CLIMATE CHANGE, CLIMATE ENGINEERING, AND THE GLOBAL HYDROLOGIC CYCLE

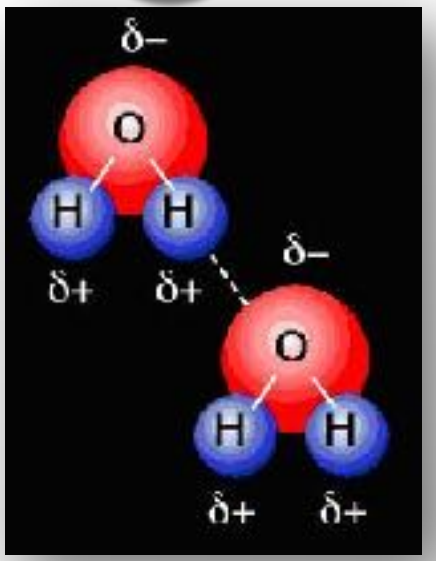
THOMAS ACKERMAN

DEPARTMENT OF ATMOSPHERIC SCIENCES

JOINT INSTITUTE FOR THE STUDY OF THE ATMOSPHERE AND OCEAN

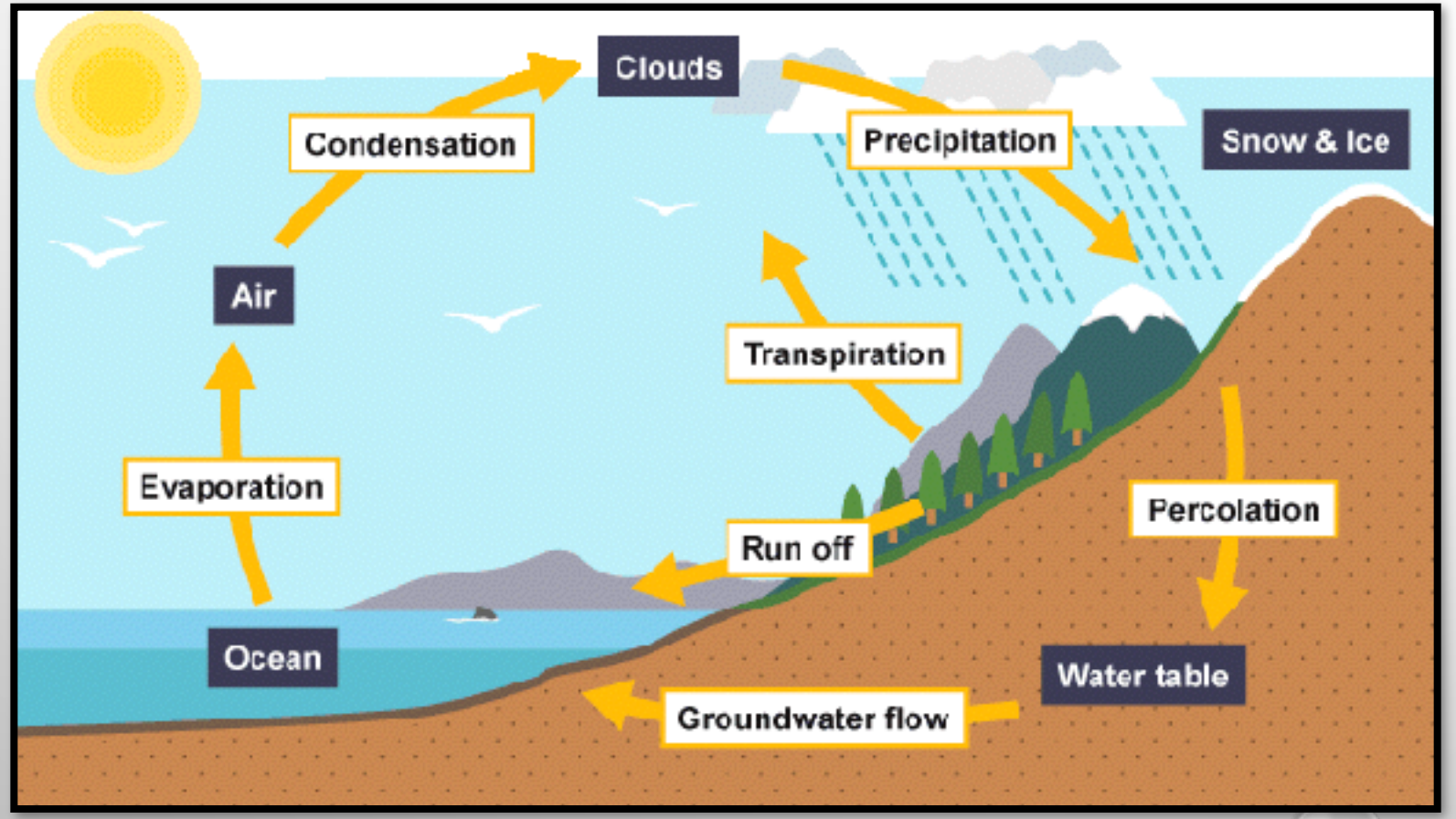
UNIVERSITY OF WASHINGTON, SEATTLE

WHY DO WE CARE SO MUCH ABOUT WATER?



- VITAL FOR LIFE
- MOST IMPORTANT GREENHOUSE GAS – BUFFERS DIURNAL TEMPERATURE CHANGE
- VERY LARGE HEAT CAPACITY AS LIQUID – BUFFERS SEASONAL TEMPERATURE CHANGE
- LARGE LATENT HEAT EFFECTIVELY TRANSPORTS ENERGY ALONG WITH WATER (PRECIPITATION WARMS THE ATMOSPHERE BECAUSE CONDENSATION RELEASES HEAT)
- CLEANSES THE ATMOSPHERE BY DISSOLVING GASES AND SCAVENGING PARTICLES
- VAPOR CONCENTRATIONS IN THE TROPICS ARE ~50-100 TIMES GREATER THAN AT THE POLES, AFFECTS THE EQUATOR-POLE TEMPERATURE GRADIENT

GLOBAL HYDROLOGIC CYCLE

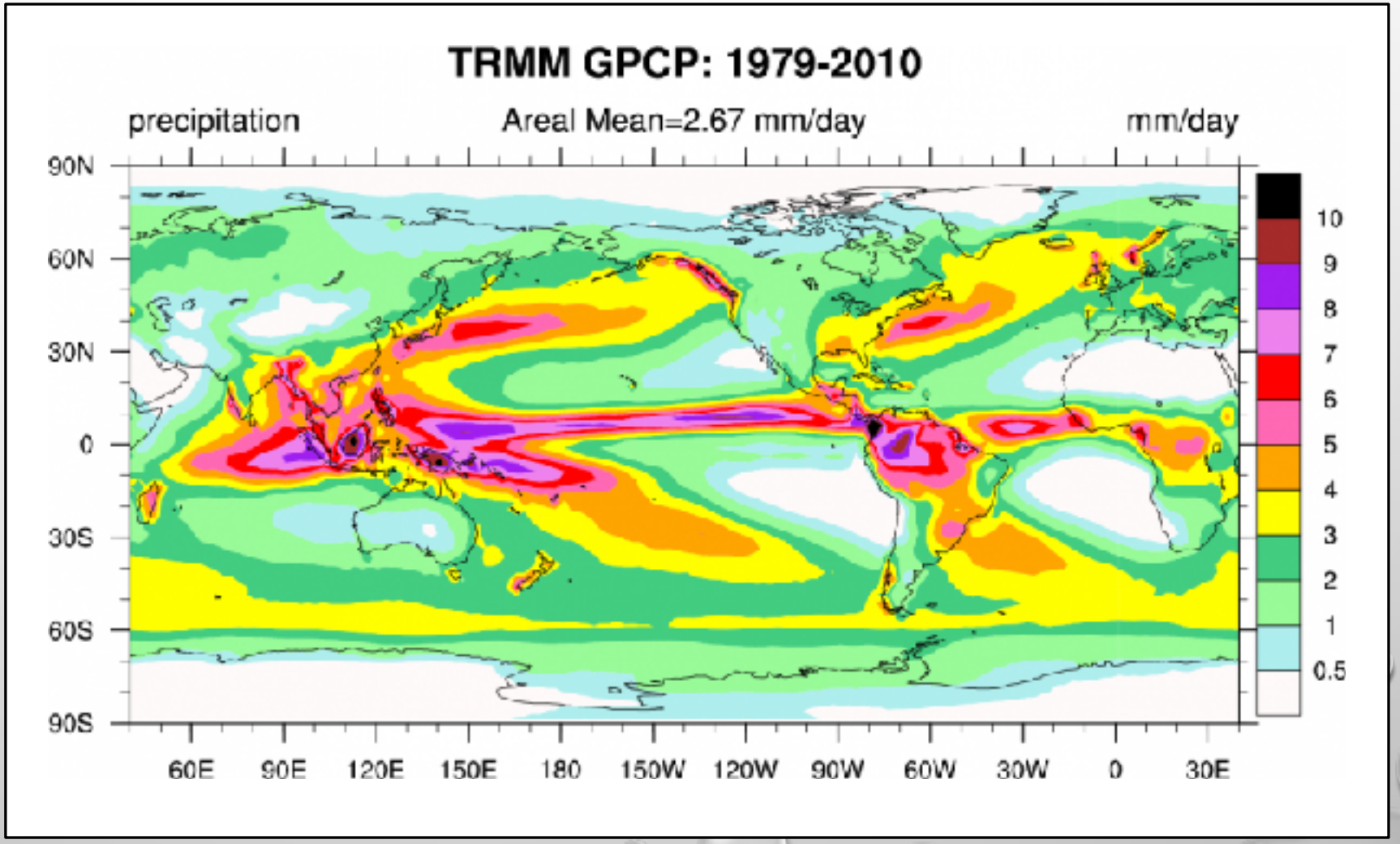


<u>Reservoirs</u>

- Ocean: 97.6%
- Land: 2.4%
- Atmosphere: 0.001%

TRMM satellite – rain radar

- Operated for 17 years
- Terminated in 2015
- Replaced with GPM satellite



76% of the rainfall occurs over the ocean

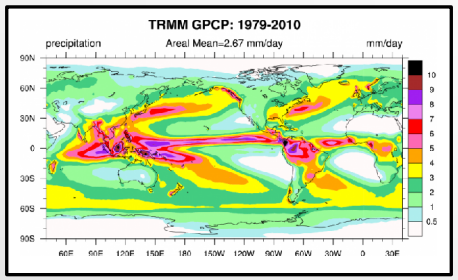
Global Annual Precipitation

More than 200 in.

