

ARctic Serenade : Dancing with Arctic Atmospheric Rivers in the Changing Climate Symphony

Rudradutt Thaker¹, Steve Vavrus¹, Christine Shields², Alice DuVivier², Marika Holland², Laura Landrum²

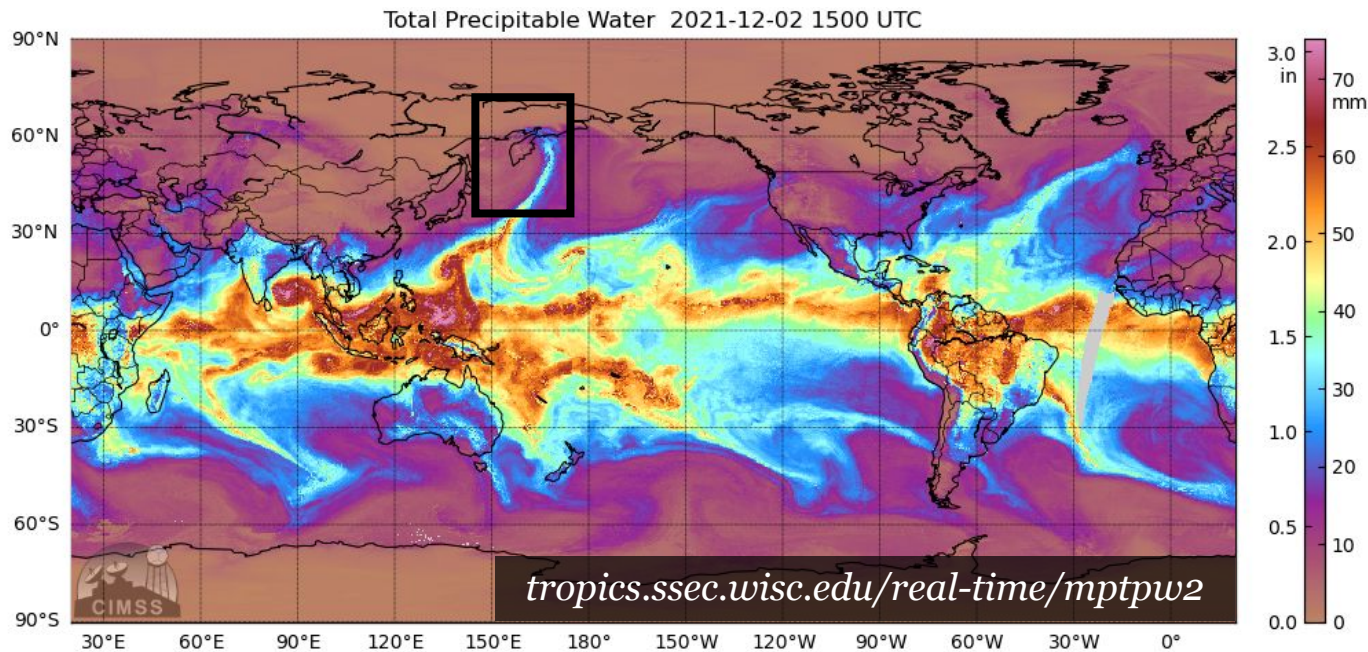
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² National Center for Atmospheric Research, Boulder, Colorado

Thaker et al. , in preparation



ATMOSPHERIC RIVERS (AR)



“ Long narrow corridors of moist and warm air from lower latitudes often associated with an extratropical cyclone. ”

- American Meteorological society (AMS) *



Sea-Ice Changes



Heatwaves



Extreme Precipitation

Changes In Extremes

Winter-time extreme warming events have been increasing in duration and frequency.

- *(Moore, G. W. K. 2016, Graham, R. et al. 2017)*

The winter trend in extreme cyclones is dominated by a **positive monthly trend** of about 3–4 events/decade in November–December

- *(Rinke, A. et al. 2017)*

Increasing trends in **Atmospheric Rivers** over **Greenland** playing a crucial role in **Greenland Ice Sheet mass loss acceleration**.

- *(Mattingly, K. S. et al. 2018)*

More **frequent Atmospheric Rivers** in the winter months **slows down the sea-ice growth**.

- *(Zhang, P. et al. 2023)*

**Should we
worry about
Atmospheric
Rivers in the
future climate?**

**I don't know!
Wait....**



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Picture by: Stephen

Q1: Does CESM2 Capture **Arctic ARs** ?

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Q2: How do **ARs change** in future climate ?

Atmospheric River Changes

Frequency

- Number of hours of AR conditions at a location.
 - Number of ARs.
 - Duration of individual ARs.

Intensity

- More Moisture flux in individual ARs
- 300 kg/m/s to 450 kg/m/s

DATASET

Reanalysis Dataset

MERRA2

Modern-Era Retrospective analysis for
Research and Applications, version 2
(Gelaro R. et al., 2017)

1980-2019

3 hourly

0.5° x 0.625° Resolution

DATASET

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Climate Model

CESM2

Community Earth System Model -2
(Danabasoglu et al., 2020)

Historical Simulation

1850 – 2015

40 Ensemble Mem

Future Simulation

SSP370 : 2015 – 2100

50 Ensemble Mem

6 hourly

1° x 1° Resolution

METHODOLOGY

Jonathan Wille's Algorithm

Widely used for Polar ARs

3 or 6 hrly Meridional Integrated
Vapor Transport (**vIVT**)



Monthly 98th Percentile of vIVT

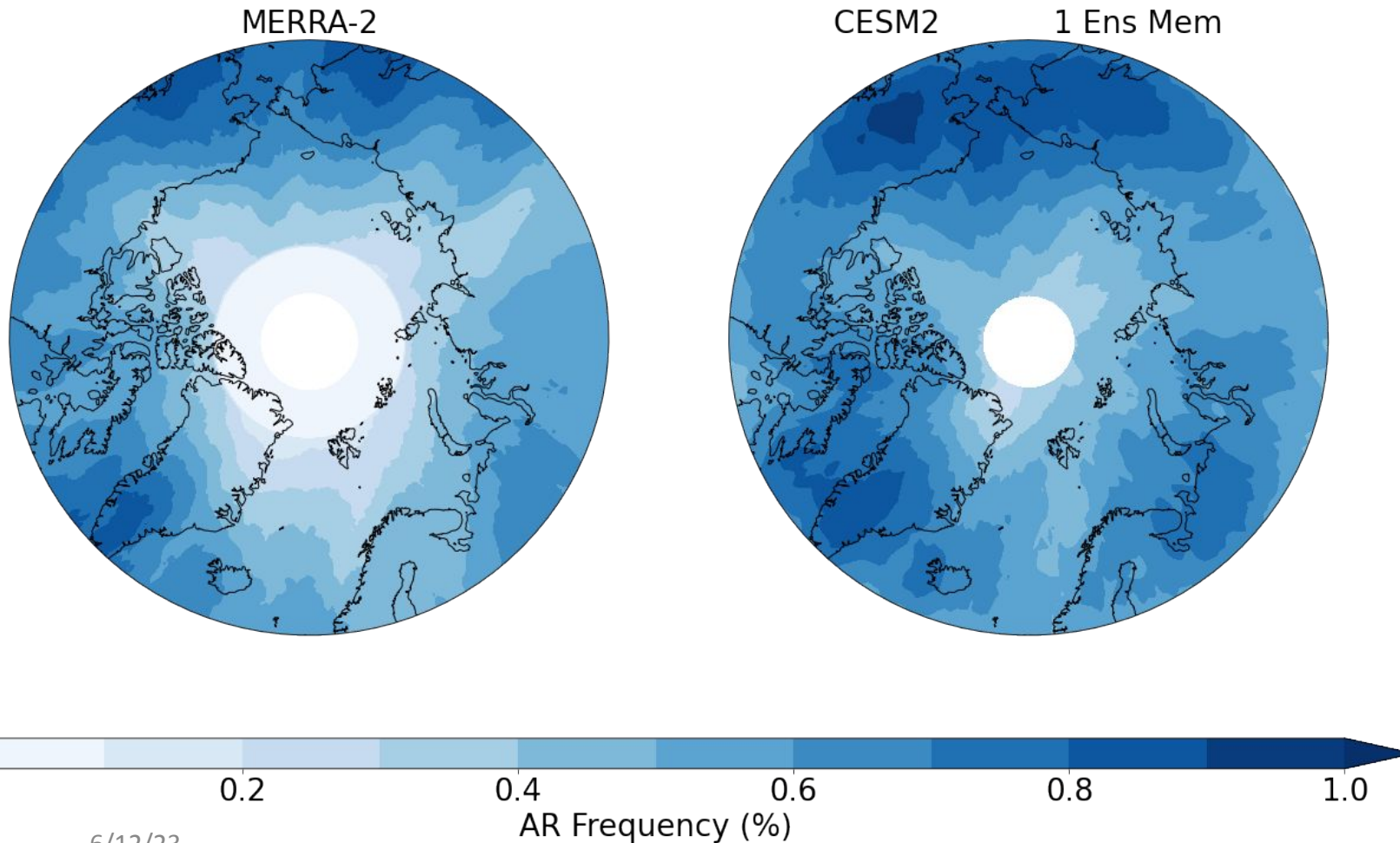


Length \geq 2000 km



AR Detected

Q1 : Does CESM2 Capture **Arctic ARs** ? Frequency

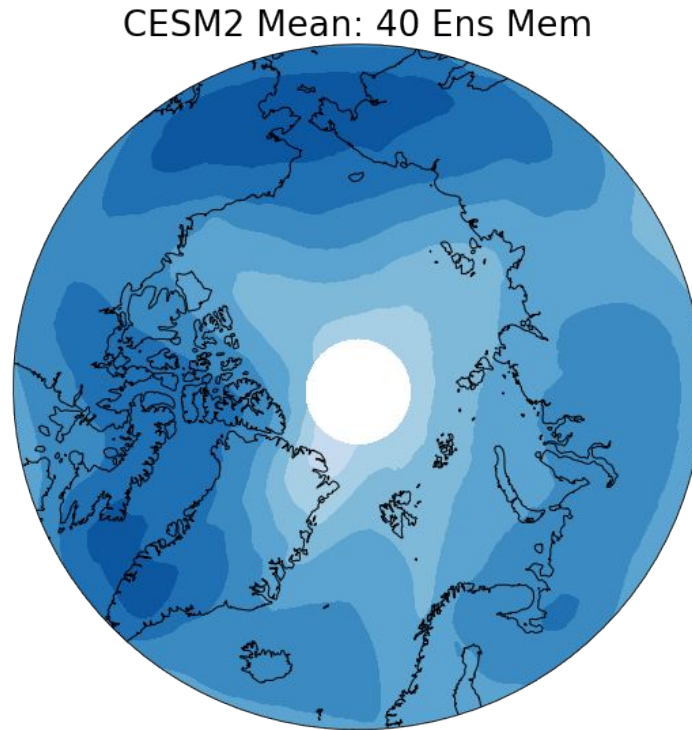
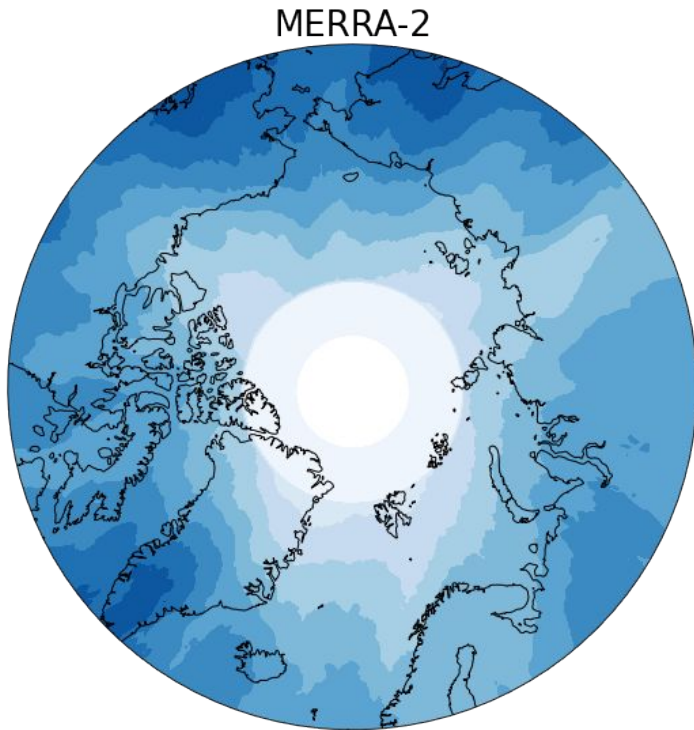


**Arctic AR Heatmap
Comparison
(1980 - 2015)**

Captures the
Spatial Features

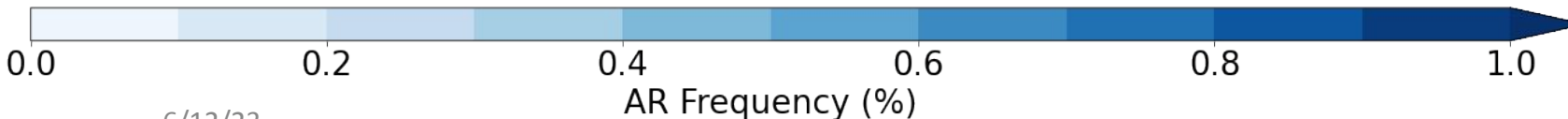
Q1 : Does CESM2 Capture **Arctic ARs** ?

