Emerging Negative Effects of Climate Change – rev a

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1. Introduction

This is a minor update of a paper originally posted in May, 2019. This paper is drawn from an issue of Scientific American, to which I subscribe. I originally read the article that prompted this paper in the March 2019 (hardcopy) issue. Reference 1, below, has a link to a reprint the article from Penn State, the author's (Dr. Michael E. Mann) institution.

I'm updating this paper in order to link it to another paper that also presents a comparable explanation from another well regarded climatologist (Dr. James Hansen).

Climate change is caused by greenhouse gases (GHG), primarily carbon dioxide (CO_2) and methane, increasing in the atmosphere. This results in atmospheric warming. There are also many secondary, tertiary and higher order effects, including the following, which we have known about for some time:

- The sea-level is rising primarily due to a secondary effect and a tertiary effect of climate change. The secondary effect is the thermal expansion of sea water as it warms. The tertiary effect is the melting of glaciers and ice sheets (primarily the Antarctic and Greenland Ice Sheets) as they warm, providing run-off into the oceans thus increasing the level of the oceans.
- Both heat and CO_2 enter the oceans and the latter acidifies them, causing major damage to coral, shellfish and possibly other aquatic life.
- The melting of the Greenland Ice Sheet has freshened the water in the North Atlantic, which has disrupted the Meridional Overturning Circulation (MOC, the Gulf Stream and other major ocean currents).
- Increasing atmospheric temperatures and the MOC disruption have caused major changes to weather patterns around the world.

This paper is about an emerging understanding of the last bullet, and the impacts (so far), especially in North America.

2. A Slowly Undulating Smoking Gun

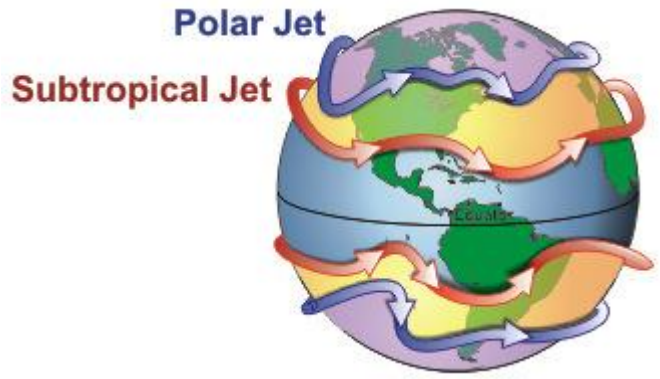
Consider the following:

"…In 2003 Europe's worst heat wave in history killed more than 30,000 citizens. In 2010 wildfires in Russia and floods in Pakistan caused unprecedented damage and death. The 2011 U.S. heat wave and drought caused ranchers in Oklahoma to lose a quarter of their cattle. The 2016 Alberta wildfires constituted the costliest disaster in Canadian history. And the summer of 2018 that the U.S. experienced was notorious: temperatures flared above 100 degrees Fahrenheit for days on end across the desert Southwest, heavy rains and floods inundated the Mid-Atlantic States, and California had repeated

successive record wildfire seasons in 2017, 2018, 2019 & 2020. Extreme heat waves, floods and wildfires raged across Europe and Asia, too."[1]

Now let's propose that all of the above disasters were caused by the same effect: a change in the jet streams caused by a climate-change-induced shift in the behavior of the atmosphere.

The jet streams are west-to-east wind currents that circle the globe. There are two jet streams each in the northern and southern hemisphere as can be seen from the picture below.[2] Note that most text below discusses the Northern Hemisphere.



The polar jets are the strongest and lowest (30,000–39,000 ft.), and the subtropical jets are weaker and higher (33,000–52,000 ft.). Both strongly influence the weather. Even the normal jet stream shifts north and south over time, and also undulates as shown above.

Two unusual changes in the jet stream during the above extreme events were noted by the referenced Scientific American article:

- The undulations became more extreme, concurrently reaching north to the arctic region, and south to the Gulf of Mexico. The larger these waves get, the more extreme the weather gets near the northern and southern extremes.
- The undulations slow down or stall. These normally move west to east across North America in a few days.

"The polar jet stream forms where warm surface air from the subtropics around the globe moves northward and meets cold surface air from the polar region-roughly where the U.S. meets Canada. The jet blows at around 35,000 feet up, along the boundary between the troposphere (the lowest level of the atmosphere, where weather happens) and the stratosphere (the next level, where airliners fly). The greater the temperature difference when the subtropical and polar air meet, the stronger the jet stream wind. During summer the temperature difference is less than during winter, so the jet stream is weaker. When it weakens, it is more likely to exhibit broad north-south bends."

