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Does meth flow

Scientists are eager to prove that the meandering river valleys and braided streambeds seen on Saturn's largest moon carry liquid methane to its vast lakes.

by Robert Zimmerman

The Huygens probe captured this 360° panorama of Titan's surface from an altitude of 6 miles (10 kilometers) as it descended through the saturnian moon's atmosphere January 14, 2005. Dark drainage channels in the brighter highland terrain appear to feed into a darker region that scientists suspect could be a lakebed.
ESA/NASA/JPL/UNIVERSITY OF ARIZONA

Nine years ago, Europe's Huygens probe dropped through the atmosphere of Saturn's moon Titan and landed on the surface. Planetary scientists reacted with unbridled joy to the mission's success.

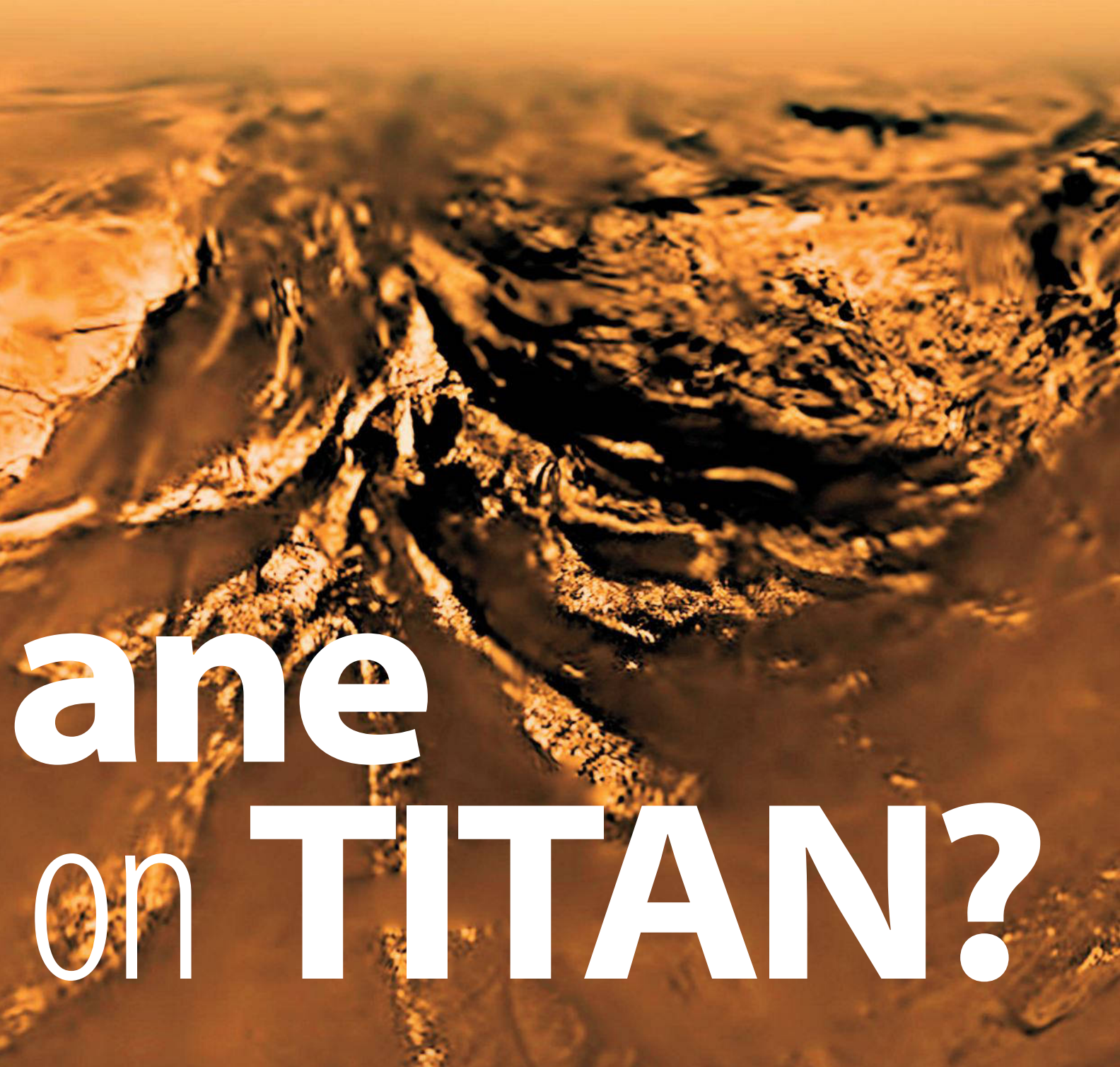
"I have to say I was blown away by what I saw," said David Southwood, then director of science programs for the European Space Agency (ESA) and now president of the Royal Astronomical Society.

