NMED
New Mexico Environment Department

Impacts of Earth's changing climate:
Global effects felt from the deserts to the poles.

September 26, 2018
NM Recycling & Solid Waste Conference

Jonathan Beyeler, Geologist (Ground Water Quality Bureau)

Brief intro of me, Jonathan Beyeler (NMED–GWQB–MECS).

- Geologist (1st) / Geomorphologist (2nd) from the west coast
  - Definition of "geomorphology"
    - study of ***form*** and ***process***
    - ***natural processes*** and ***time*** that sculpt Earth's surface
  - Intersection of geologic and human timescales
- Effects of climate change (3rd) fundamental to my PhD at University of Washington
  - focused on response of rivers to changing climate

Collectively we have to deal with the effects of climate change, within ***our*** and ***our children's*** lifetimes. This is scientific fact.

Currently observed effects of global climate change*:

- **Temperatures will continue to rise**
  - Averages, highest-highs, lowest-lows, summer highs, nighttime lows,
  - New lows in historically unprecedented regions
- **Changes in precipitation patterns**
  - Previously wet regions may get wetter
  - Regions at margins of wet and dry will dry out as wet regions migrate poleward
- **More droughts and heat waves**
  - Durations will extend
  - Severe effects on water resources
- **Frost-free season will lengthen** (*and growing season*)
- **Hurricanes will become stronger and more intense**
- **Sea level will rise 1-4 feet by 2100**
- **Arctic likely to become ice free**
- **Frequency of extreme weather events****

*Change will continue through this century and beyond.
Added by J.Beyeler, with support by USGS, IPCC, WEF, and ***many* others

Source: NASA

https://climate.nasa.gov/effects/

Definitions from NASA:

- **Weather**
  - Temperature, precipitation, humidity and wind on any given day due to ocean temperatures, atmospheric temperatures, pressures, moisture, and circulation patterns
  - ***Short-term*** (i.e., days, weeks, and seasons)
- **Climate**
  - Typical weather pattern of a region or city established over many years
  - ***Long-term*** (i.e., years, decades, centuries, millennia)
- **Earth's climate**
  - Average of all the world's climates compiled from years of regional weather
- **Greenhouse gases**
  - Heat-trapping gases in the atmosphere (e.g., CO_2, methane, others)
- **Global warming**
  - Long-term increase in Earth's ***average*** temperature
- **Climate change**
  - Changes in the usual weather found in a region or city (i.e., long-term)
    - changes in usual rainfall or temperatures from month to month, season to season, etc.
- **Global climate change**
  - Changes in Earth's climate as a whole
    - change in usual temperature at a place or where rain/snow usually fall on Earth's surface

https://climate.nasa.gov/

"Evidence for rapid climate change is compelling." –NASA

"Scientific evidence for warming of the climate system is unequivocal." –IPCC

Evidence of climate change summarized by NASA:

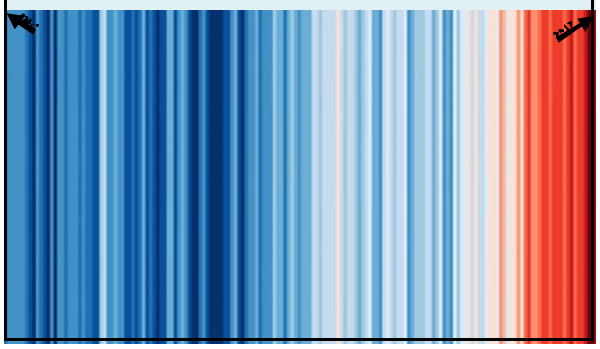
- **Global temperature rise**
  - Earth's average surface temperature has risen about 2.0 °F (1.1 °C)
- **Warming ocean temperatures**
  - Oceans have absorbed much of this increased global heat
- **Shrinking ice sheets**
  - Greenland and Antarctic ice sheets have decreased in size and volume, and are melting faster now than ever observed
- **Glacial retreat**
  - Alpine glaciers are retreating almost everywhere around the world (e.g., Mount Rainier, the Alps, Himalayas, Andes, Rockies, Alaska, and Africa)
- **Decreased snow cover**
  - Spring snow cover in Northern Hemisphere has decreased over the past 50 years and is melting earlier
- **Sea level rise**
  - Global sea level rose about 8" in the last century; however the rate in last 20 years is nearly double that of the last 100 years
- **Declining Arctic sea ice**
  - Extent and thickness of Arctic sea ice has declined rapidly
- **Extreme weather events**
  - Frequency of record high temperatures in the US has been increasing, while the number of record low temperatures has been decreasing
- **Ocean acidification**
  - Since Industrial Revolution, acidity of the surface ocean waters has increased by about 30%

