Determining the Atmospheric Wind Patterns and Cloud Development of Titan

Jenny Nguyen-Ly¹, Tersi Arias-Young¹, Jonathan Mitchell²

¹Department of Atmospheric and Oceanic Sciences, University of California, Los Angeles, Maths Science Building, 520 Portola Plaza, Los Angeles, CA 90095

²Department of Earth, Planetary, and Space Sciences, University of California, Los Angeles, Geology Building, 595 Charles Young Dr, East, Los Angeles, CA 90095

Abstract:

The general public does not think much when they see clouds in the sky. While clouds are a constant part of the everyday life on Earth, they are also a continual phenomenon found on multiple planets and moons beyond Earth. Clouds are simply an endless source of knowledge in regards to their surroundings. Just their shapes, sizes, and movements alone hold more details than one can possibly imagine. They are a tell-tale sign of what is inside the atmosphere for a planet and its climate and weather. When clouds change in number, form, or location, this is an indication of something happening in terms of climate. This is a basis for research on the clouds of Titan, a moon orbiting around Saturn. Learning about the movement of clouds on Titan gives scientists more insight into this moon, and ultimately an improved understanding of the solar system. Moreover, knowledge about the cloud development and trends on Titan could be applied to our own understanding of our planet’s atmosphere too. To accomplish such a task, a comprehensive analysis of the online NASA Planetary Data Systems (PDS) Image Atlas Archive is needed. The Cassini-Huygens mission’s recorded images of Titan lie in this archive. However, the Cassini spacecraft travels throughout the entirety of the Saturnian system, so images include not just Titan, but both Saturn and many of its moons. By looking through this archive and then
narrowing down the images that hold relevance to this research, one can then analyze the data for Titan’s atmospheric wind patterns and waves that promote cloud development. This research, conducted at the University of California, Los Angeles, focuses in finding cloud formations and trends on Titan from the beginning of the Cassini-Huygens mission and then continue onwards for the next decade of its mission. The data collected will provide insight into what the atmosphere on Titan has been like for ten years; Titan’s cloud analysis will further tell what climate and weather trends has been like and even more excitingly, what might be in store for its future. In the end, a lot of potential unearthing of information is waiting in those clouds on Titan.

**Introduction:**

Saturn is commonly known as the planet in this solar system that is the sixth farthest planet away from the sun. Moreover, the Saturnian system has a vast amount of moons. Officially, there are 53 named moons that orbit around Saturn, but there are also currently 9 provisional moons as well. Titan, the center of attention for this research, is one of those official 53 moons, and it is also the largest.¹

Titan was first discovered by Christiaan Huygens, a Dutch scientist, on March 25, 1655. Nothing from man was sent even near it until the 1980’s, but Titan has sparked interest long before satellites were being sent into the far corners of the solar system. In 1944 for instance, Gerard Kuiper in the United States first presented concrete proof of Titan and its atmosphere by looking at Titan’s spectral signatures. For a majority of the next few decades, scientists after Kuiper who researched on Titan had experienced difficulties in discovering more about the infamous moon. However, they did collectively conclude that Titan’s atmosphere was extremely

¹ Data was found on the website [http://solarsystem.nasa.gov/planets/saturn/moons](http://solarsystem.nasa.gov/planets/saturn/moons).
interesting for having aerosols, containing methane, and being unusually thick.\textsuperscript{2} What greatly helped scientists learn more about Titan was the arrival of the 1980’s and with this decade, the Voyager missions.

In 1979, Pioneer 11 was the first spacecraft to make a fly-by near Titan. It failed to collect any worthwhile information about Titan due to its basic instruments. Pioneer 11 did, on the other hand, confirm a path future spacecrafts could take to reach the Saturnian system. Voyager 1 visited the system in November 1980; Voyager 2 visited in August 1981. Voyager’s information on Titan only fueled more interest in Titan. Thus, when the Cassini-Huygens was later created, one of the Cassini-Huygen’s purpose was to collect more information on Saturn and to include a Titan lander.\textsuperscript{3}

