ATMOSPHERIC RIVERS, CLIMATE CHANGE, AND THE HOWARD A. HANSON DAM

Michael Warner, PhD
Meteorologist
US Army Corps of Engineers, Seattle District

co-authors: Cliff Mass[1], Kevin Shaffer[2], and Ken Brettman[2]
[1] University of Washington, Atmospheric Sciences
[2] US Army Corps of Engineers, Water Management

"The views, opinions and findings contained in this report are those of the authors(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other official documentation."

US Army Corps of Engineers ®

U.S.ARMY

THE HOWARD A. HANSON DAM

Wikipedia

- An earthen dam located on the Green River ~35 miles east of Tacoma
- 220 mi^2 (570 km^2) of drainage above the dam (not a big basin)
- Three authorized purposes
  - City of Tacoma water supply (July – October)
  - Fisheries conservation (July – October)
  - Winter flood risk management (October – February)

US Army Corps of Engineers®

U.S. ARMY

WATER SUPPLY, FLOOD RISK, AND CLIMATE CHANGE

Howard Hanson Reservoir relies on spring **rains** and the previous winter's **snowpack** for refill in the **spring**

- *We don't need both*… if we have either normal spring rains or normal winter snowpack, we can refill the reservoir, no problem.

Seattle PI

Seattle Times

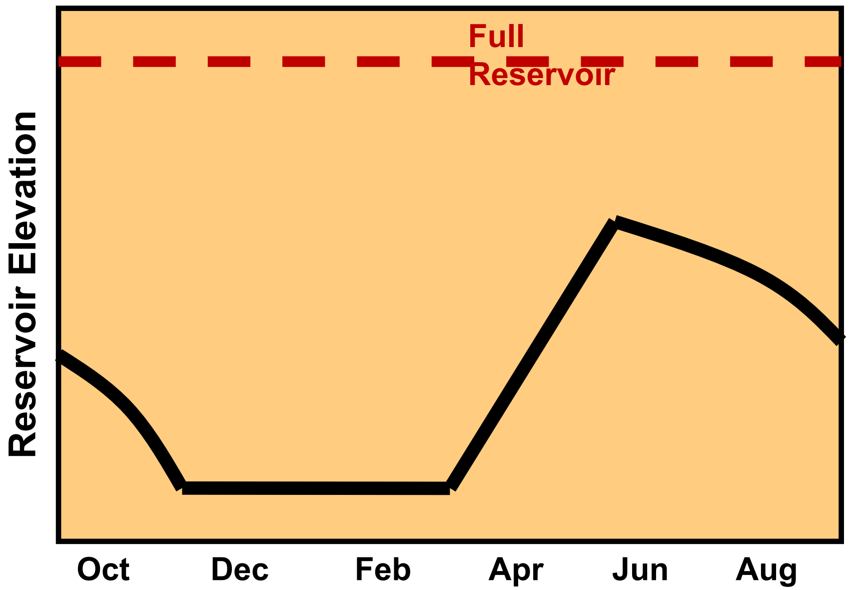
US Army Corps of Engineers®

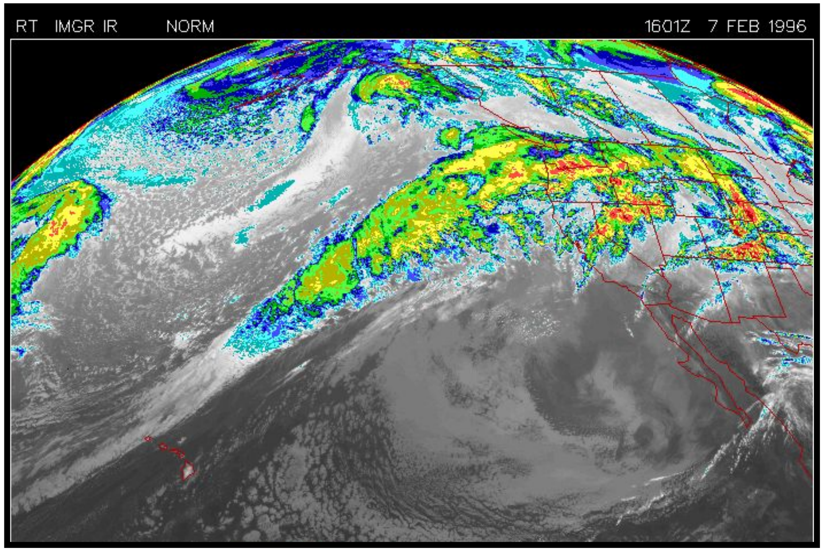
U.S. ARMY

WATER SUPPLY, FLOOD RISK, AND CLIMATE CHANGE

The reservoir is drawn down to minimum pool by 1 November in preparation for the winter flooding season

- The primary flooding concern is due to **atmospheric rivers** (ARs)
- Winter snowmelt can contribute to flooding, but is not the primary cause



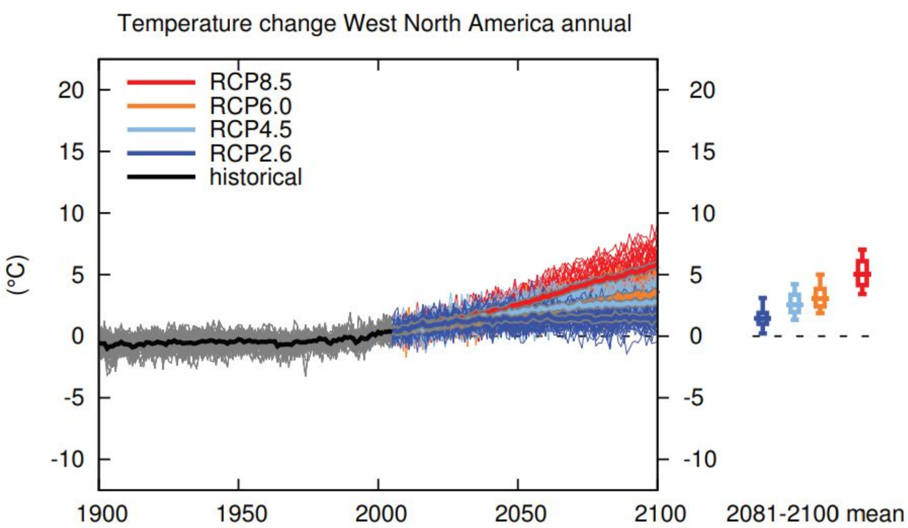


US Army Corps of Engineers ®

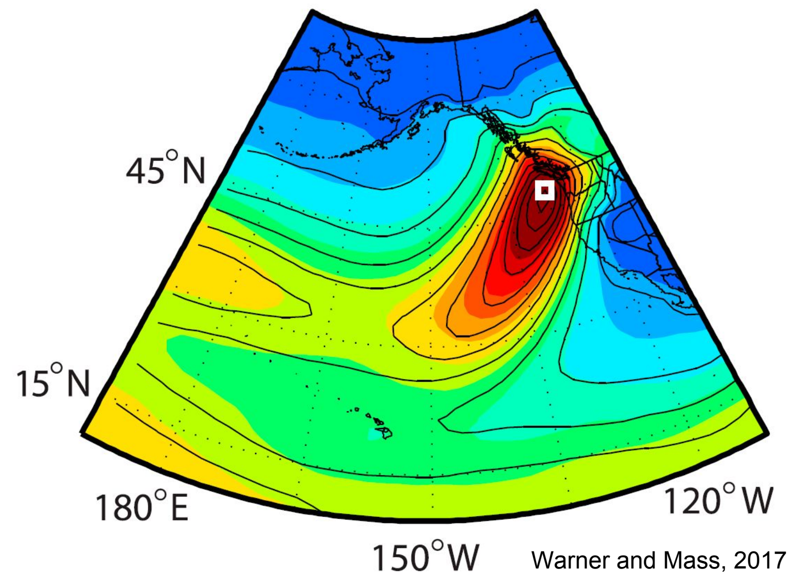
U.S.ARMY

WATER SUPPLY, FLOOD RISK, AND CLIMATE CHANGE

Climate change in the Pacific Northwest by the end of the century (on its current trajectory) stands to impact both **snowpack** AND **atmospheric rivers**.



