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Climate & Climate Change in the NC Piedmont

NC CERTIFIED MASTER Naturalist Volunteer

Walt Robinson (warobin3@ncsu.edu)
NC State University
March 16, 2024

(These slides, with links, will be made available, as a pdf.)

3 excellent references

North Carolina
Climate Science Report



Authors

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David R. Easterling | Kathie D. Dello | Walter A. Robinson
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Solomon Bililign | Gary M. Lackmann | Brooke C. Stewart
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March 2020

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Subject to final copyedit and layout.

NCICS

Climate Science Advisory Panel

Kenneth E. Kunkel | David R. Easterling | Ana P. Barros | Solomon Bililign | D. Reide Corbett
Kathie D. Dello | Gary M. Lackmann | Wenhong Li | Yuh-lang Lin | Richard A. Luettich Jr.
Douglas K. Miller | L. Baker Perry | Walter A. Robinson | Adam J. Terando

Plan language summary here



North Carolina
Climate Risk Assessment and Resilience Plan

Impacts, Vulnerability, Risks, and Preliminary Actions

A Comprehensive Strategy for Reducing North Carolina's Vulnerability to Climate Change

June 2020



Plan is here; sections 5F & 6 are most relevant to NC nature



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Go-to resource for NC Climate

North Carolina State Climate Office

About | People | ECONet | Education | Data + Products | Research | Climate Blog | C3HE



March Daffodils in Raleigh's Dorothea Dix Park in 2021.

From The Mountains To The Outer Banks

The North Carolina State Climate Office serves as the primary scientific extension resource for weather and climate science for the state of North Carolina. The office achieves its mission through climate science monitoring, education, extension, and research.

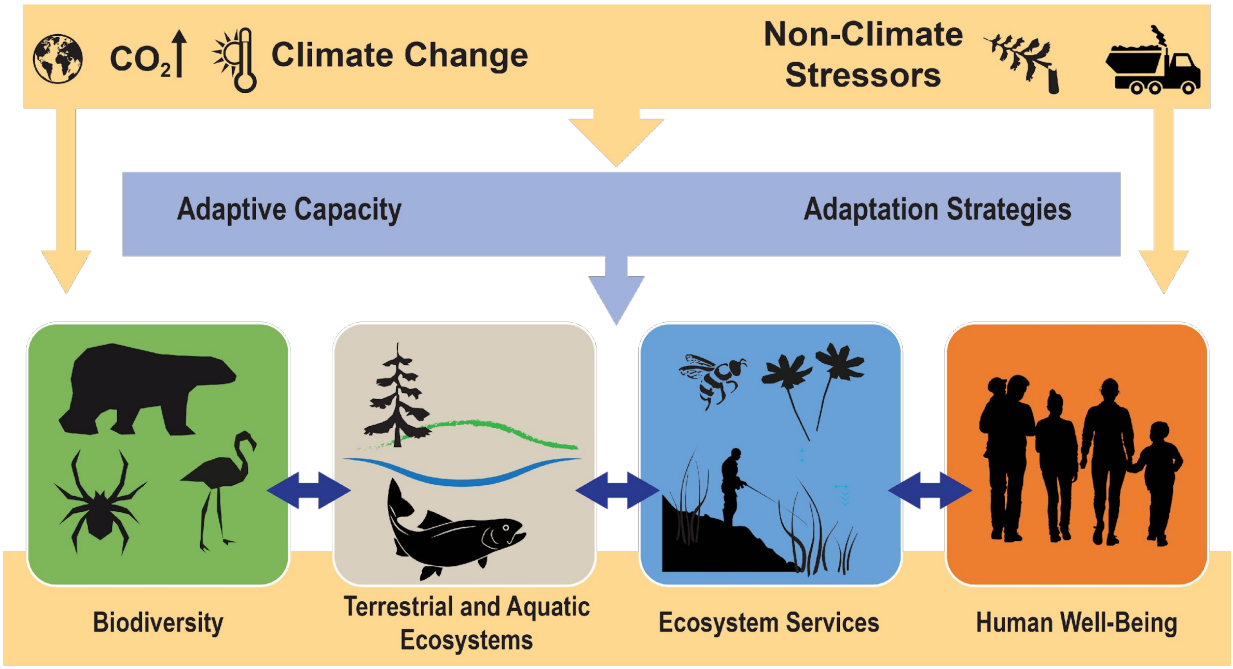


NC State Climatologist: Dr. Kathie Dello

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Today

- What is our climate here in the NC piedmont?
- Why is it the way it is?
- Is our climate changing - if so, how?
- Why is it changing?
- Does climate change matter?



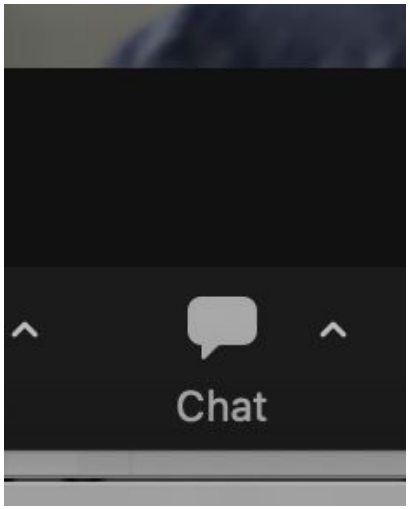
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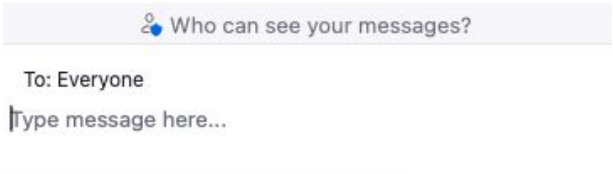


Please use the chat …

- to ask questions
- to answer questions
- to comment
- to offer information to other participants

Questions for you will look like this





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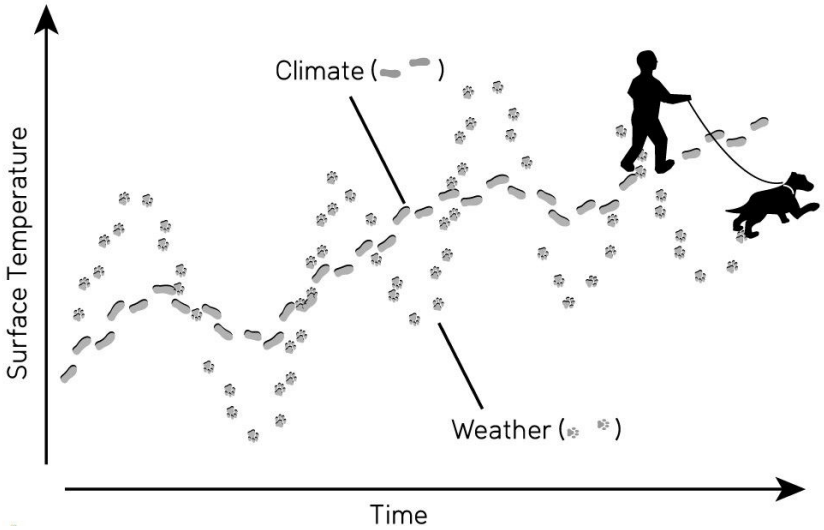
What is climate?

Climate is the *statistics* of weather, averaged over time …

- *averages* (say, of temperature) for a given location, day of year, time of day
- *averages* of accumulated rain/snow over some days of the year
- *probabilities* of extreme events: high temperatures, flooding rains, tornadoes, etc.

"Climate is what you expect; weather is what you get."

Weather is *predicted* (forecast); climate is (near term) predicted & long term *projected*

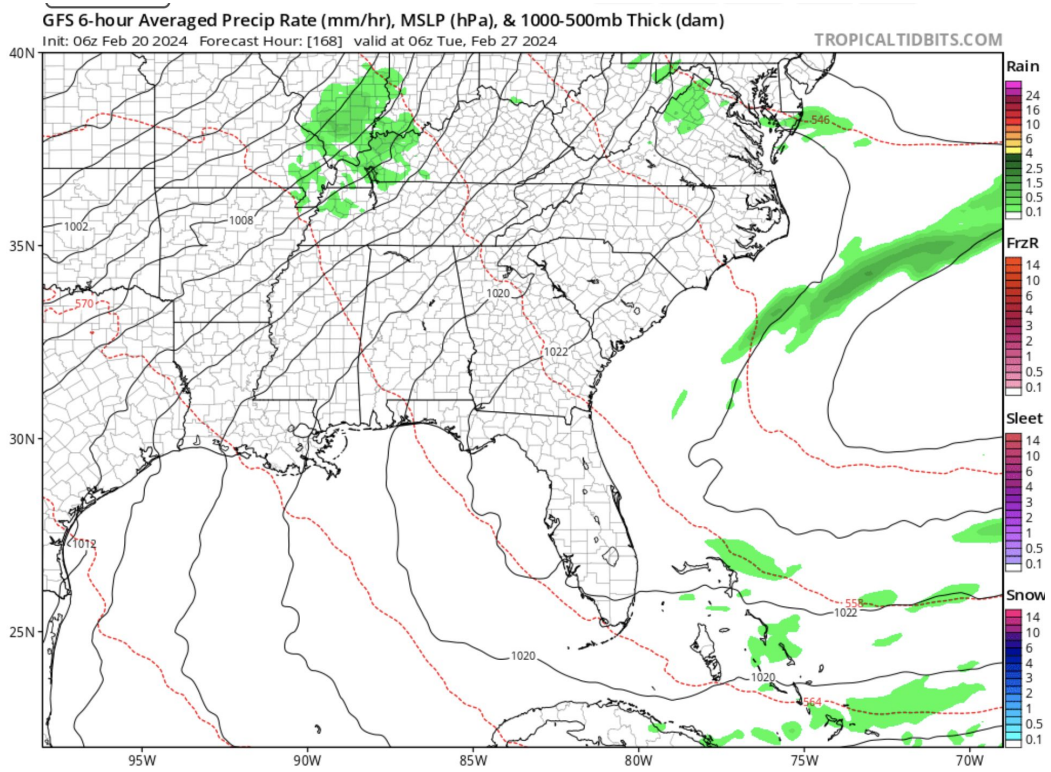


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Prediction

Weather is usefully predictable here (temperate latitudes generally) about a week ahead.

- Using computer models that solve physical equations
  - Climate models are close relatives of weather models



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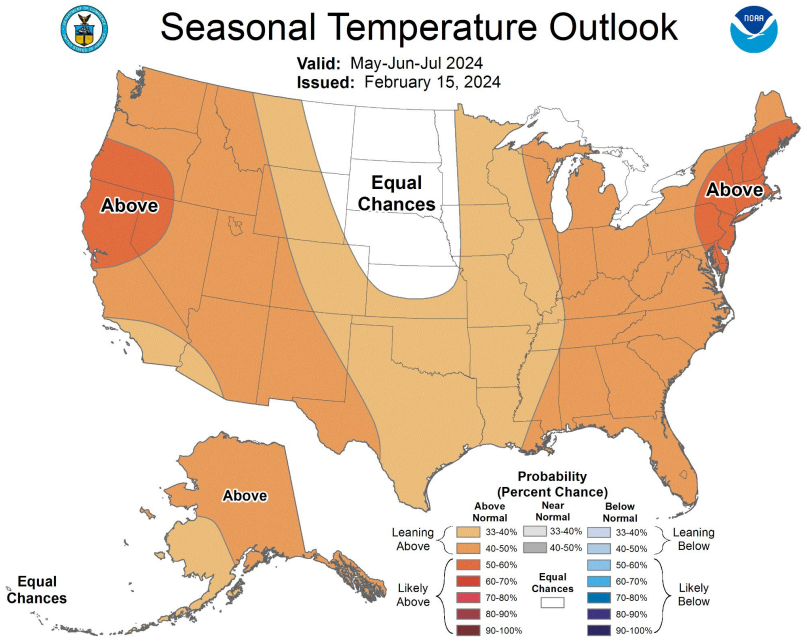
Climate prediction

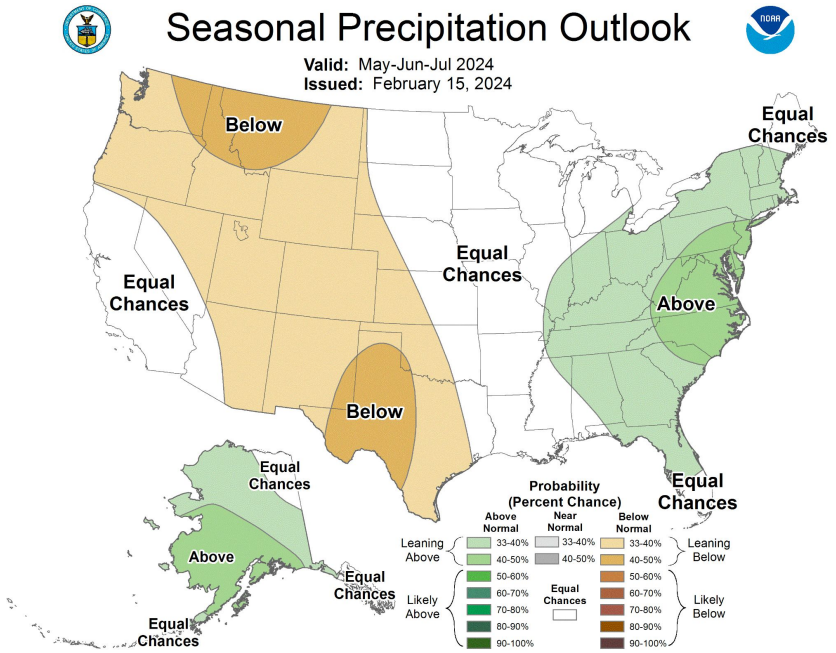
Some *skill* a season ahead

Mostly from El Niño cycles & *anthropogenic* trend (a little from soil moisture, ocean temperatures outside the equatorial Pacific, …)

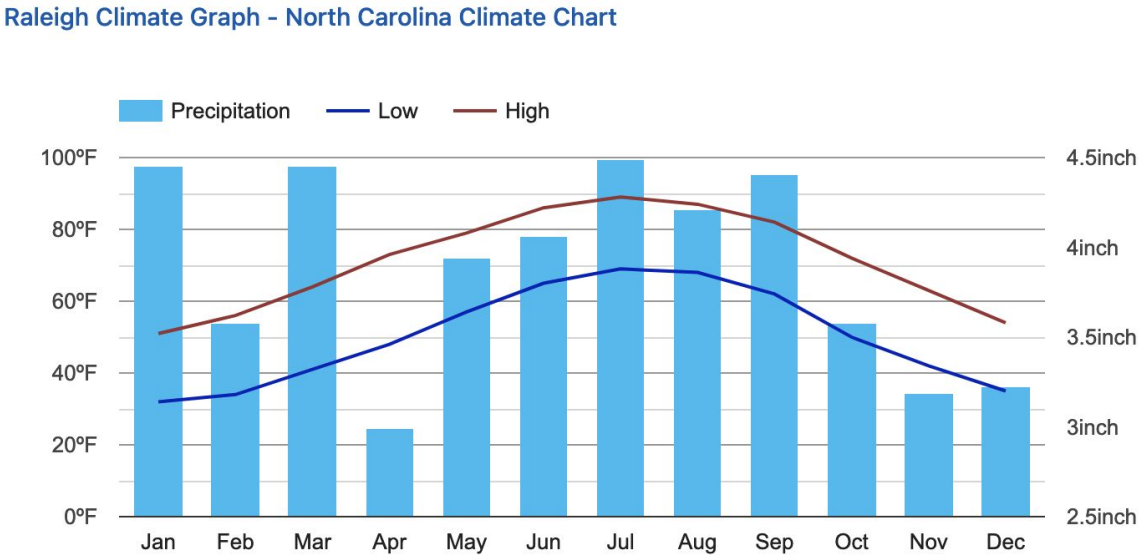
Trend adds skill, because forecasts are deviations from *normals*

30-year averages (currently 1981-2010)





The average climate of the piedmont is mild and (mostly) pleasant



Average summer highs < 90°F

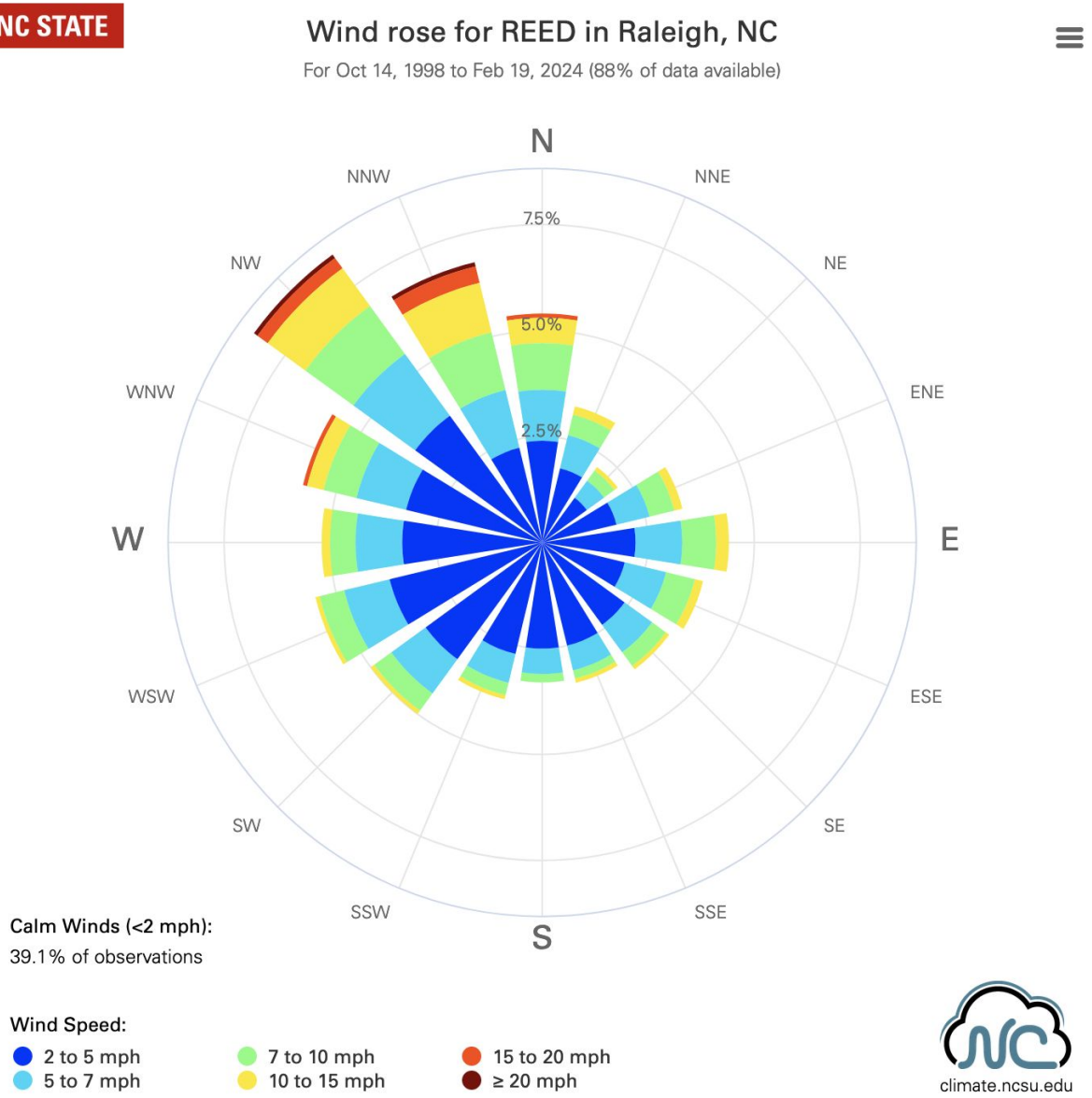
Average winter lows ~ 32°F

Precipitation spread across the year

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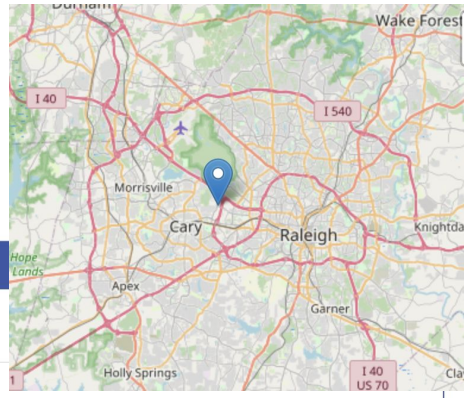
Moderate winds

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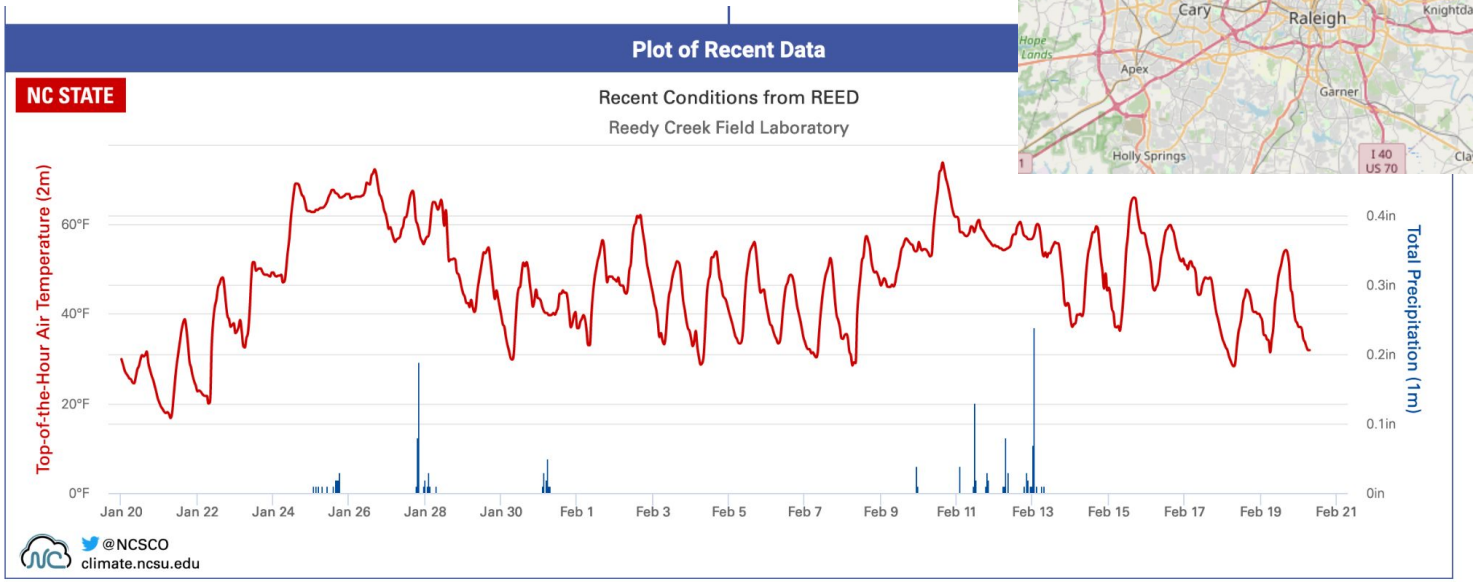
Piedmont climate features variable weather

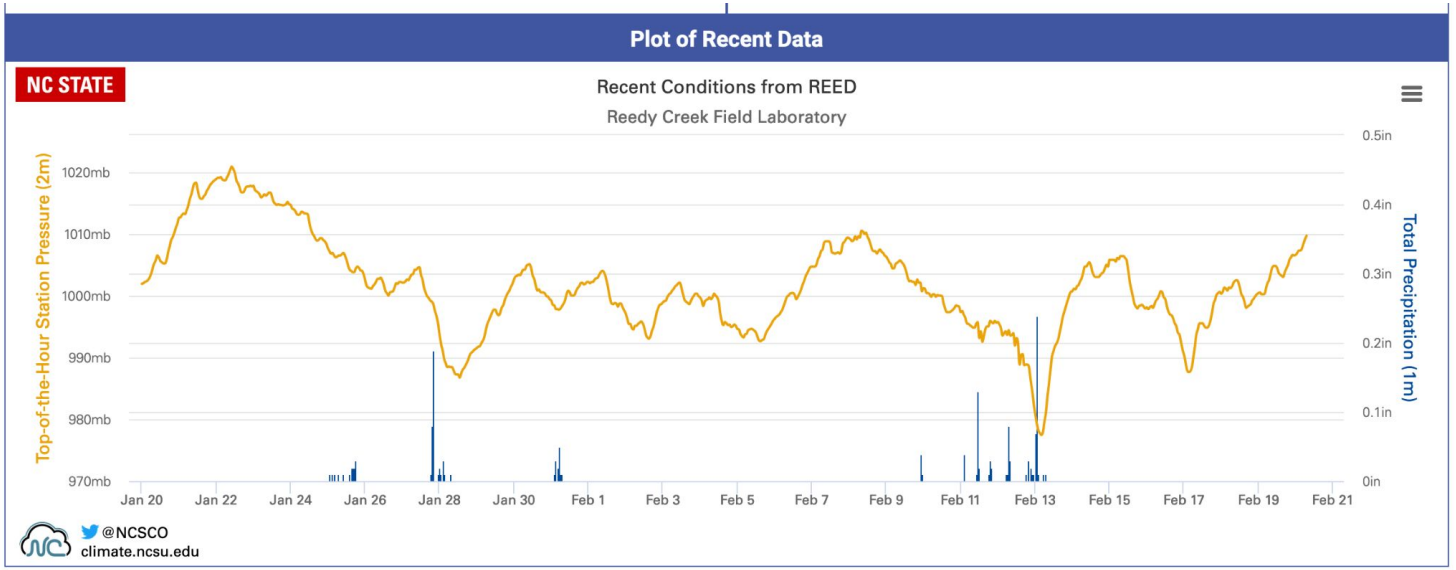


Temperature & precipitation

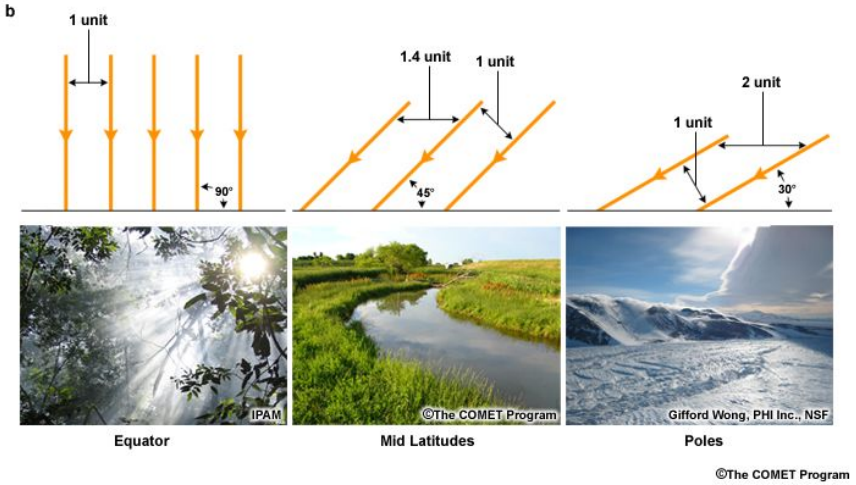
A month of data - what patterns do you see?