The information used in this research heavily relies on images collected by the Cassini-Huygens mission, so providing a little background on Cassini-Huygens seems appropriate. On October 5, 1997, Cassini-Huygens left Earth and began its space journey. It reached its goal in getting to the Saturnian system in 2004. Moreover, this spacecraft has a 3-axis stabilization schematic and is powered by three Radioisotope Thermoelectric Generators (RTGs). Cassini-Huygens is comprised of two main parts. There is the Cassini orbiter with 12 instruments on it; the other part is the Huygens probe with 6 instruments on it. These instruments can be further categorized into two sections. Some instruments do remote sensing, meaning that they are capable of collecting data far away from the instruments; remote sensing can be further classified as either optical (which would employ electromagnetic spectrum analysis) or microwave (which would employ radio wave analysis). Finally, the other instruments are “field,

\textsuperscript{2} Data was incorporated from\textit{ Titan: Exploring an Earthlike World}.
\textsuperscript{3} Further data here was provided again by\textit{ Titan: Exploring an Earthlike World}.\textsuperscript{3}
particles, and waves” and this translates to finding measurements that are on site or close to the instruments. In the end, all of these instruments were created in the hopes of completing 27 investigations in the Saturnian system.  

It is worth noting that the Huygens probe was launched and separated from the Cassini orbiter on December 24, 2004 and it landed on Titan on January 14, 2005. The probe successfully recorded many measurements on Titan’s atmosphere and the data was received by radio telescopes on Earth. A final critical aspect of the Cassini-Huygens mission worth noting is the Imaging Science Subsystem (ISS). ISS has both a wide-angle and a narrow-angle camera that captures images of Titan along with multiple filters. In conclusion, scientists hope that it will serve its purpose in finding information about Titan’s atmosphere and terrain, whether it be Titan’s aerosols, clouds, or geology.

On another note, the most important matter of this project is Titan’s atmosphere. The spotlight on Titan is primarily focused on its thick atmosphere since it shares the most similarities out of many moons and planets to Earth’s atmosphere. Titan also has an infamous haze, which is an orange photochemical smog in a dense atmosphere that problematically makes it difficult to see clouds and the surface. The atmosphere is 95% nitrogen and 5% methane, but the source of methane is remarkably still debated and unknown to this day. Because methane is normally fragmented by sunshine, scientists wonder where more methane could be produced and some experts suspect that Titan’s methane is due to cryovolcanism. When methane and nitrogen in Titan’s atmosphere gets broken down, they make organic molecules; scientists are fascinated by those organic molecules since it draws resemblances to Earth’s atmosphere.

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4 Data here was supplied from http://saturn.jpl.nasa.gov/spacecraft/overview/.
5 Dates were provided by http://saturn.jpl.nasa.gov/mission/quickfacts/.
6 Data here can be found in Titan: Exploring an Earthlike World.
It is worthwhile to note that time passes slower on Titan in some sense. A Titanic day (its orbital period) is roughly 16 Earth days, and Saturn’s orbit around the sun is 29 years. Seasons along with their implications on the climate are about seven and a half years on Earth. In addition, the seasonal changes are known to affect liquid methane and ethane on Titan. Also noteworthy is the sheer fact that Titan has liquid methane and ethane on its surface, and Titan has an extremely cold atmosphere. Temperatures have been known to average at -290°F. Lastly, the aerosols, clouds, and rain on Titan are believed to be made of methane. Therefore, a sufficient background on Titan and the Cassini-Huygens mission has been provided.

Methods:

All methods conducted for this research project are computer based. So, a basic outline of what is done for each cloud image will be described as opposed to individual accounts of every cloud image used during the project. Recall that the point of the research project is to find atmospheric wind patterns and waves promoting cloud development and by extension, summarize the ISS image archive of Titan images with a temporal plot to see long term trends in cloud formation that are not found easily when looking at single images.

The initial step is to acquire data for analysis, which is what most of the time spent was used for. To do this, cloud image data was collected from the online Planetary Image Atlas (PDS), from the Cassini-Huygens mission’s database. The PDS Archive has NASA’s archive containing the Cassini-Huygens mission’s image data. Images date back from 2004 and are continually uploaded on the NASA website to conclude images as late as 2015.

