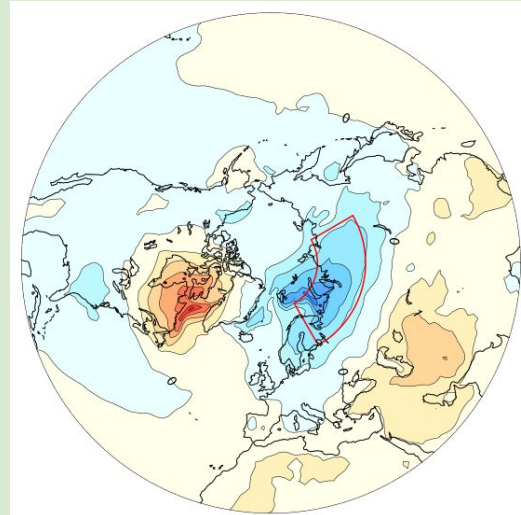




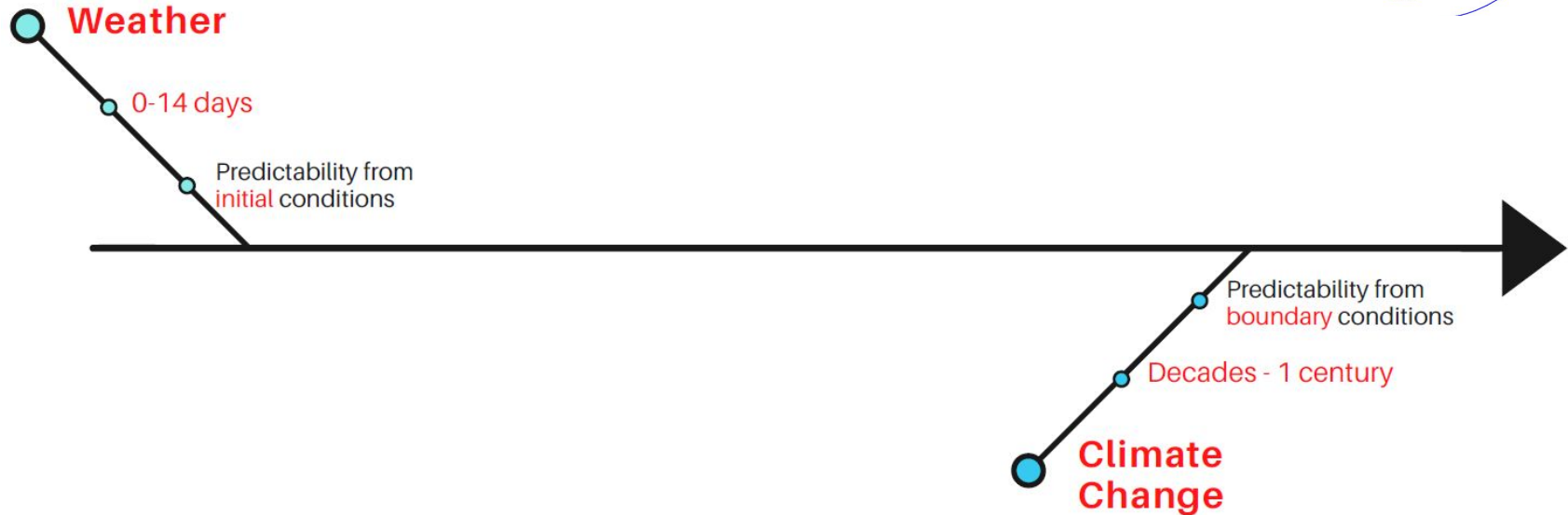
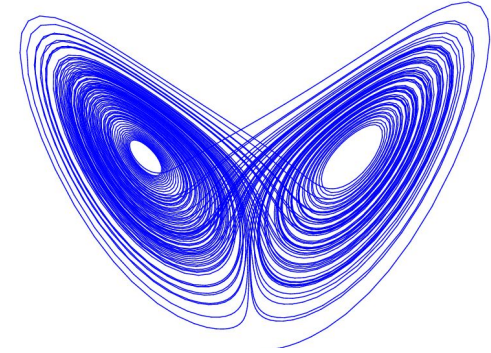
Math in the Sky: From Winter Weather to Future Climate

