PNW Climate Change, Coasts, and Coastal Infrastructure

Lara Whitely Binder
Climate Impacts Group
Center for Science in the Earth System
Joint Institute for the Study of the Atmosphere and Ocean
University of Washington

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Washington State Coast Planning/Adaptation Work Group (Coast PAWG)

Climate science in the public interest

Overview

This talk:

- Introduces the Climate Impacts Group
- Highlights projected PNW climate change impacts
- Maps key climate change impacts to general PNW coastal concerns
- Provides a brief overview on adaptation

This talk does not:

- Provide a definitive list of potential coastal impacts
- Provide specific suggestions on adaptive strategies

The Climate Impacts Group

1st of 8 U.S. Regional Integrated Sciences and Assessment (RISA) teams

Areas of study:

- Water resources
- Salmon
- Forests
- Coasts
- *[Agriculture, Human Health]*

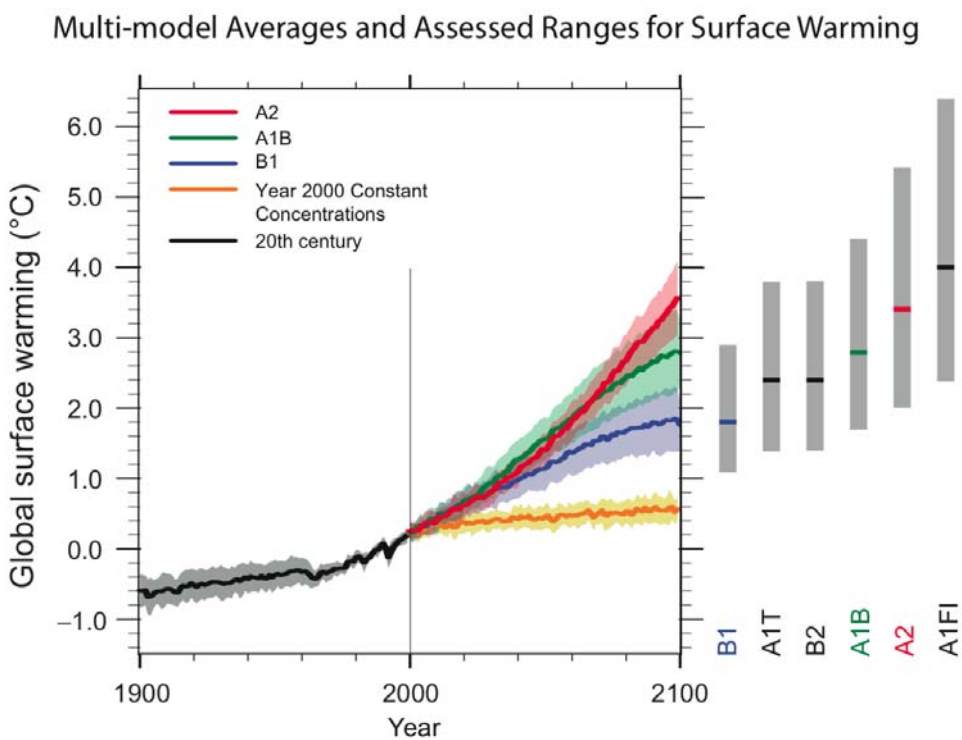
Objectives

- Increase regional resilience to climate variability and change
- Produce science useful to (*and used by!*) the decision making community

21st Century Global Warming

Projected range of global-scale warming by the 2090s: **3.2°F-7.2°F**

Warming expected through 21st century *even if CO2 emissions end today* due to persistence of greenhouse gases.

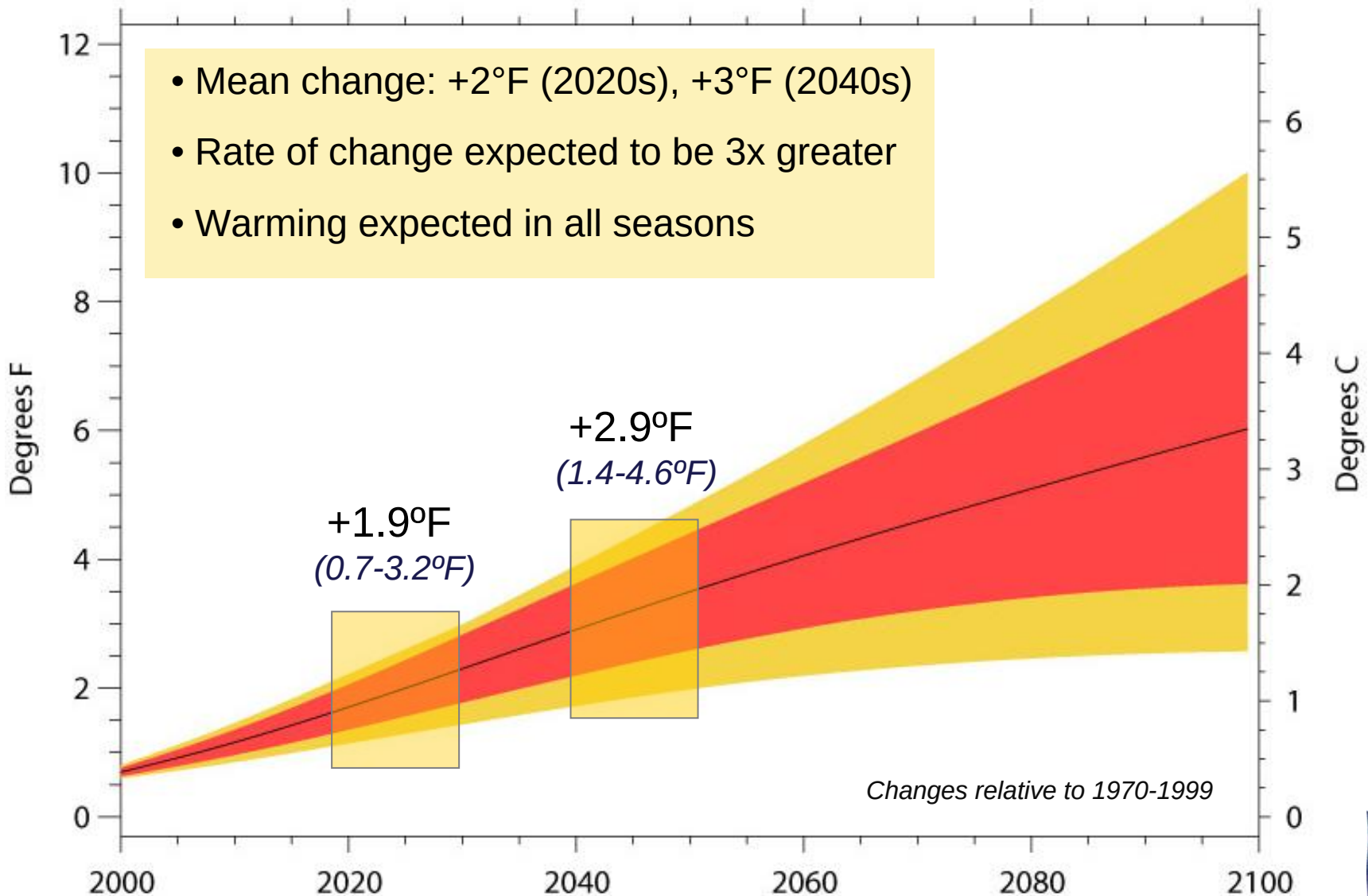


Estimated atmospheric lifetime of major greenhouse gas (per molecule)

Carbon Dioxide	~60% of warming from GHG	5 to 200 years
Methane	~20% of warming from GHG	8 to 12 years
Nitrous Oxide	~6% of warming from GHG	~120 years
CF4 (Perfluoromethane)		>50,000 years

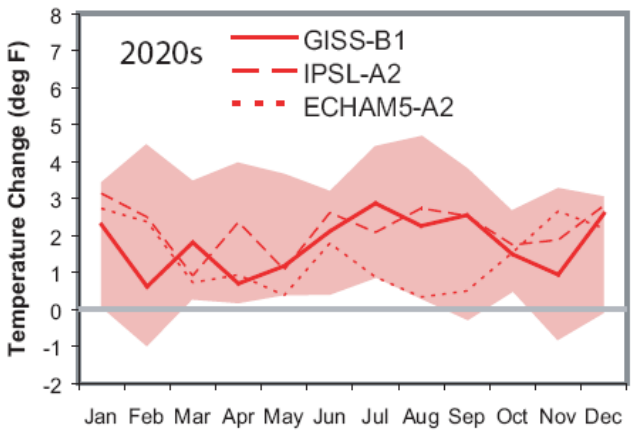
Data source: IPCC 2001

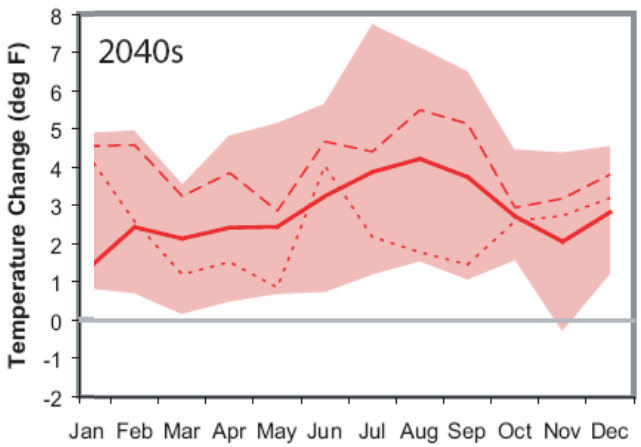
Projected 21st Century PNW Warming



More detail on the CIG scenarios is available at: http://www.cses.washington.edu/cig/fpt/ccscenarios.shtml

Projected Changes in PNW Temperature



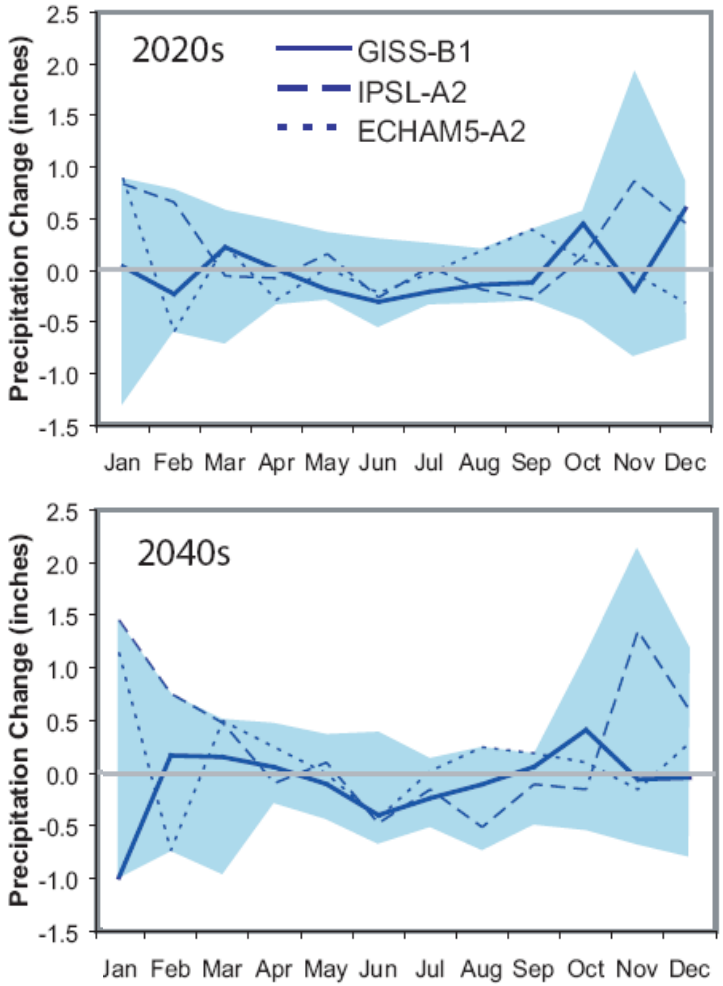


Projected changes in monthly PNW temperature. The lines show changes associated with warm (IPSL-A2), cool (GISS-B1), and "middle-of-the-road" (ECHAM5-A2) climate change scenarios

