The Biogeochemical Effects of Rising Atmospheric CO_2 on Terrestrial and Ocean Systems:

Ch. 17 of the 2nd State of the Carbon Cycle Report (SOCCR-2)

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SOCCR-2 Chapter 17 charge

- Assess the non-climatic (non-temperature-related) impacts of rising atmospheric CO_2 on land and ocean ecosystems.

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2nd State of the Carbon Cycle Report (SOCCR-2)

- An **interagency assessment** of the state of the carbon cycle across North America (i.e. U.S., Canada and Mexico).
- Written by North America's **top carbon cycle experts** from the government, national laboratories, universities, research institutions and the private sector.
- **6 stages of rigorous review** by Federal agencies and departments, the general public, and an external expert review panel convened by the NASEM.
- Contributes to **Volume Two** of the Congressionally-mandated **Fourth National Climate Assessment (NCA4)**.
- Coordination and development through the U.S. CCSP, led by the CCIWG under the USGCRP auspices

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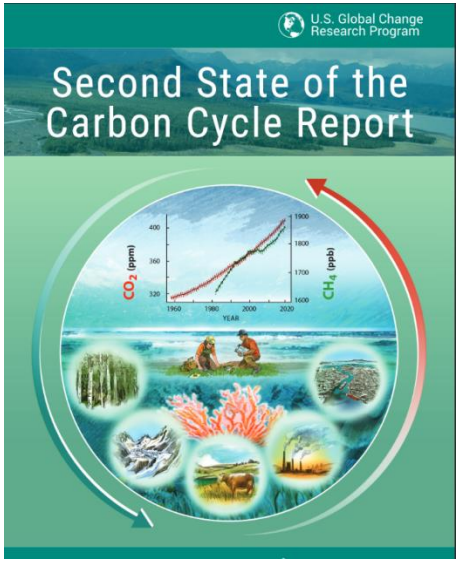
SOCCR-2 Contents

- The SOCCR2 Report-in-Brief includes
  - Highlights (plain language)
  - Executive Summary (technical)
- SOCCR2 report (878 pages) comprises four interconnected sections:
  - I. Synthesis
  - II. Human Dimensions of the Carbon Cycle
  - III. State of Air, Land, and Water
  - IV. Consequences and Ways Forward
- 19 chapters followed by 7 appendices



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See https://carbon2018.globalchange.gov/

Jumping-off point: SOCCR-1

- The CO_2 fertilization effect is defined in SOCCR-1 as the ***"phenomenon in which plant growth increases (and agricultural crop yields increase) due to the increased rates of photosynthesis of plant species in response to elevated concentrations of CO_2 in the atmosphere"***
  - Other consequences were *alluded to* throughout SOCCR-1

- Since SOCCR-1
  - Lengthened observational records in ocean, atmosphere and on land
  - Advances in physiological understanding
  - Long term ecosystem experiments
  - Advances in modelling

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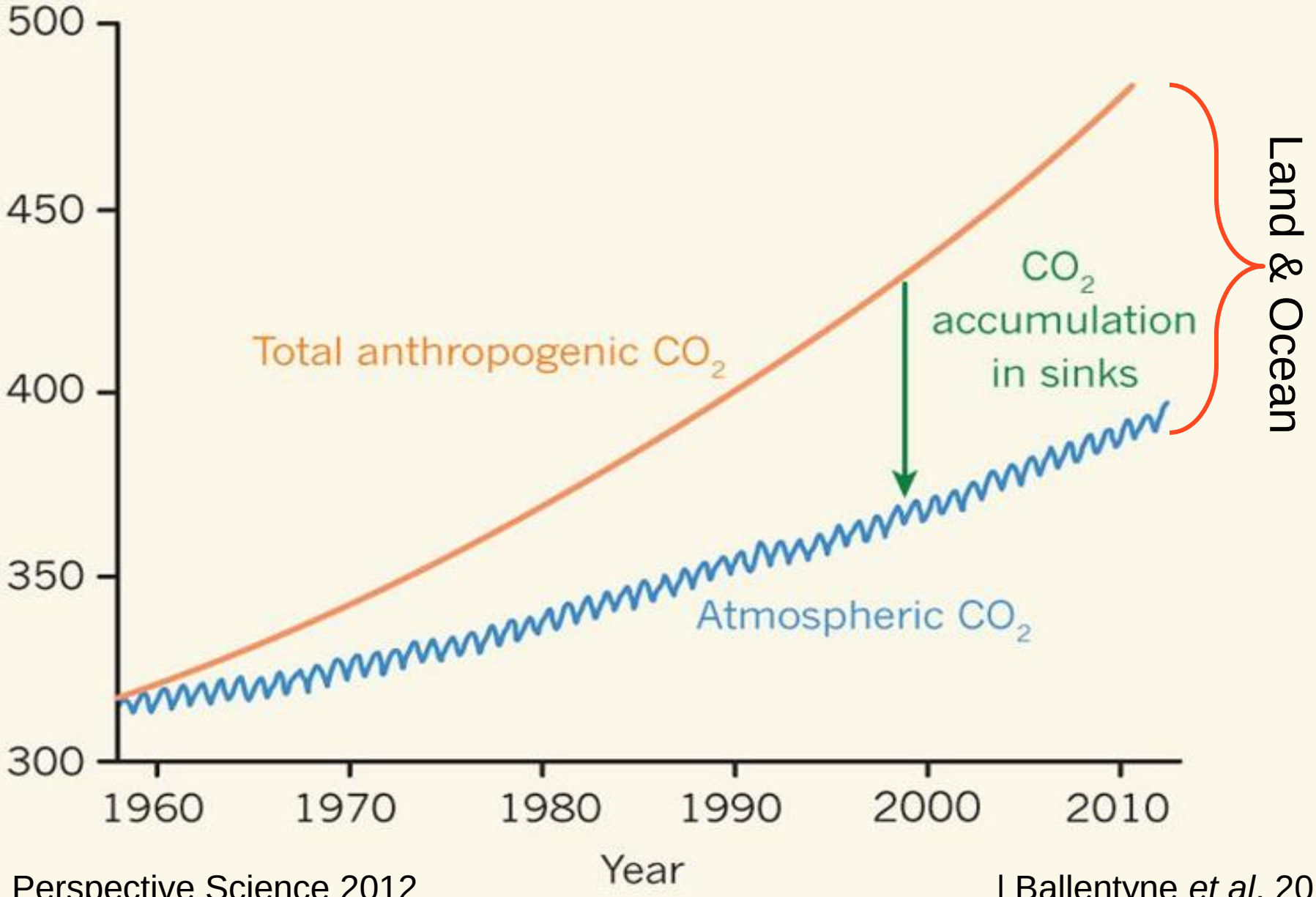
See https://cdiac.ess-dive.lbl.gov/SOCCR/pdf/sap2-2-final-all.pdf