More than 80 in.

Less than 5 in.

CLIMATE CHANGE
HOW DO WE SIMULATE THE FUTURE?



Compare model output to data

Build a model

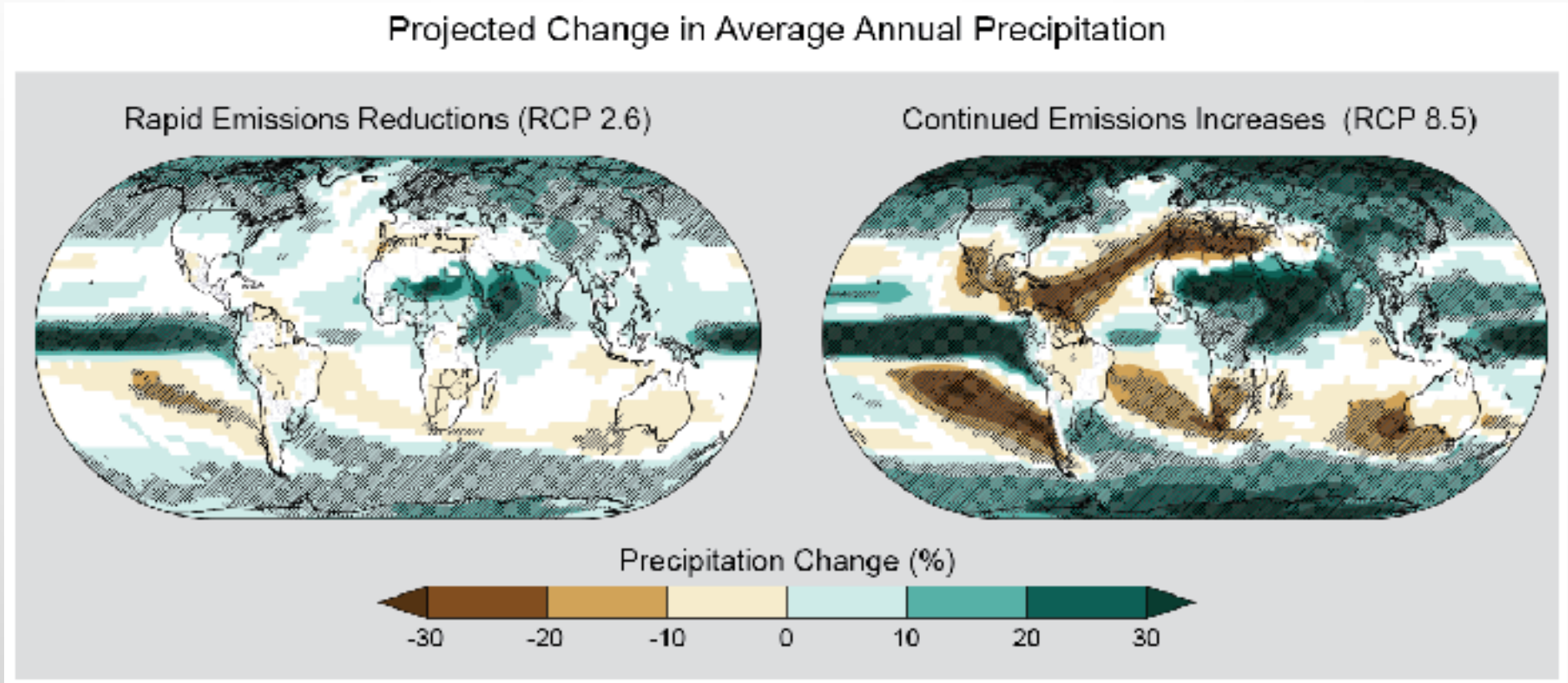
Apply a scenario
Run global model
for ~100 years

Run high-resolution model over limited region (like USA)

Compare results from multiple models; look for agreement

SCENARIOS

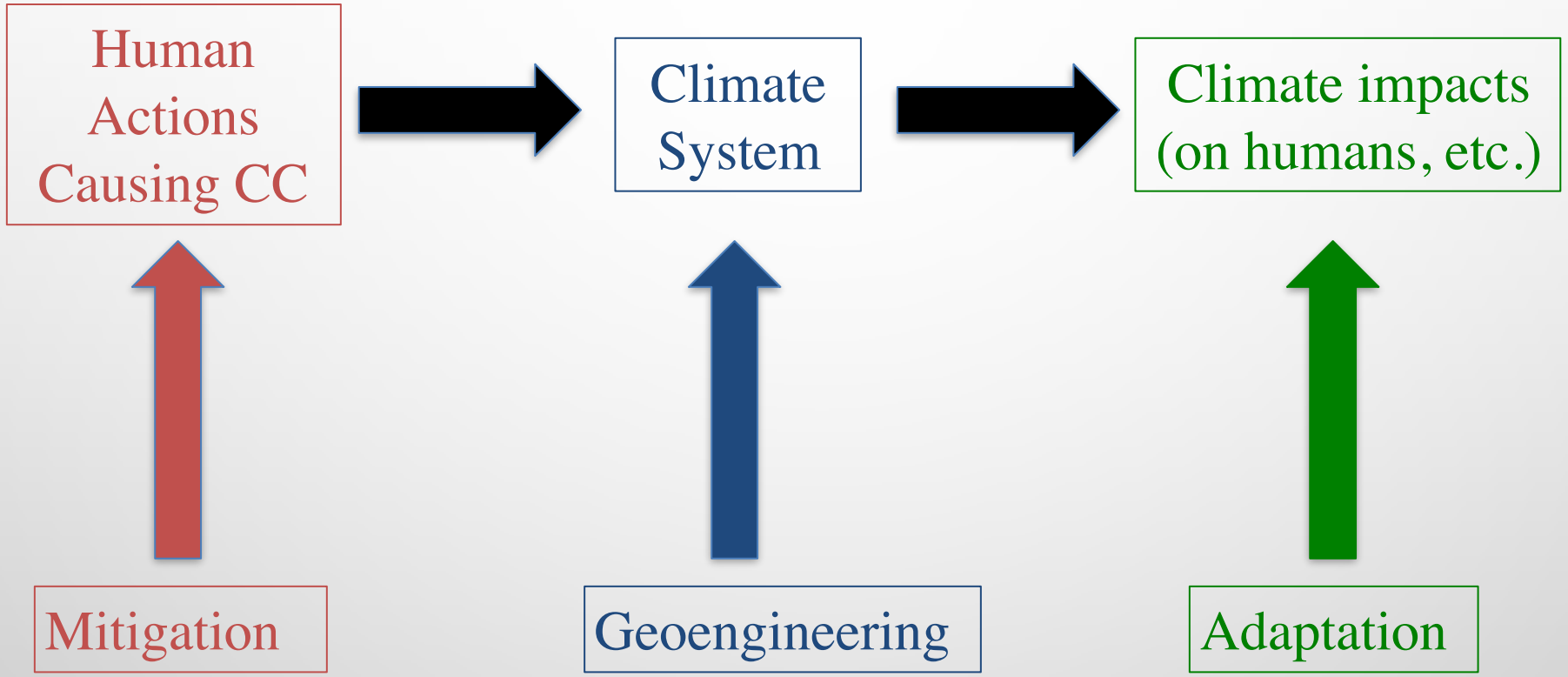
- CHANGES IN GREENHOUSE GAS CONCENTRATIONS BASED ON ASSUMED CHANGES IN ENERGY USE AND CONSUMPTION OF FOSSIL FUELS
- SCENARIOS ARE MEANT TO BE ILLUSTRATIVE, NOT PREDICTIVE
- TWO SCENARIOS SHOWN HERE
  - RCP 8.5: ASSUMES CONTINUED INCREASE IN FOSSIL FUEL USE PROPORTIONAL TO CURRENT GROWTH IN PER PERSON USAGE AND GROWTH IN POPULATION
  - RCP 2.6: ASSUMES SUBSTANTIAL DECREASE IN FOSSIL FUEL USE – GREATER REDUCTIONS THAN AGREED UPON IN PARIS ACCORD

