Atmospheric River Tracking Method Intercomparison Project

C. Shields, T. O'Brien, R. Leung

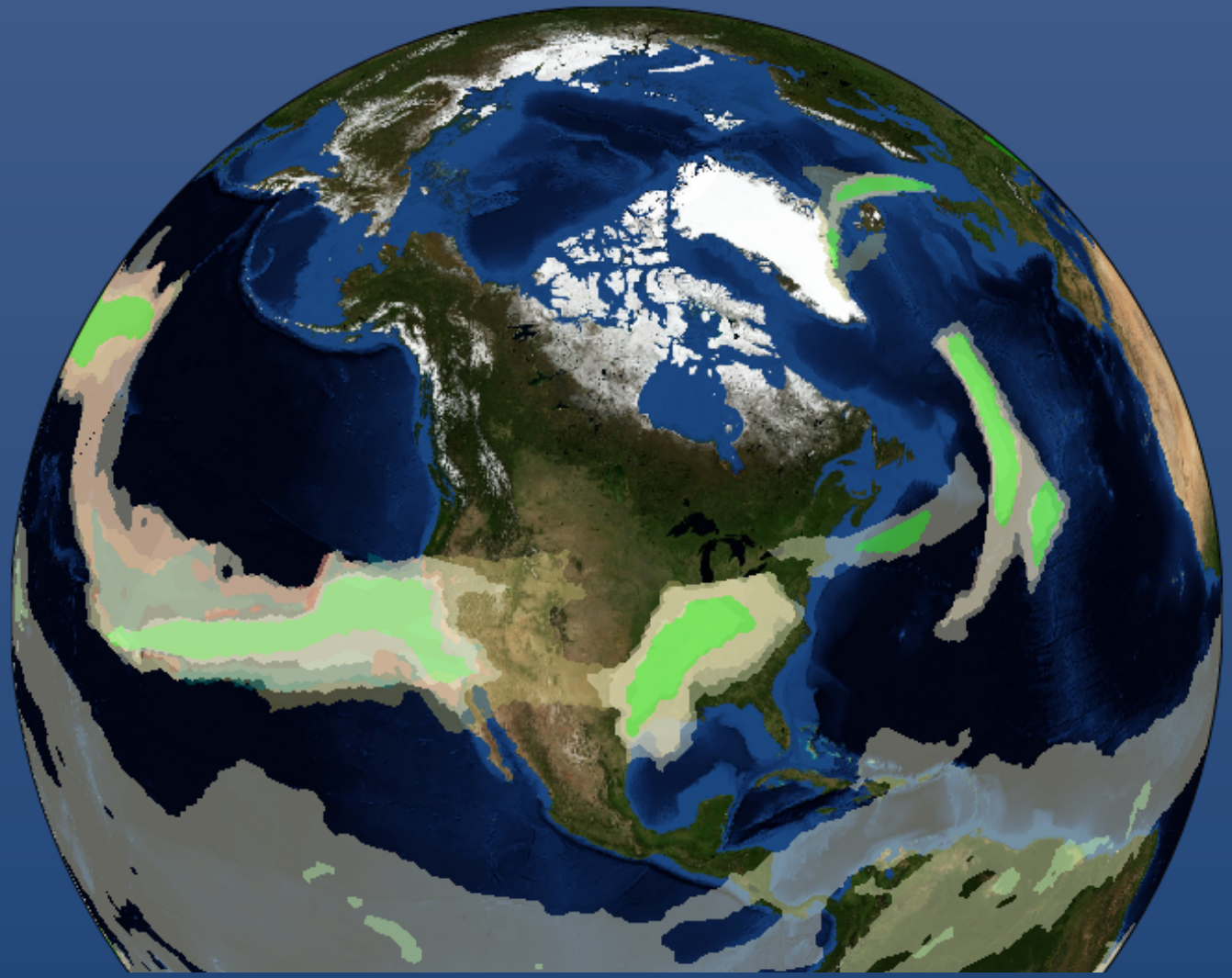
Committee/Leads: M. Wehner, M. Ralph, A. Payne, J .Rutz, A. Collow

DOE RGMA PI Meeting October 15th, 2020

ARTMIP Updates

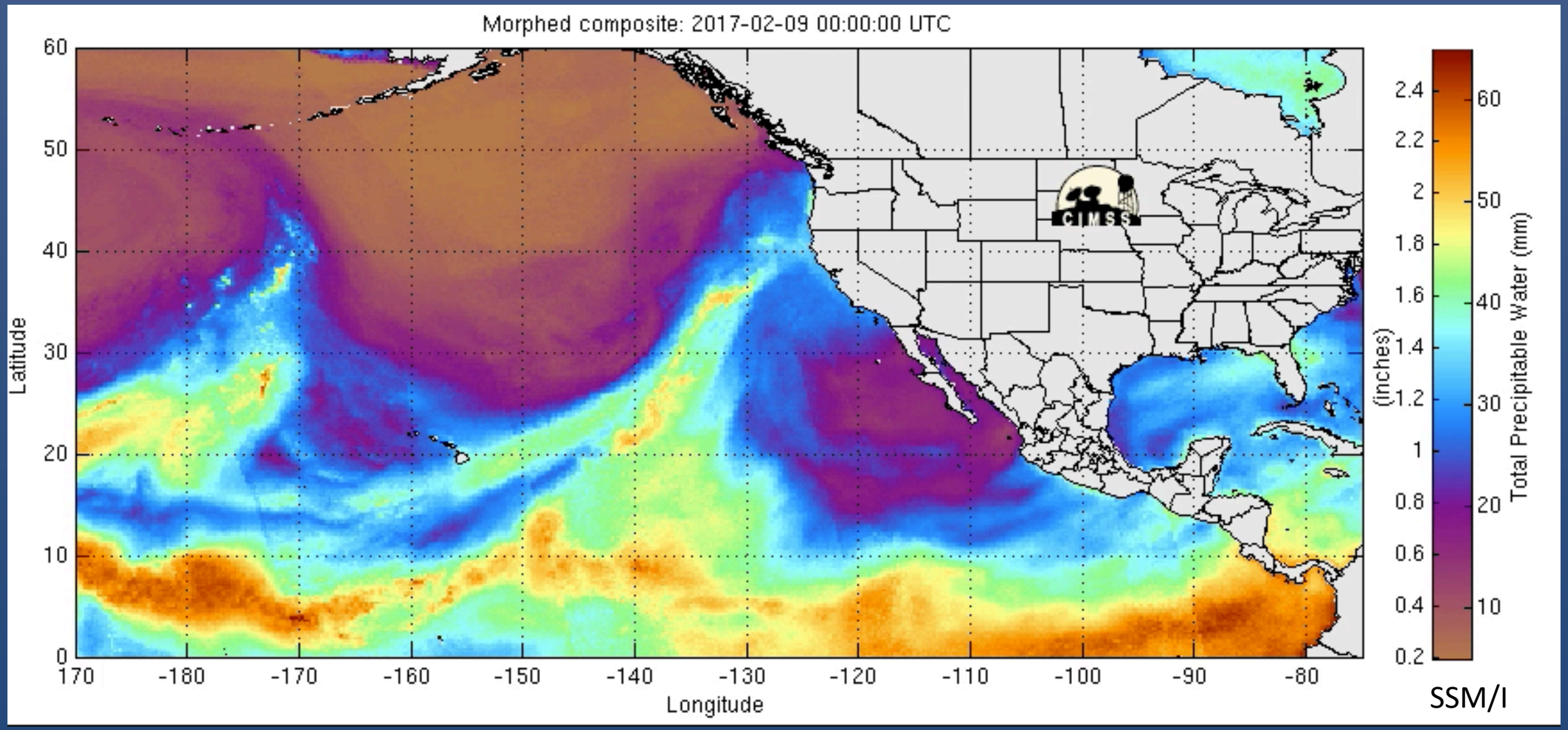
http://www.cgd.ucar.edu/projects/artmip/

- What is ARTMIP and what we've been doing!
- How ARTMIP is engaging with Machine Learning?



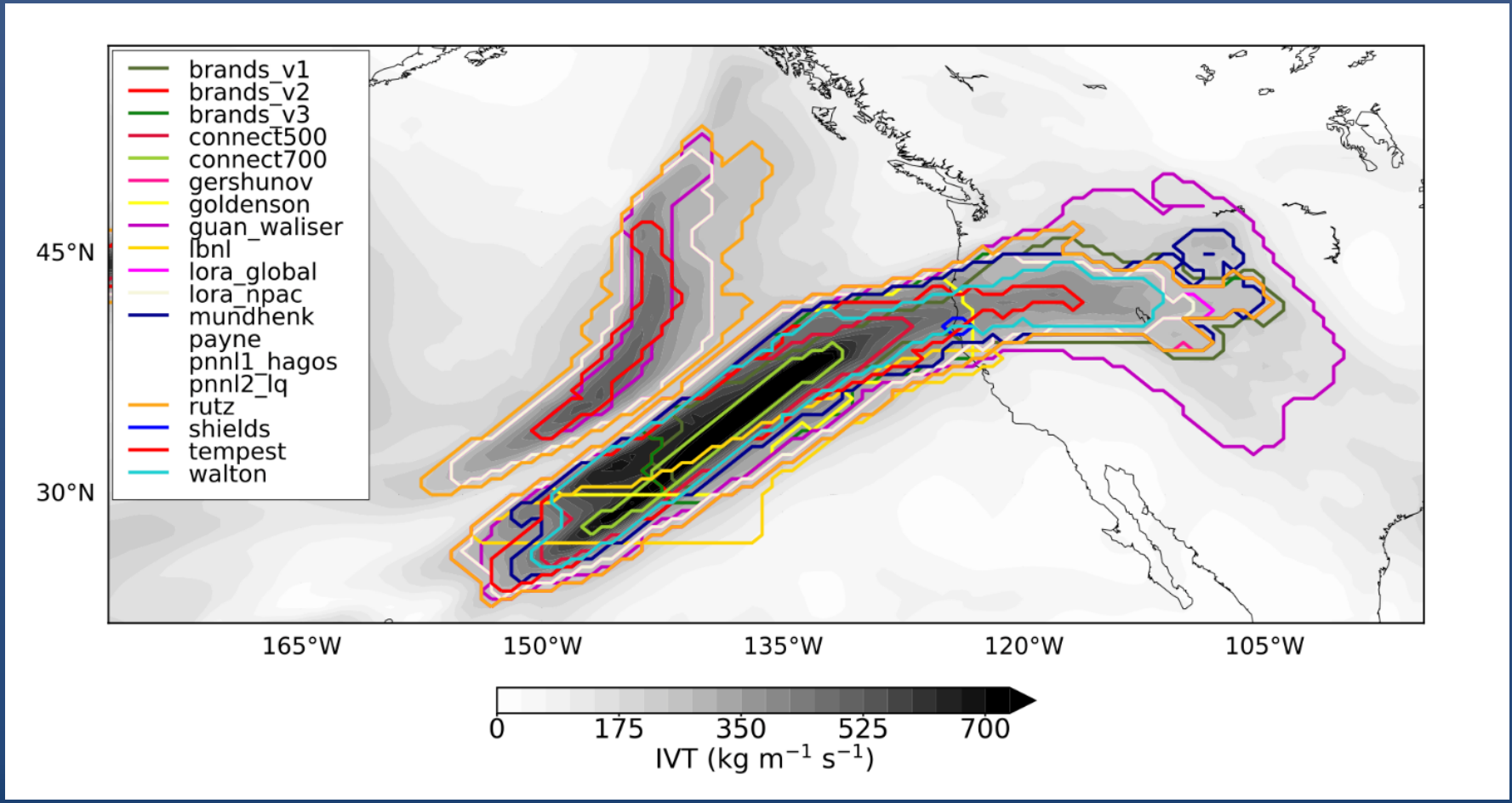
What is an Atmospheric River?

Source: http://tropic.ssec.wisc.edu/real-time/mimic-tpw/epac/main.html



Why ARTMIP? (Atmospheric Tracking Method Intercomparison Project)

Different methods result in some methods identifying ARs at specific geographic locations and observation times, whereas other methods do not. This results in uncertainty regarding the AR climatology (e.g., frequency, duration, intensity, seasonality), and how it relates to precipitation and water supply.



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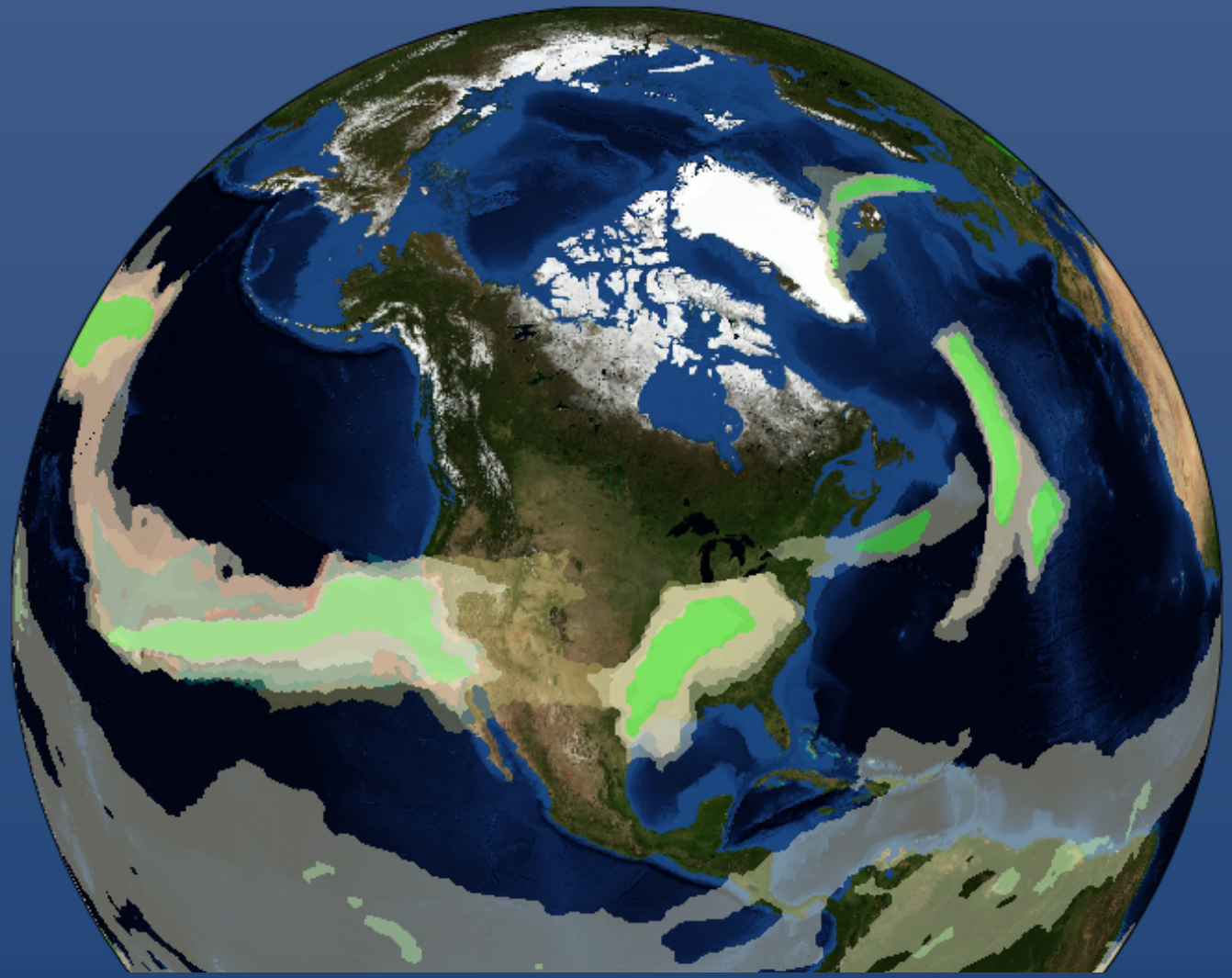
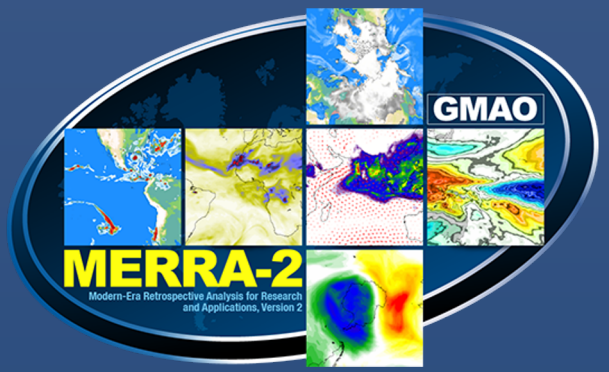
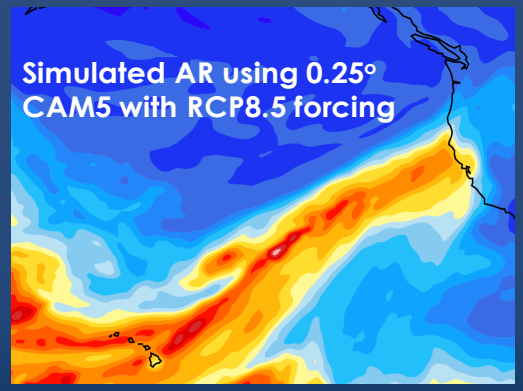