"The scientific data that we are collecting now shall unveil the secrets of this new world," raved Jean-Jacques Dordain, ESA's director general.

"I'm shocked! It's remarkable!" enthused Carolyn Porco, leader of the imaging team for NASA's Cassini spacecraft, which delivered Huygens to Titan and continues to orbit Saturn.

Porco then proceeded to describe what all these scientists had found so astonishing: "There are river channels. There are channels cut by something … a fluid of some sort is my best guess."

For almost three decades before Huygens' triumph, planetary scientists had



ane on TITAN?

theorized that methane might be able to flow on Titan like water does on Earth. Once they got close enough to get a good look, the thinking went, probes might detect methane rainstorms feeding rivers, lakes, and even oceans on that cold and distant moon, the second largest in the solar system.

And that is exactly what Huygens apparently had found in January 2005 in practically its first images: meandering river channels flowing into what looked like a large lake. For these researchers, it was almost too good to believe.

Now, nearly a decade later, planetary scientists remain as excited and baffled by Titan as they did before Huygens arrived. In the years since, the Cassini spacecraft repeatedly has flown past this giant moon, detecting what look like numerous additional phenomena that resemble things we find on Earth — large rainstorms, river channels, and lakes all produced not by water but by liquid methane.

It is as if Titan is a frozen and dark twin of Earth, similar in many ways yet also completely and weirdly alien.

Before the two probes

Dutch astronomer Christiaan Huygens discovered Titan in 1655. For centuries, scientists thought this moon was the solar system's largest. In the mid-20th century, however, observations revealed that the moon has a thick atmosphere,

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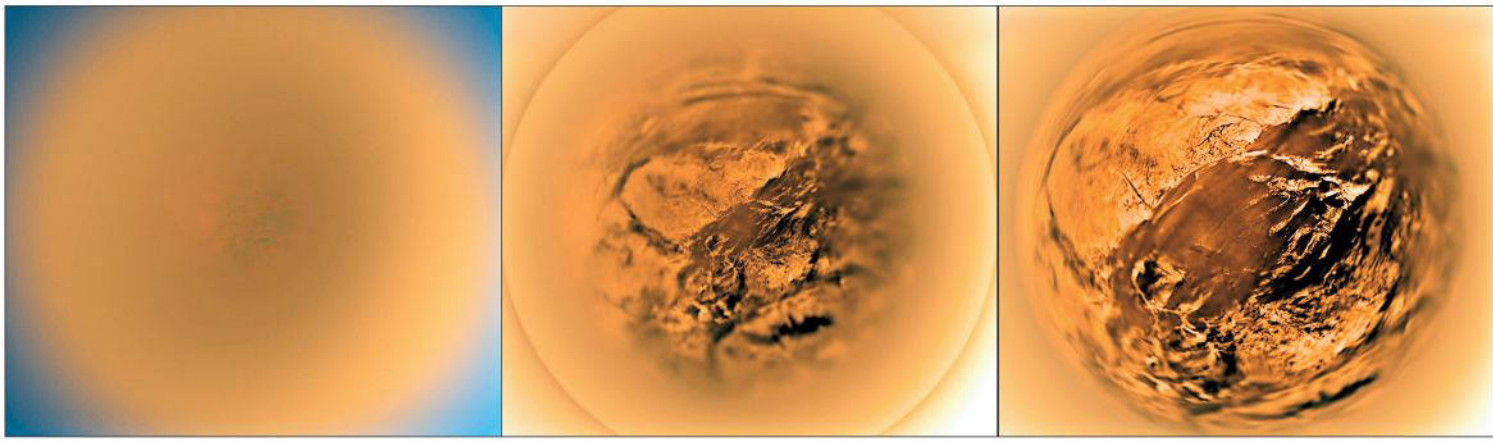


Huygens took this series of images as it neared Titan's surface January 14, 2005. From left to right, the probe captured the moon from altitudes of 95 miles (150 kilometers),

and its presumed large size was in part an illusion caused by that atmosphere. Jupiter's moon Ganymede, which has a diameter of 3,270 miles (5,262 kilometers), ranks as the solar system's biggest moon.

