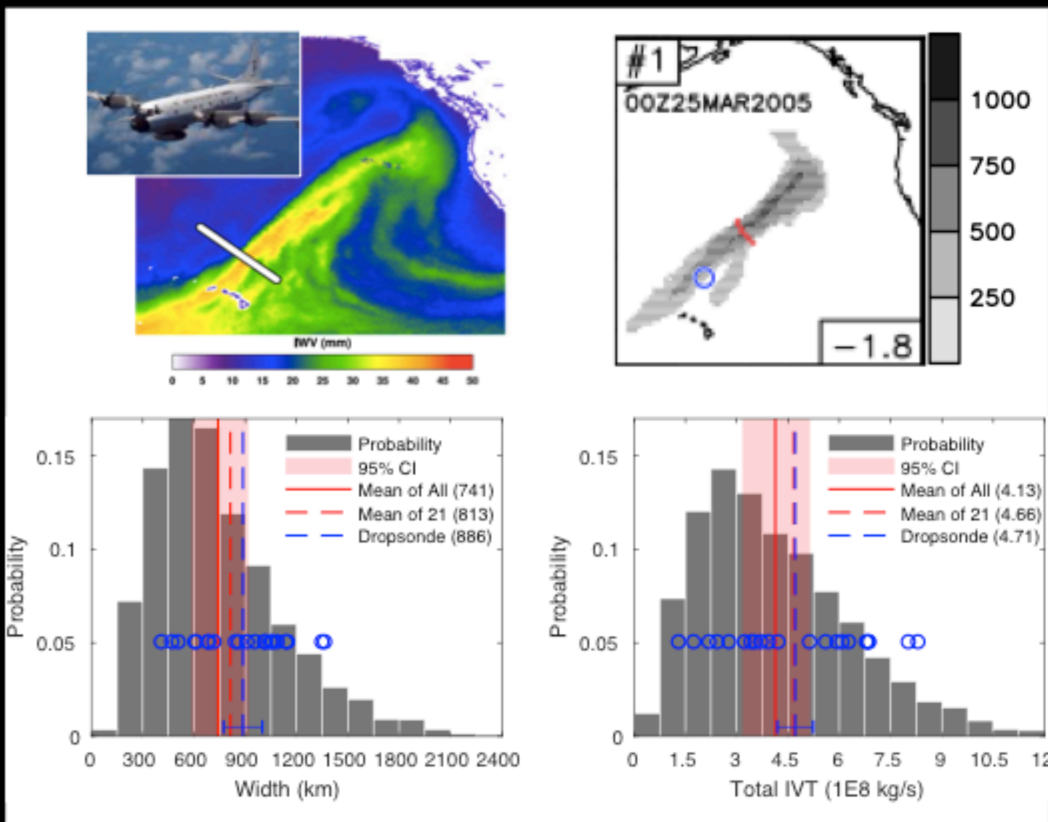
- IVT > 85th percentile
- Contiguous areas
- Length > 2000 km
- Length/Width > 2



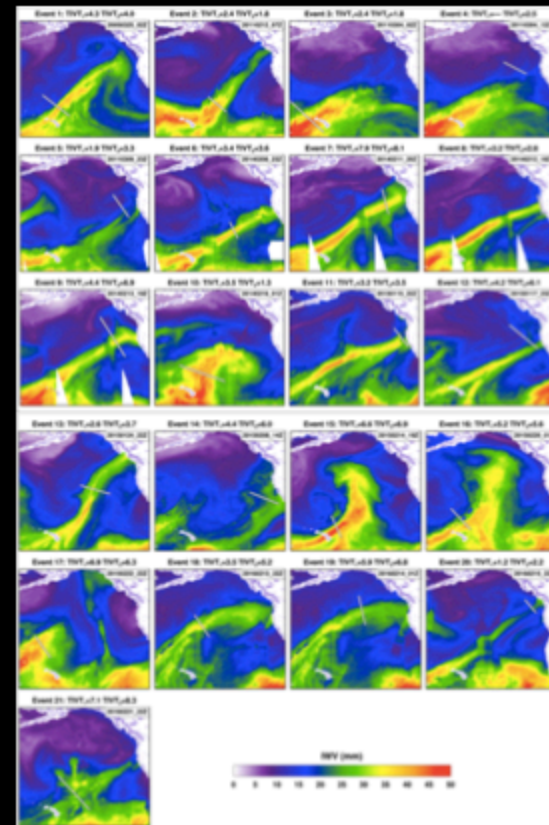
Guan and Waliser (2015)

Algorithm Validation Support from CalWater

Guan, Waliser and Ralph (2018)



