Crisis in the Crescent

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>
> Colin P. Kelley
> The Center for Climate and Security

by Laura Naranjo

The Tigris and Euphrates Rivers tumble down the mountains of Turkey, crossing Syria and Iraq as they meander toward the Persian Gulf. Together, the rivers irrigate the Fertile Crescent, an arc of rich land that fostered Mesopotamian and Middle Eastern cultures. For thousands of years, through the rise and fall of civilizations, the Fertile Crescent flourished as an oasis of arable land amid bone-dry deserts.

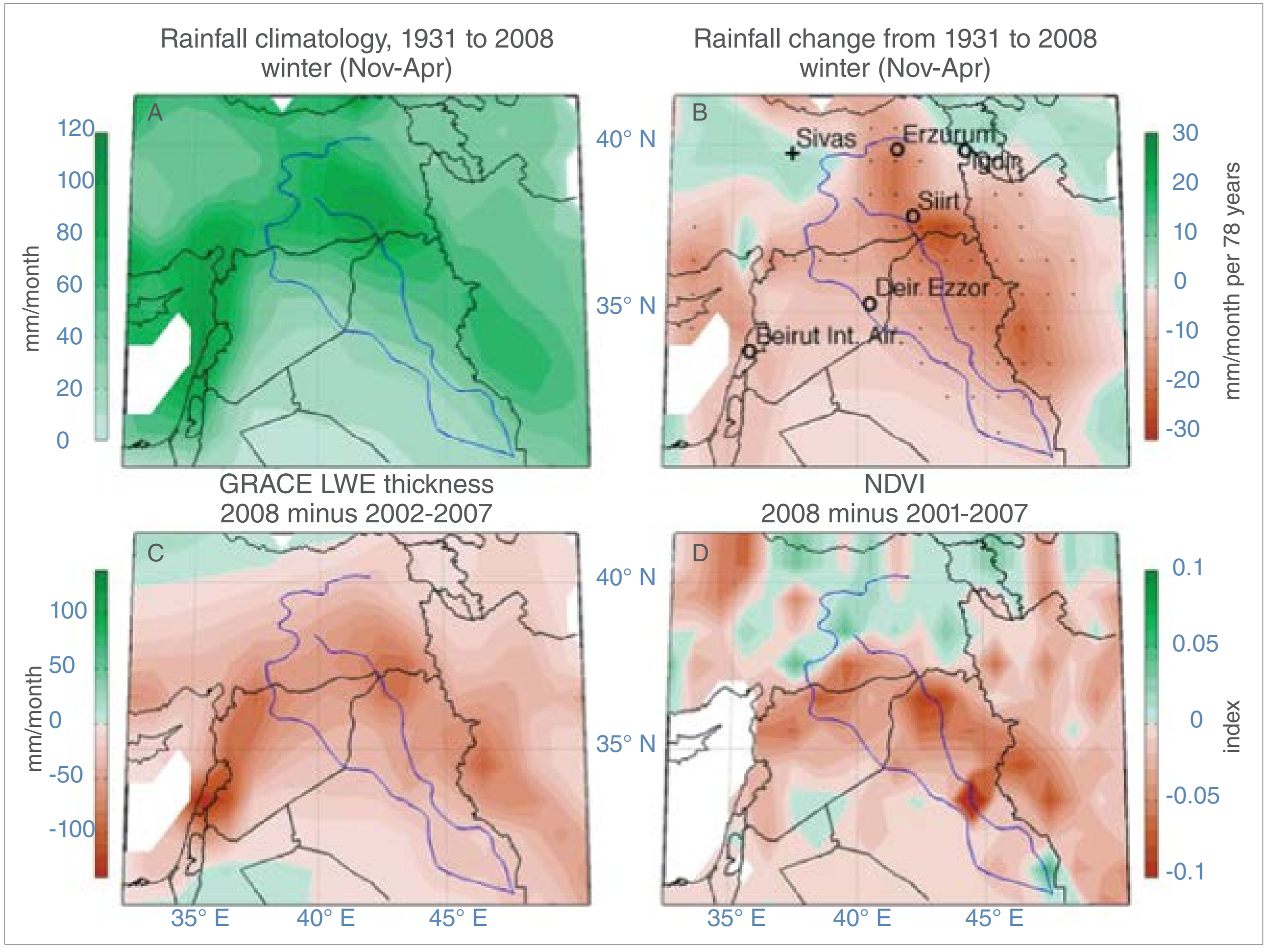
By the twentieth century, however, even this fertile region began to dry out. Much of the Middle East now struggles under the weight of political unrest, warfare, and population pressures that