Temperature change			
	Annual	**Oct-Mar**	**Apr-Sept**
2020s			
Low	+ 0.7ºF *(0.4ºC)*	+ 0.4ºF *(0.2ºC)*	+ 0.8ºF *(0.5ºC)*
Avg	**+ 1.9ºF *(1.1ºC)***	**+ 1.7ºF *(0.9ºC)***	**+ 2.1ºF *(1.2ºC)***
High	+ 3.2ºF *(1.8ºC)*	+ 2.6ºF *(1.5ºC)*	+ 3.8ºF *(2.1ºC)*
2040s			
Low	+ 1.4ºF *(0.8ºC)*	+ 1.1ºF *(0.6ºC)*	+ 1.4ºF *(0.8ºC)*
Avg	**+ 2.9ºF *(1.6ºC)***	**+ 2.5ºF *(1.4ºC)***	**+ 3.3ºF *(1.8ºC)***
High	+ 4.6ºF *(2.6ºC)*	+ 4.1ºF *(2.3ºC)*	+ 5.4ºF *(3.0ºC)*

All changes are benchmarked to average temperature and precipitation for 1970-1999

Projected Changes in PNW Precipitation

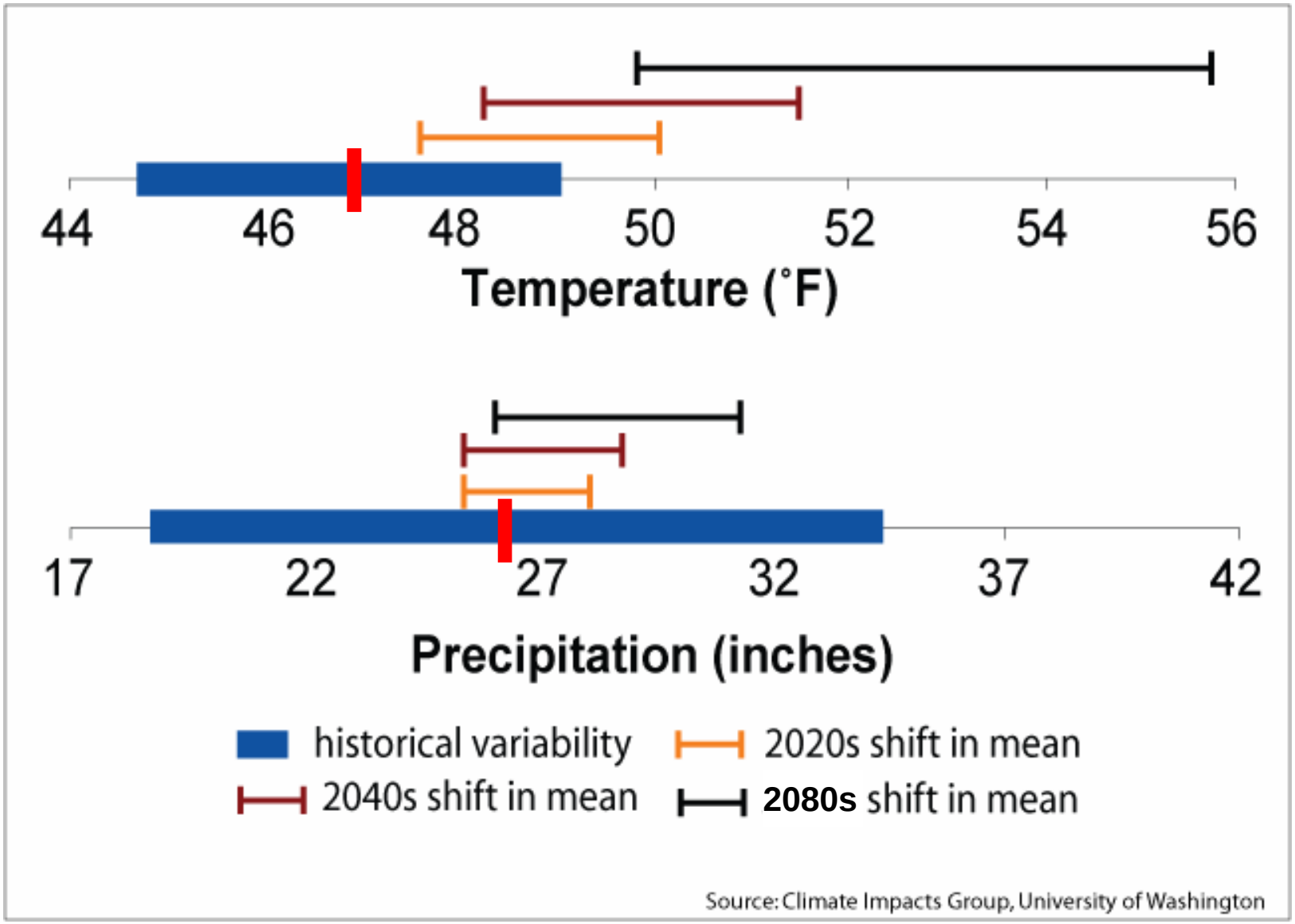


Projected changes in monthly PNW precipitation. The lines show changes associated with warm (IPSL-A2), cool (GISS-B1), and "middle-of-the-road" (ECHAM5-A2) climate change scenarios

- Modest increases (+2%) in annual avg precipitation
- Most of the increase comes in the winter months *(but in what intensity?)*
- Projected increase in average does not exceed 20th century averages

Note: there is high confidence in projected temp changes, less in precipitation changes

Changes Relative to the 20th Century

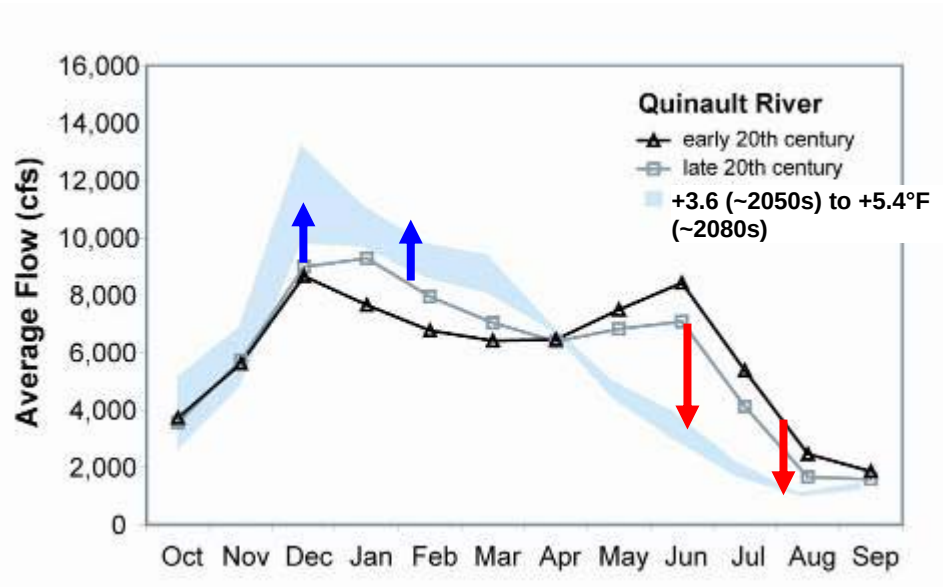


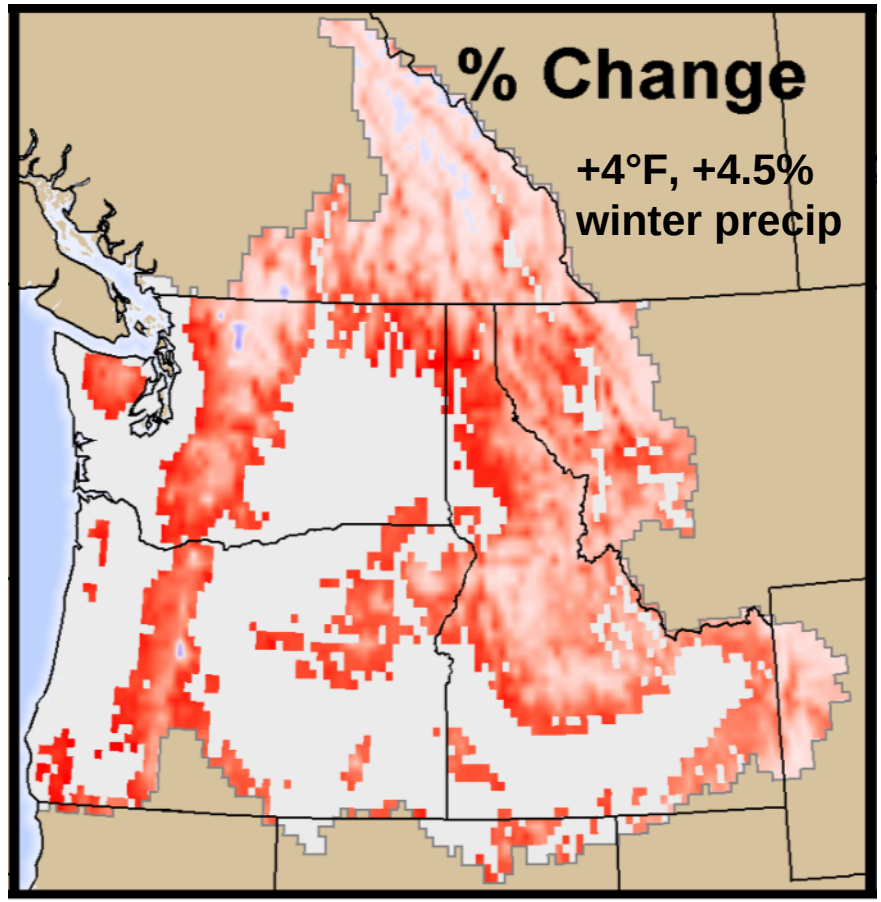
Implications for PNW Resources

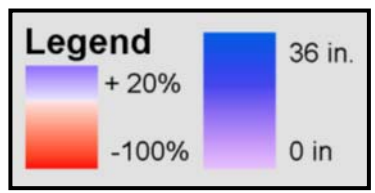
Lower Spring Snowpack and Altered Streamflow

Spring snowpack declines as more winter precipitation falls as rain rather than snow, *especially in warmer mid-elevation basins*

Warmer temperatures affect the timing and volume of spring and summer streamflow in temperature-sensitive basins







April 1 Snowpack

Overview of PNW Impacts

Water supply

- Increased competition from competing water uses, particularly during summer months
- Increased vulnerability to drought
- Decreased water quality (varies with location and parameter)

Flooding and stormwater management:

- Increased risk of winter flooding and combined sewer overflows in low and mid-elevation basins. Changes in urban flooding less certain.

Salmon:

- Increased stress from winter floods, warmer water temperature, lower summer streamflows

Overview cont'd

Forests:

- Increased risk of wildfire
- Increased vulnerability to insects
- Decreased growth & regeneration in drier low elevations (with opposite at high elevations)

Recreation and Tourism

- Shortened winter ski season likely (but improved access?), impacts in summer from forest fires

Agriculture:

- Increased production from CO2 fertilization effect and warmer spring temps?
- Opportunities for new crops, decreased irrigation supply, increased heat stress/insects

…and Coastal Systems?