The goal of ARTMIP is to understand and quantify uncertainties in atmospheric river (AR) science based on choice of detection/tracking methodology.

Participants run their algorithms on a common dataset and adhere to a common format, this is called a method catalogue.

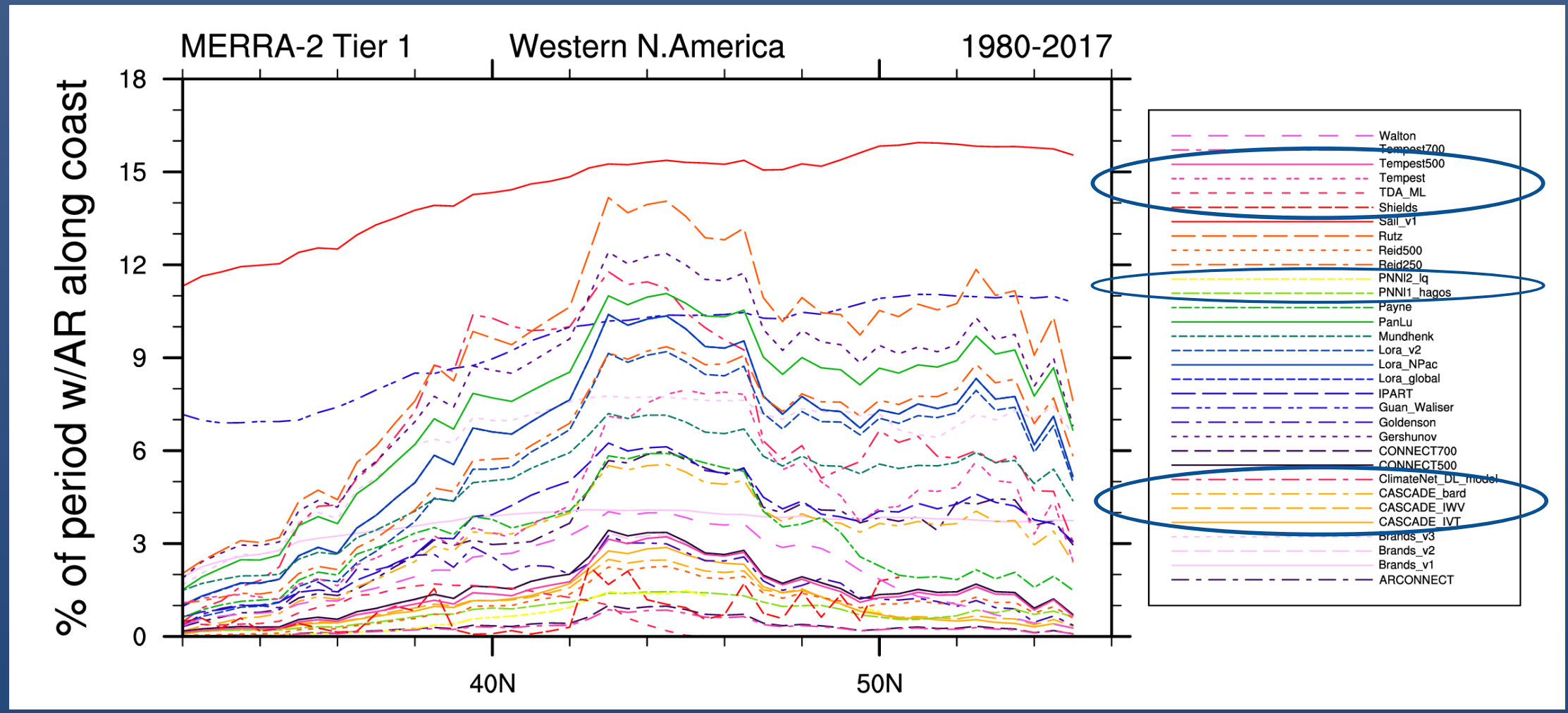


Tier 1 (MERRA2, 3-hourly dataset, baseline)
Tier 2 - C20C+ (CLIVAR C20C high resolution CAM5)
Tier 2 - CMIP5/6 (CMIP5 and CMIP6 simulations)
Tier 2 - Reanalysis (MERRA2 1hourly, ERA5, JRA55)



Continuing to add contributors…

35 Total algorithms (regional + global)
16 with global coverage



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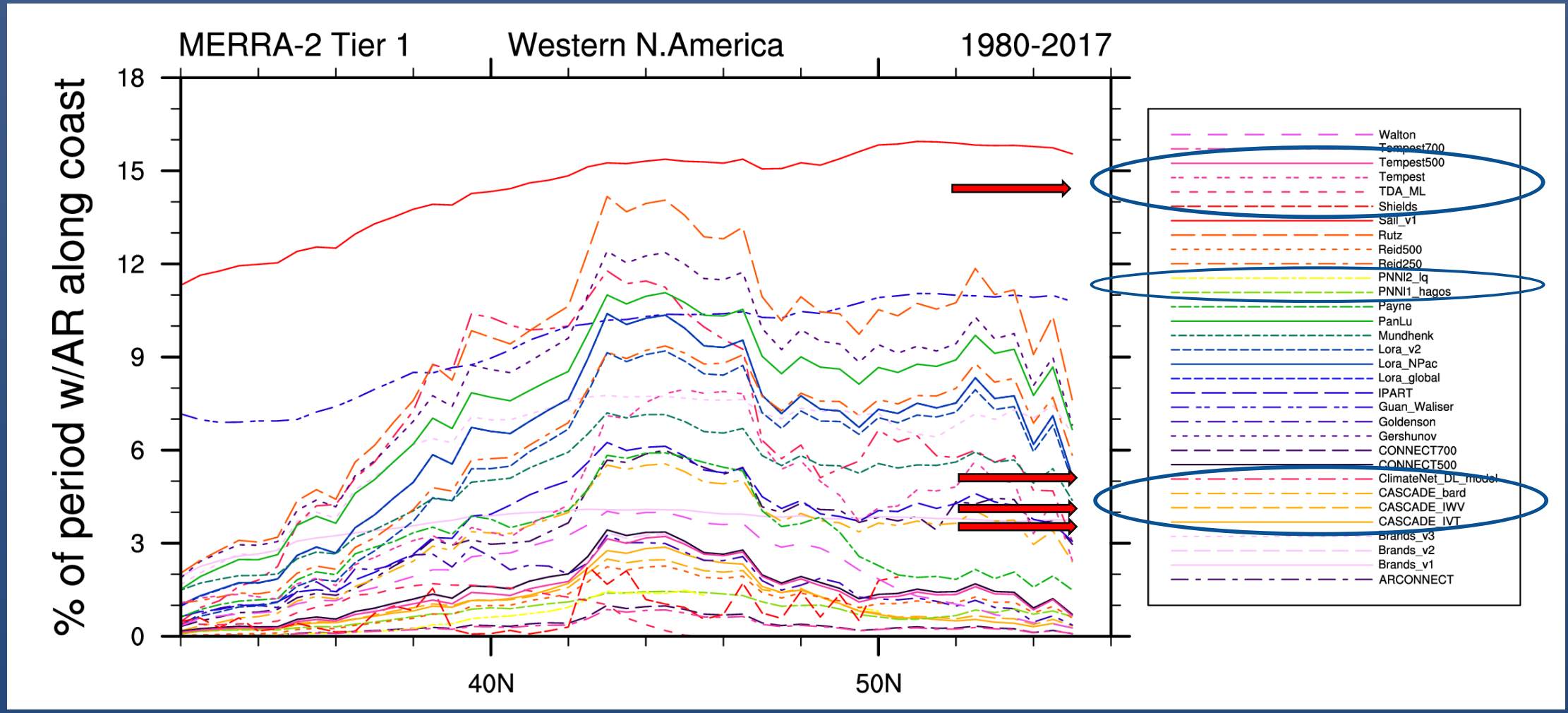

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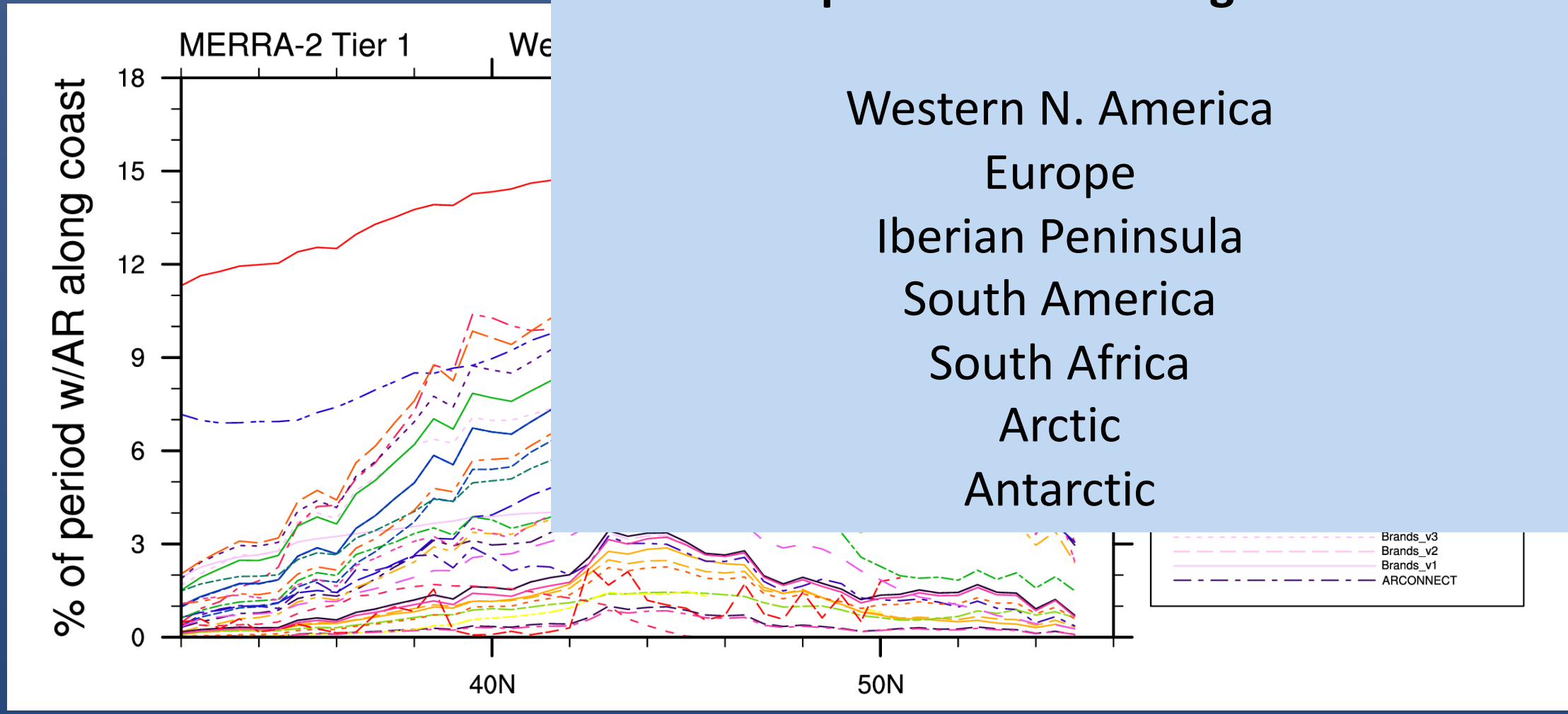
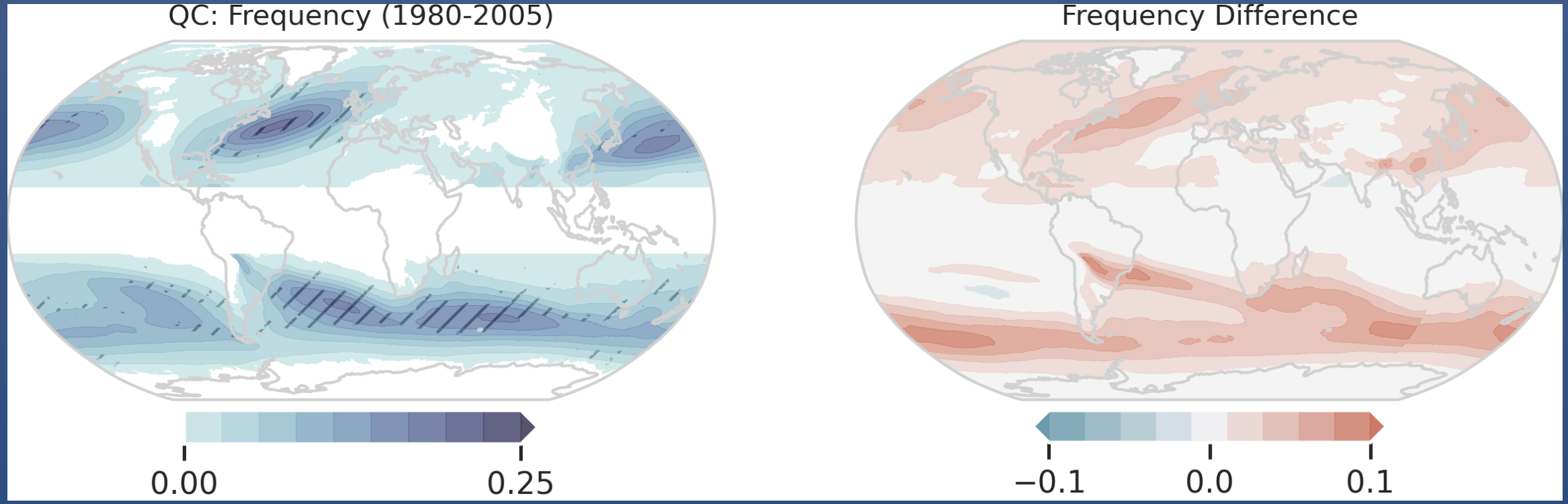


Locales represented with regional ARDTS:

Western N. America
Europe
Iberian Peninsula
South America
South Africa
Arctic
Antarctic

Tier 2 C20C+: Quality Control and Mean Global View



Hatching shows where at least half of the ARDTs are within 10% of their MERRA2 values (Tier 1).