Jessie Oehrlein
Olin CRS
December 13, 2022



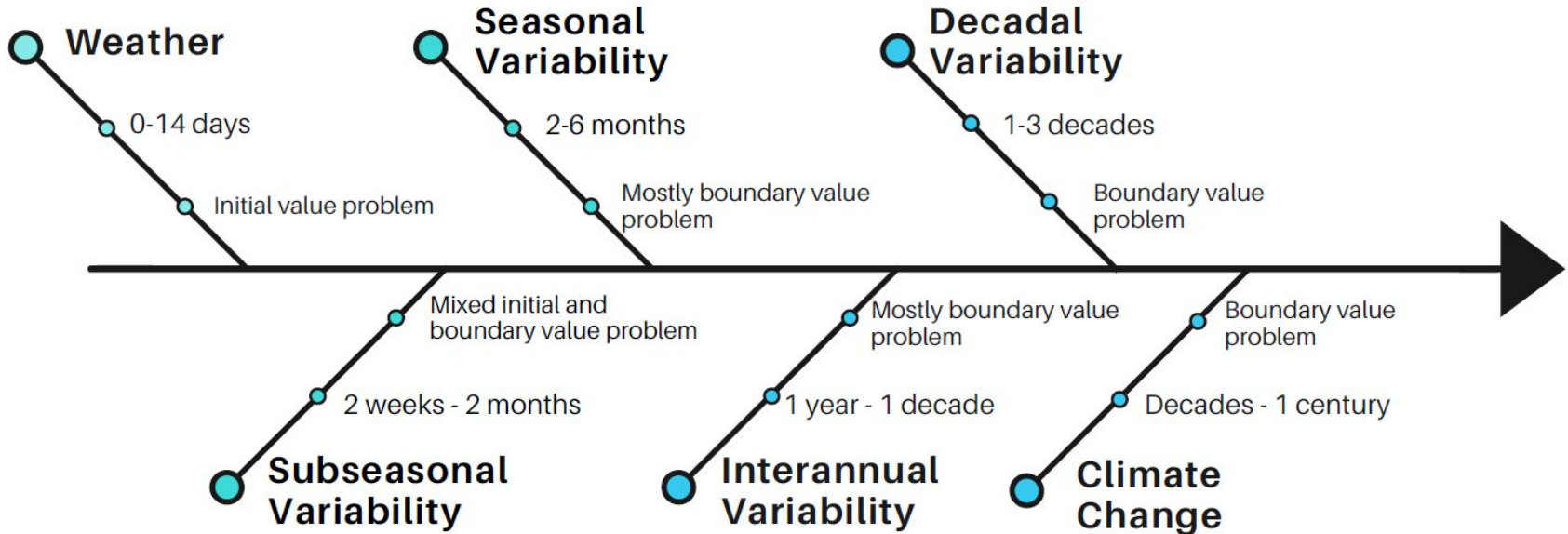


Timescales in the Atmosphere



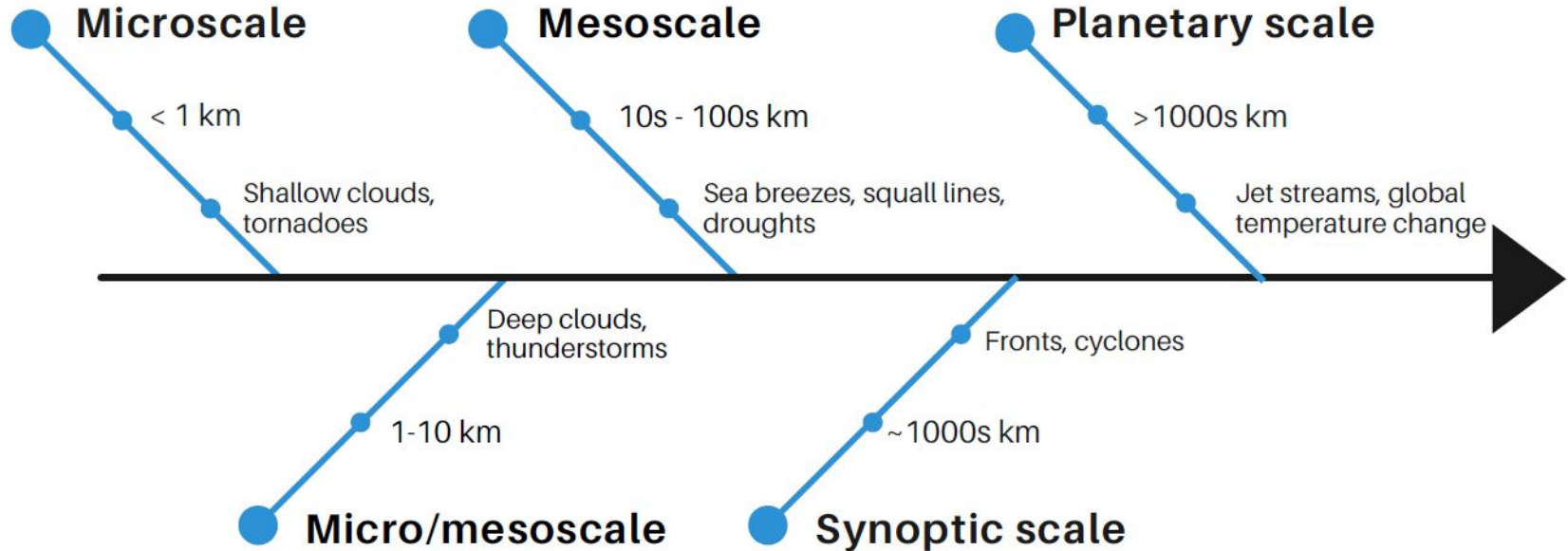


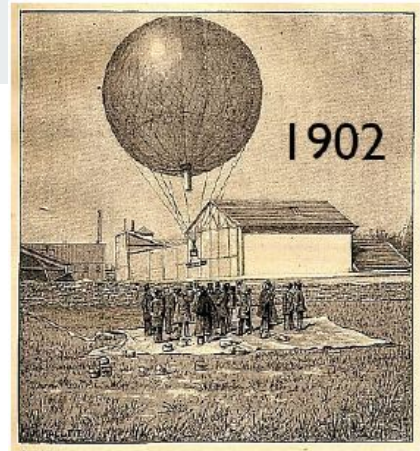
Timescales in the Atmosphere





Spatial Scales in the Atmosphere





How We Know What We Know

- Observations
- Theory
- Models

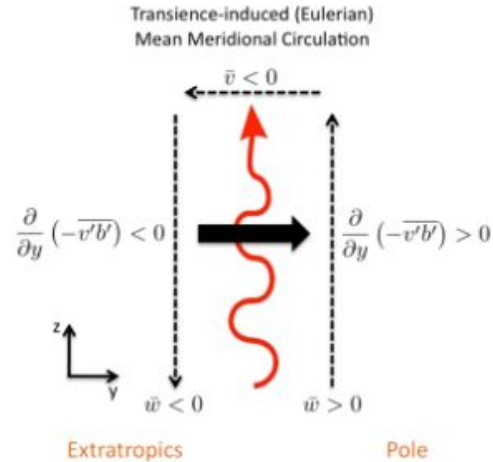
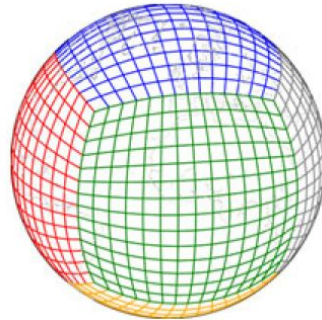


Image from Ron Miller

Contexts for Exploring What We Know

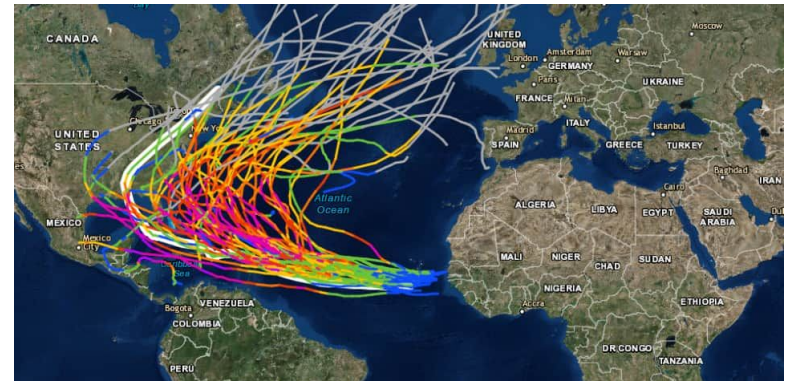
- Climate change, synoptic scale: future tropical cyclones
- Seasonal, synoptic/planetary scale: stratospheric polar vortex

§ Austin American-Statesman

Fact-check: Does climate change affect hurricanes?

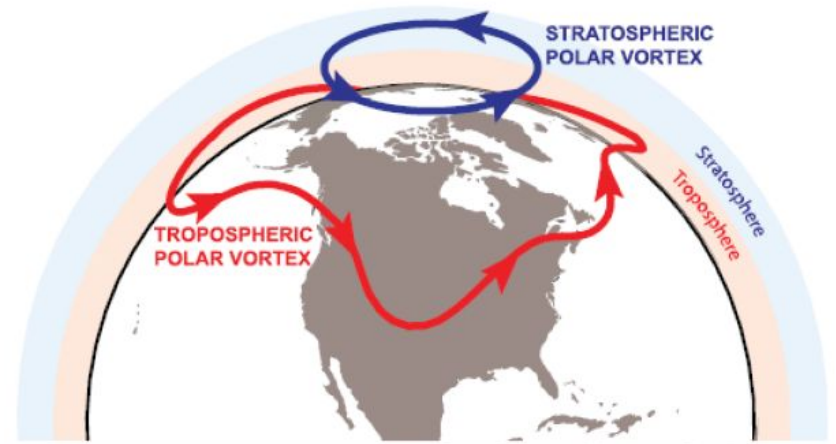
27 when CNN anchor Don Lemon asked one of the nation's leading ... out that "The acting NHC director clearly stated that 'on the whole,...