After downloading the images on the student’s account at UCLA’s Atmospheric & Oceanic Sciences data cloud storage, it is necessary to implement applications to prepare the
image data for analysis. The PDS Imaging Node supports a digital software package called ISIS3, the Integrated Software for Imagers & Spectrometers package from the U.S. Geological Survey/Astrogeology Research Program site, the ISIS3 technology is known for its abilities to manipulate past NASA planetary missions’ imagery. ISIS3 can therefore process images from the Cassini mission for viewing and editing purposes on DS9, an astronomical imaging and data visualization application that allows further in depth viewing of the images.7

Image reduction of a Titan cloud involves multiple steps in order to isolate the image from all of the data obtained from the PDS Image Atlas Archive. When raw data containing Titan clouds is first taken from the online NASA PDS Image Atlas Archive, it is downloaded as a “wget-file.” Opening the “wget-file” will produce an “.IMG” and a “LBL” file. The ISIS3 applications used to prepare Titan cloud image data for analysis are called ciss2isis, spiceinit, ciscal, cam2map, and isis2fits.8 Ciss2isis imports raw data from PDS Cassini image data into ISIS cube. This would convert the “LBL” file into a “cub” file. Spiceinit takes Spacecraft & Planetary ephemeredes, Instrument C-matrix and Event kernels (SPICE) data from image after ciss2isis application and then looks for necessary kernels to make the ISIS cube. The “cub” file remains otherwise unchanged for the next step. In the cisscal application, Cassini images are put through this application for radiometric correction. In simpler terms, the “cub” file is now converted into a calibrated image “cal.cub” file. The cam2map application will put the image cube into a map projection. The “cal.cub” file becomes a “map.cub” file in this step. Finally, the isis2fits application converts the ISIS cube into a fits format. In this last step, the “map.cub” file transforms into a “map.fits” file.

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7 The DS9 program can be downloaded at [http://ds9.si.edu/site/Home.html](http://ds9.si.edu/site/Home.html).
8 All ISIS3 applications and descriptions are provided by [https://isis.astrogeology.usgs.gov/Application/](https://isis.astrogeology.usgs.gov/Application/).
The next part of the research is the DS9 analysis. After reducing Cassini raw image data from the PDS archive with ISIS3, the image is ready to be viewed in DS9. The DS9 program will only work if the original data from the PDS Image Atlas Archive has been converted into a “fits” file from the previous ISIS3 applications discussed. It is required to take both the image with cloud and relevant image containing atmospheric haze into DS9. Then, one can adjust lighting to view the cloud or clouds more prominently. The goal is to map as much of the image as possible in the 360 degrees of longitude and latitude. The interactive computational environment, IPython, lets a user view the image of a cloud and align it with another image of the same cloud. One can also subtract images to enhance the clouds by eliminating background haze. To access IPython requires opening it from a Unix terminal, view the cloud images and cut them when necessary to fit the clouds in the same frame. Previous mappings from ISIS3 are global images while IPython focus on zooming in on just the clouds. After doing this to many images containing the same cloud, one can then “stack” the images together. Stacking the images together is basically creating a movie of a cloud moving across Titan’s atmosphere. One can then analyze the cloud movement and in time with more of these stacked images, cloud trends on Titan.

An alternative route to mapping the final image is to use Photoshop, but to do so, one must first take the “fits” file and convert it as a JPEG file in Linux with a command line in an image scaling module file called “img_scale.py.” It is also possible to use The ESA/ESO/NASA FITS Liberator 3, an Adobe Photoshop plug-in program that is specifically designed for FITS imagery conversion to JPEG formatting. The main difference between using ipython and

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9 The image scaling module file “img_scale.py” can be found at http://dept.astro.lsa.umich.edu/~msshin/science/code/Python_fits_image/.
10 FITS Liberator can be acquired at http://www.spacetelescope.org/projects/fits_liberator/.
Photoshop is that the ipython steps for this research can only be executed in a Linux environment while Photoshop and FITS Liberator are accessed in a Windows environment. Photoshop and FITS Liberator were used on the majority of the final cloud sequences during this research.

The process for using Photoshop on Titan clouds can be done in the succeeding stages. Firstly, one must copy and save the desired photos of one Titan cloud sequence into a separate folder. This is for ease and organization. Next, the files are imported into Photoshop in the “Load images into stack” option found under the “Scripts” option. The selected images are then loaded and saved as separate layers. At this point in time, one can subtract haze from the images by selecting a haze image and then subtracting it from each individual cloud photo. Then, to create an animated cloud sequence would require using the frame animation under the list of possible “Timeline” actions in Photoshop. This allows one to then use the “create new layer for each new frame” and “make frames from layers” option. Finally, after choosing how long each delay between the images are in the animation and then making sure that the animation is categorized as “forever” instead of the default “once” setting, a never-ending animation that loops for the cloud sequence is created. Saving the animation as a GIF will ensure that the final cloud sequence is preserved for this research. This entire process must be repeated for all Titan cloud sequences found from the years 2004 to 2013.