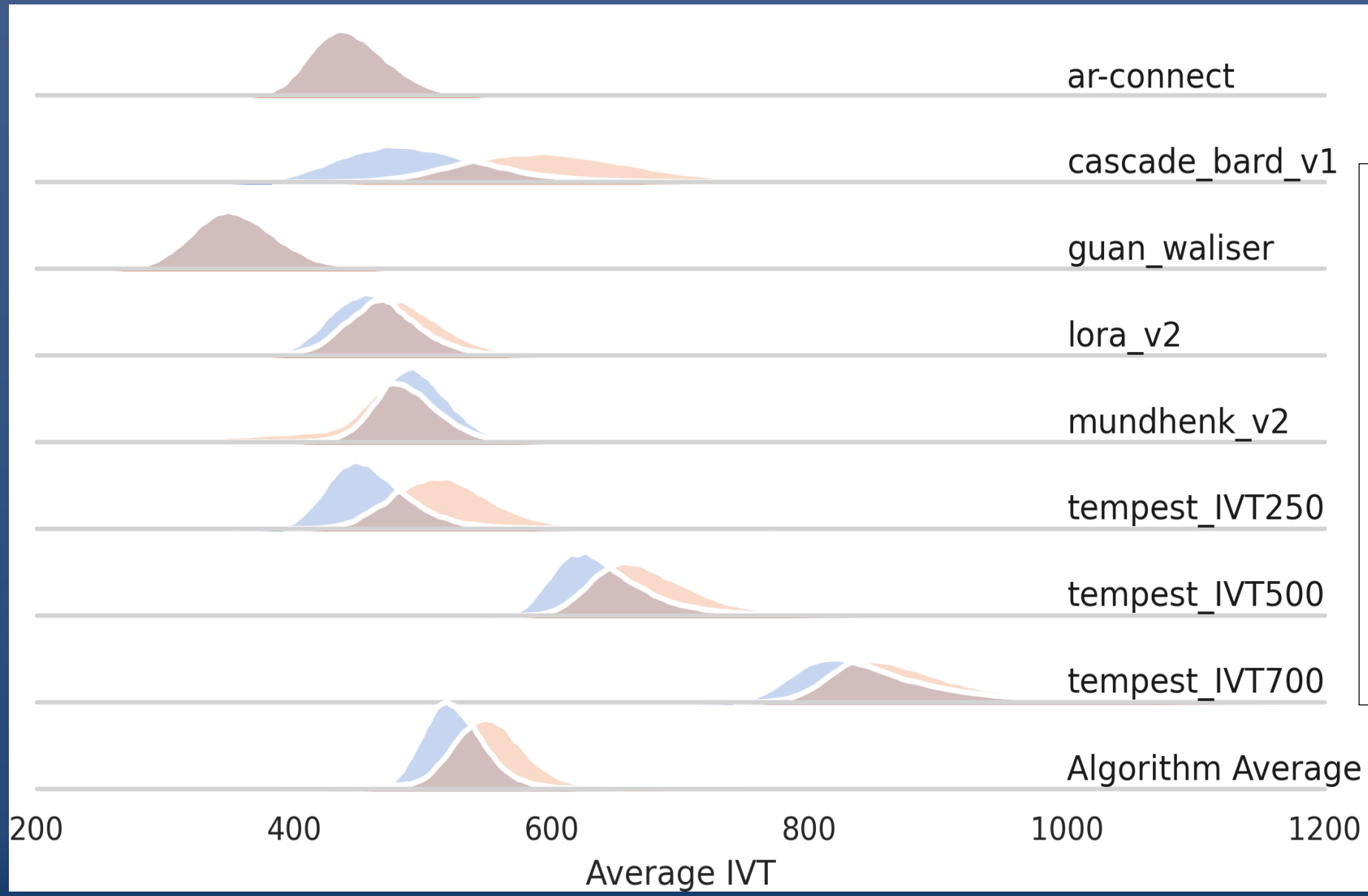
There is general good agreement over main AR tracks.

Difference between RCP85 and historical catalogues showing an overall increase in frequency over the mid-latitudes.

T2 C20C+ slides courtesy of Ashley Payne

Tier 2 C20C+: Global View

T2 C20C+ slides courtesy of Ashley Payne

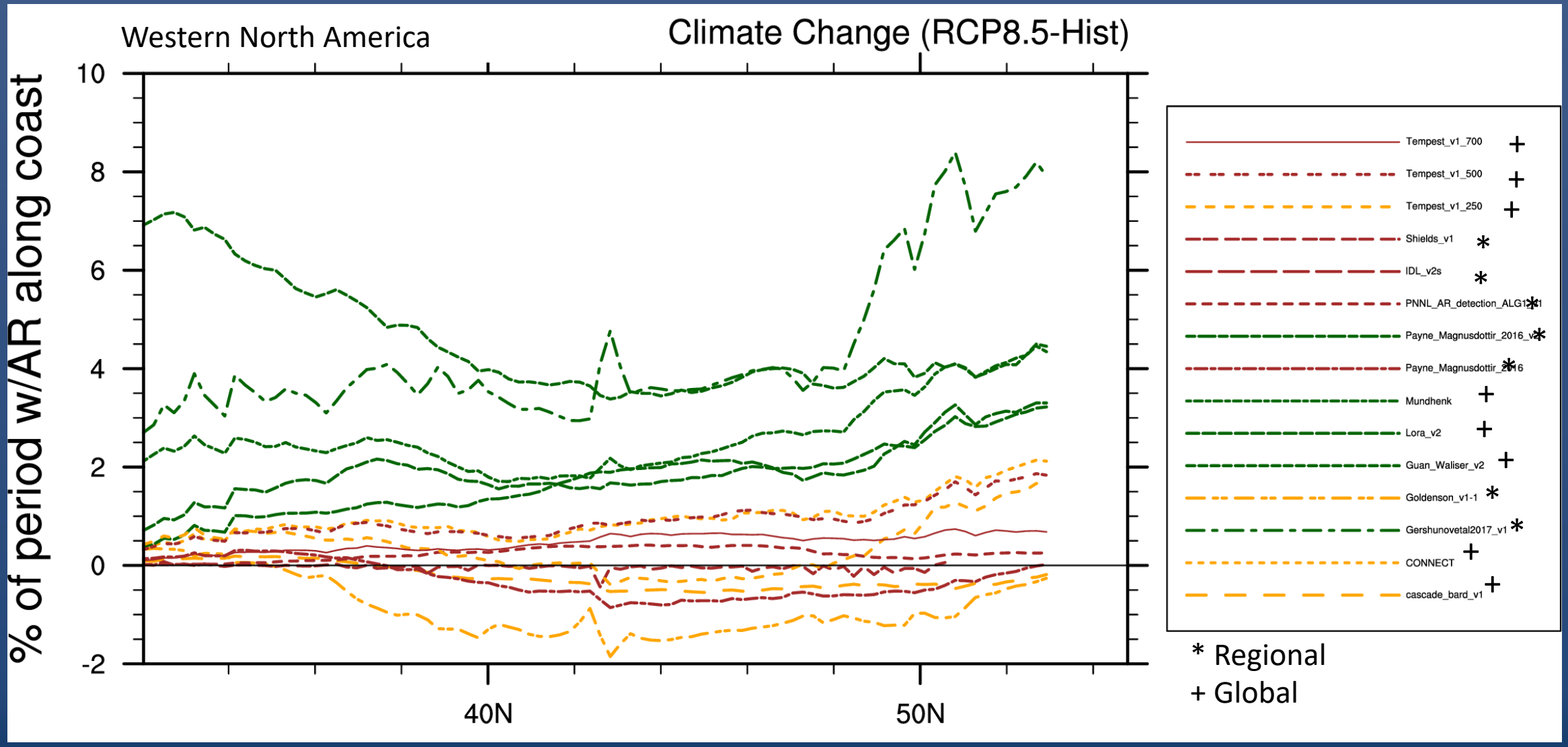


Comparison of the average IVT of AR objects for each time slice in each climate

A general shift towards higher IVT in RCP8.5, but magnitude of shift is dependent on algorithm

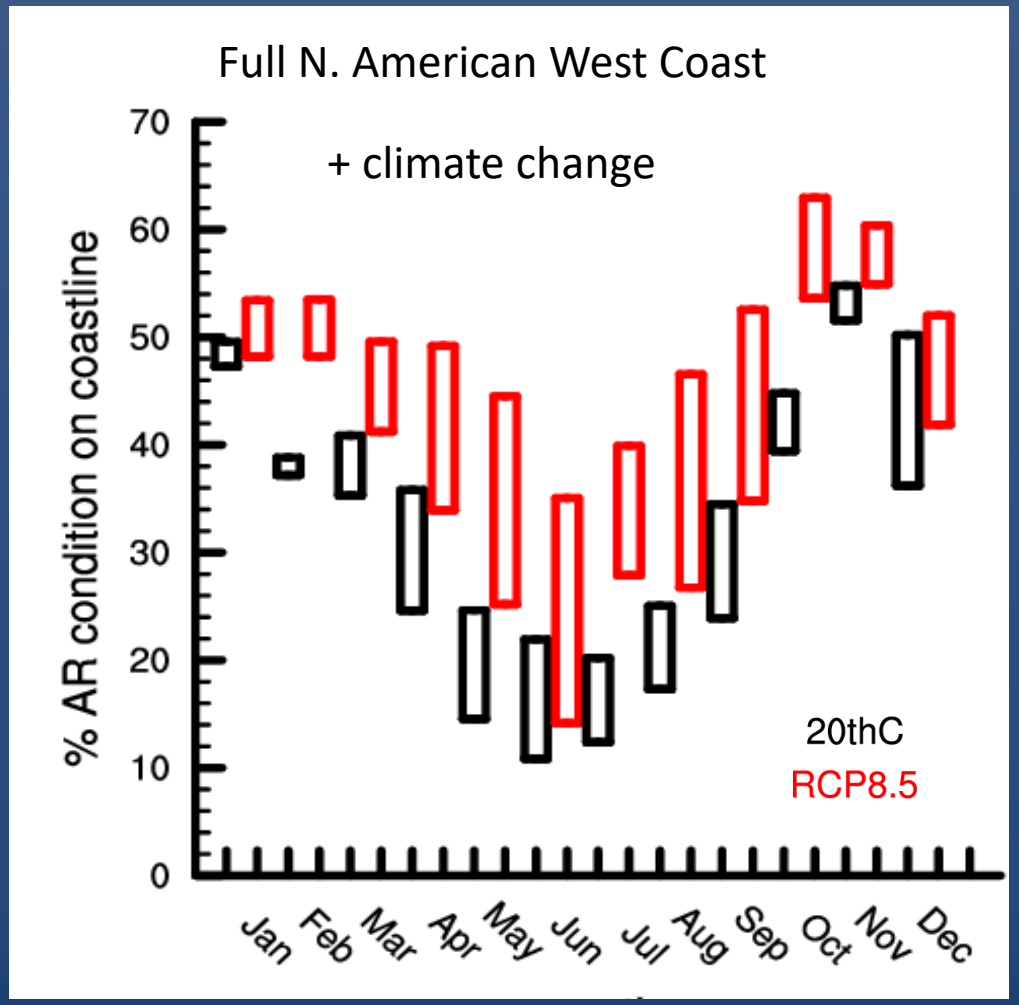
Tier 2 C20C+: How often do ARs make landfall?

(more) restrictiveness (less)

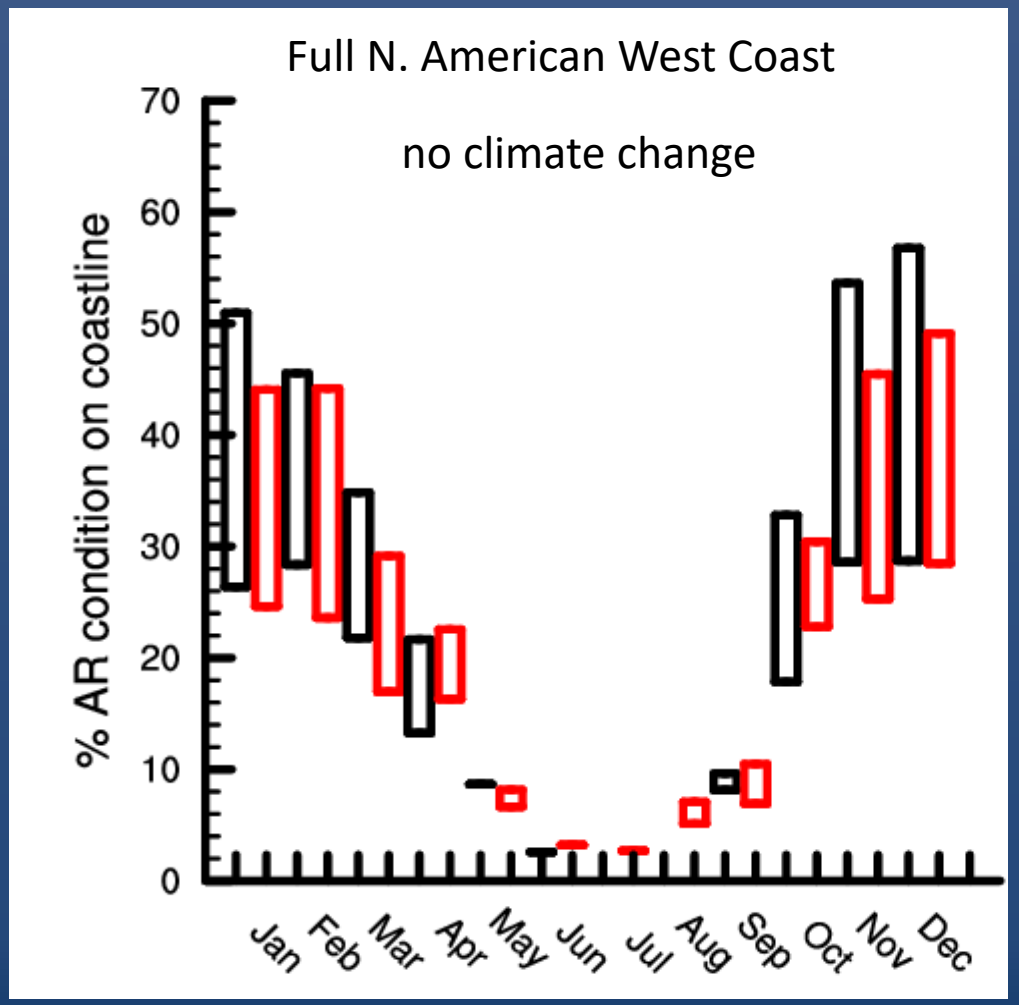


Tier 2 C20C+: What is the climatological uncertainty?

