IceCube Maintenance and Operations
Fiscal Year 2019 / 2020 PY4 Annual Report

April 1, 2019 – March 31, 2020

Submittal Date: March 20, 2020

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 FY2019/2020 (PY4) Annual Report is submitted as required by the NSF Cooperative Agreement PLR-1600823. This report covers the 11-month period beginning April 1, 2019 and concluding February 29, 2020. The status information provided in the report covers actual common fund contributions received through February 29, 2020 and the full 86-string IceCube detector (IC86) performance through February 28, 2020.

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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.

A total amount of $7,000,000 was released to UW–Madison to cover the costs of maintenance and operations in PY4 (FY2019/FY2020): $969,150 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 $6,030,850 was directed to the IceCube M&O Core account (Table 1). An additional $291,712 FY2019 funding was awarded to support an IceCube M&O supplemental proposal to further develop talent for STEM research, increase diversity and inclusion in science and related fields, and connect research-based skills and technology to societal challenges.

PY4: FY2019 / FY2020	Funds Awarded to UW for Apr 1, 2019 – March 31, 2020
IceCube M&O Core account	$6,030,850
U.S. Common Fund account	$969,150
TOTAL NSF Funds	**$7,000,000**

Table 1: NSF IceCube M&O Funds – PY4 (FY2019 / FY2020)

Of the IceCube M&O PY4 (FY2019/2020) Core funds, $981,015 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 FY2019/2020 funds for the subawardee institutions.

Institution	Major Responsibilities	Funds
Lawrence Berkeley National Laboratory	DAQ maintenance, computing infrastructure	$92,001
Pennsylvania State University	Computing and data management, simulation production, DAQ maintenance	$71,908
University of Delaware, Bartol Institute	IceTop calibration, monitoring and maintenance	$151,720
University of Maryland at College Park	IceTray software framework, online filter, simulation software	$611,444
University of Alabama at Tuscaloosa	Detector calibration, reconstruction and analysis tools	$24,963
Michigan State University	Simulation software, simulation production	$28,979
South Dakota School of Mines and Technology (added in July 2017)	Simulation production and reconstruction	$00.00
Total		**$981,015**

Table 2: IceCube M&O Subawardee Institutions – PY4 (FY2019/2020) 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 eleven months into the Year 4 of the award, and shows an estimated balance at the end of PY4.

Total awarded funds to the University of Wisconsin (UW) for supporting IceCube M&O from the beginning of PY1 through the end of PY4 are $28,360K (including the supplemental funding of $67,999 in PY2 and $291,712 in PY3). Total actual cost as of February 29, 2020 is $27,466K and open commitments against purchase orders and subaward agreements are $620K. The current balance as of February 29, 2020 is $274K. With a projection of $528K for the remaining expenses during the last month of PY4, the estimated negative balance at the end of PY4 is -$254K, which is 0.9% of the total PY1-PY4 budget (Table 3).

(a)	(b)	(c)	(d)= a - b - c	(e)	(f) = d – e
YEARS 1-4 Budget Apr.'16-Mar.'20	**Actual Cost To Date** through Feb. 29, 2020	**Open Commitments** on Feb. 29, 2020	**Current Balance** on Feb. 29, 2020	**Remaining Projected Expenses** through Mar. 2020	**End of PY4 Forecast Balance** on Mar. 31, 2020
$28,360K	**$27,466K**	**$620K**	**$274K**	**$528K**	**-$254K**

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, 2019–March 31, 2020, based on v26.0 of the IceCube Institutional Memorandum of Understanding, from May 2019.

	Ph.D. Authors	Planned Contribution	Actual Received
Total Common Funds	**151**	**$2,047,500**	**$1,646,562**
U.S. Contribution	78	$1,064,700	$1,064,700
Non-U.S. Contribution	73	$982,800	$736,851*

Table 4: Planned and Actual CF Contributions for the period of April 1, 2019–March 20, 2020

* The non-U.S. invoicing and contributions are still underway, and it is anticipated that all planned contributions will be fulfilled.

Section II – Maintenance and Operations Status and Performance

Detector Operations and Maintenance

Detector Performance — During the period from April 1, 2019 to February 28, 2020, the detector uptime, defined as the fraction of the total time that some portion of IceCube was taking data, was 99.8%, exceeding our target of 99% and close to the maximum possible, given our current data acquisition system. The clean uptime for this period, indicating full-detector analysis-ready data, was 97.5%, 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 partial-detector good uptime was 1.8% of the total and includes analysis-ready data with fewer than all 86 strings. Excluded uptime includes maintenance, commissioning, and verification data and required 0.5% of detector time. The unexpected detector downtime was limited to 0.2%.

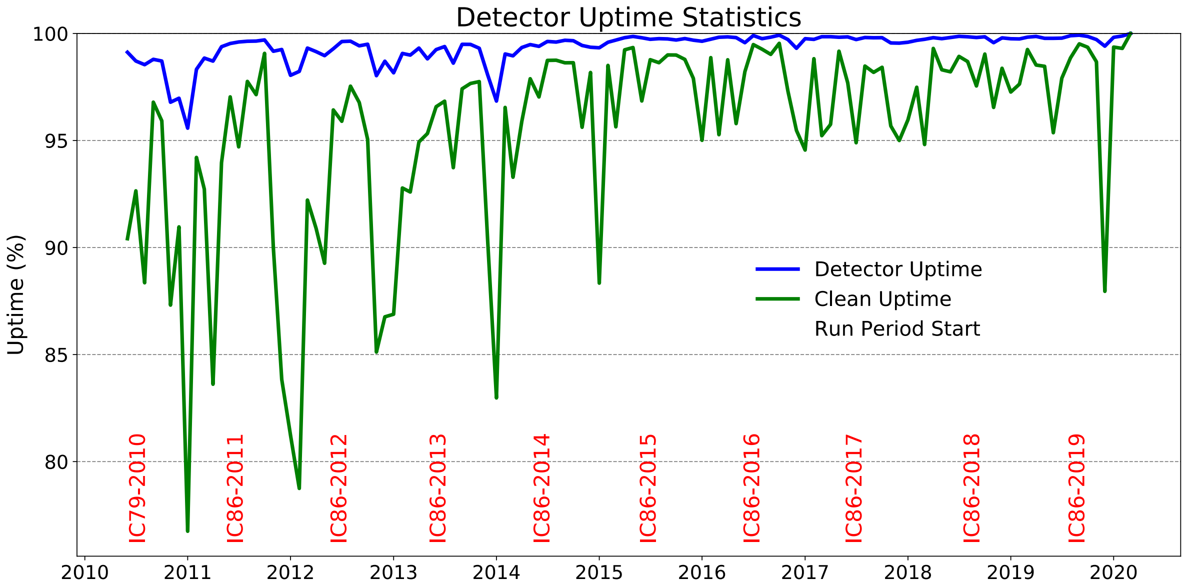


Figure 1: Total IceCube Detector Uptime and Clean Uptime

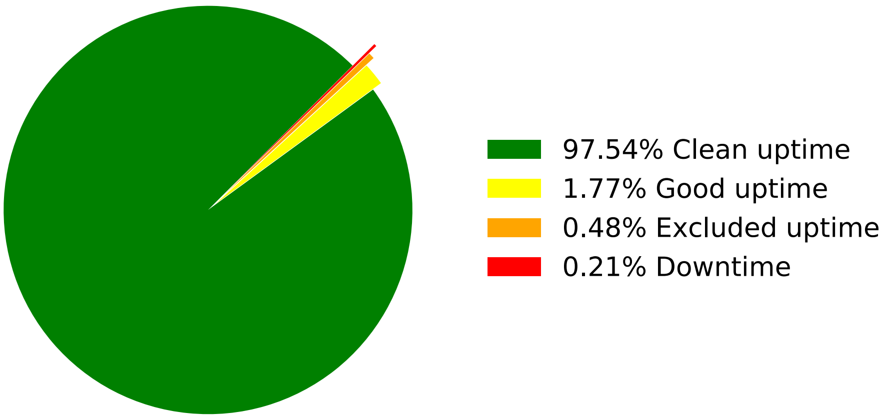


Figure 2: Cumulative IceCube Detector Time Usage, April 1, 2019 – February 28, 2020

Hardware Stability — The total number of active DOMs in the data stream is currently 5405 (98.5% of deployed DOMs), plus three DOM-mainboard-based scintillator panels. No DOMs failed during this reporting period; the previous DOM failures were in December 2018. One previously dead DOM was returned to data-taking (next section).

