An Overview of Climate Change Science

Amy Snover, PhD

Co-Director, Climate Impacts Group

University of Washington

North Cascadia Adaptation Partnership
Everett, WA
April 28, 2011

CLIMATE IMPACTS GROUP

Climate Science in the Public Interest

Weather vs. Climate

- Weather refers to the day-to-day changes in temperature, precipitation, etc. at a specific location.

- Climate refers to the average of these variables over long time periods.

  "You pick your vacation destination based on the climate but you pack your bag based on the weather."

- Individual weather events, especially extreme events, do not prove (or disprove) climate change.

Climate Change vs. Climate Variability

- **Climate change** - refers to the long-term change (e.g. decades to centennial scale) in climate.
- Also occurring: natural seasonal to decadal **climate variability**, e.g., El Niño and La Niña.
- Natural variability can affect temperature, precipitation, snowpack, sea level, storm patterns, etc. at varying time scales.

El Nino Rains Flood California -- El Nino storms brought flooding to Clearlake, California on March 1, 1998.
Credit: Dave Gatley/FEMA

Setting the Stage for Pacific Northwest Climate Change

GLOBAL CLIMATE CHANGE

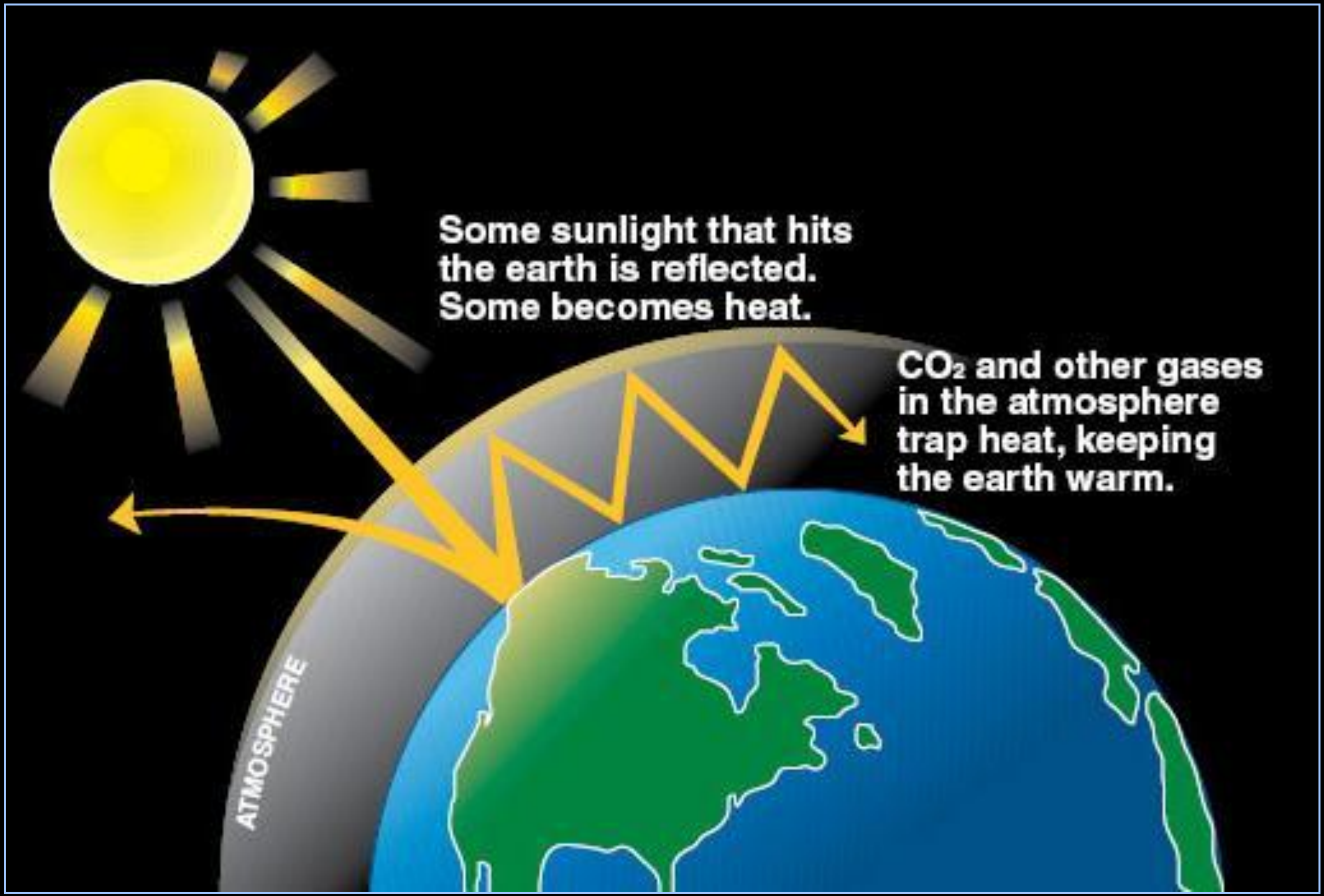
Science of climate change

- The scientific understanding comes from **thousands** of peer-reviewed scientific papers
- **Intergovernmental Panel on Climate Change (IPCC)**
  - Major IPCC reports in 1990, 1996, 2001, 2007
  - Reports are produced by hundreds of authors
- Conclusions (2007 report):
  - *"An increasing body of observations gives a collective picture of a warming world and other changes in the climate system."*
  - *"There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities."*
- Other assessments: US National Assessment, NAS America's Climate Choices, CIG regional assessments

Four main points

1. There is a natural greenhouse effect
2. Humans are increasing the greenhouse effect by adding greenhouse gases to the atmosphere
3. Effects of a changing climate are already apparent
4. There is very likely much more global warming to come

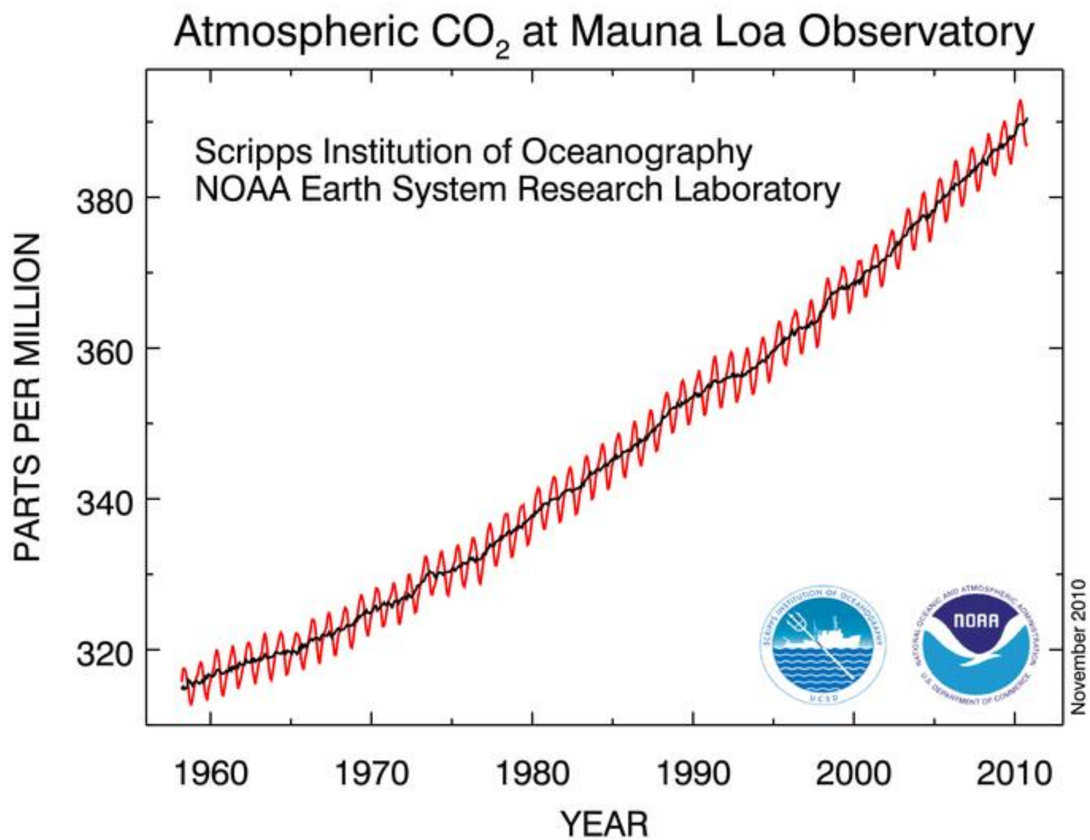
Greenhouse gases (water vapor, CO_2, CH_4, N_2O) play a critical role in determining global temperature



Rapid increases in greenhouse gases are changing this natural balance

Carbon-dioxide concentrations

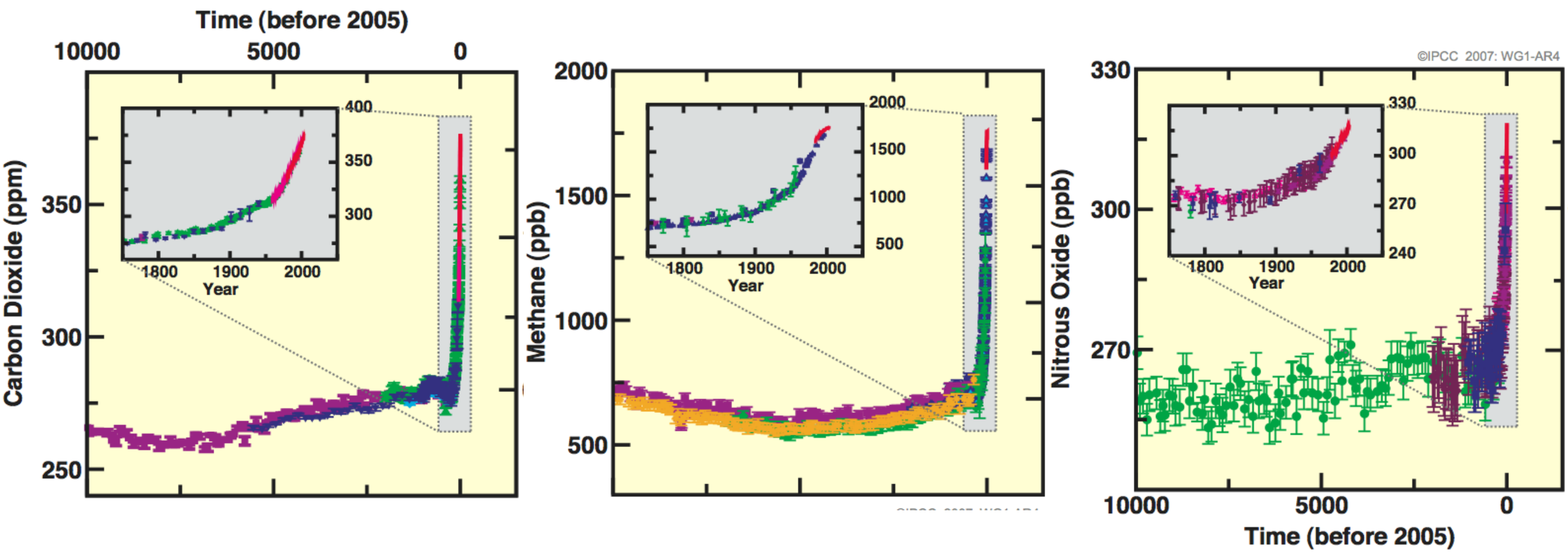
- Seasonal changes driven by the "breathing" of the biosphere have been riding on top of a rising trend



source - http://www.esrl.noaa.gov/gmd/ccgg/trends/

Industrial revolution and the atmosphere

The current concentrations of key greenhouse gases,
and their rates of change, are unprecedented in the last 10,000 years.



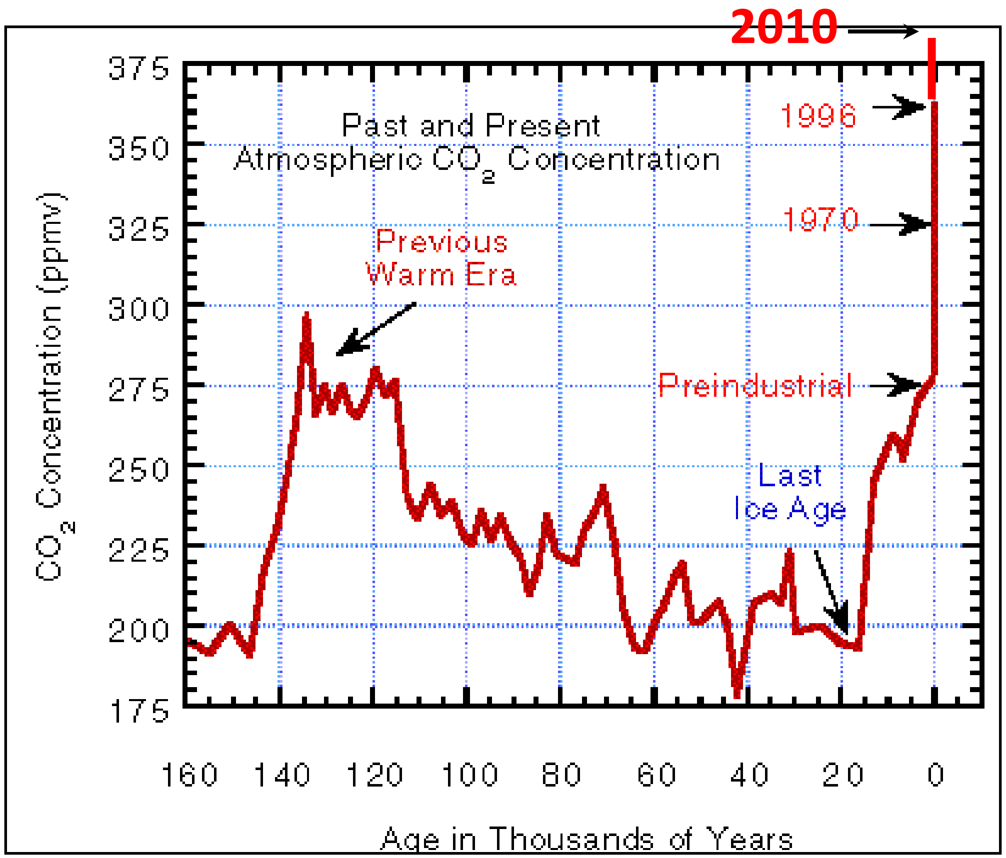
Carbon dioxide

Methane

Nitrous Oxide

CO_2 over the last 160,000 years

- Current concentrations are higher than any time in at least the past ~780,000 years
- ~70% of CO_2 emissions come from fossil fuel burning



From a long term perspective, these changes are enormous

The planet has been warming … (+1.3°F since 1906)

Warming since the 1950s very likely (>90% probability)
due to the observed increase in GHG from human activities.