Source: NASA

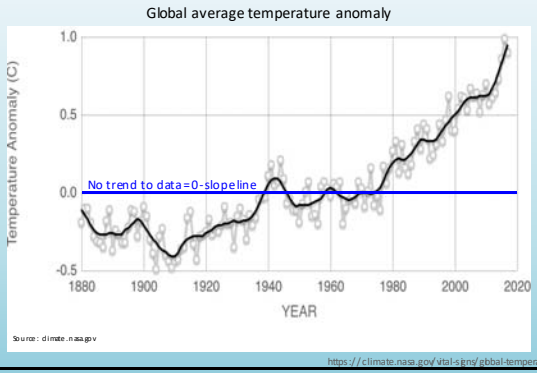
https://climate.nasa.gov/evidence/

Earth's average temperatures:
16 of the 17 hottest years since 1850 have occurred since 2001.

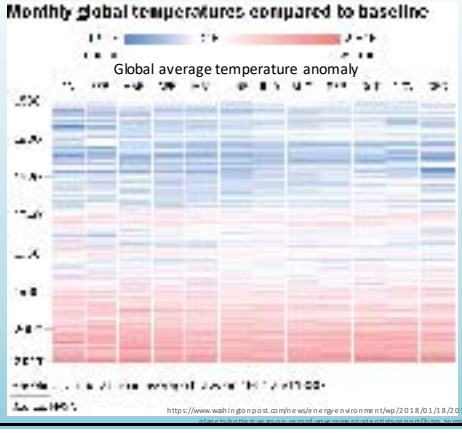
Since ~2000, Earth's temperature has been fundamentally different.



2017 was the 2nd warmest year for Earth since records began in 1850.



https://climate.nasa.gov/vital-signs/global-temperature/



https://www.washingtonpost.com/news/energy-environment/wp/2018/01/18/2017-was-among-the-

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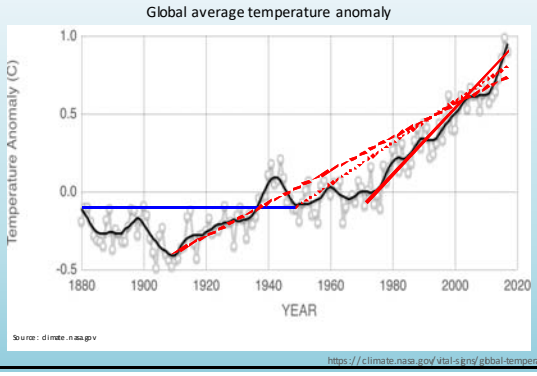

https://climate.nasa.gov/vital-signs/global-temperature/

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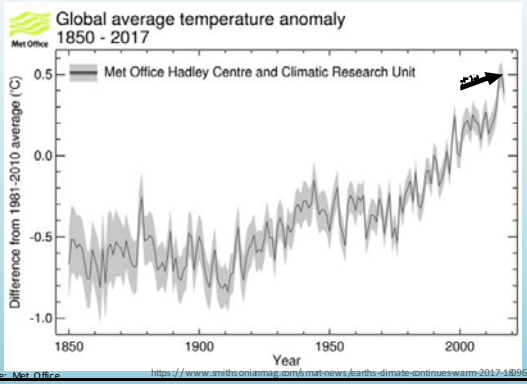

Source: Met Office https://www.smithsonianmag.com/smart-news/earths-climate-continues-warm-2017-180967886/

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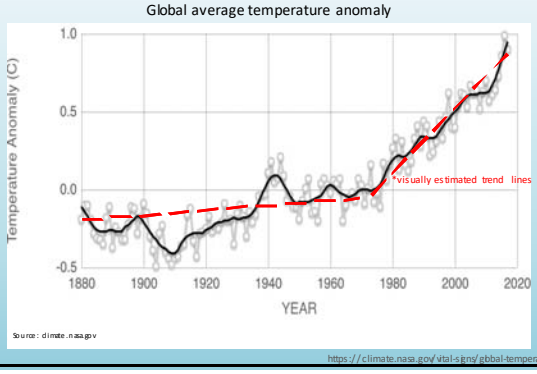