The failure rate in the commercial Acopian power supplies that supply the DC voltage to the DOMs increased in late 2015 to an unacceptably high level. We transitioned approximately half of the detector to alternate Mean Well MSP-200-48 power supplies during the 2018–19 pole season, and the remaining half was upgraded during the 2019–20 pole season. As of March 2020, none of the new supplies have failed. As a side benefit, the Mean Well supplies are more efficient than the Acopian supplies; we estimate that this upgrade has reduced IceCube's power load by approximately 2.8 kW.

The winterovers discovered in March 2019 that approximately 50% of the fans in the DOMHub ATX power supplies have failed over time. This is not necessarily unexpected, as the lifetime of this type of fan is ~8 years. We believe this is likely the cause of an elevated number of ATX module failures over the past several years, as some modules have no working fans. During December 2019, we replaced all of the failed fans with a higher-lifetime hydrodynamic bearing fan (Fig. 3). This maintenance was achieved with minimal detector downtime since the modules are redundant and hot-swappable.

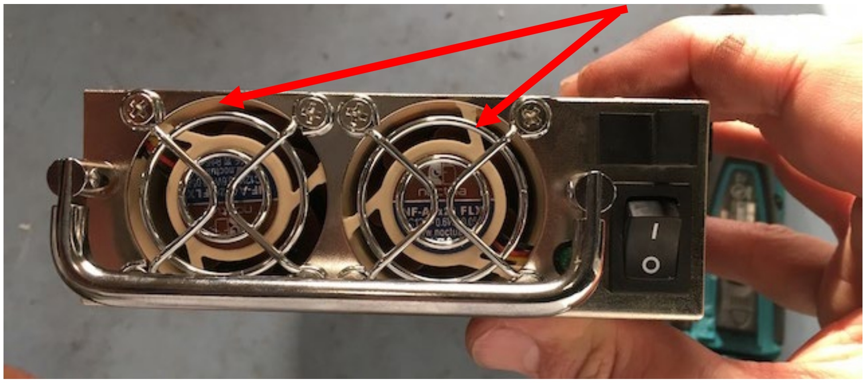


Figure 3: DOMHub ATX power supply module after replacement of both fans.

A full life-cycle replacement of the DOMHub hard drives was also performed in the 2019–20 pole season, as the previous drives had been operating 24/7 since 2013. An upgrade in size from 2TB to 4TB will allow a doubling of the hitspool pre-trigger data cache from 6.5 days to 13 days.

After an extended testing and commissioning campaign over the past two years, IceCube was successfully transitioned in March 2019 to a new master clock, a Spectracom SecureSync. The backup hot spare master clock was also successfully upgraded to a new Spectracom during the 2019–20 pole season, and the firmware on both primary and backup clocks was updated.

IC86 Physics Runs — The ninth season of the 86-string physics run, IC86–2019, began on July 18, 2019. Detector settings were updated using the latest yearly DOM calibrations from March 2019. The external trigger from the roof IceAct telescope was enabled, and a new low-energy neutrino realtime event stream was added. "Pass3" improvements to calibration and waveform unfolding were deferred, as benefits to physics analyses were not sufficiently compelling to outweigh the discontinuity that would be introduced to on-going data analyses.

One previously dead DOM, 30-60 "Rowan", spontaneously started communicating again after a full-detector power cycle in late 2018. The DOM was successfully recalibrated and returned to data-taking for the IC86–2019 run start, after a 13-year hiatus.

We have implementing automated HitSpool data captures triggered from the northern hemisphere by LIGO-VIRGO gravitational wave alerts, enabling searches for sub-threshold coincident neutrinos. Coincident hitspool data around black-hole merger candidate alerts are archived to backup disk, while data around neutron-star merger alerts are sent via satellite using a low-priority "topoff" queue.

Preparations for the IC86–2020 run start are underway, with the full-detector calibration planned for March 2020.

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. During the reporting period, the following accomplishments are noted:

- Delivery of six pDAQ:Urban_Harvest patch releases, fixing a bug affecting the IceAct trigger when rates were very low, adding improved robustness to internal component stalls, and improving the interface between pDAQ and IceCube Live.

- Work towards the pDAQ:Vintage release, which will incorporate changes necessary for migration to Python version 3 (Python version 2 will no longer be supported past 2020).

The upgrade of the trigger server at SPS uncovered an inefficiency in the pDAQ trigger algorithms. This bottleneck is exacerbated by recent computing trends towards higher numbers of lower-speed CPU cores. While a workaround at SPS was found within a matter of days (while reverting to the old server in the meantime), a long-term fix has been implemented and is currently in pre-release testing.

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. Filter changes were released to support the IC86–2019 physics run start in July 2019, as well as internal improvements to software component control.

An increased number of component crashes within the PnF system has been observed. While this only causes a temporary backlog in processing, restarting event filtering requires intervention by the winterovers. To address this, a watchdog system has been developed that can detect the crashes and restart the necessary components automatically.