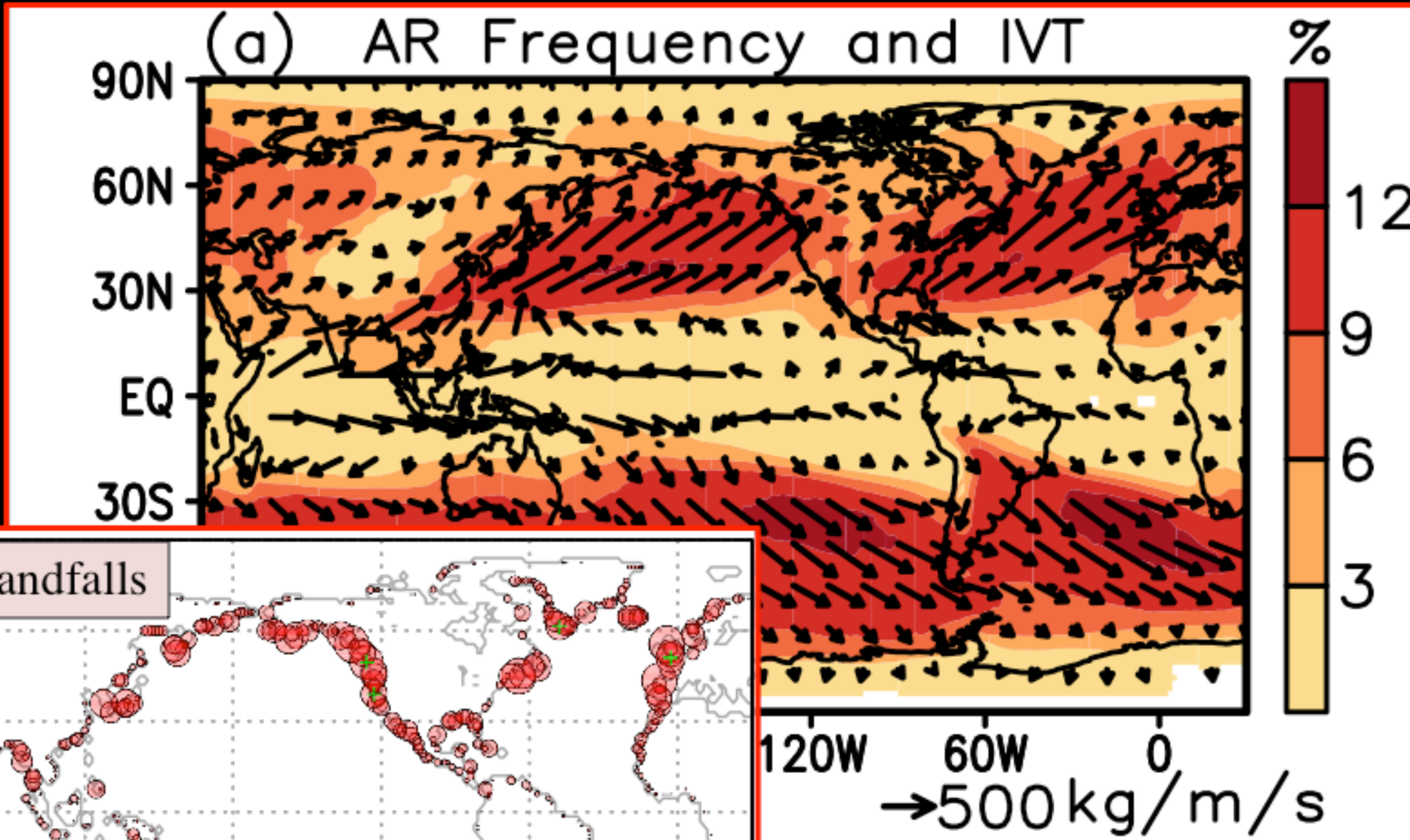
IVT Histograms Based On
5636 NE Pacific ARs from ERA-I
125-163W, 23-46N
Jan 15-Mar 25 1979-2016

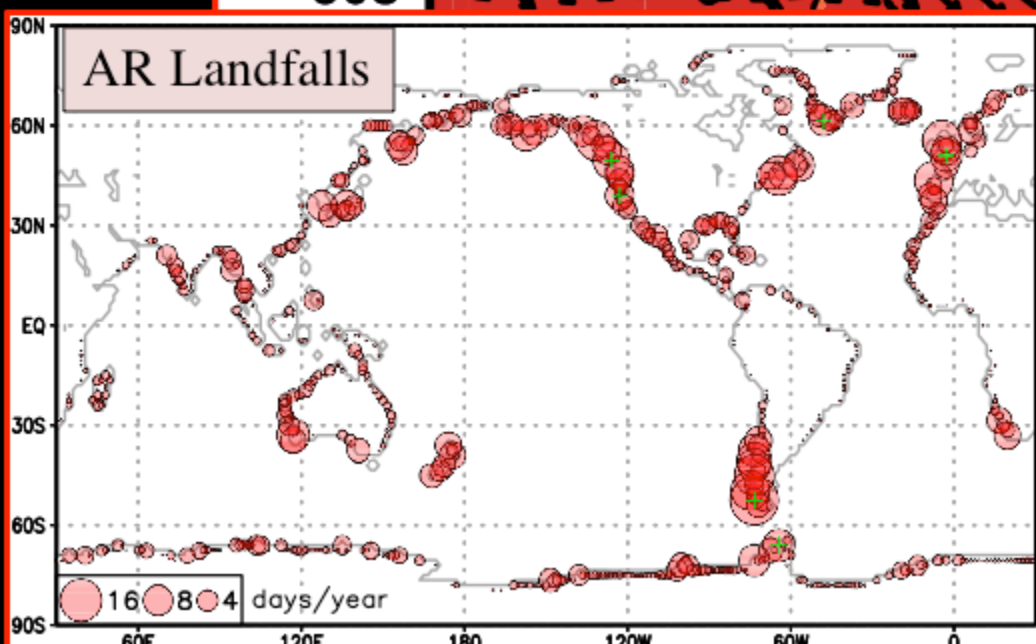


Ralph et al. (2017)

21 AR Event Transects
4.7 +/- 1.9kg/s
Min 1.3; Max 8.3

Global AR Frequency, IVT & Landfalls





Guan and Waliser (2015)