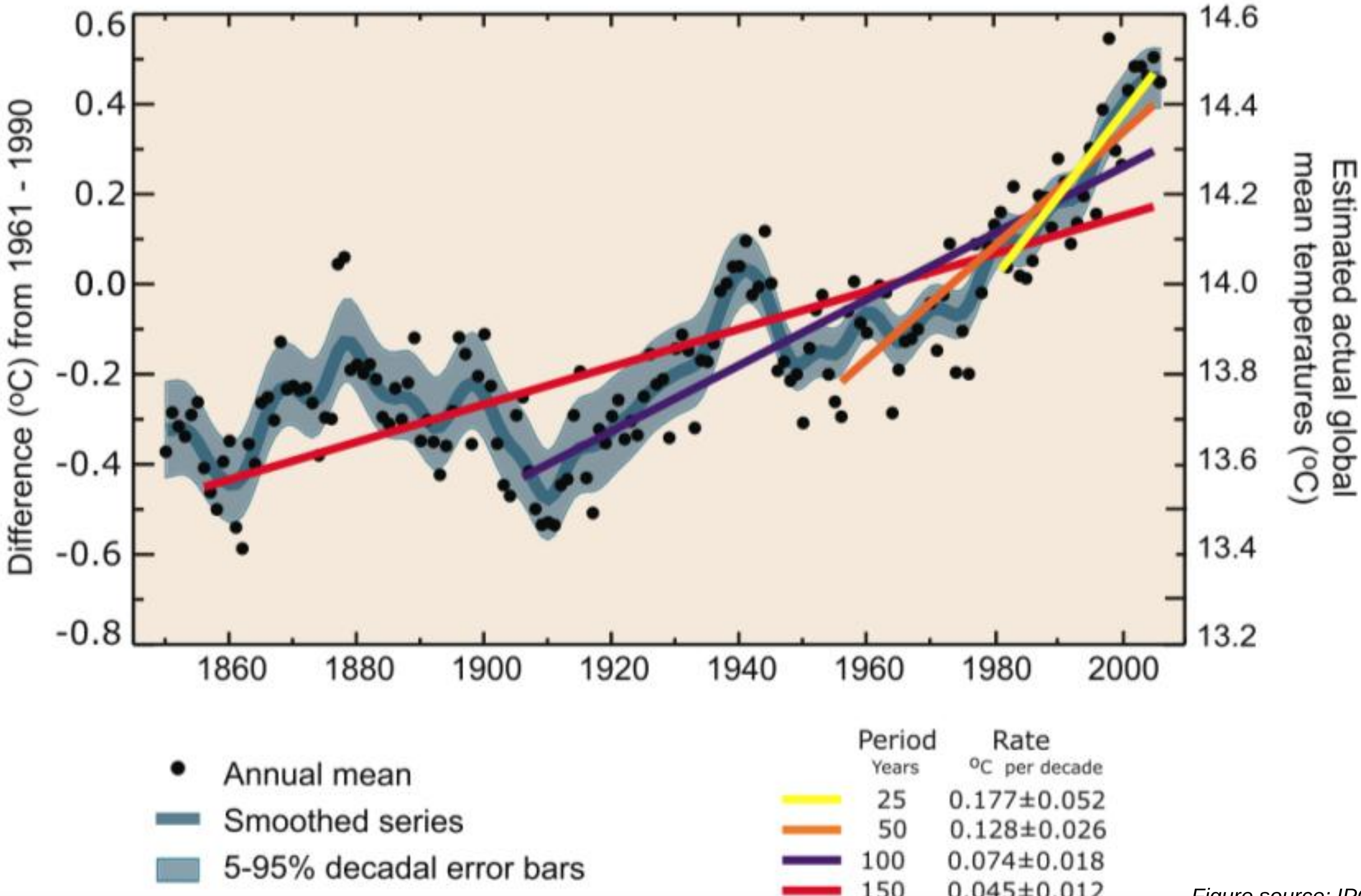
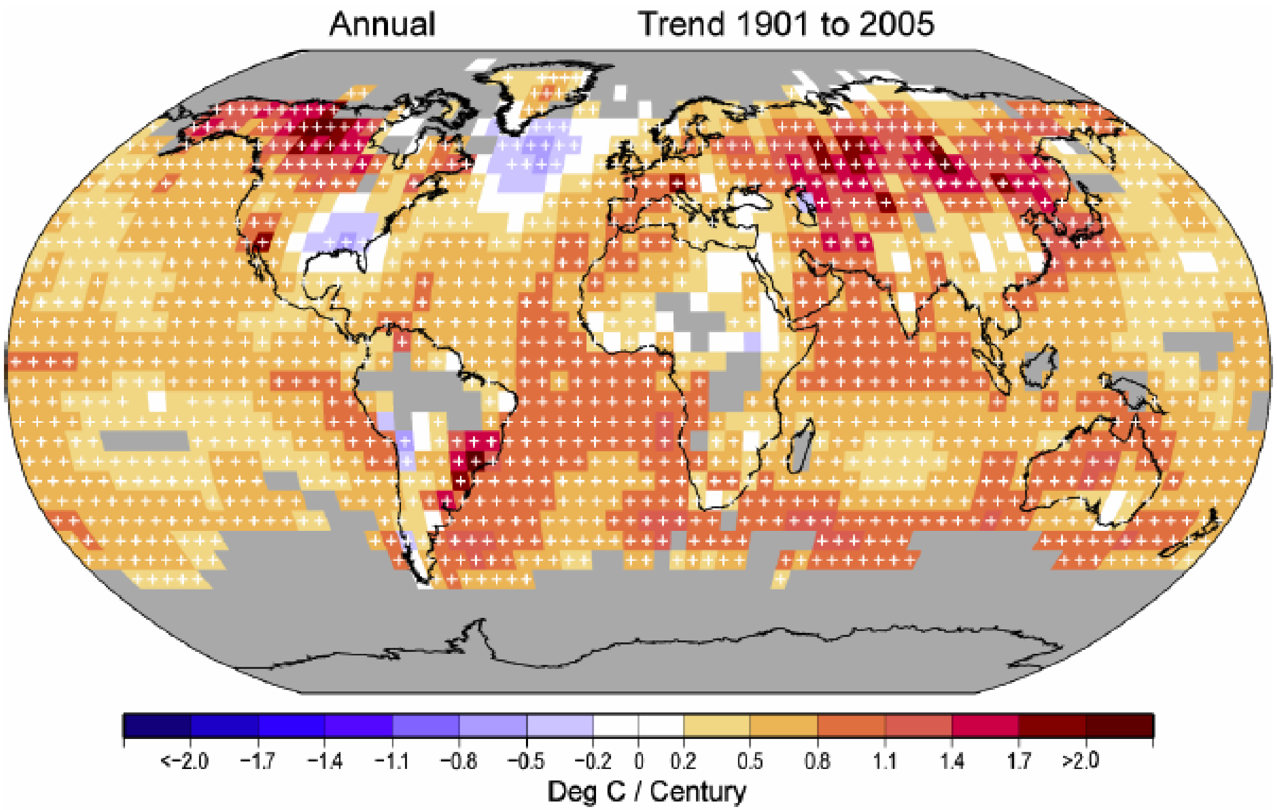


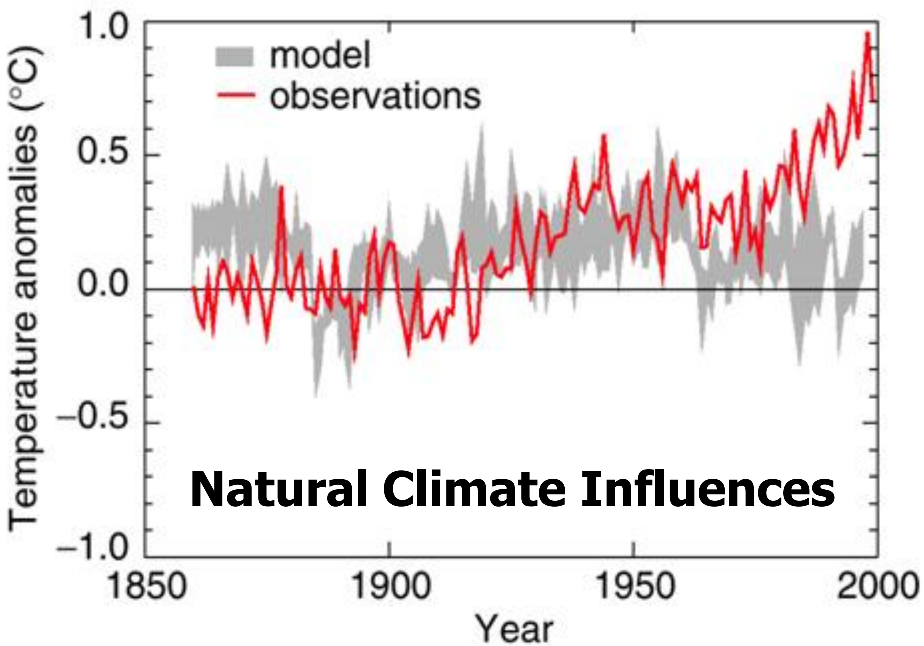
Figure source: IPCC 2007

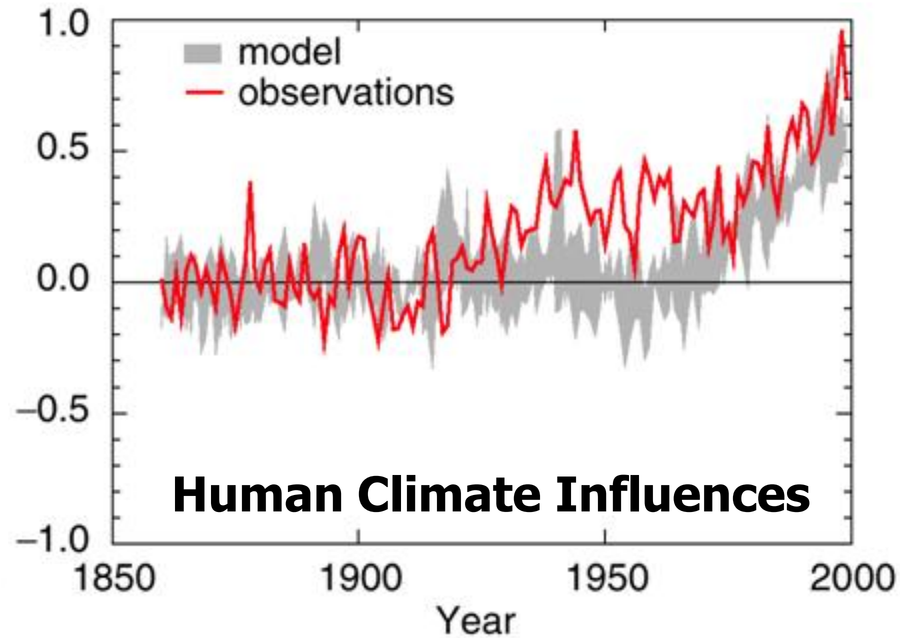
There is a pattern to the past century's warming



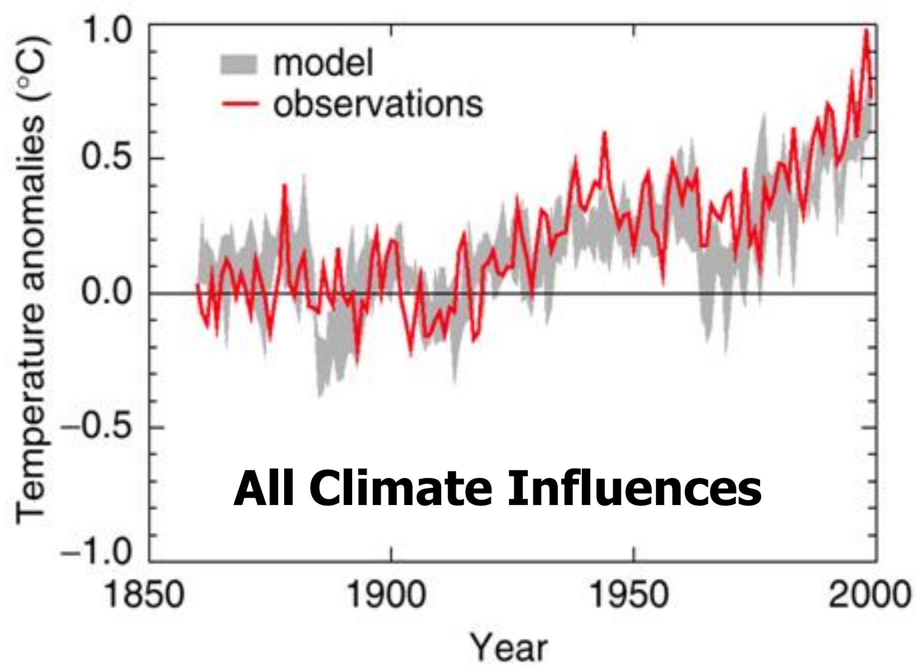
Globally averaged, the planet is about 0.75°C warmer than it was in 1860, based upon dozens of high-quality long records using thermometers worldwide, including land and ocean.

