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Superstorm Sandy
A Series of Unfortunate Events?

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As we reflect upon the rash of extreme weather observed during 2012, no single event had as large an impact on the economy and political landscape of the United States as Superstorm Sandy (e.g., Bloomberg Businessweek: http://www.businessweek.com/articles/2012-11-01/its-global-warming-stupid). Images of flooded subway stations in New York City, demolished towns on the New Jersey shore, and autumn blizzard conditions in Appalachia will be etched in the nation's psyche for quite some time. With the increasing frequency of extreme weather events serving as a backdrop, many people are asking what role, if any, did anthropogenic climate change play in the development of Superstorm Sandy? We believe that the recent record-breaking losses of Arctic sea ice may figure prominently in answering this question and in improving our understanding of Sandy's unusual nature.

While Sandy started out as a relatively normal late-season hurricane, its character became anything but normal as the storm tracked northward along the eastern seaboard (Blake et al., 2013). Unusually warm ocean temperatures helped Sandy maintain tropical storm characteristics as it headed north. However, what made Sandy become so unusual were the atmospheric interactions that transformed it into a monster hybrid storm that combined the worst features of a late-season hurricane and an extra-tropical cyclone. Unlike a typical hurricane, this huge and powerful hybrid storm did not lose strength after making landfall because it was supercharged with energy derived from a southward dip in the jet stream over the Mississippi Valley that ushered in an invasion of cold Arctic air (Figure 1). Thus, a useful way to look at the anthropogenic climate-change connection is to ask why were the extra-tropical conditions so unusual?

Let's review the facts:

First, a strong high-pressure blocking pattern over Greenland and the northwest Atlantic prevented Sandy from steering northeast and out to sea like most October hurricanes/tropical storms heading up from the Caribbean. In fact, Sandy did not just track northward toward New England like the handful of other October tropical storms that did not head out to sea (think of the 1991 Perfect Storm). Rather, Sandy did something never observed before in records going back to 1851—it took a sharp turn to the west and headed toward the most populated area along the eastern seaboard.

Second, while on this apparently unprecedented westward trajectory, Sandy converged with an extra-tropical cyclone, a developing early "winter" nor'easter, that transformed it from a weakening late-October hurricane/tropical storm into an extra-tropical hybrid superstorm. At the center of this superstorm, atmospheric pressures were the lowest ever recorded for a storm making landfall north of Cape Hatteras, NC. In addition, Superstorm Sandy exhibited the second-largest extent (> 1.4 million km^2) of storm-force winds for any extra-tropical storm derived from a hurricane (second only to Hurricane Olga in 2001).