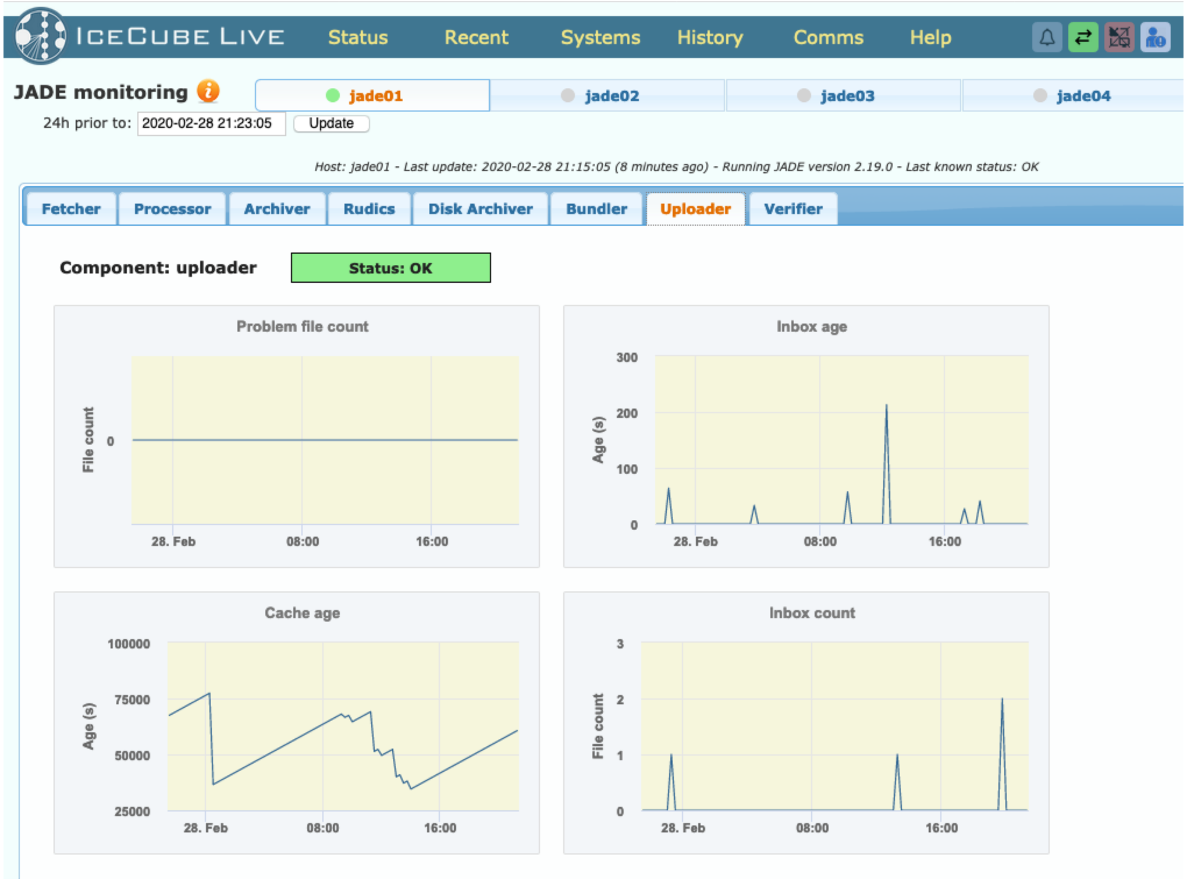
Detector Monitoring and Experiment Control — Development of IceCube Live, the experiment control and monitoring system, has transitioned to a maintenance phase after several major feature releases in 2017. This reporting period has seen the following releases:

- Live v4.0 "Arcadia" (April 2019): includes an upgrade to Python 2.7 as well as upgrades to the internal database and web framework. This release also includes an improved supernova DAQ (SNDAQ) web page.

- Live v4.1 "Basilica" (October 2019): adds support for an alert if the detector is running for extended periods in a non-standard configuration and a new monitoring page for the JADE data handling system (Fig. 4).

- Progress toward a mid-2020 release, which factors out some of the common code for monitoring and alerts used by other systems such as PnF and SNDAQ into a new "livecore" project for easier deployment and long-term maintenance.

The uptime of the I3Live experiment control system during the reporting period was approximately 99.993%.



24h prior to: 2020-02-28 21:23:05

Host: jade01 - Last update: 2020-02-28 21:15:05 (8 minutes ago) - Running JADE version 2.19.0 - Last known status: OK

Component: uploader

Status: OK

Figure 4: New IceCube Live monitoring view of the JADE satellite upload component.

Supernova System — The supernova data acquisition system (SNDAQ) found that 99.77% of the available data from April 1, 2019 to February 28, 2020 met the minimum analysis criteria for run duration and data quality for sending triggers. An additional 0.03% 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. The following developments of the SNDAQ software were achieved during the reporting period:

- Release BT16 was deployed in March 2019 and includes streamlined supernova alert messages to IceCube Live. Additionally, a new system was developed in conjunction with IceCube Live that monitors the status of alerts to the Supernova Neutrino Early Warning System (SNEWS).

- Release BT17 was deployed in June 2019 and fixes an issue with historical alert light curves reported to I3Live (regenerated from raw data). Additionally, more unit tests and support for continuous integration testing were added.

- Release BT18 was deployed in February 2020 and adds new quantities to SN alerts, e.g. automatic flux upper limit calculations. A memory leak was also fixed.

Surface Detectors — Two scintillator stations were deployed in the 2017–18 season, consisting of seven panels each. In the 2018–19 season, we successfully demonstrated that the elevated panels can be subsequently raised, as well as enhancing one station with two prototype radio antennas. Measurement of the air shower radio emission provides shower-by-shower energy and mass composition information, significantly enhancing the capabilities of IceTop.

During the 2019–20 pole season, the prototype scintillator station was upgraded to the production version of the electronics (Fig. 5), using the existing cabling infrastructure. All panels and the central electronics FieldHub have been elevated above the snow surface. A third radio antenna was also connected to the data acquisition system. The old panels and central FieldHubs have been removed.

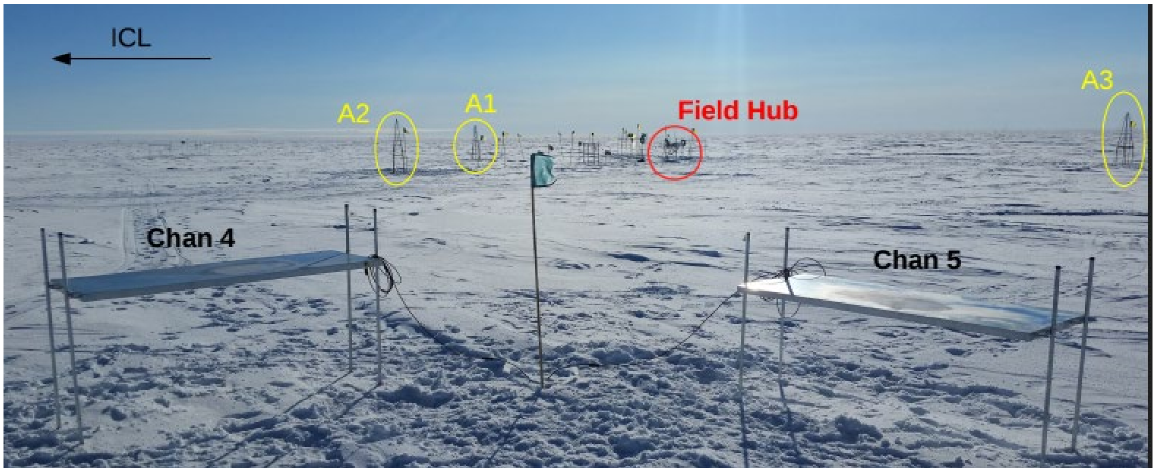


Figure 5: Upgraded scintillator + radio surface array station, showing two upgraded panels (foreground), three radio antennas (A1–3), and the new elevated FieldHub.

Both the field-deployed and ICL roof IceAct telescopes have successfully taken data during the austral winter and are now covered again until the polar sunset. The addition of a lens heater in 2018–19 partially resolved issues with ice accumulation. In January 2020, the roof telescope was refurbished with the same DAQ as the field telescope, and the lens heating system has been upgraded on both telescopes.

During removal of the wind turbine to the grid west of the ICL, the support contractor severed the optical fiber providing timing and communications to the surface array station. The fiber was subsequently repaired by an expert. This incident was partially caused by lack of metallic finder tape installed in the cable trench two years prior; IceCube and ASC are jointly reviewing the incident to ensure that any future cabling follows established procedures.

The logistics and environmental considerations of the proposed surface array upgrade were discussed with NSF in November 2019. Discussions regarding further deployments are in progress.

South Pole System — Approximately 50% of the South Pole System servers were replaced in the 2018–19 season; performance and hardware stability has been excellent. The remaining servers were upgraded during the 2019–20 season. The standard security patches to the operating system were also applied.