IPCC AR5



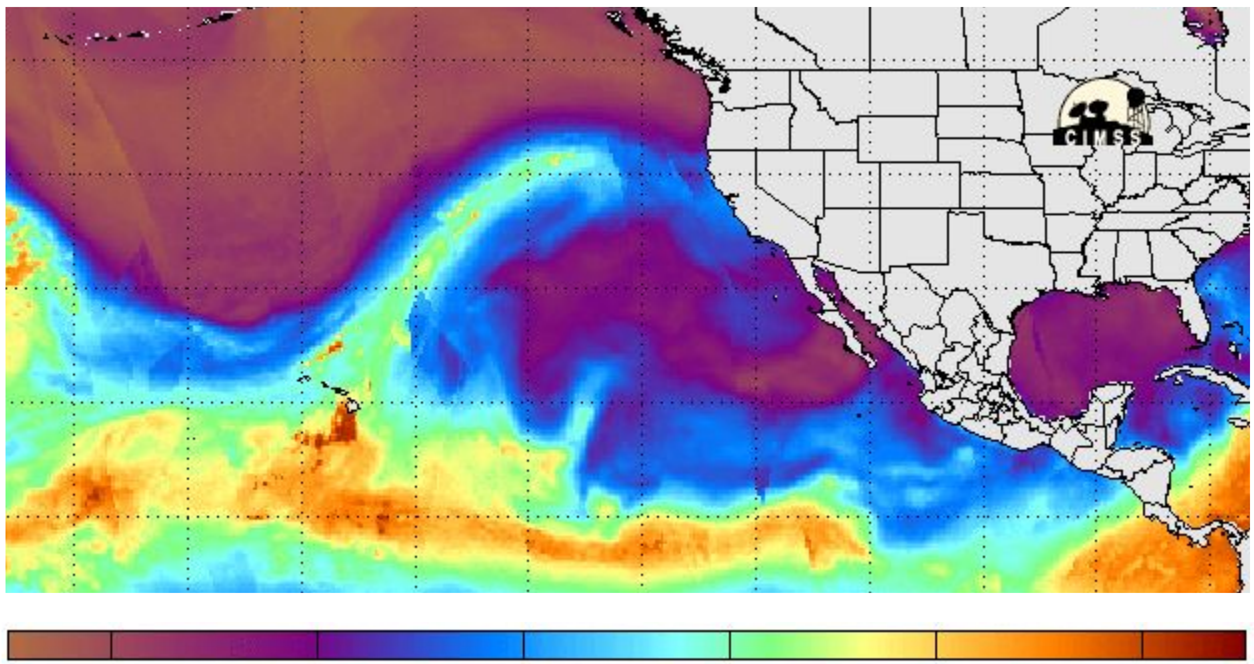
Warner and Mass, 2017

I will primarily address ATMOSPHERIC RIVERS (surprise!) **in this talk.**

WHAT IS AN ATMOSPHERIC RIVER?

Morphed composite: 2010-12-11 00:00:00 UTC

SSMI/AMSRE derived integrated water vapor



- Moisture from the tropics in narrow corridor
- Warm temperatures and high freezing levels
- Neutrally buoyant, so when they encounter terrain, they lift easily, heavy precipitation ensues.

US Army Corps of Engineers ®

U.S. ARMY

ATMOSPHERIC RIVERS

Every major flood in the Pacific Northwest has been associated with an atmospheric river event

Mt. Rainier, NPS (Nov 2006)

Hamilton, WA (Oct 2003), SVH

Chehalis, WA (Dec 2007), WSDOT

Recent big ones: February 1996, October 2003, November 2006, December 2007, January, 2009

US Army Corps of Engineers ®

U.S. ARMY

ATMOSPHERIC RIVERS

Looking forward, some natural questions to ask are:

How is climate change impacting AR intensity, frequency, and seasonality?

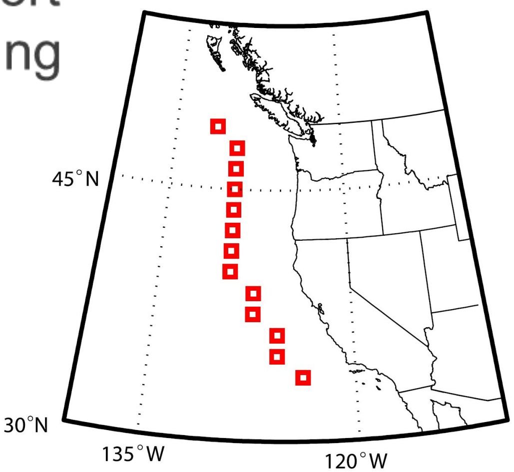
Given that information,

How would/could the US Army Corps of Engineers operations of Howard Hanson Dam change?

INTEGRATED WATER VAPOR TRANSPORT

- It turns out that integrated water vapor transport (IVT) offshore is a good measure for detecting atmospheric rivers impacting the coast.

