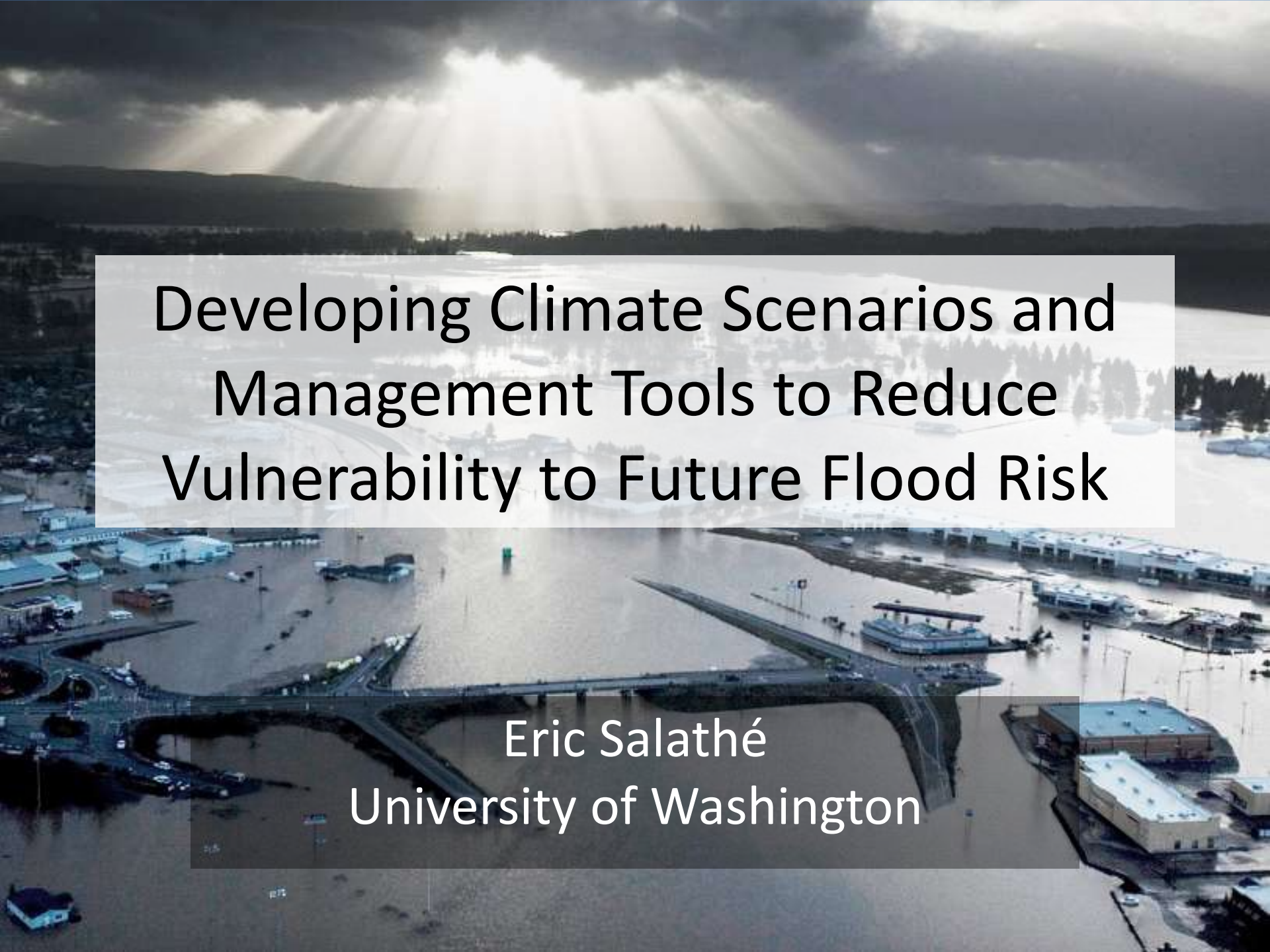
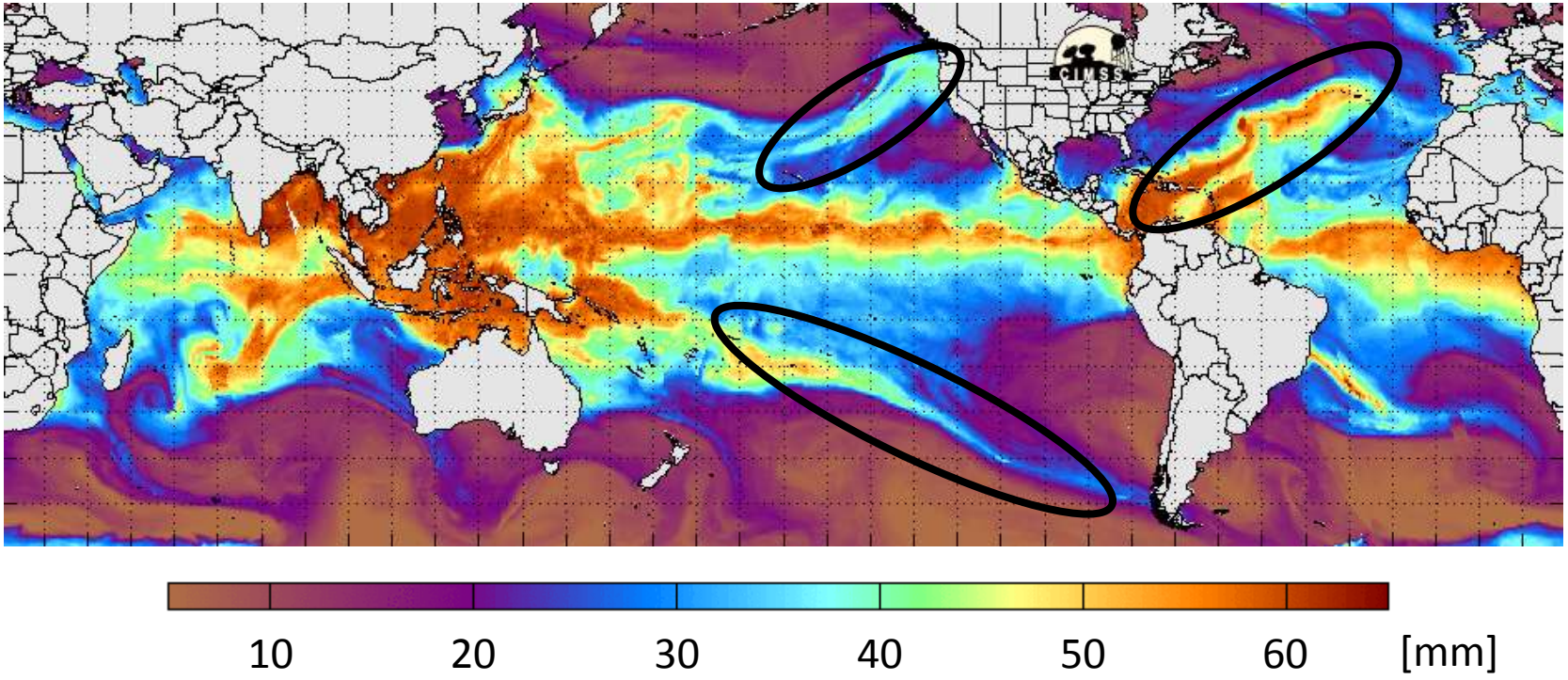


Developing Climate Scenarios and Management Tools to Reduce Vulnerability to Future Flood Risk

Eric Salathé
University of Washington

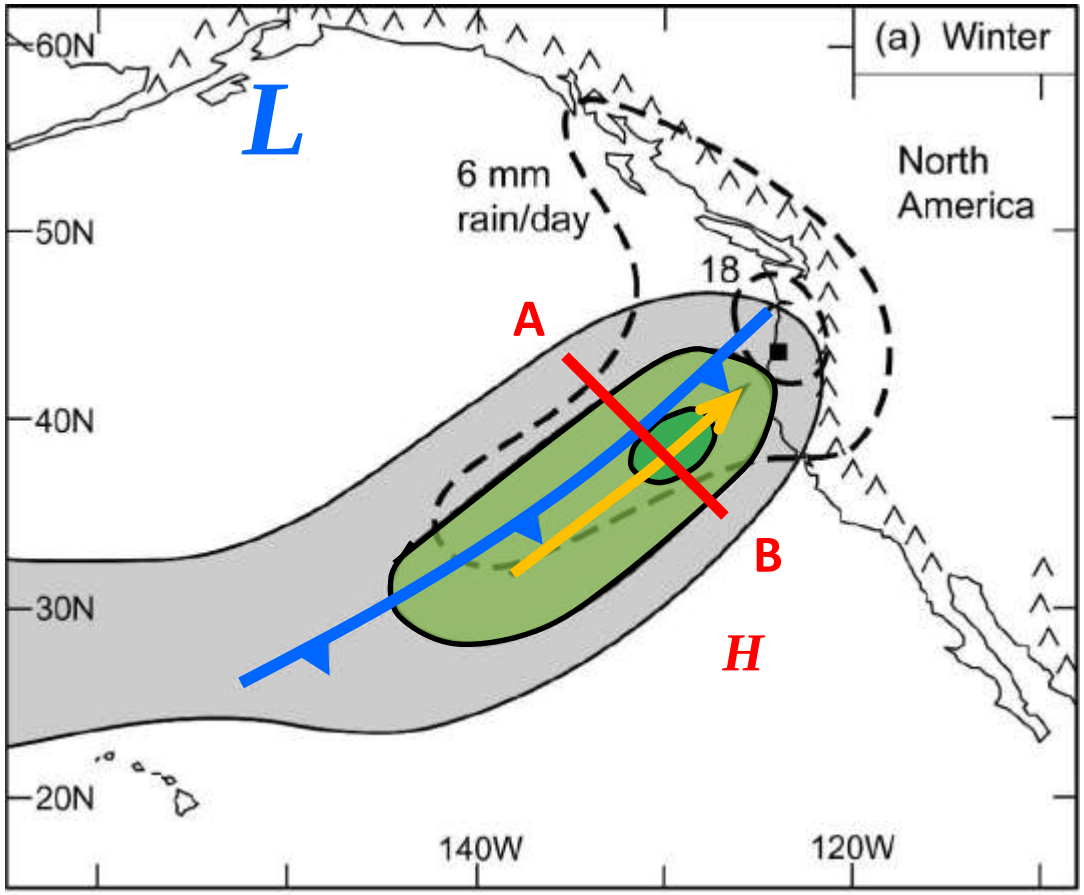
Atmospheric rivers and extreme precipitation

SSMI/AMSRE derived total precipitable water (TPW)



http://cimss.ssec.wisc.edu/tropic/real-time/tpw2/global/main.html

mean synoptic conditions

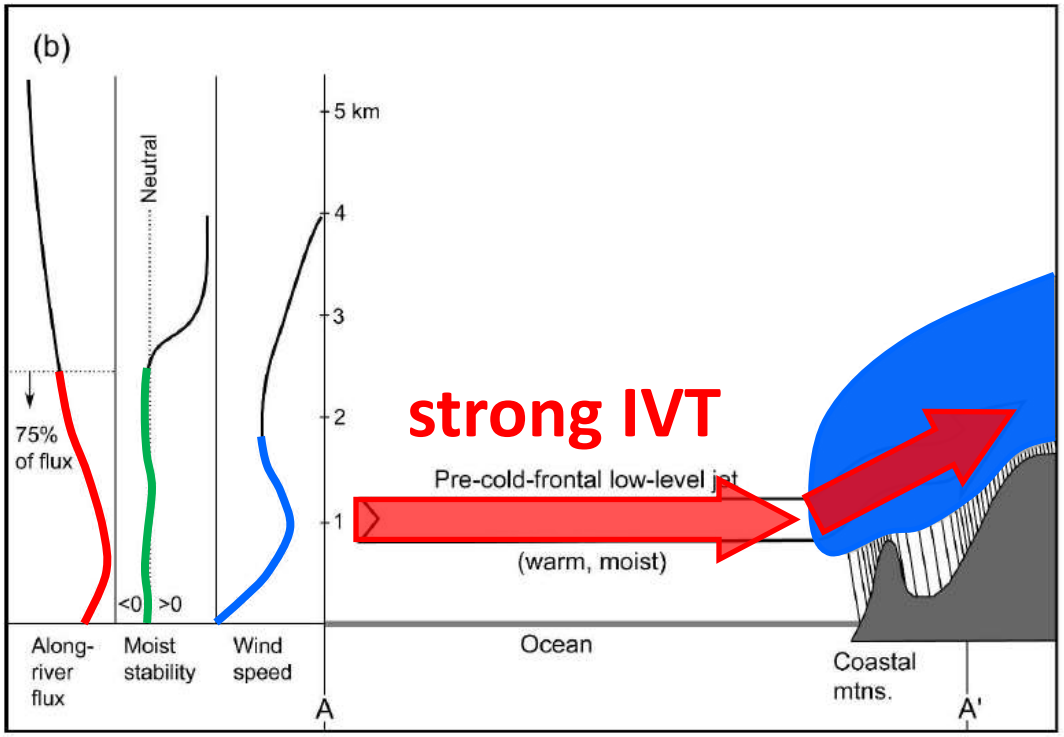


precipitation

integrated water vapor (IWV)

Neiman et al. (2008b)

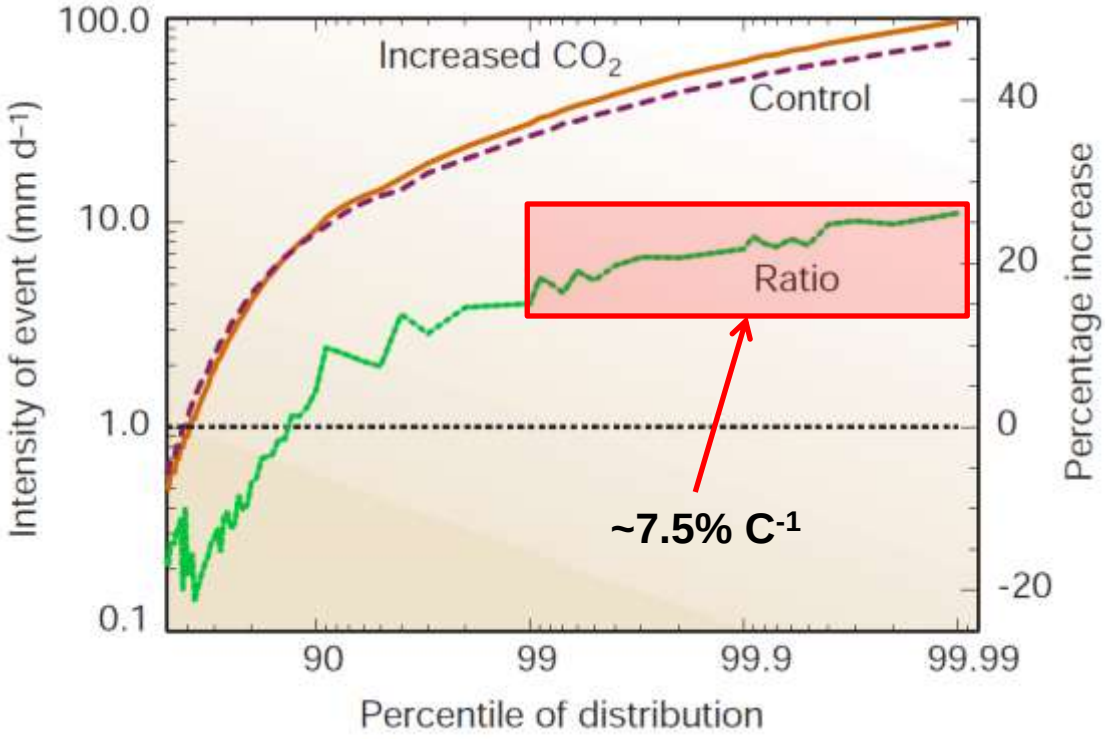
integrated water vapor transport (IVT) and precipitation