Delays in cargo delivery to pole posed a challenge for the SPS server upgrade during the 2019–20 season. Because the servers were up to three weeks late, the on-ice data acquisition system expert had left by the time the data acquisition servers were upgraded. This caused added downtime when the previously-discussed issues with the new DAQ trigger server occurred.

The South Pole System is currently running a version of Scientific Linux 6 (SL6). We are planning to upgrade all SPS computers to CentOS 8 in the 2020–21 season. This will support migration to modern versions of compilers, Python, the Linux kernel, and other key software. Two test machines at the South Pole Test System (SPTS) have been upgraded and are in use for developer testing.

Personnel & Management — No updates.

Computing Infrastructure at UW-Madison

Data Transfer – Data transfer has performed nominally over the past ten months. Between March 2019 and March 2020 a total of 26 TiB of data were transferred from the South Pole to UW-Madison via TDRSS, at an average rate of 72 GiB/day. Figure 1 shows the daily satellite transfer rate and weekly average satellite transfer rate in 73 GiB/day through September 2019. The IC86 filtered physics data are responsible for 95% of the bandwidth usage.

Since September 2016 the JADE software handles all the IceCube data flows: disk archive at the South Pole, satellite transfer to UW-Madison and long term archive to tape libraries at NERSC and DESY. JADE continues to operate smoothly and has been an effective tool for handling a variety of our routine data movement workflows. This has been confirmed over the last year with experience from both the Winterovers and IT staff at UW-Madison.

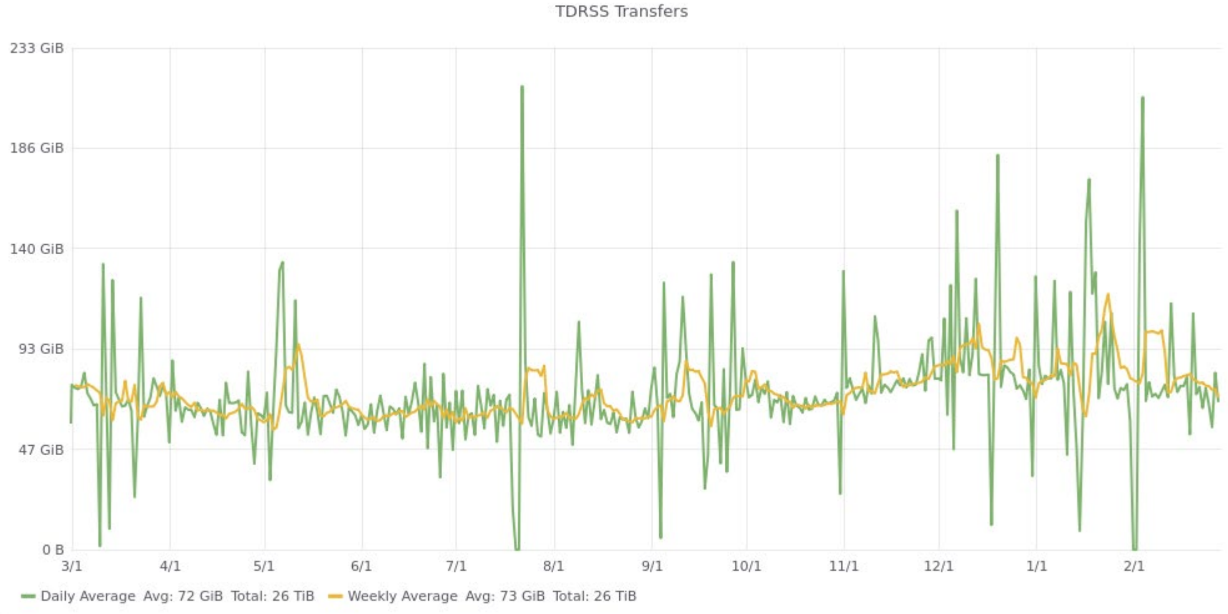


Figure 1: TDRSS Data Transfer Rates, February 1, 2019–September 25, 2019. The daily transferred volumes are shown in green and, superimposed in yellow, the weekly average daily rates are also displayed.

Data Archive – The IceCube raw data is archived by writing two copies on independent hard disks. During the reporting period (March 2019 to March 2020) a total of 0.6 PiB of unique data were archived to disk averaging 1.6 TiB/day.

In May 2019, the set of archival disks containing the raw data taken the previous season was received at UW-Madison. These disks are processed using JADE which now indexes the metadata, bundles the data files into chunks suitable for storage in tape libraries, and replicates the data to the long-term archives at DESY and NERSC.

Beginning in September 2016 we have been regularly transferring archival data to NERSC. At this time, the total volume of data archived at NERSC is 3.4 PB. Figure 2 shows the rate at which data has been archived to NERSC since the start of this service. The plan is to keep this archive stream constantly active while working on further JADE functionality that will allow us to steadily increase the performance and automation of this long-term archive data flow.

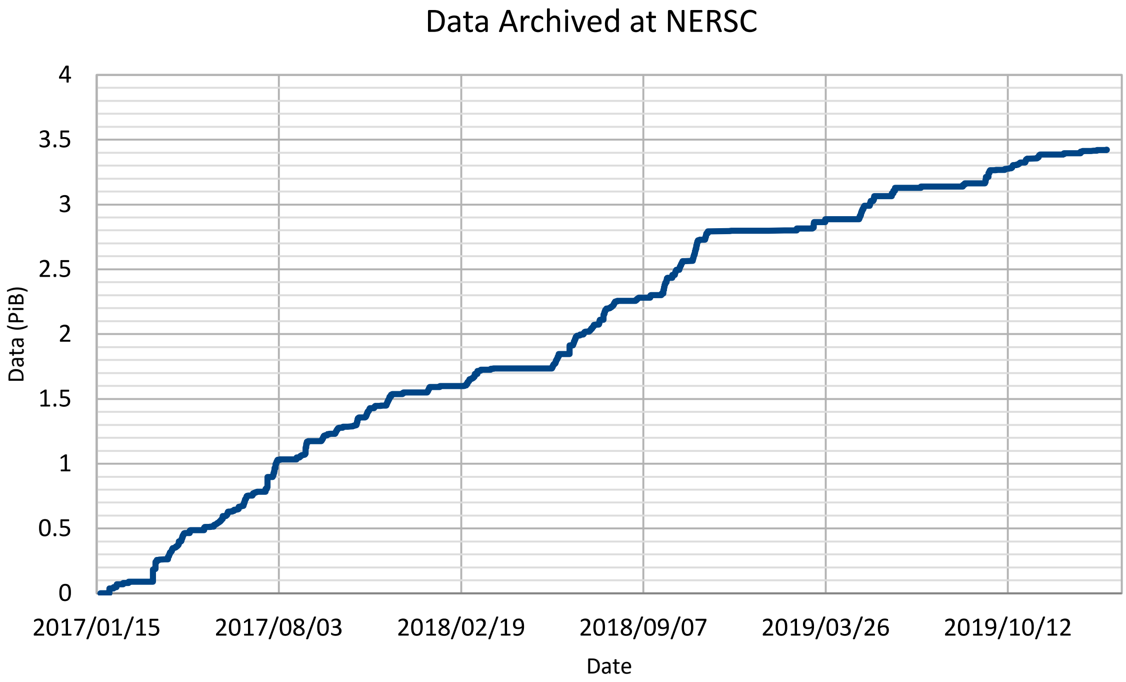


Figure 2: Volume of IceCube data archived at the NERSC tape facility by the JADE Long Term Archive service as a function of time.