Still, with a diameter of 3,200 miles (5,150km), Titan is larger than Mercury. If it were in an independent orbit around the Sun, scientists would consider it a planet.

By the 1970s, just before the twin Voyager spacecraft flew past Saturn, scientists were still unsure what made up Titan's thick atmosphere. Some believed methane was the major component while others argued that nitrogen reigned supreme. A handful of scientists even proposed that conditions on Titan might allow oceans of liquid methane to exist, but few listened to this wild idea.

Then in November 1980, Voyager 1 zipped just 4,033 miles (6,490km) above the moon's surface. Images revealed a featureless orange ball, the surface shrouded by a smog-filled atmosphere 125 miles (200km) thick with an additional haze layer that varies in altitude between roughly 240 and 310 miles (380 and 500km). The atmosphere itself turns out to be about 95 percent nitrogen with methane making up most of the rest. The surface temperature hovers at a bone-chilling –290° Fahrenheit (–178° Celsius) while the surface pressure measures 50 percent higher than on Earth.

The Voyager measurements showed that conditions on Titan were perfect for the existence of both liquid methane and ethane. It even seemed possible that these molecules could mimic the evaporation cycle of water on Earth, which might result in methane storms that produce methane rain falling into methane rivers that flow across the moon's surface into methane lakes.

This close-up view of the south polar vortex shows the swirling atmospheric feature from a distance of 301,000 miles (484,000 kilometers). Taken June 27, 2012, the true-color image shows the moon's south pole as winter approaches. NASA/JPL-CALTECH/SSI

Titan's south polar vortex appears at the bottom of this true-color Cassini image. The spacecraft took the photo July 25, 2012, from a distance of about 64,000 miles (103,000 kilometers). NASA/JPL-CALTECH/SSI

Until the arrival of Cassini and Huygens, however, these possibilities remained mere hypotheses. Although planetary scientists knew that liquid methane could exist on Titan's surface, no one had seen it.

Alien planet

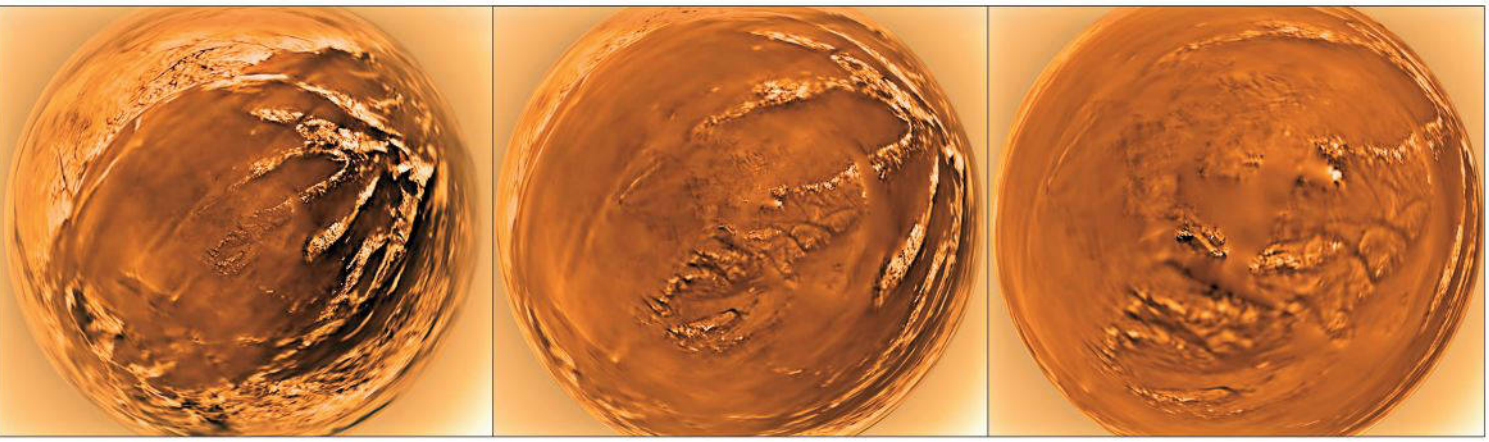
Then Huygens descended through Titan's atmosphere and landed on what appeared to be a dry lakebed. On its way down, the probe snapped some amazing pictures of what looked like ordinary meandering rivers draining into a dark area that appeared just like a lake.