$$IVT = \frac{1}{g_0} \int_{sfc}^{500} \bar{q}\, \bar{U} dp$$

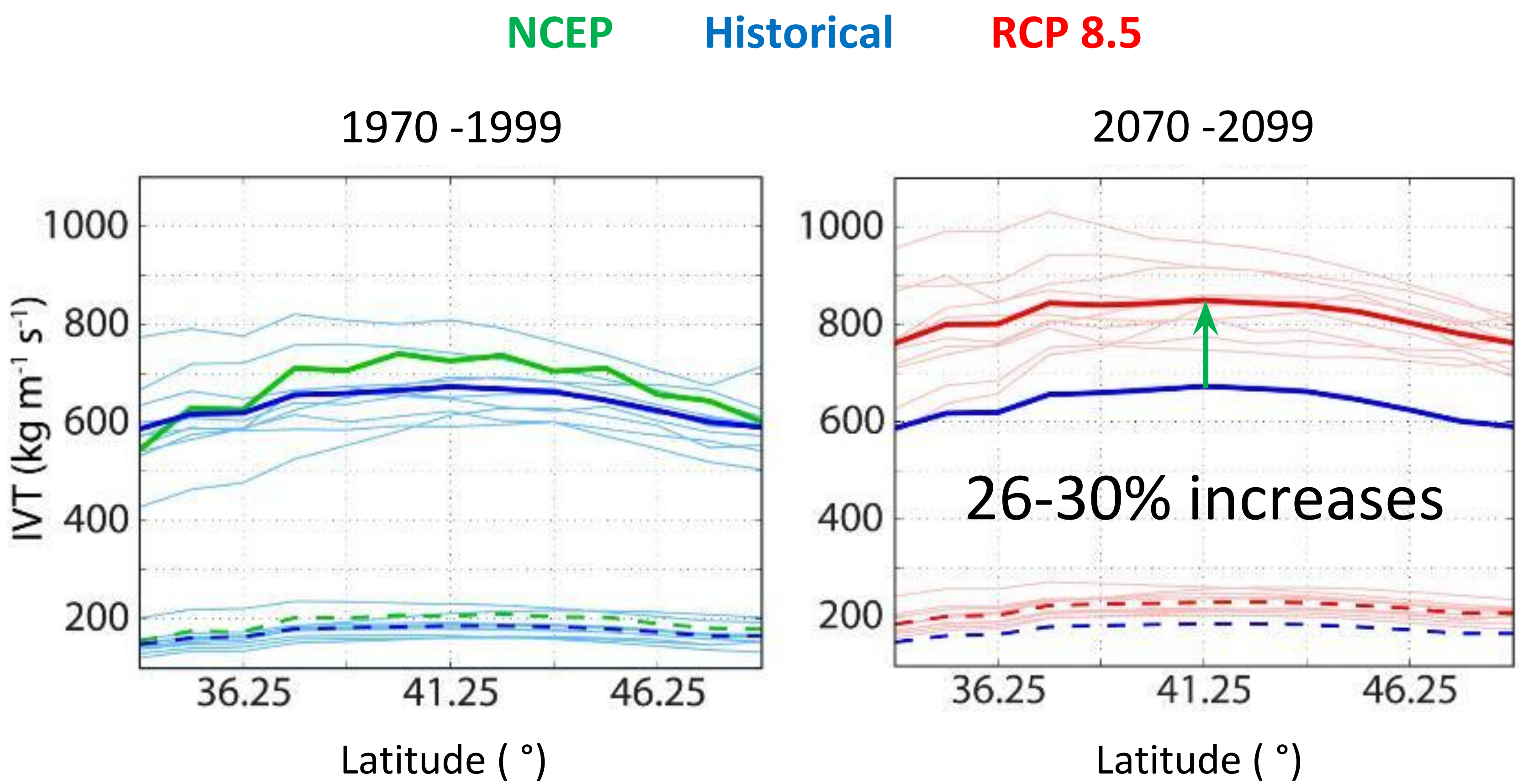


- 10 CMIP5 climate models, plus NCEP reanalysis and compared IVT in AR events from 1970-1999 and 2070-2099 (RCP 8.5, "business as usual")
- 99th percentile IVT events (the most extreme) in both period; evaluated changes in intensity, frequency, and seasonality

US Army Corps of Engineers®

U.S.ARMY

INTENSITY CHANGES VIA (IVT)

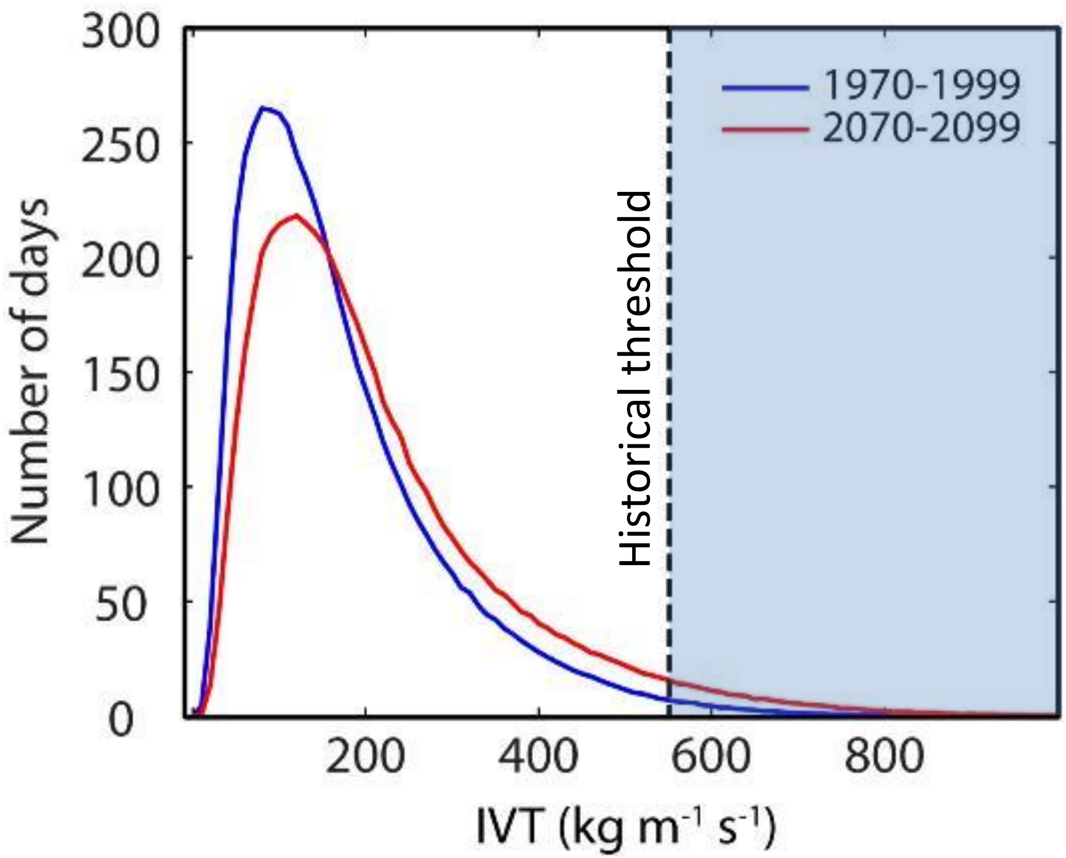


This results in similar increases in precipitation, thus, **more intense storms!**

Warner et al. (2015), JHM

US Army Corps of Engineers
U.S. ARMY

FREQUENCY CHANGES



- ~30% increases in IVT
- On average, ~250% increase in number of days above historical threshold.

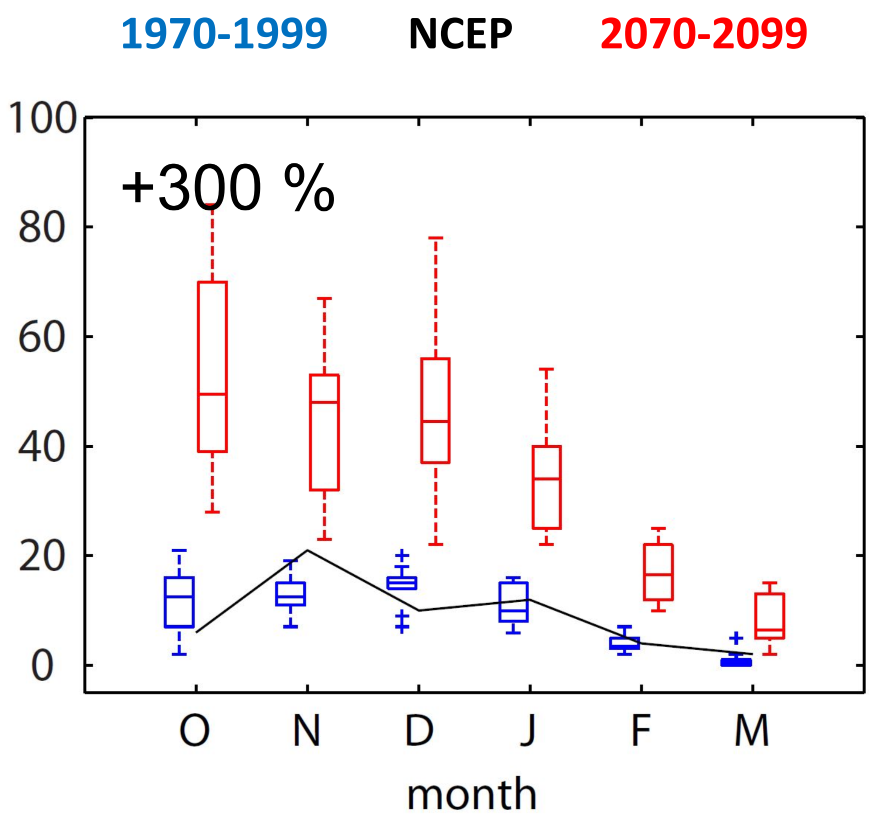
We see **more frequent storms** if we simply consider frequency over threshold.

