Institute on Science for Global Policy

Climate Change Evidence

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Summary

Observations confirm that climate change is happening, and that extreme weather is becoming the new normal. In addition to the steady rise in air temperature, ocean heat content, and sea level, there has been a decline in glacier mass, increase in permafrost thaw, and ocean acidification. Quasi-regular oscillations, such as El Niños and La Niñas, that are internal to the climate system, modulate these trends, but do not alter the direction of the changes. Accompanying circulation changes lead to regional variations in weather and weather extremes. Precipitation patterns shift; rain rates intensify; and droughts last longer. Hurricanes and other tropical storms are also more intense. The impacts of these changes in the mean and variance of climate are evident in terrestrial, riverine, and marine ecosystems.

Current realities

Atmospheric CO_2 levels exceeded 400 ppm in 2015, a value representing an 85 ppm increase since high-precision measurements began in 1957, and a 43% increase since the start of the industrial revolution. This increase is mostly due to the burning of fossil fuels as evidenced, among other things, by the concomitant decrease in atmospheric oxygen (from combustion), and the decrease in the fraction of radiocarbon (i.e. "recent" carbon, with half-life 6700 years) in CO_2. About 15% of the annual CO_2 emission in 2015 is from deforestation and land use modification.

Analysis of the energy balance at two Department of Energy (DoE) Atmospheric Radiation Monitoring sites (Southern Great Plains, North Slope of Alaska) yielded direct observational evidence of the greenhouse effect, which is well-established from theory and first principles calculations: the 22 ppm increase in CO_2 between 2000 and 2100 contributed to a 0.2 W/m^2 per decade increase in the clear-sky down-welling longwave radiation. The Sun's output fluctuates on an 11-year cycle, and is not correlated with the steady increase in temperature.

Surface air temperature continues to increase steadily since records began in the late 1800s. The trend of globally averaged surface air temperature is $+0.07^oC$/decade for 1880-2015, and is accelerating, at $+0.16^oC$/decade for 1980-2015. The 10 warmest years in the past 200 years have occurred since 1998. Since oceans absorb ~90% of the heat added to the climate system, ocean temperatures and heat content in the upper 2000m of the ocean have also increased.

The temperature increase is not the same from year to year, or from place to place, and is modulated by large-scale natural variations of the climate. The warming trend is consistently largest at high-latitudes. During La Niña, (e.g., early 2000s) when the Eastern equatorial Pacific is cooler than normal, the air temperature increase slowed, and there was greater penetration of ocean warming to depth. In contrast, the 2015 strong El Niño on top of the steady warming trend led to much-above-average annual mean temperatures in every contiguous U.S. state.

Arctic sea ice extent has declined steadily since 1979, with the rate of -7.4 +/- 1.7% per decade. September 2015 summer minimum extent was second only to 2012. Winter growth of sea ice has been "sluggish", with the 13 lowest winter extents on the satellite record occurring in the last 13 years. A new record winter low (5.607 million square miles) was set in 2015. Gravity measurements from the Gravity Recovery and Climate Experiment (GRACE) satellite show that the Greenland Ice Sheet is steadily losing mass, at a rate of -234 +/- 20 Gt per year (1 Gt = 10^9 tons) from 2003-2011. Steady decline of mid-latitude and tropical glaciers is also observed.

Permafrost thaw in the circumpolar North has accelerated in the past decade, with borehole temperatures at 20m depth increasing by up to 0.66°C per decade since 2000. Thickness of the active layer (i.e., the layer that undergoes seasonal freeze/thaw) has also increased.

Sea level has been rising, due to thermal expansion of ocean waters and input of freshwater from glaciers. The global mean sea level rise is 3.3 +/- 4 mm/yr, determined from consecutive satellite missions 1992-2015. Global mean sea level in 2015 was ~70mm higher than 1993, with 10mm due to the strong El Niño. Higher sea level increases the probability of storm surge.

Climate is defined by the statistics (e.g., mean, standard deviation) of weather over a period. Observations show that while mean temperatures have increased, so has the variance. What were considered rare weather events (e.g., heat waves, floods and droughts), 50 years ago are becoming more frequent. Cold extremes, while less frequent, continue to occur. Jet stream meanders and other features of the atmospheric circulation set up regional variations in seasonal climate and weather extremes. The winter of 2014/15 saw record or near-record warmth in western U.S., and record-breaking cold in 24 states. Oklahoma and Texas received 1.5-2 times more rain than average, while severe drought persisted in California; Eastern Canada had record snowfall (Halifax airport received 371 cm snow, significantly above the norm of 59 cm), while western Canada had four times more wild fires than the 15-year average. The equatorial region saw 101 named tropical storms in 2015, above the 1981-2010 average of 82.