(IPCC 2007)





The understanding of anthropogenic warming and cooling influences on climate has improved since the Third Assessment Report (TAR), leading to very high confidence that the globally averaged net effect of human activities since 1750 has been one of warming, with a radiative forcing of +1.6 [+0.6 to +2.4] W m-2. (spm 2007)



Summary of evidence for a human-contribution to recent warming

- Rate of warming appears to be unusually rapid
- Pattern of change matches that expected from increasing greenhouse gases
- Solar, volcanic forcing would have led to cooling in the past ~30 years

Evidence of change is increasingly visible throughout Earth's natural systems

Observed 20th century change

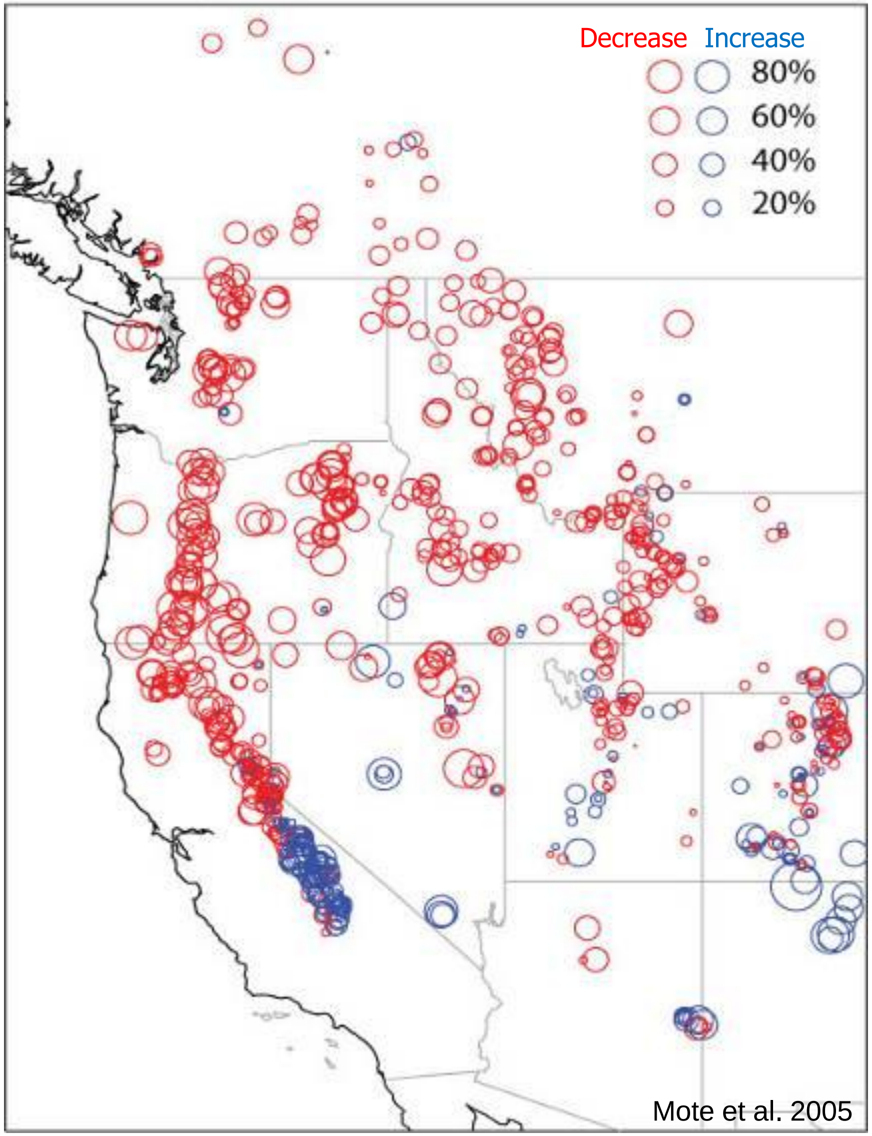
Key Trends in PNW Climate

Average annual temperature increased **+1.5°F** in the PNW during the 20th century

April 1 snowpack decreased, with losses of 30-60% at many individual stations in the PNW (1950-2000)

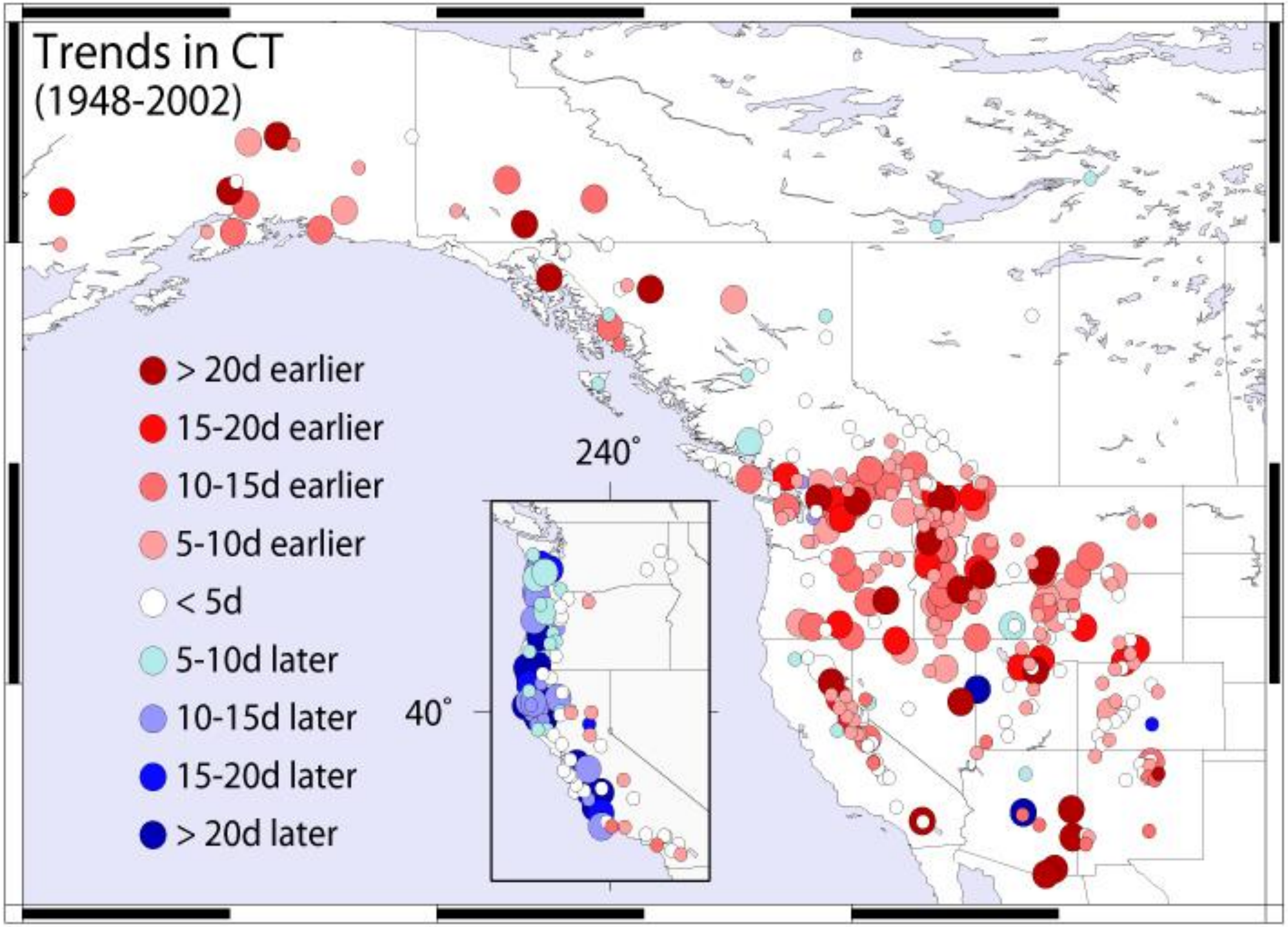
Similar snowpack declines are seen throughout the western United States

a. April 1 SWE Observations 1950-1997



Trends in Spring Runoff

Peak of spring runoff is moving earlier into the spring throughout western U.S. and Canada



Stewart et al. 2005 Stewart I.T., Cayan D.R., Dettinger M.D., 2005: Changes toward earlier streamflow timing across western North America, *Journal of Climate*, 18(8):1136-1155.

Glacier National Park

T.J. Hileman, courtesy of Glacier National Park Archives

Greg Pederson photo, USGS

Boulder Glacier

North Cascades National Park

South Cascade Glacier

Photos courtesy of Dr. Ed Josberger, USGS Glacier Group, Tacoma, WA


Nisqually Glacier
2004
Photo: NPS/Scott Beason
Slide source: Paul Kennard, Mt. Rainier National Park

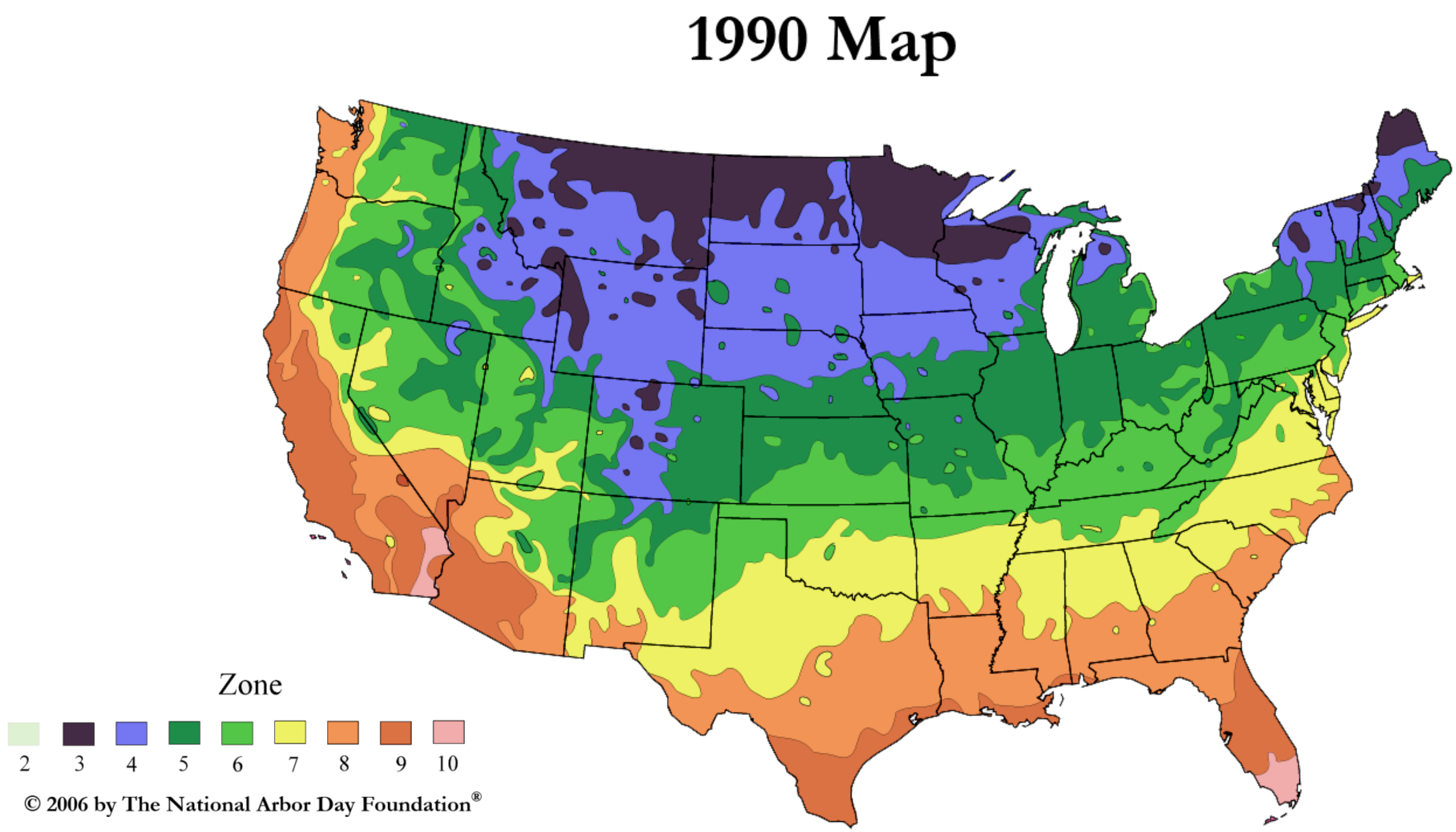
Evidence of change is increasingly visible throughout Earth's natural systems

Observed 20th century change





Changes in USDA Hardiness Zones

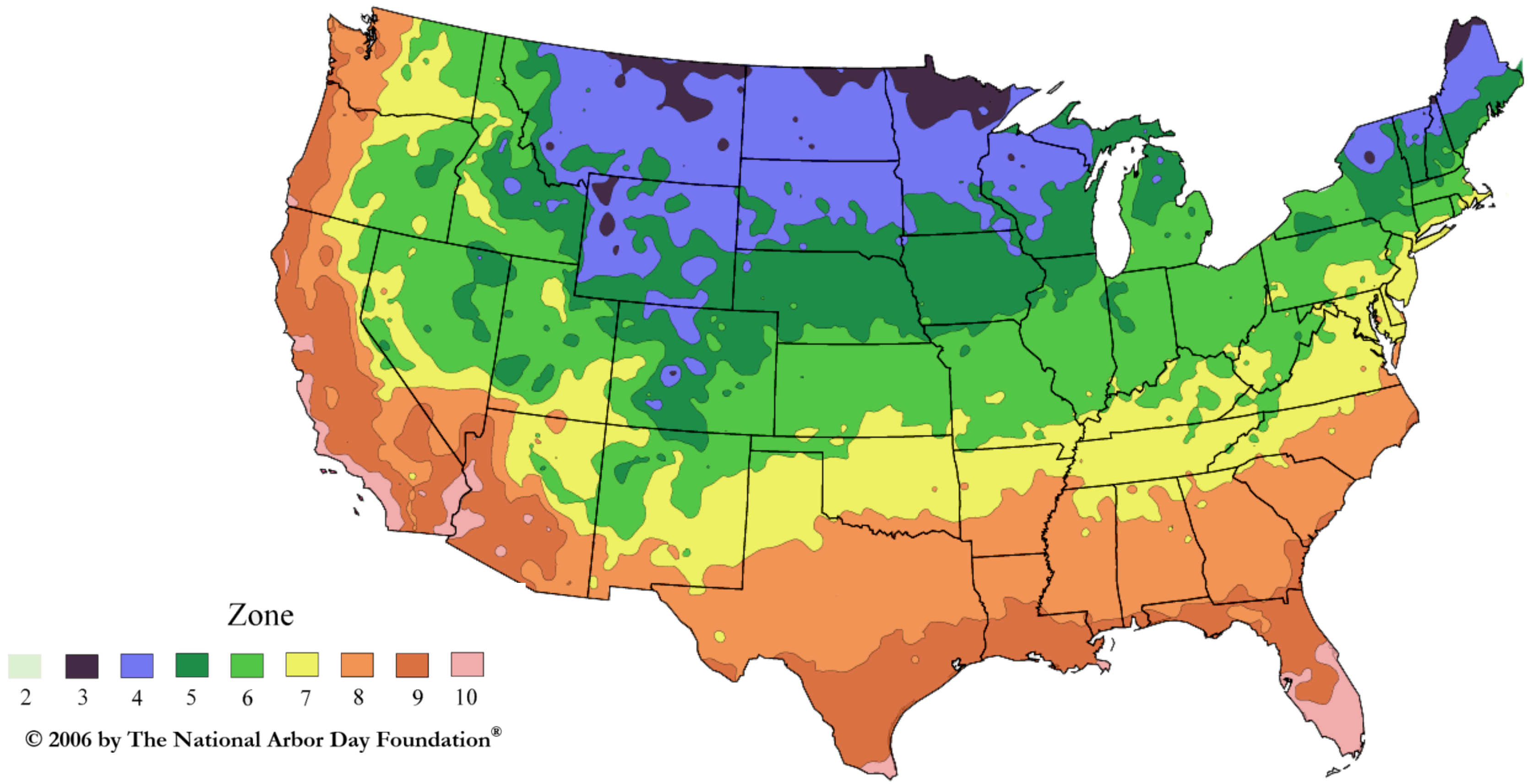


After USDA Plant Hardiness Zone Map, USDA Miscellaneous Publication No. 1475, Issued January 1990