Huygens photographed two different riverlike complexes. The more exciting image showed what seemed to be a river with many branches merging to form a single large channel that emptied into a lake. The channels themselves meandered back and forth like rivers do on Earth.

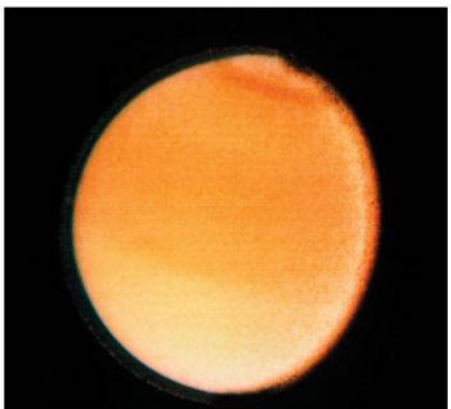
In the second image, the main channel appeared as straight as an arrow, with its tributaries joining it at sharp right angles. It seemed almost as if the flowing liquid, rather than meandering, was following natural cracks in the geology as it surged downhill to the lake.

Since the Huygens' mission, the Cassini orbiter has flown past Titan nearly 100 times. It has snapped visible-light, infrared, and radar images that cover more than 50 percent of the moon's surface.

The three key instruments used during these flybys have been the Imaging Science Subsystem (ISS), the Visual and Infrared Mapping Spectrometer (VIMS), and, most importantly, the Cassini Radar Mapper. The first two instruments take relatively low-resolution images and spectra (which break the light down into its component colors, or wavelengths) from the near ultraviolet to the infrared. Titan's thick hazy atmosphere limits the value of these tools



12 miles (20km), 4 miles (6km), 1.2 miles (2km), 0.4 mile (0.6km), and 0.12 mile (0.2km). ESA/NASA/JPL/UNIVERSITY OF ARIZONA



Voyager 2 captured Titan from 1.4 million miles (2.3 million kilometers) away as it flew past in August 1981. Unfortunately, the filters used on Voyager's camera could not penetrate the hazy atmosphere to show any surface detail. NASA/JPL

for mapping surface details. The radar mapper, however, can penetrate the haze and see objects as small as about 1,150 feet (350 meters) in diameter.

What these observations have shown scientists is that Titan is an alien environment that mimics Earth only in the most superficial ways. For example, the moon's crust is made of water ice, which is as solid as granite at the frigid surface temperature. Moreover, liquid methane does not dissolve water, so the methane flows over this frozen water without eroding it much. The ice acts like bedrock.

Yet geologists know that flowing water on Earth erodes bedrock — it just takes a long time. Similarly, as liquid methane flows downhill across Titan's bedrock, it slowly erodes the rock-hard ice and picks up small pebbles, transporting it all downstream as sediment. In the process, the methane has carved a variety of Earth-like valleys, channels, and canyons.