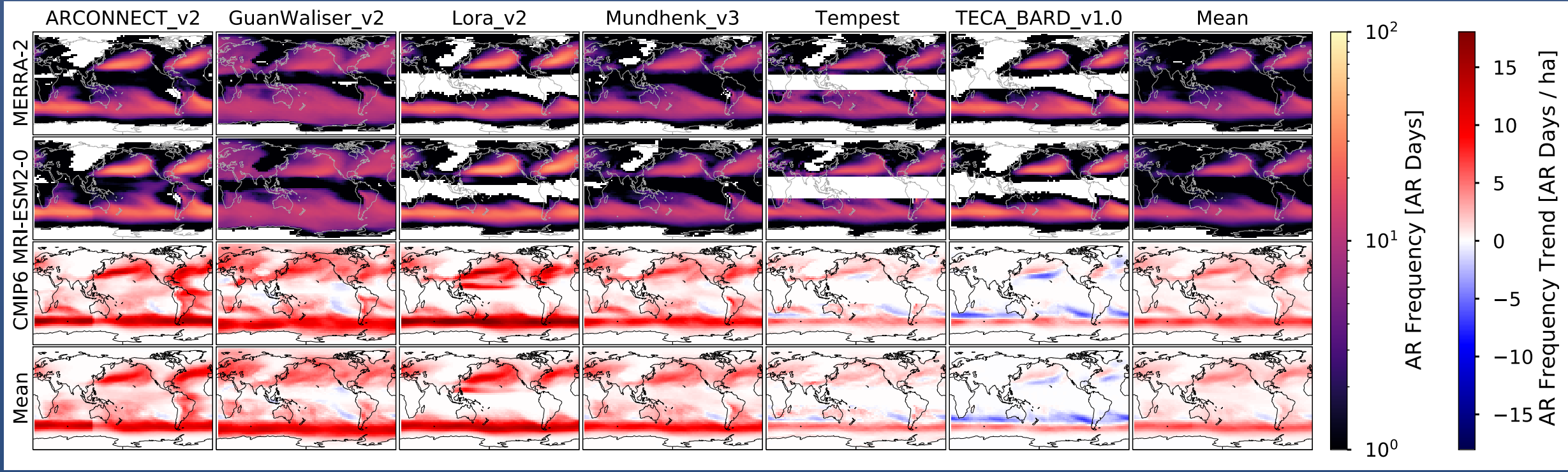
Clustered by methods with lenient thresholds



Clustered by methods with strict requirements



Tier 2 CMIP5/6: What is the uncertainty in the climate change trend?

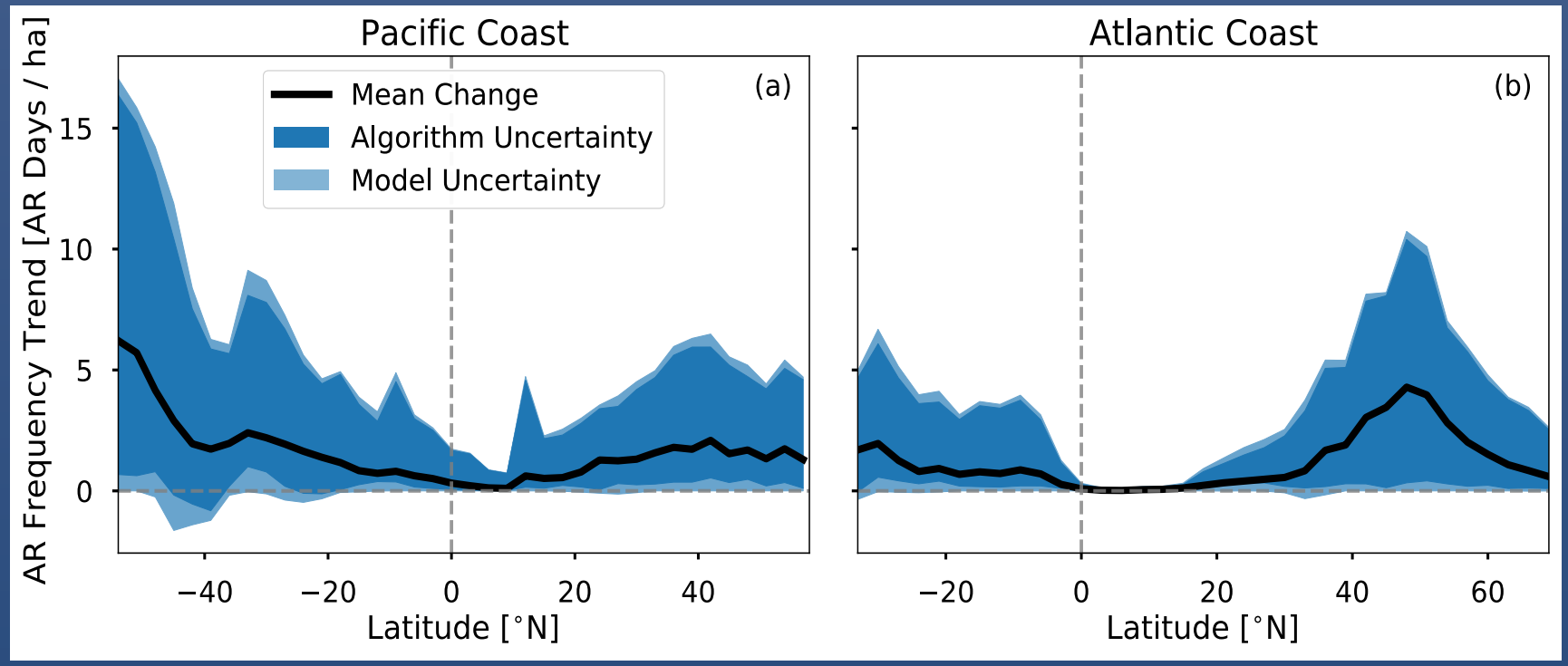


8 groups ran ARDTs on 8 models from CMIP5 and CMIP6: historical and RCP8.5 scenarios.

- Results show consistent patterns of AR tracks in historical.
- Simulations compare well w/ MERRA2 reanalysis (T1)
- Wide range of patterns of AR change

T2 CMIP5/6 slides courtesy of Travis O'Brien

Tier 2 CMIP5/6: Which dominates uncertainty, model or method?



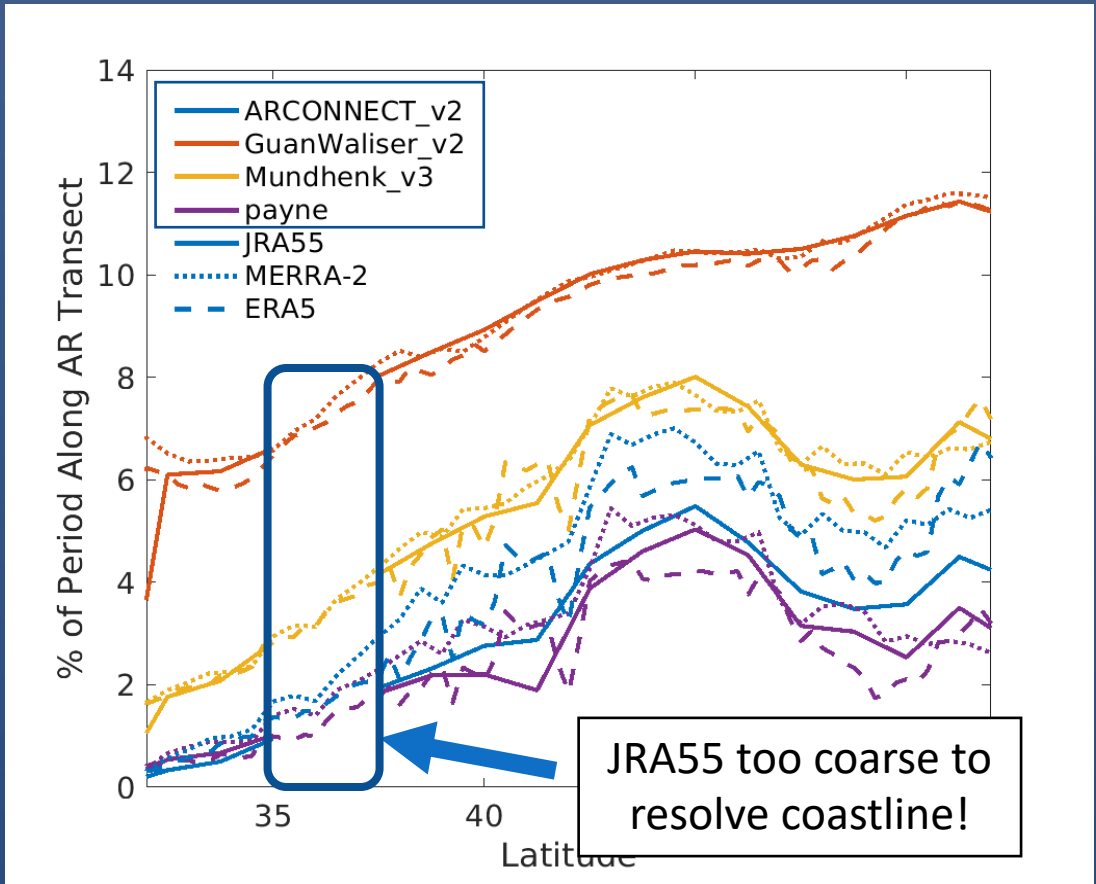
- The design or intent of an AR detection tool (ARDT) is critically important when considering your science question.
- Climate change questions versus process-oriented dynamics questions vs weather forecast applications.
- Uncertainty quantification must be included in any analysis where ARDT's are applied.

AR algorithm uncertainty dominates

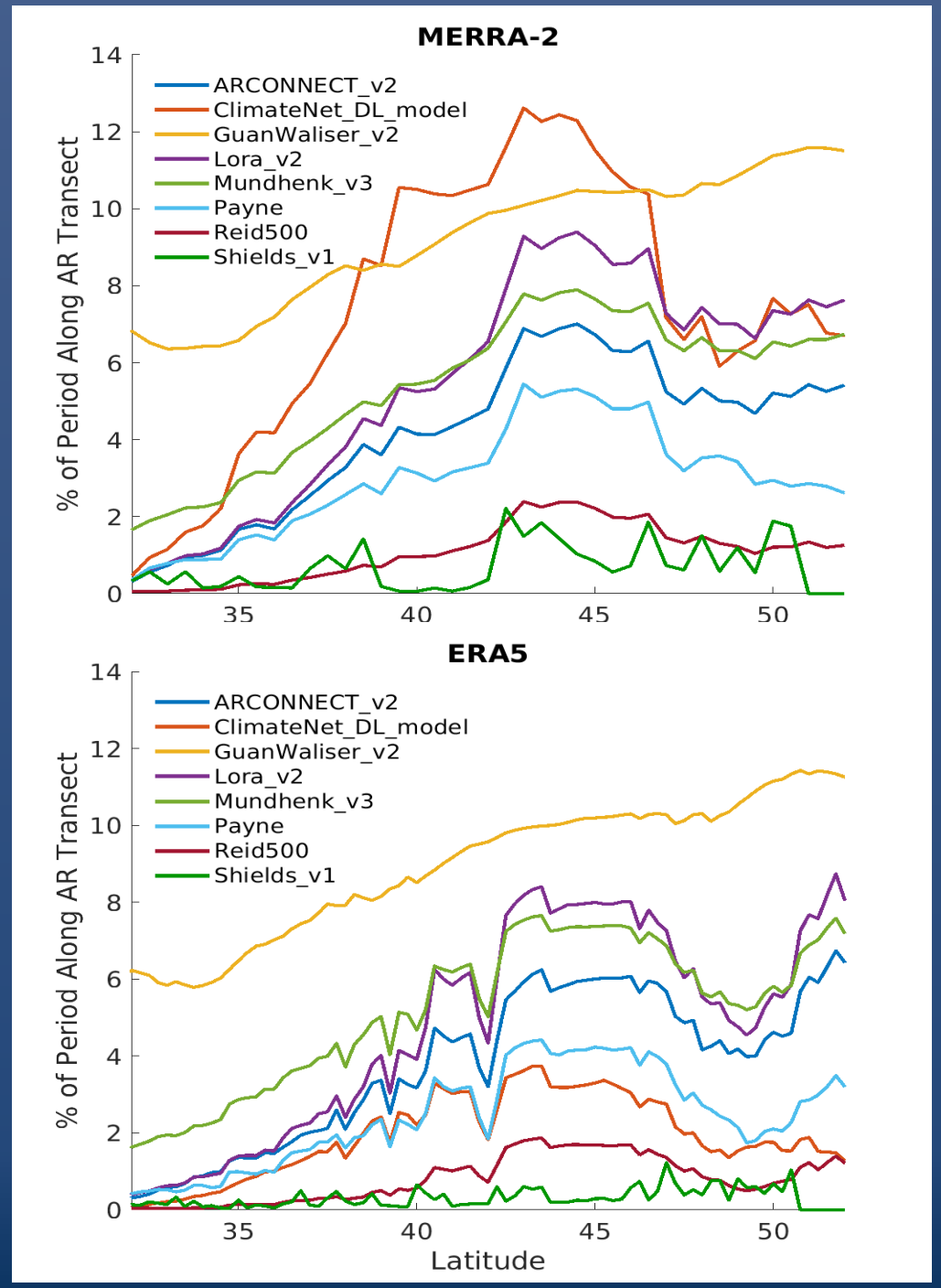
T2 CMIP5/6 slides courtesy of Travis O'Brien