http://www.arborday.org/media/mapchanges.cfm

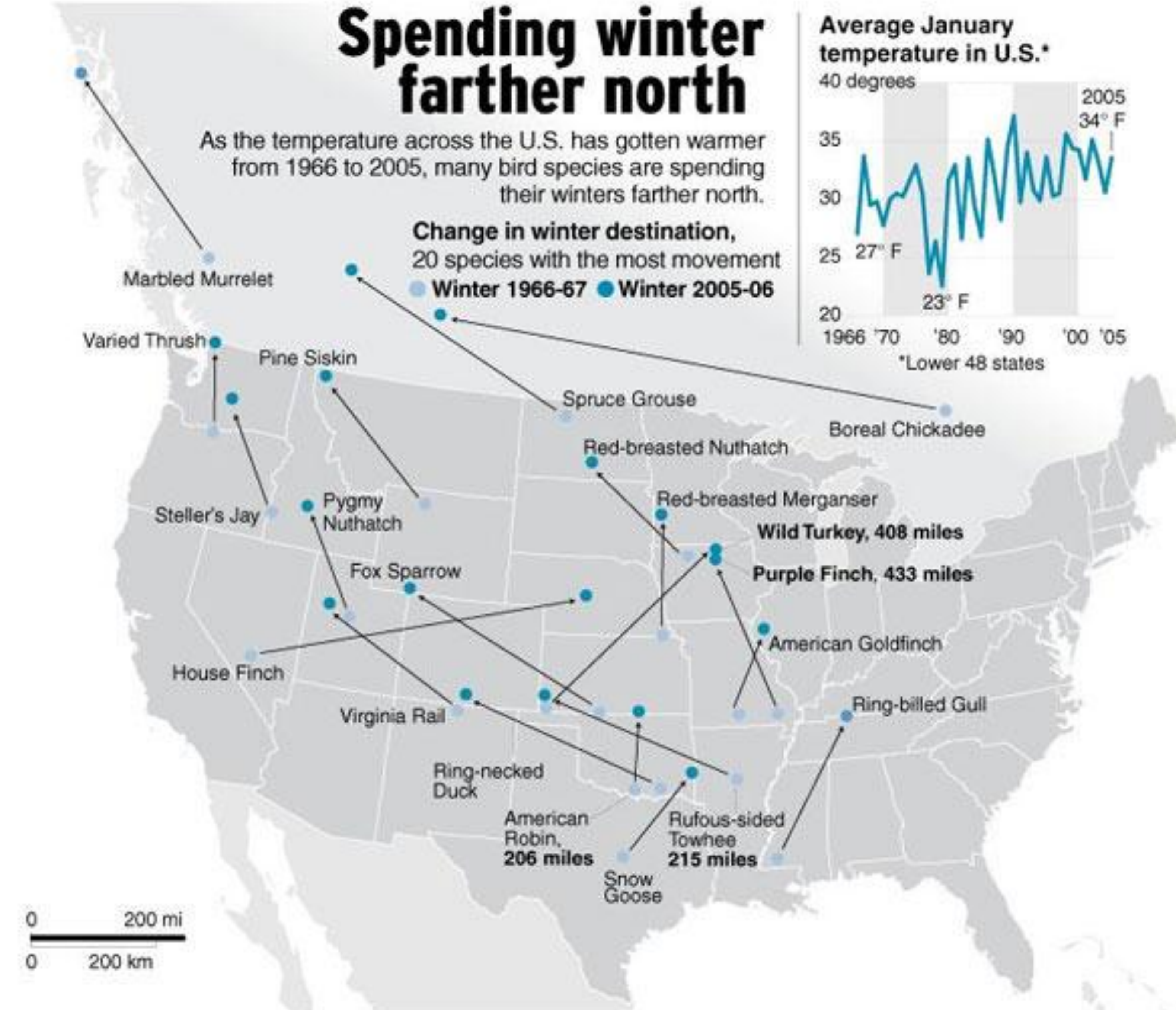
Changes in USDA Hardiness Zones

2006 Map



National Arbor Day Foundation Plant Hardiness Zone Map
published in 2006.

http://www.arborday.org/media/mapchanges.cfm



Sources: Audubon Society; NOAA

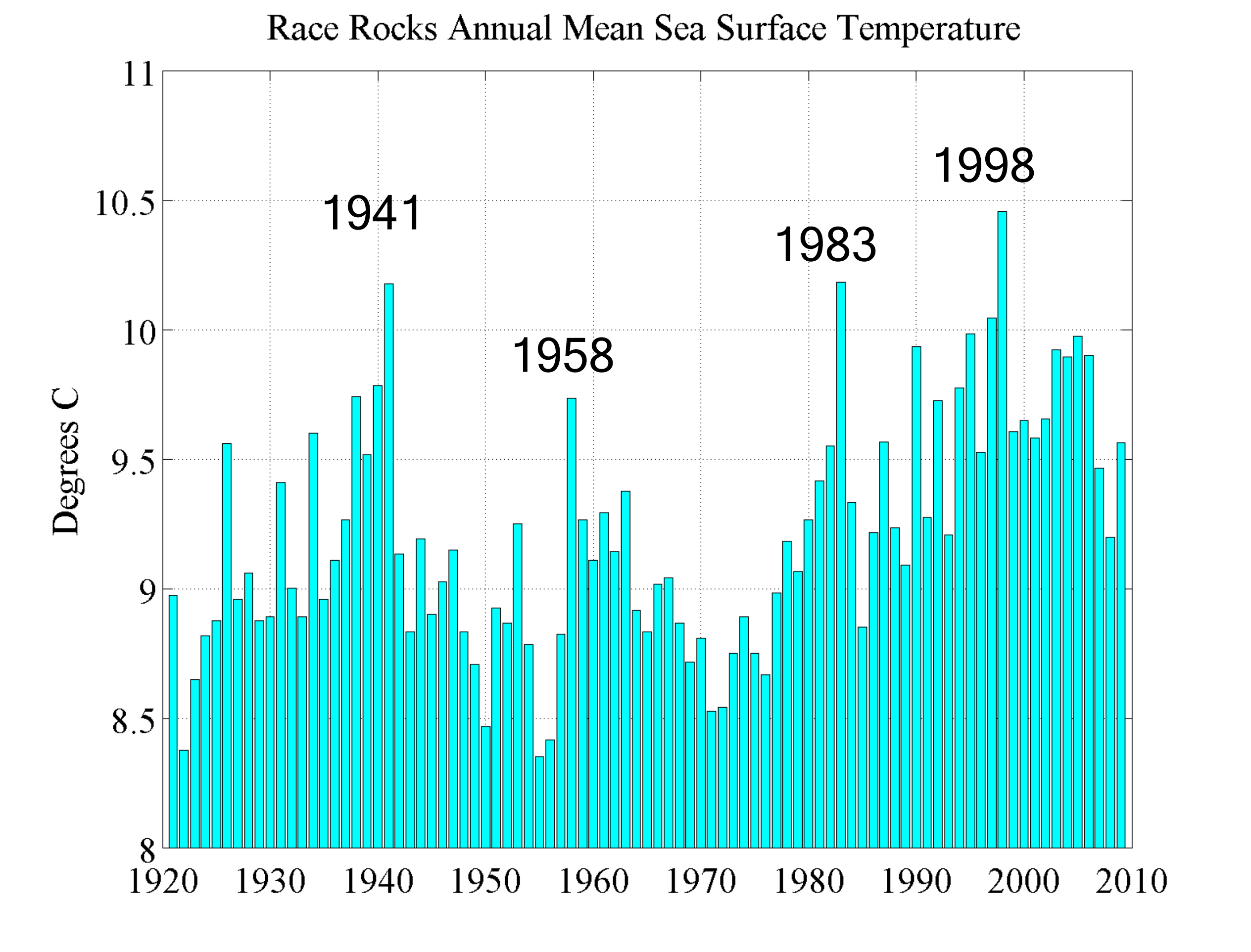
The Associated Press

Review of Past Changes

- CO_2 and other greenhouse gases warm the planet
- Human activities are changing the atmospheric concentrations of greenhouse gases (CO_2 up ~30%)
- Extensive and wide-spread evidence that the earth is warming; we are already seeing the first clear signals of a changing climate.
- The planet warmed ~0.8°C from 1860-2009, in part due to human activities.
- Observed changes in the western US (increased temperature, decreased snowpack, changes in timing of snow accumulation and streamflow) partly due to anthropogenic forcing

Race Rocks sea surface temperature: 1921-2009

- Surface temperature variations for Puget Sound as a whole closely track those at Race Rocks
- Note the large year-to-year changes, decadal cycles, and on longer-term warming trend



Future Climate Projections for the Pacific Northwest

Amy Snover, PhD
Co-Director, Climate Impacts Group
University of Washington

Projecting Future Climate

A chain of assumptions and models are needed for future climate change scenarios:

1. Start with a greenhouse gas emissions scenario

2. Choose a global climate model –

3. Downscale the coarse resolution climate model output

Projecting Future Climate:
1. How much CO_2 will be emitted?

40 emissions scenarios are used to "drive" global climate models.

Different scenarios result in different climate change projections.

Current emissions are in the current range of the A1B scenario.

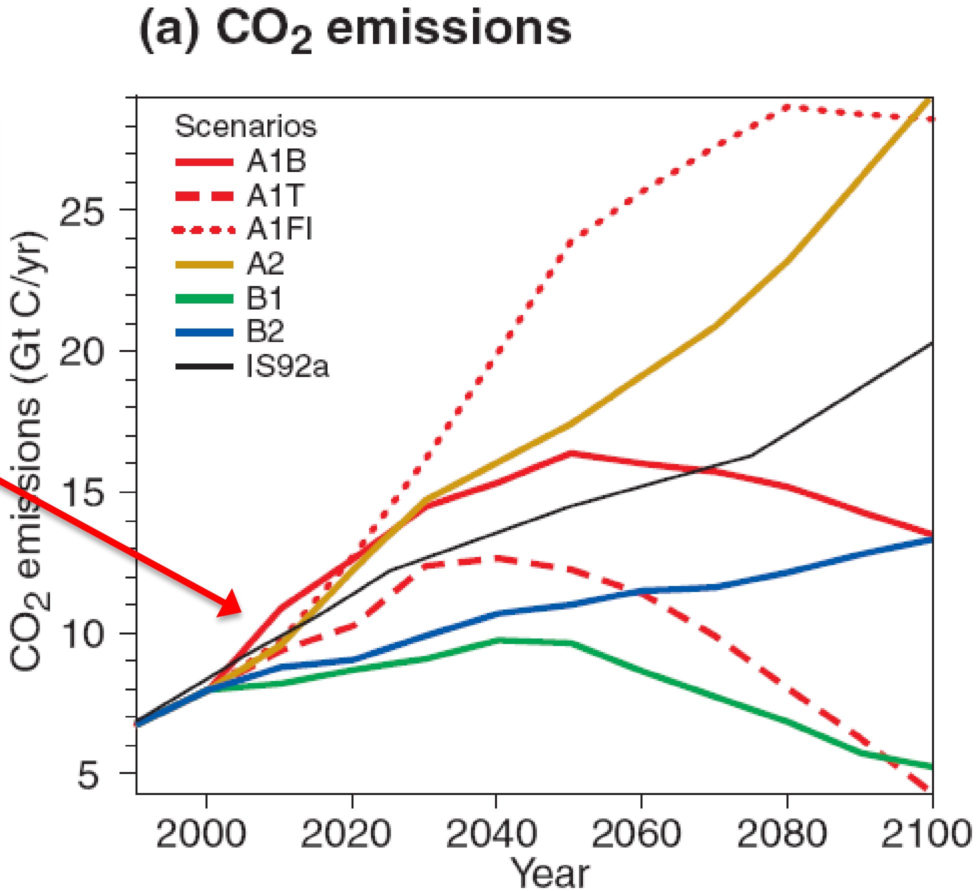
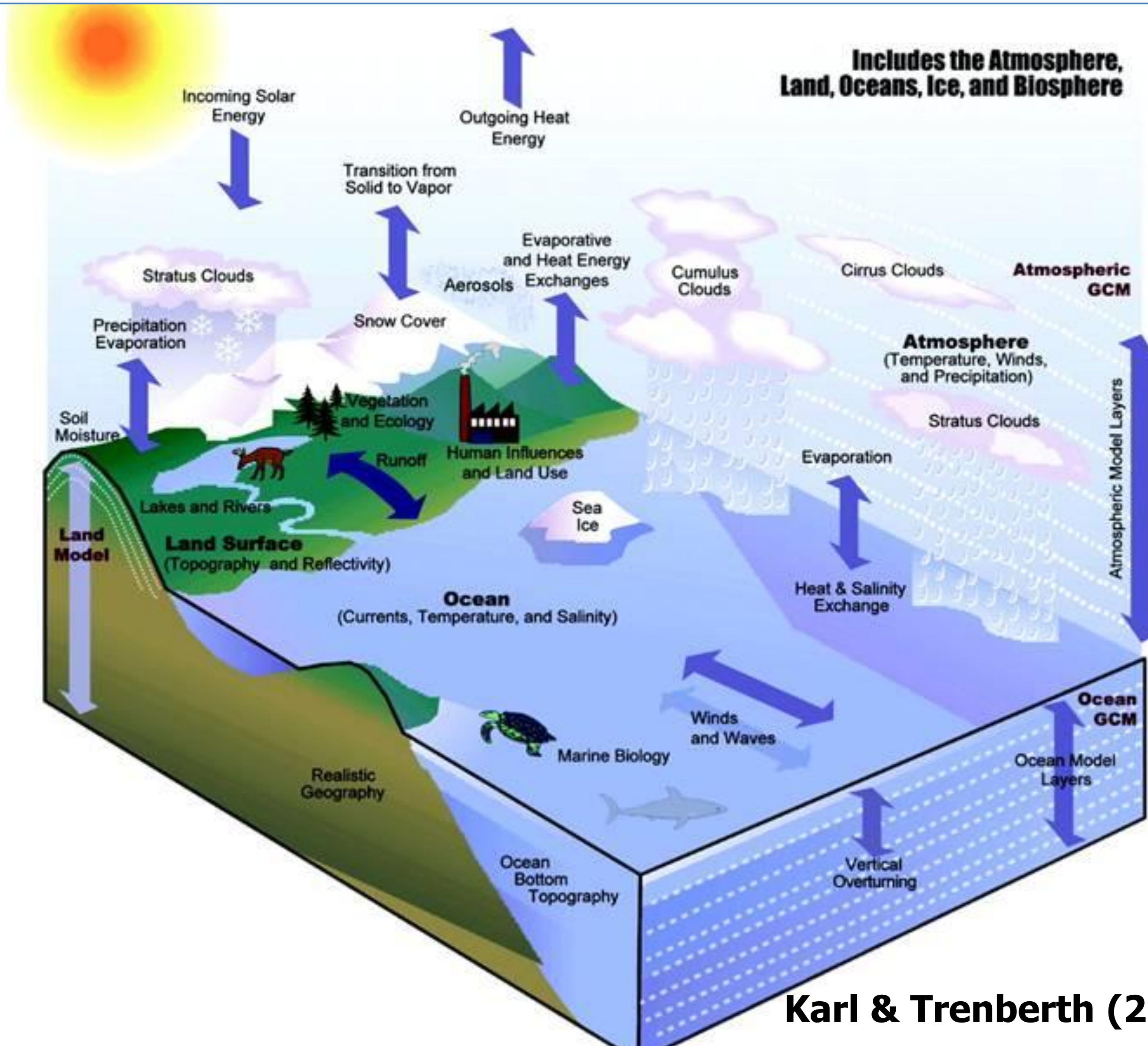