2 days ago



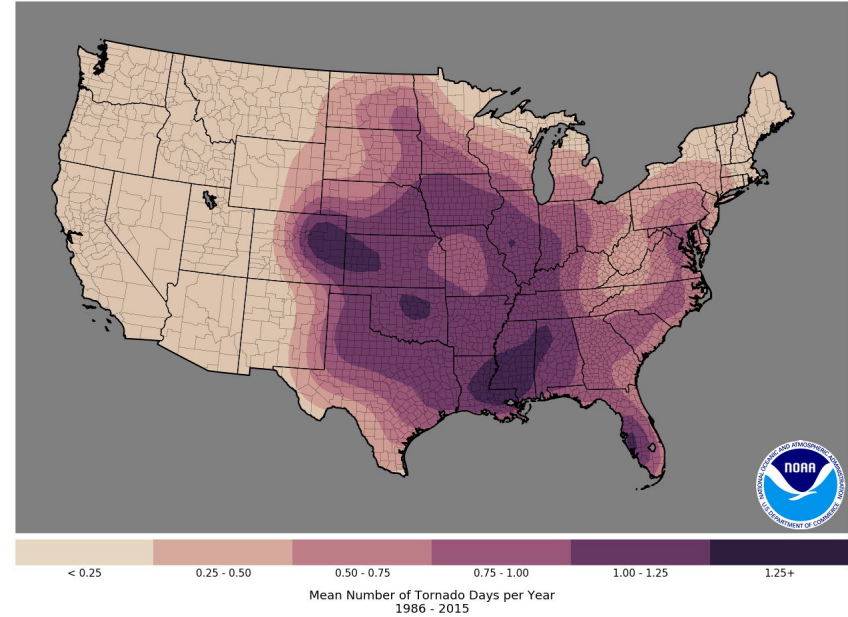
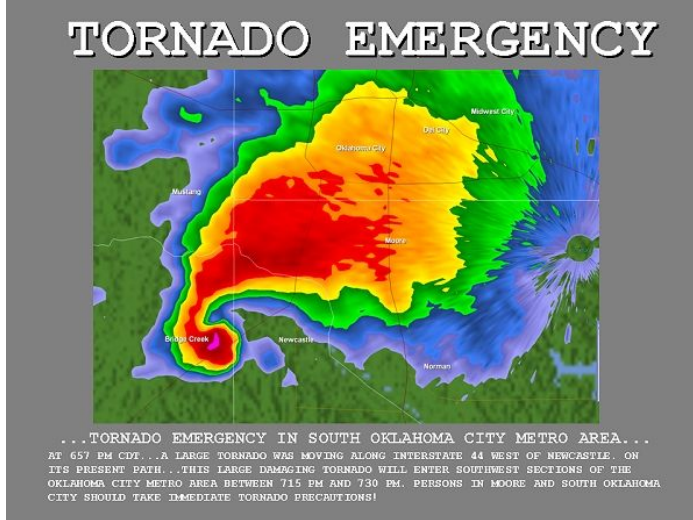
Contexts for Exploring What We Know

- **Climate change, synoptic scale:**
future tropical cyclones
- **Seasonal, synoptic/planetary scale:** stratospheric polar vortex



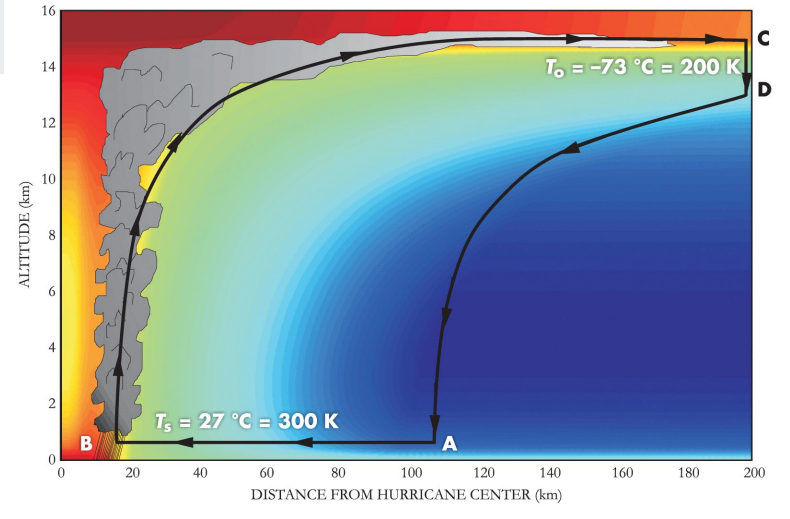
How did I get here?

Part 1: Oklahoma



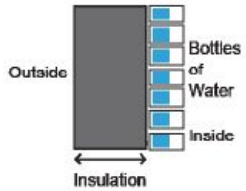
How did I get here?

Part 2: Olin coursework

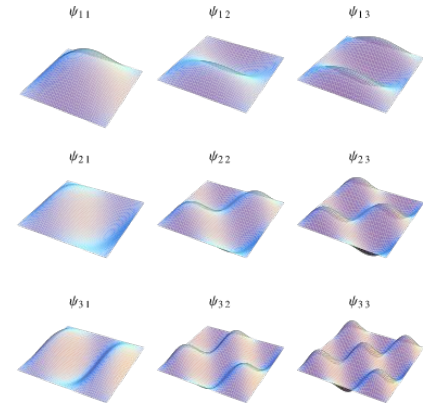


II. Passive Freezer Model

Freezer Cross-section



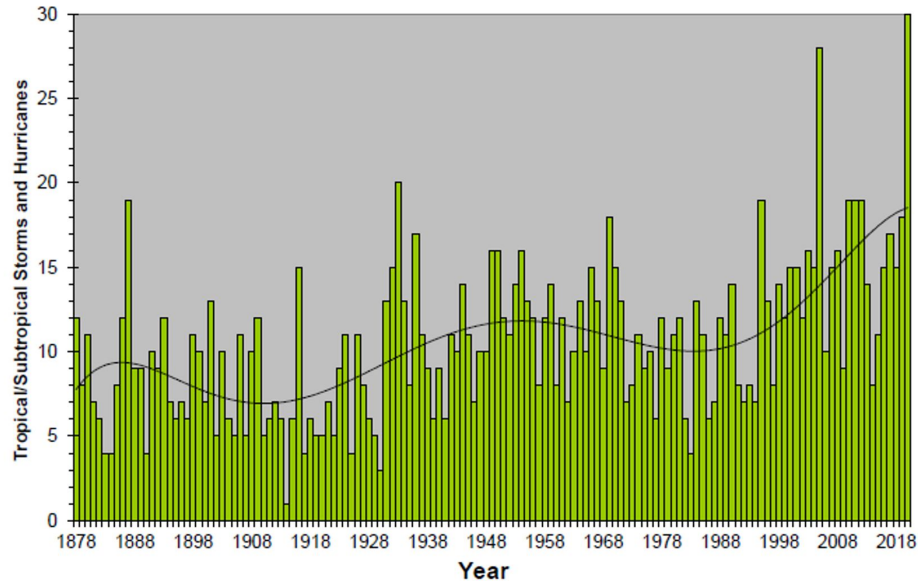
Outside
Bottles of Water
Inside





How does climate change affect tropical cyclones?