Frequency: **YES**



**Arctic AR Heatmap
Comparison
(1980 - 2015)**

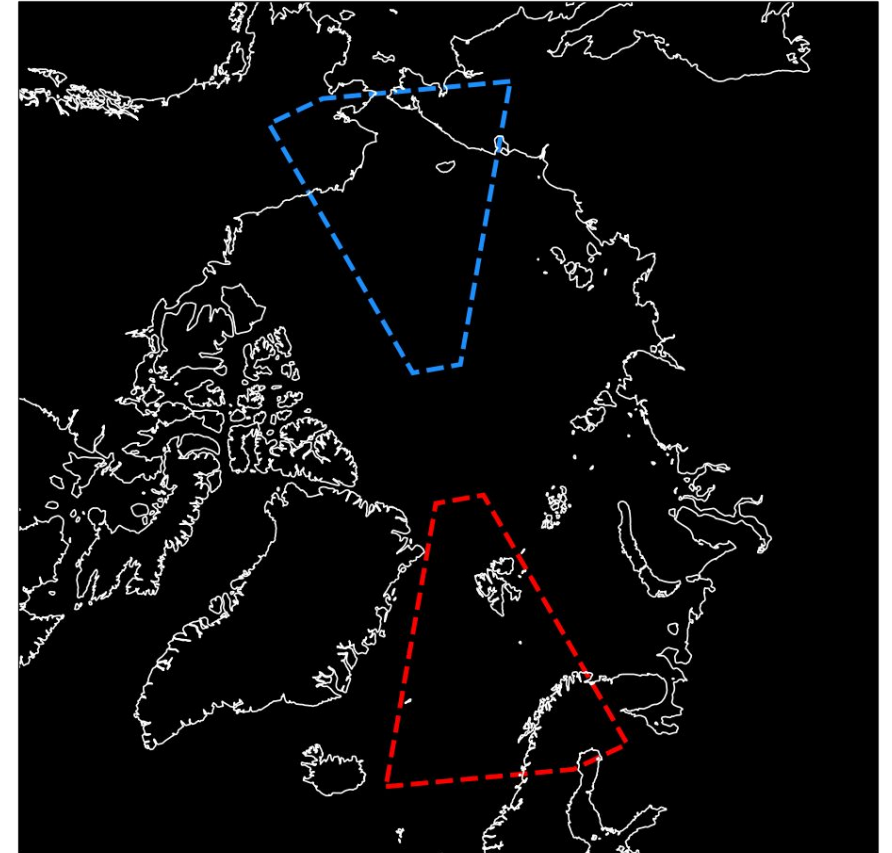
Broad Agreement
between MERRA2 and
CESM2



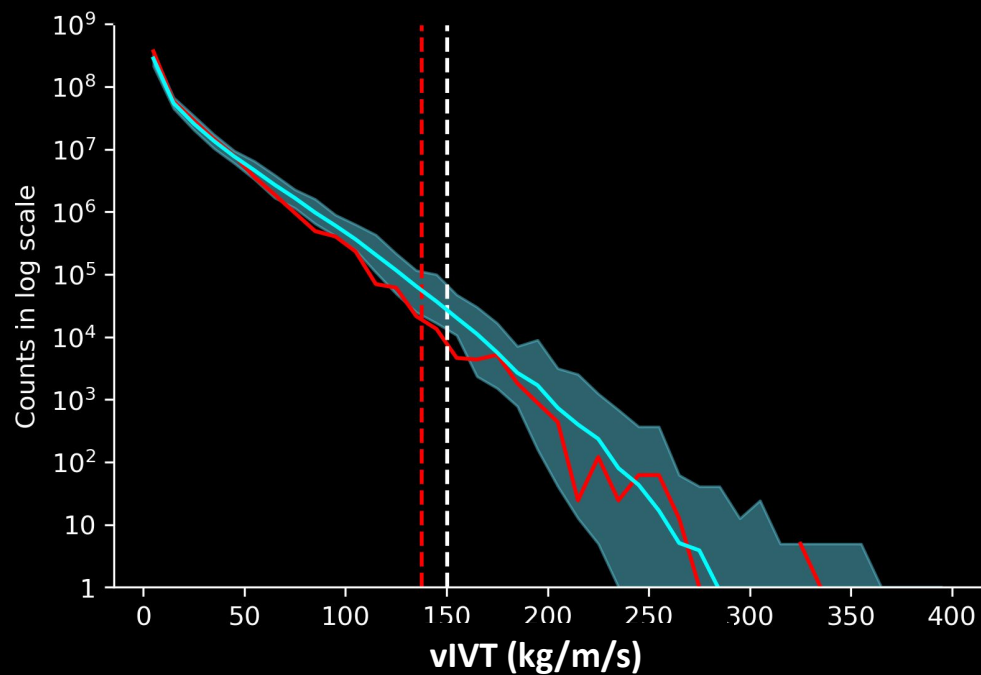
Q1: Does CESM2 Capture **Arctic ARs** ? Intensity (1996-2005)

**ALL Times and NOT
just ARs**

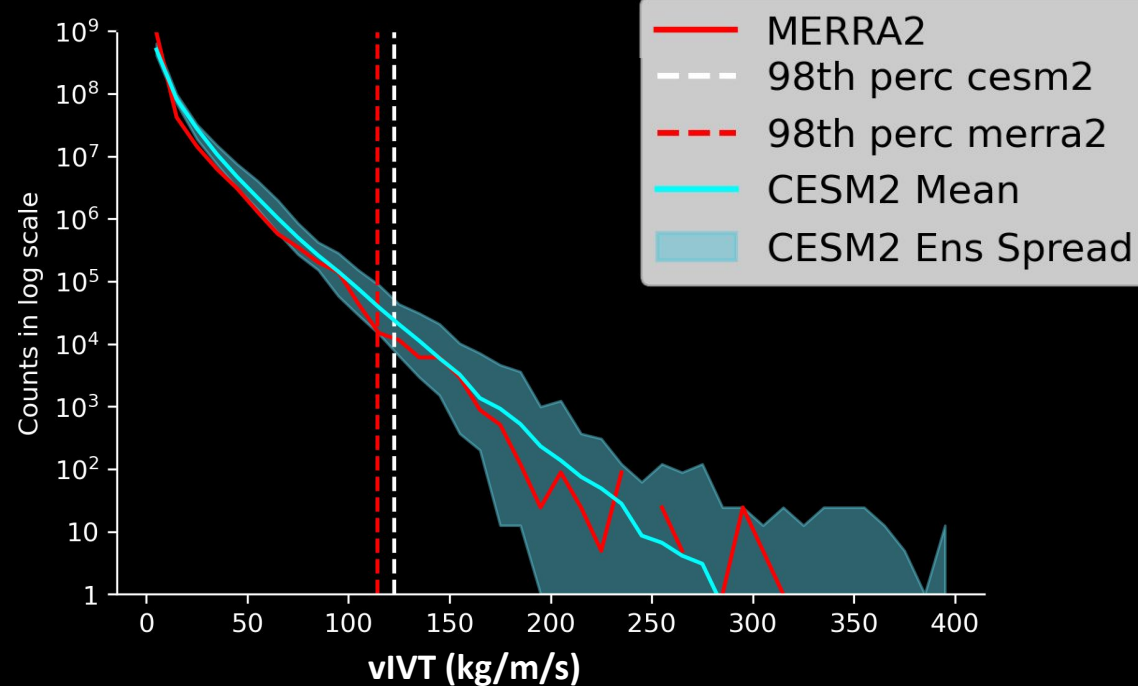
- Meridional Vapor Transport (**vIVT**)
- **Spatially averaged** over region
- **Logarithmic Y-Axis**
To focus on extremes



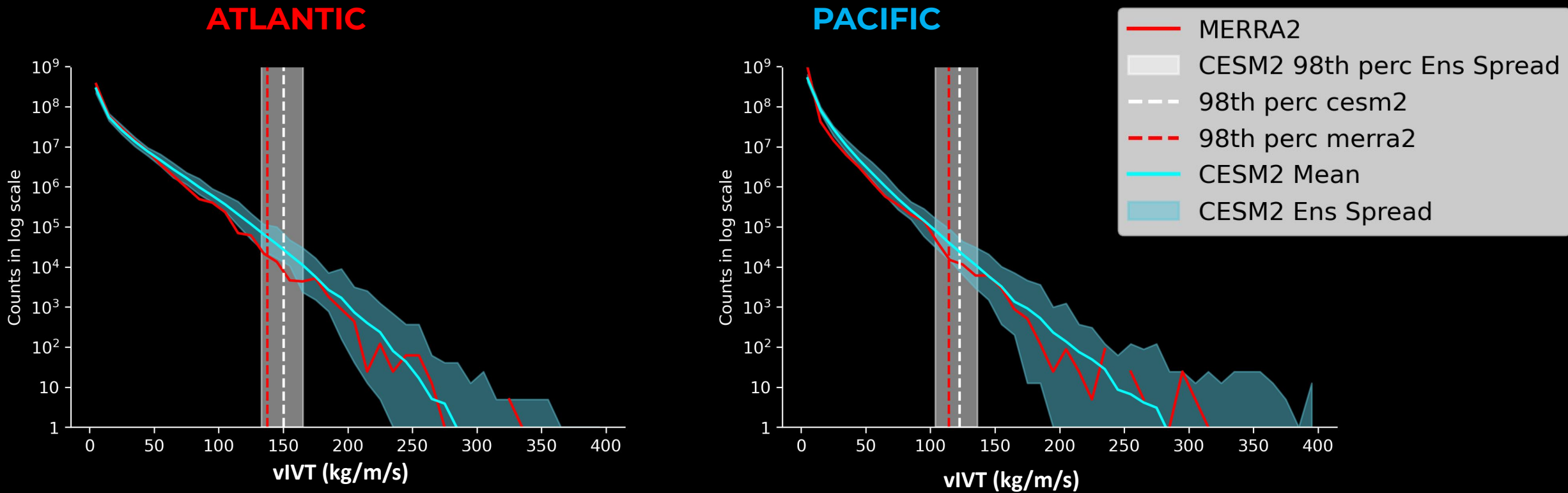
ATLANTIC



PACIFIC



CESM2 captures the magnitude of meridional vapor transport, **especially the extreme ones.**



CESM2 captures the magnitude of meridional vapor transport, **especially the extreme ones.**

Q1: Does CESM2 Capture Arctic ARs ?