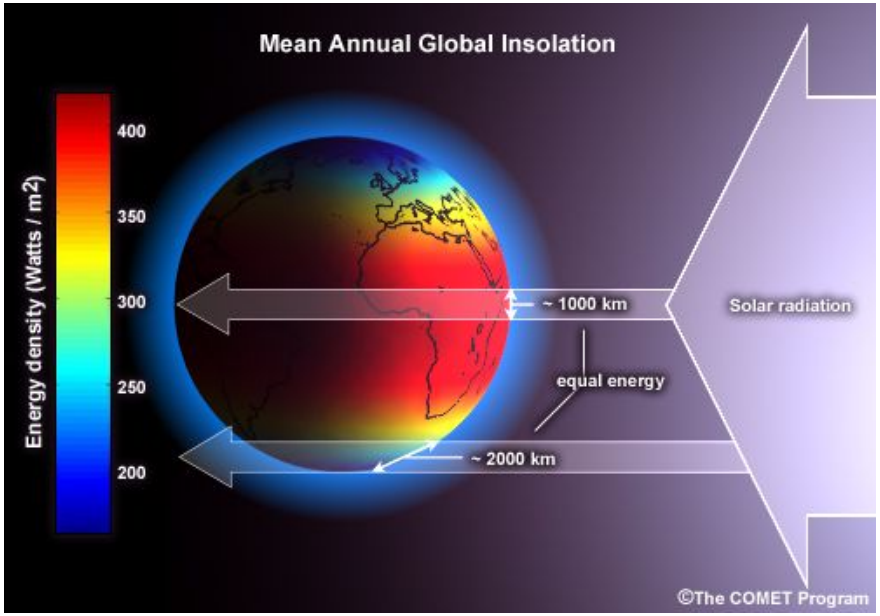
Barometric pressure & precipitation





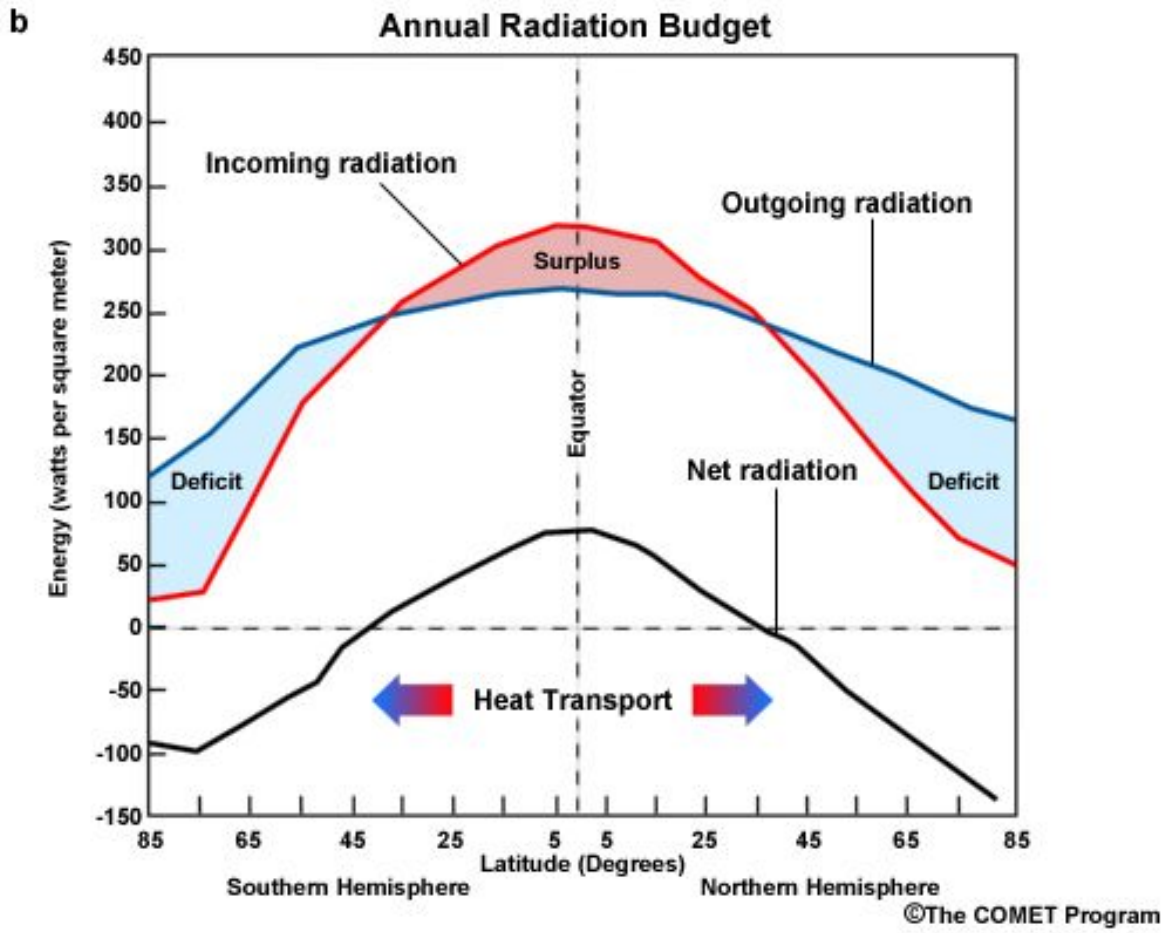
Why? Energy: solar heating strongest in the tropics





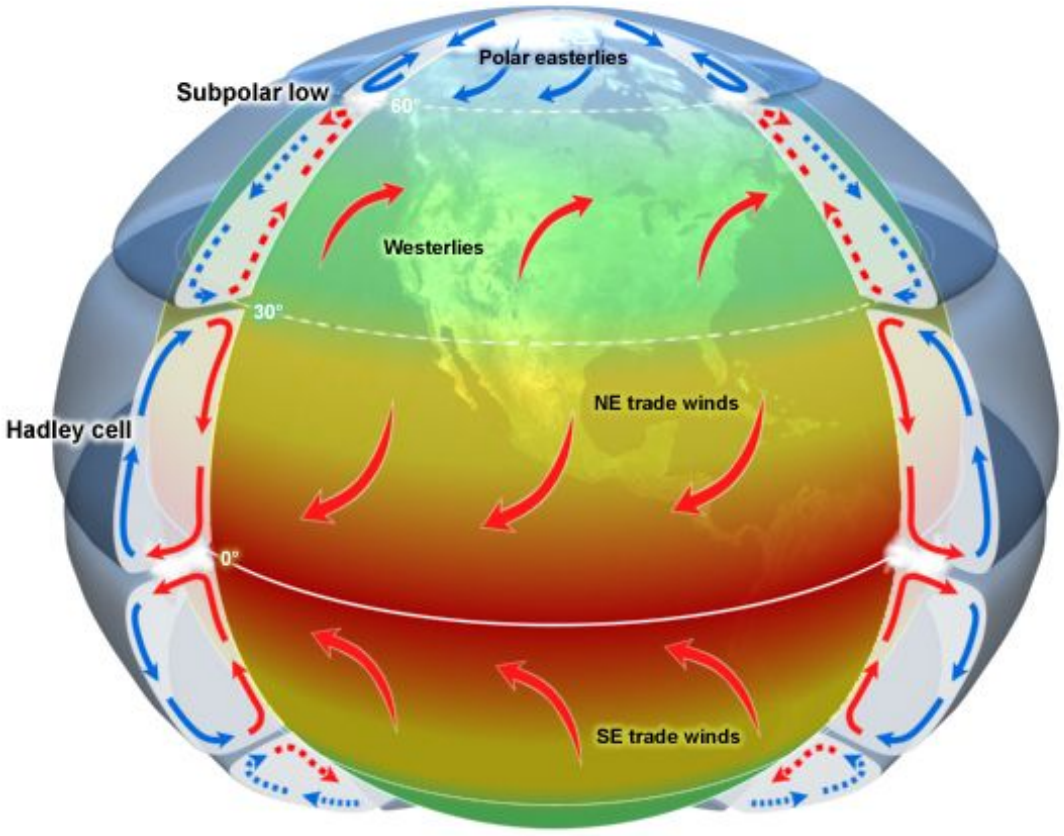
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Tropical surplus of radiative heating so atmosphere must move energy poleward



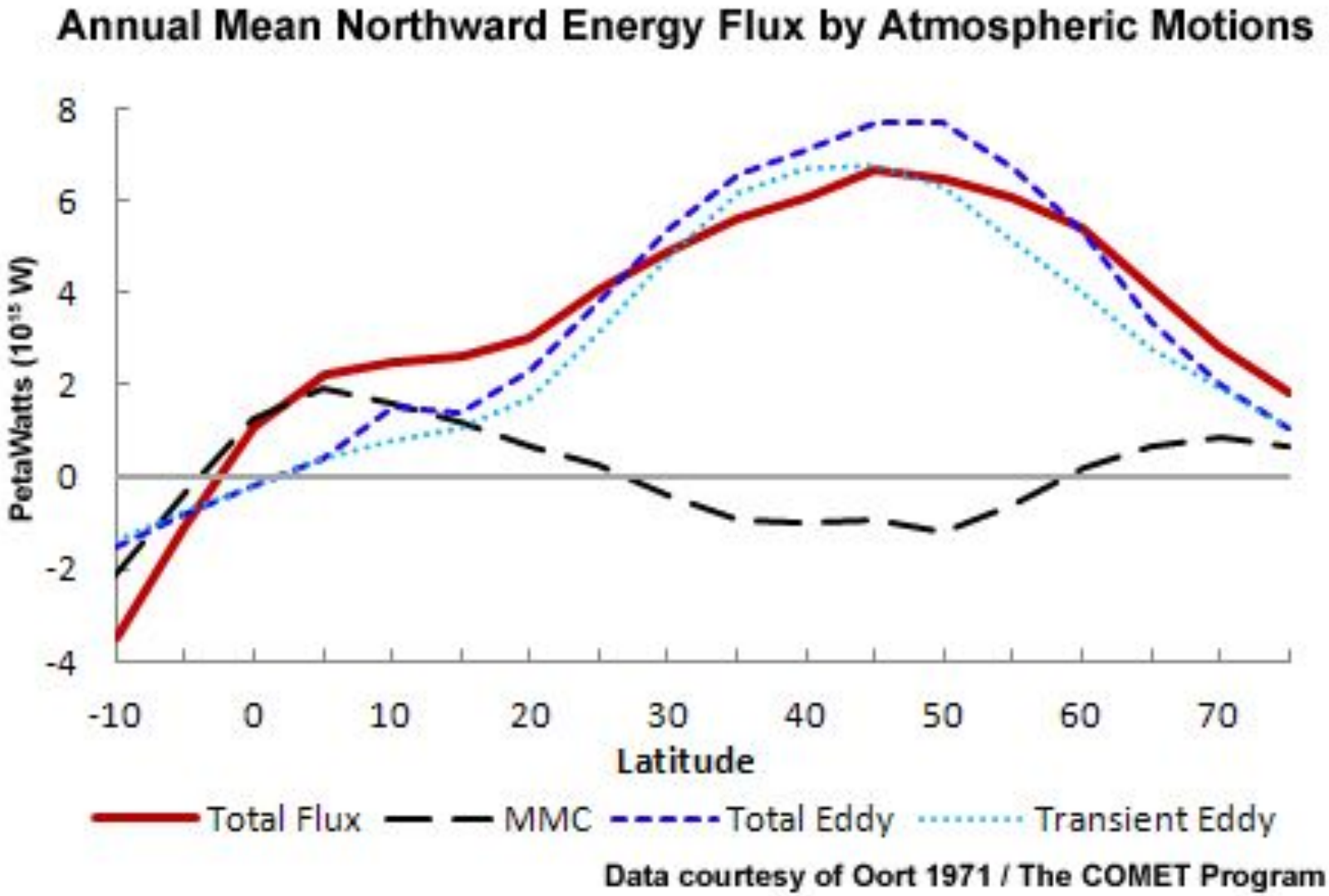
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Tropic to middle latitudes: the Hadley cells

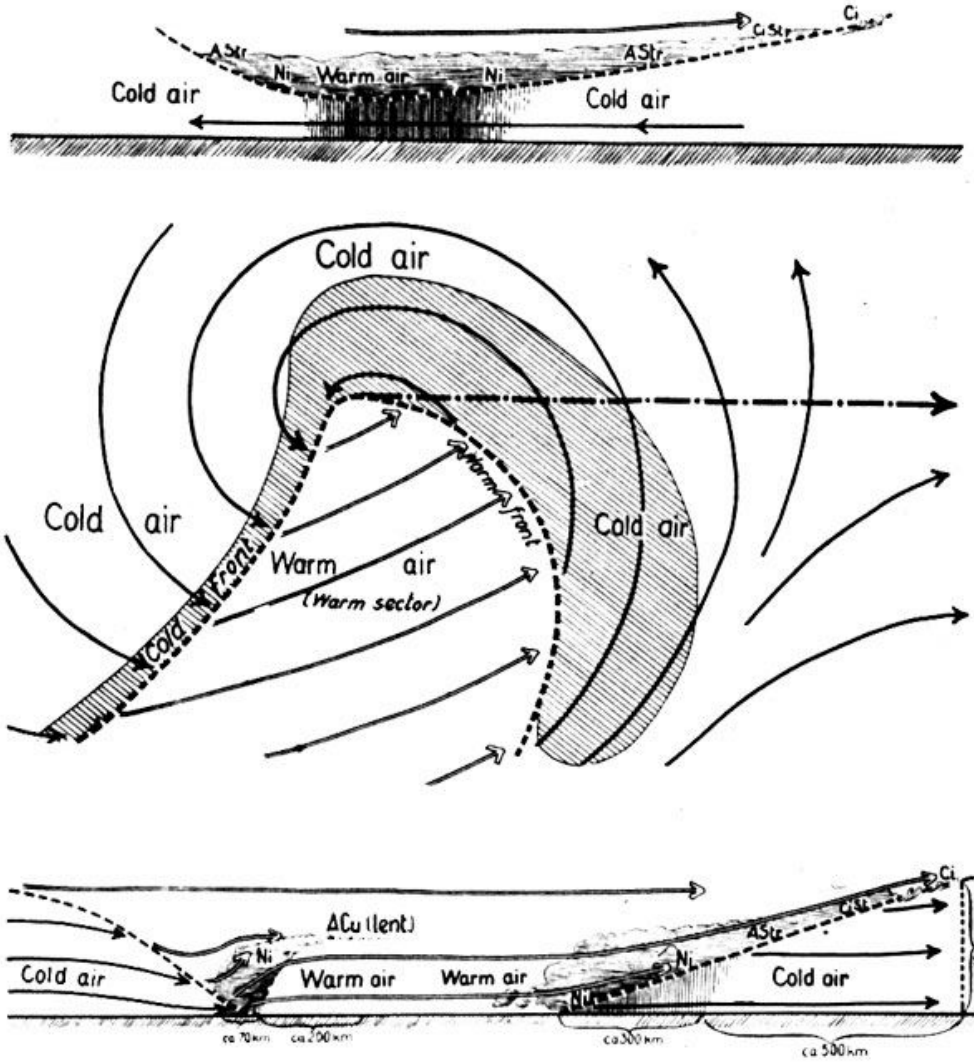


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Beyond the tropics "eddies" take over



“Eddies” are extratropical cyclones (lows): engines of midlatitude weather



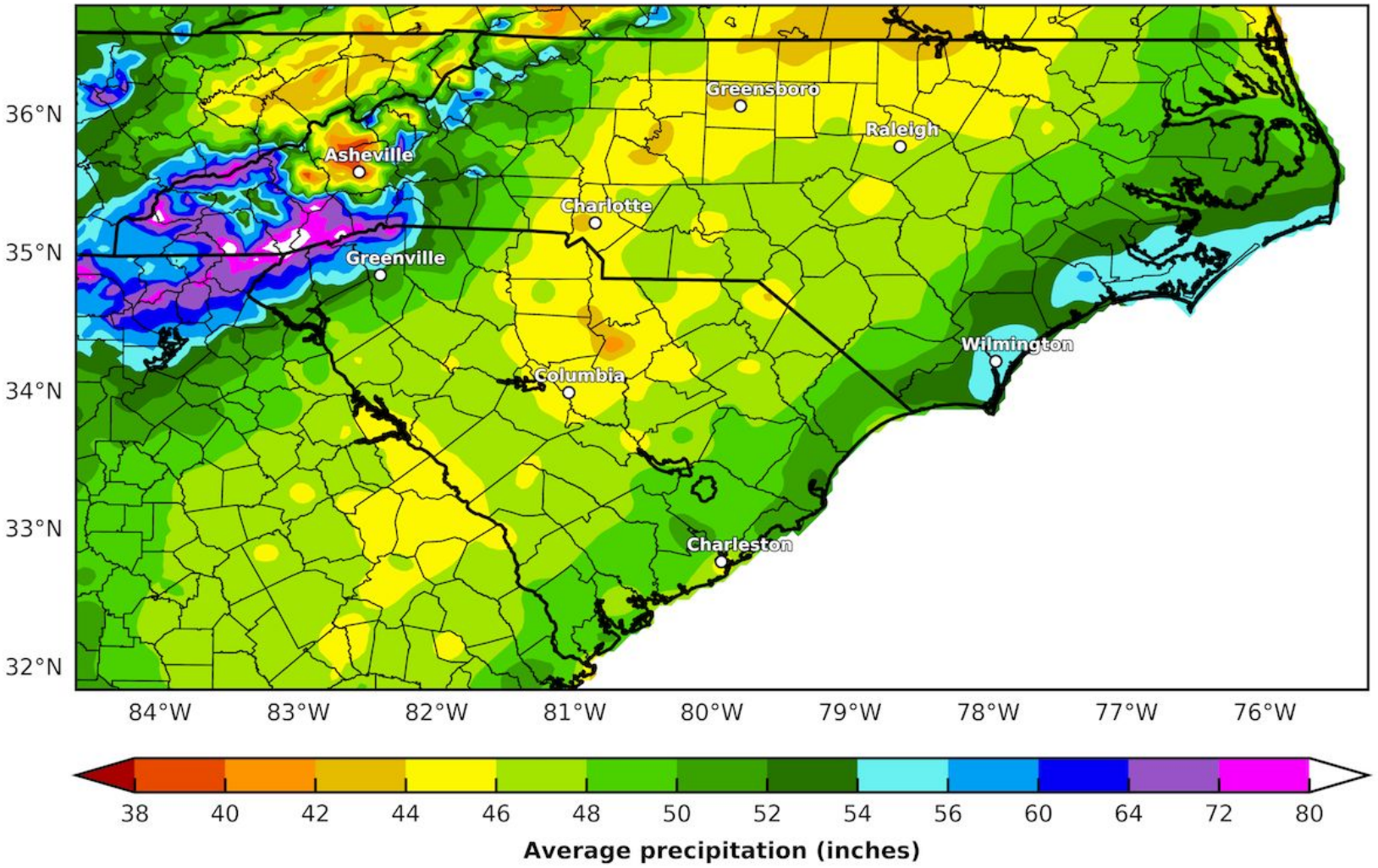
J. Bjerknes and H. Solberg, 1922: Life cycle of cyclones and the polar front theory of atmospheric circulation. *Geophysisks Publikationer*, 3

Extratropical cyclones move heat *and* moisture poleward across the temperate latitudes

“sensible” heat* + *moisture* = *energy

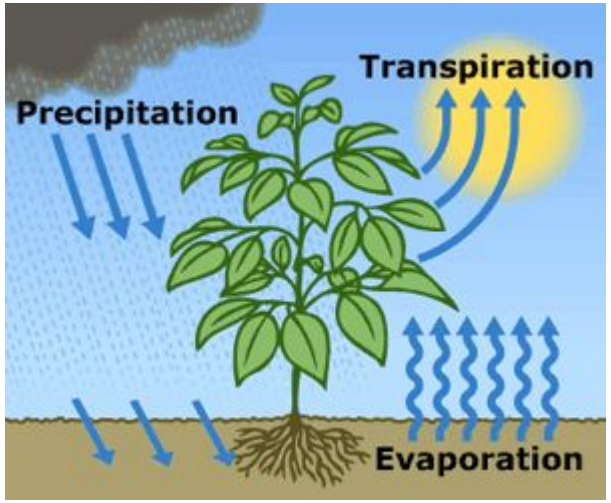
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Moisture transport => rain & snow



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Local water gain & loss at the ground



Gain: precipitation

Loss: evaporation & transpiration

evaporation + transpiration = evapotranspiration

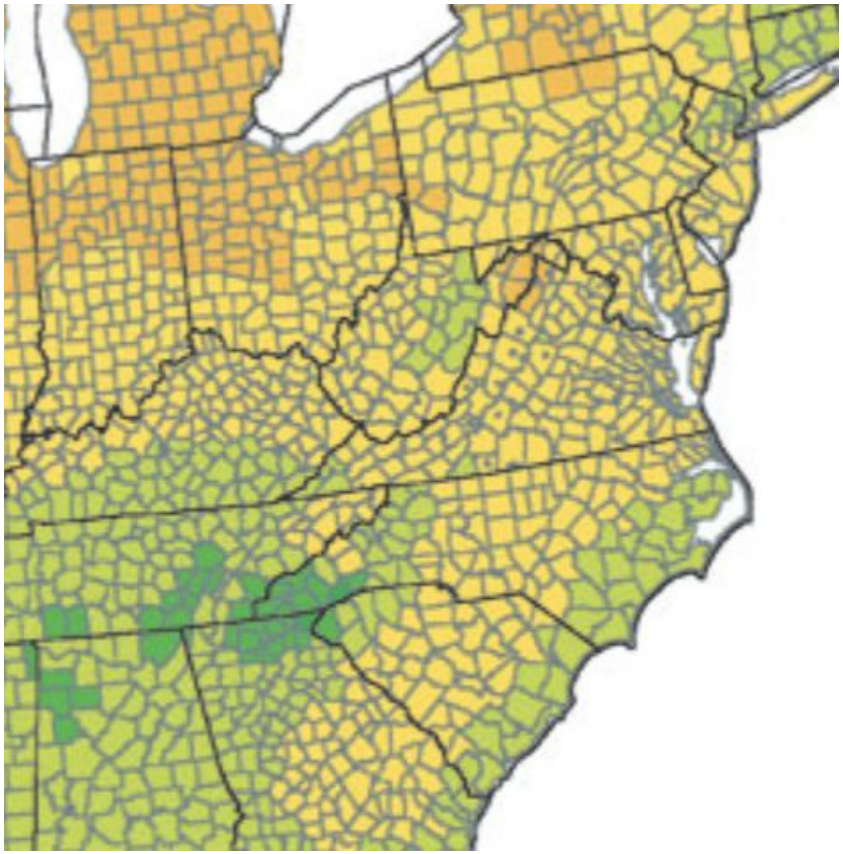
Over land (almost everywhere):

precipitation > evapotranspiration

How do we know this must be so?

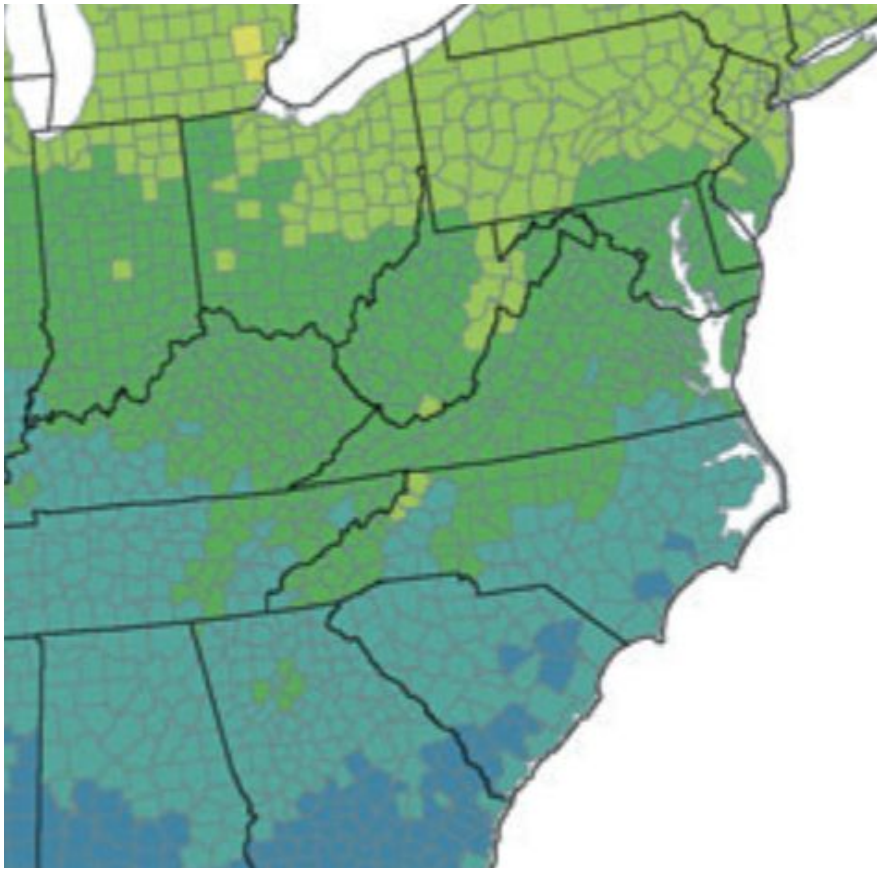
Where does the difference go?

Water budget from data



Estimated mean annual precipitation, in centimeters, 1971-2000

10 - 25	76 - 100	151 - 175	
26 - 50	101 - 125	176 - 200	
51 - 75	126 - 150	201 - 225	



Estimated mean annual actual evapotranspiration, in centimeters, during the period 1971-2000

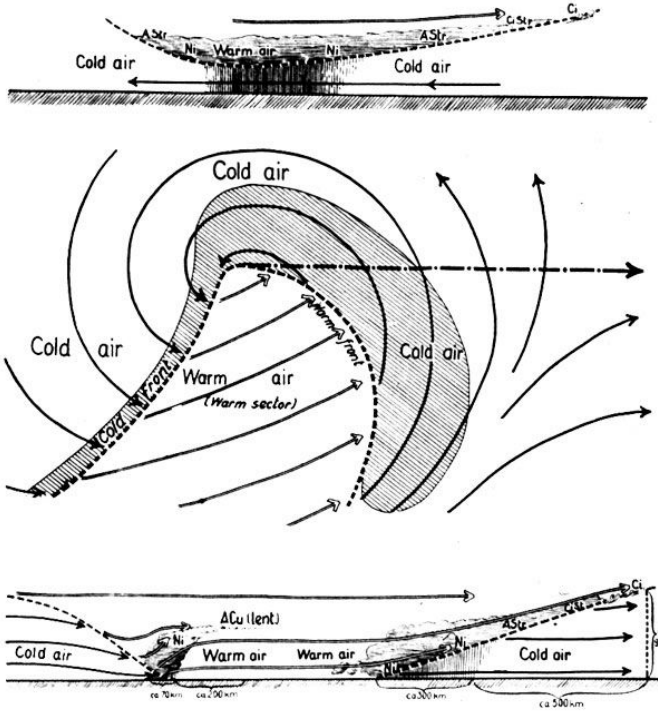
0 - 10	41 - 50	81 - 90
11 - 20	51 - 60	91 - 100
21 - 30	61 - 70	
31 - 40	71 - 80	

Extratropical cyclones …

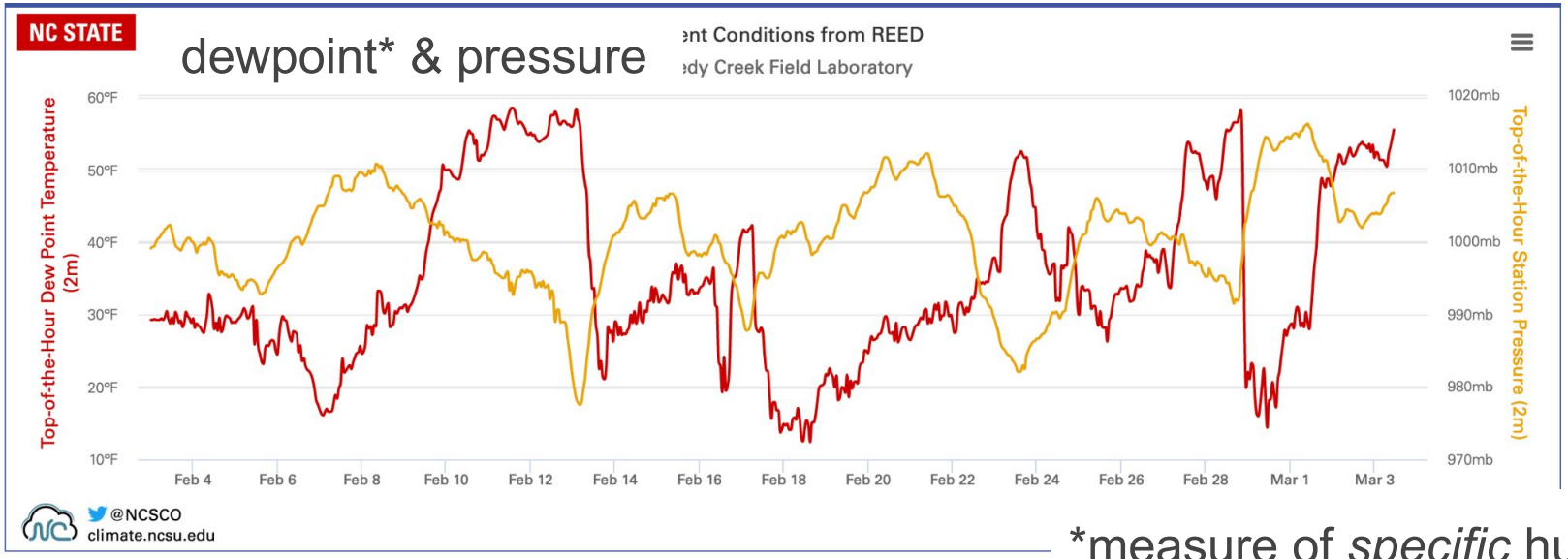
- move heat poleward
- move moisture poleward & landward

This means …

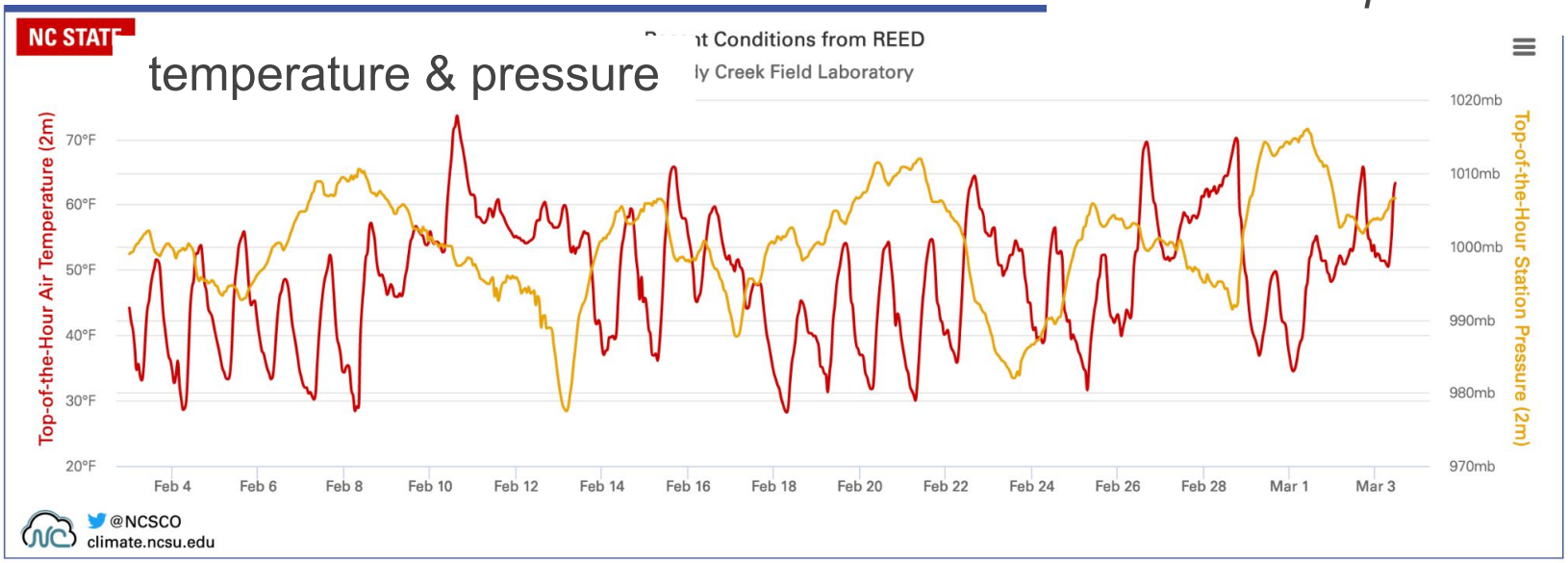
- air going north is warmer than air going south
- air going northward/landward moving air is moister than air going southward/seaward