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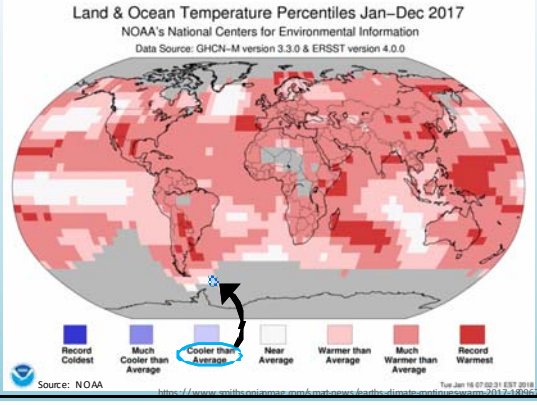
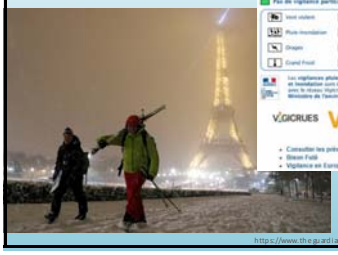
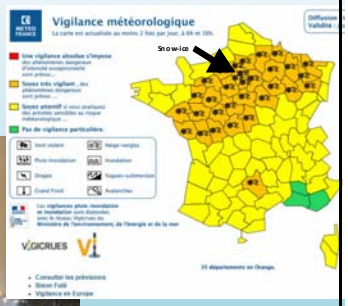


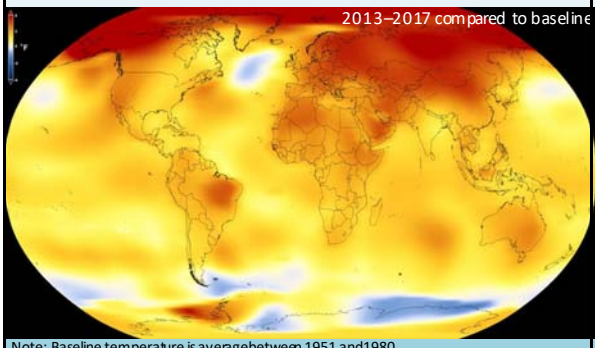
Earth is undergoing "net warming" however there will still be cold days, just ***not*** where historically expected.

- Unusual places are getting unusually cold, with snow.
  - Multiple inches of snow fell in Paris, France on February 5, 2018





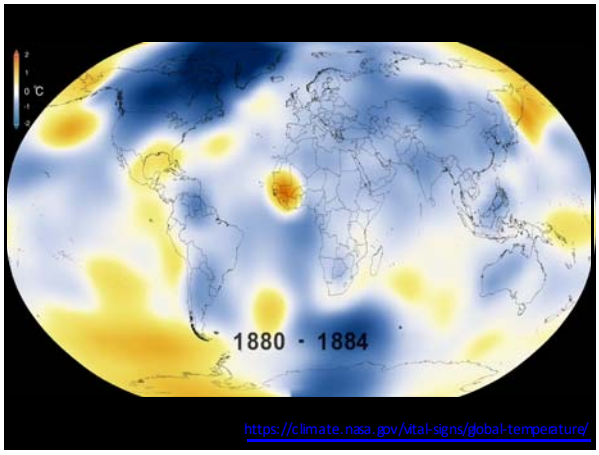
2017 was the warmest *non-El Niño* year since records began in 1880. In fact, Earth just had it's hottest 4-year period in recorded history.



Note: Baseline temperature is average between 1951 and 1980.
Source: NOAA

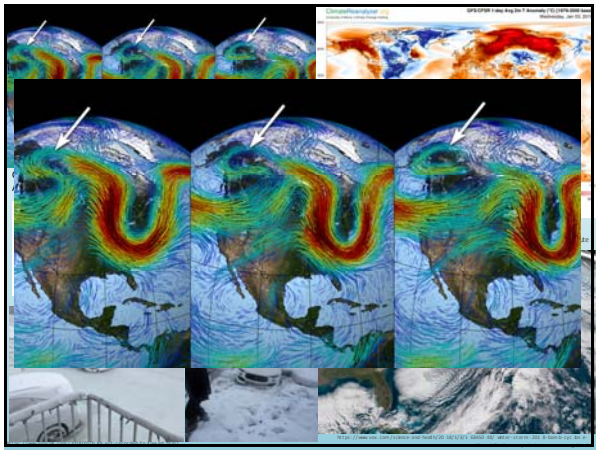
~16 inches of snow fell in the Sahara Desert in January 2018!

- Snowed 3 times in last 40 years, last seen in December 2016.
- Had not previously snowed in Ain Sefra, Algeria (nearby town) since 1979.



This year's low temperature in Oymyakon, Siberia is -89 °F (-67 °C).

January 2018: Oymyakon had eight consecutive mornings with lows at -58 °F (-50 °C) prompting eyelashes to freeze.



In 2017 global oceans were at their warmest to-date, since 1958.