Frequency : YES

Intensity : YES

Q2: How do ARs change in future climate ?

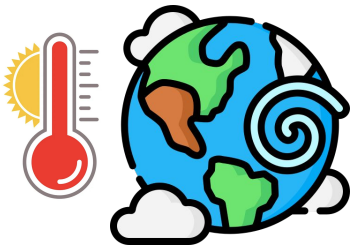
Q1: Does CESM2 Capture **Arctic ARs** ?

Frequency : **YES**

Intensity : **YES**

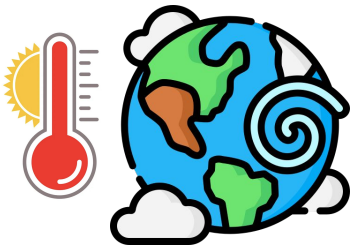
Q2: How do **ARs change in future climate?**

FUTURE CHANGES



Climate
Warms

FUTURE CHANGES

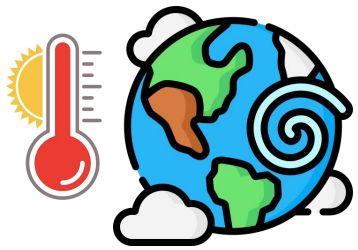


Climate
Warms

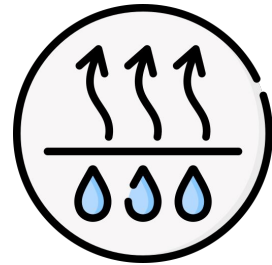


Moisture
Increases

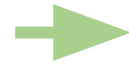
FUTURE CHANGES



Climate
Warms

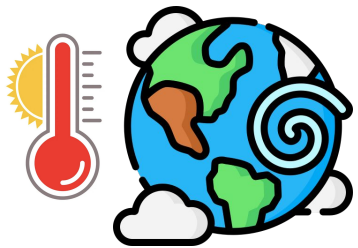


Moisture
Increases



Moisture Transport
Changes

FUTURE CHANGES



Climate
Warms



Moisture
Increases



Moisture Transport
Changes



**Atmospheric River
Changes**

Mainly because it is
threshold sensitive

Q2: How do **ARs change** in future climate ?

Frequency

Climate Change signal in CESM2



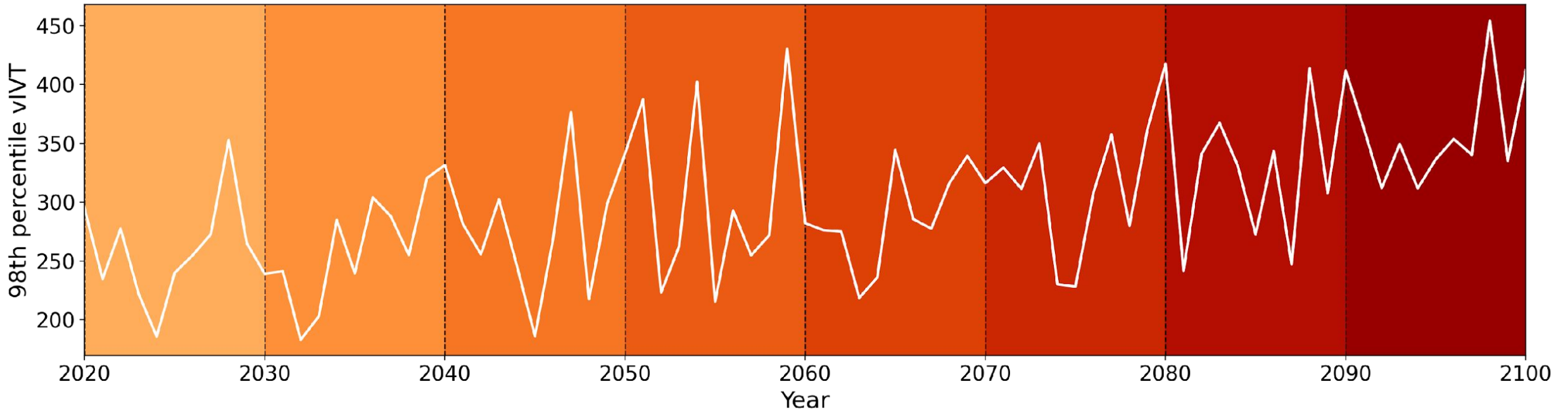
Decadal 98th percentile (*10 years*)



Unique threshold for each decade.

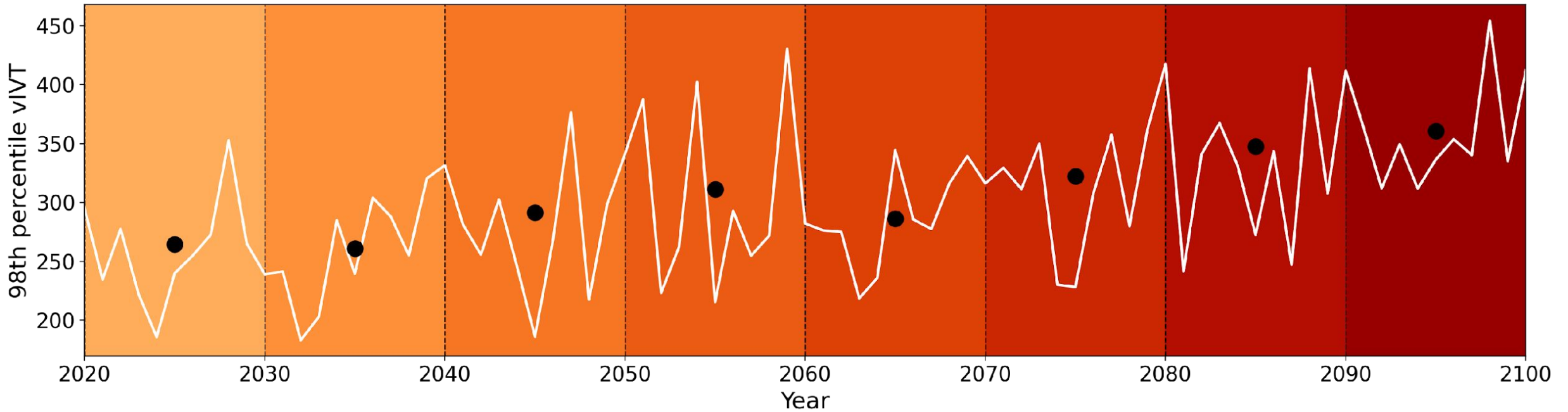
Example: One Location

Annual 98th vIVT percentile



Example: One Location

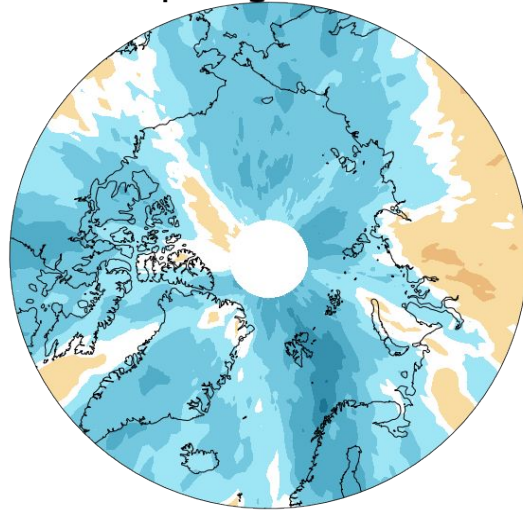
Annual 98th vIVT percentile



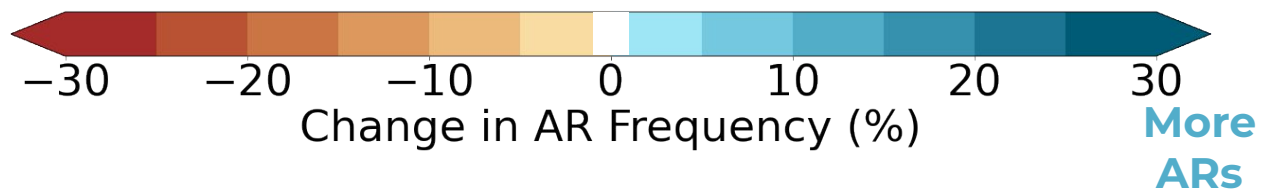
Winter: DJF



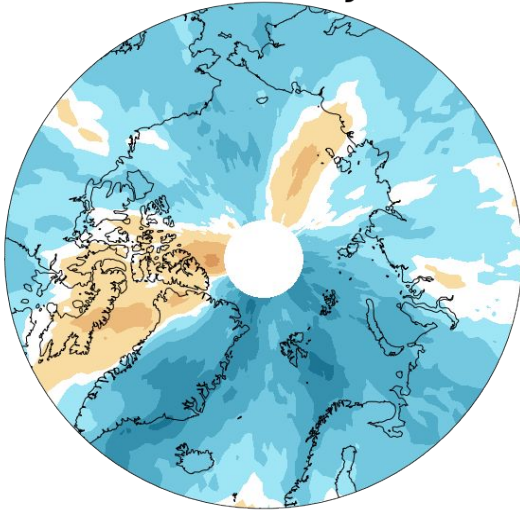
Spring: MAM



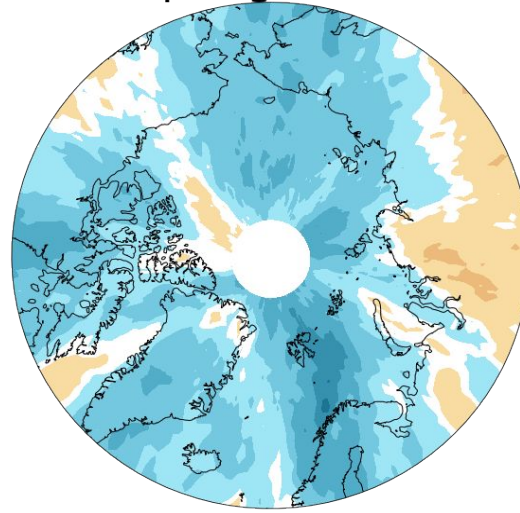
**AR Frequency
Changes in
2065-2100
based on
1980-2015
using
Ensemble
Mean**



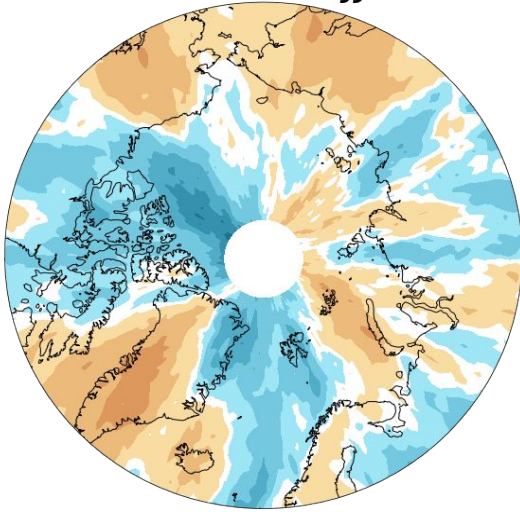
Winter: DJF



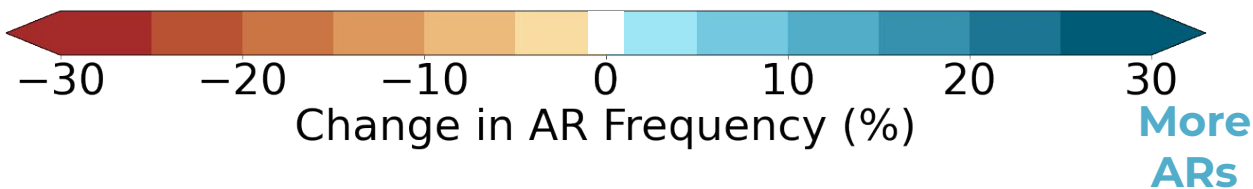
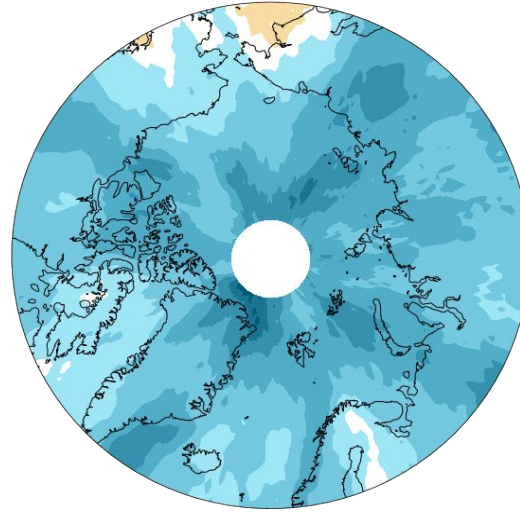
Spring: MAM