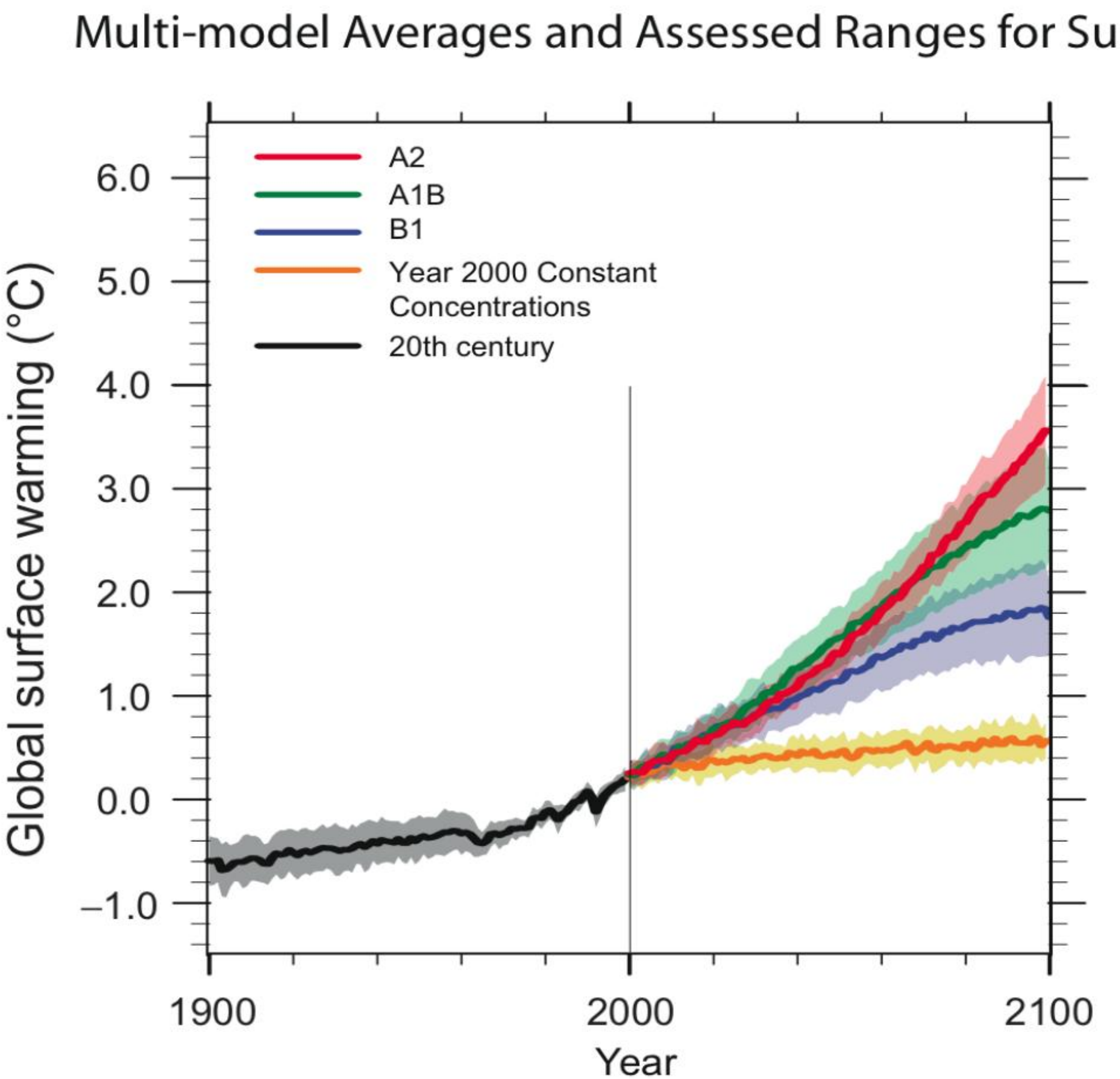
Figure source: IPCC 2001, Summary for Policy Makers

Projecting Future Climate:
2. Pick a climate model



Karl & Trenberth (2003) Science

Projected Increases in Average Global Temperature



IPCC "best estimate" range of global-scale warming by the 2090s:

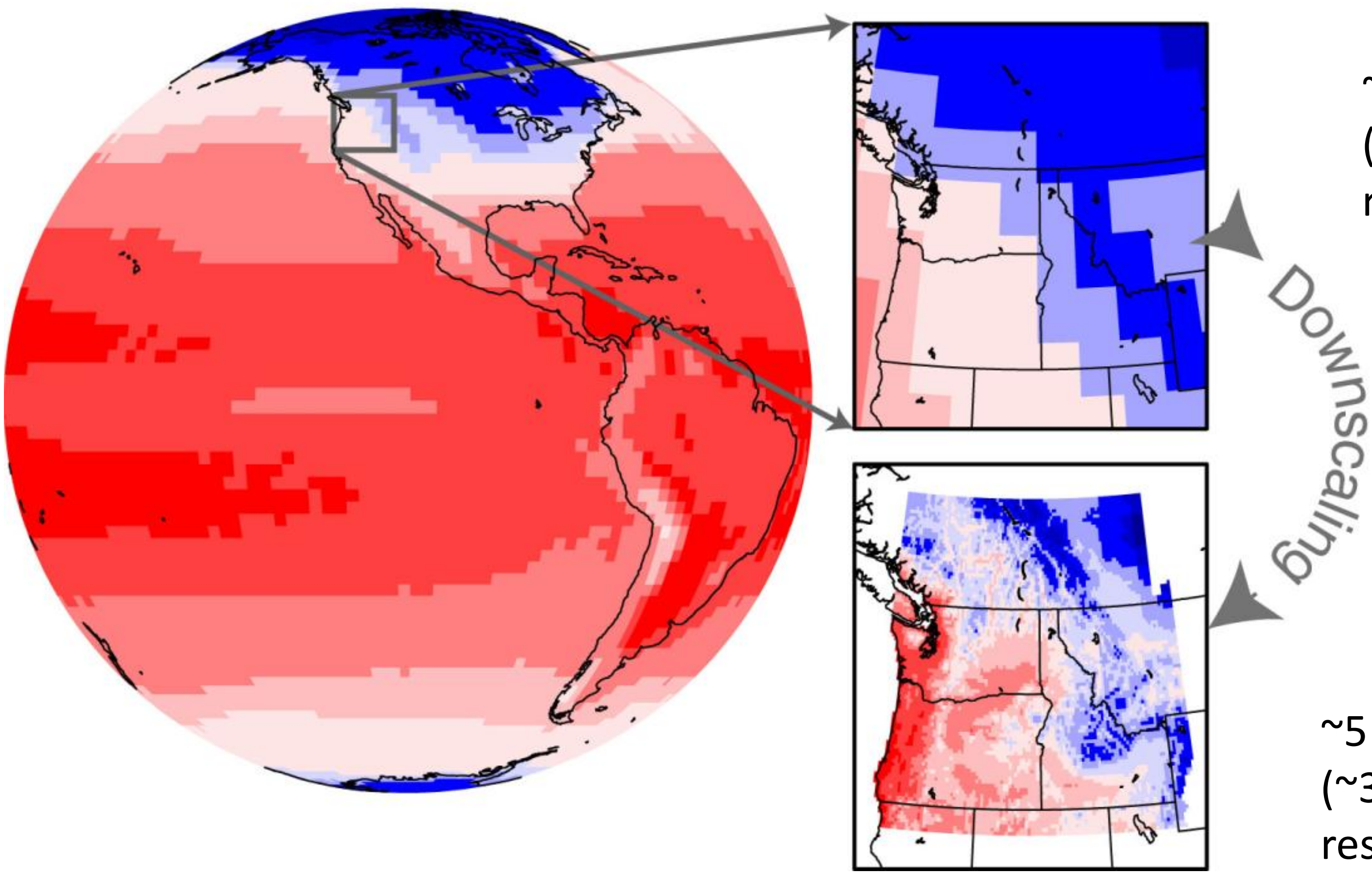
3.2°F-7.2°F

(likely range: 2-11.5°F)