Two foci

Important Coastal Processes

•Sea level rise

•Erosion

•Flooding

•Inundation

[Landslides]

Coastal Ecosystems

- Salmon
- Salt marsh habitat
- Shellfish, HABs

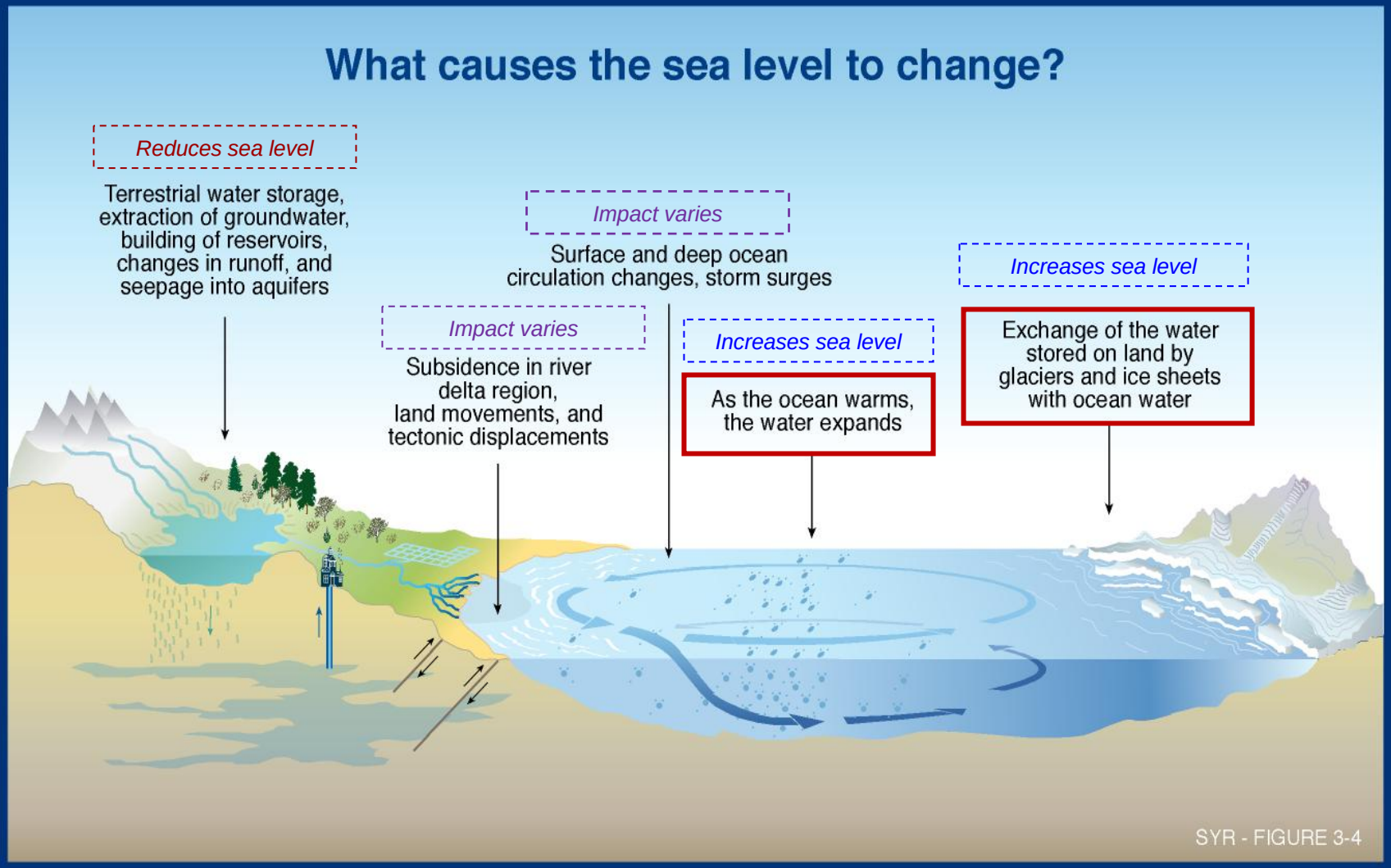


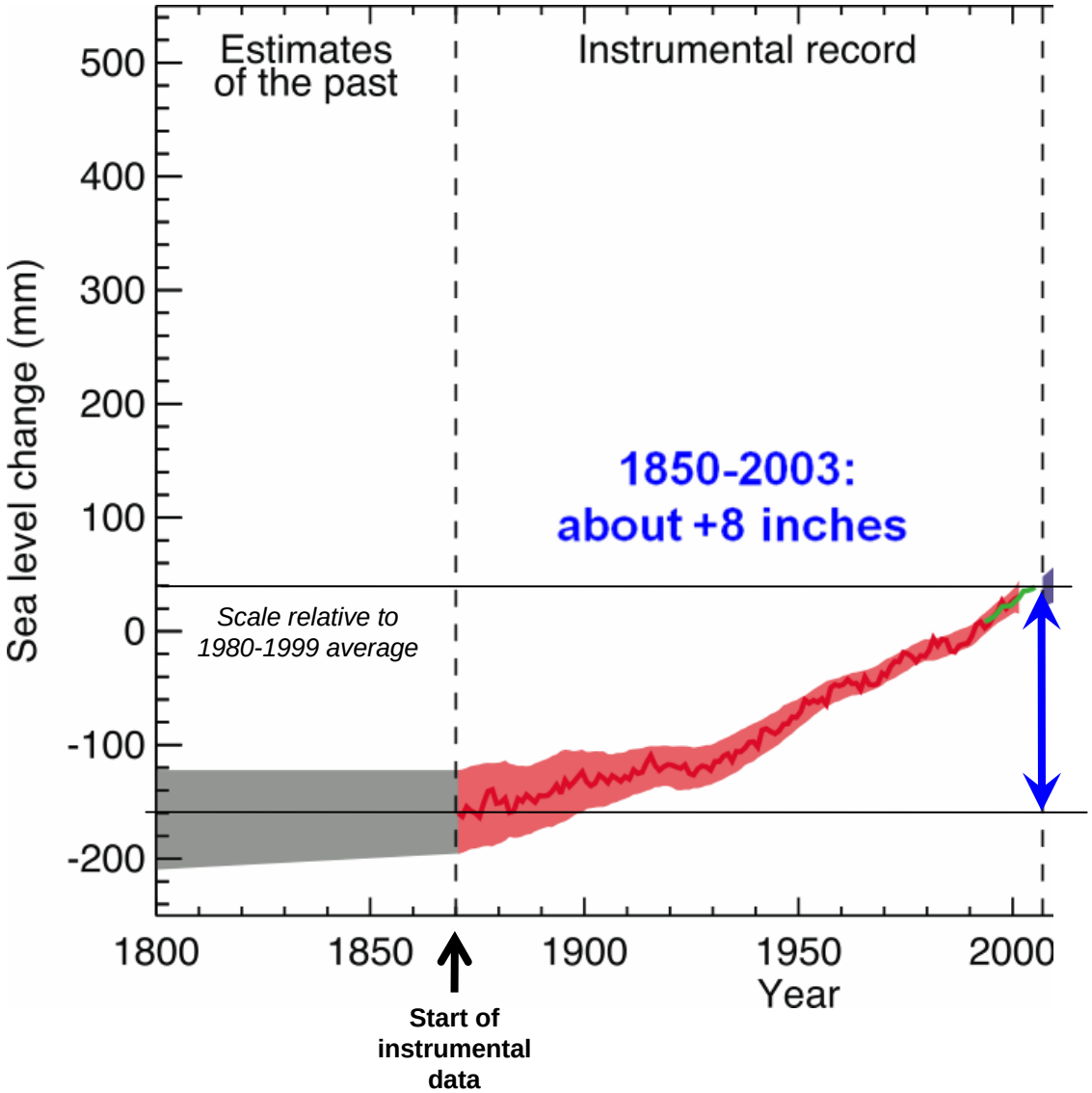
Figure source: IPCC, adapted by CIG

Observed Changes in Global Sea Level

1961 – 2003: +3 inches
(0.07 ± 0.02 inches/year)

1993-2003** (satellite data):
+1.2 inches *(0.12 inches/year)*

*** A change in the long term trend or due to decadal variability?*



Projected Global Sea Level Rise

- Projected global change: +7-23 inches *(varies w/scenario)*
- Rate of increase expected to be greater than 1961-2003 trend
- Change will not be evenly distributed around the globe

Figures show change due to thermal expansion only

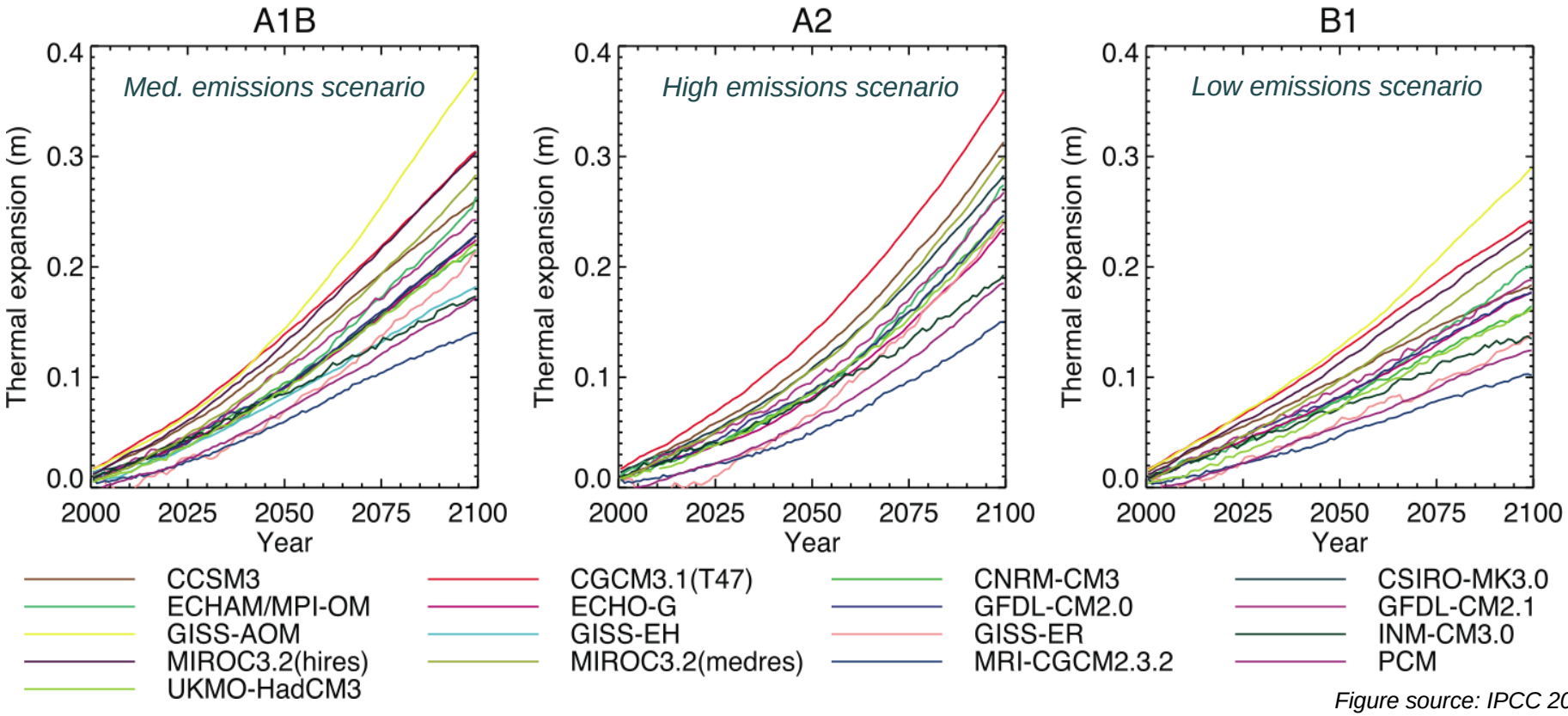


Figure source: IPCC 2007

Projected SLR Ranges by Emissions Scenario

Table SPM.3. *Projected global average surface warming and sea level rise at the end of the 21st century. {10.5, 10.6, Table 10.7}*

Case	Temperature Change (°C at 2090-2099 relative to 1980-1999)[a] Best estimate	*Likely* range	Sea Level Rise (m at 2090-2099 relative to 1980-1999) Model-based range excluding future rapid dynamical changes in ice flow	
Constant Year 2000 concentrations[b]	0.6	0.3 – 0.9	NA	
B1 scenario *(Low emissions scenario)*	1.8	1.1 – 2.9	0.18 – 0.38	*(7-15 inches)*
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45	
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43	
A1B scenario *(Med. emissions scenario)*	2.8	1.7 – 4.4	0.21 – 0.48	
A2 scenario *(High emissions scenario)*	3.4	2.0 – 5.4	0.23 – 0.51	
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59	*(10-23 inches)*

Table notes:

[a] These estimates are assessed from a hierarchy of models that encompass a simple climate model, several Earth System Models of Intermediate Complexity and a large number of Atmosphere-Ocean General Circulation Models (AOGCMs).