Ralph et al. (2005), adapted from Neiman et al. (2002)

extreme precipitation and climate change

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

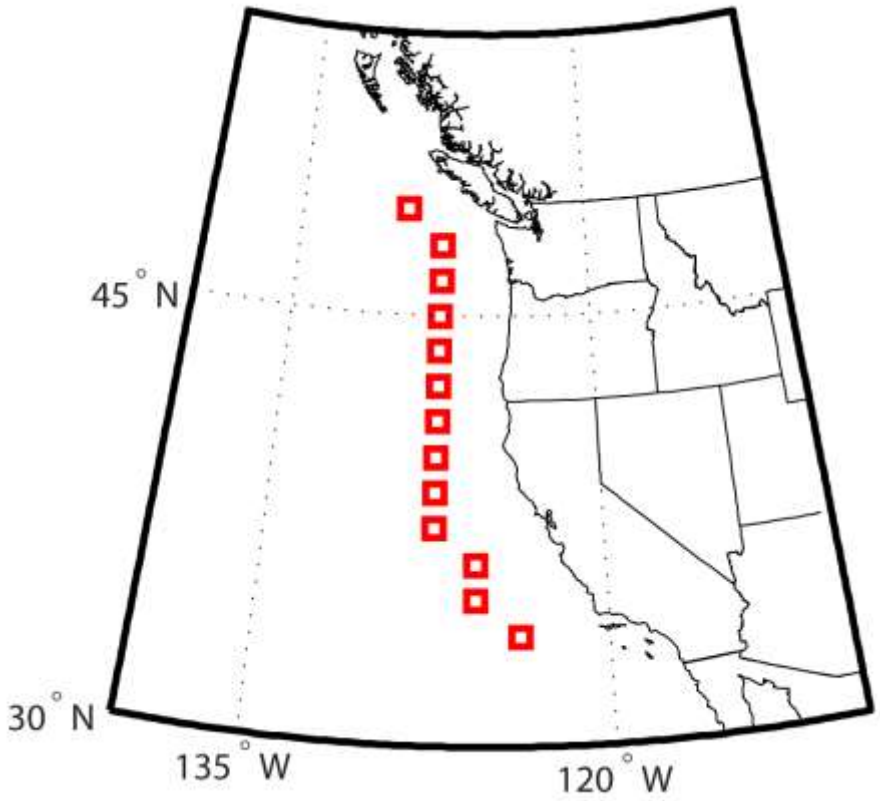


Allen and Ingram (2002)

Changes in Winter Atmospheric Rivers along the North American West Coast in CMIP5 Climate Models

Warner, Mass, and Salathé,
J Hydrometeorology, 2014

13 grid boxes, 33°N – 49°N



16 CMIP5 models (RCP 8.5):

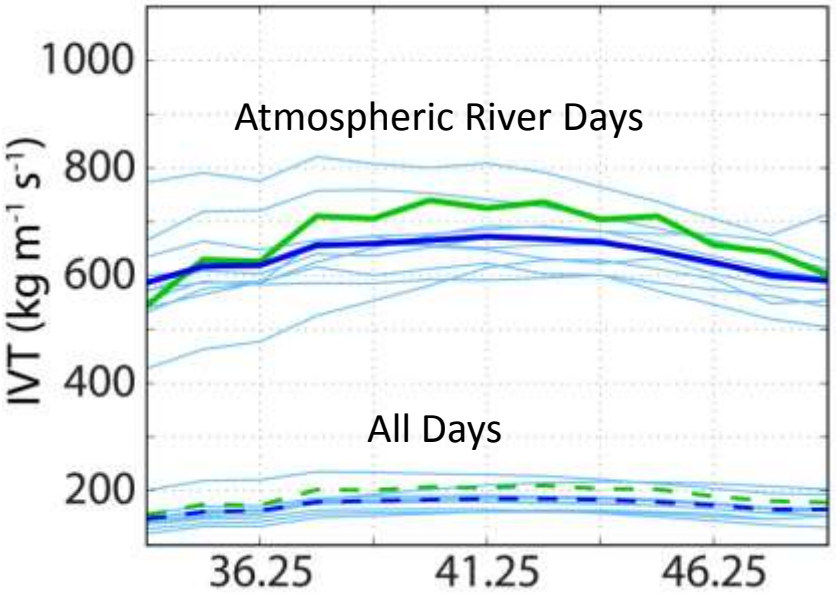
- CMCC-CM
- MRI-CGCM3
- CCSM4
- MIROC5
- CNRM-CM5
- HadGEM2-CC
- CMCC-CMS
- CSIRO-Mk3.6.0
- MPI-ESM-LR
- MPI-ESM-MR
- INMCM4
- IPSL-CM5A-MR
- NorESM1-M
- GFDL-CM3
- GFDL-ESM2M
- GFDL-ESM2G

+ NCEP reanalysis

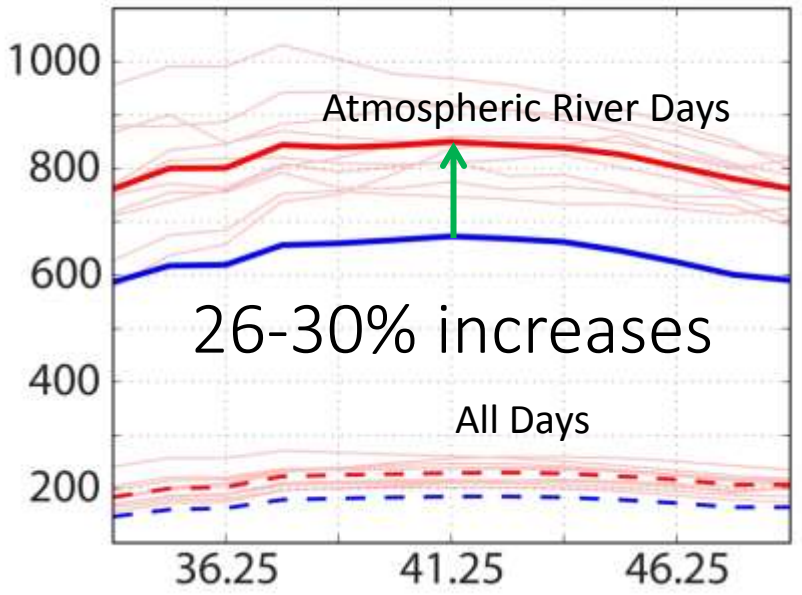
integrated water vapor transport (IVT)

NCEP **Historical** **RCP 8.5**

1970 -1999



2070 -2099



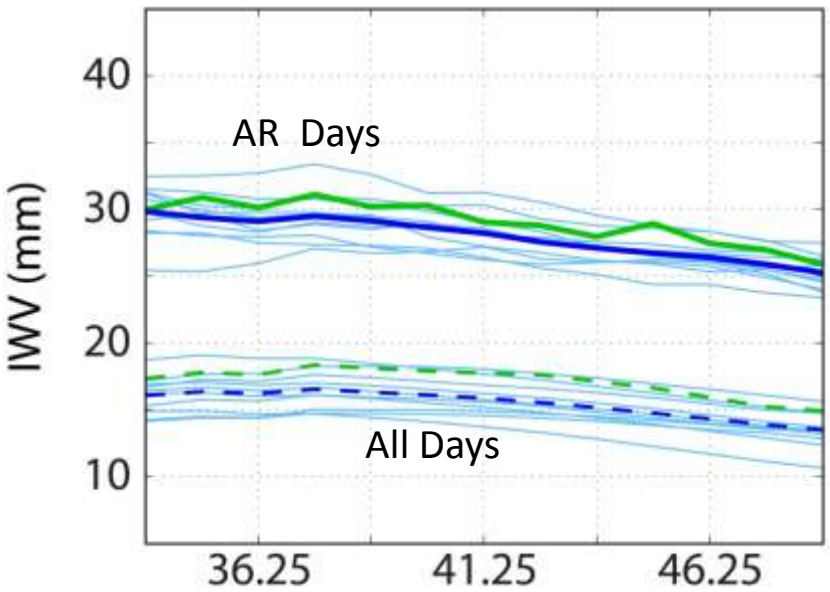
$$IVT = \frac{1}{g_0}\int_{sfc}^{500} \overline{q}\,\overline{U}\,dp$$

Warner et al. (2014)

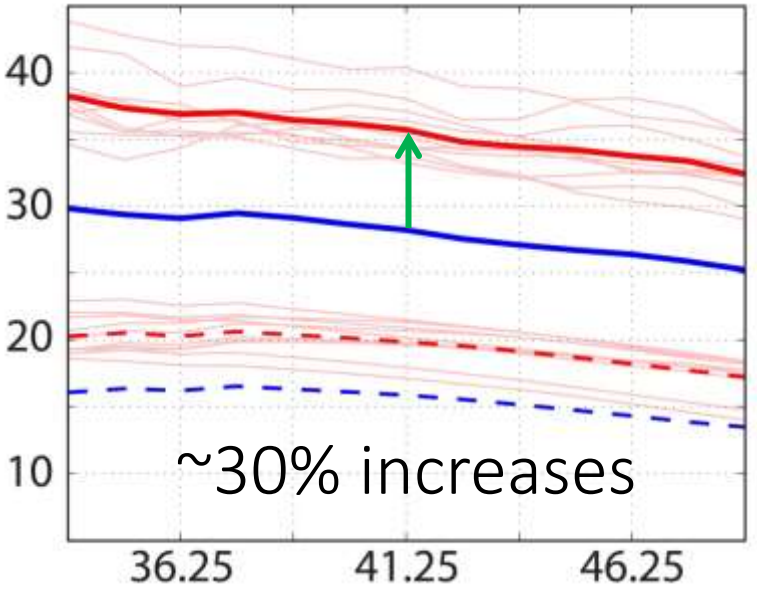
integrated water vapor (IWV)

NCEP **Historical** **RCP 8.5**

1970 -1999



2070 -2099



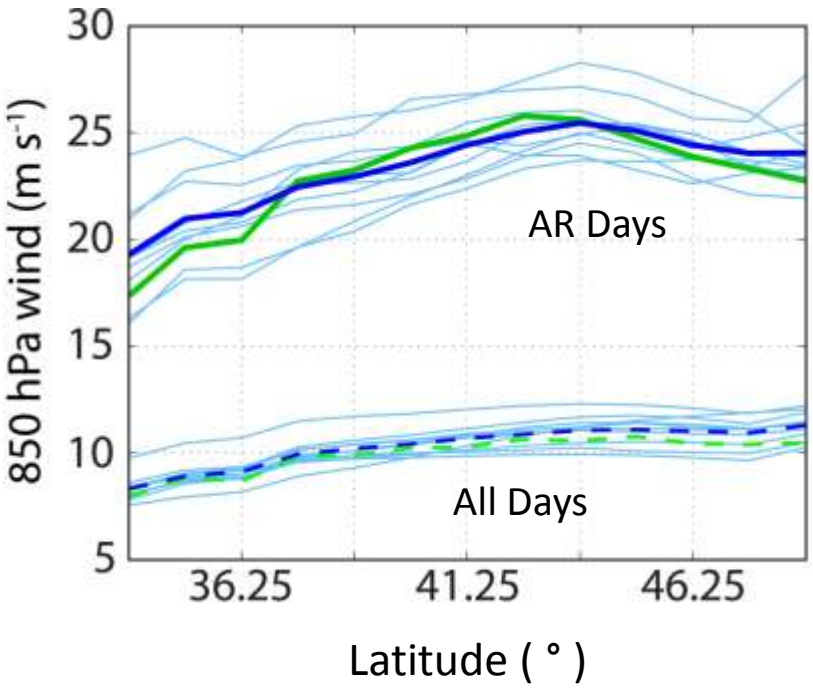
$$IWV = \frac{1}{g_0}\int_{sfc}^{500} \overline{q}\,\overline{V}\,dp$$

Warner et al. (2014)

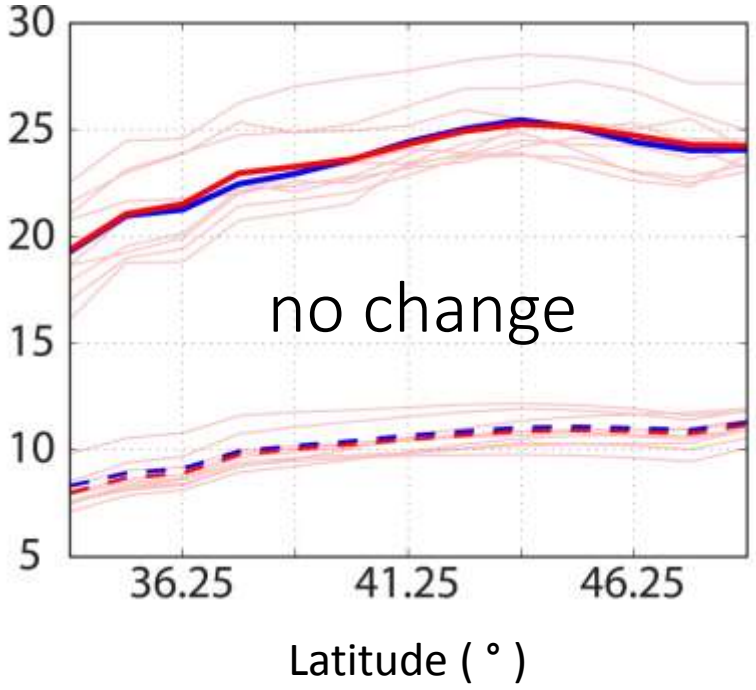
850-hPa wind

NCEP **Historical** **RCP 8.5**

1970 -1999



2070 -2099



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

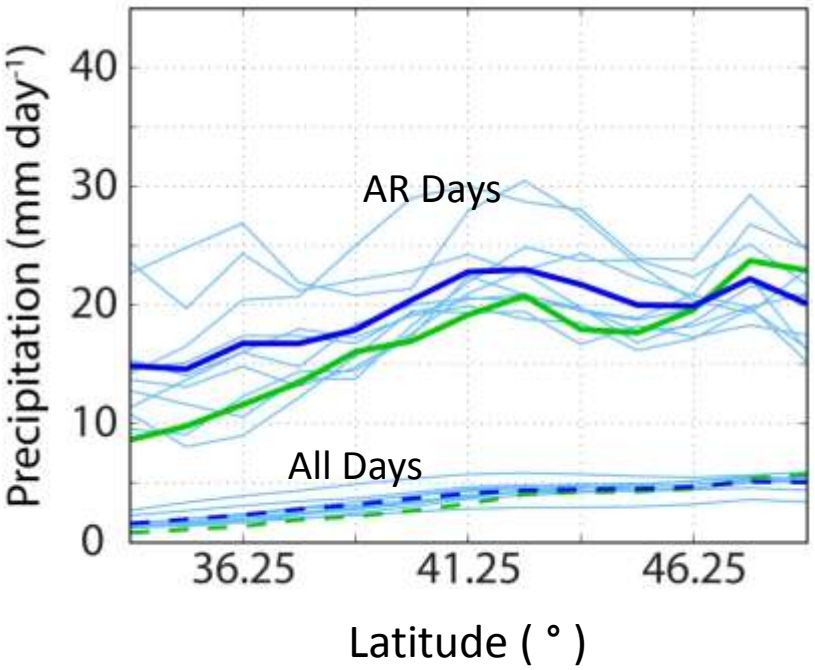
850-hPa

Warner et al. (2014)