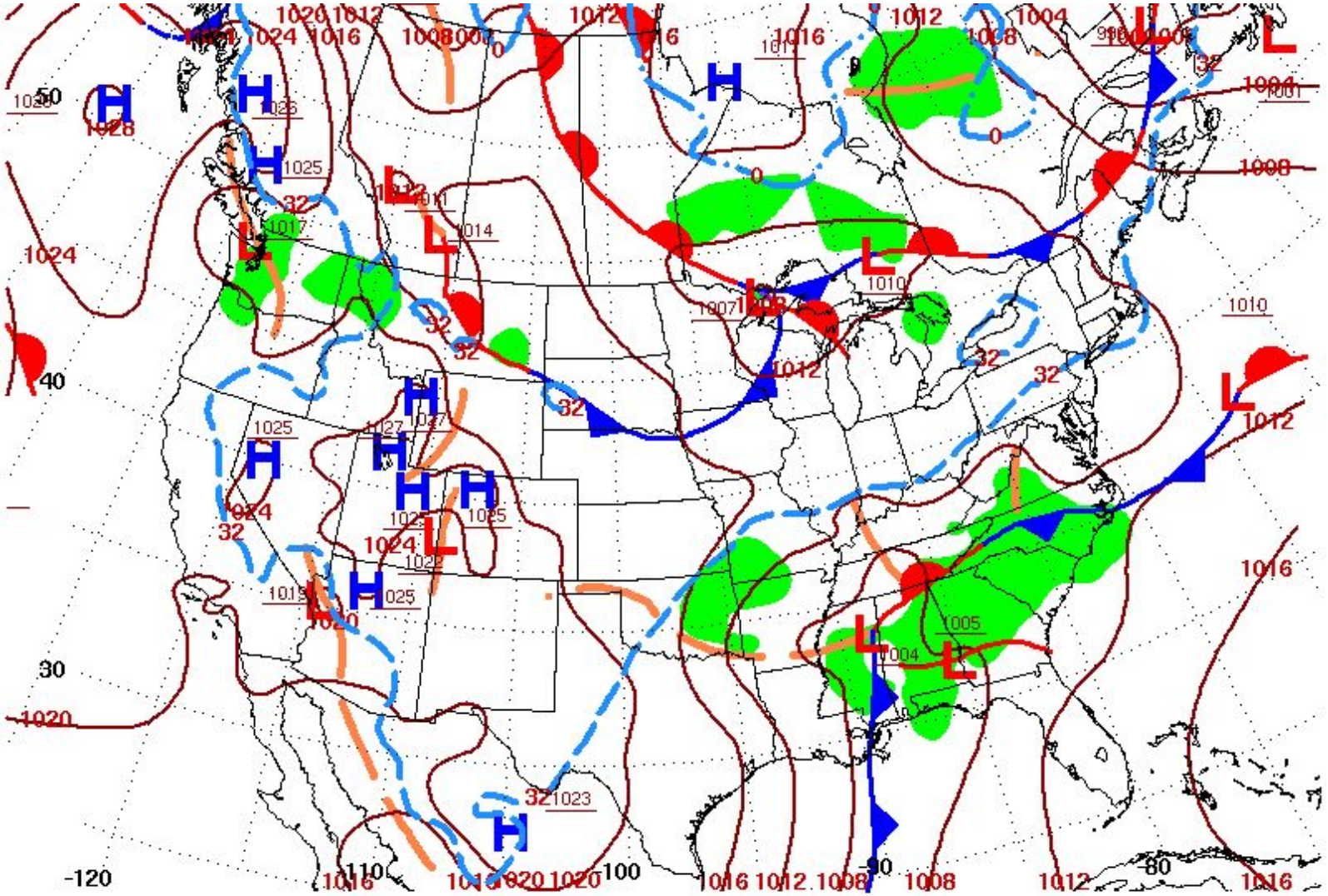
What this looks like day-to-day



*measure of *specific* humidity



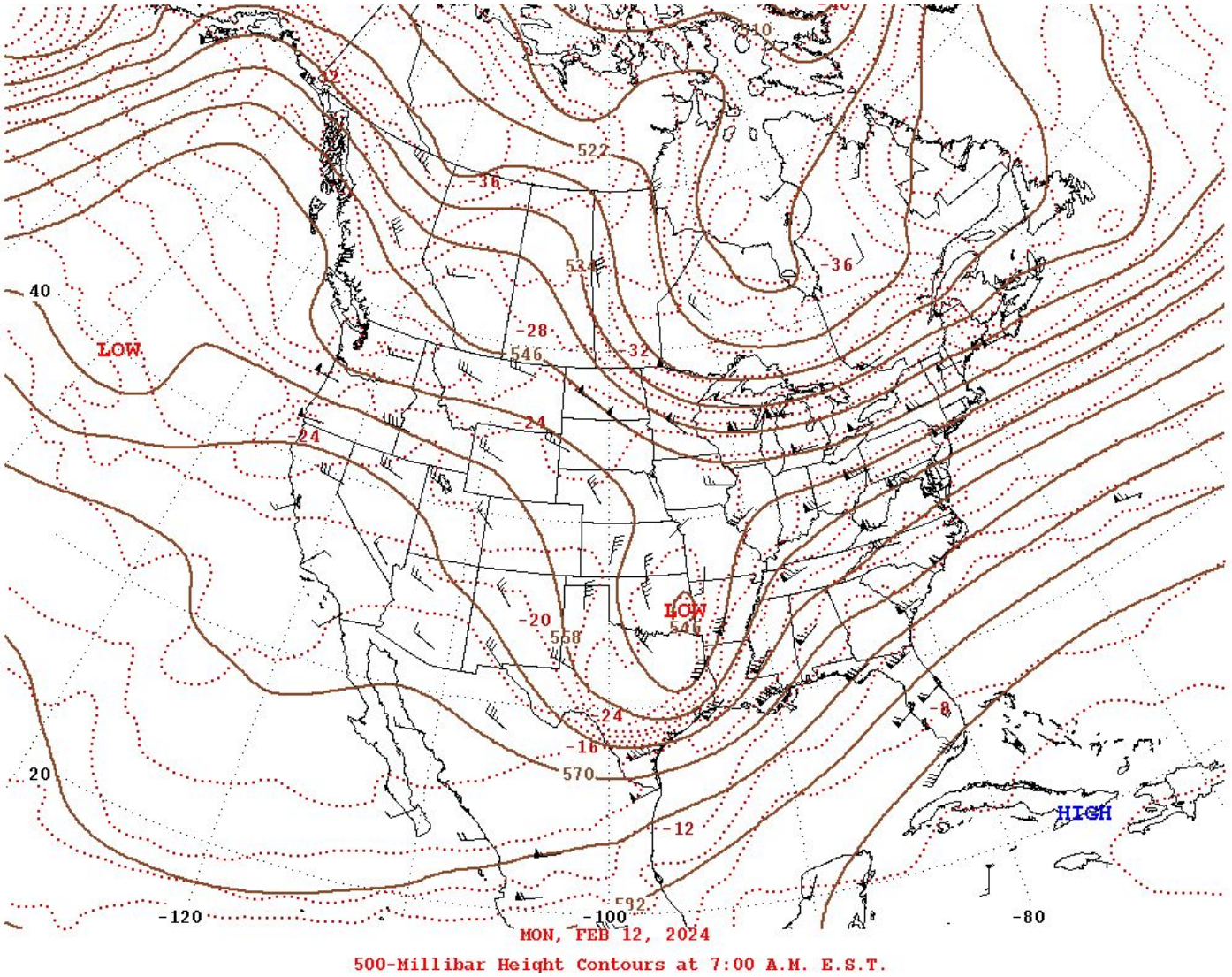
Example: pressure, fronts, precip.



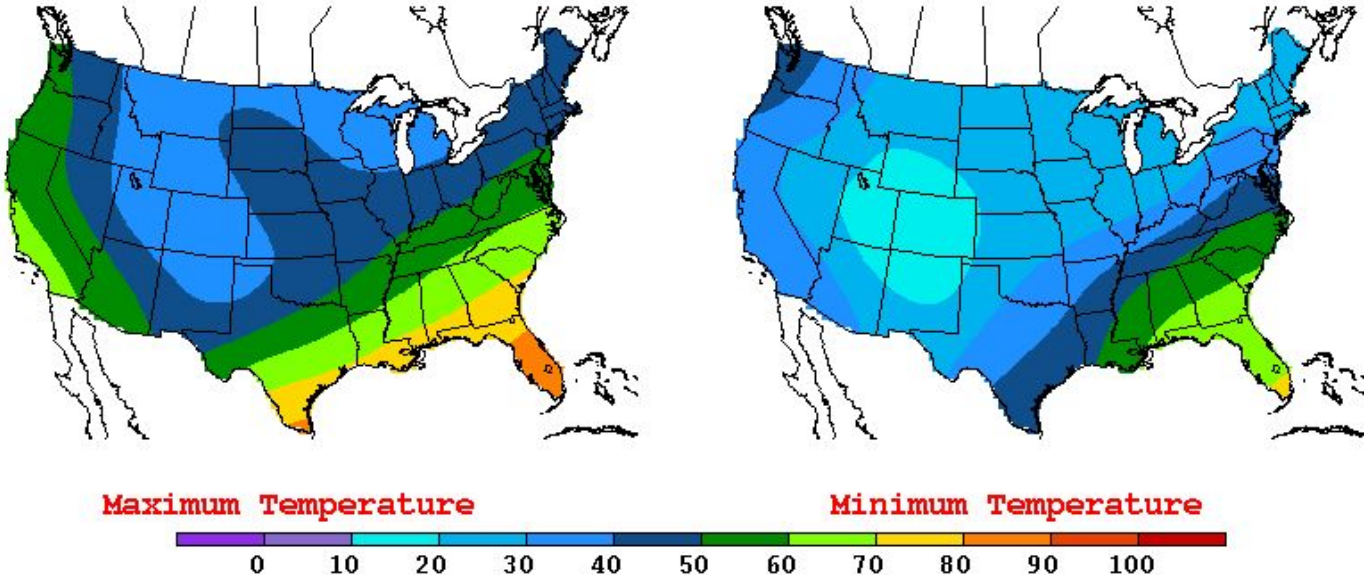
12 February 2024

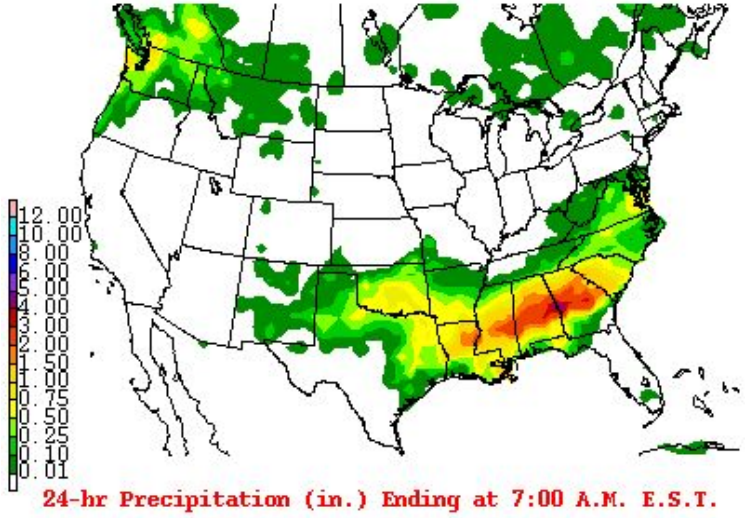
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Flow aloft

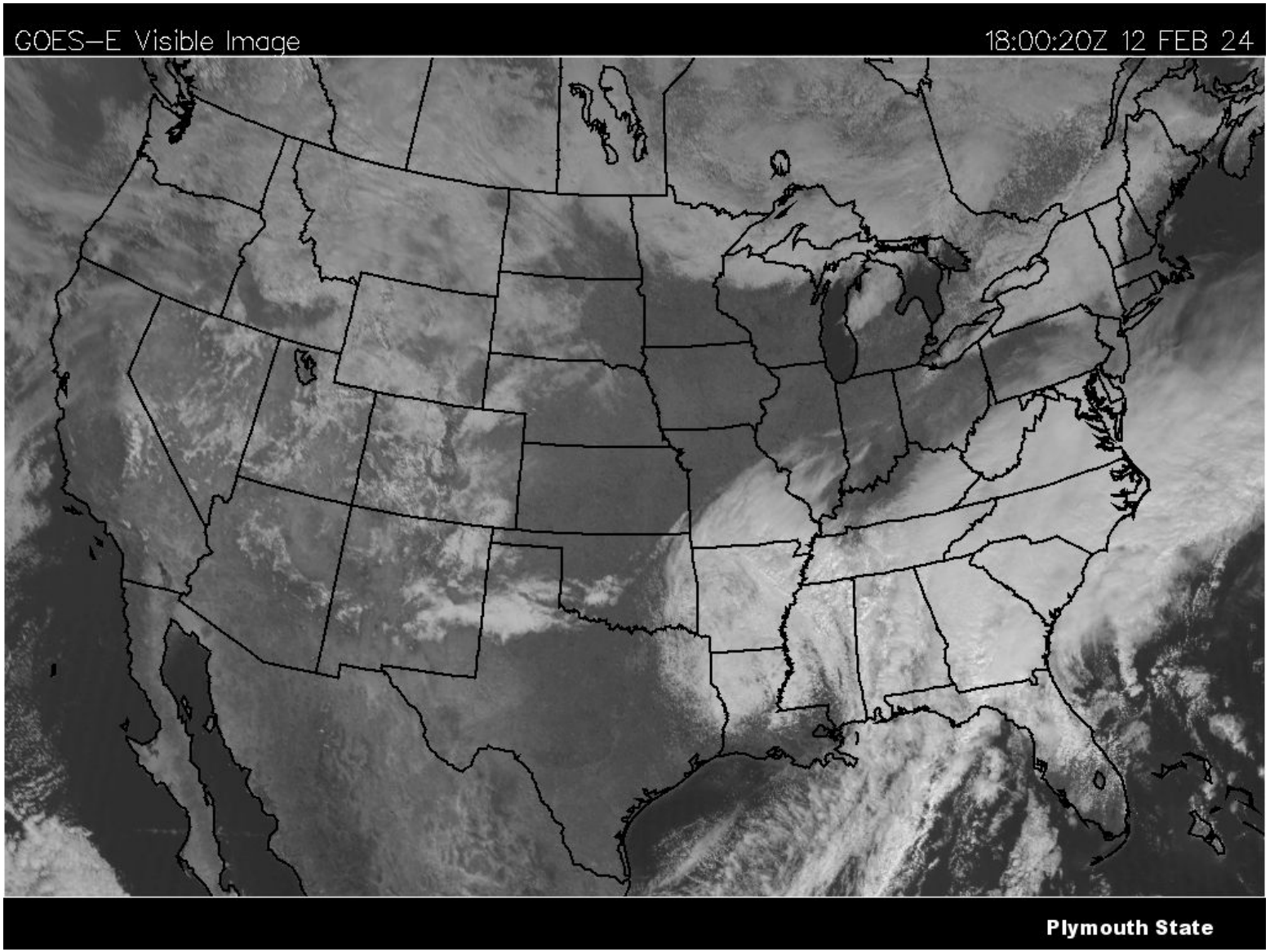


Temperatures & rainfall



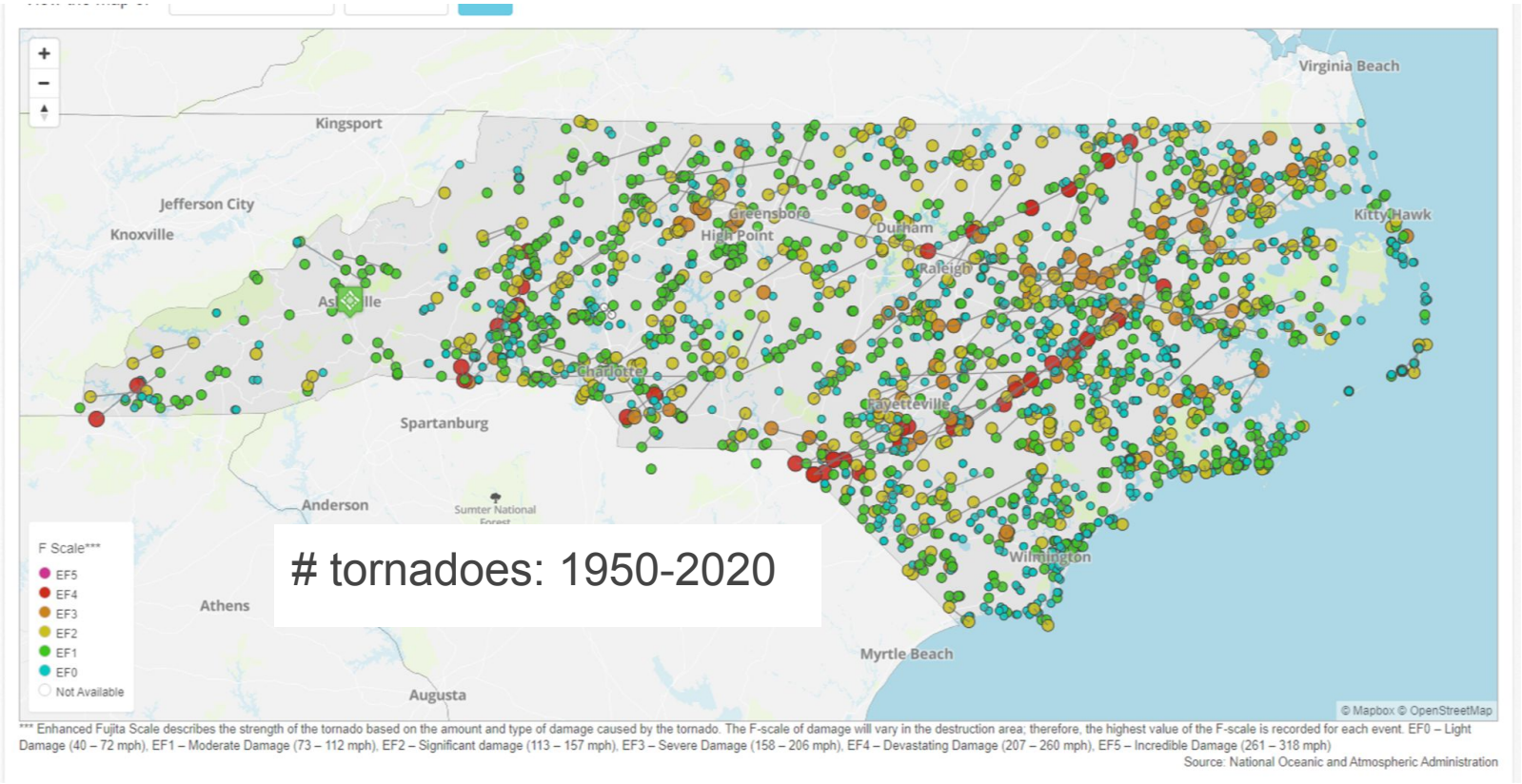


From space



Other contributors to our climate

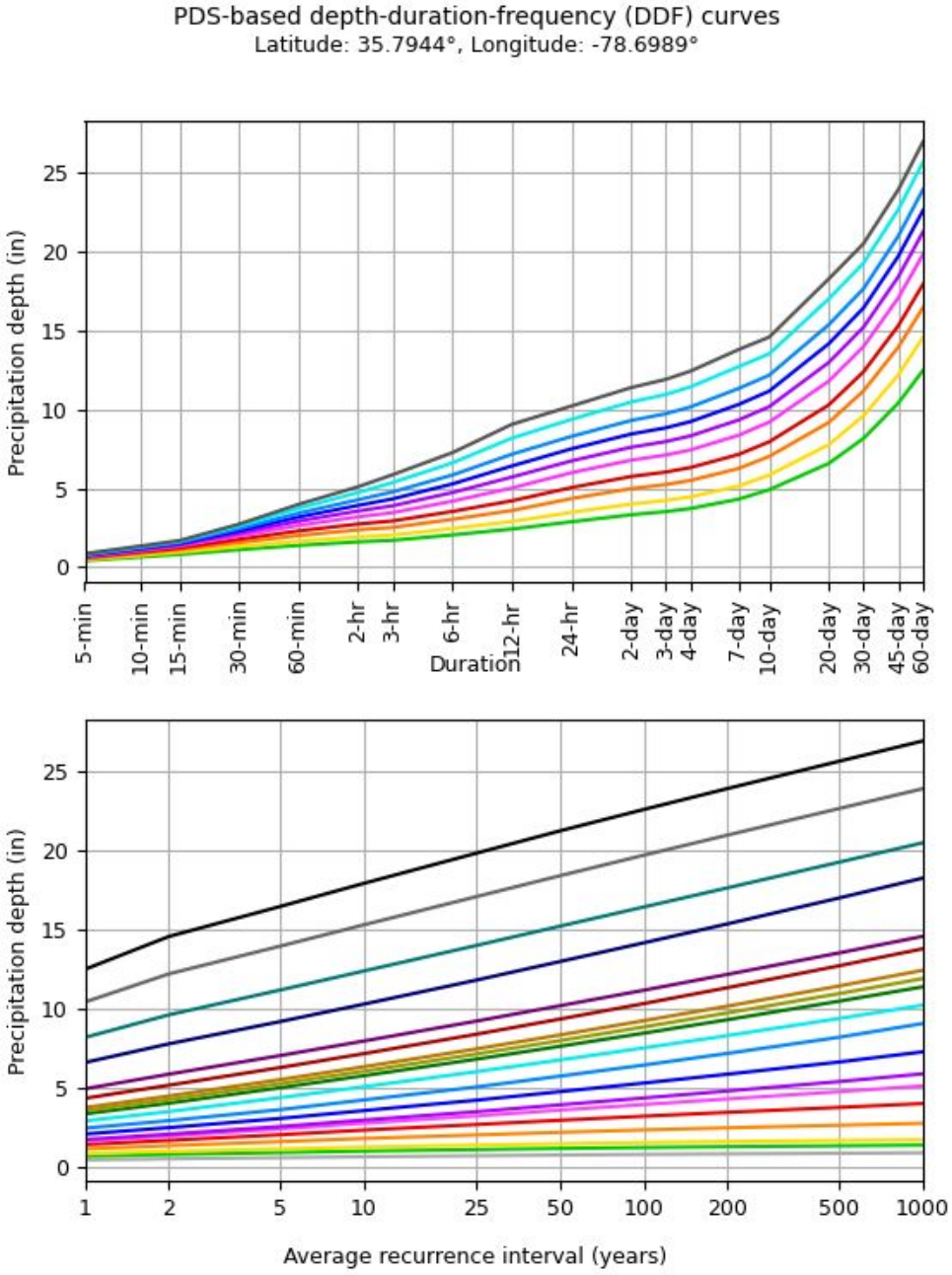
- Convective weather (a.k.a. thunderstorms)
  - Heavy rains
  - Sometimes damaging winds (tornadoes) & hail
  - Favored within the warm-sector of extratropical cyclones

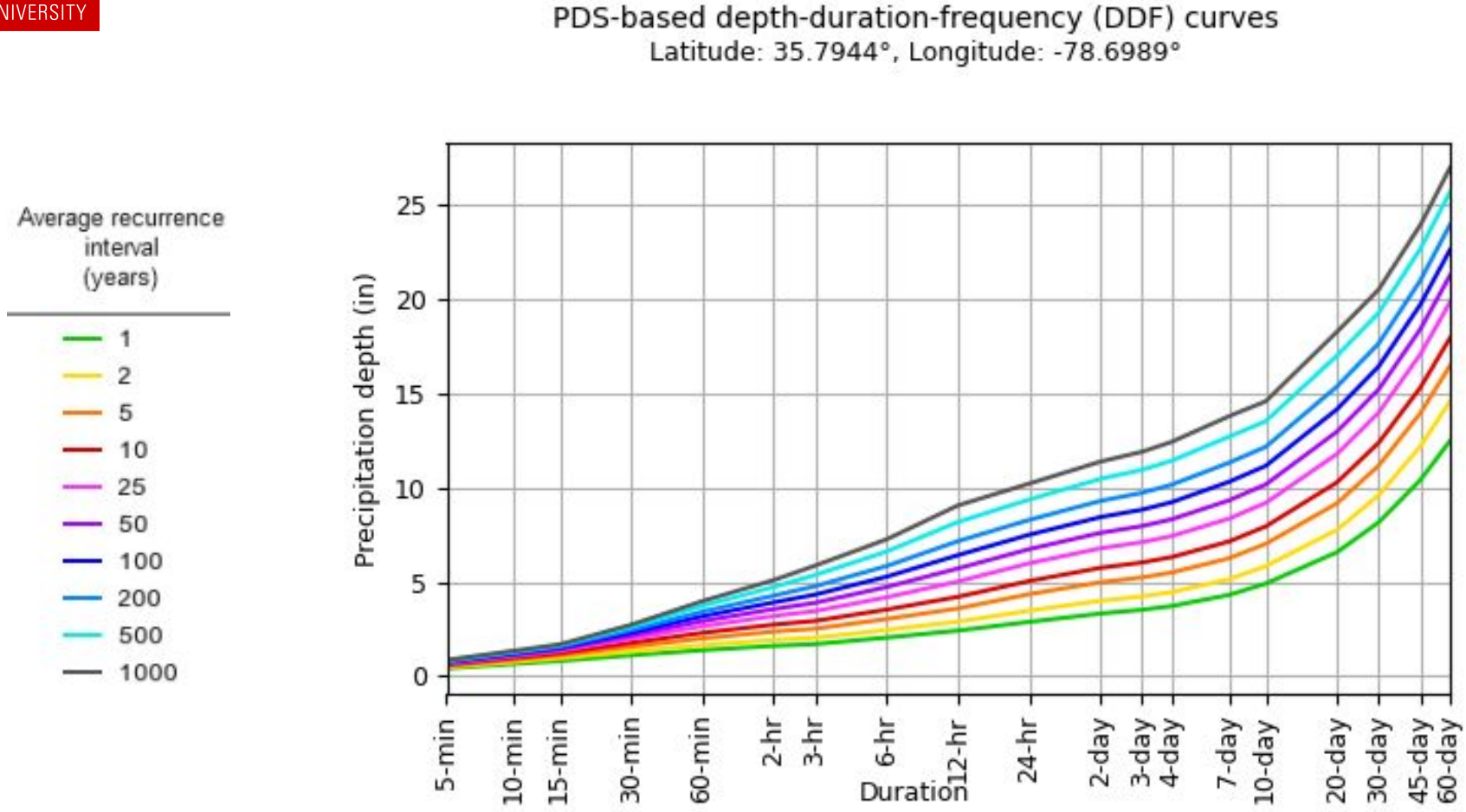


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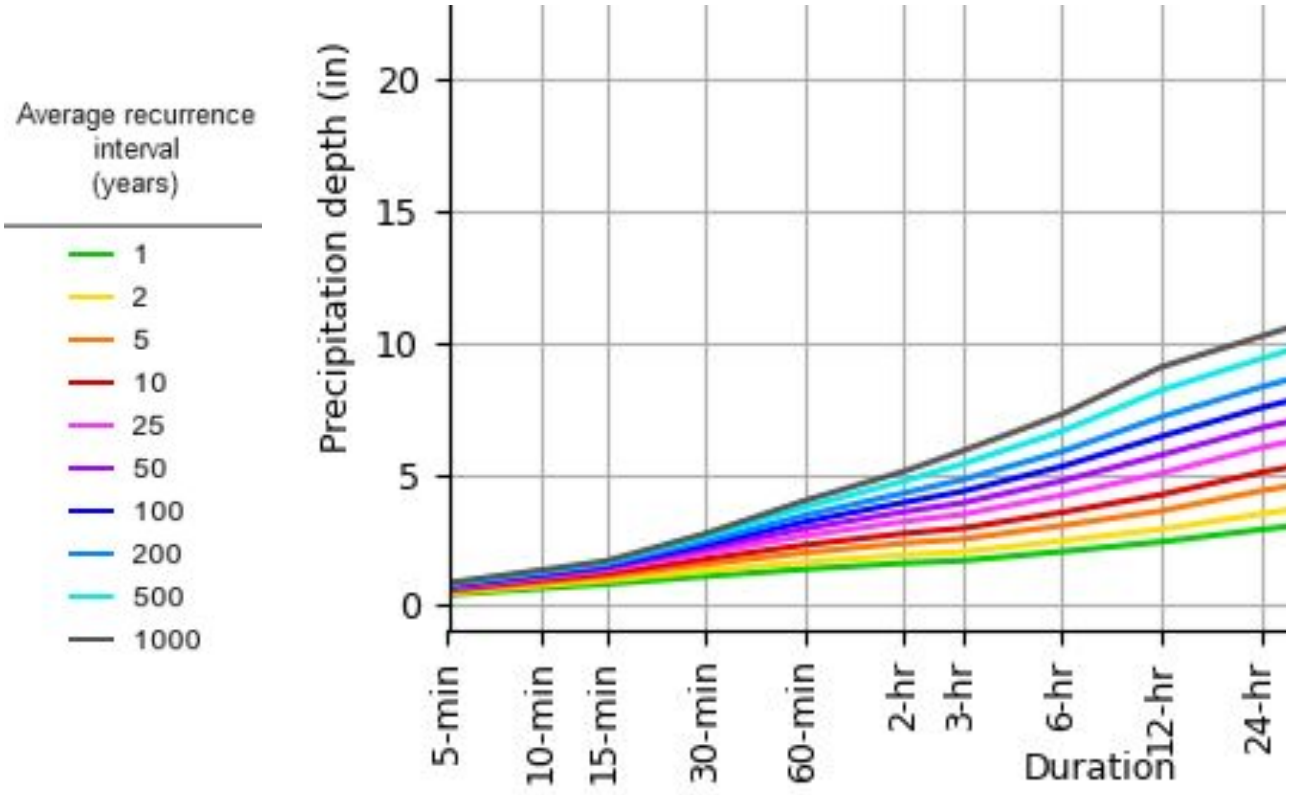
Rainfall recurrence intervals