Figure source: IPCC 2007 WG1, Summary for Policy Makers

Projecting Future Climate:
3. Downscale to obtain regional information

Global Climate Model Air Temperature



~200 km
(~125 mi)
resolution

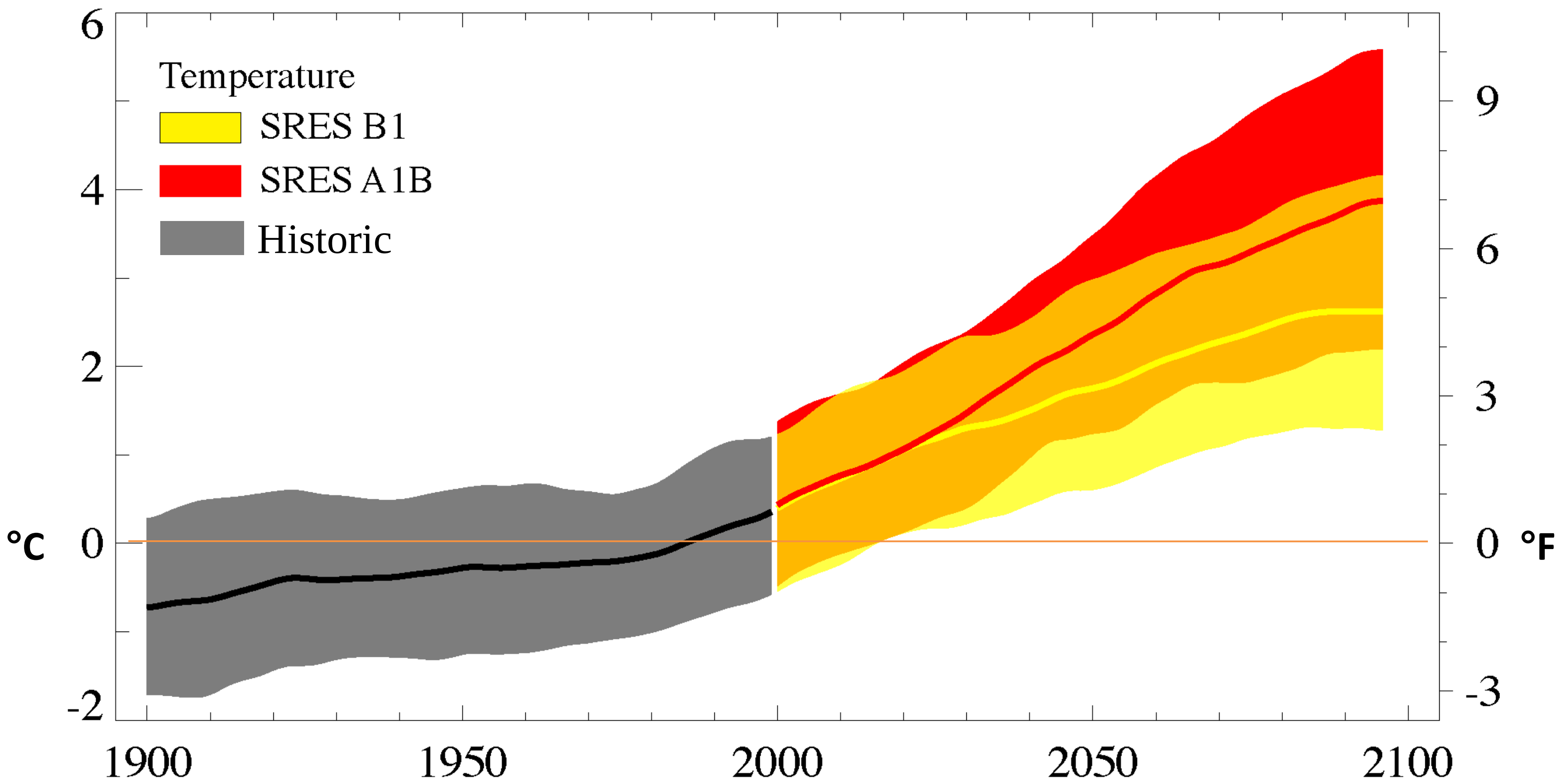
~5 km
(~3 mi)
resolution

CLIMATE IMPACTS GROUP

Projected Increases in Annual PNW Temperature

** Relative to 1970-1999 average*

2020s	+2.0°F *(1.1-3.4°F)*
2040s	+3.2°F *(1.6-5.2°F)*
2080s	+5.3°F *(2.8-9.7°F)*

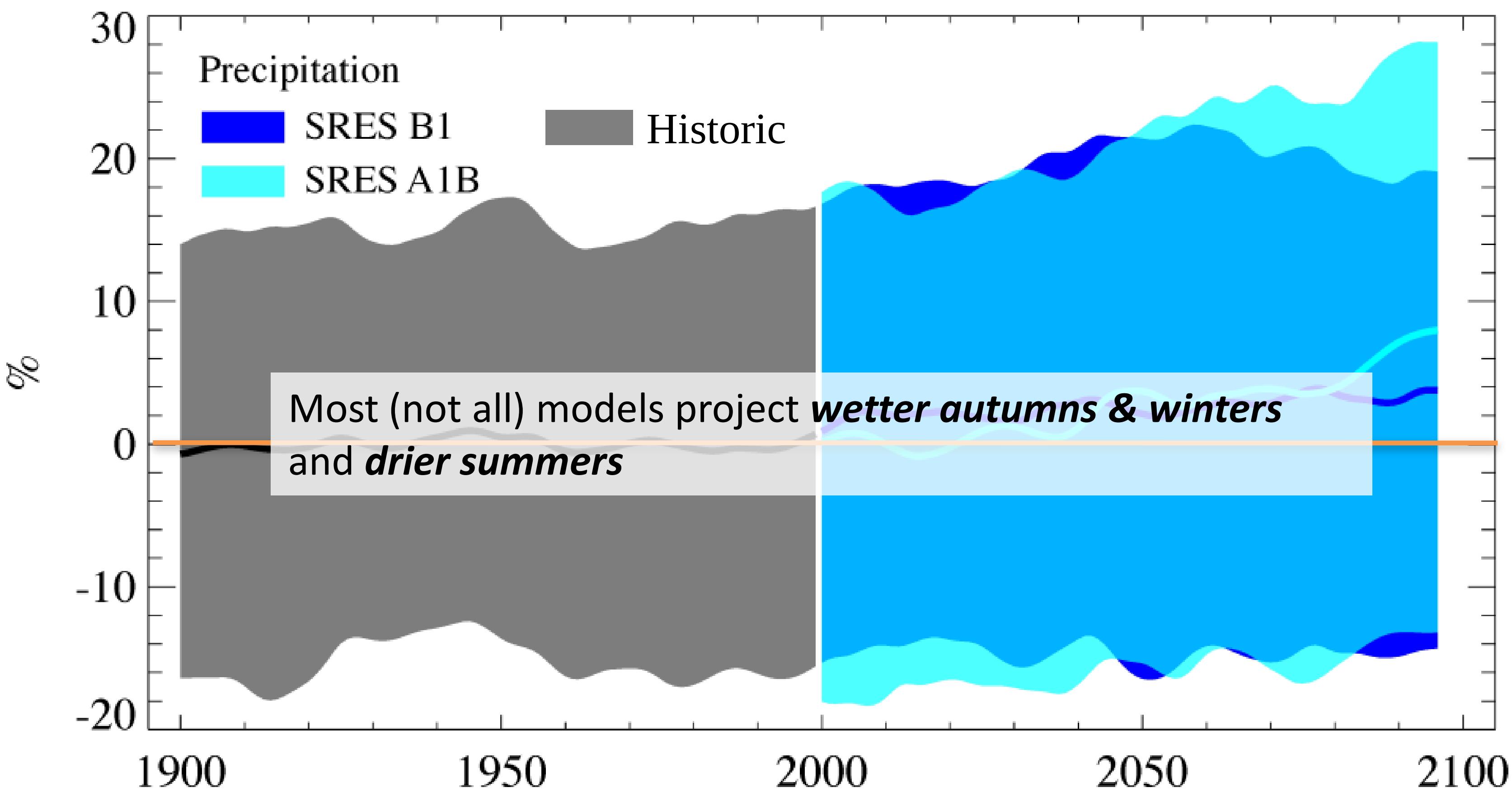


Mote and Salathé, 2009

Projected Increases in Annual PNW Precipitation

** Relative to 1970-1999 average*

2020s	+1% *(-9 to 12%)*
2040s	+2% *(-11 to +12%)*
2080s	+4% *(-10 to +20%)*



Most (not all) models project ***wetter autumns & winters*** and ***drier summers***

Mote and Salathé, 2009

21st century PNW climate scenarios relative to past variability

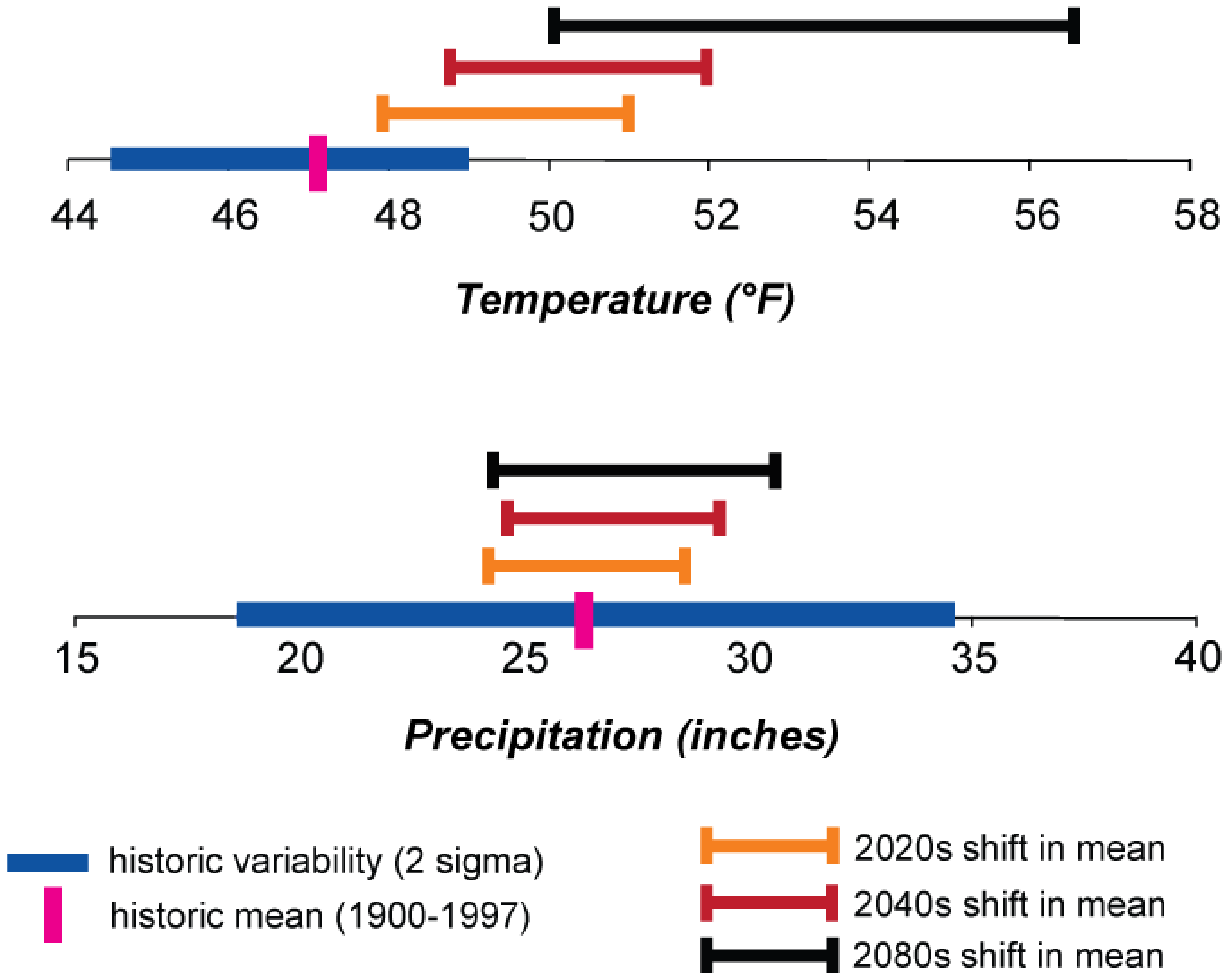


Figure source: Climate Impacts Group, University of Washington

What About Changes in Extreme Precipitation?

Simulations generally indicate increases in extreme precipitation over the next 50 years, however:

- The projections vary by model and region, and
- Actual changes may be difficult to distinguish from natural variability.

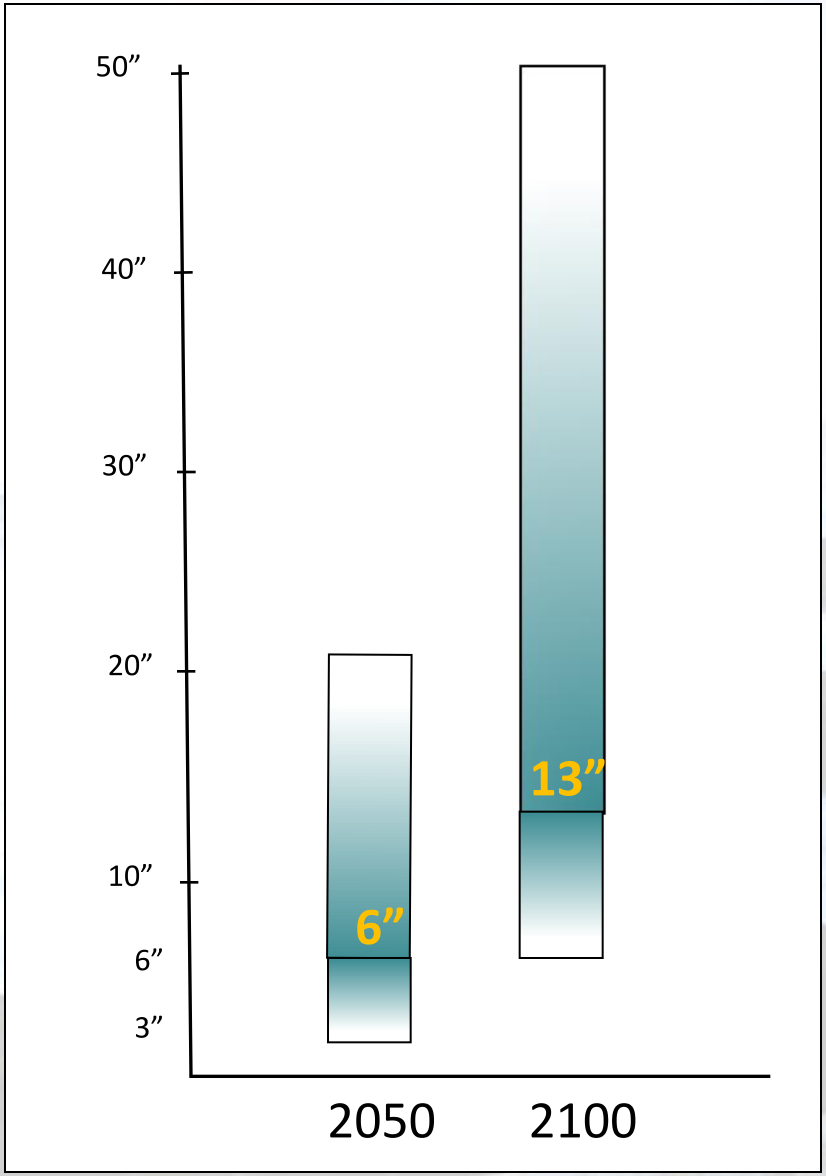
CLIMATE IMPACTS GROUP

Salathé et al. 2009, Rosenberg et al. 2009)

Coasts

Rising sea levels will increase the risk of flooding, erosion, and habitat loss along much of Washington's 2,500 miles of coastline.

- **Global SLR: 7-23" by 2100**
- **Medium** estimates of SLR for **2100:**
  +2" for the Olympic Peninsula
  +11" for the central coast
  +13" for Puget Sound
- Higher estimates (up to 4 feet by 2100 in Puget Sound) cannot be ruled out at this time.



Projected sea level rise (SLR) in Washington's waters relative to 1980-1999, in inches. Shading roughly indicates likelihood. The 6" and 13" marks are the SLR projections for the Puget Sound region and effectively also for the central and southern WA coast (2050: +5", 2100: +11").

