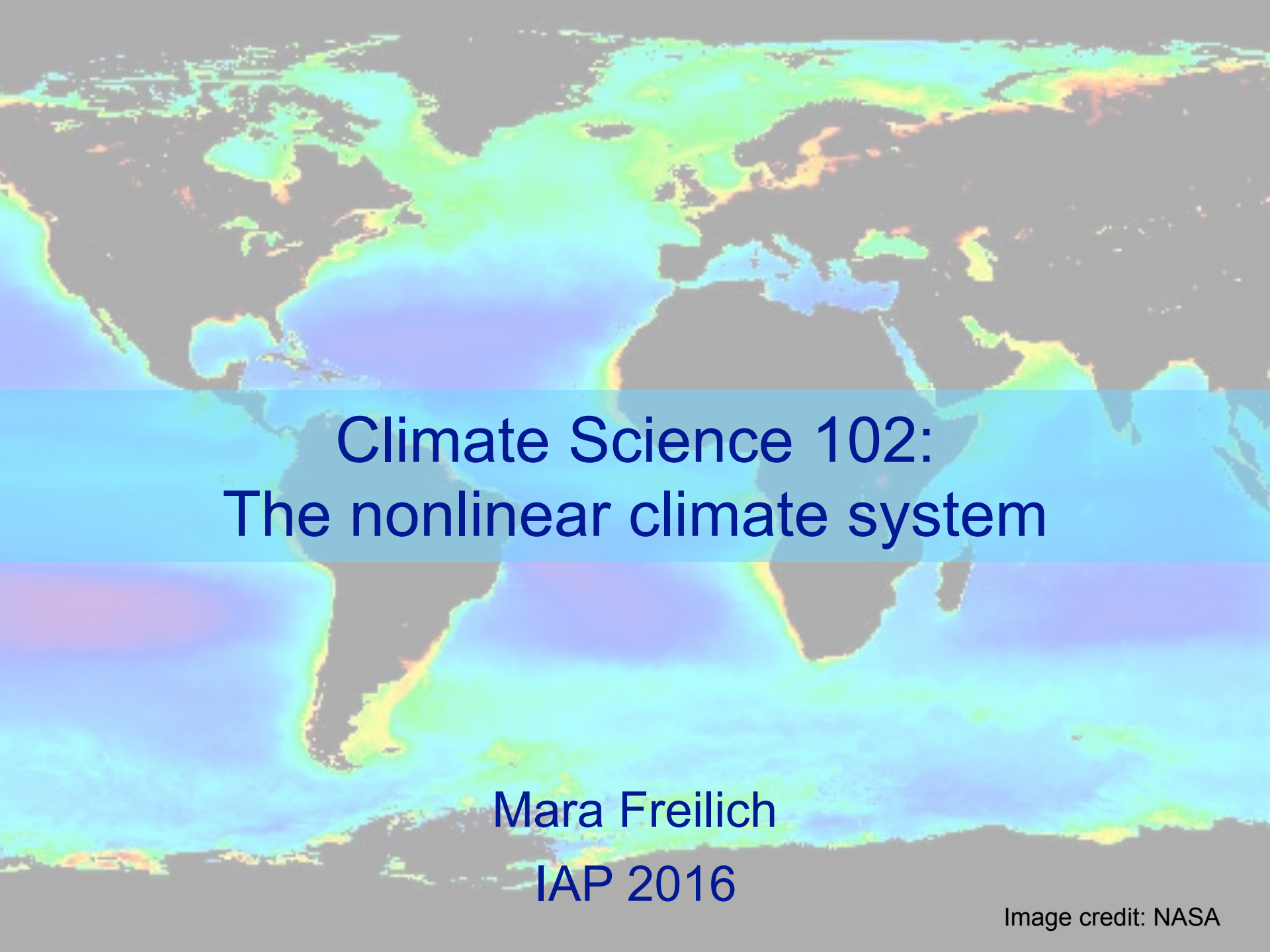


Climate Science 102:
The nonlinear climate system

Mara Freilich

IAP 2016

Image credit: NASA

Recap

Outline

- A few major components of the Earth system
  - Water
  - Clouds
  - Volcanoes
  - Ocean circulation
- Feedbacks and interactions

Summary

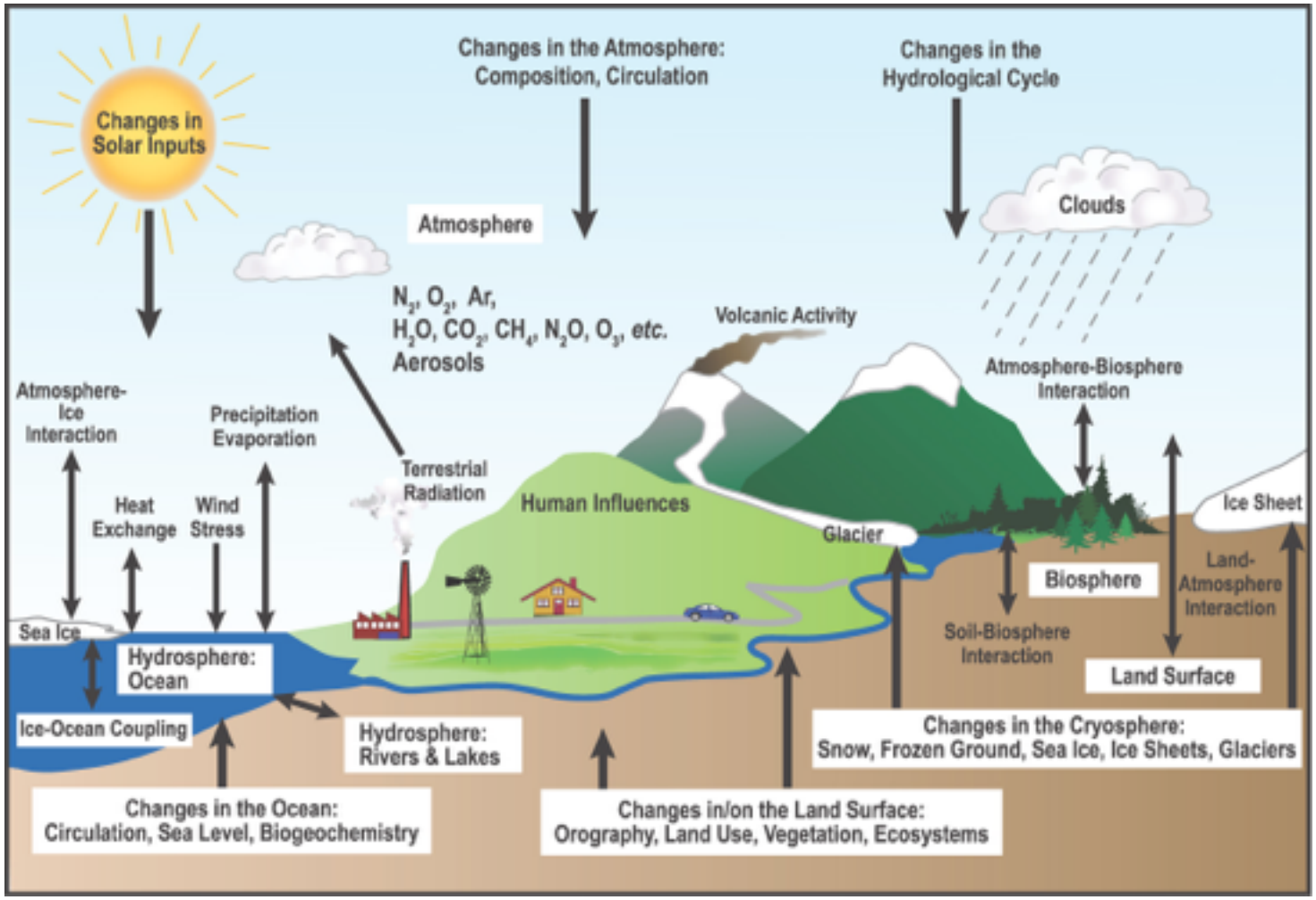
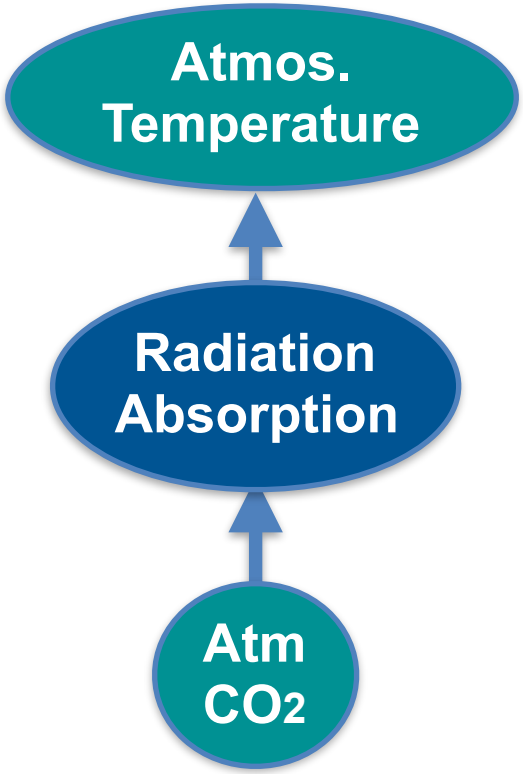
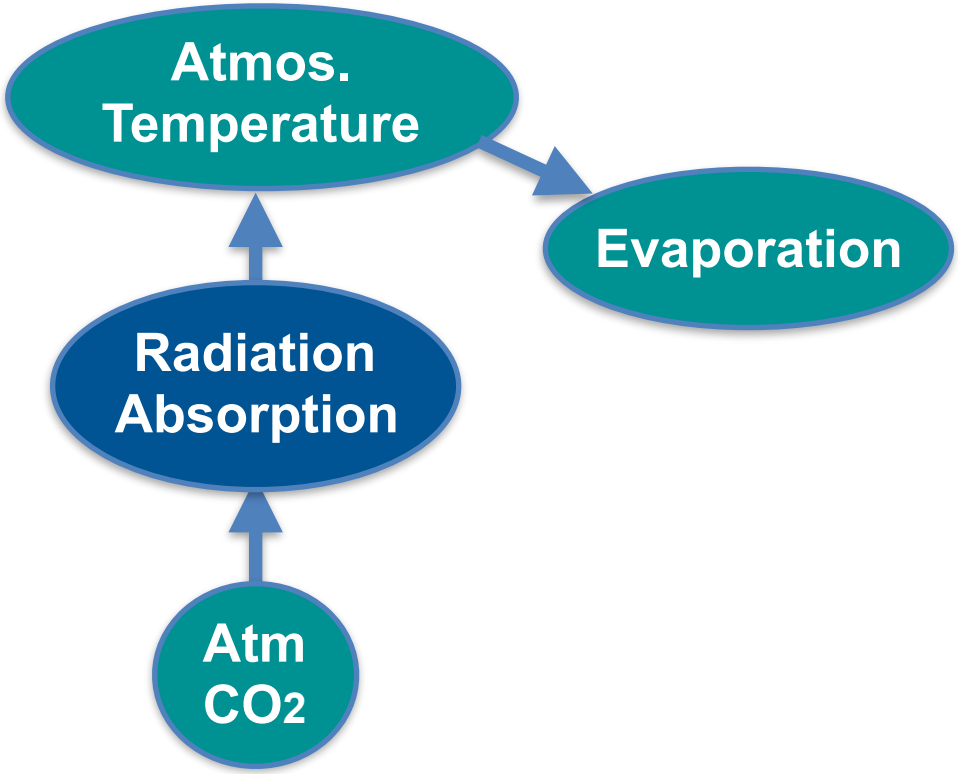


Image credit: Kay et al. (2014). "The Community Earth System Model (CESM) Large Ensemble Project: A Community Resource for Studying Climate Change in the Presence of Internal Climate Variability. Bull. Amer. Met. Soc., in press, doi: 10.1175/BAMS-D-13-00255.1. Figure 4. Available at: http://www.cgd.ucar.edu/staff/cdeser/docs/kay.cesm_le.submitted.sep14.pdf