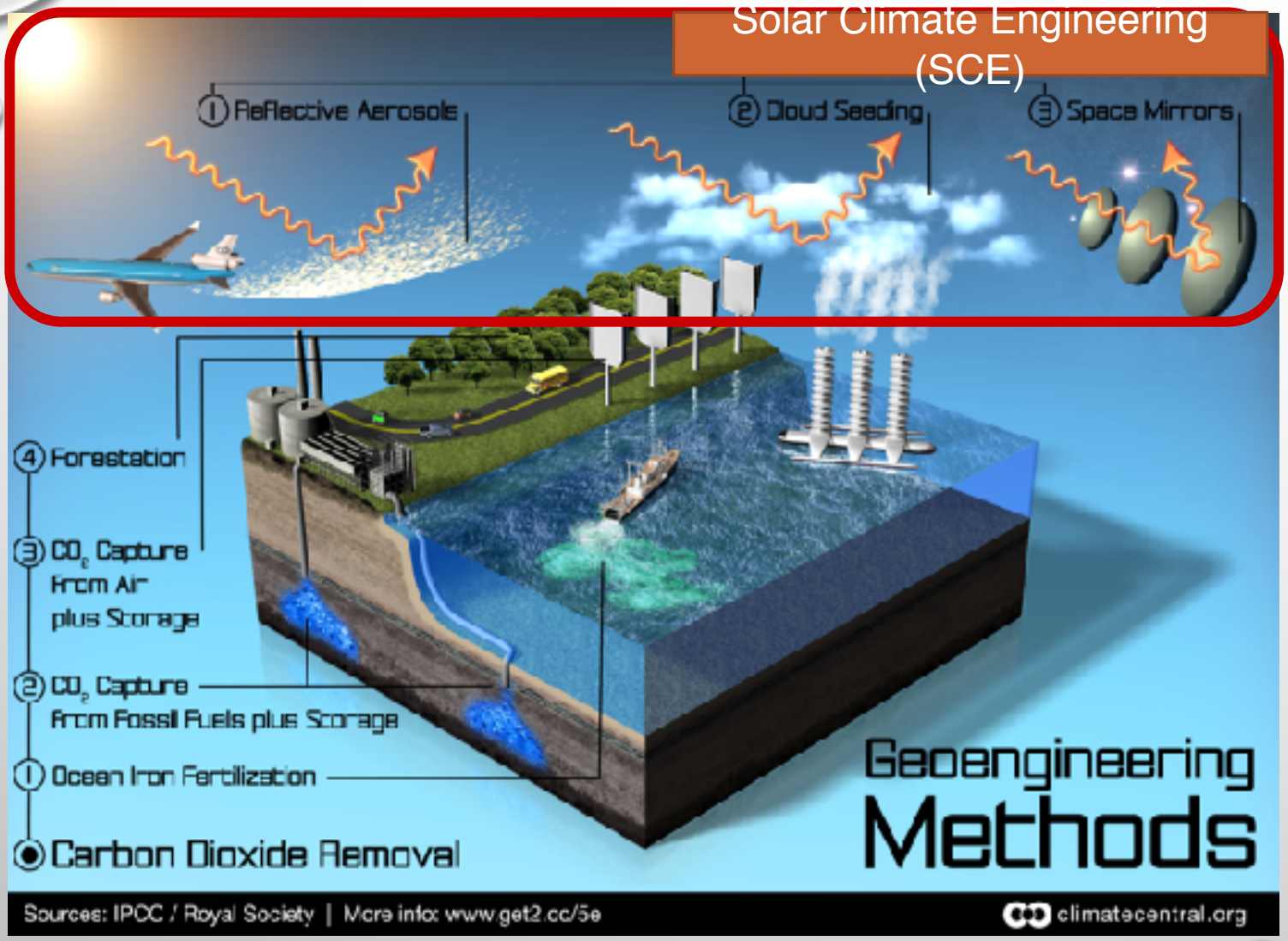


Wet get wetter and dry get dryer

WHAT WE KNOW ABOUT HYDROLOGIC CHANGES

- INCREASING GREENHOUSE GAS CONCENTRATIONS PRODUCE A WARMER CLIMATE
- A WARMER CLIMATE HAS AN ENHANCED WATER CYCLE – WARMER ATMOSPHERE HAS HIGHER WATER VAPOR CONCENTRATION
- WET PLACES GET WETTER AND DRY PLACES GET DRYER BECAUSE OF INTENSIFIED CIRCULATION
- TENDENCY FOR ENHANCED DROUGHT (LONGER PERIODS) AND MORE INTENSE RAIN
- SNOW PACKS DECREASE BECAUSE ATMOSPHERE IS WARMER SO TRANSITION FROM RAIN TO SNOW OCCURS AT HIGHER ALTITUDE
- ALL OF THIS WILL LEAD TO INCREASED COMPETITION FOR WATER RESOURCES


Human Actions Causing CC
Climate System
Climate impacts (on humans, etc.)
Mitigation
Geoengineering
Adaptation



What if we try to manage climate?

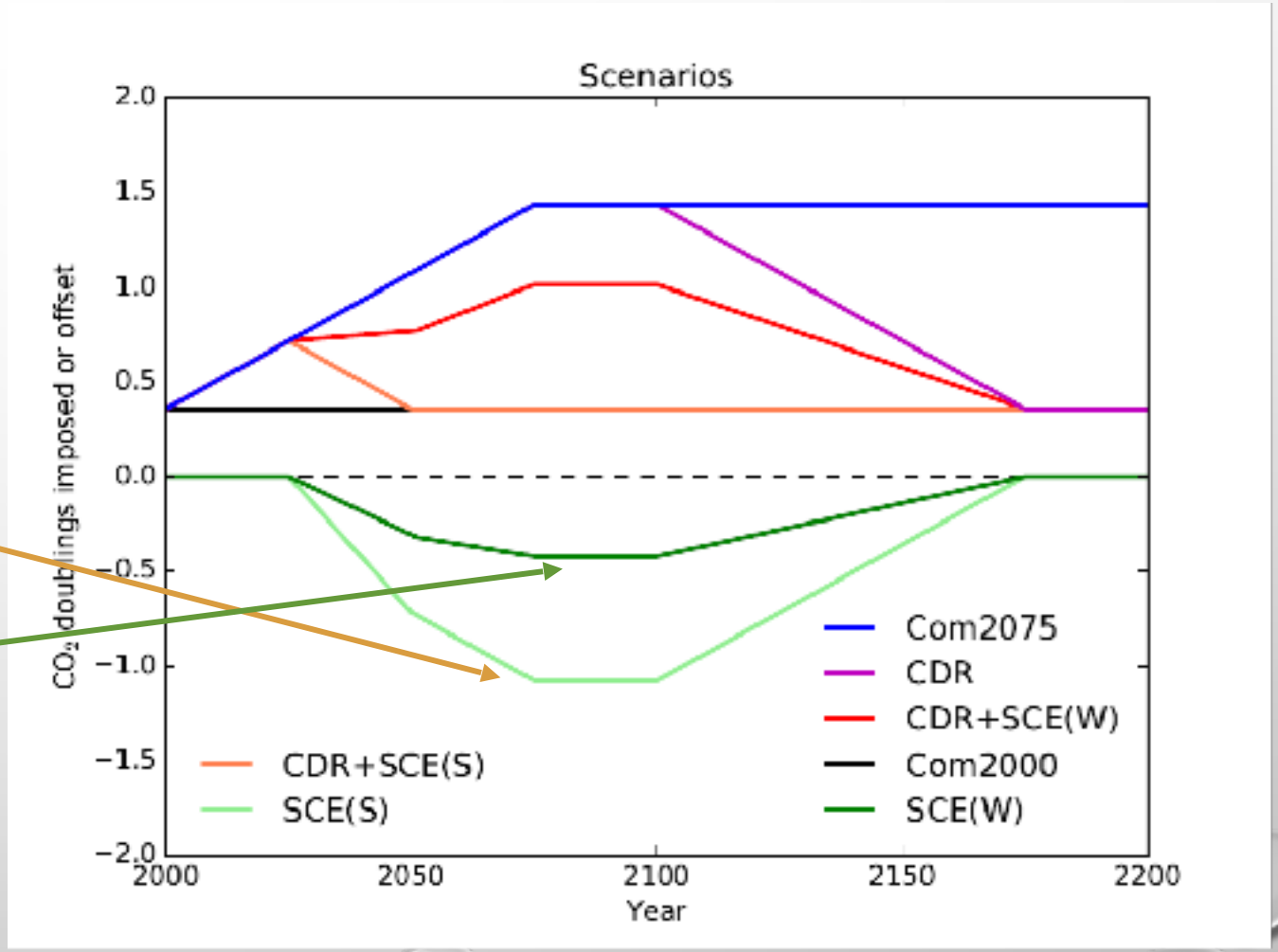
Engineer climate to compensate for global warming?

FORCING SCENARIOS

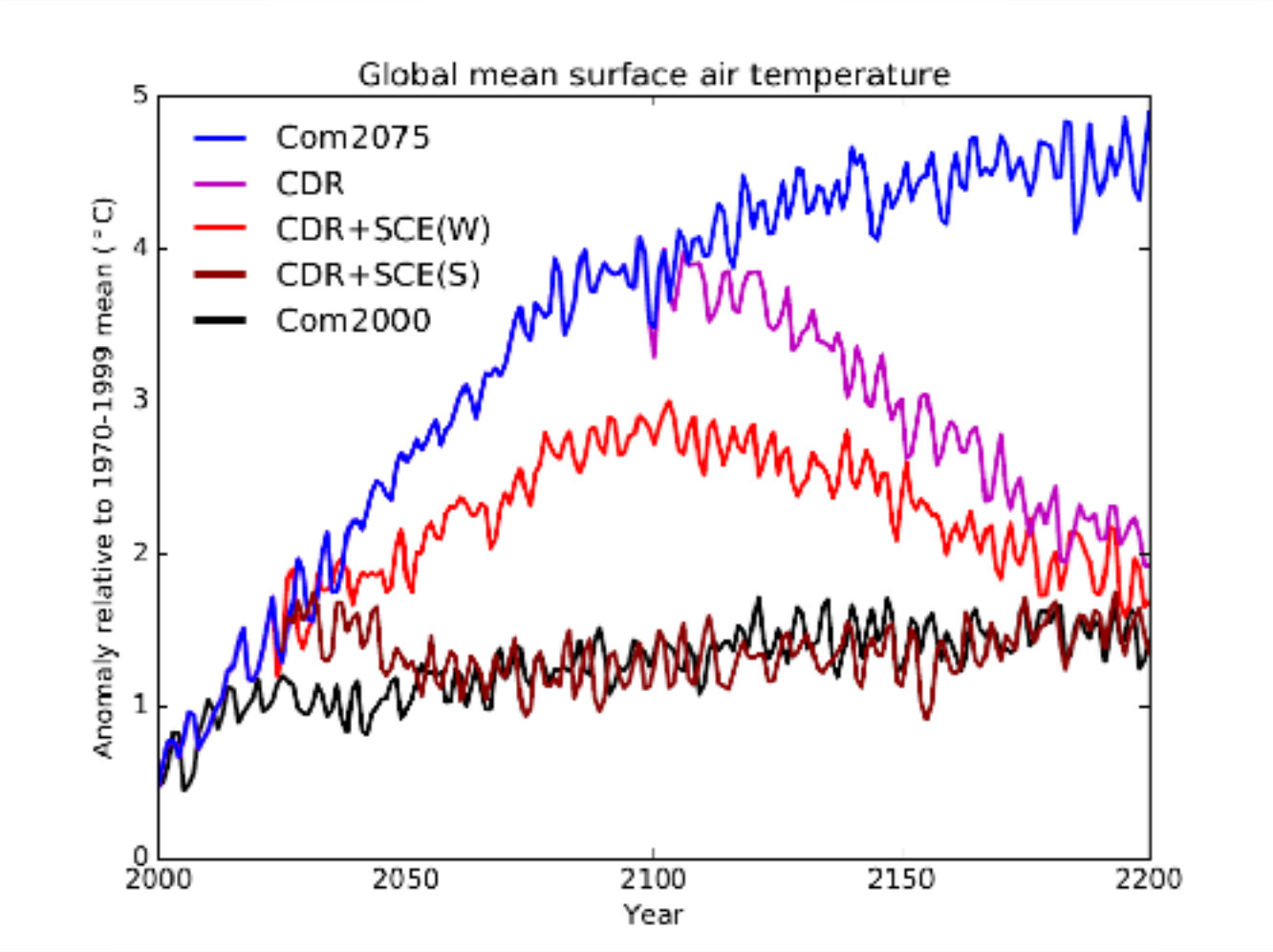
Max. CO_2 concentration = 778 ppm

Max. solar reduction = 2.5% (Strong case)