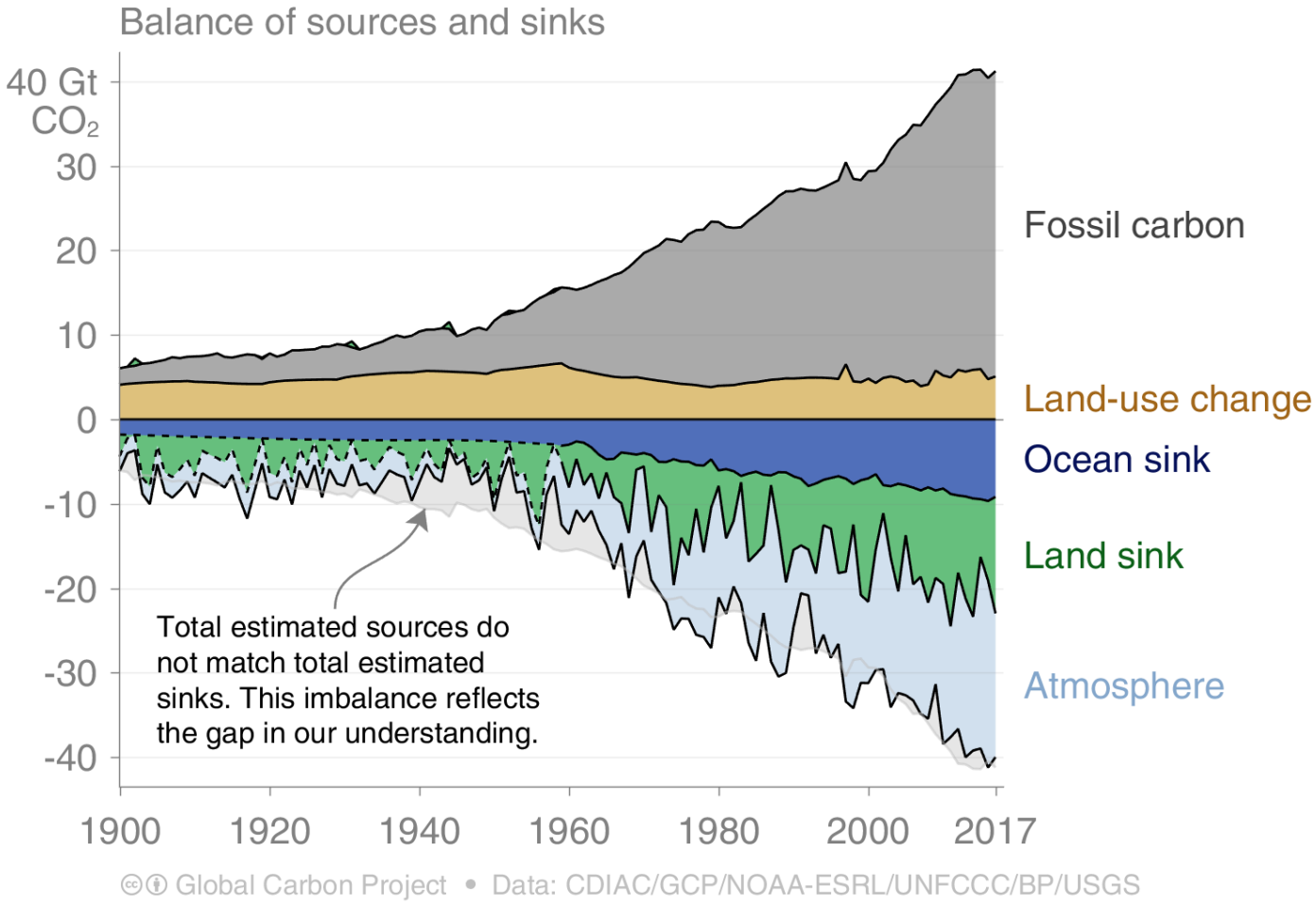
Atmospheric CO_2 rise less than emissions suggest