A Bedouin shepherd tends his sheep amid a parched landscape in Syria. (Courtesy J. Werner) have stressed water supplies. At the same time, rising temperatures and persistent drying are transforming the region's story from one of richness and fertility to one of sand and dust. Could a concurrence of climate phases coupled with a long-term drought spell the end of the Fertile Crescent? Two scientists approach the problem from opposite directions, only to reach similar conclusions.

Dust and drought

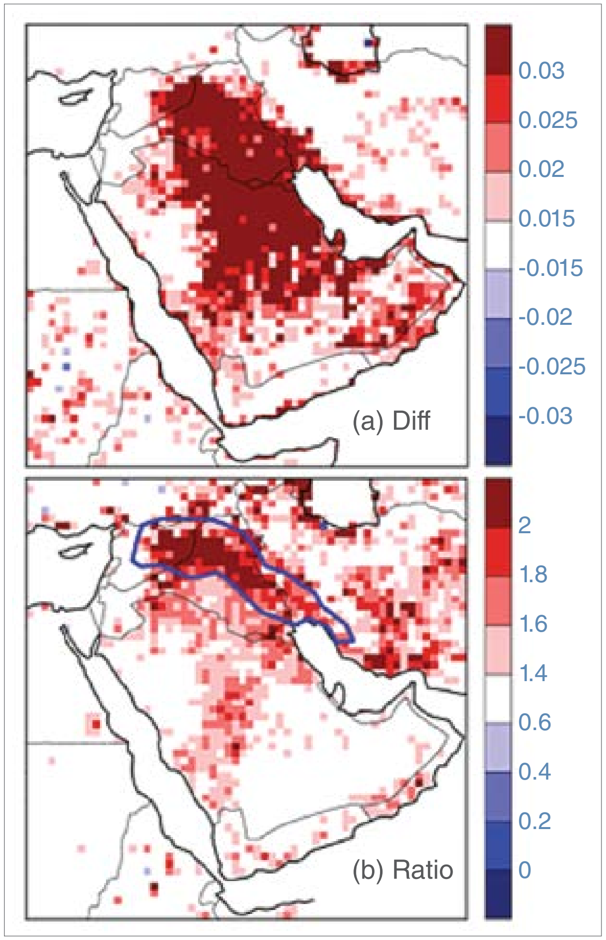
Climatologist Colin Kelley was studying rainfall across the Mediterranean when he spotted extensive drought in Syria, at the center of the Fertile Crescent. The drought started in the winter of 2006-2007 and lasted for three years, preceding the 2011 Syrian uprising. Kelley pivoted to study the Syrian drought. "We wanted to put the drought in context," he said. This drought followed several multi-year droughts in the 1980s and 1990s, so Kelley wondered if the most recent drought punctuated the drying trend, serving as a catalyst for the uprising.

Even as modernization swept across the Middle East during the twentieth century, agricultural villages and nomadic Bedouin herders relied on rivers and wells to irrigate crops and water herds of sheep and cattle. Between 2006 and 2009, these water sources dried up, forcing farmers and shepherds to abandon their land. In addition, military operations destabilized the Middle East, and by 2010, Syrian cities had absorbed more than one million Iraqi refugees—not insignificant, considering Syria's 2010 population was 21 million. "Population growth increases the demand for water," Kelley said. By the 2011 uprising, drought, national policies, and a swelling refugee population had crippled the agricultural economy in Syria.