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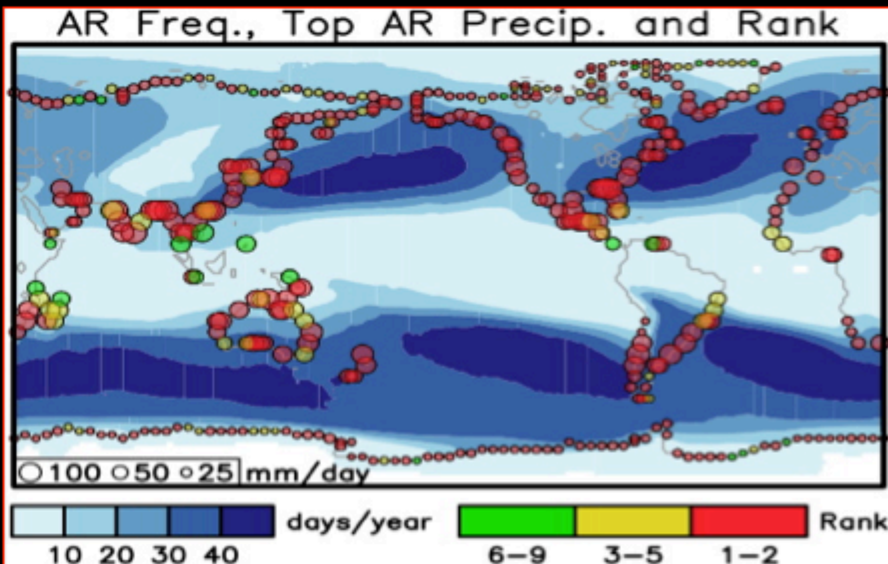
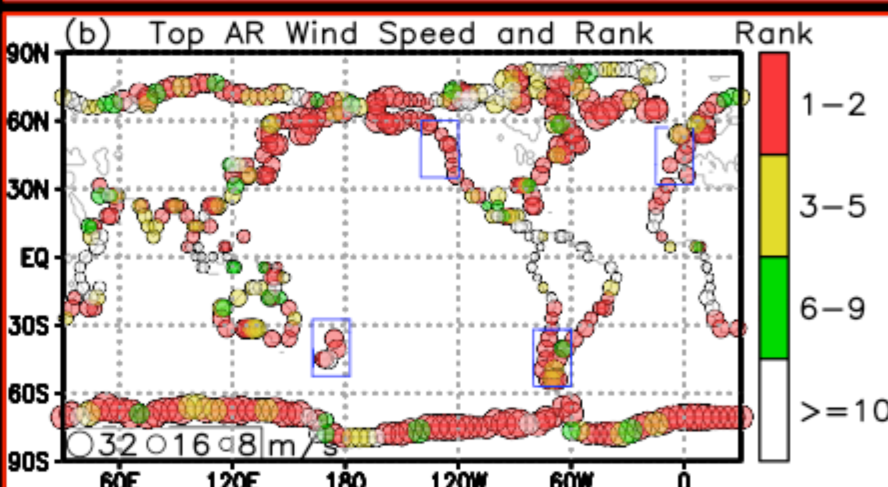
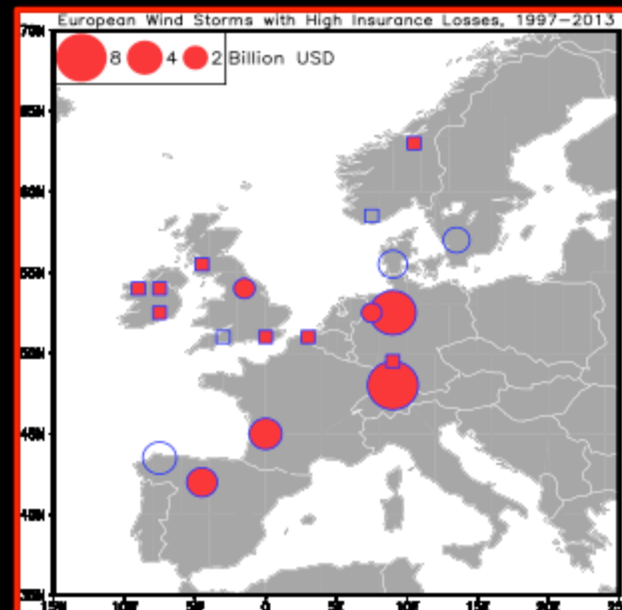
AR Impacts

Wind & Precipitation Extremes





Circle color (size) indicates the rank (speed) of 10 m wind extremes that are connected to an AR considering all 6-hourly ECWMF surface wind values from 1997-2014.



Of 19 damaging wind storms with insurance losses in $B US over Europe from 1997-2013, 14 (filled) were associated with ARs. Circle size indicates size of $ loss; squares are less than $1B.

Waliser & Guan (2017)

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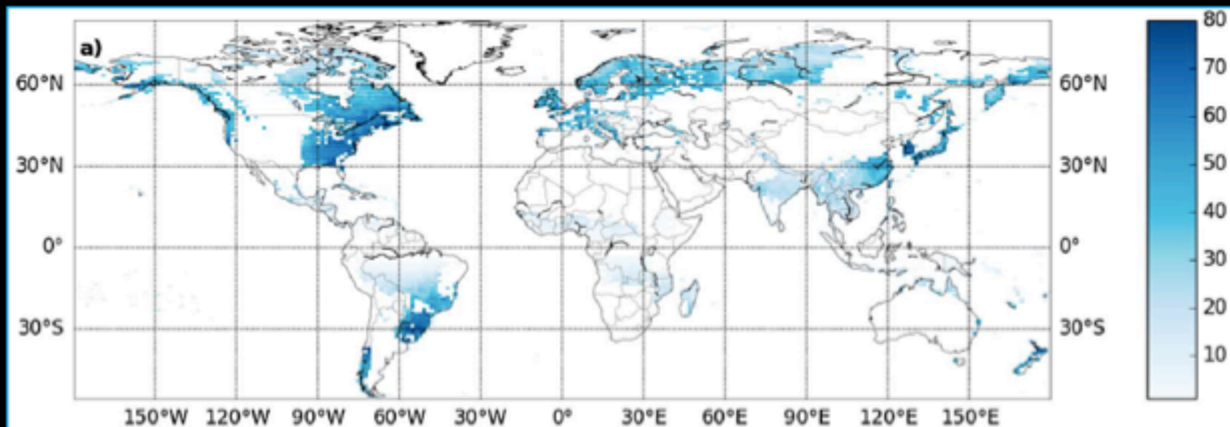
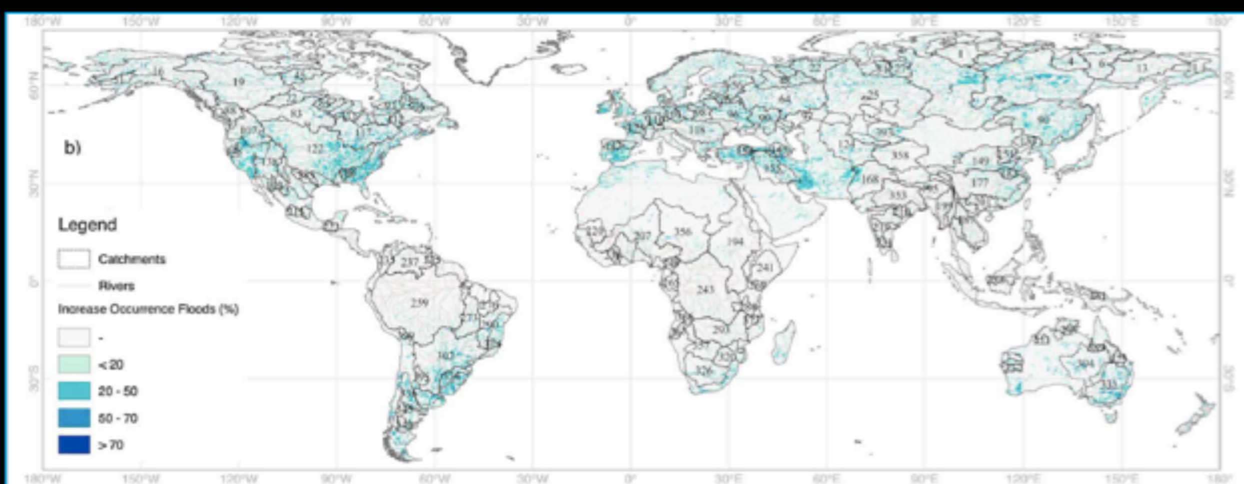
AR Impacts

