

An Ill Wind: Climate Change and Tropical Cyclones

Fintan Hughes¹, Jack Hodgkinson², Hugh Montgomery¹

¹University College London, Department of Medicine and Institute of Sport, Exercise & Health

²University of Cambridge, Department of Physics

Throughout the 60 million years of the Carboniferous Period, Carbon Dioxide (CO₂) was drawn down from the atmosphere and sequestered in fossil fuels, which have only recently been burned at scale: just over 100 years ago cars first outnumbered horses in New York, but there are now 1.2 billion vehicles on the road, and airlines carry over four hundred thousand passengers every hour. As a result of burning these fuels, atmospheric CO₂ concentrations have increased dramatically (from 280 to 406 ppm) since 1850.

In 1896, Nobel Laureate Svante Arrhenius predicted that such rising CO₂ concentrations would drive a substantial increase in global surface temperatures. This causal relationship was widely recognized amongst climate scientists by 1970, and by 2016 the average *land* surface temperature was 1.42°C higher than the 20th Century average, with an increase in average global temperature of 1.1°C.(1) The impacts of the resulting climate change on humanity in the form of food shortages and the spread of disease have been well described.(2) However, *the oceans* have also been affected: together with ice, they have absorbed 93% of the net global energy gain caused by CO₂ and other greenhouse gases, and their surface temperatures have risen by 0.7°C since pre-industrial times.(3) Polar sea ice is melting, its surface area 2,000,000 km² less in 2017 than the 1981-2010 average; and sea levels are rising by 3.4cm/decade.

From Heat to Cyclones

Heat in our atmosphere and oceans causes air to rise and water to evaporate. This water precipitates as rain and rising air creates the pressure differences that cause wind. The resulting dynamic system is our weather, which intensifies when fueled by greater heat. Tropical cyclones form as a result of rapid water evaporation from warm oceans. The rising air draws with it further warm humid air from the ocean surface. The energy (latent heat) is released when the water condenses to form clouds which are pushed outwards by the rising air at the centre. The Earth's rotation causes the system to spiral through the Coriolis effect, generating winds which move across the Earth's surface.

The energy released by a tropical cyclone is truly staggering; in a typical system, the latent heat of water condensation is released at a rate of 6×10^{14} watts – 200 times the world's electricity generating power. This destructive power is huge; cyclones convert our planet's excess heat into wind and rainfall which directly strike exposed populations. Destruction of property, freshwater and sanitation services expose the surviving population to disease. Hampered transport infrastructure and fuel shortages impede emergency services as hospitals struggle to stay operational.

2017 North Atlantic Hurricane Season

On August 27th 2017, the eye of hurricane Harvey stalled over the Gulf of Mexico, releasing up to 96 mm of rainfall per hour to its North. Total rainfall accumulations of over 50cm brought unprecedented flooding to the region. Disrupted drinking water supplies and contaminated floodwater prompted the declaration of public health emergencies in both Texas and Louisiana. The US coast guard rescued 16,800 individuals; direct traumatic injury increased pressure on the Houston health system as evacuations were initiated across 12 hospitals. As flood waters lingered, the center for disease control warned of potential public health risks from electrocution

and exposure to industrial chemicals from surrounding petrochemical plants, along with respiratory infections from mold growth.(4) Additionally there exists a risk of proliferation of the endemic Aedes mosquito, with known cases of Dengue fever, Chikungunya and Zika virus reported in the region.(5)

Less than 2 weeks later, the most powerful recorded Atlantic storm, Hurricane Irma, made numerous landfalls throughout the Caribbean, with sustained wind speeds of 295 km/h. Serious damage to health care facilities were widely reported with growing risks from mosquitos and rodents. Barbuda in particular, suffered destruction of all health care facilities and ambulances, with much of the island flooded by 7m storm surge and forcing the evacuation of the entire island as category 4 hurricane Jose approached.(6) Medical supplies were severely limited throughout the Caribbean with countries requesting aid in the form of mosquito repellants, emergency medical kits, and a vast array of drugs from the WHO List of Essential Medicines.(7) Cuba, in the midst of intense drought and still recovering from 2016's Hurricane Matthew, was exposed to 9 meter waves and coastal inundation during Hurricane Irma's landfall. Some 220,000 homes have been severely damaged, along with 70% of the hospitals in the impacted area, which is home to over 9 million people.(8) Relief efforts have been hampered as most airports throughout the Caribbean were not operational in the days following the storm. On the ground, widespread road damage presented an additional hurdle to humanitarian aid and emergency medical care, with 90% of roads on the island of Anguilla left impassible.(9)

Ten days later, Hurricane Maria rapidly intensified to a category 5 cyclone just 30 hours before damaging 90% of buildings in Dominica.(9) The next landfall cut the power supply across the entire 3.4 million population of Puerto Rico with catastrophic consequences to patient care, as over 51 of the island's 69 of hospitals stopped accepting new patients. One hospital was fully operational by the end of the week, and 10 days later weeks later only 17 hospitals had power from the grid while access generator fuel was limited.(10)