The Fertile Crescent has been steadily drying since 1931, and recent changes have exacerbated the trend. Map A shows winter precipitation from 1931 to 2008. Map B shows winter rainfall change from 1931 to 2008. Map C shows a steep decline in groundwater between 2008 and the mean of the previous six years using data from the Gravity Recovery and Climate Experiment (GRACE) satellites. Map D shows a decline in vegetation between 2008 and the mean of the previous seven years using Normalized Difference Vegetation Index data from the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite instrument. (Courtesy C. P. Kelly, et al., 2015, *PNAS*)

Kelley and his colleagues searched for evidence among the data. Ground measurements of agricultural production were sparse, so Kelley and his colleagues looked at imagery from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on the NASA Aqua and Terra satellites. MODIS can measure the greenness of land surfaces, as a proxy for crops and vegetation. The data revealed a decrease in vegetation abundance during the most recent Syrian drought, beginning in 2006, which corresponded with skyrocketing prices for imported wheat and rice. But changes on the surface only told part of the story. In addition to irrigation, farmers rely



These plots show the ratio of change in dust activity across the Arabian Peninsula between 2008 and 2012, compared to the time period 2001 to 2005. The blue polygon shows the area of greatest vegetation decline. Data are from the Multi-angle Imaging Spectroradiometer (MISR) satellite instrument. (Courtesy M. Notaro, et al., 2015, *Journal of Geophysical Research: Atmospheres*)

heavily on groundwater. So Kelley also needed to know whether groundwater supplies had been depleted. Again, however, ground measurements were largely unavailable, so Kelley relied on data from the Gravity Recovery and Climate Experiment (GRACE) satellites, which can detect groundwater by measuring small gravity changes. "GRACE measures actual soil moisture as well as subsurface water, including underground aquifers," Kelley said. GRACE data showed a clear decline in both surface moisture and groundwater supplies.

In addition, historical climate data revealed an unrelenting rise in temperatures across the region, which further dried out the soil and increased evaporation. "When agriculture collapsed in Syria, there was a real dearth of cultivation," Kelley said. "So all of a sudden, there's a lot more soil that's exposed to the wind." And when the shamal winds sweep in, the deserts take flight.

Dust in the wind

Beginning around 2007, researchers at King Saud University in Saudi Arabia had noticed a distinct uptick in dust storms sweeping across the Arabian Peninsula. To understand the rise, they partnered with climatologist Michael Notaro, who studies vegetation and rain in the context of global climate processes. They hoped he could help them discover the dust's origin and improve the seasonal predictability of dust activity.

The Middle East is second to the Sahara Desert as a source of sand and dust. Dust storms are nothing new here, but they have become more frequent. In April 2015, a massive dust storm billowed across the Arabian Peninsula, turning bright blue skies an ominous orange. Clouds of sandy grit enveloped entire cities, snarling traffic. Flights to the United Arab Emirates and Qatar had to be diverted or delayed. Schools in Saudi Arabia's capital, Riyadh, cancelled classes. The storm was so large that it was clearly visible from space.

Notaro and his graduate student, Yan Yu, along with Olga Kalashnikova at the NASA Jet Propulsion Laboratory (JPL) dug into the problem. At first, they discovered that there was little existing research to build on, so they attacked the problem step by step. First, they analyzed observations from ground-based meteorological stations across Saudi Arabia dating back to the mid-1970s. These data revealed that the dusty season tended to run February through June, although dust storms could batter the peninsula well into August.

Next, in collaboration with JPL, they looked at atmospheric dust, available to form these towering storms, using remote sensing. They retrieved data from the Multi-angle Imaging Spectroradiometer (MISR) instrument on the NASA Terra satellite. MISR can distinguish dust—which typically consists of non-spherical particles—from spherical particles, such as water droplets and other chemical particles in the atmosphere. This helped the researchers coax out an intriguing trend. Consistent between the MISR data and station observations, they discovered anomalously high levels of dust in the atmosphere between 2007 and 2013—coinciding with the most recent drought across the Fertile Crescent.