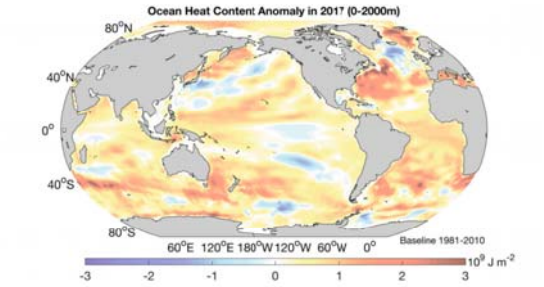
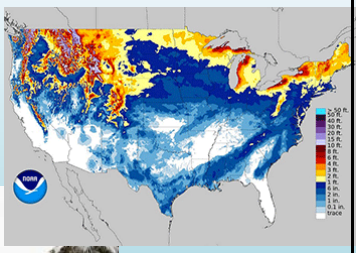


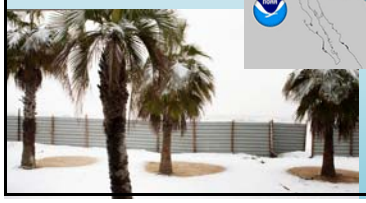
Fig. 2. Annual mean ocean heat content anomaly in 2017 relative to a 1981–2010 baseline. Units: 10^9 J m^{-2} Source: IAP ocean analysis.

Cheng, L.J., and J. Zhu, 2018: 2017 was the warmest year on record for the global ocean. *Adv. Atmos. Sci.*, **35**(3), 261–263, https://doi.org/10.1007/s00376-018-8011-1

Earth is undergoing "net warming" however there will still be cold days, just ***not*** where historically expected.

- Unusual places are getting unusually cold, with snow.
  - Inches of snow fell in Florida in January 2018
  - Snow fell in every US state by January 4 during 2017/18 winter.





https://www.sciencenewsforstudents.org/article/wacky-

In 2017, global oceans were at their warmest since 1900s.

See ocean temperatures video:

https://news.vice.com/en_us/article/wjpm7m/the-oceans-have-never-been-hotter-than-they-are-now

2017 saw Earth's warmest oceans on record (to-date since 1958).

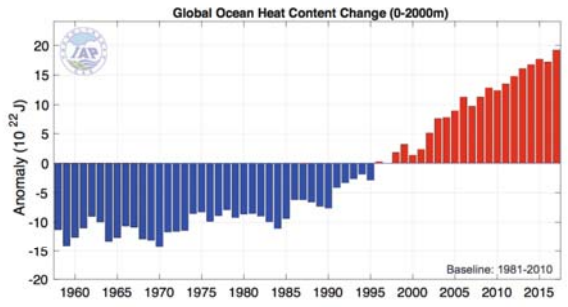
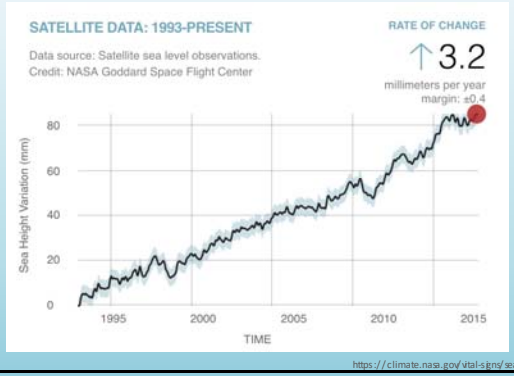


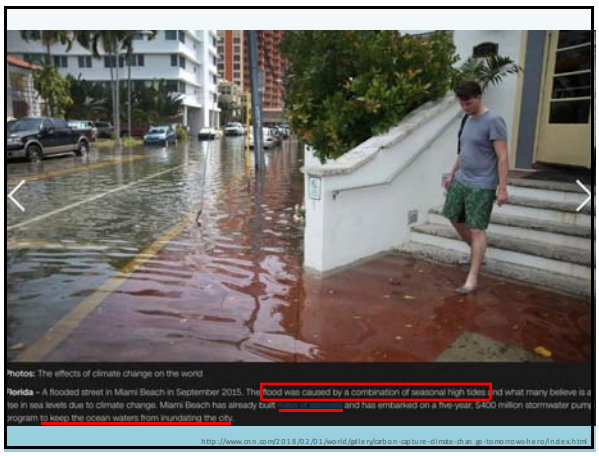
Fig. 1. Change in global upper-level (0–2000 m) ocean heat content since 1958. Each bar shows the annual mean relative to a 1981–2010 baseline. The final bar on the right shows the 2017 value. Reliable ocean temperature records date back to 1958. Source: IAP ocean analysis.