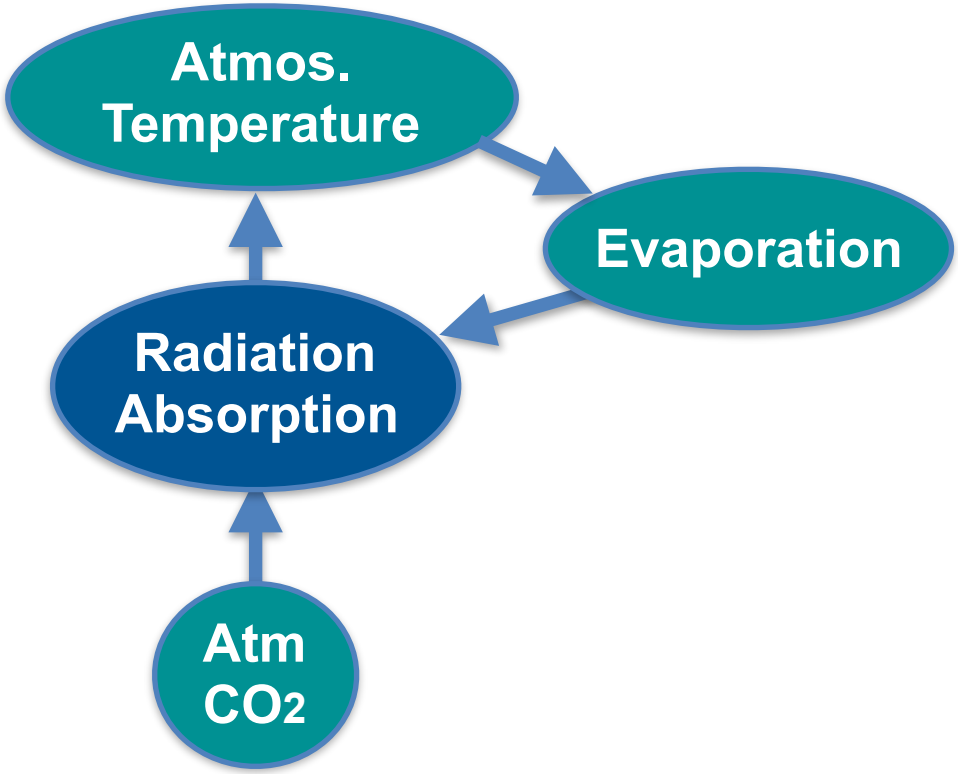
Feedbacks



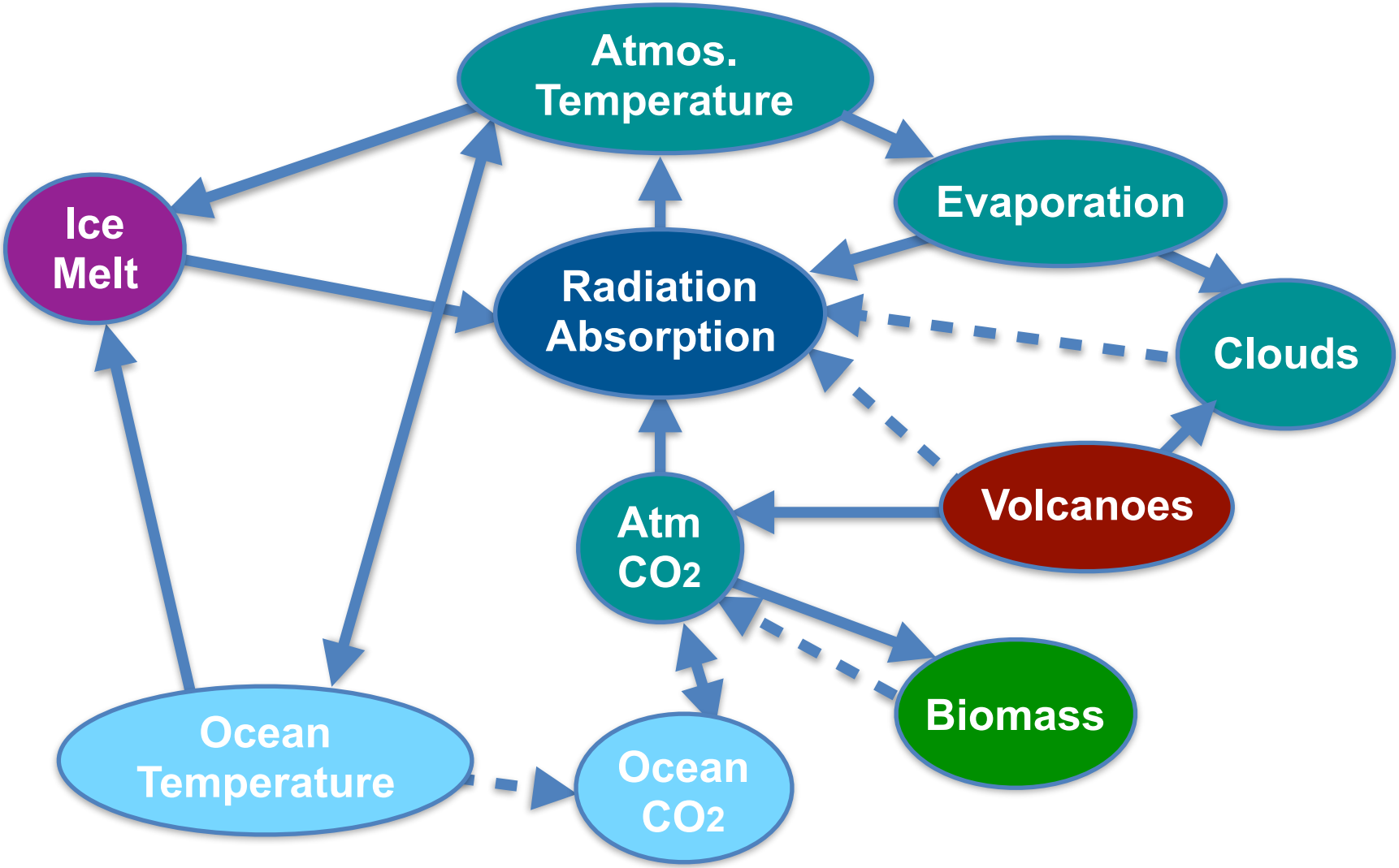
Feedbacks


Atmos.
Temperature
Evaporation
Radiation
Absorption
Atm
CO_2

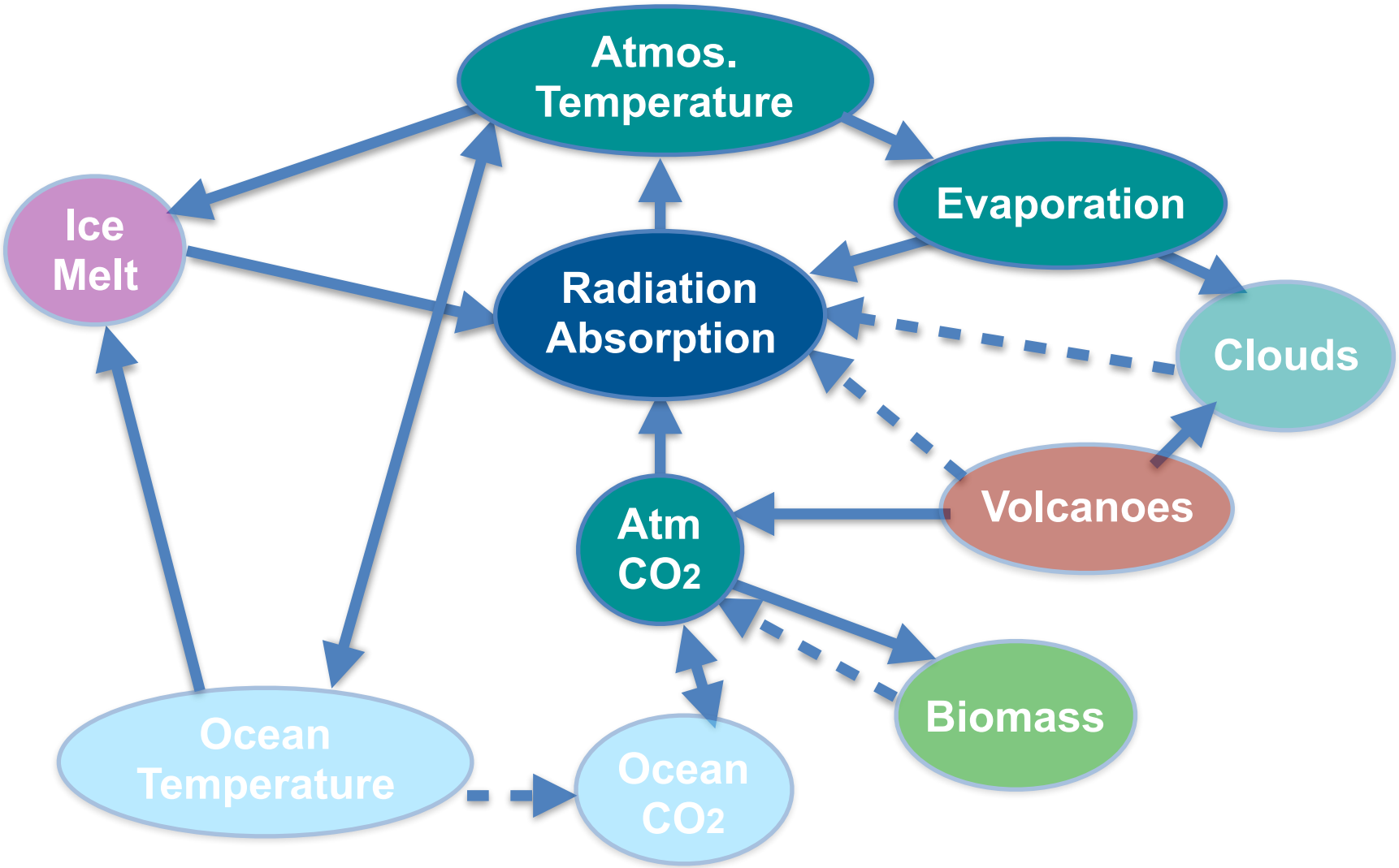
Feedbacks


Atmos.
Temperature
Evaporation
Radiation
Absorption
Atm
CO_2

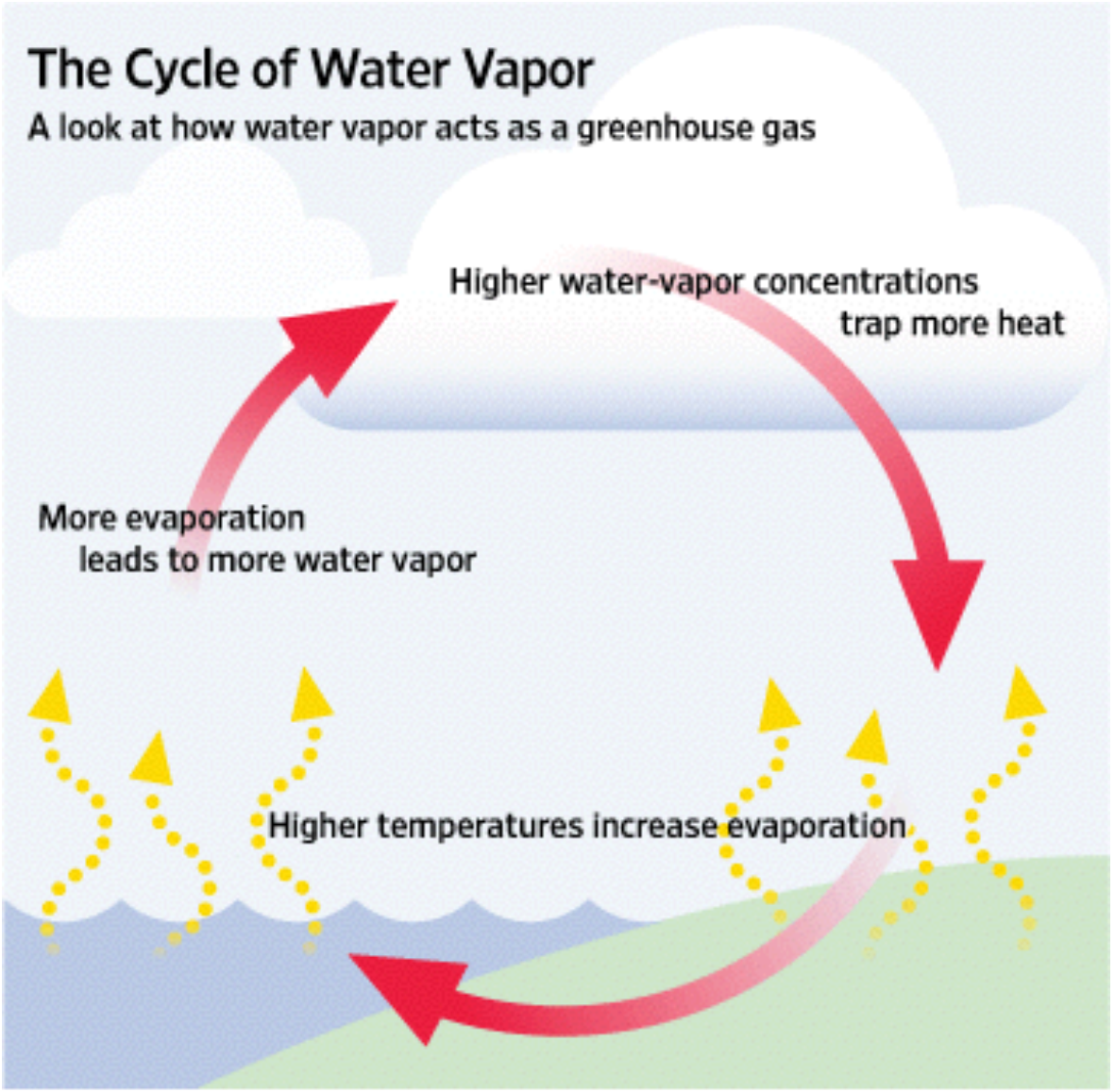
Feedbacks


Atmos. Temperature
Ice Melt
Evaporation
Radiation Absorption
Clouds
Volcanoes
Atm CO_2
Biomass
Ocean Temperature
Ocean CO_2

Feedbacks


Atmos. Temperature
Ice Melt
Evaporation
Radiation Absorption
Clouds
Volcanoes
Atm CO_2
Biomass
Ocean Temperature
Ocean CO_2