Perspective Science 2012 | Ballentyne *et al*. 2012

Global carbon budget: models & observations

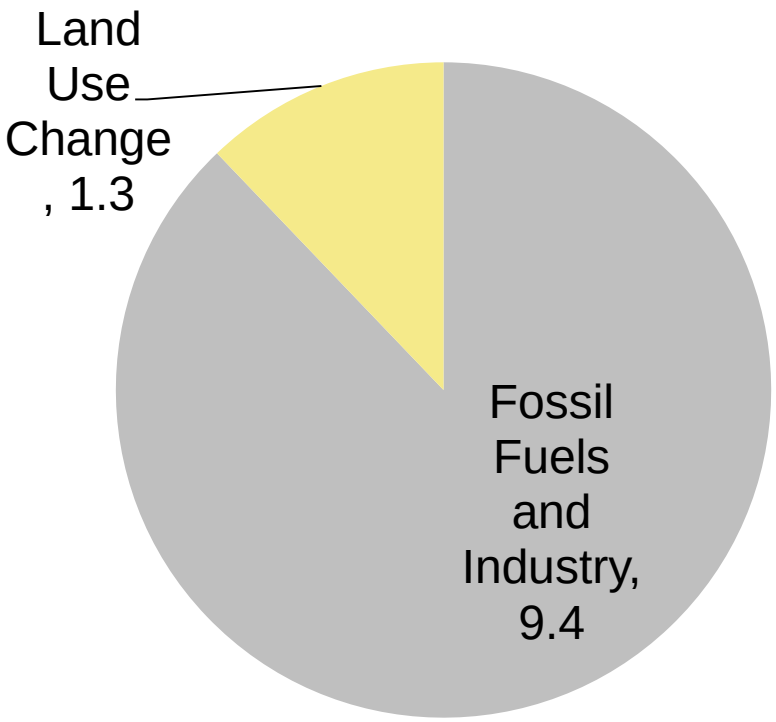
Carbon emissions are partitioned among the atmosphere and carbon sinks on land and in the ocean
The "imbalance" between total emissions and total sinks reflects the gap in our understanding



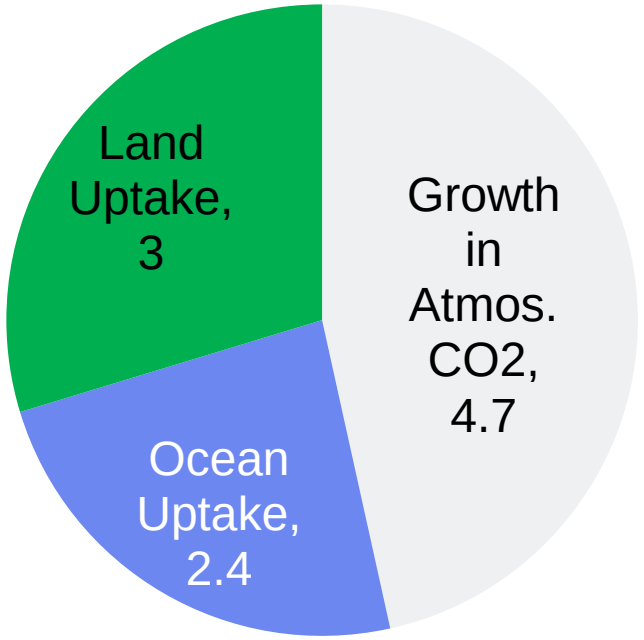
Source: CDIAC; NOAA-ESRL; Houghton and Nassikas 2017; Hansis et al 2015; Joos et al 2013; Khatiwala et al. 2013; DeVries 2014; Le Quéré et al 2018; Global Carbon Budget 2018

Rising atmospheric CO_2: sources & partitioning

Global mean CO_2 emissions, Pg C per year for 2007-2016



Mean partitioning of global CO_2 emissions, Pg C per year for 2007-2016



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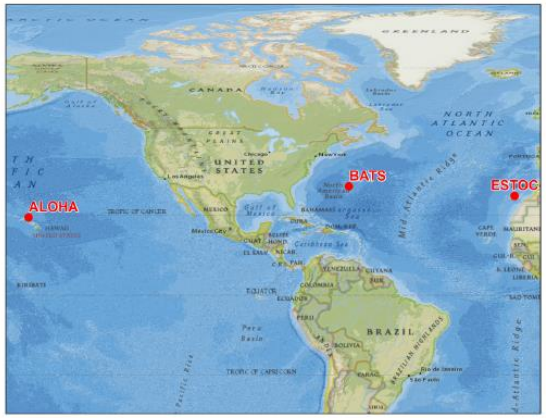
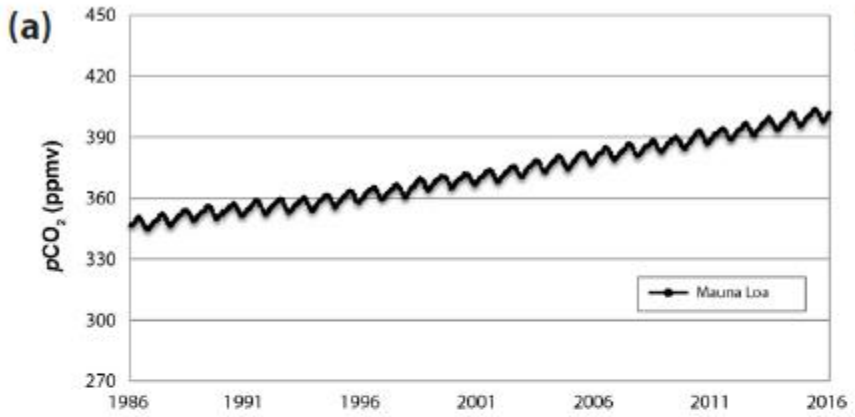
Data from SOCCR-2 Ch. 1, Table 1.1