What caused this change? Were shifting winds kicking up more dust from the same locations, or were newly desertified regions—perhaps those in Syria—adding dust? So the researchers compiled wind trajectories for all past recorded dust events, looking backwards in time to trace where the dust came from. "The Rub' al Khali Desert in the southern peninsula is a major dust source to the peninsula," Notaro said. In Arabic, Rub' al Khali means "empty quarter," an apt description for one of the world's largest deserts. But the Rub' al Khali was not the only source. "There were also some key remote sources of dust from outside of Saudi Arabia," Notaro said. Although the Sahara Desert to the west contributed dust, the wind trajectories and MISR data both pointed to the north, where the shamal winds—a northwesterly wind from the mountains of Turkey—blew down toward the Tigris and Euphrates River basins across Syria and Iraq. "We ended up with greater dust generation and transport when the northerly winds blew out of the Fertile Crescent to the Arabian Peninsula," Notaro said.

Once Notaro and his colleagues discovered when dust storms occurred across Saudi Arabia, and where the dust came from, they needed to understand why the storms had rapidly increased. Had something converted the Fertile Crescent into a dust bowl?

A larger climate shift

"Since 1931, the whole Fertile Crescent has been experiencing a drying trend," Notaro said. Over the course of his research, he had also analyzed MODIS vegetation data for the region, and had become familiar with Kelley's research. While Kelley zoomed in to investigate groundwater, Notaro zoomed out. He suspected larger-scale climate factors might have helped trigger the drought. In particular, Notaro looked at the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO), a similar but longer-term pattern that shifts between warm and cool phases over decades rather than years. When the cool phases of these related patterns are in sync, as occurred during the Fertile Crescent drought, they can amplify changes in precipitation and surface water that lead to drier conditions.

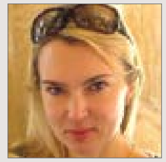
A massive sandstorm engulfs Riyadh, the capital of Saudi Arabia, on March 10, 2009. (Courtesy Associated Press)

In its positive phase, the PDO can bring more rainfall to the Mediterranean and Middle East. The Tigris and Euphrates Rivers, along with their tributaries, rely almost entirely on winter rainfall. In 2006, the PDO shifted to a negative phase, reducing rainfall across the Fertile Crescent. At about the same time, the ENSO cycle shifted from a wet El Niño phase to a drier La Niña phase. Notaro thinks synergy between the two states may have coincided with the most recent Syrian drought. “There’s a very clear regime shift around 2006,” he said. “When you have both La Niña and a negative PDO, they can reinforce each other.” Indeed, the winter of 2007-2008 proved to be the driest in Syrian climate records.

When the wind trajectory, vegetation, and climate data were compiled, Notaro concluded that the regime shift seemed to be associated not only with drought across the Fertile Crescent, but the increase in dust storms as well. Prior to the Syrian agricultural collapse, the highest levels of atmospheric dust were contained over the Rub’ al Khali Desert. Afterward, high levels of atmospheric dust extended across Syria, Iraq, and northern Saudi Arabia.

Drought, heat, population pressures, and civil unrest spread havoc across the Syrian countryside, driving farmers and shepherds to seek refuge in cities. Less agriculture led to more untended soil, and ultimately, more dust as surrounding deserts closed in. Kelley likened the situation to the 1930s Dust Bowl across the United States prairies. “Why that drought occurred and why this drought occurred is different,” Kelley said. “But what we’re seeing here is similar, so it’s possible that these mega dust storms that occurred in the U.S. during the Dust Bowl may be what we’re starting to see here.”

About the scientists



Olga Kalashnikova is a research scientist at the NASA Jet Propulsion Laboratory (JPL). She uses remote sensing to study aerosol optical properties and is a member of the Multi-angle Imaging Spectroradiometer (MISR) science team. The University of Wisconsin-Madison Climate, People, and Environment Program supported her research. Read more at https://goo.gl/7SNNtJ. (Photograph courtesy O. Kalashnikova)

Colin P. Kelley is a senior research fellow at the Center for Climate and Security. His research focuses on climate variability and change, particularly drought, in semiarid and arid regions that are especially vulnerable. The Office of Naval Research, the National Oceanic and Atmospheric Administration, and the Department of Energy supported his research. Read more at https://goo.gl/X69lsc. (Photograph courtesy C. P. Kelley)