Water Vapor Feedback



→ positive feedback

Increases original forcing by factor of 2-3

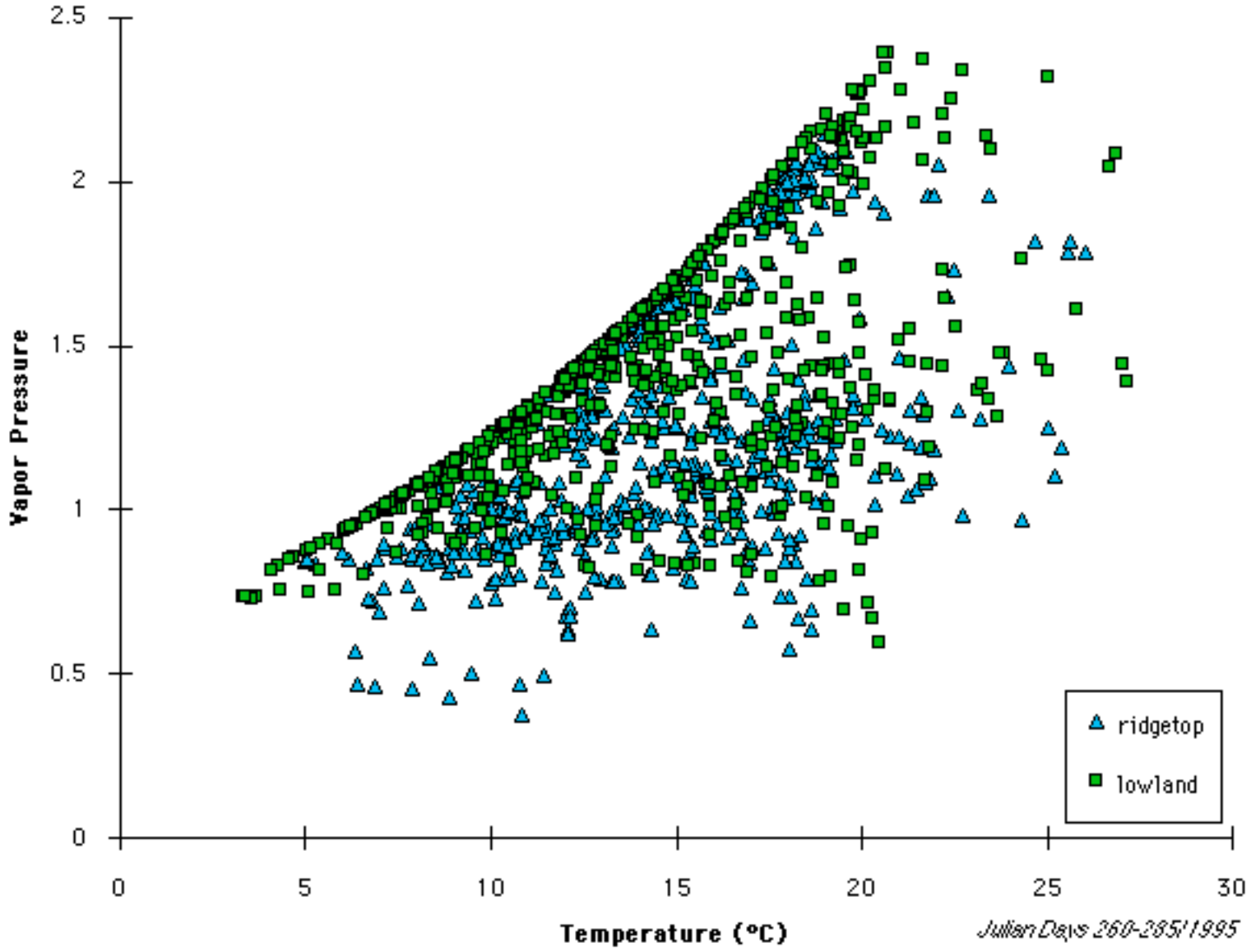
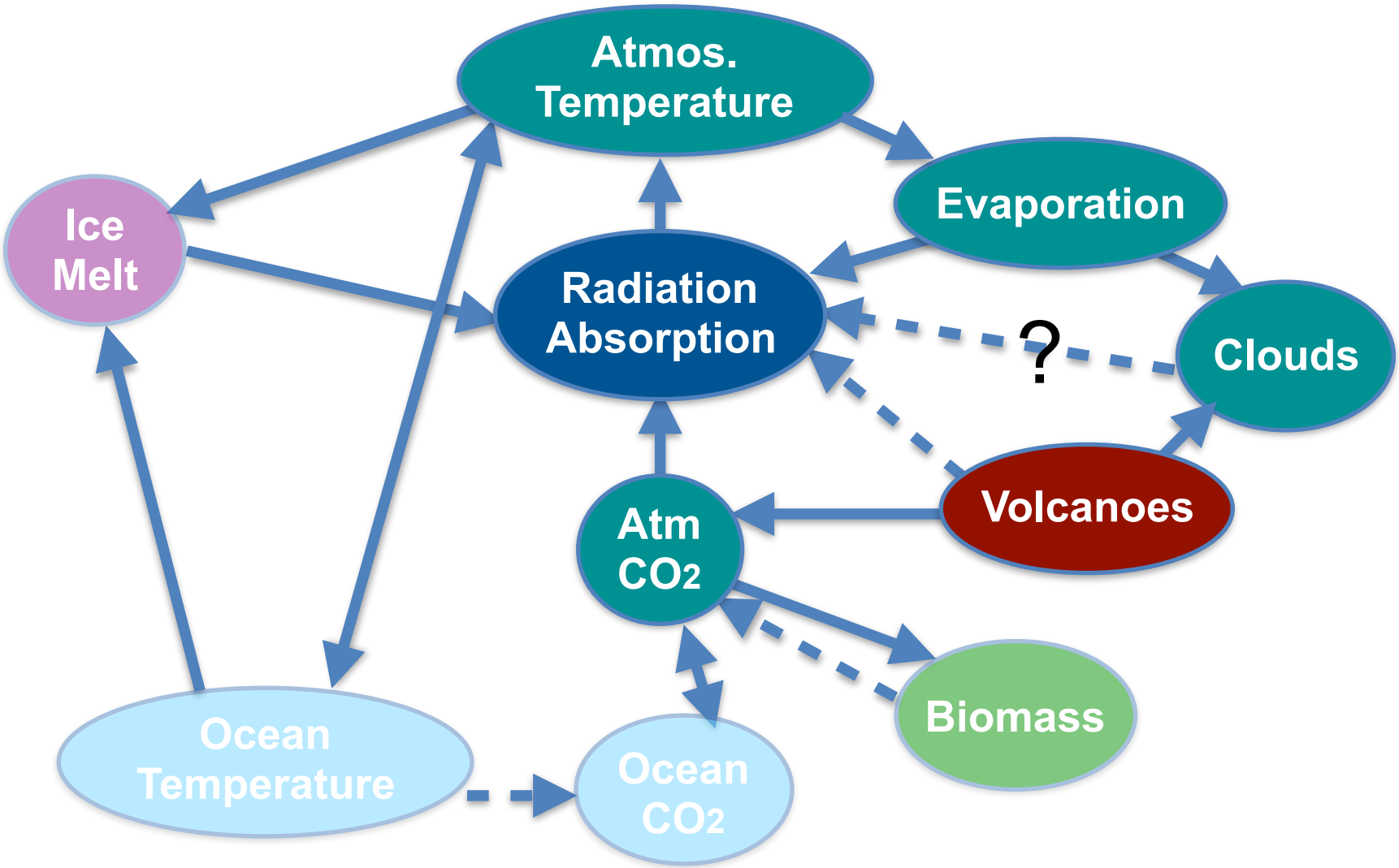
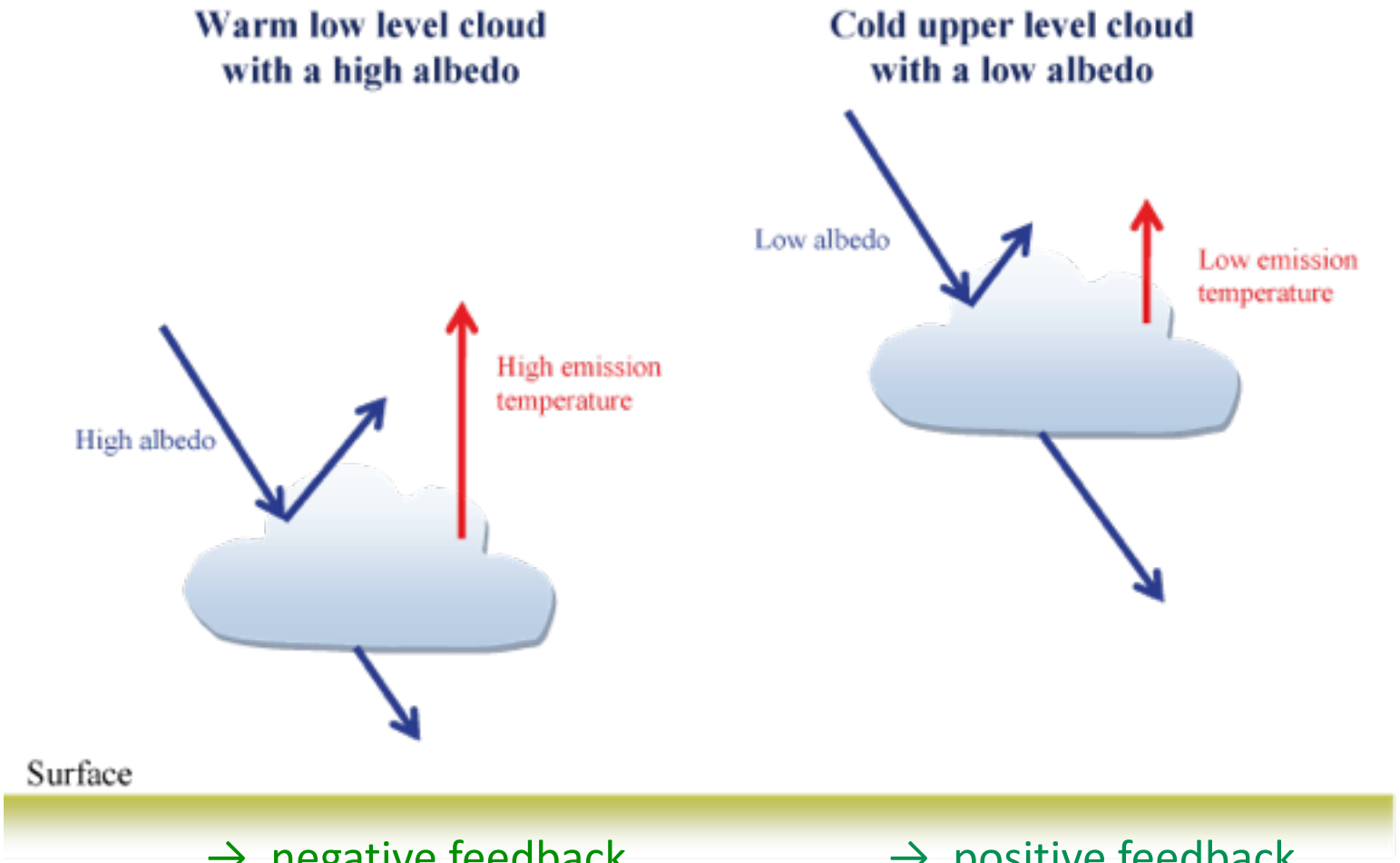


Image credit: John Knox, http://eesc.columbia.edu/courses/ees/slides/climate/Lec2Fig6cclap.html

Feedbacks


Atmos. Temperature
Ice Melt
Evaporation
Radiation Absorption
?
Clouds
Volcanoes
Atm CO_2
Biomass
Ocean Temperature
Ocean CO_2

Cloud Feedback

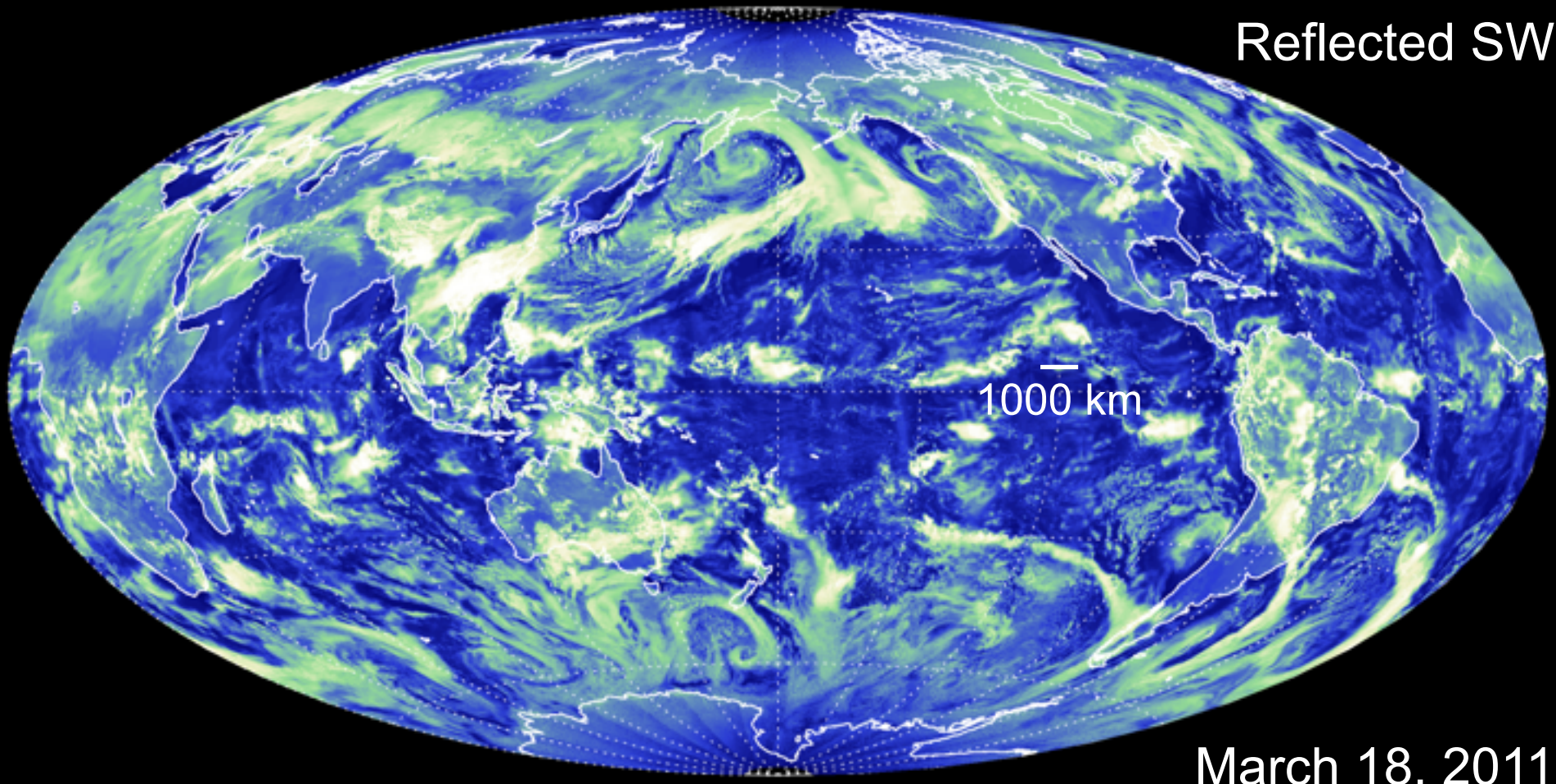


→ negative feedback

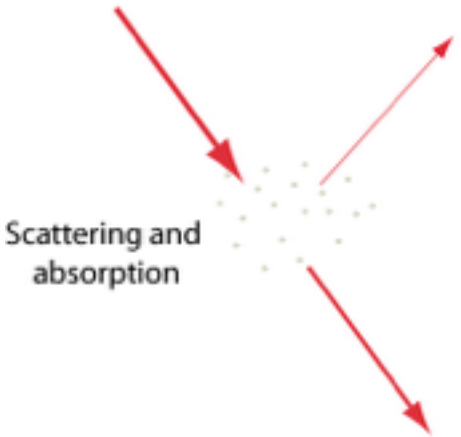
→ positive feedback

Changes in cloud cover in climate models are highly variable, and clouds themselves are not resolved.