Warner et al. (2015), JHM

US Army Corps of Engineers ®

U.S. ARMY

SEASONALITY CHANGES



We see a shift of ARs occurring **earlier in the season**, or a big increase in October ARs.

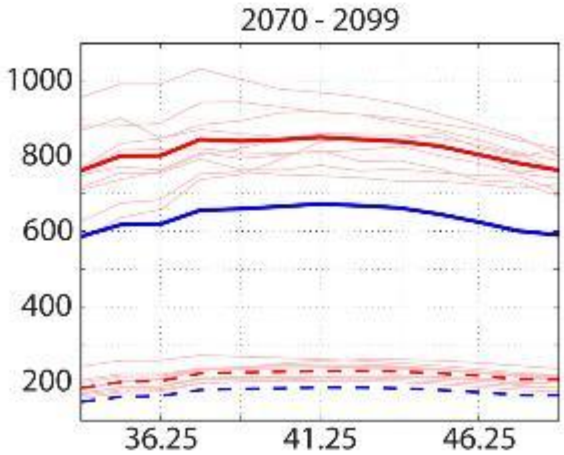
Warner and Mass (2017), JHM

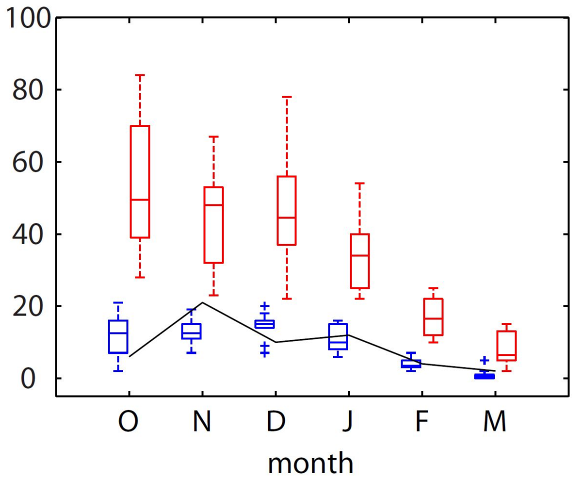
US Army Corps of Engineers ®

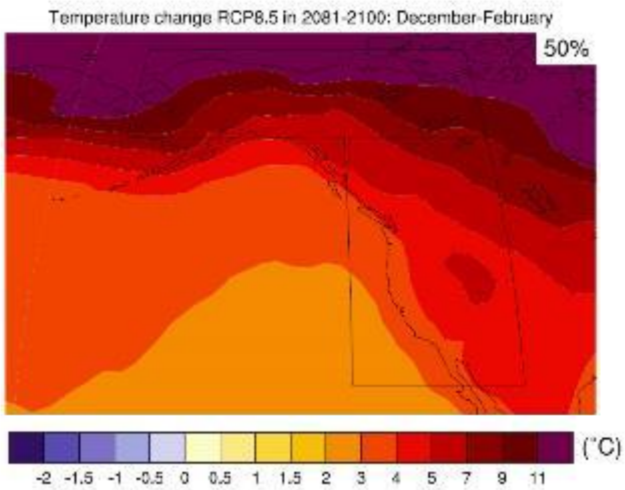
U.S.ARMY

WHAT DOES THIS ALL MEAN FOR OPERATIONS?

- More **intense** and **frequent** AR events in a future climate
- A **seasonal shift** to more ARs earlier in the rainy season
- **Warmer** temperatures







US Army Corps of Engineers®

U.S.ARMY

WHAT DOES THIS ALL MEAN FOR OPERATIONS?

- More **intense** and **frequent** AR events in a future climate
- A **seasonal shift** to more ARs earlier in the rainy season
- **Warmer** temperatures

- **During** a more intense storm, water might need to be evacuated more quickly, leading to potential flooding downstream.

- **After** an event, water may need to be evacuated more quickly in preparation for another incoming event, leading to flooding downstream.

WHAT DOES THIS ALL MEAN FOR OPERATIONS?

- More **intense** and **frequent** AR events in a future climate
- A **seasonal shift** to more ARs earlier in the rainy season
- **Warmer** temperatures

- More storms earlier in the season would actually **NOT** impact dam operations that much.
    - In October, there is very little water in the reservoir on the way to minimum pool by November 1
    - If a large AR is forecast, the water behind the dam could be dumped in approximately 1-2 days, within the forecast window, and without much consequence.

US Army Corps of Engineers®

U.S.ARMY

WHAT DOES THIS ALL MEAN FOR OPERATIONS?

- More **intense** and **frequent** AR events in a future climate
- A **seasonal shift** to more ARs earlier in the rainy season
- **Warmer** temperatures

- **Higher temperatures** will likely result in less snowpack and an earlier melt out.
  - Less snowpack will make it harder to refill the reservoir with JUST snowpack
  - An earlier melt out might require the need to capture runoff earlier in the year, increasing flood risk
  - This will increase the need to rely on spring precipitation for refill (see WY 2015)

US Army Corps of Engineers®

U.S. ARMY

QUESTIONS?

Michael Warner, PhD
Meteorologist, USACE Seattle
michael.d.warner@usace.army.mil

HOW WOULD THAT CHANGE OUR OPERATIONS?

Intensity/frequency Changes → More intense storms impacting HAH throughout the season.

- This could be problematic in how we regulate during flood events.

Precipitation seasonality changes → more intense storms happening earlier in the winter season

- This would likely not impact the USACE too much. The reservoir is already low and we could evacuate the small amount of water quickly to free up storage space.

Snowpack decrease → relying on spring rain to refill more often (or always)

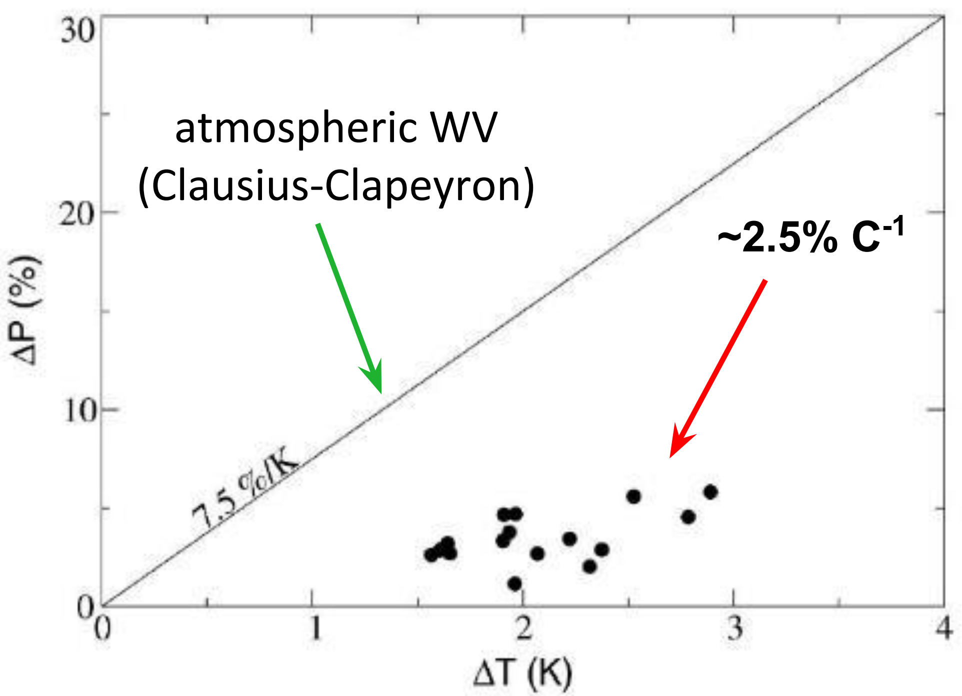
- If the snowpack is gone, years like 2015 could occur more often and we might need to consider holding on to water sooner (potentially before the winter flood season ends)