Results:

For the purposes of this paper, only a select number of cloud sequences were chosen to be shown, clouds are seen as white bright areas against the background. To feature every single sequence would not be practical. However, a discussion of the overall anomalies, patterns, trends, and findings of these clouds will be included. The following data are a record of fly-by
dates of all possible cloud sightings from the years 2004-2013 and sample sequences of cloud images from the years 2004-2013.

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Cloud Sequence Animations
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Discussion:

It is valuable to know that the overall research done here involves a great deal of time. While the process to do all of the steps in this research is not difficult, it still needs time on its side. There are currently 38,226 images of Titan inside the PDS Image Atlas Archive. Approximately 1,000 images were gathered from this database and selected for possible cloud sequences on Titan. This is roughly 2.6% of the database’s Titan images. A considerably long time is involved to firstly sift through the database and secondly (and also more importantly) determine whether an image has clouds or not. To proceed onto the next research steps cannot be done unless all images of the years selected for this project (2004-2013) must first be completed. Only finding clouds for one year is not the best method because a fly-by containing images in December could continue into January. Consequently, it is wiser to finish finding all clouds from 2004 to 2013 to prevent cutting off a cloud sequence in half.

The next part of the research using the ISIS3 applications is also time consuming. To process each image with the ISIS3 application and to apply this step over thousands of images is a very lengthy process. The process also greatly dependent on the speed of internet access used as well since the images are all stored and accessed on an online cloud data storage. Even at 100
Mbps and higher, the time it takes for ISIS3 applications to be completed for about 20 images is at least half an hour long. In addition, Photoshop can only load individual cloud sequences in one sitting. Adding multiple cloud sequences in one Photoshop session will combine the sequences together. Loading images into Photoshop also involves waiting as well. Simply put, waiting with patience and putting in the time are the two most important aspects of this research. Having said and done this, one can finally draw some findings about the cloud development and atmospheric wind patterns on Titan.

Briefly, there are some facts about the seasons on Titan that are important to remember. One season alone on Titan is about seven and a half Earth years. The North and South Poles of Titan are in basically opposite seasons of each other due to Titan’s axial tilt. If it is summer on the northern end, then the North Pole is what is leaning to the sun while the South Pole is sloping away from the sun. Therefore, if it is spring season in the north, then the South Pole is experiencing fall. In 2004 when Cassini began taking images of Titan, the north pole was in wintertime. In 2007, the South Pole was experiencing a late summer. When 2009 came, Titan was in equinox. The seasons began to change to wintertime in 2011 for the South Pole. By 2017, the South Pole shall remain in winter. One can then determine the North Pole’s seasonal changes based on this data.¹¹

Much of the research done aligns with the findings in E.P. Turtle et al. “Seasonal Changes in Titan’s Meteorology”¹² for Titan cloud discussion that the paper holds from the years 2004 to 2010. Turtle et al.’s paper notes a large amount of clouds during 2004 throughout the South Pole on Titan. During the 2007 summer season in the South Pole, many cloud instances

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¹² The majority of analysis for many Titan clouds will be from this paper.
can be found in that region. Such sightings were common in the June 14th fly-by and especially the July 2nd fly-by. Turtle states that this is due to “enhanced solar heating…[and] upwelling motion in the atmosphere.”

![Figure 1](image1.png)

Figure 1 shows some clouds at the South Pole on July 3, 2004.

However, research done by this student also notes that there are times where clouds appeared on Titan in other regions of the globe besides the South Pole.

![Figure 2](image2.png)

Figure 2 shows clouds on October 25, 2004.

When 2005 approached, clouds were more scarce and harder to find in the PDS database. The clouds mostly appeared around June 4th to June 6th. These clouds lingered around the equinox and in regions close to the North Pole. Otherwise, there did not appear to be much atmospheric disturbances on Titan in 2005.

![Figure 3](image3.png)

Figure 3 displays clouds on June 4th and June 5th respectively.

For 2006, there were few clouds on Titan. The most prominent clouds that year were in December; they were found near the North Pole region. At this point in time, The North Pole
was experiencing winter. In Mike Wall’s “Suprise! Methane Ice Cloud Floats High Above Saturn’s Moon Titan” article, Michael Flasar (Cassini’s Composite Infrared Spectrometer principal investigator) believes that clouds appearing in this region mimic Earth’s stratospheric clouds’ behavior. No other planet or moon in this solar system has been known to be so similar in this manner regarding clouds. Hence, the similarities are fascinating to observe.