Computing Infrastructure at UW-Madison

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 activity since the Collaboration decided to use GPUs for the photon propagation part of the simulation chain in 2012. Direct photon propagation provides the precision required, and is very well suited to GPU hardware, running about 100 times faster than in CPUs. We have decommissioning the data center facility at our 222 West Washington Avenue location, and relocating the equipment to a commercial facility leased by UW-Madison.

The facility is located approximately seven miles from our 222 West Washington Avenue location. It is a commercial facility offering redundant battery-backed generator power and biometric physical security. UW-Madison leases space, power, and cooling in this facility to support internal needs as well as project needs for the campus as a whole. As such, they have extended the campus high speed networks to the facility which offers us easier integration with the rest of our campus systems without the higher costs typically associated with commercial rates for network transit. We have a full 200 Gb/s network path between this facility and our other facilities on campus.

The total amount of data stored on disk in the data warehouse at UW-Madison is 8.3 PB: 3.6 PB for experimental and analysis data, 4.4 PB for simulation and analysis and 297 TB for user data. Storage comprises the largest user-visible infrastructure. A number of other critical systems (access to South Pole, for example) have been migrated to the new facility. The work was completed in early 2020. Only hardware under warranty was migrated to the facility. Older hardware that is still usable but out of support will be re-purposed for testing or moved into the compute cluster in Chamberlin Hall on the UW campus as needed. Any old hardware not needed for these purposes will be disposed of.

The other focus has been the continued expansion of the GPU cluster is to provide the capacity to meet the Collaboration direct photon propagation simulation needs. Still, the GPU needs have been estimated to be higher than the capacity of the GPU cluster at UW-Madison. Additional GPU resources have been deployed at Michigan State University , plus specific supercomputer allocations, allow us to try and reach that required capacity.

IceCube has been awarded or participated in several cyberinfrastructure-related projects. Namely, UW-Madison participated in an EAGER award (NSF OAC 1941481). UW-Madison has been awarded Phase I of Internet2's Exploring Clouds for Acceleration of Science (E-CAS) project for $100,000 in credits with Amazon Web Services and Google Cloud Platform and 0.4 FTE. We also unsuccessfully submitted two proposal for a GPU cluster to be hosted at UCSD/SDSC, and to create a data catalog of high-energy neutrino events and gamma-ray sources.

Distributed Computing - In March 2016, a new procedure to formally gather computing pledges from collaborating institutions was started. This data is collected twice a year as part of the already existing process by which every IceCube institution updates its MoU before the Collaboration week meeting. Institutions that pledge computing resources for IceCube are asked to provide information on 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 March 2020:

Institution	CPU	GPU
Aachen	10	0
Alberta	1200	144
Brussels	400	14
DESY	1400	180
Dortmund	400	48
LBNL	114	0
Marquette	96	16
MSU	750	100
NBI	0	10
Queen's/King's College	0	55
UMD	350	36
UW-Madison	6000	400
Wuppertal	500	64

Table 1: Computing pledges from IceCube Collaboration institutions as of March 2020.
*** indicates maximum shared resources, not exclusively for IceCube.**

We are implementing 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 manage 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 enlarge the distributed infrastructure and make it more efficient. The main strategy to accomplish this has been to try and simplify the process for sites to join the IceCube distributed infrastructure, and 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[1]. 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[2] 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.

Some of the IceCube collaborating institutions that provide access to local computing resources do not have a Grid interface. Instead, access is only possible by means of a local account. To address those sites we have 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, Dortmund, LBNL, Mainz, Marquette, NBI, and UMD. There are ongoing efforts at the Delaware, and Chiba sites to deploy the pyGlidein system. We continue observing a growing trend both in the number of sites integrated, as well as the computing time delivered.

Beyond the computing capacity provided by IceCube institutions, and the opportunistic access to Grid sites that are open to share their idle capacity, IceCube has received additional computing resources from targeted allocation requests submitted to Supercomputing facilities such as the NSF Extreme Science and Engineering Discovery Environment (XSEDE). IceCube submitted a first research allocation request to XSEDE in October 2015 (allocation number TG-PHY150040) that was awarded with compute time in two GPU-capable systems: SDSC Comet[3] and PSC Bridges[4]. The latest renewal for this research allocation, in July 2019, was awarded with compute time in two systems: SDSC Comet with 150,000 SUs and PSC Bridges with 150,000 SUs. IceCube stands out as one of the largest GPU users in XSEDE, and has been acknowledged in several XSEDE

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

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

[3] https://portal.xsede.org/sdsc-comet

[4] https://portal.xsede.org/psc-bridges

press releases. An additional 10,000 CPU SUs was awarded on Stampede2. We have also submitted a request for resources under the Large-Scale Community Partnerships for NSF's leadership-class HPC system Frontera.

With the aim to continue exploring the possibilities to expand the pool of available computing resources for IceCube, IceCube took part in demonstration at Supercomputing 2019 funded through an EAGER award (NSF OAC 1941481) from the NSF OAC. A UCSD/SDSC and UW-Madison team created one of the largest GPU clusters ever using the resources of commercial cloud providers while using the IceCube photon propagation code as a payload. (citation needed???).

In order to integrate all these heterogeneous infrastructures, we strongly rely on the HTCondor software and the various services that the Open Science Grid (OSG) project has built and operates around it. We continue being active in the OSG and HTCondor communities by participating in discussions and workshops. During the reporting period, IceCube members made oral contributions to the OSG all hands meeting at Jefferson Lab in Virginia, and the HTCondor workshop in Madison.

Personnel

We have had two personnel changes in 2019. Davy Mayer was hired in May 2019 as a web developer. Eric Evans (also shared with data processing, see below) was hired in September 2019 to work on analysis software and monitoring infrastructure.

Data Release

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 is released after the main analyses are completed and results are published by the IceCube Collaboration.

Since summer 2016, thanks to UW-Madison subscribing to the EZID[5] service we have the capability of issuing persistent identifiers for datasets. These are Digital Object Identifiers (DOI) that follow the DataCite metadata standard[6]. We are in the process of rolling out a process for ensuring that all datasets made public by IceCube have a DOI and use the DataCite metadata standard capability to "link" it to the associated publication, whenever this is applicable. The use of DataCite DOIs to identify IceCube public datasets increases their visibility by making them discoverable in the search.datacite.org portal (see https://search.datacite.org/works?resource-type-id=dataset&query=icecube)

Datasets (last release on 12 Jul 2018): http://icecube.wisc.edu/science/data

The list below contains information about the data that were collected and links to the data files.