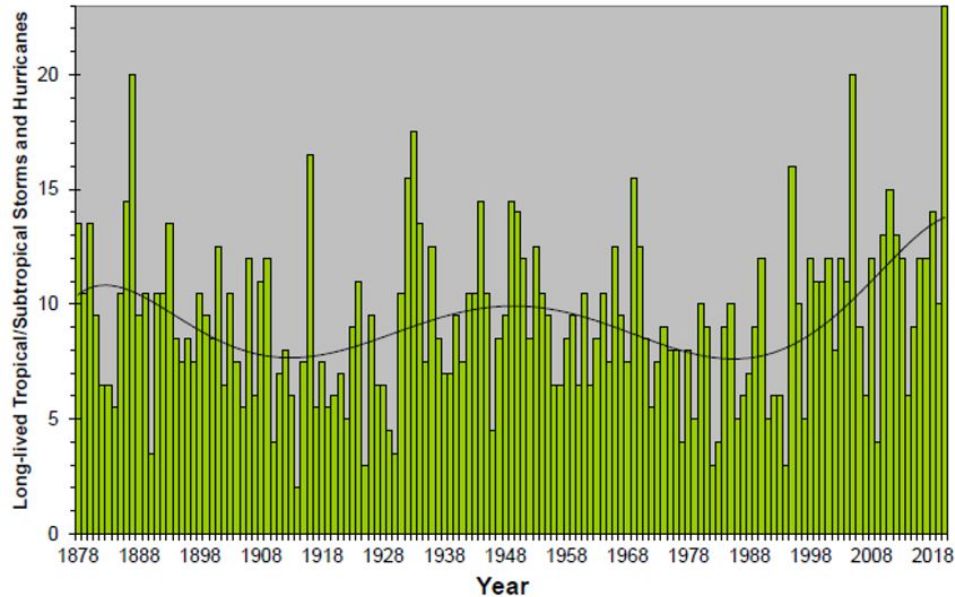
Tropical/Subtropical Storms and Hurricanes
1878 to 2020



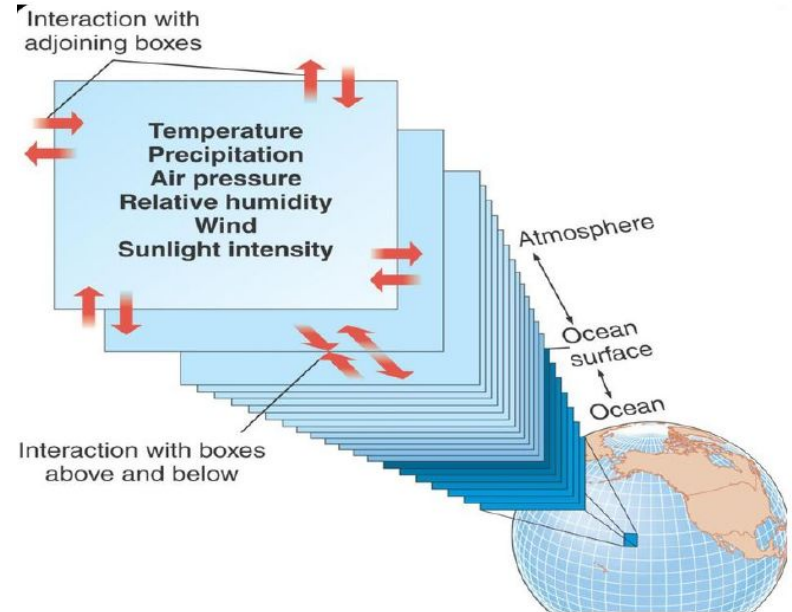
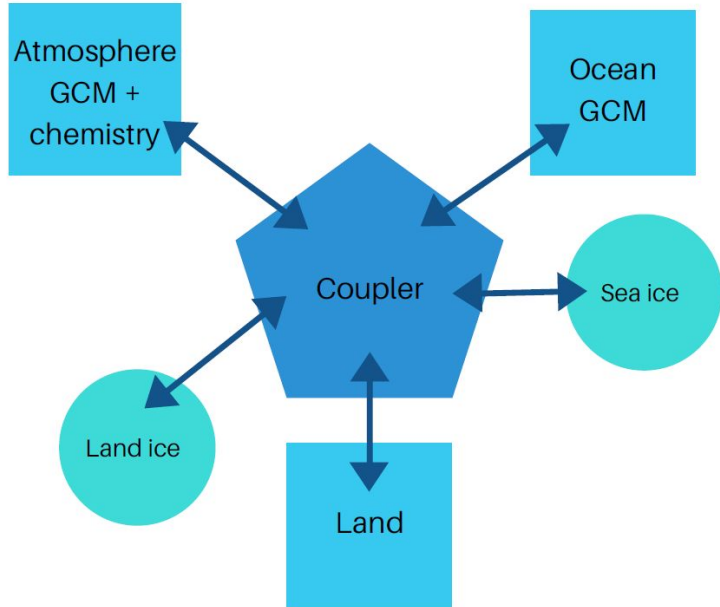


How does climate change affect tropical cyclones?

Adjusted Long-lived Tropical/Subtropical Storms and Hurricanes
Adding "Missed" Systems - Duration greater than 2.0 days - 1878 to 2020



Okay, so how might models help?





How does climate change affect tropical cyclones?

