IceCube Maintenance and Operations
Fiscal Year 2016 PY1 Mid-Year Report

April 1, 2016 – September 30, 2016

Submittal Date: November 7, 2016

University of Wisconsin–Madison

This report is submitted in accordance with the reporting requirements set forth in the IceCube Maintenance and Operations Cooperative Agreement, PLR-1600823.

Foreword

This FY2016 (PY1) Mid-Year Report is submitted as required by the NSF Cooperative Agreement PLR-1600823. This report covers the six-month period beginning April 1, 2016 and concluding September 30, 2016. The status information provided in the report covers actual common fund contributions received through September 30, 2016 and the full 86-string IceCube detector (IC86) performance through September 30, 2016.

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Section I – Financial/Administrative Performance

The University of Wisconsin–Madison is maintaining three separate accounts with supporting charge numbers for collecting IceCube M&O funding and reporting related costs: 1) NSF M&O Core account, 2) U.S. Common Fund account, and 3) Non-U.S. Common Fund account.

The first PY1 installment of $3,500,000 was released to UW–Madison to cover the costs of maintenance and operations during the first six months of PY1 (FY2016): $498,225 was directed to the U.S. Common Fund account based on the number of U.S. Ph.D Authors in the last version of the institutional MoU's, and the remaining $3,001,775 was directed to the IceCube M&O Core account. The second PY1 installment of $1,750,000 was released to UW–Madison to cover part of the costs of maintenance and operations during the remaining six months of PY1 (FY2017): $249,113 was directed to the U.S. Common Fund account, and the remaining $1,500,888 was directed to the IceCube M&O Core account. The last PY1 (FY2017) installment of $1,750,000 is planned to be released to cover part of the second half of PY1 (Figure 1).

PY1: FY2016 / FY2017	**Funds Awarded to UW for Apr 1, 2016 – Sept 30, 2016**	**Funds Awarded to UW for Oct 1, 2016 – March 31, 2017**	**Funds to Be Awarded to UW for Oct 1, 2016 – March 31, 2017**
IceCube M&O Core account	$3,001,775	$1,500,888	$1,500,888
U.S. Common Fund account	$498,225	$249,113	$249,113
TOTAL NSF Funds	**$3,500,000**	**$1,750,000**	**$1,750,000**

Table 1: NSF IceCube M&O Funds – PY1 (FY2016 / FY2017)

Of the IceCube M&O PY1 (FY2016/FY2017) Core funds, $952,147 were committed to the U.S. subawardee institutions based on their statement of work and budget plan. The institutions submit invoices to receive reimbursement against their actual IceCube M&O costs. Table 2 summarizes M&O responsibilities and total FY2015 funds for the subawardee institutions.

Institution	**Major Responsibilities**	**Funds**
Lawrence Berkeley National Laboratory	DAQ maintenance, computing infrastructure	$82,889
Pennsylvania State University	Computing and data management, simulation production, DAQ maintenance	$68,771
University of Delaware, Bartol Institute	IceTop calibration, monitoring and maintenance	$162,158
University of Maryland at College Park	IceTray software framework, online filter, simulation software	$587,577
University of Alabama at Tuscaloosa	Detector calibration, reconstruction and analysis tools	$23,870
Michigan State University	Simulation software, simulation production	$26,882
Total		**$952,147**

Table 2: IceCube M&O Subawardee Institutions – PY1 (FY2016/2017) Major Responsibilities and Funding

IceCube NSF M&O Award Budget, Actual Cost and Forecast

The current IceCube NSF M&O 5-year award was established in the middle of Federal Fiscal Year 2016, on April 1, 2016. The following table presents the financial status six months into the Year 1 of the award, and shows an estimated balance at the end of PY1.

Total awarded funds to the University of Wisconsin (UW) for supporting IceCube M&O from the beginning of PY1 through mid-year PY1 are $5,250K. With the last PY1 planned installment of $1,750K, the total PY1 budget is $7,000K. Total actual cost as of September 30, 2016 is $3,262K and open commitments are $423K. The current balance as of September 30, 2016 is $3,315K. With a projection of $3,452K for the remaining expenses during the final six months of PY1, the estimated negative balance at the end of PY1 is -$137K, which is 2.0% of the PY1 budget (Table 3).

(a)	(b)	(c)	(d)= a - b - c	(e)	(f) = d – e
YEARS 1 Budget Apr.'16-Mar.'17	**Actual Cost To Date** through Sept. 30, 2016	**Open Commitments** on Sept. 30, 2016	**Current Balance** on Sept. 30, 2016	**Remaining Projected Expenses** through Mar. 2017	**End of PY1 Forecast Balance** on Mar. 31, 2017
$7,000K	**$3,262K**	**$423K**	**$3,315K**	**$3,452K**	**-$137K**

Table 3: IceCube NSF M&O Award Budget, Actual Cost and Forecast

IceCube M&O Common Fund Contributions

The IceCube M&O Common Fund was established to enable collaborating institutions to contribute to the costs of maintaining the computing hardware and software required to manage experimental data prior to processing for analysis.

Each institution contributes to the Common Fund, based on the total number of the institution's Ph.D. authors, at the established rate of $13,650 per Ph.D. author. The Collaboration updates the Ph.D. author count twice a year before each collaboration meeting in conjunction with the update to the IceCube Memorandum of Understanding for M&O.

The M&O activities identified as appropriate for support from the Common Fund are those core activities that are agreed to be of common necessity for reliable operation of the IceCube detector and computing infrastructure and are listed in the Maintenance & Operations Plan.

Table 4 summarizes the planned and actual Common Fund contributions for the period of April 1, 2016–March 31, 2017, based on v20.0 of the IceCube Institutional Memorandum of Understanding, from April 2016. The final non-U.S. contributions are underway, and it is anticipated that most of the planned contributions will be fulfilled.

	Ph.D. Authors	Planned Contribution	Actual Received
Total Common Funds	**139**	**$1,917,825**	**$1,671,395**
U.S. Contribution	78	$1,064,700	$1,064,700
Non-U.S. Contribution	61	$853,125	$757,425

Table 4: Planned and Actual CF Contributions for the period of April 1, 2016–March 31, 2017

Section II – Maintenance and Operations Status and Performance

Detector Operations and Maintenance

***Detector Performance* —** During the period from March 1, 2016, to October 1, 2016, the detector uptime, defined as the fraction of the total time that some portion of IceCube was taking data, was 99.79%, exceeding our target of 99%. The clean uptime for this period, indicating full-detector analysis-ready data, was 98.01%, exceeding our target of 95%. Historical total and clean uptimes of the detector are shown in Figure 1.

Figure 2 shows a breakdown of the detector time usage over the reporting period. The good uptime was 0.68% of the time and includes partial detector (not all 86 strings in operation) analysis-ready data. Excluded uptime includes maintenance, commissioning, and verification data and required 1.09% of detector time. The unexpected detector downtime was limited to