[b] Year 2000 constant composition is derived from AOGCMs only.

Figure source: IPCC 2007

Projections of Global Sea Level Rise Relative to 20th Century Changes
from the A1B (medium emissions) scenario

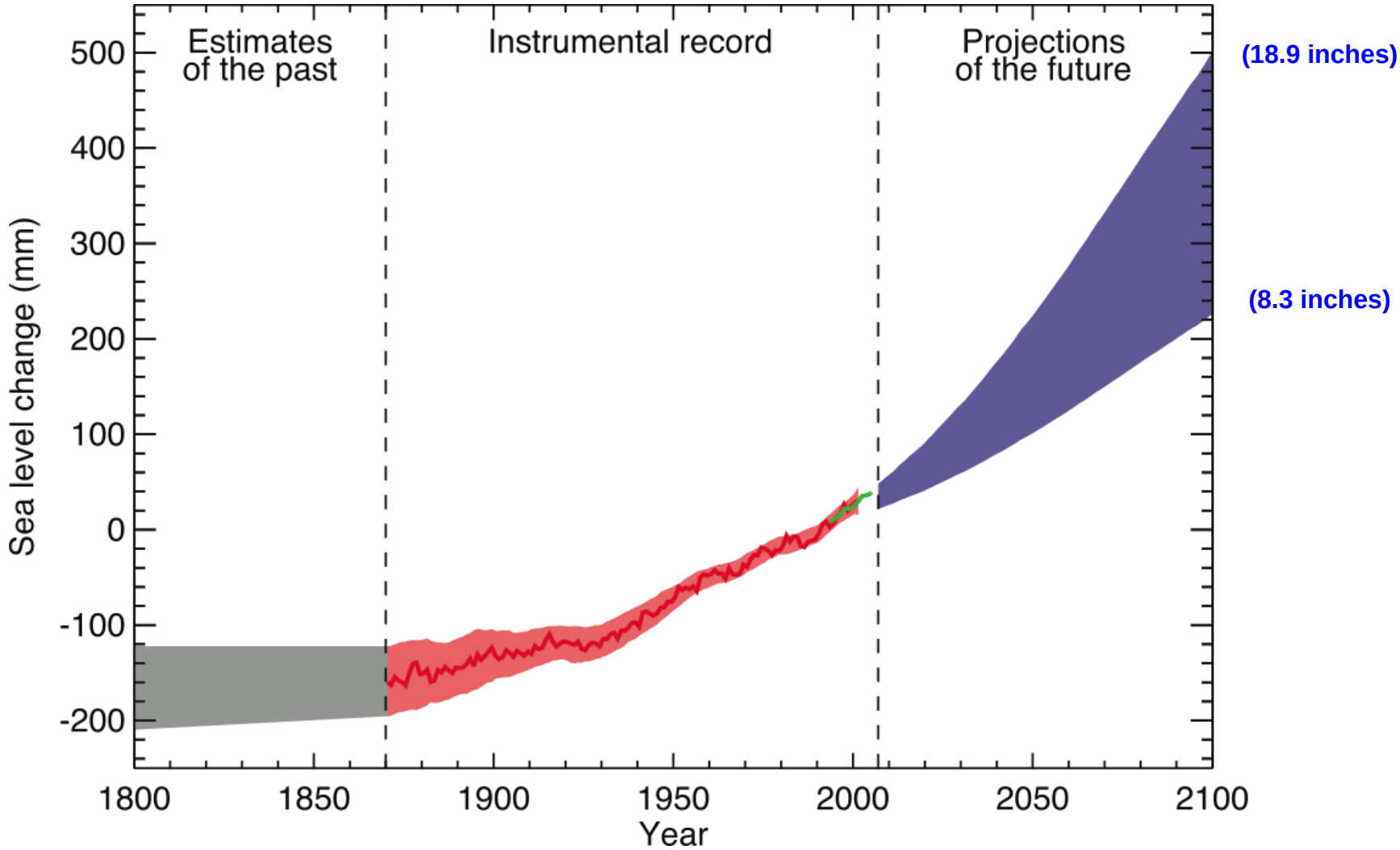
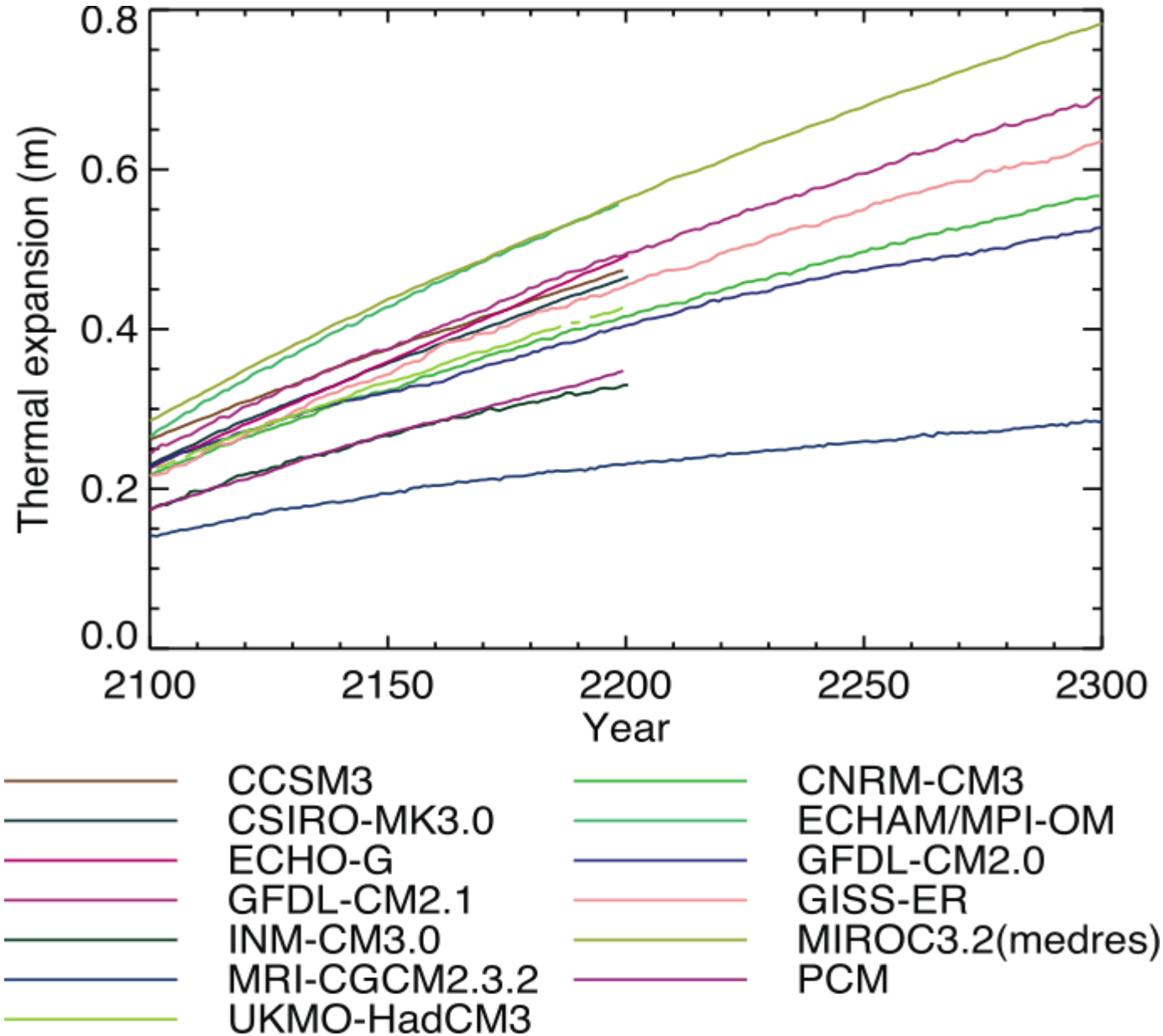


Figure source: IPCC 2007

Sea level rise is a multi-century challenge



Projected changes in thermal expansion through 2300 for the A1B ("middle of the road") emissions scenario

Figure source: IPCC 2007

And What About Greenland and Antarctica?

- IPCC 4th Assessment Report SLR scenarios include a contribution for ice flow from Greenland and Antarctica at rates observed for 1993-2003

- Recent increase in flow rates not included due to uncertainty about persistence of the change – a shift in the long-term trend or short-term blip?

- If contribution increased in step with temperature change, upper range would increase 4-8 inches but larger values cannot be excluded (i.e., response may be non-linear).

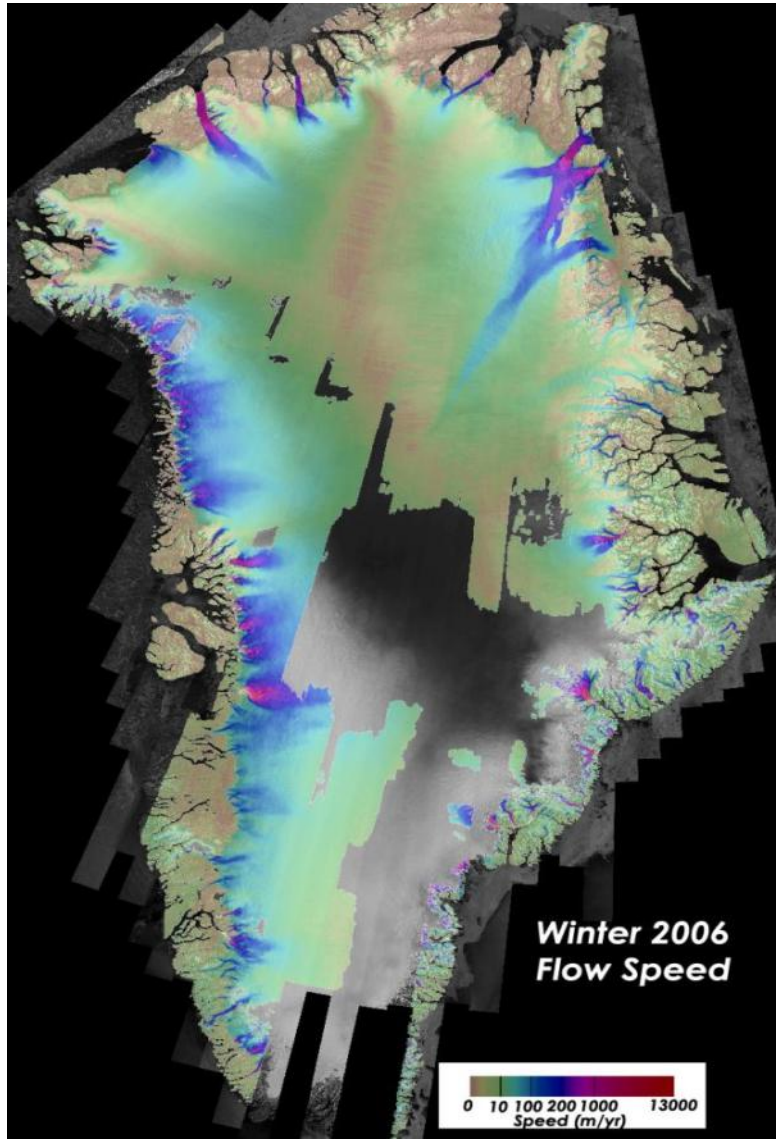


Figure courtesy of Ian Joughin, University of Washington Polar Science Center

SLR in the Pacific Northwest

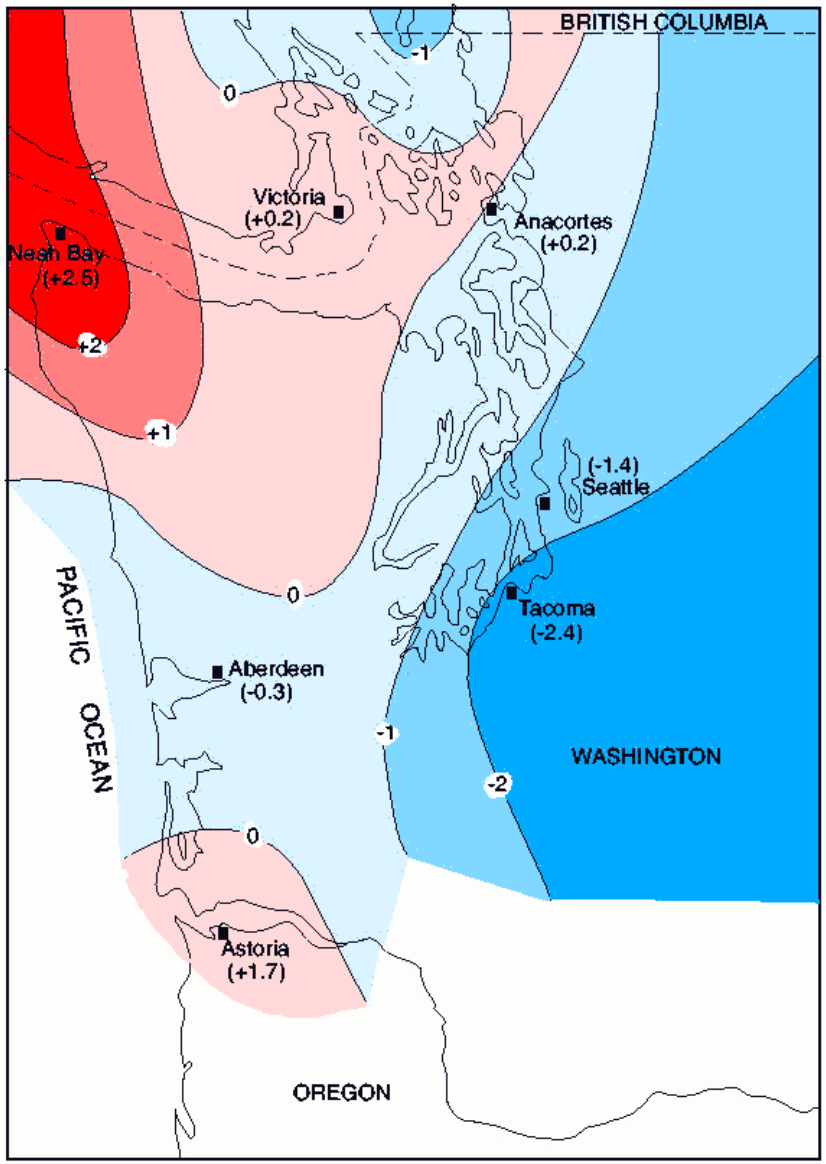
Relative sea level rise in the PNW affected by

- Global sea level rise *(thermal expansion, freshwater inputs)*
- Tectonic processes *(subsidence and uplift)*
- Interannual climate variability *(e.g., El Niño and La Niña events)*
- Ocean/coastal winds *(can increase regional sea level about +8 inches)*
- Topography/geology *(e.g., gently sloping beach versus bluffs)*
- Short-term events *(e.g., low pressure storms)*

Vertical Land Movement

… alters sea level rise rates

- Subduction zone tectonic forces ‘wrinkle’ the land surface
- Uplift occurs on most of the Ocean coast
- Subsidence occurs in most of Puget Sound



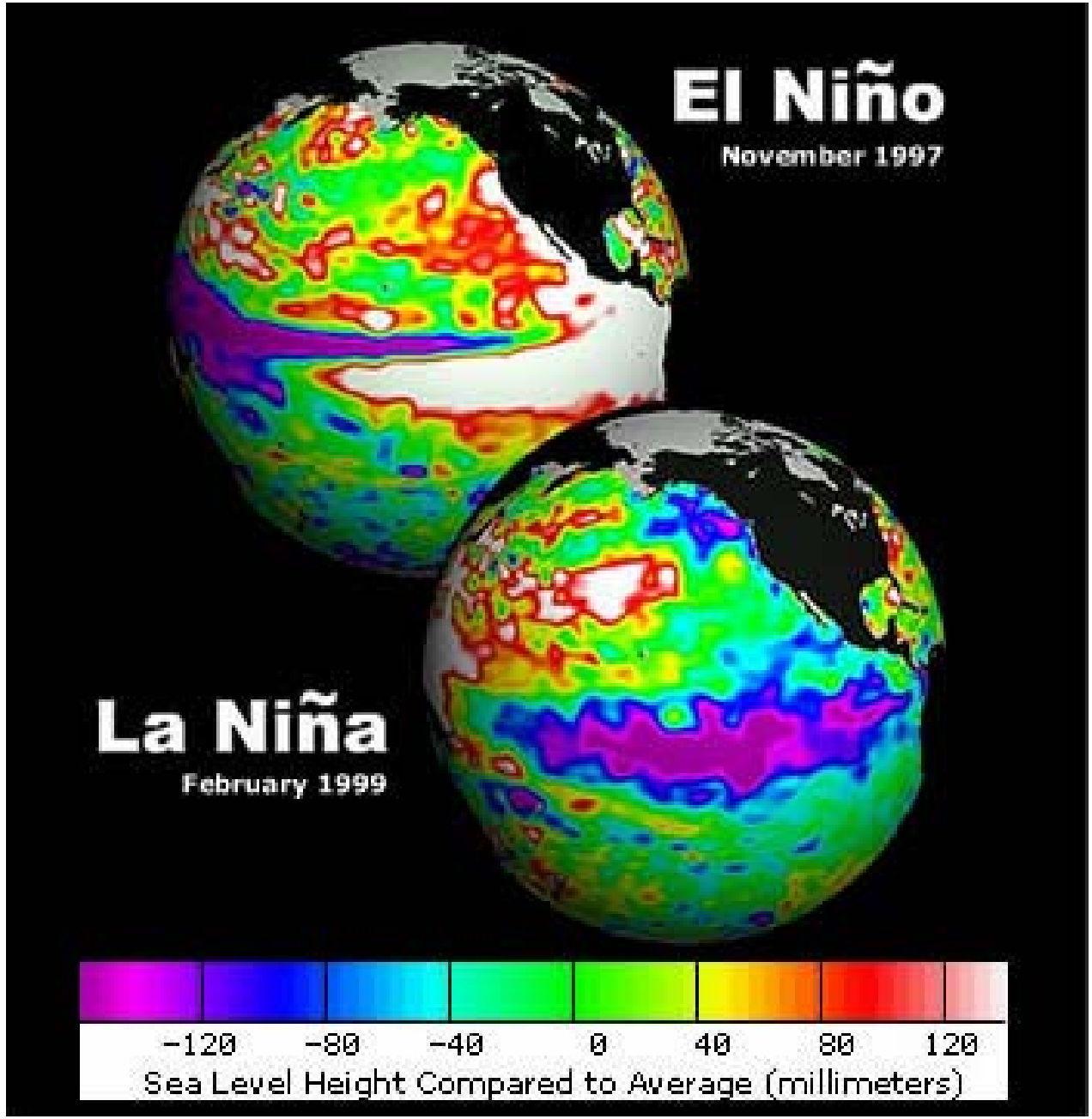
Changes in vertical land elevation in Western Washington (in mm/year)

Note that these values are estimates of changes in land surface elevation based on data from the late 1980s. Additional research is needed to confirm these conclusions, particularly in the areas between the specified point locations.

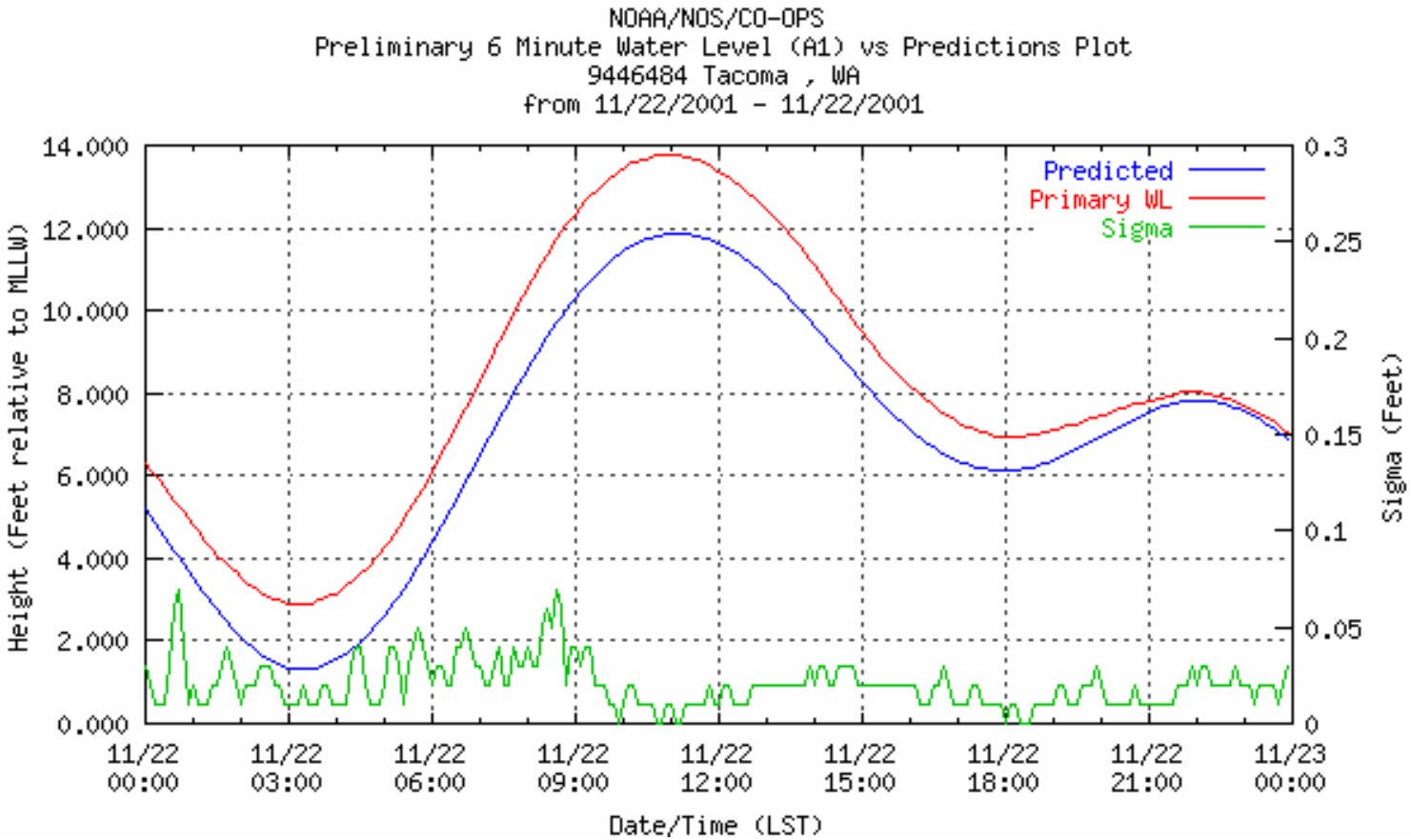
(Canning 1991, modified from Shipman 1989 and Holdahl et al. 1989)

Barometric pressure shifts over the Pacific Ocean basin typically lead to **higher sea levels** in the eastern Pacific during winter months **when an El Niño is occurring**.

El Niño events also increase southerly winds, which increase the shoreward flow of ocean water.