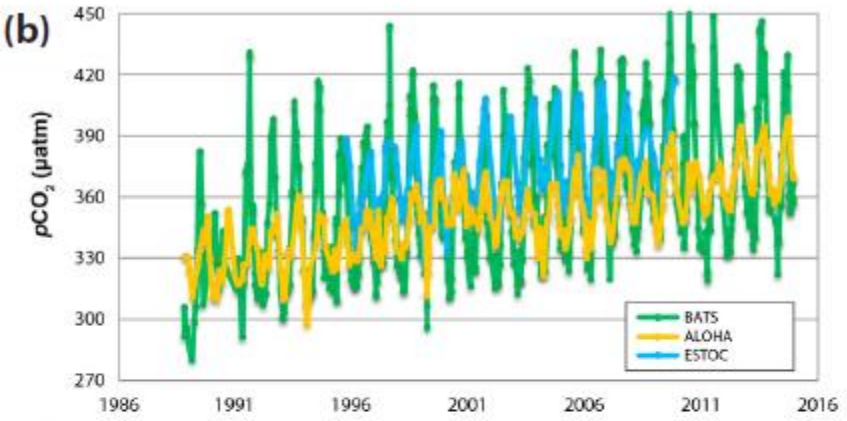


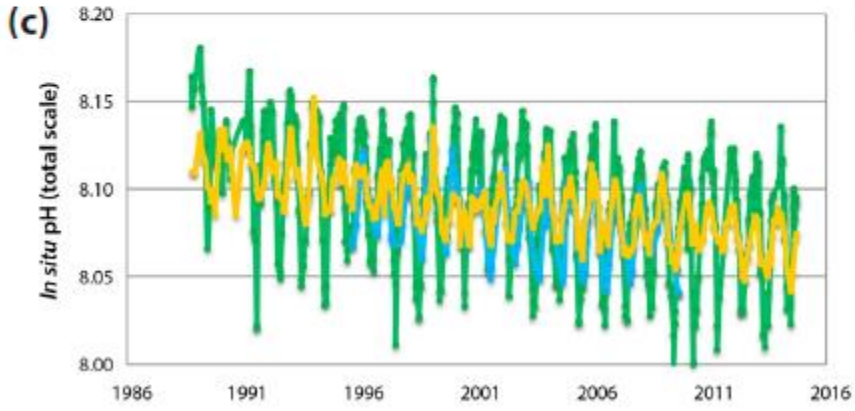
Ocean effects of rising CO_2

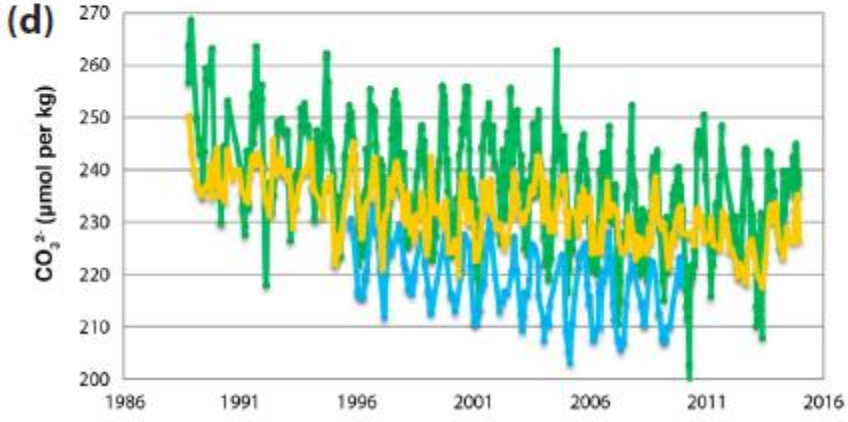
Ocean acidification around the world

- Increasing seawater CO_2 content
- Decreasing seawater pH









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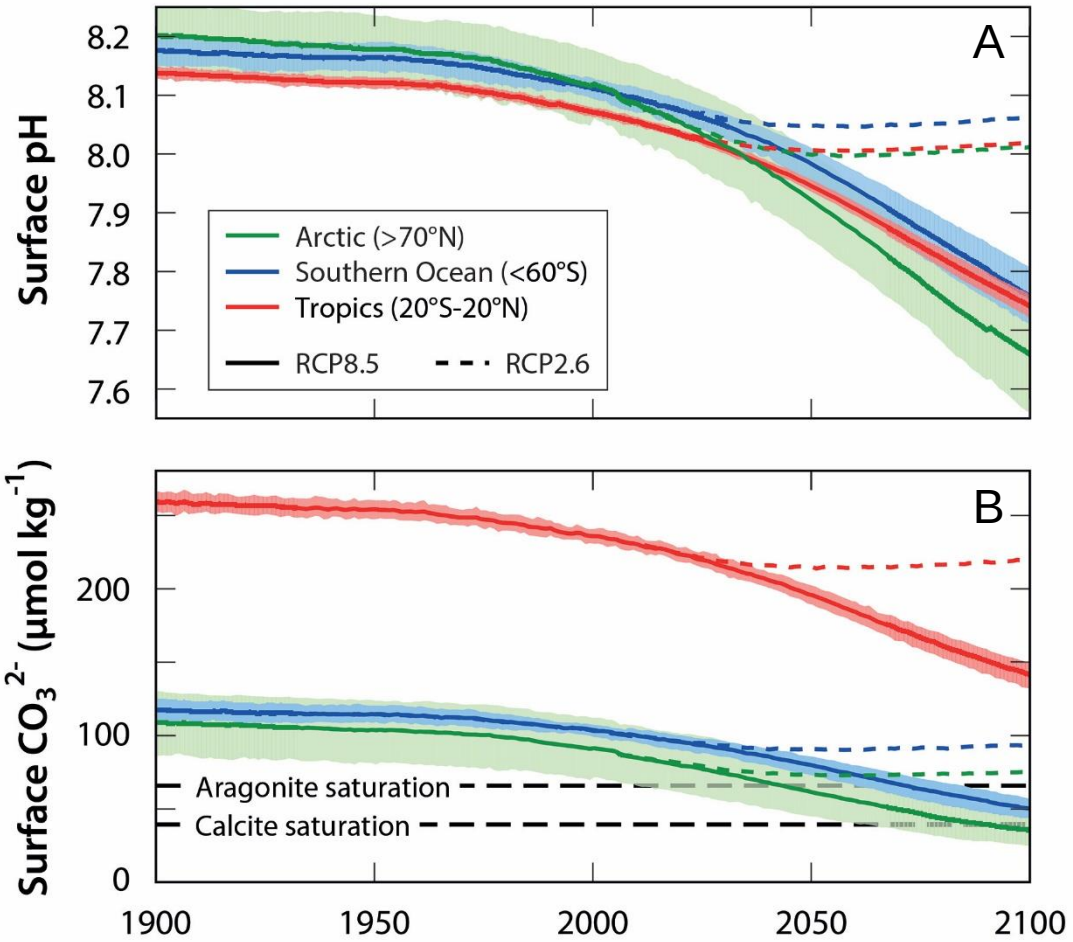
Suboptimal conditions for marine species

Some current and all projected values are outside of historical bounds

Novel carbonate conditions for most marine animals



Changes in: (A) surface ocean pH; and (B) surface carbonate ion concentration for the IPCC RCP 2.6 and 8.5 scenarios (after Ciais et al., 2013; based on the CMIP5 model analysis).

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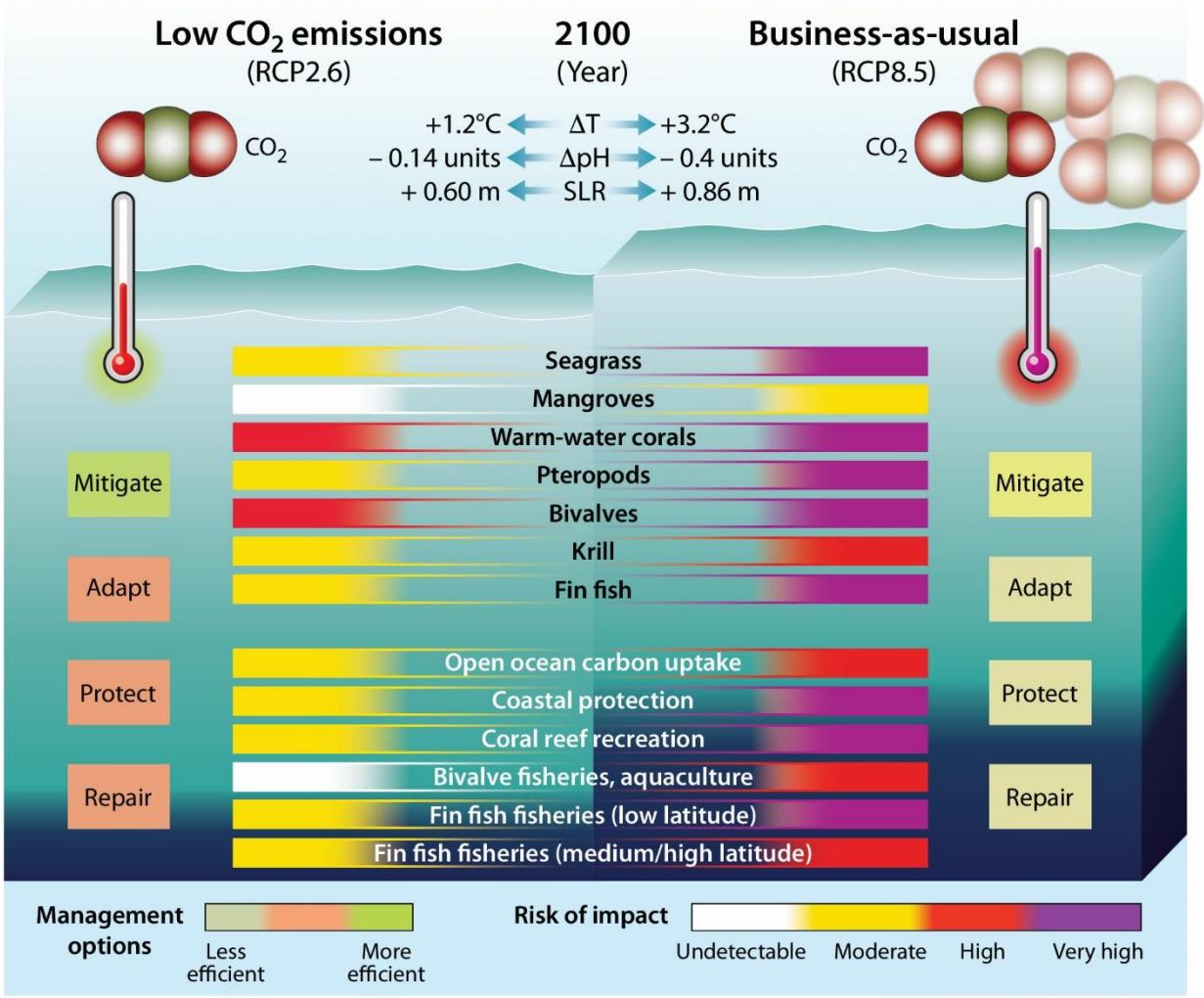
Follow-on impacts likely