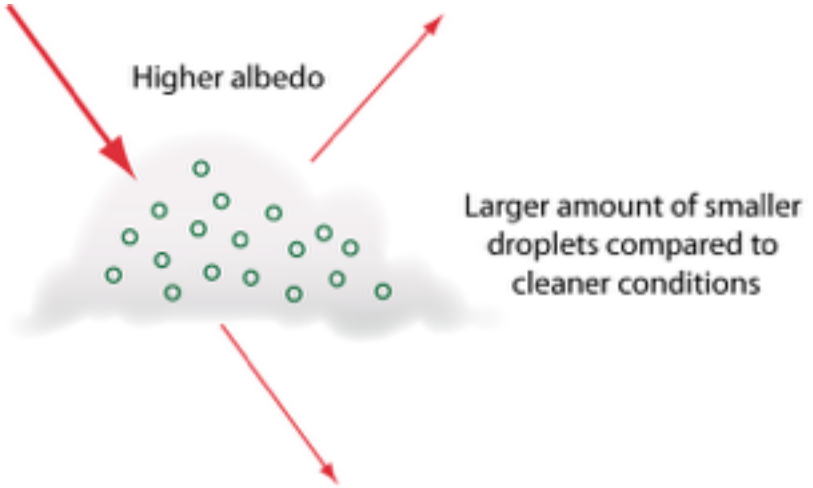
Clouds are small-scale with highly variable reflectivity



Aerosols



Direct effects

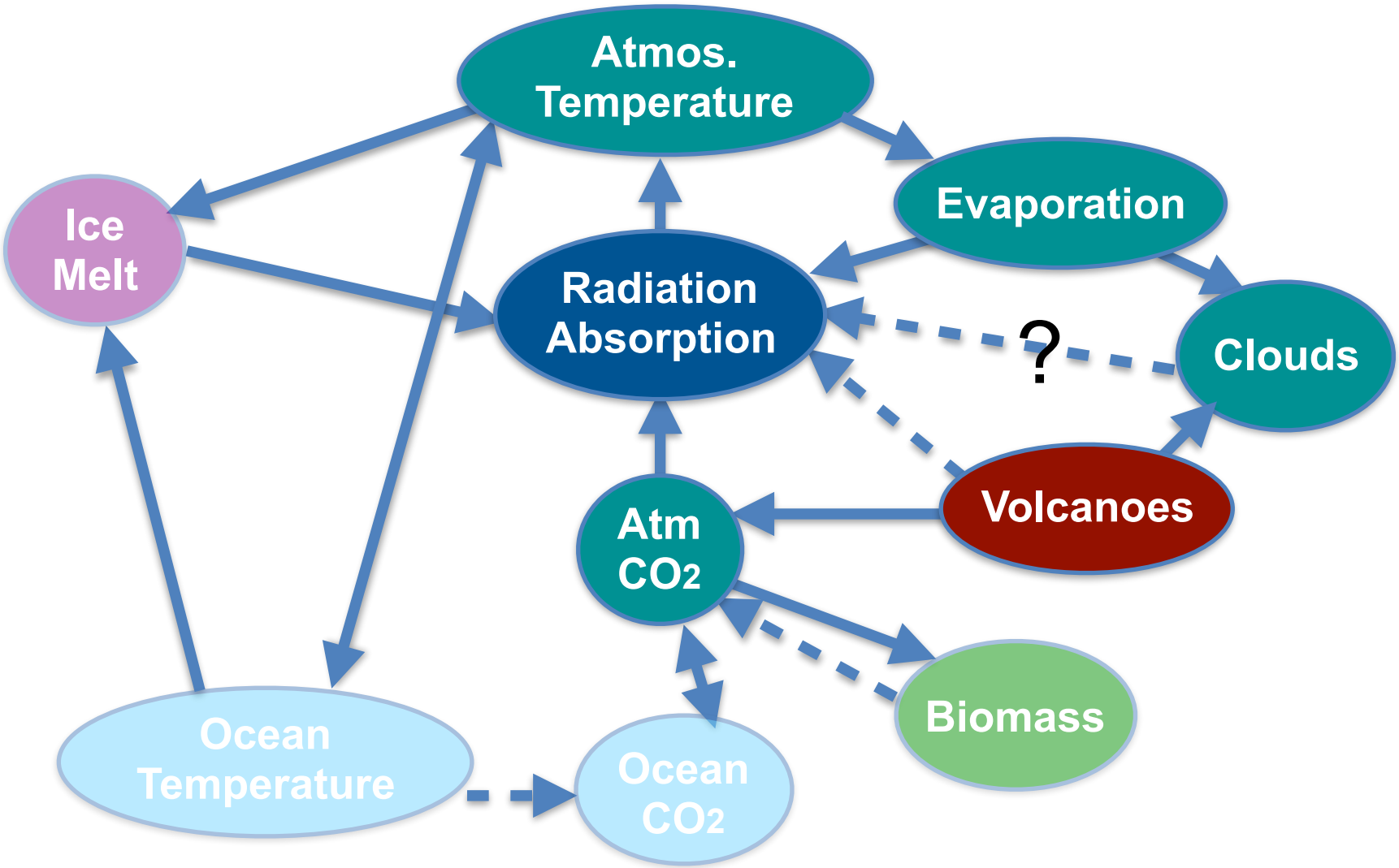


First indirect effect: cloud-albedo effect

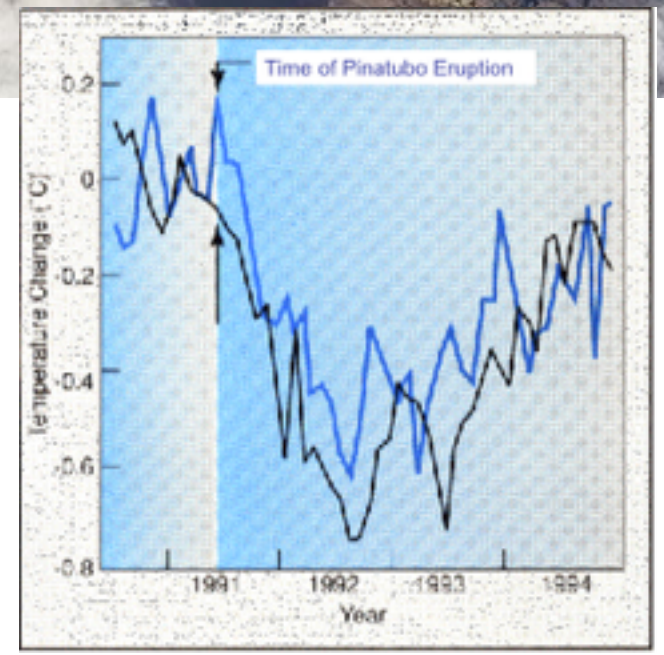
High aerosol concentrations!

NASA MODIS satellite

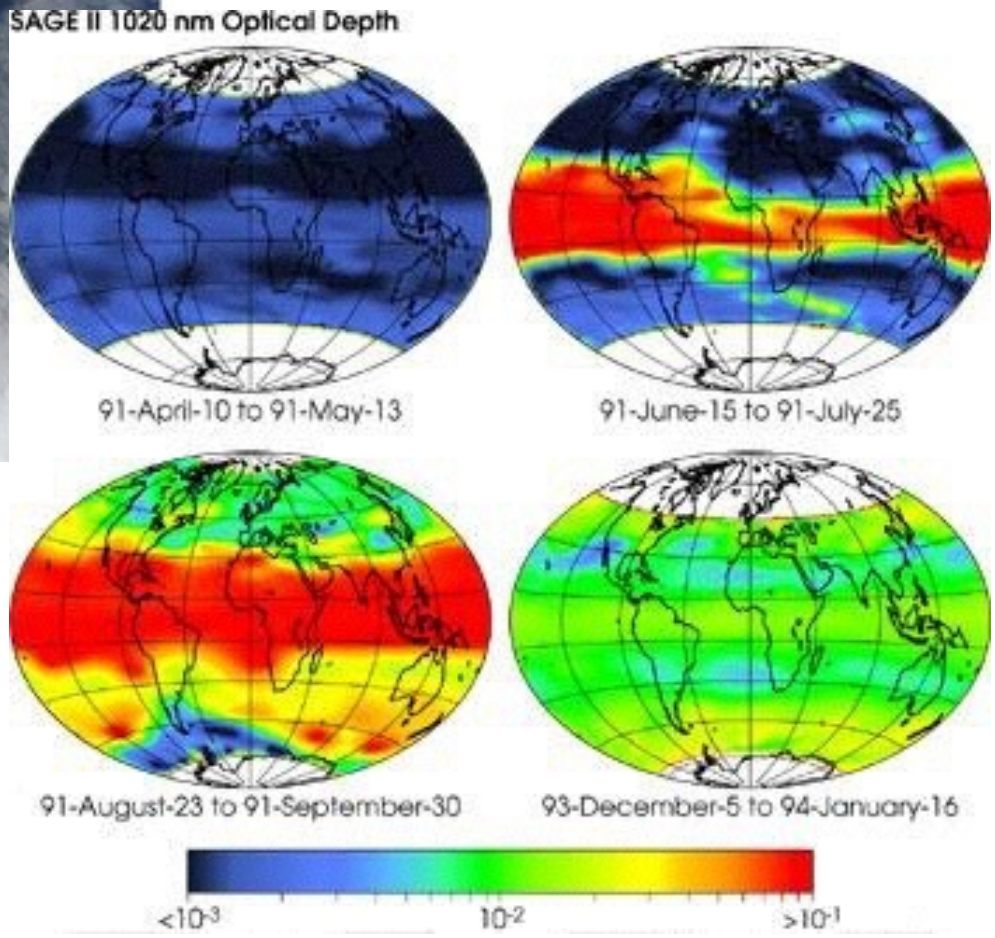
Feedbacks


Atmos. Temperature
Ice Melt
Evaporation
Radiation Absorption
?
Clouds
Volcanoes
Atm CO_2
Biomass
Ocean Temperature
Ocean CO_2

Volcano Data and Models



Source: Hansen et al 1993

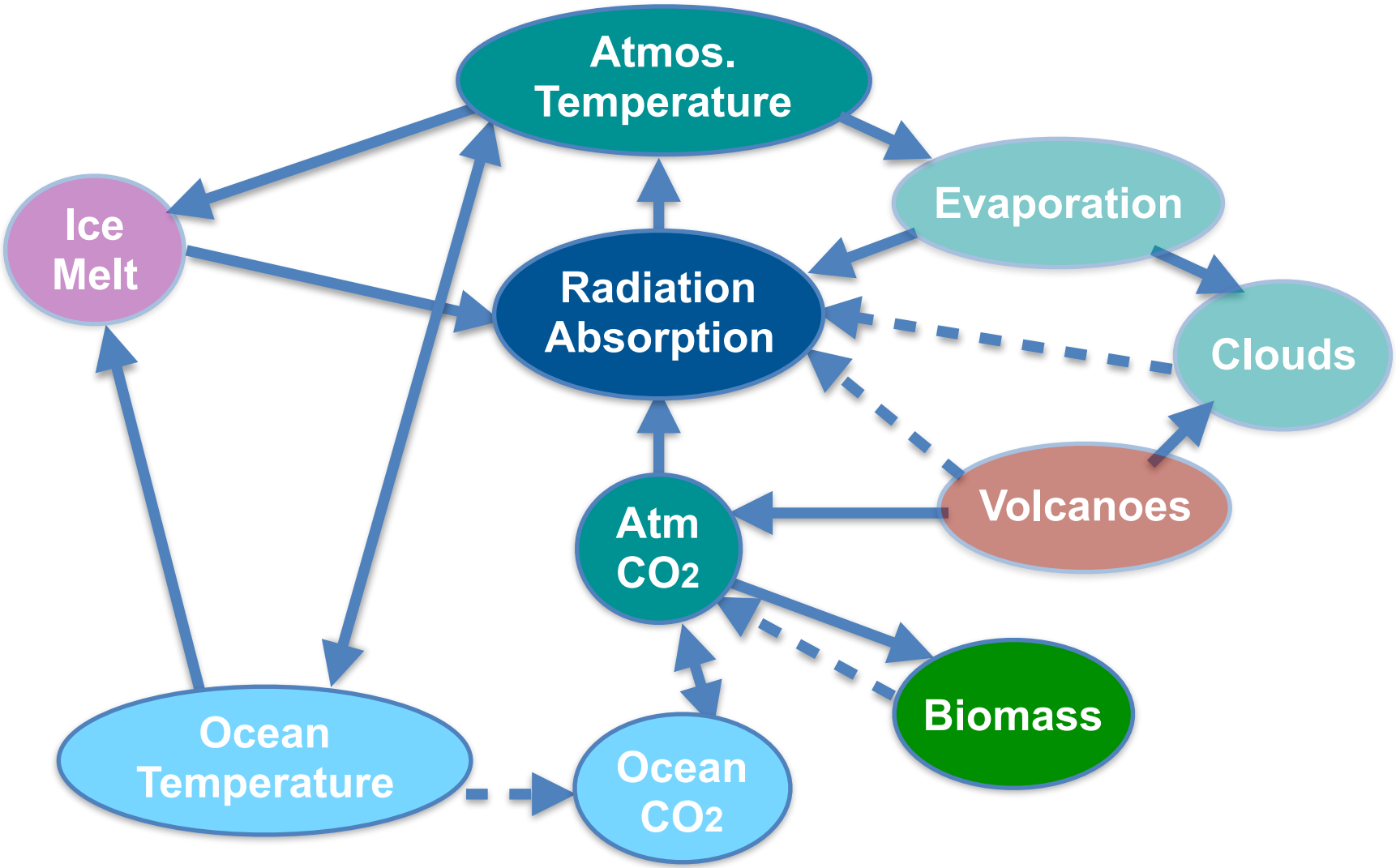


Source: NASA

Past Eruptions Had Global Effects

Image credit: William Ascroft via thepublicdomainreview.org

Feedbacks


Atmos. Temperature
Ice Melt
Evaporation
Radiation Absorption
Clouds
Volcanoes
Atm CO_2
Biomass
Ocean Temperature
Ocean CO_2

Carbon Reservoirs

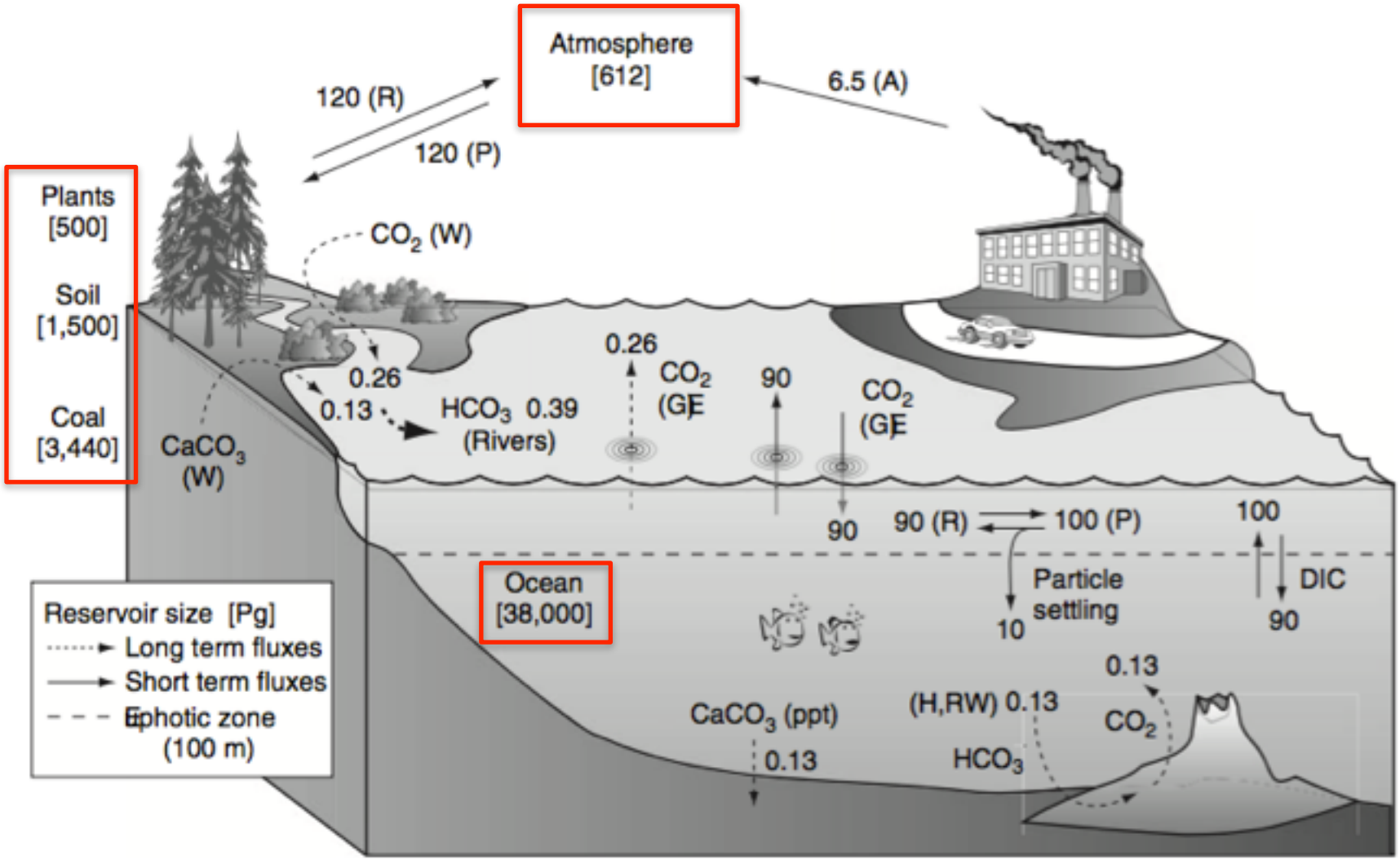
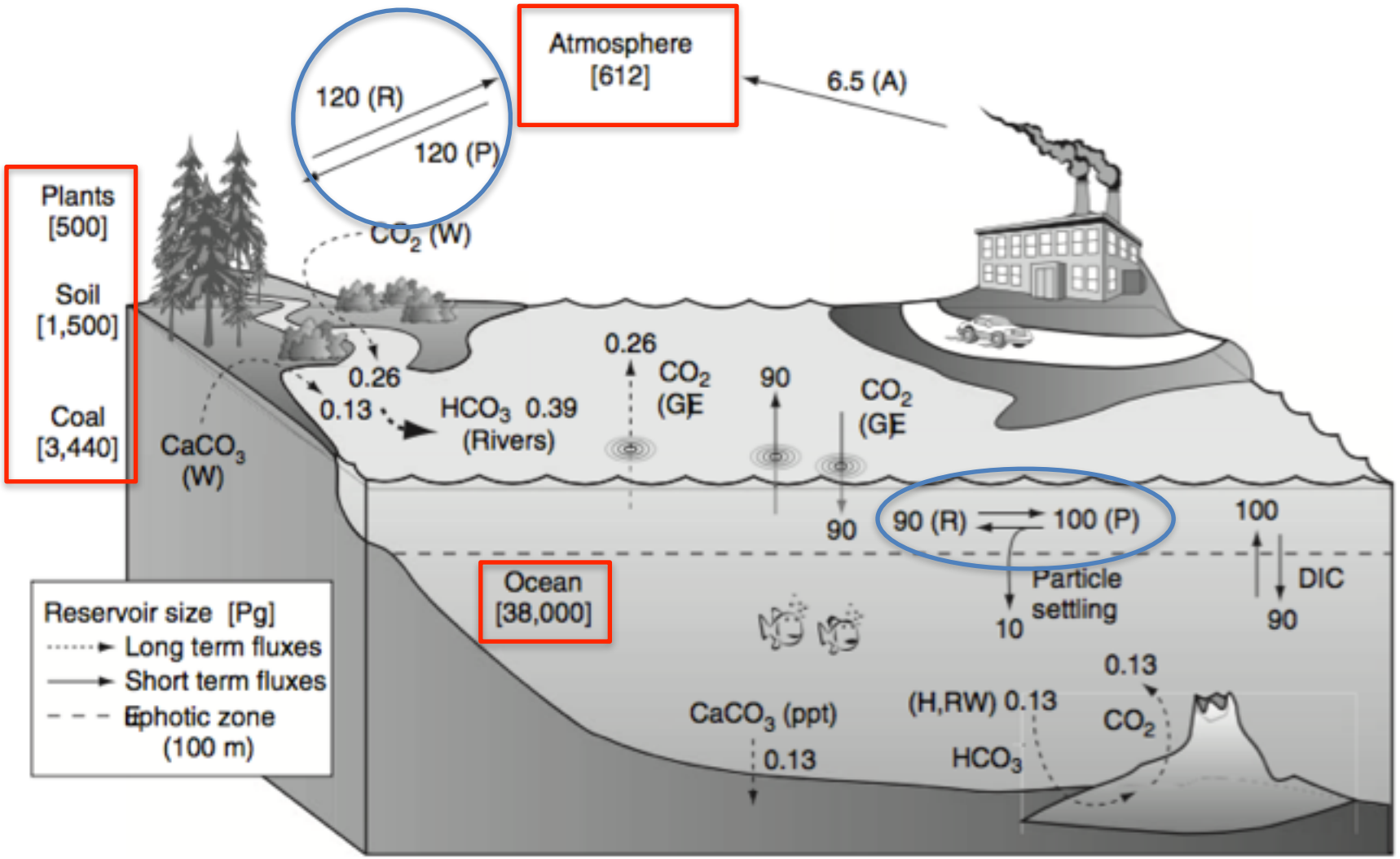


Image credit: Sarmiento and Gruber, Ocean Biogeochemical Dynamics

Carbon Reservoirs



How Does Carbon Get Into the Ocean?

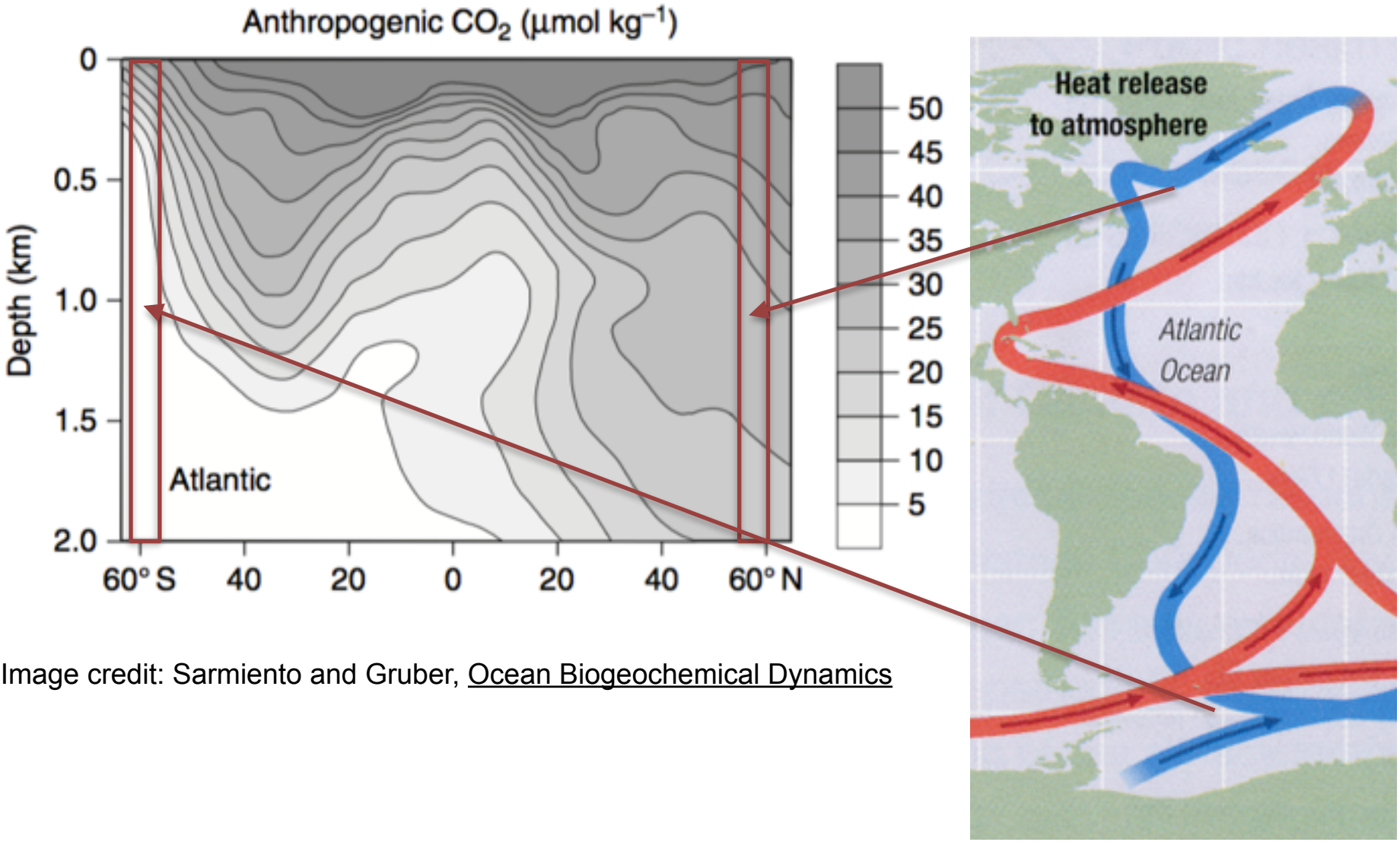
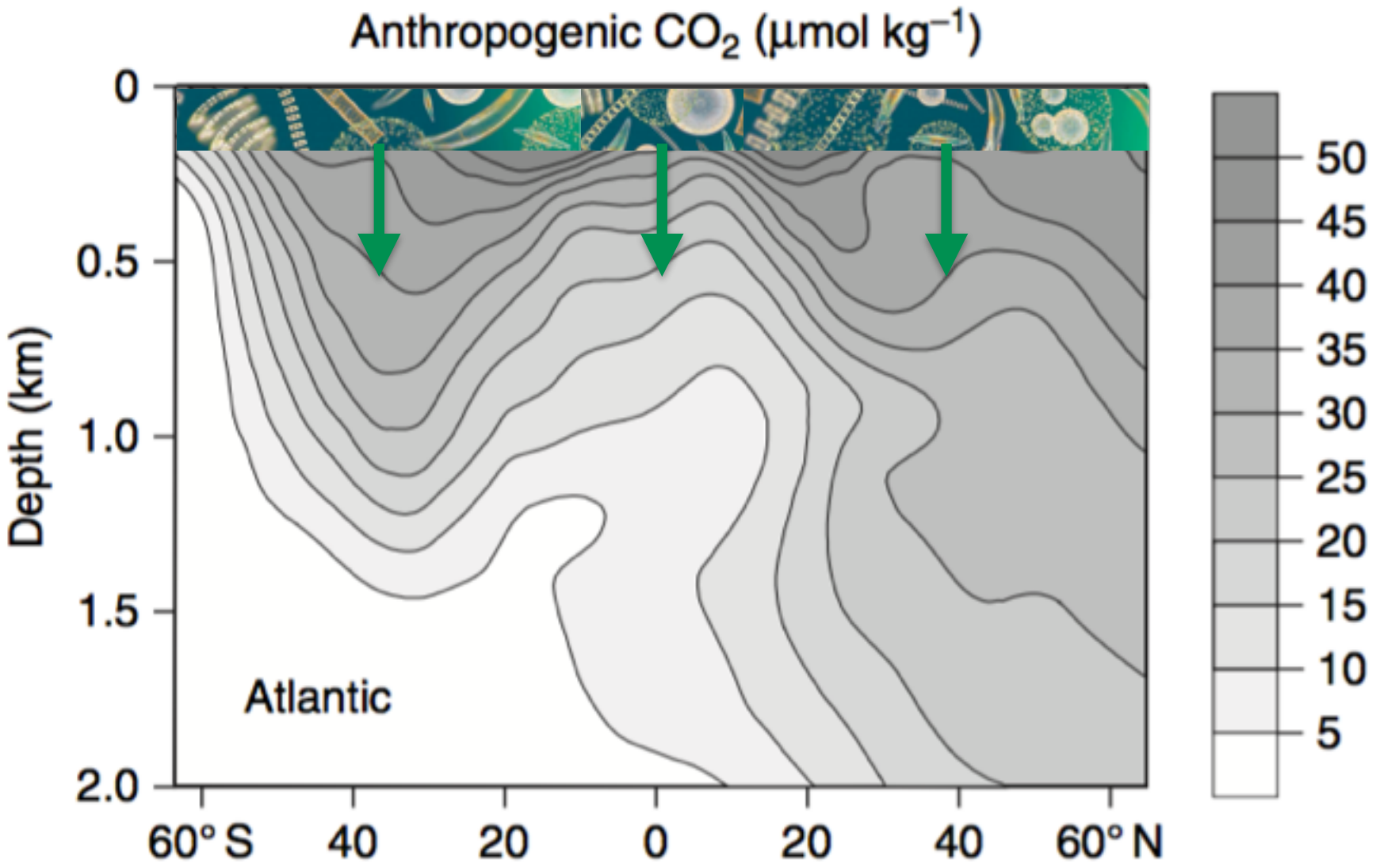
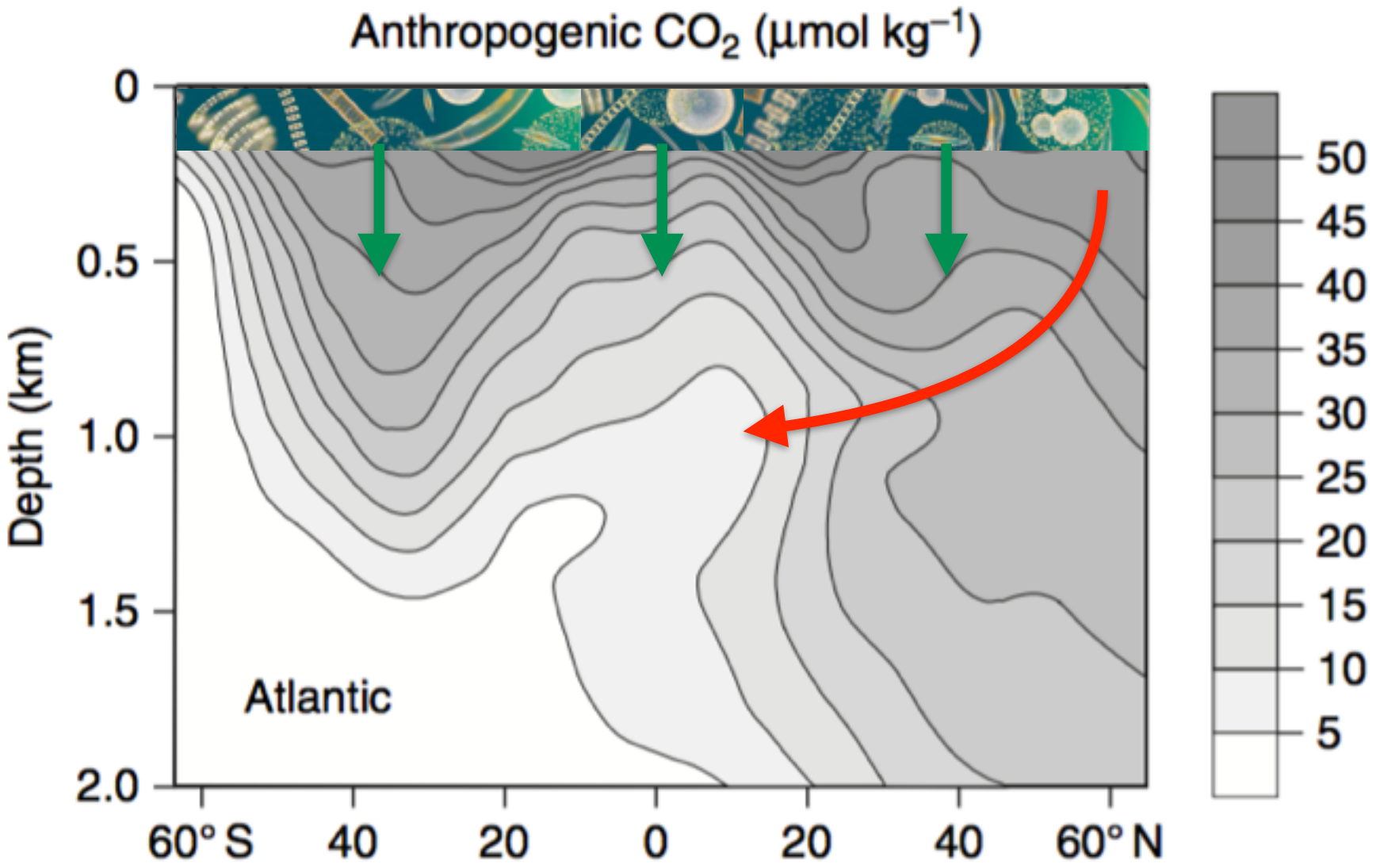


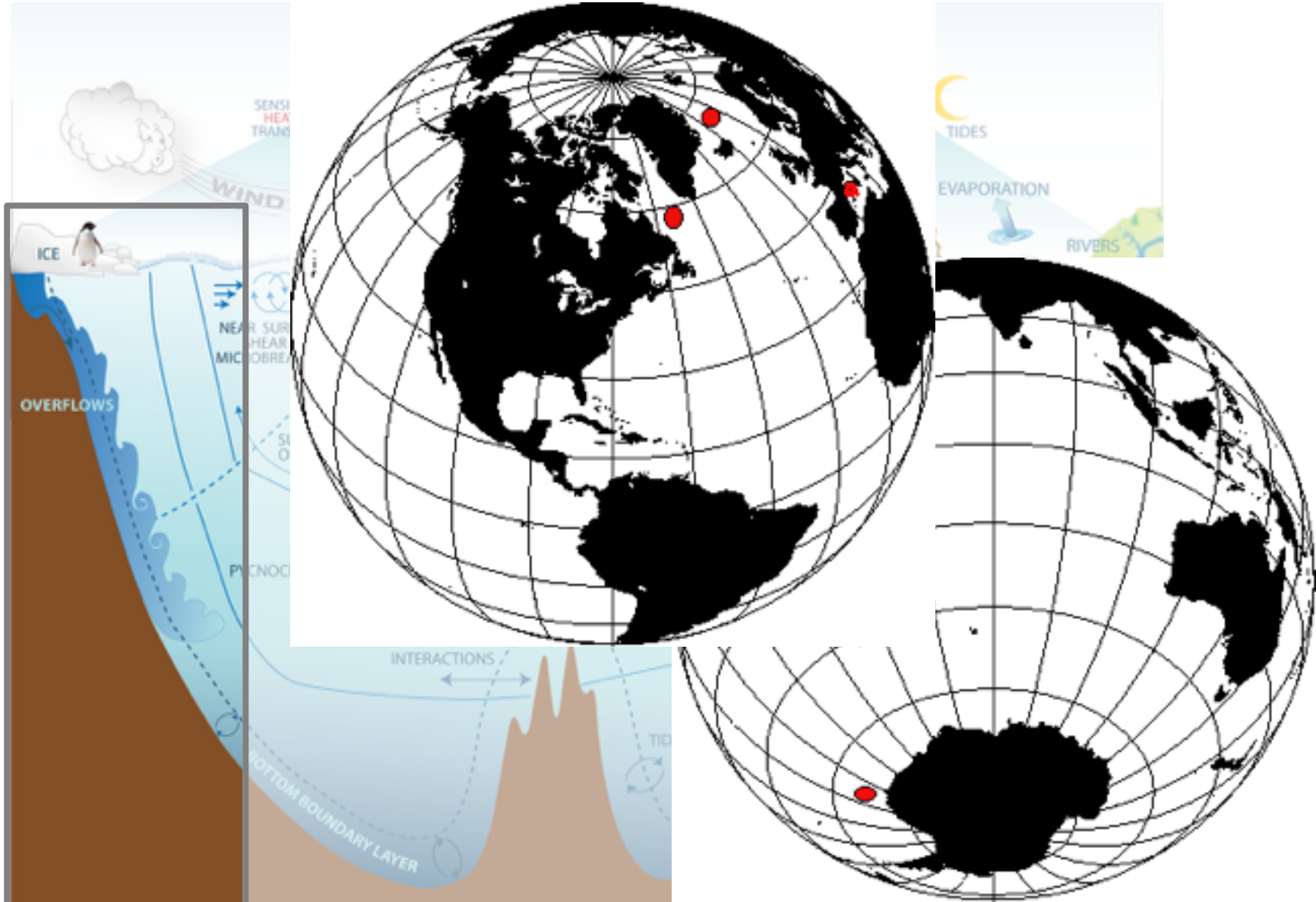
Image credit: Sarmiento and Gruber, Ocean Biogeochemical Dynamics

http://www.geol.umd.edu/sgc/lectures/climatepart2.html

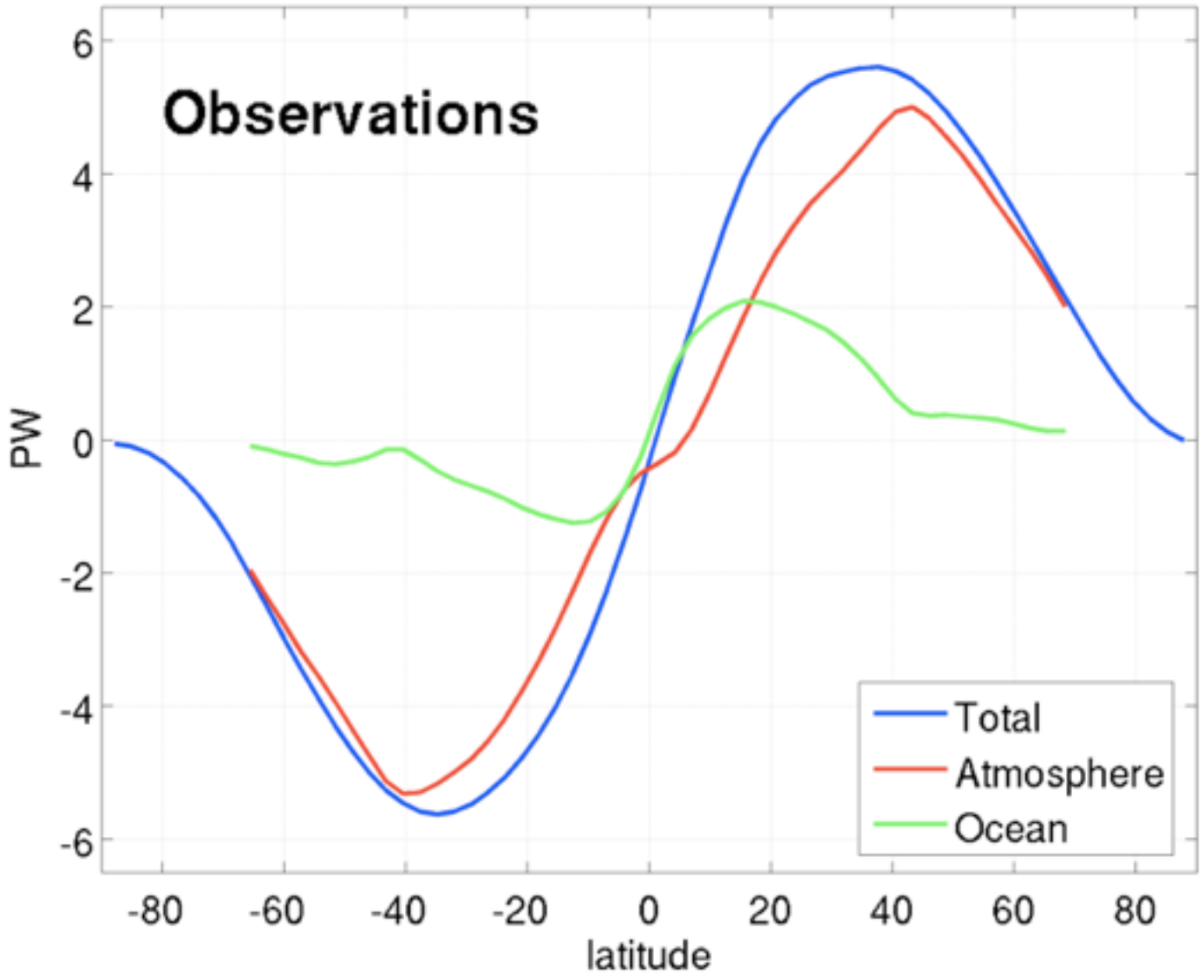

Anthropogenic CO_2 (µmol kg^{-1})
Depth (km)
0
0.5
1.0
1.5
2.0
Atlantic
60° S
40
20
0
20
40
60° N
50
45
40
35
30
25
20
15
10
5