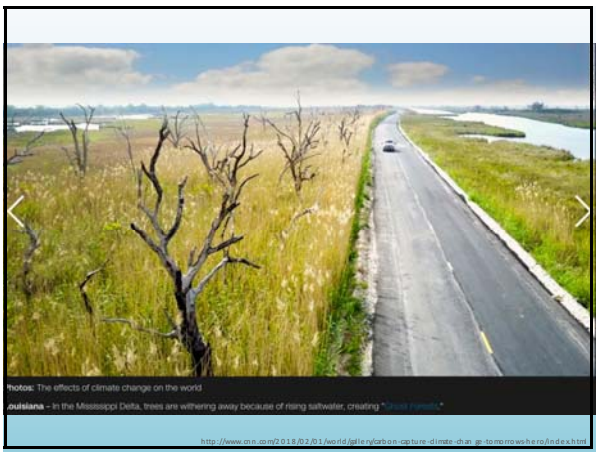
Cheng, L.J., and J. Zhu, 2018: 2017 was the warmest year on record for the global ocean. *Adv. Atmos. Sci.*, **35**(3), 261–263, https://doi.org/10.1007/s00376-018-8011-1

Global "mean sea level" has rapidly risen in last 20 years.

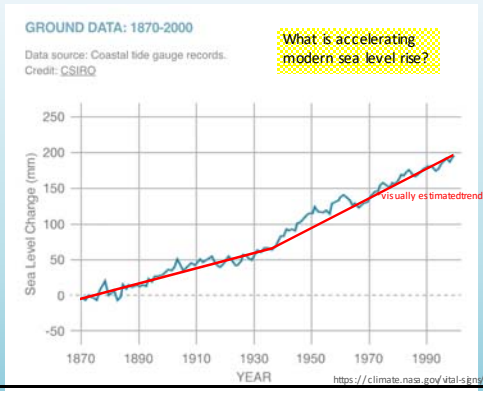


https://climate.nasa.gov/vital-signs/sea-level/

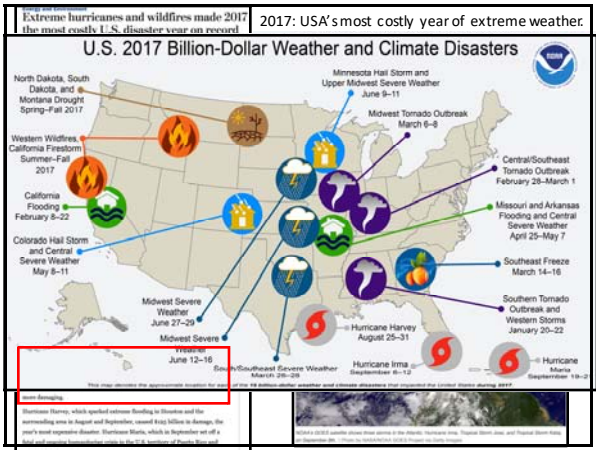


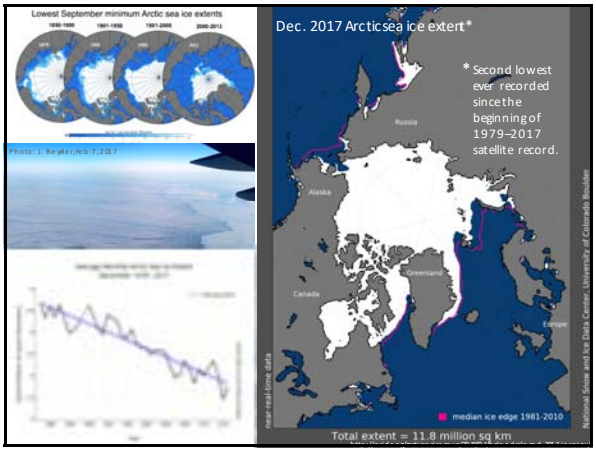


Sea level has risen almost ***twice as fast*** in the second half of the record (1940–2000) compared to the first half (1870–1940).



2017: USA's most costly year of extreme weather.





Arctic ice (i.e., Greenland, sea ice around North pole) is melting earlier and faster than ever observed.

- Complete melting of Antarctica and Greenland ice (i.e., ~99% of Earth's freshwater ice) would lead to hundreds of feet of sea level rise.