Number of storms:

- Observations – no increase globally, some in the Atlantic basin
- Models – mixed results globally

Strength of storms:

- Theory & most models – an increase on average
- Observations – some evidence for increase

Rainfall amounts & surge:

- Theory & most models – increase!
- Observations – evidence for increase

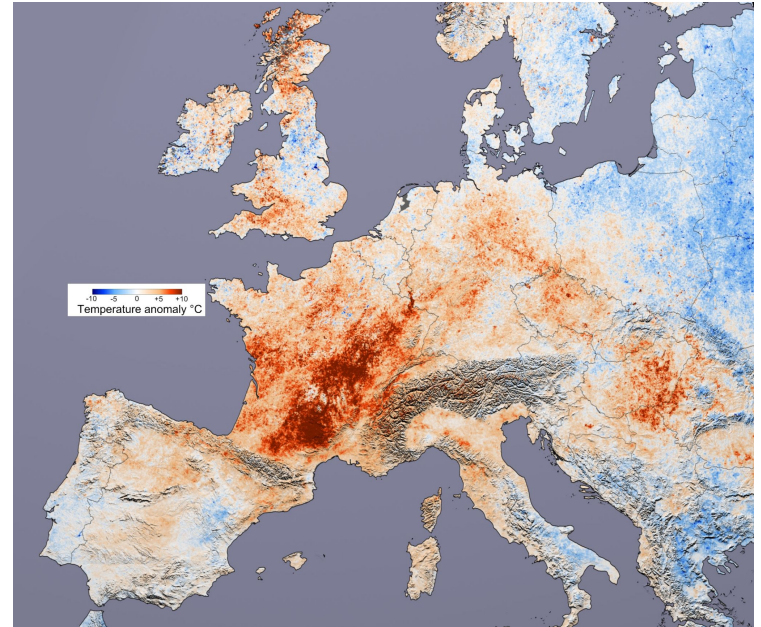
Rapid intensification & slowing of storms:

- Observations – some evidence
- Theory & models – unclear

“Was (insert event here) caused by climate change?”

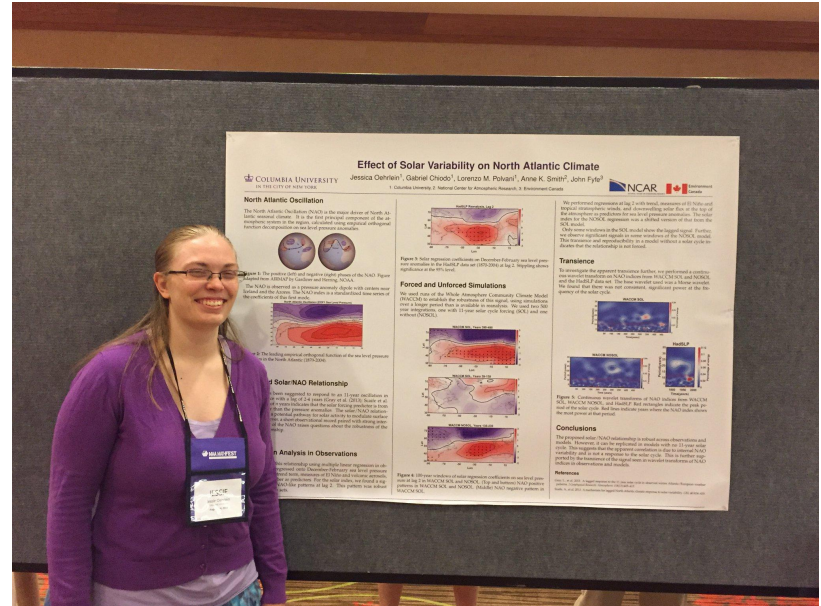
Weather and climate are noisy! But **attribution studies** look at how much more likely a certain event was to occur because of climate change. They use:

- Observations to measure severity/extremeness of the event
- A variety of model setups to compare event occurrence in past vs. current vs. future climate.

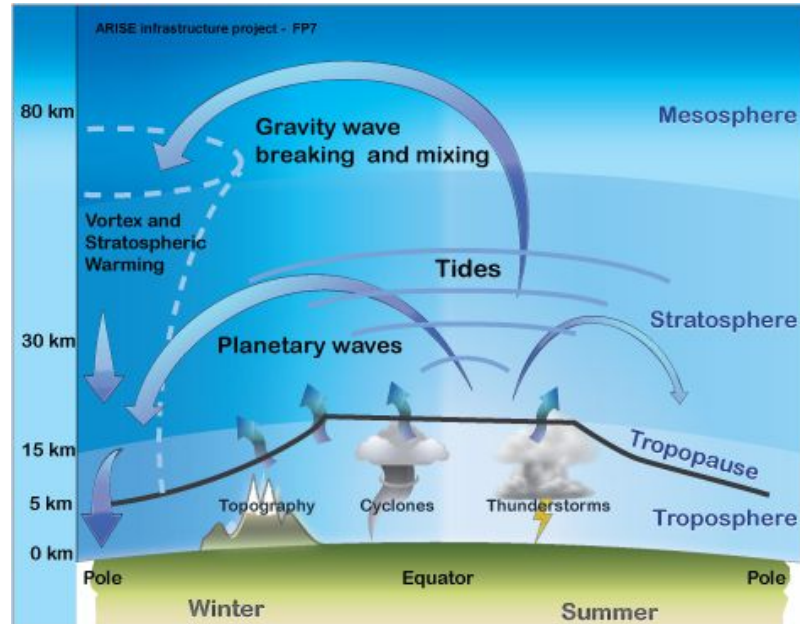


How did I get here?