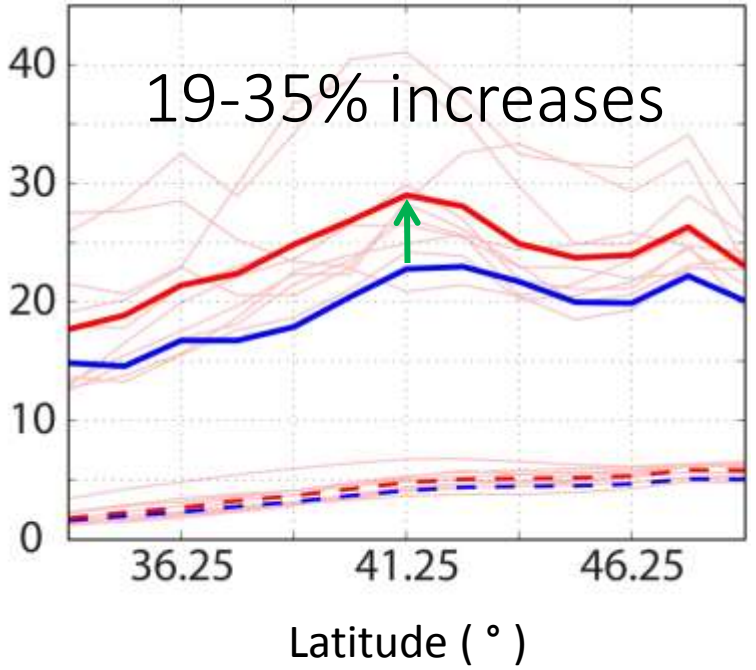
precipitation

NCEP **Historical** **RCP 8.5**

1970 -1999

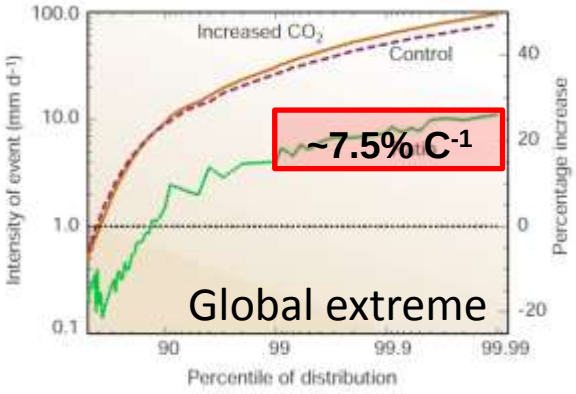


2070 -2099

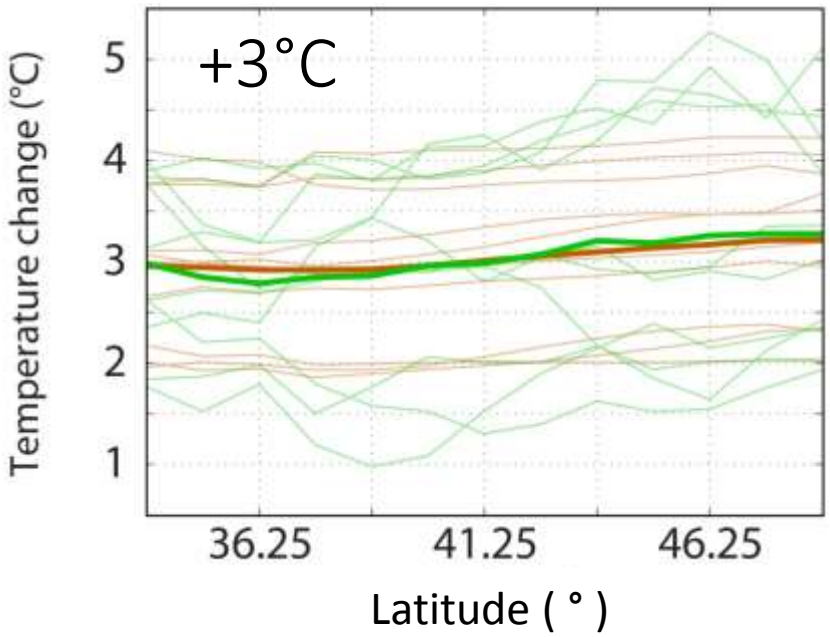


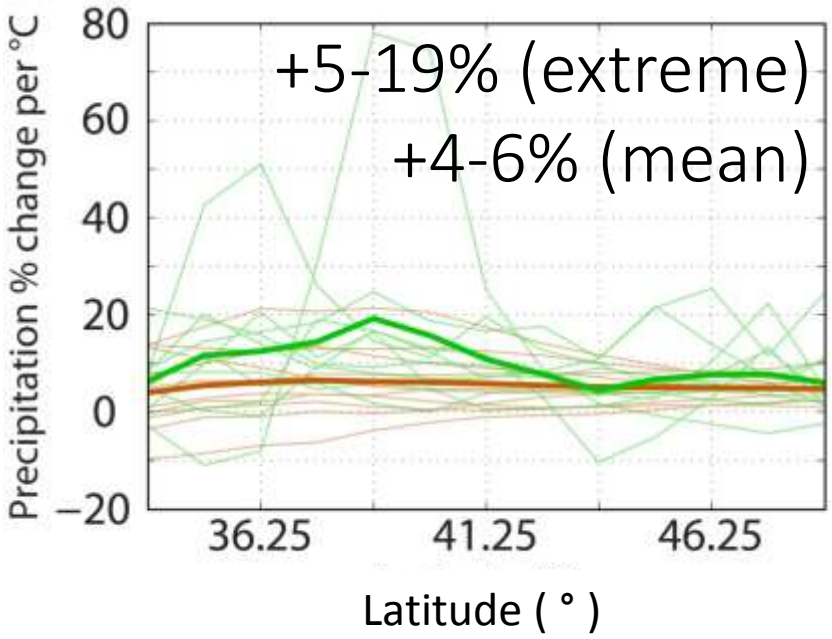
Warner et al. (2014)

ΔT and %ΔP °C^{-1}



All Days **AR Days**





Warner et al. (2014)

Conclusions

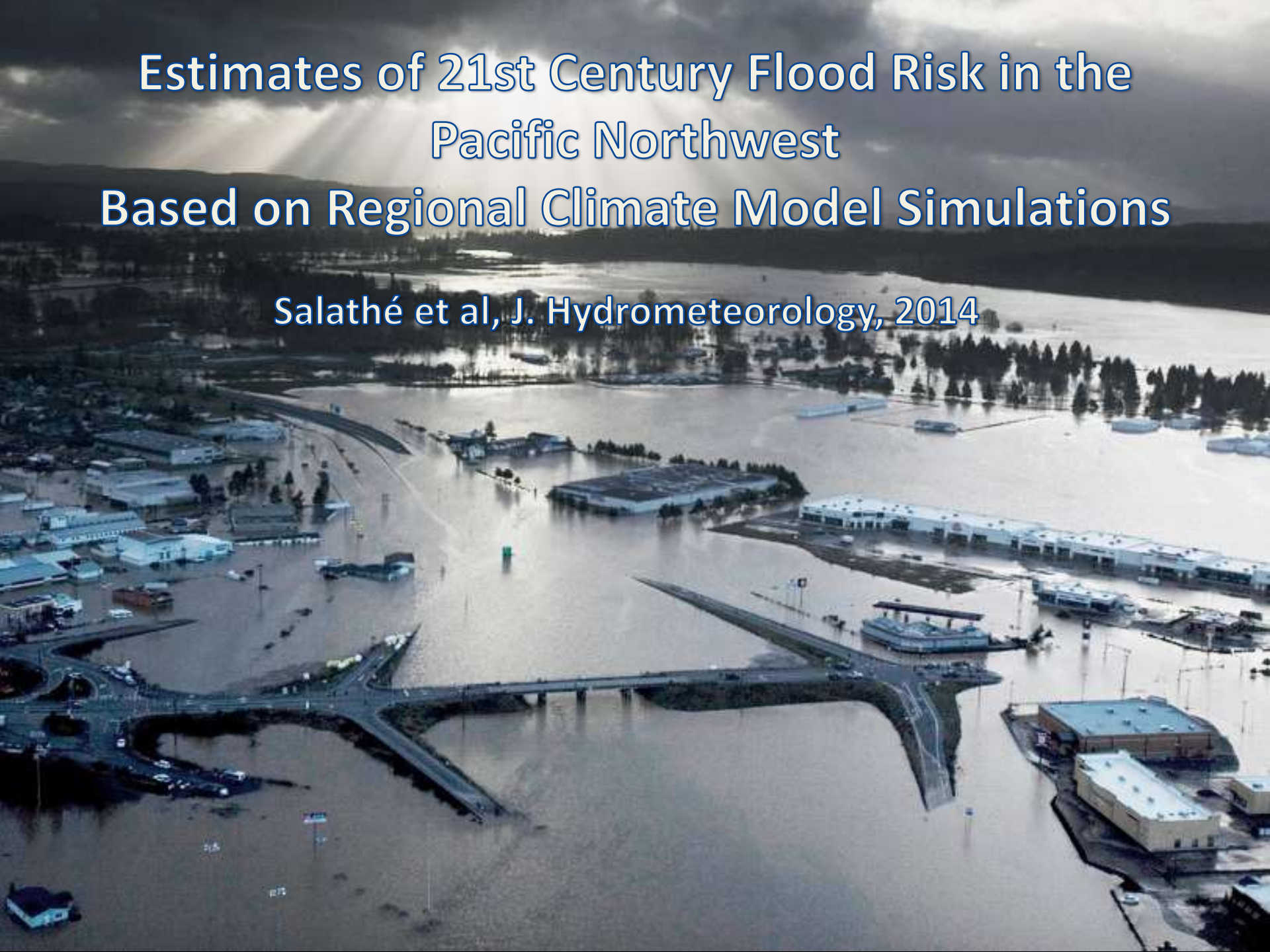
- In a 16 member CMIP5 ensemble, large increases are apparent in IWVF, the main metric for extreme precipitation along the North American west coast.

- The IWVF increase is due almost entirely to increases in column integrated water vapor and not due to increases in low-level wind.

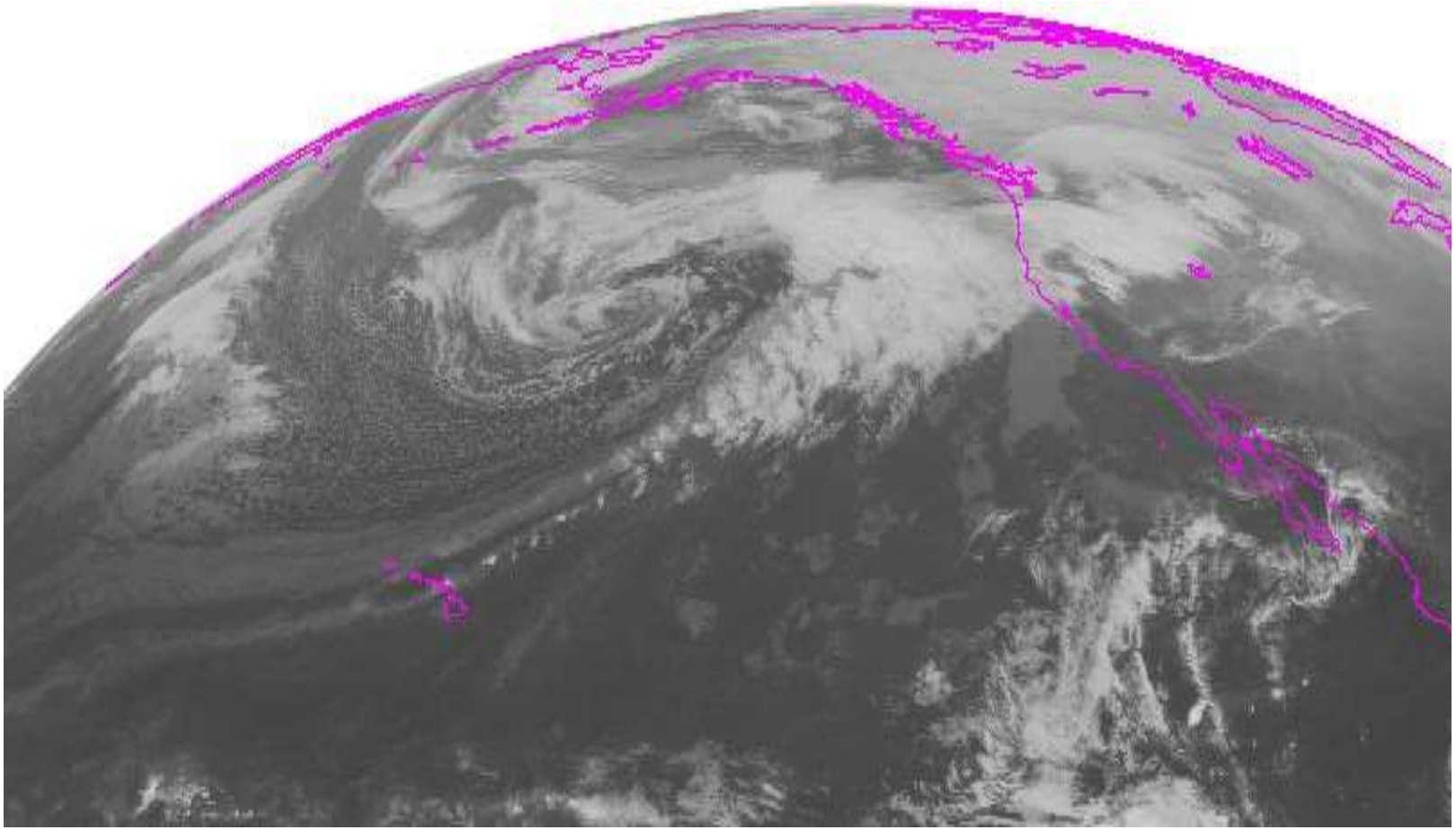
- The models reproduce theoretical increases in mean precipitation (1.6-3.6%/K) and extreme precipitation (6.5-10.7%/K) for this region.

Estimates of 21st Century Flood Risk in the Pacific Northwest Based on Regional Climate Model Simulations

Salathé et al, J. Hydrometeorology, 2014



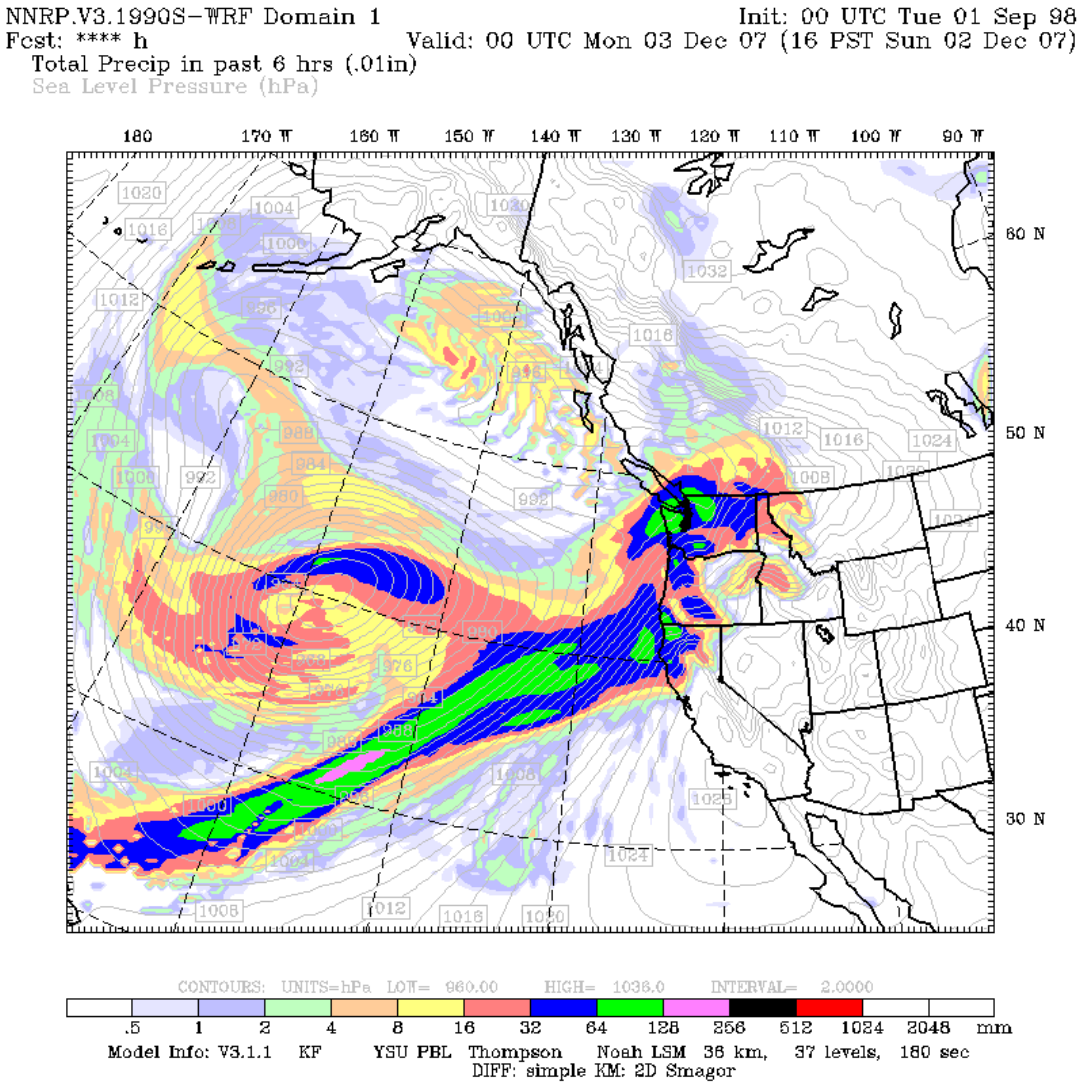
“Great Coastal Gale of 2007”



