Ocean and Biosphere Feedbacks

EES 2110

Introduction to Climate Change

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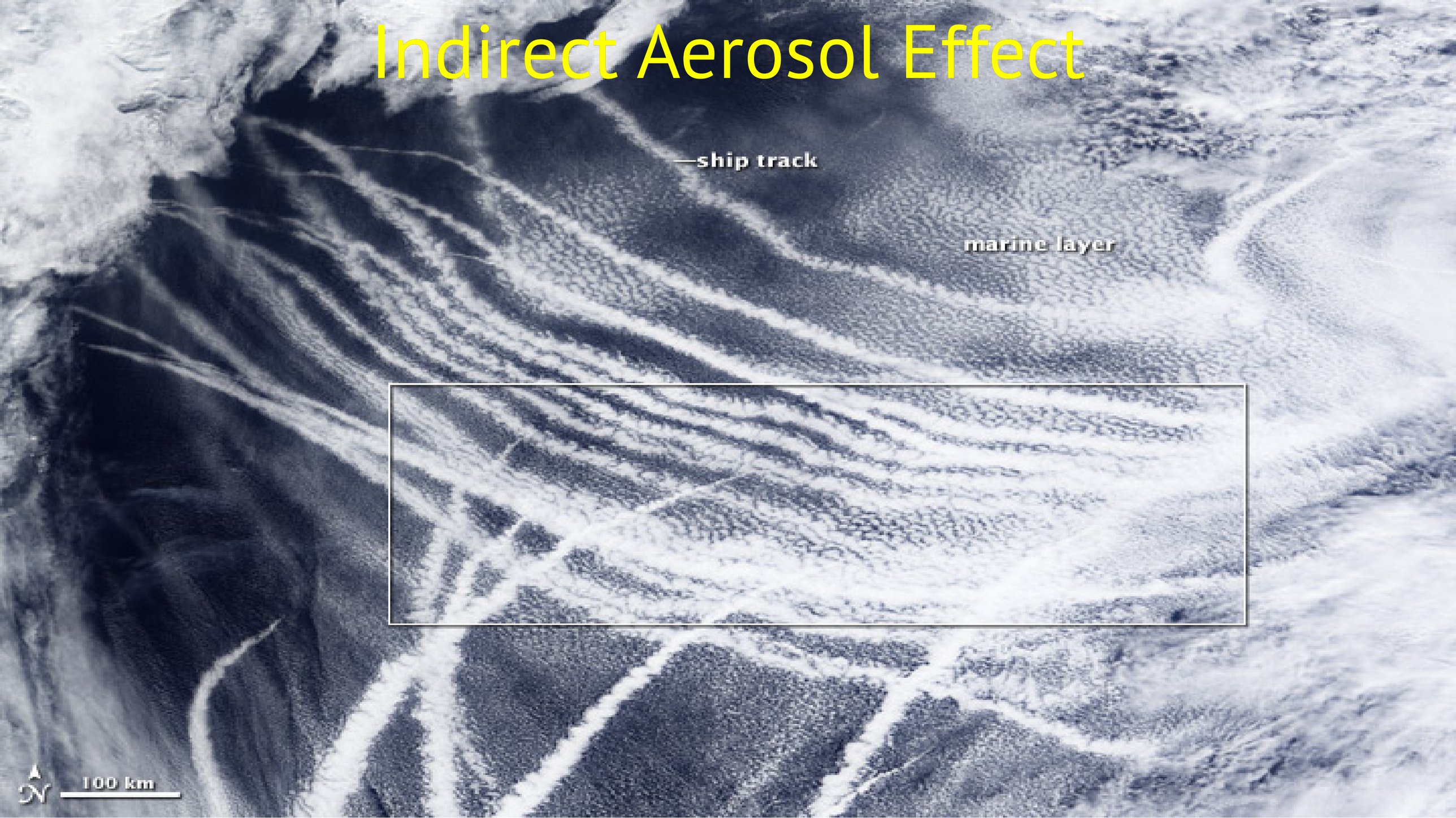
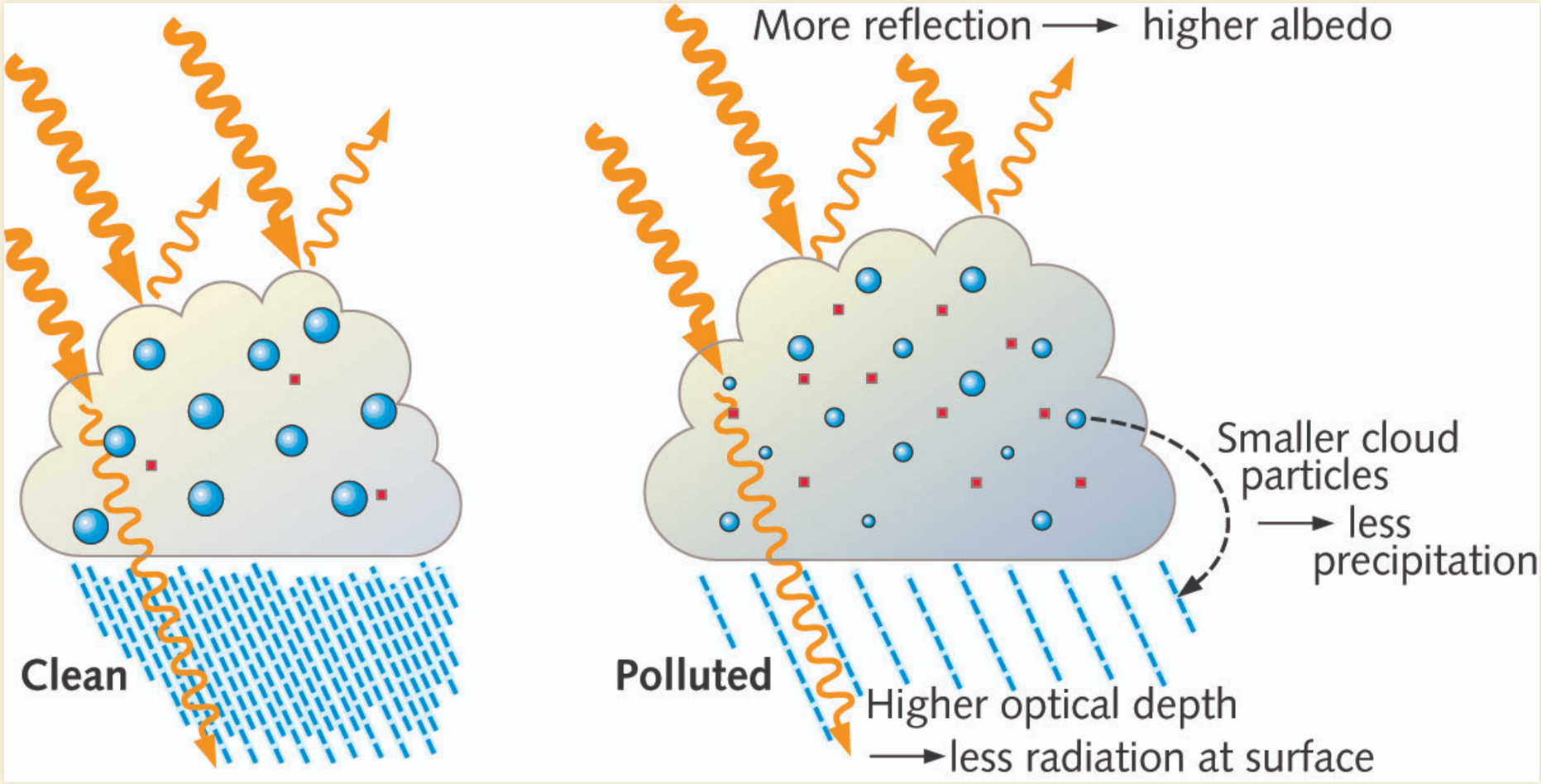
Class #12: Monday, February 06 2023

Indirect Aerosol Effect

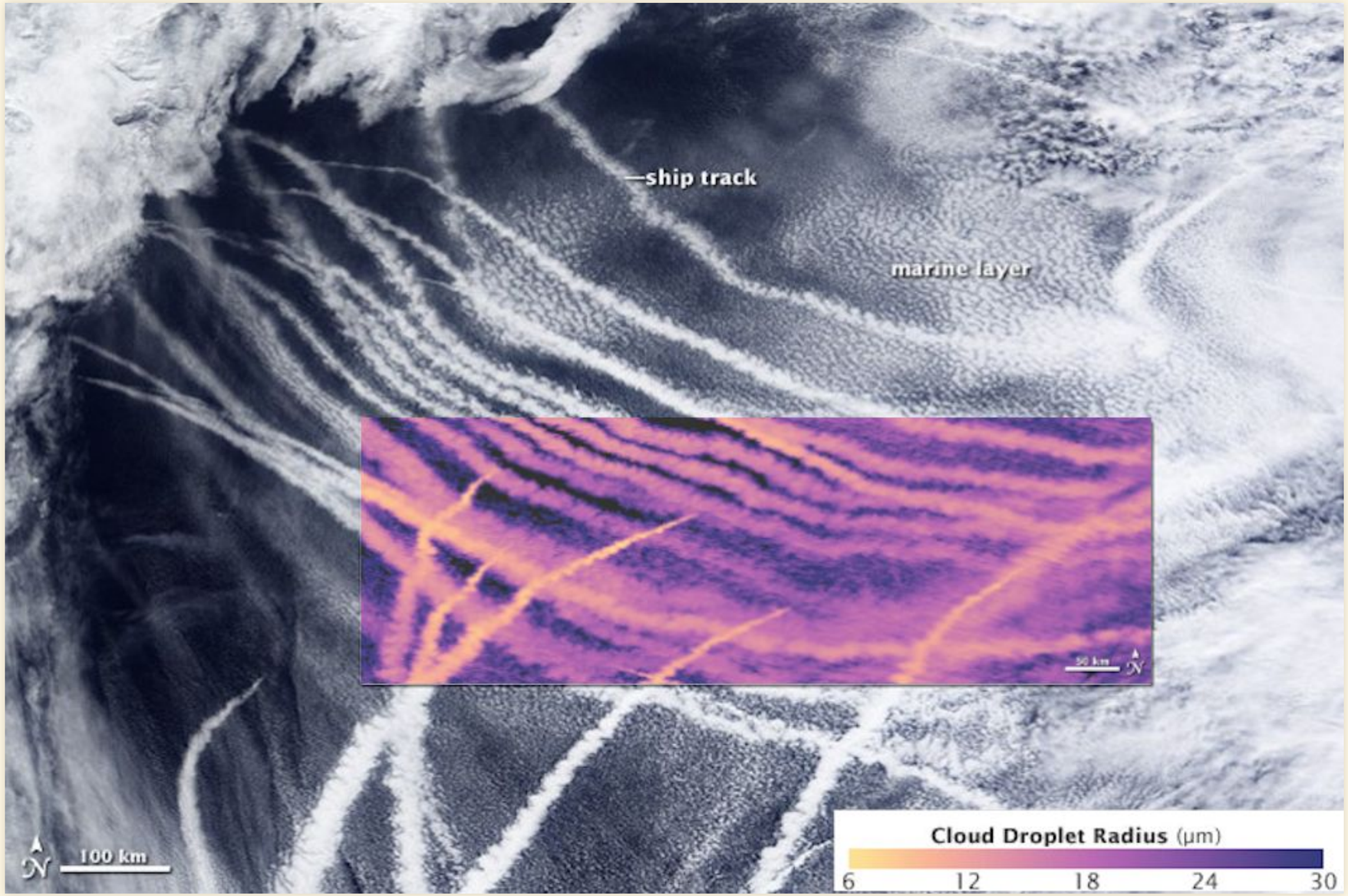


Indirect Aerosol Effect

- Aerosol particles → more, smaller droplets
- Smaller droplets → greater albedo, longer lifetime
- More droplets → greater albedo, more absorption



Indirect Aerosol Effect



Summary of Feedbacks

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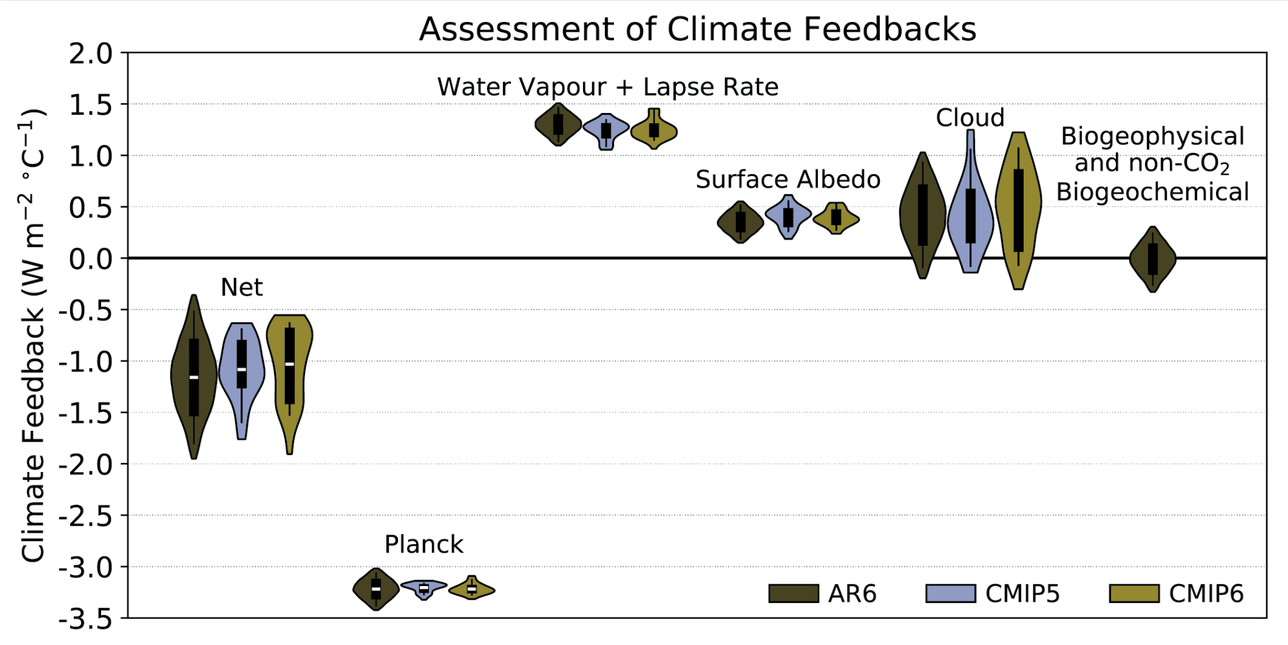


- Ice-Albedo has been extensively studied:
  - It’s known to be moderately positive.
- Water vapor has been studied:
  - It’s known to be strongly positive (factor of 2).
- There is some uncertainty about clouds:
  - Most likely they’re positive,
  - Strength is very uncertain

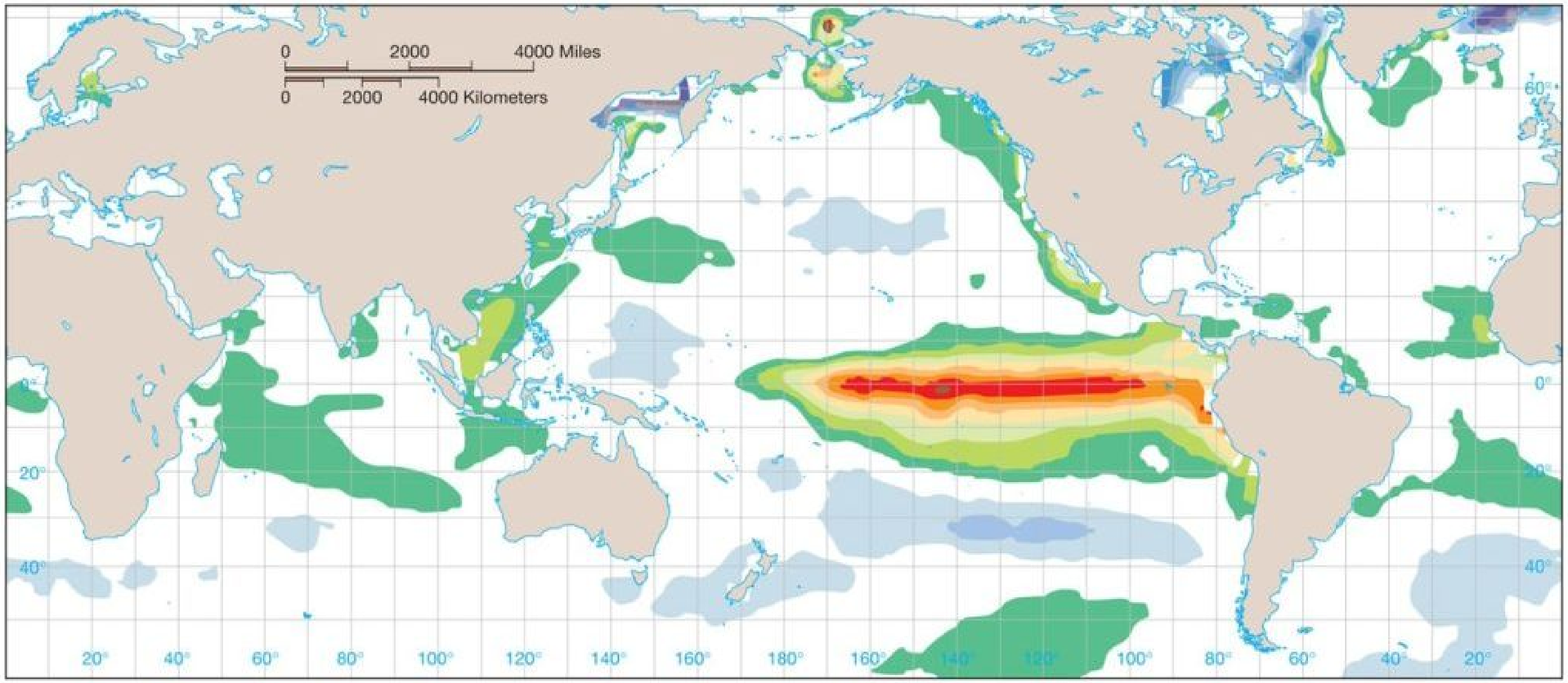
Planck Feedback

- The biggest feedback in the climate system is the Planck feedback
  - Also called the Stefan-Boltzmann feedback
- Stefan-Boltzmann equation: $I = \varepsilon \sigma T^4$
  - $Q = Q_{\text{in}} - Q_{\text{out}}$
  - Higher temperature $\rightarrow$ more heat out to space
    - Q_{out} gets larger, so $\Delta Q < 0$
  - $\Delta T > 0 \rightarrow \Delta Q < 0$
  - $f = \dfrac{\Delta Q}{\Delta T} < 0$: negative feedback
- Creates stable climate

Stability of the Climate

- Most feedbacks we've discussed are positive:
  - Ice-albedo
  - Water vapor
  - Clouds (mostly)
- Why don't these positive feedbacks make the climate unstable?
  - (e.g., runaway greenhouse)
  - They are smaller than the negative Planck feedback
    - so the total feedback remains negative.
  - Positive feedbacks amplify warming:
    - More than we'd get with just Planck feedback,
    - But they are too small to destabilize the planet.
- Many scientists worry about a possible "tipping point":
  - Is there a temperature threshold where positive feedbacks become greater than Stefan-Boltzmann?
    - This would destabilize the climate.

El Niño/Southern Oscillation



Sea Surface Temperature Composite Anomaly, November to March

1958, 1966, 1973, 1983, 1987, 1992, 1996, 1998

-2.0 °C -1.5 °C 1.0 °C -0.5 °C 0.0 °C 0.5 °C 1.0 °C 1.5 °C 2.0 °C

Normal Conditions

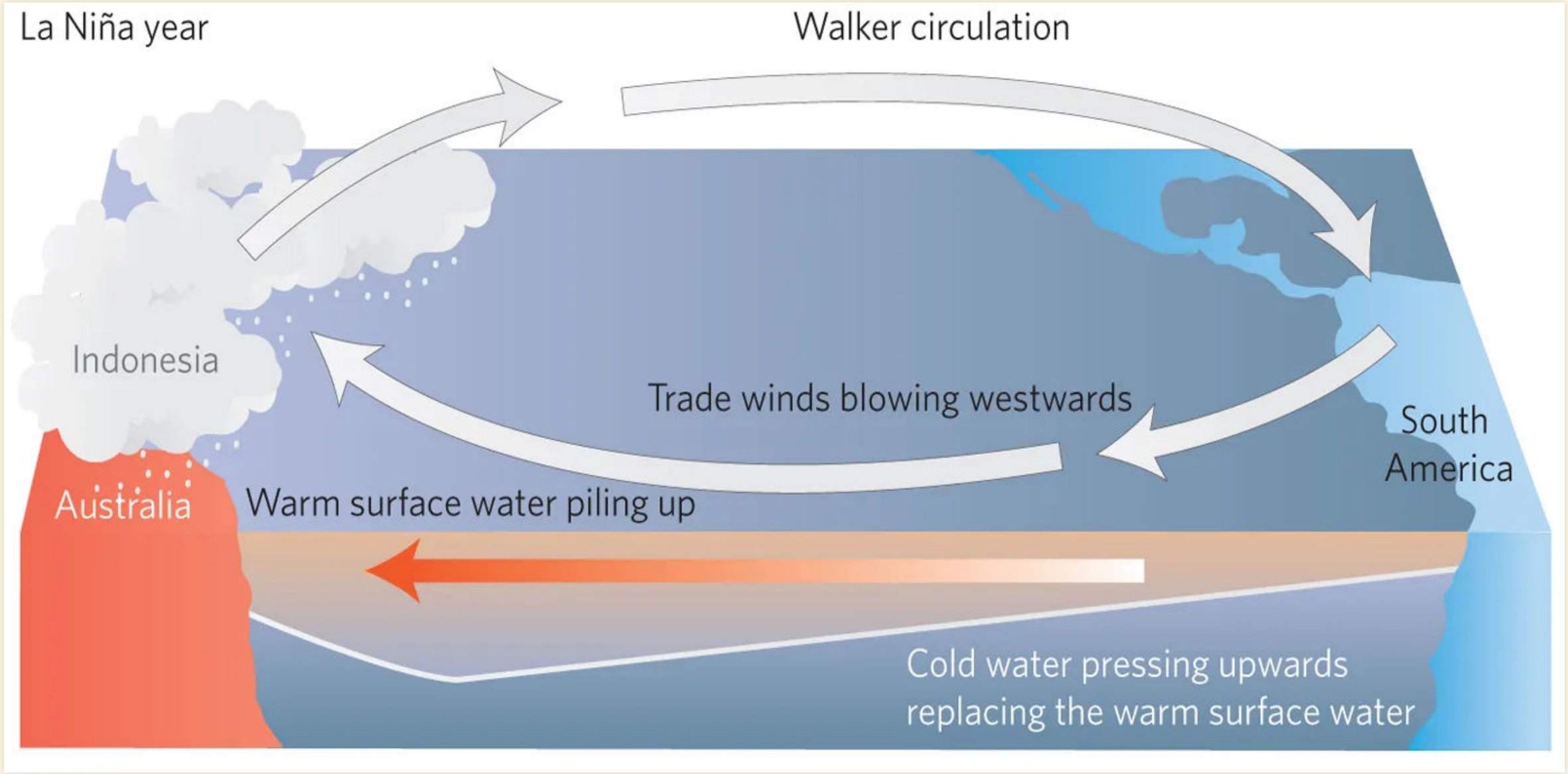


Image credit: O. Heffernan, Nature Climate Change **4**, 167 (2014). doi 10.1038/nclimate2149

El Niño

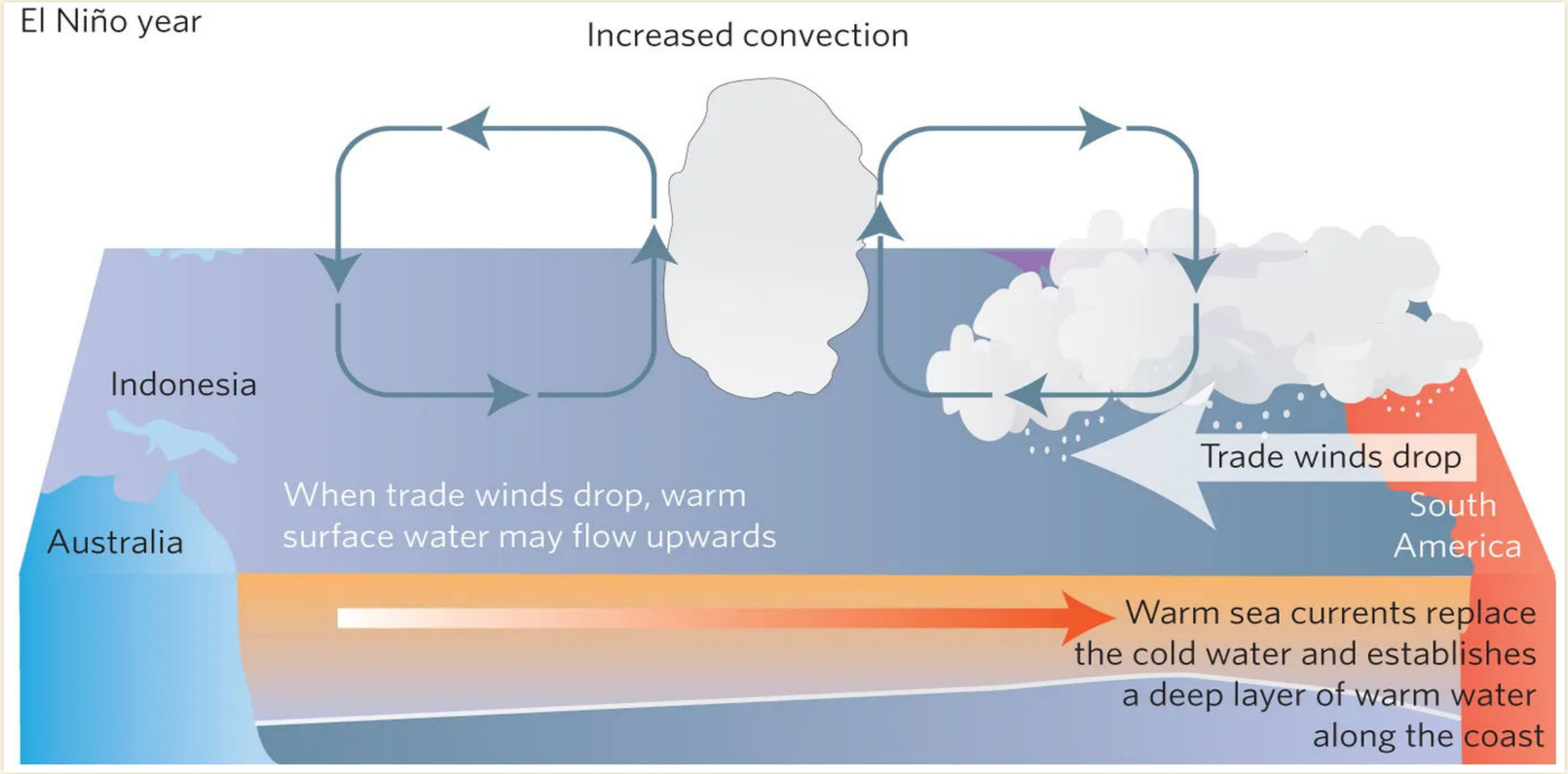


Image credit: O. Heffernan, Nature Climate Change **4**, 167 (2014). doi 10.1038/nclimate2149

Schematic of ENSO Wind & Temperature

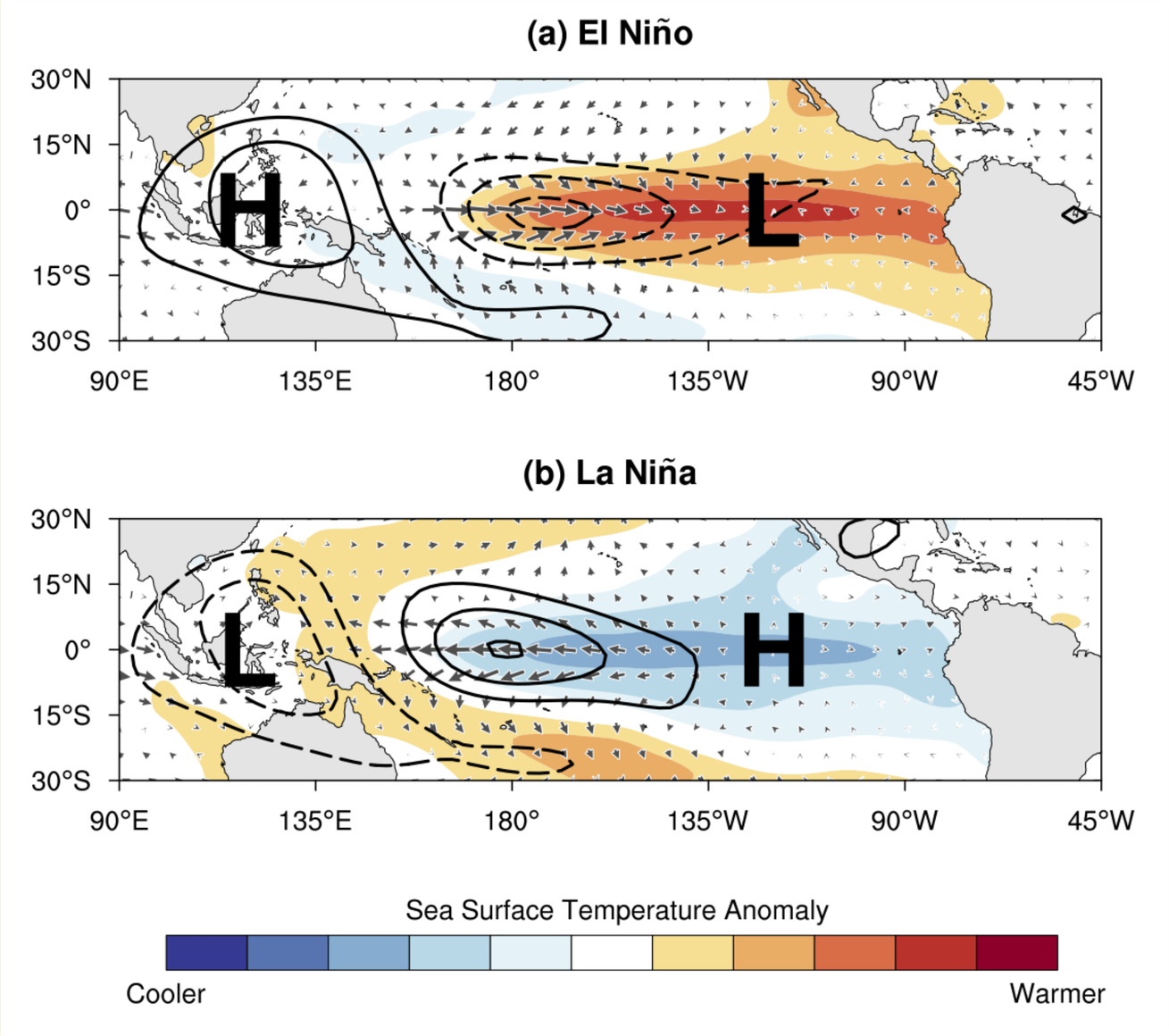
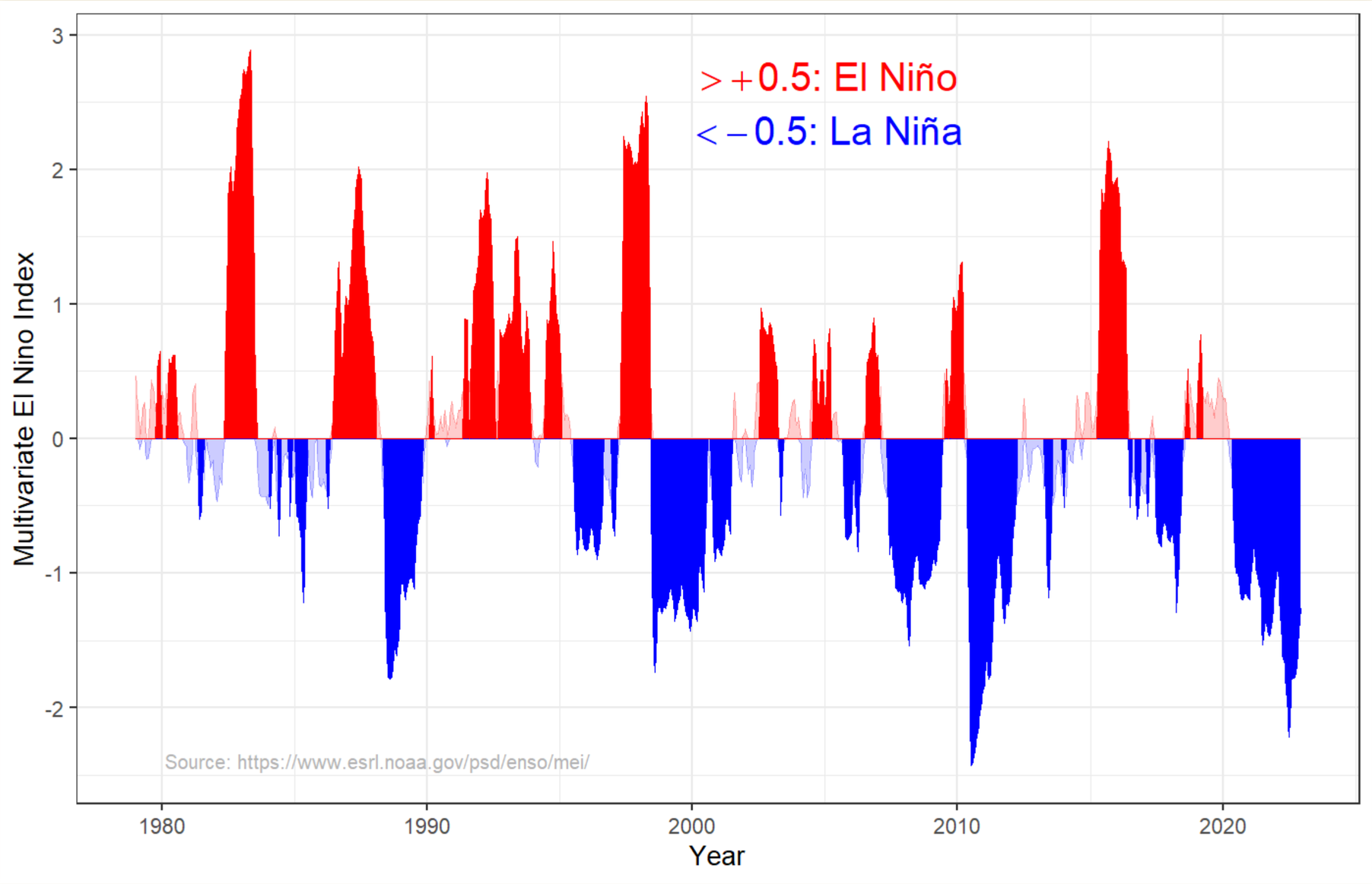


Image credit: National Oceanic & Atmospheric Administration, Multivariate ENSO Index Version 2 https://www.esrl.noaa.gov/psd/enso/mei/

Multivariate El-Niño Index (MEI)



Climate Connection

- El Niño phase:
  - Hotter sea-surface
  - More evaporation
  - Bigger greenhouse effect
  - Higher global air temperatures
- La Niña phase:
  - Cooler sea-surface
  - Less water vapor
  - Smaller greenhouse effect
  - Cooler global air temperatures

Biosphere Feedbacks

Hydrological Cycle

- Transpiration in plants:
  - Roots take water from ground
  - Leaves emit water vapor
    - Evaporation cools the air
    - Can be an important source of water vapor

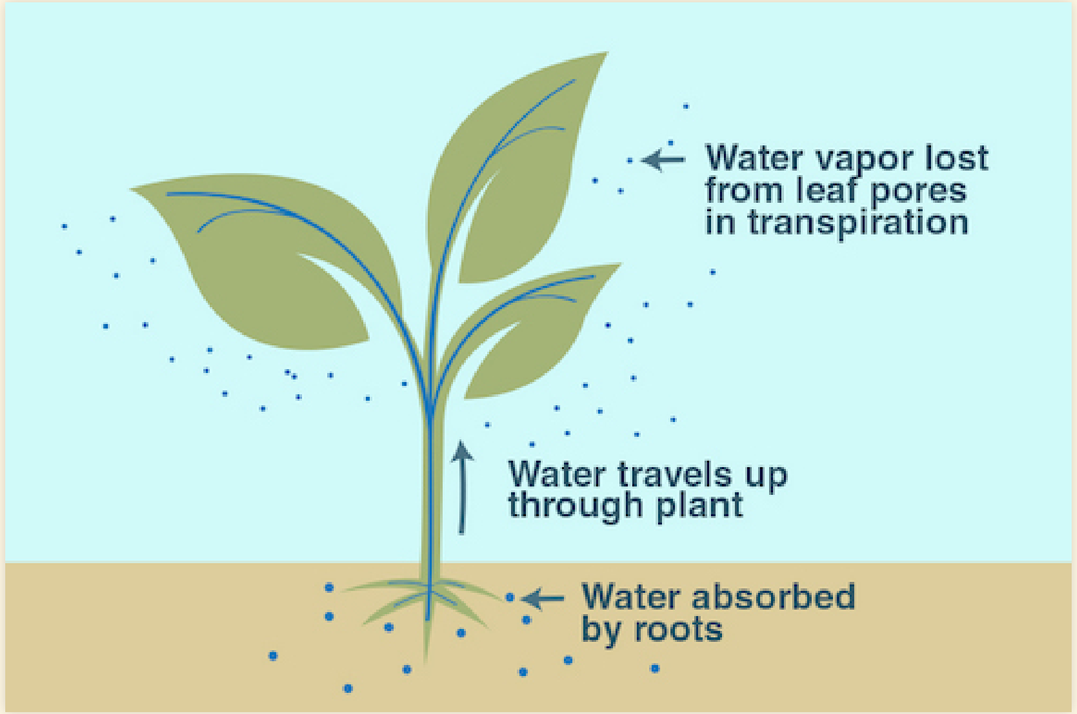


Image credit: NASA/JPL-Caltech https://climatekids.nasa.gov/heat-islands/

Transpiration and CO_2

- Transpiration occurs through “stomata” in leaves
- Tradeoff: stomata
  - Allow plant to get CO_2
  - Cause plant to lose water
- More CO_2 in atmosphere:
  - Fewer stomata
  - Less transpiration

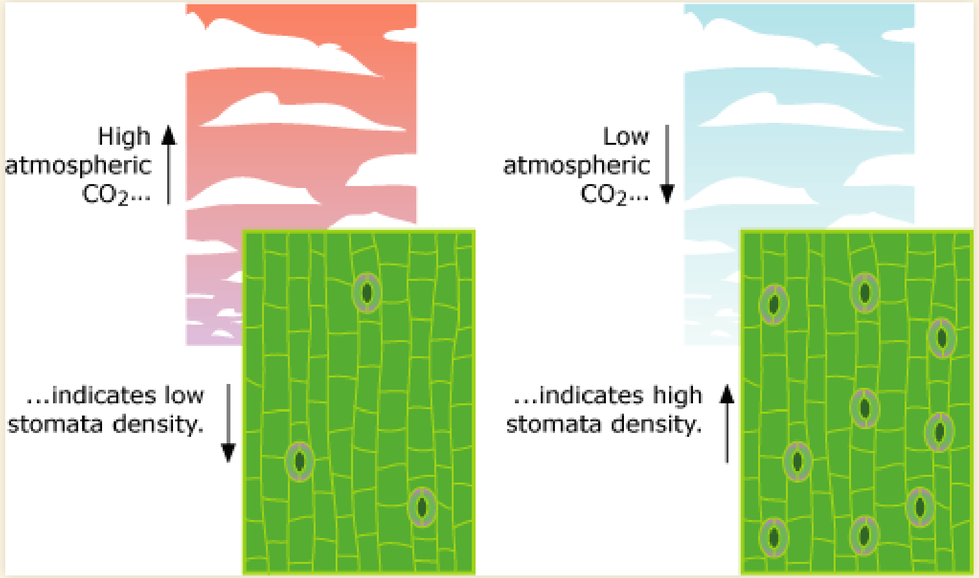


Image credit:
- Photo of stomata on duckweed: Micrographia http://www.micrographia.com/specbiol/plan/planaq/plaq0100/lemna-01.htm.
- Diagram of response to CO_2: University of California Museum of Paleontology’s Understanding Evolution http://evolution.berkeley.edu.