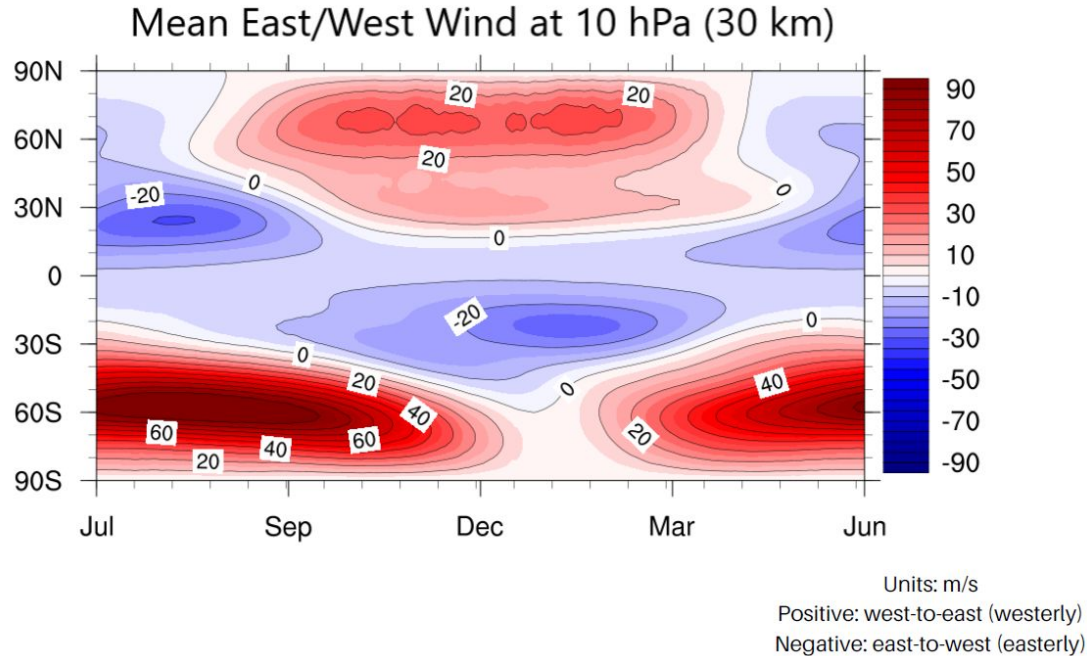
Part 3: Graduate school



Troposphere & Stratosphere



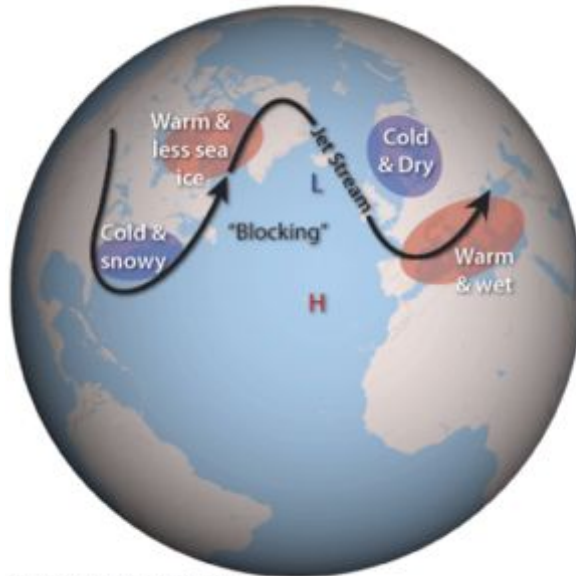
Stratospheric Polar Vortex



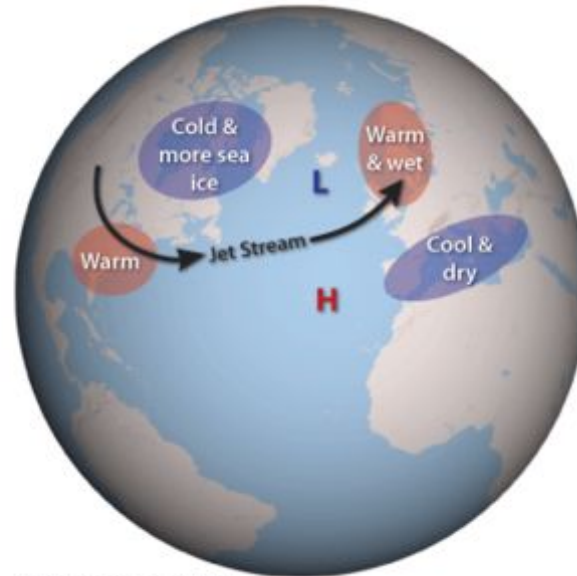
Why does the polar vortex matter to us?

Weak polar vortex

Strong polar vortex



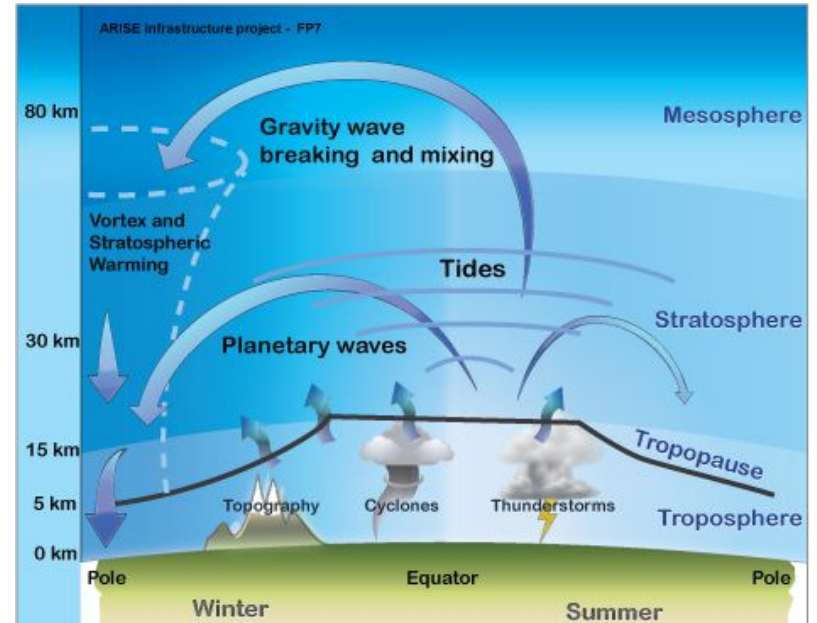
NAO Negative Mode



NAO Positive Mode

Polar Vortex: What We Know from Theory

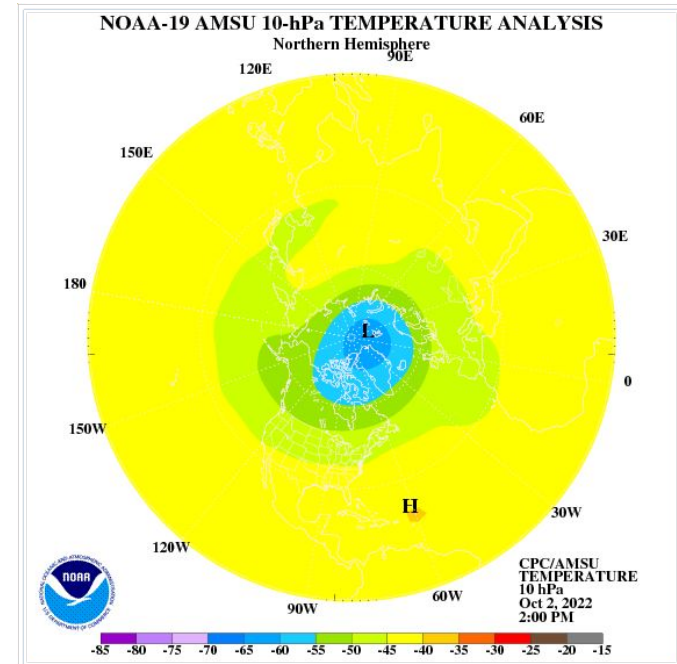
- Why the polar vortex forms
- The ingredients for weak and strong vortex events occur
- Why the Southern Hemisphere polar vortex is much stronger than the Northern Hemisphere vortex





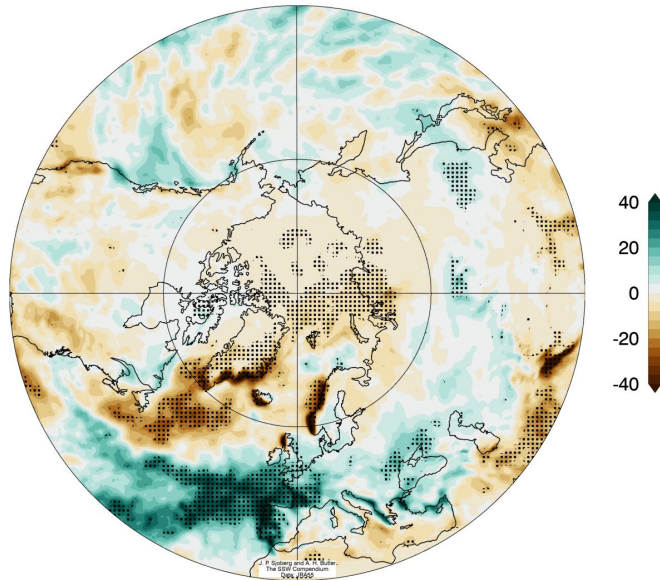
Observing the Stratospheric Polar Vortex

- **1940s:** First weather balloon measurements of the Arctic stratosphere
- **1952:** First observation of extremely weak polar vortex
- **International Geophysical Year (1957-58):** many measurements of Arctic & Antarctic stratosphere.
- **1979-present:** Stratospheric Sounding Units on satellites!