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[5] http://ezid.cdlib.org

[6] http://schema.datacite.org

1. IceCube data from 2008 to 2017 related to analysis of TXS 0506+056
   - https://doi.org/10.21234/B4QG92
2. IceCube catalog of alert events up through IceCube-170922A
   - https://doi.org/10.21234/B4KS6S
3. Measurement of atmospheric neutrino oscillations with three years of data from the full sky
   - https://doi.org/10.21234/B4105H
4. A combined maximum-likelihood analysis of the astrophysical neutrino flux:
   - https://doi.org/10.21234/B4WC7T
5. Search for point sources with first year of IC86 data:
   - https://doi.org/10.21234/B4159R
6. Search for sterile neutrinos with one year of IceCube data:
   - http://icecube.wisc.edu/science/data/IC86-sterile-neutrino
7. The 79-string IceCube search for dark matter:
   - http://icecube.wisc.edu/science/data/ic79-solar-wimp
8. Observation of Astrophysical Neutrinos in Four Years of IceCube Data:
   - http://icecube.wisc.edu/science/data/HE-nu-2010-2014
9. Astrophysical muon neutrino flux in the northern sky with 2 years of IceCube data:
   - https://icecube.wisc.edu/science/data/HE_NuMu_diffuse
10. IceCube-59: Search for point sources using muon events:
    - https://icecube.wisc.edu/science/data/IC59-point-source
11. Search for contained neutrino events at energies greater than 1 TeV in 2 years of data:
    - http://icecube.wisc.edu/science/data/HEnu_above1tev
12. IceCube Oscillations: 3 years muon neutrino disappearance data:
    - http://icecube.wisc.edu/science/data/nu_osc
13. 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
14. IceCube String 40 Data:
    - http://icecube.wisc.edu/science/data/ic40
15. IceCube String 22–Solar WIMP Data:
    - http://icecube.wisc.edu/science/data/ic22-solar-wimp
16. AMANDA 7 Year Data:
    - http://icecube.wisc.edu/science/data/amanda

Data Processing and Simulation Services

Offline Data Filtering – The data collection for the IC86-2019 season started on July 18, 2019. 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 IC86-2018 season scripts are minimal. An effort was done to clean up filters reconstructions and libraries no longer needed in offline reconstruction resulting in a 36% reduction of CPU utilization and a comparable reduction in memory requirements. We therefore estimate that the resources required for the offline production will be about 480,000 CPU hours on the IceCube cluster at UW-Madison datacenter. 100 TB of storage is required to store both the Pole-filtered input data and the output data resulting from the offline production. Additional savings in storage resulted from a switch to a more efficient compression algorithm in the 2017 season. As of the start of the 2018 season. We switched to a new database structure at pole and in Madison for offline production. The transition went smoothly, with no significant issues. Level2 data are typically available one and a half weeks after data taking.

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.

We are currently reviewing existing filters and reconstructions with the aim of streamlining offline processing at Level 2 and Level 3.

Data Reprocessing – The data re-processing (pass2) started on June 1st, 2017, and completed in August of 2018 to (a) unify the multi-year data set; (b) profit from improvements in our understanding of low-level DOM calibration parameters. Seven years (2010 - 2016) are currently re-processed. Four years start at sDST level (2011 - 2014) and three years at raw data. Starting at raw data was required for 2010 since sDST data was not available. Since sDST data for 2015 and 2016 has already been SPE corrected, a re-processing of sDST data was required in order to apply the latest SPE fits as we perform for the other seasons.

The reprocessing of pass2 utilized 10,905,951 CPU hours and 520 TB storage for sDST and Level2 data. An additional 2,000,000 CPU hours and 30 TB storage were required process the pass2 Level2 data to Level3.

More recent improvements in calibration and feature extraction prompted an evaluation for the need to implement such changes in the online filter and subsequently reprocess previous data a second time. However, after careful studies it was determined that there was not sufficient evidence that a pass3 would result in improved science at this time. The question will be revisited before next season, after we have made more detailed studies on the matter.

Offline Processing on IceProd2 – We are currently working to migrate offline processing of data at Level2 and Level3 to the IceProd 2 framework. We are coordinating with the distributed infrastructure team to implement additional features needed to support this task. We anticipate a transition to IP2 to coincide with the run start for the 2020-2021season.

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 pass previous trigger and filter configurations included in pass2. These include 2012, 2013, 2014, 2015 and 2016, as well as more recent configurations such as 2017 and 2018. As with previous productions, direct generation of Level 2 background simulation data is used to reduce storage space requirements. The transition to the 2016 configuration was done in conjunction with a switch to IceSim 5 and IceSim 6 which contain improvements in memory and GPU utilization in addition to previous improvements to correlated noise generation, Earth modeling, and lepton propagation. Simulations have been running on IceSim 6.1.1 and are now switching to Combo 0.0.1 with further improvements and bug fixes for various modules. With the new restructuring of offline software, the Combo software suite includes both simulation and reconstruction software libraries. New features in this simulation package include, individually calibrated PMT waveforms, optimized event resampling for low-energy background simulation as well as new, more detailed ice models along with further improvements in GPU utilization. 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 team organizes periodic workshops to explore better and more efficient ways of meeting the simulation needs of the analyzers. This includes both software improvements as well as new strategies and providing the tools to generate targeted simulations optimized for individual analyses instead of a one-size-fits-all approach. New strategies are being developed for dynamically simulating of systematic uncertainties in our understanding of ice properties, hole-ice and DOM sensitivity and determining their impact on physics analyses. A new production campaign will begin as soon as validation of these tools has been completed.

The centralized production of Monte Carlo simulations has moved away from running separate instances of IceProd to a single central instance that relies on GlideIns running at satellite sites. Production has been transitioning to a newly redesigned simulation scheduling system IceProd2. A full transition to IceProd 2 was completed during the Spring 2017 Collaboration Meeting. Production throughput on IceProd2 has continually increased due to incorporation of an increasing number of dedicated and opportunistic resources and a number of code optimizations. A new set of monitoring tools is currently being developed in order to keep track of efficiency and further optimizations. New procedures are being implemented for allocating resources and priorities to simulations produced by working groups.

Personnel – Ric Evans joined the simulation production team in September 2019.

IceCube Software Coordination

The software systems spanning the IceCube Neutrino Observatory, from embedded data acquisition code 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. In the last year, software working group leads have been appointed to the following groups: core software, simulation, reconstruction, science support, and infra-structure. Continuing efforts are underway to ensure the software group is optimizing in-kind contributions to the development and maintenance of IceCube's physics software stack.

The IceCube collaboration contributes software development labor via the biannual MoU updates. Software code sprints are organized seasonally (i.e. 4 times per year) with the software developers to prepare for software releases. Progress is tracked, among other means, by tracking open software tickets tied to seasonal milestones. The IceCube software group has several major projects, labeled as ‘on-going’ that are nearing completion:

- Program management software extended to other M&O groups (on-going);
- Developing an app to help track collaboration-wide service work (in-development);
- Working on repository migration scheme (on-going);
- Prepared codebase for Python2 EOL (deployed);
- New release plan w/ ICC resulted in three releases (deployed);
- Included new systematics method (on-going);
- Included new and novel primary generator (on-going);
- Included new monopole-generator in production (deployed);
- Included refactored photon PDF project for testing (on-going);
- Reduced memory usage in simulation production (deployed);
- Increasing real-time production efficiency (on-going);
- Improving sensitivity of nightly test CI/CD/CB system (on-going);
- Extending production comparison tool to L2 data (on-going);
- Significant progress towards a new background simulation model was made and is close to deployment. This model is designed to achieve more efficient simulations by sampling important parameter space instead of brute force methods to simulate easily identified background cosmic-ray showers. This dynamic-stack CORSIKA framework provides a realistic path to achieve a rate of simulation production comparable to that of data taking.

Calibration

We continue to refine measurements of the South Pole ice that comprises the majority of our detector, as well as the IceCube DOM response to photons.