More Damaging Cyclones on the Horizon

Increasing ocean temperatures lead to more powerful storms: the maximum wind speed in a tropical cyclone is directly proportional to the square root of the difference in temperatures between the ocean surface and the stratosphere. Greenhouse gas-induced climate change also results in a colder stratosphere, further amplifying the intensity of tropical cyclones.(11) Meanwhile, higher ocean temperatures lead to greater surface water evaporation. The Clausius-Clapeyron relation predicts an increase in atmospheric water content of approximately 6.5% per 1°C increase in atmospheric temperature, correlating strongly with an increase in extreme rainfall events. Through such effects, climate change drives increasing cyclone intensity. In keeping, the number of tropical cyclones reaching categories 4 and 5, like Harvey, Irma, Jose and Maria, has increased since 1930. Forward projection of the CMIP5 models predict that global power dissipation (the total energy released by tropical cyclones in a given year) will increase by 8 – 80% by the end of the century, depending on the extent of global temperature increase.(12) Owing to higher CO₂ concentrations and increased humidity gradients in the troposphere it is predicted that the frequency of tropical storm formation will reduce by 7-28%.(13) This increased power will therefore be dissipated across a smaller number of larger storms. Models predict an increase in global storm of intensity of 4.1%.(14) This amplification of mean intensity elevates frequency of the extreme storms at the upper distribution of the Saffir/Simpson scale. As such there IPCC models predict a 28% increase in frequency of the maximum intensity category 4&5 storms. This is further reflected by a predicted 25% increase in tropical cyclone precipitation.(15)

As global temperatures rise, the destructive impacts seen from hurricanes Harvey, Irma and

Maria are predicted to become regular occurrences. This unique hurricane season provides a worrying glimpse of a future Earth in which warming is not curtailed. With an increase in average storm intensity, there is a reduction in return time, or the length of time between any two catastrophic storms. With less time to rebuild damaged infrastructure before the next storm makes landfall, those areas unable to adapt will become uninhabitable. Importantly, a combination of continued sea level rise and the predicted northward shift of the most intense tropical cyclones(16) will make the eastern US increasingly vulnerable to these extreme events, as seen with Hurricane Sandy in 2012. Similar effects in the Pacific and Indian oceans may combine to substantially increase the population exposed to high intensity tropical cyclones over the course of the century.

Key Global Actions

Currently no viable engineering solutions exist which would protect exposed population from the impact of these extreme tropical cyclones; sea walls have proved ineffective against storm surge, affordable buildings are unable to withstand 200km/h winds, and drainage systems cannot clear the flooding of such extreme rainfall. As such we do not have the solutions required to adapt to this predicted increase in storm intensity. It is not sustainable for humans to continue emitting greenhouse gasses while providing disaster relief from the resulting high intensity storms. It is thus essential that greenhouse gas emissions are substantially and rapidly reduced.

As these extreme weather events show, *any* further warming which can be avoided *must* be avoided. Governments of the world must go beyond the minimum requirements set out by the 2015 Paris Agreement. The United States should rejoin the Paris process with honest commitment and vigor; it is vulnerable to inaction. Fossil fuel subsidies of 5.3 trillion dollars annually amount to subsidies on suffering, and must stop.(17) This money could instead be used to help hasten the transition to renewable energy sources. Industries which develop renewable energy technologies, facilitate their widespread adoption and establish independent renewable energy supplies should be financially rewarded, as they lead by example. Similarly, carbon taxation is an essential tool in reprimanding those industries which knowingly endanger the planet.

The doctors can use their prominent trusted position in the scientific community to lead the education of politicians, policy-makers and the general public.(18) A medical community well versed in public health impacts of climate change, and the subtleties of climate science should pressure their politicians for immediate and meaningful action on climate change as the major global health opportunity of our time.

The future of human civilization as we know it is threatened; global temperatures are accelerating towards potential irreversible tipping points. Wishful thinking will not calm the storm, and instead we must advocate for a concerted global effort to protect ourselves from the mistakes made by those before us.

Contributors & Sources

Fintan Hughes is a human physiology researcher at the University College London Institute for Sport Exercise & Health, a medical student of the National University of Ireland Galway and former physics student at Trinity College Dublin.

Jack Hodkinson is a PhD candidate within the Dutton Research Group at the University of Cambridge Department of Physics, and a former physics student at Trinity College Dublin.

Hugh Montgomery is the professor of intensive care medicine at University College London, director of the UCL Institute for Sport Exercise & Health and co-chair of the Lancet Countdown.

Declarations

All authors declare that the answer to the questions on your competing interest form (<http://bmj.com/cgi/content/full/317/7154/291/DC1>) are all No and therefore have nothing to declare

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