NOAA “Atlas 14”
(*out of date!*)



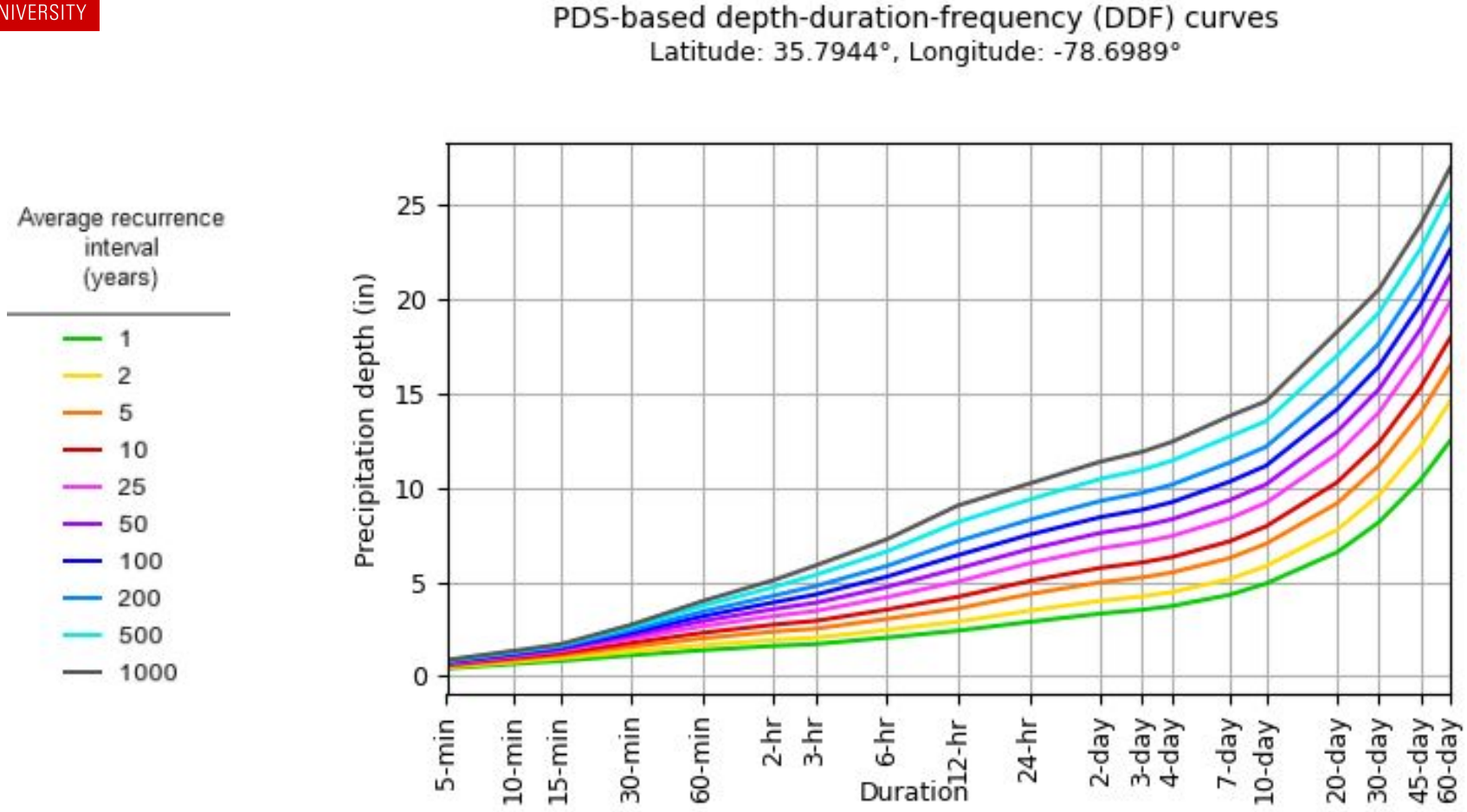


What is the probability (%) of getting 5" of rain in one day in Raleigh in a given year?

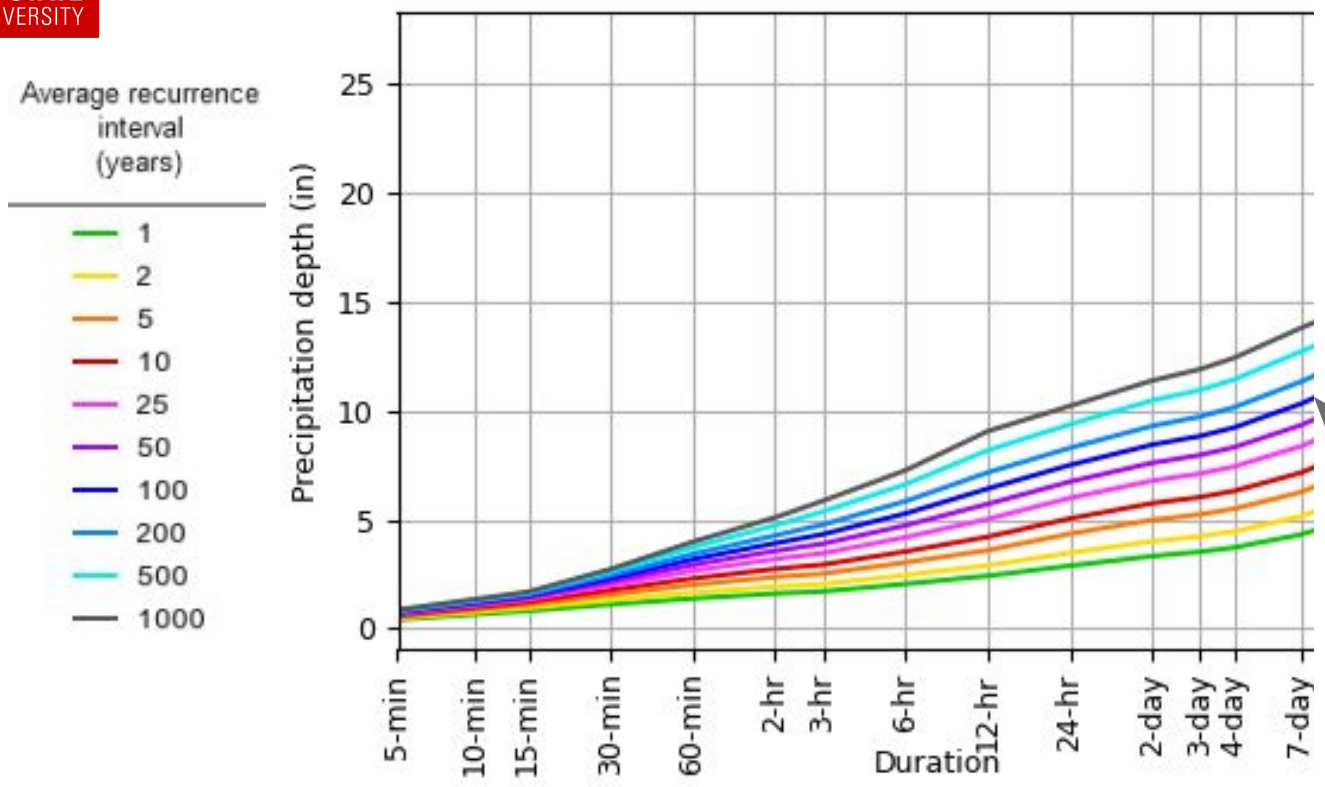


What is the probability (%) of getting 5" of rain in one day in Raleigh in a given year?

~10 year recurrence of 5" of rain. Chance in a given year is ~10%



Say next week, 11" of rain falls in Raleigh. What is the probability we will get 11" of rain in one week in Raleigh in 2025?



~100 year recurrence. Chance in *any* given year is ~1%

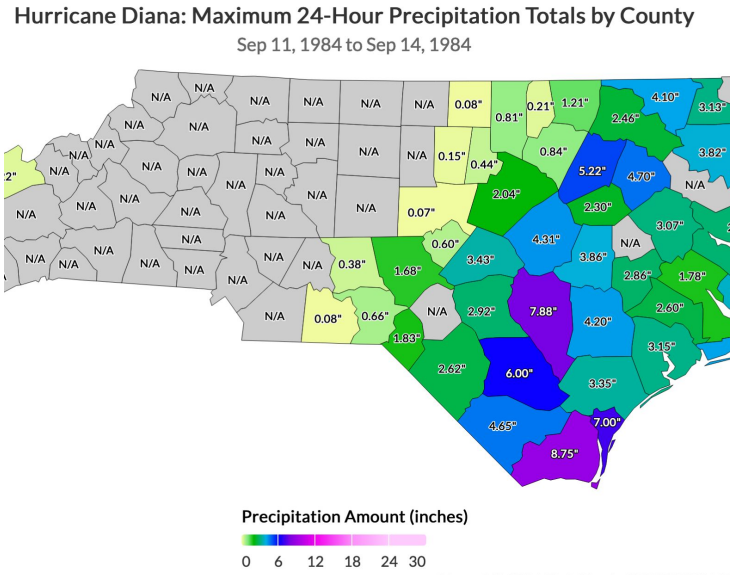
Next week, 11" of rain falls in Raleigh. What is the probability Raleigh will get 11" of rain in one week in 2025?

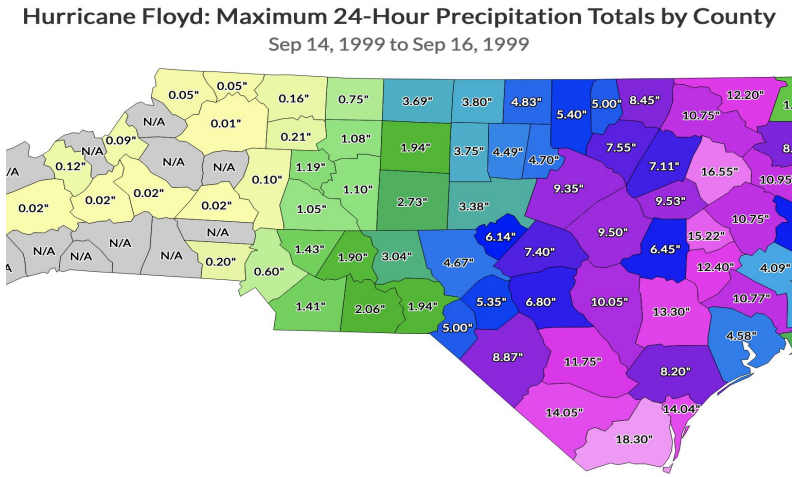
"100-year flood" terminology is misleading. Each year is independent (or maybe not - to come) "Gambler's fallacy"

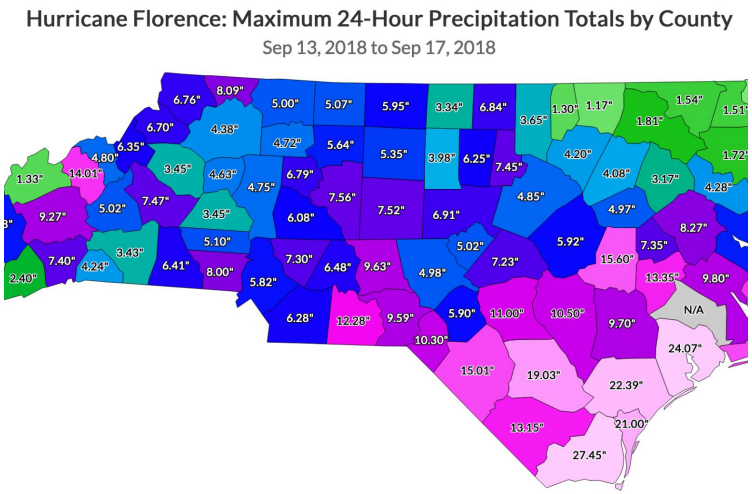
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Hurricanes

- A hurricane makes landfall in NC in roughly 2 years out of 3
- In piedmont, some damaging winds & rarely tornados, but lots of rain







- 10% of annual rainfall in 1 event
- Hurricane falls are wet; others tend to be dry

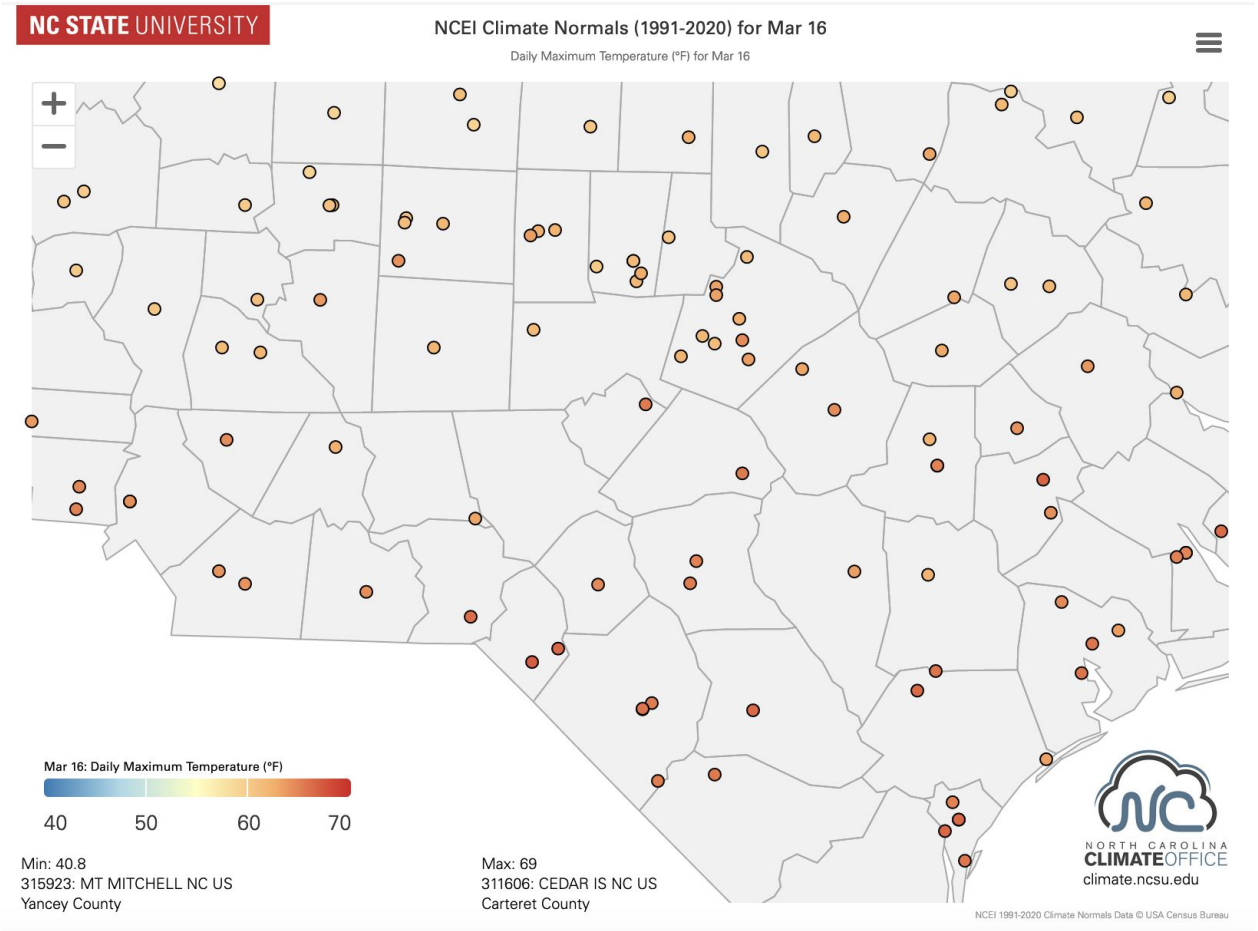
So far …

- What is our climate here in the NC piedmont?
- Why is it the way it is?

Questions/comments?

(use chat or unmute & speak up)

30 year (1991-2020) normal high T for today (3/16)



Next up …

- Is our climate changing - if so, how?
- Why is it changing?
- Does climate change matter?



Mark Robinson, NC Lieutenant Governor

One view: *"I know the climate changes, it happens four times a year, it's called seasons."*

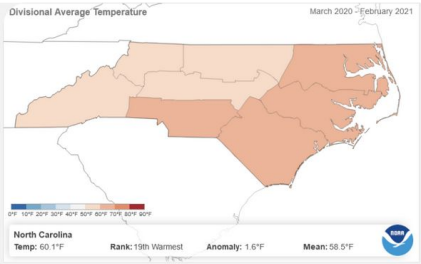
See for yourself!

- Go here: https://products.climate.ncsu.edu/climate/ (QR code above)
- Choose Statewide Climate Data *or* Climate Trends Plotter
  - SCD: how do recent years compare with past years? Warmer or cooler, wetter or drier?
  - CTP (simpler): trends in temperature and rainfall at specific locations

Take 20 minutes for this (& a cup of coffee)

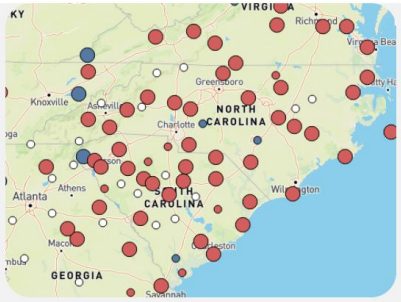
Then report your most interesting findings

I'll stay online to help



Statewide Climate Data (NCEI)

Retrieve temperature, precipitation and drought indices data for North Carolina and its climate divisions from the National Centers for Environmental Information (NCEI)



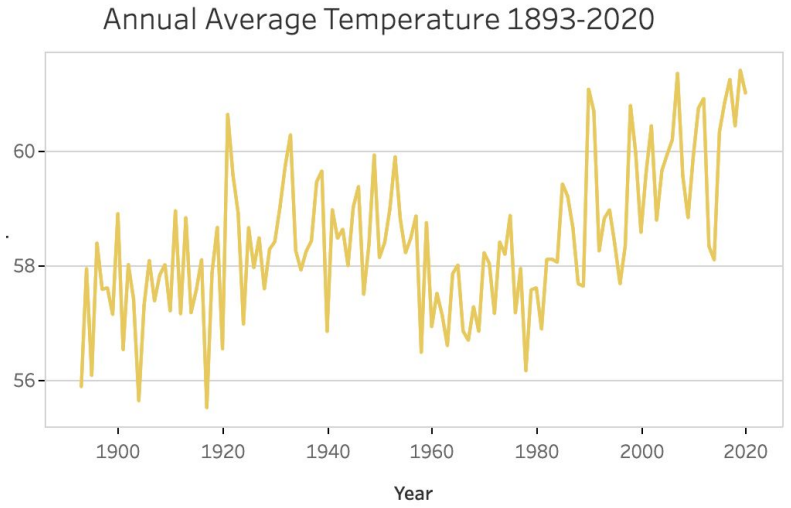
Climate Trends Plotter

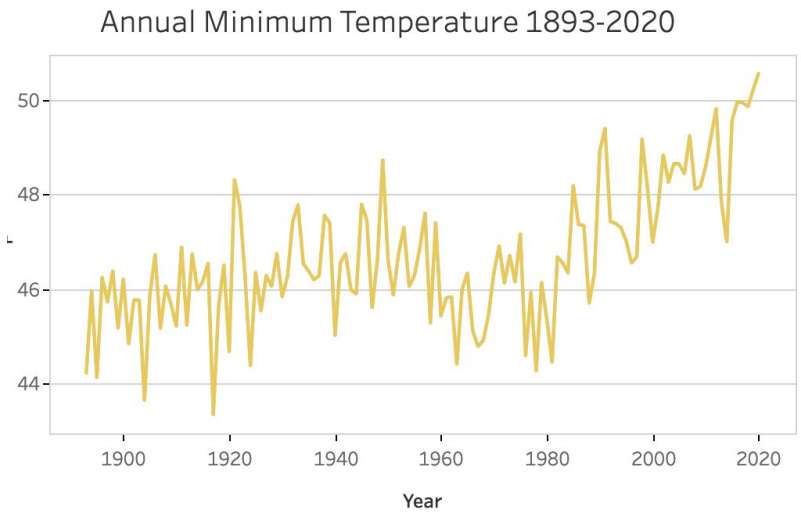
A tool to visualize historical temperature and precipitation trends across North Carolina and surrounding states.

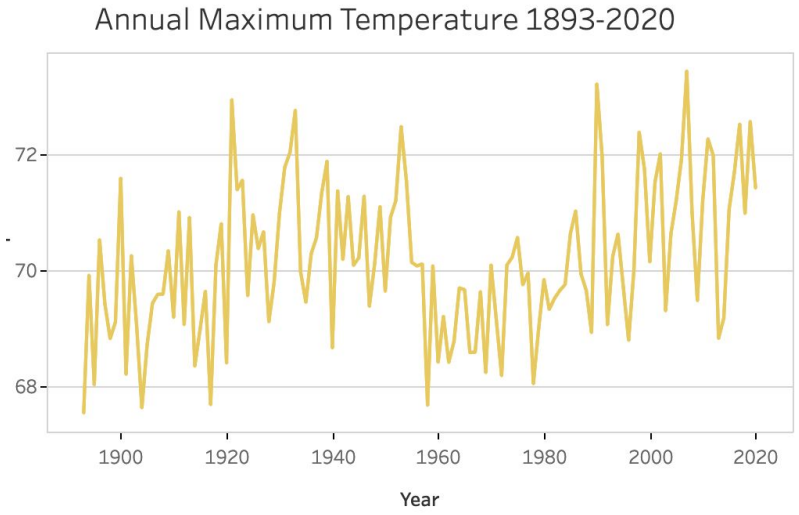
Example: Climate Trends Plotter

Annual average temperature:
Chapel Hill

- Stronger trend in lows than highs
- Trend in average*
  - 0.17°F/decade since 1893
  - 0.63°F/decade since 1960





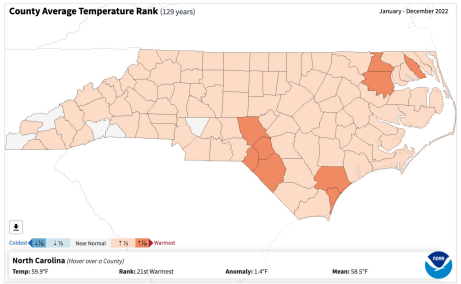


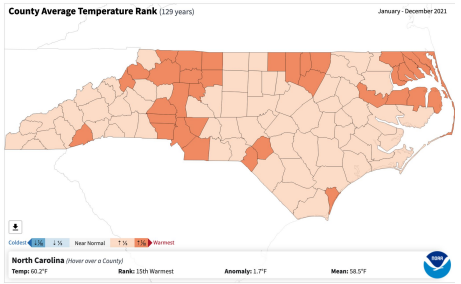
*daily average $T = (T_{high}+T_{low})/2$

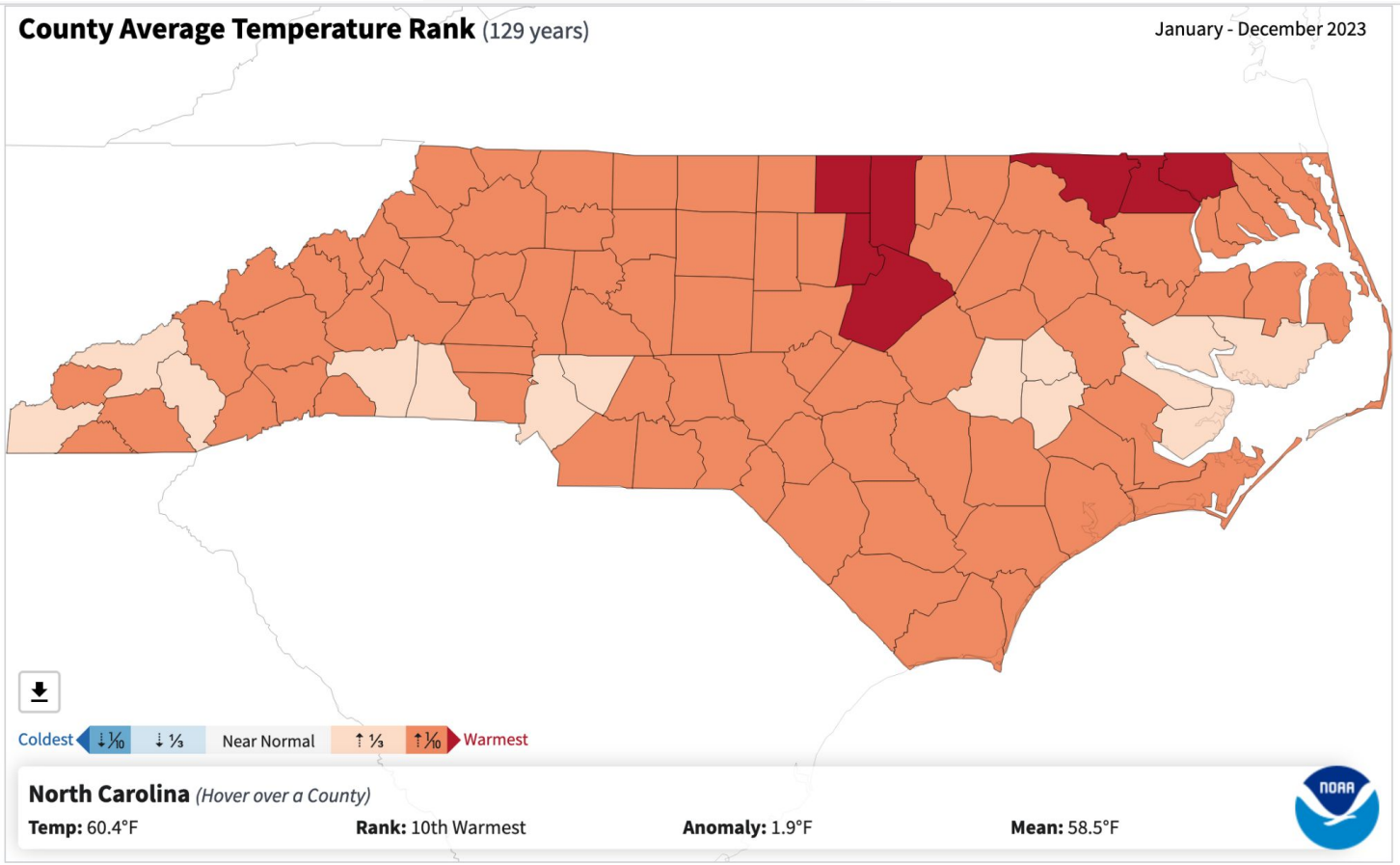
Example: Statewide Climate Data

2023 annual average T

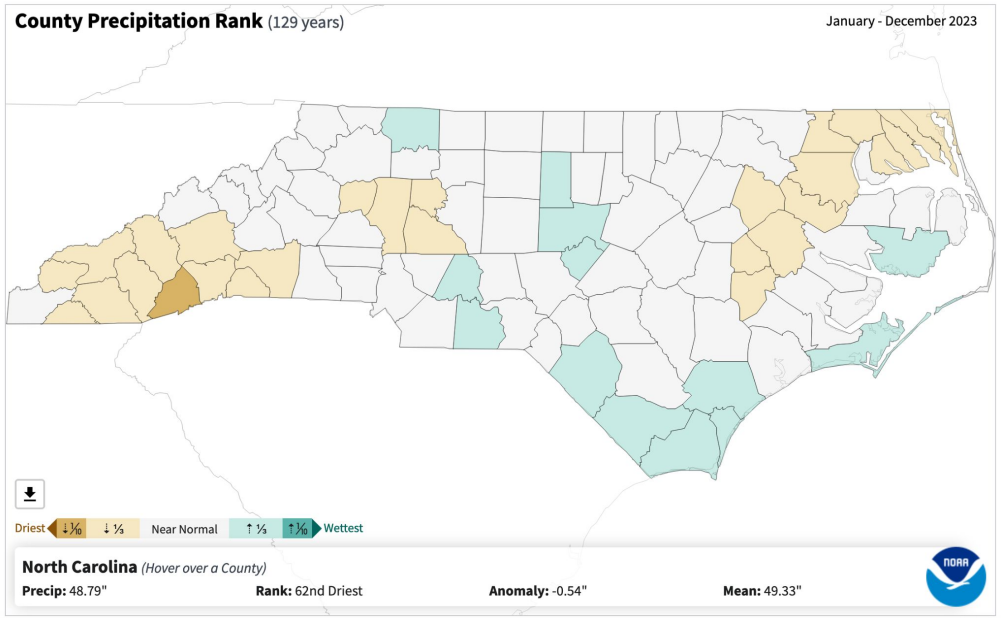
- county ranks since 1894
- Most in top tenth