Moving onto 2007 and its scientific endeavors, the year itself did not actually hold any new findings for Titan’s atmosphere. Clouds continued to form albeit in small numbers.

Figure 4 shows clouds from June 30th. The photo on the left is a raw, unedited image. The photo on the right has been mapped and enhanced so that the clouds are better defined.

By the time it was 2008, cloud sightings did not dwindle, but there was not a big increase either. The majority of clouds spotted were usually found in the northern hemisphere and close to the North Pole.

Figure 5 Clouds from January 20, 2008.

When 2009 came, this was when the moon was in equinox. Clouds at this point would disappear mostly due to both hemispheres getting the same amount of sunlight. However, some clouds still appeared around the North Pole.

This article is used to analyze clouds in 2012 and 2013 later in the paper.
In comparison to previous years and their lack of large clouds, 2010 is an immensely notable year for Titan. The equatorial region apparently had a great storm in the later half of the year. Turtle et al. describes the sighting as “an arrow-shaped cloud which extended for >1000 km!” This occurred on September 27th to September 28th. Turtle further remarks that this large storm and its atmospheric influences could result in clouds in the later months for 2010. It is important to note that Mitchell et al. paper “Locally Enhanced Precipitation Organized by Planetary-Scale Waves on Titan” demonstrate with computer simulations that an arrow shaped cloud is formed during the equinoctial season, just as seen in the Cassini ISS observations (Figure 7). Both Turtle and Mitchell’s work provide a general physical interpretation of observed storms, their relation to atmospheric dynamics through a combined analysis of cloud observations and computer models of general circulation on Titan.

14 “Locally Enhanced Precipitation Organized by Planetary-Scale Waves on Titan” is a tremendously helpful and knowledgeable paper for further Titan atmospheric findings.
2010 was the last year that Turtle et al. included since the paper was published in 2011. The research conducted by the student were similar to what was generally discussed in Turtle et al.’s paper. Further analysis for the years 2011, 2012, and 2013 will draw upon other articles and papers. After the large storm in late 2010, there were essentially no clouds in 2011. In fact, none were found during the student’s research. According to Amy Shira Teitel’s article, “What Summer is Like on Saturn’s Moon Titan,” the lack of clouds was irregular and was not predicted by scientists to occur since “computer models using available data said there should be a lot more weather activity on the distant body.” Thus, the reasons why 2011 had few to little cloud activity remains a mystery.

For the final two years 2012 and 2013 in this research, a particular, new cloud came to light in Titan. Clouds were spotted again on Titan near the South Pole in July 2012. The interesting part is that these new clouds were large and round-ish. Previous cloud activity did not look as big and circular as the ones in 2012 and 2013. These clouds occurred more frequently for the two years. In fact, 2012 and 2013 hold the record for most cloud sightings during the course of this student’s research. According to Elizabeth Zubritsky’s article, “NASA’s Cassini Finds Monstrous Ice Cloud in Titan’s South Polar Region,” this new type of cloud is made of ice. The article also says that ice clouds on Titan would indicate Titan’s South Pole to be at least -238 degrees Fahrenheit. During these years, the South Pole experiences winter and judging by the ice clouds, winter is extremely cold. Moreover, Titan’s new ice clouds are created in a different manner than that of hail or rain storms form on Earth. Zubritsky states that “circulation… transports gases from the pole in the warm hemisphere to the pole in the cold hemisphere” and

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15 “What Summer is is Like on Saturn’s Moon Titan” has many facts related to Titan cloud analysis.
16 “NASA’s Cassini Finds Monstrous Ice Cloud in Titan’s South Polar Region” has many facts needed to understand clouds in 2012 and 2013.
then, this would cause “sinking gases” which would further “condense at different temperatures, resulting in a layering of clouds.” Therefore, these new ice clouds are exciting and give great insight into Titan’s fascinating and unpredictable atmosphere.

![Images of Titan's atmosphere from 2012 and 2013](image)

**Figure 8** The two images on the left are from 2012 and the images on the right are from 2013.

In summary, clouds have shown to be a unique part of Titan. They are a great indicator of the weather throughout the long Titan seasons. The way clouds move and form give a lot of insight about what Titan’s atmosphere. The years 2004 to 2013 were very exciting to analyze. In the end, the research was an honor to be a part of and it will be absolutely fascinating to see what the future holds for Titan as Cassini continues to take images of this great moon.

References:


