Future of the North American Carbon Cycle

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Globally - Land & oceans vital for regulating atmospheric CO_2

Sources = **Sinks**

88%

9.4 ± 0.5 PgC/yr

12%

1.3 ± 0.7 PgC/yr

4.7 ± 0.1 PgC/yr

46%

30%

3.0 ± 0.8 PgC/yr

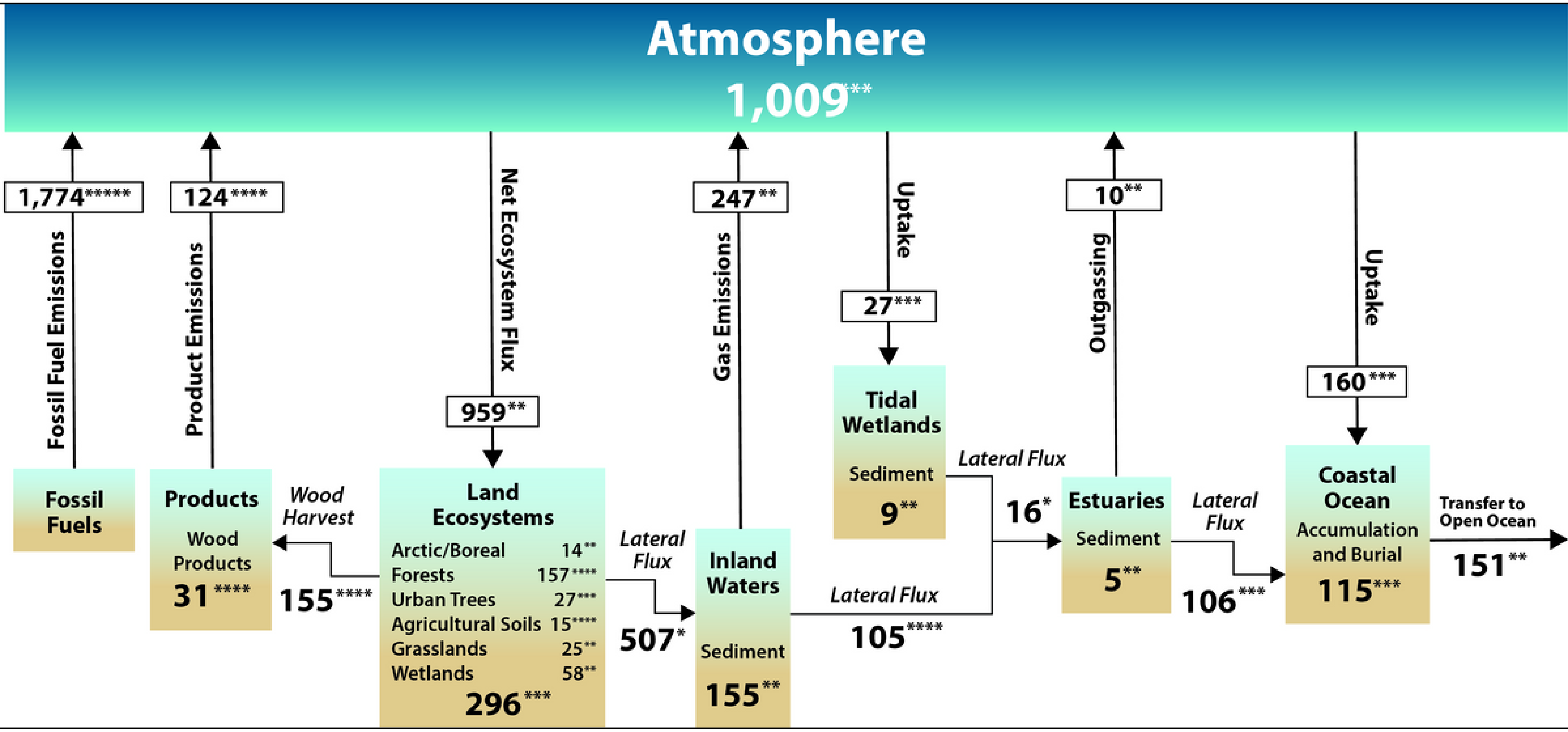
24%

2.4 ± 0.5 PgC/yr

Adapted from [Global Carbon Budget 2016]

Numbers based on Chapter 1, SOCCR-2; Table 1.1 (2007-2016 avg)

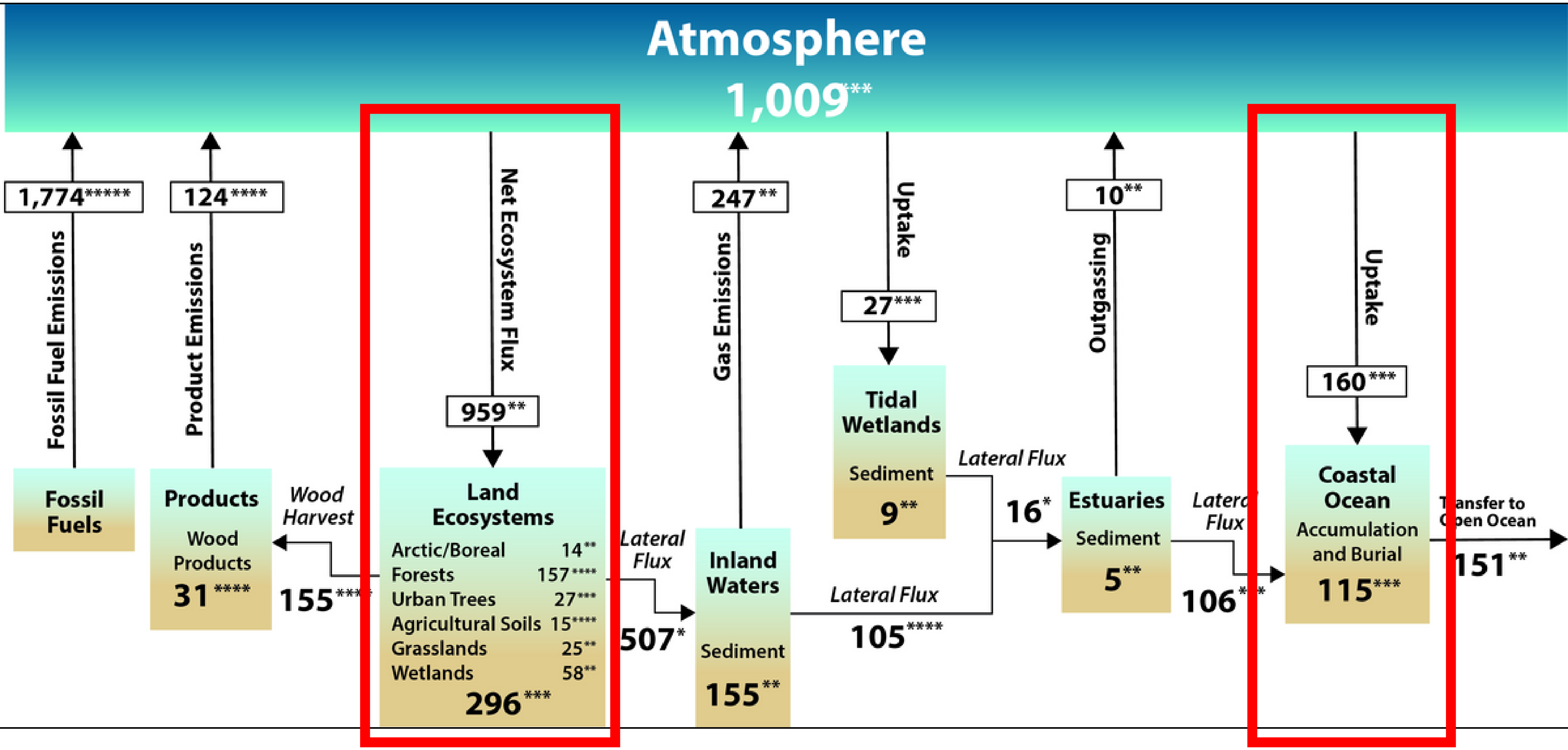
Major Components of the NA Carbon Cycle



Values in Tg C

From Chapter 2 of SOCCR-2, Hayes et al.

Major Components of the NA Carbon Cycle



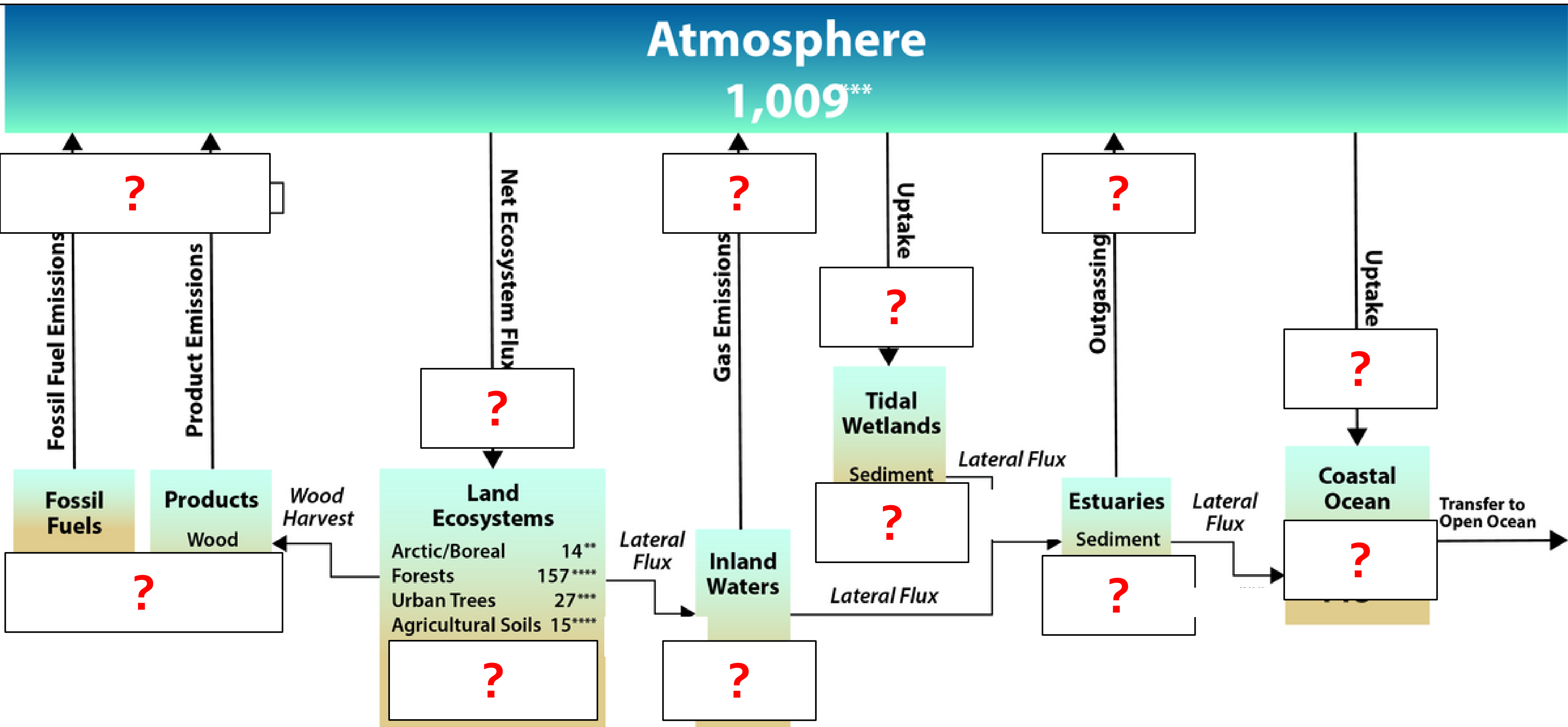
Land and coastal oceans currently a net sink of carbon

By taking up atmospheric CO_2, land and oceans play a <u>critical</u> role in slowing the accumulation of carbon in the atmosphere – thereby <u>slowing</u> rate of climate warming

Will the land and oceans continue to provide this service into the future?

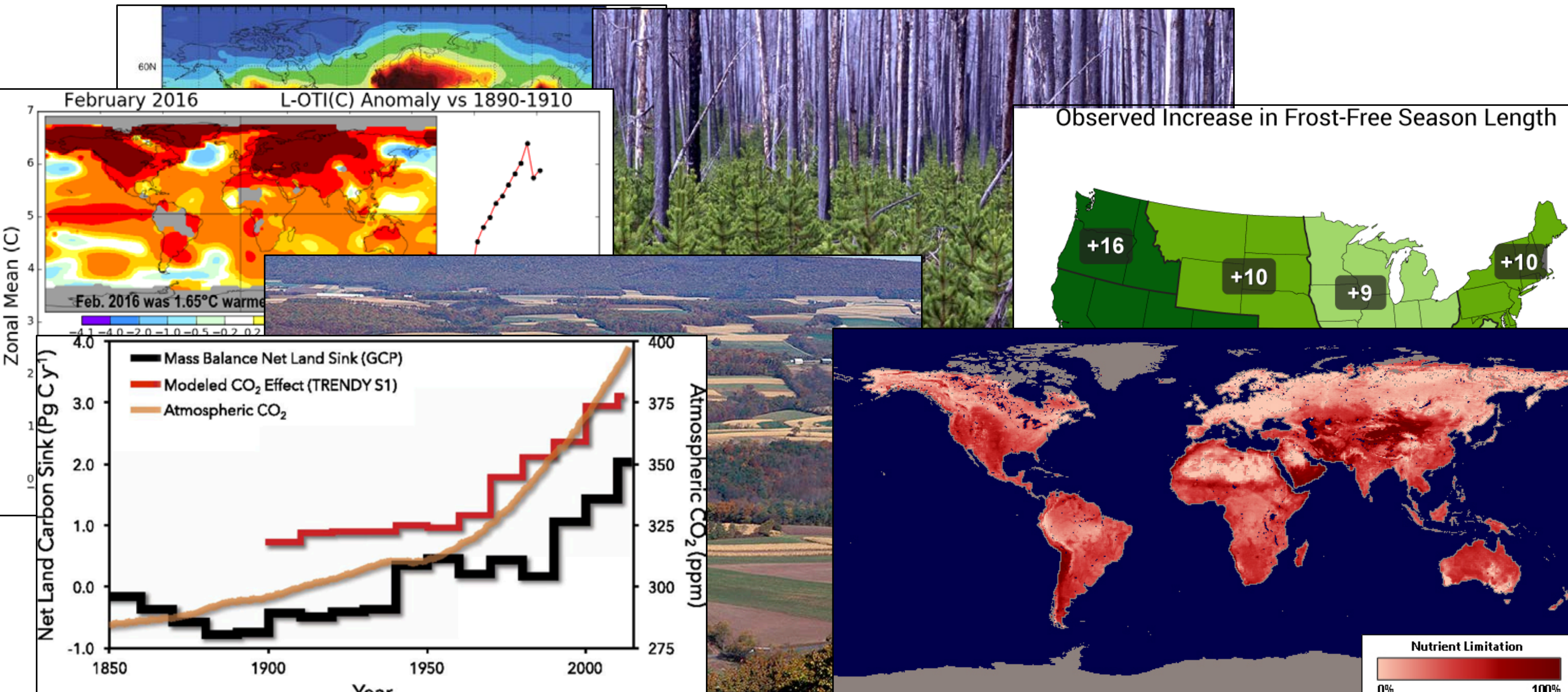
Or, will the ocean and land carbon sinks decrease (or switch to source) under changing environmental conditions?

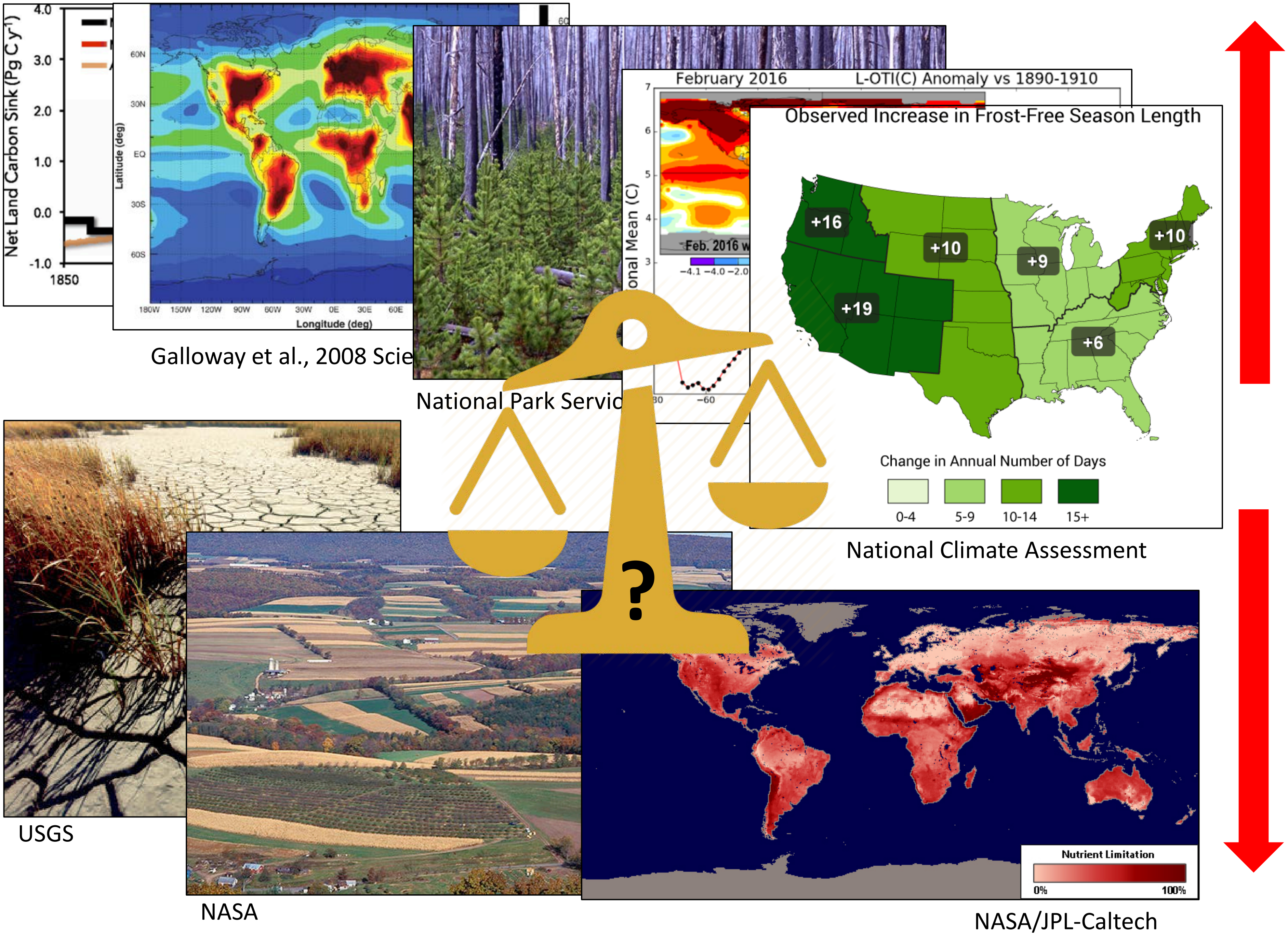
Future of the North American Carbon Cycle?



Predicting future carbon cycle changes

Requires ability to estimate response of land and aquatic systems to numerous, often competing, drivers.





Net Land Carbon Sink (Pg C y⁻¹)
4.0
3.0
2.0
1.0
0.0
-1.0
1850
Latitude (deg)
60N
30N
EQ
30S
60S
180W 150W 120W 90W 60W 30W 0E 30E 60E
Longitude (deg)
Galloway et al., 2008 Scie
National Park Servic
February 2016
L-OTI(C) Anomaly vs 1890-1910
Feb. 2016
onal Mean (C)
Observed Increase in Frost-Free Season Length
+16
+10
+9
+10
+19
+6
Change in Annual Number of Days
0-4
5-9
10-14
15+
National Climate Assessment
?
USGS
NASA
Nutrient Limitation
0%
100%
NASA/JPL-Caltech

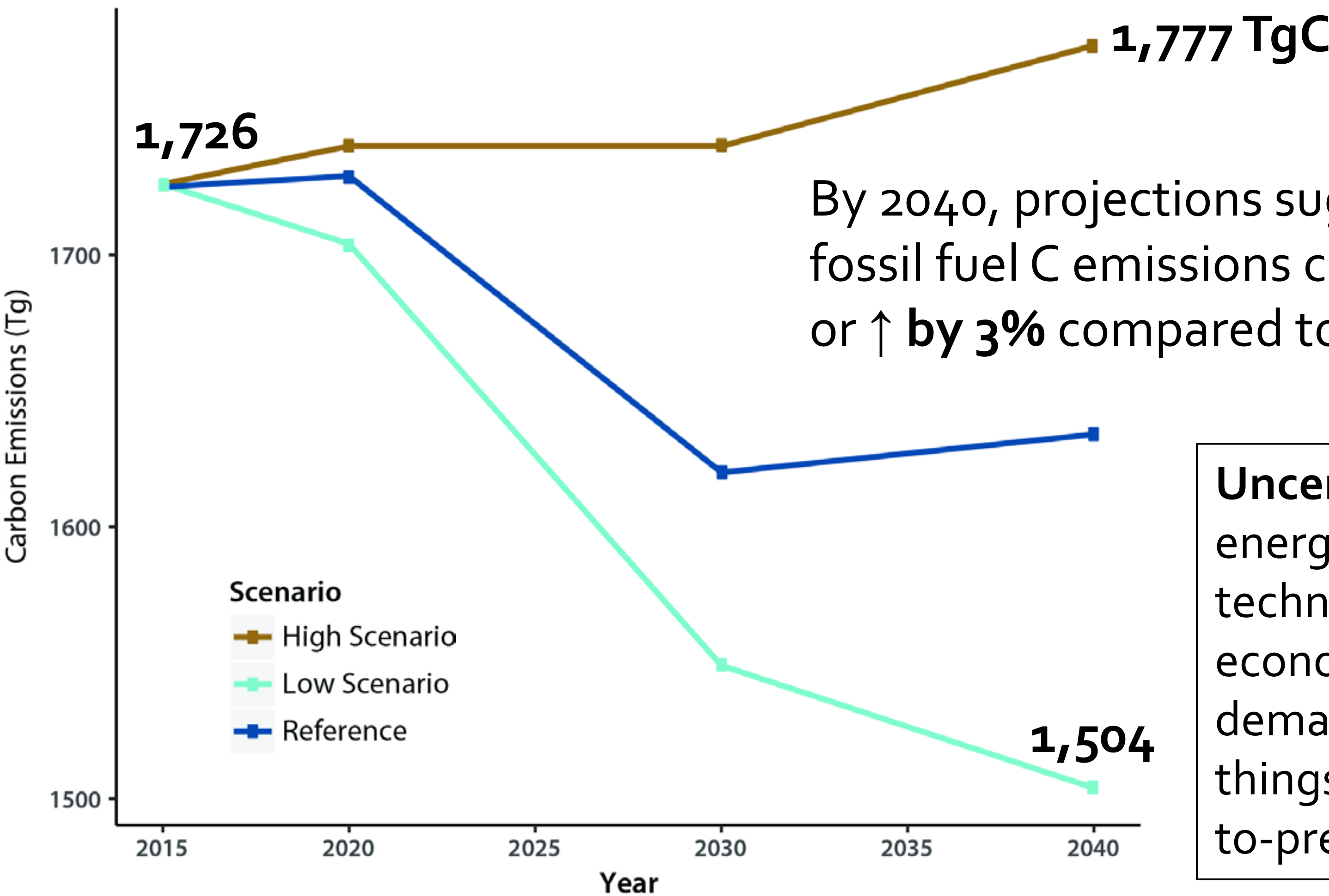
<u>This talk</u> – review current understanding of potential changes in NA carbon cycle.

- What are major **drivers** of future change?
- What can we say about land and coastal ocean **response** to these drivers?
- What are major knowledge **gaps**?

- **What are major drivers of future change?**
- What can we say about land and coastal ocean response to these drivers?
- What are major knowledge gaps?

Drivers – Fossil Fuel Emissions (↑ in atmospheric CO_2)

Emissions from fossil fuel burning are a source of carbon to atmosphere, and will continue to be a source into the future.



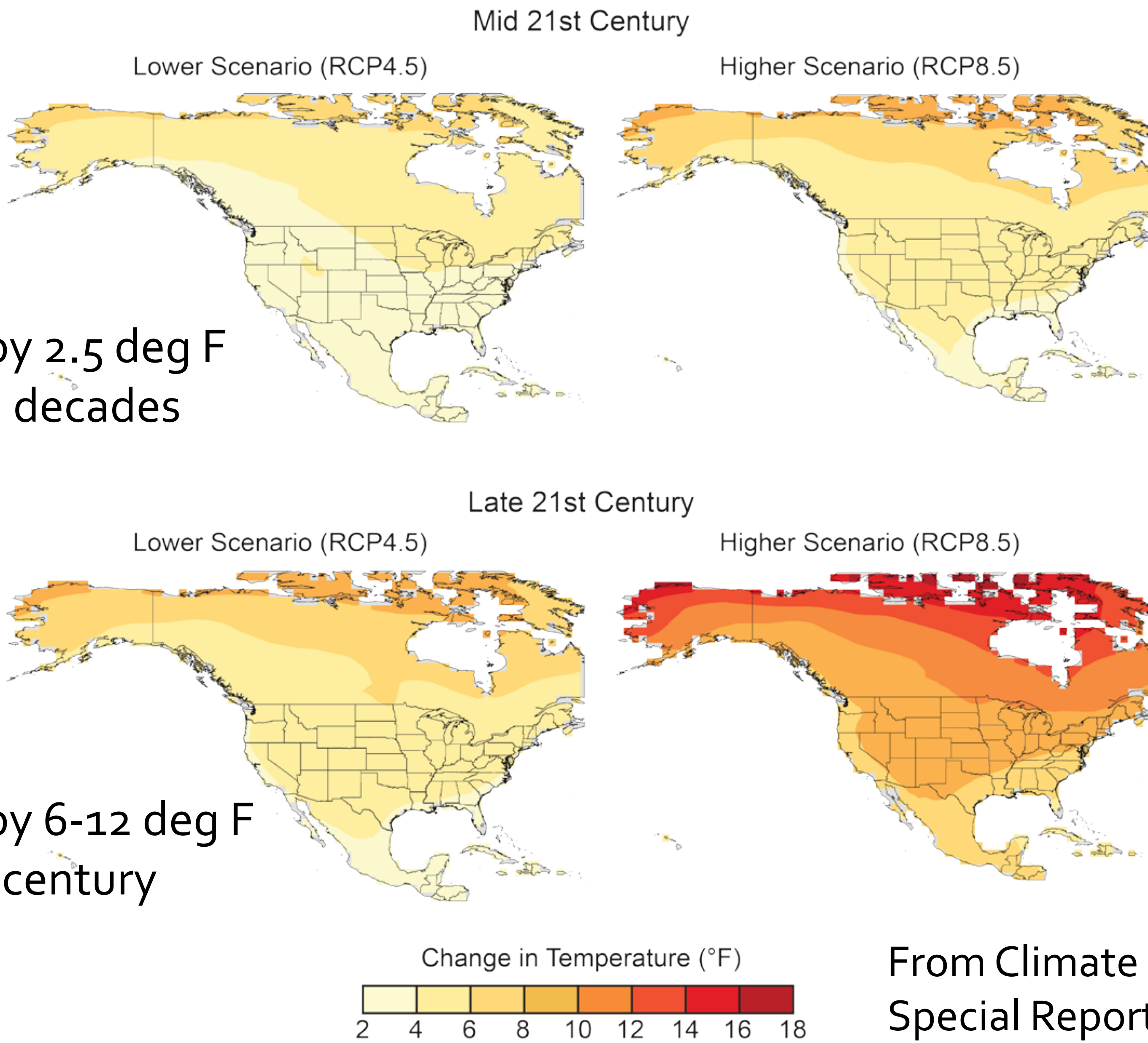
By 2040, projections suggest total NA fossil fuel C emissions could ↓ **by 12.8%** or ↑ **by 3%** compared to 2015 levels

Uncertainties → future energy policies, technologies, prices, economic growth, demand, and other things that are difficult-to-predict

Drivers – Land-Use Management & Land-Cover Change

- Human-driven changes in land-cover & land-use will continue to be a key driver of carbon cycle changes into the future.
- Globally, land use change is projected to **add** carbon to the atmosphere.
- But in U.S., future land-use activities are projected to **take** carbon from atmosphere through **increased** carbon uptake of ~**4 PgC by 2030** by terrestrial ecosystems.

Drivers – Climate (Temperature)

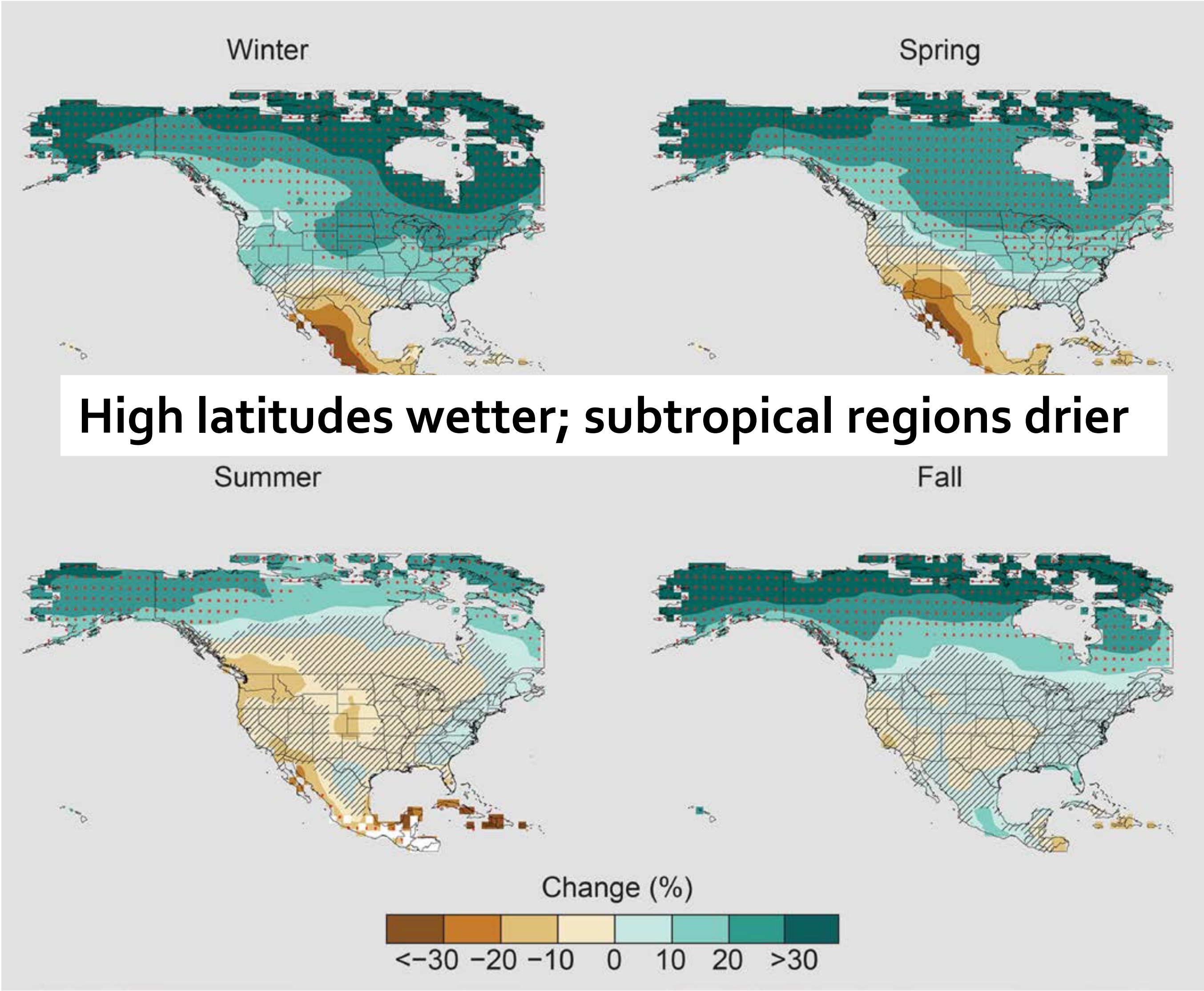


Increase by 2.5 deg F in coming decades

Increase by 6-12 deg F by end of century

From Climate Science Special Report, 2018

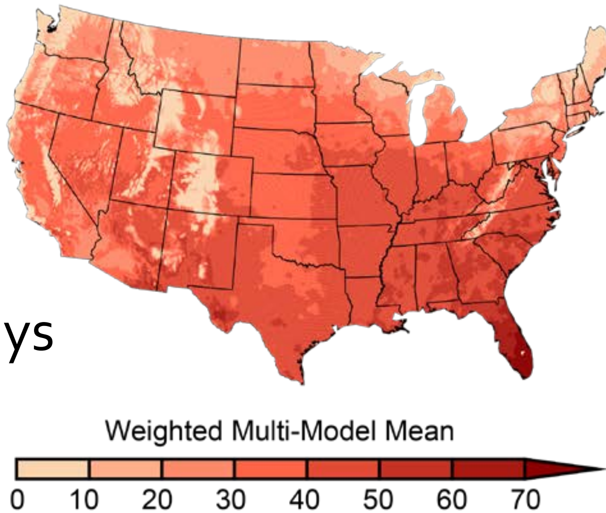
Drivers – Climate (Precipitation)



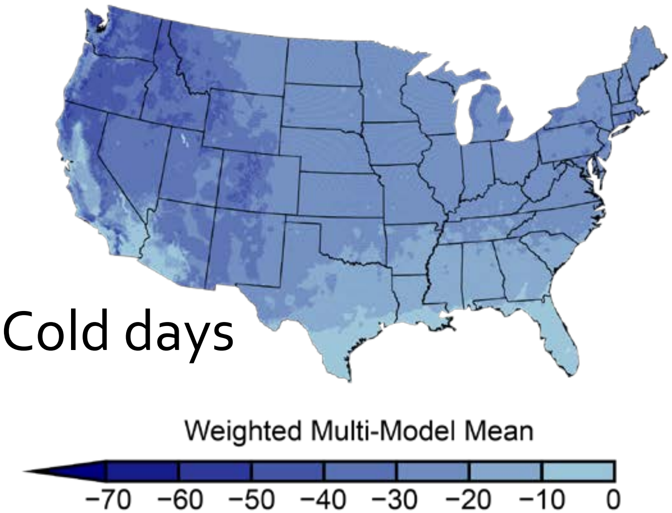
High latitudes wetter; subtropical regions drier

From Climate Science Special Report, 2018

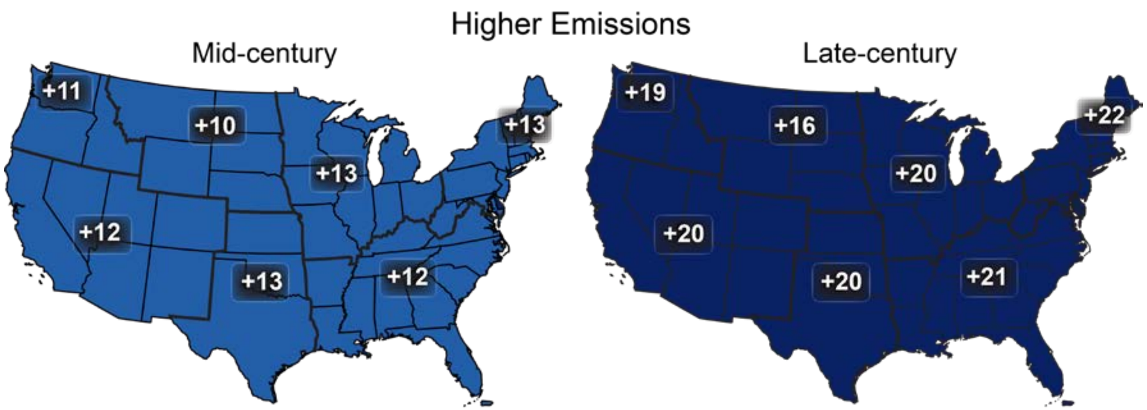
Drivers – Climate (Extremes)



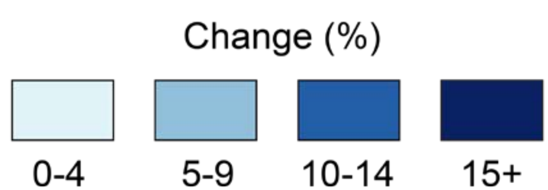
Hot days



Cold days



Extreme precip. events



From Climate Science Special Report, 2018

- What are major drivers of future change?
- **What can we say about land and coastal ocean response to these drivers?**
- What are major knowledge gaps?

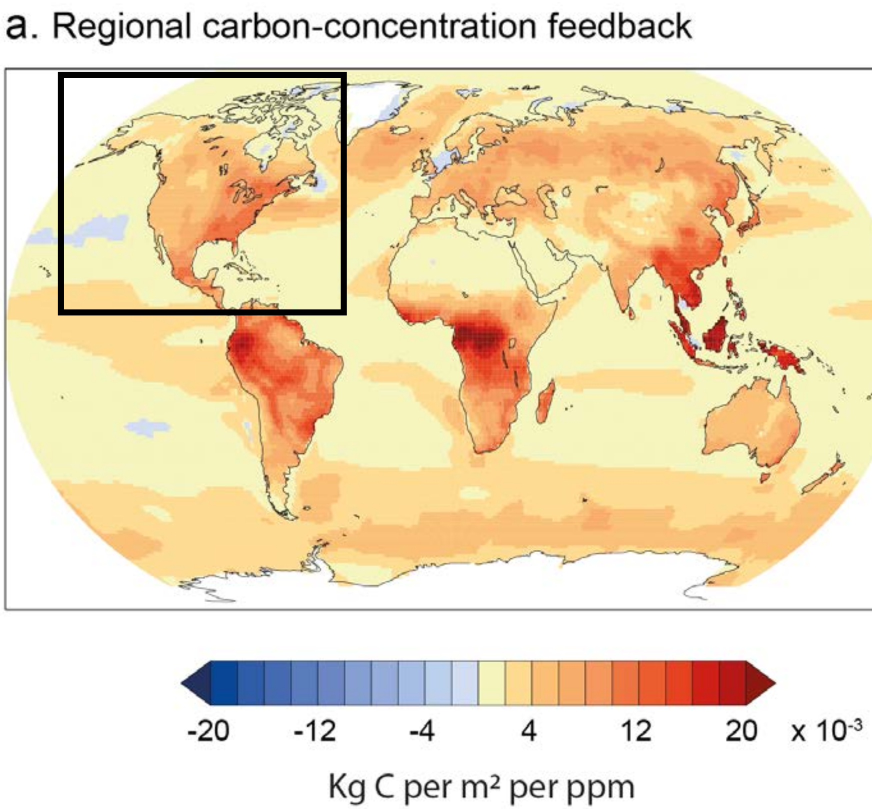
Changes – Land Carbon

Land carbon cycle sensitive to:

- Atmospheric composition (e.g., CO_2)
- Temperature and precipitation
- Disturbances (e.g., fire, disease)
- Land-use and land-cover change
- Nutrient availability

Changes – Land Carbon

Response to rising atmospheric CO_2

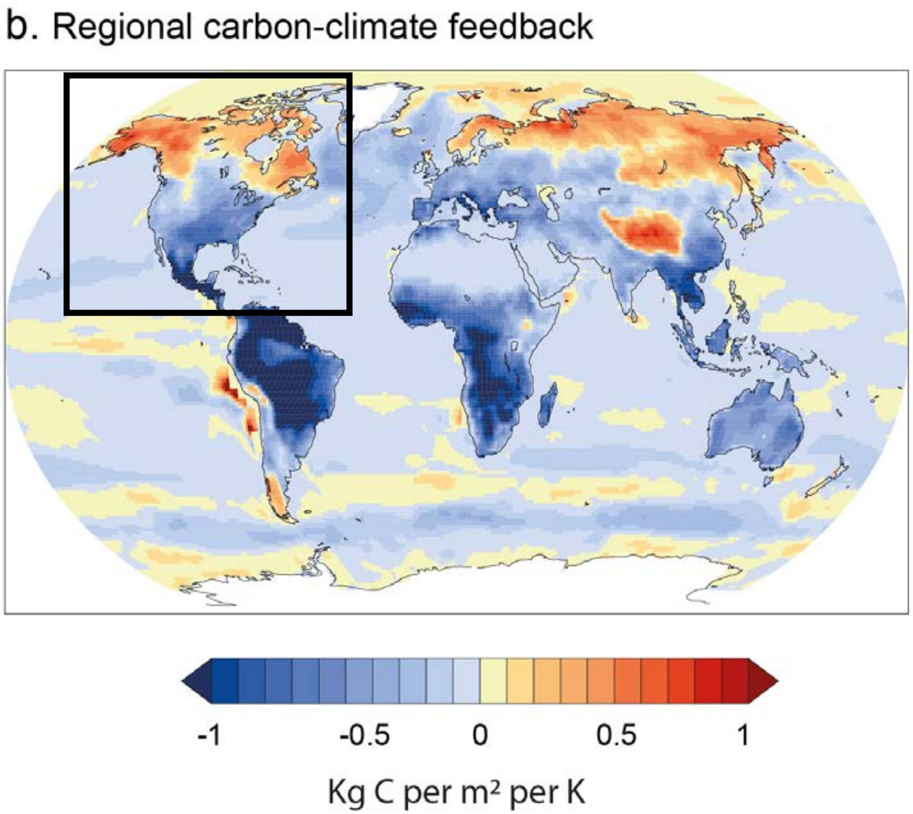


- Land C uptake projected to ↑ with ↑ **atmospheric CO_2**
- **Magnitude of response uncertain:**
  - Depends on age of trees
  - Nutrients will likely constrain response
  - Uncertain impact on soil carbon stocks

From IPCC, 2013

Changes – Land Carbon

Response to climate warming

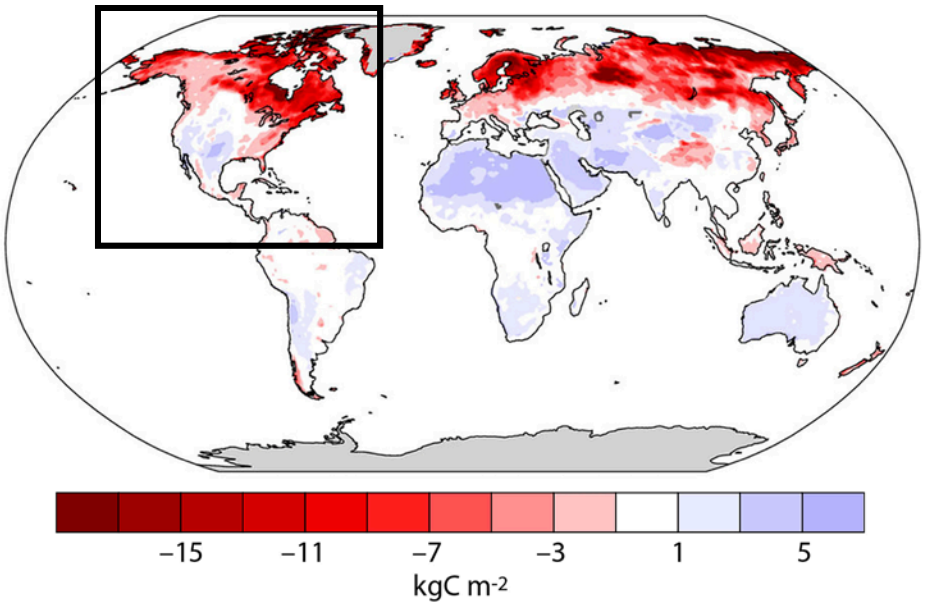


From IPCC, 2013

- Carbon losses due to climate warming projected to partially **offset** carbon gains caused by ↑ atmospheric CO_2.
- **Magnitude of response uncertain:**
  - Heat stress and respiration projected to ↓ land C uptake in temperate NA
  - Lengthened growing season at high northern latitudes could ↑ land C uptake