Anthropogenic CO_2 (µmol kg^{-1})
Depth (km)
0
0.5
1.0
1.5
2.0
Atlantic
60° S
40
20
0
20
40
60° N
50
45
40
35
30
25
20
15
10
5

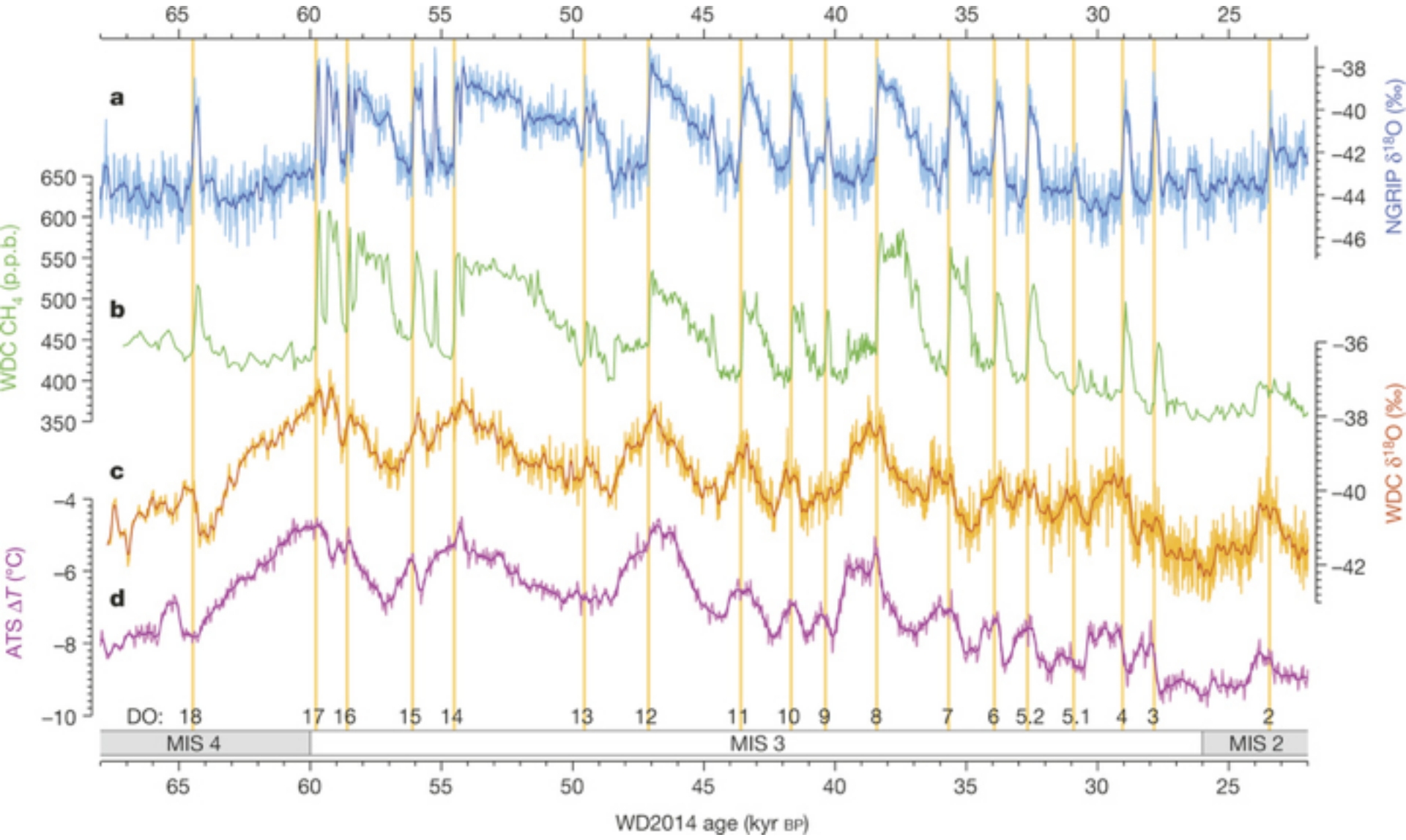
Ocean Circulation



Heat Transport



Abrupt Climate Change

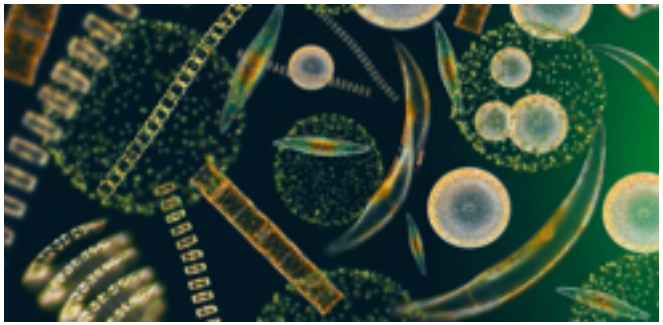


WAIS Divide Project Members, *Nature*, 2015

Timescales

Processes	Time scale (years)	Reactions
Photosynthesis–respiration	$1–10^2$	$6CO_2 + 6H_2O + \text{photons} \rightarrow C_6H_{12}O_6 + 6O_2$ $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{heat}$
Ocean invasion: Seawater buffer	$10–10^3$	$CO_2 + CO_3^{2-} + H_2O \rightleftharpoons 2HCO_3^-$
Reaction with calcium carbonate	$10^3–10^4$	$CO_2 + CaCO_3 + H_2O \rightarrow Ca^{2+} + 2HCO_3^-$
Silicate weathering	$10^4–10^6$	$CO_2 + CaSiO_3 \rightarrow CaCO_3 + SiO_2$

Photosynthesis-respiration



Seawater buffer

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

Timescales

Processes	Time scale (years)	Reactions
Photosynthesis–respiration	$1–10^2$	$6CO_2 + 6H_2O + \text{photons} \rightarrow C_6H_{12}O_6 + 6O_2$ $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{heat}$
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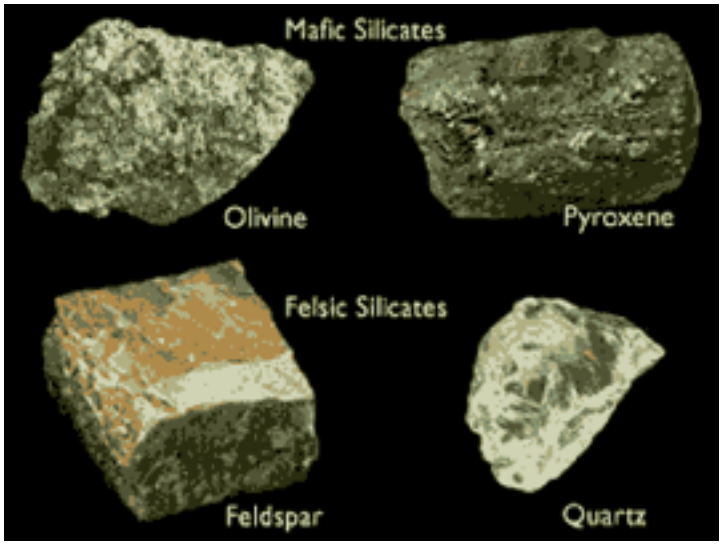
Reaction with calcium carbonate

Silicate weathering



Timescales

Processes	Time scale (years)	Reactions
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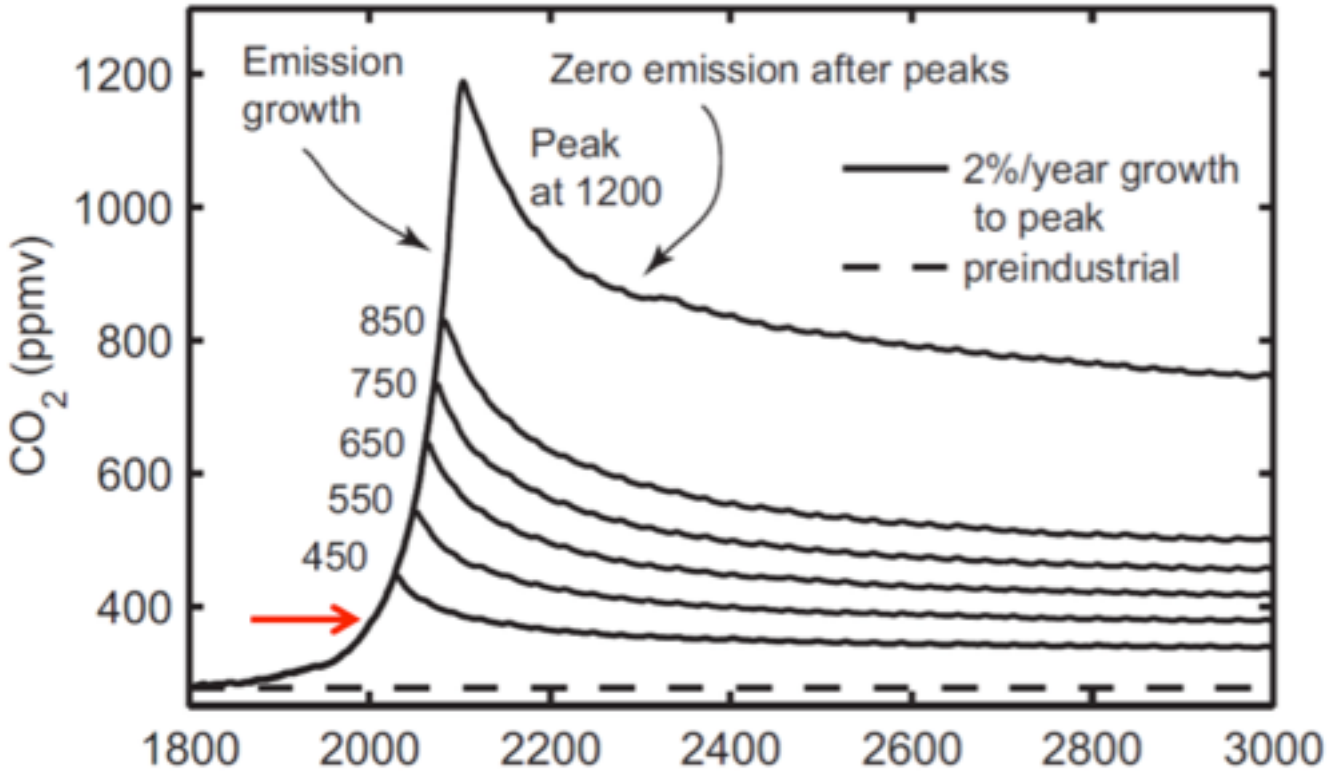
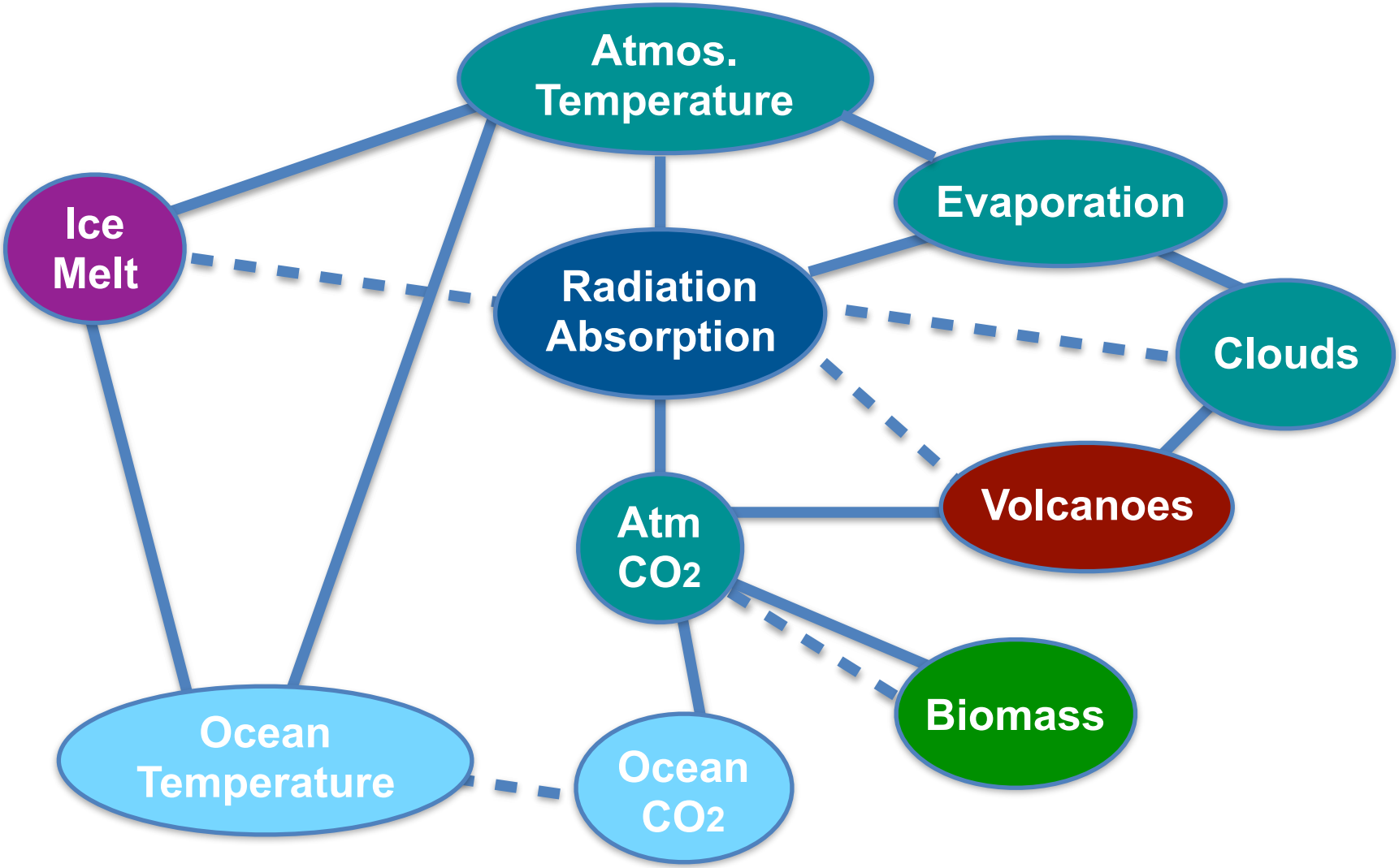
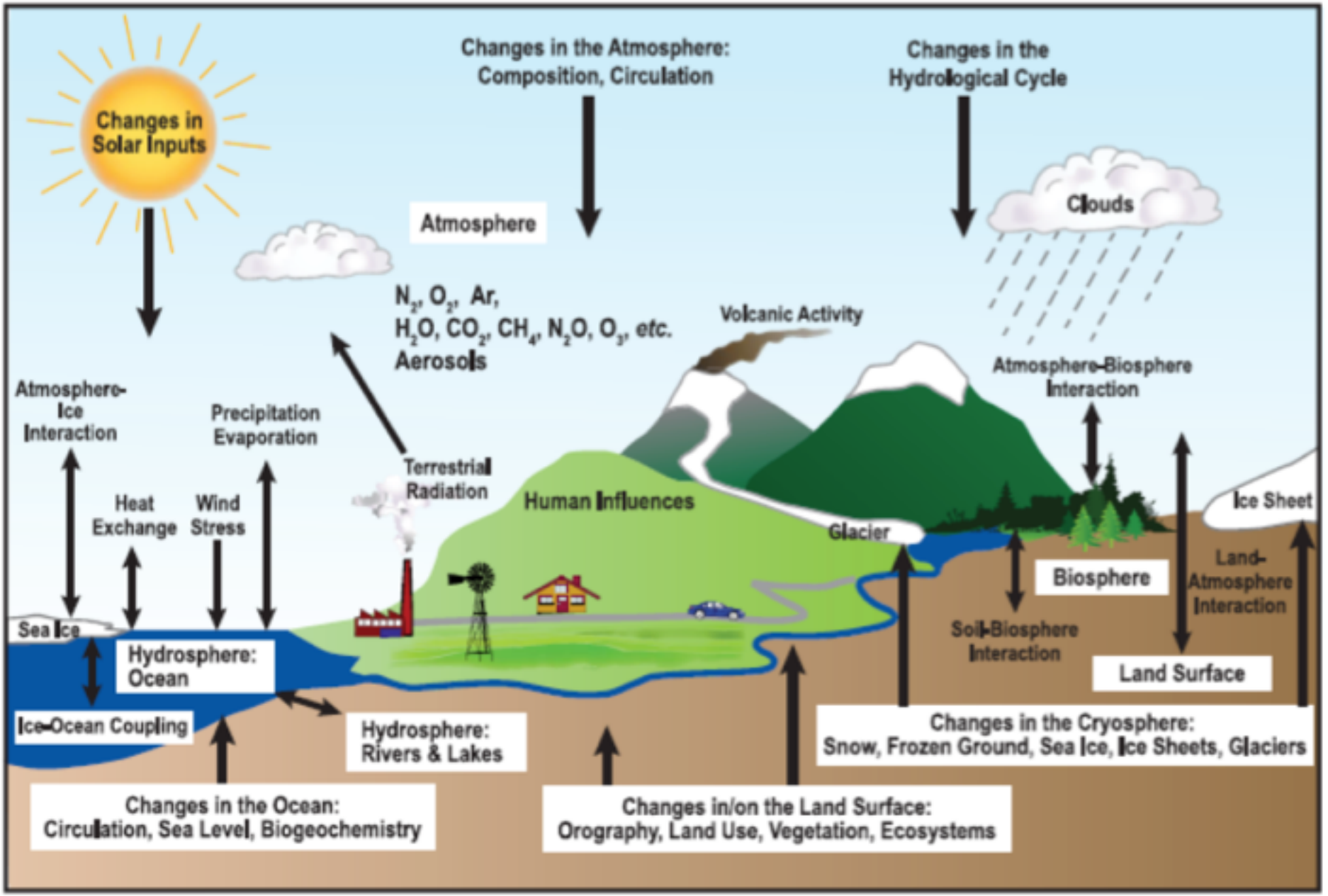


Feedbacks


Atmos. Temperature
Ice Melt
Evaporation
Radiation Absorption
Clouds
Volcanoes
Atm CO_2
Biomass
Ocean Temperature
Ocean CO_2

Summary


Changes in Solar Inputs
Changes in the Atmosphere: Composition, Circulation
Changes in the Hydrological Cycle
Atmosphere
Clouds
N_2, O_2, Ar,
H_2O, CO_2, CH_4, N_2O, O_3, *etc.*
Aerosols
Volcanic Activity
Atmosphere-Biosphere Interaction
Atmosphere-Ice Interaction
Precipitation Evaporation
Terrestrial Radiation
Heat Exchange
Wind Stress
Human Influences
Glacier
Ice Sheet
Biosphere
Land-Atmosphere Interaction
Soil-Biosphere Interaction
Land Surface
Sea Ice
Hydrosphere: Ocean
Ice-Ocean Coupling
Hydrosphere: Rivers & Lakes
Changes in the Cryosphere: Snow, Frozen Ground, Sea Ice, Ice Sheets, Glaciers
Changes in the Ocean: Circulation, Sea Level, Biogeochemistry
Changes in/on the Land Surface: Orography, Land Use, Vegetation, Ecosystems

THU • JAN 21

CLIMATE CHANGE & UNCERTAINTY

E51-315 · 5:30PM–6:30PM · Megan Lickley

In this session we will discuss the sources of uncertainty in climate projections, the range of possible future outcomes, and how that translates into uncertainty in climate impacts both globally and locally. We will cover topics such as the rate of warming, sea level rise, storm activity, and precipitation changes and how uncertainty in these changes make it more challenging to adequately prepare and adapt to climate change.

CLIMATE POLICY IN ACTION

E51-315 · 6:30PM–7:30PM · Interactive Panel Discussion

Local climate science and policy leaders discuss implementing creative solutions to climate change, from community activism to policy at the local and national scale.

FRI • JAN 22

WORLD CLIMATE NEGOTIATIONS SIMULATION

E51-315 · 5:30PM–7:30PM · Interactive Group Project

Designed as part of Climate Interactive's World Climate Project, this activity provides participants with some insight into the challenges of coming to a global climate agreement. Participant groups will represent regions of the world with various goals for mitigation, adaptation, and economic growth, then participate in a mock international climate negotiation. The computer simulation C-ROADS will be used to examine the outcomes of the mock negotiation in real-time.

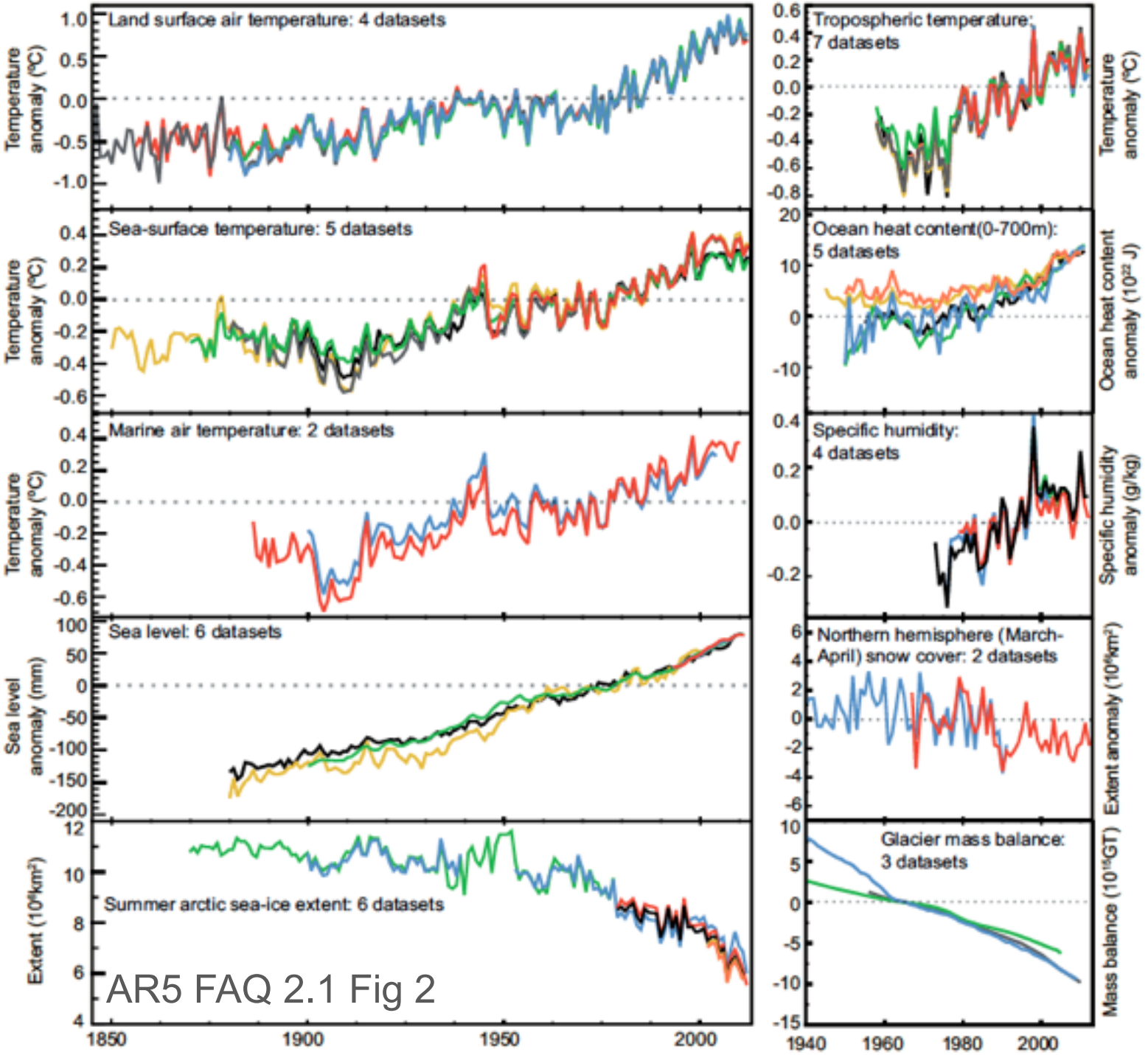
Sunday Jan 24, 6pm: Arlington St Church 351 Boylston St
Tu BiShvat Seder for Palestine, Climate, and Racial Justice

Monday Jan 25, 5:30pm: E51-315 (here!)
Dispatches from Paris: Reflecting on the Climate Talks with COP21 Attendees (RSVP to askmitei-ed@mit.edu)

Monday and Tuesday Jan 25-26, 10am-12pm: E51-085
From Turbines to Tariffs: Technical and Regulatory Issues for Scaling Up Wind Energy

Wednesday Jan 27, 8:30am-5:30pm: MIT 32-123
MIT on Climate = Science + Action

Friday Jan 29, 9am-5pm: MIT 3-415
Hackathon for Climate


Land surface air temperature: 4 datasets
Temperature anomaly (°C)
Sea-surface temperature: 5 datasets
Temperature anomaly (°C)
Marine air temperature: 2 datasets
Temperature anomaly (°C)
Sea level: 6 datasets
Sea level anomaly (mm)
Summer arctic sea-ice extent: 6 datasets
Extent (10⁶km²)
1850
1900
1950
2000
Tropospheric temperature: 7 datasets
Temperature anomaly (°C)
Ocean heat content(0-700m): 5 datasets
Ocean heat content anomaly (10²² J)
Specific humidity: 4 datasets
Specific humidity anomaly (g/kg)
Northern hemisphere (March-April) snow cover: 2 datasets
Extent anomaly (10⁶km²)
Glacier mass balance: 3 datasets
Mass balance (10¹⁵GT)
1940
1960
1980
2000
AR5 FAQ 2.1 Fig 2