Max. solar reduction = 1.0% (Weak case)

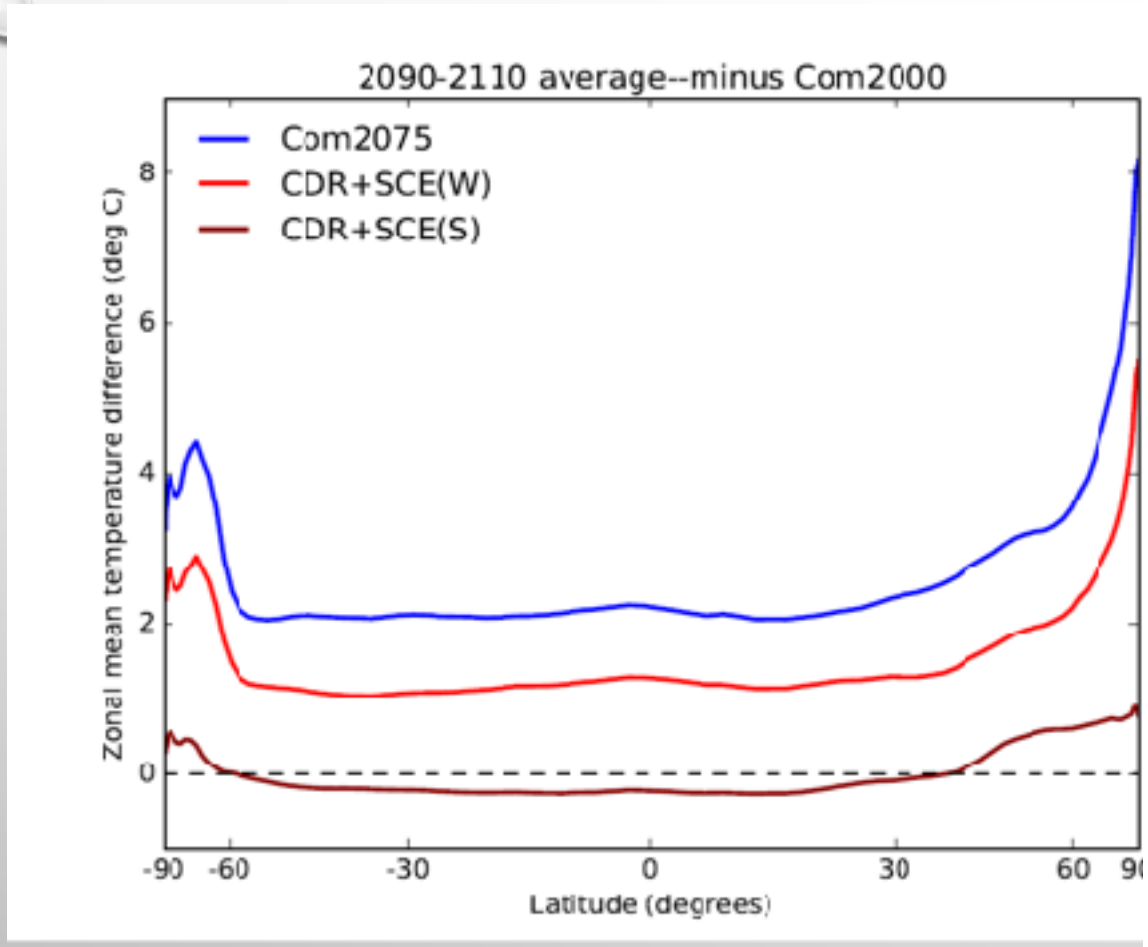


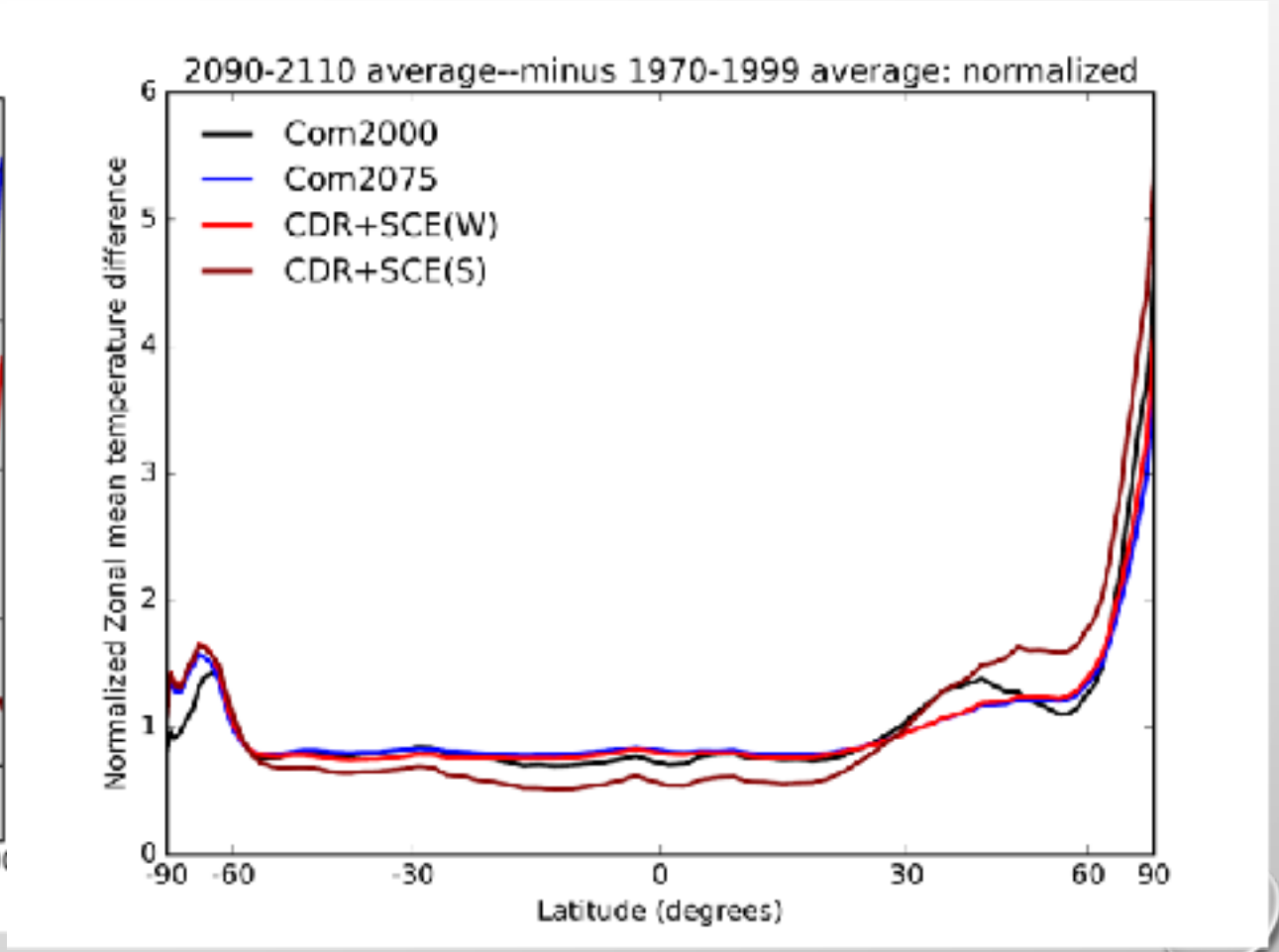
GLOBAL MEAN TEMPERATURE



T_{sfc} as anomaly relative to 1970-99 mean

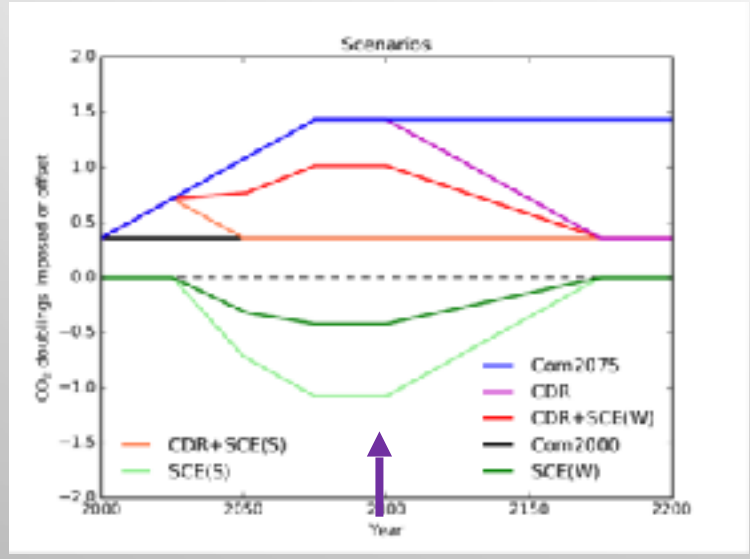
ZONAL MEAN TEMPERATURE DIFFERENCES

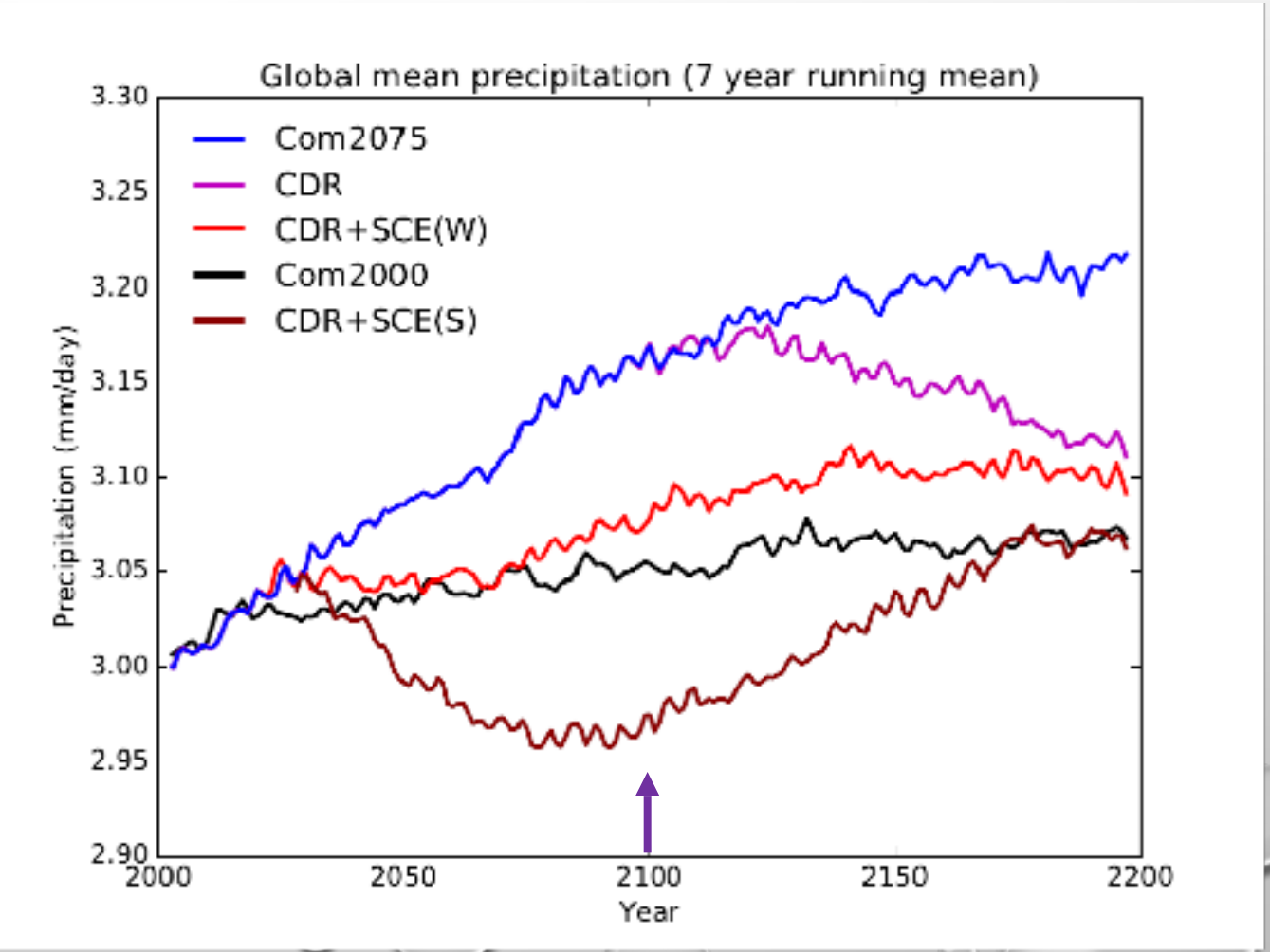