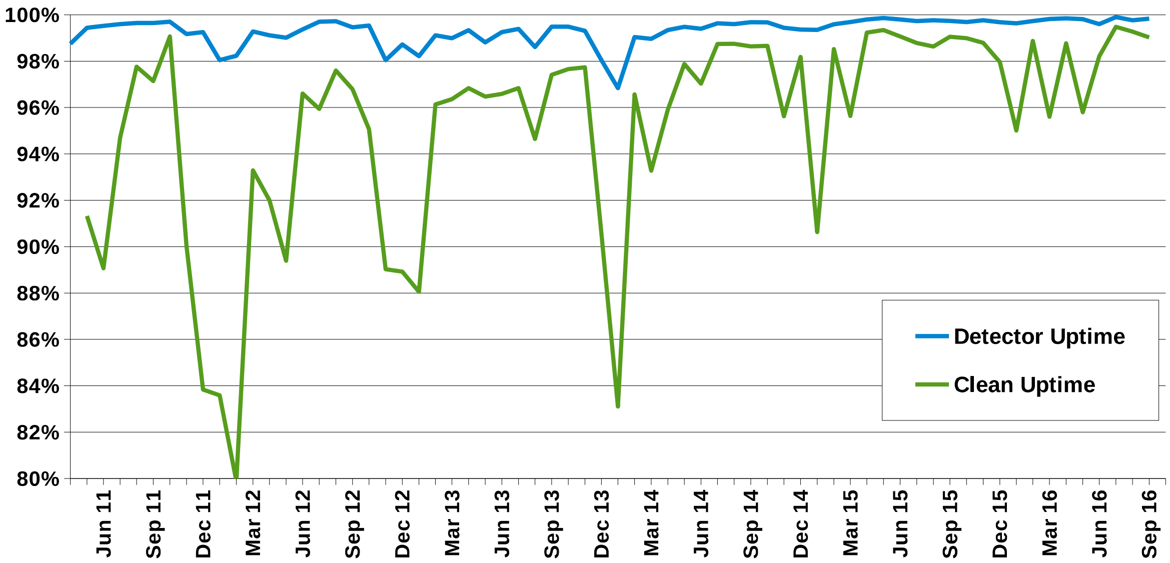

Figure 1: Total IceCube Detector Uptime and Clean Uptime

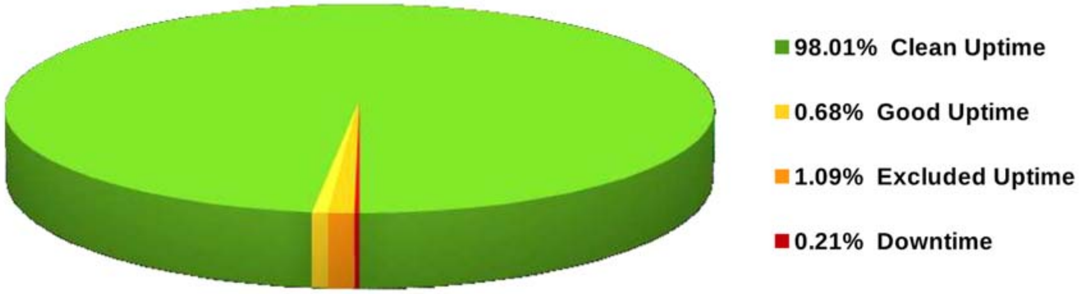

Figure 2: Cumulative IceCube Detector Time Usage, September 1, 2015 – March 1, 2016

Hardware Stability **—** The last DOM failures (2 DOMs) occurred during a power outage on May 22, 2013. No DOMs have failed during this reporting period. The total number of active DOMs remains 5404 (98.5% of deployed DOMs), plus four scintillator panels and the IceACT trigger mainboard. No custom data acquisition hardware components in the ICL have failed during the reporting period.

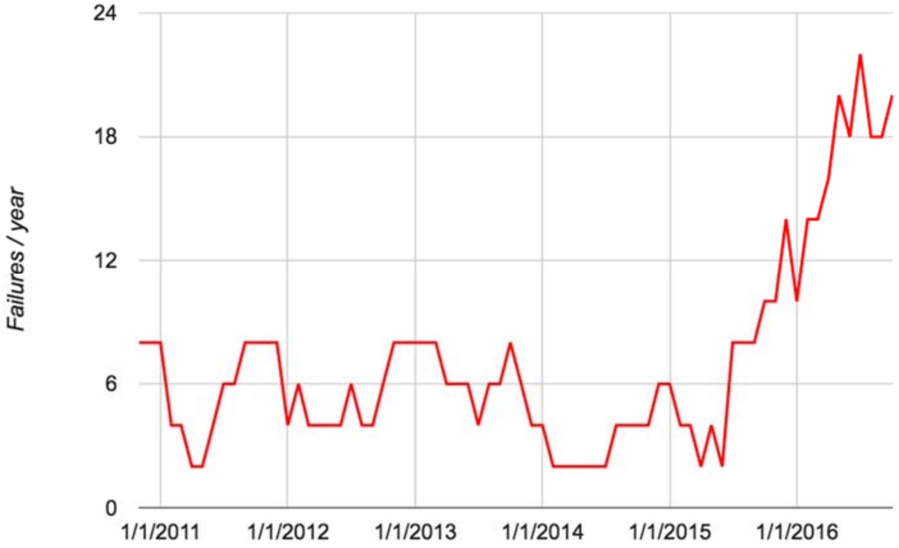

Figure 3: Acopian (DOM) power supply failure rate vs. time.

The failure rate in the commercial Acopian power supplies that supply the DC voltage to the DOMs from the DOMHubs has increased, starting in late 2015 (Figure 3). Sufficient spares at South Pole and prompt repair by the Winterovers have ensured no significant loss of clean uptime. No external cause of the increase can be identified, and the behavior is consistent with aging. Failed units from the past two seasons have been sent back to the manufacturer for analysis, leading to a modified design with improved robustness. We plan a complete replacement of the supplies this coming austral summer using the updated units from Acopian.

IC86 Physics Runs **—** The sixth season of the 86-string physics run, IC86–2016, began on May 20, 2016. Detector settings were updated using the latest yearly DOM calibrations from March 2016. Two new DAQ triggers were added to the configuration: an IceTop infill trigger, using the infill tanks in the core of the array to target low-energy cosmic ray air showers, and a scintillator calibration trigger. Filter changes include a new magnetic monopole search filter, a unified selection for optical and gamma-ray follow-up events, and retirement of the Galactic Center filter.

Starting with IC86–2015, we have implemented changes to the methodology for producing online quasi-real-time alerts. Neutrino candidate events at a rate of 3 mHz are now sent via Iridium satellite, so that neutrino coincident multiplets (and thus candidates for astrophysical transient sources) can be rapidly calculated and distributed in the Northern Hemisphere. This change enables significant flexibility in the type of fast alerts produced by IceCube. With the IC86–2016 release, we have completed this transition, retiring the South Pole analysis components and moving all follow-up analysis to WIPAC.

For this reporting period, the average TDRSS daily transfer rate is approximately 70 GB/day, which includes the yearly minimum from seasonal cosmic-ray rate variations. The bandwidth saved from filter optimizations has allowed us to reserve more for HitSpool data transfer, saving all untriggered IceCube hits within a time period of interest. We have recently added an alert mechanism by which we save HitSpool data around Fermi-LAT solar flares, in order to search for low-energy neutrino bursts from these events. We are also prepared to save HitSpool data around gravitational wave alerts from LIGO, when their new physics run starts.

Data Acquisition — The IceCube Data Acquisition System (DAQ) has reached a stable state, and consequently the frequency of software releases has slowed to the rate of 3–4 per year. Nevertheless, the DAQ group continues to develop new features and patch bugs. During the reporting period of March–October 2016, the following accomplishments are noted:

- Delivery of the pDAQ:New_Glarus release in May 2016, providing support for the new IceTop infill trigger, performance enhancements in the DOMHub components, and delivery of time calibration monitoring quantities to IceCube Live.

- Delivery of the pDAQ:One_Barrel release in September 2016, providing speed improvements to IceCube's primary trigger algorithm and better cleanup in the case that DOMs drop from data-taking.

- Work towards the next DAQ release in late 2016, which will include a major refactor towards separating the hub-based data processing from the run-based DAQ system to pare detector downtime to the absolute minimum.

Online Filtering — The online filtering system ("PnF") performs real-time reconstruction and selection of events collected by the data acquisition system and sends them for transmission north via the data movement system. In addition to the standard release for the IC86–2016 physics run start including the filter changes for the season, two additional releases (V16-07-01 and V16-07-02) addressed stability issues seen when delivering large quantities of monitoring data for the new I3Moni 2.0 system to IceCube Live.

All PnF monitoring quantities are now being delivered to the new system; an example is shown in Figure 4. Some instability has still been observed as seasonal event rates start to increase, and work is ongoing to address these issues.

Monitoring — The IceCube Run Monitoring system, I3Moni, provides a comprehensive set of tools for assessing and reporting data quality. IceCube collaborators participate in daily monitoring shift duties by reviewing information presented on the web pages and evaluating and reporting the data quality for each run. The original monolithic monitoring system processes data from various SPS subsystems, packages them in files for transfer to the Northern Hemisphere, and reprocesses them in the north for display on the monitoring web pages. In a new monitoring system under development (I3Moni 2.0), all detector subsystems report their data directly to IceCube Live. Major advantages of this new approach include: higher quality of the monitoring alerts; simplicity and easier maintenance; flexibility, modularity, and scalability; faster data presentation to the end user; and a significant improvement in the overall longevity of the system implementation over the lifetime of the experiment.

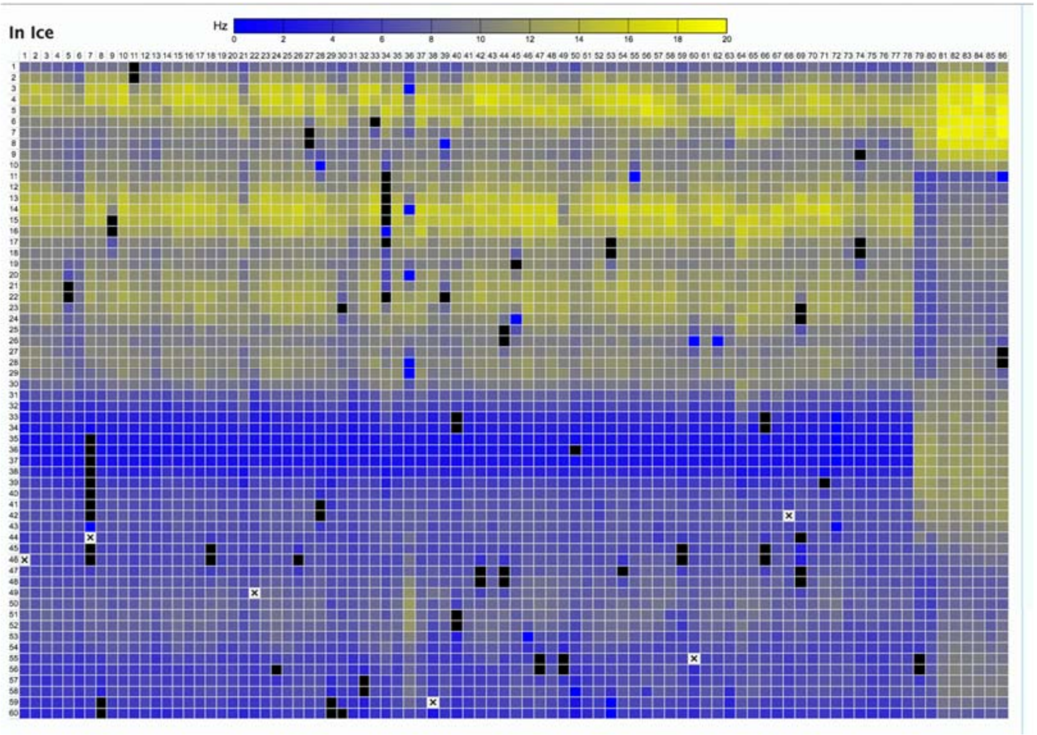

Figure 4: HLC launch rates for in-ice DOMs (the rate at which a DOM participates in an event in coincidence with a neighbor DOM), collected from PnF and displayed with the I3Moni 2.0 system. The effect of the horizontal dust layers in the ice is clearly visible.

The I3Moni 2.0 infrastructure for collecting the monitoring data is in place at SPS, and monitoring quantities are now being collected from all major subsystems and displayed on IceCube Live web pages (Figure 4). Since December 2015, the I3Moni 2.0 beta release has been active. The public release has been delayed from mid-2016 primarily due to the additional PnF development needed to deliver high-bandwidth monitoring quantities and is now planned for late 2016 or early 2017.

Experiment Control — Development of IceCube Live, the experiment control and monitoring system, is still quite active. This reporting period has seen one major release with the following highlighted features:

- Live v2.9.3 (May 2016): 31 separate issues and feature requests have been resolved. This release adds tracking of problematic DOMs within IceCube Live, support for script-initiated HitSpool requests from the Northern Hemisphere, and improvements to the beta release of the I3Moni 2.0 system.

Features planned for the next few releases include: continuing development of Moni2.0 into its public release, and creating or improving dedicated monitoring pages for the JADE, SNDAQ, and realtime follow-up subsystems. The uptime for the I3Live experiment control system during the reporting period was above 99.999%.

Supernova System — The supernova data acquisition system (SNDAQ) found that 99.77% of the available data from March 25th, 2016 through September 7, 2016 met the minimum analysis criteria for run duration and data quality for sending triggers. An additional 0.02% of the data is available in short physics runs with less than 10-minute duration. While forming a trigger is not possible in these runs, the data are available for reconstructing a supernova signal.

A new SNDAQ release (2016-09-09) was deployed that continues the cleanup of the build and deployment system. The build system has been completely revised and simplified and is now in line with other IceCube software. Efforts to include a data-driven trigger that is independent of an assumed signal shape are under way.

On July 30, 2016, a malfunctioning DOM caused the muon-subtraction calculation to report a false high-significance supernova alert. While this was quickly confirmed as a likely false alarm, the Winterovers followed the documented procedures and saved relevant secondary data. The error in the significance calculation has been corrected to make it robust against this rare DOM failure mode. Once power-cycled, the problematic DOM behaved normally again.

Calibration — The effect of refrozen "hole ice" on the angular response of the DOM continues to be studied with LED flashers. A new simulation and flasher analysis technique uses direct propagation of photons in the hole ice via GPUs to fit the width and effective optical scattering length "bubble column" seen with the Sweden Camera system (Figure 5). This technique has provided the first ability to distinguish between different hole ice models in simulation and has led to a new ice model, SpiceHD. The improvement in the overall model error is marginal, at 0.4%, but the method will for the first time allow detailed studies of the impact of hole ice properties on physics analyses.

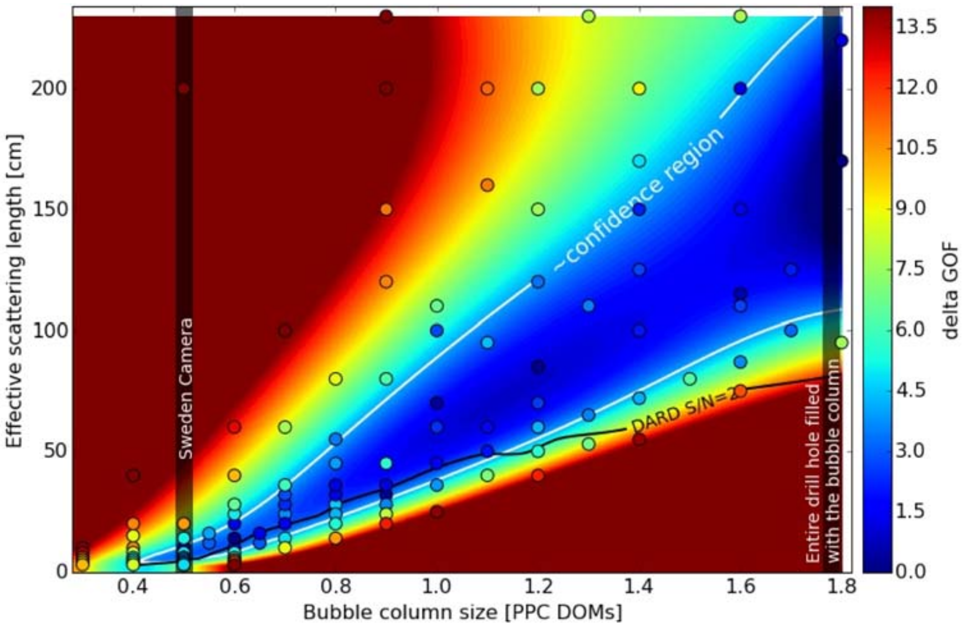

Figure 5: Hole ice bubble column parameter contours extracted with SpiceHD flasher fitting. The color scale indicates goodness-of-fit (GOF). The best-fit point suggests a bubble column diameter of 0.6 DOM diameter and an effective scattering length of 14 cm, close to the size observed by the Sweden Camera.

The 3–4% DOM-by-DOM gain corrections introduced in IC86–2015 were updated for the IC86–2016 physics run and are working well in the online PnF system. Because this shift is observable in some physics analyses, we are investigating a “Pass 2” reprocessing of data taken before 2015 to add these corrections. The gain corrections have been extracted from historical minimum bias data, and we are now developing the reprocessing scripts.

Surface Detectors — Snow accumulation on the IceTop tanks continues to reduce the trigger rate of the surface array by ~10%/year. Uncertainty in the attenuation of the electromagnetic component of air showers due to snow is the largest systematic uncertainty in IceTop’s cosmic ray energy spectrum measurement (Figure 6). The snow also complicates IceTop’s cosmic-ray composition measurements, as it makes individual air showers look “heavier” by changing the electromagnetic/muon ratio of particles in the shower.

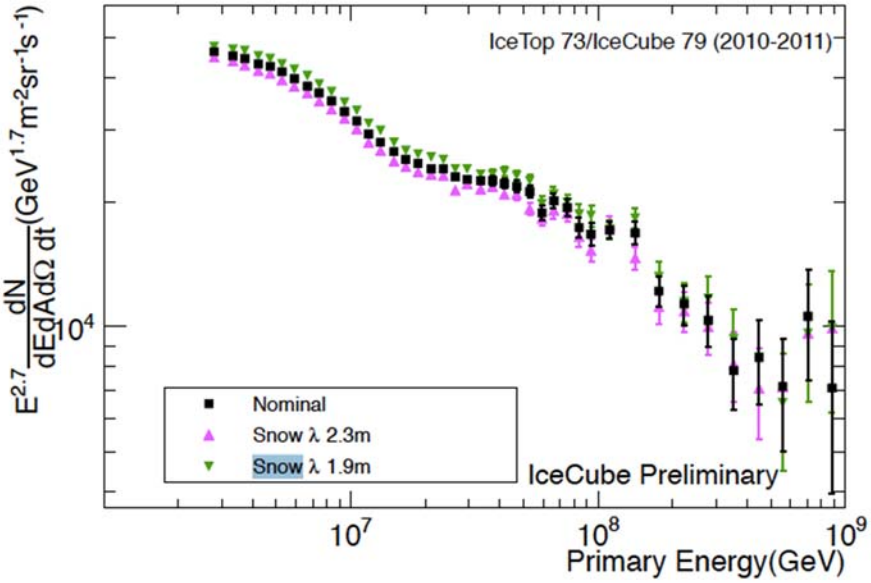

Figure 6: Cosmic ray energy spectrum measurement by IceTop, including the effects of varying the snow attenuation within uncertainties.

A recent decision by the NSF and the support contractor has been taken to stop any further snow management efforts. With this in mind, we are investigating techniques to restore the full operational efficiency of the IceCube surface component using plastic scintillator panels on the snow surface above the buried IceTop tanks.

Four scintillators were deployed during the 2015–16 pole season at IceTop stations 12 and 62. The initial deployment used spare tank freeze control cables left in place after deployment in order to read out the scintillator data and connect into the IceCube DAQ, with minimal changes necessary. Current efforts are focused on cross-checking the panel and tank responses, as well as understanding seasonal calibration changes with temperature. Development of a new version of the scintillators is underway, which will include a new digitization and readout system, a different photodetection technology (SiPMs), and a streamlined, lighter housing to ease deployment.

Additionally, a prototype air Cherenkov telescope (IceACT) was installed on the IceCube Lab. During the polar night, IceACT can be used to cross-calibrate IceTop by detecting the Cherenkov emission from cosmic ray air showers; it may also prove useful as a supplementary veto technique. After commissioning last austral summer, IceACT was uncovered at sunset and took data during the austral winter. The mainboard trigger system allowed cross-calibration of the time offset between IceTop and IceACT, and coincident events are being analyzed (Figure 7). Upgrades to the IceACT electronics and a new LED calibration system are planned for the 2016–17 pole season.

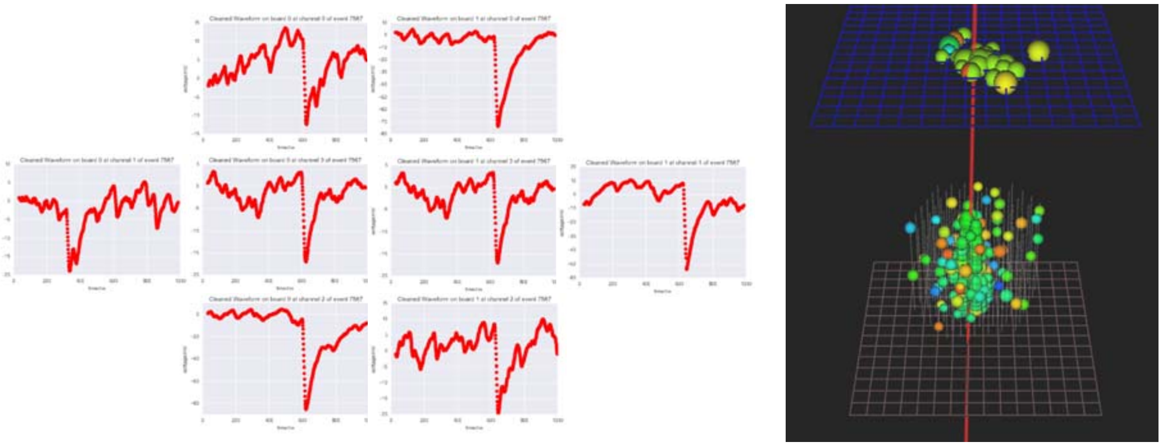

Figure 7: A cosmic ray air shower event detected both by IceACT (left, pixel waveforms) and IceTop+IceCube (right, event view display).

***Operational Communications & Real-time Alerts* —** Communication with the IceCube winterovers, timely delivery of detector monitoring information, and login access to SPS are critical to IceCube's high-uptime operations. Several technologies are used for this purpose, including interactive chat, ssh/scp, the IMCS e-mail system, and IceCube's own Iridium modem(s).

We have now developed our own Iridium RUDICS-based transport software (IceCube Messaging System, or I3MS) and have moved IceCube's monitoring data to our own Iridium modems as of the 2015–16 austral summer season. We retired the Iridium short-burst-data sytem (ITS) in October 2016 and will add its modem to the I3MS system to increase bandwidth.

Additionally, the contractor is installing a new antenna housing "doghouse" on the roof of the ICL this austral summer season. This will alleviate overcrowding and self-interference of antennas in the existing doghouse. We will commission the new doghouse this season but will operate both in parallel for the coming year. Assuming no problems are encountered, we plan to migrate the remaining antennas to the new housing in the 2017–18 season.

***Personnel* —** No changes.

Computing and Data Management

South Pole System – The main focus during this time period was on upgrading the Nagios/CheckMK central monitoring infrastructure for SP(T)S. Nagios Core was upgraded from version 3.5 to version 4.1, providing a significant performance improvement due to multi-threading ability of the new release. The new system is capable of processing multiple host and service checks in parallel and therefore allows for tighter check intervals and quicker notification to the operators in case of problems. The CheckMK plugin was upgraded to the latest 1.2.6p16 release, which includes miscellaneous bug fixes and minor enhancements. As part of this upgrade the notification system (email and paging) were re-written and implemented in a more flexible way that offers finer tuning on which conditions alarms can be triggered and whom to notify. As part of our efforts to fully manage our systems via the new central configuration management tool (Puppet) the entire server and client monitoring infrastructure for Nagios/CheckMK has been moved from the old kickstart profiles into Puppet. Additional check components, like monitoring of Mongo databases, etc., have been added to the setup and rolled out to appropriate machines at SPTS.

A significant amount of time was spent on training and (re-)hiring our new WinterOvers. Unfortunately, both of our primary candidates had to be replaced late in the training period. Due to the long time scales for review of medical information and lack of transparency during this process only one of our replacement WinterOvers could be hired in time to receive even very basic training in Madison. The second replacement operator will be trained on site. The current PQ review policies and PQ expiration policies are being addressed for next year in order to ensure continuity in operator training and availability as well as to help reduce the unnecessary costs associated with hiring multiple WinterOver candidates.

The cable and freezer test setups at the Physical Sciences Lab (PSL) were upgraded to operate on reliable UPS power. Power instabilities in these areas have caused problems for some of the ongoing tests, including scintillator & IceTop development. The new UPSes provide sufficient battery backup to ensure long-term system availability.

A new test server was installed for testing of a IceTop snow depth sensor. This new sensor will be deployed at South Pole during the upcoming season.

The RUDICS iridium installation at the IceCube Lab (ICL) is experiencing electro-magnetic interference as a result of the antennas being located too closely to each other and to other antennas. We filed a request with ASC/FEMC to build a second antenna shelter (“doghouse”) on top of ICL this season. After several detailed discussions with ASC over the last few months, it was eventually decided to move the “penthouse” structure, currently on top of the Baloon Inflation Facility (BIF), over to ICL. Building drawings and designs were submitted and iterated and ASC engineering has now signed off on the project and latest designs.

The usual annual security patches were successfully applied to the test machines in SPTS. Testing by the system experts is ongoing and if there are no problems identified these patches will be rolled out to SPS come November.

As an ongoing process, several components of our automated system install procedures were moved out of the kickstart and into the new Puppet configuration tool. New Puppet modules were produced and tested at SPTS and are scheduled to be rolled out to South Pole.

A new firmware release will be rolled out to the Dell SonicWall firewalls at Pole together with some configuration changes to improve failover reliability in case one of the units goes down.

To ensure uninterrupted data taking for the next year we ordered, tested and shipped over 4,000lbs of cargo to South Pole via NSF's cargo stream. This includes batteries to replenish ~50% of our UPSes, replacements for the ATX and Acopian power supplies in all of our DOMHub readout computers, as well as miscellaneous spare parts used during the current winter (hard drives, power supplies, etc.).

Data Movement – Data movement has performed nominally over the past six months. Figure 8 shows the daily satellite transfer rate and weekly average satellite transfer rate in GB/day through September 2016. The IC86 filtered physics data are responsible for 95% of the bandwidth usage. One can notice in the Figure that the daily transfer rates have been quite stable during the reporting period.

After fully replacing the old data handling system at the South Pole by the new software JADE in December 2015, in April 2016 we completed the replacement of the Northern hemisphere part of the data transfer system. The INGEST software that had been running since 2005 for receiving the data from the SPTR satellite system and storing it in the data warehouse at UW-Madison was replaced by the new JADE software. The new software is much more stable and resilient than its predecessor. This has been confirmed by the last months experience from the winterovers and IT staff at UW-Madison operating the system, which has run smoothly with less maintenance effort.

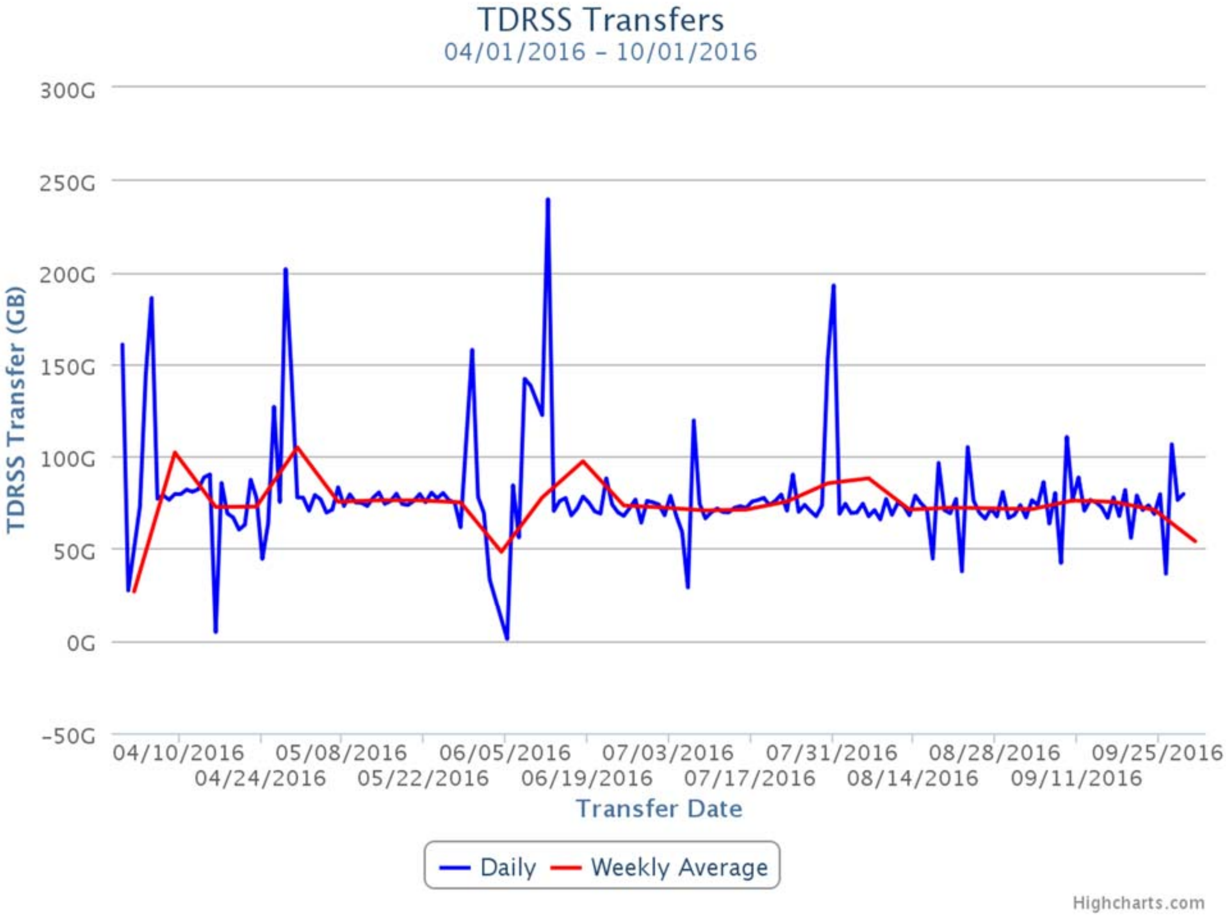

Figure 8: TDRSS Data Transfer Rates, April 1, 2016–September 31, 2016. The daily transferred volumes are shown in blue and, superimposed in red, the weekly average daily rates are also displayed.

Data Archive – The IceCube raw data are archived to two copies on independent hard disks. During the reporting period (April 2016 to September 2016) a total of 432 TB of data were archived to disk (including the two copies) averaging 2.4 TB/day. A total of 14 TB of data were sent over TDRSS satellite, averaging 76.7 GB/day.

In May 2016, we started using the new JADE software for handling the raw data received from the South Pole. This data arrives to Madison once a year and represents about 400 TB of files that have been recorded in archival disk drives at the South Pole during the previous year. Once JADE has processed the files, their metadata is indexed and the files are ready for being replicated to the long term archive.

In December 2015, a Memorandum of Understanding was signed between UW-Madison and NERSC/LBNL by which NERSC agreed to provide long-term archive services for the IceCube data until 2019. By implementing the long-term archive functionality using a storage facility external to the UW-Madison data center, we can aim for a better service at lower cost, since large facilities that routinely manage data at the level of hundreds of petabytes benefit of economies of scale that ultimately make the process more efficient and economical.

During the reporting period, additional functionality has been developed as part of the JADE software that allows handling the long-term archive data flows. One of the main requirements driving this development is the need for bundling small files into larger ones of few hundred Gigabytes size, in order to ensure that the tape drives operate in a high efficiency regime. The first version of JADE that was able to manage long-term archive data flows was available in September. Since then, we have been using it to bundle IceCube data files at UW-Madison and transfer them to NERSC at a rate of up to 5TB/day. The plan is to keep this archive flow constantly active while working on further JADE functionality that will allow us to steadily increase the performance.

Computing Infrastructure at UW-Madison –The total amount of data stored on disk in the data warehouse at UW-Madison is 4994 Terabytes[1] (TB): 1023 TB for experimental data, 3735 TB for simulation and analysis and 236 TB for user data.

Two Dell Compellent SCv2080 appliances, each containing 168 4TB drives, were purchased during the reporting period to expand the capacity of the data warehouse. The main need for additional space was mostly to have room to handle the raw data received yearly from the South Pole, which is now ingested into the system as soon as archival hard drives arrive to Madison. The first appliance was brought online in May, and the second one in August. Together they added up about 1024 TB of usable space to the system.

Unfortunately, a configuration mistake was made in the deployment of the first appliance by which the space allocated was larger than the one actually available. This caused the appliance to fill up to 100% and enter read-only emergency mode on July 15th. As a consequence of this, one of the main file systems was unavailable until the appliance could be restored on July 19th with the help of Dell support. On July 21st a hardware error in the controllers of that same appliance triggered another crash of the file system. This time the damage was larger and the final recovery involved restoring the file system metadata from backup. In order to manage the risk in handling this delicate situation, we took the decision to contract Lustre support for the affected file system. With the help from support, the system was finally recovered on August 5th. About 110,000 files were lost as a result of this incident, less than 0.1% of the total. Fortunately, all the lost files were processed or simulated data that could be re-generated within days. A number of actions were taken to ensure an incident like this does not happen again: implementing consistent policies for backing up metadata servers in all our filesystems, deploying metadata targets in shared storage in order to be able to configure MDS servers in High Availability mode, or upgrading Lustre servers to the last stable version are some examples. The contacted Lustre support will be very helpful in streamlining all these actions as well as in addressing any potential issues in the future.

The IceCube computing cluster at UW-Madison has continued to deliver reliable data processing services. Boosting the GPU computing capacity has been a high priority of the project since the Collaboration decided to use GPUs for the photon propagation part of the simulation chain back in 2012. Direct photon propagation was found to provide the precision required, and it happens to be very well suited for the GPU hardware, running about 100 times faster than in CPUs.

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[1] 1 Terabyte = 10^{12} bytes

An expansion of the GPU cluster was purchased in September, consisting of seven SuperMicro 4027GR-TR chassis each containing eight Nvidia GTX 1080 GPU cards, two Xeon E5-2637 v4 processors, 64 GB of RAM and 2TB of disk. This cluster has been deployed at the Wisconsin Institutes for Discovery (WID) datacenter and it has replaced the old IceCube GPU cluster that was deployed there in January 2012. The Memorandum of Understanding signed by the WID IT department, the Center for High Throughput Computing (CHTC) and WIPAC by which WIPAC could host one rack of GPU servers at WID in exchange of sharing 30% of the cluster with CHTC is still active and was used to update this cluster. The new servers provide a compute power about five times larger than the old ones, using the same amount of electrical power.

After this upgrade, the IceCube GPU cluster at UW-Madison has a total of 376 GPU cards. The breakdown of GPU types and purchase years is as follows:

- 56 GPUs Nvidia GTX 1080, purchased in September 2016
- 256 GPUs Nvidia GTX 980, purchased in November 2014
- 32 GPUs Nvidia GTX 690, purchased in June 2013
- 32 GPUs AMD ATI Radeon 7970, purchased in June 2013

The focus for the GPU cluster is to provide the required capacity to fulfill the Collaboration direct photon propagation simulation needs. These needs have been estimated to be around 30% higher than the capacity of the GPU cluster at UW-Madison. Additional GPU resources at several IceCube sites, plus XSEDE allocations, allow us to provide that required capacity.

Distributed Computing – In March 2016, a new procedure to formally gather computing pledges from collaborating institutions was started. This data will be collected twice a year as part of the already existing process by which every IceCube institution updates its MoU before collaboration weeks. Institutions that are pledging computing resources for IceCube are asked to provide two figures: the average number of CPUs and GPUs that they commit to provide for IceCube simulation production during the next period. Table 1 shows the computing pledges per institution as of September 2016:

Site	**Pledged CPUs**	**Pledged GPUs**
Aachen	83	29
Alabama		6
Canada	1055	41
Brussels		14
Chiba	196	6
Delaware	272	
DESY-ZN	1050	160
Dortmund	2642	10
LBNL	114	
Mainz	24	8
Marquette	60	16

MSU	500	8
UMD	350	24
UW-Madison	700	301
TOTAL	7046	622

Table 1: Computing pledges for simulation production from IceCube Collaboration institutions as of September 2016.

The plan is to implement a feedback planning process by which the numbers from available resources from computing pledges are regularly compared to the simulation production needs and resources used. The goal is to be able to mange more efficiently the global resource utilization and to be able to react to changes in computing needs required to meet IceCube science goals.

A strong focus has been put in the last years to expand the distributed infrastructure and make it more efficient. The main strategy to accomplish this has been to simplify the process for sites to join the IceCube distributed infrastructure, and also to reduce the effort needed to keep sites connected to it. To do this, we have progressively implemented an infrastructure based on Pilot Jobs. Pilot Jobs provide a homogeneous interface to heterogeneous computing resources. Also, they enable more efficient scheduling by delaying the decision of matching resources to payload.

In order to implement this Pilot Job paradigm for the distributed infrastructure IceCube makes use of some of the federation technologies within HTCondor[2]. Pilot Jobs in HTCondor are called “glideins” and consist of a specially configured instance of the HTCondor worker node component, which is then submitted as a job to external batch systems.

Several of the sites that provide computing for IceCube are also resource providers for other scientific experiments that make use of distributed computing infrastructures. Thanks to this they already provide a standard (Grid) interface to their batch systems. In these cases we can leverage the standard GlideinWMS infrastructure operated by the Open Science Grid[3] project for integrating those resources into the central pool at UW-Madison and provide transparent access to them via the standard HTCondor tools. The sites that use this mechanism to integrate with the IceCube global workload system are: Aachen, Canada, Brussels, DESY, Dortmund, Wuppertal and Manchester.

Following the negotiations to integrate Manchester in the IceCube distributed infrastructure, in June the UK Grid management (GridPP) officially took the decision to support IceCube across the UK sites and added it to the list[4] of UK approved VOs. This is a nice example of the advantages we see of using standard tools and interfaces for building the IceCube distributed system.

Some of the IceCube collaborating institutions that provide access to local computing resources

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[2] http://research.cs.wisc.edu/htcondor/

[3] https://www.opensciencegrid.org/

[4] https://www.gridpp.ac.uk/wiki/GridPP_approved_VOs

do not have a Grid interface. Instead, access is only possible by means of a local account. To address these cases we developed a lightweight version of a glidein Pilot Job factory that can be deployed as a cron job in the user's account. The codename of this software is "pyGlidein" and it allows us to seamlessly integrate these local cluster resources with the IceCube global workload system so that jobs can run anywhere in a way which is completely transparent for users. The sites that currently use this mechanism are: Canada, Brussels, DESY, Mainz and MSU. There are ongoing efforts at the Delaware, Chiba and LBNL sites to deploy the pyGlidein system.

Beyond the computing capacity provided by IceCube institutions, and the opportunistic access to Grid sites that are open to share their idle capacity, IceCube started exploring the possibility of getting additional computing resources from targeted allocation requests submitted to Supercomputing facilities such as the NSF Extreme Science and Engineering Discovery Environment (XSEDE). In October 2015 a research allocation was submitted to XSEDE that obtained positive reviews and was finally awarded a sizeable amount of resources (allocation number TG-PHY150040). The allocation included compute time in two GPU-capable systems: Comet[5], with 5.543.895 Service Units (SU) granted, and Bridges[6], with 512.665 SU.

The integration with Comet was completed with the support of XSEDE ECSS resources in March with no major issues. This could be done relatively quickly since this system was already in production and it had a friendly interface to the two core components of the IceCube distributed workload system: software distribution via CVMFS and Pilot Job framework based in HTCondor glideins. The graph in Figure 9 shows the Comet utilization by IceCube jobs as seen in the XSEDE accounting portal. This shows that we can integrate specialized resources such as XSEDE supercomputers with the IceCube workload system and make use of them for several months in a sustained manner. It should be pointed out though that the Comet system has a limited amount of GPU nodes (36 nodes with two Nvidia K80 each) therefore the total GPU capacity in this machine is quite limited. In particular IceCube can not fully utilize its allocated 5.543.895 SUs using only GPU time. In order to be able to make maximal usage of the allocated resources, we are currently considering the possibility of requesting a 6 months extension for the XSEDE allocation, plus studying the possibility of transferring part of the Comet allocation into other systems with larger GPU capacity such as XStream[7].

The Bridges XSEDE system, at the Pittsburgh Supercomputing Center, was not fully commissioned until May 2016. We were in contact with the local administrators to prepare the system to be usable by IceCube. A special configuration had to be developed to enable outgoing connectivity from the worker nodes as required by the Pilot Job system. This was in place in August. Since then we have been testing the system and adapting IceCube workloads to use the CentOS7 Operating System. Bridges is the first site in production using CentOS7 for IceCube, therefore some adaptation work is required.

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[5] https://portal.xsede.org/sdsc-comet
[6] https://portal.xsede.org/psc-bridges
[7] https://portal.xsede.org/stanford-xstream

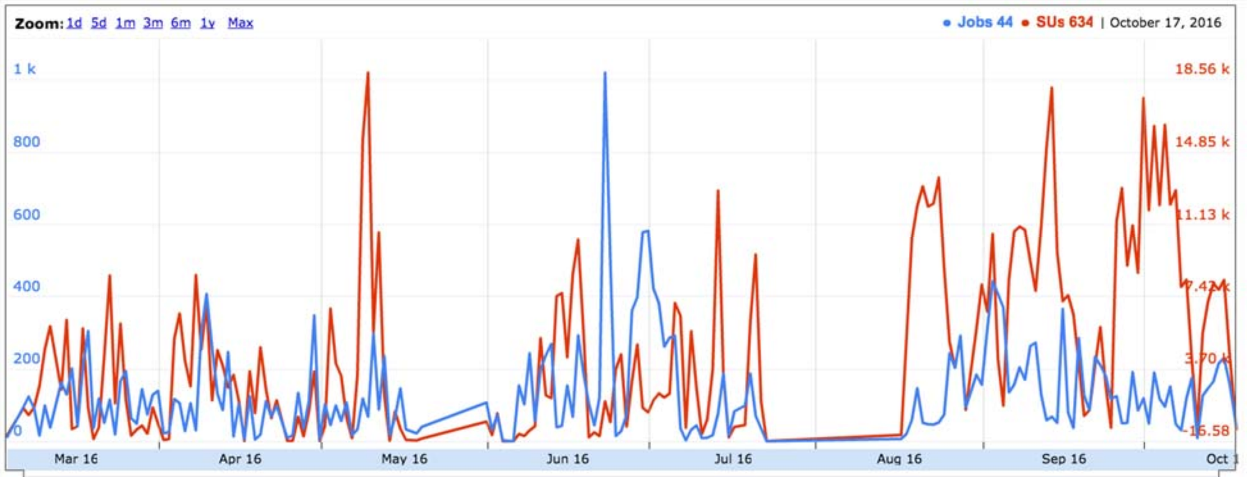

Figure 9: Usage accounting for the IceCube allocation TG-PHY150040 in the Comet system. Source: xsede.org portal.

Data Reprocessing – At the end of 2012, the IceCube Collaboration agreed to store the compressed SuperDST as part of the long-term archive of IceCube data. The decision taken was that this change would be implemented from the IC86-2011 run onwards. A server and a partition of the main tape library for input were dedicated to this data reprocessing task. Raw tapes are read to disk and the raw data files processed into SuperDST, which is saved in the data warehouse. Now that all tapes from the Pole are in hand, we plan to complete the last 10% of this reprocessing task. The total number of files for seasons IC86-2011, IC86-2012 and IC86-2013 is 695,875; we have 67,812 remaining to be processed. The file breakdown per year is as follows: IC86-2011: 221,687 already processed out of 236,611. IC86-2012: 215,934 processed out of 222,952. IC86-2013: 190,442 processed out of 236,312. About 58,000 of the remaining files are in about 100 tapes; the rest are spread over about another 350. Tape dumping procedures are being integrated with the copy of raw data to NERSC.

Offline Data Filtering – The data collection for the IC86-2016 season started on May 20 2016. A new compilation of data processing scripts had been previously validated and benchmarked with the data taken during the 24-hour test run using the new configuration. The differences with respect to the IC86-2015 season scripts are minimal. Therefore, we estimate that the resources required for the offline production will be about 750,000 CPU hours on the IceCube cluster at UW-Madison datacenter. 120TB of storage is required to store both the Pole-filtered input data and the output data resulting from the offline production. In the first three months we had to re-process five weeks of Level2 data due to database issues. The cause of this problem will be resolved for next season since we replaced the entire database structure. After this issue no problems have occurred and the data processing is proceeding. Level2 data are typically available one and a half weeks after data taking.

In order to ensure correct re-production of Level2 and Level3 data, additional metadata have been added for each set of run files that include, for instance, software versions for each processing step and personnel in charge.

Additional data validations have been added to detect data value issues and corruption. Replication of all the data at the DESY-Zeuthen collaborating institution is being done in a timely manner.

Level3 data production is currently executed for three physics analysis groups. The Level3 data for the current season is usually available eight hours after Level2 completion. This short latency has been realized by fully automating Level3 and partly automating Level2 data processing. The Level3 production in the last six months included more than five years of data. The cataloging and bookkeeping for Level3 data is the same as for Level2.

Simulation – The production of IC86 Monte Carlo simulations of the IC86-2012 detector configuration concluded in October of 2016. A new production of Monte Carlo simulations has since begun with the IC86-2016 detector configuration. This configuration is representative of previous trigger and filter configurations from 2012, 2013, 2014 and 2015 as well as 2016. As with previous productions, direct generation of Level 2 simulation data is now used to reduce storage space requirements. This transition also included a move to a new release of the IceCube simulation software release, IceSim 5. IceSim 5 contains improvements in memory and GPU utilization in addition to previous improvements to correlated noise generation, Earth modeling, and lepton propagation. All current simulations are now based on direct photon propagation using GPUs or a hybrid of GPU and splined photon PDF tables for high-energy events. Direct photon propagation is currently done on dedicated GPU hardware located at several IceCube Collaboration sites and through opportunistic grid computing where the number of such resources continues to grow.

The simulation production sites are: CHTC – University of Wisconsin campus; Dortmund; DESY-Zeuthen; University of Mainz; EGI – German grid; WestGrid – U. Alberta; PSU – Pennsylvania State University;UMD – University of Maryland; RWTH Aachen; IIHE – Brussels; Ruhr-Uni – Bochum; Michigan State University - ICER; The Extreme Science and Engineering Discovery Environment (XSEDE); Niels Bohr Institute, Copenhagen Denmark; PDSF/Carver/Dirac – LBNL; Open Science Grid; and NPX – UW IceCube.

Personnel – Ian Saunders left WIPAC in June 2016 to work in Hitachi Data Systems. A new Linux system administrator position to work on the IceCube distributed computing infrastructure was posted and filled in by Vladimir Brik. A new Linux system administrator position to work on the UW-Madison cluster and VM infrastructure has been posted and is currently open.

Data Release

Data Use Policy – IceCube is committed to the goal of releasing data to the scientific community. The following links contain data sets produced by AMANDA/IceCube researchers along with a basic description. Due to challenging demands on event reconstruction, background rejection and systematic effects, data will be released after the main analyses are completed and results are published by the international IceCube Collaboration.

Datasets (last release on 24 Jun 2016): http://icecube.wisc.edu/science/data
The pages below contain information about the data that were collected and links to the data files.

Search for sterile neutrinos with one year of IceCube data:

http://icecube.wisc.edu/science/data/IC86-sterile-neutrino

The 79-string IceCube search for dark matter:

http://icecube.wisc.edu/science/data/ic79-solar-wimp

Observation of Astrophysical Neutrinos in Four Years of IceCube Data:

http://icecube.wisc.edu/science/data/HE-nu-2010-2014

Astrophysical muon neutrino flux in the northern sky with 2 years of IceCube data:

https://icecube.wisc.edu/science/data/HE_NuMu_diffuse

IceCube-59: Search for point sources using muon events:

https://icecube.wisc.edu/science/data/IC59-point-source

Search for contained neutrino events at energies greater than 1 TeV in 2 years of data:

http://icecube.wisc.edu/science/data/HEnu_above1tev

IceCube Oscillations: 3 years muon neutrino disappearance data:

http://icecube.wisc.edu/science/data/nu_osc

Search for contained neutrino events at energies above 30 TeV in 2 years of data:

http://icecube.wisc.edu/science/data/HE-nu-2010-2012

IceCube String 40 Data:

http://icecube.wisc.edu/science/data/ic40

IceCube String 22–Solar WIMP Data:

http://icecube.wisc.edu/science/data/ic22-solar-wimp

AMANDA 7 Year Data:

http://icecube.wisc.edu/science/data/amanda

IceCube Software Coordination **–** The software systems spanning the IceCube Neutrino Observatory, from embedded data acquisition codes to high-level scientific data processing, benefit from concerted efforts to manage their complexity. In addition to providing comprehensive guidance for the development and maintenance of the software, the IceCube Software Coordinator, Alex Olivas, works in conjunction with the IceCube Coordination Committee, the IceCube Maintenance and Operations Leads, the Analysis Coordinator, and the Working Group Leads to respond to current operational and analysis needs and to plan for anticipated evolution of the IceCube software systems.

Program Management

Management & Administration – The primary management and administration effort is to ensure that tasks are properly defined and assigned and that the resources needed to perform each task are available when needed. Efforts include monitoring that resources are used efficiently to accomplish the task requirements and achieve IceCube's scientific objectives.

- The FY2016-FY2021 M&O Plan was submitted in June 2016.
- The detailed M&O Memorandum of Understanding (MoU) addressing responsibilities of each collaborating institution was revised for the collaboration meeting in Stony Brook, April 16-22, 2016.

IceCube M&O – PY1 (FY2016/2017) Milestones Status:

Milestone	**Month**
Revise the Institutional Memorandum of Understanding (MOU v20.0) - Statement of Work and Ph.D. Authors head count for the spring collaboration Meeting	**April 2016**
Report on Scientific Results at the Spring Collaboration Meeting	**April 16-22, 2016**
Submit for NSF approval, a revised IceCube Maintenance and Operations Plan (M&OP) and send the approved plan to non-U.S. IOFG members.	**June 2016**
Revise the Institutional Memorandum of Understanding (MOU v21.0) - Statement of Work and Ph.D. Authors head count for the fall collaboration meeting	**September 2016**
Report on Scientific Results at the Fall Collaboration Meeting	**Sept. 26-30, 2016**
Submit for NSF approval a mid-year report which describes progress made and work accomplished based on objectives and milestones in the approved annual M&O Plan.	**October 2016**
Revise the Institutional Memorandum of Understanding (MOU v22.0) - Statement of Work and Ph.D. Authors head count for the spring collaboration meeting	April 2017

Engineering, Science & Technical Support – Ongoing support for the IceCube detector continues with the maintenance and operation of the South Pole Systems, the South Pole Test System, and the Cable Test System. The latter two systems are located at the University of Wisconsin–Madison and enable the development of new detector functionality as well as investigations into various operational issues, such as communication disruptions and electromagnetic interference. Technical support provides for coordination, communication, and assessment of impacts of activities carried out by external groups engaged in experiments or potential experiments at the South Pole. The IceCube detector performance continues to improve as we restore individual DOMs to the array at a faster rate than problem DOMs are removed during normal operations.

Education & Outreach (E&O) – The IceCube collaboration continues to make progress on E&O efforts organized around four main themes:

1) Reaching motivated high school students and teachers through IceCube Masterclasses
2) Providing intensive research experiences for teachers (in collaboration with PolarTREC) and for undergraduate students (NSF science grants, International Research Experience for Students (IRES), and Research Experiences for Undergraduates (REU) funding)
3) Engaging the public through web and print resources, graphic design, webcasts with IceCube staff at the Pole, and displays
4) Developing and implementing semiannual communication skills workshops held in conjunction with IceCube Collaboration meetings.

New initiatives include citizen science and immersive and interactive learning projects to engage the public in STEM research and related activities. The citizen science project was encouraged by the M&O review panel to increase the reach of IceCube's E&O activities. The goal is for the public to participate in activities that help advance scientific research. Summer students at UW–Madison and UWRF worked on projects based on the Zooniverse platform that prompt amateur scientists to find interesting neutrino events that aren't identified with current computer algorithms. Through NSF's Advancing Informal STEM Learning projects, WIPAC is partnering with the Wisconsin Institutes for Discovery to create interactive and immersive learning programs based on touch tables and virtual reality devices. The groups will compare game-based learning strategies for different audiences using these technologies and further develop current IceCube virtual reality experiences for larger audiences. This two-year project is a pilot grant for larger projects involving research in Antarctica.

The IceCube Masterclasses continue to be promoted within the collaboration, to recruit more participation of IceCube institutions and to develop new topics, as well as externally at national and international levels. A workshop featuring the IceCube Masterclasses has been accepted and will be offered at the 2017 summer American Association of Physics Teachers meeting in Cincinnati, Ohio. The IceCube cosmic ray masterclass was held in conjunction with a special lecture series, *Recent Discoveries in Particle and Astroparticle Physics*, at Sungkyunkwan University at Suwon, Korea, on August 18, 2016. The IceCube Masterclasses were also described in a talk at the Scientific Committee on Antarctic Research meeting in Kuala Lumpur, Malaysia, on August 22, 2016.

Plans are coalescing for deployment to the South Pole in the 2016-17 season for PolarTREC teacher Kate Miller, a physics teacher from Washington-Lee High School in Arlington, VA. Kate worked with former IceCube PolarTREC teacher Liz Ratliff and TEA teacher Eric Muhs, who deployed with the AMANDA project in the 2011-12 season. They developed and delivered a nine-day math-science enrichment course that included IceCube research for the UW–River Falls Upward Bound program (July 11-22, 2016). IceCube PolarTREC teacher Armando Cassuade, 2014-15 season, published a book on his experiences with IceCube, A Puerto Rican in the South Pole.

Five undergraduate students (two women, one of whom is African American) worked at Stockholm University for ten weeks in the summer of 2016, supported by NSF IRES funding. The students are from UW–River Falls, UW–Madison, and the University of Minnesota. The UW–River Falls astrophysics NSF REU program supported six students (two men, one of whom is African American, four students total from two-year colleges) from over 60 applicants for ten-week summer 2016 research experiences, including attending the WIPAC IceCube software and science boot camp. Multiple IceCube institutions also supported undergraduates. Two of the students from the 2015 UWRF IRES program attended the IceCube Collaboration meeting in April, 2016, at Stony Brook, NY.

The IceCube scale model, with one colored LED for each of the 5,160 DOMs and audio mapping of the data, was seen by thousands of people at the World Science Festival in New York City on June 5, 2016. It was also featured in a New York Times Science Facebook Live event. A more transportable 1m x 1m x 1m model is under construction at York University with art/science professor Mark-David Hosale as well as at Stockholm and Drexel Universities. The model at Drexel University was completed as a part of their first high school internship program.

The E&O team continues to work closely with the communication team. Science news summaries of IceCube publications, written at a level accessible to science-literate but nonexpert audiences, are produced and posted regularly on the IceCube website and highlighted on social media. Ten research news articles were published in the review period along with seven project updates. Results of the IceCube sterile neutrino search were featured in press releases at a few IceCube institutions and included a video and new multimedia resources. The video was watched over 12,000 times in two months and was embedded in space.com and Wisconsin State Journal websites, reaching many more viewers. Media mentions, tracked since January 2016, include over 200 news pieces appearing in 20 different countries, with over 60% of those in the US. In addition to national and international coverage in the media, we have documented local news mentions in twelve different U.S. states and in Puerto Rico.

The communication training program targeting PhD students and postdocs, launched at the spring 2015 IceCube Collaboration in Madison, continues to be held during the biannual collaboration meetings. The spring training in Stony Brook featured an interactive presentation from The Story Collider group focusing on using narratives to explain research, connecting to audiences in meaningful ways, and engaging in cultural conversations about science. At Mainz University in September, participants had podcast training in which they thought about storytelling as a way to share their research and learned about the equipment needed to produce podcasts.

Finally, the IceCube Diversity and Inclusion task force was launched in September 2016. This new initiative is hosted by the E&O and communications teams and includes several other researchers and staff who have volunteered their time to lead and promote activities to increase diversity within the IceCube Collaboration, including fostering a more inclusive and supportive work environment for all, and contribute to the advancement of a more diverse student and workforce population in STEM fields, especially in the U.S.

Section III – Project Governance and Upcoming Events

The detailed M&O institutional responsibilities and Ph.D. author head count is revised twice a year at the time of the IceCube Collaboration meetings. This is formally approved as part of the institutional Memorandum of Understanding (MoU) documentation. The MoU was last revised in September 2016 for the Fall collaboration meeting in Mainz, Germany (v21.0), and the next revision (v22.0) will be posted in April 2017 at the Spring collaboration meeting in Madison, WI.

IceCube Collaborating Institutions

Following the April 2016 Spring collaboration meeting, Universität Münster with Dr. Alexander Kappes as the institutional lead, and SNOLAB with Dr. Ken Clark as the institutional lead, were approved as full members of the IceCube Collaboration. University of Toronto left IceCube after Dr. Ken Clark moved from Toronto to SNOLAB.

After the September 2016 Fall collaboration meeting, the University of Texas at Arlington with Dr. Benjamin Jones as the institutional lead joined the IceCube Collaboration, and the University of Mons left IceCube.

As of September 2016, the IceCube Collaboration consists of 48 institutions in 12 countries (25 U.S. and Canada, 19 Europe and 4 Asia Pacific).

The list of current IceCube collaborating institutions can be found on:

http://icecube.wisc.edu/collaboration/collaborators

IceCube Major Meetings and Events

Software & Computing Advisory Panel (SCAP) Review, Madison, WI	March 21-22, 2016
IceCube Spring Collaboration Meeting – Columbia / Stony Brook, New York	April 16-22, 2016
IceCube Fall Collaboration Meeting – Mainz, Germany	September 26-30, 2016

Acronym List

CnV	Calibration and Verification
CPU	Central Processing Unit
CVMFS	CernVM-Filesystem
DAQ	Data Acquisition System
DOM	Digital Optical Module
E&O	Education and Outreach
I3Moni	IceCube Run Monitoring system
IceCube Live	The system that integrates control of all of the detector's critical subsystems; also "I3Live"
IceTray	IceCube core analysis software framework, part of the IceCube core software library
MoU	Memorandum of Understanding between UW–Madison and all collaborating institutions
PMT	Photomultiplier Tube
PnF	Processing and Filtering
SNDAQ	Supernova Data Acquisition System
SPE	Single photoelectron
SPS	South Pole System
SuperDST	Super Data Storage and Transfer, a highly compressed IceCube data format
TDRSS	Tracking and Data Relay Satellite System, a network of communications satellites
TFT Board	Trigger Filter and Transmit Board
WIPAC Wisconsin IceCube Particle Astrophysics Center	