A lake by any other name

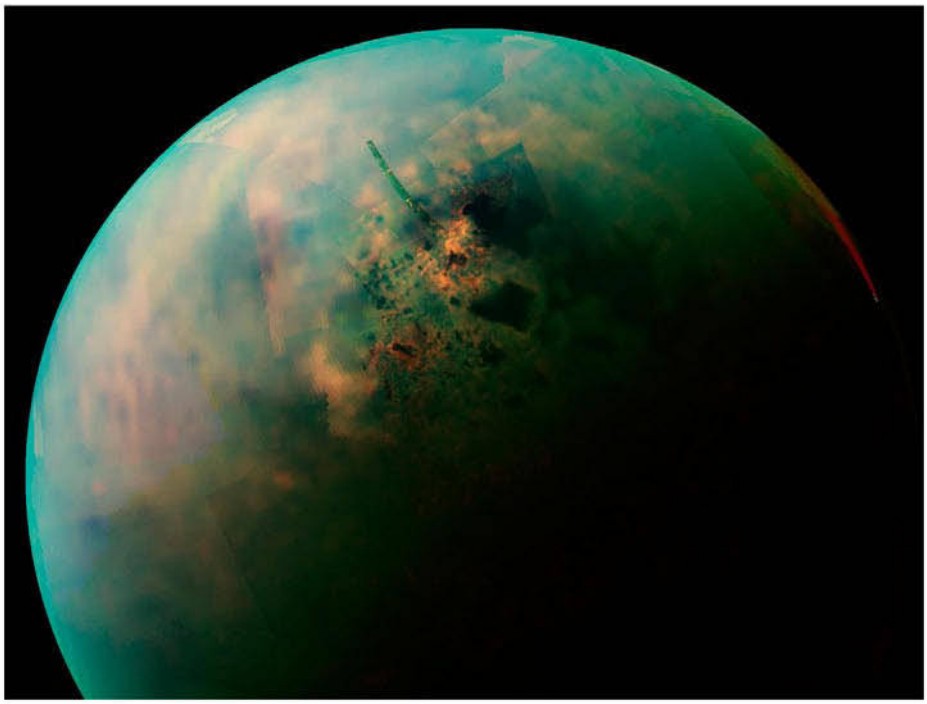
This is just one of Titan's strange parallels with Earth. Cassini observations also have revealed hundreds of dark patches on the moon's surface that scientists interpret as lakes. Some of them appear filled with liquid while others seem to have dried up partially. Sinuous channels lead into some of them, but others look like lakes that have filled ancient impact craters or calderas — depressions at volcanoes' centers created when their magma chambers empty and the overlying surfaces collapse.

In one case, Cassini images show that the southwestern shoreline of Ontario Lacus — at 146 miles (235km) across, the largest lake known in Titan's southern hemisphere — retreated by several miles (10km) between 2005 and 2009. This suggests that the lake is drying up slowly. In another instance, repeated observations of one area showed what looked like several new lakes forming shortly after a storm burst. Radar images taken several years later showed that these dark patches had disappeared, once again implying that they had dried up.

Figuring out the exact nature of these geological features remains a difficult challenge, however. Looking at an image produced by radar is not the same as looking at an ordinary photograph. With radar, the brightness of the reflection correlates with the roughness of the surface. Thus, the smooth surface of a Titan lake looks dark in radar images, while bright areas usually suggest rough hilly terrain.

The problem is that the data don't always follow this pattern. For example, a large number of the detected river valleys and lakes appear bright compared to the surrounding terrain. Scientists think that the radar brightness in such images suggests a generally dry riverbed or lakebed filled with gravel, cobble, and rocks typically

The only image taken from Titan's surface shows the dry riverbed the Huygens probe landed in. The foreground rocks measure some 6 inches (15 centimeters) across while those in the distance are roughly 3 feet (1 meter) in diameter. Huygens took this photo January 14, 2005. ESA/NASA/JPL/UNIVERSITY OF ARIZONA



Cassini's Visible and Infrared Mapping Spectrometer took this infrared view of Titan on September 12, 2013. Green represents the water-ice bedrock that covers most of the moon. Orange reveals areas where liquid methane likely evaporated, similar to salt flats on Earth. NASA/JPL-CALTECH/UNIVERSITY OF ARIZONA/UNIVERSITY OF IDAHO

bigger than an inch (a couple of centimeters) across. In this scenario, methane flows only in narrow braided streams that wind and intertwine through different parts of the wider cobble-filled valley, similar to the dry washes seen in the American Southwest.

"A desert wash is a very good analogy," says planetary scientist Devon Burr of the University of Tennessee, Knoxville. "They have wonderful rounded stones that are transported during summer monsoons, but most of the time they are dry or the flows are confined to the lowest parts of the wash."

As for the dark meandering river valleys, researchers have devised several theories. One idea is that they are deeply incised bedrock channels, which look dark in radar images because the valleys' steep walls shadow the signal.

A second possibility is that the eroded sediment in the riverbed possesses a much finer, sandlike consistency. The dry riverbed thus has a smooth beachlike surface made up of a dry soft snow — sediment laid down by a methane river that flows intermittently.

Finally, it is even possible that the dark channels are dark because they, like the lakes, are filled with liquid methane. Unfortunately, the observations cannot yet tell scientists which of these possibilities might be true.

The mere existence of the meandering channels poses an even more perplexing puzzle. On Earth, plants help hold the banks of a meandering river in place. There are no plants — and no life that we know of — on Titan, so the presence of meandering river valleys requires some other, as yet unknown mechanism to keep the shoreline stable for long periods.

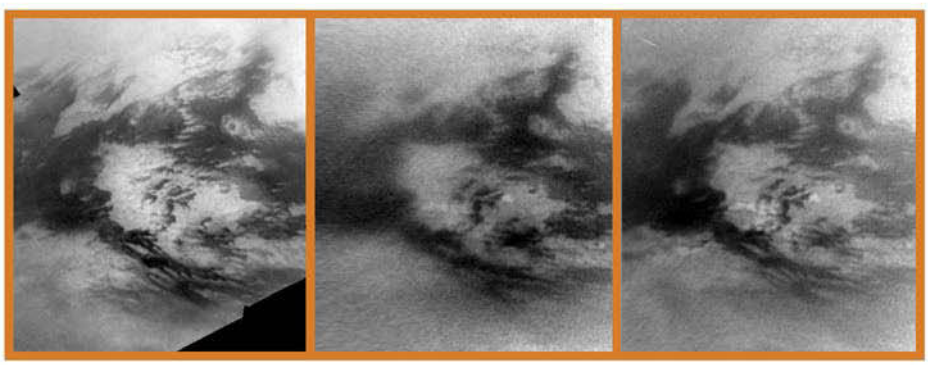
Rain and floods

To create Titan's river channels and fluctuating lakes requires rainfall. Although scientists think the moon's methane cycle of evaporation, precipitation, and runoff mimics the water cycle on Earth, most of the details — how much rain falls how often and where — remain uncertain.

"Because Titan is so far away from the Sun and doesn't get as much energy as Earth, there isn't as much rainfall or precipitation," explains Burr. "When it does occur, however, it has been storing itself up for a long time and therefore can be very energetic."

Based on Cassini and Huygens data, scientists estimate that the heaviest thunderstorms on Titan can drop as much as 100 inches (250cm) of methane in only two hours. Compare that with the largest Earth storm on record, which dumped 12 inches (30.5cm) of water in one hour.

Once again, the analogy of the dry washes and flash floods of the American Southwest come to mind, though the ones on Titan occur on a much more violent



Methane rain falls from Titan's clouds, producing the changes seen here. The left image shows an area near the moon's equator May 13, 2007, while the other two were taken 15 hours apart January 15, 2011. The bright points in the latter two appear to be low clouds above where rain fell recently. NASA/JPL/SSI

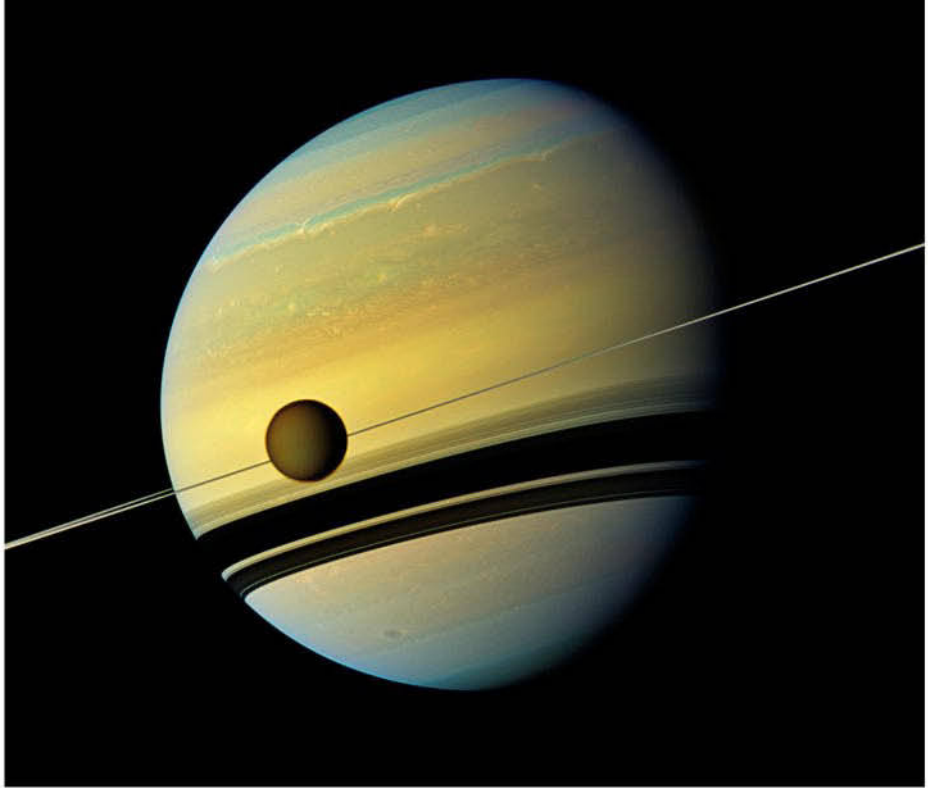
On April 10, 2007, Cassini's radar mapper took this swath that spans more than 4,100 miles (6,700 kilometers). Dunelike features appear near the left edge, but the terrain changes as the view moves northward (to the right) to reveal several large lakes. NASA/JPL-CALTECH/ASI