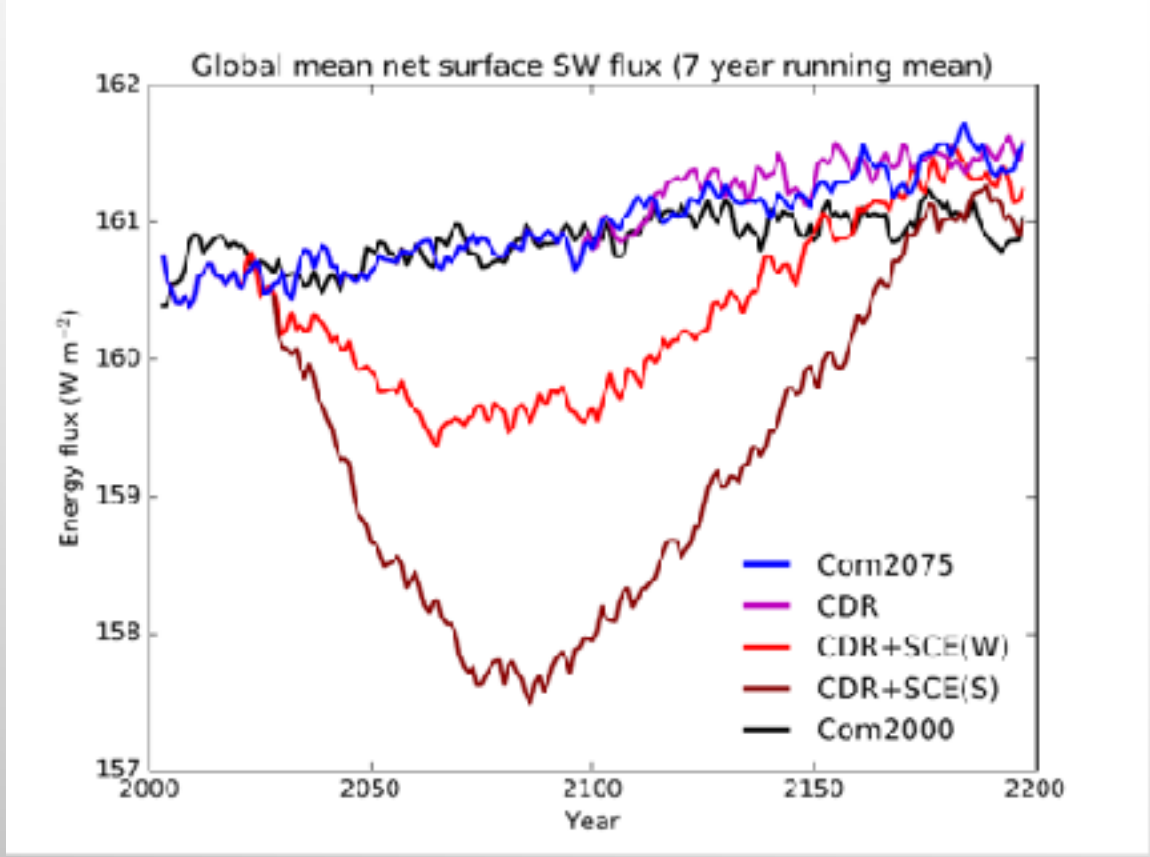
GLOBAL MEAN PRECIPITATION

- PRECIPITATION INCREASES WITH INCREASED CO_2
- SCE *OVER*COMPENSATES – SLOWS HYDROLOGIC CYCLE EVEN THOUGH T_{SFC} SAME

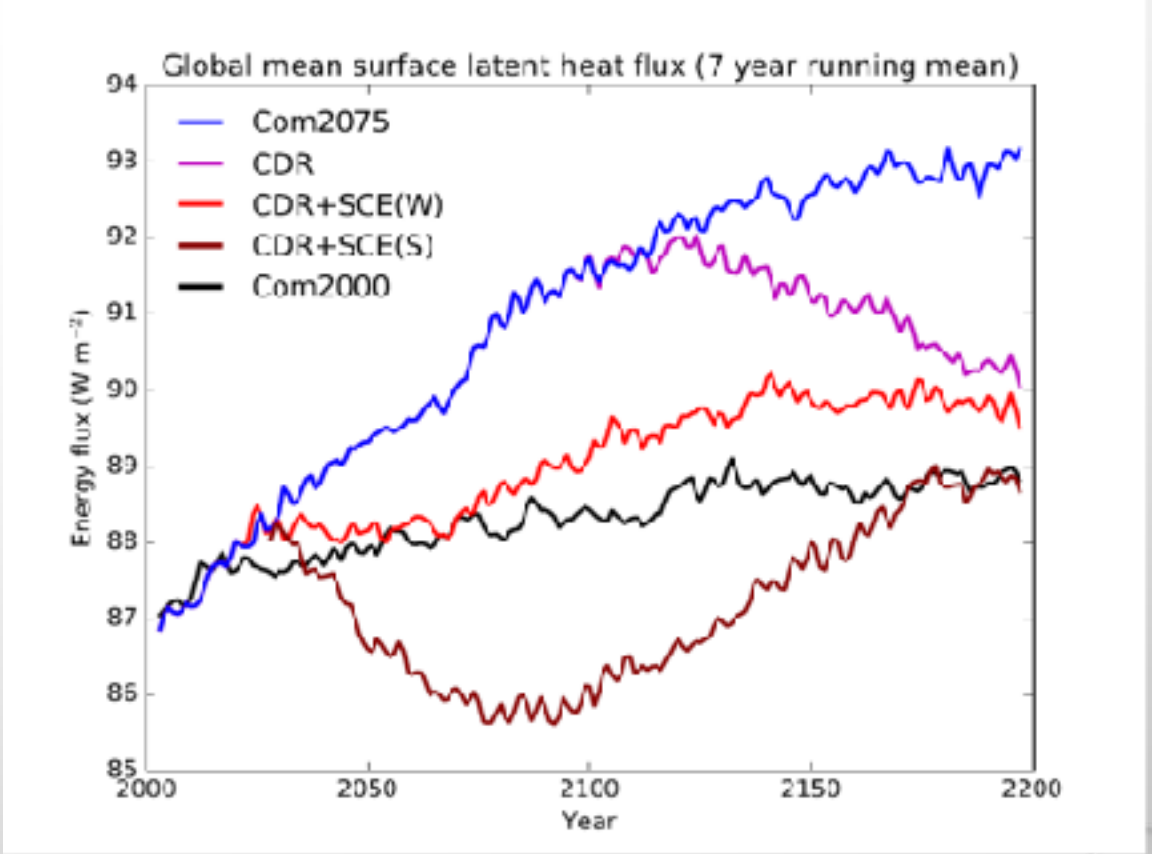




SURFACE SOLAR AND LATENT HEAT FLUXES



Shortwave flux (positive downward)



