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

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THE HOWARD A. HANSON DAM

An earthen dam located on the Green River ~35 miles east of Tacoma

Three authorized purposes

- City of Tacoma water supply (July – October)
- Fisheries conservation (July – October)
- Winter flood risk management (October – February)
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.
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
Climate change in the Pacific Northwest by the end of the century (on its current trajectory) stands to impact both snowpack AND atmospheric rivers. I will primarily address ATMOSPHERIC RIVERS 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.
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

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?
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”)
- 99\textsuperscript{th} percentile IVT events (the most extreme) in both period; evaluated changes in intensity, frequency, and seasonality
INTENSITY CHANGES VIA (IVT)

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

Warner et al. (2015), JHM
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
We see a shift of ARs occurring **earlier in the season**, or a big increase in October ARs.

Warner et al. (2017), JHM
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
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** during and event, leading to potential flooding downstream.

• **After** an event, water may need to be **evacuated more quickly** in preparation for another 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.
  
  o In October, there is very little water in the reservoir on the way to minimum pool by November 1
  
  o 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.
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.
  
  o Less snowpack will make it harder to refill the reservoir with JUST snowpack
  
  o An earlier melt out might require the need to capture runoff earlier in the year, increasing flood risk
  
  o Will increase the need to rely on spring precipitation for refill (see WY 2015)
QUESTIONS?

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

Held and Soden (2006)
Global extreme increases of $\sim7.5\% \text{ C}^{-1}$ (similar to IWV)

Allen and Ingram (2002)
IVT = \frac{1}{g_0} \int_{sfc}^{500} \bar{q} \bar{U} dp

IWV

wind

integrated water vapor piece
INTEGRATED WATER VAPOR

NCEP  
Historical  
RCP 8.5

1970 -1999

2070 -2099

\[ \text{IWV (mm)} \]

\[ \text{Latitude (°)} \]

\[ \sim 30\% \text{ increases} \]

Warner et al. (2015)
850 HPA TOTAL WIND

NCEP  Historical  RCP 8.5

1970 -1999

2070 -2099

no change

Warner et al. (2015)
Precipitation

1970-1999

2070-2099

NCEP  Historical  RCP 8.5

19-35% increases

Warner et al. (2015)
ΔT and %ΔP °C⁻¹

Global mean

~2.5% C⁻¹

model mean 99th percentile

+3°C

+5-19% (extreme) +4-6% (mean)

Global extreme

Warner et al. (2015)
FREQUENCY EXCEEDING THRESHOLD

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

Warner et al. (2015)
SEASONAL IWV INCREASES

2070-2099 minus 1970-1999

October

January

March

Warner et al. (2017)
Zonal mean storm track anomalies

Chang et al. (2012)

Barnes and Polvani (2013)