US Army Corps of Engineers®

U.S.ARMY

PRECIPITATION AND CLIMATE CHANGE

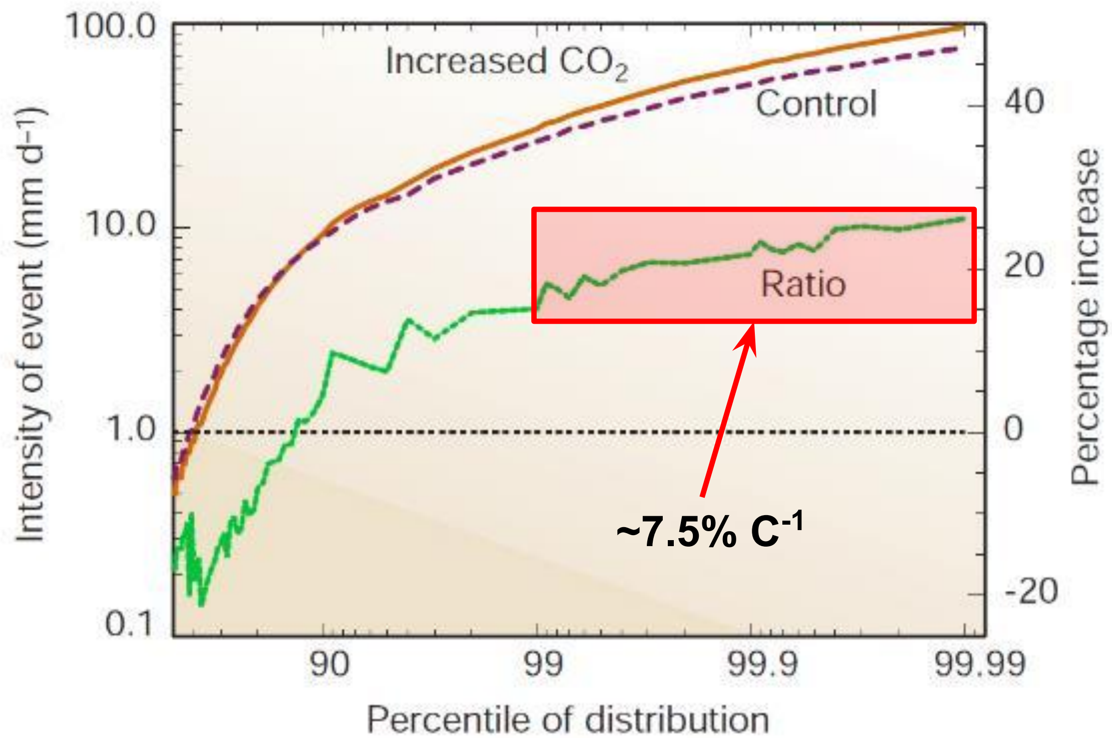
Global **mean** precipitation increases of about **2-3% C^{-1}**



Held and Soden (2006)

PRECIPITATION AND CLIMATE CHANGE

Global **extreme** increases of **~7.5% C^{-1}** (similar to IWV)



Allen and Ingram (2002)