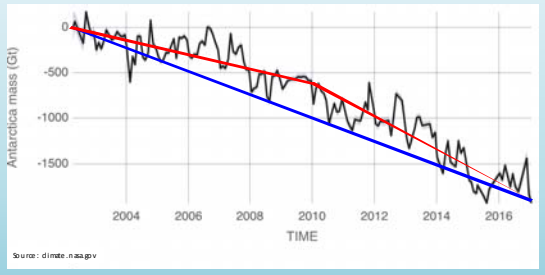
–National Ice and Snow Data Center, University of Colorado, Boulder

See NASA scientific visualization:

https://climate.nasa.gov/vital-signs/arctic-sea-ice/

Antarctica melted more and faster in 2017 than ever before observed. – NASA

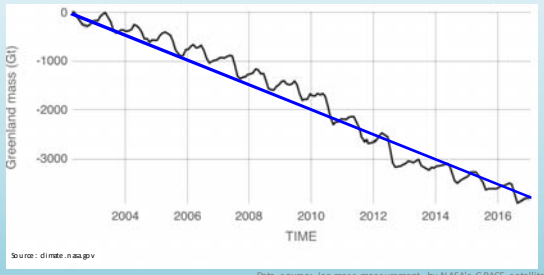
Antarctica mass variation since 2002 (rate of change is ↓127.0 gigatonnes/year)



Data source: Ice mass measurement by NASA's GRACE satellites.
Credit: NASA

Arctic ice (i.e., Greenland, sea ice around North pole) is melting earlier and faster than ever observed.

Greenland mass variation since 2002 (rate of change is ↓286.0 gigatonnes/year)



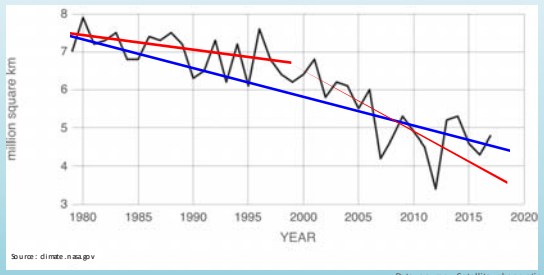
Data source: Ice mass measurement by NASA's GRACE satellites.
Credit: NASA

Antarctica melted more and faster in 2017 than ever before observed. – NASA

- Why does this matter a tiny bit more than arctic ice melt?
  - Sea ice is floating
    - only ~10% is above "mean sea level"
  - Land-based ice ***adds*** liquid to the oceans
  - Majority of the continent of Antarctica actually lies below sea level, but it is covered by 100s to 1000s of feet of "terrestrial" ice that is melting faster and more than ever observed
  - If sea level rises and floats the ice sheets = large-scale effects
    - "marine ice instability" that led to rapid melt and sea level rise during late Pleistocene, ~10,000-20,000 years ago

Arctic sea ice is extending less and less, year by year and is melting *more*, *earlier*, and *faster* than ever observed.

Average September extent variation since 2002 (rate of change is ↓13.2% per decade)



Data source: Satellite observations
Credit: NSIDC/NASA

Why is climate changing?
…greenhouse gas additions to the atmosphere.

- Earth's climate has always been changing.
  - Geologically it happened slowly, until the industrial revolution.
    - Volcanic eruptions, wildfires, the carbon cycle, Earth's axial tilt
  - *Only difference:* ***human behavior*** *since ~1850*
    - *Fossil fuel combustion, concrete construction, beef production, etc.*
  - What really killed the dinosaurs?
    - ***slowly changing global climate*** that reduced food and habitat with the final blow of "nuclear winter" from that fabled asteroid impact.

Earth's atmosphere is a "system".

- System is a balance of "inputs" and "outputs"
- Input +/– output = change in storage
  - e.g., like a checking account
- Influences to atmosphere build up and change ***slowly*** through geologic time
- Lately they've been ***rapidly*** changing…
  - Because of the rapid release of geologically sequestered carbon (i.e., combustion of **fossil fuels** by humans)

Take home messages: the punch line of "climate change"

- Change has always been happening, but human activity has grossly accelerated the ***rate of change.***
  - i.e., rapid increases in the rate of temperature change, ice melt, sea level rise, and occurrence of extreme weather
- Changes are ongoing now, have been ongoing throughout our lifetimes, and will continue for 100+ years.
- Extreme weather, rising global temperatures (i.e., highest-highs, lowest-lows, and averages), and disruptions of historical weather patterns are rapidly becoming the new normal.

Atmospheric CO_2 levels:
From recent geologic time, through 1950, to where we are today.

Questions?

Thanks for listening!!