Summer: JJA

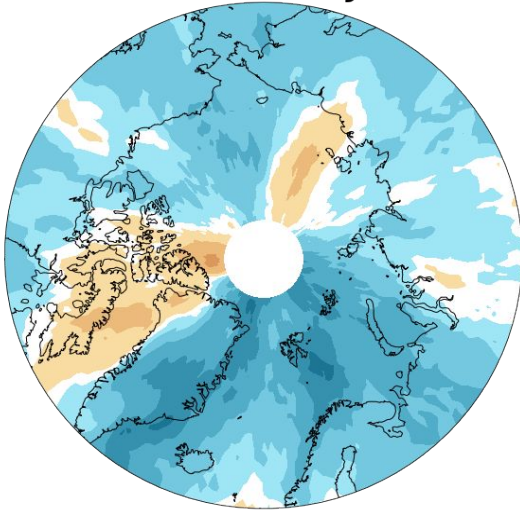


Fall: SON

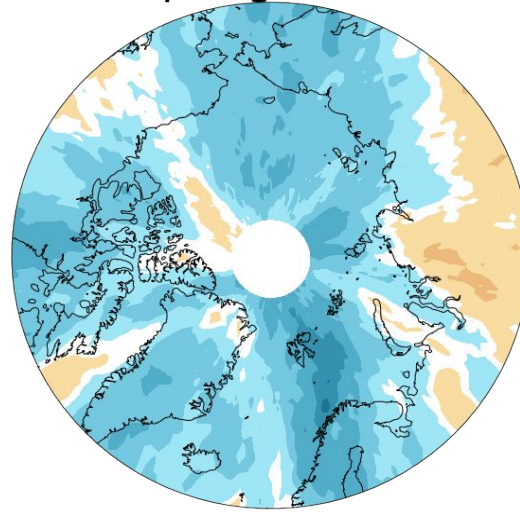


**AR Frequency
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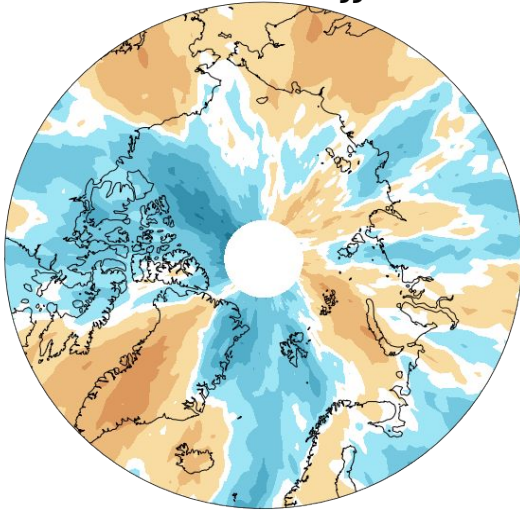
Winter: DJF



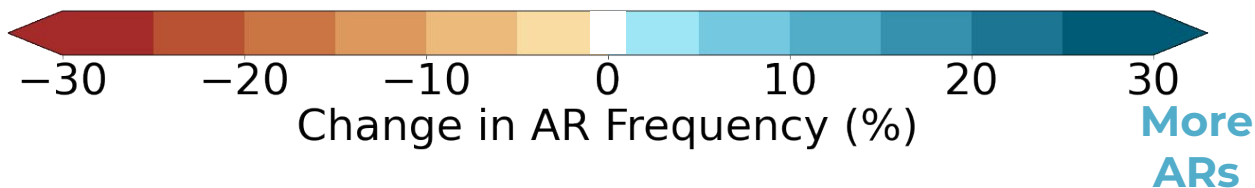
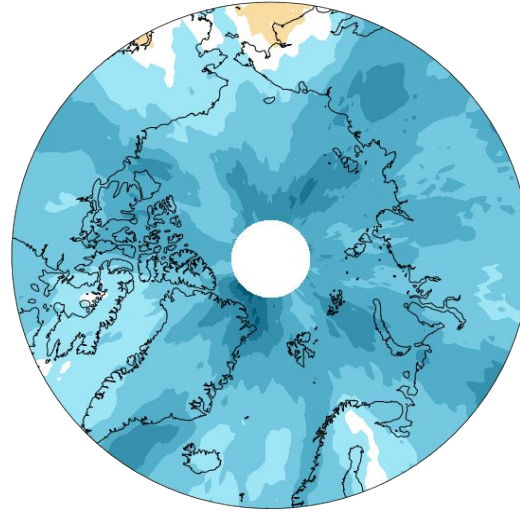
Spring: MAM



Summer: JJA



Fall: SON



MORE ARs in Arctic

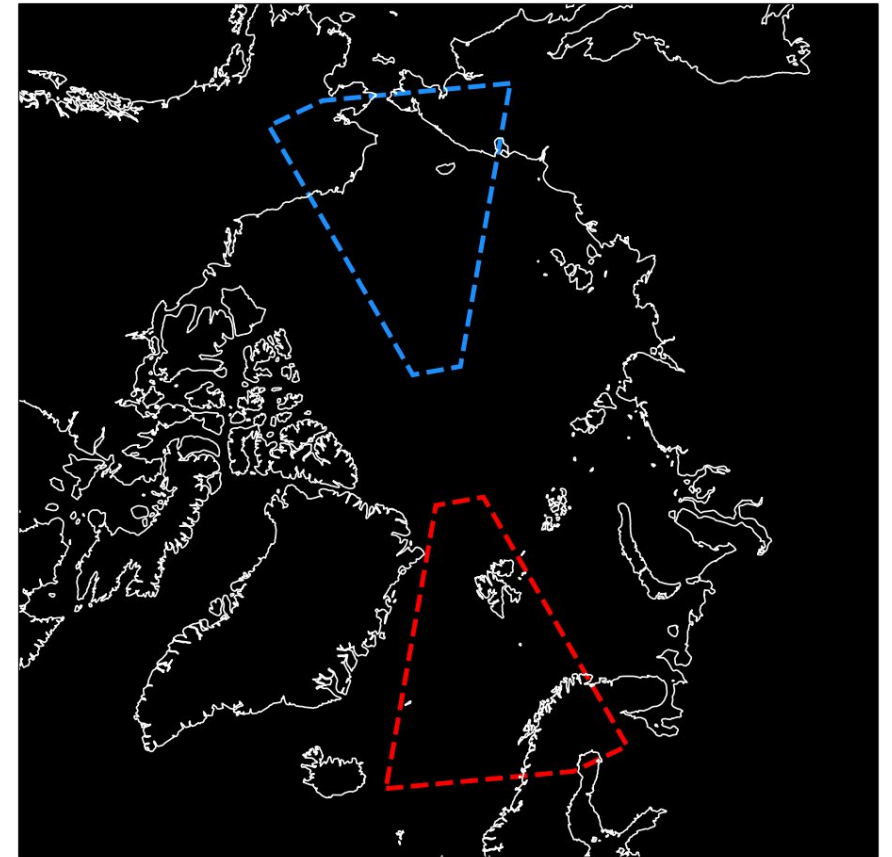
- **Moving Threshold**
- The increasing frequency is due to **extratropical cyclones**.
- Frequency increase in Pacific and Atlantic sector during Winter, Fall, and Spring.
- **Greater Increase** in Central Arctic.

Q2: How do **ARs change** in future climate ?

Intensity

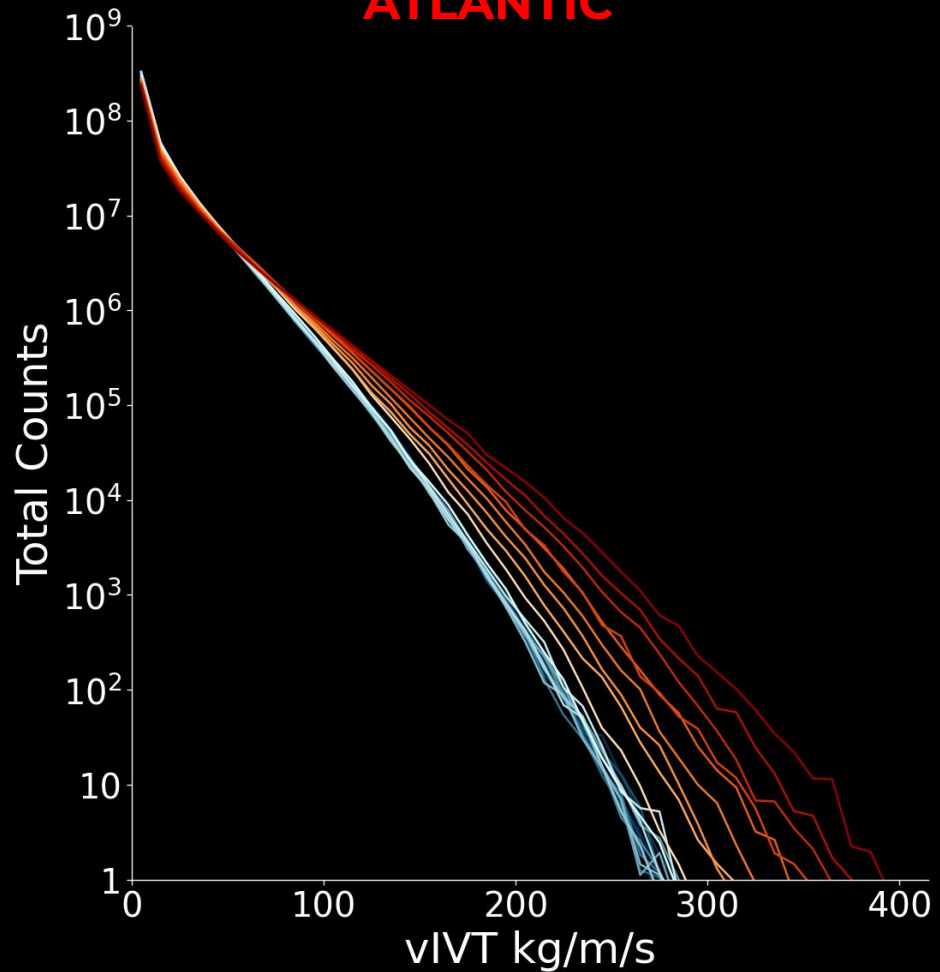
**ALL Times and NOT
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- Meridional Vapor Transport (**vIVT**)
- **Spatially averaged** over region
- **Ensemble Mean**

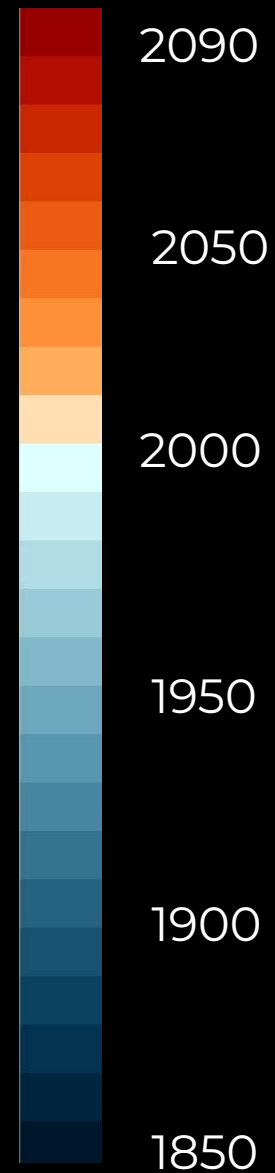
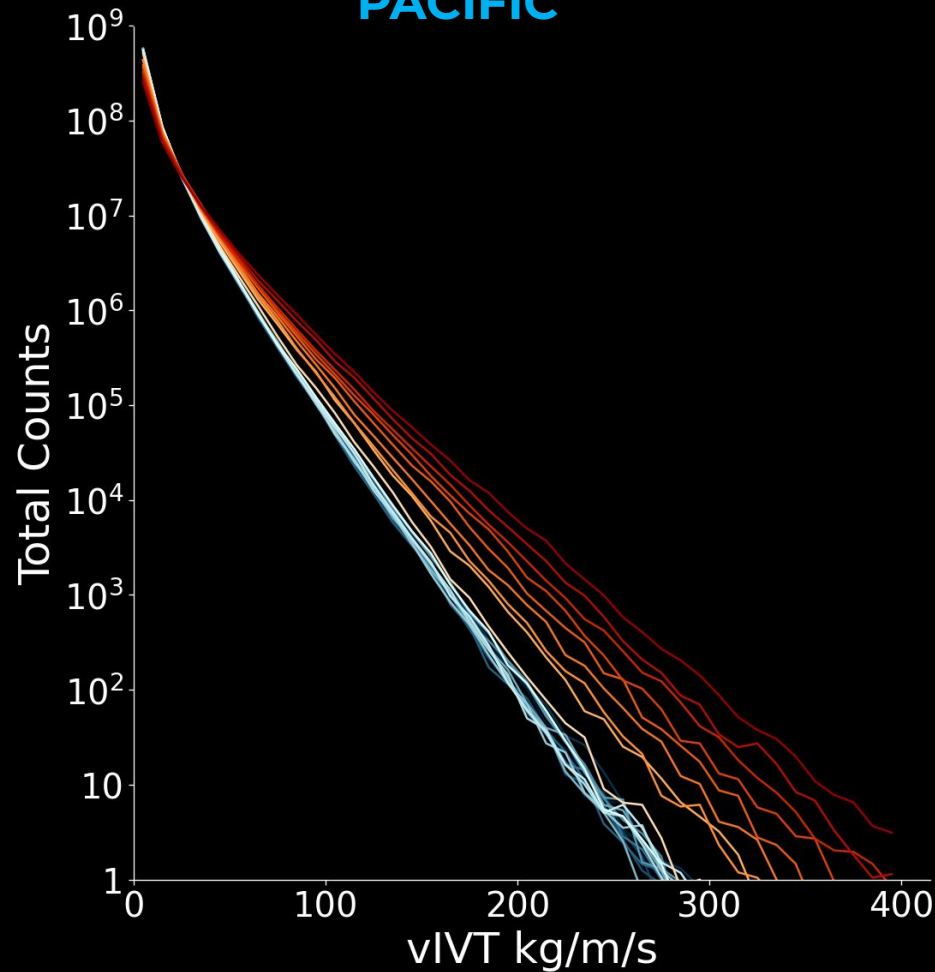