IVT

$$IVT = \frac{1}{g_0}\int_{sfc}^{500} \bar{q}\,\bar{U}\,dp$$

IWV

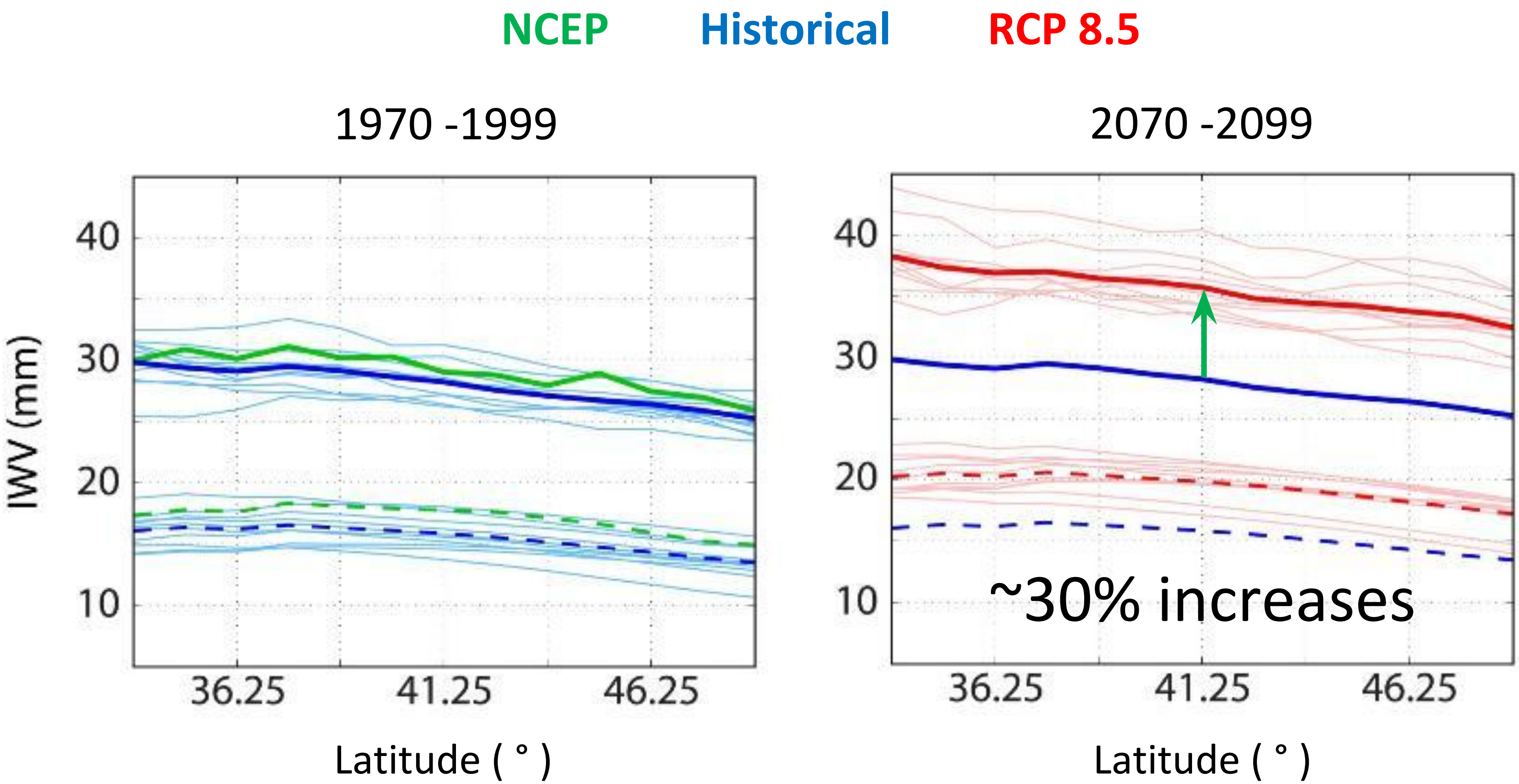
integrated water vapor piece

$wind$

US Army Corps of Engineers®

U.S. ARMY

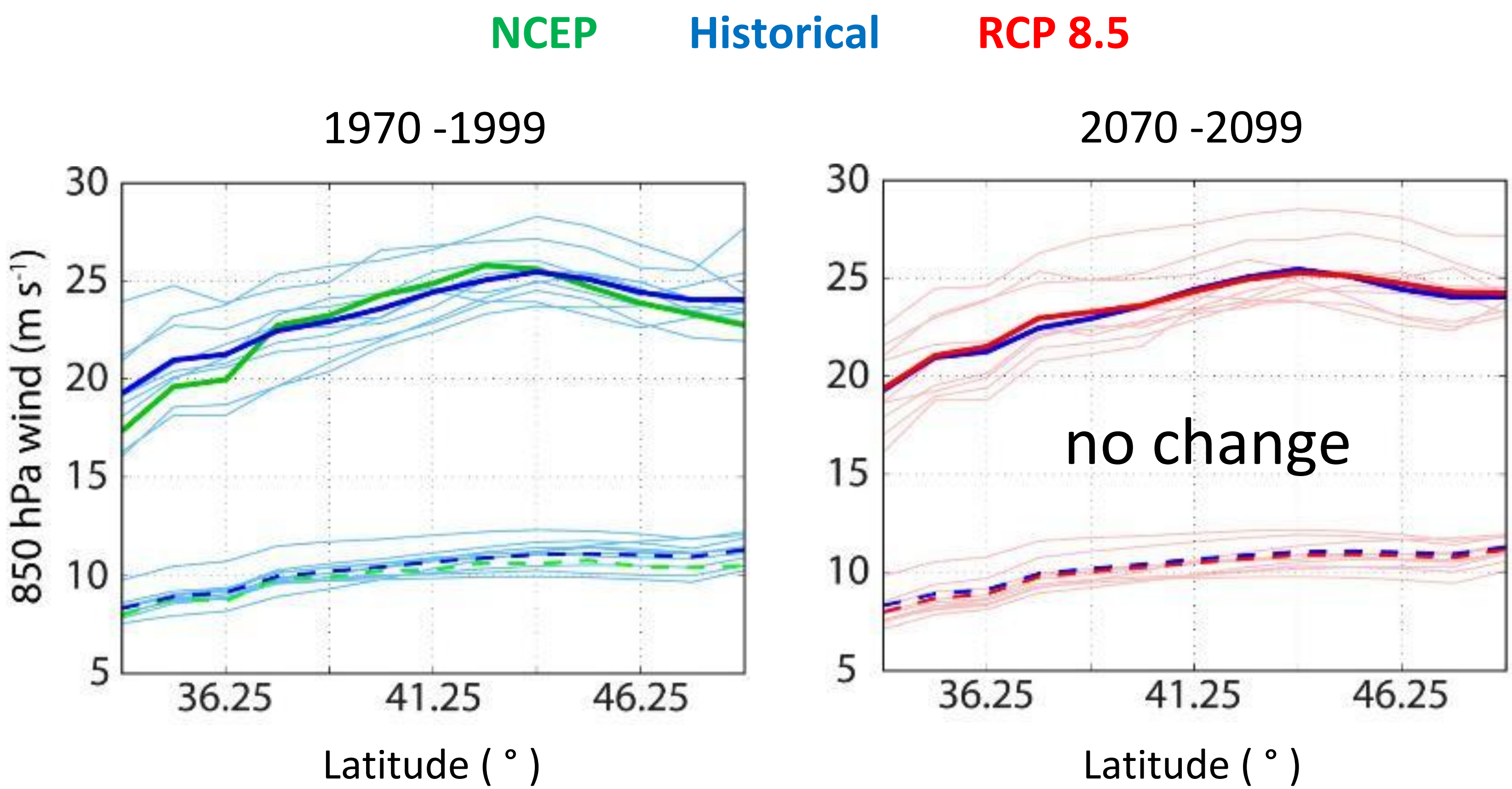
INTEGRATED WATER VAPOR



Warner et al. (2015)