Acidification varies by latitude

Marine species health

Coral bleaching

Harmful algal blooms



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Ch. 17, Key Message 1

Rising CO_2 has decreased seawater pH; this process of ocean acidification has affected some marine species and altered fundamental ecosystem processes with further effects likely.

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Terrestrial effects of rising CO_2 on plants

- Physiological Adjustment
  - Increased photosynthesis per leaf area
    - Increased biomass cycling
    - Nutrient limitation, root investment
    - Greater carbon inputs to soil?
  - Decreased water conductance per leaf area

- Plant Species Responses
  - C4, CAM plants have higher WUE
  - Changing competition
  - Upper bound to productivity in forests?
  - Weedy species more enhanced?
- Food and Crop Responses
  - Protein per leaf area/yield will probably decrease
  - Pollen production may increase

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Terrestrial effects of rising CO_2 on ecosystems

- Observations
  - Greening from satellite record
  - Tree rings, growth, water use efficiency (WUE)
- Experiments
  - Changes in allocation, growth, competition & nutrition (Experiments)

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Terrestrial effects of rising CO_2

- Elevated CO_2 affects:
  - photosynthesis & growth
  - water use efficiency
  - hydrology
- Relative effects differ by species

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Ch. 17, Key Message 2:

On land, rising atmospheric CO_2 concentrations are expected to ***increase plant photosynthesis, growth, and water-use efficiency***, though these effects are reduced when nutrients, drought, or other factors limit plant growth. Rising CO_2 would likely change carbon storage and influence terrestrial hydrology and biogeochemical cycling, but concomitant effects on vegetation composition and nutrient feedbacks are challenging to predict, making decadal forecasts uncertain.

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Effects of rising CO_2 on benefits to people

Difficult-to-predict changes in the benefits that terrestrial and oceanic systems provide to humans.

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Photos: USDA, NOAA

Effects of rising CO_2 on benefits to people

Difficult-to-predict changes in the benefits that terrestrial and oceanic systems provide to humans.

- Shellfish and crustaceans
  - Growth slower, and survival to adulthood lower
  - Market quality changes – taste?
- Fishery impacts
  - Predator-prey relationships?
  - HAB-related disruptions?
- Coral reef communities
  - Altered 3D structure?
  - Altered community composition?

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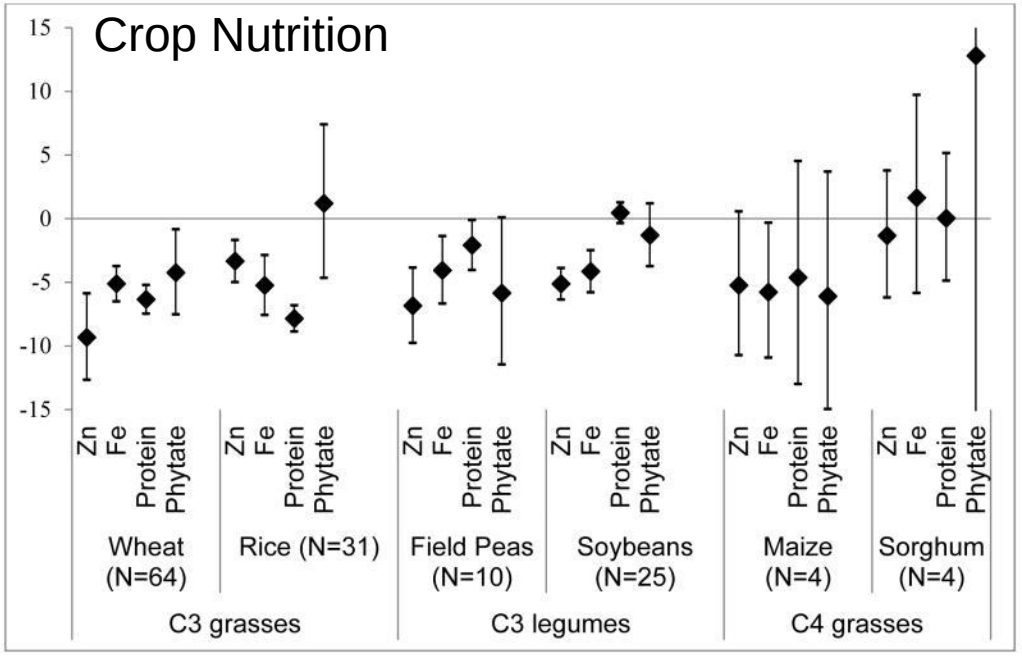
Photo: NOAA

Effects of rising CO_2 on benefits to people

Difficult-to-predict changes in the benefits that terrestrial and oceanic systems provide to humans.