GOES-11 IR Image 00 UTC 3 Dec 2007

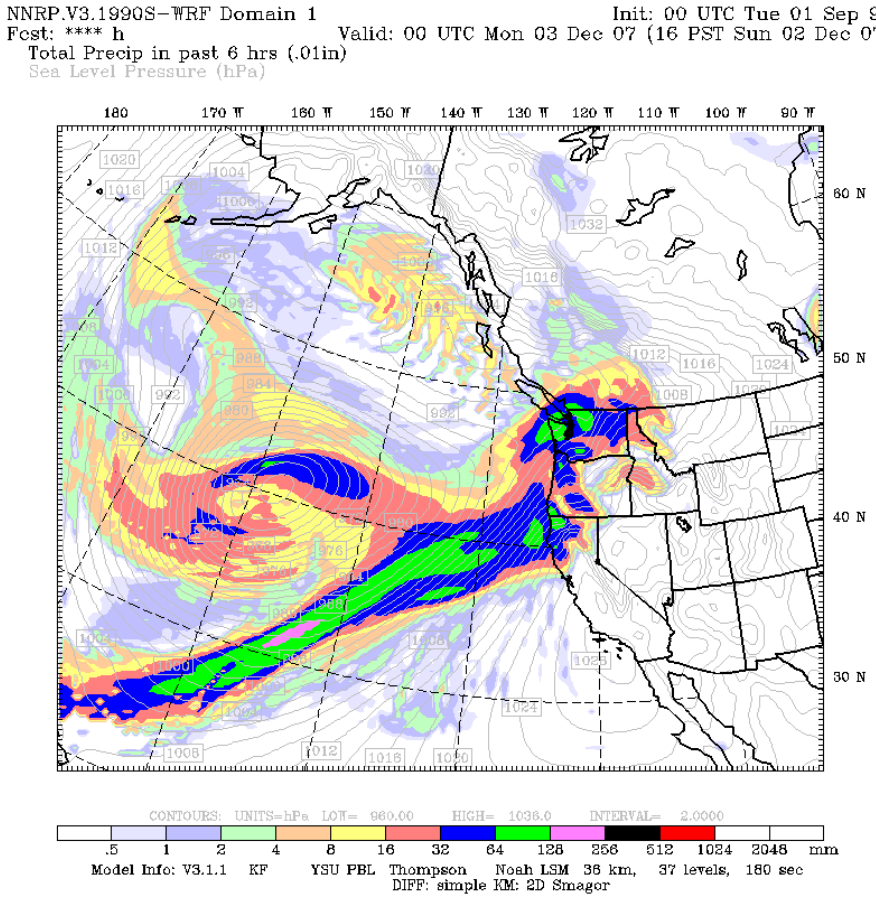
WRF Retrospective Simulation

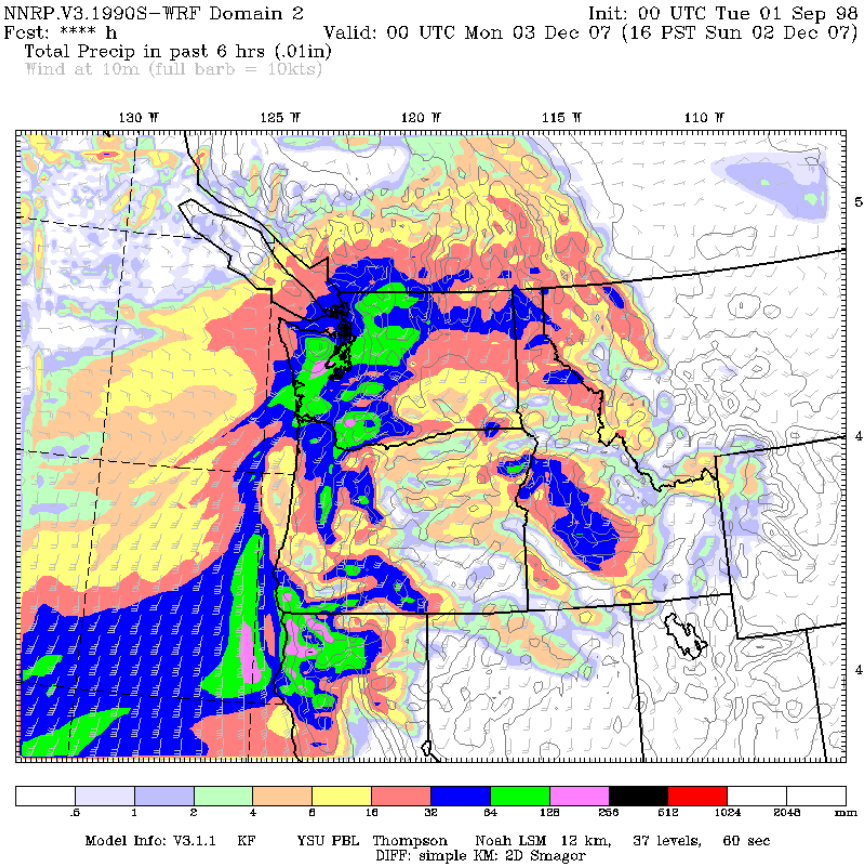
6-hour Precipitation

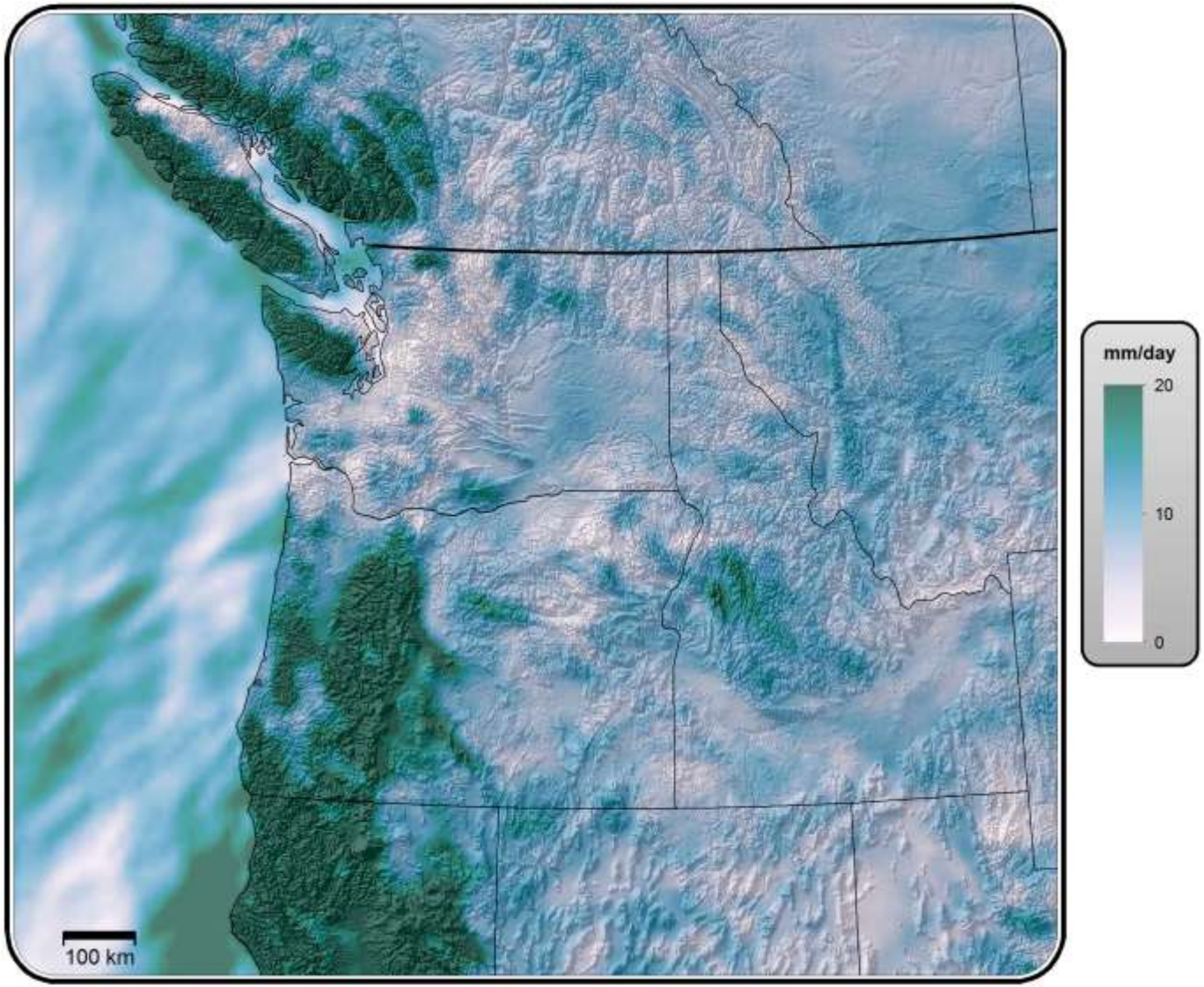


- 60-year Simulation 1950-2009
- 36km outer nest
- 15km inner nest
- Boundary Conditions from NCEP-NCAR Reanalysis

6-Hour Precipitation
00UTC 03 Dec 2007



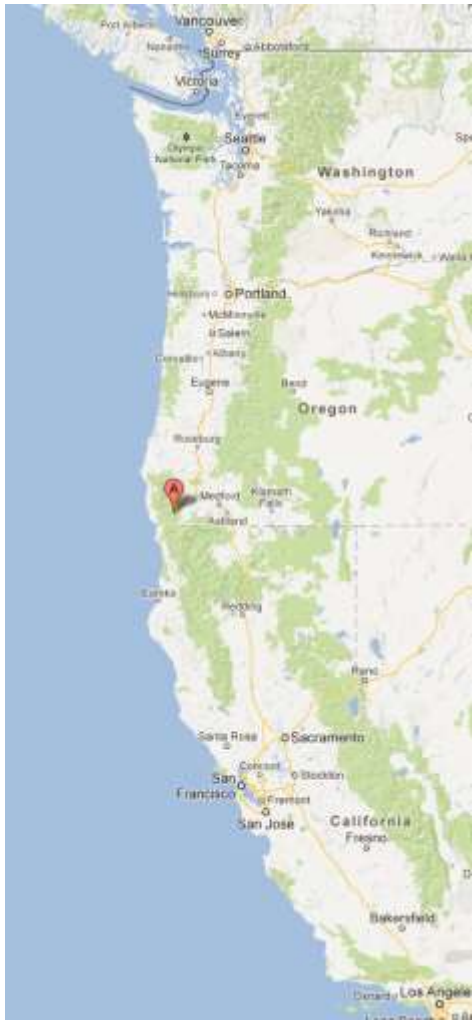




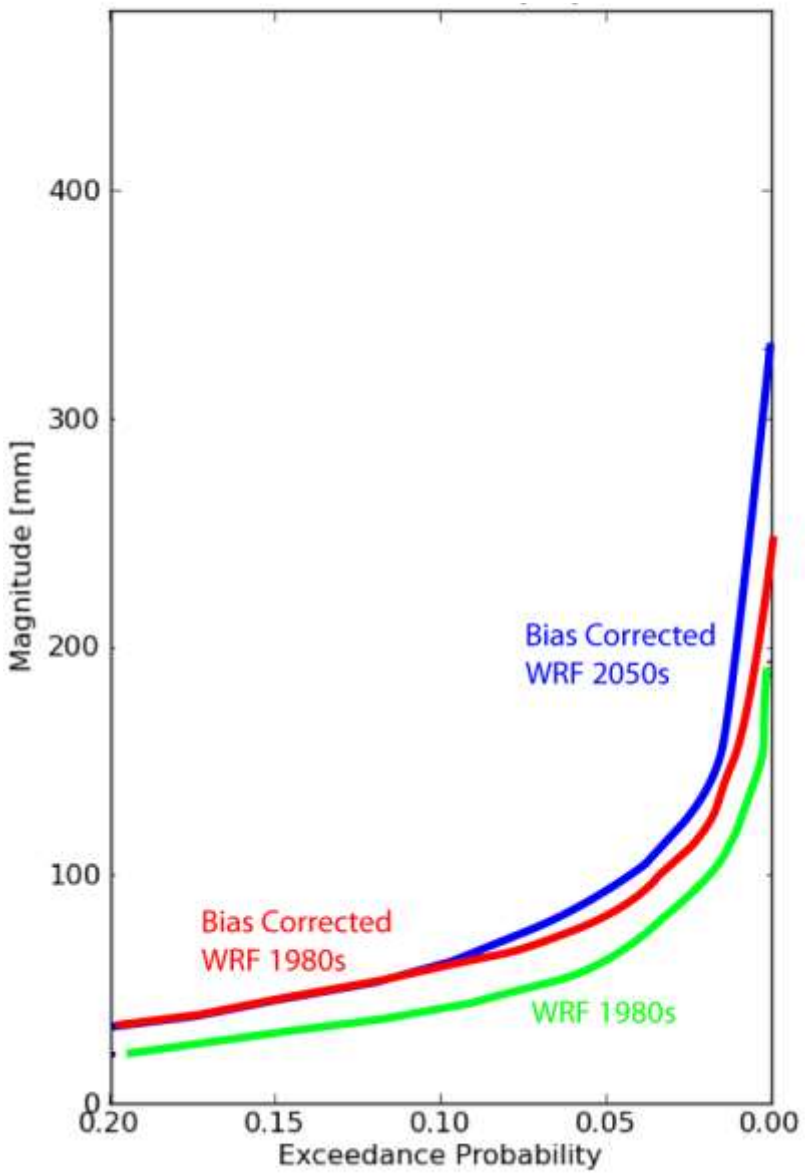
ECHAM5 Downscaled with WRF Regional Climate Model

Simulated difference in the 30-year average annual maximum wintertime precipitation from current climate (1970-1999) to future climate (2030-2069) conditions. Contour lines indicate model terrain height in meters.