US Army Corps of Engineers
U.S.ARMY

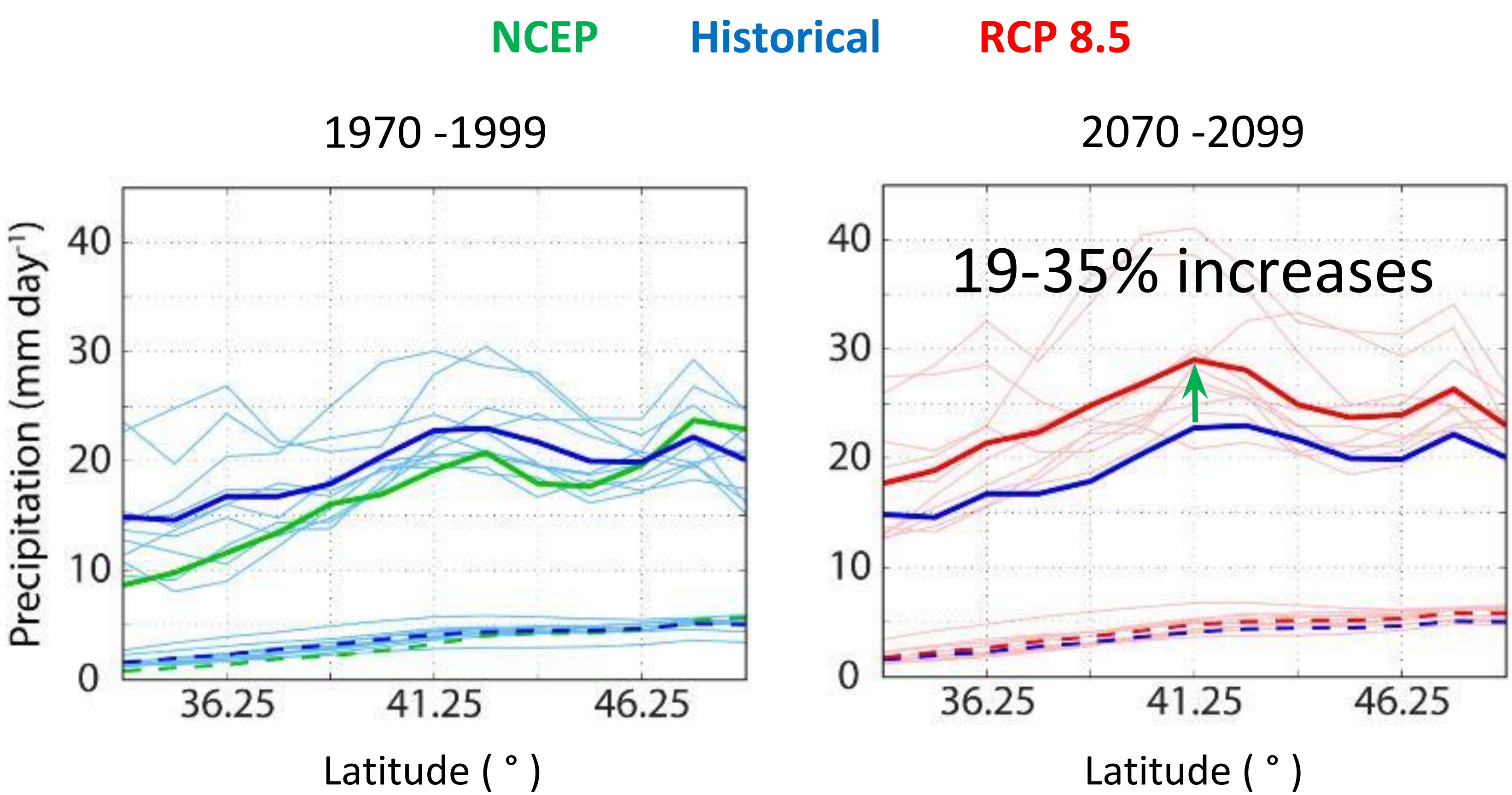
850 HPA TOTAL WIND



Warner et al. (2015)

US Army Corps of Engineers
U.S. ARMY

PRECIPITATION

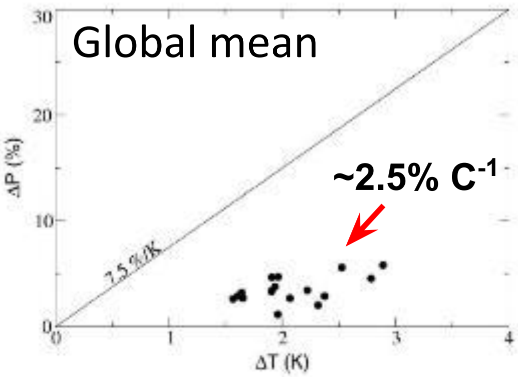


Warner et al. (2015)

US Army Corps of Engineers ®

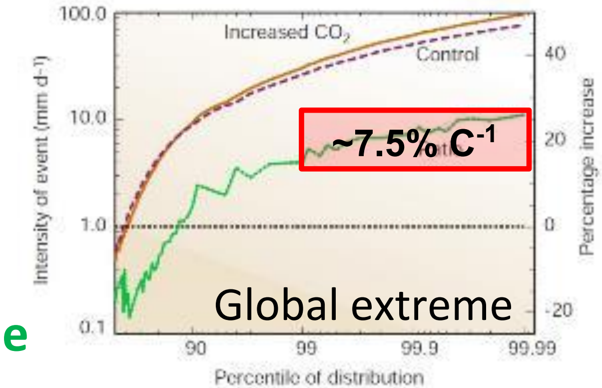
U.S.ARMY

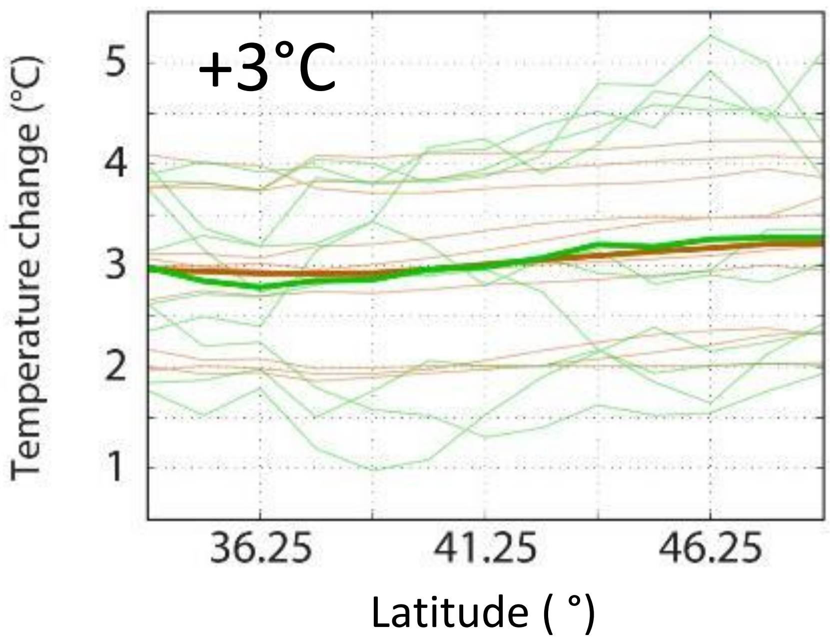
ΔT and %ΔP °C^{-1}

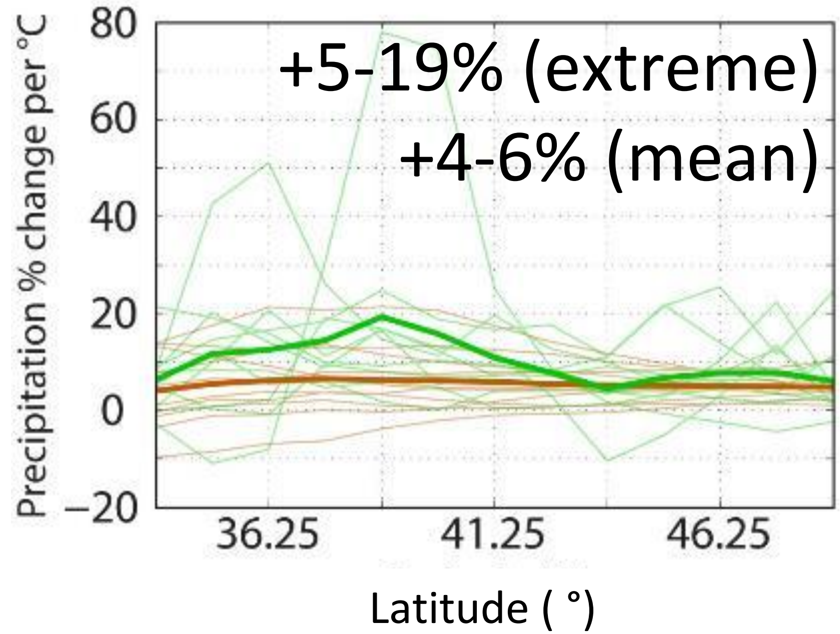


model mean

99th percentile

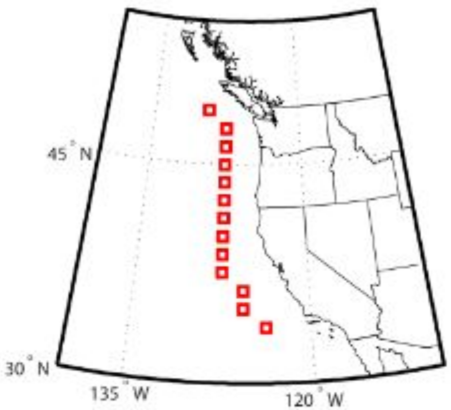






Warner et al. (2015)

FREQUENCY EXCEEDING THRESHOLD



Latitude (°N)	Mean historical threshold (kg m^{-1} s^{-1})	Mean # days above historical threshold for 2070-2099	Mean % increase over historical threshold
48.75	524.08	215	291
47.50	521.40	209	280
46.25	551.51	206	275
45.00	566.58	211	285
43.75	579.32	210	283
42.50	591.06	198	260
41.25	597.17	180	228
40.00	586.97	185	236
38.75	578.60	186	239
37.50	577.99	183	234
36.25	540.99	182	231
35.00	534.76	182	232
33.75	499.60	179	227