Climate change has severe impacts on terrestrial, riverine, and marine ecosystems since their lifecycles are finely tuned to the weather: too little, too much, too early, too late, may all be damaging. Observations show that many terrestrial freshwater and marine species have shifted the ranges of their seasonal activities. Many weeds, pests, and fungi thrive in warm, wet conditions and with higher CO_2. Higher nighttime temperatures lowered corn yields in the U.S. It is noteworthy that agricultural production in California has not declined, despite the prolonged drought, because of the continued reliance on ground water — a very finite and limiting resource.

Ocean acidification, documented in continuing observations near Hawaii and Bermuda, has already impacted the shellfish industry. Furthermore, warm sea surface temperatures are conducive to harmful algal blooms. In late spring and summer of 2015, the largest and longest lasting bloom of *Pseudo-nitzchia* was found from central California to British Columbia, Canada, and the potent neurotoxin, domoic acid, led to the closure of razor clam digs along beaches, and shellfish and Dungeness crab harvesting off the coasts of Oregon and California.

Climate change is happening, at a pace faster than that anticipated 20 years ago. Even if emissions were stopped, the climate would not return to the conditions 200 years ago. This is because it would take many thousands of years for atmospheric CO_2 to transfer to the deep ocean for ultimate burial in ocean sediments.

Scientific opportunities and challenges

The Earth system is rapidly entering a climate space not experienced in human history. Vigilant monitoring to capture surprises and to understand the changes demands a sustained climate observation system. The general commitment to maintaining geostationary weather satellites must be, but is not, in place for the orbiting satellites that observe atmospheric chemistry, photosynthesis, sea level, glacial mass, winds over the oceans, etc. Real-time warning systems could be complemented with autonomous sensors and *in-situ* observing systems.

Non-stationary statistics of the climate system means that the past is not an analog of the future. Climate models are perforce a critical tool for projecting future changes, for identifying vulnerable areas or sectors, and for exploring the multidimensional multisectorial responses to different emission, mitigation or adaptation strategies. Yet, our ability to provide warnings about high-impact weather, and robust estimates of the risk to society, particularly from possible catastrophic changes in regional climate, is constrained, not only by incomplete understanding of the dynamics of the climate system, but also by limitations in computer power and an insufficiently large scientific workforce. Mitigation and adaption measures take place at the regional and local levels, and their research has been carried out, in relay mode, using climate model results. A national multiagency coordinated enterprise in climate prediction need to be created, to synthesize understanding, knowledge and questions across the many sectors, and project not only the regional and local changes in climate and ecosystems, but also the impacts to national security, food security, water security, human health, and civic society.

Policy issues
Since policy to reduce carbon emissions will only slow the warming and postpone the inevitable consequences, preparing and adapting to climate change is urgent:

Government policies

- Implement national program to identify sectors and assets that are vulnerable to the threats of climate change.
- Increase standards that regulate energy efficiency of vehicles (e.g., Corporate Average Fuel Economy) and appliances (e.g., DoE Appliance and Standards Program).
- Implement state and local programs to encourage renewable energy and to increase the fraction of renewable energy in the supply (e.g., 50% of California's energy to be supplied by renewables by 2030)

Food and water security

- Implement programs to manage fresh water resources, especially ground water.
- Build standards to mandate water efficiency savings, and revise pricing structure for water so as to discourage wastage.
- Implement programs to incentivize the development of crops with high water-use efficiency, high tolerance to the vicissitudes of weather.

Modernizing infrastructure

- Revise building codes and land development regulations to minimize damage in coastal areas, or post-disaster development in vulnerable areas.
- Include sea level and other climate change impacts in plans for new airport runways, highways and coastal structures.
- Increase resilience of urban areas to severe weather (e.g. develop flood risk maps, increase size of storm drains).

Preparedness

- Require back-up systems for electricity, water supply, and health and emergency services.
- Develop emergency plans, especially for large urban areas (e.g. Manhattan plan for sea level rise) for extended heat waves, and storm surge.
- Develop heat exposure protocols for outdoor personnel and equipment.