Hydrology Extremes

AR influence on runoff



AR influence on floods

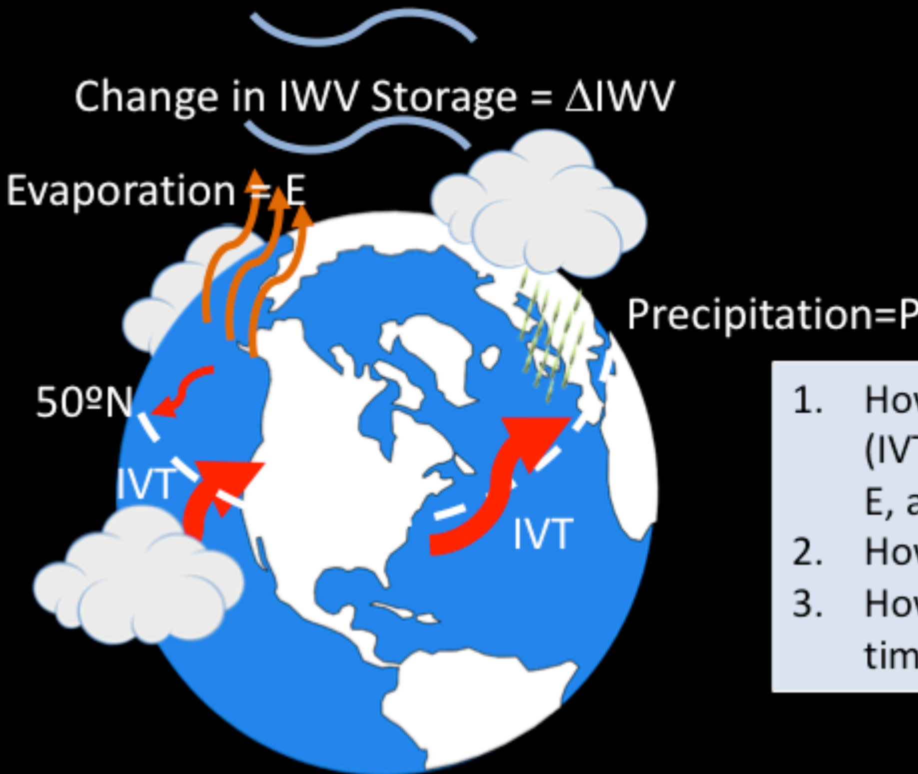


Paltan et al. 2017

- Precipitation from ARs contributes 22% of total global runoff, with a number of regions reaching 50% or more.
- In some regions, ARs increase the occurrence of floods by 80%, whilst absence of ARs may increase the occurrence of hydrological droughts events by up to 90%.
- ~300 million people per year are exposed to floods and droughts due the occurrence of ARs.
- Other results for soil moisture and snowpack.

Atmospheric Rivers : Back to Newell…

Extra-tropical Hydroclimate



$$IVT = P - E + \Delta IWV$$

1. How does the meridional integrated vapor transport (IVT) across a given latitude drive the variations in P, E, and/or ΔIWV in the region poleward?
2. How much do ARs account for this influence?
3. How do these relationships vary depending on timescale (e.g. annual, monthly, pentad)?

$$IVT = P - E + \Delta IWV$$

IVT ~ P

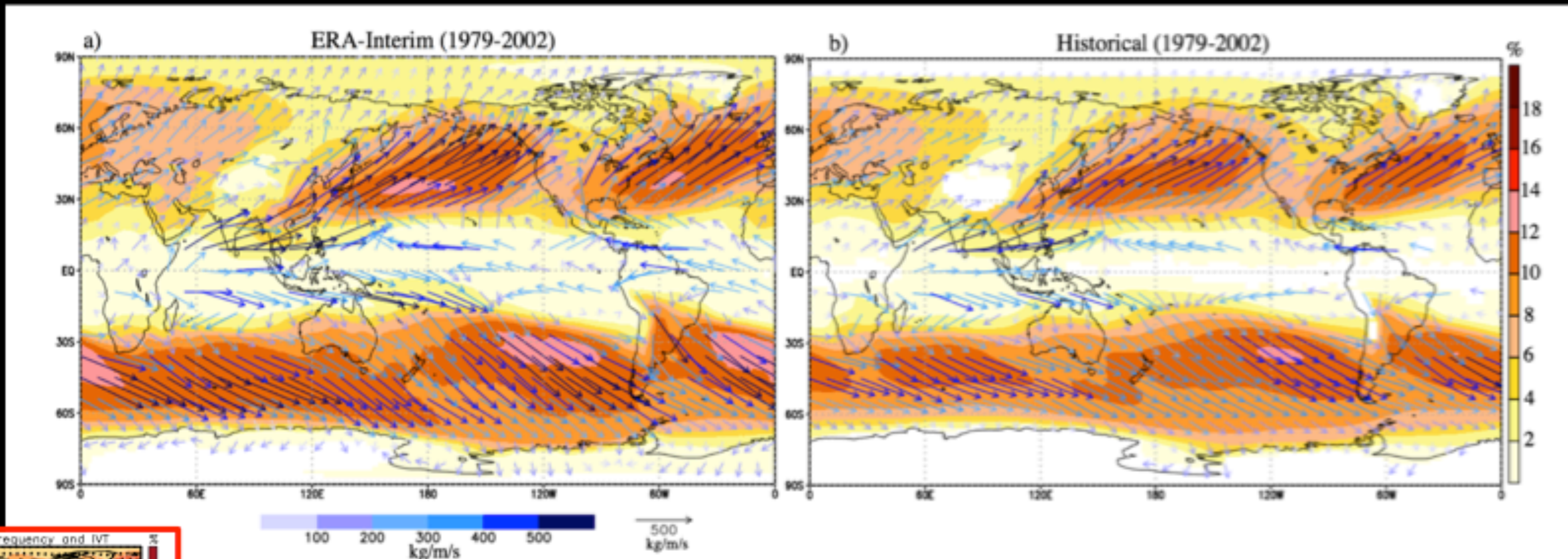
AR IVT ~ P

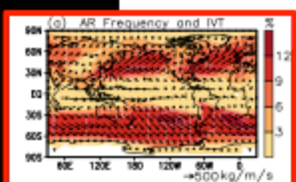
ARs account for 20-60% of monthly extra-tropical Prec variability

Nash, Waliser, Guan, Ralph (2018, Submitted)

Climate Change & ARs

AR Frequency, Size & Transport: 21 CMIP5 Models





Espinoza, Waliser, Guan, Lavers, Ralph (2018)

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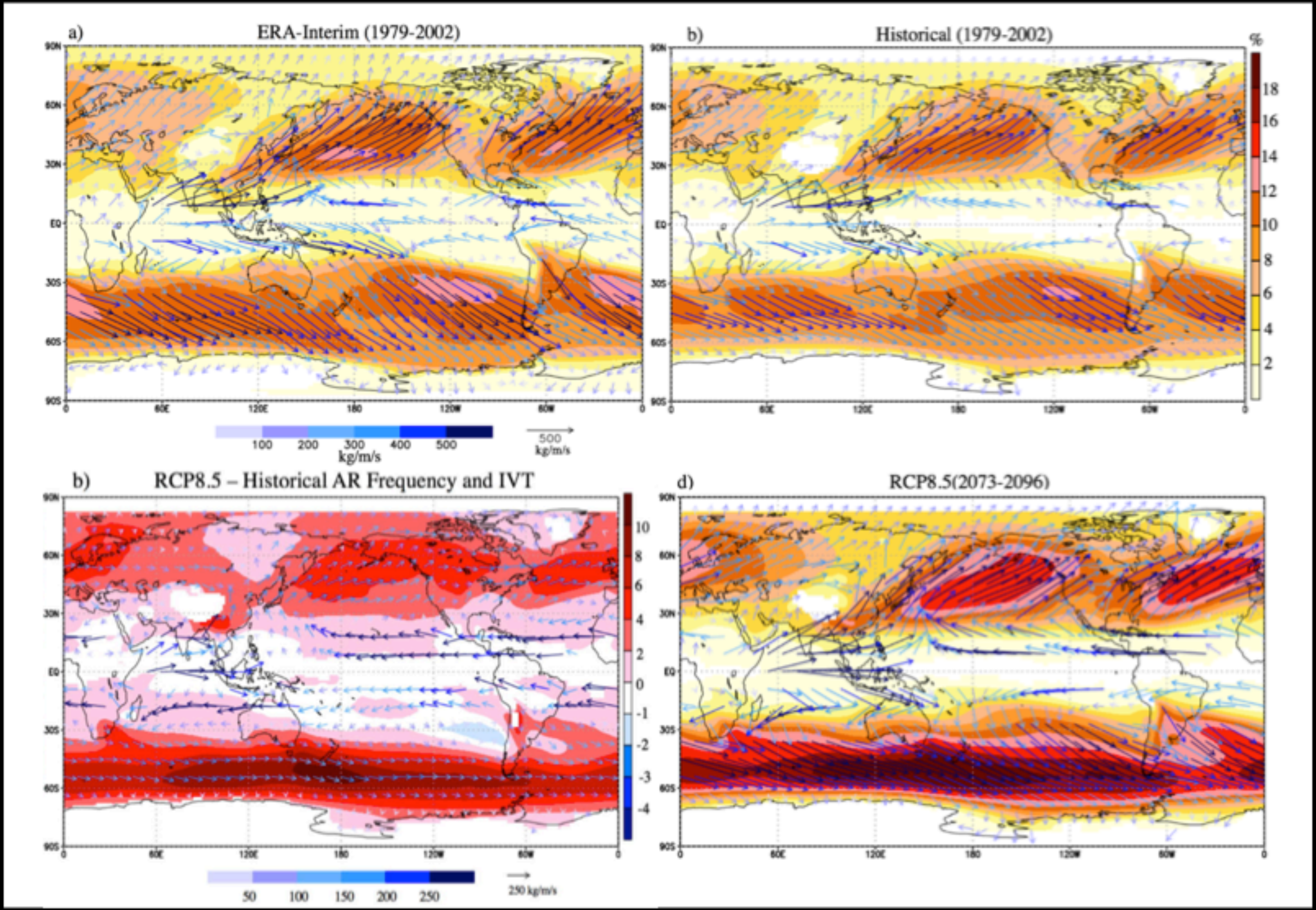
AR Frequency, Size & Transport: 21 CMIP5 Models



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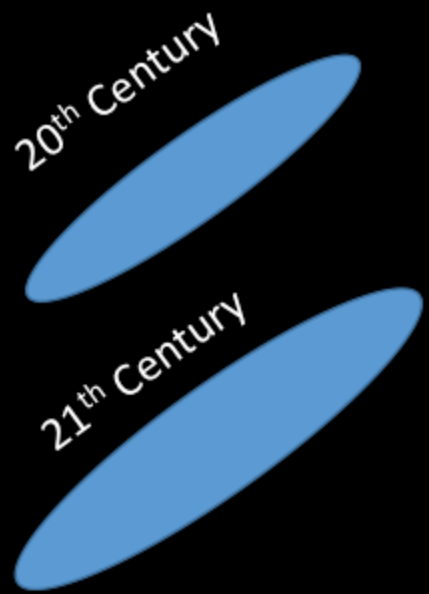


Typical AR Object
Length 4300km
Width 700km
Number* 1.53M

Typical AR Object
Length 5400km
Width 855km
Number* 1.40M

Changes in ARs

About 25% longer
About 25% wider
About 10% fewer

AR Conditions = Number ARs * Length * Width

Present = 4.61×10^{12} km^2

Future = 6.46×10^{12} km^2

** Total Number in 20 Year Period*

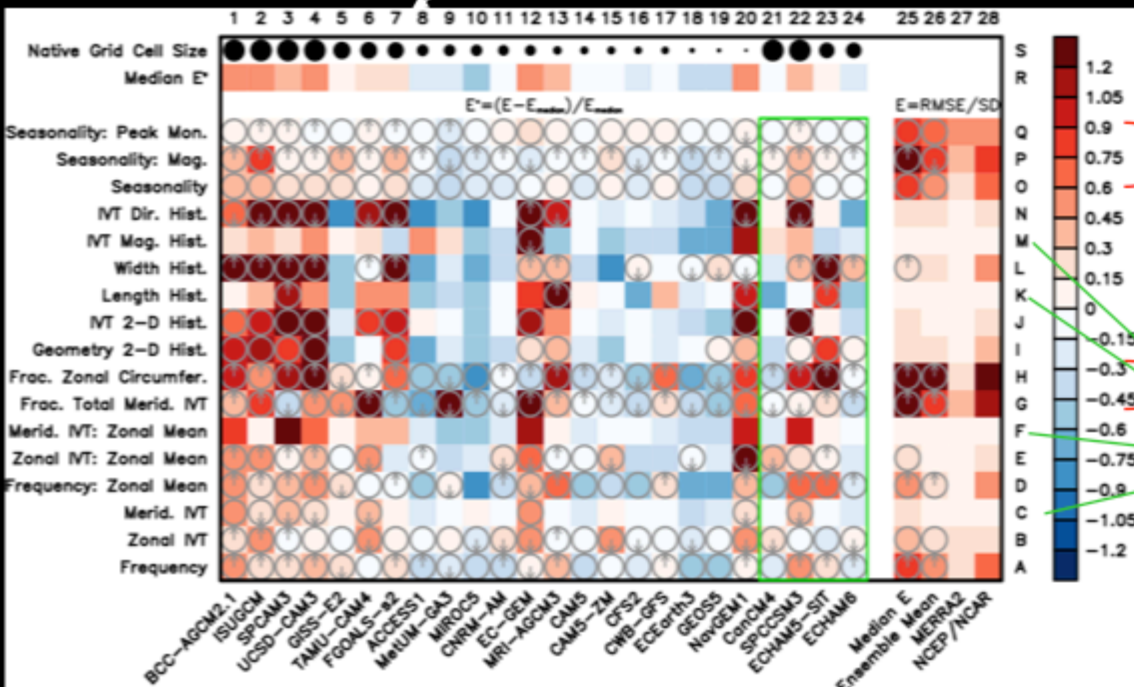
About 40% Increase in AR Conditions

Occurrence of extreme IVT values within ARs ~double.

Espinoza, Waliser, Guan, Lavers, Ralph (2018)

Weather/Climate Simulations of ARs

Models fidelity is resolution dependent, suggesting about 1.5 degree or better is a necessary but not sufficient condition [i.e. mostly red (blue) to the left (right)].



7 AR metrics relatively challenging:

- Seasonality (3 metrics)
- Fractional zonal circumference
- Fractional total meridional IVT
- Zonal IVT
- Frequency

4 AR metrics relatively good:

- IVT magnitude histogram
- Length histogram
- Meridional IVT, and its zonal mean

***CAPTION**: Portrait diagram showing evaluation result for 17 metrics, with cool (warm) colors indicating better(worse)-than-average models, gray circles (arrows) indicating large RMSE (bias) relative to observation. Green outline marks 4 coupled models. Top row indicates model horizontal resolution, with biggest (smallest) circle about 280 (40) km.*

Evaluation based on 20-year simulations from 24 global weather/climate models from the GASS-YOTC Physical Processes Experiment

Guan and Waliser (2017)

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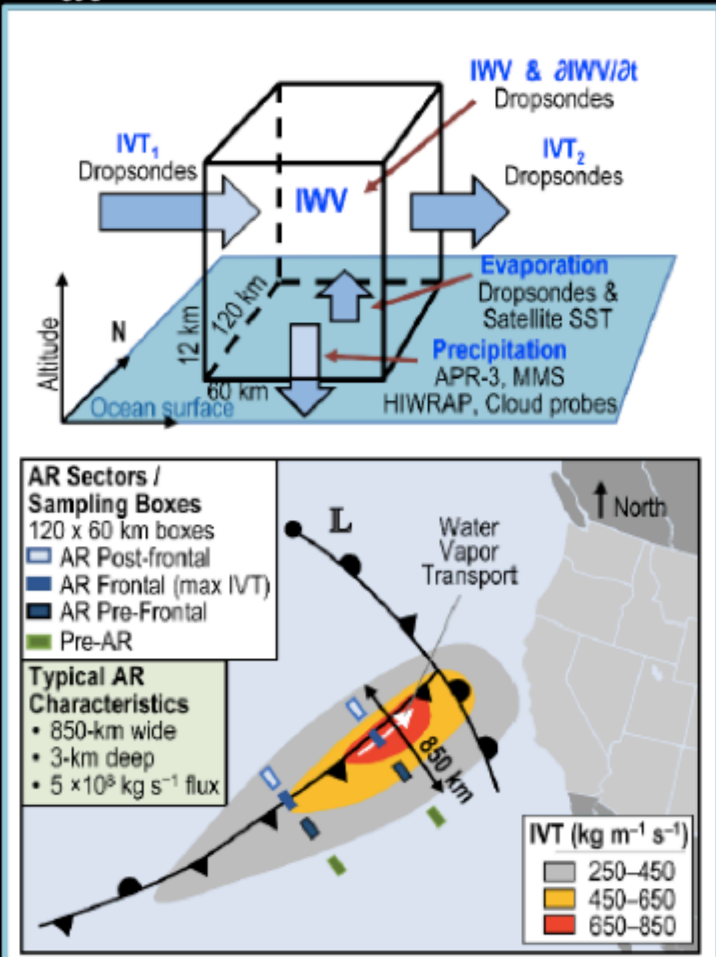
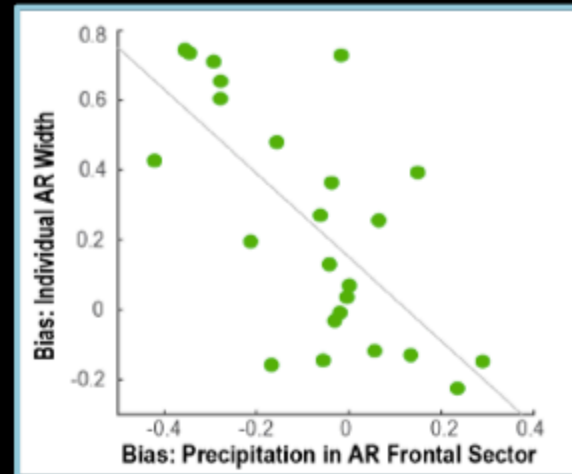
Weather/Climate Simulations of ARs