Michael Notaro is the associate director and senior scientist for the Nelson Institute Center for Climatic Research at the University of Wisconsin-Madison. He studies land-ocean-atmosphere interactions, climate change impacts on ecosystems, monsoon dynamics, and dust storm mechanisms. The University of Wisconsin-Madison Climate, People, and Environment Program supported his research. Read more at https://goo.gl/Z8ofxG. (Photograph courtesy D. M. Zimmerman)

Natural variations, such as a swing back to wetter phases of PDO and ENSO patterns, may temporarily relieve drought conditions in Syria and reduce dust storms plaguing the Arabian Peninsula. Long-term climate models, however, indicate temperatures in the region will continue to rise, in response to rising levels of greenhouse gases, and the hot, dry trend will continue. Notaro said, “This is all one big story, connecting drought, land use, agriculture, politics, and climate change.”

To access this article online, please visit https://earthdata.nasa.gov/sensing-our-planet/crisis-in-the-crescent.

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About the remote sensing data

Satellites	Terra	Terra and Aqua	Terra and Aqua	Gravity Recovery and Climate Experiment (GRACE)
Sensors	Multi-angle Imaging Spectroradiometer (MISR)	Moderate Resolution Imaging Spectroradiometer (MODIS)	MODIS	K-Band Ranging System
Data sets	MISR Component Global Aerosol Product	MODIS Aerosol Product (MOD04_L2 and MYD04_L2)	MODIS Vegetation Indices Monthly L3 Global 0.05Deg CMG (MOD13C2)	RL05.DSTvSCS1409 GRACE Tellus Monthly Mass Grids – Land
Resolution	0.5 degree x 0.5 degree grid	10 x 10 1-kilometer pixel array	0.05 degree (5600-meter)	4,000 x 4,000 kilometer
Parameters	Aerosol optical depth	Aerosol optical depth	Vegetation	Gravity
DAACs	NASA Atmospheric Science Data Center Distributed Active Archive Center (ASDC DAAC)	NASA MODIS Level 1 and Atmosphere Archive and Distribution System DAAC (MODAPS LAADS DAAC)	NASA Land Processes DAAC (LP DAAC)	NASA Physical Oceanography DAAC (PO.DAAC)

and Science (EROS) Center, Sioux Falls, SD (https://lpdaac.usgs.gov), at https://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table/mod13c2.

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About the data

Platforms	Temperature, sea level, and pressure stations	
Data sets	Global Historical Climatology Network, 1753-1990	NASA Modern Era Retrospective-Analysis for Research and Applications (MERRA)
Resolution		0.5 degree x 0.66 degree grid
Parameters	Temperature, precipitation, sea level pressure, and station pressure	850 hPa v-wind, humidity and 500 hPa vertical motion
DAACs	NASA Oak Ridge National Laboratory DAAC (ORNL DAAC)	NASA Goddard Earth Sciences DAAC (GES DAAC)

For more information

NASA Atmospheric Science Data Center Distributed Active Archive Center DAAC (ASDC DAAC)
https://eosweb.larc.nasa.gov

NASA Goddard Earth Sciences DAAC (GES DAAC)
http://daac.gsfc.nasa.gov

NASA Land Processes DAAC (LP DAAC)
http://lpdaac.usgs.gov

NASA MODIS Level 1 and Atmosphere Archive and Distribution System DAAC (MODAPS LAADS DAAC)
http://laadsweb.nascom.nasa.gov

NASA Oak Ridge National Laboratory DAAC (ORNL DAAC)
https://daac.ornl.gov

NASA Physical Oceanography DAAC (PO.DAAC)
http://podaac.jpl.nasa.gov

NASA Gravity Recovery and Climate Experiment (GRACE)
https://www.nasa.gov/mission_pages/Grace

NASA Multi-angle Imaging Spectroradiometer (MISR)
http://terra.nasa.gov/about/terra-instruments/misr

NASA Moderate Resolution Imaging Spectroradiometer (MODIS)
http://modis.gsfc.nasa.gov

Global Historical Climatology Network (GHCN)
http://daac.ornl.gov/CLIMATE/guides/CDIAC_NDP41.html

NASA Modern-Era Retrospective Analysis for Research and Applications (MERRA)
http://gmao.gsfc.nasa.gov/merra