Latent heat flux (positive upward)

LESSONS LEARNED ABOUT SOLAR CLIMATE ENGINEERING

- SCE CAN BE USED TO REDUCE CLIMATE WARMING WHILE WAITING FOR CDR TO TAKE PLACE => *THERE MAY BE A ROLE FOR SCE*
- SCE HAS A LARGER IMPACT ON THE HYDROLOGIC CYCLE THAN ON TEMPERATURE
  - LARGEST CHANGES IN T ARE IN POLAR REGIONS; LARGEST CHANGES IN PRECIPITATION ARE IN TROPICS
- REDUCTION IN SOLAR RADIATION REDUCES EVAPORATION OVER OCEAN AND SLOWS THE HYDROLOGIC CYCLE

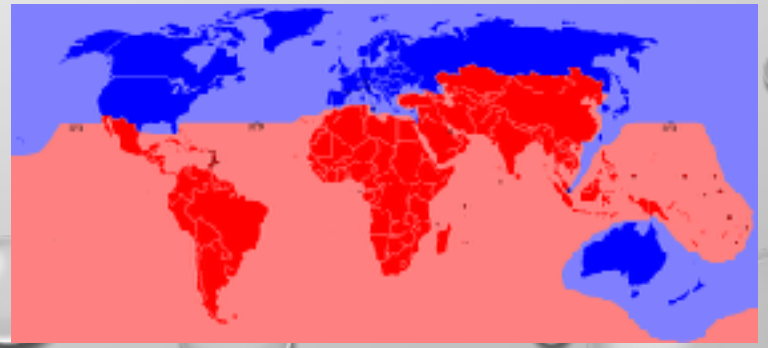
REFRAMING THE PROBLEM

LINKAGES

- SCIENCE IS TIED TO ETHICS – SOME ETHICAL ARGUMENTS SUGGEST NO RESEARCH ON CLIMATE ENGINEERING SHOULD EVER BE DONE
- SCIENCE IS TIED TO GOVERNANCE – ANY SUGGESTED EXPERIMENT IMMEDIATELY BRINGS CALLS FOR CONTROL AND RESTRICTION
- ETHICS IS TIED TO SCIENCE – DIFFERENT ETHICAL ARGUMENTS PERTAIN TO SMALL-SCALE RESEARCH, LARGE-SCALE TESTS, AND DEPLOYMENT
- GOVERNANCE AND ETHICS ARE HIGHLY LINKED – HOW TO DO IT IS COUPLED WITH WHAT YOU THINK SHOULD BE DONE

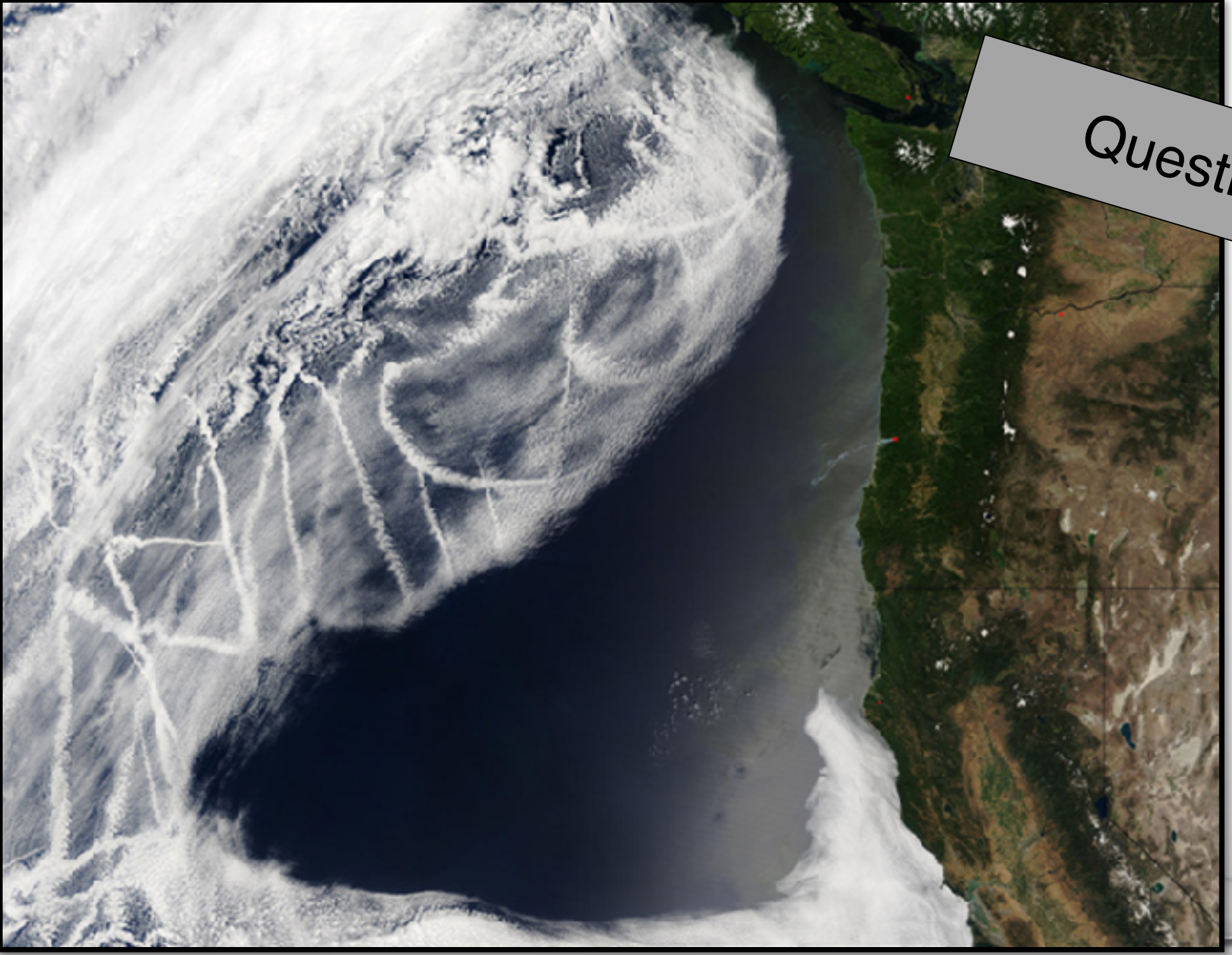
SOME ETHICAL ISSUES

- INTENT → IS SOLAR CLIMATE ENGINEERING ETHICALLY DIFFERENT THAN EMITTING CO2?
- MORAL HAZARD → DOES SCE OFFER PEOPLE A TECHNOLOGICAL OUT?
- LESSER OF TWO EVILS → IS SCE LESS "EVIL" THAN CO2 GROWTH? CRITERIA?
- TRAGEDY OF DISPROPORTIONATE EFFECTS → THOSE WHO SUFFER THE MOST CONTRIBUTE LEAST TO THE PROBLEM
- JUSTICE FOR FUTURE GENERATIONS → WHAT ARE WE LEAVING TO SUCCEEDING GENERATIONS
- GOVERNANCE → WHO MAKES THE DECISIONS? HOW?



SOME THOUGHTS TO PONDER

- INCREASING GLOBAL TEMPERATURE WILL ALTER THE HYDROLOGIC CYCLE
  - SOME EFFECTS ARE PREDICTABLE, OTHERS LESS SO
- CHANGING WATER AVAILABILITY WILL LEAD TO COMPETITION AMONG SOCIETAL VALUES AND LIKELY POLITICAL AND SOCIAL CONFLICT
- GEOENGINEERING OFFERS THE POSSIBILITY OF PREVENTING THESE SHIFTS BUT RAISES DIFFICULT ETHICAL AND GOVERNANCE ISSUES
- THE CHRISTIAN COMMUNITY SHOULD PLAY AN IMPORTANT ROLE IN THIS ETHICAL DEBATE BUT SO FAR IS LARGELY MISSING FROM THE DISCUSSION



Questions?