scale. Such megastorms would produce horrendous flash floods that could easily carve out the many meandering channels and canyons that Cassini and Huygens have detected.

These are extremes. Cassini observations indicate that methane rain on Titan also can occur in a gentle steady drizzle.

It remains unclear how frequently and with what strength these rainstorms occur. So far, most of the observed storms that have taken place have been in the high latitudes of the southern hemisphere, which experienced more direct sunlight during Cassini's first several years in orbit. Some clouds built and disappeared in as little as two hours.

Spring arrived in Titan's northern hemisphere in 2009. Scientists expect that as sunlight grows stronger in the north, the rainstorms will migrate there as well. But the changes will come slowly because each of the moon's four seasons lasts a bit more than seven years.



Titan appears silhouetted against Saturn's edge-on rings and massive atmosphere in this true-color image taken May 6, 2012. Cassini's Imaging Science Subsystem wide-angle camera captured this view from a distance of 483,000 miles (778,000 kilometers) from Titan. NASA/JPL-CALTECH/SSI

Fuzzy vision

Unfortunately, the reality of Titan's rivers remains uncertain. The chief problem is the haze-choked atmosphere and the resulting lack of resolution. Without sharp optical images of the surface, scientists must depend on the radar data. And although radar provides better resolution, it leaves many questions unanswered.

The only high-resolution images of Titan's surface scientists can study are those sent back by Huygens during its descent and landing. As the probe parachuted through the thick atmosphere, it took images that revealed objects as small as 65 feet (20m) across. Once on the ground, Huygens took a single image that showed a cobble-strewn flat plain fading away into the distance with rocks and pebbles ranging from 0.1 inch (2.5 millimeters) to about 6 inches (15cm) across.

Thus, except for this handful of Huygens images, all the so-called river networks identified on Titan's surface to date are not rivers but wide valleys. If rivers of methane actually run down these meandering valleys, scientists have not yet been able to see them.

Moreover, the lack of crisp resolution means that many of Titan's most important surface details remain either unseen or undetermined. For example, it is difficult from radar measurements alone to determine the downstream direction for many of these valleys. In some cases, the valleys wind from a bright area thought to be mountainous to a dark area thought to be a dry or wet lakebed. Although the radar instrument includes an altimeter to measure elevations, the observations typically don't resolve features as small as the valleys.

As often is the case, the way to resolve these questions is to go back to Titan with better equipment. Planetary scientists have proposed several missions to accomplish this: an orbiter to circle the moon, a hot air balloon designed to float through Titan's atmosphere for years, and a boat that would land in one of Titan's lakes and remain afloat to gather data for up to 30 days.

Although budget cuts at NASA have slashed the agency's planetary program for the next decade, they have not prevented any of these missions from getting underway. Instead, planetary scientists decided that the technology for many of these missions was simply not ready, so they chose not to include them in their recommendations to NASA in 2011. The researchers asked for the engineering design work to continue but wanted to defer mission funding until the following decade.

In 2017, the Cassini mission will end. NASA will send the spacecraft into Saturn's atmosphere, where it will collect its last data before the growing pressure crushes it.

Once that happens, scientists will have no probe available to study Titan's surface. It will then be years, and probably decades, before another spacecraft returns. Until then, the meandering rivers of Titan shall remain veiled beneath the moon's hazy atmosphere, unmapped and unseen by human eyes.

A+ TO SEE A MOVIE OF HUYGENS' DESCENT AND LANDING, VISIT **www.Astronomy.com/toc.**