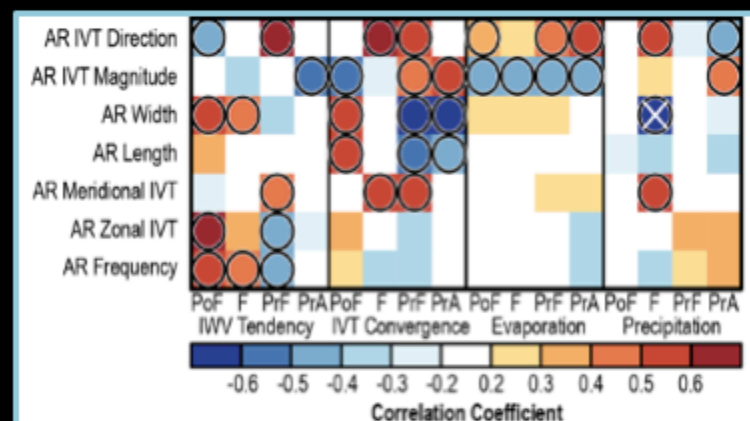
Process Level Considerations & Water Budget

$$\frac{d}{dt}IWV = DEL \bullet IVT - P + E$$



Courtesy of CW3E/Ralph





Above Courtesy of Guan et al. 2018

Summary

- Atmospheric Rivers are a global phenomena that shape the Earth's climate, water and energy cycles, as well as account for regional weather and water extremes.
- We've developed a detection algorithm that can be *consistently* used on global "observations" (i.e. re-analyses), climate simulations and forecast models.
- Using this detection algorithm, we are developing model diagnostics and performance metrics, in conjunction with other observations (e.g. in-situ CalWater, satellite), to:
  - Identify and characterize hydrometeorological impacts from ARs
  - Evaluate model performance and identify weaknesses to guide model improvement.
  - Characterize projected 21^{ST} century changes in Atmospheric Rivers.
  - Quantify forecast skill in operational S2S/weather prediction models.
- Water budget processes and model biases within ARs relate to bulk AR characteristics and their model biases. Field work on AR water budgets would be valuable in better guiding / constraining model improvements.

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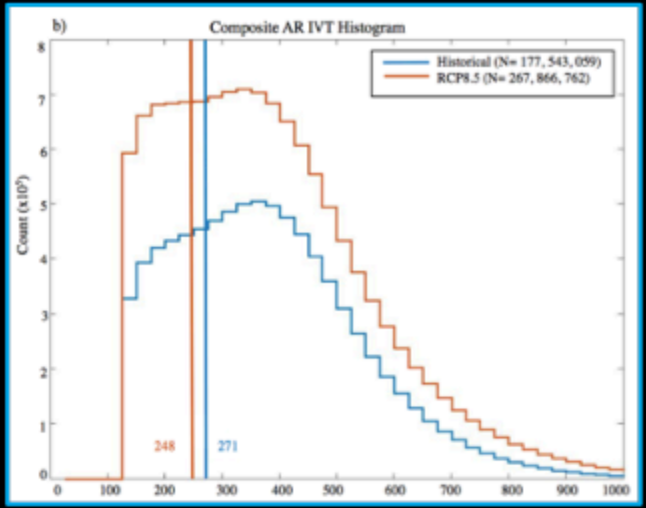
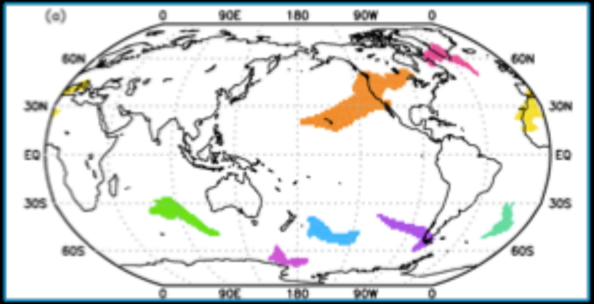
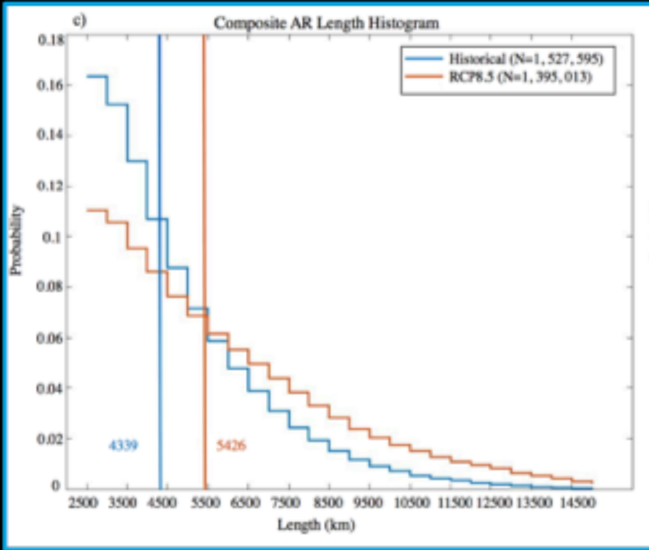
Climate Change & ARs