Increase in the Most Extreme Events

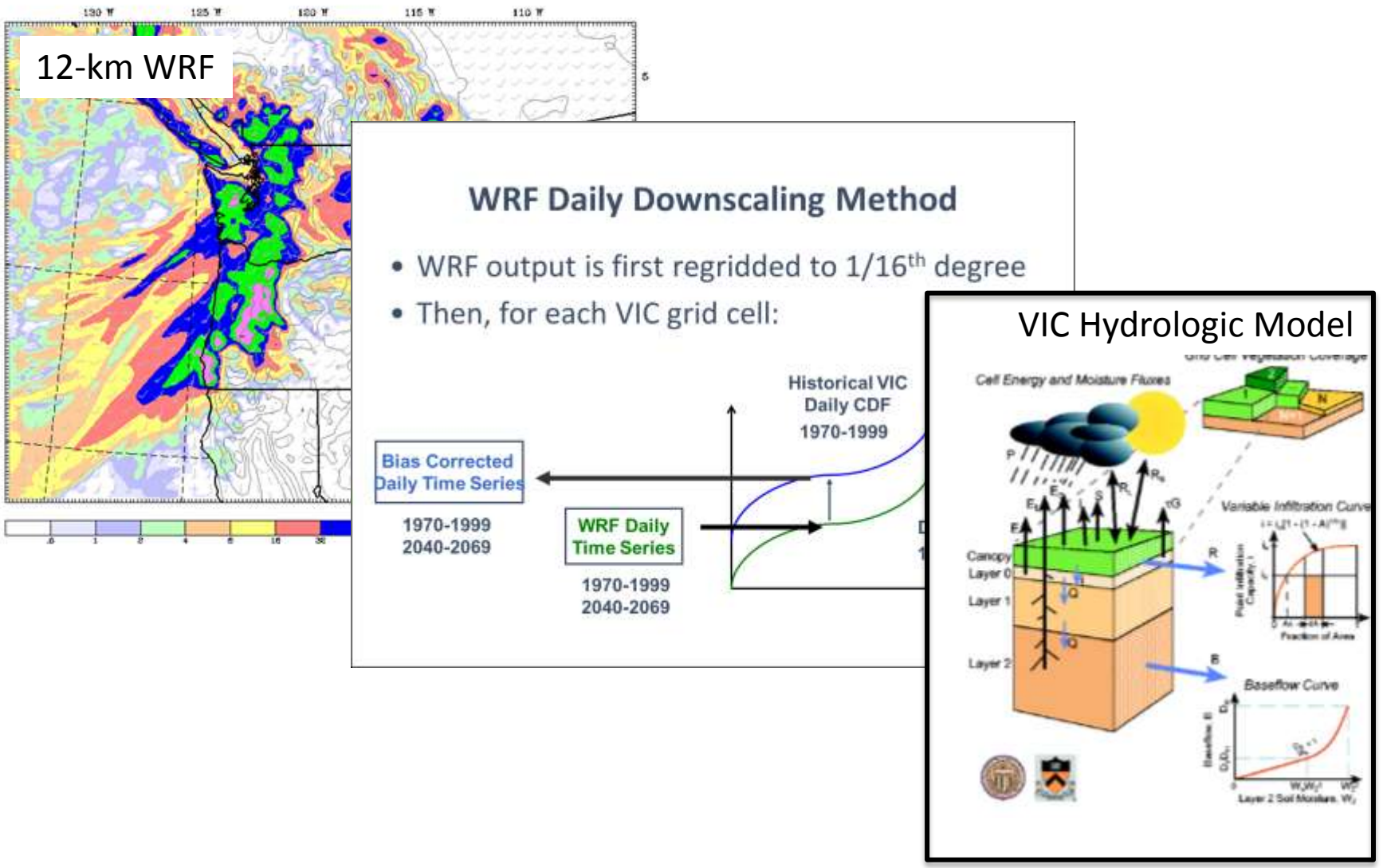


January Precipitation

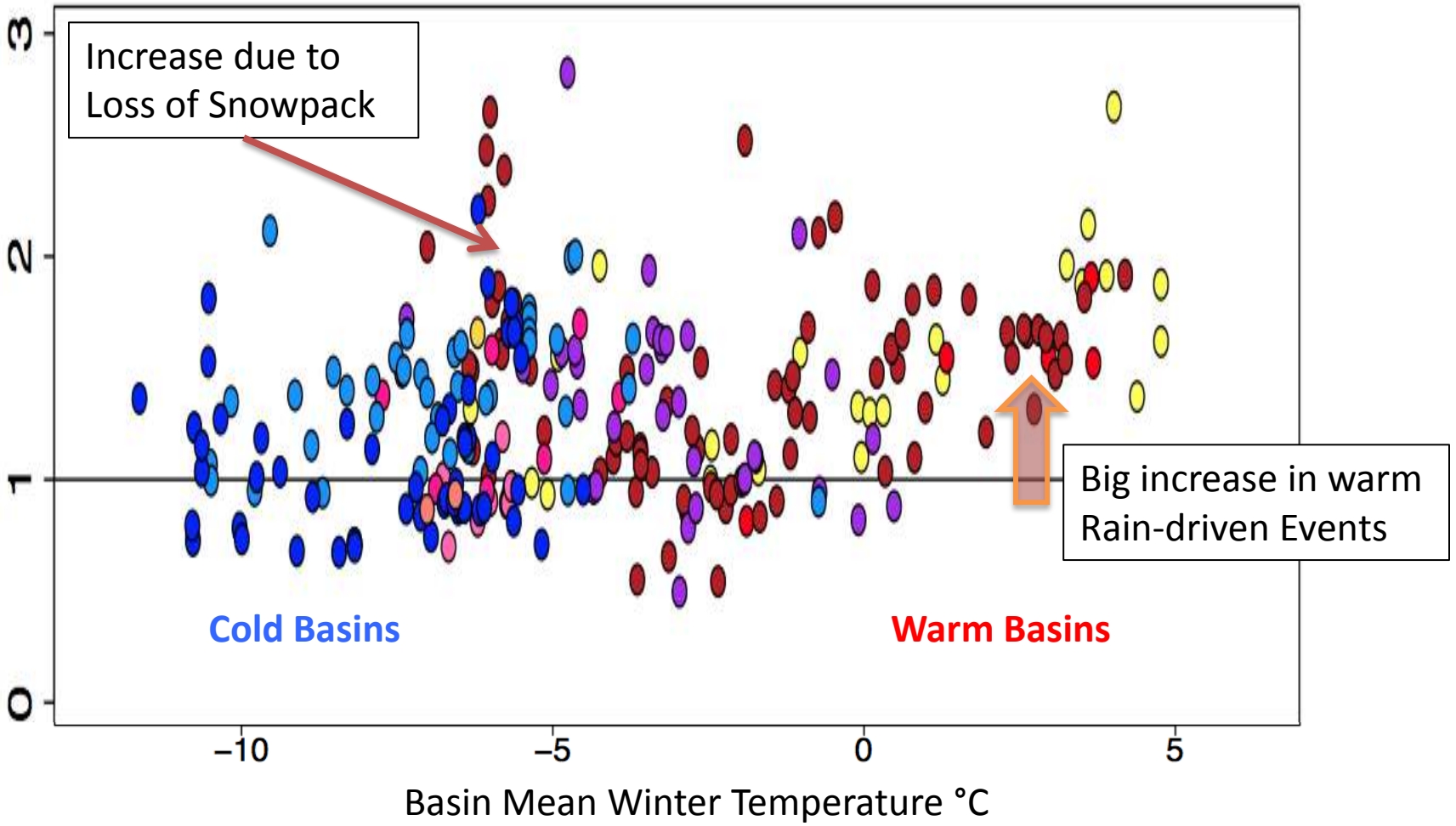


Top 20% Events

Regional Climate Model Projections of Future Flood Risk



Results from Statistical Downscaling



Conclusions

- Projected changes in Atmospheric Rivers yield increases in local intense precipitation
- Changes in intense precipitation substantially alter flood risk in warm basins
- Orographic effects likely contribute to shifts in flood risk

- Pathways for Climate Change:
  - Connection to Subtropics
  - Thermodynamics
  - Orographic Enhancement

CLIMATE CHANGE IMPACTS AND ADAPTATION PILOT STUDY

HOWARD HANSON DAM

Green River, Washington

Kevin Shaffer, P.E.

Hydraulic Engineer

Seattle District

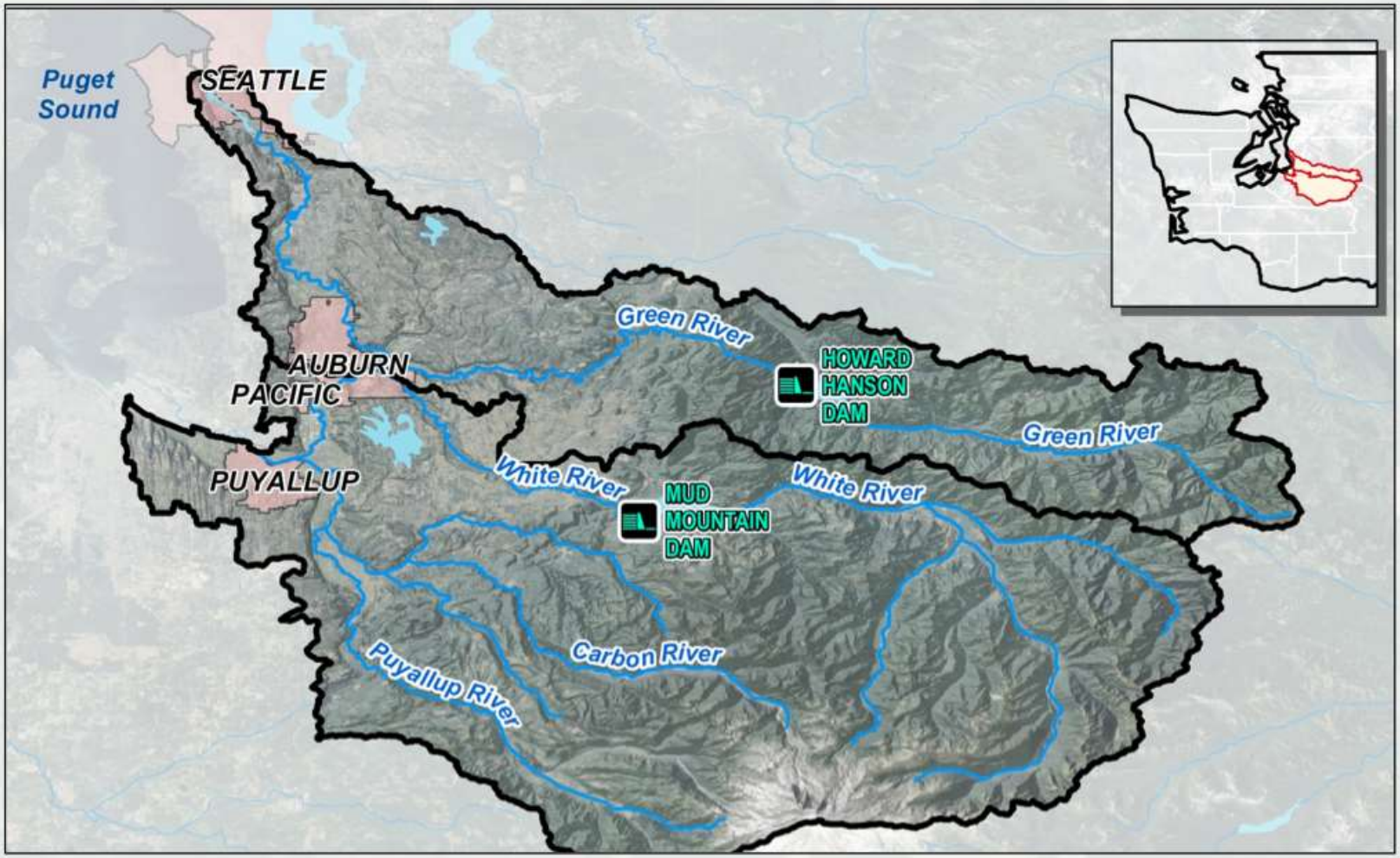
10 September 2014

U.S.ARMY

US Army Corps of Engineers

BUILDING STRONG®

Howard Hanson Dam

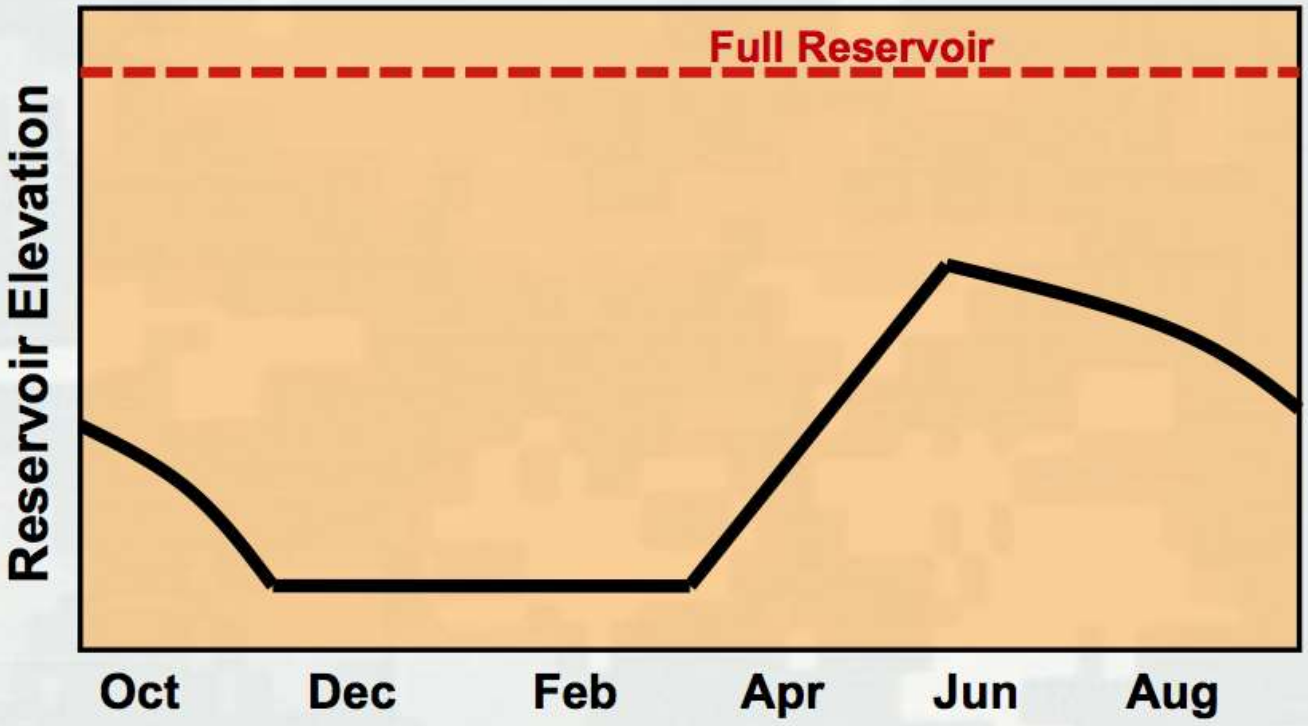


U.S.ARMY

BUILDING STRONG®

Authorized Purposes

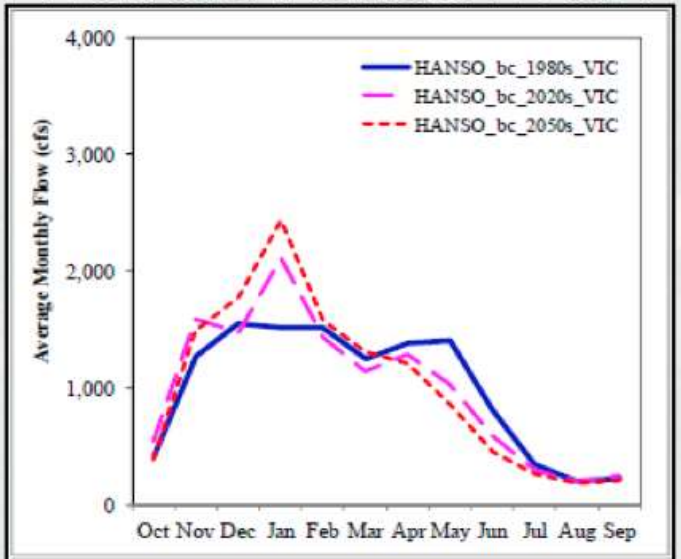
1. Flood Risk Management (October – February)
2. Fisheries Conservation (July – October)
3. Water Supply for City of Tacoma (July – October)