References
Blunden, J. and D.S. Arndt, Eds., (2016). State of the Climate in 2015. *Bull. Amer. Meteoro. Soc.*, 97(8), S1-S275, DOI:10/1175/2016BAMSStateoftheClimate.1. Highlights in https://www.ncdc.noaa.gov/sotc/global/201609

Global Climate Dashboard: https://www.climate.gov/maps-data

*** A policy position paper prepared for presentation at the conference on Climate Impact on National Security (CINS), convened by the Institute on Science for Global Policy (ISGP) in partnership with the U.S. Army War College (USAWC), Nov. 28 – Dec. 1, 2016, at the USAWC, Carlisle, Pennsylvania, U.S.*

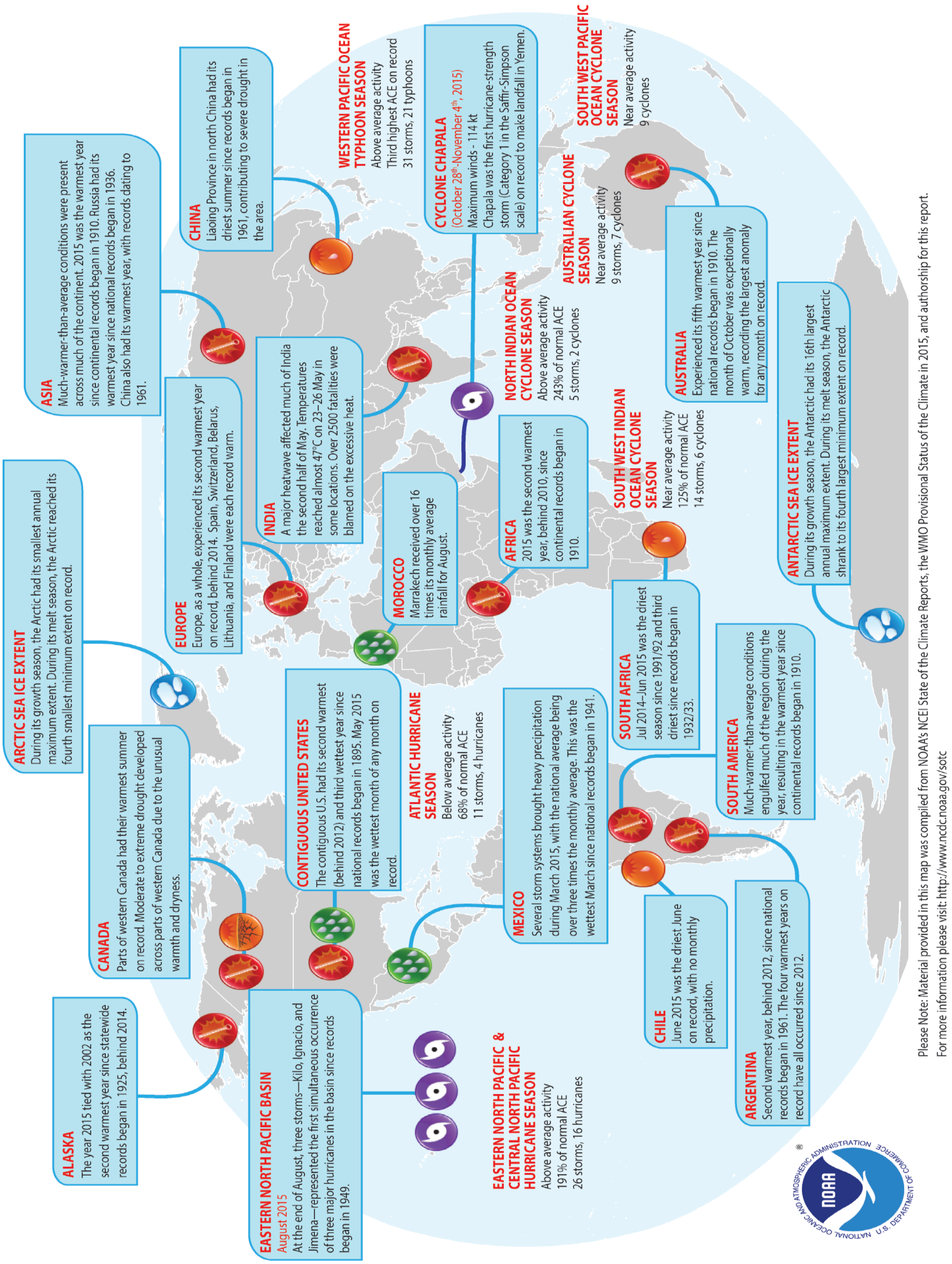

Figure. Map of notable climate anomalies and climate events in 2015 (from Blunden and Arndt, 2016).