Earth and Space Science Open Archive, 2020, DOI = 10.1002/essoar.10504170.1, https://doi.org/10.1002/essoar.10504170.1

Tier 2 Reanalysis: Preliminary results



- Larger spread among algorithms than reanalyses
- Less ARs detected in ERA5 than MERRA-2
- ERA has suppressed frequency of ARs in most algorithms at 42N where coastline shifts east along California/Oregon border



T2 Reanal slides courtesy of Allison Collow

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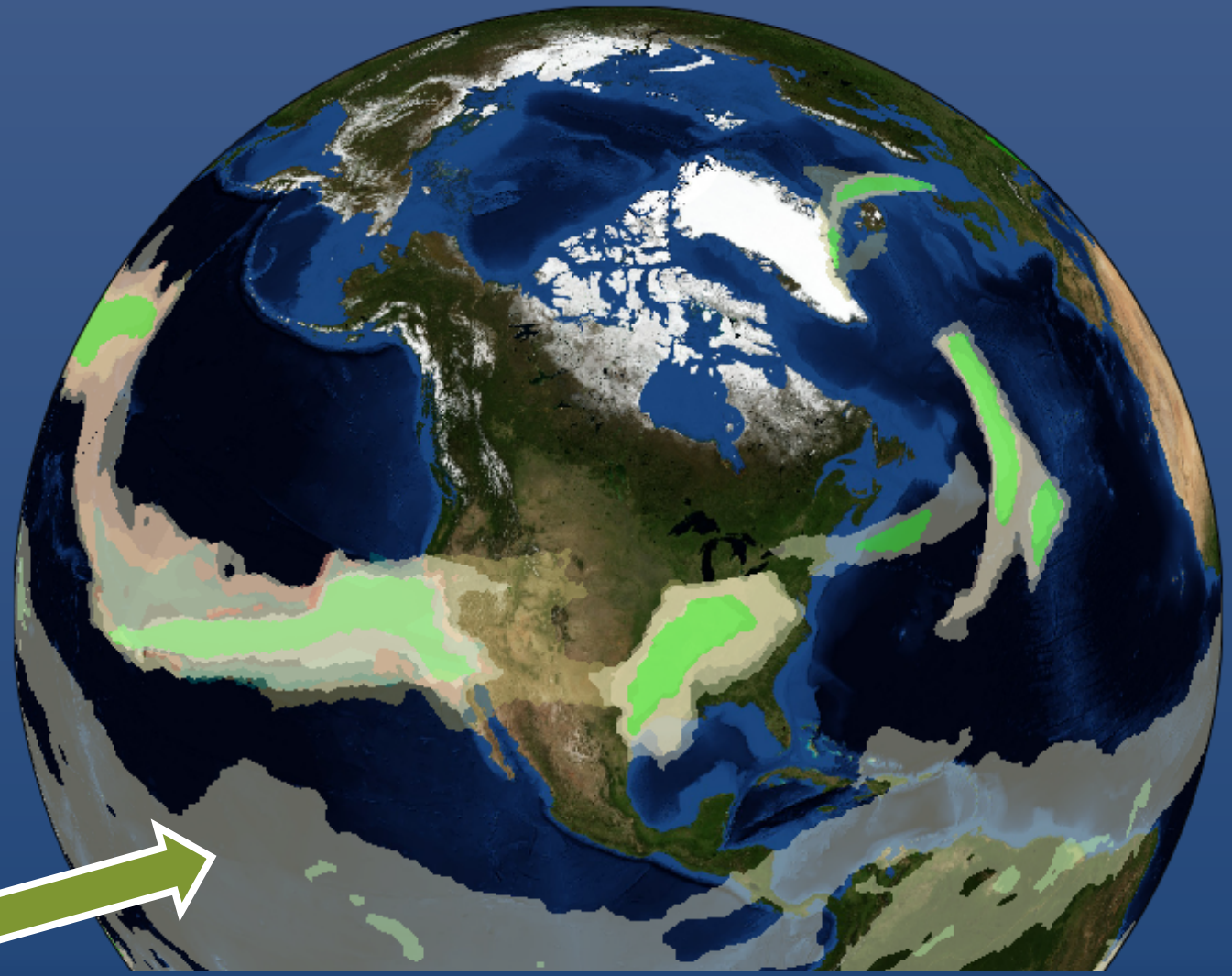
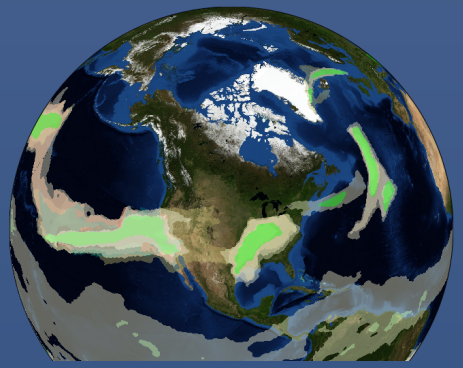


Mahesh and O'Brien CNN trained with ARTMIP data

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



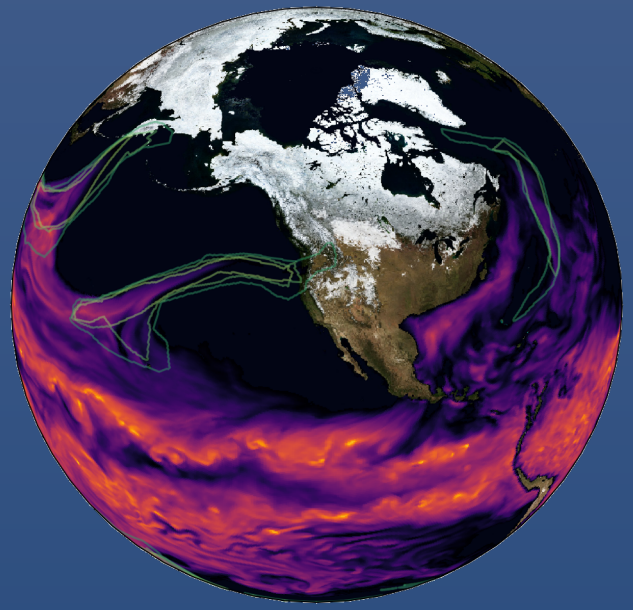
3rd ARTMIP Workshop Outcomes

- Creation of hand-labeled AR dataset for machine learning
- Specifications and timelines for three new Tier 2 experiments:
  - Tier 2 Reanalysis
  - Tier 2 High-Latitude
  - Tier 2 paleo-ARTMIP
- Production of a workshop report and meeting summary

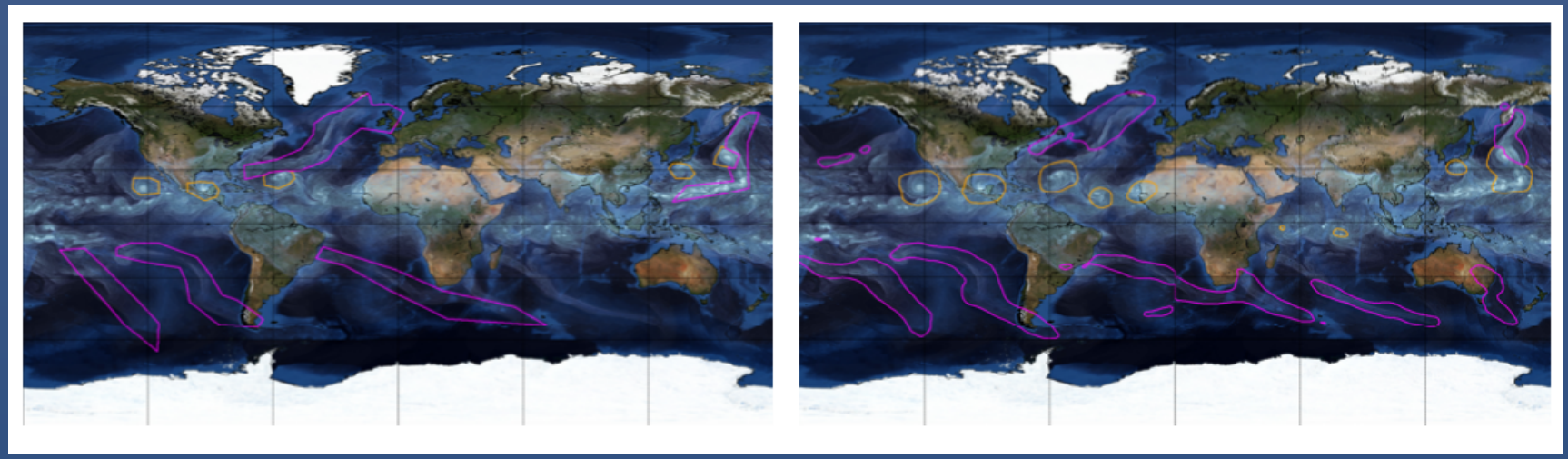
O'Brien, T. A., and Coauthors, 2020: Detection Uncertainty Matters for Understanding Atmospheric Rivers. Bull. Amer. Meteor. Soc., 101, E790–E796, *Bull. Amer. Meteor. Soc.* , https://doi.org/10.1175/BAMS-D-19-0348.1

ML slides courtesy of Travis O'Brien

ARTMIP facilitated expert contribution to ClimateNet



AR identification by multiple experts (green) and precipitable atmospheric water (colors)



(left) ClimateNet; (right) DeepLab v3+ machine learning model trained on ClimateNet

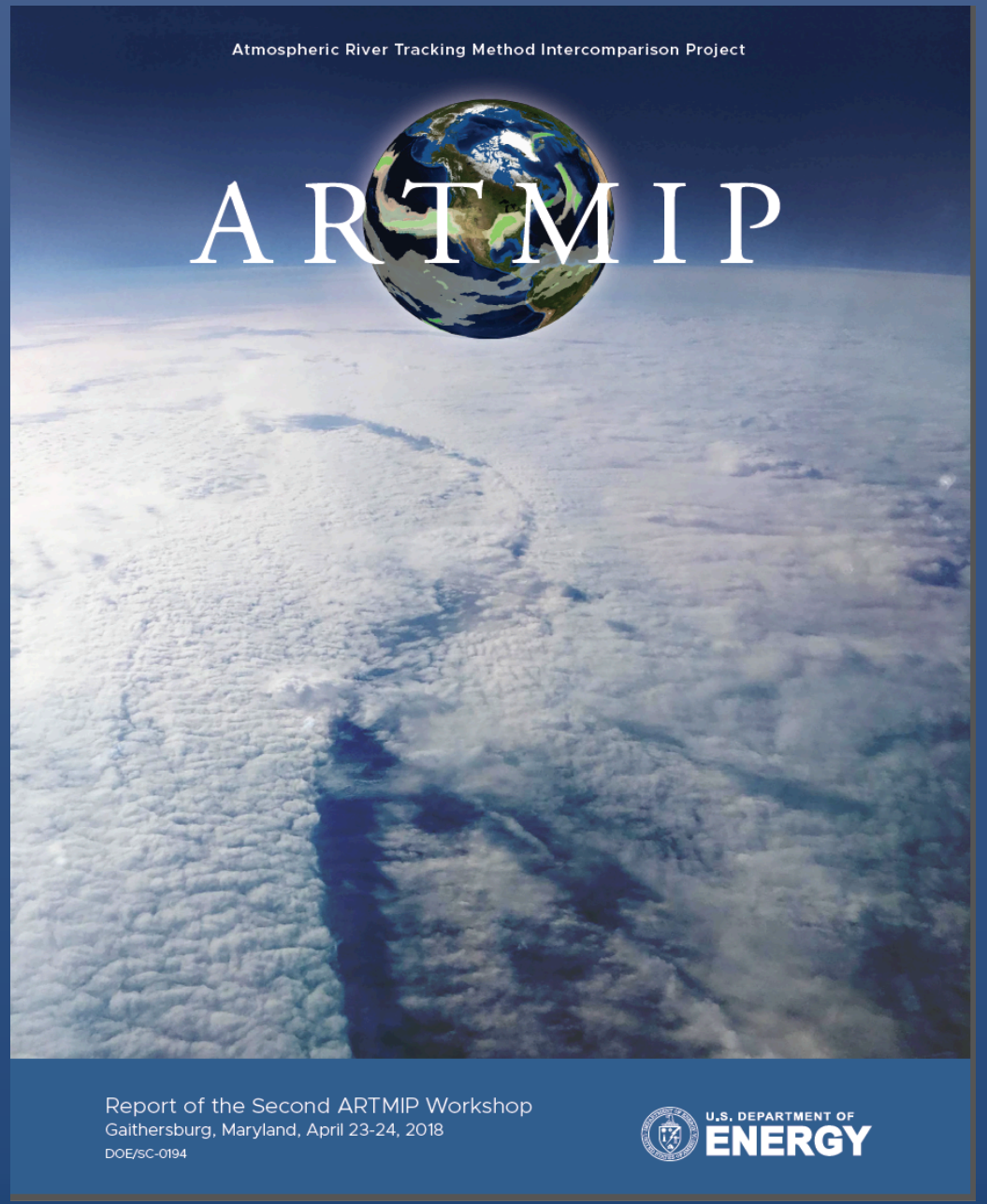
Image taken from Prabhat et al. 2020

Prabhat, Kashinath, K., Mudigonda, M., Kim, S., Kapp-Schwoerer, L., Graubner, A., Karaismailoglu, E., von Kleist, L., Kurth, T., Greiner, A., Yang, K., Lewis, C., Chen, J., Lou, A., Chandran, S., Toms, B., Chapman, W., Dagon, K., Shields, C. A., O'Brien, T., Wehner, M., and Collins, W.: ClimateNet: an expert-labelled open dataset and Deep Learning architecture for enabling high-precision analyses of extreme weather, Geosci. Model Dev. D, https://doi.org/10.5194/gmd-2020-72, accepted, 2020.

ML slides courtesy of Travis O'Brien

AR science gaps that can be addressed by ARTMIP

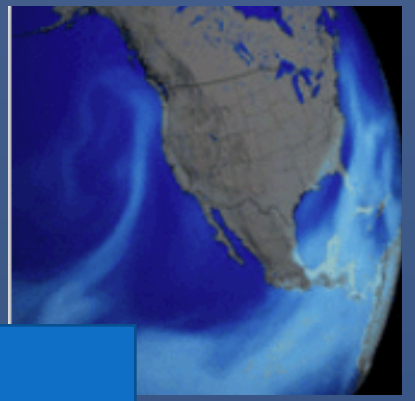
- Develop (physical) process-oriented constraints for ARDTs
- Mechanistic difference between AR flavors and regions, how ARDT choice matters
- AR predictability and connections with climate modes of variability
- Aerosol transport (AARs)
- AR life cycle quantification and processes
- Deeper dive into how algorithm choice affects precipitation, streamflow, and hydrology
- Resolution impacts on AR metrics and hydrology
- High latitude ARs
- Continue development of expert database of ARs for machine learning



ARTMIP publications

Atmospheric Rivers: Intersection of Weather and Climate

Special Issues | First published: 10 June 2019 | Last updated: 4 September 2020



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Geosci. Model Dev., 11, 2455–2474, 2018
https://doi.org/10.5194/gmd-11-2455-2018
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Article | Assets | Peer review | Metrics

Methods for assessment of models

Atmospheric River Tracking Method Intercomparison Project (ARTMIP): project goals and experimental design

Christine A. Shields[1], Jonathan J. Rutz[2], Lai-Yung Leung[3], F. Martin Ralph[4], Michael Wehner[5], Brian Kawzenuk[4], Juan M. Lora[6], Elizabeth McClenny[7], Tashiana Osborne[4], Ashley E. Payne, Paul Ullrich[7], Alexander Gershunov[4], Naomi Goldenson[9], Bin Guan[10], Yun Qian[3],

Geophysical Research Letters

Research Letter

Experimental Design: Shields et al., GMD, 2018

Tier 1 Overview: Rutz et al., JGR-A, 2019

JGR Atmospheres

Research Article

The Atmospheric River Tracking Method Intercomparison Project (ARTMIP): Quantifying Uncertainties in Atmospheric River Climatology

Jonathan J. Rutz, Christine A. Shields, Juan M. Lora, Ashley E. Payne, Bin Guan, Paul Ullrich, Travis O'Brien, L. Ruby Leung, F. Martin Ralph, Michael Wehner, Swen Brands ... See all authors

First published:24 November 2019 | https://doi.org/10.1029/2019JD030936 | Citations: 6

Research

Impact o… in Western …

…c Rivers on Surface Hydrological Processes …sheds

Xiaodong Chen, L. Ru…, Mark Wigmosta, Marshall Richmond

First published:05 August 201… https://doi-org.cuucar.idm.oclc.org/10.1029/2019JD030468 | Citations: 5

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…lexandre M. Ramos, …ele Villarini, Alex Hall &

Nature Reviews Earth & Environment **1**, 143–157(2020) | Cite this article

4242 Accesses | **2** Citations | **22** Altmetric | Metrics

Published: 10 September 2018

ARTMIP-early start comparison of atmospheri… detection tools: how many atmospheric rivers … northern California's Russian River watershed

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Climate Dynamics **52**, 4973–4994(2019) | Cite this article

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June 2020

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Detection Uncertainty Matters for Understanding Atmospheric Rivers

Travis A. O'Brien; Ashley E. Payne; Christine A. Shields; Jonathan Rutz; Swen Brands; Christopher Castellano; Jiayi Chen; William Cleveland; Michael J. DeFlorio; Naomi Goldenson ... Show more

Bull. Amer. Meteor. Soc. (2020) **101** (6): E790–E796.

Volume 100, Issue 2
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https://doi.org/10.1175/BAMS-D-18-0200.1 Article history

GRL: accepted DOI: DOI: 10.1029/2020GL089302

Consensus and disagreement in atmospheric river detection: ARTMIP global catalogues

J. M. Lora[1], C. A. Shields[2], J. J. Rutz[3]

[1]Department of Earth and Planetary Sciences, Yale University, New Haven, CT
[2]Climate and Global Dynamics Division, National Center for Atmospheric Research, Boulder, CO
[3]Science and Technology Infusion Division, National Weather Service, Salt Lake City, UT

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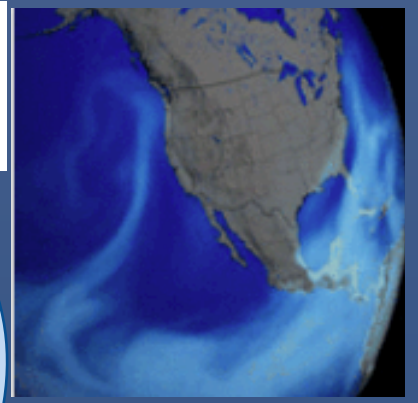

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In revision, Tier 2 CMIP5/6 Overview O'Brien et al., GRL, "Increases in Future AR Count and Size: Overview of the ARTMIP Tier 2 CMIP5/6 Experiment".

JGR Atmospheres

Research Article

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First published:24 November 2019 | https://doi.org/10.1029/2019JD030936 | Citations: 6

In prep, Tier 2 C20C+ Overview, Payne et al., Earth's Future, "Regional Impacts of Future Atmospheric Rivers: Overview of the ARTMIP Tier2 C20C+ Experiment ".

…arch 2020

… impacts of atmospheric …nate change

…, Marie-Estelle Demory, L. Ruby Leung, Alexandre M. Ramos, …ields, Jonathan J. Rutz, Nicholas Siler, Gabriele Villarini, Alex Hall & …Ralph

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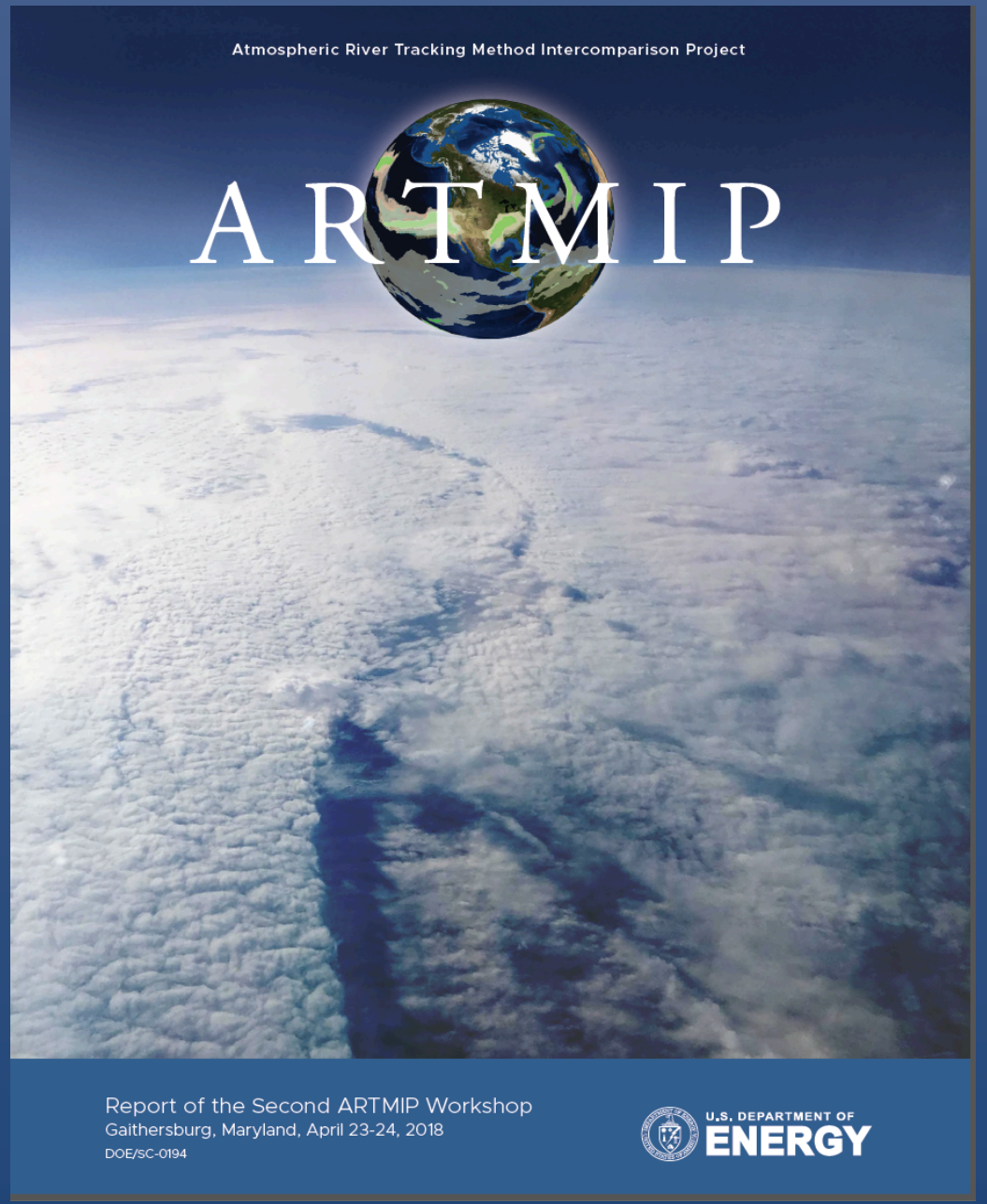
[2]Climate and Global Dynamics Division, National Center for Atmospheric Research, Boulder, CO
[3]Science and Technology Infusion Division, National Weather Service, Salt Lake City, UT

Important Points…

- Different methods for different problems (Evaluate what method is best for your science).
- Method threshold and/or restrictiveness of algorithm influences climate change response
- Method uncertainty swamps model uncertainty for CMIP5/6 experiments, and perhaps across reanalyses.
- Tier 2 - Reanalysis sensitivity just beginning, but resolution appears to be key
- ARTMIP database can help address AR science gaps
- http://www.cgd.ucar.edu/projects/artmip/



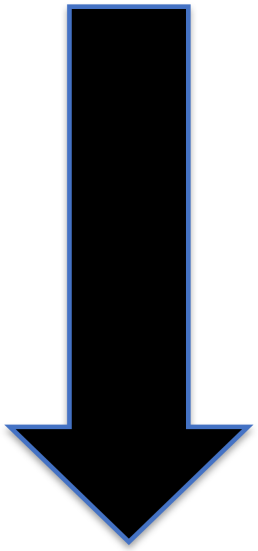
Extra Slides

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

Diverse algorithmic choices motivated by diverse science questions

Parameter Type

Parameters Choices



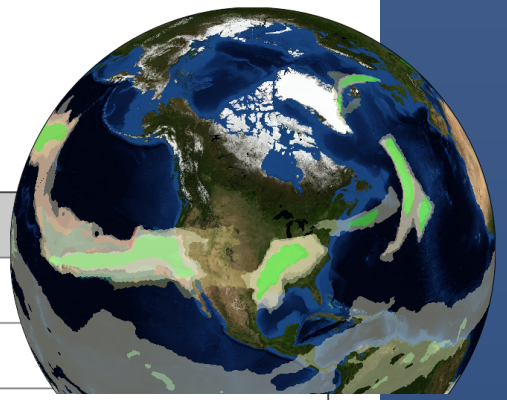
Computation Type	Geometry Requirements	Threshold Requirements	Temporal Requirements	Regions (Examples)
Condition If conditions are met, then AR exists for each time instance at each grid point. This counts time slices at a specific grid point.	Length	Absolute Value is explicitly defined.	Time slice Consecutive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

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

ARTMIP Timeline

Completed targets are in bold.

Target Date	Activity
May 2017	1st ARTMIP Workshop
August/September 2017	1-Month Proof of Concept Test
November 20 2017	Full Tier 1 Catalogues Due
January 2018	Last Call Tier 1 Catalogues (to be included in Tier 1 results paper)
April 23-24, 2018	2nd ARTMIP Workshop
Spring 2018	Tier 2 High Resolution Climate Catalogues Begin
Winter 2018-2019	Tier 2 High Resolution Climate Catalogues (C20C+) due for overview paper
October 16-19, 2020	3rd ARTMIP Workshop
Spring 2020	Tier 2 CMIP5/6 Catalogues due for overview paper
March 27, 2020	Tier 2 Reanalysis Telcon
August 2020	Tier 2 Reanalysis Required Catalogues Due
Fall 2020	Tier 2 Reanalysis Optional Catalogues Due and Analysis
On-going 2020/2021	Tier 1 and Tier 2 Analysis and Scientific Papers



On-going activities:

- ❑ Tier 1 MERRA-2 analysis, catalogues are public and on thee Climate Data Gateway (CDG).
- ❑ Tier 2 C20C+ analysis, overview paper will be submitted October 2020, then catalogues public on CDG, (Payne et al.)
- ❑ Tier 2 CMIP5/6 analysis, overview paper is in revision, then catalogues public on CDG, (O'Brien et al.)
- ❑ Tier 2 Reanalysis, Analysis has begun! (Allison Collow, NASA), presenting at AMS (Jan 2021).

ARDT's

AR Detection Tools

Tier 1 algorithms available on CDG (Climate Data Gateway) 35 ARDTs

Absolute Methods	Relative Methods		
	Latitude-dependent		
	Anomaly above zonal or spatial mean	Anomaly above climatology	Percentile based
Gershunov Goldenson Hagos (*PNNL_1*) Leung and Qian (*PNNL_2*) Mahoney Ralph Reid Rutz Sellars (*CONNECT*) Shearer (*AR_CONNECT*) Wick	Gorodetskaya Ulrich and McClenny (Tempest) O'Brien (*Cascade_Bard*) Shields and Kiehl Pan and Lu (*Panlu*)	Krinitsky (*SAIL*) Mundhenk Walton Wille	Brands (*v1,v2,v3*) Guan and Waliser Ramos (*IDL*) Viale
Threshold Free	Latitude-independent		
O'Brien (*Cascade_IVT/IWV*) Muszynski (*TDA_ML*) Xu (*IPART*) Prahbat *(ClimateNet)*	Lavers Payne and Magnusdottir	Lora	

This category includes a wide variety of methods; full description available at http://www.cgd.ucar.edu/projects/artmip/algorithms.html