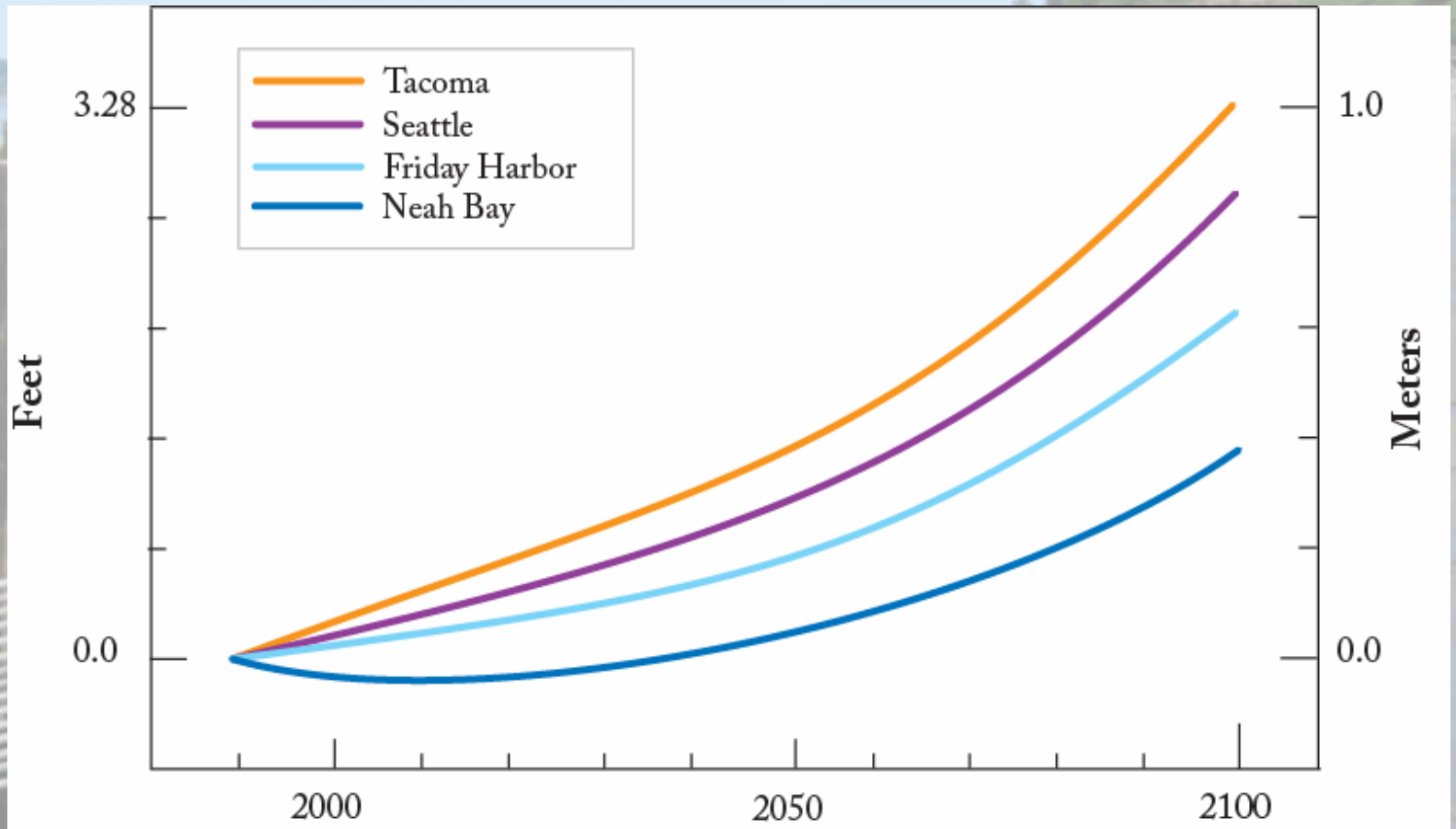
Barometric Pressure Effects



Short term low pressure cells allow water level to rise: up to 2.0 feet on 22 Nov 2001 at Tacoma

Puget Sound Sea Level Rise

Relative sea level rise <u>may</u> be greatest in South Puget Sound (~3 ft by 2100) and least near Neah Bay (~1 ft by 2100)



Sea Level Rise Scenarios (based on 20” rise)

Changes in Other Coastal Processes….

Erosion

- **Factors contributing to coastal erosion:**
  - Geology/topography/vegetation
  - Storm intensity/frequency and related impact on waves**
  - Elevated sea level (e.g., high tide, seasonal increases due to El Niño events, global SLR)**
  - Presence of erosion control barriers

- Climate change likely to increase the risk of erosion in some areas via global sea level rise (especially when factors converge). We do not have confident estimates of changes in storm intensity at this time.

** indicate climate-related element

Coastal Flooding

- **Factors contributing to coastal flooding:**
  - Winter streamflows**
  - Topography (e.g., beach slope)
  - Storm intensity and frequency (storm surges)**
  - Elevated sea level (e.g., high tide, seasonal increases due to El Niño events, global SLR) **
  - Presence of flood control structures

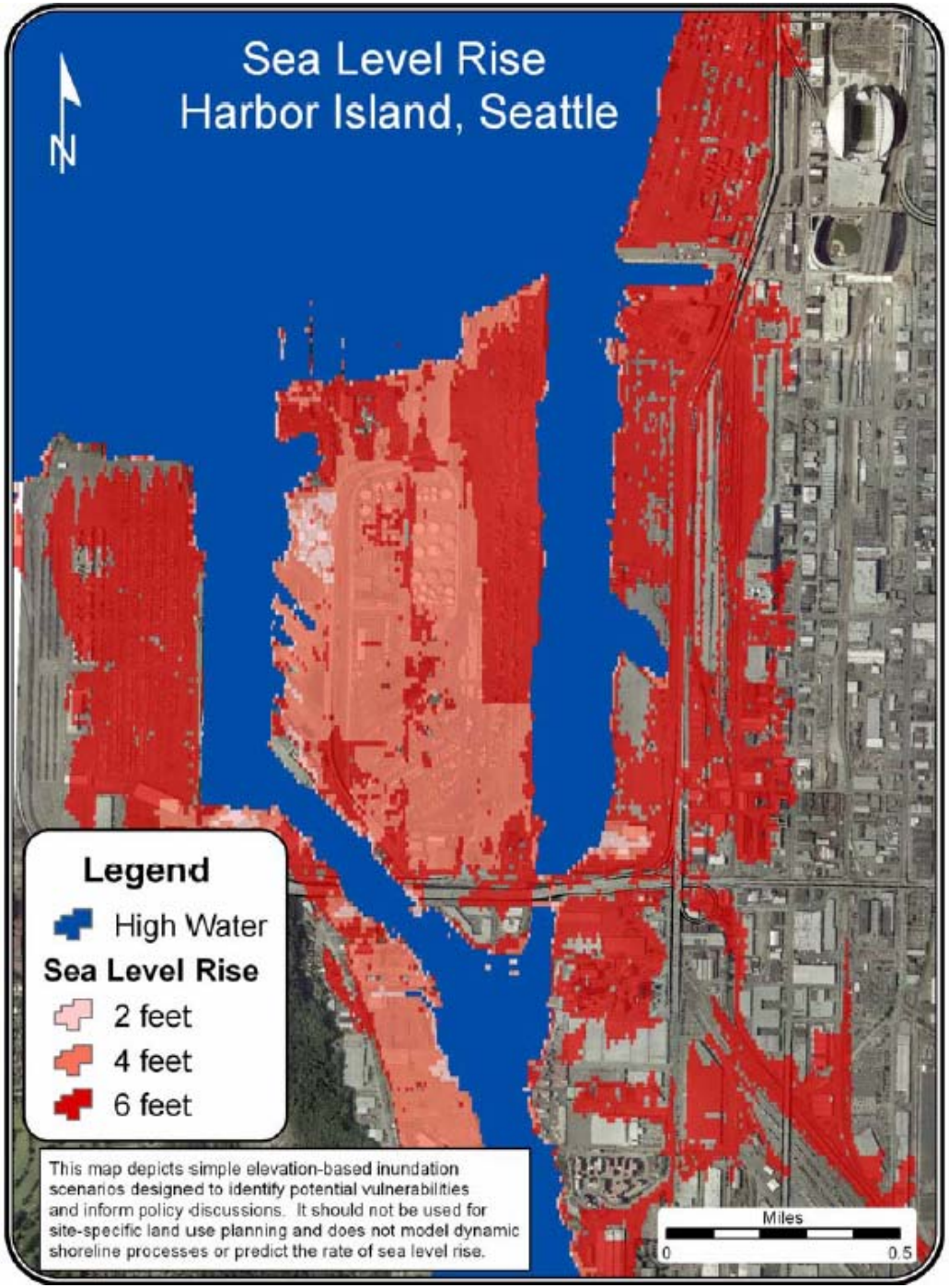
- Climate change likely to increase risk, particularly in snowmelt-fed basins, due to projected increases in:
  - Winter streamflows,
  - Global sea level rise

We do not have confident estimates of changes in storm intensity at this time.

Inundation

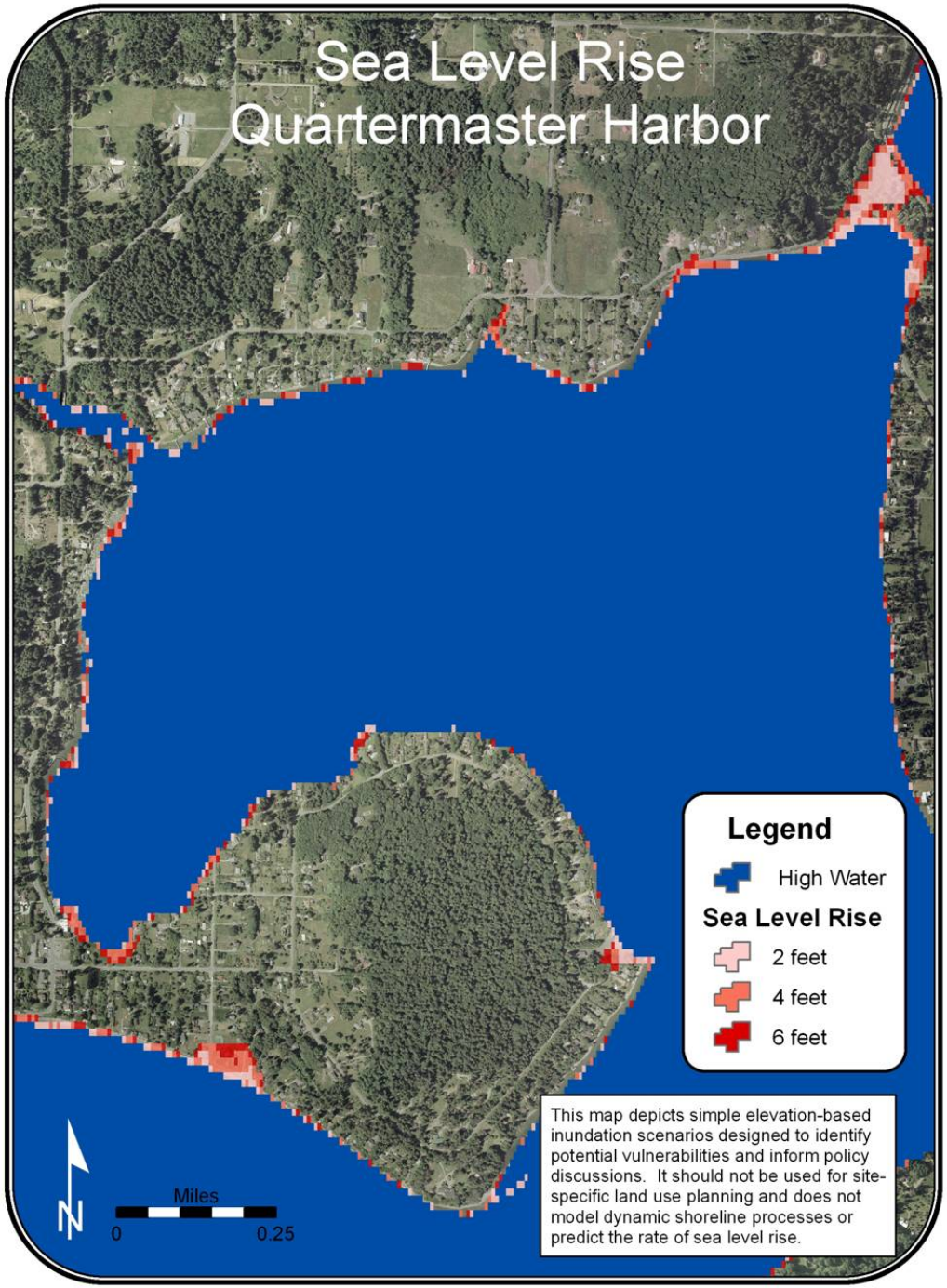
- **Factors contributing to permanent inundation:**
  - Topography (e.g., beach slope vs. bluffs)
  - Tectonic processes
  - Elevated sea level (e.g., high tide, seasonal increases due to El Niño events, global SLR) **
  - Presence of flood control/erosion barriers

- Climate change likely to increase risk due to projected increases in global sea level.



Sea level rise inundation scenarios (two-feet, four-feet, and six-feet) for Harbor Island, Seattle

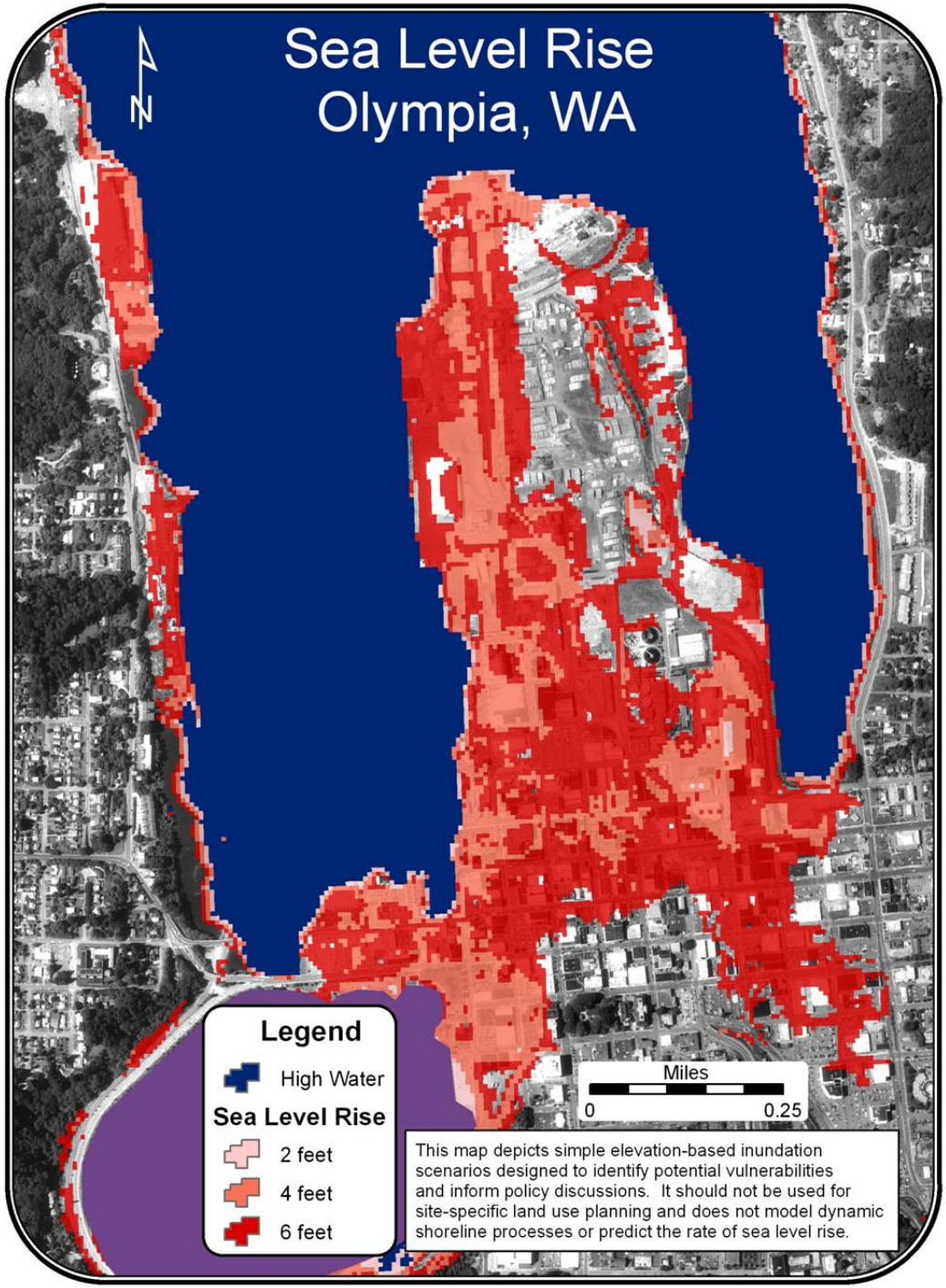
Source: Petersen 2007



Sea level rise inundation scenarios (two-feet, four-feet, and six-feet) for Quartermaster Harbor between

Vashon and Maury Islands

Source: Petersen 2007



Sea level rise inundation scenarios (two-feet, four-feet, and six-feet) for downtown Olympia

(Petersen 2007)

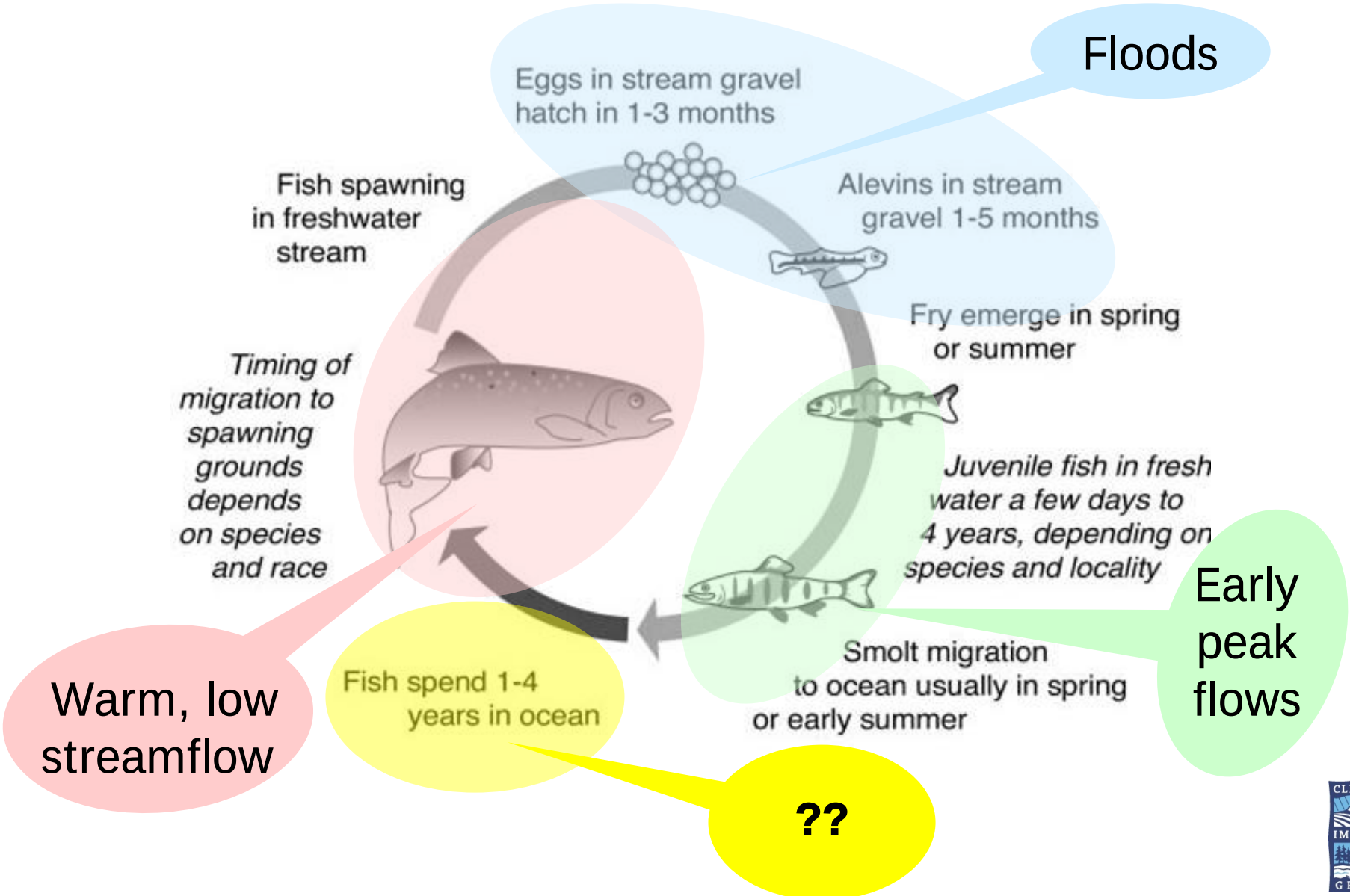
Overview of Marine Impacts

- Climate change likely to impact several key parameters, e.g. water temperature, salinity, stratification, dissolved oxygen, nutrient availability *(direction/magnitude of impact varies with parameter, location, time of year)*

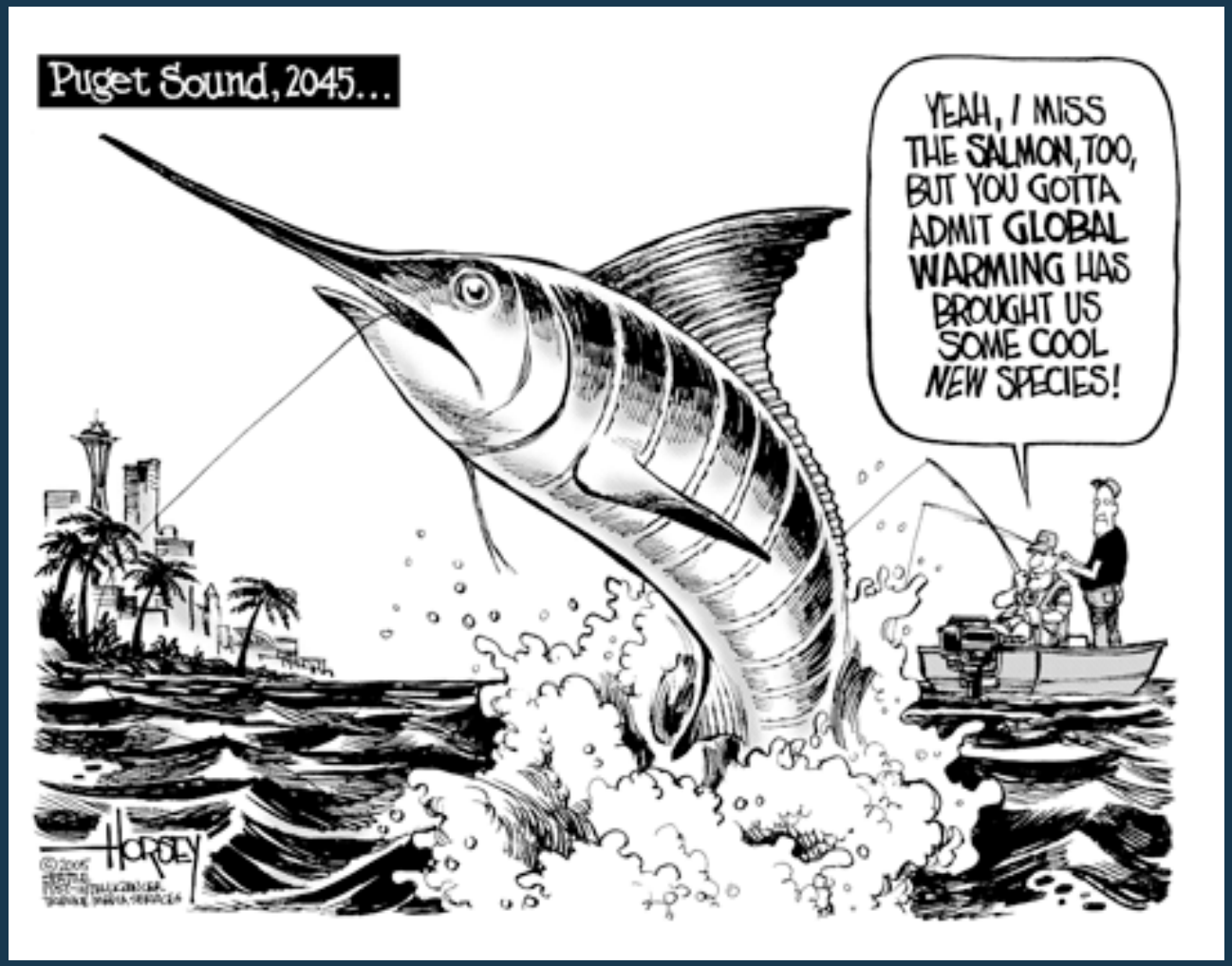
- Climate change will affect the Puget Sound **[coastal]** ecosystem from the bottom-up *(e.g., via impacts to phytoplankton)* and top-down *(e.g., via impacts to salmon, marine mammals)*