Myers *et al*. 2014 Natu

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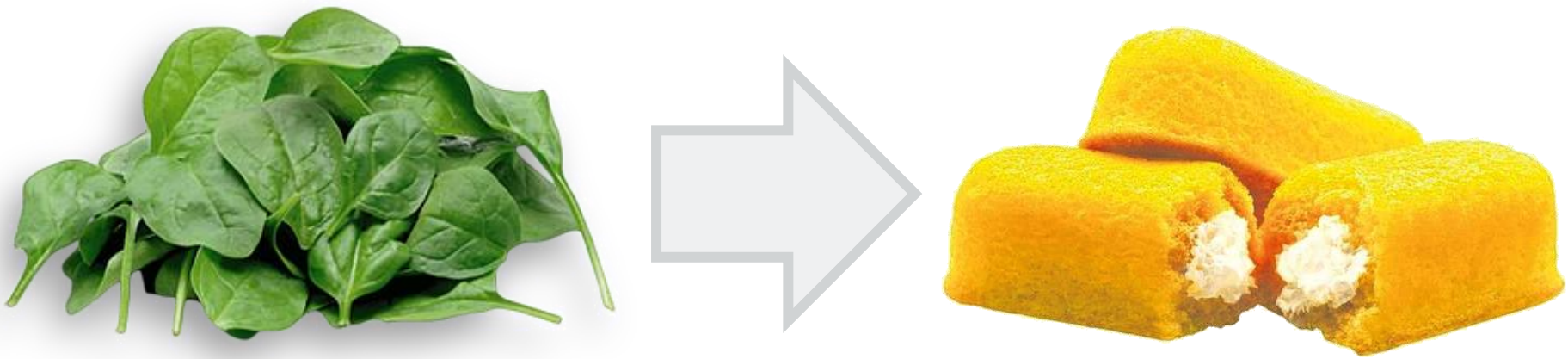
Photo: USDA

Effects of rising CO_2 on benefits to people

- Some crops will likely have **reduced nutritional yield**



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Ch. 17, Key Message 3:

Consequences of rising atmospheric CO_2 are expected to include difficult-to-predict changes in the ecosystem services that terrestrial and oceanic systems provide to humans.

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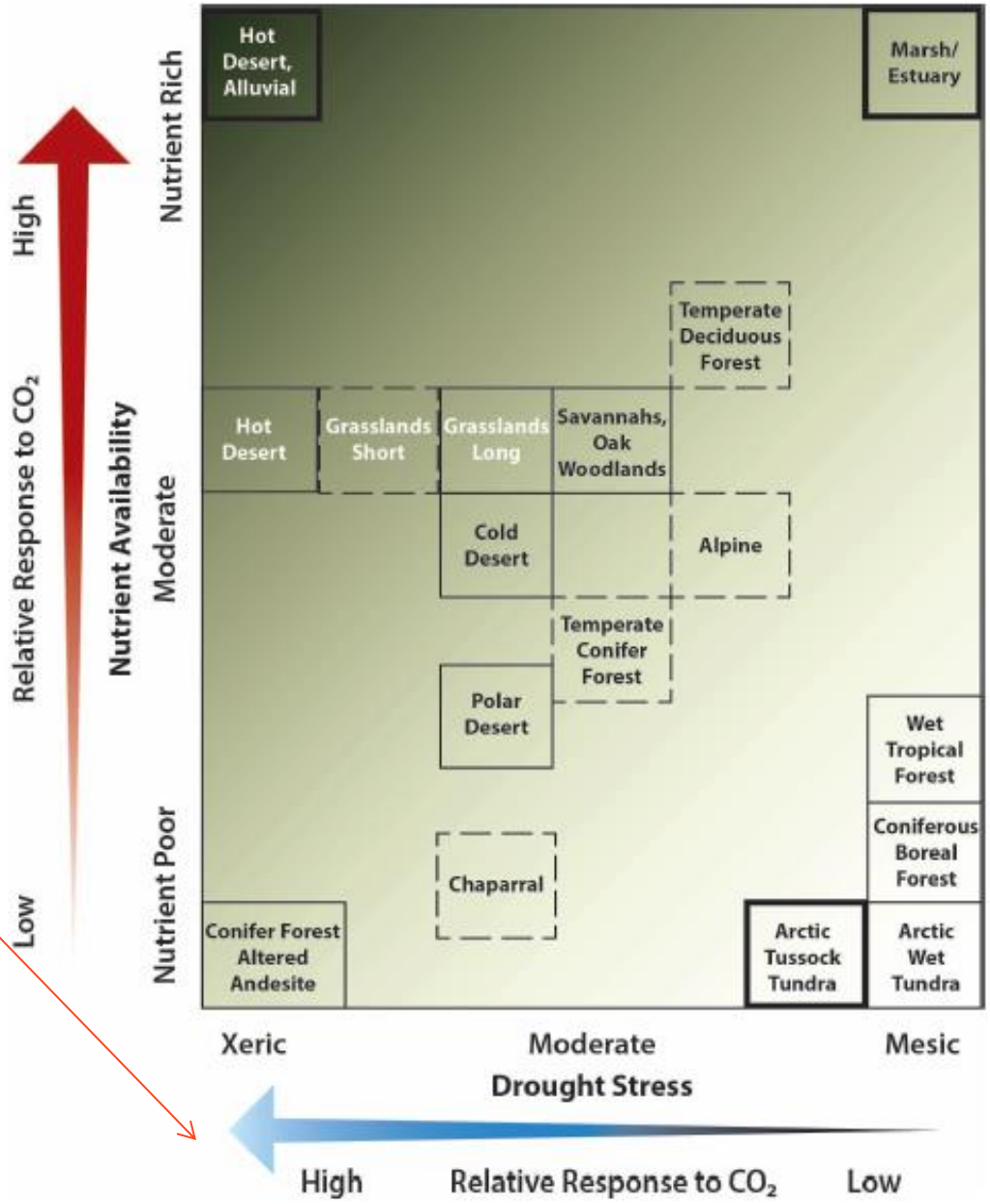
Effects of rising CO_2 (besides climate)