Ice characterization - These studies are typically subdivided into those that concern the naturally formed bulk ice, and those that concern the refrozen ice in the columns where DOMs were deployed. Using 12 LEDs embedded inside each DOM, the bulk ice scattering and absorption lengths are calibrated as a function of depth. New calibration data was collected in 2017/18 where each LED was flashed individually on a DOM, and processed with improved data quality criteria. This single-LED data set has allowed us to not only calibrate the azimuthal orientation of each DOM, but also revisit the calibration of the bulk ice properties that previously suffered from the lack of knowledge of LED pointing. The reanalysis of bulk ice properties, which included a thorough assessment of all known systematic uncertainties, is now complete. The resulting uncertainties on absorption and scattering have been reduced from ~10% down to ~5%. An internal note detailing the analysis is being compiled in order to improve transparency and reproducibility for posterity.

Photon propagation through the ice at the South Pole exhibits anisotropic behavior, with light apparently traveling more efficiently along the glacial flow direction and less efficiently in directions perpendicular to the flow. This has been independently confirmed using a retrievable, laser-based calibration device deployed in the open borehole (SPICEcore) ~1km away from the IceCube array. We continue to improve our modeling of the underlying birefringence of ice that we believe is at least partially responsible for these observations. This has involved the development of new photon propagation algorithms, and strong collaboration with the SPICEcore team who can provide inputs to the model such as ice grain size and orientation as a function of depth. Preliminary results show a dramatic improvement in the ice model fit, and are currently under review.

In addition to the laser device, several other retrievable loggers were deployed in the SPICEcore in Pole seasons 2018/19 and again in 2019/20. These included a logger to measure the luminescence light yield of the ice, which is an important component of light production near or just below the Cherenkov-threshold, and a UV-logger to measure the efficiency of UV photon propagation, which is important to know for the development of future possible UV-sensitive devices in IceCube extensions. The analysis of data from these loggers is still on-going (see Fig. 1), but preliminary results are already being incorporated and tested in IceCube simulations.

The primary effect of the refrozen hole ice, and bubbles contained within it, is a modification of the DOM angular acceptance relative to lab measurements. Our uncertainty on the angular acceptance continues to be a leading systematic for many IceCube physics analysis, and has therefore been the target of many studies over the years. This led to a plethora of previously incompatible models. Using a principle component analysis of the various parametrizations, a single, unified model has now been obtained that has only two free parameters that can be used to map between any of the old models.

DOM characterization - The calibration of each DOMs single photoelectron (SPE) response was finalized, leading to a significant improvement in data/MC agreement of a fundamental observable: charge-per-DOM. All new IceCube simulations now include this per-DOM SPE distribution, which should improve the performance of reconstruction algorithms, particularly for dim events with few detected photons. The *in situ* SPE calibration method and results were summarized in an article submitted to JINST. Understanding the delayed pulse characteristics of the PMTs are critical for analyses that rely on delayed light, e.g. searches for signals of neutron capture from extremely high energy hadronic interactions. High-brightness LED flasher data was collected with a hitspool request such that very delayed pulses in the waveforms could be analyzed. A previously unanticipated component of after-pulsing was discovered on a time-scale of ~100 microseconds (see Fig. 2), and appears to vary by DOM. A run plan to calibrate the delayed pulsing behavior for each DOM *in situ* is currently under development.

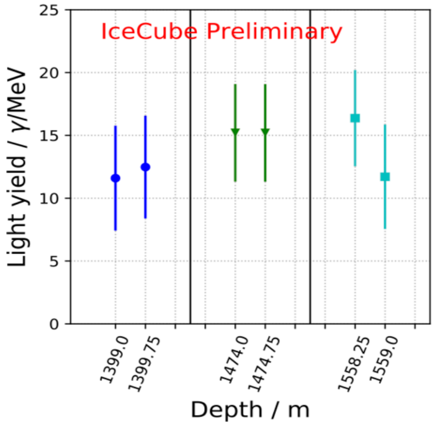


Figure 1: Light yield from South Pole ice luminescence as measured with a β-radiation device in the SPICEcore.

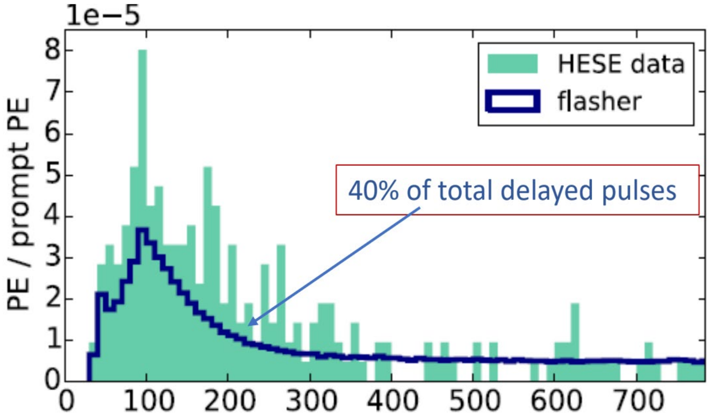


Figure 2: Comparison of very delayed afterpulse rate found in IceCube HESE data waveforms and those found in wavefroms from high brightness flasher events. The x-axis in time in µs.

Program Management

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

- A complete re-baseline of the IceCube M&O Work Breakdown Structure to reflect the structure of the principal resource coordination entity, the IceCube Coordination Committee.
- Submission of PY4 M&O Plan.
- The detailed M&O Memorandum of Understanding (MoU) addressing responsibilities of each collaborating institution was revised for the collaboration meeting in Chiba, Japan, September 15-20, 2019.

IceCube M&O – PY4 (FY2019/2020) Milestones Status:

Milestone	Month
Revise the Institutional Memorandum of Understanding (MOU v26.0) - Statement of Work and Ph.D. Authors head count for the spring collaboration Meeting	**May 2019**
Report on Scientific Results at the Spring Collaboration Meeting	**Apr 30 – May 4, 2019**
Revise the Institutional Memorandum of Understanding (MOU v27.0) - Statement of Work and Ph.D. Authors head count for the fall collaboration meeting	**September 2019**
Report on Scientific Results at the Fall Collaboration Meeting	**Sept. 15-20, 2019**
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 2019**

Submit for NSF approval, a revised IceCube Maintenance and Operations Plan (M&OP) and send the approved plan to non-U.S. IOFG members.	**December 2019**
Revise the Institutional Memorandum of Understanding (MOU v28.0) - Statement of Work and Ph.D. Authors head count for the spring collaboration meeting	April 2020

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)/Communications – The IceCube Collaboration has had significant outcomes from their efforts, organized around four main themes:

1) *Reaching motivated high school students and educators* through internships, IceCube Masterclasses, and the University of Wisconsin-River Falls' (UWRF) and University of Rochester's (UR) Upward Bound programs
2) *Providing intensive research experiences* for educators (in collaboration with PolarTREC) and for undergraduate students (NSF science grants and Research Experiences for Undergraduates (REU) funding) to increase STEM awareness
3) *Engaging the public through various means,* including web and print resources, graphic designs, an IceCube comic, live talks, virtual reality gaming, and displays
4) *Developing and implementing communication skills and diversity workshops*, held semiannually in conjunction with IceCube Collaboration meetings

WIPAC's annual 10-week high school astrophysics internship had a record number of thirty participants this year. The group met weekly for two-hour afterschool sessions. The program focused on cosmic rays, with projects centered around the CosmicWatch detector, which had been previously developed by an IceCube graduate student. The 7th annual IceCube Masterclasses are underway with the first class given in Belgium in January 2020 and about twenty more scheduled for March and April 2020 in the US and Europe. The UWRF REU program provided summer research experiences to six students, five women and one man. Both UWRF and UR provided IceCube-science–inspired summer enrichment courses for their respective Upward Bound programs. Upward Bound provides additional mentoring and skill-building activities for low-income/first-generation high school students to help prepare them for post-secondary school success. Multiple IceCube institutions also supported research opportunities for undergraduates, including Aachen University in Germany, who hosted a UWRF undergraduate for 10 weeks in summer 2019.

Bilingual science educator Jocelyn Argueta deployed with IceCube to the South Pole in November-December 2019 as part of the PolarTREC program. Argueta has a nationally touring one-person science show, "Jargie the Science Girl," where she presents science concepts in a fun and engaging fashion for young audiences. She posted her PolarTREC updates in both English and Spanish.

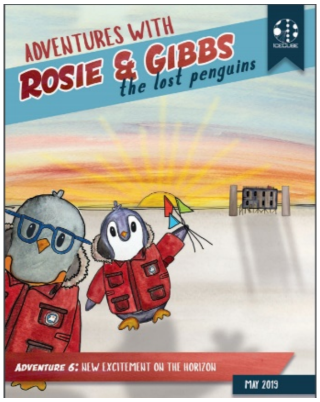
Portraits at the ICRC2019 gallery show.

WIPAC organized the IceCube booth at the World Science Festival in New York City on June 2, 2019, with volunteers from Columbia, Delaware, Stony Brook and WIPAC. WIPAC also participated in several significant events in Madison, including a two-day IceCube exhibit at Science Expeditions in April on the UW campus that drew thousands of visitors, a two-day event for UW alumni and their grandchildren that introduced IceCube science in an accessible way, and a day of IceCube activities at the Saturday Science program on July 13, 2019, and three days of IceCube interactives at the WI Science Festival in October. In conjunction with the 2019 International Cosmic Ray Conference held on the UW campus, WIPAC co-sponsored and curated a gallery show with York University Art-Science Associate Professor Mark-David Hosale and UW Art Associate Professor Faisal Abdu'Allah that explored what we know and how we know it and took a look at who does cosmic ray research. A particularly rewarding aspect of this event was working with local teens who assisted with taking the portraits of ICRC2019 participants, which were added to the exhibit during the conference.

Local and national media covered the Smithsonian Institution's request for an IceCube DOM to be sent in June 2019 for installation in the National Air and Space Museum. We are also arranging to have a DOM sent to the permanent collection of the Corning Museum of Glass, and we will lend a DOM for a yearlong "Discovering Antarctica 1820-2020" exhibit at the Mystic Seaport Museum that opens in November 2020.

The IceCube virtual reality experience developed for the Oculus Rift system continues to be a big hit. It has been utilized by thousands of people in the last year at venues including the NSF Large Facilities Workshop, South by Southwest, the World Science Festival, UW's Science Expeditions, the WI Science Festival and the 2019 Council of Managers of National Antarctic Program (COMNAP) workshop in Bulgaria. As of December 2019, the experience is freely available via the Oculus store.

IceCube receives multiple requests for talks each week and works hard to provide speakers for all opportunities. IceCube had a large presence at ICRC2019, with about 80 presentations in total, including posters on the gallery show and on a collaboration between NSF Antarctic Artists and Writers Program participant Donald Fortescue and IceCube collaborator Gwenhael De Wasseige to convert IceCube data to music by associating each IceCube string with a string on a piano. IceCube collaborators play leading roles on national and international organizing committees including the previously mentioned hosting of ICRC2019 as well as leadership roles in the SCAR Astronomy & Astrophysics from Antarctica scientific research program.



Rosie and Gibbs 6th issue discusses the IceCube Upgrade.

The IceCube communication office manages press and other communication activities for both the neutrino observatory and the IceCube Collaboration. A sixth issue of the IceCube comic series "Rosie & Gibbs" was published in May 2019 that featured the IceCube Upgrade and a collection of all six issues was compiled. We continue to produce multimedia content for social networks, which has increased the reach of IceCube communication from a few thousand to tens of thousands on an average week, with peaks of hundreds of thousands associated with big announcements. Soon, we plan on using Twitter to publicly share neutrino event alerts as IceCube detects and analyzes them, providing our followers with a behind-the-scenes look at our science in nearly real time.

In February 2020, we submitted an essay to the Antarctica200 project, a book about Antarctica's unique role in the fields of architecture, engineering, science, glaciology, international law, anthropology, fashion technology, literature, and art. The project is directed by UNA, an international architecture studio based in Hamburg and Venice, and the final publication will be launched at the Venice Biennale in May 2020.

IceCube Collaboration meetings include professional development opportunities to improve skills and help create a more inclusive environment. Science journalist Angela Posada-Swafford presented a communication workshop and participated in the evening women's networking event at the Madison IceCube Collaboration meeting in May, which also included an interactive workshop on interviewing tips. At the Chiba IceCube Collaboration meeting, there was an evening gathering for LGBTQ+ and allies, a women and allies networking event, and a communication workshop that included presentations by IceCube collaborator Lu Lu on her augmented reality project to display IceCube events and by manga artist Dr. Yuki Akimoto who also attended the women and allies event. These events were supported by an M&O supplemental award to further develop talent for STEM research, increase diversity and inclusion in science and related fields, and connect research-based skills and technology to societal challenges (INCLUDES). IceCube participated in social media campaigns supporting Pride month and LGBTSTEM Day on July 5, 2019, and the International Day of Women and Girls in Science in 2019 and 2020.

The Multimessenger Diversity Network, also funded by the M&O INCLUDES supplemental award, has been active. Representatives from the initial four collaborations met for training in Madison on March 9-10, 2019 and again on July 22-24, 2019. An Astro2020 APC White Paper, "Pursuing diversity, equity, and inclusion in multimessenger astronomy collaborations over the coming decade," was produced. The number of participating collaborations grew by three, reaching a total of seven. Ellen Bechtol gave a presentation on the MDN at the Inclusive Astronomy 2 Conference held at the Space Telescope Science Institute in Baltimore, MD, on October 14-15, 2019. Jim Madsen presented at the International Astronomical Union Symposium for Equity, Diversity and Inclusion in Tokyo, Japan, in November 2019 and prepared a paper of the presentation for the conference proceedings.

Section III – Project Governance and Upcoming Events

The detailed M&O institutional responsibilities and Ph.D. author head count are 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 2019 for the fall collaboration meeting in Chiba, Japan (v27.0), and the next revision (v28.0) will be posted in May 2020 at the spring collaboration meeting in Brussels, Belgium.

IceCube Collaborating Institutions

As of September 2019, the IceCube Collaboration consists of 52 institutions in 12 countries (29 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/institutions

IceCube Major Meetings and Events

IceCube spring collaboration meeting – Madison, WI	April 30 – May 4, 2019
IceCube fall collaboration meeting – Chiba, Japan	September 15-20, 2019
International Oversight and Finance Group – Chiba, Japan	September 20, 2019
ICNO M&O site visit and business systems review – Madison, WI	March 16-19, 2020

Acronym List

CPU	Central Processing Unit
CVMFS	CernVM-Filesystem
DAQ	Data Acquisition System
DOM	Digital Optical Module
E&O	Education and Outreach
GPU	Graphical Processing Unit
I3Moni	IceCube Run Monitoring system
IC86	The 86-string IceCube Array completed Dec 2010
IceACT	IceCube Air Cherenkov Telescope
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
PQ	Physical Qualification
SNDAQ	Supernova Data Acquisition System
SPE	Single photoelectron
SPS	South Pole System
SuperDST/sDST	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