Third, the combination of Superstorm Sandy's extremely low atmospheric

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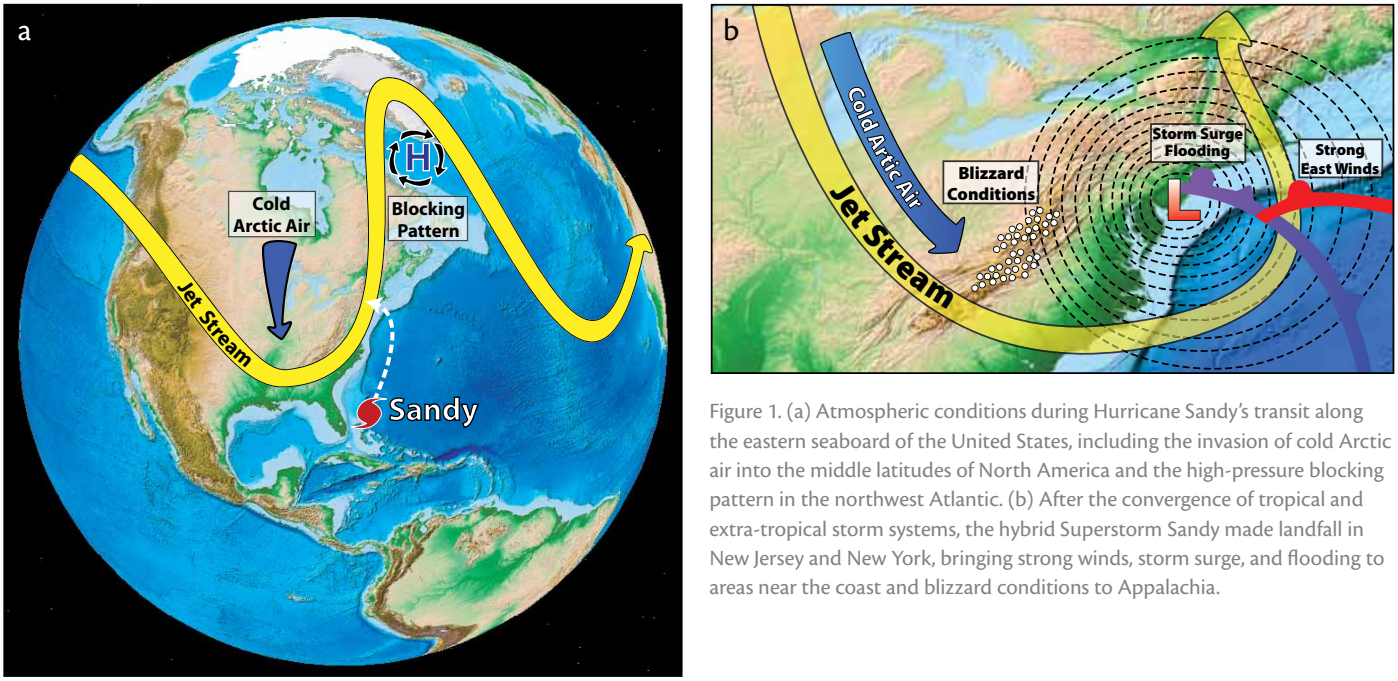

Figure 1. (a) Atmospheric conditions during Hurricane Sandy's transit along the eastern seaboard of the United States, including the invasion of cold Arctic air into the middle latitudes of North America and the high-pressure blocking pattern in the northwest Atlantic. (b) After the convergence of tropical and extra-tropical storm systems, the hybrid Superstorm Sandy made landfall in New Jersey and New York, bringing strong winds, storm surge, and flooding to areas near the coast and blizzard conditions to Appalachia.

pressure and the unusually strong high-pressure block to the north created a huge area of violent east winds that pushed water up against the eastern seaboard from Nova Scotia to New Jersey, greatly exacerbating the storm surge. To literally top it off, the storm surge combined with full-moon high tides and huge ocean waves to produce record-high water levels that exceeded the worst-case predictions for certain parts of New York City.

Now, some might argue that this was just a series of unfortunate events resulting from the coincidence of many rare and/or unprecedented acts of nature. For those convinced that it is very difficult or impossible to attribute the occurrence of any single extreme weather event to anthropogenic climate change, this argument is, indeed, valid. However, there is increasing evidence that the loss of summertime Arctic sea ice due to greenhouse warming stacks the deck in favor of (1) larger amplitude meanders in the jet stream, (2) more frequent invasions of Arctic air masses into the middle latitudes, and (3) more frequent blocking events of the kind that steered Sandy to the west (Francis and Vavrus, 2012; Greene, 2012; Greene and Monger, 2012; Liu et al., 2012). Although a direct causal link has not been established between the atmospheric phenomena observed in late October 2012 and the record-breaking sea-ice loss observed during the preceding summer months, all of the observations are consistent with such an interpretation. Therefore, if one accepts this evidence and line of reasoning, and also takes into account the record loss of Arctic sea ice this past September, then perhaps the likelihood of greenhouse warming playing a significant role in Sandy's evolution as an extra-tropical superstorm is at least as plausible as the idea that this storm was simply a freak of nature. And, the subsequent invasion of Arctic air that unleashed a fully developed nor'easter on the victims of Sandy only a few days later just makes the argument even less convincing that this series of unfortunate events was largely an act of nature.

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