Forests vs. Grasslands

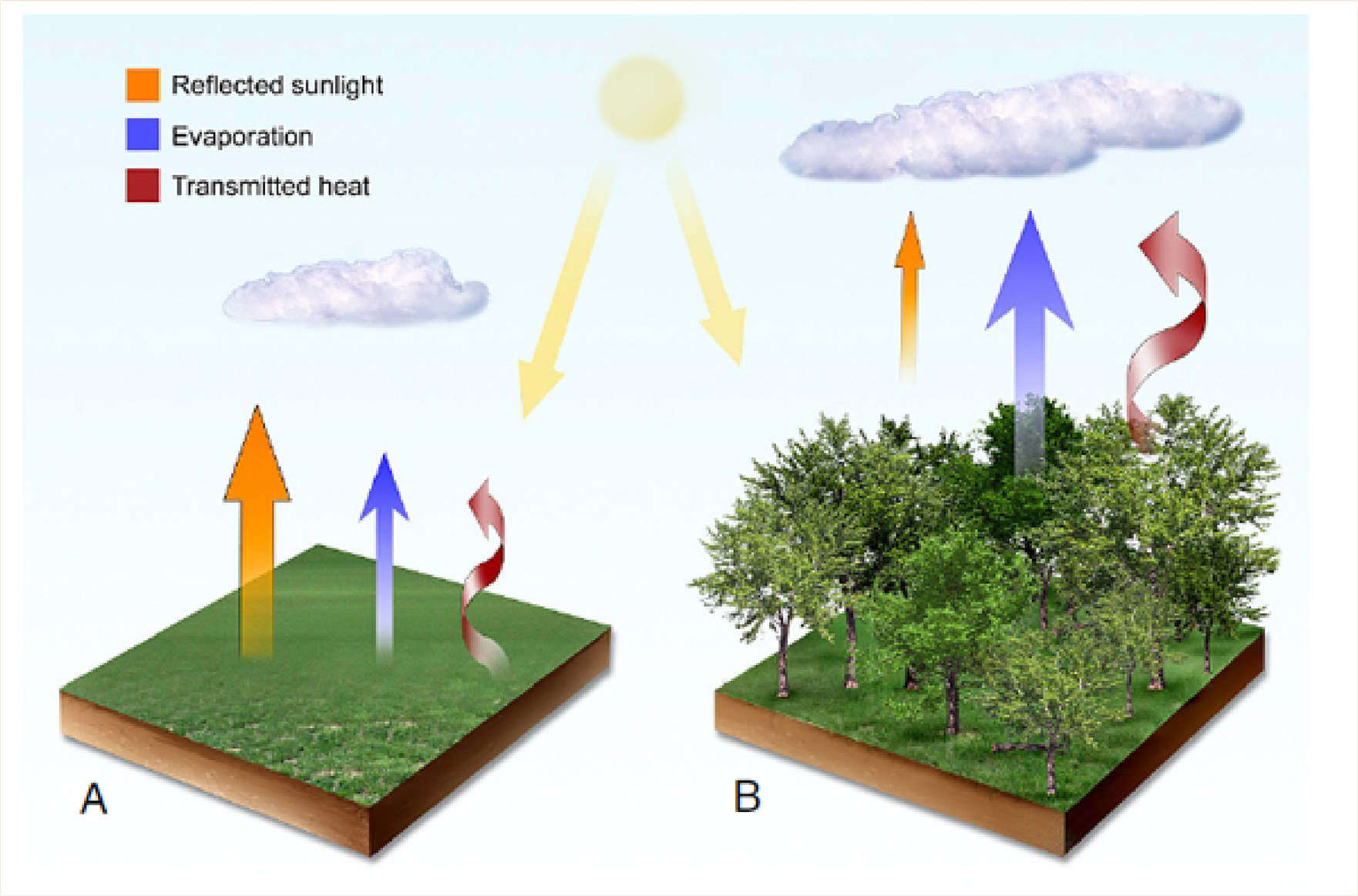


Image credit: R.B. Jackson *et al.*, Environ. Res. Lett. **3**, 044006 (2008). doi: 10.1088/1748-9326/3/4/044006

Carbon Cycle Feedbacks

- Dead organic matter in ground (leaves, roots, etc.) stores carbon
- Warming temperatures accelerate decomposition
  - Bacterial/fungal metabolism
- Huge amounts of dead organic matter in arctic tundra & permafrost
  - Concerns about accelerated greenhouse gas emissions as ground thaws & warms
  - Amplifies global warming, but unlikely to run away uncontrollably.

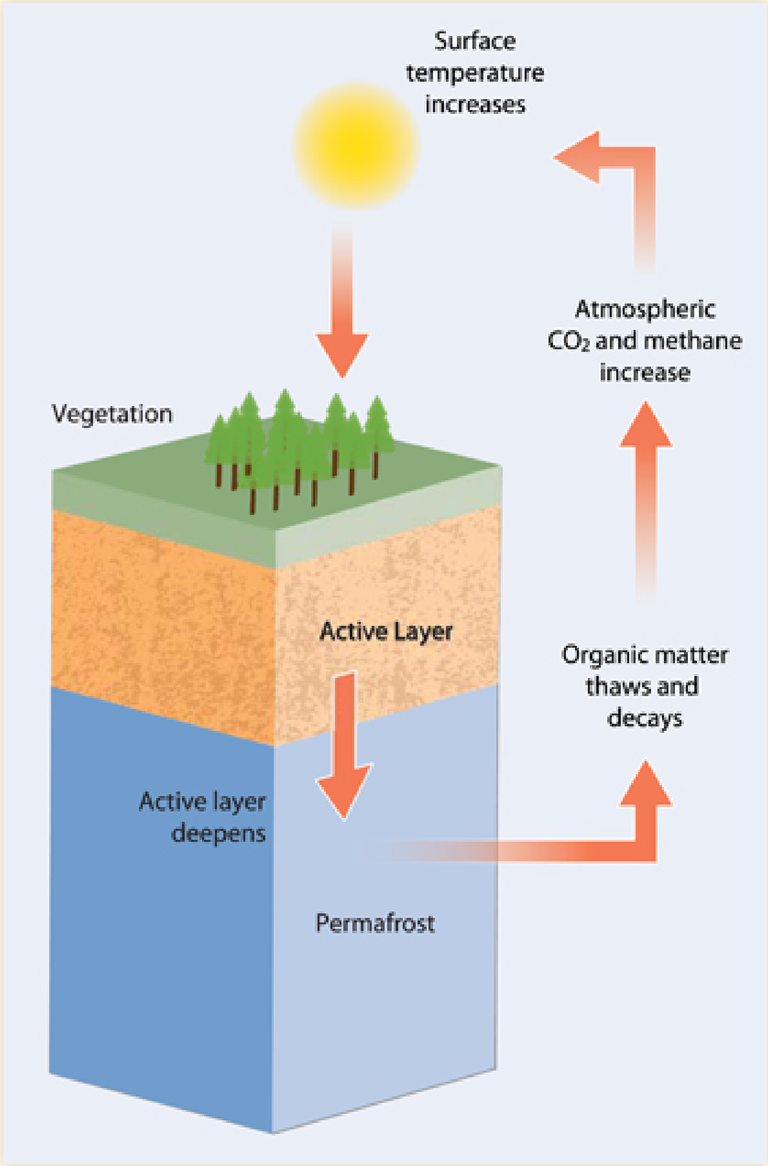


Image credit: K. Schaefer *et al.*, Environ. Res. Lett. **9**, 085003 (2014). doi: 10.1088/1748-9326/9/8/085003