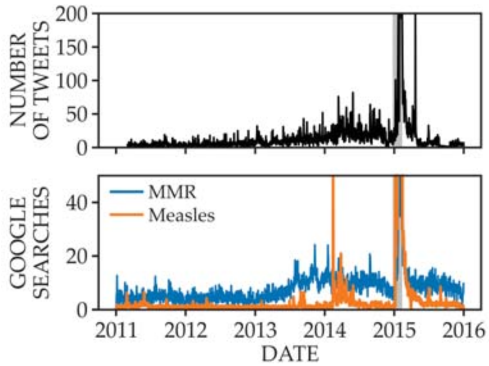
PHYSICS UPDATE

These items, with supplementary material, first appeared at www.physicstoday.org.

VACCINATION BEHAVIOR AS A CRITICAL PHENOMENON

The 2014–15 measles outbreak at Disneyland in California brought heightened attention to the decision by some people to refuse vaccination for themselves and their children. Such personal decisions play into the complex relationship between vaccination behavior and disease dynamics, which influence each other in a nonlinear feedback loop that also incorporates societal norms and perceived risks. Chris Bauch and his colleagues at the University of Waterloo, Dartmouth College, and École Polytechnique Fédérale de Lausanne have now analyzed Twitter and Google search data related to measles and the measles-mumps-rubella (MMR) vaccine before and after the outbreak. Treating trends in the social-media data as a proxy for trends in the evolution of people's attitudes toward vaccination, they find signs that the coupled vaccination–disease system was approaching a critical transition, a tipping point leading to a new dynamical regime—in this case an epidemic. The numbers of tweets and Google searches containing measles-related terms peaked sharply in early 2015, just after the outbreak began. For several years leading up to the outbreak, a period in which the vaccination rate was decreasing, the variations in the data from both platforms revealed so-called critical slowing down—a declining rate of recovery from small perturbations that is a signature of critical phenomena. In the wake of the outbreak, the vaccination rate increased and the system moved away from the tipping point, even before new requirements went into effect in California. The team's mathematical model qualitatively reproduces both trends. Since statistical indications of an approaching tipping point appeared well before it was evident in the raw time series, the researchers suggest that online social data can provide early warning signals of approaching outbreaks in vaccination and disease dynamics. (A. D. Pananos et al., *Proc. Natl. Acad. Sci. USA* **114**, 13762, 2017.) —RJF



GRAVITY HERALDED THE MIGHT OF THE 2011 JAPAN EARTHQUAKE

US AIR FORCE/TECH. SGT. DENORIS A. MICKLE

Ruptures in Earth's crust—earthquakes—generate elastic waves that travel through the crust and upper mantle at speeds of several kilometers per second. When observed at seismic stations, those waves provide information about the interior structure of the planet and the magnitude of the quake that generated them.

The earthquake's initial rupture and subsequent seismic waves redistribute mass and thus alter Earth's gravitational acceleration, or field. The change in the field, like an electromagnetic disturbance, propagates at the speed of light, and a seismometer feels it almost immediately. The perturbed gravitational field also induces small mass redistributions, which generate their own mini seismic waves that jiggle the ground at seismic stations before the arrival of the main elastic waves. The two tiny effects combine to give a seismometer reading of something like 1 nm/s^2 for the largest of earthquakes. If only its magnitude mattered, such a small gravitational effect would be swamped by the elastic waves generated at the epicenter, which show up as ground displacements five orders of magnitude greater. But thanks to their earlier arrival, the gravitational perturbations can, in principle, be registered by seismometers.

Now Martin Vallée (Institut de Physique du Globe de Paris) and his team have revisited the data taken by 11 seismic stations located 427–3044 km from the site of the 2011 Tohoku earthquake in Japan and have teased out the combined gravitational signal. Given that the quake had a magnitude of 9.1, the researchers' numerical modeling matched the observed data well. The researchers hope that, in the future, information carried by the gravitational signal can be inverted to give a prompt estimate of a large earthquake's magnitude. (M. Vallée et al., *Science* **358**, 1164, 2017.) —SKB

WHAT CAUSES MEGADROUGHTS?

The severe and prolonged drought that beset North America in the 12th century likely caused the collapse of the Ancestral Puebloan and some other civilizations on the continent. Given that no megadroughts of comparable magnitude have yet recurred, evaluating their likelihood is challenging as well as prudent. Rare events can arise either from purely statistical fluctuations or as the result of rare exogenous events, such as a prolonged yet transient uptick in solar activity. Toby Ault of Cornell University and his collaborators set out to determine the causes of megadroughts using a so-called linear inversion model (LIM), which presumes that a system's dynamics consist of a linear deterministic component and a nonlinear component of random fluctuations. Feeding the LIM with data yields the two components. Recent, well-sampled measurements of Earth's sea-surface temperatures and other climate variables can be used to investigate past climates—provided the underlying dynamics have remained the same. Indeed, Ault and his collaborators explicitly assumed that was the case. They found that their LIM could reproduce the 12th-century megadrought, but not the four other megadroughts that clustered in the preceding five centuries during the Medieval Climate Anomaly. The researchers conclude that the megadroughts were caused by external forcing or by a type of internal climate behavior that was quiescent in the recent past and therefore not manifested in the data fed to the LIM. (T. Ault et al., *J. Climate* **31**, 3, 2018.) —CD PT