Changes – Land Carbon

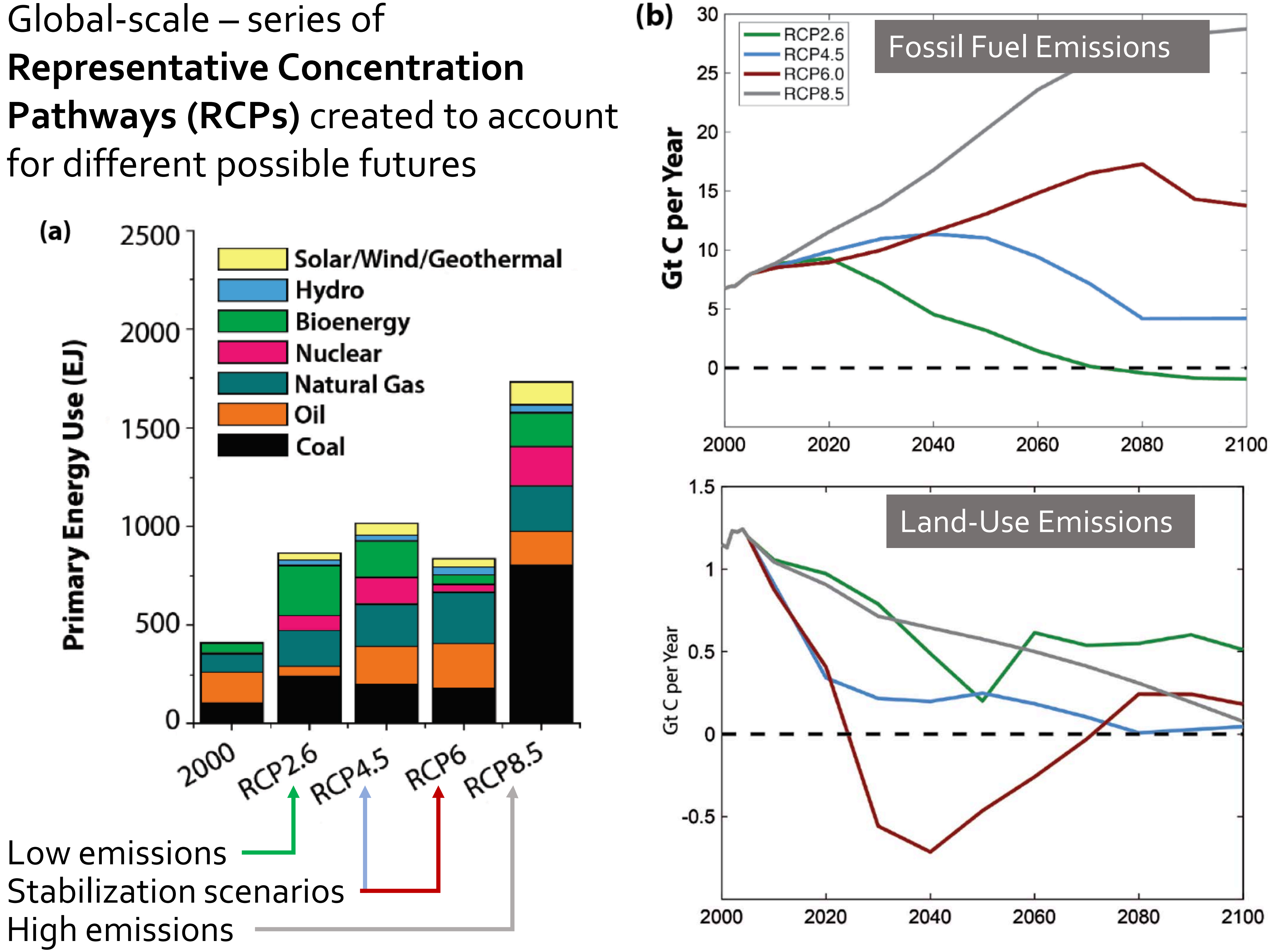
Response to climate warming - soils



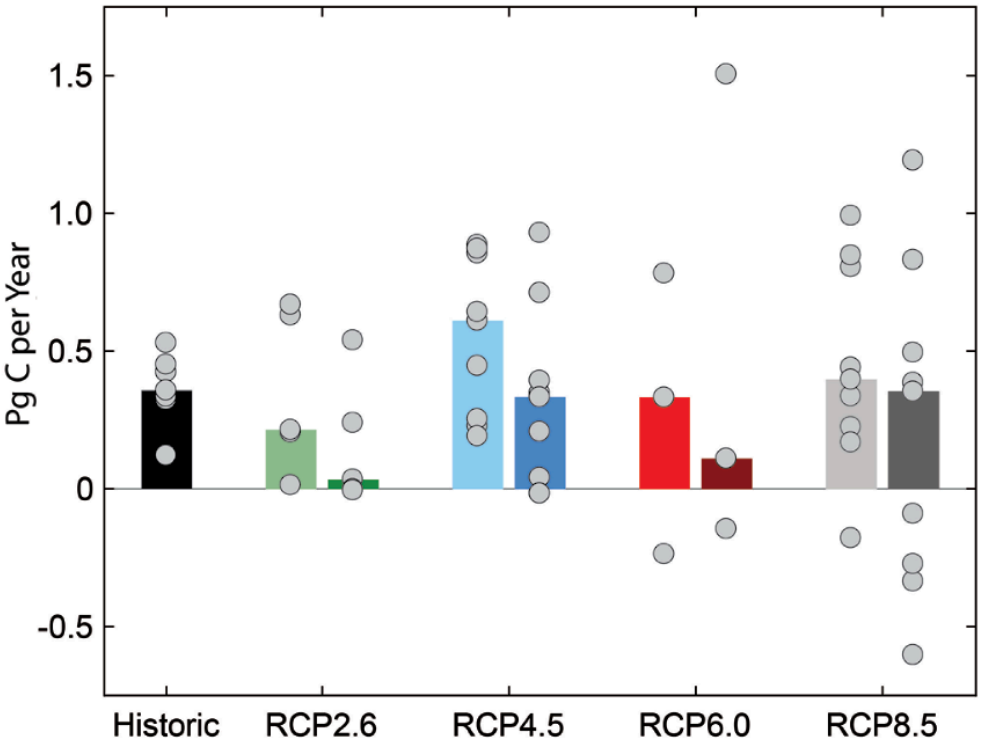
From Crowther et al., 2016

- Globally, soil store 1,500 to 2,400 Pg C (more than twice C in atmosphere)
- Warming in the Northern high-latitudes (Alaska and Canada) is making carbon stored in permafrost soils vulnerable to release to the atmosphere
- These losses could shift region from net sink to net source of carbon.

Global-scale – series of **Representative Concentration Pathways (RCPs)** created to account for different possible futures

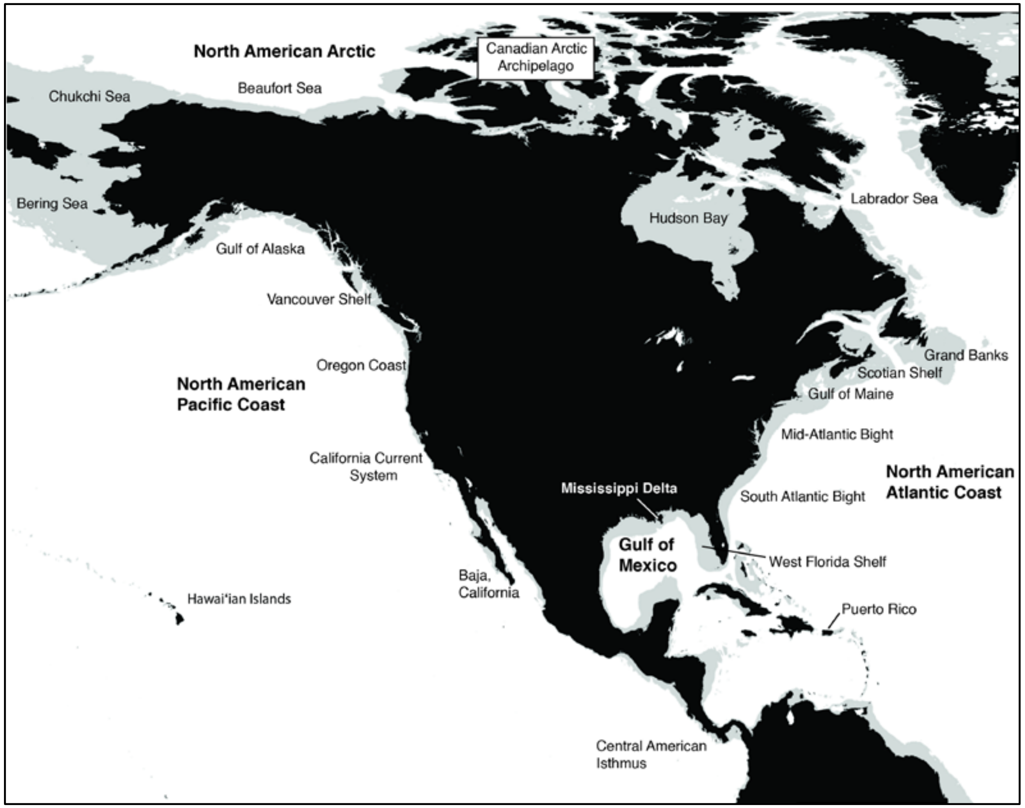


Changes – Land Carbon



- **By 2050**, models project a slight decrease to a doubling of the current land C sink strength
- **By 2100**, strength of the NA net land C sink projected to either remain near current levels or decline significantly
- **Uncertainty** comes from combined and uncertain effects of rising CO_2, climate change, emission scenarios and land-use management

Changes – Coastal Ocean

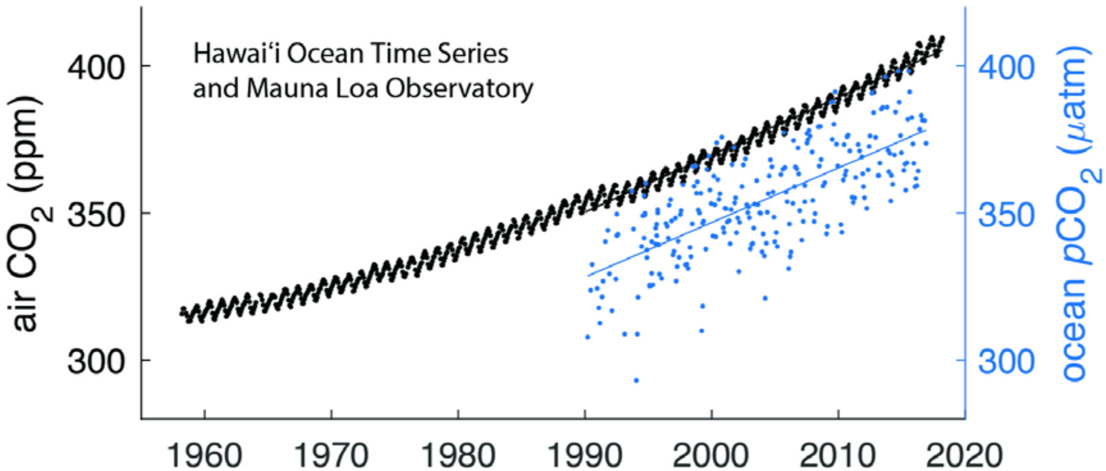


From Chapter 16, SOCCR-2

- Globally, **coastal oceans** account for 41% of ocean area.
- NA makes up 10% of global coasts and includes rivers, estuaries, tidal wetlands, and continental shelf.

Changes – Coastal Ocean

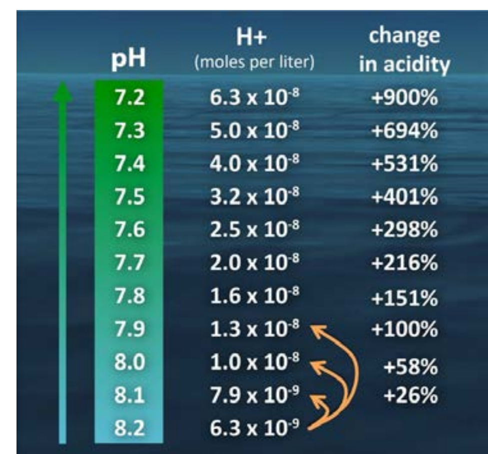
Response to rising atmospheric CO_2



↑ atmospheric CO_2 is projected to ↑ coastal ocean carbon uptake.

From Chapter 16, SOCCR-2

- The **pH** of ocean waters boarding NA are projected to **decrease** by 0.4 to 0.5 pH units by 2100 (under highest emission scenarios).
- Warmer and more CO_2 enriched waters are expected to take up **less** additional CO_2 and have **reduced** buffering capacity (due to ocean acidification)



pH	H+ (moles per liter)	change in acidity
7.2	6.3×10^{-8}	+900%
7.3	5.0×10^{-8}	+694%
7.4	4.0×10^{-8}	+531%
7.5	3.2×10^{-8}	+401%
7.6	2.5×10^{-8}	+298%
7.7	2.0×10^{-8}	+216%
7.8	1.6×10^{-8}	+151%
7.9	1.3×10^{-8}	+100%
8.0	1.0×10^{-8}	+58%
8.1	7.9×10^{-9}	+26%
8.2	6.3×10^{-9}	

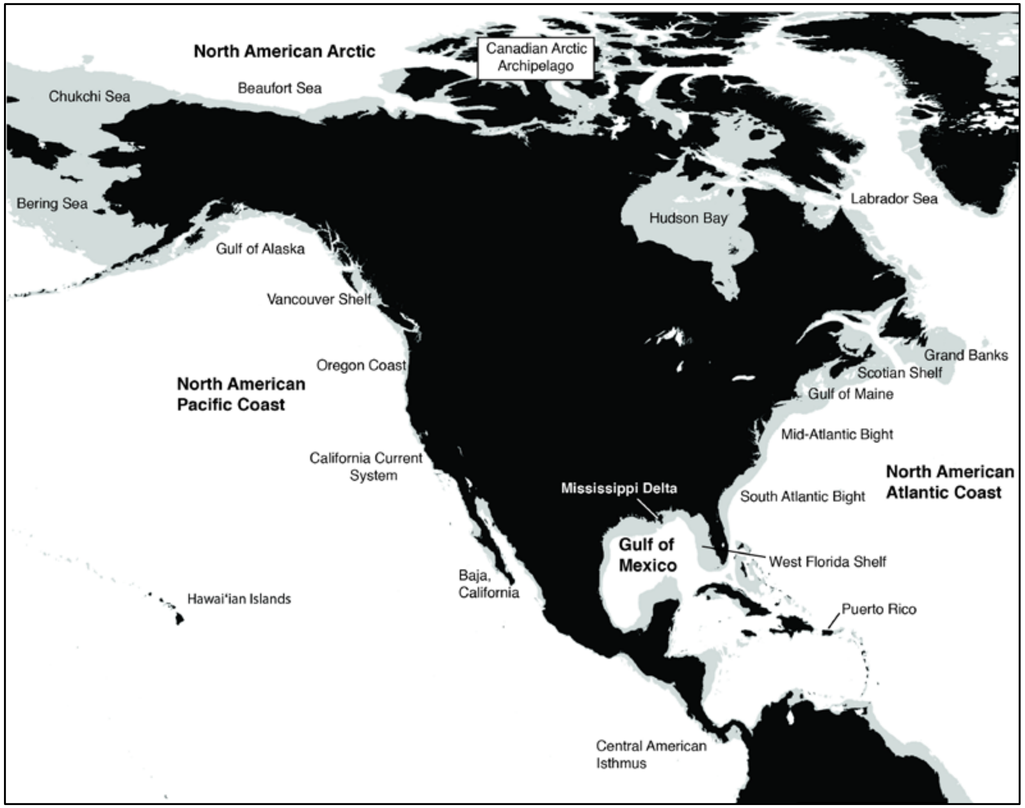
From NOAA

Changes – Coastal Ocean

Response to climate warming

- Warming climate is projected to **reduce** coastal ocean carbon uptake in most regions of NA.
  - Increase stratification
  - Slow ocean circulation
  - But impacts are regional and uncertain
- Warming and changes in precipitation may **impact river carbon fluxes**
  - Extreme rainfall events could shift timing of carbon delivery to coastal oceans

Changes – Coastal Ocean



From Chapter 16, SOCCR-2

- Since 1870, NA coastal oceans have taken up 2.6 to 3.4 Pg C from atmosphere.
- Under highest emission scenarios, projected to take up an **additional** 10 to 12 Pg C by 2050.
- And **another** 17 to 26 Pg C in between 2050 and 2100.
- **Uncertainties** due to climate warming, changing circulation, ocean acidification, human pressures, and land processes

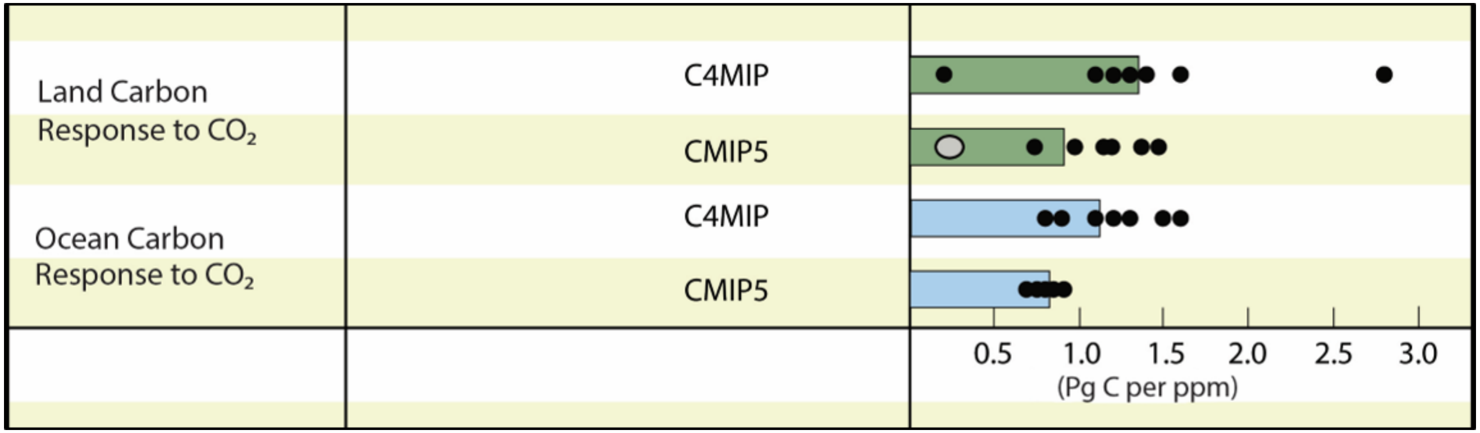
Summing up – Key Takeaways

- Primary contributors to carbon cycle change over North America are, and will continue to be, emissions from **fossil fuel** combustion, changes in **land cover and land use**, and changing **climate** conditions.
- Projections suggest that natural carbon sinks of North America (land, coastal ocean systems) are **diminishing in strength** and many are at risk into the future.
- Accelerated warming in the Northern high-latitudes (Alaska and Canada) is making **large stores of carbon in permafrost soils vulnerable** to release to the atmosphere by the end of the century.

- What are major drivers of future change?
- What can we say about land and coastal ocean response to these drivers?
- **What are major knowledge gaps?**

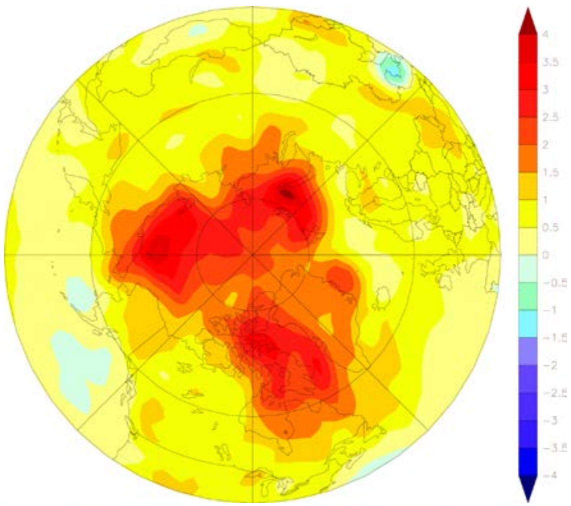
Knowledge Gaps – CO_2 Fertilization

- Crucial for projecting future changes in carbon cycle.
- Lack of understanding about carbon-nitrogen coupling and its controls on CO_2 fertilization response
- Models agree on direction, but not on magnitude of response



From IPCC, 2013

Knowledge Gaps – Permafrost Carbon-Climate Feedback



Warming Arctic surface air temperatures

Figure 11.1 SOCCR2

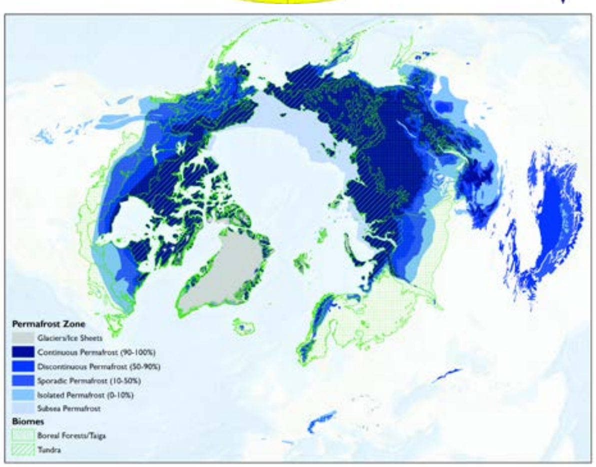


Figure 11.4 SOCCR2

- By 2100, soil carbon losses from the northern high-latitudes will **determine the trajectory** of the carbon cycle
- Vegetation may help regulate / offset the net response of this region to warming
- **Knowledge gaps →**
  - Area and depth of vulnerable permafrost
  - Speed of carbon release from thawing soils
  - Form of carbon release

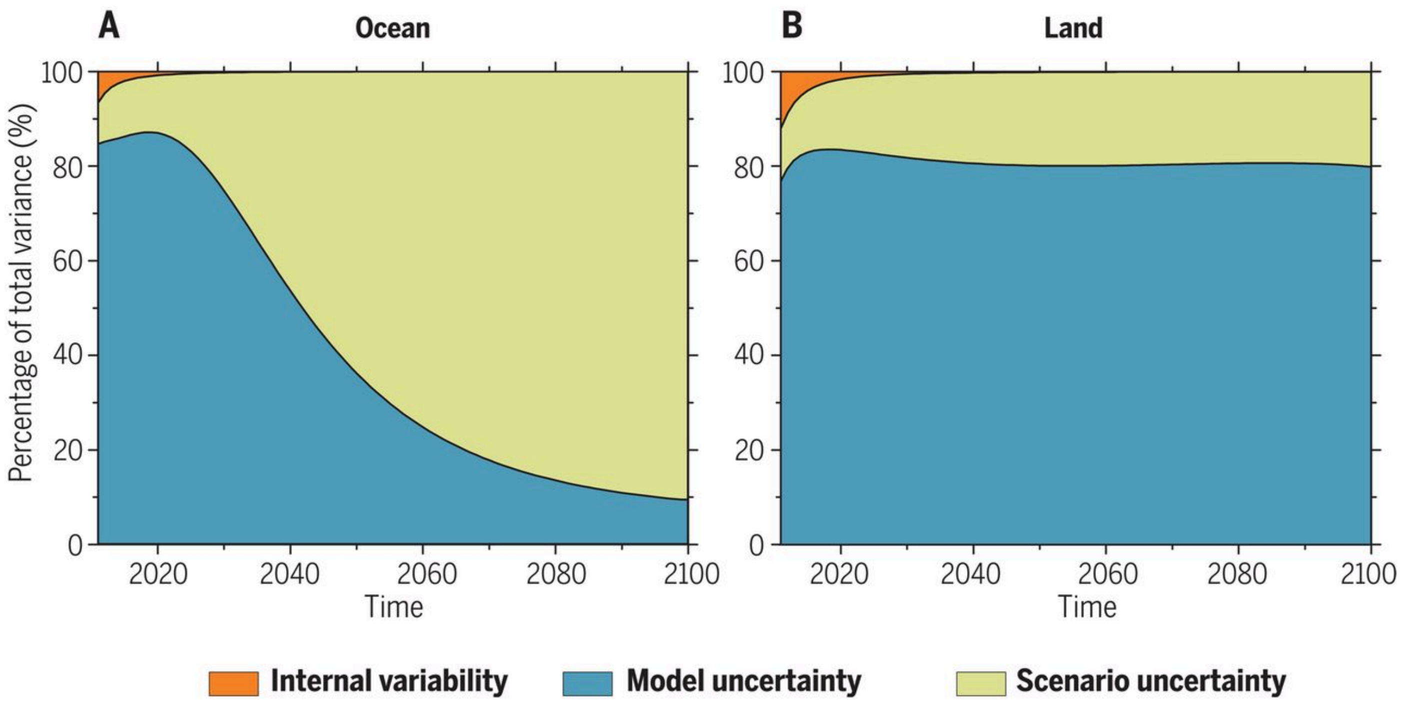
Knowledge Gaps – Disturbance, Drought, Land-Use Change

- **Disturbance (fire, insect outbreaks, other)** - largely expected to increase, but timing, magnitude and impacts uncertain.
- **Droughts** – expected to increase in severity, area, and duration. Vegetation response to future drought conditions unclear, particularly long-term impacts.
- **Land-use and land-cover changes** – challenging to predict, both in terms of ecosystem changes and because of social, economic, and climate impacts on land use.

Knowledge Gaps – Models

Key sources of uncertainty in models –

- Model uncertainty – structure and parameterization
- Scenario uncertainty – input data and forcing scenarios



From Bonan and Doney, 2018

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