Distribution of vIVT for Ensemble Mean

ATLANTIC

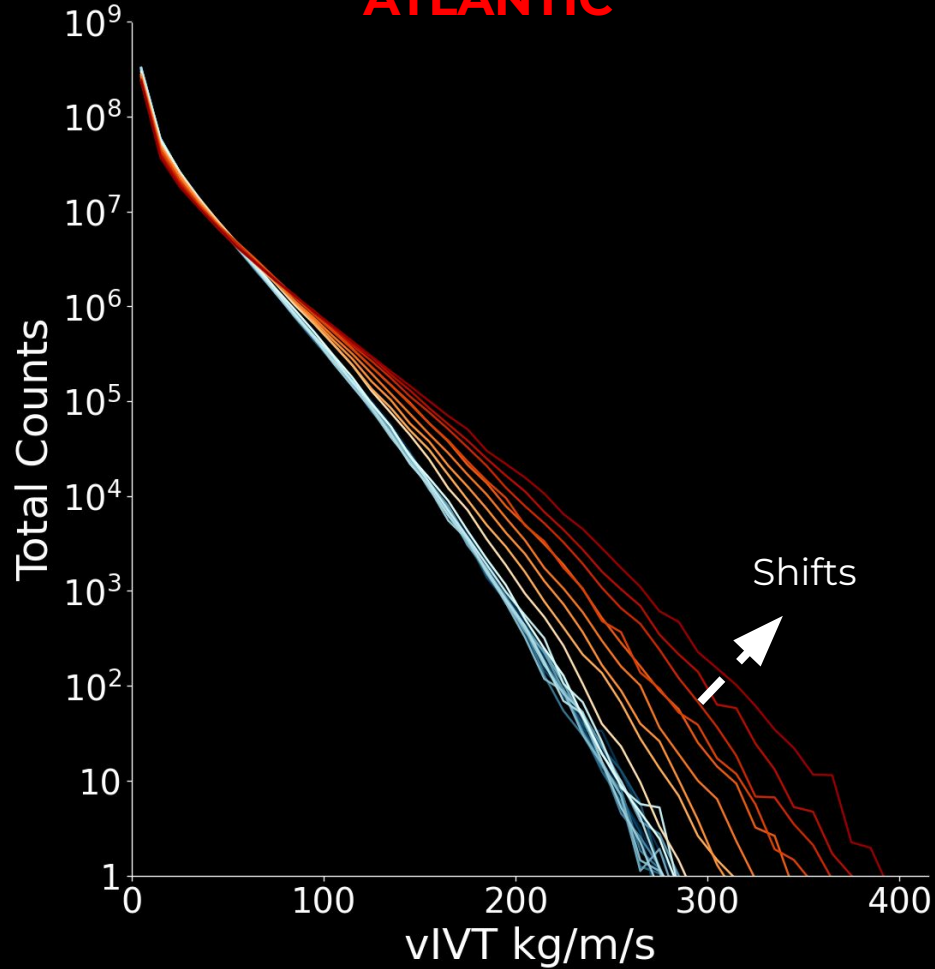


PACIFIC

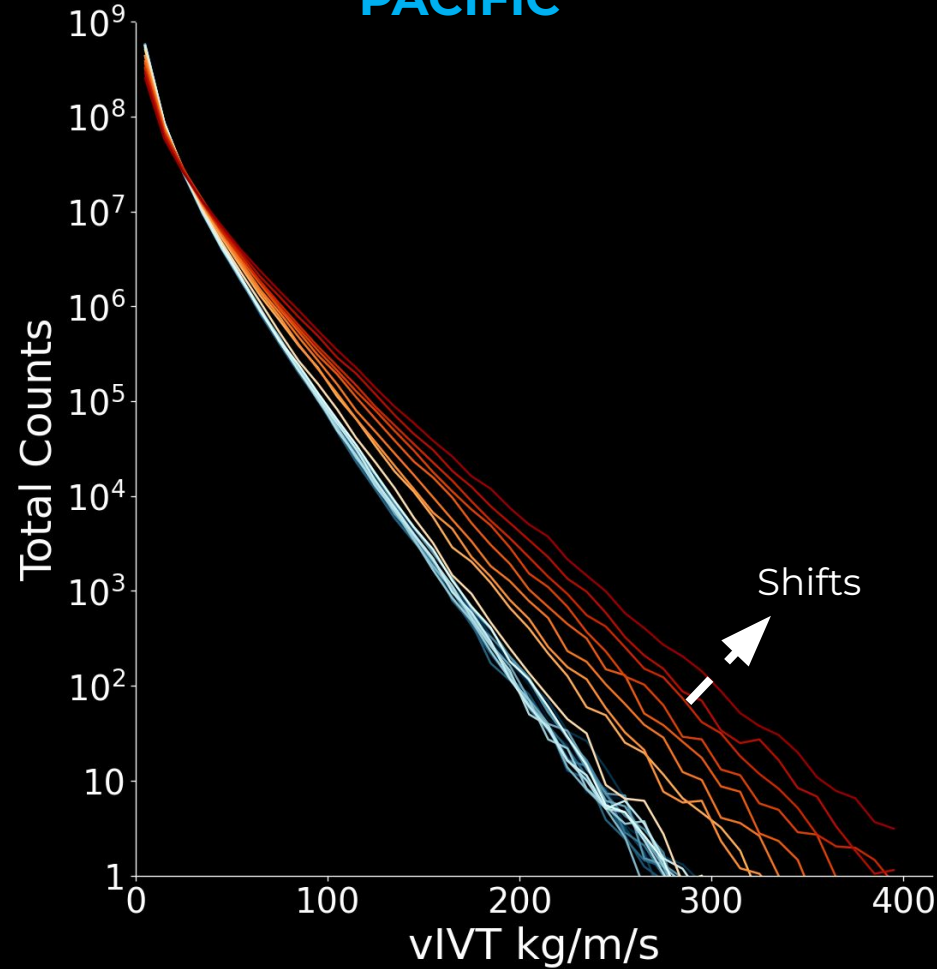


Distribution of vIVT for Ensemble Mean

ATLANTIC



PACIFIC

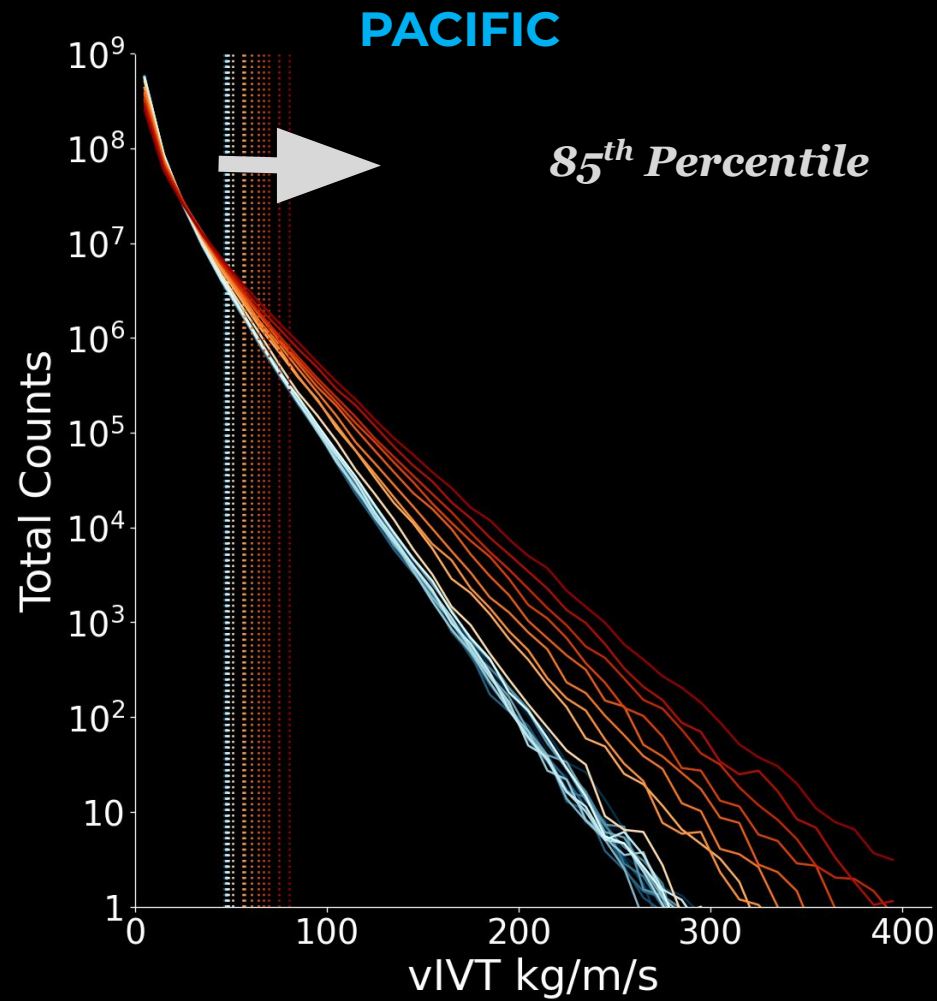
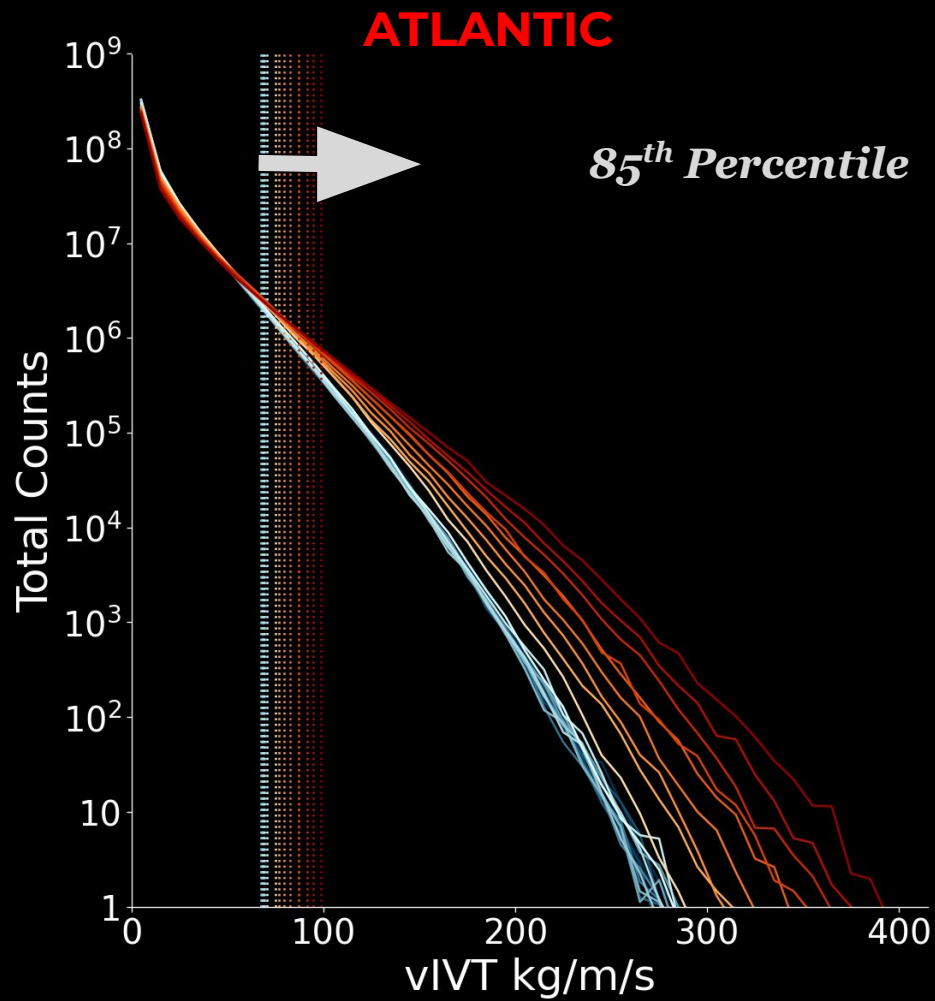


**The Extremes
are getting
more Extreme**

- The tails of the distribution is changing shown by the arrows.



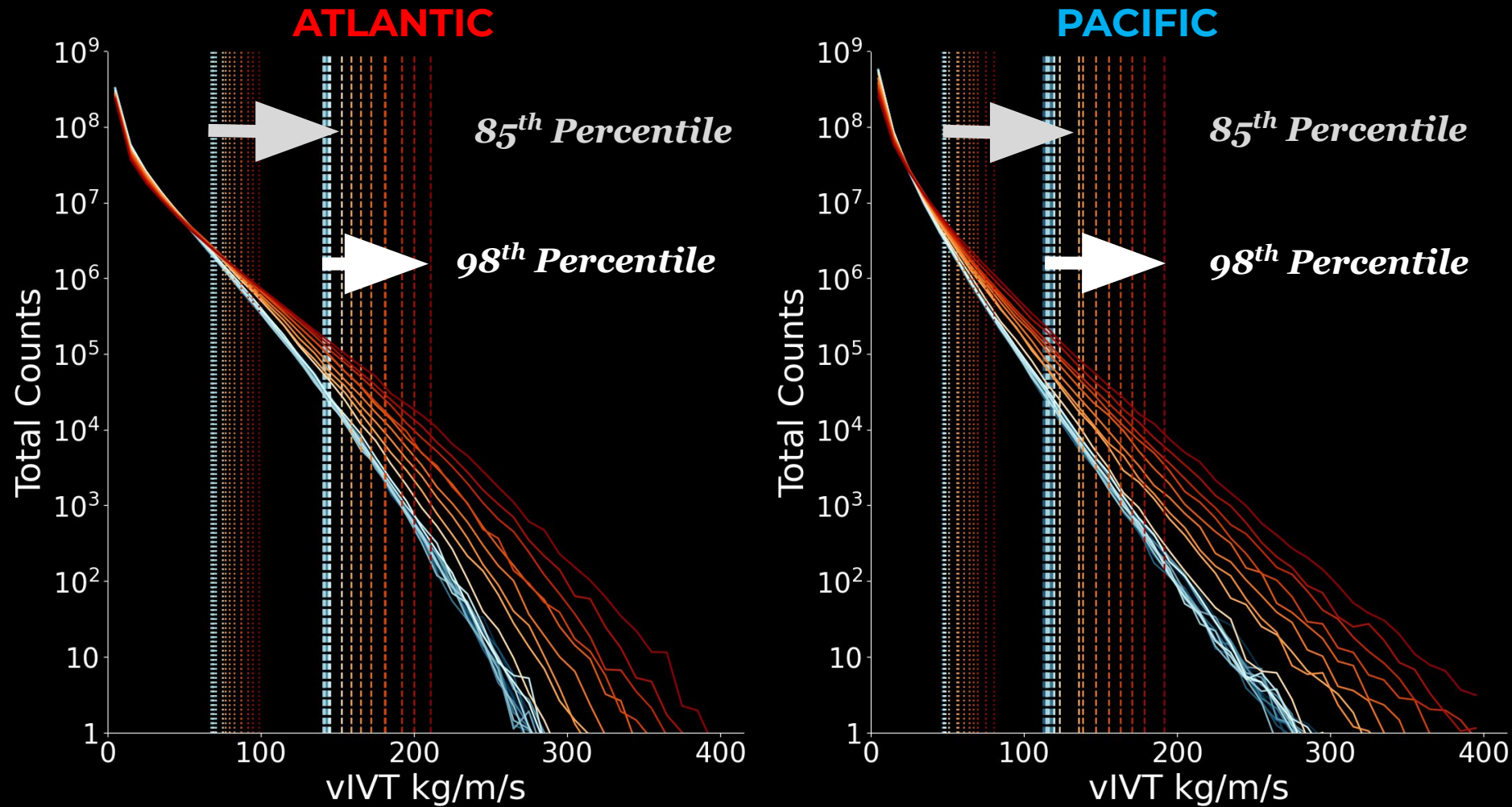
Distribution of vIVT for Ensemble Mean



The **Extremes**
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Distribution of vIVT for Ensemble Mean

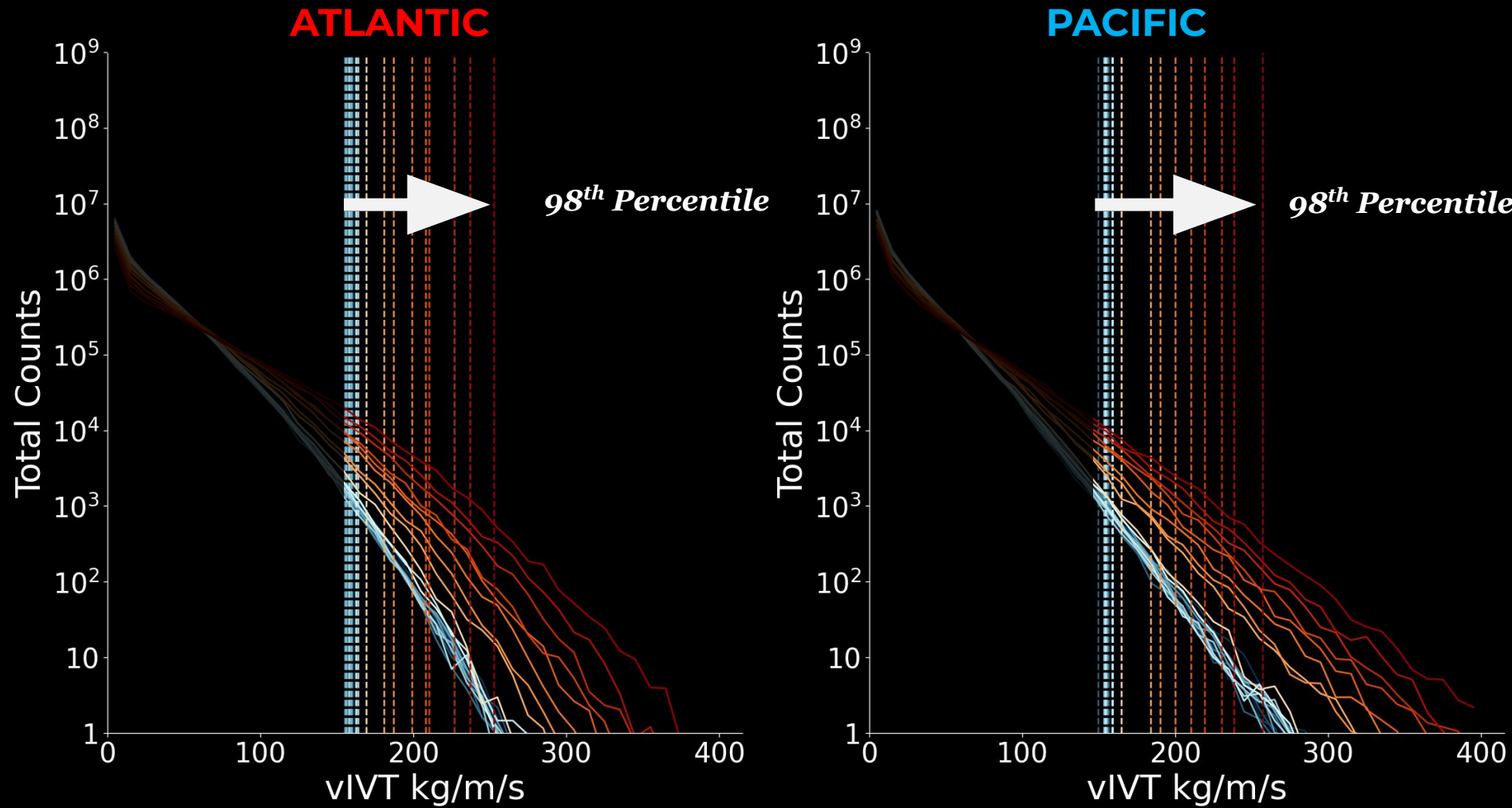


The **Extremes** are getting more **Extreme**

- The 98th percentile threshold shows larger changes with each decade.



Summer JJA : Distribution of vIVT for Ensemble Mean



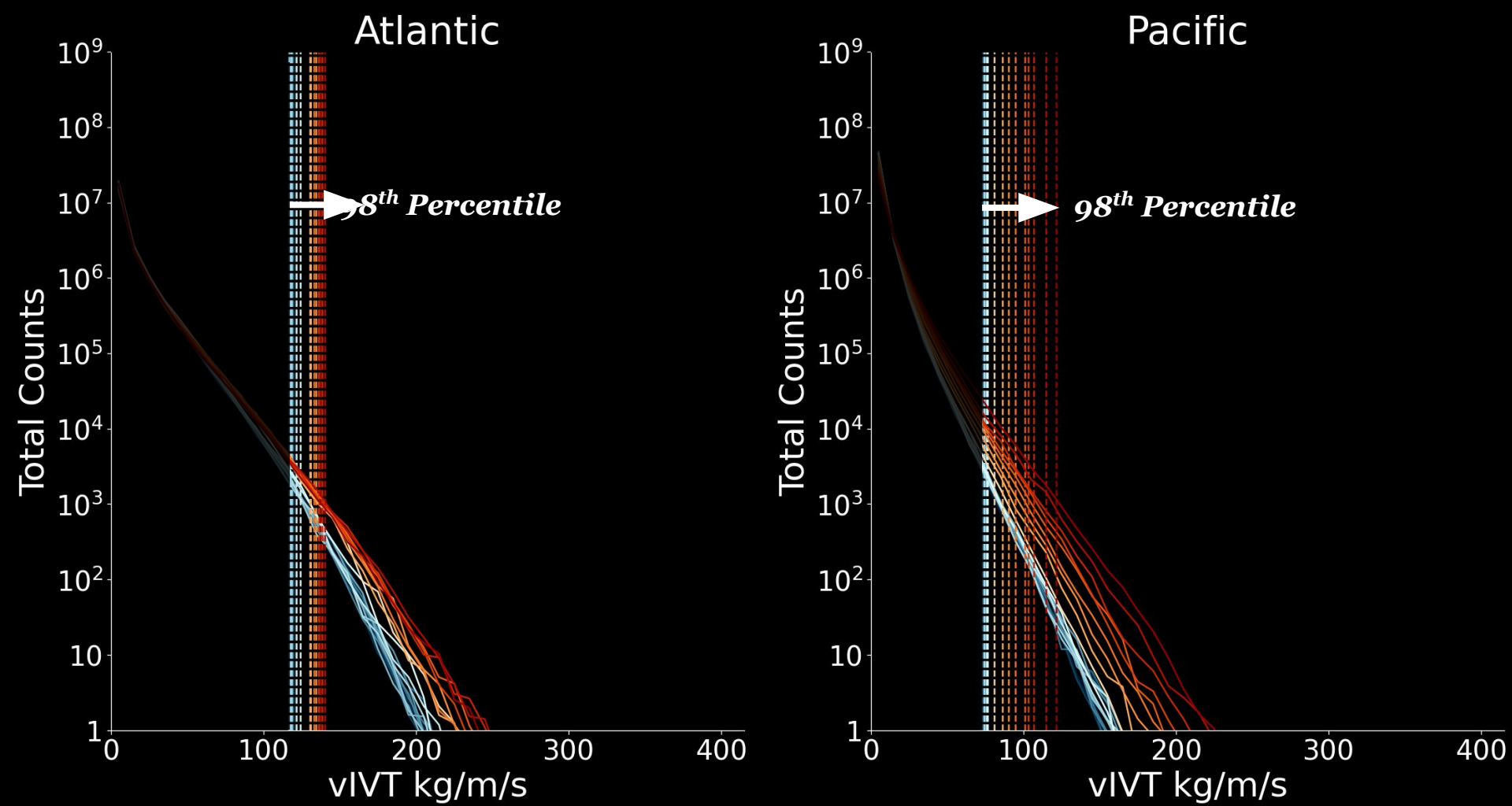
**Warmer and
Moister.**

**Higher Moisture
Transport**

However, not much
increase in
frequency.
(Seen Earlier)



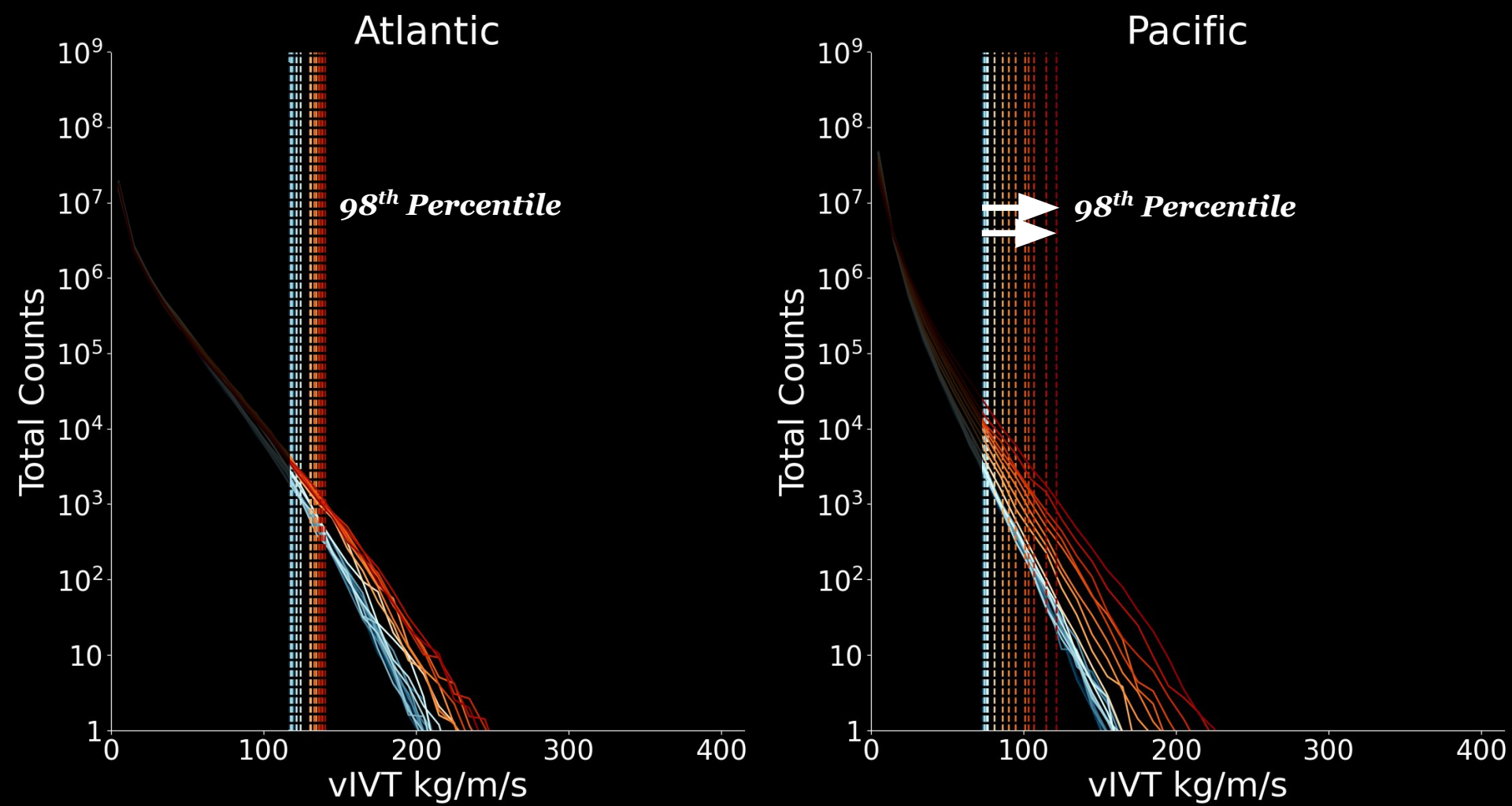
Winter DJF : Distribution of vIVT for Ensemble Mean



The Increase in Pacific is more pronounced in Winter



Winter DJF : Distribution of vIVT for Ensemble Mean



The Increase in Pacific is more pronounced in Winter



Q1: Does CESM2 Capture **Arctic ARs** ?

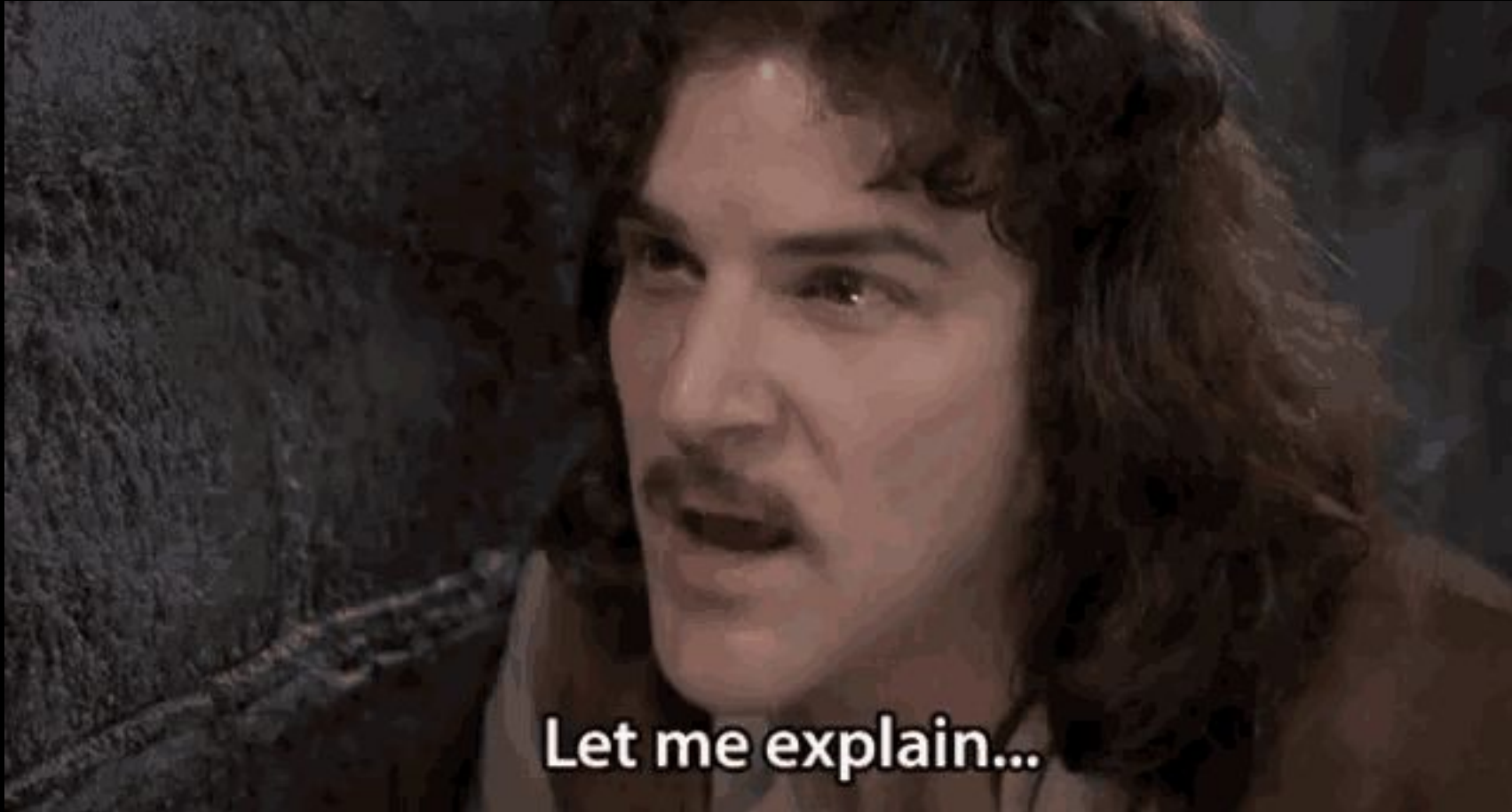
Frequency : **YES**

Intensity : **YES**

Q2: How do **ARs change in future climate?**

Frequency : **Increases**

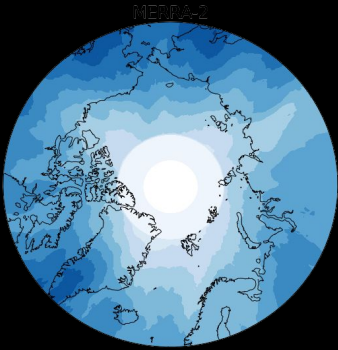
Intensity : **Increases**



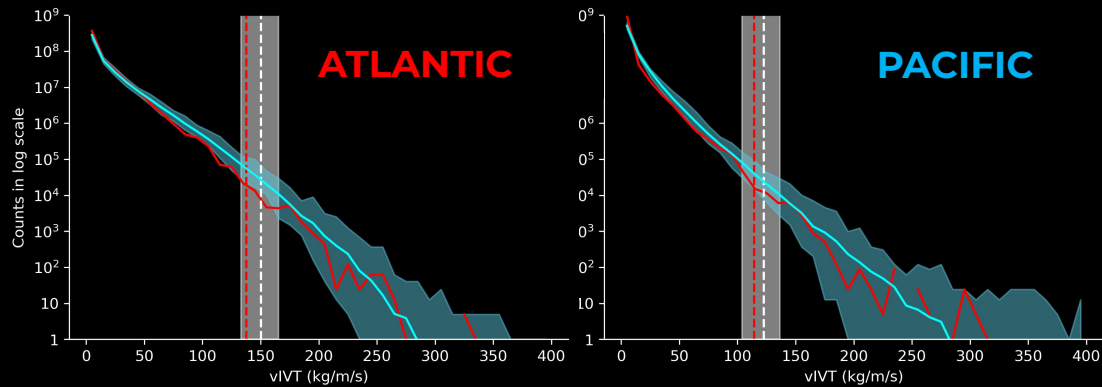
Summary and Discussion

- CESM2 captures this extreme events well.