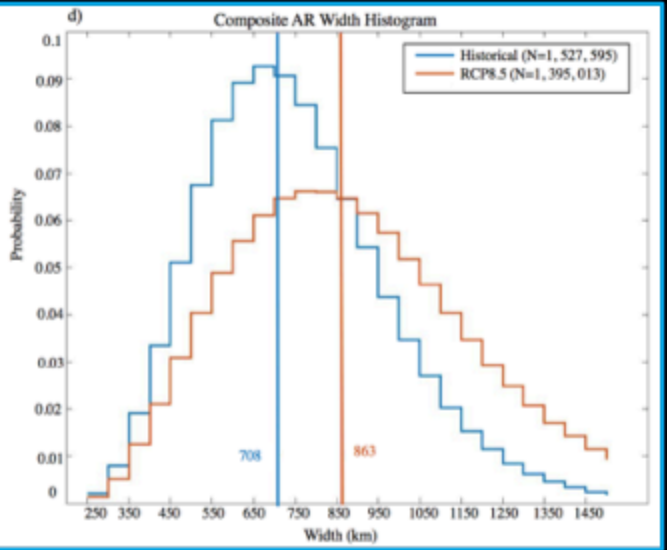
AR Frequency, Size & Transport: 21 CMIP5 Models



AR conditions vs AR Events



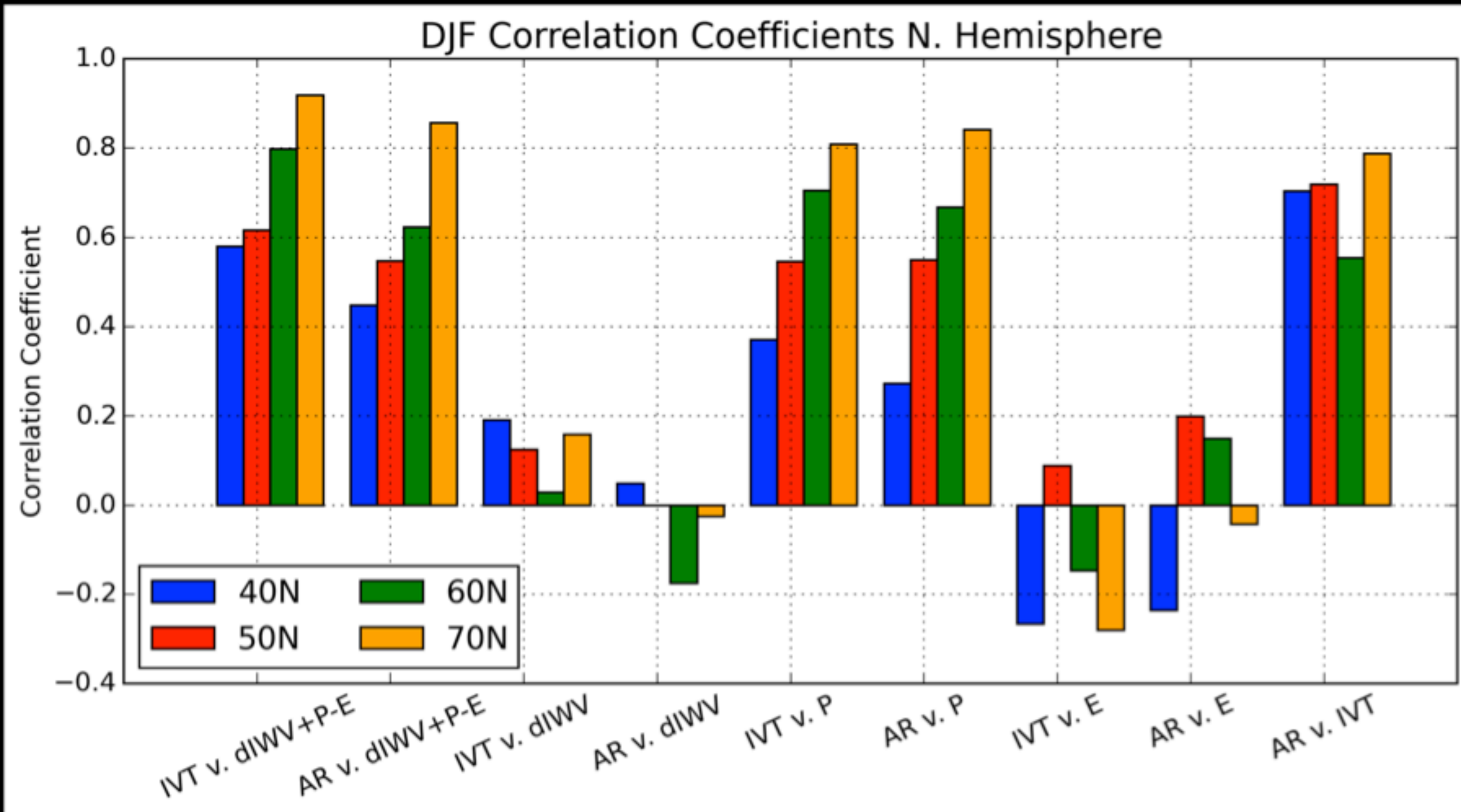




Espinoza, Waliser, Guan, Lavers, Ralph (2018, submitted w/ revisions)

Water Budget

Monthly Anomaly Correlations: N. Hemisphere



For monthly anomalies, total IVT accounts for ~84% and AR IVT accounts for ~73% of the variations in the water budget at 70ºN.

Nash, Waliser, Guan, Ralph (2018, Submitted)