Jonathan.Beyeler@state.nm.us

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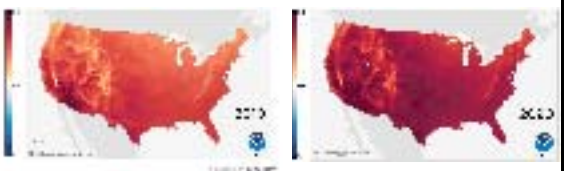
"Scientific evidence for warming of the climate system is unequivocal." –IPCC

Evidence of climate change summarized by NASA:

- **Global temperature rise**
  - Earth's average surface temperature has risen about 2.0 °F (1.1 °C) since late 1800s
  - Driven by increased CO2 and other GHG concentrations in atmosphere
  - 2016 (hottest year of record): 8 of 12 months were the warmest of record for those respective months (January through September, except June)
- **Warming ocean temperatures**
  - Oceans have absorbed much of this increased global heat
  - The top ~2,000 feet (~700 meters) of ocean showing warming of ~0.3 °F since 1969
- **Shrinking ice sheets**
  - Greenland and Antarctic ice sheets have decreased in mass, and are melting faster now than ever
- **Glacial retreat**
  - Alpine glaciers are retreating almost everywhere around the world (e.g., Mount Rainier, the Alps, Himalayas, Andes, Rockies, Alaska, and Africa)
- **Decreased snow cover**
  - Spring snow cover in Northern Hemisphere has decreased over the past 50 years and is melting earlier
  - Intense ramifications for water resources and resource management boking forward
- **Sea level rise**
  - Global sea level rose about 8" in the last century
  - However the rate in last 20 years is nearly double that of the last 100 years
- **Declining Arctic sea ice**
  - Extent and thickness of Arctic sea ice has declined rapidly over the last several decades
- **Extreme weather events**
  - Frequency of record high temperature events in the US has been increasing, while the number of record low temperature events has been decreasing since 1950
  - increasing frequency of intense rainfall events
- **Ocean acidification**
  - Since the Industrial Revolution, acidity of the surface ocean waters has increased by about 30% due to more CO_2 in the atmosphere and absorbing into the oceans

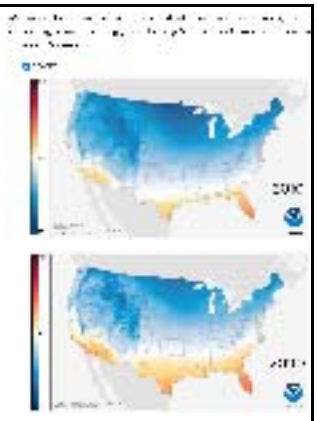
Source: NASA https://climate.nasa.gov/evidence/

Looking forward with uncurtailed emissions scenario: maps comparing 2010 and 2090 US summer temperatures



https://www.popsci.com/noaa-map-summer-temperature-2090

Looking forward with uncurtailed emissions scenario: maps comparing 2010 and 2090 US winter temperatures



By Associated Press
February 7, 2018 at 3:24 PM

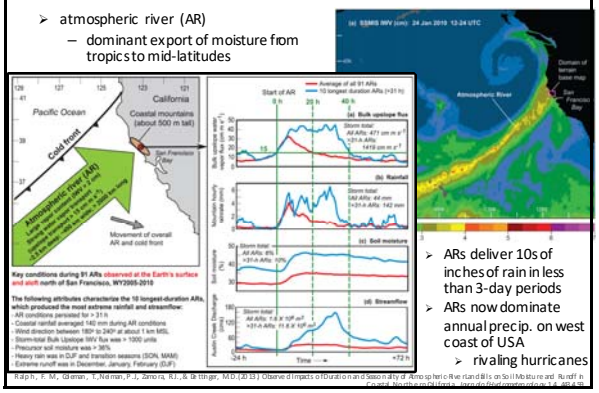
DENVER — Forecasters say one of the most important reservoirs in the Southwestern U.S. will likely collect less than half its normal amount of spring runoff this year because of a warm, dry winter across much of the region.

Hydrologist Greg Smith of the National Oceanic and Atmospheric Administration said Wednesday Lake Powell is expected to get 47 percent of its average inflow because of scant snow in the mountains that feed the Colorado River.

https://www.popsci.com/noaa-map-summer-temperature-2090
http://kunm.org/post/water-forecast-bleak-southwest-reservoir-land-commissioner-files-libertarian

West coasts of USA and Europe are increasingly experiencing flooding due to extreme precipitation (i.e., "atmospheric rivers").

- atmospheric river (AR)
  - dominant export of moisture from tropics to mid-latitudes



- ARs deliver 10s of inches of rain in less than 3-day periods
- ARs now dominate annual precip. on west coast of USA
  - rivaling hurricanes

Ralph, F. M., Coleman, T., Neiman, P. J., Zamora, R. J., & Dettinger, M. D. (2013). Observed Impacts of Duration and Seasonality of Atmospheric-River Landfalls on Soil Moisture and Runoff in Coastal Northern California. Journal of Hydrometeorology, 14, 443-459.