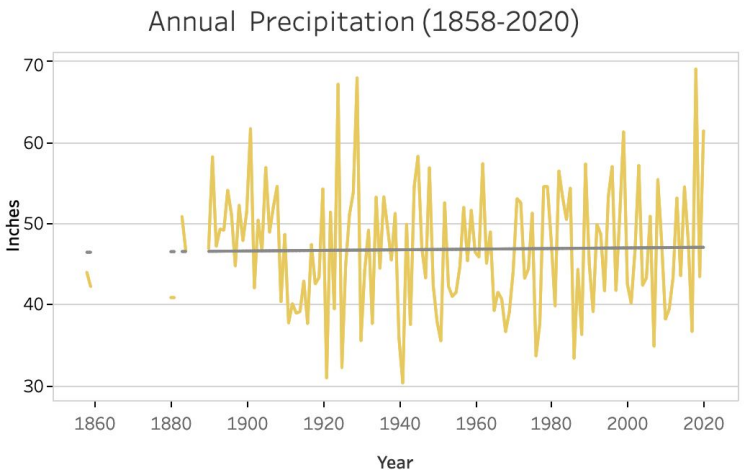


No clear trends in precipitation



Annual precipitation: 2023 rank

Annual precipitation: Chapel Hill

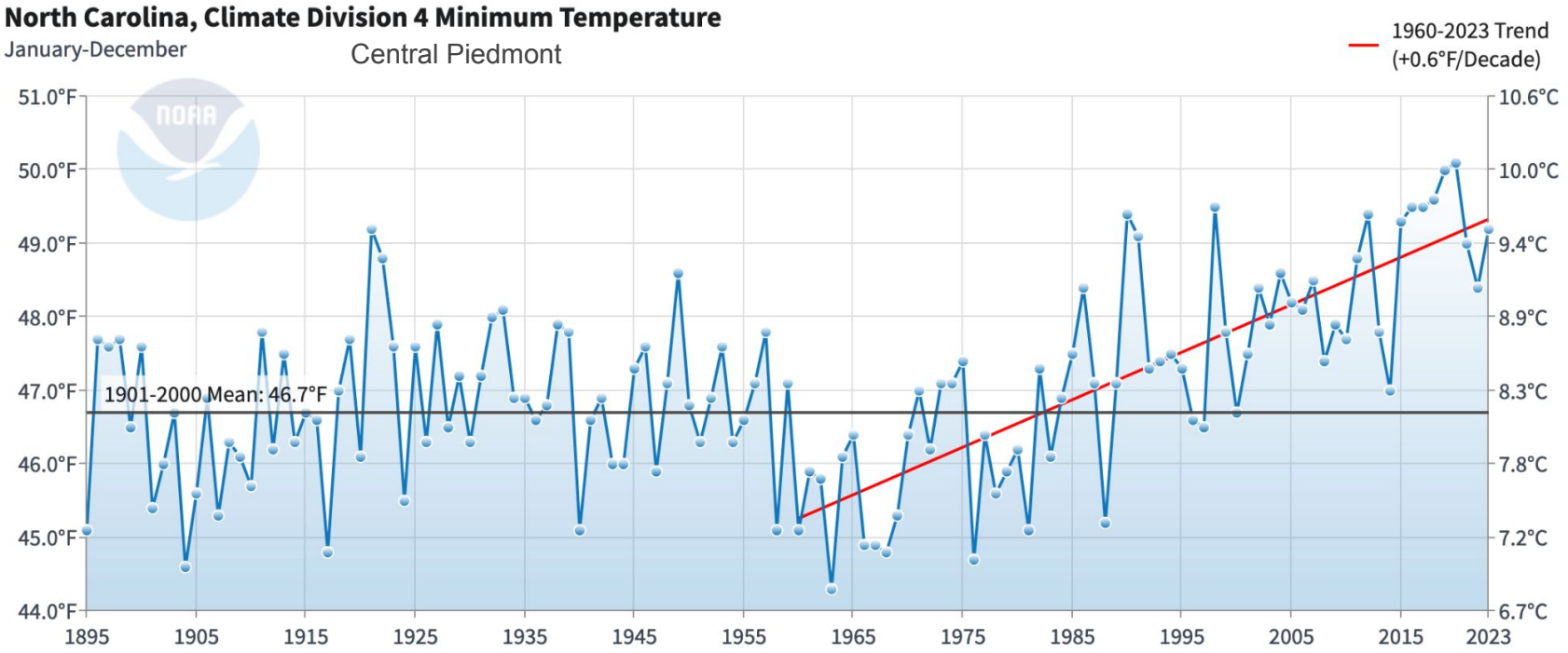


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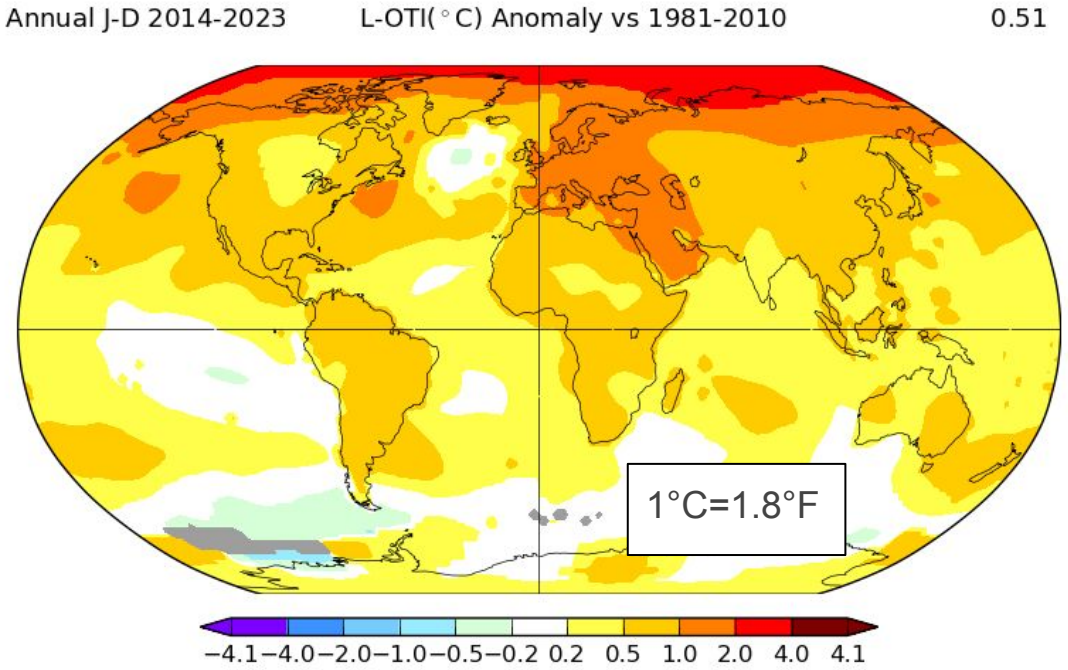
NC climate trends

It is a <u>policy</u> decision to collect & disseminate these data; policies can change

- Warming
  - especially at night
  - especially since 1960
    - but 1st half of 20th century was warm
- No trends in precipitation

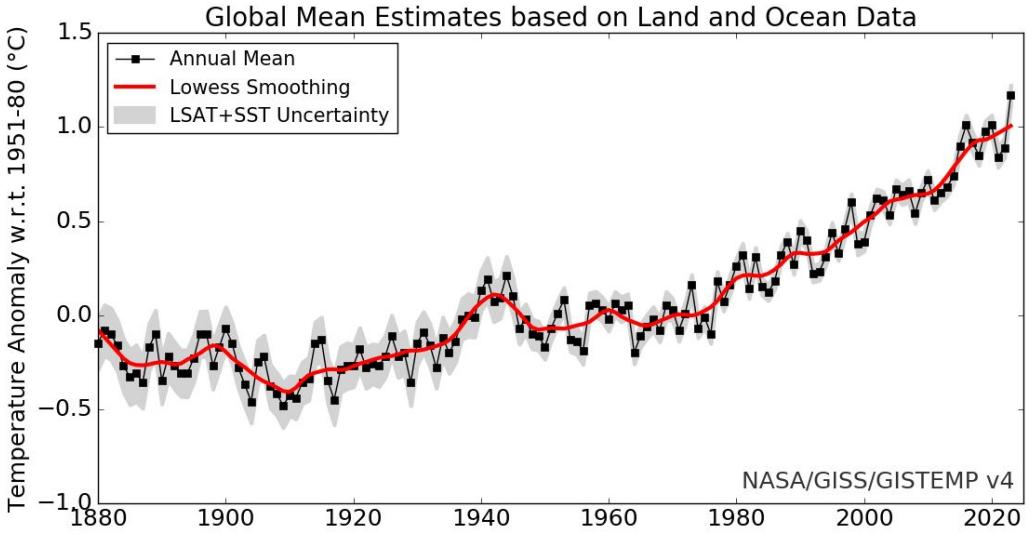


Global context



- Warming nearly everywhere
- Most over Arctic
- Least over oceans

- About 2°F global warming since 1900
- Last 10 years warmer than any previously

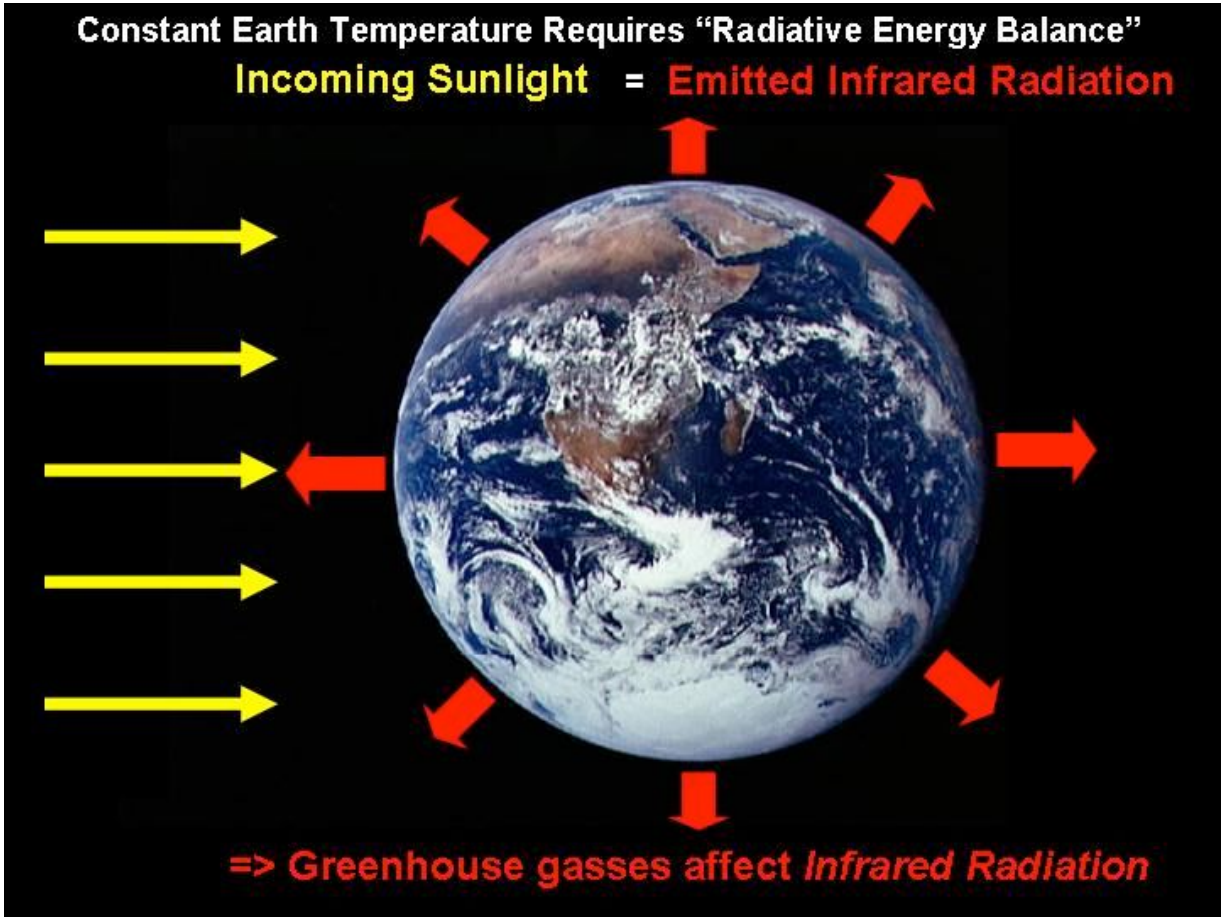


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Why is climate changing?

- Earth
  - gets energy from the sun
  - loses energy by emitting infrared radiation (IR)
- This balance sets the global temperature

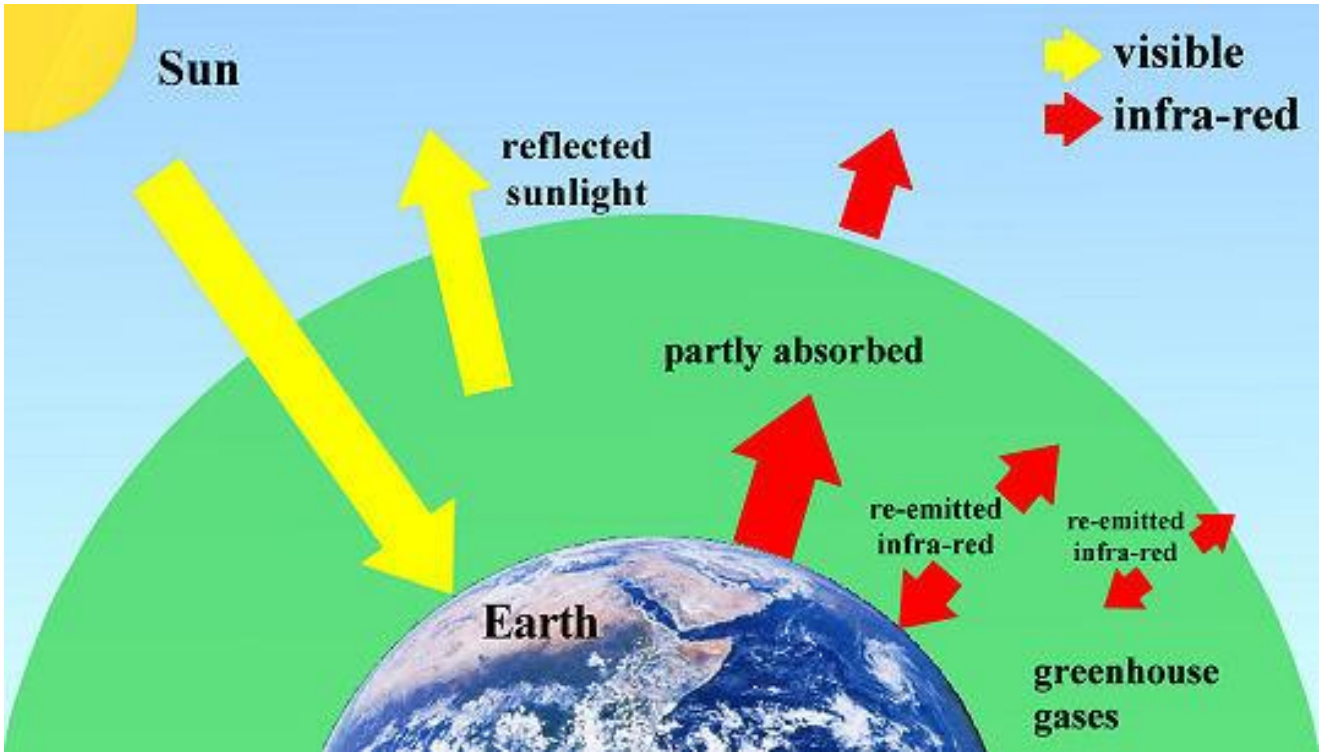
(as measured by an astronomer on Mars)



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The greenhouse effect

Greenhouse gases absorb outgoing IR & emit IR (Kirchoff's law) warming Earth's surface

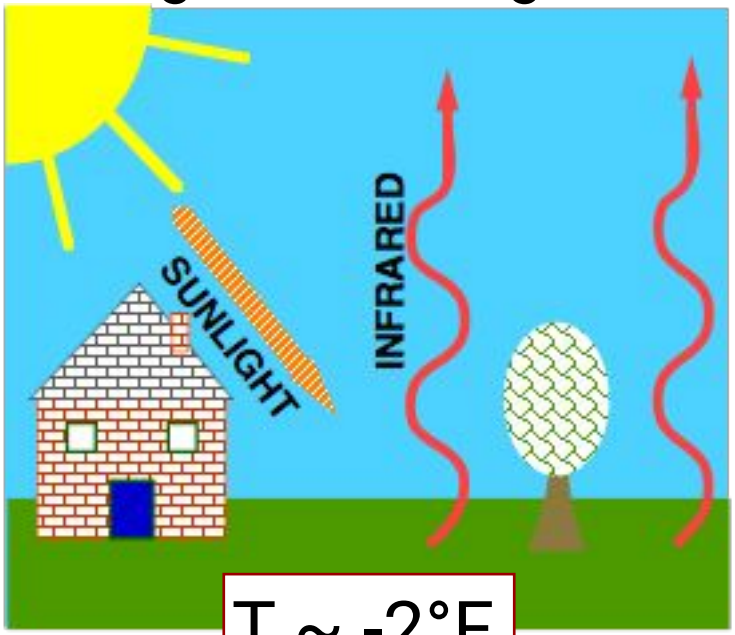




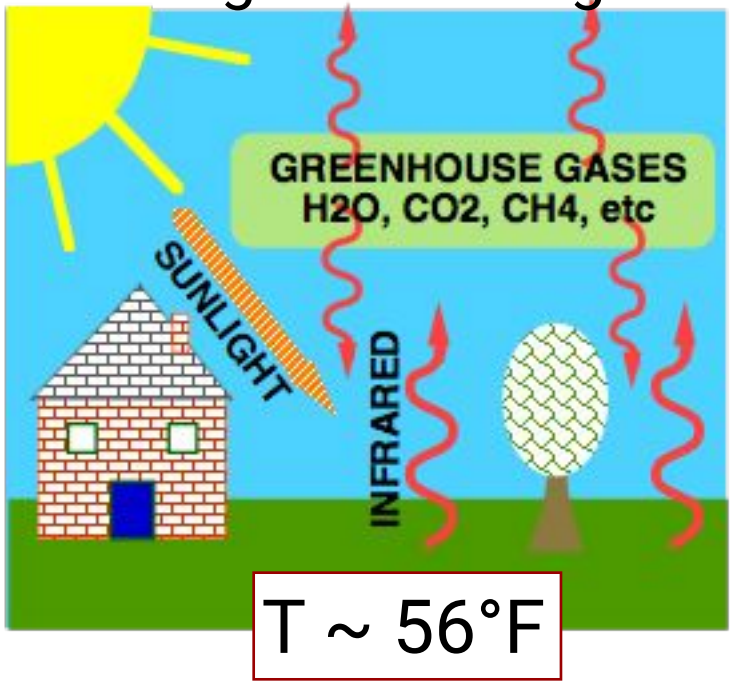
Gustav Kirchhoff

Greenhouse effect => Earth's T

No greenhouse gases

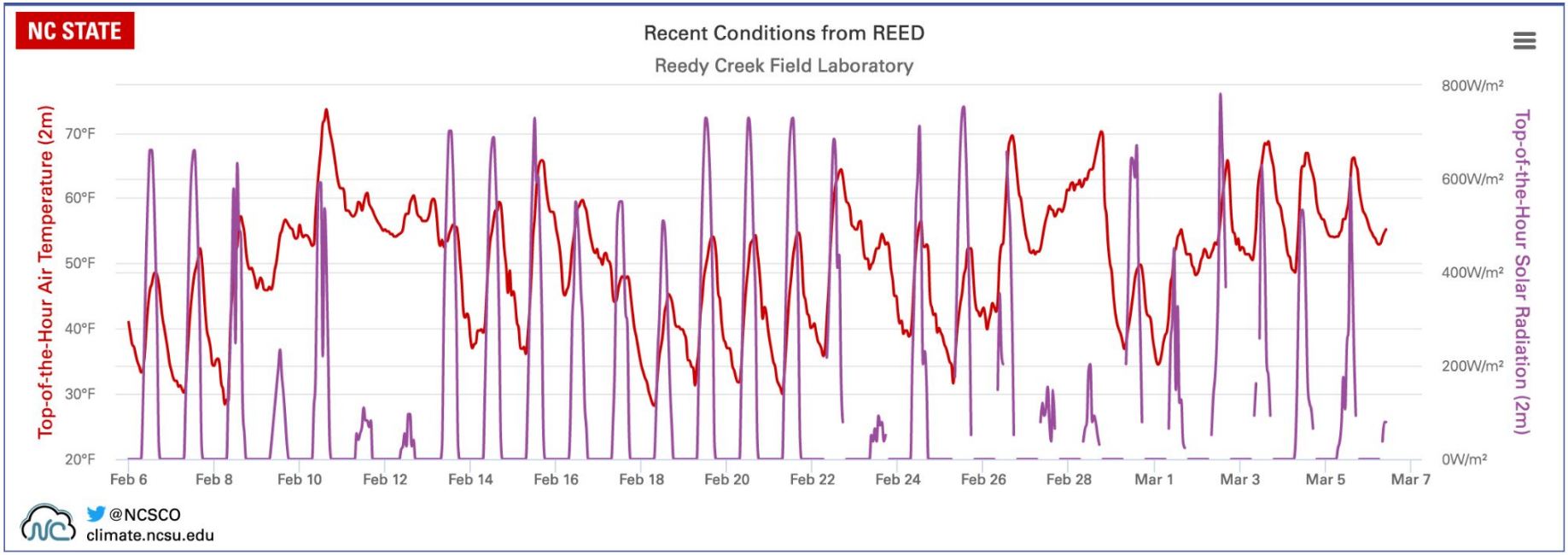


Natural greenhouse gases



Without the natural greenhouse effect, Earth would be much to cold for life.

Greenhouse effect day-to-day



Look at the relationship between peak daytime solar radiation & the following overnight low T. What does this have to do with the greenhouse effect?

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Greenhouse gases



- Water vapor
  - Controlled by weather & climate
- Carbon dioxide
  - Burning coal, oil, & gas
  - Clearing forests
- Methane
  - Livestock
  - Rice paddies
  - Shale-gas production
  - Landfills
- Nitrous oxide
  - Denitrification (e.g. of fertilizer)

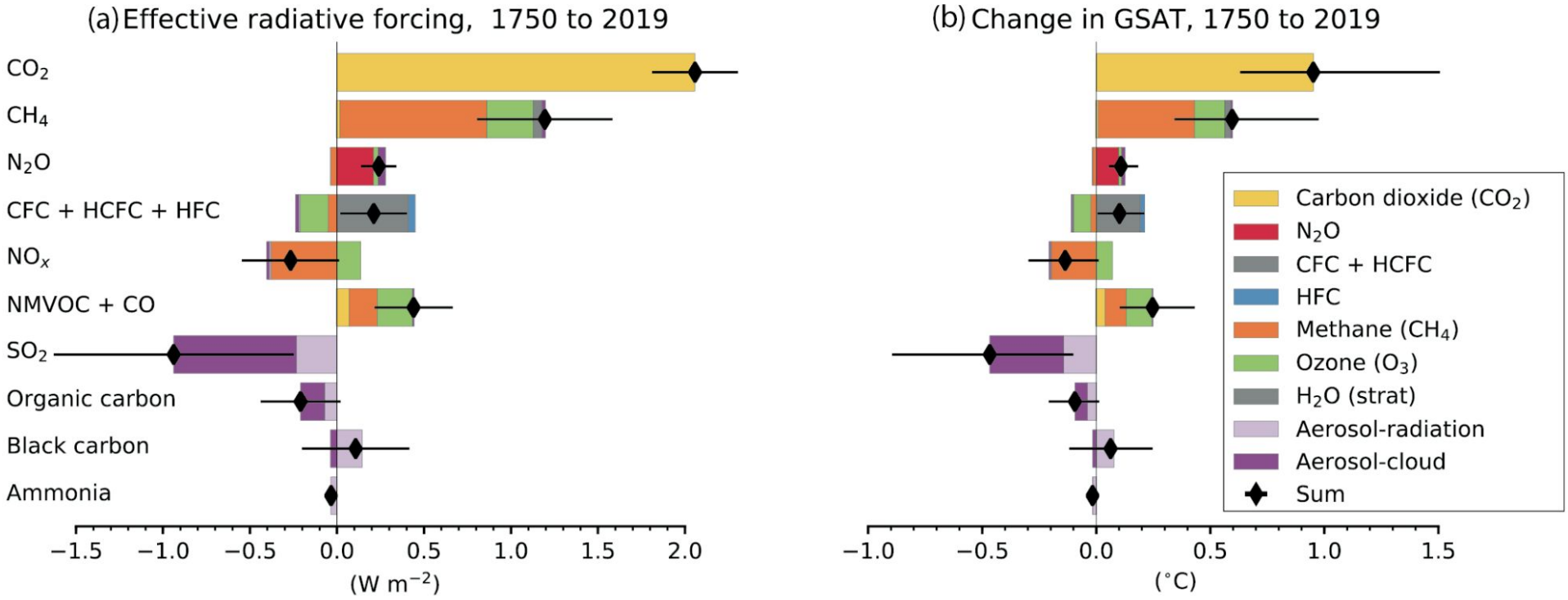




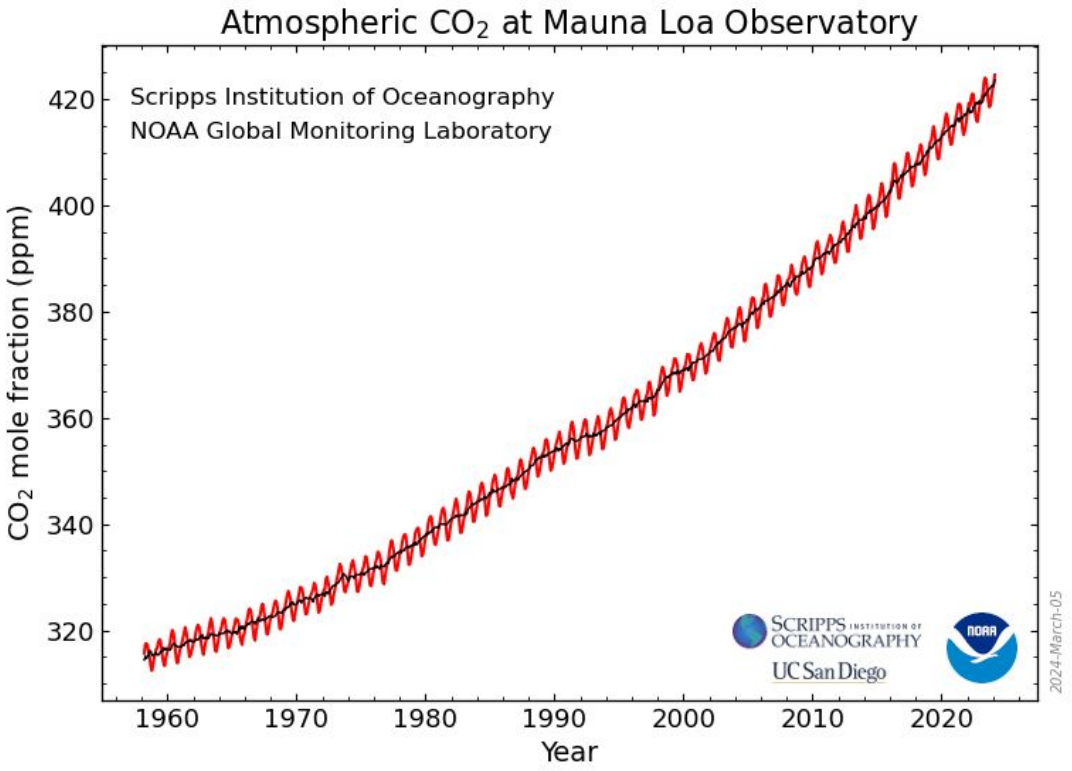


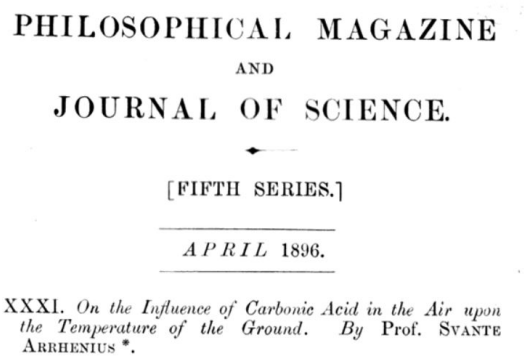
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Human “radiative forcing”



Increasing CO_2 & expected warming





PHILOSOPHICAL MAGAZINE

AND

JOURNAL OF SCIENCE.

[FIFTH SERIES.]