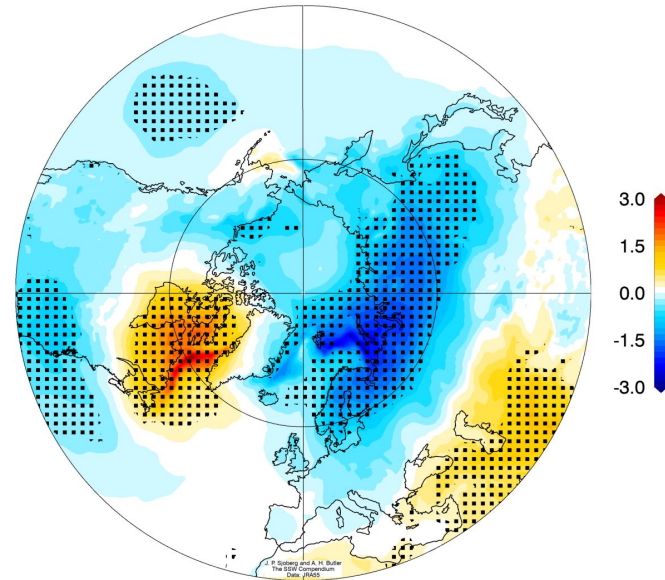


Weak Vortex: What We Know from Observations

Precipitation anomaly [mm] - Day 000 to 060



Tsfc anomaly [°C] - Day 000 to 060



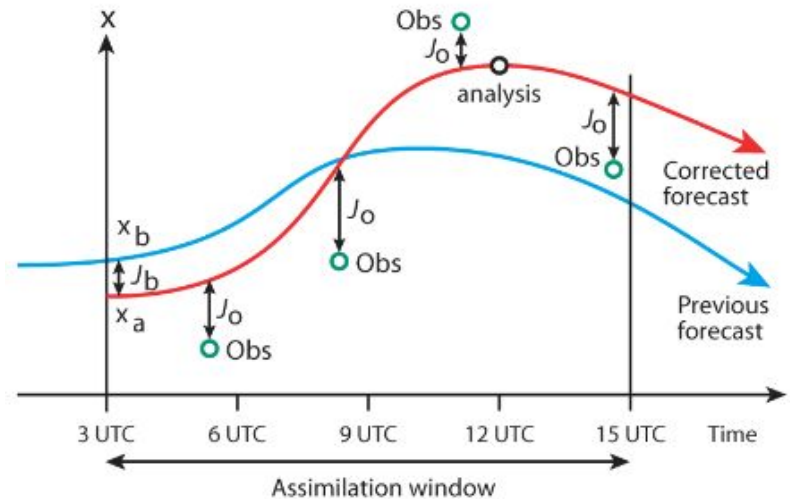
Not Technically Observations: Reanalysis

Observations

- Measurements of what really happened
- Irregular in space and time
- From a variety of sources
- Some error

Models

- True to our understanding of atmospheric dynamics
- Information everywhere
- Extremely sensitive to initial conditions
- Some bias





Polar Vortex: An Example Model Study

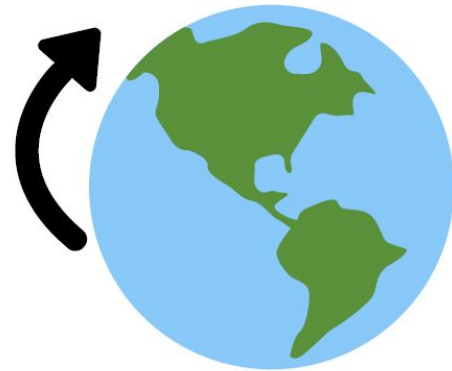
Conjecture from observations:

When the tropical Pacific sea surface is warmer, the polar vortex is weaker, but the number of weak vortex events is not affected.

Model approach:

Three different setups with different sea surface temperatures

Run each setup for 200 model years.
Compare polar vortex across runs!



Warm Pacific

Neutral Pacific

Cold Pacific

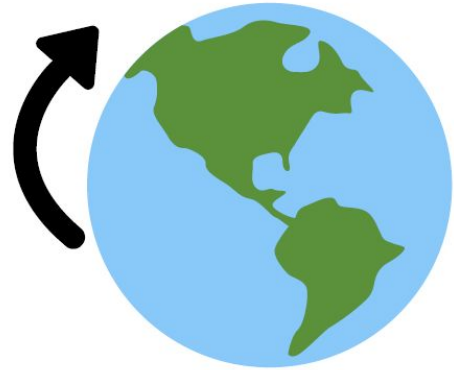
Polar Vortex: An Example Model Study

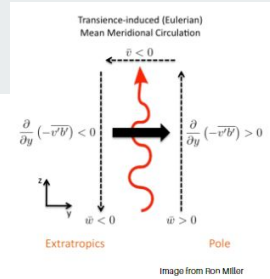
Model Conclusions:

Warm Pacific – weaker polar vortex on average, more weak vortex events

Cold Pacific – stronger polar vortex on average, fewer weak vortex events

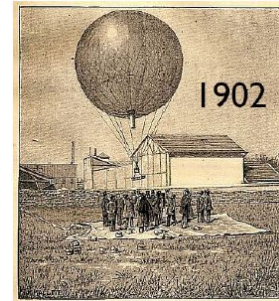
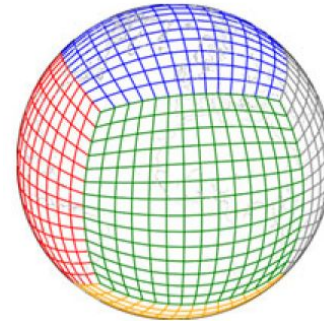
Still trying to reconcile the model conclusions with observations!

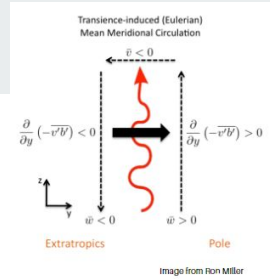




We Need All of These Tools

- **Theory/Conceptual Models:** We want intuition about what happens and why
- **Observations:** What really happens is what matters most
- **Climate Models:** Flexible exploration and prediction



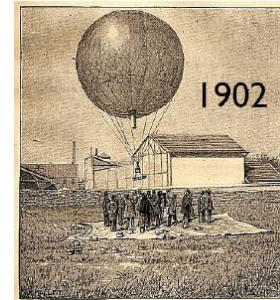
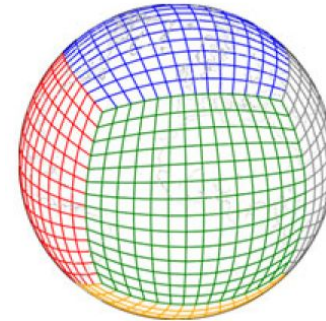


We Need All of These Tools (And they all use math!)