Ship tracks in low clouds over the Pacific Ocean

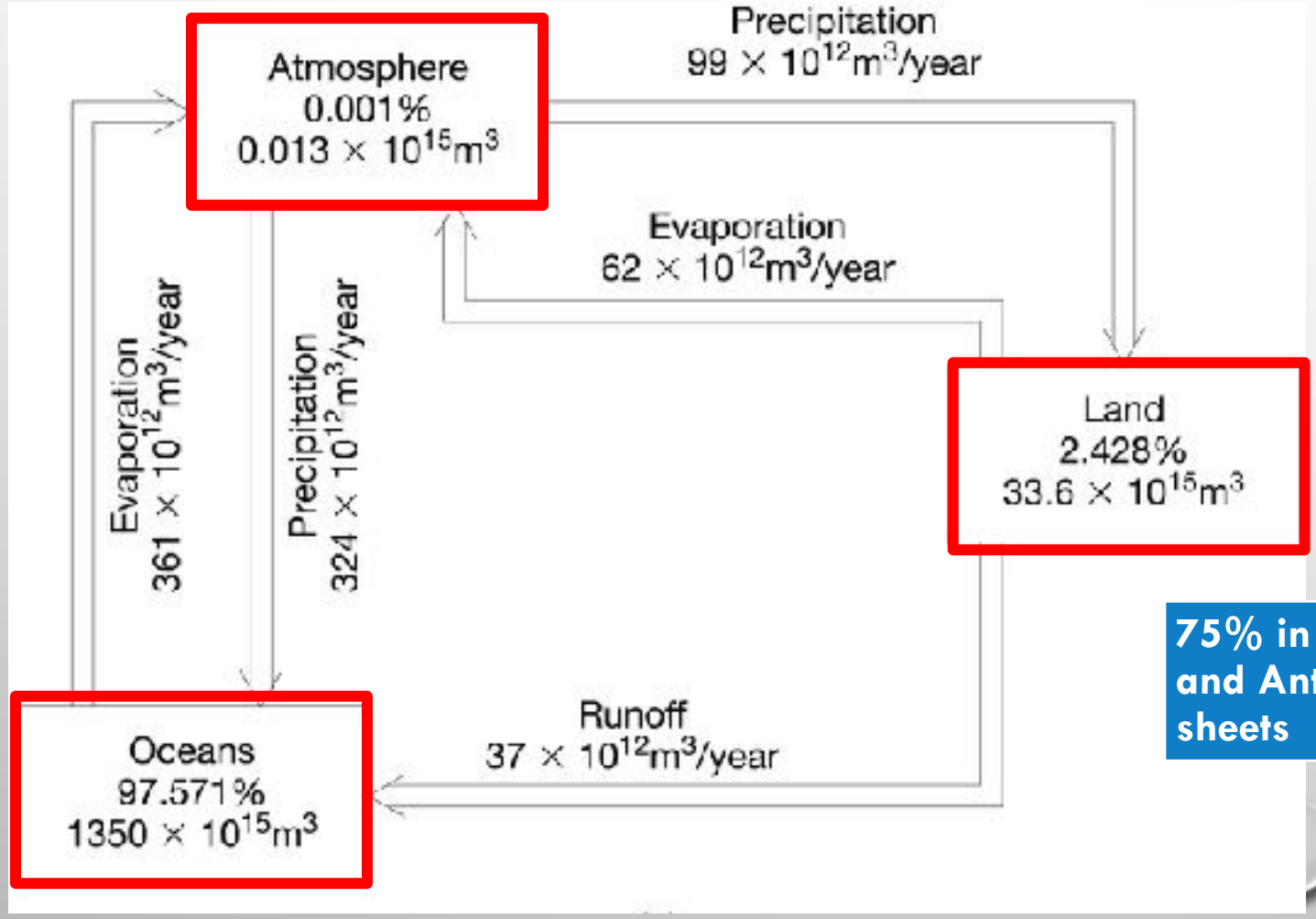
Example of solar climate "engineering"

Box Model

Reservoir = specific location (box in diagram)

Burden = amount in the reservoir

Source (sink) = rate at which material is added to (lost from) reservoir

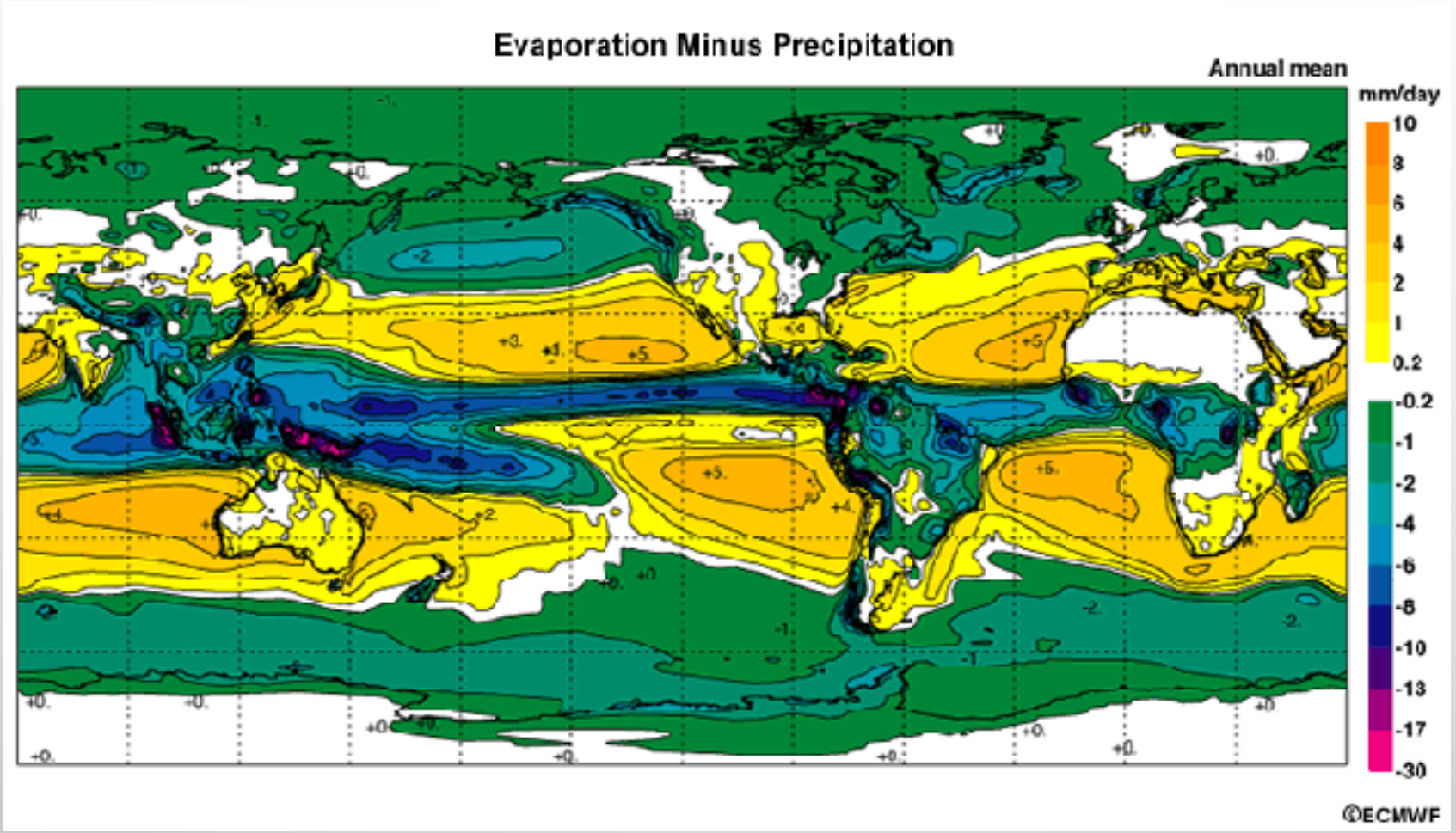


If we took all the water in the air column over our head and condensed it into a single layer of water on the ground, that layer would be

1) About 1 cm in Golden
2) About 6 cm in Jakarta
3) < 0.1 cm in Barrow, AK

75% in Greenland and Antarctica ice sheets

Tropical rain belt

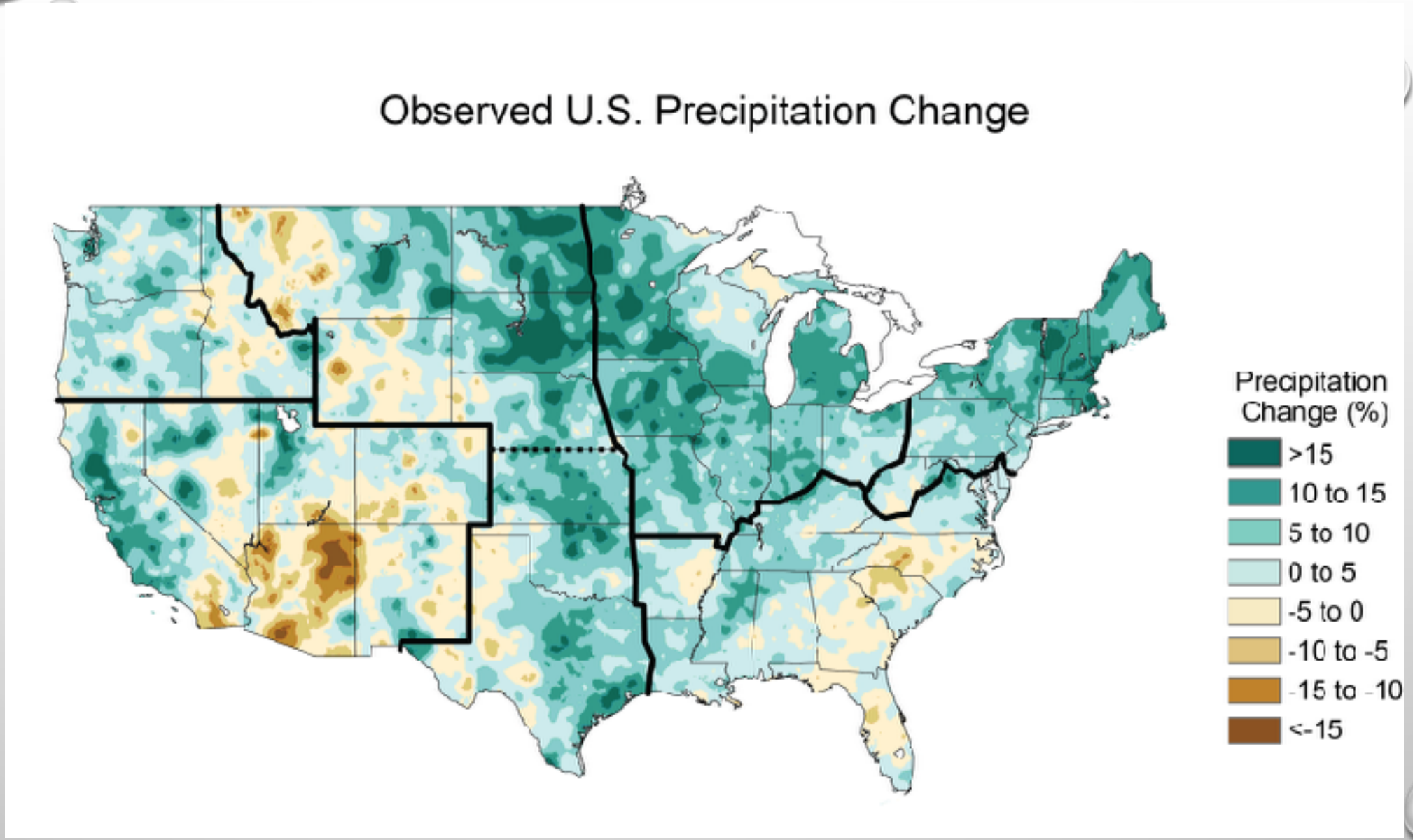


Water into atm.