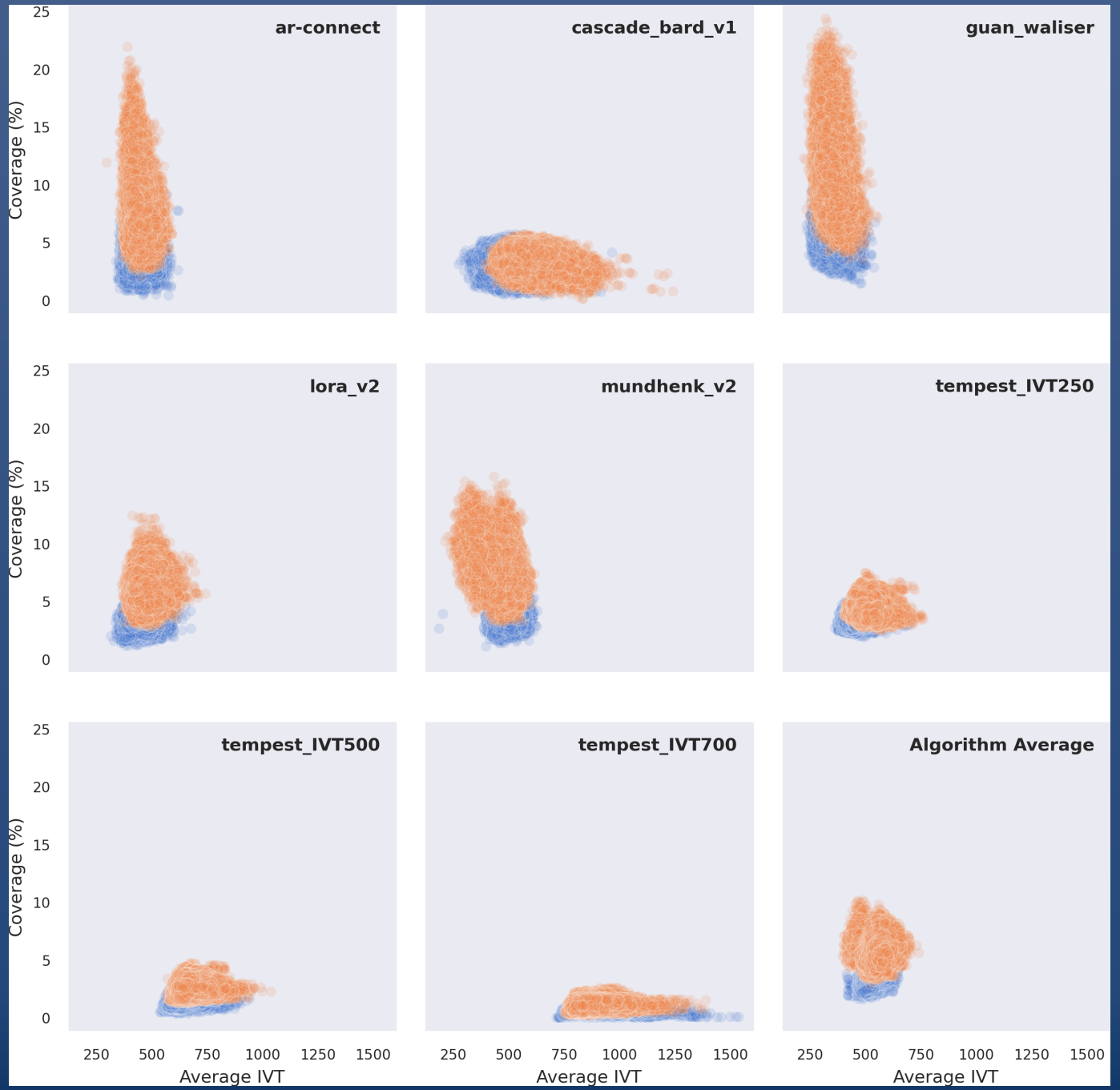
Slide courtesy of J. Rutz

Tier 2 C20C+: Global View

Algorithms showing little shift in average IVT show the largest increases in percent coverage (number of grid points covered by AR objects at each time slice)

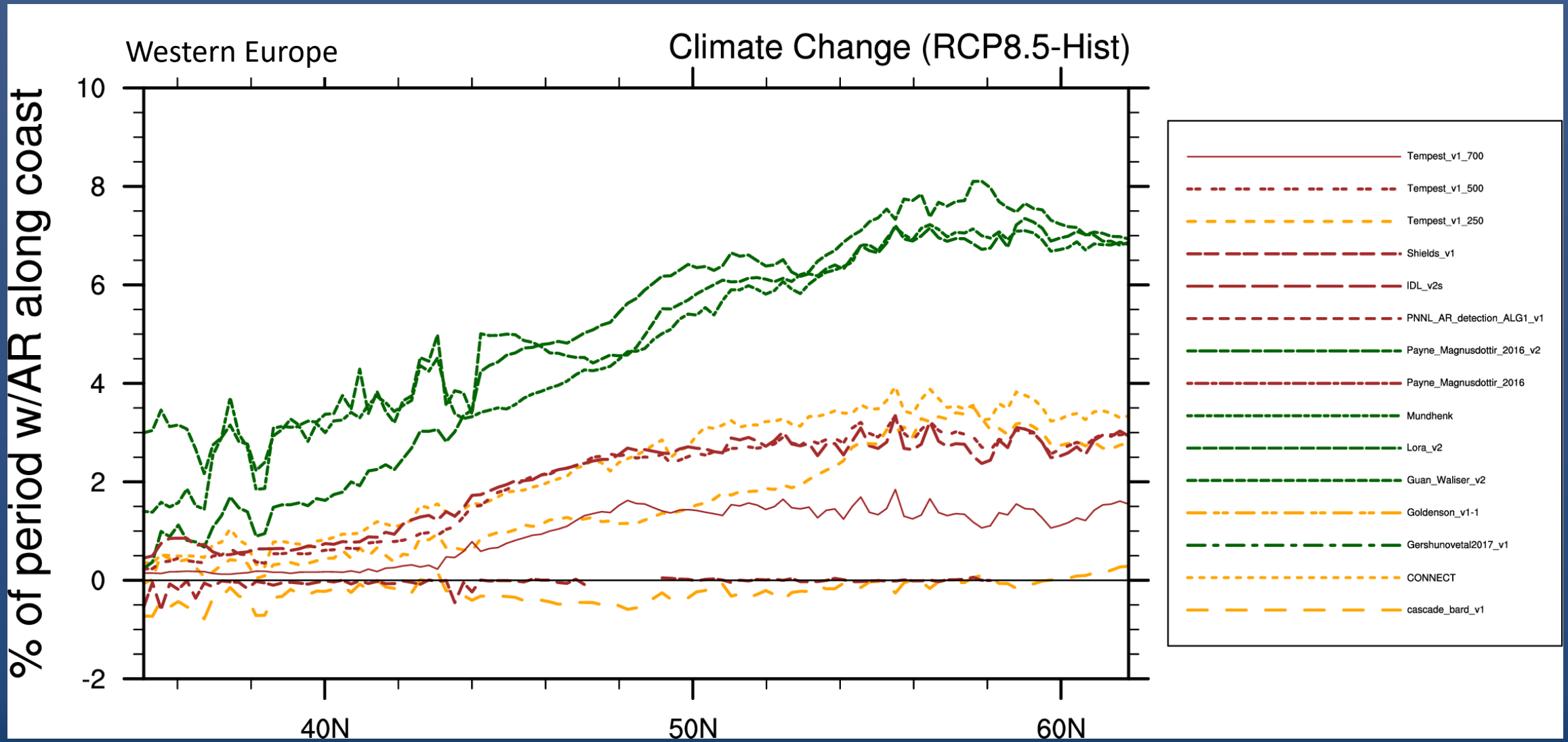
Looking at a global average…very different picture at the regional scale.

Requires a nuanced comparison – various treatments among algorithms of thresholds between the two climates



T2 C20C+ slides courtesy of Ashley Payne

Tier 2 C20+: How often do ARs make landfall?

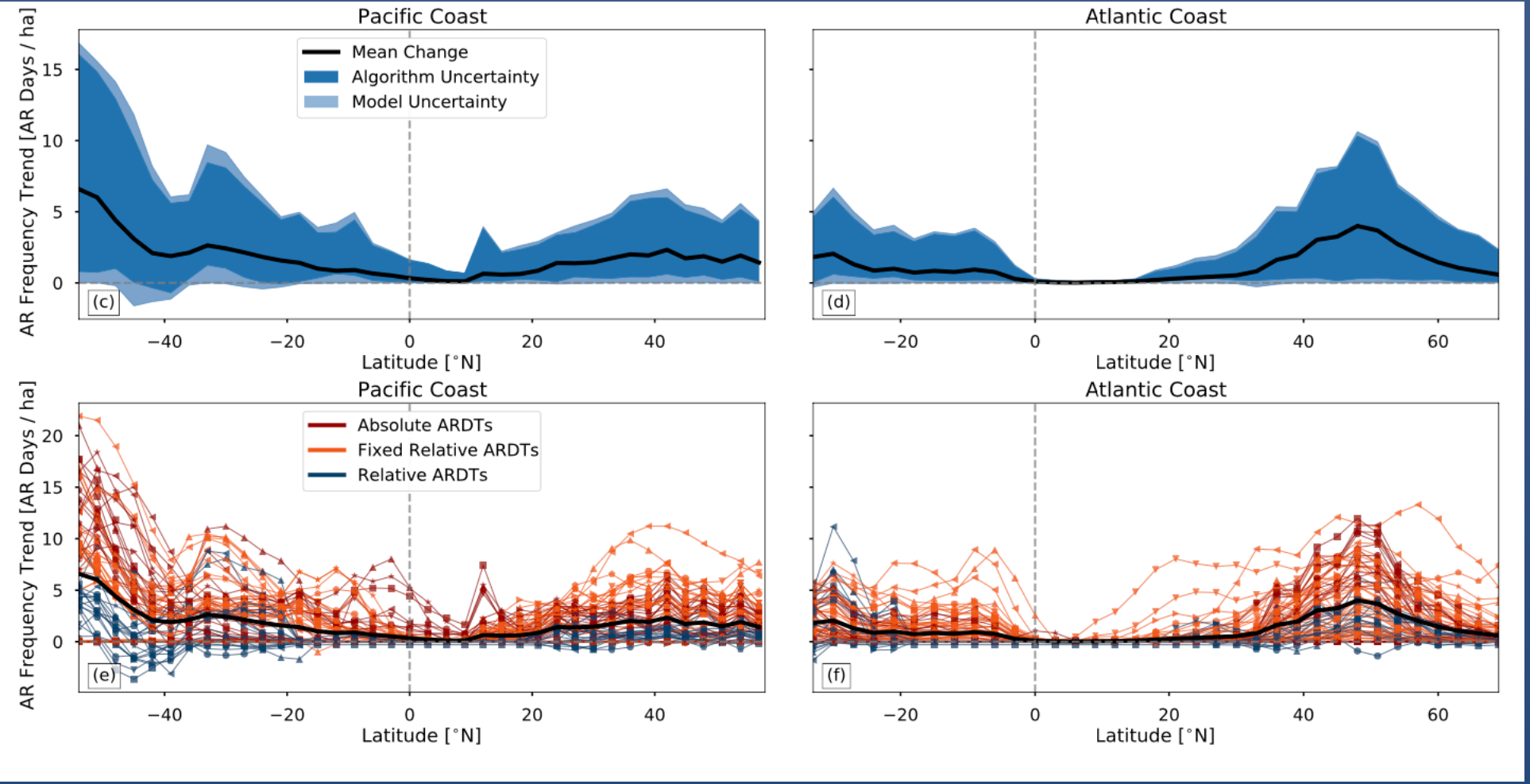


Tier 2 CMIP5/6: Models and Methods

Table S1. (left) ARDT algorithms, and associated metadata, that contributed to the Tier 2 CMIP5/6 experiment. ARDT classifications ('Class.') are described in Text S2. (right) Details of CMIP5/6 models used in the Tier 2 experiment.

ARDTs				Models			
Algorithm ID	Contrib.	Class.	Region	MIP Era	Model Name	Inst.	~Res. [km]
ARCONNECT_v2	Shearer	abs.	Global	CMIP5	CCSM4	NCAR	120
GuanWaliser_v2	Guan	fix. rel.	Global	CMIP5	CSIRO-Mk3-6	CSIRO	207
IDL_rel_future	Ramos	fix. rel.	W. Europe, S. Africa	CMIP5	CanESM2	CCCMA	310
IDL_rel_hist	Ramos	fix. rel.	W. Europe, S. Africa	CMIP5	IPSL-CM5A-LR	IPSL	296
Lora_v2	Lora	abs.	Global	CMIP5	IPSL-CM5B-LR	IPSL	296
Mundhenk_v3	Nardi	fix. rel.	Global	CMIP5	NorESM1-M	NCC	242
PNNL_v1	Sarangi	abs.	W. U.S.	CMIP6	BCC-CSM2-MR	BCC	124
Tempest	McClenny	rel.	Global	CMIP6	IPSL-CM6A-LR	IPSL	198
TECA_BARD_v1.0	O'Brien	rel.	Global	CMIP6	MRI-ESM2-0	MRI	124

Tier 2 CMIP5/6: Which dominates uncertainty, model or method?



Most variation can be explained by algorithm type:

Absolute:
uses absolute thresholds

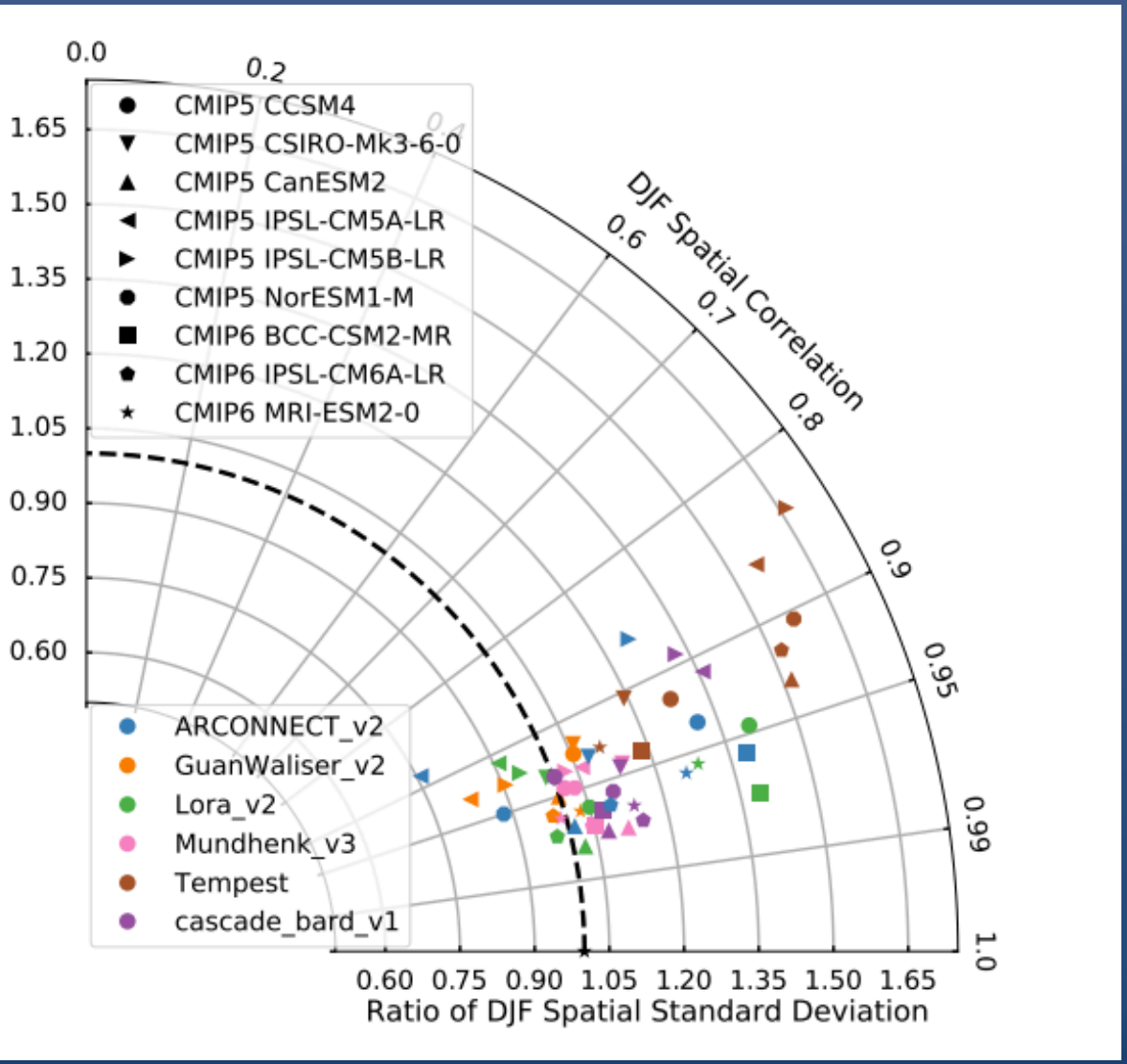
Fixed-relative:
Uses time-invariant relative values