MERRA2

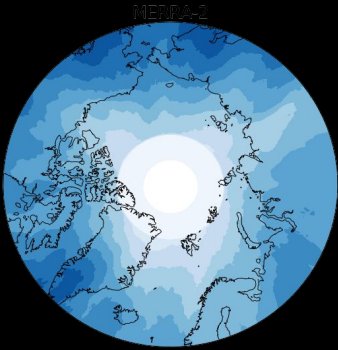


CESM2

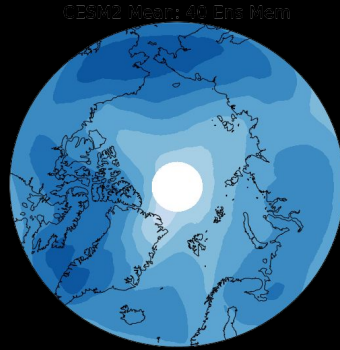


Summary and Discussion

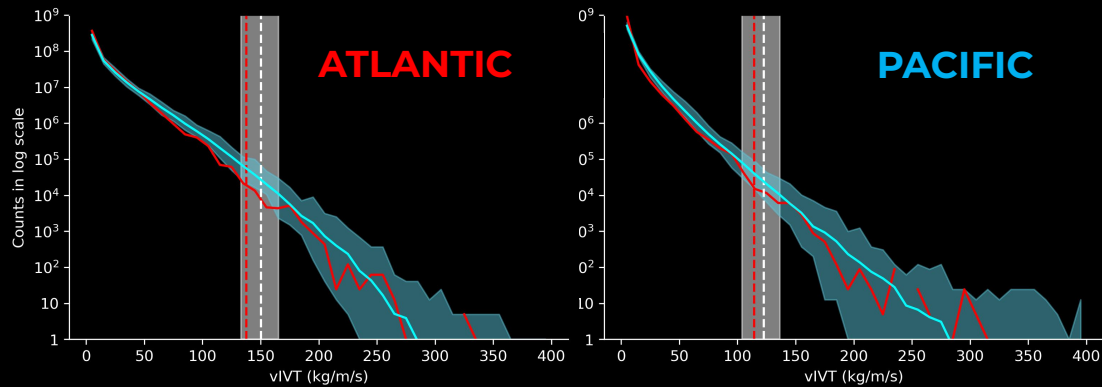
MERRA2



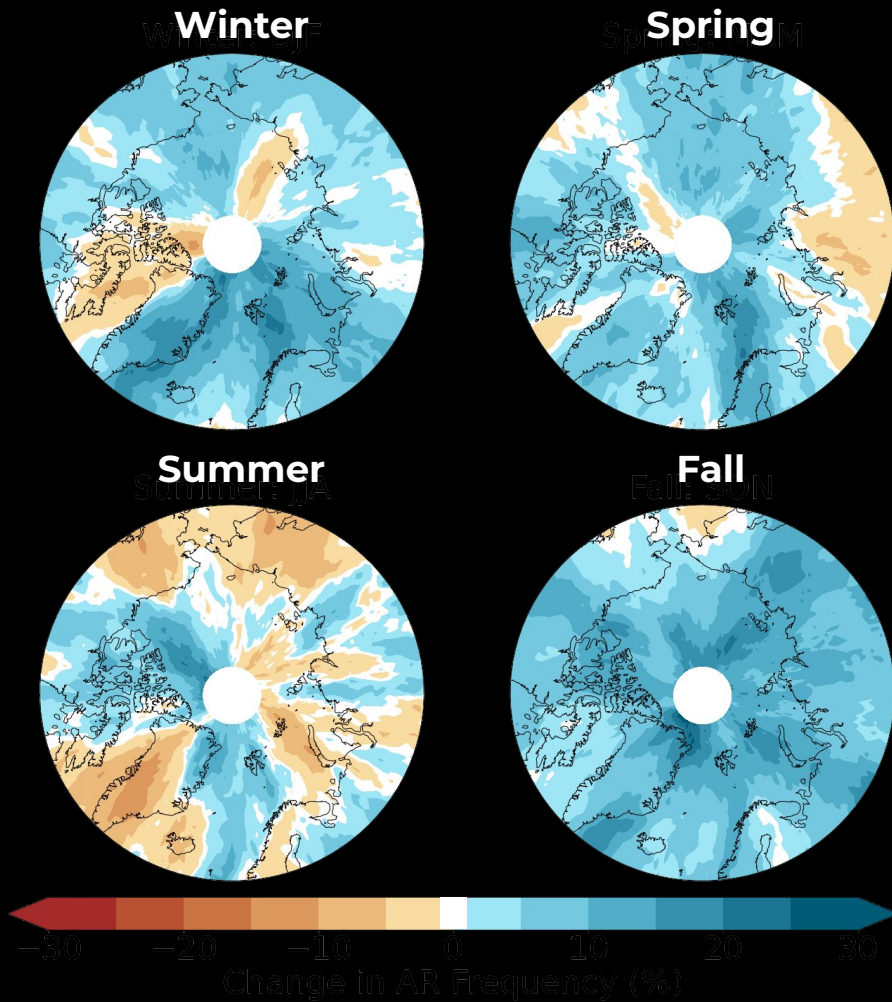
CESM2



- CESM2 captures this extreme events well.
!! Results show that the model tends to capture fewer individual ARs than observations.

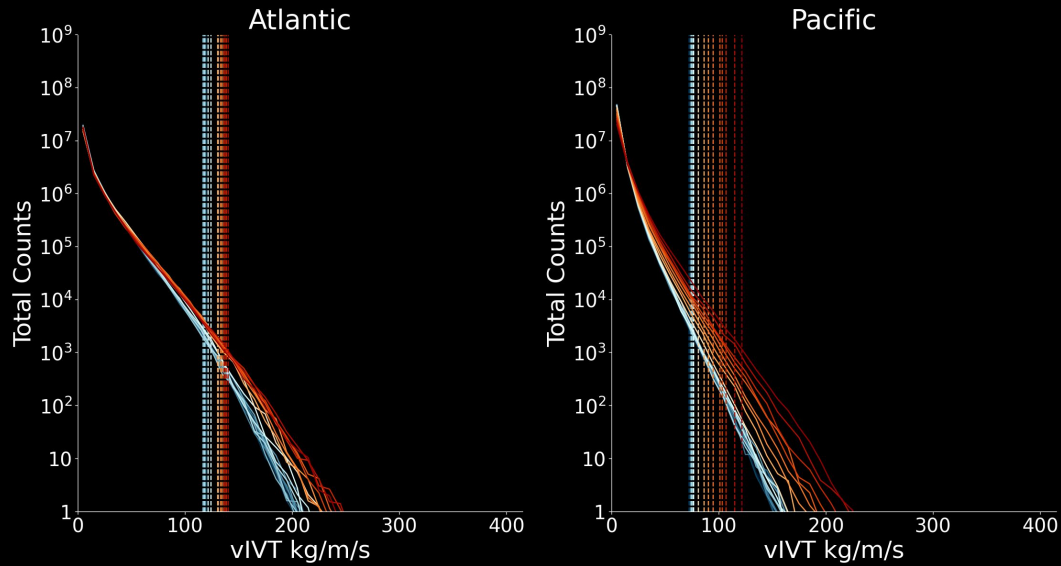


Summary and Discussion



- CESM2 captures this extreme events well.
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- Increase in ARs in the future:
 - Frequency increases across all seasons except summer.

Summary and Discussion

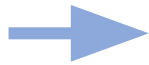


- CESM2 captures this extreme events well.
 - !! Results show that the model tends to capture fewer individual ARs than observations.
- Increase in ARs in the future:
 - Frequency increases across all seasons except summer.
 - Intensity increases across all seasons.

FUTURE WORK

Increase in ARs :

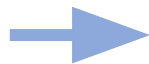
Thermodynamic



Scale the future changes in
MOISTURE

+

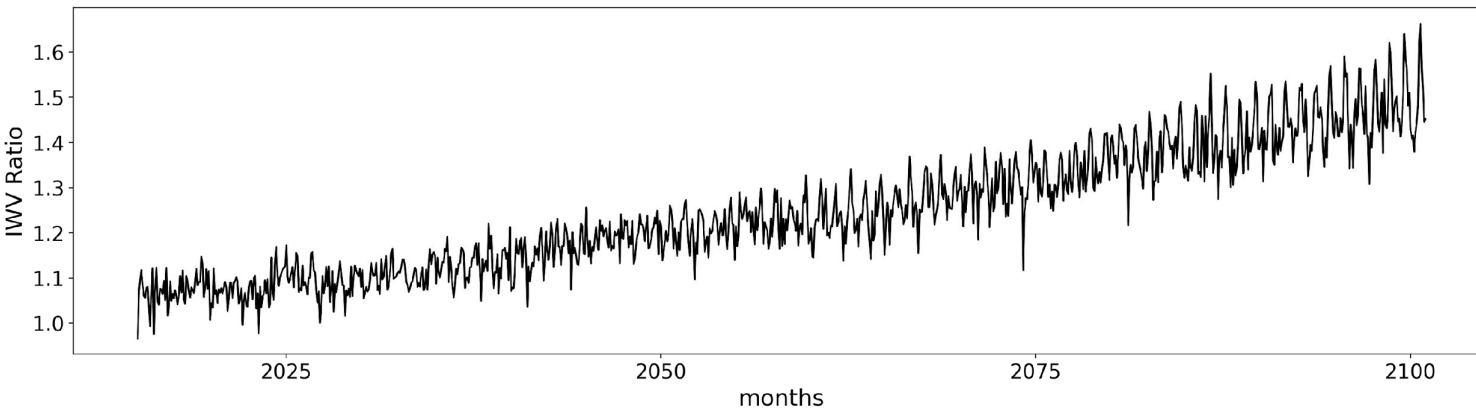
Dynamic



Scale the future changes in
MERIDIONAL VELOCITY

FUTURE WORK

One Location - Ensemble Mean



$$IWV \text{ Ratio} = \frac{IWV_t(2015-2100)}{\text{Monthly Avg IWV } 1980 - 2015}$$

New Threshold = 98th percentile vIVT 1980-2015 (12 months) × IWV Ratio



QUESTIONS

Email: thaker2@wisc.edu

Twitter: @Rudradutt09

Original Picture: Mark Ross

Painstakingly modified: Rudra Thaker