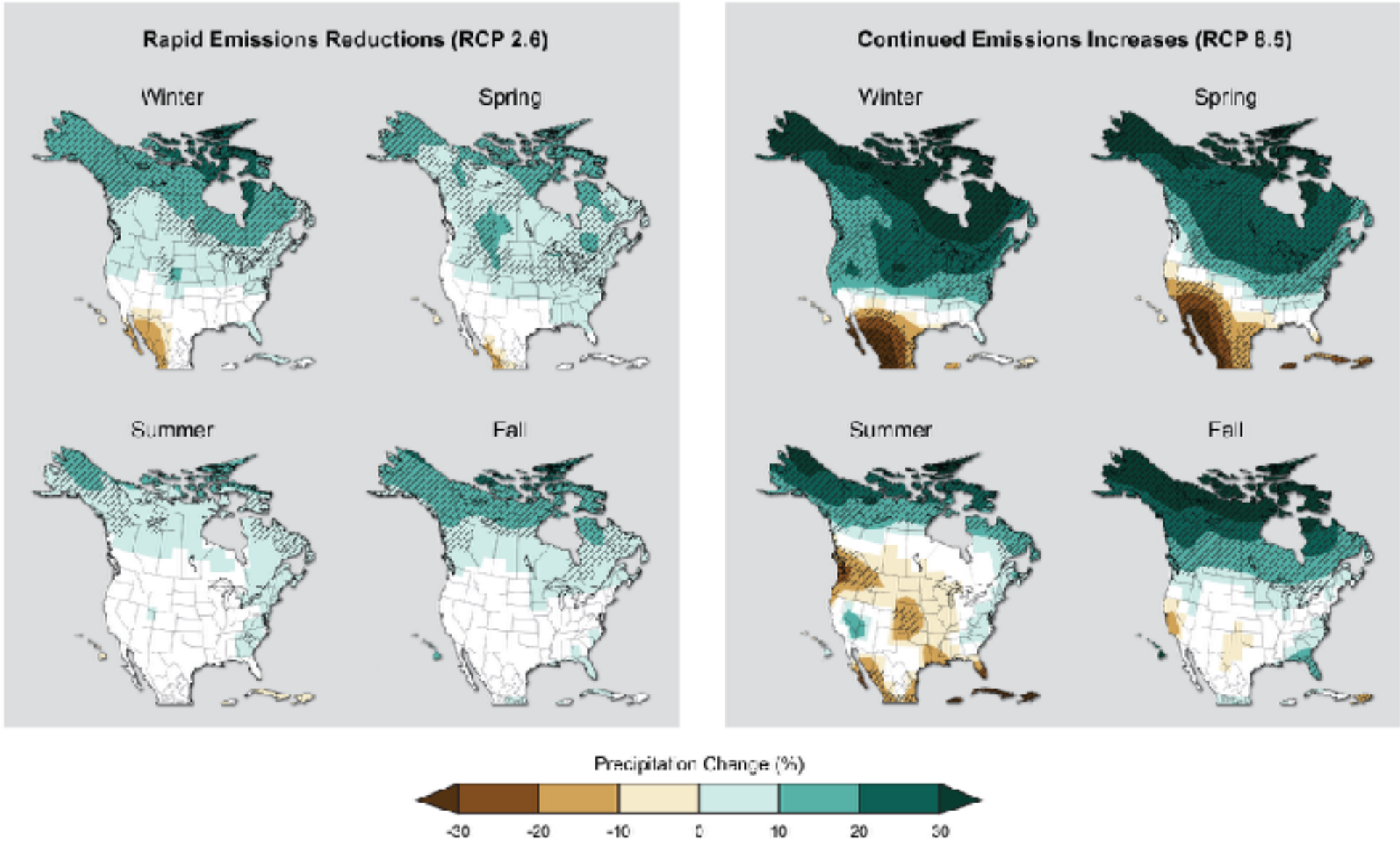
Horse latitudes
Great deserts

Water out of atm.

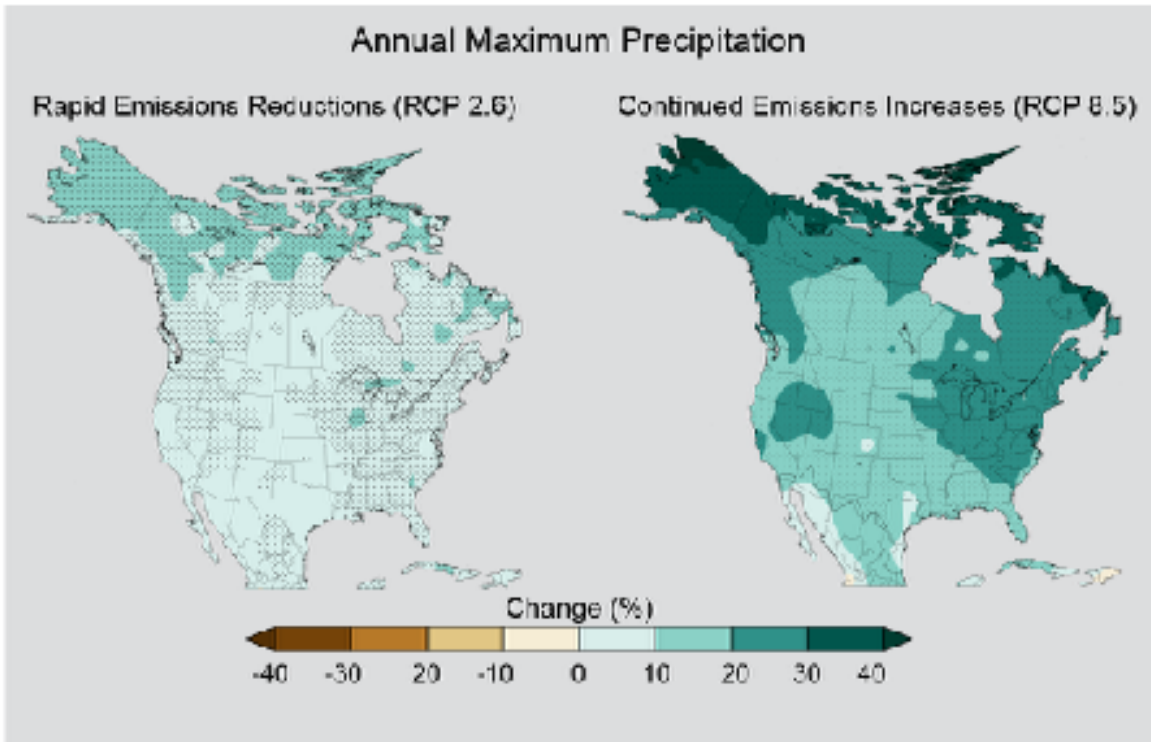
Annual total precipitation changes for 1991-2012 compared to the 1901-1960 average

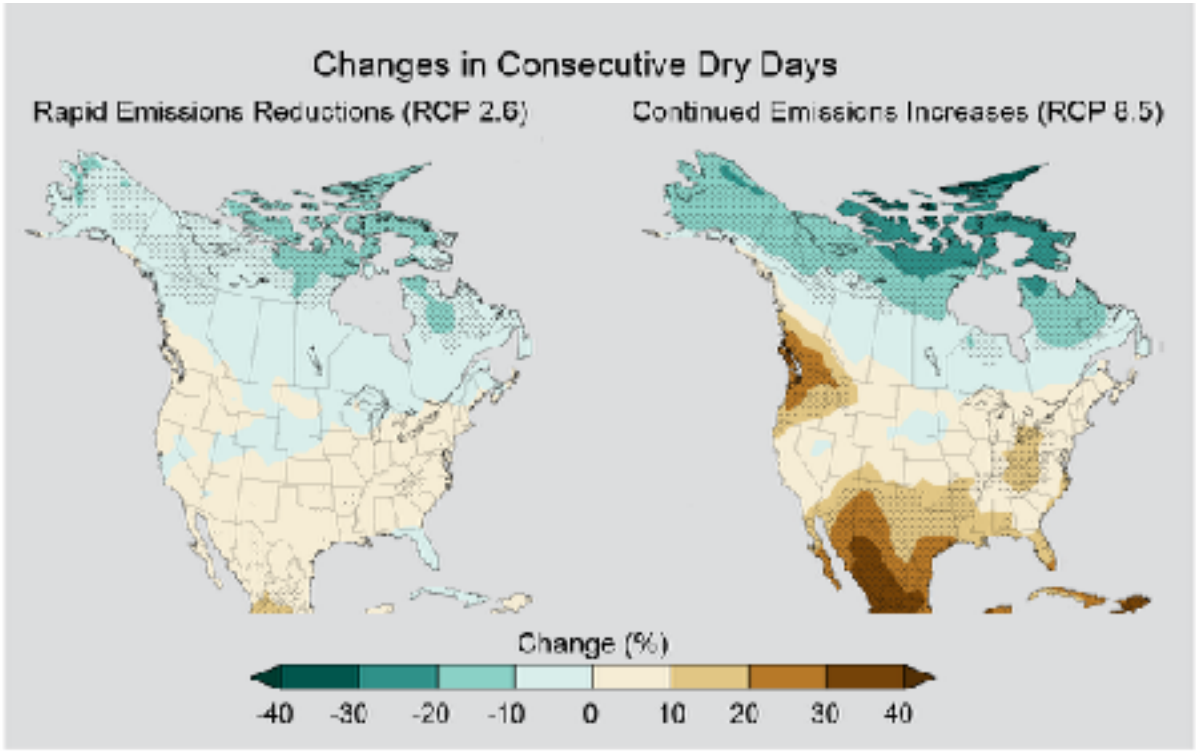


Precipitation is increasing => higher temperaturesh



Precipitation increases towards poles and decreases towards subtropics





Maximum precipitation increases
=> more intense rainfall events
=> higher probability of flooding and erosion

Number of consecutive dry days
increases in the south
decreases in the north
=> more intense droughts in south