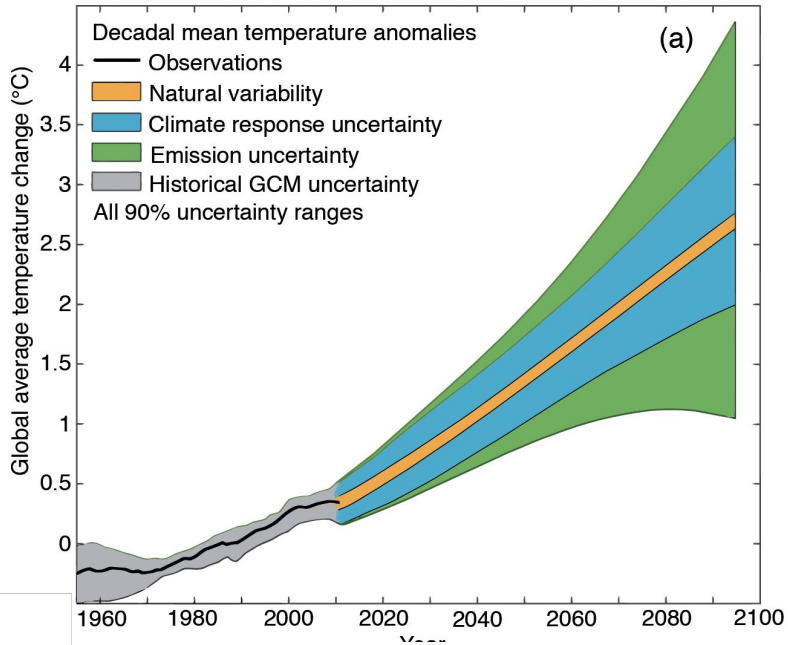
APRIL 1896.

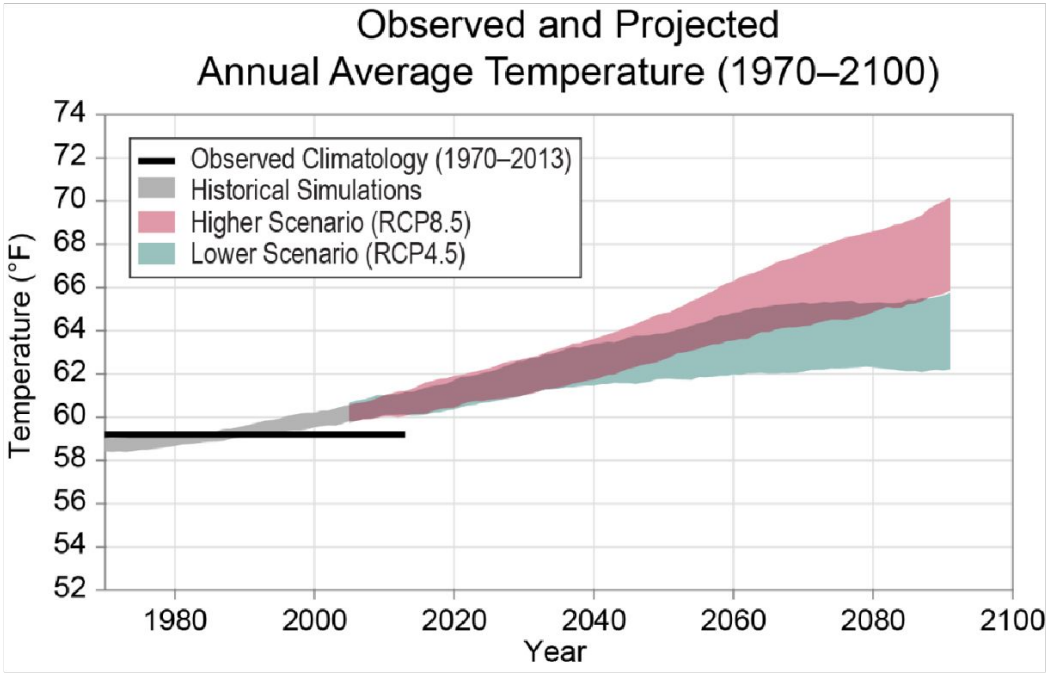
XXXI. *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground.* By Prof. SVANTE ARRHENIUS *.

- Increase of ~50% since 1800
- Doubling CO_2 expected to yield 3 to 8°F global warming.
- Result originally obtained by Svante Arrhenius in 1896



For Earth & NC, future emissions are most important

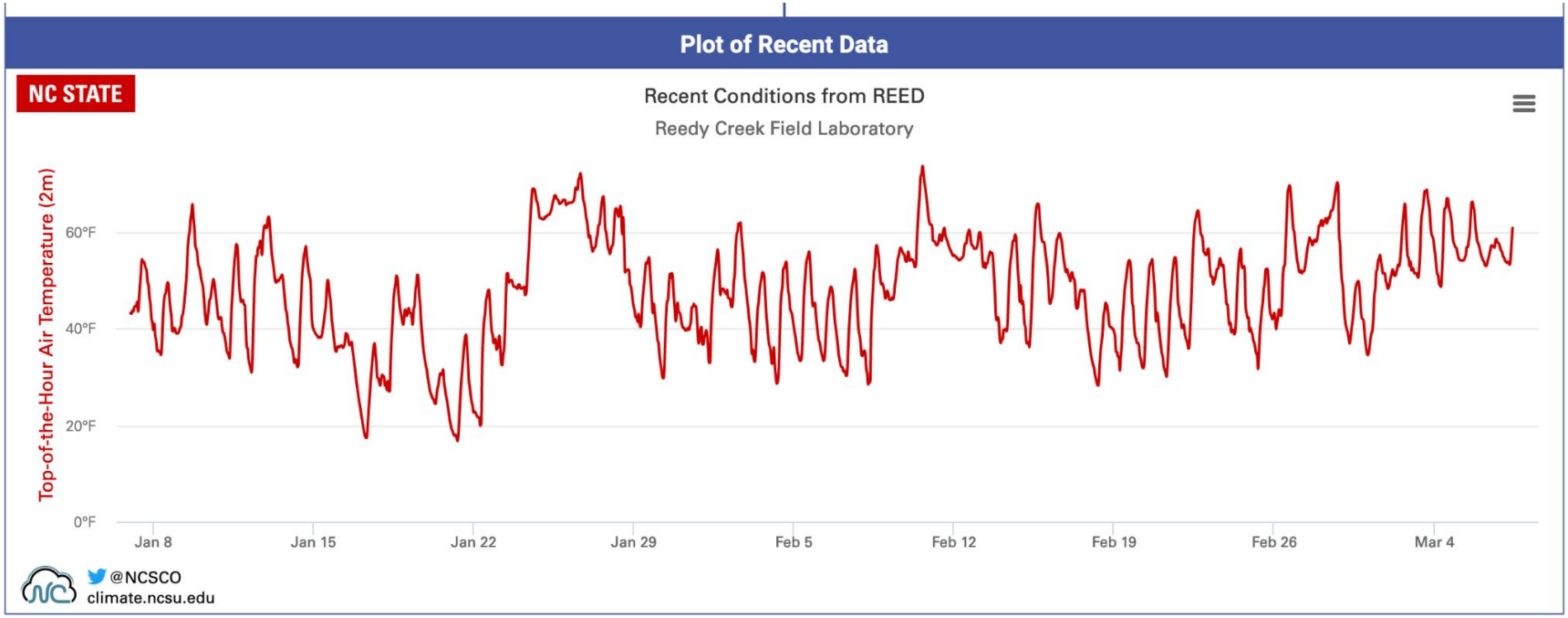




Does climate change matter?

If so, why?

- Claim is that 2°C warming (3.6°F) represents "dangerous anthropogenic interference with the climate system"
- Why? After all, temperatures can swing 10 times that in a few days.



What do you think?

Impacts on nature



Species viability – 3 R's

- Representation

  breadth of genetic and environmental diversity within and among populations

- Resiliency

  The ability of a species to withstand stochastic disturbance; increases with population size, growth rate, & connectivity among populations

- Redundancy

  The ability of a species to withstand catastrophic events by spreading risk among multiple populations or across a large area

Smith *et al.* 2017

Climate change & the 3 R's

- Representation

  Reduced genetic diversity – subpopulations poorly adapted to new conditions removed

  Reduced environmental diversity as some environments cross thresholds (temperature, etc.) of viability

- Resiliency

  More frequent & severe extreme events increase strengths of stochastic disturbances

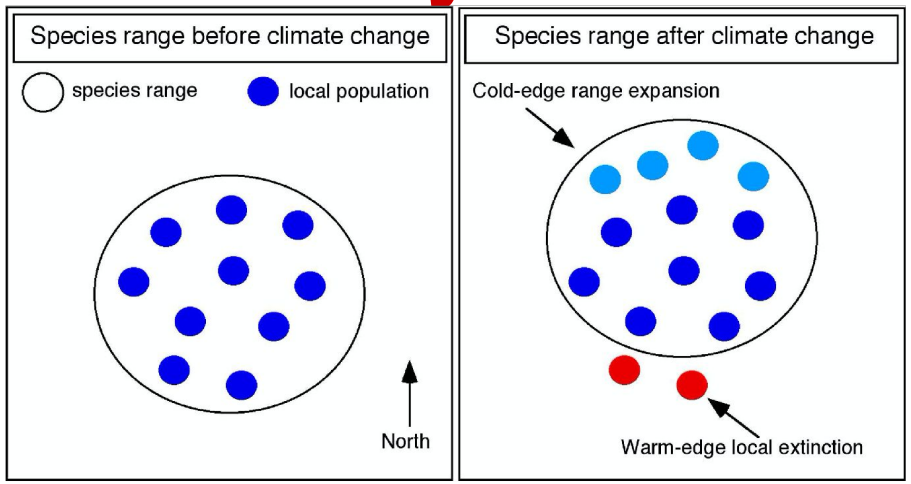
- Redundancy

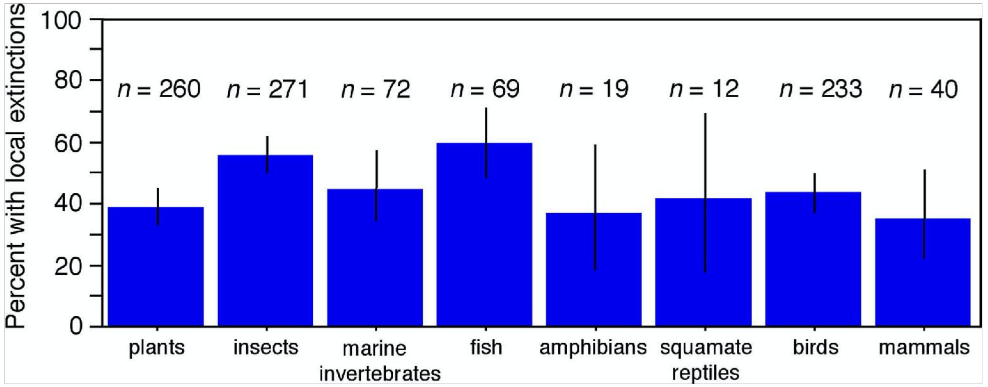
  Reduced, if range contracts

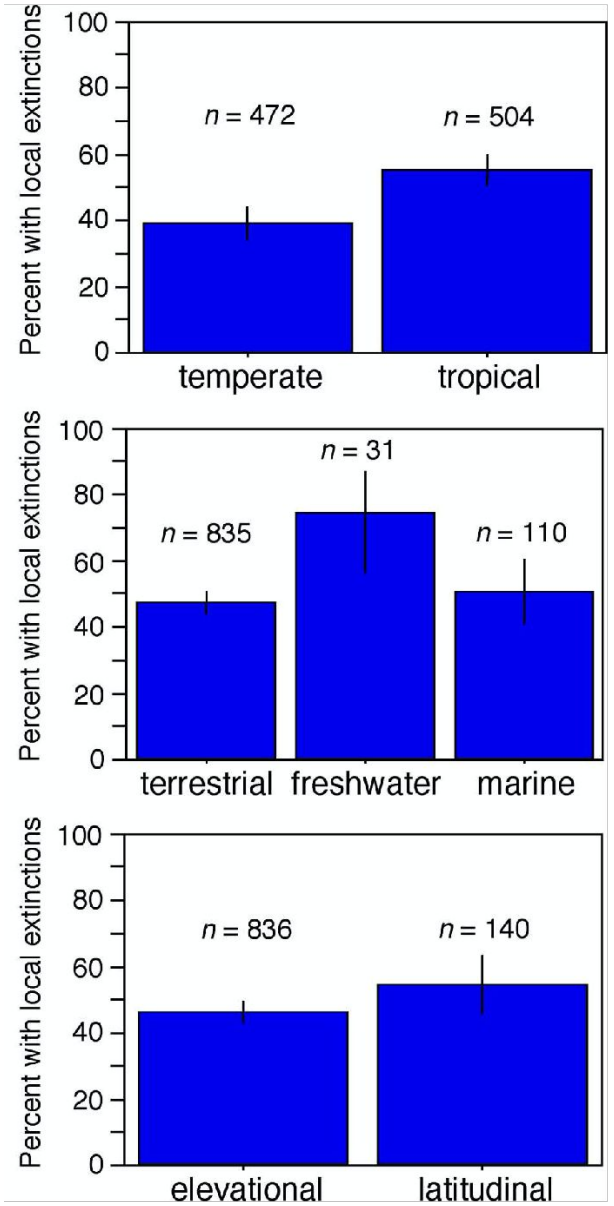
Exacerbated by other human influences: habitat destruction, introduction of invasive species, pollution, etc.


ANIMALS & PLANTS FLEEING CLIMATE CHANGE ARE MIGRATING TOWARD THE POLES AT 20 CM PER HOUR.
Dad, when will we get to Canada?
This is Canada.
©2011 S. McMILLAN

Range shifts & local extinctions reduce redundancy



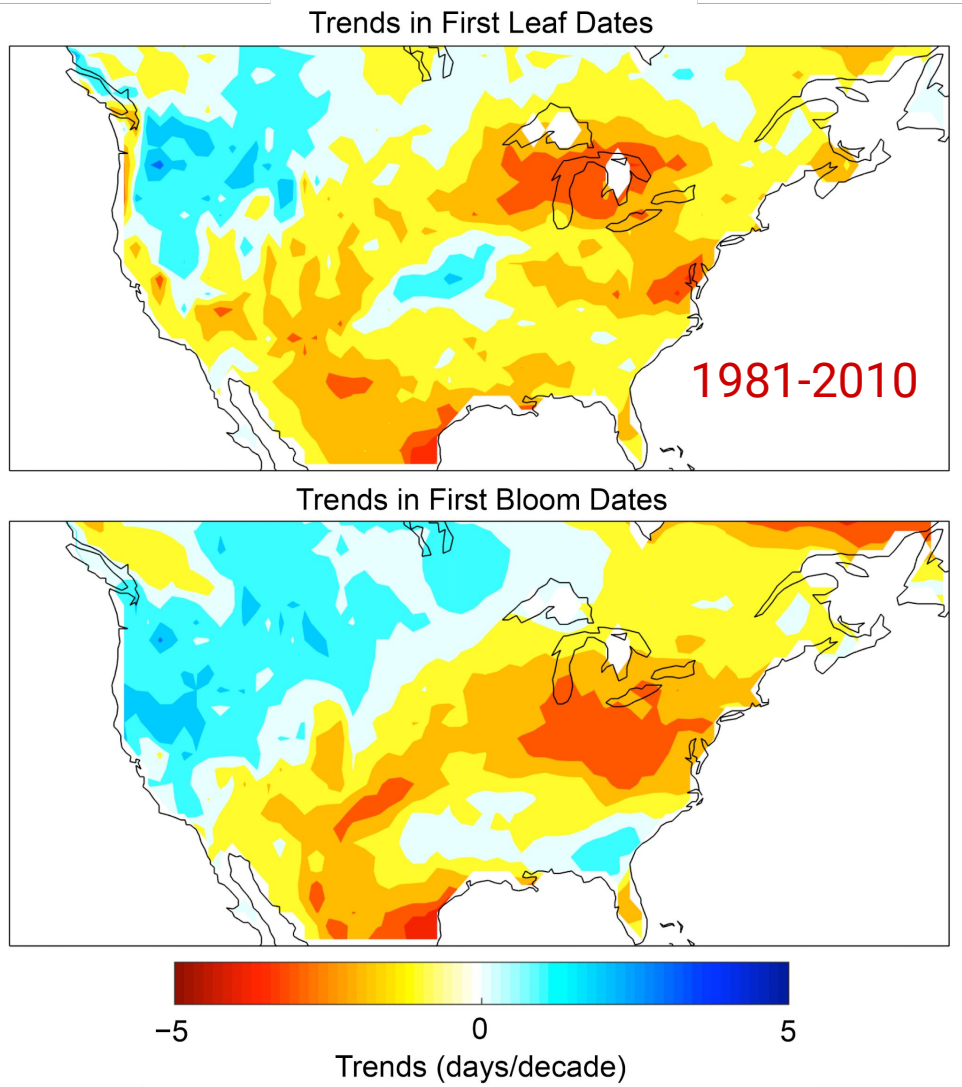




Climate-Related Local Extinctions Are Already Widespread among Plant and Animal Species
Wiens, 2016

Phenology

- Advance of spring
- But “rate of phenological change varies across trophic levels”
- Migratory species at risk if they arrive at the “wrong” time

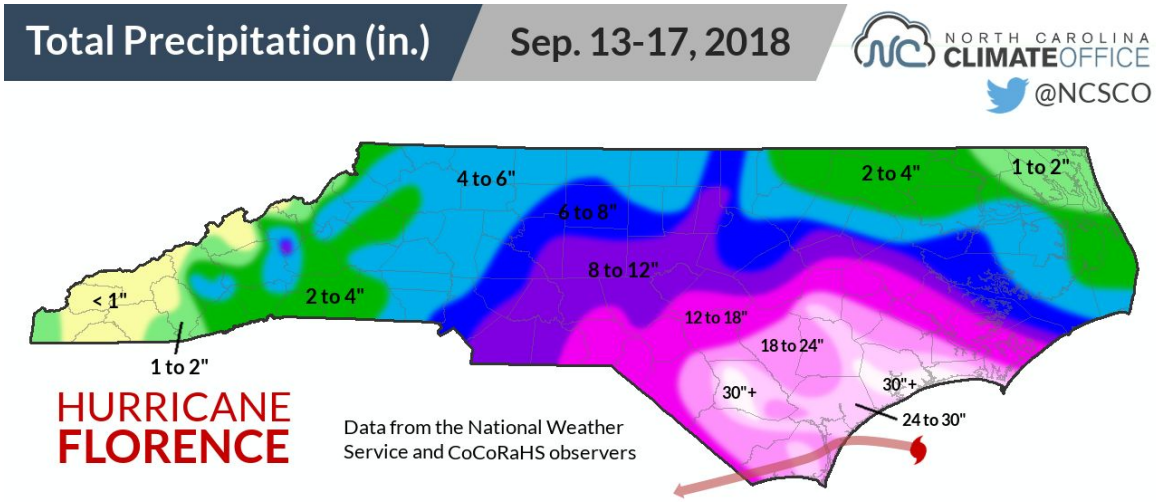


NCA

Extremes (disturbances) increase with climate change

- New temperature extremes
- New hydrologic extremes (wet & dry)

These changes arise from fundamental statistics & physics



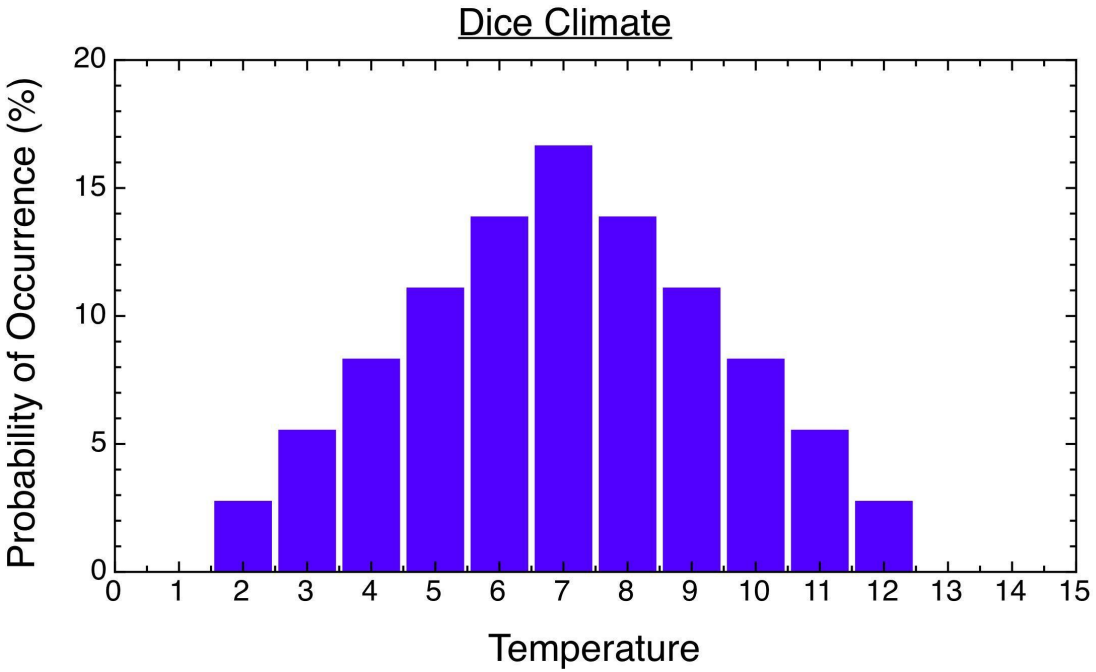
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Weather & climate dice



- Think of the weather on a day as a roll of dice
- Dice “weather”: the number from a single roll
- Dice “climate”: the statistics accumulated over many rolls
  - Average roll = 7

Chances of rolls:



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Greenhouse dice

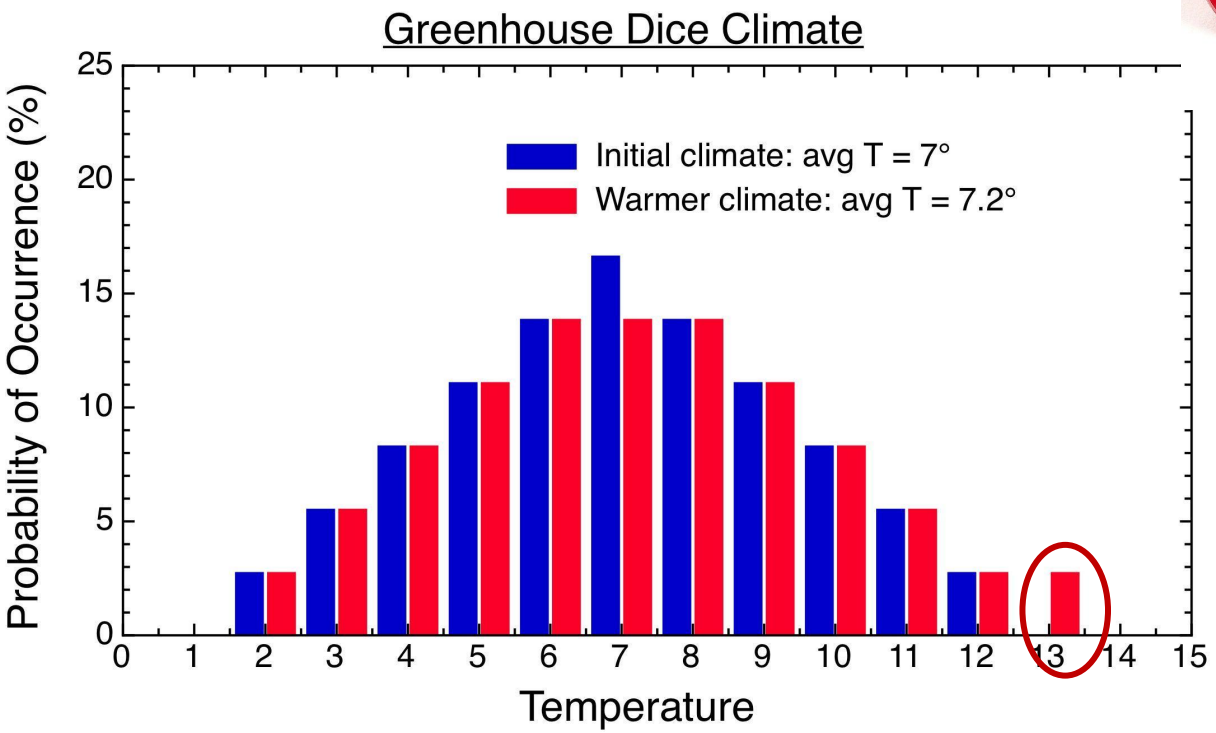




(Courtesy Jim Hansen)

- "Greenhouse dice": add a dot to the 6 on one die
- Average climate changes a little (7 to 7.17)
- *But* … 13s!



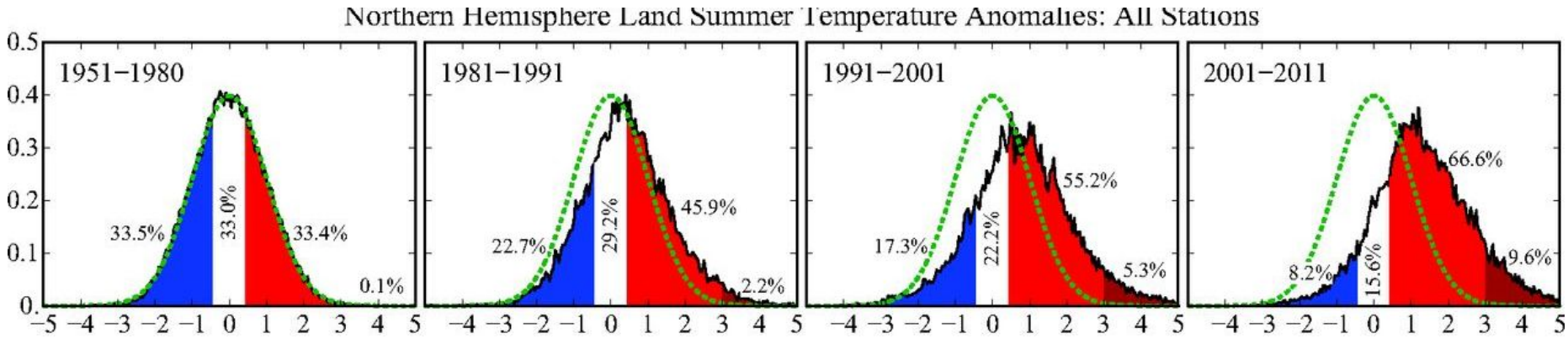


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Greenhouse dice in the real world

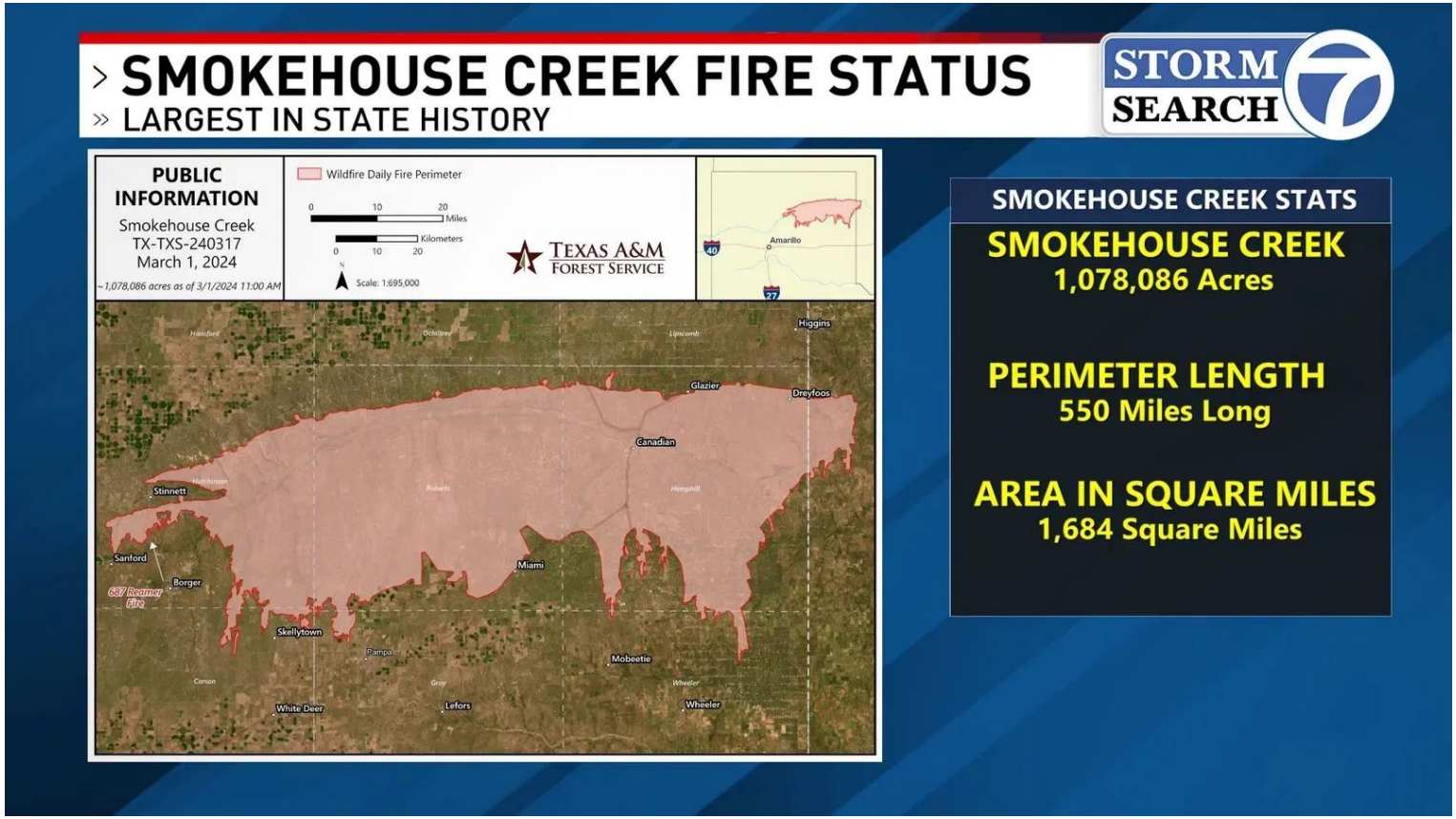
Northern Hemisphere summer temperatures (land stations)

- Heat that came once in 3 years now occurs several times *each* year.



