# TMC/TEA

## Introduction

The phenomenal success of the Cassini Mission at Saturn is largely due to flagship instruments, in a target rich environment, for a long period of time, executing almost error free complex mission operations. A smooth transition from cruise operations through the prime science mission and extended science (Equinox) mission culminating in the Solstice mission folded in necessary procedural alterations due to improved understanding of the spacecraft, instruments, uplink and planning systems as well as additional science objectives. These came with the maturation of the mission along with management of workforce reductions. One important set of operational changes was initiated due to scientific findings highlighting "missed" science opportunities. This was the case for the Titan Meteorology Campaigns. These observations involved long term monitoring of the atmospheres of Titan while the spacecraft and science teams were focused on other high priority targets of opportunity (like Enceladus). This was a highly successful non-invasive strategy to get additional remarkable science and implemented in a mission with an already well-defined operational plan.

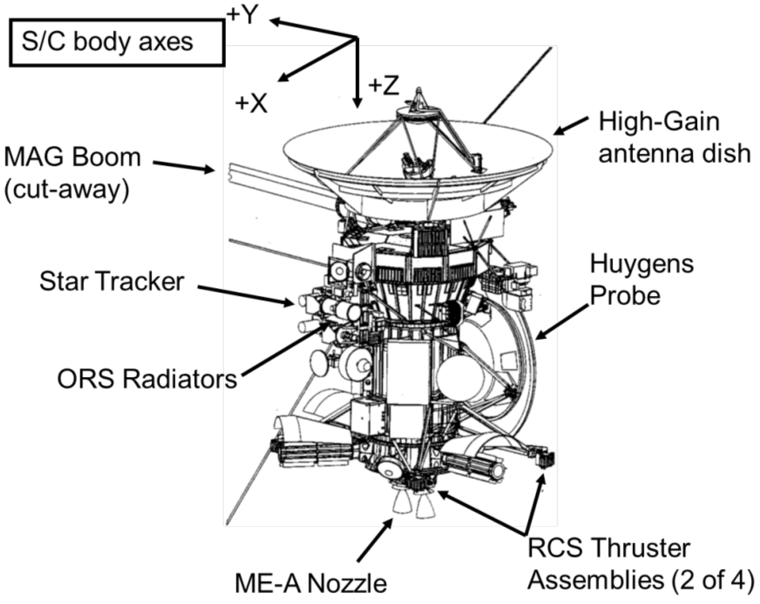
## How Cassini Planned Science in Solstice Mission

The chosen trajectory for the Cassini Solstice Mission (CSM) contained a wealth of competing multi-disciplinary science opportunities. Making the most of these opportunities presented challenges in allocating observing time to different instruments, and in preserving the precise timing required for individual observations when there could be a gap of years from initial high level planning to execution. Fairly allocating observing time among the instruments required intense advance planning, complicated by needing consensus among five science disciplines (Saturn, Titan, MAPS, Rings and Icy Satellites). To accommodate all of these concerns, the science planning process was designed along the five science discipline lines[4].

After the selection of the final trajectory, Science Planning divided the entire trajectory into smaller segments that were overseen by the science discipline working groups. Each had a team of representatives, referred to as Orbiter Science Team (OST) or Target Working Team (TWT), made up of science planning and spacecraft engineers, scientists from instrument teams, and interdisciplinary scientists. Each TWT/OST focused on a different aspect of Cassini science: the Titan Orbiter Science Team (TOST) concentrated on Titan observations, the Satellite Orbiter Science Team (SOST) on observations of all other satellites, and the Saturn and Rings Target Working Teams (Saturn TWT and Rings TWT) were responsible for Saturn and the ring system, respectively. The Magnetosphere TWT focused on Saturn's magnetosphere and plasma environment. A separate Cross Discipline TWT (XD TWT) considered all science objectives occurring during apoapse periods (at distances greater than 18 Saturn radii) when multiple disciplines would tend to share the time. Each TWT or OST's segments included opportunities especially of interest to their respective science disciplines. For example, TOST segments generally ran from a day before each Titan encounter closest approach to a day after. The science observations contained in each TWT/OST segment were considered against one more metric. CSM funding levels was significantly lower than prime and extended mission funding. Consequently, all CSM science was driven by a carefully honed set of prioritized science objectives. To establish these objectives, each discipline working group identified their top priority science objectives for the CSM. These objectives either *i)* addressed the goal of observing seasonal change in the Saturnian system, understanding underlying processes, and preparing for future missions, or *ii*) were new questions that arose out of prime and extended mission science (e.g. determining the composition and distribution of Titan's newly discovered lakes). Scientists then constructed a matrix of CSM science objectives, and slotted them as Priority 1, 2, or 3. Each TWT/OST would plan Priority 1 objectives and as many Priority 2 and 3 objectives as is possible within the observation time allotted to that discipline. Each TWT/OST group was responsible for developing fully integrated timelines of the science that would be accomplished during their segments. Fully integrated segments were delivered to the Science Planning Team, which combined the segments into 10 week sequences that were uplinked to the spacecraft at the end of the implementation process. Each discipline developed its own method of getting from raw unintegrated segments to detailed designs ready to be included in a sequence. The “creation” of discipline-focused segments resulted in each segment focusing solely on their preferred target (e.g. the Saturn segments focused on Saturn). Naturally, there would be instances of “missed” science opportunities for other “out of discipline” targets. It was therefore important to find a way to add some of those “out of discipline” observations without impacting the discipline science being planned. Titan Meteorology Campaigns (TMC) was one such opportunity.

## RBOT (RWA Bias Optimization Tool)

Science observation placement and design was largely impacted by the capability of the spacecraft team to safely operate and preserve the health of the spacecraft’s reaction wheels. Cassini-Huygens was a three axis stabilized spacecraft using three electrically-powered reaction wheels (also called momentum wheels) for routine control of the spacecraft's orientation. They provided a means to trade angular momentum back and forth between spacecraft and wheels. At launch three wheels were mounted near the bottom of the spacecraft, mutually perpendicular to each other. The fourth reaction wheel was a spare that could be articulated into a position in order to take over from any one of the others in case of failure. In 2001–02, reaction wheel #3 exhibited signs of a bearing cage instability[6]. As a result, reaction wheel #4 was articulated to align with reaction wheel #3. Beginning in July 2003, Cassini was controlled using wheel #1, #2, and #4. The fact that there were no additional spare wheels added to the importance of efforts to protect the wheels. The operational aspects of the mission imposed a number of requirements on the reaction wheels[6]. The reaction wheels provided sufficient torque for various attitude maneuvering tasks subject to maximum wheel speed and torque limitations. Near zero wheel rates had to be minimized to prevent large attitude error build up that could trigger an autonomous fault protection response (transition to thruster control). The reaction wheels needed to have sufficient margin to absorb the momentum build up due to small environmental torques such as solar radiation torque and RTG torque. Finally, in order to avoid excessive friction loading on the reaction wheel ball bearings (especially an issue when they were operated at low spin rate) and thus preserve RWA health, the operations of the wheel had to be performed in such a way to minimize the time the wheels spent inside a low rpm limit.



**Cassini Spacecraft showing the direction of the three axes**

The need to protect the reaction wheels lead to the birth of the RWA Bias Optimization Tool (RBOT)[6,8] and the RBOT process, by which the AACS (Attitude and Articulation Control System) team generated RWA rate bias commands for the Cassini spacecraft. RBOT’s algorithm optimized wheel speeds to minimize low RPM dwell time, RPM over-speeds, zero crossings, and total revolutions. If a science observation resulted in an “unhealthy” RWA state, the scientists would be asked to redesign the observation to make it “RBOT friendly”. In some cases, observations could be removed entirely from the sequence if they could not be redesigned to be compatible with RBOT rules. Even with such a capable tool, a complicating factor was the seemingly unpredictable mapping of spacecraft pointing to reaction wheel speed, which often frustrated the science teams and prompted a great deal of additional work for the flight team. In response, AACS developed basic rules that science teams could use when developing their pointing designs which could help produce “RBOT-friendly” designs[8]. These conditions were absolutely necessary for health and safety of the spacecraft. However, these rules further increased the number of

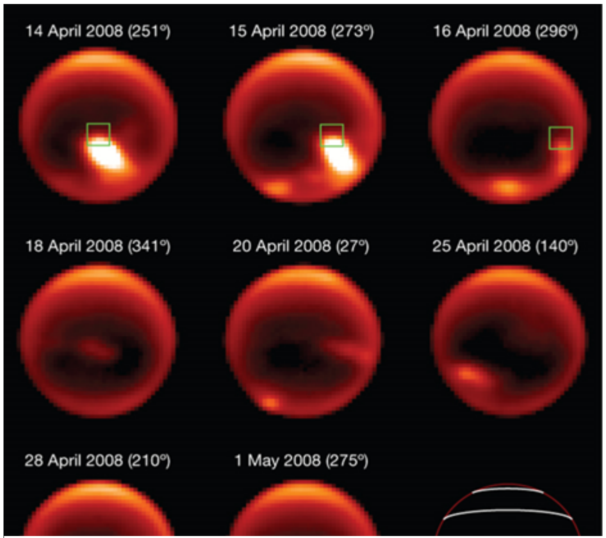
"missed" scientific opportunities. One constraint that was put into place as the solstice mission started was the "two out of three" rule[7]. "*No more than two of the following three items shall be included in any segment:*
*i. downlink rolls (e.g. rolls about z) and other science pointing activities where Neg-Z to Earth angle is less than 15 degrees; ii. rolls about one of either the spacecraft x or y axes-typically this will be an x-axis roll for calibration of the MAG instrument; iii. pointing changes for other science (e.g. ORS) activities that share a common pointing.*"
The rule was meant to apply to segments near the apoapses (outside of 20Rs); by making these parts of Cassini's orbit less work-intensive for the AACS team, more time could be dedicated to devising RBOT strategies for segments in the periapsis region (usually the region of higher priority science), giving those segments more planning flexibility. This constraint was followed diligently. Though overall the RBOT process has been a boon for Cassini science, it had impacted planning for Titan long-range observations. The next few sections describe how the Titan science discipline learned to work with the RBOT process

## Science Planning with emphasis to Titan

In the solstice mission Titan science was to be planned only during the TOST segment during and around the planned flybys. A TOST segment generally ran from a day before each Titan encounter closest approach to a day after. The CSM TOST planning used a successful "jumpstart" process prior to the delivery of the trajectory[7]. The jumpstart process was driven by three main objectives: the desire to balance Titan science across all flybys, the desire to increase Titan science by influencing the flyby altitudes in the Cassini Solstice mission and also to find an efficient way to use the Titan scientists' time. However as time progressed it was realized there were several instances of "missed science" due to the fact that Titan science observations were only being scheduled in the TOST segments. TOST leads and scientists realized, that in order to get a real picture of Titan's changing appearance as the seasons moved towards northern summer, it was necessary to capture "snapshots" which would be planned outside the realm of TOST segments and spread across other disciplines' segments.

## Missing Science gave birth to Titan Metereology Campaigns (TMC)

Even after years spent in orbit around Saturn and dozens of flybys of Titan, the Titan science community needed to find a process that would ensure Titan observations at regular intervals. Several different science campaigns required this support. Changes in weather patterns have accompanied Titan's seasons. In 2004-2005, large convective methane cloud systems were common around Titan's South Pole[9,10] including one observation of possible surface flooding[9], which appeared to have given way to cloud outbursts at lower latitudes[11,13]. Cassini observed Titan on April 26, 2008 and then only at northern latitudes, missing a huge low latitude tropical cloud outbreak on April 14, 2008 seen by ground based observers[11] (Figure 5). These low latitude clouds became less common in time, and clouds were seen further north as the northern vernal equinox approached. In 2009, clouds at high-north latitudes had become more common and extensive although they still differed in morphology from the south-polar clouds seen early in the Cassini mission[13]. Mid-latitude clouds tended to be smaller and had elongated morphologies. Also VIMS had observed a large north-polar ethane cloud[12] that seemed to be deteriorating. The overarching objective was to determine how the distribution and behavior of clouds change as northern spring began. In order to monitor the change of cloud systems, it was necessary to have frequent observations. Cloud appearances were sporadic and were not necessarily observed during a Titan flyby. In order to monitor



**Images of Titan showing a huge low latitude cloud outbreak April 2008 Clouds were first detected on 13 April 2008. Images from 28 April 2008 and 1 June 2008 show a faint cloud persisting over the same location as the north westernmost extent of the initial large cloud from 14 April 2008 (15° S, 250° W; green box), perhaps indicating that the initial cloud outburst may have been localized here (Schaller, et al[11])**

Titan with the change of season, Titan needed to be observed all the time, not just in Titan segment during the Titan flyby. Low resolution was sufficient to detect and locate clouds and large-scale haze structure. Titan has a massive atmosphere laden with layers of photochemical haze. Images of Titan from Voyagers 1 and 2 revealed a hemispheric contrast and a nearly global 'detached' (forming a distinct local maximum) haze layer near 350 km altitude at latitudes outside of the polar vortex[14,15]. The persistent detached haze layer observed by Cassini was found to be at an altitude of over 500 km[19,17], which was higher than the Voyager observations by over 150km. This needed to be investigated further with Titan haze observations at regular intervals. During the Voyager encounter in 1980 (Titan northern spring equinox), a dark polar collar or hood was seen at high northern latitudes,.[14,15], and the situation was reversed two seasons later when Titan was observed by Hubble Space Telescope (HST)[16] in 1994-1995. The arrival of Cassini in the Saturnian system afforded a new perspective on Titan. Assuming that seasonal cycle repeats, the northern spring equinox seen by Voyager 1 was to be observable by Cassini's extended mission in 2009-2012. It was anticipated that the UV-dark polar hood would switch hemispheres early in northern spring. Indeed, several features reminiscent of the Voyager appearance were already observable in data from Cassini's first encounters (TA and TB) in October and December of 2004[19]. There was no south polar hood visible in 2004 and a detached haze layer was observable against the blackness of space at all latitudes and appeared to merge with a complex of haze material standing high above the north polar region[18]. These investigations and more necessitated the Titan Meteorology Campaign (TMC). Clearly, a more "regular" observation scenario was needed in order to fill the data gaps left by (roughly) monthly Titan flybys. Low resolution observations were able to detect and locate clouds and large scale haze structures, thus distant observations would be sufficient for this purpose. In September 2008 (within Cassini extended mission), a distant Titan monitoring campaign began which continued till the end of the mission. These observations provided isolated snapshots and improved our understanding of how often there were clouds on Titan, how quickly they appeared and dissipated, where they were appearing as the seasons changed, how fast and in what direction the winds would blow and how the haze evolved with the seasons. There were hundreds of these short observations until the end of the mission. The frequency of requests was no more than once a day and usually a few every week. Instrumental in addressing Titan science, the goal was to get as many as possible integrated into the final observation plan which was done effectively.

## Initial Requirements and Implementation of TMC

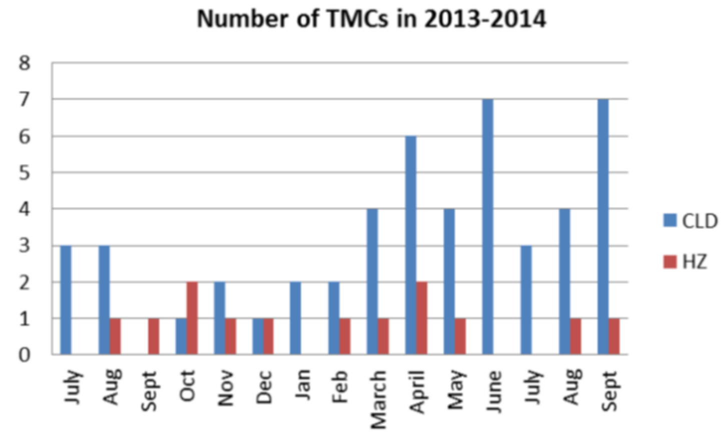
Preliminary TOST internal meetings were held to agree on the least intrusive strategy for TMCs, to be put forth to the science planning team and the Cassini project in early 2008. Scientists initially proposed specifications for TMC observations of a range < 9 million km (pixel scale ~ 50 km), phase angle < 90 degrees for cloud observations and > 90 degrees for haze observation. The time with the ORS instruments pointed to Titan would be approximately 30 minutes, with the desired data volume to be negotiated for each instance. ISS would be the prime instrument, thus charged with doing the pointing designs, with the CIRS, UVIS and VIMS teams riding along. Two methods of implementing TMCs were suggested:

**(1) OpNav Strategy**: Optical navigation (Opnav) is the use of pictures of target bodies in spacecraft orbit determination.

Opnavs started at a waypoint or a downlink and ended at a downlink or a (sometimes different) waypoint. The Opnav team also implemented its own turns. A typical Opnav request would start from a waypoint, slew to a satellite, take a picture, then slew to the next target and so on. It would then slew from the last target to the downlink attitude or waypoint. The pictures were then transmitted to the Earth. If the request did not end at a downlink, the pictures were transmitted the next time the spacecraft was at a downlink attitude. The Titan team proposed a strategy similar to the Opnavs as the least intrusive method for implementing TMCs. Just before or after a downlink, science planning would do a waypoint turn to Titan and a 15 minute ISS prime observation and then SP would do a waypoint turn to target. The observations would be next to the downlinks. This would achieve the waypoint orientation for that day of the segment, a significant savings of time and effort. However, if an Opnav was already in place, Opnav would turn to Titan followed by a 15 minute ISS observation and an SP turn to target. TMC observations would be put on the other side of down link.

**(2) Standalone observation :** The other option would be a standalone observation which could be moved anywhere in the day of the segment. This would be more flexible for the scientists, but could prove more disruptive to the planning process.

To do a study of the time required for each proposed option, the range and phase of every downlink in the Extended Mission was calculated to see if it met Titan Monitoring Campaign requirements. Turn times were calculated for turns from Earth and Titan and Titan to Saturn. The time was calculated for both options with an additional 15 minutes margin added in the event of a longer-than-usual turn. It was no surprise that the standalone observation strategy (plus time for an additional waypoint turn) was always larger than the Opnav strategy. However, option 1 was not entertained due to its greater workload for the science planning team. The choice was the second option modified to streamline the process. Each TMC was set to begin at Each TMC was set to begin at 40 minutes after the downlink. This process was used until end of mission.



**Number of "Cloud" and "Haze" observing planned TMCs between July 2013 and September 2014, the number varied every month.**

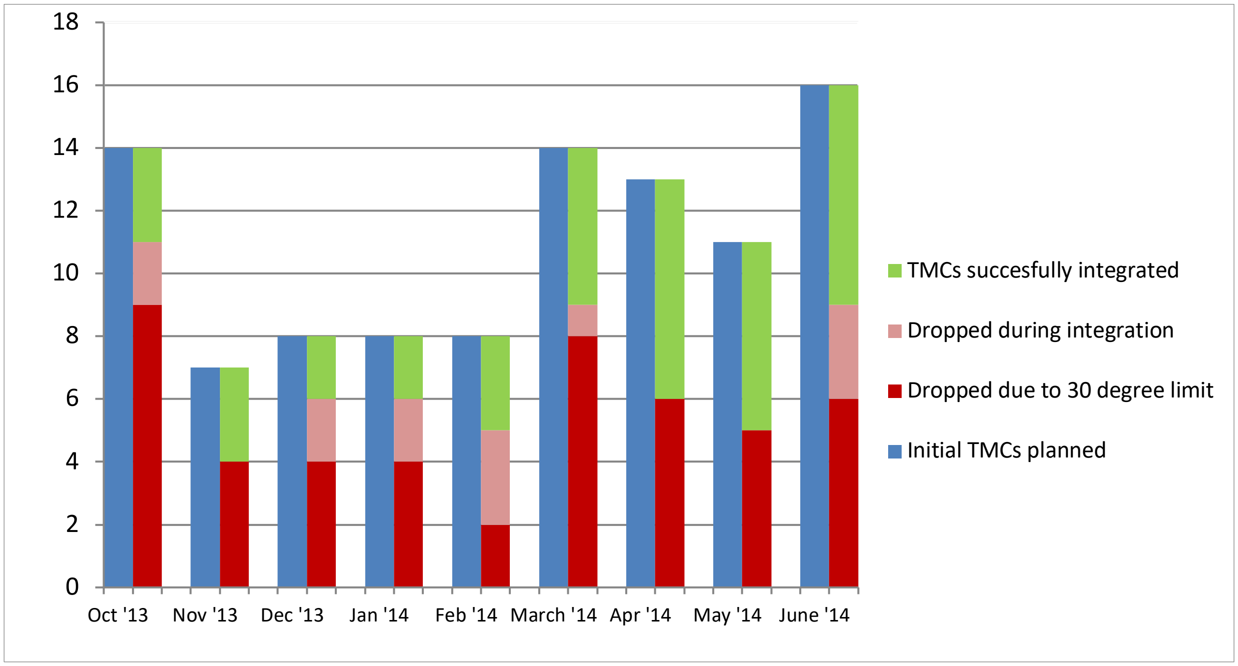
## Gradual Progression of TMCs through the years

Many Titan TMC were requested. These were short requests about 30 minutes on Titan on roughly 50% of time during the apoapsis time frame outside +/- 18 Rs (hence handled by XD) and were also integrated by other disciplines. Ideally 6-8 observations per month were required. Agreed-upon observing requests were recorded in the Cassini Information Management System (CIMS), the starting point for planning observations. Discussed below is the step by step progression of the TMC implementation

**Started in Equinox Mission:** The observations were split into 3 range bins: <1Mkm (R1); 1 to 2 Mkm (R2); > 2Mkm (R3). R1 required a mosaic 1X2 aligned along the North/South poles. The start and return waypoints were assumed to be –Y to Saturn and –X to Sun. Observations with phase angle < 90 degrees were cloud observations, observations with any other angle were for haze observations. ISS was the prime instrument with the VIMS, CIRS and UVIS teams riding along. The entire allocated data volume was decided to be ~75Mb (10 Mb for VIMS; 18 Mb for CIRS; 35 Mb for ISS; 4.5 Mb for UVIS). The end result was about 300 requests entered into CIMS across all of the Equinox Mission for consideration by the TWT leads.

**Revised for Solstice Mission**: The Titan group met with implementers and identified areas for easing their work load. The TMC were made independent of secondary so that all RBOT changes could easily be accommodated. Efforts were made for them to start at identified RBOT friendly waypoints. Margin was added for unexpected changes in secondary. The fixed duration and data volume aspects were maintained. Integration leads requested blocks that were multiples of an hour. The observations continued to be split into the same range bins. However R1 required a 2X2 mosaic so that the observations were independent of the secondary. R1 increased in duration by 35 minutes to get the additional 2 footprints. The observations were split into phase bins (for example <30, 30-60, 60-90) and prioritized for lower phase and closer range. The UVIS team chose to drop out of the campaign. The data volume was changed to ~65Mb for R2 and R3 and ~ 125 Mb for R1. Additional time margin was needed for implementers because the RBOT secondaries were not known during the time of entry into CIMS. The R2 and R3 were made 90 minutes long and R1 observations being 2 hours long.

**Revised for RBOT constraints:** The RBOT protective restrictions impacted the integration of TMCs due to the "two out of three" rule (see previous section). In practice, for the majority of apoapse time, this meant choosing one type of roll--either downlink rolls or a MAG calibration roll--and pointing at or near Saturn. The majority of Cassini observations away from periapse periods were of Saturn or objects close to Saturn (for example the rings or inner satellites), which comfortably kept the spacecraft pointed within a single 30 degree cone. Titan, however, was often more than 30 degrees away from Saturn as seen from Cassini; any potential TMCs occurring during this geometry were removed from further consideration. The figure below shows as an example how the two of three rule significantly reduced the possible TMC candidates.



**This figure shows how the number of TMCs which met the geometric constraints and were subsequently dropped due to RBOT and other integration constraints ending with on many cases TMCs lesser than the required number of 6-8/month**

**The Titan-Saturn angle limitation extended to <= 50 degrees** In several sequences, the orbit geometry of where Cassini found itself relative to Saturn and Titan meant that a large fraction of the proposed TMC observations were rejected from the integration process due to the 30-degree cone restriction. The AACS team agreed to explore the possibility of relaxing this constraint for the TMC observations because the RBOT rules applied across the entire mission had led to a significant reduction in the workload for the AACS team. After approval from the SCO team extra TMC requests were added back in 2015.

**Limited number of TMC candidates added back**: During periods when there were downlink rolls the 2 of 3 rule could also be satisfied if an observation was adjacent to the downlink and the required spacecraft orientation kept the -Z to Earth angle at 15 degrees or less. This meant if using the optical instruments the desired target was 75 to 105 degrees away from the Earth. Adding back any TMC opportunities during these geometries increased the number of TMC candidates.

**Addition of UV3 images to cloud observations:** Geometric and RBOT constraints seriously reduced TMC haze observations. Specifically, in 2011 it was observed that 10 months passed at a critical part of Titan's seasonal cycle without any images using the preferred UV3 filter, which was the best for detecting the detached haze. This was mitigated by adding a "haze segment"—observations using the UV3 filter to all the TMC cloud observations. We also needed to add data volume to cover the additional filter.

**Importance of TMCs during conjunction periods:** During conjunction, when Saturn could not be seen from ground based telescopes, Cassini was the only way to observe Titan for a 3 month period. The TMCs planned during those conjunction time periods—roughly once per Earth year-- were given higher priority because Cassini would be the sole observer of Titan. The TWT leads were requested to give importance to TMCs over other scientific observation during these times.

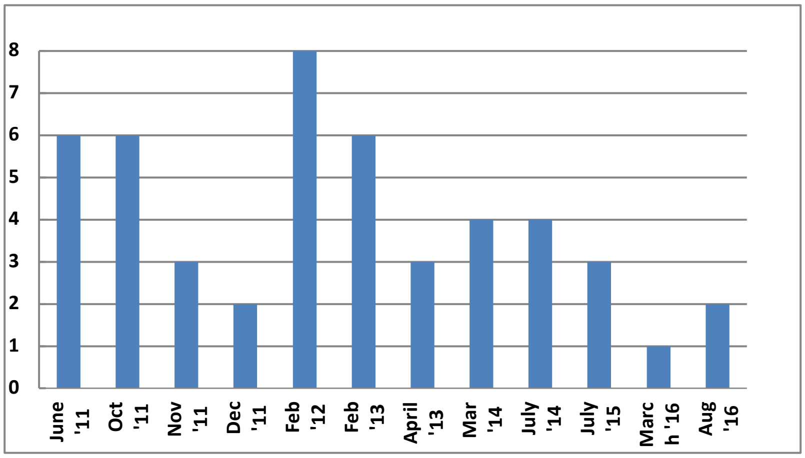
# Some Science Goals met by TMCs

**A. Monitoring Titan's Seasonal Weather Pattern**.

**B. Monitoring Titan's Haze**

**C. Titan Polar Hood changes**

## Titan Exploration at Apoapses (TEA)



**TEA campaign from 2011-2016**

Another dedicated long range Titan observation campaign was the Titan Exploration observations at Apoapsis (TEA). TEA were first proposed in early 2010 when it was noticed that that there were several opportunities to observe Titan at decent phase angles and distances for a very long stretch of time. These stretches were well over a week and approaching (even exceeding) an entire Titan rotation (16 days). Being capable of observing an entire Titan rotation (removing longitude bias) was beneficial. TEAs, which took place over periods of days to weeks, occured 1-2 times a year at ranges of ~1MKm with low to moderate phase angle. The TEA campaign started in the Solstice mission with the first observation being in June 2011. The goal was to get ~2 TEA opportunities per year (i.e. individual TEA observations in multiple observation periods in two XD segments a year). The CIRS instrument was the prime instrument with ISS and VIMS riding along. The primary science driver for the TEA's was to observe the onset and evolution of methane clouds on Titan using ISS and VIMS. The secondary science driver was to detect trace constituents and isotopic ratios from long CIRS integrations. Since ISS and VIMS have square arrays, it was CIRS that determined the secondary orientation. A north/south alignment gave pole to pole latitude coverage. An east/west orientation yielded spectra over a wide range of emission angles. New stratospheric gas species were most easily observed at high emission angle due to a longer slant path through Titan's stratosphere. TEAs were expected to play a major role in studies of seasonal change on Titan. TEA results have confirmed that seasonal change is indeed well underway on Titan[20]**.** The 2011 TEA observations showed dramatic change between June (no $HC_3N$ in the south) and October (clear $HC_3N$ in the South). The 2012 TEAs showed no $HC_3N$ observed at equator with North and South poles having comparable amounts of $HC_3N$. In 2013, CIRS detected large enhancements in $C_6H_6$ and $HC_3N$ over Titan's South Pole. Prior to 2010, all these molecules were seen in the north, but not in the south. Post-equinox we saw a buildup in the south. TEAs were also used to calibrate earth based far-IR measurements of Titan. There was a dedicated TEA in July 2014 to use CIRS' far-IR focal plane to calibrate Earth-based Titan observations from Herschel. The TEA campaign ended in August 2016. TEA measured seasonal change at Titan's poles using tracer molecules such as $HC_3N$ and $C_6H_6$. Long observing times during TEAs provided sufficient signal/noise to retrieve abundances of isotopic species such as $C_2HD$ (deuterated acetylene). Whole disk integrations using the far-infrared focal plane of CIRS provided accurate radiance calibration for Earth-based measurements by Herschel and other investigations.

## Integrating TMCs

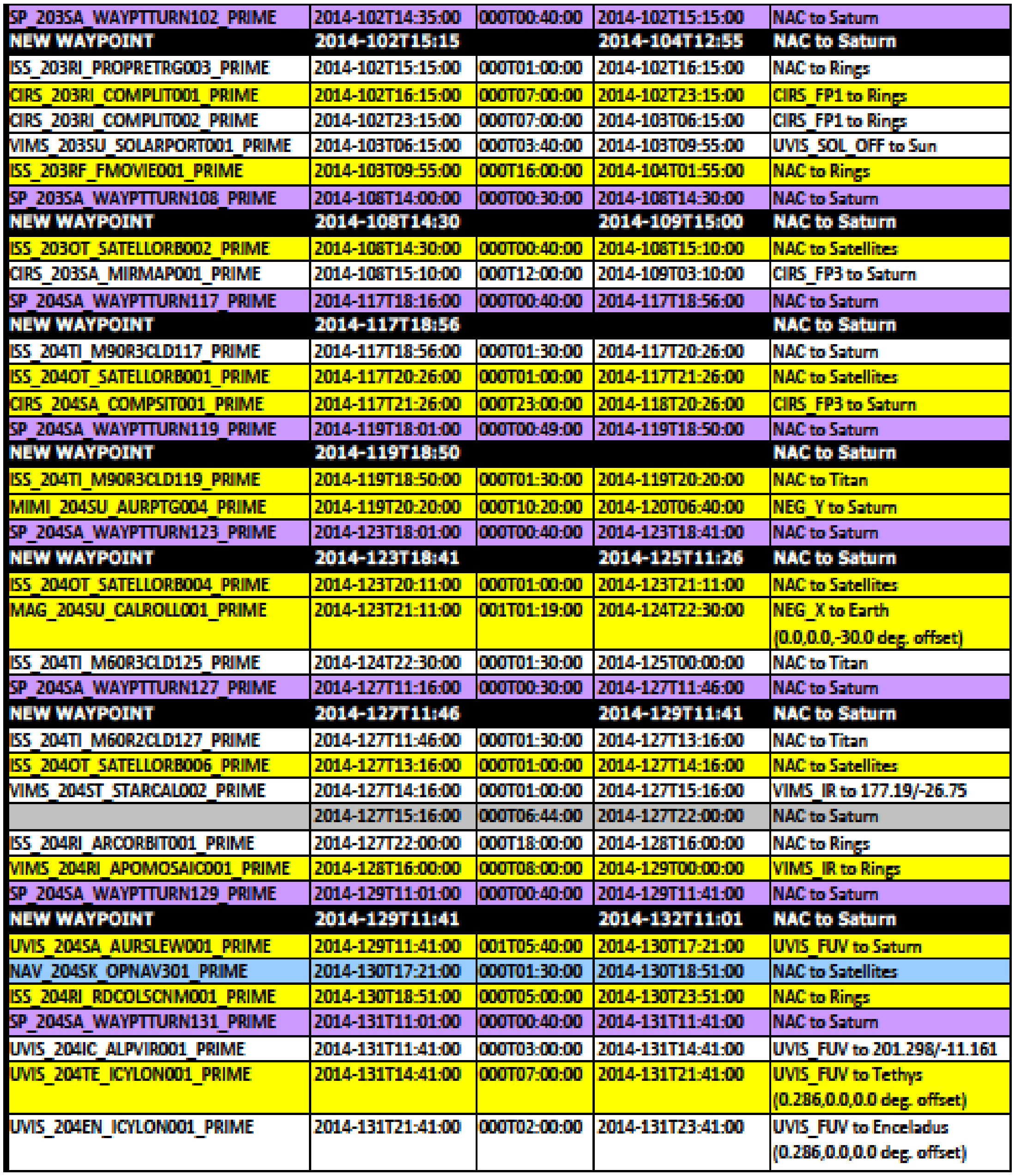
TMCs were developed with the realization of missed science opportunities. This involved setting up processes for smoothly inserting them into the existing integration plan non-invasively. When integration began for a particular period of sequence, TMC requests already existed in the observation database. They required minimal data volume. The primary constraint on the number of observations that could be included in the final integrated plan was compatibility with the pointing required for all the other types of observations included.

During integration there were multiple, often conflicting, desires that had to be considered. For example, either rolling downlinks or a MAG calibration roll was allowed, but not both. In practice, activities were prioritized within each TWT/OST based on science priority and the ability to achieve the optimal science within geometric constraints. Whether or not a TMC activity was added, depended on the results of the TWT/OST negotiations.

In the case of the TMCs, short prime observations placed just after every downlink provided specific geometrical requirements were satisfied, the biggest constraint was the "two of three rule" (see Section III) designed to extend the life of the spacecraft's reaction wheels. The majority of Cassini observations during apoapse periods were distant views of Saturn, rings, or inner satellites, which comfortably kept the spacecraft pointed within a single 30 degree cone. Titan however was often more than 30 degrees away from Saturn as seen from Cassini and usually TMCs could not be integrated when the Titan-Saturn separation was more than 30 degrees, which was later increased to 50 degrees on negotiation with the Spacecraft team. Sometimes the Titan-Saturn separation had to be significantly less than 30 degrees. If, for example, there was an observation of a satellite, that was 20 degrees away off Saturn's right ansa and Titan was 20 degrees off the left ansa, then the spacecraft pointing would preclude a TMC. During time periods when downlink rolls were planned, a TMC satisfying the requirement that the spacecraft orientation was kept within 15 degrees of the -Z to Earth vector. To this end, prior to integration, the Titan-Saturn and Titan-Earth angles as well as the relative position of Titan with reference to Saturn were calculated for every TMC request. Within the above limitations, as many compatible TMC requests as possible were then integrated until a desired number per month value was achieved; often it was not possible to achieve this target. The final TMC was the 4th to last ISS observation ISS_293TI_M90R1CLD256_PRIME on 13 September 2017 about two days before the final Cassini plunge. Return of detached haze layer was observed starting Spring 2016. These observations provide an important test of Titan General Circulation models. Most notable of all TMC observations are the ones capturing the 2010 storm and aftermath.

## Conclusions

The Titan Meteorological Campaigns proved to be very successful and were one of the most important vessels for Cassini Titan science. These campaigns continue as planned throughout the CSM and F Ring and Proximal Orbits till end of mission to monitor Titan climate changes and for other science goals. TMCs have been instrumental in bringing forth phenomenal scientific results that would have been "missed" with regular science operations. The nonintrusive and successful way of how both these observations entered regular Cassini mission plans should show the path to future missions as well.



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|---|---|---|---|---|
| SP_203SA_WAYPTTURN102_PRIME | 2014-102T14:35:00 | 000T00:40:00 | 2014-102T15:15:00 | NAC to Saturn |
| **NEW WAYPOINT** | **2014-102T15:15** | | **2014-104T12:55** | **NAC to Saturn** |
| ISS_203RI_PROPRETRG003_PRIME | 2014-102T15:15:00 | 000T01:00:00 | 2014-102T16:15:00 | NAC to Rings |
| CIRS_203RI_COMPLIT001_PRIME | 2014-102T16:15:00 | 000T07:00:00 | 2014-102T23:15:00 | CIRS_FP1 to Rings |
| CIRS_203RI_COMPLIT002_PRIME | 2014-102T23:15:00 | 000T07:00:00 | 2014-103T06:15:00 | CIRS_FP1 to Rings |
| VIMS_203SU_SOLARPORT001_PRIME | 2014-103T06:15:00 | 000T03:40:00 | 2014-103T09:55:00 | UVIS_SOL_OFF to Sun |
| ISS_203RF_FMOVIE001_PRIME | 2014-103T09:55:00 | 000T16:00:00 | 2014-104T01:55:00 | NAC to Rings |
| SP_203SA_WAYPTTURN108_PRIME | 2014-108T14:00:00 | 000T00:30:00 | 2014-108T14:30:00 | NAC to Saturn |
| **NEW WAYPOINT** | **2014-108T14:30** | | **2014-109T15:00** | **NAC to Saturn** |
| ISS_203OT_SATELLORB002_PRIME | 2014-108T14:30:00 | 000T00:40:00 | 2014-108T15:10:00 | NAC to Satellites |
| CIRS_203SA_MIRMAP001_PRIME | 2014-108T15:10:00 | 000T12:00:00 | 2014-109T03:10:00 | CIRS_FP3 to Saturn |
| SP_204SA_WAYPTTURN117_PRIME | 2014-117T18:16:00 | 000T00:40:00 | 2014-117T18:56:00 | NAC to Saturn |
| **NEW WAYPOINT** | **2014-117T18:56** | | | **NAC to Saturn** |
| ISS_204TI_M90R3CLD117_PRIME | 2014-117T18:56:00 | 000T01:30:00 | 2014-117T20:26:00 | NAC to Saturn |
| ISS_204OT_SATELLORB001_PRIME | 2014-117T20:26:00 | 000T01:00:00 | 2014-117T21:26:00 | NAC to Satellites |
| CIRS_204SA_COMPSIT001_PRIME | 2014-117T21:26:00 | 000T23:00:00 | 2014-118T20:26:00 | CIRS_FP3 to Saturn |
| SP_204SA_WAYPTTURN119_PRIME | 2014-119T18:01:00 | 000T00:49:00 | 2014-119T18:50:00 | NAC to Saturn |
| **NEW WAYPOINT** | **2014-119T18:50** | | | **NAC to Saturn** |
| ISS_204TI_M90R3CLD119_PRIME | 2014-119T18:50:00 | 000T01:30:00 | 2014-119T20:20:00 | NAC to Titan |
| MIMI_204SU_AURPTG004_PRIME | 2014-119T20:20:00 | 000T10:20:00 | 2014-120T06:40:00 | NEG_Y to Saturn |
| SP_204SA_WAYPTTURN123_PRIME | 2014-123T18:01:00 | 000T00:40:00 | 2014-123T18:41:00 | NAC to Saturn |
| **NEW WAYPOINT** | **2014-123T18:41** | | **2014-125T11:26** | **NAC to Saturn** |
| ISS_204OT_SATELLORB004_PRIME | 2014-123T20:11:00 | 000T01:00:00 | 2014-123T21:11:00 | NAC to Satellites |
| MAG_204SU_CALROLL001_PRIME | 2014-123T21:11:00 | 001T01:19:00 | 2014-124T22:30:00 | NEG_X to Earth (0.0,0.0,-30.0 deg. offset) |
| ISS_204TI_M60R3CLD125_PRIME | 2014-124T22:30:00 | 000T01:30:00 | 2014-125T00:00:00 | NAC to Titan |
| SP_204SA_WAYPTTURN127_PRIME | 2014-127T11:16:00 | 000T00:30:00 | 2014-127T11:46:00 | NAC to Saturn |
| **NEW WAYPOINT** | **2014-127T11:46** | | **2014-129T11:41** | **NAC to Saturn** |
| ISS_204TI_M60R2CLD127_PRIME | 2014-127T11:46:00 | 000T01:30:00 | 2014-127T13:16:00 | NAC to Titan |
| ISS_204OT_SATELLORB006_PRIME | 2014-127T13:16:00 | 000T01:00:00 | 2014-127T14:16:00 | NAC to Satellites |
| VIMS_204ST_STARCAL002_PRIME | 2014-127T14:16:00 | 000T01:00:00 | 2014-127T15:16:00 | VIMS_IR to 177.19/-26.75 |
| | 2014-127T15:16:00 | 000T06:44:00 | 2014-127T22:00:00 | NAC to Saturn |
| ISS_204RI_ARCORBIT001_PRIME | 2014-127T22:00:00 | 000T18:00:00 | 2014-128T16:00:00 | NAC to Rings |
| VIMS_204RI_APOMOSAIC001_PRIME | 2014-128T16:00:00 | 000T08:00:00 | 2014-129T00:00:00 | VIMS_IR to Rings |
| SP_204SA_WAYPTTURN129_PRIME | 2014-129T11:01:00 | 000T00:40:00 | 2014-129T11:41:00 | NAC to Saturn |
| **NEW WAYPOINT** | **2014-129T11:41** | | **2014-132T11:01** | **NAC to Saturn** |
| UVIS_204SA_AURSLEW001_PRIME | 2014-129T11:41:00 | 001T05:40:00 | 2014-130T17:21:00 | UVIS_FUV to Saturn |
| NAV_204SK_OPNAV301_PRIME | 2014-130T17:21:00 | 000T01:30:00 | 2014-130T18:51:00 | NAC to Satellites |
| ISS_204RI_RDCOLSCNM001_PRIME | 2014-130T18:51:00 | 000T05:00:00 | 2014-130T23:51:00 | NAC to Rings |
| SP_204SA_WAYPTTURN131_PRIME | 2014-131T11:01:00 | 000T00:40:00 | 2014-131T11:41:00 | NAC to Saturn |
| UVIS_204IC_ALPVIR001_PRIME | 2014-131T11:41:00 | 000T03:00:00 | 2014-131T14:41:00 | UVIS_FUV to 201.298/-11.161 |
| UVIS_204TE_ICYLON001_PRIME | 2014-131T14:41:00 | 000T07:00:00 | 2014-131T21:41:00 | UVIS_FUV to Tethys (0.286,0.0,0.0 deg. offset) |
| UVIS_204EN_ICYLON001_PRIME | 2014-131T21:41:00 | 000T02:00:00 | 2014-131T23:41:00 | UVIS_FUV to Enceladus (0.286,0.0,0.0 deg. offset) |

**A list of observations in a typical Cross Discipline TWT segment showing 4 planned TMC observations on days 117, 119, 125 and 127 (to understand naming convention as an example TMC on day 117 is ISS_204TI_M90R3CLD117_PRIME).**

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