- **Theory/Conceptual Models:** We want intuition about what happens and why
 - Translating physical world into mathematical descriptions

- **Observations:** What really happens is what matters most
 - Dynamical systems & probability give us reanalysis
 - Statistics for analysis

- **Climate Models:** Flexible exploration and prediction
 - Translating physical world into mathematical descriptions
 - Numerical solving
 - Statistics for analysis

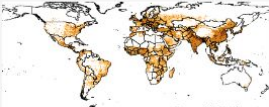


What do we do with what we know?

- **Weather:** forecasts, advisories, and warnings with the public
- **Weather to Interannual:** work with governments & industries on appropriate planning

Are the areas at risk of heavy rainfall densely populated?

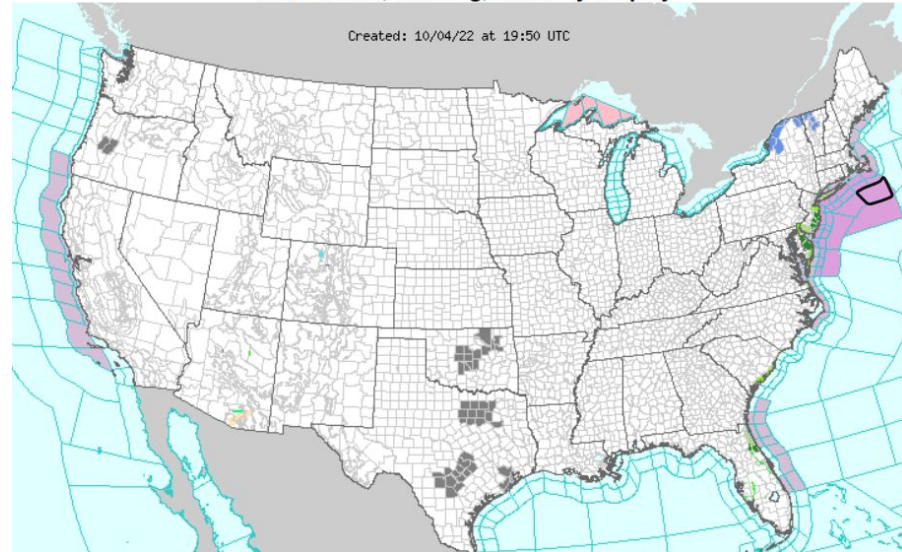
This map shows human population density.



Are the areas at risk of heavy rainfall inhabited by vulnerable populations?

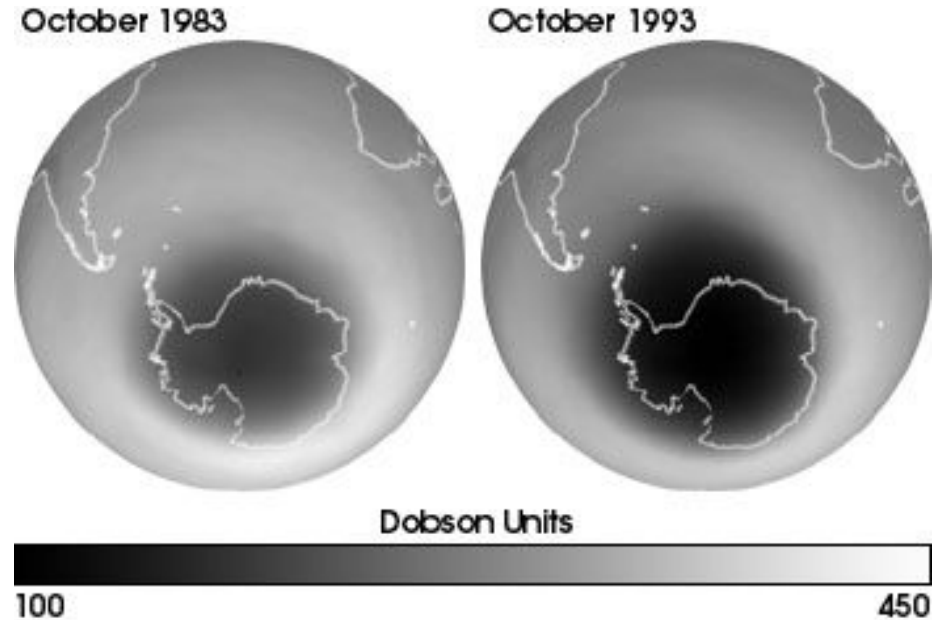
NWS Watch, Warning, Advisory Display

Created: 10/04/22 at 19:50 UTC



What do we do with what we know?

- **1974:** Rowland & Molina propose that chlorofluorocarbons could lead to stratospheric ozone depletion.
- **1976:** National Academy of Sciences concludes that this is supported.
- **1985:** *Nature* paper documenting Antarctic ozone hole is larger than expected



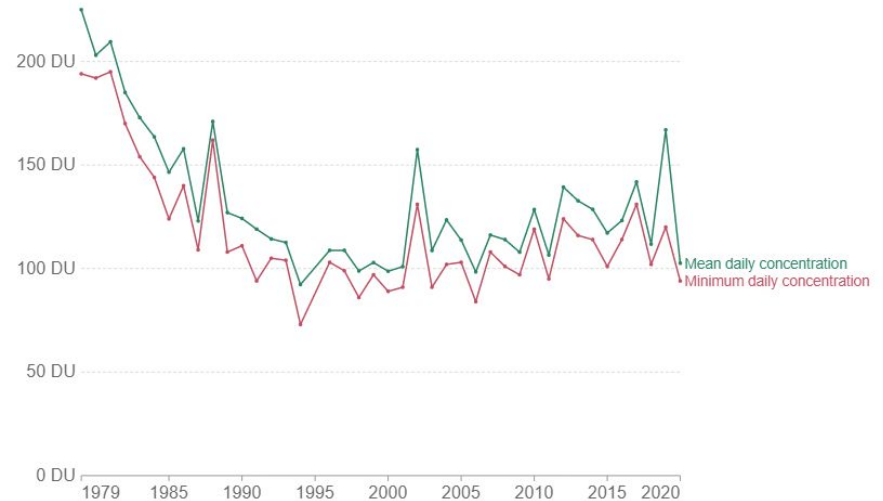
What do we do with what we know?

- **1978:** US starts phasing out CFCs in aerosol spray cans
- **1987:** Montreal Protocol is agreed to, planning complete phasing out of CFCs
- **2050-2070:** Expected recovery to 1980 levels

Stratospheric ozone concentration

Stratospheric ozone concentration in the Southern Hemisphere – based on satellite measurements south of 40°. This is measured in Dobson Units (DU).

Our World
in Data



Source: NASA Ozone Watch

OurWorldInData.org/ozone-layer • CC BY



Thank you!