[1] Michael E. Mann, Scientific American, The Weather amplifier: Strange waves in the jet stream foretell a future full of heat waves and floods (February 21, 2019), Penn State Site reprint of this article: http://www.meteo.psu.edu/holocene/public_html/Mann/articles/articles/MannSciAmFeb19.pdf

[2] Wikipedia Article on the Jet Stream, https://en.wikipedia.org/wiki/Jet_stream World figure is by Lyndon State College Meteorology

Normally the undulations in the jet stream create the low and high pressure cells that generate most of our weather. Like the jet stream, they mainly move west-to-east. A high pressure cell, carried by a northern undulation, rotates in a clockwise direction and brings hot, dry weather. A low-pressure cell is inside of a southern bend in the jet stream, rotates counter-clockwise, and brings rainy, cool weather.

During extreme weather, the undulations in the jet stream become extreme as described above, and the weather created from the high and low pressure cells becomes more extreme.

A primary driver of the undulations in the jet stream are Atmospheric Rossby waves. These *"…result from the conservation of potential vorticity and are influenced by the Coriolis force and pressure gradient. The rotation causes fluids to turn to the right as they move in the northern hemisphere and to the left in the southern hemisphere…* [in earth's atmosphere] *Rossby waves are due to the variation in the Coriolis Effect with latitude. Carl-Gustaf Arvid Rossby first identified such waves in the Earth's atmosphere in 1939 and went on to explain their motion.*[3]

From reference 1: "*The amplitude that routine Rossby waves can attain is limited by the energy they radiate away as they bend north and south and as they proceed eastward. Under certain conditions, however, the atmosphere can act as a kind of waveguide. Imagine a west-east line across central Canada and another one across the southern U.S. A bent Rossby wave stays put, within these "walls," losing little energy… When waves are stuck in place as standing waves, under certain circumstances, the bends can grow readily in amplitude – what is known in physics as resonance. When this happens to Rossby waves, more common in summer, it is called quasi-resonant amplification, or QRA…*

"In the early 1980s David Karoly, now at Australia's Commonwealth Scientific and Industrial Research Organization, and Brian Hoskins of the University of Reading in England, demonstrated that the atmosphere can behave like a waveguide for stalled…Rossby waves that have certain short wavelengths (roughly the width of the continental U.S., or six to eight full wavelengths all the way around the Northern Hemisphere).

"The standing Rossby wave becomes trapped inside the waveguide, with only minimal leakage of energy through the northern and southern boundaries… In this situation, the waves can grow in amplitude because of QRA. Stuck in place, the now huge standing wave creates extreme weather systems inside the ridges and troughs that persist for days."

3. Causes and Effects

If you review the list of disasters at the beginning of this section, you see two major categories – (1) droughts, frequently leading to wildfires, and "stuck" rainstorms or hurricanes, frequently leading to floods.

In California, we are very familiar with a high pressure cell that is "stuck" over the Pacific, just west of our coast. This is a major source of our droughts. These patterns sometimes follow the sequence of events described below:

[3] Wikipedia Article on Rossby wave, https://en.wikipedia.org/wiki/Rossby_wave

- Incoming storms frequently ride the jet stream up and over the Pacific high pressure cells into the Pacific Northwest.
- These storms (low pressure areas) then frequently slide south down the wave into Nevada and points east.
- When these low pressure areas slide close enough to the Pacific high pressure cell, the clockwise rotation around the Pacific high, and the counterclockwise rotation around the Nevada low reinforce each other and result in near-hurricane-force winds out of the north in California.
- When the jet stream undulations are stuck, these winds may last for several days.
- The winds cause many trees (usually diseased or dead due to factors like drought worsened by climate change) to fall and large limbs to break off.
- A few of the trees and limbs hit power lines, which provide ignition-sources (human-carelessness can also start a fire but usually in a single location).
- The above occurs concurrently in several locations in the same general area, but may also happen in other areas in the state at the same time (like the 2018 Camp and Woolsey fires in Northern and Southern California, which started at the same time).
- The resulting wildland fire(s) spread very rapidly and is/are too intense to fight.
- By the time the wind abates, the fire(s) have/has spread to several hundred square miles.

Similar effects to the above cause major rainstorms in the Midwest and hurricanes on the east and gulf coast to stall in place and greatly increase flooding.