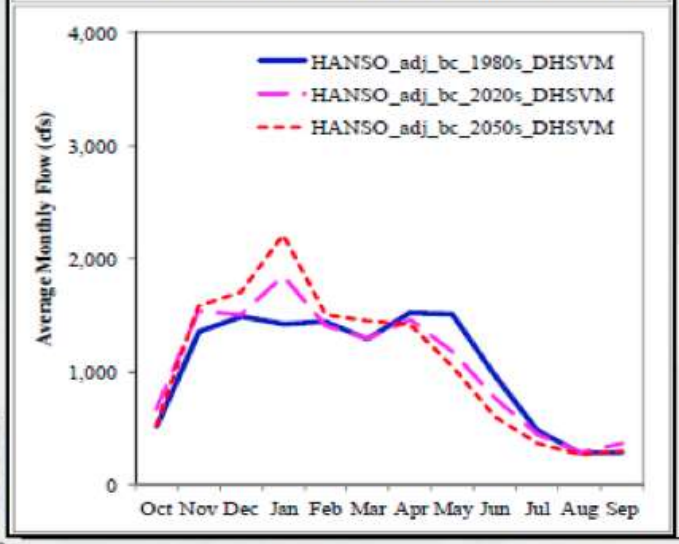
Unregulated Hydrology

Howard Hanson Dam

VIC

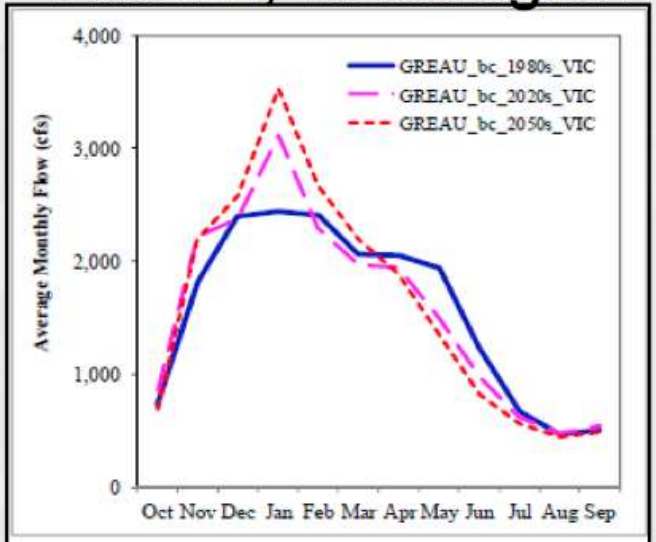


DHSVM

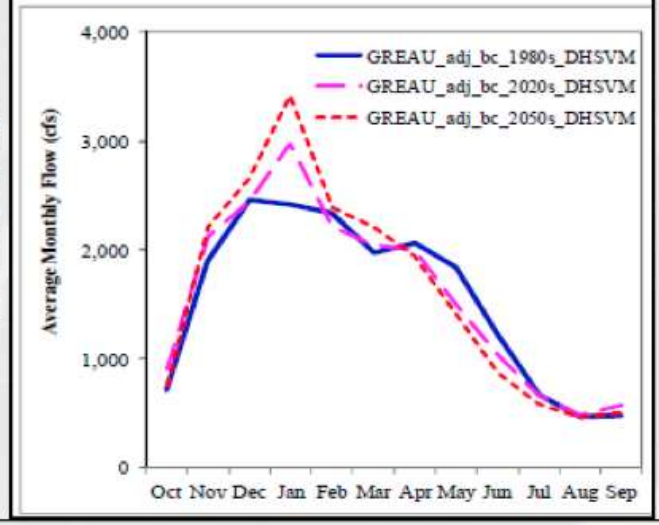


Auburn, Washington

VIC



DHSVM

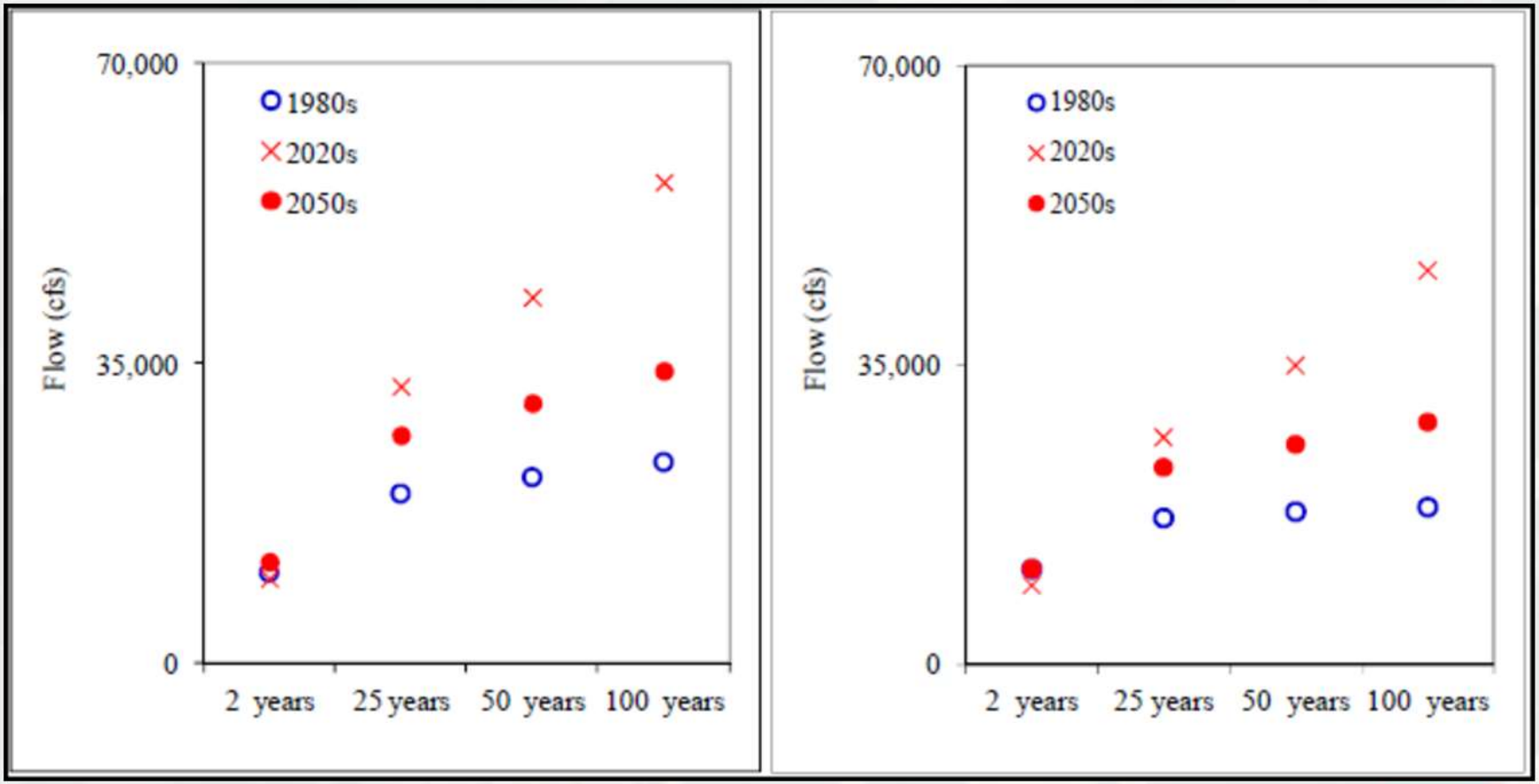


U.S.ARMY

BUILDING STRONG®

Hydrologic Modeling

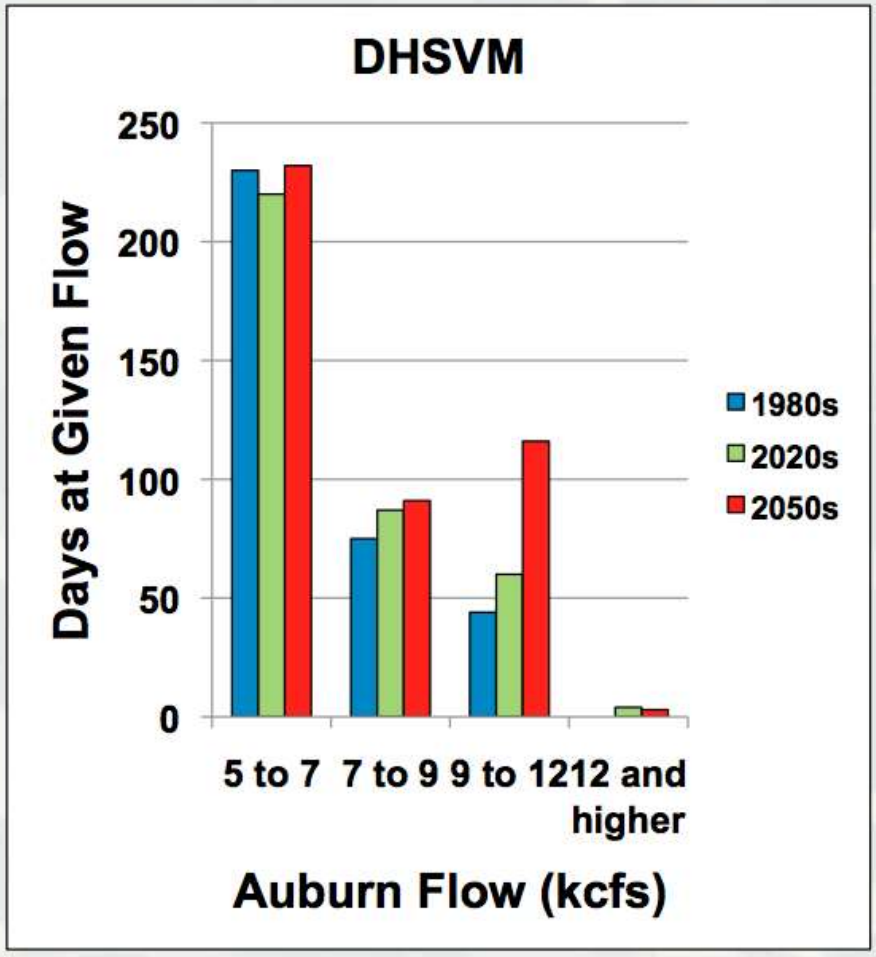
Flood statistics for Howard Hanson Dam inflow