Vary, depending on other factors:

- Climate
- Dominant species
- Nutrient availability
- Drought Stress



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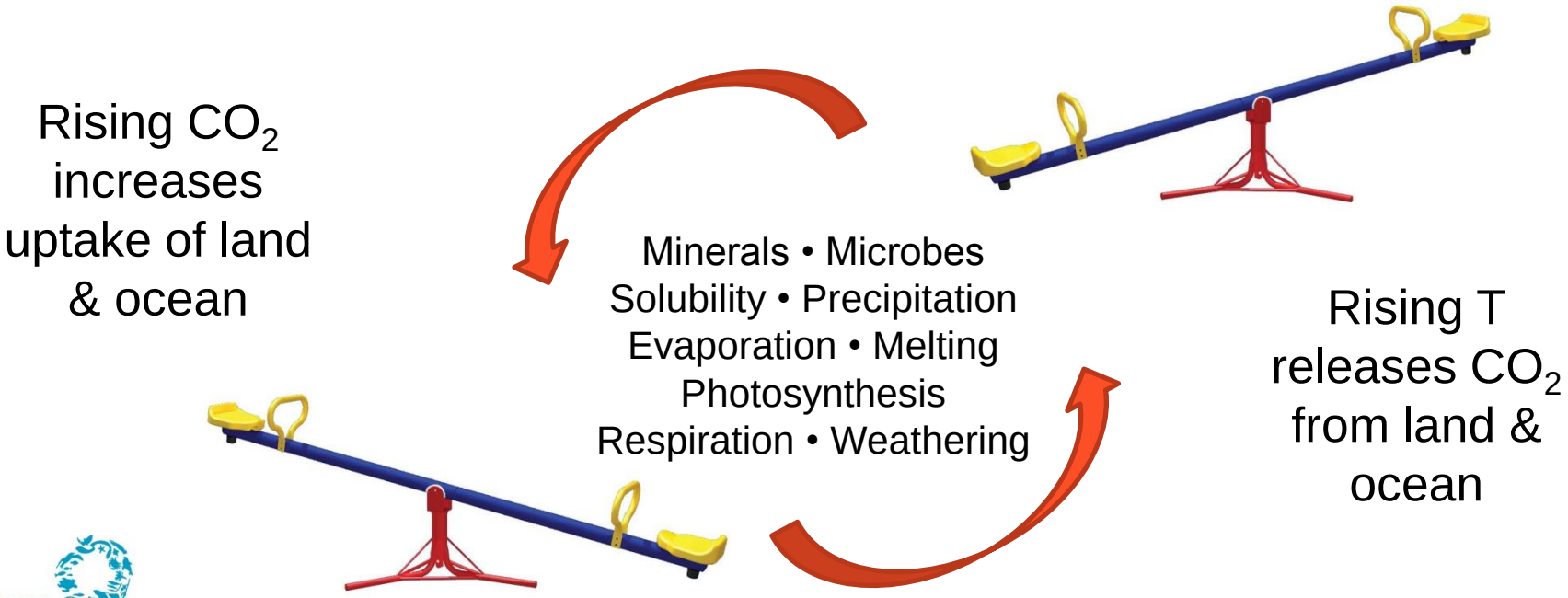
Effects of rising CO_2 on the future

It is uncertain that the land and ocean will continue taking up CO_2 at a similar rate.

- Still unclear: how climate and environmental feedbacks to the carbon cycle will interact with carbon sinks and rising atmospheric CO_2.



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Bottom line: Rising CO_2 doesn't act alone

Ocean and terrestrial effects are contingent on, and feed back to, global climate change.

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Ch. 17, Key Message 4:

Continued persistence of uptake of carbon by the land and ocean is uncertain. Climate and environmental changes create complex feedbacks to the carbon cycle; how these feedbacks modulate future effects of rising CO_2 on carbon sinks is unclear. There are several mechanisms that would reduce the ability of land and ocean sinks to continue taking up a large proportion of rising CO_2.

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Thanks to all the SOCCR-2 Science Leads and Organizing Team

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