Relative:
Uses relative values that change with time

T2 CMIP5/6 slides courtesy of Travis O'Brien

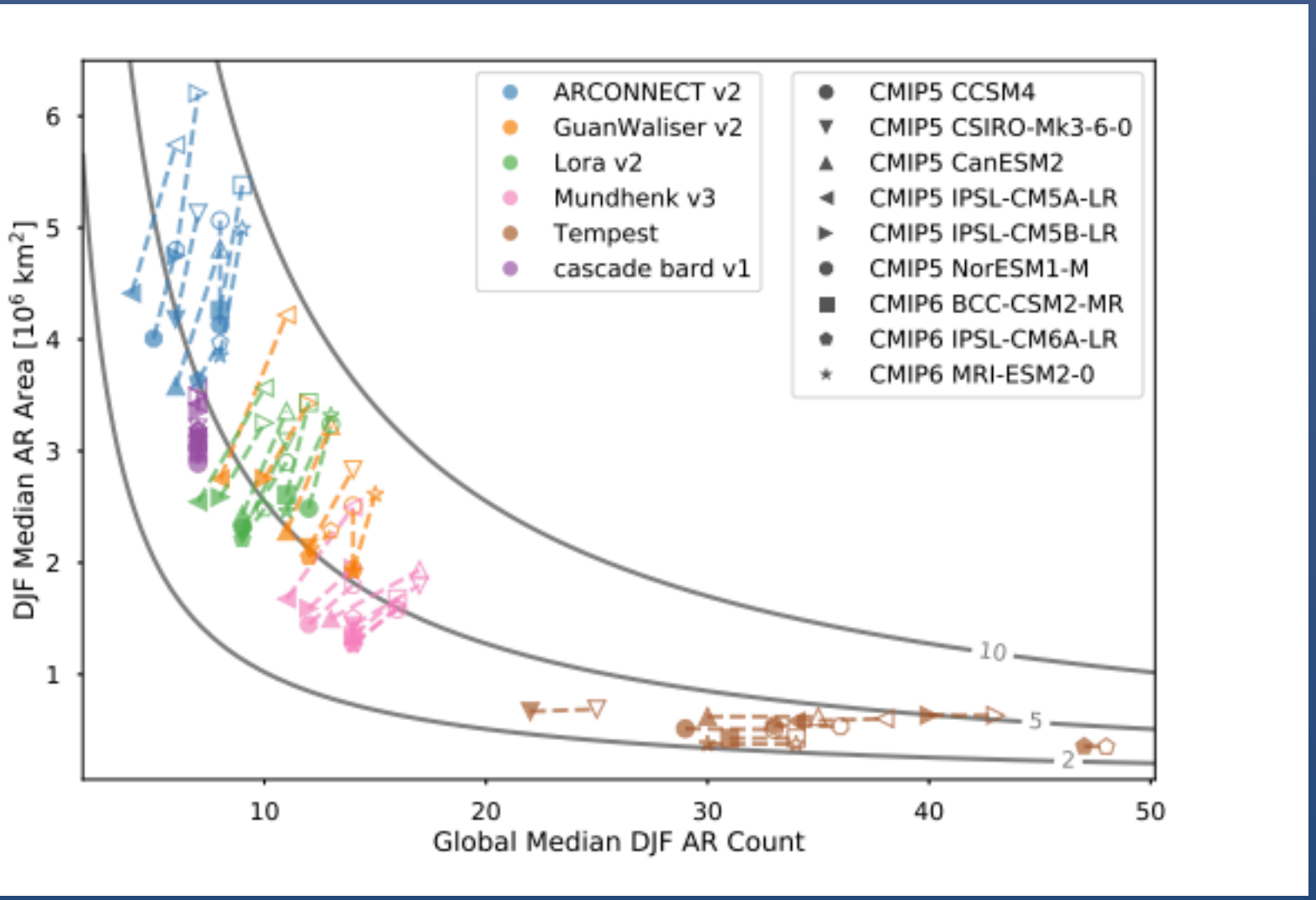
O'Brien et al, 2020, in revision GRL

Tier 2 CMIP5/6 Taylor Diagram



- Spatial correlation (azimuthal axis) and spatial variability (radial axis) of DJF AR frequency
- CMIP5/6 simulations denoted by different symbols
- Colors indicate different AR detection algorithms (legend in panel b)
- (MERRA-2) Tier 1 and (CMIP5/6) Tier 2 pairs are considered
- Shows that simulations compare well with observations when compared within a single ARDT

Tier 2 CMIP5/6 DJF AR Counts and Size



- Median AR area vs global median AR
- Filled symbols indicate calculations for 1981-2010
- Open symbols indicate calculations for 2070-2099
- Gray contours show lines of constant fractional are coverage of ARs
- Most algorithms detect more and larger ARs

T2 Renalysis Datasets

Participants must submit Tier 1 MERRA-2 catalogue, MERRA-2 at native resolution (full period), and ERA5 (2000-2019)

Reanalysis	Resolution	Time Period
MERRA-2	0.5˚ x 0.625˚ , 1 hr	1980-2019*
ERA5	0.25˚, 1 hr	1980-2019 (2000-2019*)
JRA55	1.25˚, 6 hr	1980-2019
JRA55C	1.25˚, 6 hr	1972-2012

T2 Reanal slides courtesy of Allison Collow

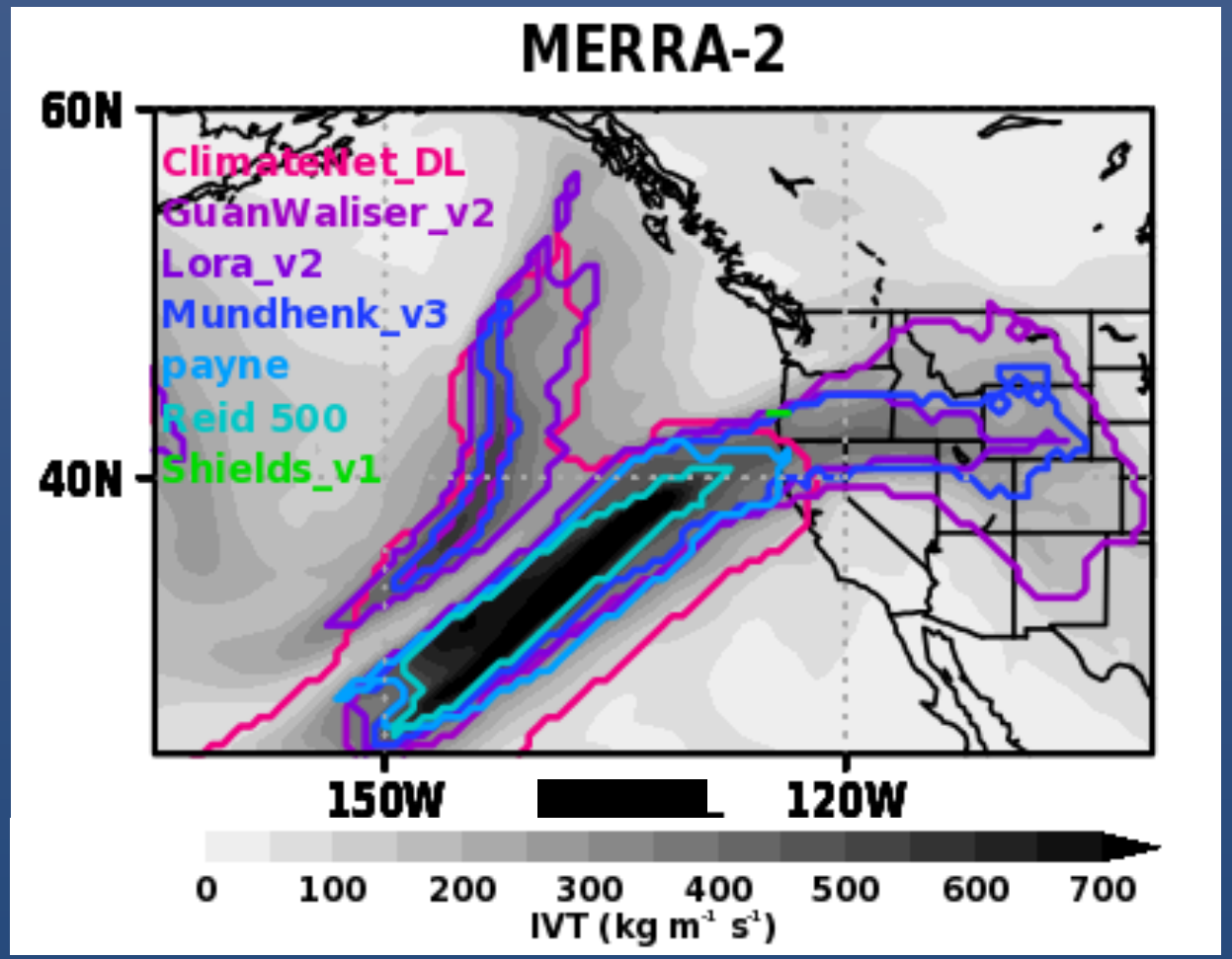
T2 Renalysis Algorithms

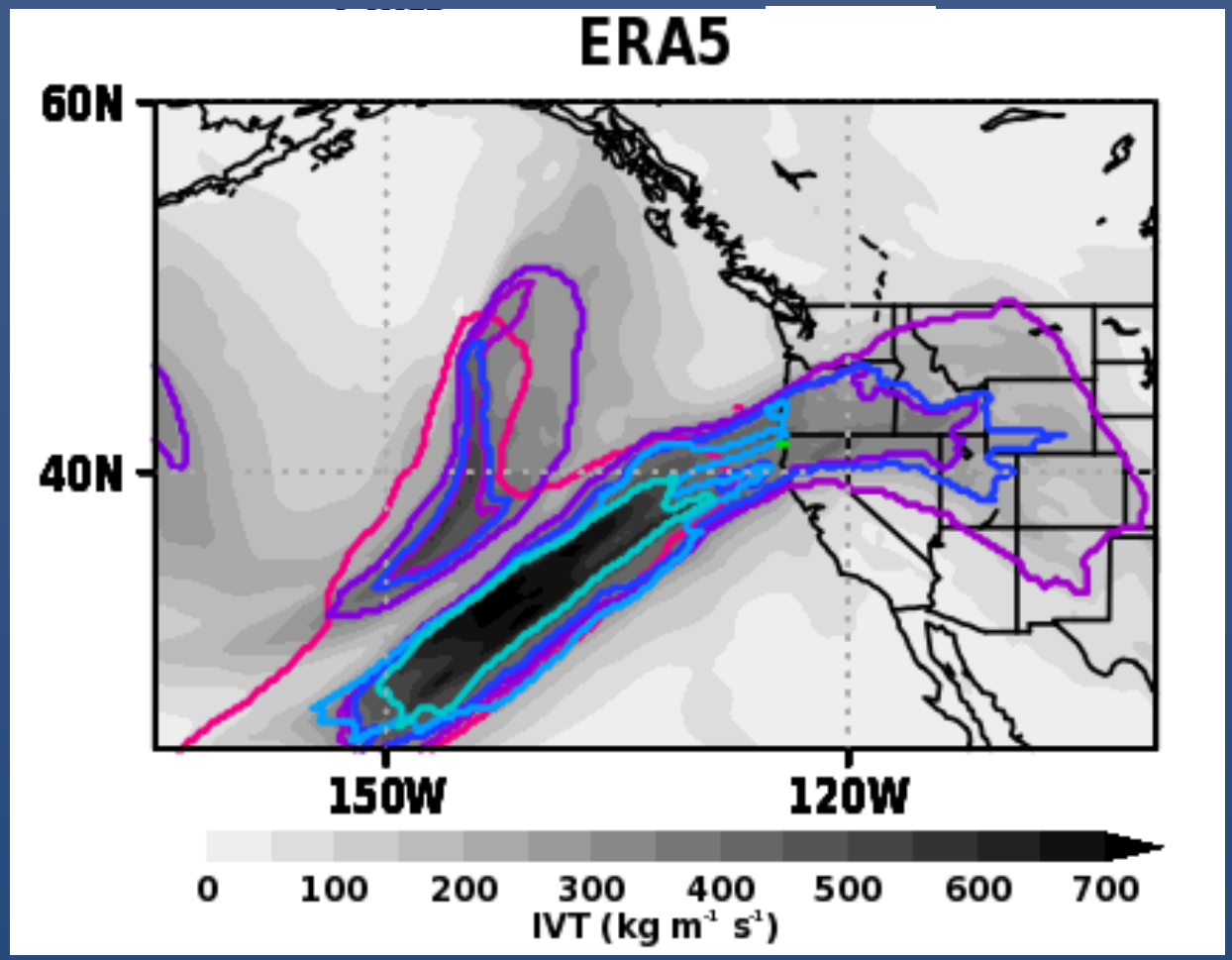
- Combination of machine learning, absolute threshold, relative threshold, regional, global
- A few more are on the way
- New submissions will not be accepted after the end of the month

Algorithm	Participant	Institution
ClimateNet_DL_model	Sol Kim	UC Berkeley (US)
GuanWaliser_v2	Bin Guan	JPL (US)
IDL_v2b	Ricardo Tome	U Lisbon (Portugal)
Lora_v2	Juan Lora	Yale (US)
Mundhenk_v3	Kyle Nardi	Penn State (US)
Payne	Ashley Payne	U Michigan (US)
Reid500	Kim Reid	U Melbourne (Australia)
Shields_v1	Christine Shields	UCAR (US)
Wille_v2.4	Jonathan Wille	U Grenoble (France)

T2 Reanal slides courtesy of Allison Collow

AR Detection for a Single Event: 0z 15 February 2014





- Subtle differences between MERRA-2 and ERA5, both in IVT and AR detection
- Contrary to results along the coast, ERA5 has smoother AR contours