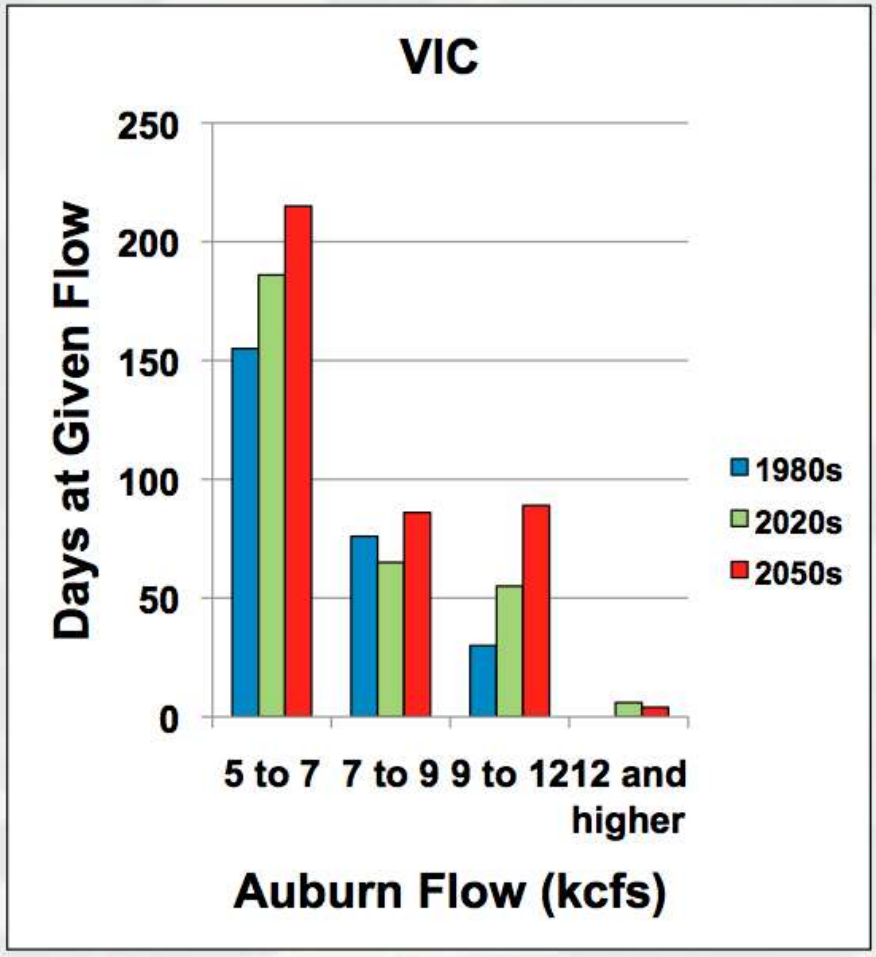


VIC

DHSVM

Flooding - Magnitude



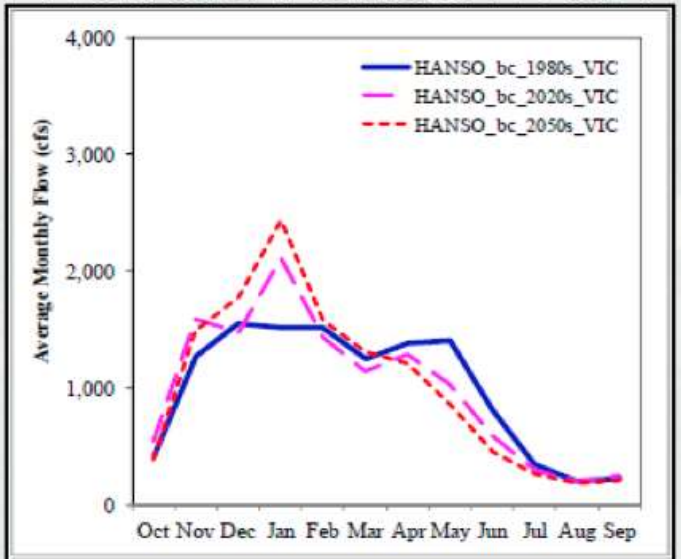


Flood Flow = 12 kcfs

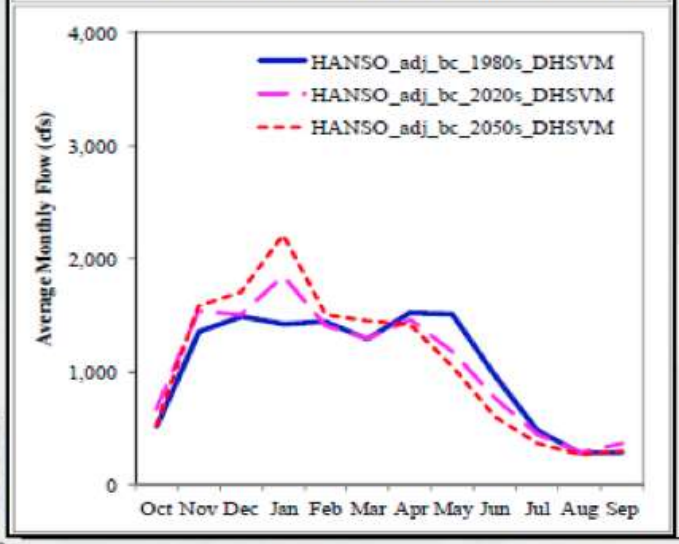
Unregulated Hydrology

Howard Hanson Dam

VIC

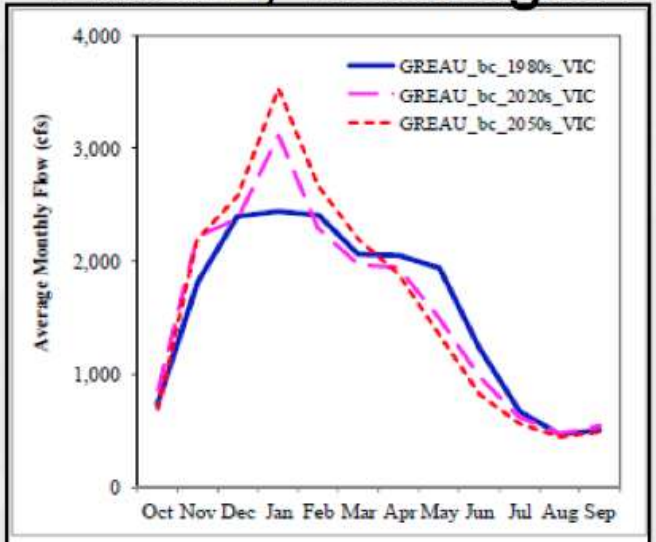


DHSVM

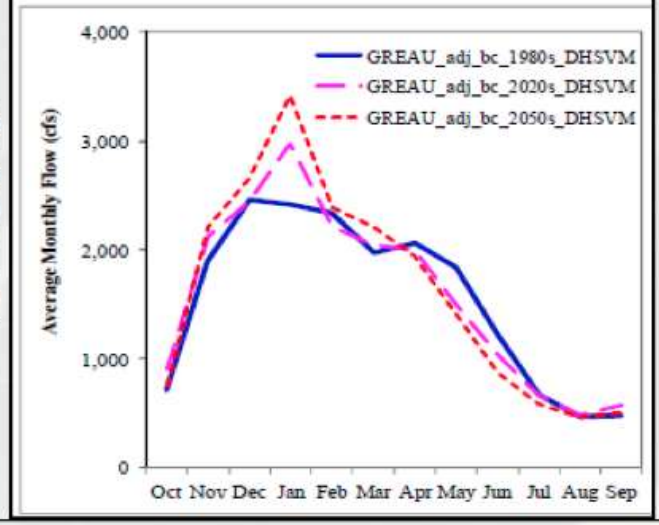


Auburn, Washington

VIC



DHSVM

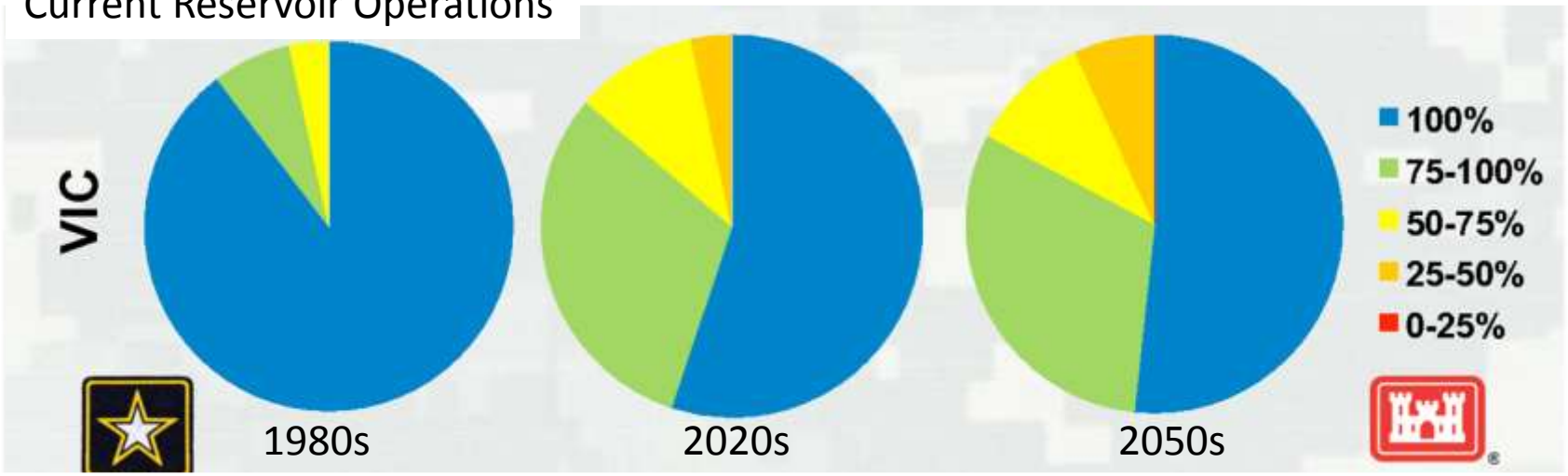


U.S.ARMY

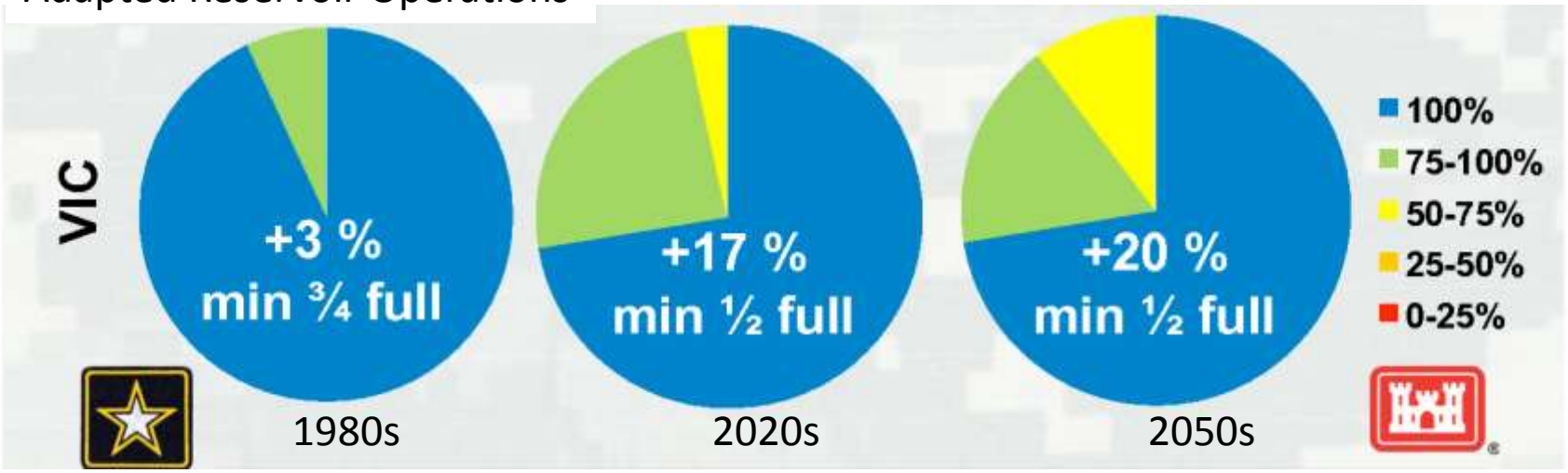
BUILDING STRONG®

Reservoir Refill for Summer Water Storage

Current Reservoir Operations



Adapted Reservoir Operations



Flooding in the lower Snohomish:

Sea Level Rise, Flooding, and Inundation

Source: WSDOT

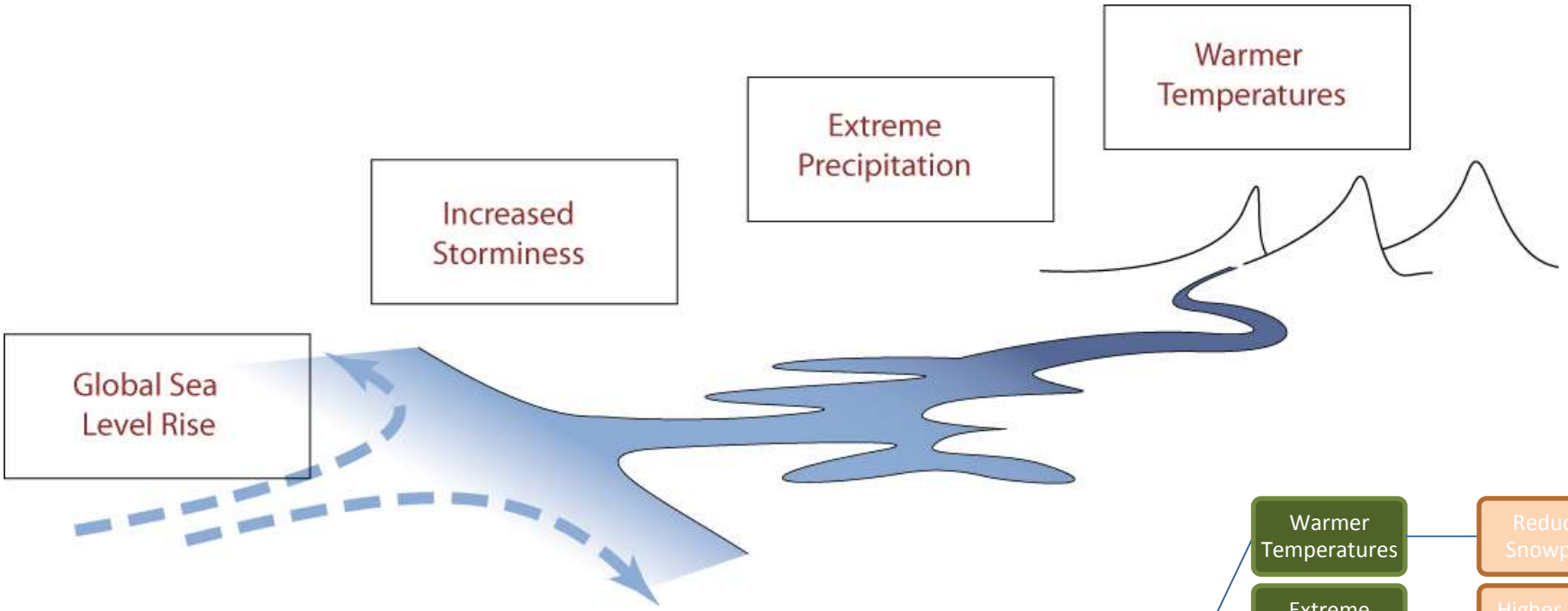
Guillaume Mauger, UW CIG
Se-Yeun Lee, UW SEFS
Kris Johnson, TNC
Ray Walton, WEST consultants

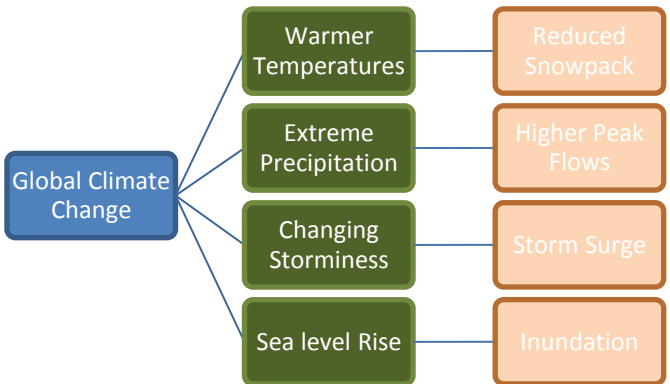
WEST Consultants, Inc.

The Nature Conservancy

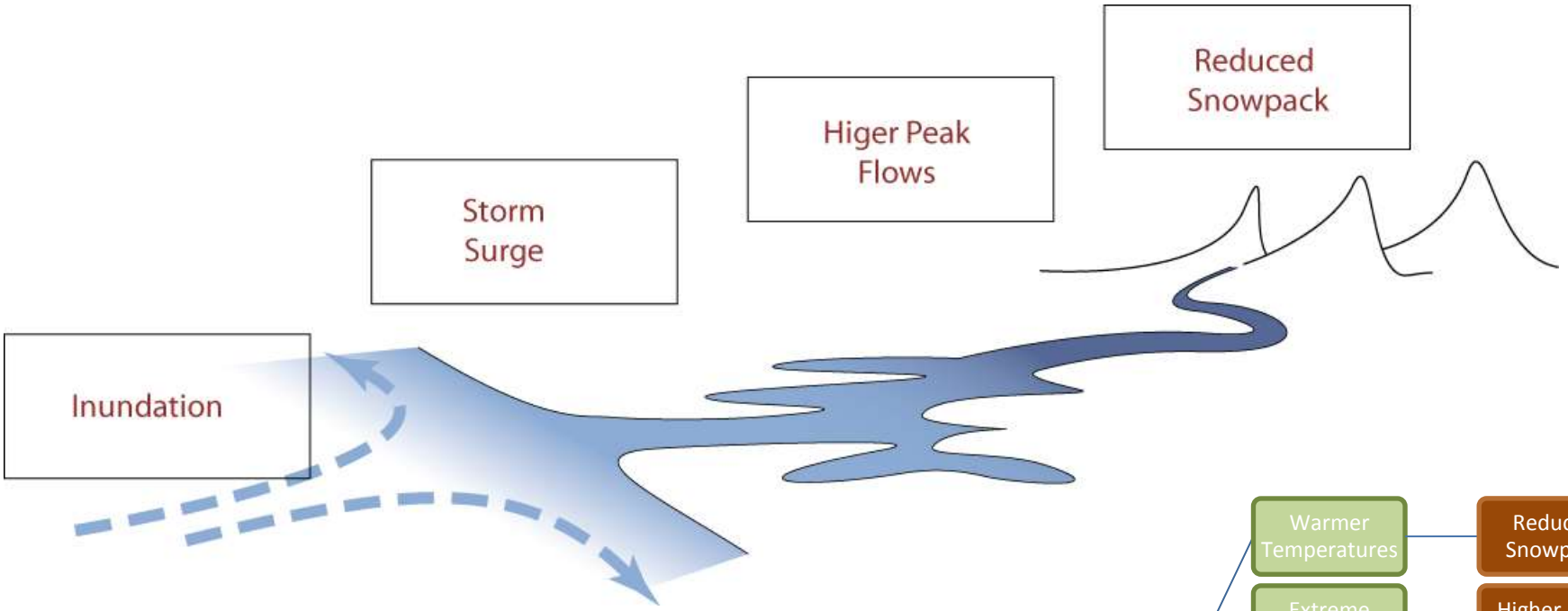
Climate Impacts Group
Climate Science in the Public Interest

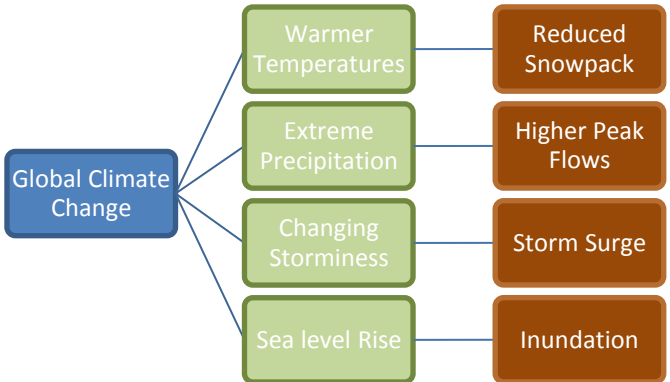
Climate Change Pathways: Physical Drivers

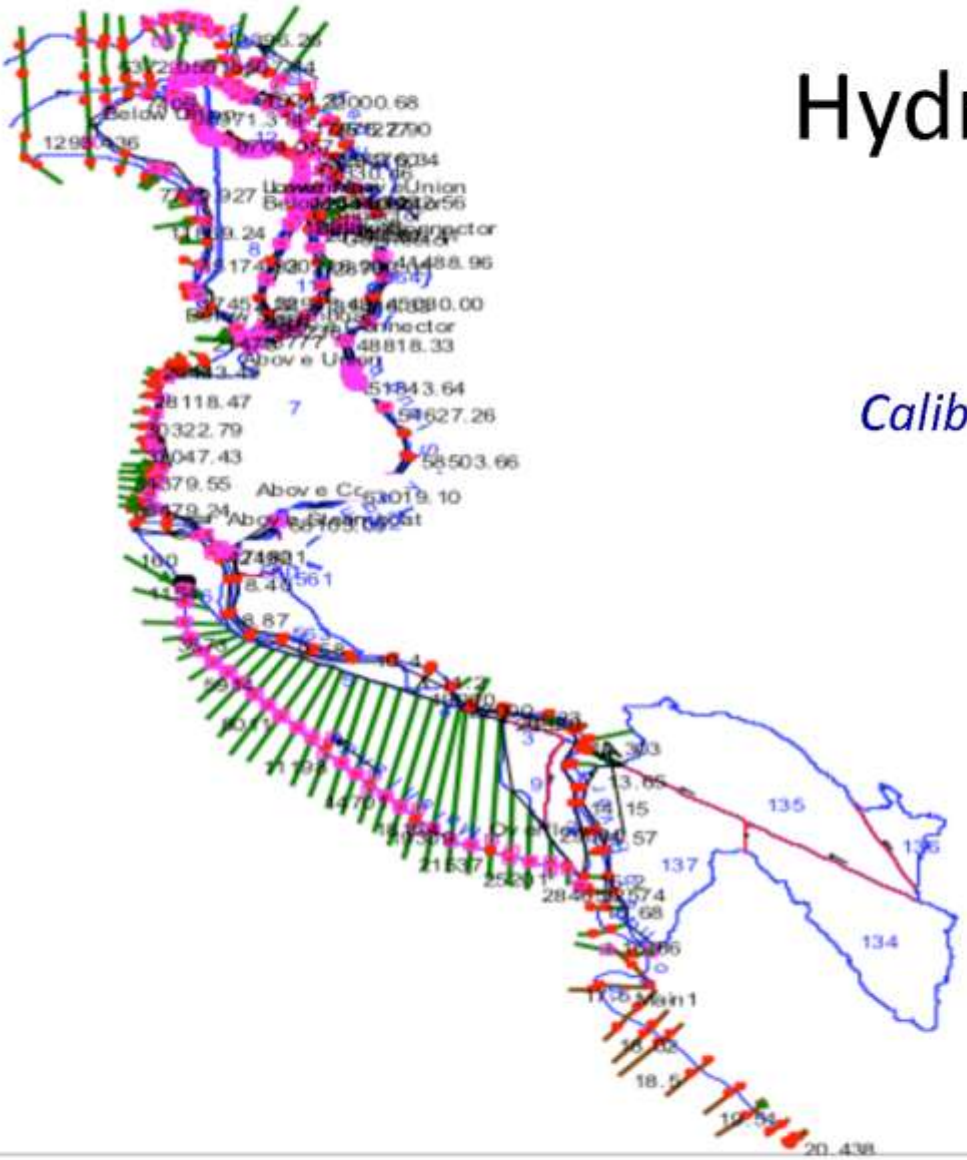




Climate Change Pathways: Climate Impacts







Hydraulic model: 1D HEC-RAS

Calibrated on Nov 1990 and Jan 2009 floods

WEST Consultants, Inc.