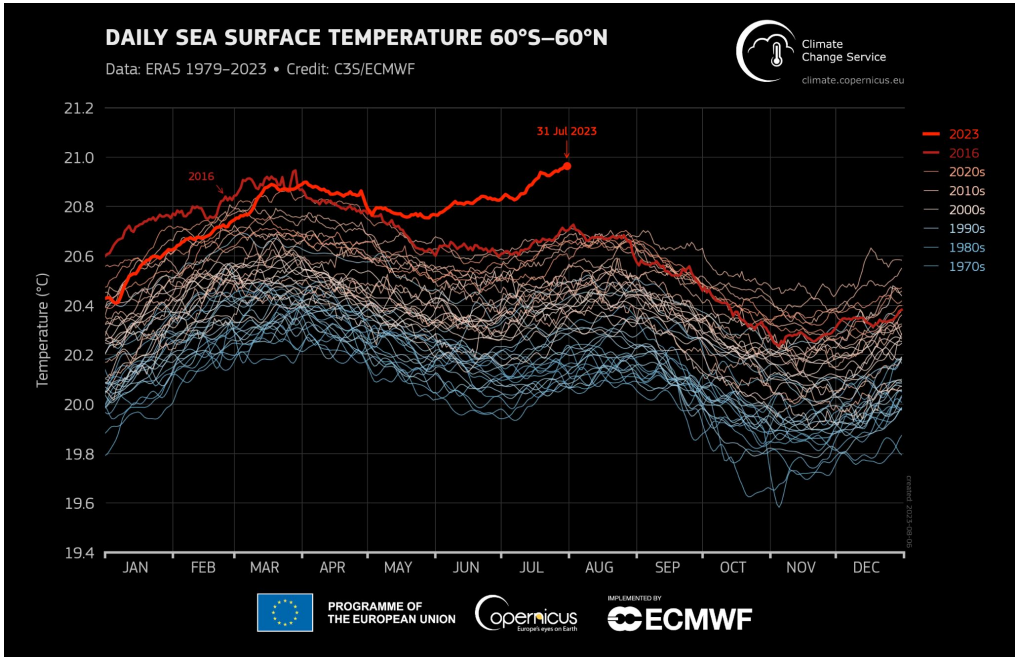
13s

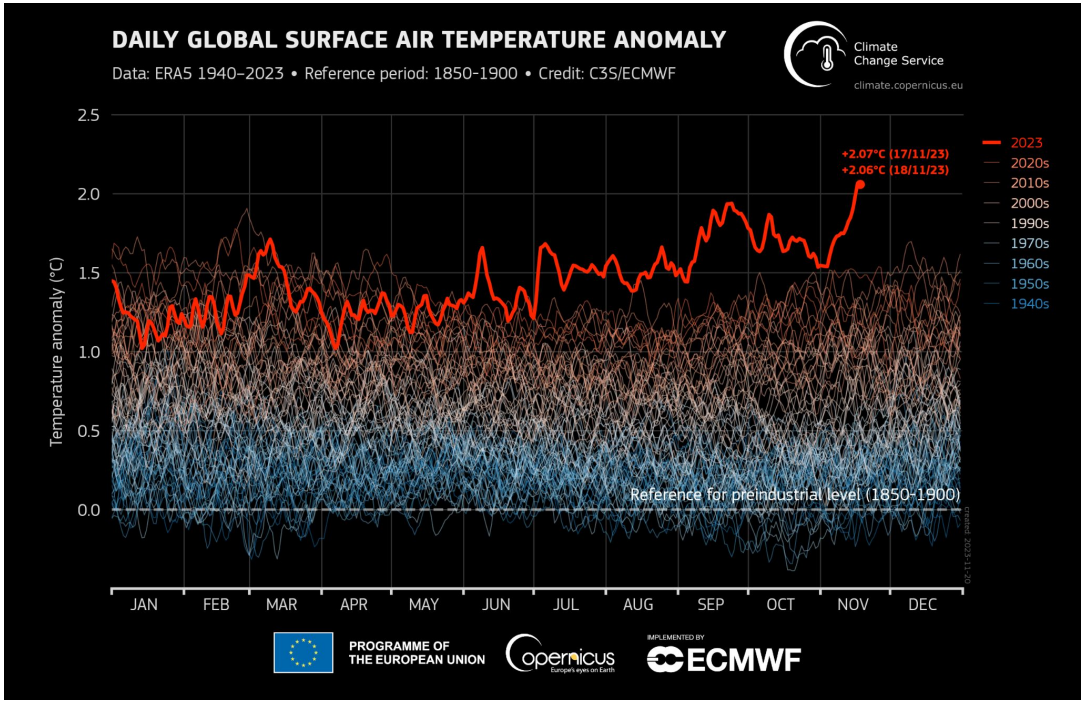
- As Earth heats up, the hottest high temperatures, heaviest rains, most severe droughts are worse than we've ever seen
- *Happening now*



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Global 13 in 2023





Hydrologic extremes

Water saturation vapor pressure rises exponentially with temperature

- nearly 4% for 1°F warming

What does this mean?

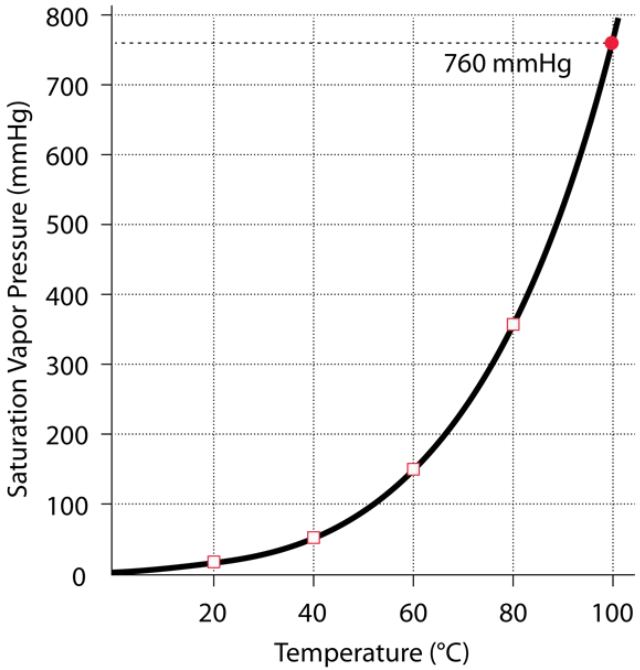
- Air "holds" more water vapor at higher temperatures

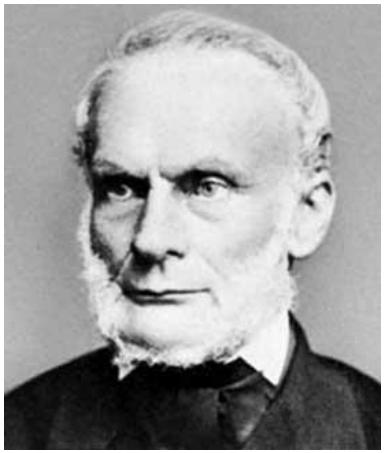
  Heavier rains

- Air "demands" more water at higher temperature

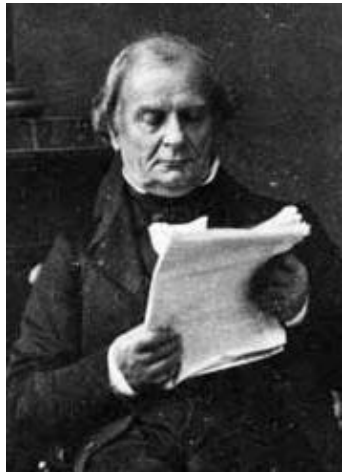
  Increased potential evapotranspiration

  Faster, more intense drought





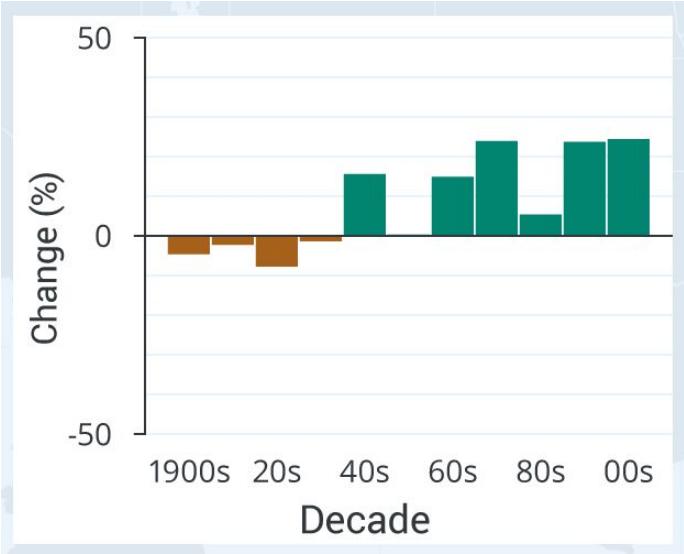
Rudolf Clausius
1822-1888



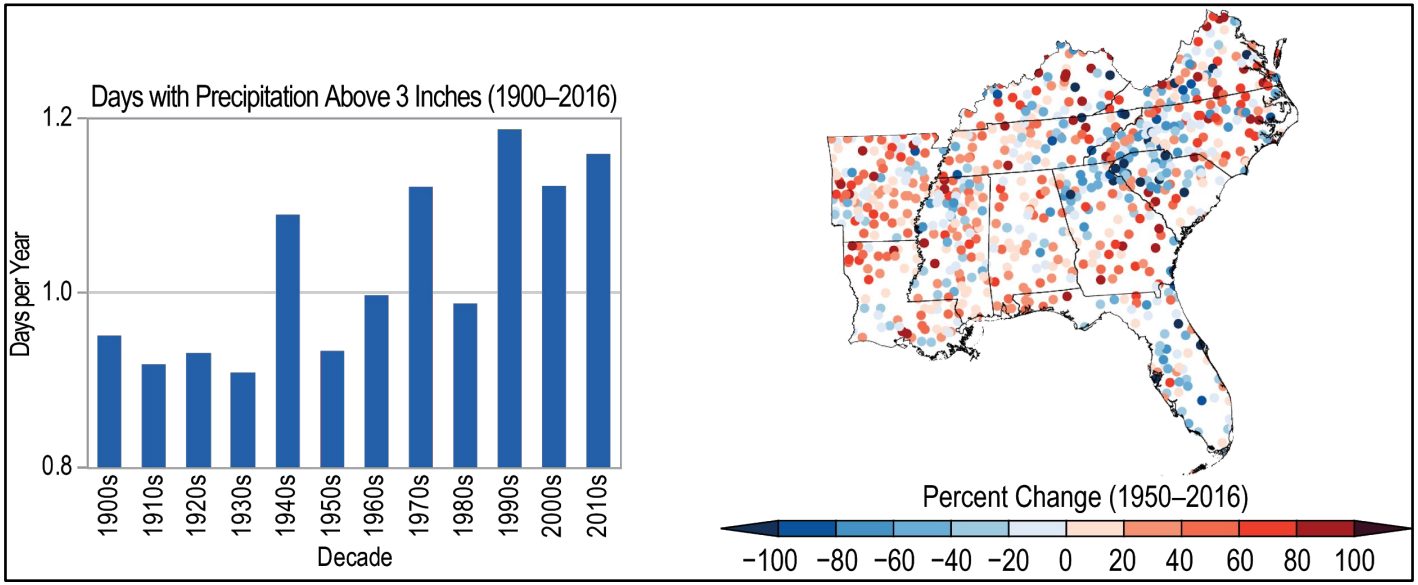
Benoit Clapeyron
1799-1864

Observed increase in heavy rain

US Southeast: change (%) in amount of rain in top 1% of rain events

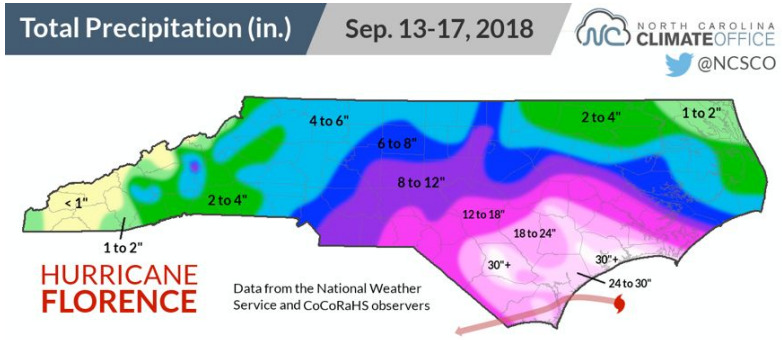


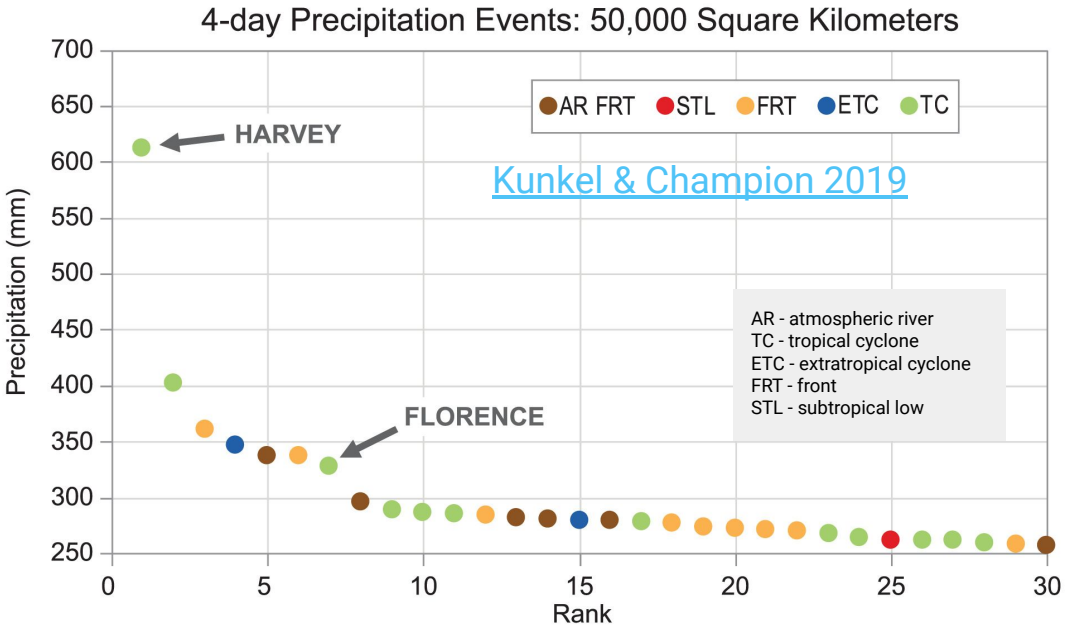
US Southeast – days with rain above 3”



More rain from hurricanes

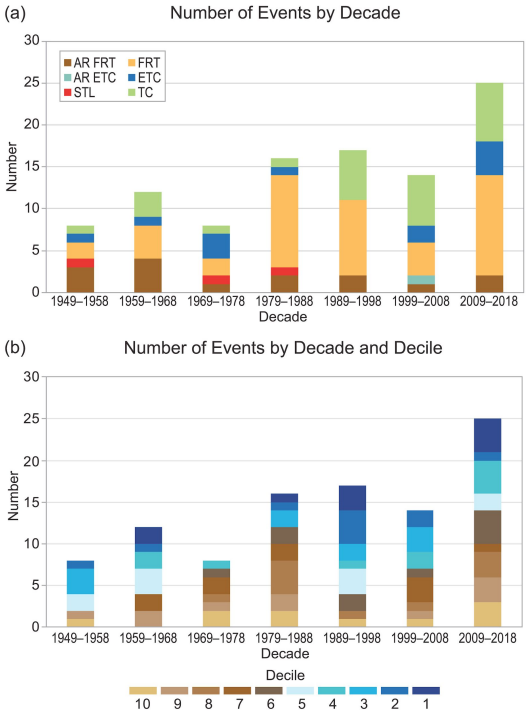
… and other storms





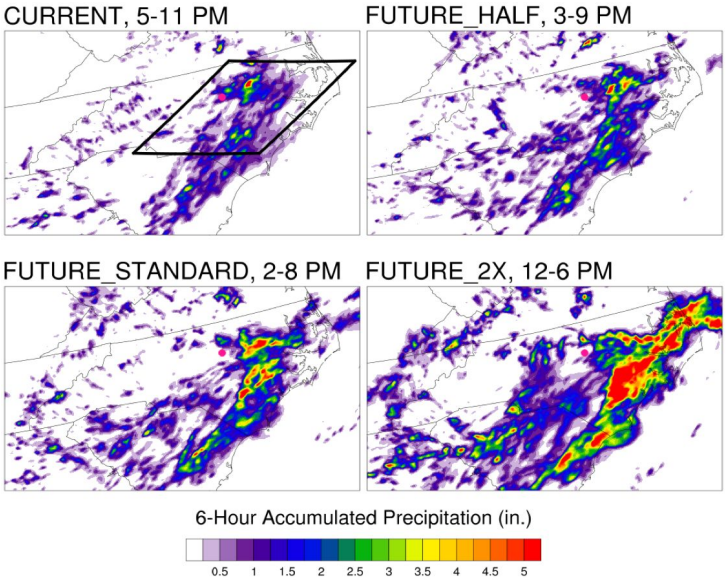


Ken Kunkel NC State/NCICS



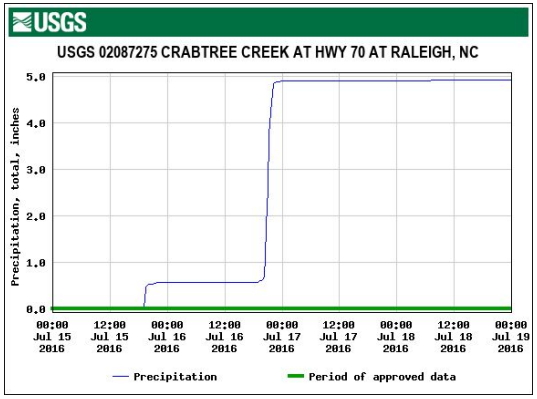
Stronger cloudbursts

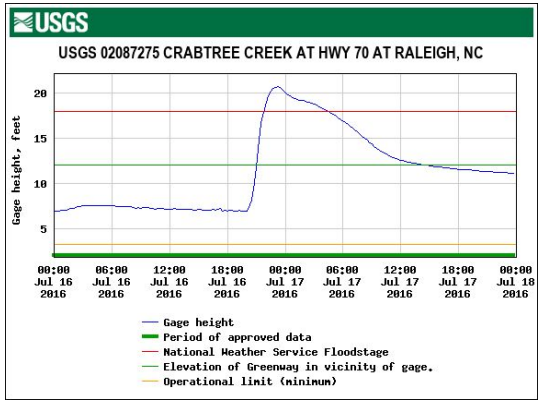
- Model July 2016 Raleigh storm under current & future climates
- Peak rain increases ~6% per °F warming
- Observed storm raised Crabtree Creek 14’ in minutes
  - Damage to greenway & scouring
  - Flood damage along Walnut Creek

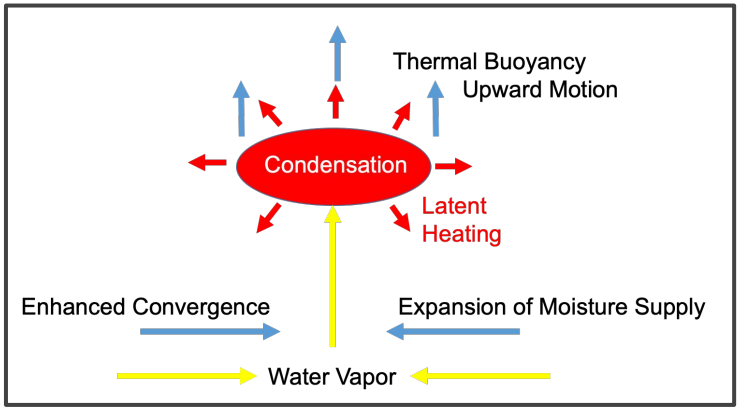




Mike Madden (recent NC State PhD))



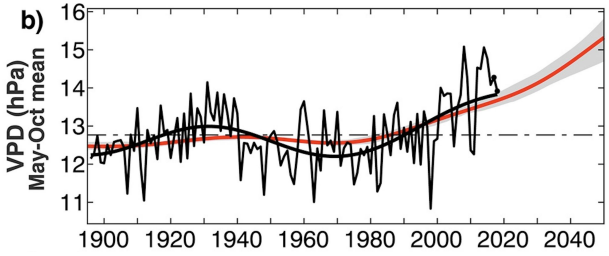


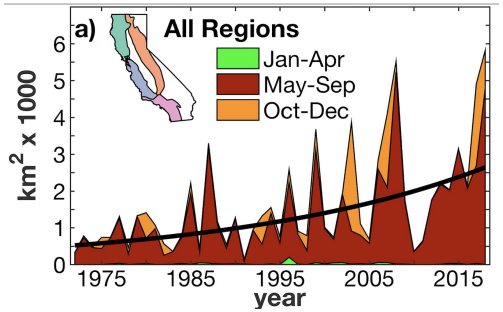


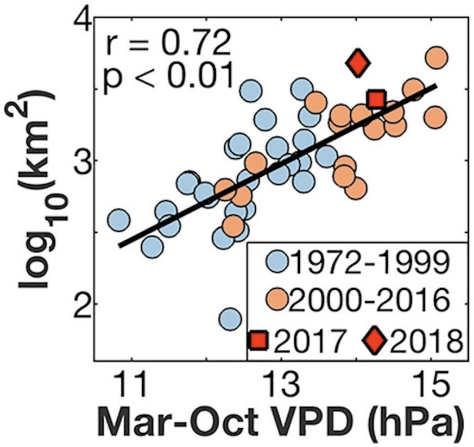
Drought & fire



- Vapor pressure deficit (VPD) contributes to drying => fire
- VPD in California increases with warming (CC relation)
- Also less snowpack - land dries earlier in spring/summer







Williams *et al.* 2019

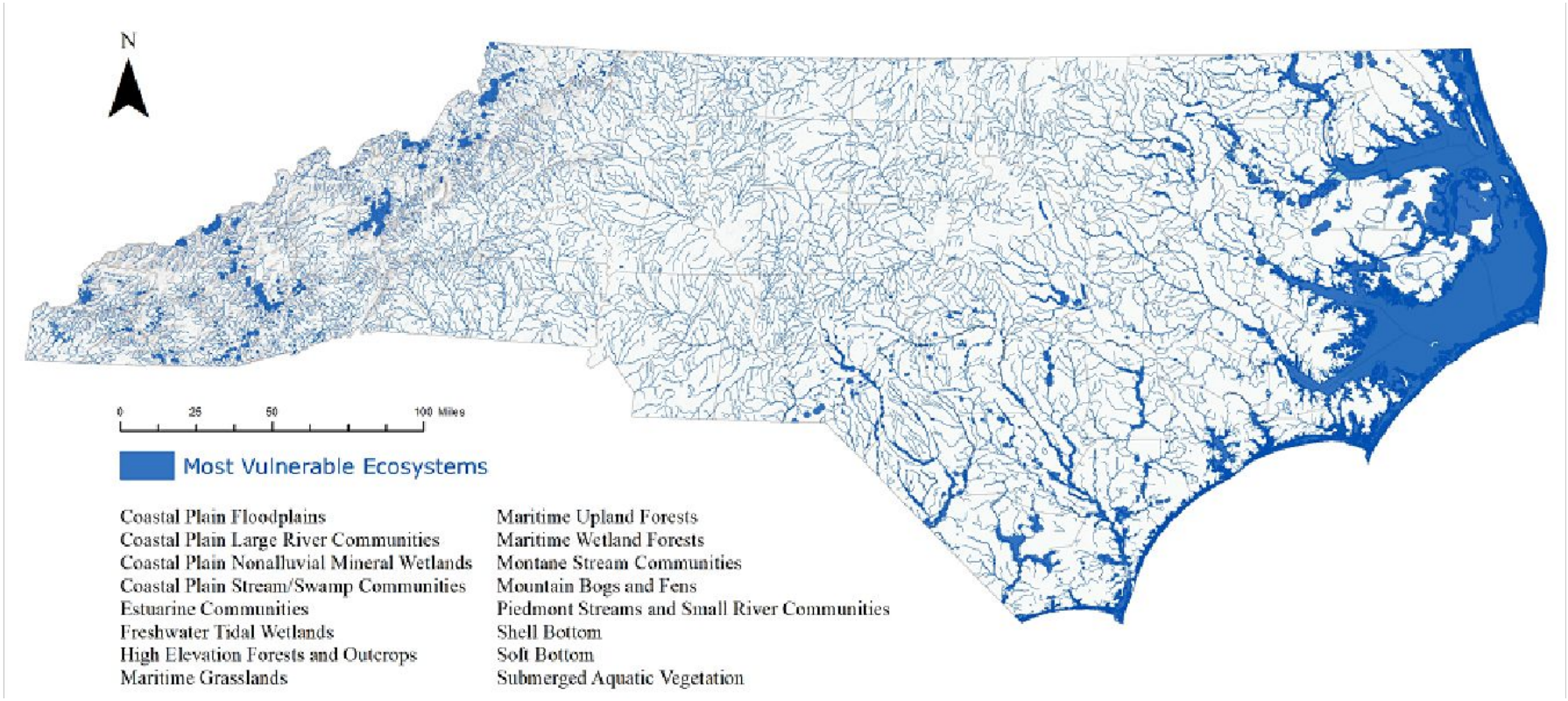


Also NC?

- Sauratown Mountain fire
  Stokes County, Nov. 2023

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Ecosystems at risk from climate change



In piedmont: mostly riparian communities

Nature as a solution



North Carolina Natural & Working Lands Action Plan

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NC matters!