All above-average rain events at Mount Rainier, WA since 2000 have been due to atmospheric river precipitation. –USGS (personal communication, 2017)

- 2006 "100-yr" event was an AR
  - >18 inches of rain fell in <36 hours
  - Events since 2006 lengthen the record, and lead to a reevaluation of older events in the context of new data
- In 2017, the 2006 event was reclassified as ***~20-yr*** recurrence interval event

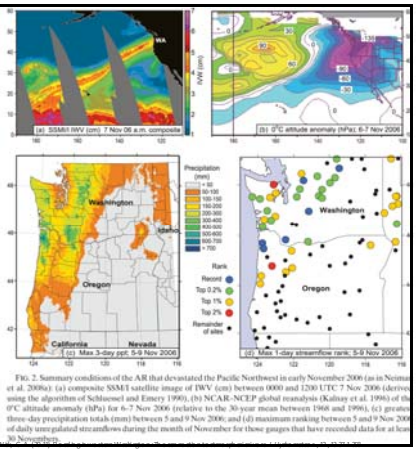
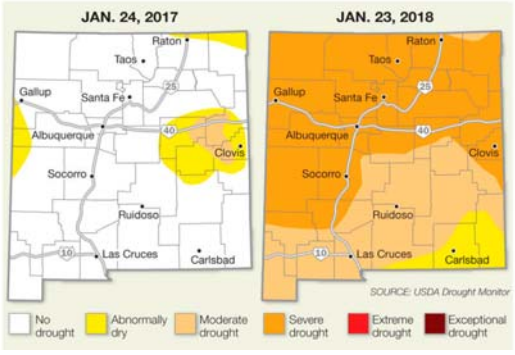


FIG. 2. Summary conditions of the AR that devastated the Pacific Northwest in early November 2006 (as in Neiman et al. 2008a): (a) composite SSM/I satellite image of IWV (cm) between 0000 and 1200 UTC 7 Nov 2006 (derived using the algorithm of Schluessel and Emery 1990), (b) NCAR-NCEP global reanalysis (Kalnay et al. 1996) of the 0°C altitude anomaly (hPa) for 6–7 Nov 2006 (relative to the 30-year mean between 1968 and 1996), (c) greatest three-day precipitation totals (mm) between 5 and 9 Nov 2006; and (d) maximum ranking between 5 and 9 Nov 2006 of daily unregulated streamflows during the month of November for those gauges that have recorded data for at least 20 Novembers.

All of New Mexico is beyond "abnormally dry". Northern New Mexico is currently in severe drought.



Source: USDA

https://www.abqjournal.com/1124388/a-dry-winter-leaves-new-mexico-thirsty.html

https://www.nps.gov/mora/learn/news/images-of-the-flood-of-2006.htm

Some unusual places are getting unusually cold (e.g., "bomb cyclone" and "polar vortex").

Water resources are fundamentally sensitive to a changing climate.

Exposed shoreline of Lake Mead, Boulder City, Nevada on June 3, 2015.

Source: Bloomberg

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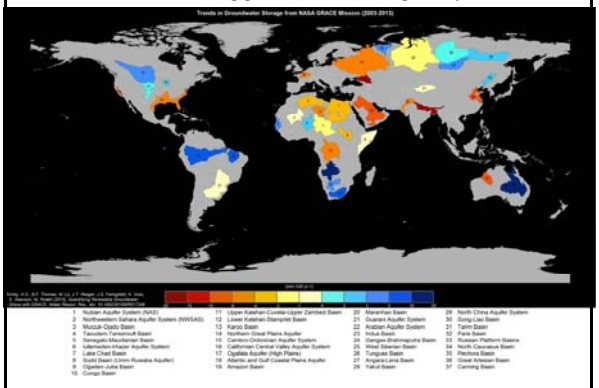
US COAST GUARD

Coast Guard crew members spotted a coyote on the frozen harbor.

By Steve Annear | GLOBE STAFF FEBRUARY 27, 2015

NASA data shows 1/3 of big groundwater basins globally are distressed.



Source: NASA

https://www.jpl.nasa.gov/images/earth/grace/20150616/grace20150616.jpg

This cartoon ran on the front page of the Boston Sunday Globe on Dec. 30, 1917, as the city endured a record-setting bitter cold snap.

By Matt Rocheleau and Jeremiah Manion | GLOBE STAFF DECEMBER 27, 2017