Floodplains by Design | Washington

www.floodplainsbydesign.org

Reader

Floodplains by Design

· REDUCING RISK, RESTORING RIVERS ·

Approach Partnerships Projects Perspectives Priorities Science

Resilient floodplains support farming and protect water quality

Innovation Through Collaboration

Puget Sound's major rivers and their floodplains deliver a wealth of economic, natural and cultural benefits and make the region a place we all love to call home. Yet floodplain management has not

News

Floodplains by Design | Puget Sound, Washington

maps.coastalresilience.org/pugetsound/

Reader

FLOODPLAINS BY DESIGN | PUGET SOUND, WASHINGTON | GET STARTED | TOUR | GO TO ▼ | The Nature Conservancy | Partners | Legal Disclosure

Regional Layers

Coastal Defense

Flood Level Rise

Integrated Community Planning

Switch To Map 2

Split View

Save & Share

Export Page

Search by Address

Streets ▼

Flood Level Rise

Flood and Sea Level Rise

Flooding is increasing along the coast and certain rivers. Use this app to view areas affected today and in the future due to increased sea level rise, surge from storms and hurricanes, and inland flooding.

Current coastal and floodplain inundation scenario

Future coastal and floodplain inundation scenario

Don't Show This on Start | Continue

Map Legend

Current Flood Depth__10%

- > 0 and < 2ft
- 2.01 - 4ft
- 4.01 - 6ft
- 6.01 - 8ft
- 8.01 - 12ft
- 12.01 - 16ft
- 16.01 - 20ft

Granite Falls

Mount Pilchuck State Park

Marysville

Tulalip Reservation

84th St NE

Useless Bay

Woods Creek

Monroe

US-2

Edmonds

Maltby

Kingston

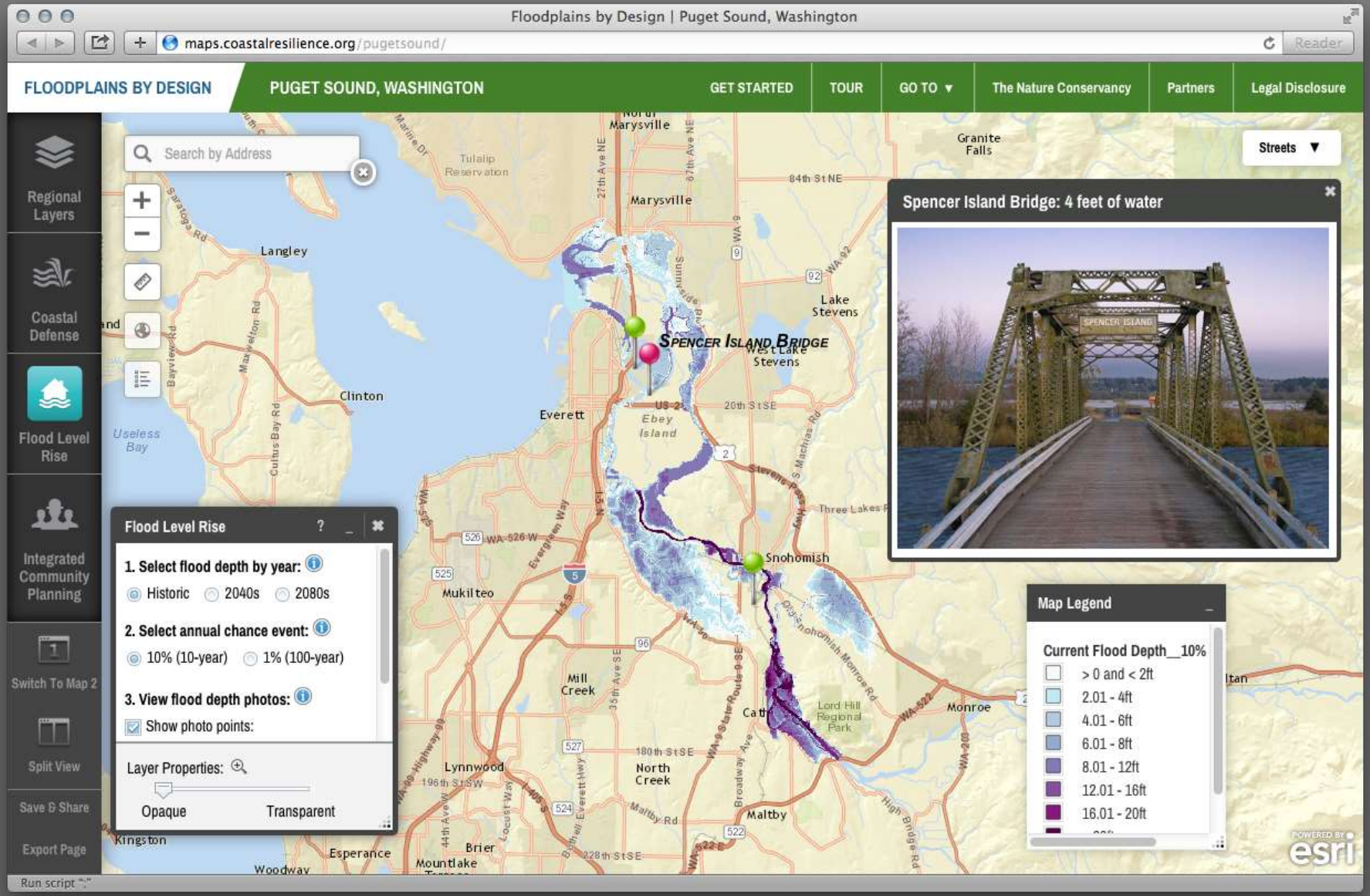
Esperance

Brier

Mountlake Terrace

Woodway

Powered by esri


Floodplains by Design | Puget Sound, Washington
maps.coastalresilience.org/pugetsound/
Reader
FLOODPLAINS BY DESIGN
PUGET SOUND, WASHINGTON
GET STARTED
TOUR
GO TO
The Nature Conservancy
Partners
Legal Disclosure
Regional Layers
Coastal Defense
Flood Level Rise
Integrated Community Planning
Switch To Map 2
Split View
Save & Share
Export Page
Search by Address
Streets
Spencer Island Bridge: 4 feet of water
SPENCER ISLAND
Spencer Island Bridge
Flood Level Rise
1. Select flood depth by year:
Historic
2040s
2080s
2. Select annual chance event:
10% (10-year)
1% (100-year)
3. View flood depth photos:
Show photo points:
Layer Properties:
Opaque
Transparent
Map Legend
Current Flood Depth__10%
> 0 and < 2ft
2.01 - 4ft
4.01 - 6ft
6.01 - 8ft
8.01 - 12ft
12.01 - 16ft
16.01 - 20ft
Marysville
Granite Falls
Tulalip Reservation
Langley
Clinton
Useless Bay
Everett
Ebey Island
Lake Stevens
West Lake Stevens
Snohomish
Mukilteo
Mill Creek
North Creek
Lynnwood
Maltby
Monroe
Lord Hill Regional Park
Kingston
Esperance
Brier
Mountlake Terrace
Woodway
esri

Floodplains by Design | Puget Sound, Washington

maps.coastalresilience.org/pugetsound/

Reader

FLOODPLAINS BY DESIGN | PUGET SOUND, WASHINGTON | GET STARTED | TOUR | GO TO ▼ | The Nature Conservancy | Partners | Legal Disclosure

Regional Layers

Coastal Defense

Flood Level Rise

Integrated Community Planning

Switch To Map 2

Split View

Save & Share

Export Page

Search by Address

Streets ▼

Spencer Island Bridge: 6 feet of water

Spencer Island Bridge

Flood Level Rise

1. Select flood depth by year:
Historic | 2040s | 2080s

2. Select annual chance event:
10% (10-year) | 1% (100-year)

3. Select climate change scenerio:
Low | High

Layer Properties:
Opaque | Transparent

Map Legend

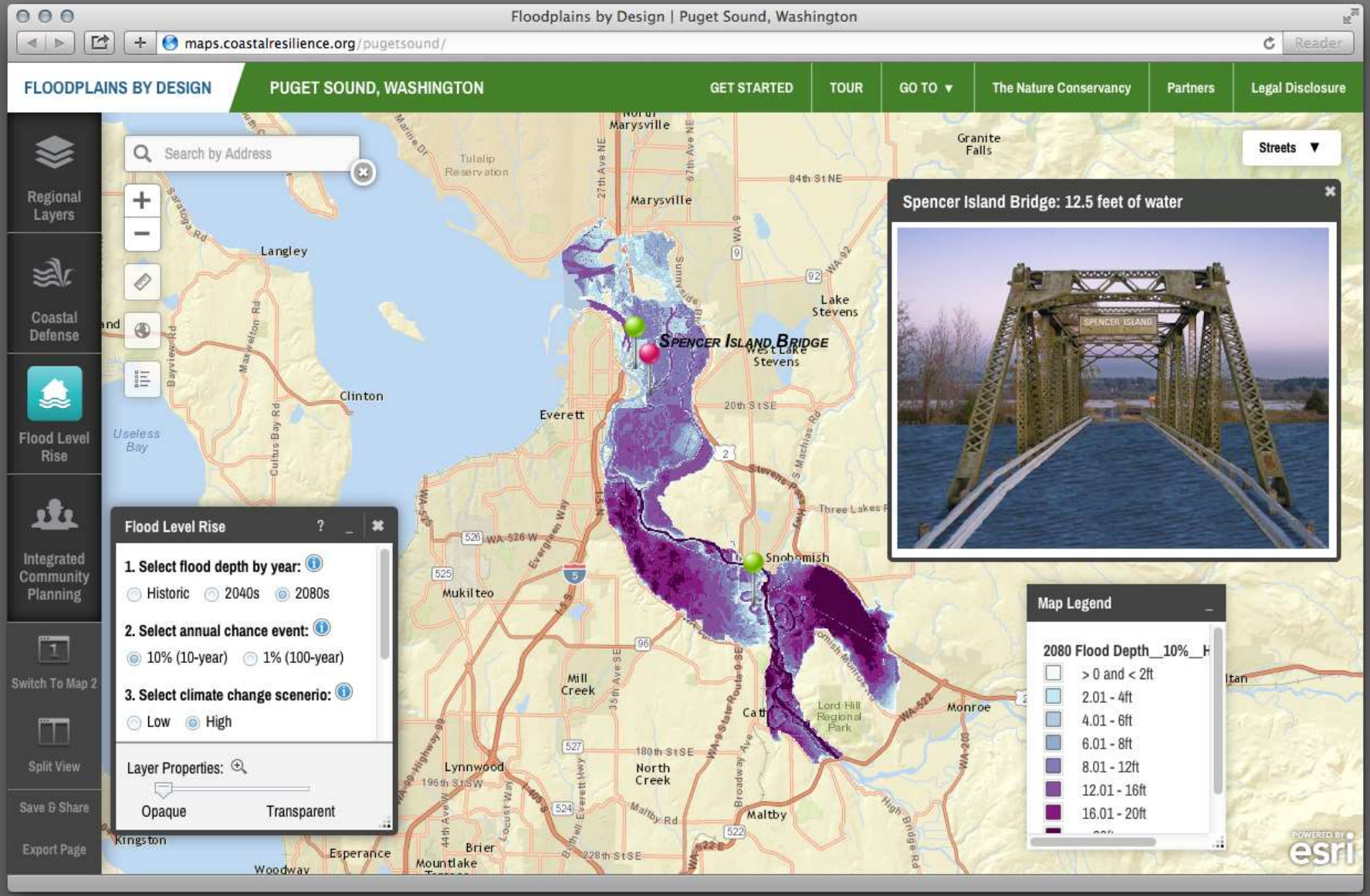
2040 Flood Depth__10%__H

- > 0 and < 2ft
- 2.01 - 4ft
- 4.01 - 6ft
- 6.01 - 8ft
- 8.01 - 12ft
- 12.01 - 16ft
- 16.01 - 20ft

Marysville | Tulalip Reservation | Granite Falls | 84th St NE | Lake Stevens | West Lake Stevens | Langley | Clinton | Useless Bay | Everett | 20th St SE | Three Lakes | Snohomish | Mukilteo | Mill Creek | Lord Hill Regional Park | Monroe | Lynnwood | North Creek | Maltby | Kingston | Esperance | Brier | Mountlake Terrace | Woodway

POWERED BY esri

Display a menu


Floodplains by Design | Puget Sound, Washington
maps.coastalresilience.org/pugetsound/
Reader
FLOODPLAINS BY DESIGN
PUGET SOUND, WASHINGTON
GET STARTED
TOUR
GO TO
The Nature Conservancy
Partners
Legal Disclosure
Regional Layers
Coastal Defense
Flood Level Rise
Integrated Community Planning
Switch To Map 2
Split View
Save & Share
Export Page
Search by Address
Streets
Spencer Island Bridge: 12.5 feet of water
SPENCER ISLAND
Spencer Island Bridge
Flood Level Rise
1. Select flood depth by year:
Historic
2040s
2080s
2. Select annual chance event:
10% (10-year)
1% (100-year)
3. Select climate change scenerio:
Low
High
Layer Properties:
Opaque
Transparent
Map Legend
2080 Flood Depth__10%__H
> 0 and < 2ft
2.01 - 4ft
4.01 - 6ft
6.01 - 8ft
8.01 - 12ft
12.01 - 16ft
16.01 - 20ft
Marysville
Granite Falls
Tulalip Reservation
Langley
Clinton
Useless Bay
Everett
Lake Stevens
West Lake Stevens
Snohomish
Mukilteo
Mill Creek
North Creek
Lynnwood
Maltby
Monroe
Lord Hill Regional Park
Three Lakes
Kingston
Esperance
Brier
Mountlake Terrace
Woodway
84th St NE
20th St SE
180th St SE
196th St SW
228th St SE
Maltby Rd
Broadway Ave
Stevens Pass Hwy
Everglen Way
S Machias Rd
Marine Dr
Bayview Rd
Maxwelton Rd
Cultus Bay Rd
Locust Way
Bothell Everett Hwy
High Bridge Rd
WA-9
WA-92
WA-526 W
WA-522
WA-203
I-5
I-405
Highway 99
State Route 9 SE
35th Ave SE
44th Ave W
27th Ave NE
67th Ave NE
Snohomish River
Powered by esri

Conclusion

1. Atmospheric rivers and heavy precipitation show a clear response to climate change
2. Stream flows in warm river basins increase
3. These changes are manageable by US Army Corps of Engineers at Howard Hansen Dam
4. Scenarios of flood plain inundation show substantial impacts