California border

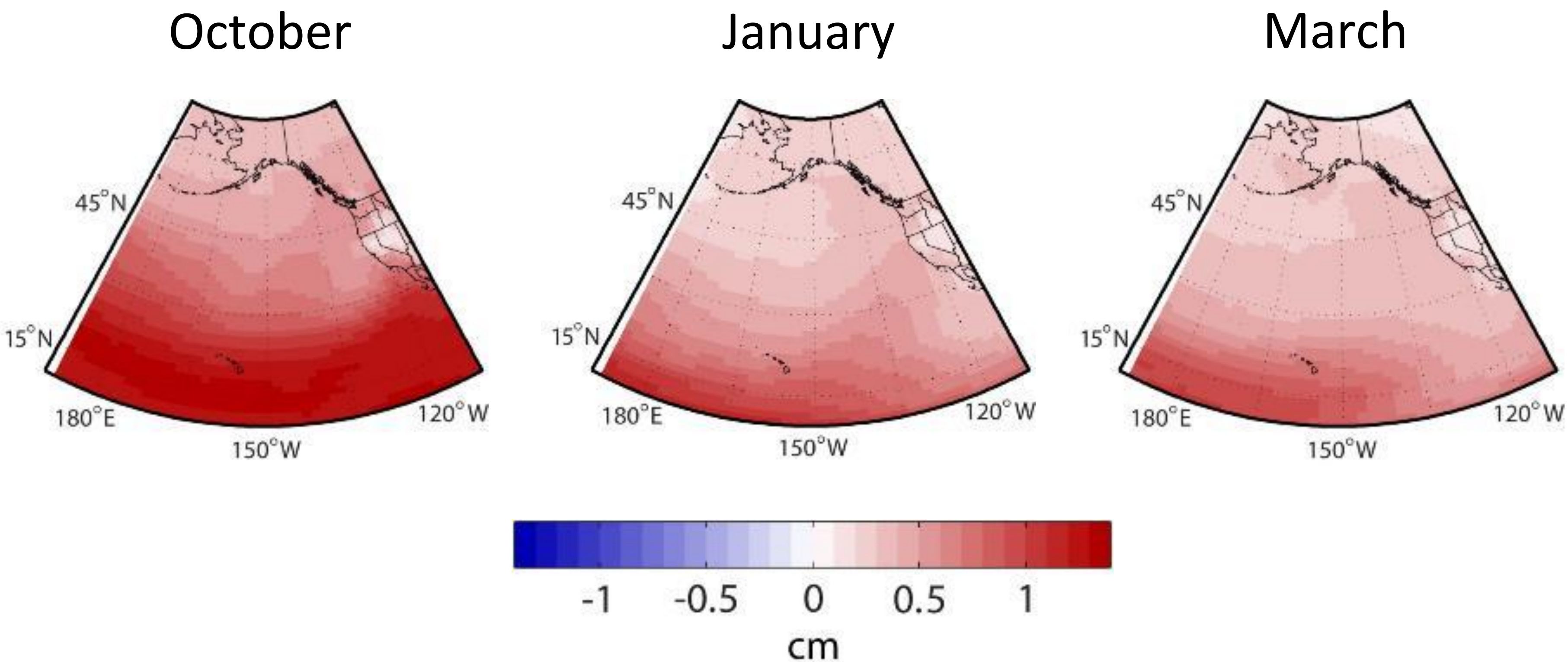
Warner et al. (2015)

US Army Corps of Engineers®

U.S. ARMY

SEASONAL IWV INCREASES

2070-2099 minus 1970-1999



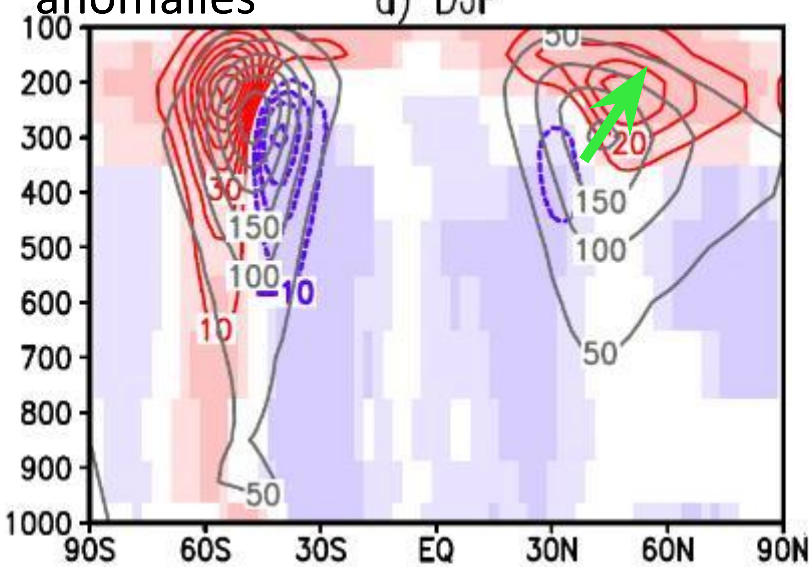
Warner et al. (2017)

US Army Corps of Engineers®

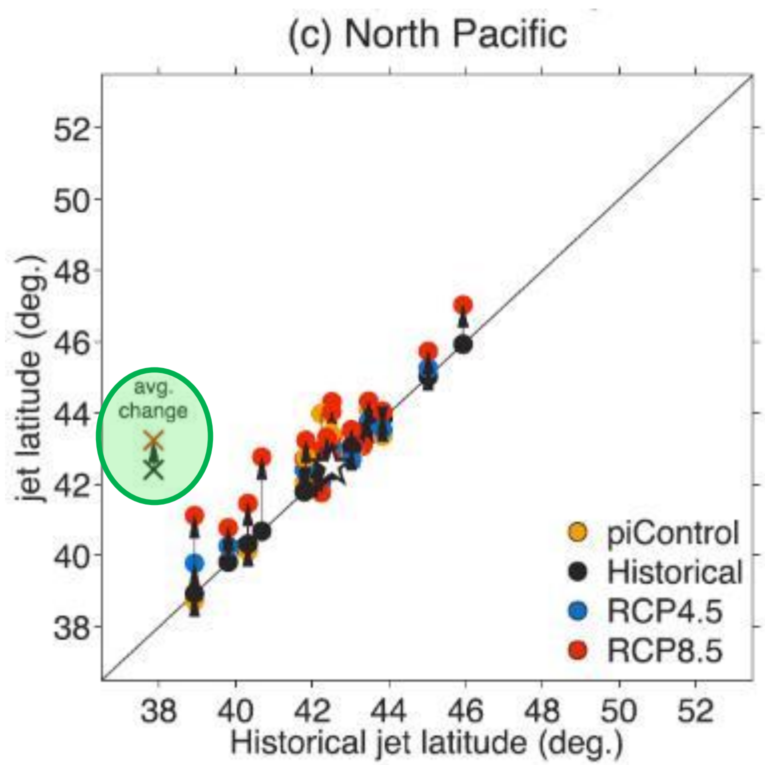
U.S.ARMY

ATMOSPHERIC RIVERS AND THE JET STREAM

Zonal mean storm track anomalies



Chang et al. (2012)



Barnes and Polvani (2013)