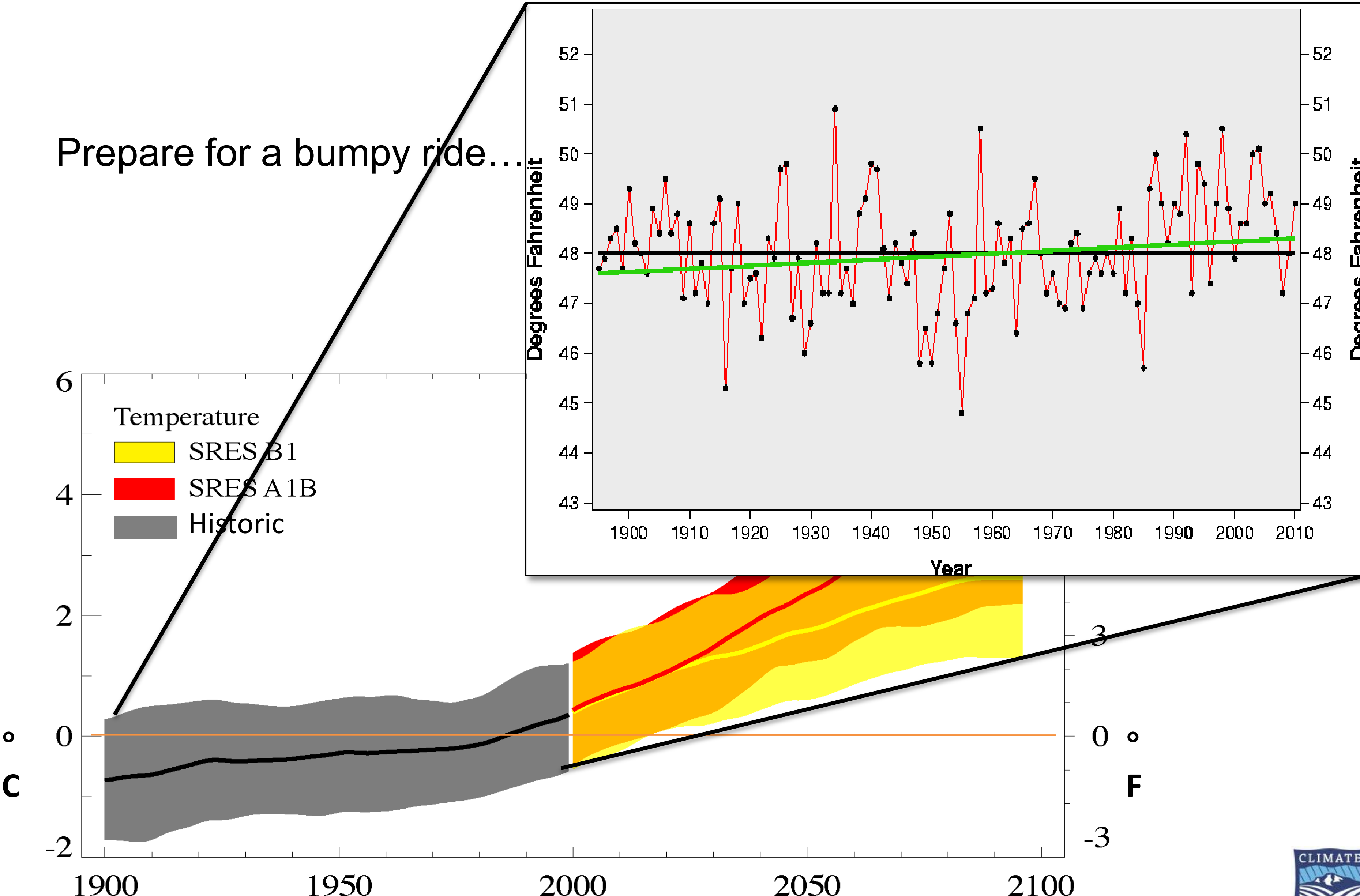
Climate change and natural variations

Climate change may be manifest partly as a change in the relative frequency of natural variations (e.g., El Niños vs. La Niñas)

- Likely changes with ENSO are very uncertain
- It currently isn't clear if ENSO will be stronger, weaker, or unchanged in a warmer future! (see Collins et al 2010, Nature Geosciences)

Regardless of nature of future change, climate **variability** will continue

Prepare for a bumpy ride…



Some Closing Thoughts

All climate model projections for the future will be wrong

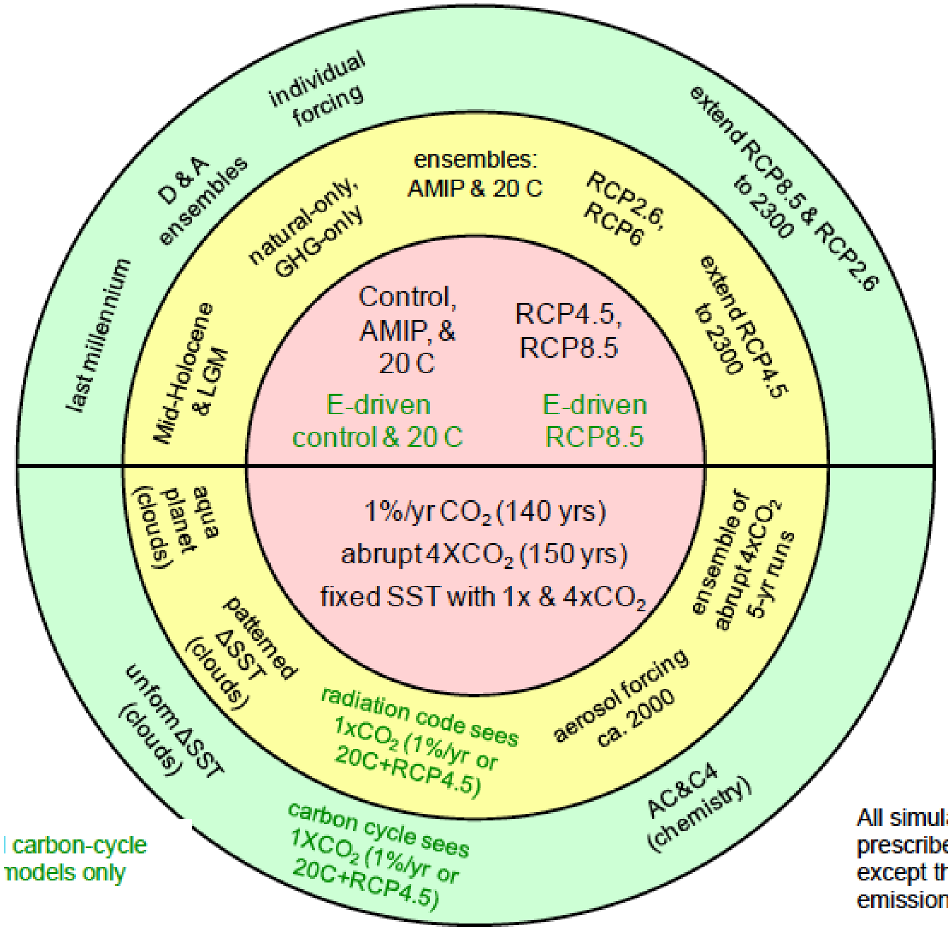
> Emissions scenarios are stories about what might happen; informing climate system models with these stories yields "scenarios", not predictions, for future climate

There are good reasons for screening GCM scenarios, using weighted average ensembles, selecting specific methods for downscaling, and choosing specific tools for impacts assessments

Even with all these careful steps, you still end up with scenarios about future climate

CLIMATE IMPACTS GROUP

Many new scenarios are being generated for the IPCC's 5th Assessment (due in 2013)



- A torrent of climate model scenarios will be released over the next few years!
- One strategy for making use of these scenarios is to first focus on a "bottom-up" vulnerability assessment

The Vulnerability Assessment Approach

Evaluate a system's vulnerability to climate by evaluating component parts:

Vulnerability =

(sensitivity x exposure)/adaptability

Climate change scenarios provide information only about exposure to future climate events; the system you're interested in can tell you about adaptability and sensitivity

The Vulnerability Assessment Approach

The vulnerability assessment approach (at the least) compliments a "top-down" impacts assessment approach

In my opinion, this "bottom-up" framework is superior for many reasons including an explicit recognition that there are and will always be many future scenarios to choose from, and our ability to narrow down future climate uncertainties is sharply limited.

The Climate Impacts Group

www.cses.washington.edu/cig

CLIMATE IMPACTS GROUP

Hydrologic Climate Change Scenarios for the Pacific Northwest Columbia River Basin and Coastal Drainages

Hydrologic Products

Climate change is projected to have substantial impacts on Pacific Northwest water resources and ecosystems. Recognizing this, resource managers have expressed growing interest in incorporating climate change information into long-range planning. The availability of hydrologic scenarios to support climate change adaptation and long-range planning, however, has been limited until very recently to a relatively small number of selected case studies. More comprehensive resources needed to support regional planning have been lacking. Furthermore, ecosystem studies at the landscape scale need consistent climate change information and databases over large geographic areas. Products using a common set of methods that would support such studies have not been readily available.

To address these needs, the Climate Impacts Group worked with several prominent water management agencies in the Pacific Northwest to develop hydrologic climate change scenarios for approximately 300 streamflow locations in the Columbia River basin and selected coastal drainages west of the Cascades. Study partners are listed below. The scenarios, provided to the public for free via this website, allow planners to consider how hydrologic changes may affect water resources management objectives and ecosystems.

Access to the data and summary products is available from the menu to the left. The hydrologic data produced by the study are based on climate change scenarios produced for the IPCC Fourth Assessment effort. Information on the methods and modeling tools used in the study is provided in the summary report. For new users of the site, a guide to the website and the data resources contained within it is also

...e Impacts Group was funded by the following research partners to develop ...ia River Basin and coastal drainages climate change scenarios:

- ...State Department of Ecology
- ...eville Power Administration
- Northwest Power and Conservation Council
- Oregon Department of Water Resources
- British Columbia Ministry of Environment

http://www.hydro.washington.edu/2860/

Available PNW Scenarios (80!)

Downscaling Approach			A1B Emissions Scenario	B1 Emissions Scenario
Hybrid Delta	hadcm cnrm_cm ccsm3 echam5 echo_g cgcm3.1_t4 7 pcm1 miroc_3.2 ipsl_cm4 hadgem1	2020s	10	10
		2040s	10	10
		2080s	10	10
Transient BCSD	hadcm cnrm_cm ccsm3 echam5 echo_g cgcm3.1_t4 7 pcm1	1950-2098+	7	7
Delta Method	composite of 10	2020s	1	1
		2040s	1	1
		2080s	1	1

2020s – mean 2010-2039; 2040s – mean 2030-2059; 2080s – mean 2070-2099

Resilience to a changing climate requires recognizing and updating the expectations about climate embedded in our infrastructure, plans, operations, and decision processes.

The Climate Impacts Group

www.cses.washington.edu/cig

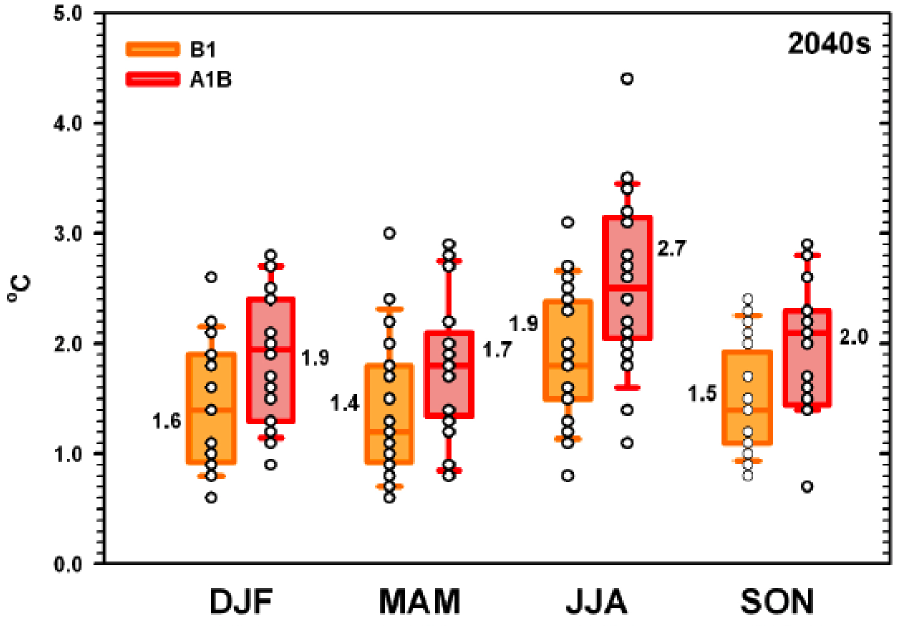
Extreme Events

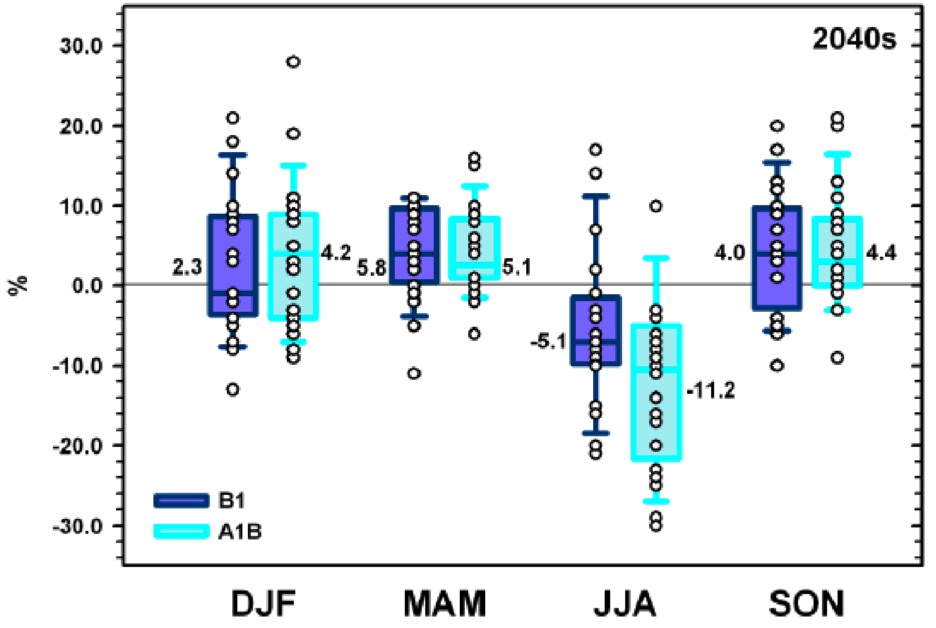
Phenomenon[a] and direction of trend	Likelihood that trend occurred in late 20th century (typically post 1960)	Likelihood of a human contribution to observed trend [b]	Likelihood of future trends based on projections for 21st century using SRES scenarios
Warmer and fewer cold days and nights over most land areas	*Very likely* [c]	*Likely* [e]	*Virtually certain* [e]
Warmer and more frequent hot days and nights over most land areas	*Very likely* [d]	*Likely (nights)* [e]	*Virtually certain* [e]
Warm spells / heat waves. Frequency increases over most land areas	*Likely*	*More likely than not* [f]	*Very likely*
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	*Likely*	*More likely than not* [f]	*Very likely*
Area affected by droughts increases	*Likely* in many regions since 1970s	*More likely than not*	*Likely*
Intense tropical cyclone activity increases	*Likely* in some regions since 1970	*More likely than not* [f]	*Likely*
Increased incidence of extreme high sea level (excludes tsunamis) [g]	*Likely*	*More likely than not* [f, h]	*Likely* [i]

*Judgmental estimates of confidence by IPCC: *very likely* - 90-99% chance, *likely* - 66-90% chance.