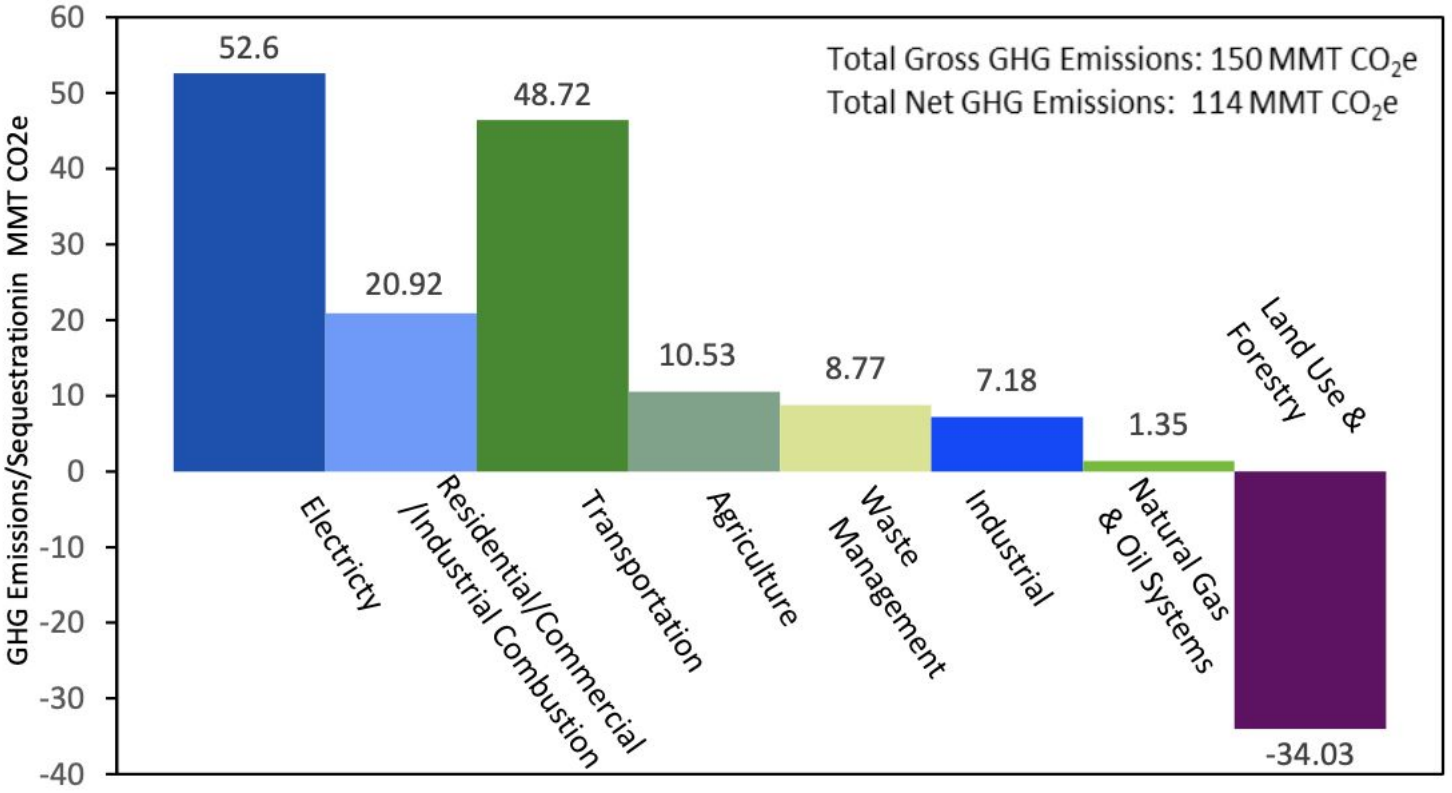
- NC annual emissions: 150 Mt CO_2e
  https://deq.nc.gov/energy-climate/climate-change/greenhouse-gas-inventory
- Global annual emissions: 36.6 Gt CO_2e
  https://www.globalcarbonproject.org/carbonbudget/19/highlights.htm

NC produces 0.41% of global emissions (1 part in 244)

- with just 0.14% Earth's population
  - 1 out of every 738 people on Earth is in NC

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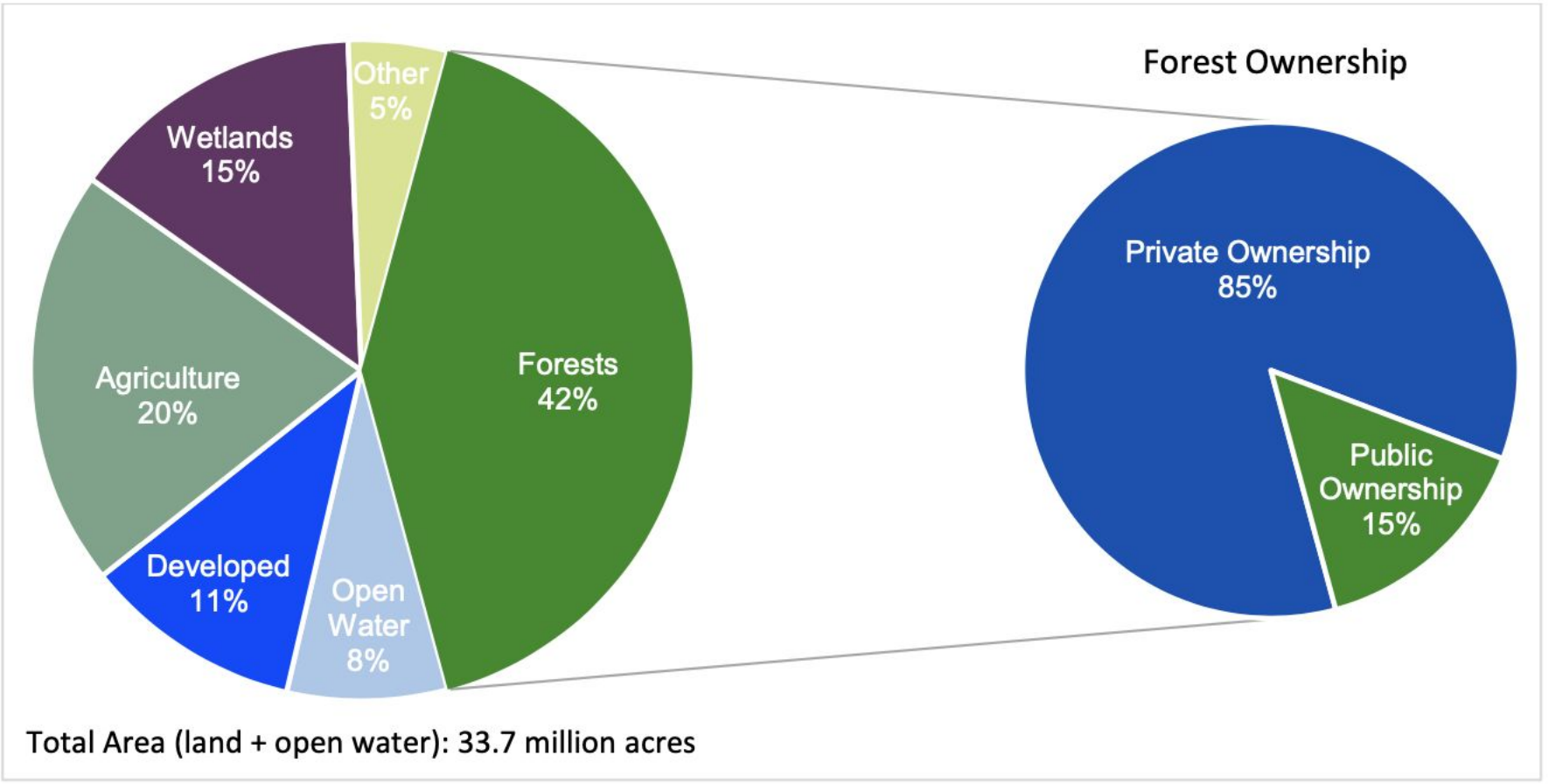
Natural land offsets for NC emissions



Land already mitigates 23% of NC emissions

NC: land of (mitigation) opportunity

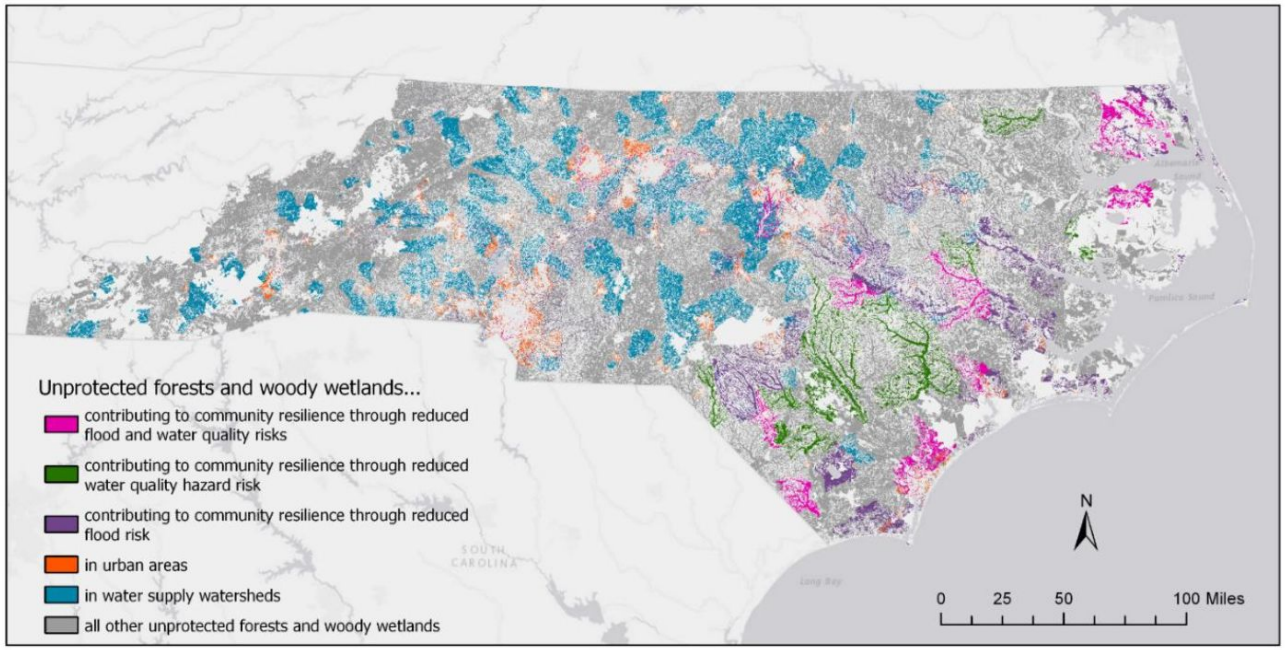
Figure 2-1: North Carolina Land Cover Types by Area in 2016

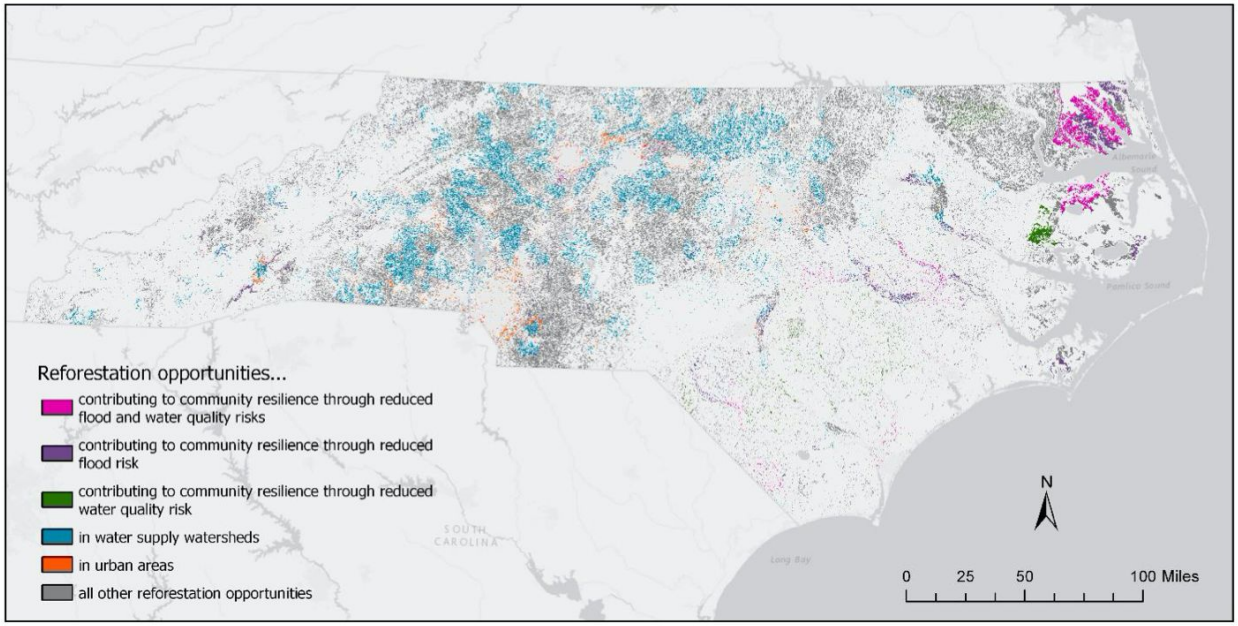


Plenty of undeveloped land, mostly private, so mitigation must be incentivized

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Protection of extant forests





Possible reforestation

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Wrapping up

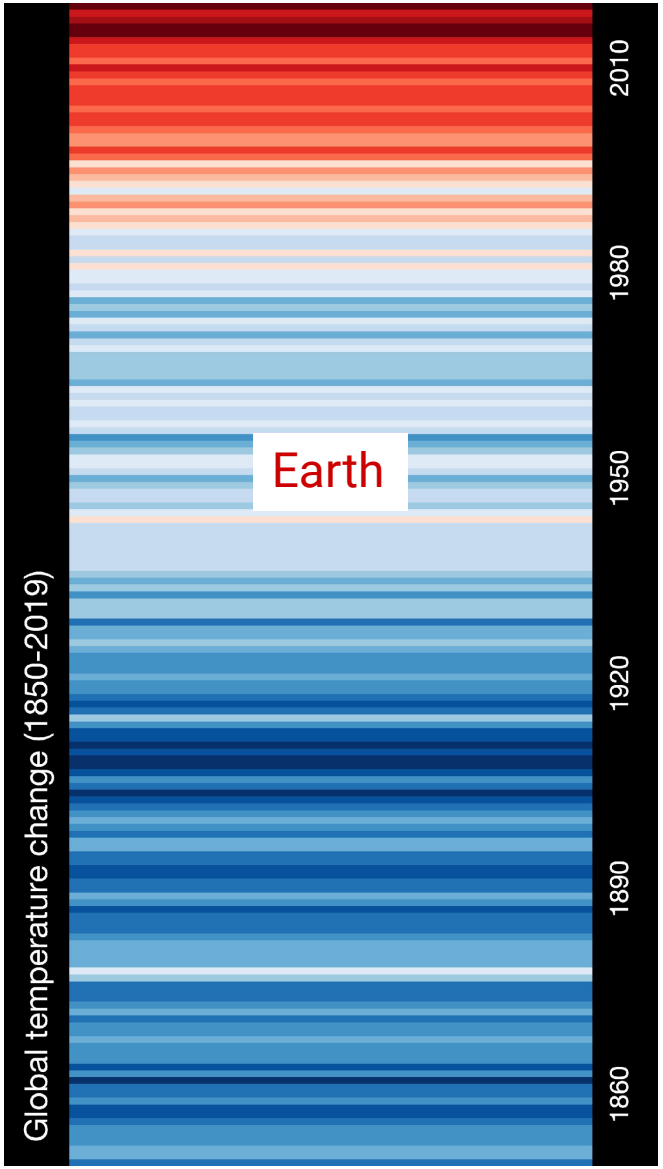
- North Carolina's piedmont climate is mild and variable
  - variations mostly due to extratropical cyclones (lows)
- North Carolina's piedmont climate is changing
  - warming (as expected)
  - no trends in precipitation
- Climate change matters most in its impact on extremes
  - heavy rains
  - heat/drought => fire
- NC matters for climate change
  - our management of natural lands can make a difference

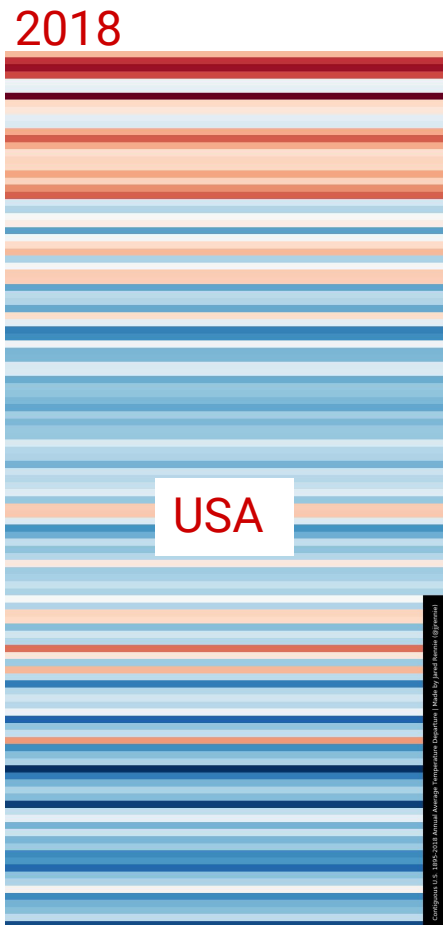
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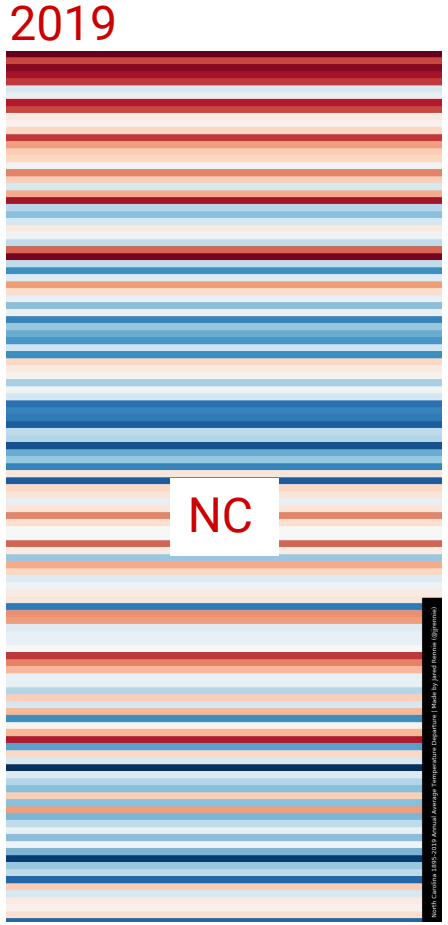


Questions/Conversation?

Climate stripes:







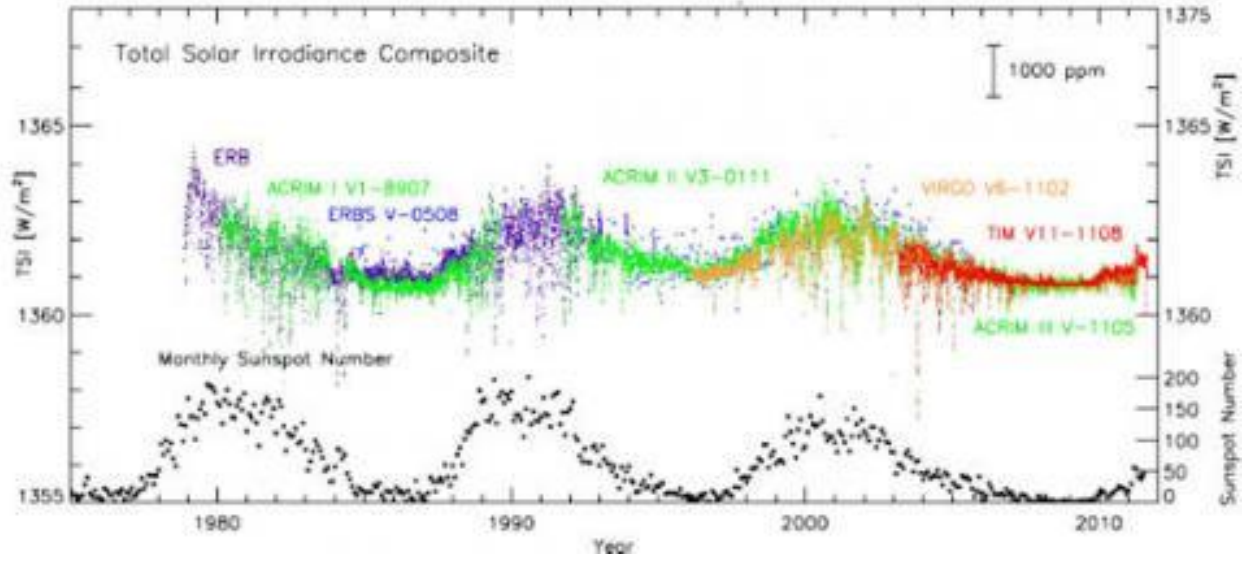
tim
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https://ncics.org/cics-news/climate-stripes-for-us-temperature-and-precipitation-by-county/

https://showyourstripes.info/

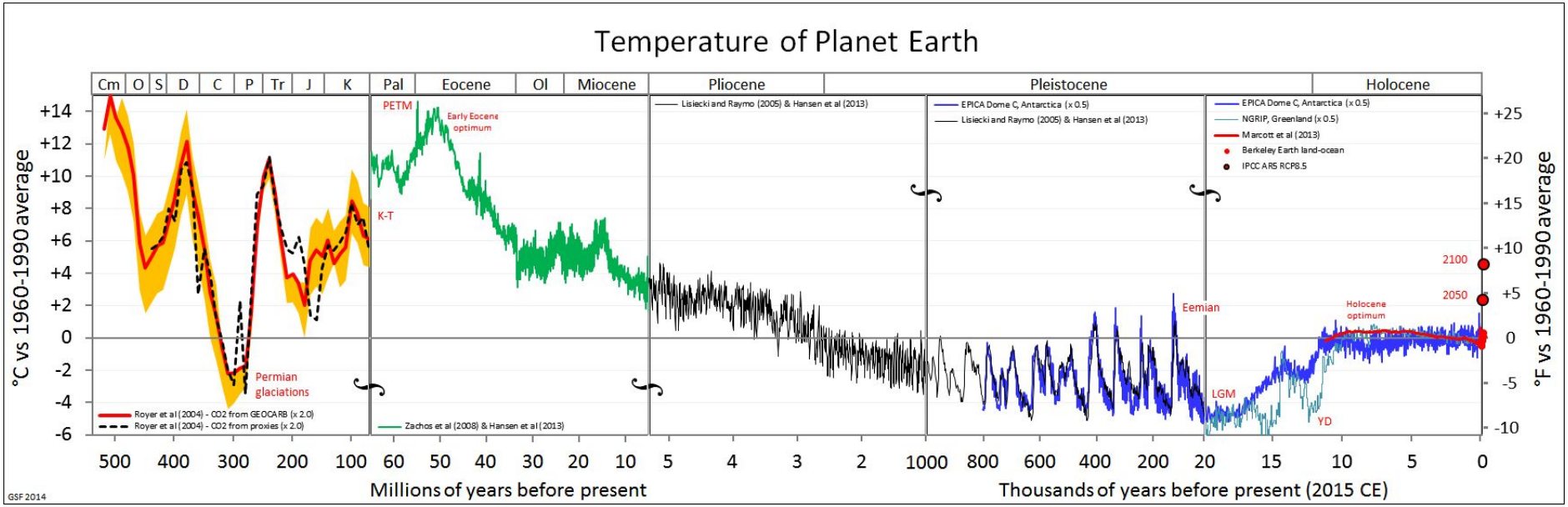
The Sun

Solar output varies 2 W/m^2 with the sunspot cycle



Because of geometry and albedo, that's a radiative forcing of 0.3 W/m^2

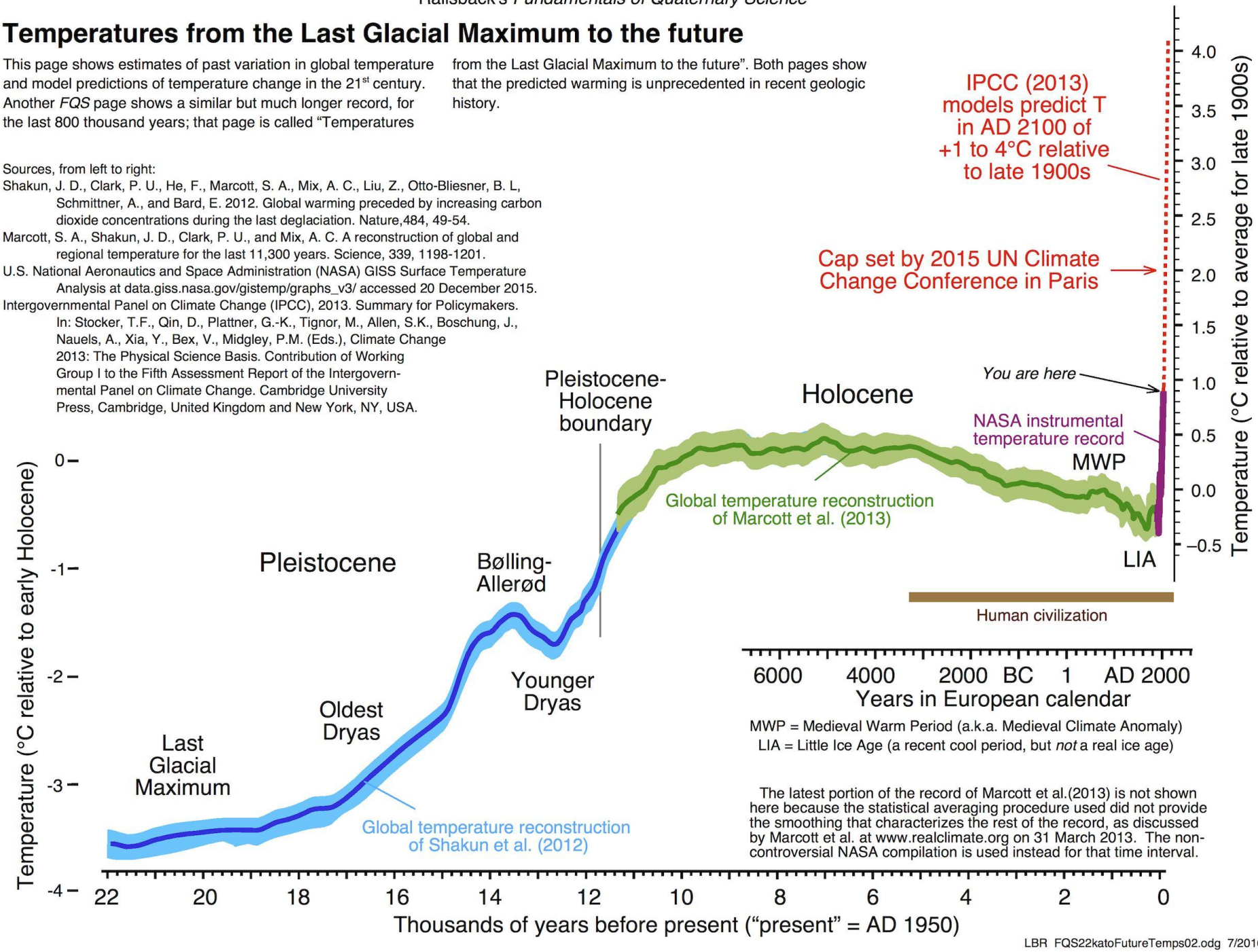
500 million years of climate history



Temperatures from the Last Glacial Maximum to the future

This page shows estimates of past variation in global temperature and model predictions of temperature change in the 21st century. Another *FQS* page shows a similar but much longer record, for the last 800 thousand years; that page is called "Temperatures from the Last Glacial Maximum to the future". Both pages show that the predicted warming is unprecedented in recent geologic history.

Sources, from left to right:
Shakun, J. D., Clark, P. U., He, F., Marcott, S. A., Mix, A. C., Liu, Z., Otto-Bliesner, B. L, Schmittner, A., and Bard, E. 2012. Global warming preceded by increasing carbon dioxide concentrations during the last deglaciation. Nature,484, 49-54.
Marcott, S. A., Shakun, J. D., Clark, P. U., and Mix, A. C. A reconstruction of global and regional temperature for the last 11,300 years. Science, 339, 1198-1201.
U.S. National Aeronautics and Space Administration (NASA) GISS Surface Temperature Analysis at data.giss.nasa.gov/gistemp/graphs_v3/ accessed 20 December 2015.
Intergovernmental Panel on Climate Change (IPCC), 2013. Summary for Policymakers. In: Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.



MWP = Medieval Warm Period (a.k.a. Medieval Climate Anomaly)
LIA = Little Ice Age (a recent cool period, but *not* a real ice age)

The latest portion of the record of Marcott et al.(2013) is not shown here because the statistical averaging procedure used did not provide the smoothing that characterizes the rest of the record, as discussed by Marcott et al. at www.realclimate.org on 31 March 2013. The non-controversial NASA compilation is used instead for that time interval.

What to do?

Resilience



Mitigation

Manage ecosystems to maximize 3Rs

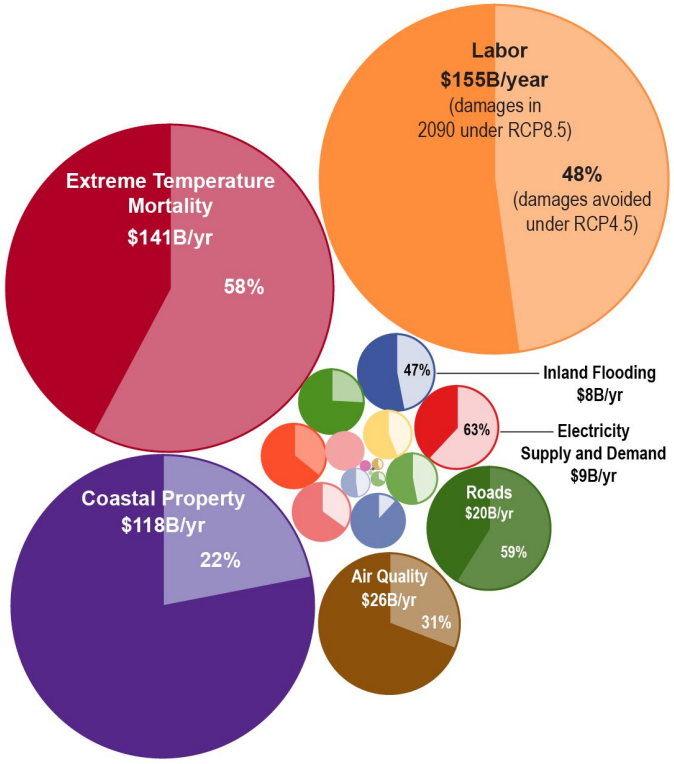
(managing water on the landscape is key)

All reductions of emissions of greenhouse gases reduce risks & damage to species & ecosystems

Lower emissions reduce economic risk (infer extension to ecological risk)

- Lower projected US costs from lower emissions

https://nca2018.globalchange.gov/



Annual Economic Damages in 2090			
	Sector	**Annual damages under RCP8.5**	**Damages avoided under RCP4.5**
	Labor	$155B	48%
	Extreme Temperature Mortality◊	$141B	58%
	Coastal Property◊	$118B	22%
	Air Quality	$26B	31%
	Roads◊	$20B	59%
	Electricity Supply and Demand	$9B	63%
	Inland Flooding	$8B	47%
	Urban Drainage	$6B	26%
	Rail◊	$6B	36%
	Water Quality	$5B	35%
	Coral Reefs	$4B	12%
	West Nile Virus	$3B	47%
	Freshwater Fish	$3B	44%
	Winter Recreation	$2B	107%
	Bridges	$1B	48%
	Munic. and Industrial Water Supply	$316M	33%
	Harmful Algal Blooms	$199M	45%
	Alaska Infrastructure◊	$174M	53%
	Shellfish*	$23M	57%
	Agriculture*	$12M	11%
	Aeroallergens*	$1M	57%
	Wildfire	−$106M	−134%