- The ultimate impact of climate change on any individual species depends on how changes move through the food web and the ecosystem's ability to adapt to rapidly changing conditions

Salmon Impacted Across Full Life-Cycle



Species distributions change with temperature, affecting the overall food web



From the Seattle Post-Intelligencer, October 20, 2005

134 lb marlin caught 40 mi. west of Westport, WA, Sept 2, 2005

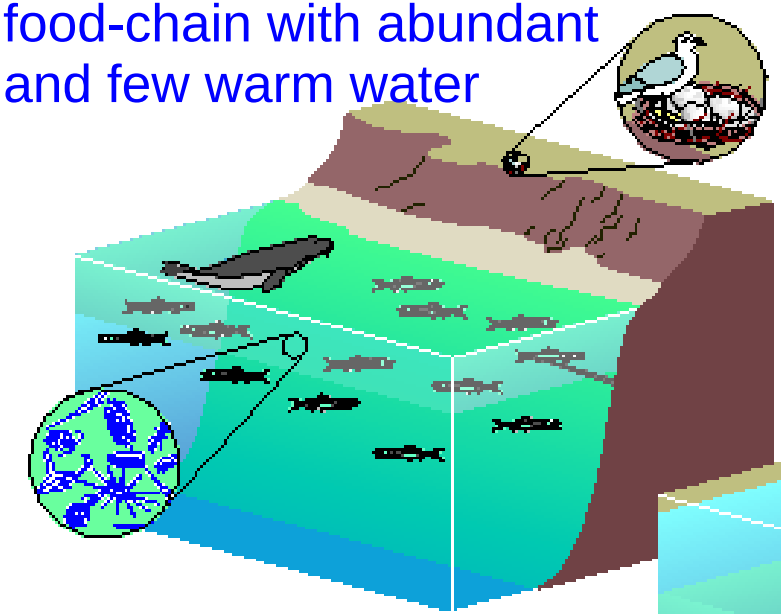
Photo obtained from the Seattle Times web-archives

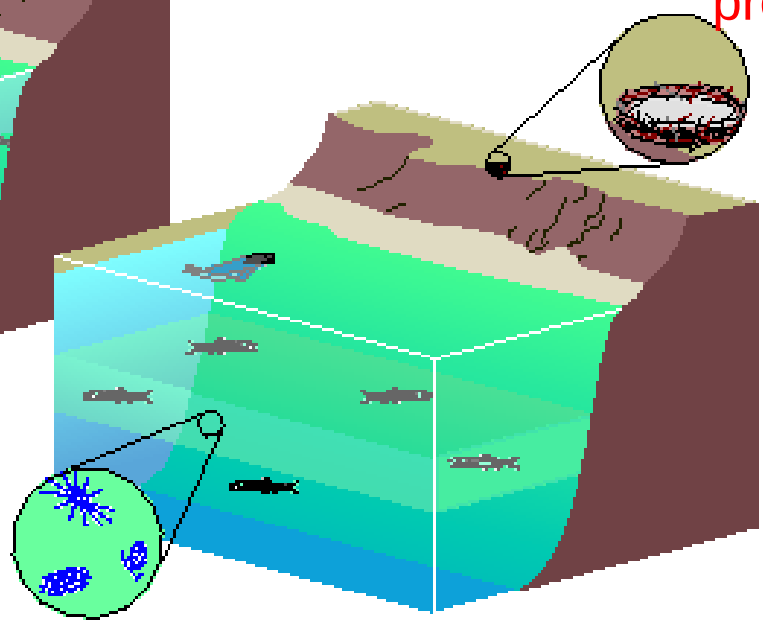
Upwelling food webs in our coastal ocean

Cool water, weak stratification

high nutrients, a productive "*subarctic*" food-chain with abundant forage fish and few warm water predators

Warm stratified ocean, few nutrients, low productivity "*subtropical*" food web, a lack of forage fish and abundant predators





Recently, warm ocean years have generally been poor for NW chinook, coho and sockeye, but good for Puget Sound pink and chum salmon.

Salt Marshes and Eelgrass

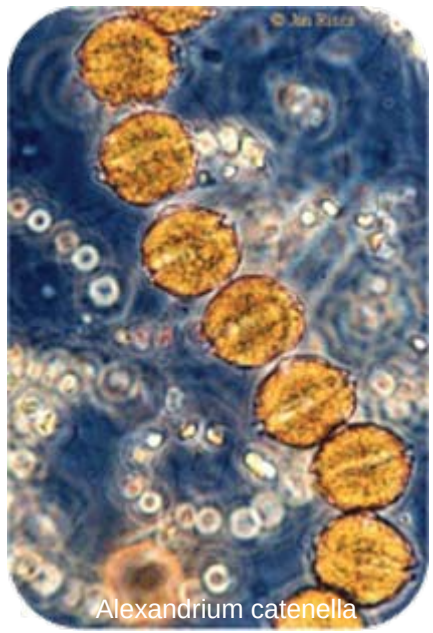
- Salt marshes and eelgrass provide critical habitat for wide variety of species
- Sea level rise may lead to further loss of salt marsh habitat, particularly where land areas are sinking (south Puget Sound) and/or where inland migration is inhibited by development
- Climate change impacts on eelgrass uncertain due to competing factors
  - warming may favor growth via shifts in streamflow but could lead to loss if water temp exceeds tolerance thresholds (59°F), or if sea level rise reduces available light for photosynthesis

Shellfish and Harmful Algal Blooms (HABs)

- Puget Sound one of the largest shellfish producing regions in US *(estimated value in 2000: $77 billion)*

- Climate change could increase toxin-causing algae (but not necessarily outbreaks) via increased winter stratification and warmer temperatures, which may encourage growth of HABs at the surface

- Ultimate impact depends on environmental change and human development in the Sound (a major source of toxins)



Fish and Other Animals

- Fish and other animals affected via changes in habitat and changes in food availability

- Warmer temperatures can increase growth rates but may also stress an organism if too warm
  - Stress linked to decreased growth and survival, weakened immune systems, and disease epidemics in marine populations and seabirds

- Warmer temperatures may be especially severe for species unable to seek out cooler temperatures, especially at vulnerable life stages

Preliminary Mapping of Potential Coastal Impacts

Projected Change	Potential Impact to Coasts	+ or - impact?
Higher sea level	Increased risk of permanent inundation in low-lying areas	Neutral to negative
	Increased risk of episodic lowland flooding	Neutral to negative
	Increased risk of erosion	Neutral to negative
	Increased risk for habitat loss, particularly where there are natural or human-caused barriers to inland migration	Negative
	Increased need for structures to control erosion, flooding, inundation	Negative

Projected Change	Potential Impact to Coasts	+ or - impact?
Higher sea level	Increased risk of displacement from flooding, erosion, and/or permanent inundation	Negative
	Increased risk of contamination from inundated coastal hazardous waste sites	Negative
	Potential for salt water intrusion into coastal aquifers	Negative
	Increased risk of corrosion of (and therefore contamination from) underground storage tanks and piping	Negative
	Increased risk of infiltration and hydraulic surcharge of sewer systems discharging to coastal waters	Negative
	Increased risk to transportation infrastructure in areas vulnerable to sea level rise and associated impacts	Negative

Projected Change	Potential Impact to Coasts	+ or - impact?
Higher winter streamflows	Increased risk of flooding and erosion	Negative
	Reduced winter water quality in areas influenced by freshwater inflows *(via changes in salinity, stratification, non-point source pollution, etc.; overall changes vary with parameter and location)*	Negative but could vary with parameter, location
Higher summer temperatures	Reduced summer water quality *(via warmer water temperatures, changes in salinity, stratification, oxygen demand, etc.; overall changes vary with parameter and location)*	Negative
Lower summer streamflows	Reduced winter water quality in areas influenced by freshwater inflows *(via changes in salinity, stratification, non-point source pollution, etc.; overall changes vary with parameter and location)*	Negative but could vary with parameter, location

Other Coastal Impact Considerations

- Impacts to coastal Native cultures from decline or loss of key species, loss of reservation land/cultural sites to sea level rise.

- Potential economic impacts to coastal economies based on changes in fishing, shellfish harvesting, birding, etc. (exact impacts will vary and have yet to be explored)

- Key unknowns:
  - Changes in ENSO events (El Niño, La Niña)
  - Changes in storm intensity/frequency
  - Exact subsidence/uplift rates
  - Changes in winds and coastal upwelling rates
  - Future of recent ice sheet melt rates

What Is Adaptive Planning?

"Adaptation is not one activity or decision, but rather a continuous set of activities, actions, decisions, and attitudes undertaken by individuals, groups, and governments."

-- Adger et al. 2005

…with the objective of

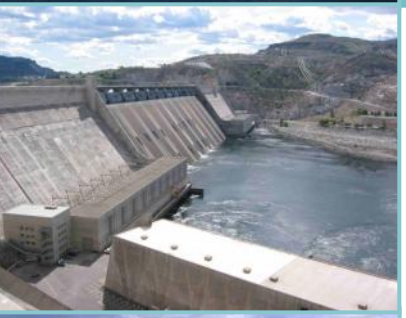
Increasing community and ecosystem **resilience** to climate change impacts

What Do We Mean By Resilient?

A *climate resilient community* is one that has taken proactive steps to reduce the risks associated with known climate change impacts while increasing its capacity to quickly recover from or adapt to those impacts it cannot avoid or anticipate at this time.

Why Adaptive Planning?

- Significant climate change impacts are projected, and the impacts expected within the next few decades are largely unavoidable.
- Decisions with long-term impacts are being made every day. Today's choices will shape tomorrow's vulnerabilities.
- Significant time is required to motivate and develop adaptive capacity, and to implement changes
- Increasing evidence that it will cost more to retrofit for climate resilience than to build it in in the first place.



General Goals in Planning for Climate Change

- Improve community awareness of and preparedness for global warming impacts.
- Build in recognition of a changing climate.
- Reverse trends that increase vulnerability to climate.
- Increase the robustness of long term climate-sensitive decisions and investments.
- Increase the flexibility and adaptability of vulnerable managed systems.
- Enhance the adaptability of vulnerable natural systems.

CLIMATE IMPACTS GROUP

CIG's HB1303 Costal Planning

Related research questions:

- Coasts, Estuaries, and Harbors: *To what extent will rising sea levels and ocean temperatures impact the coasts, estuaries, and harbors of the state through inundation, increased flooding, and/or erosion?*

- Infrastructure: *What are the most vulnerable elements of the state's civil infrastructure to climate change, and what adaptations can best reduce these impacts?*

CIG's HB1303 Costal Planning cont'd

Proposed research will focus on:

- Specific regions and economic sectors expected to experience high levels of impact including Puget Sound ports, the Skagit Delta and Fidalgo Island, and one or more coastal estuaries, possibly including Willapa Bay and Grays Harbor.

- **For each of these regions, CIG will:**
  - Accumulate available evidence from published and un-published information;
  - Collect site-specific information and perspectives through conversations and collaboration with key local personnel;
  - Update coastal maps, as feasible, with tide gauge data, and coastal flooding will be forecasted consistent with the range of predicted sea level rise ; and
  - Examine the potential effects on salinization of coastal freshwater aquifers.

Summary

- Global and regional climate is already changing.
- These changes are expected to accelerate in the coming decades.
- Climate change affects coasts on multiple through potential changes to factors influencing coastal processes on short-term (e.g., via potential changes in storm intensity), seasonal (e.g., El Niño events), and long-term (e.g., global sea level rise) bases
- Changes in coastal processes have impacts on ecosystems and human systems in complex ways that warrant additional research

More information on PNW climate impacts and planning for climate change is available from

The Climate Impacts Group

www.cses.washington.edu/cig

Lara Whitely Binder

lwb123@u.washington.edu