Source: IPCC SPM 2007

Climate Change Scenarios for the Pacific Northwest



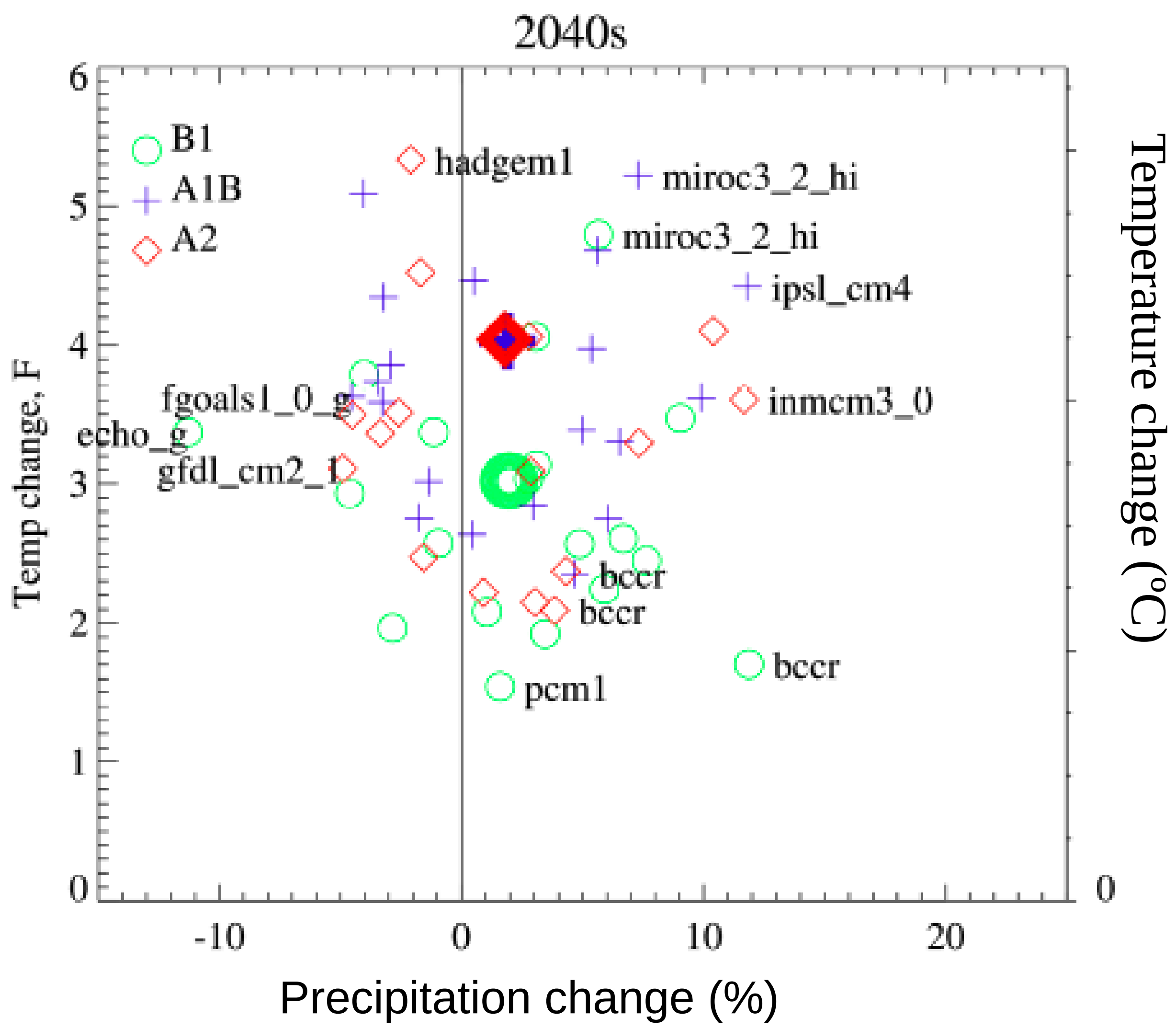


All of these scenarios show warming for the 2040s, but different scenarios warm at different rates

Most (not all) show increasing precipitation in winter, spring and fall, and decreasing precipitation in summer

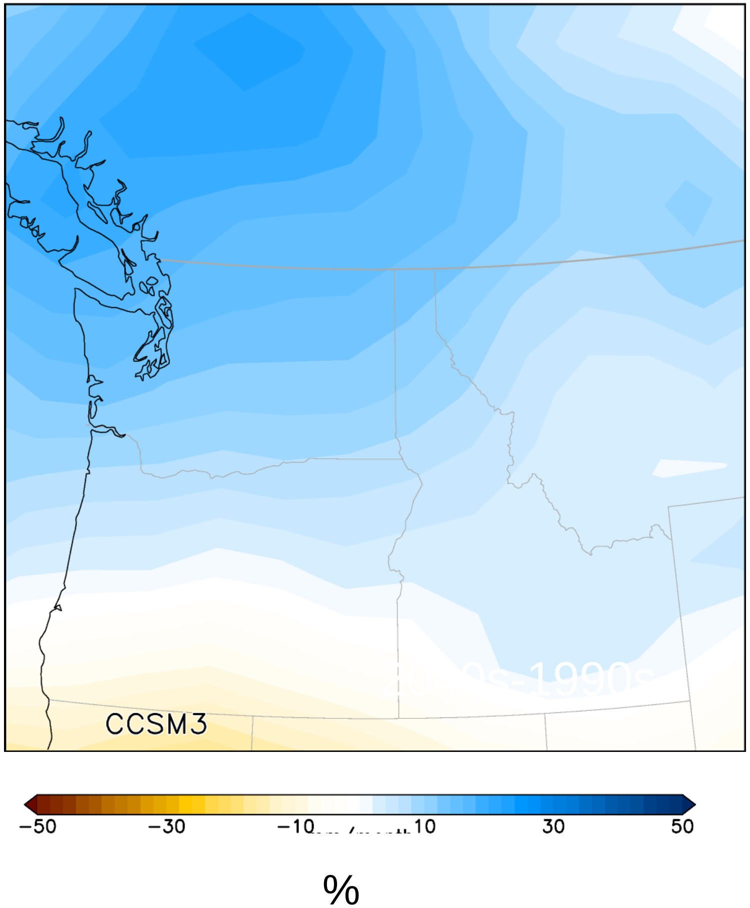
Mote and Salathé (2009)

Climate model + emissions scenario combinations yield a range of temperature and precipitation change scenarios

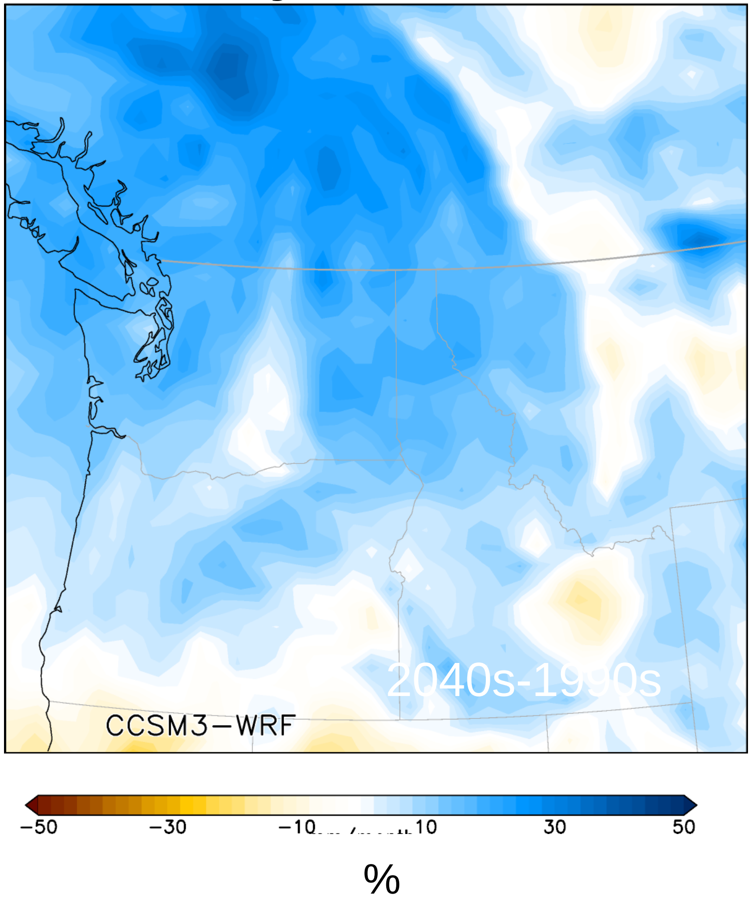


"Dynamical vs Statistical Downscaling" CCSM3

Statistical

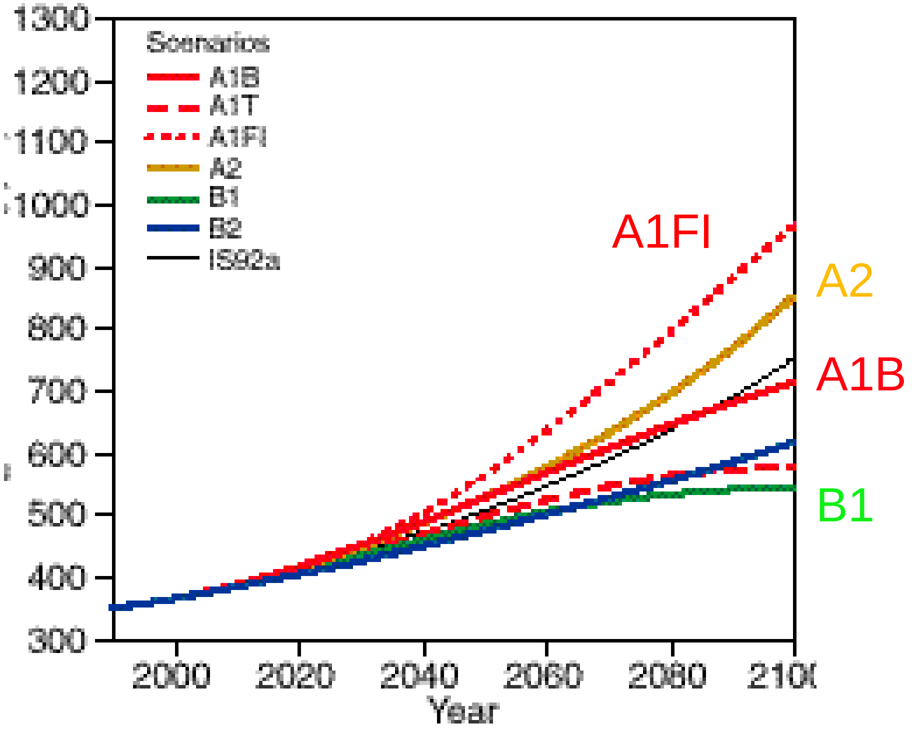


Dynamical



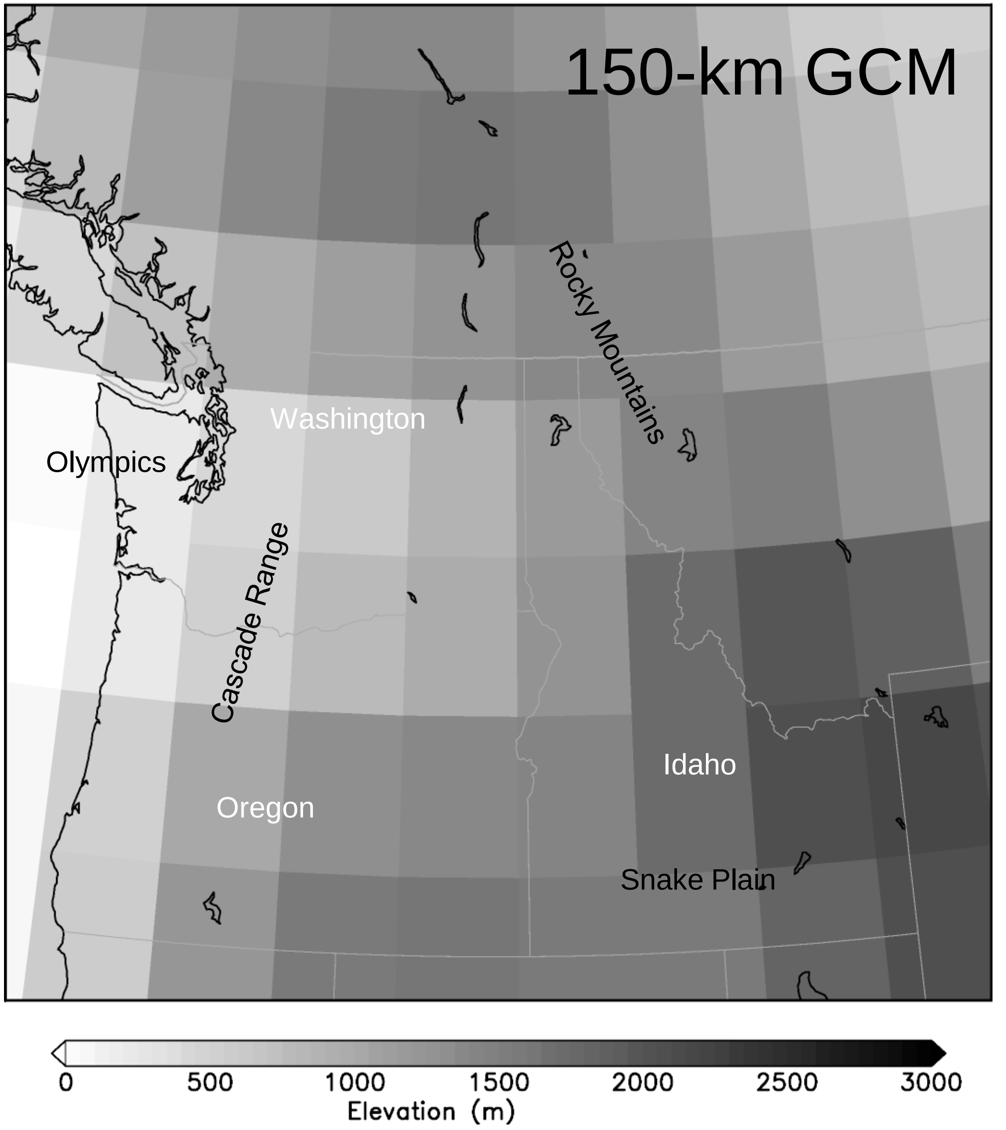
Dynamical downscaling redistributes the precipitation changes from the global models in a more physically realistic way
(Salathè et al. 2010)

CO_2 Concentrations



High resolution is needed for regional studies

- Global Models Typically have 100-200 km resolution
  - Cannot distinguish Eastern WA from Western WA
  - No Cascades
  - No Land cover differences



High resolution is needed for regional studies

- Global Models Typically have 100-200 km resolution
  - Cannot distinguish Eastern WA from Western WA
  - No Cascades
  - No Land cover differences

- Regional Models Typically have 12-50 km (resolution
  - 12 km WRF at UW/CIG
  - Can represent major topographic features
  - Can simulate small extreme weather systems
  - Represent land surface effects at local scales